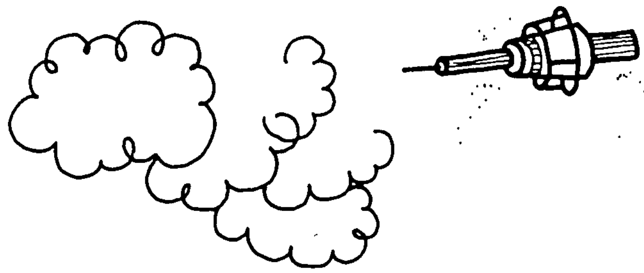

ESA/ESO Workshop on

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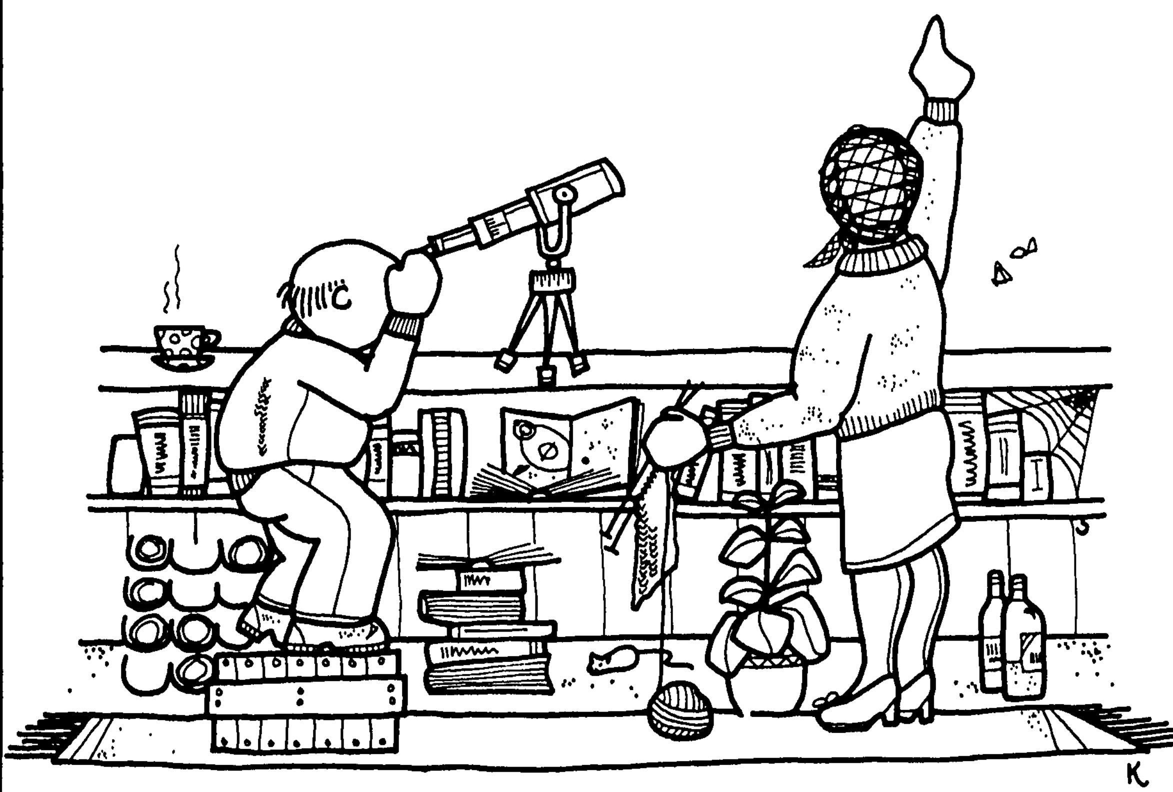

Proceedings

Edited by

F. Macchetto,
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EDITOR'S NOTE

Our approach to the publishing of the Proceedings has followed closely that followed for the previous ESO Conferences: all speakers were asked to submit their manuscripts on sheets supplied which were then used directly for off-set printing. We are grateful to the speakers for providing us with most of the papers within six weeks of the end of the Workshop.

Questions and replies after papers are only printed where the question was confirmed in written form.

We would like to express our grateful thanks to all those who helped us in the organisation of this conference and the preparation of these Proceedings, in particular, Ann Dolan of ESA, Kurt Kjär, and Renate Tröndle of ESO.

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CONTENTS

GENERAL INTRODUCTION

INTRODUCTION

L. Woltjer
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During the past decades, space research and ground based astronomy have become more and more intimately connected. It would be difficult to think of the latter without at the same time thinking of X- and γ-ray sources and other objects discovered through space based instruments. Similarly, the work with Copernicus and IUE has already shown the importance of supplementing the work in the optical range with data in the ultraviolet.

With the advent of ST, space based research moves directly into fields which until now were the exclusive preserve of optical astronomers on the ground. While this by no means implies the end of ground based astronomical research, it certainly is true that optical astronomers could forget about ST only at their peril. Future progress will in a large measure depend on a close coordination between ST and ground based work.

The main reason for organizing this workshop was to insure that Europe will be prepared to make effective use of the opportunities provided by ST. In many cases this will require preparatory work with ground based facilities and in view of the schedule for ST, now is the time for initiating such work.

The very strong response to this workshop by the European astronomical community shows that there is much awareness of the importance of ST. The fact that this workshop could be organized jointly by the European Space Agency and the European Southern Observatory augurs well for the proper integration of ST into European astronomy.

THE SPACE TELESCOPE AND ITS CAPABILITIES

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1. INTRODUCTION

The subject of this workshop is astronomical uses of the NASA Space Telescope with the emphasis on the astronomical significance of these observations. The purpose of this brief survey is to highlight the capabilities of the Space Telescope. There are many ways in which the Space Telescope will revolutionise astronomy but it also has its limitations. In particular, certain classes of observation will still be executed more effectively with ground-based telescopes. Since there will be a vast over-subscription of observing proposals for the available observing time, it is important to select projects which take maximum advantage of its unique capabilities.

The most important message which will come out of this workshop will be, I hope, that EVERYONE INTERESTED IN MAKING OBSERVATIONS WITH THE SPACE TELESCOPE MUST PLAN THEIR SPACE TELESCOPE OBSERVING PROGRAMME NOW. Plainly, any observer will be in the best position to obtain telescope time if he can demonstrate that he has done everything possible from ground-based observatories. In extragalactic astronomy, in particular, any major project requires substantial amounts of large telescope time and the last quarter of 1983, the launch date of the Space Telescope, is only 4½ years away. This is already barely adequate to complete such programmes.

There are two other aspects of the Space Telescope project which I believe are very important. First, the quality of Space Telescope observations will be consistently very high and they will all be retrieved in digital form. It will be very important for us all to familiarise ourselves with the instrumentation and with the type of data produced by Space Telescopes. For example, it will be very valuable to have had first-hand experience of using IPCS and CCD cameras and the problems associated with their data and image processing. The other aspect is that I believe that we should regard observations with the Space Telescope as being complementary to all other types of astronomy, in particular ground-based optical and radio astronomy and all types of space astronomy. Because of the severe restraints of observing time, I believe it is unrealistic to believe that many of us will become full time Space Telescope astronomers. Most astronomy will still be done from the ground and with Space Telescope we will fill in many crucial bits of the picture which are inaccessible from the surface of the Earth. Viewed in this light, the Space Telescope may be regarded as the greatest stimulus for all other branches of astronomy.

My intention is to survey briefly the most important characteristics of the telescope and its scientific instruments, to compare the performances of the two cameras, the Wide Field/Planetary Camera and the Faint Object Camera, and then to study a possible programme of observations which indicates how much data one can accumulate in a given amount of observing time. This survey is my own personal view of the Space Telescope and is based upon my understanding of the present state of the project.

2. THE SPACE TELESCOPE COMPARED WITH GROUND BASED TELESCOPES

The three main advantages of the Space Telescope over ground-based telescopes can be appreciated from the specification and performance goals of the project which are summarised in Table 1.

Table 1

Specification and performance goals of the NASA Space Telescope

Telescope aperture	2.4 m
System focal ratio	f/24
Optical design	Ritchey-Chretien Cassegrain
Central obscuration	14% aperture area
Field of view for science	18 arcmin diameter
Spectral range	120 nm - 1 mm
Optical performance: system wavefront error	λ/13.5 r.m.s. at 632.8 nm
Radius of 70% encircled energy from a point source at 633 nm	0.1 arcsec
Faint object sensitivity subject to viewing in directions greater than i) 50° from Sun ii) 70° from Earth's limb iii) 15° from Moon	Point objects having m_V = 27 or brighter; extended sources to a limit of 23 magnitudes (arcsec)$^{-2}$ in visual wave-band. Both in 10 hours of integration.
Pointing stability	0.007 arcsec on a target having m_V = 13 in the range 400-800 nm
Minimum reflectivity	85% at 632.8 nm 70% at 120 nm

Satellite orbit

Circular Earth orbit serviceable by the Space Shuttle

Altitude	about 500 km
Inclination	28.8°

Perhaps the most significant entry in the Table is the requirement that the radius of 70% encircled energy from a point source at 633 nm be 0.1 arcsec. This figure corresponds to roughly a factor of 10 improvement over the typical performance of the largest ground-based telescopes.

2.1 <u>The improvement in angular resolution</u>. Of these three advantages, the most significant is the order of magnitude improvement in angular resolution. In ground-based observations, the limiting magnitude to which observations can be usefully made using normal photographic techniques is set by the brightness of the night sky which is mostly due to air-glow and which in the best dark sites corresponds to a surface brightness of about 22 magnitudes $(\mathrm{arcsec})^{-2}$ in the visual waveband. This figure includes about a 10% contribution from zodiacal light which is sunlight scattered by interplanetary dust grains. Because of the phenomenon of "seeing", the scattering of starlight by fluctuations in the refractive index of the atmosphere, the images of point sources are blurred to about 1 arcsec^2. Thus, in the visual waveband the signal from a point source is the same as that from the sky if it has $m_V \approx 22$. If photographic plates are used to record the stellar images, it is difficult to improve significantly over this limiting magnitude because in an exposure which attins this magnitude, the background light begins to darken the whole plate. If photon counting techniques or the stacking of deep plates is used, fainter magnitudes can be reached.

In space, the background sky noise does not decrease to zero because there remain the contributions of zodiacal light and of diffuse interstellar light originating from starlight scattered by interstellar dust. Even looking in favourable directions a reasonably typical value for the background light is about 23 magnitudes $(\mathrm{arcsec})^{-2}$ in the visual waveband. There is a corresponding requirement in the specification of the Space Telescope that, when it is pointing in directions consistent with the pointing constraints listed in Table 1, the scattered stray light within the telescope structure which reaches the focal plane must be less than the surface brightness corresponding to 23 visual magnitudes$(\mathrm{arcsec})^{-2}$.

The advantage in having a large improvement in angular resolution is that the sky background in each resolution element of dimensions $\sim 0.2 \times 0.2$ $(\mathrm{arcsec})^2$ is roughly 25 times smaller i.e. the corresponding limiting magnitude for the photography of stars would correspond to $m_V \approx 26.5$. When we recall that most of the detectors will be of the photon-counting type, or can be used in a similar mode, it is clear that fainter point-like objects can be detected. The ultimate limiting magnitude achievable is set by the efficiencies of the telescope and the detectors and by the maximum integration time which is considered feasible. The specification of the telescope is that it should be able to achieve $m_V = 27$ or a surface brightness of 23 visual magnitudes$(\mathrm{arcsec})^{-2}$ in an integration time of 10 hours. It is fully expected that these goals will be surpassed by the cameras selected for the mission.

The implication of these figures is that point objects 50 times fainter than the faintest observable from the ground can be detected by the Space Telescope. Roughly speaking, these objects can be observed to distances a factor of 7 greater than at present, or, if the objects are uniformly distributed in space, 350 times more of this class of object become accessible to observation.

For extended objects, the gain in sensitivity is more difficult to calculate precisely because it depends upon the brightness distribution across the object. In the limiting case of a uniformly diffuse object of angular size 1 x 1 $(\text{arcsec})^2$, there would be little advantage in making observations with the Space Telescope in the visual waveband, the only gain over ground-based observations being the reduction of the sky background by about one magnitude. There would, however, be a much greater gain at longer wavelengths at which the sky background increases rapidly and of course a huge gain in the ultraviolet region of the spectrum which has yet to be explored with "photographic" detectors to the faintest magnitudes. In practice, objects such as galaxies have strong variations in surface brightness, the maximum occurring in the central regions. As a rough guide to the redshift to which galaxies may be observed in the visual waveband, a galaxy having absolute magnitude M*, where M* is the value corresponding to the break in the luminsoity function, should be observable with reasonable signal to noise ratio at a redshift $z \approx 1$ in a 10-hour exposure. Correspondingly, SO, spiral and irregular galaxies will all be distinguishable at very much larger distances than at present.

2.2 "24-hours per day" observing time. Subject to the viewing constraints listed in Table 1, the Space Telescope will operate under perfect observing conditions all the time and thus the quality of the observations will be consistently very high. The heading of this sub-section is written in inverted commas because in practice the telescope will perform astronomical observations for much less than 24-hours per day. This is because, for half of the time, the telescope will be on the sunlit side of the Earth and a limited range of targets will be observable, subject to the viewing constraints in Table 1. The typical object will only be observable for at most half an orbit and the longest continuous exposure on a single object will normally be about 2000 seconds. There are exceptions to this rule; for example, there is always some small patch of sky which could be viewed continuously by the telescope. What fraction of the total clock time is usable for astronomical observations also depends to some extent upon how observing programmes are scheduled. If the Space Telescope were run like a ground-based observatory in which the observer is allocated a certain number of "nights", the efficiency of the use of the telescope might be rather low if his targets lay in unfavourable positions on the sky for movements of the telescope. The opposite extreme would be to adopt a sequence of observations from a number of different programmes which would be optimised to result in the maximum amount of usable telescope time. It is likely that the usable observing time will be about 40%.

2.3 The observable waveband. The design of the telescope is such as to permit observations in the wavelength range 120 nm - 1 mm, i.e. in the ultraviolet, infrared and submillimetre wavebands as well as the optical. Because of the size of the mirror, the Space Telescope will have very much greater sensitivity in the ultraviolet waveband than the Copernicus and IUE observatories. Deep pictures may be taken in the ultraviolet for the first time. The selection of scientific instruments for launch in 1983 does not include any instrument which operates in the infrared or submillimetre waveband. However, there is the possibility of the inclusion of such instruments following the first and subsequent visits of the telescope by the Space Shuttle. The flight of the IRAS satellite in 1981 will surely stimulate much new astronomy to be undertaken in the infrared waveband. It would seem a pity if many of the unique capabilities of the Space Telescope were not to be harnessed to studies in the infrared and submillimetre waveband at some stage.

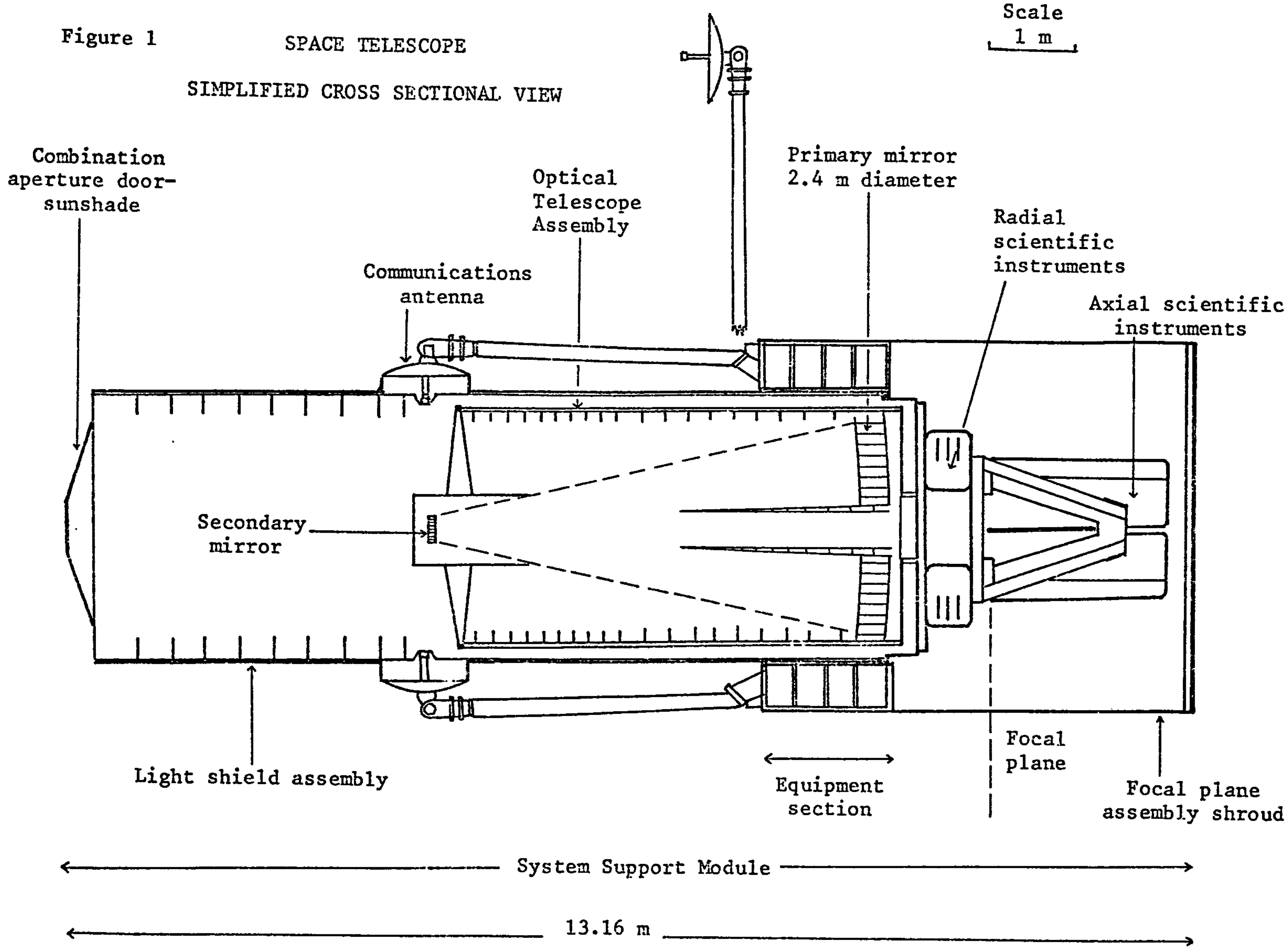
3. THE SPACE TELESCOPE AND THE SCIENTIFIC INSTRUMENTS

A simplified view of the Space Telescope is shown in Figure 1 which indicates some of the main components which make up the spacecraft. The main components are the Optical Telescope Assembly which consists of the telescope itself, the Support Systems Module, the Scientific Instruments and the Solar Array (not shown).

A Cassegrain configuration of Ritchey-Chretien design has been adopted for the telescope so that all the scientific instruments can be accommodated at the focal plane which lies behind the primary mirror. The primary mirror has focal ratio f/2.4 and the secondary is such that the overall focal ratio of the Optical Telescope Assembly is f/24. The outer radius of the field of view of the focal plane is 24.56 cm corresponding to an angular radius of 14.7 arcmin. On axis, there is a square area of side 10 cm which is dedicated to the Wide Field Camera. This instrument will be housed in one of the radial boxes. Around this area are four segments allocated to the four other scientific instruments which are housed in long coffin-shaped boxes parallel to the axis of the telescope; these are known as the four axial instruments. The outer radius of these segments is 9 arcmin and each comprises the data field for one of the axial instruments. Between these segments are three focal plane wavefront sensor mirrors

Figure 1 SPACE TELESCOPE

SIMPLIFIED CROSS SECTIONAL VIEW



which will be used to check the alignment and performance of the Optical Telescope Assembly in orbit. Outside the data fields for the four axial instruments are three 90° angular segments which are dedicated to the Fine Guidance Sensors. The associated optical and electronic systems are housed in or near the remaining three radial instrument bays.

The optical performance of the telescope is specified at a wavelength of 632.8 nm and a wavefront error of less than $\lambda/13.5$ must be achieved. There is no specification on the performance at any other wavelength and thus the ultraviolet performance will depend upon how much better the system can be manufactured than $\lambda/13.5$. The overall performance of the telescope will only be known in detail once it is in orbit and the point spread function as a function of wavelength measured directly by the Faint Object Camera. The final adjustments to the alignment and figure of the telescope will only be made in orbit.

3.1 The Wide Field/Planetary Camera. The impressive performance of the Wide Field/Planetary Camera summarised in Table 2 results from the proposal of the PI team to base the design upon the detectors known as Charge-Coupled Devices (CCDs). These devices have only recently reached the state of development at which they may be used in an astronomical context. They have the important property of having a very high quantum efficiency in the spectral range 400-1000 nm, about 60% in the best cases, and also that they are highly linear over a wide dynamic range. The principal sources of instrumental noise are thermal leakage of electrons and read-out noise when the amount of charge on each element is read-out by a high gain amplifier. To ensure a low rate of leakage of electrons, the CCD detectors will be operated in the Space Telescope at a low temperature of about -100°C. The read-out noise is anticipated to be about 12 electrons rms per read-out per picture element. Prototype detectors have already been successfully used on the Hale 200-inch telescope and detectors consisting of 800 x 800 elements have now been manufactured.

The design of the Wide Field/Planetary Camera is such that the field of view is split by a pyramidal mirror into 4 separate portions and each will be focussed onto a CCD detector consisting of 800 x 800 elements. Separate optical trains with different focal ratios are included to provide the Wide Field and Planetary modes although they share the initial part of the optical train including the pyramidal mirror. Which of the modes is selected is simply effected by rotating the pyramidal mirror through 45°. The camera thus contains 8 CCD detectors each consisting of 800 x 800 elements. The detectors will be specially coated with a film of a stable organic substance in order to improve their quantum efficiencies in the ultraviolet and a figure of 10% has been achieved in the wavelength range 100-300 nm.

Table 2

The Wide Field/Planetary Camera

The Camera can operate with two different focal ratios, f/12.9 or f/30. The former gives a field of view 2.67 x 2.67 $(arcmin)^2$ and is referred to as the Wide Field Camera; the latter gives a field of view of 68.7 x 68.7 $(arcsec)^2$ and is called the Planetary Camera.

	Wide Field Camera	Planetary Camera
Picture Format	1600 x 1600 pixels	1600 x 1600 pixels
Angular Field of View	2.67 x 2.67 $(arcmin)^2$	68.7 x 68.7 $(arcsec)^2$
Pixel Size	0.1 arcsec	0.043 arcsec
Dynamic Range (per pixel, single exposure)	> 15,000	> 15,00
Maximum S/N (per pixel, single exposure)	450	450
Photometric Precision	Better than 1%	Better than 1%
Photometric Accuracy	Better than 2%	Better than 2%
Overall Dynamic Range for stars (m_V)	+3 to +29	+1 to +29

The camera design includes filter wheels which can accommodate up to 50 spectral filters. It is proposed that there will be filters having bandwidth $\Delta\lambda/\lambda = 0.2$ throughout the range 120-1000 nm, including UBVRI filters and also filters with $\Delta\lambda/\lambda = 0.1$ in the visible and near infrared wavebands. There will also be narrow band filters for particular spectral lines such as Lyman-α, Hα, Hβ as well as polarisation filters. An important proposal is the use of visual, infrared and ultraviolet transmission gratings which will produce low dispersion spectra of the objects in the field.

3.2 The Faint Object Spectrograph. The aim of the Faint Object Spectrograph is to obtain the spectra of astronomical objects to the faintest possible magnitudes in the ultraviolet and visible wavebands. The design selected has been based upon the Digicon detectors which have proved their reliability in ground-based observations. By rapid electronic switching between the object and a blank region of sky, sources of background noise can be subtracted from the observed spectrum of the object.

In order to achieve the faintest possible magnitude limit, the design has been chosen to optimise the optical efficiency of the spectrograph which has been kept as simple as possible. The specification of the spectrograph is given in Table 3. The primary spectral resolving power of the spectrograph is the $R = \lambda/\Delta\lambda = 1000$ mode over the wavelength range 114 to 1010 nm. However, the spectrographic efficiency falls off rapidly at wavelengths longer than about

Table 3

Faint Object Spectrograph

Spectral range	114 to 1010 nm
Spectral resolving power R = λ/Δλ	R = 10^3 first priority R = 10^2 second priority
System Absolute Efficiency	> 1%
Radiometric precision	< 1% of maximum scene signal
Slot sizes: fixed apertures	1.00 arcsec diameter 0.50 arcsec diameter 0.25 arcsec diameter (fail-safe position) 0.10 arcsec diameter Special purpose occulting mask Closed
Centering stability	± 0.03 arcsec
Angular resolution	0.1 arcsec
Dynamic Range	10^7
Relative wavelength calibration	20% of resolving power
Detectors	512 diode linear array Digicons
Exposure times	Minimum gate time 50 μs Minimum periodicity 10 ms No limit on maximum length of target integration

650 nm. The secondary priority is for an R = 100 mode operating in the wavelength range 265-800 nm. The instrument will utilise Digicon detectors, each of which consists of a linear array of 512 independent diode elements and which will operate in a photon-counting mode. To achieve full spectral coverage in the primary R = 10^3 mode, 6 separate gratings are used which are mounted on a carousel. It is planned that there will be three other positions on the carousel. One will be used in conjunction with a linear polarisation filter which will enable linear spectropolarimetry to be performed with spectral resolution R = 10^3 in the wavelength range 180-285 nm. The second will consist of a compound prism which provides spectral resolving power R = 100 in the wavelength range 265-800 nm. The third will contain a camera mirror which is non-dispersive in the wavelength range 114-1010 nm and which is used for direct imaging so that target objects can be accurately centred on the slit.

With this system, the design goals for faint object spectroscopy described in the announcement of opportunity will be met, i.e. m_V = 22 in 3 hours of observation in the R = 10^3 and m_V = 25 in the same time in the R = 100 mode.

3.3 <u>The Faint Object Camera</u>. The aim of the Faint Object Camera is to exploit the full resolution capability of the Space Telescope on the very faintest objects detectable. It was decided to adopt an Image Photon Counting System similar to that developed with great success by Dr A. Boksenberg at University College, London. Every photon detected by the system is recognised as a single photon event which is stored in the computer and thus the noise performance approaches that of an ideal detector. The disadvantages are that, with the requirement to oversample the point spread function of the telescope, the field of view of the Faint Object Camera is limited by the large data storage requirements. Furthermore, the system saturates at high brightness levels, about 15 visual magnitudes $(\text{arcsec})^{-2}$, because the rate of arrival of photons becomes too great for them to be identified individually.

Table 4

Faint Object Camera

This table shows the proposed instrumental parameters which will be achieved by the Faint Object Camera operating in the f/96 mode.

Field of view	11 x 11 $(\text{arcsec})^2$
Angular resolution	Essentially limited by the performance of the Optical Telescope Assembly at wavelengths longer than 300 nm
Wavelength range	120 to 800 nm
Dynamic Range (single observation)	m_V = 21 to 28 on point sources; 15 to 22 visual magnitudes $(\text{arcsec})^{-2}$ for extended sources
Photometric accuracy	∿1% when not photon-noise limited
Focal ratio	f/96 assuming 25 μm pixels Additional focal ratios are desirable (see text)
Number of pixels	500 x 500
Exposure time	Up to 10 hours
Calibration	Internal sources and standard stars, necessary to provide required photometric accuracy

The design specification of the Faint Object Camera is given in Table 4. The design uses a 3 stage image intensifier which is magnetically focussed by a permanent magnet together with an intensified silicon target television camera tube. In the baseline design, an image consisting of 1000 x 1000 picture elements (pixels) can be obtained with elements of size 0.022 arcsec but the data store of 4 Mbits limits the usable field of view to 512 x 512 pixels. The quantum efficiency of the system is determined by the cathode efficiency of the photocathode which is greater than 10% over the waveband 150 - 500 nm. It is estimated that in a 10-hour exposure a stellar object of m_V = 28 can be detected with signal-to-noise ratio of 6. To express the sensitivity in another way, in 1000 seconds a star of m_V = 26 will be observed with signal-to-noise ratio of 5.

There will be three filter wheels in the optical path, each with 16 positions. It is proposed that each wheel will include three neutral density filters so that by combining any one or two of them a range of magnitudes $\Delta m = 0$ to $\Delta m = 16$ can be obtained. The third wheel may then be used to select whichever filter is desired. The band-passes of the other filters have not been decided yet but it is probable that they will be similar to those selected for the Wide Field/Planetary Camera. It is planned that there will be a dispersion prism in the optical path thus providing low resolution spectra for the objects in the field. There will also be a coronographic facility so that very faint structure can be studied close to bright objects. The mask will be placed in the focal plane and a second apodiser mask included further along the optical train to remove light scattered and diffracted by the Optical Telescope Assembly secondary mirror and spider.

One of the major concerns about the performance of the Faint Object Camera has been its limited field of view and, for this reason, the decision has been taken that the second back-up camera operate in an f/48 mode, thus quadrupling the field of view as compared with the f/96 camera. A second change is the incorporation of a spectrographic capability in the proposed f/48 mode of the second optical relay. This is achieved by inserting a grating into the second optical train which would have the effect of converting the Faint Object Camera into a "long-slit" spectrograph. In the proposed design, a two-dimensional spectrum is obtained for a cut 10 arcsec long and 0.1 arcsec wide through the object with spectral resolving power $R = \lambda/\Delta\lambda = 3000$. Thus, with angular resolution 0.2 arcsec, 50 separate spectra along this axis are taken in a single observation.

3.4 The High Resolution Spectrograph. The High Resolution Spectrograph is designed to exploit the capabilities of the Space Telescope in taking high resolution spectra in the ultraviolet region of the spectrum 105-320 nm with spectral resolving powers $R = \lambda/\Delta\lambda = 2 \times 10^4$ (equivalent to velocities of 15 km s^{-1}) and in the region 110-320 nm with $R = 1.2 \times 10^5$ (corresponding to 2.5 km s^{-1}). The details of the proposed spectrograph are given in Table 5. These characteristics represent a major improvement over the performance of previous generations of ultraviolet space observatories such as Copernicus and the International Ultraviolet Explorer (IUE) although it will not be possible to explore the spectral range $\lambda < 105$ nm which was opened up by the Copernicus

Table 5

High Resolution Spectrograph

Spectral resolving power $R = \lambda/\Delta\lambda$	2×10^4	1.2×10^5
Detector channel width: at 150 nm at 230 nm	0.0075 nm 0.0115 nm	0.0013 nm 0.0019 nm
Detector step or sub-step size	variable 0.001 - 2.3 nm	variable 0.002 - 0.38 nm
Overall spectral range	105-170 nm 110-320 nm	110-170 nm 170-320 nm
Spectral range per integration at 150 nm at 230 nm	 3.5 nm 5.9 nm	 0.56 nm 1.02 nm
Minimum and maximum integration times (seconds)	0.05 to ∞	0.05 to ∞
Field view	1.0×1.0 (arcsec)^2 0.30 arcsec	1.0×1.0 (arcsec)^2 0.30 arcsec
Dynamic range per resolution element per exposure	10^7	10^7
Photometric resolution	count-limited	count-limited

satellite and in which important spectral lines such as O VI and weaker lines of hydrogen and deuterium were detected. Objects 1000 times fainter than those which can be detected by these observatories will be observable. The very high spectral resolution will enable very sharp-lined spectra to be studied. The very high spatial resolution means that stars in crowded fields can be readily observed and close visual binaries studied separately. The spectral resolution is so high that only for a limited range of extragalactic objects of high surface brightness will observations be possible. It is expected, however, that quasars as faint as $m_v = 17$ will be observable with good signal-to-noise with spectral resolution $R = 2 \times 10^4$. Equally, the brighter active galaxies with active nuclei, such as Seyfert galaxies will be observable with the $R = 10^5$ mode.

The design of the spectrograph is straight-forward and is similar in some respects to that of the Faint Object Spectrograph. The detector is again a Digicon detector consisting of a linear array of 512 diode elements and there is a carousel which brings different gratings into the optical train (see Section 3.2). For the $R = 2 \times 10^4$ mode, there are 4 gratings which cover the spectral ranges 105-170, 110-165, 160-230 and 220-320 nm. A complication is that the bandwidth observed in a single observation in any given order is very much less than the spectral bands given above. However, by changing the angle of the grating, different orders may be focussed onto the array of diodes. For example, to cover the wavelength range 105-170 nm, 19 different angles of the grating will be required. A further way of selecting precisely the required region of the spectrum is by changing the magnetic focussing of the image tube onto the Digicon array.

The high dispersion mode, R = 1.2 x 10^5, is provided by an Echelle grating and again different wavelength ranges are selected by choosing different orders and by changing the angle of the grating. In this way the complete waveband between 110 and 325 nm may be observed with very high resolution by a single grating.

3.5 The High Speed Photometer/Polarimeter. The High Speed Photometer/Polarimeter is the simplest of the scientific instruments on board the Space Telescope. The device consists of a number of image dissectors, their associated electronics and a focal plane aperture mask and filter plate. The principle of the device is that the face plate in the focal plane contains a number of filter strips, each having a pair of three different aperture stops. Portions of some strips are coated with a polarising film in four orientations at 45^o, enabling linear polarisation to be measured. The image dissector aperture is determined by the largest field stop which is 0.8 mm diameter, corresponding to 2.9 arcsec diameter, the other apertures being 1.4 and 0.7 arcsec in diameter. Changing from one aperture to another is effected by moving the Space Telescope as a whole. The dissectors can be commanded to receive photoelectrons from any one of the filter-diaphragm-polariser combinations available. The characteristics of the High Speed Photometer/Polarimeter are shown in Table 6.

Table 6

High Speed Photometer/Polarimeter

Spectral range	115-850 nm (photometry) 210-700 nm (polarimetry)
Spectral resolution	∿ 2 nm (200-300 nm) ∿ 25 nm (115-350, u,b,v,y,Hβ) ∿ 80 nm (UBVR) ∿ 200 nm (110-350 nm) ∿ 500 nm (300-800 nm)
Fields of view	0.7, 1.4, 2.8 arcsec
Temporal resolution	As fast as 16 μs
Photometric characteristics	Pulse counting over dynamic range of 10^6 with no dead-time correction over first five decades; analogue mode extends range to 10^7 and overlaps counting mode over four decades with 2% A/D conversion accuracy.

The main purpose is to enable fast time resolution photometric observations of rapidly varying objects to be made with the Space Telescope. By "fast" are meant phenomena on timescales $\sim$ 1 ms and longer. There is also, however, the capability of looking for signals on timescales shorter than 1 ms, down to about 16 μs if necessary. The range of timescales, 1 ms to 1 s is particularly difficult to study from the ground because in this range atmospheric noise is large. This new domain of time resolution will be opened up by the High Speed Photometer. A very important aspect of this instrument will be that it will establish an accurate link between observations made on existing visual and ultraviolet photometric systems and the corresponding observations made with the Space Telescope.

3.6 Astrometry. Because of the very high resolution of the Space Telescope and its very high pointing stability (0.007 arcsec over 10 hours), there is great astrometric potential. Many of the observations will be made with the Fine Guidance System, the three independent sensors and detectors located in annular segments around the field of view in the focal plane. The field of view of each of these segments is 180 $(\text{arcmin})^2$ and the specifications on the sensors are that they should be able to identify and made acquisition of stars of $m_v = 13$ to an accuracy of 0.007 arcsec in 60 seconds. The specification of the magnitude limit to which the Fine Guidance Sensors must work has been selected so that there is always a high probability that suitable guide stars will be found in the fields of view of the sensors. The Space Telescope will be able to point rather precisely in the direction of the target object and then the Fine Guidance Sensors will search the fields of view of the sensors until they locate the appropriate guide stars. The correctness of the identifications will be established both by measurement of the relative positions of the guide stars and by their apparent magnitudes.

Two sensors are enough to point the Space Telescope precisely at the target and to maintain this position with an accuracy of 0.007 arcsec throughout the observation. The third sensor may therefore be used in a search mode to measure precisely the positions of stars in its field of view relative to the other two stars used for guidance. Obviously, the very high precision obtainable with the Space Telescope will enable an order of magnitude improvement in many types of astrometric observation. By repeated observation, relative accuracies of 0.002 arcsec will be achieved. Those aspects of astrometry which involve the precise measurement of angles over large arcs in the sky will be difficult with the Space Telescope. This can only be done by patching together adjacent regions of sky which are separated by no more than about 25 arcmin.

4. COMPARISON OF THE WIDE FIELD/PLANETARY CAMERA AND THE FAINT OBJECT CAMERA

There is already considerable experience in ultraviolet spectroscopy from space vehicles, principally as a result of the series of OAO satellites and most recently the International Ultraviolet Explorer. The two cameras are perhaps the most novel feature of the Space Telescope and are complementary in performance. We can distinguish two aspects in the comparison of the cameras, their angular resolving power and their sensitivity to faint objects as a function of wavelength.

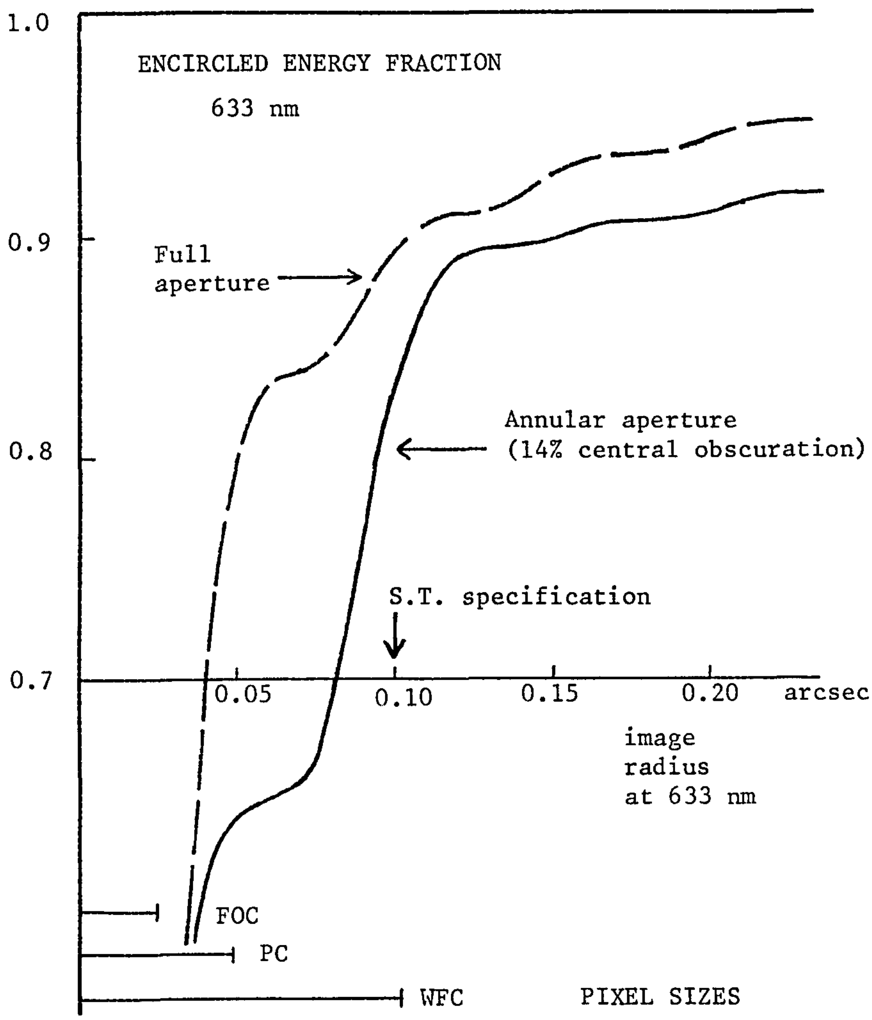


Figure 2

Figure 2 shows the encircled energy fraction of the Space Telescope. The dashed line indicates the encircled energy fraction as a function of radius (in arcsec at 633 mm) for a mirror of 2.4 metres full aperture. The points of inflection along the curve correspond to those radii at which the point spread function of a perfect mirror go to zero. As expected from the Rayleigh criterion, 70% of the incident energy falls within about 0.04 arcsec radius. If there is 14% central obscuration of the aperture area, power is removed from the central peak to the outer wings of the point-spread function whilst the width of the central "lobe" is slightly narrowed with the result shown in Figure 2 by the solid line. This curve is the theoretical prediction for a perfect mirror. Provided the system wavefront error is less than $\lambda/13.5$, the encircled energy fraction should be similar to that indicated by the solid line in Figure 2. The origin of the performance specification of the Space Telescope by NASA can be appreciated from this figure. 70% of the encircled energy lies within about 0.08 arcsec radius and thus the requirement that 70% of the energy should fall within 0.1 arcsec radius is a reasonable goal. It is interesting to note, however, that more than 50% of the power lies within about half of that radius which means that it will be possible to obtain significantly better angular resolution than might be thought from the figures quoted in the performance specification.

Also shown in Figure 2 are the sizes of the picture-elements (pixels) of the two cameras; the pixel sizes for both the Wide Field and Planetary Camera modes are shown. Clearly the Faint Object Camera is superior to the Wide Field/ Planetary Camera in terms of angular resolution at all wavelengths and will provide proper sampling of the point spread function of the telescope, in particular in sampling the central "core" of angular radius 0.04 arcsec.

The second aspect of this comparison is the relative speeds of the cameras as a function of wavelength. The differences in performance result from the following characteristics of the detectors: (a) the maximum quantum efficiency of the CCD detectors in the Wide Field Camera lies at wavelengths longer than about 500 nm and is about 60% whereas that of the photo-cathodes in the Faint Object Camera lies at wavelengths shorter than about 400 nm and reaches about 25%. (b) The dark current in the CCD camera amounts to about 0.1 events per pixel per second whereas that of the IPCS camera is about 2 or 3 orders of magnitudes smaller. (c) Every time the charge on each element of the CCD array is read-out, it is accompanied by amplifier read-out noise which it is estimated will amount to about 12 electrons r.m.s. per pixel; there is no read-out noise in the IPCS. When these differences are taken into account, the relative speeds of the cameras in detecting faint objects can be compared. In Figure 3, the comparison is made for the detection of a star with a flat spectrum having $m_V = 27$ with S/N = 5 using a band-pass of 100 nm. When the exposure time exceeds 10 hours for any of the cameras, this is indicated by letters on the diagram. It can be seen that the two cameras are of roughly the same speed at about 500 nm. At longer wavelengths, the Wide Field/Planetary Camera is superior, whereas at shorter wavelengths, the Faint Object Camera has the better performance. Since this diagram was prepared, the performance of the Faint Object Camera at wavelengths longer than about 500 nm has been somewhat degraded because of the decision to use a bialkali photocathode. In compensation, the ultraviolet response has been improved and the sense of Figure 3 remains quantitatively unchanged.

In comparing the cameras, it should also be recalled that the Wide Field Camera always has the larger field of view (2.67 x 2.67 arcmin^2) compared

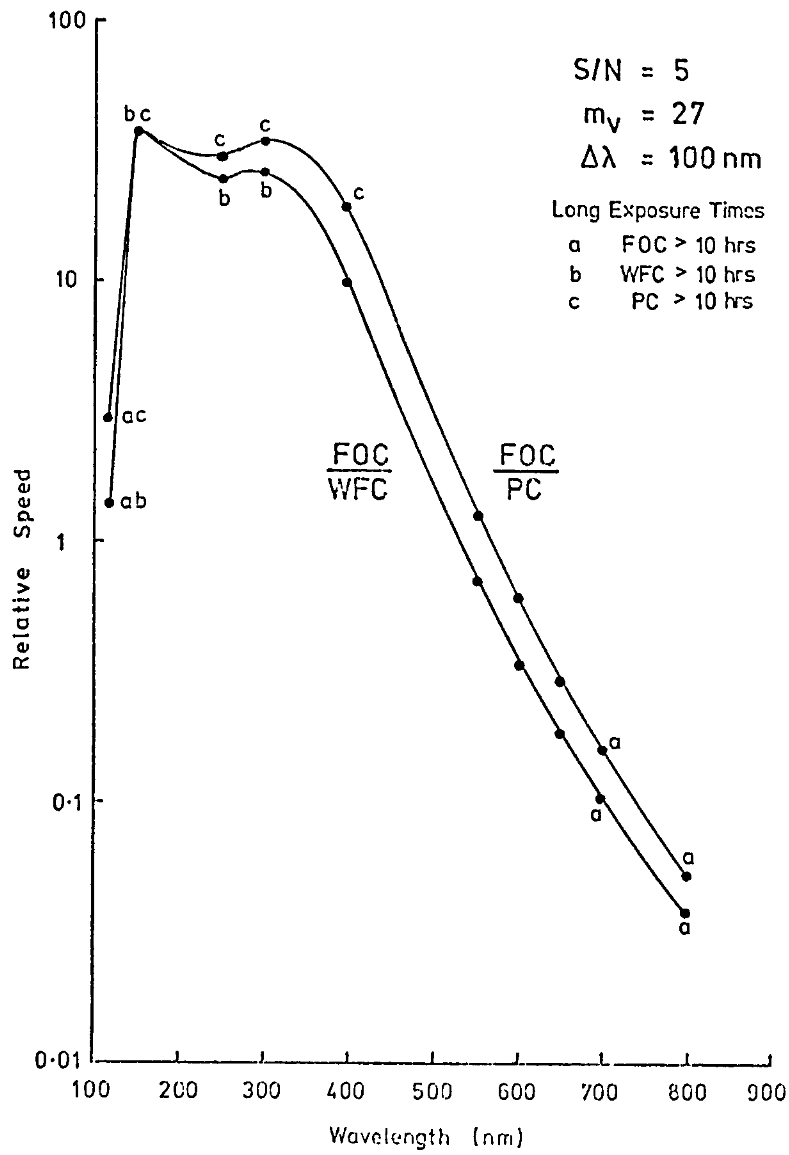


Figure 3

with 11 x 11 $arcsec^2$ for the Wide Field Camera in the f/96 mode and 22 x 22 $arcsec^2$ in the f/48 mode. On the other hand, the Faint Object Camera does possess the spectrographic mode which has the unique capability of providing two dimensional or "long-slit" spectra.

In summary, it can be seen that, whether by design or good fortune, the two cameras complement each other in a most gratifying way. In view of the importance of the cameras in the Space Telescope project, there is also an advantage in having redundancy in this area.

5. OBSERVING PROGRAMMES AND THE SPACE TELESCOPE

It is informative to investigate how a specimen observing programme might be implemented in practice. It is not necessary at this stage to know how time will be allocated, block time or as part of an integrated programme. The aim of this exercise is to estimate how much astronomy can be achieved in different types of programmes. So far as the spectrographs are concerned, we already have extensive experience from the Copernicus and IUE satellites. It is of most interest to investigate programmes for the cameras, in particular the Wide Field/Planetary Camera which generates by far the largest amount of data. I will not discuss the spectrographic mode of the Faint Object Camera which is the subject of a later paper by Professor M. Disney.

The Wide Field Camera Team suggested a specimen observing programme as part of their successful proposal and I have extracted some examples from that programme to illustrate how different programmes can be executed. It must be noted that these are order of magnitude estimates only and the priorities for observation will change as the full capabilities of the Space Telescope become more precisely defined. Equally, the Wide Field Camera Team are likely to modify the aims of their programmes in the light of changing astronomical priorities. However, these examples will provide a good indication of the constraints which are important and which are driven not only by the capabilities of the telescope but also by the scientific requirements of the programme. I have selected some programmes of obvious astronomical and cosmological significance.

First of all, how much time is usable? The Wide Field Camera team is guaranteed about 2.2 months observing time out of the first 30 months of the telescope in orbit, i.e. about 7.5% of the first 2½ years of operation of the telescope. Except for planetary observations, most of the programmes can only be carried out when the telescope is on the dark side of the Earth. We will therefore only consider dark-time half orbits. Of these orbits, 2/3 do not pass through the South Atlantic Anomaly, being equivalent to 630 half-orbits of dark time. Each of these half-orbits corresponds to an exposure time of about 2000 seconds during which the telescope satisfies the pointing constraints in Table 1 to enable the faintest objects to be observed. Because of the high quantum efficiency of the Wide Field Camera at wavelengths longer than about 400 nm, this exposure time is adequate to detect stars having $m_V = 27$. It is likely that this will be the longest exposure used in most observations with the Wide Field Camera. To make a longer exposure, more than one half-orbit of observations would have to be made and, since the CCD detectors would have to be read-out after each half-orbit and each read-out adds a noise signal of about 12 electrons r.m.s., the cumulative effect of the read-out noise means that for faint objects, the limiting magnitude attained increases only slowly with increasing exposure time. About 1/3 of the orbits pass through the South Atlantic Anomaly and hence exposure times of only about 500 seconds will be possible.

Cepheid variables. One of the drivers behind the design of the Space Telescope was to enable Cepheid variables to be detected in the Virgo cluster of galaxies and thus provide a direct calibration of the extragalactic distance scale using the most successful of the extragalactic distance indicators. At the distance of the Virgo cluster,the 2.67x2.67 arcmin^2 field of the Wide Field Camera corresponds to a physical size of about 30 kpc so that the image of Virgo cluster galaxies can be observed in a single exposure. A possible programme would be to observe 10 galaxies with radial velocities in the range 200-1000 km s^{-1}, three of them being members of the Virgo cluster. To determine light curves, say 10 images of each of these galaxies would be required and a further image in, say, the I waveband would be needed to provide colour information. This programme would require about 100 2000-second exposures. The analysis of the images of the galaxies would follow procedures similar to those used by Hubble but the whole procedure will be done digitally.

Globular clusters and HII regions. To extend the distance scale to velocities $\approx$ 6000 km s^{-1}, the techniques of using the sizes of giant HII regions and the luminosity function of globular clusters may be employed. If 20 galaxies are observed in the velocity range 300-6000 km s^{-1}, 20 2000-second exposures would be required to provide a single image of each galaxy.

Distant clusters of galaxies. One of the most important projects for the Space Telescope is the extension of the redshift-magnitude relation for the brightest galaxies in clusters to redshifts $z \approx 1$. The hope is that these observations may provide information about the evolution of the properties of clusters with cosmic epoch and, potentially, to estimates of the deceleration parameter q_o. A conceivable pilot programme would be to study 10 clusters in the redshift interval $0.4 \lesssim z \lesssim 1.0$. There are a number of problems in performing such a programme with the Space Telescope.

First of all, following Gunn and Oke's analysis of the redshift-magnitude relation, it is preferable to measure the spectra of each galaxy used in the test rather than assume that a standard galaxy spectrum is appropriate for all galaxies. To compare the distant galaxies with those already observed at low redshifts, it is necessary to measure the optical spectra of the former at wavelengths $\lambda > 600$ nm. The sensitivity of the faint object spectrograph has been optimised for observations in the ultraviolet waveband and is not suitable for these observations. Indeed, even obtaining a redshift for a galaxy at $z = 1$ will be difficult if one has to rely solely upon absorption lines as is likely to be the case for these galaxies. The Wide Field Camera team propose taking images of the clusters using 10% filters which will enable K-corrections to be estimated directly for each galaxy as well as redshift estimates from the overall energy distribution. In addition, these studies will provide direct evidence on the astrophysical evolution of the cluster members from their colours. Broad-band pictures will provide detailed information on the morphological types of galaxies present and empirical evidence on the importance of phenomena such as "cannibalism". This programme of observation of 10 clusters would require about 140 2000-second exposures.

This example illustrates how difficult the redshift-magnitude relation for cluster galaxies is. These numbers should be compared with Gunn's estimate of the number of galaxies needed to determine q_0 to an accuracy of 0.2 - 100 brightest cluster galaxies at $z \approx 0.4$. At the larger redshifts which become accessible with the Space Telescope, the evolutionary changes are expected to be much more important that at small redshifts and this complicates the whole problem in ways which cannot be precisely predicted at present.

There remains of course the problems of finding these distant clusters. Probably about one in every 10-20 Wide Field Camera pictures will contain a cluster as rich as an Abell cluster at a redshift $z \approx 1$. Alternatively, one may look in the direction of extended X-ray sources which have thermal bremsstrahlung spectra at high galactic latitudes. Some of these are likely to be associated with the X-ray emission of hot gas in rich clusters. Another possibility is to look in the direction of unidentified radio sources with steep low frequency radio spectra.

It will be observed that even these 3 programmes in classical cosmological studies use up 260 of the dark half-orbits out of a maximum possible of 630. Observations of individual galaxies and systems of galaxies are not so demanding of telescope time but they are still considerable. For example:

Stellar populations in galaxies. A typical programme might consist of, say, 6 fields in 6 colours in M31, 4 fields in 6 colours in the Large and Small Magellanic Clouds and so on. Each of these images would require a 2000-second exposure.

High resolution pictures of active nuclei. Observations of 10 galactic nuclei using 10 filters to isolate particular spectral lines would require 100 2000-second exposures.

The nature of the optical structure around quasars. For quasars with redshifts $z < 0.6$, the underlying galaxy, if such there be, should be readily distinguishable in 500 seconds of integration.

Radio source identifications. These will all require 2000-second exposures because all the identifications with objects brighter than $m_V \approx 22.5$ will have been made from ground-based observations.

These are only a few of the examples in extragalactic astrophysics of the types of programmes which can be envisaged and how much data can be compiled. The reader may work out readily how a given amount of observing time could be used in any problem from the above examples. A useful guide is that there are roughly 16 dark half-orbits per day.

Similar examples could be given in Galactic astronomy - studies of the populations of globular clusters to very faint magnitudes, of HII regions and planetary nebulae, supernovae and so on.

The message from these simple examples is that observing programmes must be planned with great care. For many of the most important programmes, the amount of Space Telescope time required is very large. On the other hand, the information contained in a single Wide Field Camera frame is vast and can be used in more than one programme. For example, the galaxies studied for Cepheid variables can also be used for many other studies of galactic structure and evolution. Studies of radio source fields will provide information about the distribution of galaxies at very faint magnitudes. There is thus great scope for collaborative projects on objects which appear in different observing programmes.

These examples reinforce the remark made at the beginning of this paper. It is essential to plan your Space Telescope observing programme now because there will not be time available for making mistakes. Everything possible should be done from ground-based observatories so that when the Space Telescope observations are made we are all in a position to make the optimum use of them.

ACKNOWLEDGEMENTS

This review is based upon an article entitled "The Space Telescope and its Opportunities" which will be published in March 1979 in the Quarterly Journal of the Royal Astronomical Society. In preparing that paper, I received valuable advice from Drs W. M. Burton, I. King, D. C. Morton, C. R. O'Dell, N. E. Roman and L. Spitzer. I again gratefully acknowlege their help.

P.E. NISSEN : I was surprised to see that the FOC should be much faster than the WFC in the ultraviolet for faint objects. Is that due to a higher quantum efficiency of the FOC?

M.S. LONGAIR : It is partly due to the higher quantum efficiency of the FOC ($\sim$25%) compared with that of the WFC ($\sim$10%) but mostly due to the differing noise characteristics of the cameras (see text of lecture). In the ultraviolet, the noise due to leakage and read-out noise becomes relatively much more important for the WFC in comparison with the FOC.

P.E. NISSEN : For which kind of stars did you make the comparison?

M.S. LONGAIR : A flat spectrum was assumed.

STATUS OF THE ST PROJECT IN THE UNITED STATES

C. R. O'Dell

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The Space Telescope (ST) project is well underway, having begun its design and development phase in October 1977. Since launch is not planned until late 1983, we are still in the process of preliminary design and have yet much to do. However, the basic structure and plans for the development are already well determined and can be described now.

Within the National Aeronautics and Space Administration (NASA) organization, two of its field centers play primary roles. The Marshall Space Flight Center in Alabama has overall responsibility for the design and development of the Space Telescope and the Goddard Space Flight Center near Washington, DC is responsible for development of the Scientific Instruments and the post-launch control of the observatory. Contractors have been selected for the optics and the entire observatory, in addition to contracts for the individual Scientific Instruments and scientific involvement with the spacecraft as an observatory. In all, we now have some 1000 engineers and staff people and 50 scientists working on the Space Telescope. It is the largest science project currently being conducted by the NASA.

All facets of the Space Telescope project are important, but none more so than the primary mirror. The nature of the mirror was thoroughly determined in our extended preliminary design phase, and this mirror is already under construction. The Perkin-Elmer Corporation has responsibility for development of the Optical

Telescope Assembly, and they have already received delivery of the mirror blank that will eventually become the flight mirror. The machining processes preparatory to actual grinding of the optical surfaces are now underway. Perkin-Elmer intends to grind the mirror using a computer-controlled polisher; and they are now completing a precise, light-weight 1.5-m test mirror using this system. In the event of an accident in this crucial area, a second mirror will be developed by the Eastman Kodak Corporation.

The primary activity on the observatory is the preparation of preliminary designs for the Preliminary Design Review, to be held late this spring and early summer. At that time, we will see a good approximation of our final solutions and configurations. Probably even more important is the development of the interface requirements, which must be settled prior to proceeding into design.

We are presently in the midst of a critical review cycle for the Scientific Instruments. The complement of four United States provided Scientific Instruments was originally selected contingent upon a final confirmation about one year after the initial selection. This confirmation is being conducted now. The characteristics of the five Scientific Instruments are enclosed in Table 1. Preliminary Design Reviews have been held for all of these instruments, and they are all technically ready to proceed into design and development.

NASA has adopted a plan whereby Science Operations will be the responsibility of a contracted corporation which will operate a Space Telescope Science Institute. This approach has been presented as part of the budget proposed by NASA to the Congress for fiscal year 1980 (starts 1 October 1979). The underlying motive is to give the scientific direction over to the user community for whom the ST is being built. Direct operational control will be executed from NASA's Payload Operations Control Center. The call for proposals will be issued in early October 1979, and we expect to have the successful organization under contract in the summer of 1980. Since the selection will be done by all procedures applying to a competitive selection and these procedures are not familiar to most scientific groups, a seminar on proposal preparation will be held 7 March 1979 and a draft copy of the solicitation document will be issued in early April. The primary purpose of this release is to allow potential proposers to accurately determine the staffing requirements for preparing the proposal. A secondary purpose is to allow potential respondents to give suggestions to NASA about the solicitation document contents.

NASA is interested in having serious international use of the Space Telescope and intends that all scientists are able to compete equally for observing time and will direct the Science Institute accordingly. However, the NASA cannot fund foreign use of the Space Telescope; and it will be up to individual users to arrange this aspect. The European Space Agency (ESA) and NASA do have a Memorandum of Understanding which guarantees ESA members at least 15% of the Space Telescope time, in recognition of the financial contribution of ESA in providing the Faint Object Camera, the Solar Arrays and some 12-16 persons for the Science Institute. The exact nature of the Science Institute participation is now being specified, but it is expected that the ESA-provided personnel will include scientists who will be in a good position to make use of the Space Telescope.

TABLE 1

PARAMETER	UNITS	WIDE FIELD/ PLANETARY CAMERA	FAINT OBJECT CAMERA	FAINT OBJECT SPECTROGRAPH	HIGH RESOLUTION SPECTROGRAPH	HIGH SPEED PHOTOMETER
f/Number	---	12.9/30	48/96	N/A	N/A	N/A
Resolution	arc-sec	0.2/0.086	0.022/0.044	N/A	N/A	N/A
Resolving Power	$\frac{\lambda}{d\lambda}$	N/A	N/A	100/1000	1.2×10^5 / 2.4×10^4	N/A
Field of View	$\frac{\text{arc-min}^2}{(\text{arc-sec})^2}$	2.67/1.1 arc min	(8.8) / (4.4)	.1 - .2 arc sec	.25/2 arc sec	(0.4 - 10)
Spectral Range (Note 4)	nm	120 - 1000	120 - 600	120 - 650	120 - 280	120 - 800
Dynamic Range (Note 1)	---	8.5 - 28 mv	Note 3	10^7	10^7	10^7
Photometric Precision	%	Note 2	Note 2	Note 2	Note 2	Note 2
Detector	---	CCD	Ebsicon w/Intensifier	Digicon	Digicon	Image Dissector
Pixel Size	µm	15	25	40	40	N/A
Pixel Array	---	1600 x 1600	512 x 512	1 x 512	1 x 512	N/A

NOTES:
(1) Single Observation
(2) Photon Counting
(3) Up to .8 events/pixel/sec
(4) WF/PC specified at 3% instrument efficiency; FOC specified at 1% photo cathode efficiency; all others specified at 1% instrument efficiency.

P.A. WEHINGER : What is the present status concerning the selection of a site and organization that will operate the Science Institute?

C.R. O'DELL : NASA will know nothing of an official nature until the proposals for the Science Institute are received late this year. I understand that representatives of a number of prospective sites and prospective operators are negotiating, in anticipation of submitting proposals.

M.S. LONGAIR : Can you clarify the situation with respect to real-time operations of the Space Telescope? I understand there will be the possibility of 85% real-time communication with Space Telescope but what precisely does that mean in terms of control of the instrument?

C.R. O'DELL : Access to the Tracking & Data Relay Satellite System will determine how much real time use there can be. We expect to be able to listen in to Space Telescope at a low (4 Kps) data rate for 85% of the time. Our command links will be shared with 20 other users, and it has yet to be determined just how this will work. True real-time observation may not be possible and if this were to occur, we would then push for a sophisticated, on-board branching capability. This capability would be usable even if only a small fraction of the time was available for commands.

STATUS OF THE ST PROJECT IN EUROPE

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I. INTRODUCTION.

The NASA Space Telescope is the most ambitious project in space astronomy presently planned and will dominate astronomical research for the rest of the century.

ESA had been discussing with NASA the possibility of cooperating in this programme since 1975. In October 1976 ESA's Science Programme Committee approved the Agency's participation in the programme subject to the successful conclusion of negotiations with NASA and overall approval of the ST programme in the USA. The project was approved for a new start by the United States Congress in the Summer of 1977 and the Memorandum of Understanding between NASA and ESA was signed in October 1977.

According to the terms of this agreement, ESA's participation in the ST programme consists of three basic elements:

- a contribution to the spacecraft hardware; these are the solar arrays and associated deployment mechanisms
- the contribution of one of the focal plane instruments namely the Faint Object Camera
- the provision of personnel support to the activities of the Science Institute.

In return for this participation, European astronomers from the ESA member states will be guaranteed a minimum of 15% of the ST observing time, and this can be utilized on every instrument on-board the ST. The 15% minimum does not seem a large figure at first sight, but even this would be invaluable to Europe: in terms of hours per year, this share would exceed the entire clear dark time on a ground-based telescope and it will give European astronomers the chance to share in the order-of-magnitude improvement offered by ST.

II. THE ESA ADVISORY STRUCTURE FOR THE ST.

From the very beginning of this programme one of ESA's concerns was to promote the interest and direct involvement of the European astronomers in the ST programme. To this end it has established two advisory groups, the ST Working

Group and the FOC Instrument Science Team.

The role of the ST Working Group is to represent the prospective European users of ST and its tasks are to advise ESA on its involvement in the Science Institute, on how to maintain an open dialogue with the European community on the ST project and in preparing the European astronomers to utilizing the Space Telescope. The ST Working Group is chaired by Prof. F. Pacini and its members are Prof. G. Courtès, Prof. M. Disney, Prof. A. Dollfus, Prof. M. Hack, Dr. H.O. Keller, Prof. R. Kippenhahn, Dr. M. Longair, Dr. G.A. Tamman, Dr. H. van Woerden, Prof. B.E. Westerlund and Prof. R. Wilson, with Dr. F. Macchetto the ST Project Scientist ensuring the necessary liaison with ESA.

The second group is the Faint Object Camera Instrument Science Team whose task it is to provide advise to ESA on the scientific integrity of the definition and design of the Faint Object Camera. It is responsible for defining the detailed scientific objectives of the Faint Object Camera and its performance requirements and provide continued scientific guidance throughout all the phases of the programme including the post launch commissioning of the instrument. The Instrument Science Team is chaired by Prof. H. van de Hulst and its members are: Dr. R. Albrecht, Prof. C. Barbieri, Dr. A. Boksenberg, Dr. P. Crane, Dr. J.M. Deharveng, Prof. M. Disney, Ir. Th. Kamperman, Prof. I. King, Dr. C. Mackay and Dr. R. Wilson, with Dr. F. Macchetto ensuring the liaison with ESA and the ST project.

III. THE FAINT OBJECT CAMERA.

The most interesting aspect of ESA's contribution to the ST programme is undoubtedly the Faint Object Camera (FOC). The aim of the FOC is to fully exploit the spatial resolution capability of the Space Telescope over a broad wavelength range on the very faintest objects detectable.

With the FOC it will be possible to obtain imagery and accurate photometry of stellar objects as faint as $m_V = 28$, for which a cumulative exposure of 10 hours will yield a signal-to-noise ratio of not less than 4. In the u-band a similar exposure will yield $s/n \approx 3$ on a 29th magnitude star with an A0 V flux distribution. For observations of extended objects such as galaxies, at full resolution of the telescope, an exposure of 10 hours will yield a $s/n \approx 3$ at the 24th magnitude per arc sec^2 (u-band) brightness level. With these performance capabilities the scientific applications are essentially unlimited. They include, for example, observations of RR Lyrae stars, Cepheids, bright supergiants, globular clusters and giant HII regions as distance indicators out to expansion velocities greater than 10^4 km $\cdot$ s^{-1}; resolution of spectroscopic and astrometric binaries to establish fundamental stellar masses, detailed studies of shock fronts, condensing gas clouds and the relationship of young stars to the gas around them in regions of star formation; optical identification of X-ray sources; velocity dispersion and mass densities studies in the central regions of normal and compact elliptical galaxies; spectrography of active nuclei of galaxies and objective prism surveys of high latitude X-ray sources.

The FOC is one of the four axial scientific instruments located at the focal plane of the Space Telescope and has overall dimensions of about 0.9 x 0.9 x 2.2 meters. The FOC configuration is modular and interchangeable with other axial scientific instruments; this design ensures that removal and installation can be achieved in-orbit by a suited astronaut. The basic performance characteristics of the FOC are shown in Table 1 and a photograph of the full-size mock-up is shown in Fig. 1. The FOC consists of two main elements; the Camera Module which includes the optics, mechanisms and electronics and the Photon Detector Assembly which consists of two detectors and the associated electronics.

The Camera Module provides two optical relays which image a dedicated part of the field of view of the Space Telescope onto one of the two detectors, Fig. 2. The baseline mode of the FOC involves imaging at f/96. A three-element optical relay corrects for the astigmatism of the ST off-axis image and focusses it on the photocathode of a detector dedicated to f/96. At this focal ratio, the 25μm pixels of the FOC detector subtend 0.022 arc sec thus oversampling the ST point spread function. There will be four filter wheels in this optical path located near the pupil, each with 12 positions. They will carry a wide range of colour and neutral density filters, polarizers and two objective prisms optimized for response at 150 nm and 250 nm respectively. By suitably combining the neutral density filters a maximum attenuation of $\Delta m = 12$ can be achieved thus allowing the overall linear dynamic range of the FOC to extend from about $m_V = 5$ to $m_V = 29$. In addition the f/96 camera includes a coronographic facility consisting of a small (0.6 arc sec diameter) spot in the ST focal plane and an apodizer mask located at the pupil. This combination ensures the removal of the light from the bright source and the scattered light from the telescope mirror and spider and will allow the imaging of a faint object near a bright one with a difference in magnitudes of $\Delta m_V \simeq 14$ to 16.

The second optical relay, is an f/48 system which provides images at a reduced resolution but over a field of view four times as large. Also in this case a three element system images the aperture onto its dedicated detector. In this optical relay two filter wheels are included. In addition the f/48 can be converted into a long slit spectrograph, Fig. 3. This is achieved by inserting a mirror into the beam to relay it to a fixed grating which disposes and focusses the light onto the f/48 detector. The entrance slit of the spectrograph is 0.1 x 10.0 arc sec, thus with a Space Telescope spatial resolution of 0.2 arc sec, 50 separate spectra are taken in a single observation.

The two detectors included in the FOC are of indentical design. They consist of a three stage, magnetically focussed image intensifier tube which is lens coupled onto the faceplate of a television type camera tube, Fig. 4. The intensifier utilizes a "hot-bialkali" photocathode deposited on a MgF_2 window. This combination allows the useful response of the detector to extend from 115 nm $< \lambda <$ 700 nm, with an extremely low dark current characteristic. The detector operates in a photon counting mode where every photon detected by the photocathode is recognized as a single photon event whose positions of arrival is stored as an x-y coordinate in a dedicated accuracy. The advantages of this system are that the spatial resolution is maintained, the dark noise contribution minimized and the linearity of the system extends over many decades being limited only by the rate of arrival of photons, when it becomes too great for each of them to be identified individually. The main limitation of this detector system stems from the requirement of storing, at a high speed of 10 MHz, the x, y coordinates of the photon events. This can be achieved by utilizing a dedicated memory, which in the FOC case is limited because of power and mass reasons to a maximum of 4 Megabits. With a 16 bit word this translates to a total number of pixels capability of 512 x 512 or equivalent combinations. A new mode has been recently implemented which utilizes an 8 bit address allowing a total number of 1024 x 512 pixels to be scanned. Thus the limitation on the number of pixels arise from the data store size rather than from the detector as this would be capable in principle to deliver 1024 x 1024 pixels. Another useful characteristic of the detector is that the size of the pixel can be changed, by command, from 25μm to 50μm thus allowing a longer field of view to be scanned, albeit at a lower resolution.

The combination of the detector and optics result in a total system performance for the FOC (including ST) illustrated in the Tables 2, 3, 4, 5, 6, 7. These performance characteristics have been computed in magnitudes for a point object, or magnitudes per arc sec^2 for extended objects. In each case the spectrum of the source has been taken to be equivalent to an A0 V star and the integration has been carried out over a bandpass of 100 nm centered around the U band for the imaging mode and around the V band for the spectroscopic mode. These performance characteristics together with the versatility of the instrument make of the FOC one of the most exciting instruments ever to be flown.

TABLE 1A

Performance Characteristics of the Faint Object Camera

Optical Paths	f/96 and f/48
Angular Resolution	Performance essentially limited by telescope
Field of View (nominal)	11x11 arc sec, 22x22 arc sec
Pixel Format (nominal)	500 x 500
Pixel Sizes	25μm and 50μm
Angular Pixel Sizes (arc sec)	f/96 : 0.022 : 0.044; f/48 : 0.044, 0.088.
Wavelength Range	120 nm to 700 nm
Photometric Accuracy	∿ 1% when not photon-noise limited
Linear Dynamic Range (single observation)	m_V = 21 to 28 point sources m_V = 15 to 22 (arc sec)^2 extended objects
Linear Dynamic Range (including neutral densities)	m_V = 5 to 28 point sources
Maximum S/N per exposure	∿ 400

TABLE 1B

Selectable Pixel Formats and Resulting Field of Views in units of arc seconds.

FORMAT	f/96	f/48
1000 x 500 (8 bit only)	22 x 11	44 x 22
1000 x 250	22 x 5.5	44 x 11
500 x 500	11 x 11	22 x 22
250 x 250	5.5 x 5.5	11 x 11
120 x 120	2.6 x 2.6	5.5 x 5.5
60 x 60	1.3 x 1.3	2.6 x 2.6

TABLE 2

F/96 Nominal Performance for Point Sources

Mu	TIME FOR S/N = 10	S/N IN 1000 S	S/N IN 10 HRS
21	25	63.58	381.45
22	63	39.97	239.84
23	160	25.00	150.01
24	419	15.44	92.67
25	1163	9.27	55.64
26	3615	5.26	31.56
27	13456	2.73	16.36
28	61411	1.28	7.66
29	328468	.55	3.31
30	1924277	.23	1.37

TABLE 3

F/96 Nominal Performance for Extended Objects
(in magnitudes per arc sec^2)

Mu	TIME FOR S/N = 10	S/N IN 1000 S	S/N IN 10 HRS
15	35	58.19	319.12
16	89	33.55	201.29
17	224	21.15	126.91
18	564	13.32	79.93
19	1429	8.37	50.19
20	3673	5.22	31.31
21	9758	3.20	19.21
22	17863	1.89	11.37
23	91131	1.05	6.29
24	362313	.53	3.15
25	1751807	.24	1.43

TABLE 4

F/48 Nominal Performance for Point Sources

Mu	TIME FOR S/N = 10	S/N IN 1000 S	S/N IN 10 HRS
21	25	63.61	381.68
22	62	40.03	240.20
23	159	25.10	150.58
24	412	15.59	93.52
25	1115	9.47	56.82
26	3312	5.50	32.97
27	11543	2.94	17.66
28	49340	1.42	8.54
29	252301	.63	3.78
30	1443688	.26	1.58

TABLE 5

F/48 Nominal Performance for Extended Objects

(in magnitudes per arc sec^2)

Mu	TIME FOR S/N = 10	S/N IN 1000 S	S/N IN 10 HRS
17	14	83.62	501.71
18	36	52.69	316.11
19	91	33.13	198.75
20	233	20.72	124.31
21	611	12.80	76.78
22	1694	7.68	46.09
23	5270	4.36	26.14
24	19634	2.26	13.54
25	89679	1.06	6.34
26	479913	.46	2.74
27	2812231	.19	1.13

TABLE 6

SPECTROSCOPIC MODE PERFORMANCE AO POINT STAR, 480 NM BAND

Mv	TIME FOR S/N = 10	S/N IN 1000 S	S/N IN 10 HRS
12	5	138.48	830.87
13	13	87.37	524.23
14	33	55.12	330.73
15	83	34.77	208.63
16	208	21.93	131.56
17	524	13.82	82.89
18	1325	8.69	52.12
19	3388	5.43	32.60
20	8879	3.36	20.14
21	24638	2.01	12.09
22	76617	1.14	6.85
23	285393	.59	3.55

TABLE 7

SPECTROSCOPIC MODE PERFORMANCE AO EXTENDED OBJECT, 480 NM BAND

(magnitudes per arc sec^2)

Mv	TIME FOR S/N = 10	S/N IN 1000 S	S/N IN 10 HRS
8	8	115.38	692.27
9	19	72.80	436.77
10	47	45.92	275.55
11	119	28.97	173.80
12	300	18.26	109.57
13	756	11.50	69.00
14	1919	7.22	43.31
15	4941	4.50	26.99
16	13180	2.75	16.53
17	37951	1.62	9.74
18	125892	.89	5.35

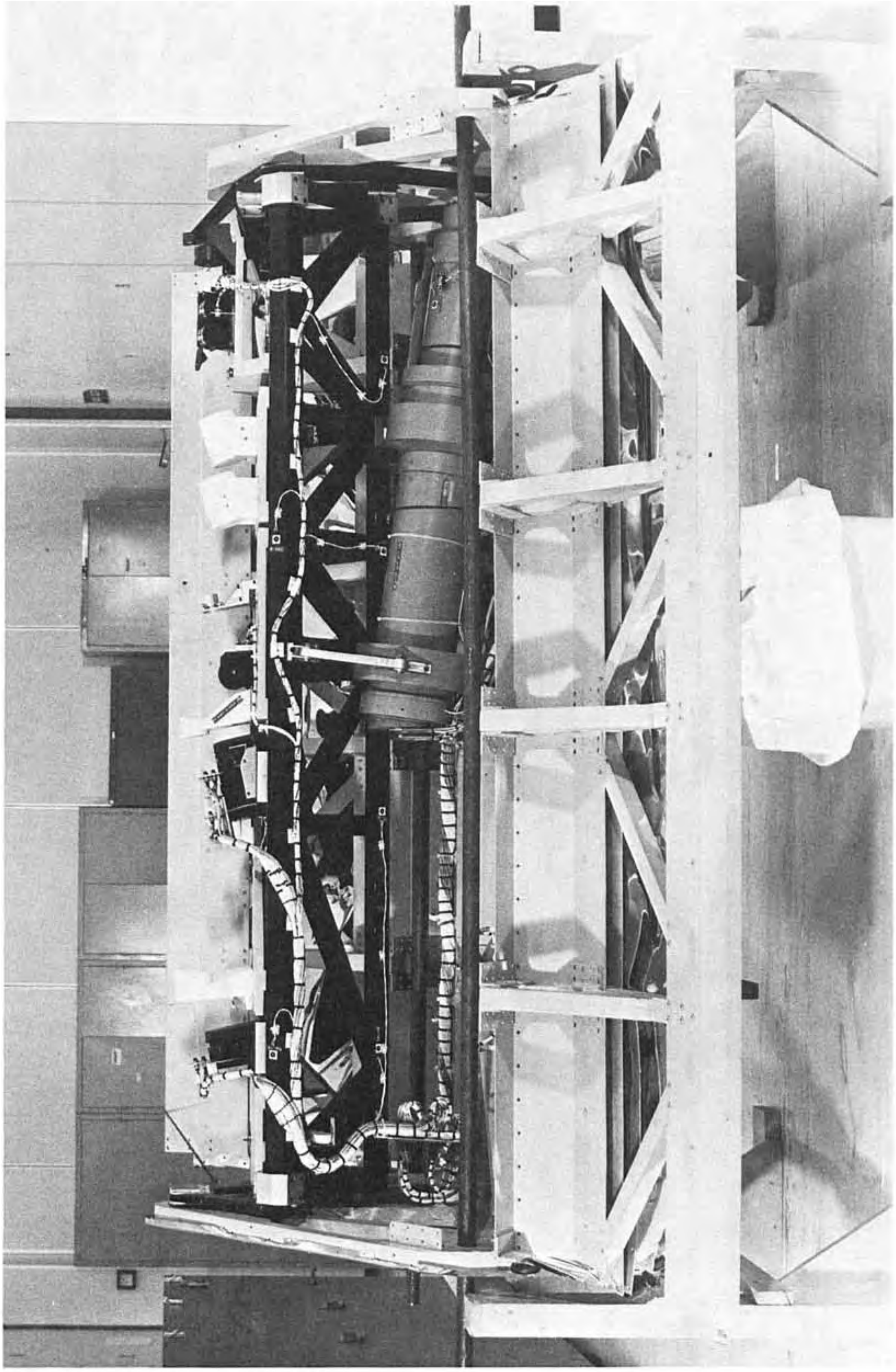

Fig. 1. Full Size Mock-up of the Faint Object Camera

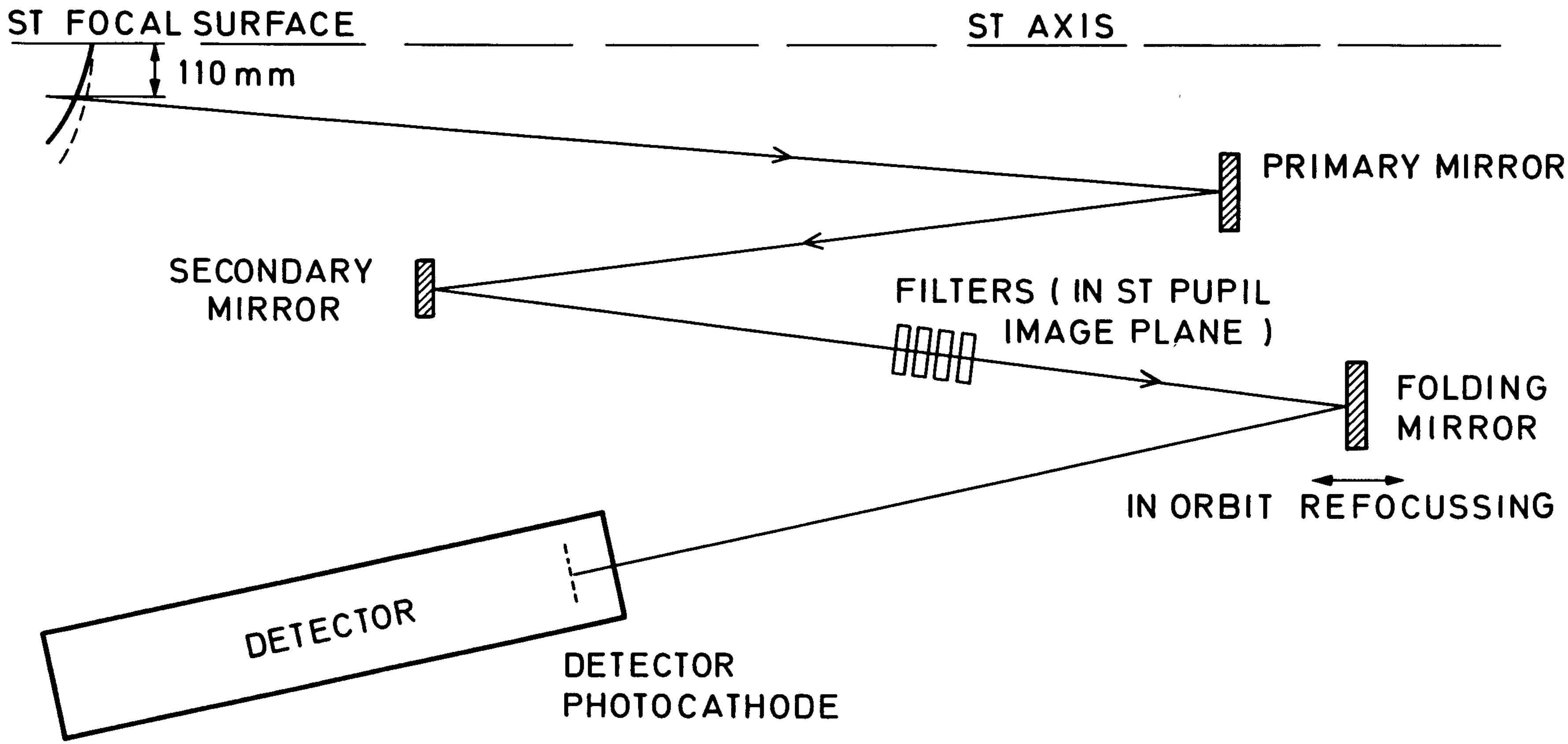

FIG. 2 F/96 OR F/48 IMAGING MODES OPTICAL LAY-OUT

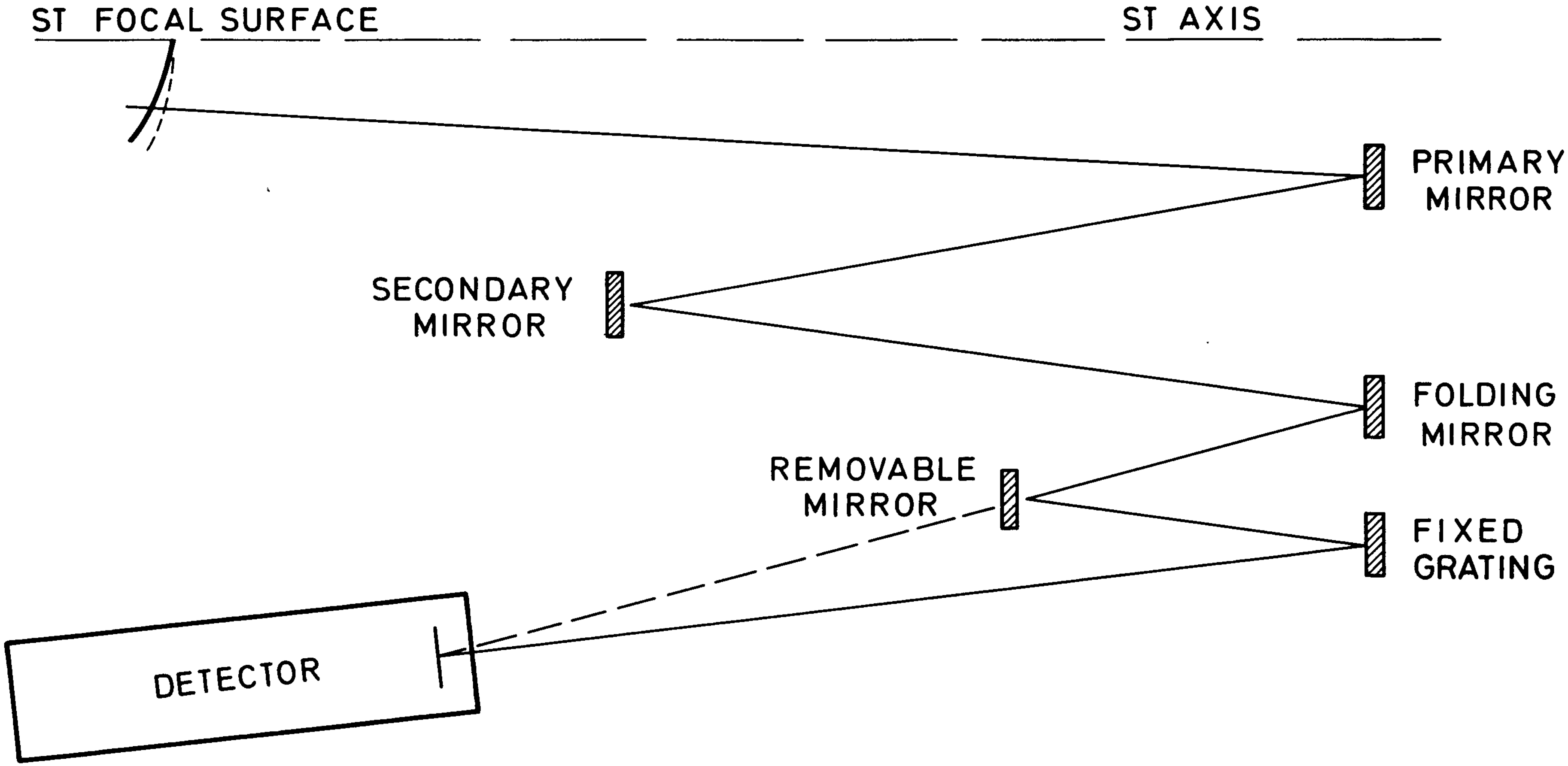

FIG.3 F/48 SPECTROGRAPHIC MODE LAY-OUT

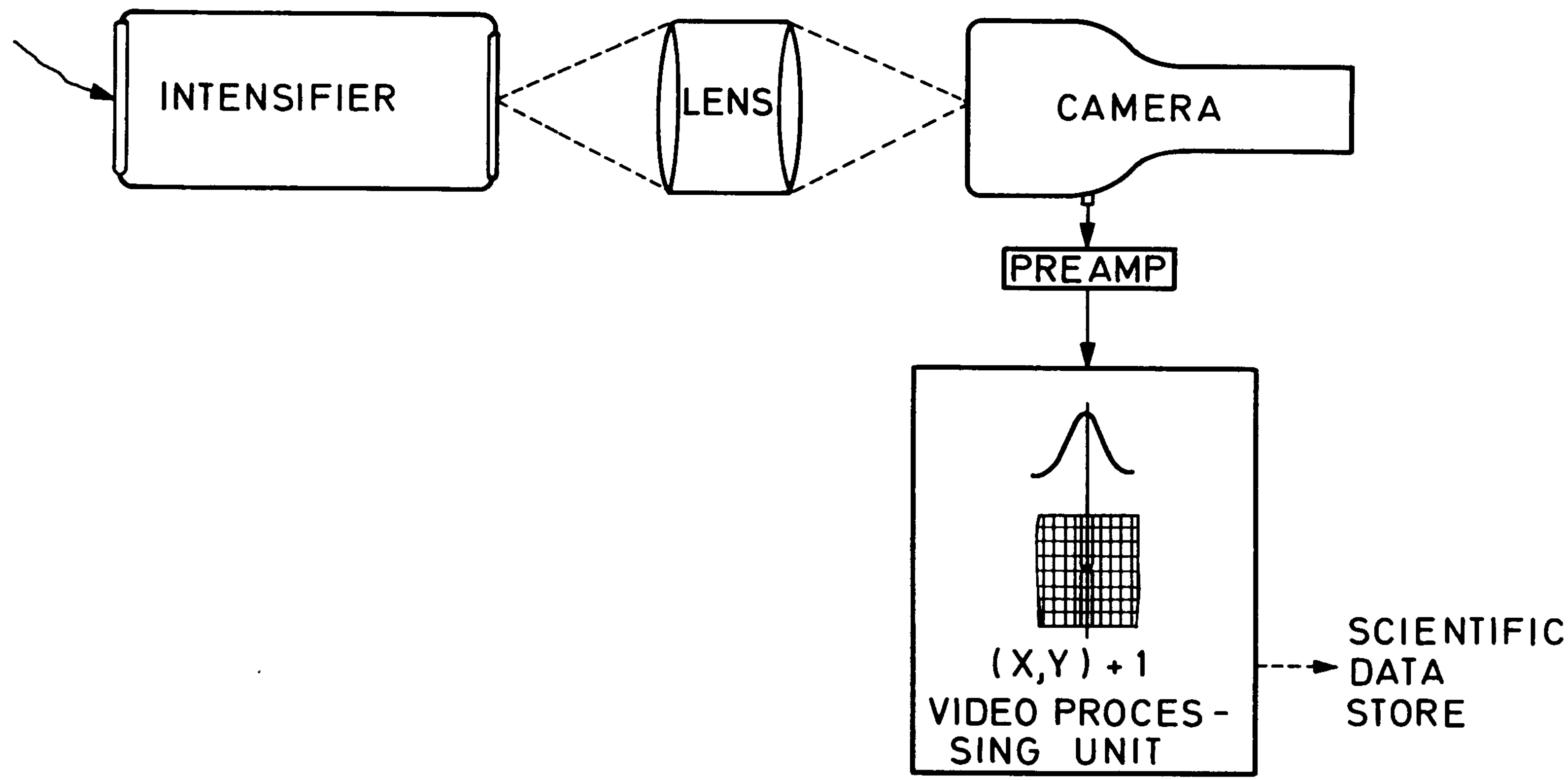

FIG.4 DETECTOR CONFIGURATION

STARS

INVESTIGATING STAR FORMATION WITH THE SPACE TELESCOPE

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Introduction

At all stages of its development the main motivation for building the Space Telescope (ST) has been our desire to look deeper into our universe and to study more effectively the large scale structure of our world. Nevertheless, the ST will also provide an opportunity for significant progress in other more "conventional" fields of astronomy. One of these conventional problems where the ST may have a particularly strong impact is the old but still only partly solved question of the formation of stars and planetary systems. In this paper I shall discuss a few crucial observations related to the star formation problem which will (at least in principle) be possible with the ST - and only with the ST. In order to put these observations into their proper context I shall start my discussion by outlining very briefly and very schematically our present knowledge of the star formation process.

As pointed out by various different authors, the basic answer to the question of how stars are formed has already been given by Isaac Newton in his famous first letter to Dr. Bentley (written in 1692) where Newton pointed out that (in the absence of adequate internal pressure) rarified homogeneously dispersed matter will tend to contract gravitationally to form denser bodies and that in this way the sun und the stars might have been formed. But Newton left it to us to sort out the details. Unfortunately these details turned out to be fairly complex. Very schematically the various stages of the star formation process are summed up in Figure 1: The raw material out of which stars are formed is generally assumed to consist of massive (10^4 - 10^5 $M_\odot$) interstellar H I clouds, which are assumed to be initially not too far from a state of hydrostatic (or magneto-hydrostatic) equilibrium. Various processes (like cooling, mass increase, compression by an outside pressure increase, or certain hydromagnetic effects) may lead to a relative increase of the gravitational forces and consequently to a collapse of the cloud

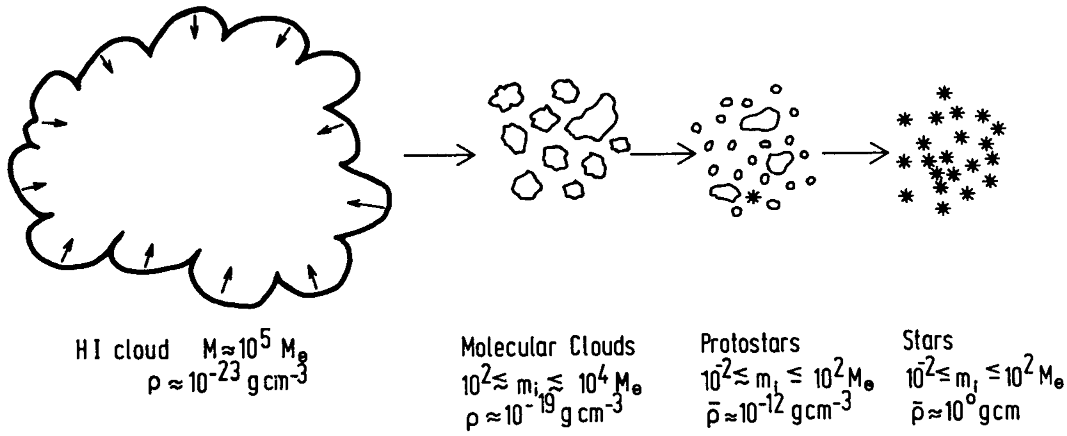


Figure 1: Schematic outline of the star formation process.

due to selfgravitation. Because of the cooling function of the interstellar H I gas, in a contracting or compressed H I cloud the gravitational forces increase more rapidly than the pressure forces. As a result (progressively smaller) subsections of a gravitationally contracting cloud will also become unstable and the large initial cloud will break up into (even more rapidly contracting) fragments. This fragmentation process continues until the smallest and densest cloud fragments become in their interior opaque to their own (mainly microwave and infrared) radiation and start to form hydrostatic cores. The theoretical astrophysicists call these final cloud fragments (which have already hydrostatic cores but free falling outer layers) "protostars". As we know from theoretical model computations as well as from observations, low mass protostars evolve gradually from the protostellar stage to become fully hydrostatic pre-main-sequence stars by slowly depleting their infalling envelopes. Massive protostars, on the other hand, evolve rather suddenly from the protostellar stage to the main sequence (without a significant pre-main-sequence phase) when the nuclear reactions start in their hydrostatic core.

Since the evolutionary time scale depends basically on the density, the evolution is rather slow during the initial collapse and fragmentation phases and then becomes progressively faster. Moreover, because of statistical fluctuations of the density (and other parameters) in the initial cloud, different parts of the initial cloud will usually evolve at somewhat different time scales. As a result in a given star formation region different evolutionary stages will usually coexist. Therefore in the protostellar cluster of Figure 1 some still existing larger cloud fragments as well as one symbolic fully developed star have also been included.

Practically all astronomers working in this field will probably agree with the basic scheme outlined in Figure 1. However, as noted already, there are many details which still are either unknown, or uncertain, or disputed. How can the ST help to fill these gaps in our knowledge?:

The Initial Interstellar Clouds

Interstellar H I clouds are cool very extended objects radiating mainly at very low frequencies (typically at radio wavelengths). The Space Telescope is designed for optical (UV, visual, and IR) observations of point sources or small fields. Thus the ST is certainly not well suited to study galactic H I clouds. However, ultraviolet and infrared stellar photometry with the ST will probably improve our knowledge of the properties of the interstellar dust and the interstellar medium in general. Indirectly this information will also be helpful for studies of the early stages of the star formation process.

The Fragmentation (or Molecular Cloud) Phase

At present this phase of the star formation process is still the least explored one and even basic details and parameters are largely unknown. On the other hand, a particularly large amount of work (observational as well as theoretical) is being done right now to investigate the fragmentation of contracting interstellar clouds and the properties of the resulting very dense (molecular) clouds. Most of the observational work is being carried out at radio wavelengths. In contrast to optical radiation the radio waves penetrate even these very dense clouds. The very high spectral resolution typical of radio receivers and the intrinsic narrowness of the molecular radio lines are particularly valuable to study the velocity fields of clouds undergoing fragmentation. Finally, interferometric techniques result in an angular resolution of modern radio observations which are not only comparable but (in the case of VLBI observations) clearly superior to even the most optimistic predictions for the Space Telescope. Therefore, I believe that the fragmentation phase of the star formation process will become well understood (within perhaps ten years or so) on the basis of the radio data that are now being accumulated. In comparison to the radio data the contribution of the ST to this particular detail problem will probably be small. The only direct observations of dense fragments or gravitationally contracting clouds with the ST could possibly be high resolution images of small globules or boundaries of dark clouds projected against underlying H II regions. However, in my opinion, groundbased observations of this type have never been particularly successful in deriving meaningful physical parameters. (ST observations may also be very useful to study certain properties of the H II regions themselves. However H II regions are outside the scope of the present paper and such observations will therefore not be discussed here).

There is nevertheless one observed quantity related to the fragmentation process whose accuracy the ST will possibly improve dramatically: This is the mass distribution of the final fragments

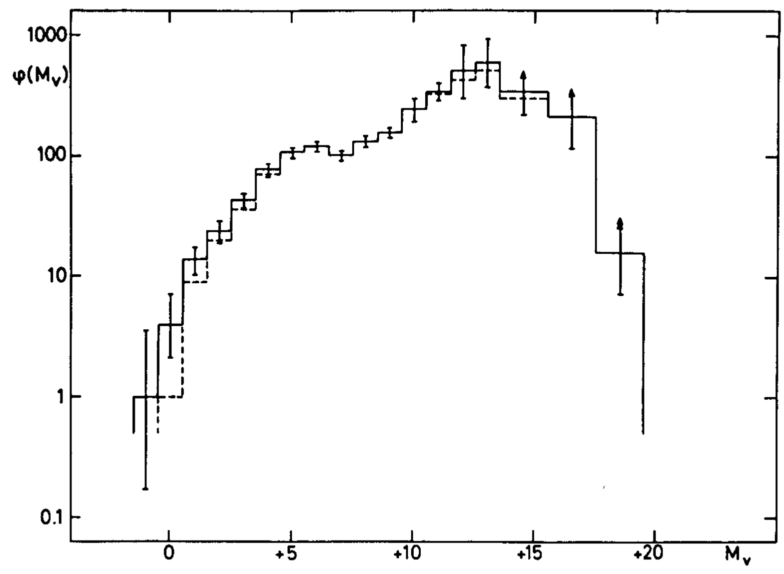


Figure 2: The luminosity function of the solar neighbourhood (according to H. Jahreiß, unpublished Ph.D. Thesis).

which is closely related to the resulting stellar mass distribution and the luminosity function of stellar clusters or the solar neighbourhood. The potential of the ST in this respect is illustrated by Figure 2 where the solar neighbourhood luminosity function (compiled by H. Jahreiß, Heidelberg using the most recent edition of the Gliese catalogue of nearby stars) is given. As shown by this figure, right now not even the maximum of this function is reliably known. With the ST it should be possible to increase significantly the accuracy at the faint end of the luminosity function not only for the solar neighbourhood but also for the nearby young open clusters. Such programs will be obviously rather time consuming since they will require repeated direct observations of not too small test fields. On the other hand, the possibility to use different focal plane instruments of the ST simultaneously will prehaps provide such repeated direct images as a byproduct of other programs.

Protostars

As noted already, protostellar evolution is quite different for the low mass ($M \lesssim 4\ M_{\odot}$) and the high mass ($M \gtrsim 4\ M_{\odot}$) protostars. This is illustrated by Figures 3 and 4. All protostars start out as cool infrared objects. However, in the case of the low mass protostars the IR stage is only a small fraction of the protostellar lifetime. As shown e.g. by Figure 3, during most of its existence a low mass protostar has an effective surface temperature slightly lower than that of a fully convective pre-main-sequence model of the same mass, while its luminosity is typically higher by a factor of $\lesssim 10$ than that of a main-sequence star of similar mass. Young objects with spectroscopic evidence for circumstellar matter are known in this part of the HR-diagram since several decades. According to Joy these objects are called "T Tauri stars". Some of these objects (like the well studied variable S CrA) could be identified rather reliably as low mass protostars. (However, it should be noted that not all T Tau stars appear to be protostars. Some T Tauri stars are in fact ejecting mass rather than accreting matter).

In the case of high mass protostars (cf. Figure 4) hydrogen burning in the center of the hydrostatic core starts while these objects are still in the infrared part of the HR-diagram. When this happens the luminosity increases rapidly, the outer still collapsing layers are blown away, and the protostar evolves very rapidly di-

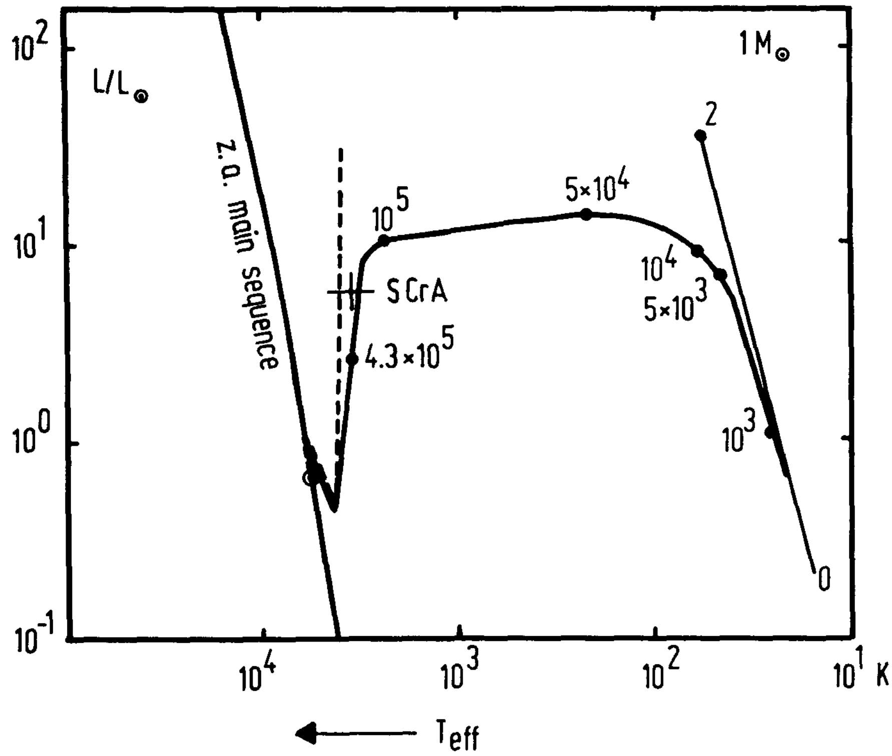


Figure 3: Computed evolutionary track in the HR diagram of a 1 $M_\odot$ protostar (solid line). For comparison the hypothetical 1 $M_\odot$ hydrostatic track (broken line) is also included. The numbers give the age after formation of the hydrostatic core in years. The cross indicates the position in the HR diagram of the T Tauri star S CrA.

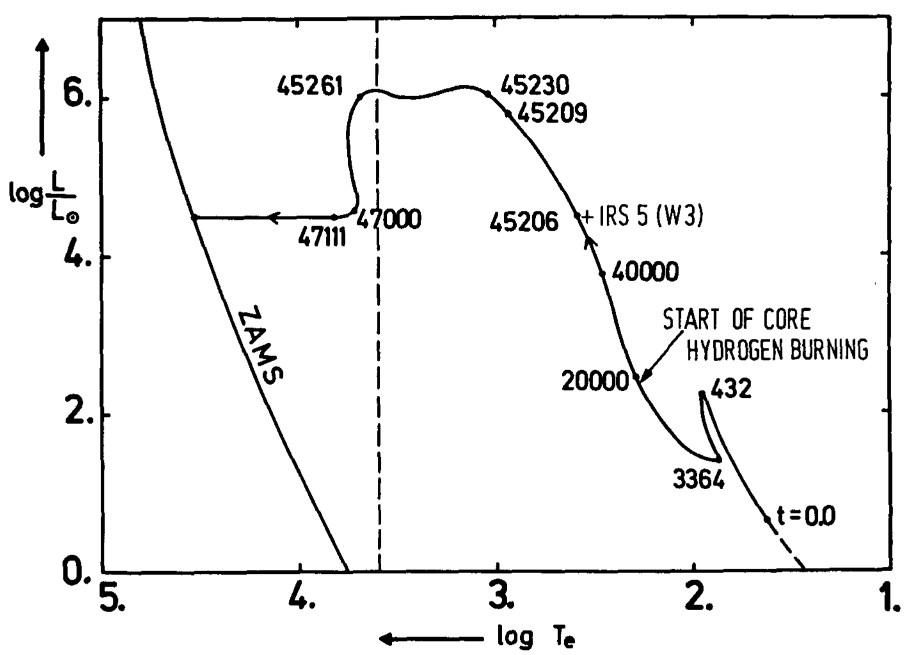
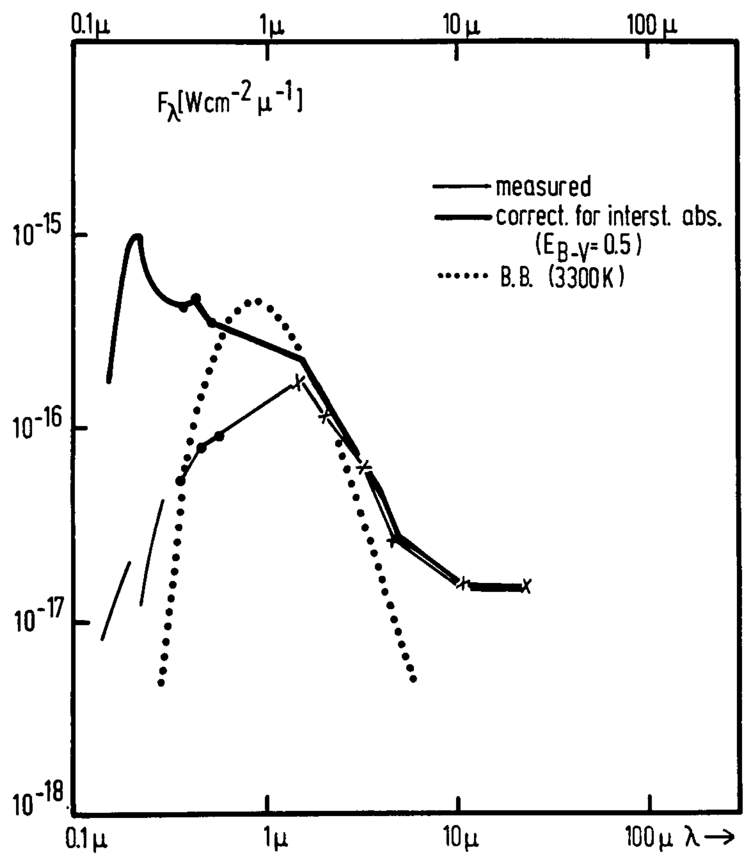


Figure 4: Same as Figure 3 for a massive protostar (initial mass 60 $M_\odot$, resulting stellar mass 17 $M_\odot$, corresponding to a main-sequence spectral type O 9.5). The cross indicates the position of the infrared source IRS 5 in W3.

rectly to the main sequence. This final part of the evolution of massive protostars proceeds so rapidly that so far not a single really massive pre-main-sequence star could be discovered, although many luminous young infrared objects (presumably proto-O-stars) are known. Thus, both the model computations as well as the observational evidence shows that (quite in contrast to later evolutionary stages) during the protostellar phase the low mass objects are typically relatively hot with almost stellar effective temperatures while the massive protostars are typically very cool but luminous infrared sources.

Since the Space Telescope will be most effective in the UV and visual spectral range it will obviously be much better suited to investigate the low mass protostars. As pointed out above, the effective temperature of these objects is slightly lower than that of cool stars. However, because of the presence of a very hot accretion shock and of moderately hot gas in the innermost parts of the infalling envelopes, low mass protostars show a very strong ultravio-

Figure 5: Approximate energy distribution of the T Tauri star S CrA, corrected for interstellar extinction (heavy solid line).



let excess. This is illustrated by Figure 5 where the approximate absolute energy distribution of S CrA (derived from low resolution IUE observations) is given. Unfortunately, since T Tauri stars are always associated with dark clouds, many of the most interesting objects of this kind are strongly reddened by interstellar dust which is obviously particularly troublesome in the UV. Therefore, although a considerable number of T Tauri stars will be observable with the IUE satellite, in some of the most interesting cases only the much more sensitive UV-equipment of the Space Telescope will make it possible to derive the absolute energy distribution reliably. But much more important will be the fact that the ST will allow for the first time to obtain high resolution UV spectrograms of T Tauri stars. Such observations are urgently needed to disentangle the complex velocity fields and other physical parameters of the moving envelopes of these objects. A better knowledge of this mass flow is e.g. a prerequisite for studying the early history of planetary systems, including the solar system. We know from investigations of other objects with moving extended envelopes that resonance lines and transitions originating from metastable lower states are particularly useful to study circumstellar envelopes. In the case of the low mass protostars practically all interesting lines of this type are in the UV spectral range. Only quite recently it has become possible to obtain at least low resolution UV spectrograms of T Tauri stars. An example is given in Figure 6. (Other beautiful examples of IUE low resolution spectrograms of a T Tauri star are reproduced in Dr. Gösta Gahm's contribution to this conference elsewhere in this volume). While the low resolution spectrograms show that the spectral lines of interest are present in these objects, these IUE spectrograms unfortunately cannot give any information on on the line profiles. The magnitude of the information jump which the ST will certainly cause in this field can be estimated by comparing published low resolution UV spectrograms of luminous early type stars (with expanding envelopes) with high resolution COPERNICUS or IUE observations of the same objects. It seems safe to predict that the impact of the ST on our knowledge of the moving envelopes of the T Tauri stars will be at least comparable to the impact of the COPERNICUS and IUE satellites on the physics of the mass loss of luminous early type stars.

As noted above, high mass protostars emit practically all their

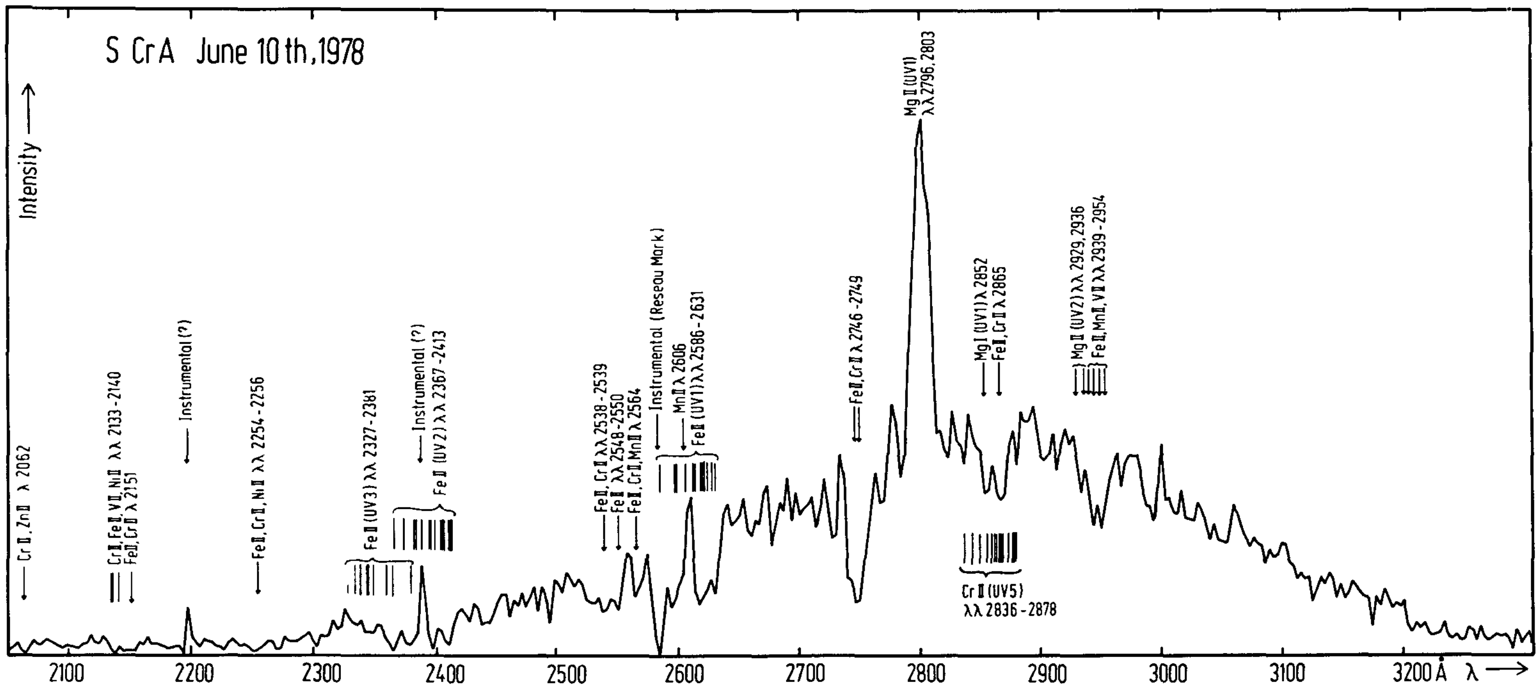


Figure 6: Low resolution IUE spectrogram of the T Tauri star S CrA
(According to Appenzeller and Wolf).

energy at infrared wavelengths. Since the ST will (at least initially) not contain infrared detectors, massive protostars will not be observable from the ST. This is of course regretable. On the other hand, during the past years it has become possible to observe protostellar objects (of high mass) at radio frequencies with very high angular and spectral resolution. Compared to the IR radiation, which is basically emitted by the surface of a protostar, the radio radiation seems to originate in the physically important somewhat hotter inner layers close to the accretion shock. These radio observations seem highly promissing and I therefore regard it as likely that most progress in the investigation of the physical structure of massive protostars will come from the radio observations and not from the IR data. Still, IR observations over a wide wavelength range from the ST would be valuable to supplement the radio data. I therefore hope, that IR equipment can be added to the ST instrumentation at a later date.

Planetary Systems

During the past years considerable progress has been made in the theory of the formation of planetary systems. However, observationally there is still only one planetary system (our solar system) to compare theory and observations. We have no idea whether our solar system is typical or exceptional. The ST will possibly change this situation dramatically. For illustration I sketched in Figure 7 our solar system as it might be seen with the ST from a distance of 2.6 pc (i.e. at the distance of Sirius or at twice the distance of α Cen). The field of Figure 7 is approximately that of the ST FOC camera and it was assumed that the (too bright) sun can be screened out by a coronographic mask of $0.4''$ diameter. One of the most serious simplifications of Figure 7 is of course that background objects have been neglected. If we would observe in a direction towards the galactic plane, there would be in addition to the planets on the average about 10^2 randomly distributed background stars brighter than $m_v = 29$. Thus, some proper motion technique will have to be used to separate the planets. I should like to add that (in contrast to photographs of lower limiting magnitude) at the galactic poles the confusion problem will probably be worse rather than better, since although the field will then contain practically no stars it will contain several thousand galaxies and QSOs. Nevertheless, the above estimates show that the ST does indeed have the potential to observe extrasolar planetary systems.

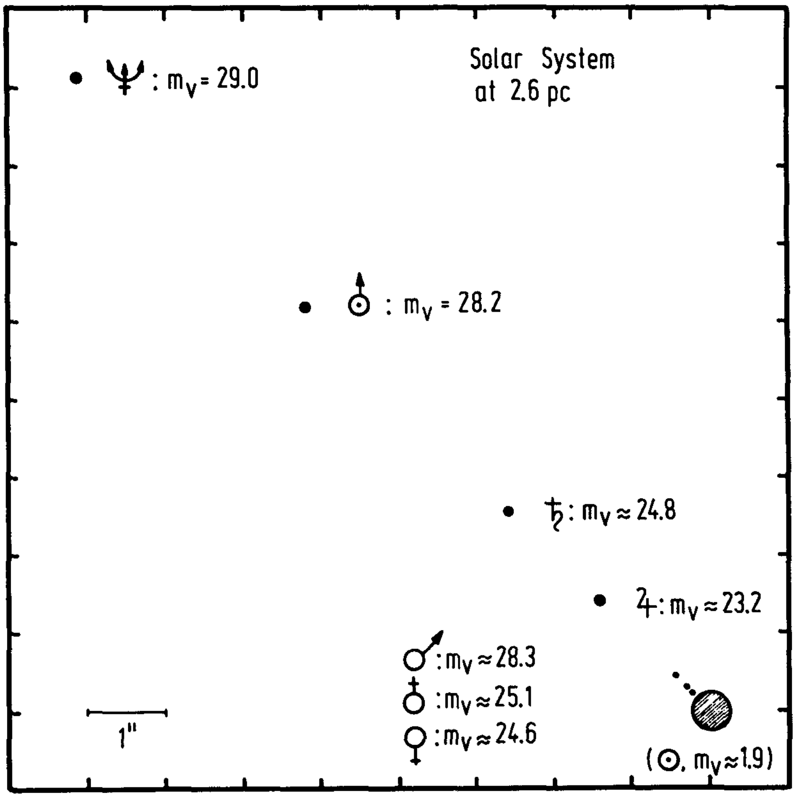


Figure 7: The solar system seen from a distance of 2.6 pc. The values m_V are estimates of the expected maximum visual brightness.

Star Formation in Extragalactic Systems

The faint limiting magnitude of the ST will also for the first time allow to study details of the star formation process in extragalactic systems. One of the most readily observable but neverthless highly interesting detail information will again be the luminosity function in other galaxies. Of particular interest in this respect will be ST observations of the nuclear regions of nearby spiral galaxies. From the presence of large H II regions and the strong infrared radiation from such nuclear regions it seems beyond doubt that massive stars are formed in these regions. But little is known about the mass spectrum. The high effectiveness in the UV and the high angular resolution of the ST may be decissive in establishing the mass spectrum of galactic nuclei star formation. It would e.g. be highly interesting to confirm or disprove the hypothesis (put forward by various authors) that more massive ($M > 10^2\ M_\odot$) or perhaps "supermassive" ($10^5 \leq M/M_\odot \leq 10^9$) stars may form in galactic nuclei. As noted by many different authors, such objects could possibly give rise to the strange and violent events which are sometimes observed in galactic nuclei.

However, the organizers of this meeting may regard the last few sentences (on the formation of supermassive stars ect.) to be clearly outside the range of topics on which I was asked to give an introduction. Therefore I shall stop at this point. I wish to conclude this paper by expressing my hope that the wise experts who will carry out the difficult task of distributing the valuable observing time on the ST will not totally disregard applications related to the star formation problem and that at least some of the observations discussed above will indeed be carried out sometime.

J. AUDOUZE : From recent studies of isotope anomalies observed in some meteorites we have evidence that supernovae played a major role in the formation of the solar system. Therefore it would be most useful to be able to make far UV observations of the regions where star formation processes are suspected. The available wavelength range of Space Telescope might be too much limited because it does not allow detection of OVI or NV lines (corresponding to temperatures of about a few 10^5K) which should be detectable in regions in the vicinity of supernova remnants. Therefore investigations made on star formation regions by Space Telescope should be supplemented by far UV observations performed at wavelengths $\lambda < 1200$ Å.

B.E.J. PAGEL : H_2 and CO both have (0,0) bands somewhere near λ 1100 Å and therefore it seems that some molecular observations are possible with the high-resolution spectrograph. I should be grateful if this point could be clarified by an expert.

I. APPENZELLER : As far as I know the ST will be rather ineffective at this wavelength. But a more reliable answer to your question can probably be given by Dr. O'Dell.

C.R. O'DELL : The ST-spectrograph efficiency drops sharply at about 1150 Å; however, the sensitivity is non-zero and we expect some performance there.

Observations of Pre-Main-Sequence Objects in the Far-UV

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1. Introduction

Recognized pre-main-sequence objects, like T Tauri stars and the Herbig Ae- and Be-stars (stars of the Orion population) show as a rule broad emission lines superimposed on photospheric absorption lines. The objects have continuous excess emission over the ultraviolet and infrared spectral domains. In addition, several stars show continuous excess emisison in the blue spectral region and for a few extreme objects this so called blue veiling extends into the red spectral region. Most objects undergo irregular changes in brightness with time. Also, variability in the appearance of the emission line spectrum has been reported for a few objects. The characteristic time-scale for the light and spectral variations differs enormously from object to object and can vary for one and the same object. Variations on time-scales as short as a few minutes have been found.

A number of divergent ideas on the physical structure of these objects and the cause of the light and spectral variations exist. The frames set by the observations are still so wide as to permit a number of completely different theoretical models to grow. Many scientists in the field feel that the true behaviour of the stars may call for a combination of different theoretical approaches. One can think of several types of observations which could better encircle the problems. Here, we will stress the importance of high resolution spectroscopy in the far-UV. This can be accomplished for the first time with the Space Telescope.

2. Current results in the Far-UV

The IUE-satellite has provided the first far-UV spectrograms of Orion population stars. Before the launch of the IUE-satellite the only direct information on far-UV fluxes of such objects were from the broad-band photometry obtained with the ANS satellite by de Boer (1977). To my knowledge there is now information on far-UV spectra of S CrA (Appenzeller and Wolf, 1979), RU Lup (Gahm *et al.*, 1979a), DI Cep (Gahm *et al.*, 1979b), V 380 Ori, AB Aur and RW Aur (Imhoff, 1978), T Tau (UK POP, 1978) in addition to HR 5999 which should possibly be included as an Orion population star (Thé *et al.*, 1979).

The optical spectra of these stars show what can be interpreted as a stellar object surrounded by an emitting volume of relatively low temperature ($T \sim 10^4$ K). The broad emission lines indicate large mass motions in this emitting volume. Interpretations based on the concept of infalling as well as outflowing material have been presented. In addition, large rotation and/or macro turbulence have been proposed.

In Fig. 1 we present the flux calibrated spectrogram of RU Lup. The enormously intense emission from lines of C III, C IV, Si IV and Si III indicate the presence of extended regions of very high temperatures ($T = 5 \cdot 10^4$ to 10^5 K). In addition we note the presence of a flat excess continuous emission shortward of λ 2000 Å.

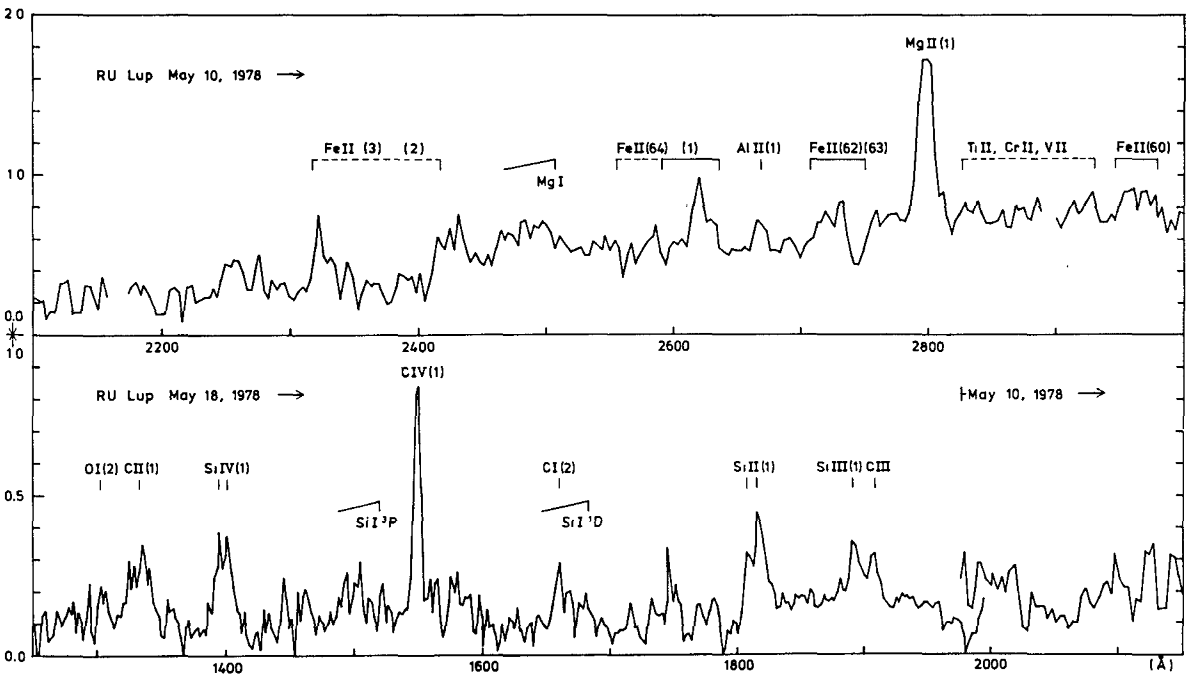

Fig. 1. Observed flux (in 10^{-13} erg cm^{-2}s^{-1} Å^{-1}) as function of wavelength. The spectrum shortward of λ 1250 Å includes the geocoronal Ly α and is not given in this diagram. Longward of λ 3000 Å the major part of the spectrogram is defect due to cosmic ray events. In the region λλ 1950-2200 Å the signal to noise level is low. Identifications of some dominant contributors to emission features are given with UV Multiplet number in parenthesis. Spectral regions with complex superposition of several lines are embraced (dashed: only weak emission is expected).

This continuum was interpreted by Gahm et al. (1979a) as the result of hydrogen free-free and free-bound emission from such hot regions. The presence of these hot regions could, at least for some stars, be the result of heating of infalling material at the shock front produced when infalling material is violently decelerated close to the stellar surface (Appenzeller and Wolf, 1979). Alternatively, it could be the result of an enhanced chromsphere-corona region relevant to these stars as modeled by for instance Thomas and Heidmann (1979).

The IUE-spectrograms show strong emission from lines of C I, II, III and IV and it is obvious that the stars are surrounded by an emitting envelope where the temperature varies markedly with geometrical position. The IUE-spectrograms give important information on fluxes of the stronger emission lines. These lines are most likely saturated, however, and for the construction of atmospheric models a great deal of uncertainty remains. Furthermore, there is no information on line profiles to gain from the IUE-spectrograms. However, when combined with simultaneous ground-based observations of optical fluxes, the IUE-data may provide important clues to the problem of what causes the stars to vary. This type of observations has just started.

3. Far-UV studies with the Space Telescope

From what has been said above, it is obvious that the Space Telescope represents a great leap forward if used for studies of Orionpopulation stars. This instrument can provide far-UV spectrograms at high spectral resolution ($\sim$ 0.1 Å). Not only will the line profiles of individual emission lines be resolved but also weaker emission lines from a number of elements at different ionization states can be detected. If such a spectroscopic investigation can be combined with multi-color photometry over a wide spectral range with the same telescope, a very good base has been set up for a detailed understanding of the nature of the stars.

It may be premature to spectulate over the possible outcome of such a program, but referring to current ideas, I would like to bring up a few possibilities.

The analysis of line profiles of emission lines from different ions that are formed in different regions of the envelope will permit a more precise picture of the velocity field around the stars. Anything can be expected from purely symmetric but possibly velocity shifted lines to strongly asymmetric profiles with normal as well as inverse P Cygni profiles. It would be no surprise to find that lines forming in different temperature zones have completely different profiles.

In addition to the temperature, the density for the different zones can be established from weaker lines, much in the same way as is presently done for active regions on the sun (see e.g. Feldman and Doschek, 1978).

Such results would help to delineate the temperature/density/velocity structure of the envelope for further comparisons to models assuming mass outflow, mass infall, turbulence etc. Moreover, the question of the energy balance of the emitting volume can be tackled in a more substantial way. Let us assume, as an illustration only, that the velocity field is ordered in the sense that it can be described as a simple function of distance r from the star with radius R_o, e.g. as v(r). The equation of continuity gives:

$$\rho(r)\ v(r)\ r^2 = \rho(R_o)v(R_o)R_o^{\ 2}$$

where $\rho(r)$ is the density at distance r. At present, we can only give certain limits to how the functions $\rho(r)$ and v(r) may look. Undoubtedly, these limits will be narrowed by high resolution data. Moreover, the measured fluxes of weaker unsaturated lines provide direct means of deriving the geometrical extent of the volume in which a certain ion emits. Consequently, the geometrical structure of the envelope can be outlined which in turn works as a consistancy check on the velocity/density structure obtained through the equation of continuity above.

If, on the other hand, the velocity field is unordered, and the envelope is in a chaotic state with mixed hot and cool bubbles which are rising and falling, then repeated spectroscopic and photometric observations would be a way of mapping the structural changes with time. If, as has been suggested, the occurence of sudden brightenings on these stars are due to infalling interstellar cloudlets, then again repeated observations with far-UV spectroscopy and photometry on board the Space Telescope is the way to verify such events.

Closely connected to the question of the atmospheric structure of Orion population objects is the question of coronal emission from these objects. On a T Tauri star like RU Lup the metal line emission that dominates the optical spectral region is formed in regions with temperatures of $T \sim 10^4$ K (Gahm et al., 1974). This emission line spectrum is reminiscent of the solar chromospheric spectrum. These low temperature lines on RU Lup are enhanced by factors $\sim 10^4$ relative to the corresponding solar chromospheric lines, however. From our IUE-spectrograms we can conclude that the "hot" lines of C III, C IV, Si IV etc. are enhanced by factors of again $\sim 10^4$ relative to the corresponding solar lines. We have made a careful search for coronal lines in the far-UV and optical spectra of RU Lup. We conclude that coronal lines if present are $< 10^5$ stronger than the corresponding solar lines.

If this star, like other stars with intensive emission lines, has a coronal region emitting at a rate of $\sim 10^4$ compared to the sun, then important implications would follow. First of all we expect the stars to be strong emitters of soft X rays. By pure analogy with the sun we would expect a star of this kind to have a soft X ray luminosity of $5 \cdot 10^{30}$ erg s^{-1} in the range 0.15-1. keV. Such an estimate seems reasonable when compared to peak X ray luminosities of $\sim 10^{29}$ erg s^{-1} observed for flare stars during outbursts. The flare stars look very similar to T Tauri stars during outbursts, still their optical luminosities are generally smaller than those of T Tauri stars, with strong emission line spectra.

The so estimated X ray flux for nearby, unreddened T Tauri stars is

$\sim 5 \cdot 10^{-12}$ erg cm^{-2} s^{-1} (0.15-1. keV). We note that Bisnovatyi-Kogan and Lamzin (1977) predict considerably larger X ray fluxes to be observed from these stars. Their estimates are based on a theoretical model.

One consequence of enhanced coronal emission from Orion population objects is that local enhancements in the soft X ray sky can be expected in regions of star formation. We expect such enhancements primarily from the Orion nebula complex and NGC 2264 which have clusterings of T Tauri stars for which the interstellar absorption is relatively small. We note that on the soft X ray maps by Zwijnenberg (1976) there are local enhancements in these directions. These enhancements could be of different origin, however.

Another consequence would be that since the soft X rays may penetrate far out in the circumstellar region around a T Tauri star that is imbedded in a dust cloud, the production and destruction of molecules in the cloud will be affected. Reaction channels involving O^+ and N^+ will be opened since soft X rays are capable of ionizing these elements. Hence, the chemistry in such clouds must be reviewed.

There is also a possibility that the nature of the Herbig-Haro objects could be connected to the production of soft X rays by young stars imbedded in the clouds. The total visual luminosity of bright condensations in the Herbig-Haro object HH 2 amounts to 10^{32} erg s^{-1} or more according to Böhm (1975). It therefore seems that the total X ray luminosity estimated above does not suffice to maintain the power radiated from Herbig-Haro objects, at least not from our estimate based on an extrapolation of existing IUE-data.

The important point to make in connection with these very tentative estimates is that firstly: carefully selected T Tauri stars should be observed from X ray satellites (this will hopefully be accomplished during 1979) and secondly: far-UV spectroscopy with the Space Telescope will provide detailed information on the degree and character of coronal emission from these stars.

Finally, I would like to point out that since many stars of the Orion population are surrounded by circumstellar dust shells possibly interwoven with gas, it is clear that high resolution far-UV spectroscopy of such objects could reveal circumstellar absorption features connected to the interstellar dust grains or to the atoms and molecules in the gas. The detection and identification of such features is of obvious importance in connection to for instance discussions on the formation of planetary systems.

It is my hope that the nearby T Tauri stars shall not be overlooked when the Space Telescope once is there in the first place to solve important cosmological questions. The gain in knowledge about how stars come into being can easily be predicted to be enormous.

References

Appenzeller, I., Wolf, B.: 1979, private comm.

Bisnovatyi-Kogan, G.S., Lamzin, S.A.: 1977, Sovj. Astron. J. 54, 1268

Böhm, K.H.: 1975, Problems in Stellar Atmospheres and Envelopes (ed. B. Baschek, W.H. Kegel, G. Traving), New York: Springer-Verlag, p. 205

de Boer, K.S.: 1977, Astron. Astrophys, 61, 605

Feldman, U., Doschek, G.A.: 1978, Astrophys. J. Suppl. 37, 443

Gahm, G.F., Nordh, H.L., Olofsson, S.G., Carlborg, N.C.J.: 1974, Astron. Astrophys. 33, 399

Gahm, G.F., Fredga, K., Liseau, R., Dravins, D.: 1979a, Astron. Astrophys. Lett. in press

Gahm, G.F., Liseau, R., Malmort, M., Petrov, P., Fredga, K.: 1979b, in preparation

Imhoff, C.: 1978, according to NASA (IUE) Newsletter No. 1, Sept. 1978

Thé *et al.*: 1979, in preparation

Thomas, R., Heidmann, N.: 1979, in preparation

UK POP: 1978, The UK High Priority Program, according to NASA (IUE) Newsletter No. 2, Nov. 1978

Zwijnenberg, E.: 1976, thesis, Huygens Laboratorium, Leiden

OBSERVING THE "MISSING MASS" WITH SPACE TELESCOPE

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Abstract

We have estimated the number of faint stars ($M_V < 26^m$) that should be observable with the Space Telescope wide-field camera in the directions of the galactic poles. Such observations will provide information about the low-mass end of the local stellar luminosity function ($0.01 \lesssim M/M_\odot \lesssim 0.1$). Those low-mass stars (sometimes called "black dwarfs") probably account for the "missing mass" in the solar neighbourhood.

Several observational studies with the aim of determining the local space density of faint late-type stars have been carried out or are presently under way at the Astronomical Institute in Amsterdam (Thé and Staller, 1974; Staller and Thé, 1979; Staller and Bochem-Becks, 1979). One of these studies concerns a blink-survey of red and blue copies of Mt. Palomar Sky Survey plates of a six square degree field centered at the South Galactic Pole (Staller and Bochem-Becks, 1979). The aim of this study is to obtain a sample of faint red ($R < 18^m$) local dwarf stars that is unaffected by selection effects which are introduced by selecting such stars on the basis of kinematic criteria (large proper motion, e.g. Luyten, 1968). Preliminary results of this blink-survey are summarized in Table 1. Altogether about 2600 red objects are found. Those objects denoted "extremely red" are distinguished from the others by the fact that they are completely invisible on the blue plate. A small fraction of the objects with fuzzy images might be galaxies.

Table 1
Number of faint red ($R < 18^m$) objects in a six square degrees field towards the South Galactic Pole

group characteristic	number
extremely red	36
very red	329
red	1150
fed (fuzzy image)	1062
total	2577

The colours of the stars found in this blink-survey are much too roughly estimated to be used for a photometric distance determination so that we cannot directly determine their space distribution. In an attempt to still interpret the results we have calculated the number of K and M dwarfs that we expect to find in a six square degree field in the direction of the galactic poles on the basis of the local luminosity function, assuming a space density distributution of the form

$$\nu(z) = \nu(0)\ \exp(-z/H).$$

For the local space density $\nu(0)$ of K and M dwarfs ($M_v \geq 7$) we have used Luyten's (1968) luminosity function. For the scale height of the density distribution we have adopted H = 260 pc, obtained by combining the most recent velue of the velocity dispersion of late-type dwarfs in the z-direction of 15 km s^{-1} (Upgren, 1978) with the force law K_z as tabulated by King (1977). The predicted number of stars with $7 \leq M_v \leq 16$ are displayed in Table 2. The limiting R magnitude of 18 corresponds to a distance z_{lim} out to which stars with absolute visual magnitude M_v can be seen. The predictions are quite sensitive to the adopted scale height.

Table 2

Predicted numbers of red dwarf stars with $R < 18^m$ per magnitude interval in a six square degrees field towards the galactic poles

M_v	V-R	Z_{lim}(pc)	number
7	1.0	2500	198
8	1.2	1740	217
9	1.4	1200	243
10	1.5	790	316
11	1.6	525	194
12	1.7	350	100
13	1.8	230	39
14	1.9	151	14
15	2.2	110	5
16	2.5	79	1
		Total	1327

On the basis of the predictions in Table 2 it seems that Luyten's luminosity function is too small by a factor two for $M_v \geq 7$ to account for the number of stars observed in the blink-survey. This is probably caused by the selection criteria used by Luyten (Staller and Bochem-Becks, 1979).

The local mass density due to the stars of Luyten's luminosity function equals about 0.06 $M_\odot$ pc^{-3}. If the total number of stars at the faint end of

Luyten's luminosity function is about twice as large as seems indicated by the blink-survey results, the dynamically infered stellar mass density of 0.12 $M_\odot pc^{-3}$ (Oort, 1965) could be accounted for (the so-called "missing mass").

A large contribution to the stellar mass density could be due to very faint stars with masses $M \leq 0.08\ M_\odot$ that are unable to ignite Hydrogen in their cores (so-called "black dwarfs"). In order to study this question more thoroughly we have constructed a theoretical luminosity function based on the following assumptions:

(i) stars are born with a Salpeter mass function $\frac{dN}{dt}(M) \propto M^{-2.35}$,

(ii) with a lower mass limit of 0.007 $M_\odot$ (Low and Lynden-Bell, 1976),

(iii) at a constant rate over 1.5×10^{10} years.

Black dwarfs evolve in the Hertzsprung-Russell diagram first along a vertical Hayashi track with $T_{eff} \simeq 2000$ K on a Kelvin-Helmholtz time scale and then to the right towards lower luminosity and lower effective temperature on a degenerate cooling track (Stevenson, 1977). A theoretical luminosity function (arbitrarily normalized) in the visual (5500 Å) pass band is shown in figure 1.

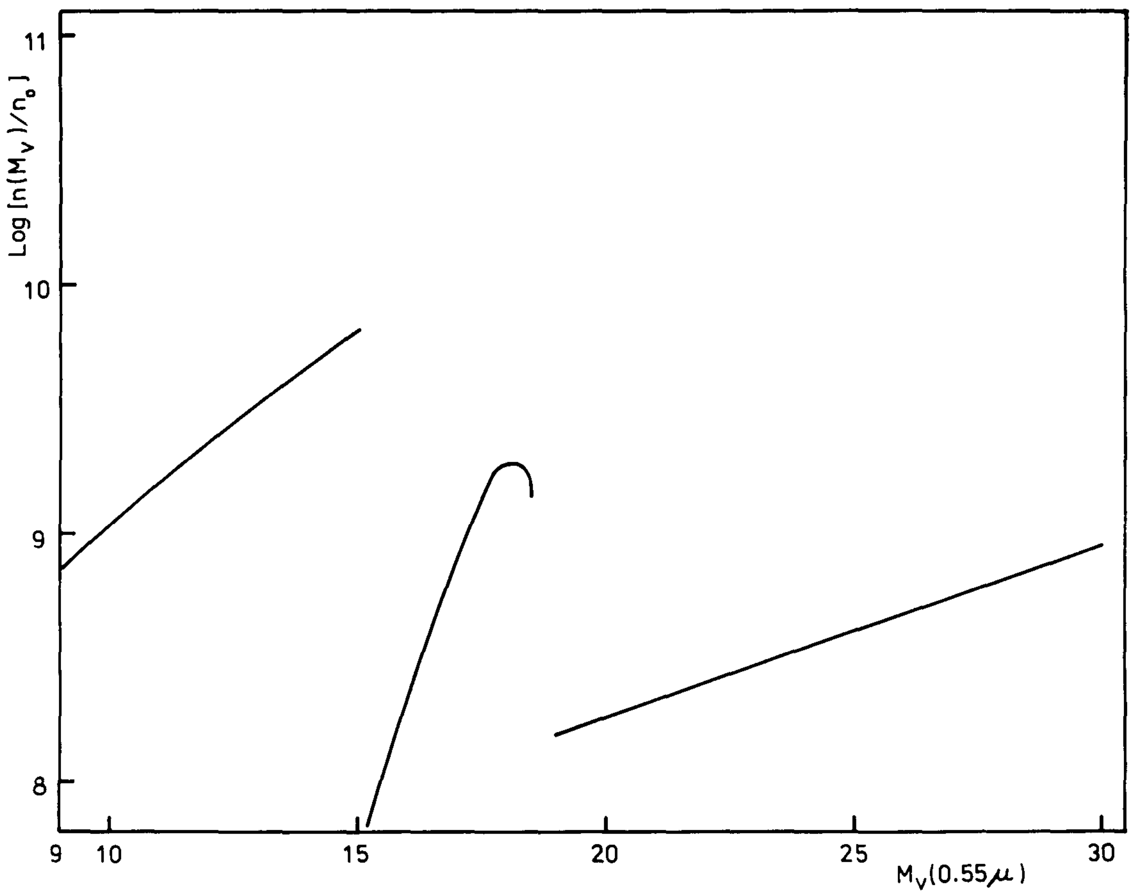

Figure 1. A theoretial luminosity function including "black dwarfs" in the 0.55 micron pass band.

The red dwarfs, the stars on Hayashi tracks and the degenerate black dwarfs can be clearly distinguished in figure 1. If we normalize this theoretical luminosity function to Luyten's at $M_V = 7$ assuming that the latter is complete at that magnitude we predict a total stellar mass density in the solar neighbourhood of $0.16\ M_{\odot}\ pc^{-3}$ so that indeed the "missing mass" can easily be accounted for in this way.

The number of stars that should be observable with the Space Telescope can be estimated in the same way as before, but now using our theoretical luminosity function including the black dwarfs. Down to a limiting magnitude of $V = 26^m$ we predict 2200 red dwarfs and 370 black dwarfs per square degree in the direction of the galactic poles. In the 7 (arcminute)^2 field of view of the wide-field camera one should observe about 6 dwarf stars down to $V = 26^m$ per plate.

To discriminate between red and black dwarfs and to determine their distances and their space density distribution, observations of a sample of about 100 stars in at least two pass bands (R and V for instance) are required. With an exposure time of about one half hour per plate this amounts to a total observing time of about one day. By observing fields at several galactic latitudes the scale height of the distribution could be determined and the required observing time increases correspondingly. We note that the observations proposed here can probably be done in the so-called "serendipidy mode", as byproducts of (extragalactic) observational programs at high galactic latitudes.

In summary we conclude that observations with the ST wide-field camera will enable us to study for the first time in a systematic way the low-mass end of the local luminosity function (slope and lower mass limit of the stellar mass function) and to improve the determination of the stellar space and mass density in the solar neighbourhood.

References

King, I.R. 1977, in *Highlights of Astronomy*, vol. 4 (part II), ed. E.A. Müller, Reidel Publ. Co., Dordrecht, p. 41.

Low, C. and Lynden-Bell, D. 1976, Mon. Not. Roy. Astr. Soc. 176, 367.

Luyten, W.J. 1968, Mon. Not. Rou. Astr. Soc. 139, 221.

Oort, J.H. 1965, in *Stars and Stellar Systems*, vol. V, eds. A. Blaauw and M. Schmidt, University of Chicago Press, p. 455.

Staller, R.F.A. and Bochem-Becks, A.Ch.Th. 1979, in preparation.

Staller, R.F.A. and Thé, P.S. 1979, in preparation.

Stevenson, D.J. 1978, preprint.

Thé, P.S. and Staller, R.F.A. 1974, Astron. Astrophys. 36, 155.

Upgren, A.R. 1978, Astron. J. 83, 626.

J. AUDOUZE : In the computations of the missing mass you have many free parameters, in particular the slope of the initial mass function which may vary from one mass range to another. It seems impossible to obtain a single solution to this problem given the so many degrees of freedom involved.

R.F.A. STALLER : Of course it is true that our estimates depend on a number of parameters, like the slope of the mass function, the lower limit of the mass spectrum and the scale-height. However, we do not want to solve the missing mass problem in this way; we only give an example of what can be expected. On the contrary we intend to observe the late type dwarfs, and maybe the "black" dwarfs, as faint as possible just to determine these parameters.

HIGH RESOLUTION SPECTROSCOPY WITH SPACE TELESCOPE

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High resolution spectroscopy is generally considered to be a second priority program for ST, because (1) ST is especially dedicated to reaching very faint objects, which would be never observable from the ground, (2) because ST is the first instrument capable of obtaining diffraction-limited spatial resolution (which is generally not requested for stellar spectroscopy), (3) because other moderately high resolution spectrometers were flown aboard Copernicus and IUE.

However there are many problems which need very high resolution (R 10^4 to 10^5) spectroscopy in the UV region of relatively faint objects, and whose solution is very important for understanding the chemical evolution of the galaxy and the continuous interaction between stars and interstellar gas.

In preparing programs for the projected high resolution spectrograph for ST we have to remember that regions of only 5.6 A in the far UV (1100-1700 A) and of 10.2 in the near UV (1700-3200) can be observed simultaneously in the high resolution mode, R = 1.2 10^5, and of 35 A and 59 A respectively in the low resolution mode, R = 2 10^4, (which is the high resolution mode of Copernicus). Hence the instrument is especially well-fitted for studying selected line profiles, or the abundance of some particular element, after previous UV studies with other satellites or a general inspection of the whole spectrum with the FOS have identified the most important spectral regions to be studied.

The planned detectors for the HRS are photon-counting devices. Hence the exposure time requested for obtaining a given S/N is: $t\ (sec) = (S/N)^2 / C_\lambda$ where C_λ are the counts, $C = N\ \Delta\lambda\ A_{eff}$, with N the number of incoming photons $cm^{-2}\ s^{-1}\ A^{-1}$, $\Delta\lambda$ the channel width and A_{eff} the product of the telescope area by the chromatic sensitivity. The channel width is about 0.01 A in the high resolution mode and 0.1 A in the low resolution mode (Brandt, 1978).

Since the large majority of the resonance lines of the abundant ions and of several other ions fall in the ultraviolet, this spectral region is particularly useful for studying rarefied gas like the interstellar medium or the outer envelopes of stars. I will consider three groups of problems: Motions, distribution, density and chemical composition of the interstellar gas; the structure of the outer envelopes of stars and mass-loss; the chemical composition of stars and chemical evolution of the galaxy. The feasibility of the relevant observations is indicated by the exposure times requested for obtaining S/N = 10 for some indicative objects (Table 1).

Motions, density and chemical composition of the IS gas in the vicinity of the sun ($d \lesssim 10$ pcs) can be studied by observing the interstellar absorption lines in the spectra of the white dwarfs and in the chromospheric emission lines of dG - dM stars. Copernicus observations have shown that the density of hydrogen in the vicinity of the sun is 0.05 - 0.1 cm^{-3} and D/H $\sim 10^{-5}$, at least in the direction of four bright near-by stars (Procion, ε Eri, ε Ind, α Cen A, all within 3.5 pc from the earth, Mc Clintock et al, 1978; Anderson et al, 1978. D/H was measured by the Ly α absorptions of H I and D I in the chromospheric Ly α emission. They have found no evidence

Table 1

Exposures needed for obtaining S/N = 10

Object	V	λ	$R \sim 2\ 10^4$	$R \sim 10^5$
O4(star E (B-V) =1 (d ∿ 10^4 pc)	13	1400 2800	20^m 8^m	$2^h.9$ $1^h.2$
E (B-V) = 1 (d ∿ 10^5 pc)	18	1400 2800	18^h 5^h	- -
E (B-V) = 0 (d ∿ 10^5 pc)	15	1400 2800	100^s 100^s	25^m 25^m
Ap star	12	1500 2000 3000	400^s 100^s 100^s	3^h 15^m 20^m
Hot WD	15	1400 2740	150^s 100^s	65^m 26^m
Red dwarf (chrom. em.)^x	15	1215 Ly α 2800 Mg II	3^h 13^m	- $3^h.25$
G2V (chrom. em.)^x	10	Ly α 2800 Mg II	2^m 8^s	16^m 2^m
G2V (cont.)	10	2200 2500 2800	10^m 5^m 40^s	80^m 50^m 10^m
G2V (cont.)	15	2500 2800	8^h 1^h	

x - assuming that the emissions are 10^4 (V = 15) or 10^2 (V = 10) fainter than those the sun would have if located at 10 pcs from the earth.

of clouds, but the Copernicus high resolution is 12 km/s. Higher resolution (up to 3 km/s) will made it possible to detect cloud structure and also to obtain better determinations of density, temperature and chemical composition (which can be affected by errors due to interpreting lines formed in different non-resolved clouds as having been originated in a single cloud). More than 40 white dwarfs with U-B bluer than -0.2, hundreds of red dwarfs and 22 dMe flare stars are observable for this purpose.

Interstellar gas in different spirals and at different galactic longitudes: Copernicus has reached OB stars with $E_{B-V} \sim 0.40$ and $V \sim 6$. ST can reach OB stars with $E_{B-V} \sim 1$, placed at a distance of 10^4 pcs and also (with $R = 2\ 10^4$ at $d \sim 10^5$ pc, Magellanic clouds) and therefore can observe any correlation between depletion of "metals" and interstellar dust. The M/H ratio can be measured in different parts of the galaxy by the IS absorption lines in the near UV of the red supergiants ($V = 10$ can be reached, i.e., distances of 10^4 pcs for $E_{B-V} = 0$ and 400 pcs for $E_{B-V} \sim 1$).

High-velocity, high-galactic-latitude clouds: The existence of these clouds was known from 21 - cm observations (Dieter, 1965; Hulbosch and Raimond, 1966; Muller et al.,1966). We do not know their distance and it is not clear yet if they belong to our galaxy or to the intergalactic gas (for a complete review see Vershuur, 1975). Optical observations have shown the existence of high latitude galactic clouds, and a lower limit for their distance has been estimated using the distance of the stars (e.g. Münch, 1952). Two high-velocity clouds, V = -55 and -34, were found through the interstellar absorption lines in the spectrum of the high galactic latitude O star HD 93521, whose height on the galactic plane is between 750 and 1400 pcs. It will be possible to measure faint lines ($W \sim 0.001$ A) due to the resonance transitions of the abundant ions in the hot halo stars ($V \sim 10$ to 17; $M_V = 0$ to +3) at a distance ranging from 25000 pcs to a few hundreds of pcs (since the IS extinction in the halo is negligible or generally low), and therefore to detect the presence, if any, of gas in globular clusters, to study low density regions of gas and to separate clouds with velocity differing by more than 3 km/s. It is important to study the motions and the chemical composition of this gas. What is its origin, galactic or extragalactic? are the metal depletion and the chemical composition different from those observed in the gas clouds relatively near to the sun? Shull and York,(1977) found that IS lines due to high-velocity clouds (V -50) and to normal low-velocity clouds ($V \sim 0$) were present in the spectrum of Mu Col, b -27, and HD 28497, b -370, and that the typical depletion of heavy elements was present in the low-velocity clouds, but less or no depletion was observed in the high-velocity clouds.

Hot interstellar gas: Theoretical arguments for the existence of hot gas in the galactic halo were given by Spitzer as far back as 1956. Lines of Si IV, C IV, N V could be observable if $T \sim 10^5$. For higher temperatures the gas will be in higher ionization states; unfortunately the region at $\lambda \sim 1035$ where the OVI resonance lines fall, will not be observable with ST. Copernicus has not found evidence of these lines (we expect very faint lines) but interstellar O VI has been found in various parts of the galactic disk and also in a few cases at high galactic heights (Jenkins, 1978), but N V has been found only in the vicinity of one SN remnant (Jenkins et al., 1976).

A few O stars behind SN remnants could be found by comparing the Catalogue of O stars (Cruz-Gonzales et al., 1974; Goy, 1973) and the catalogue of SN remnants (van den Bergh et al., 1973). Five SN remnants, beside Vela, are found at almost the same coordinates as O-type stars, whose spectra should be studied: SNR in Monoceros and HD 47483; MSH 10 -53 and BS 4043; W 28 and 7 Sgr; 3C 400.2 and HDE 353446; Cas A and HD 221335. The presence of hot gas in the galactic halo could be detected by observing OB supergiants in the LMC and SMC. Several stars are brighter than V = 13 and can be studied at R = 10^5. At the same time the composition of the stellar atmopheres and of the IS gas in the Magellanic clouds could be studied.

Outer envelopes of stars: Study of mass-loss and stellar winds are important because they can considerably affect stellar evolution. Mass-losses at a rate of 10^{-5} ☉/y have been observed in early-type stars. (Hutchings, 1976: visual observations; Snow and Morton, 1976, Copernicus observations). Shortward-shifted lines of O VI have been found in several OB stars, indicating the existence of expanding hot atmospheres. This field has been studied extensively both with Copernicus and with IUE. Winds have been shown to be present also in red giants (Bernat, 1977). The main importance of a systematic study of the outer layers of late type stars (F-M) consist in the fact that the characteristics of these layers are correlated to overall characteristics of the star, such as the luminosity (relation Wilson-Bappu) and the age (the intensity of the chromospheric H and K emission generally increases with decreasing age) and are affected by the presence of a companion. (Spectroscopic binaries generally have much stronger emissions than single stars of the same type and age). A better knowledge of these layers can be obtained by studyng the emission lines in the far UV where the stellar continuum is practically missing. Only a few bright stars have been studied up to now. It will be possible to extend these studies to stars with very different ages (like the young T Tauri stars and the old members of globular clusters) and different chemical composition (like SMR stars and very metal-poor stars) and to investigate the effect of all these variables (mass, age, chemical composition) on the chromospheres and coronas.

There is an observational gap in the HR diagram between stars presenting evidence of hot coronas and stars presenting evidence of cool winds (Reimers, 1977). The latter have been observed, through the presence of violet-shifted CS absorption of Ca II H and K lines, in stars cooler and more luminous than a boundary line defined by K5, M_V = 0.0 and G5, M_V = -4. The limit to the observability of the H and K lines is probably due to ionization of Ca II. Ultraviolet observations will permit us to observe cool winds by means of the resonance lines of Mg II, which has a higher IP (15 ev against 11.8 of Ca II). Moreover magnesium is about 10 times more abundant than calcium. It is suggested by Reimers that some short-scale (on the order of hours) variations observed in the chromospheric H and K emissions of Alpha Tau are not real (Liller, 1968).In a relatively near object like Alpha Tau the re-emitting CS envelope is partially resolved and therefore the observed variations may be due to variations in the seeing which produces a variable amount of re-emission collected on the spectrograph slit. The high spatial resolution of ST can solve this problem.

We have no data about stellar winds and coronas in metal-poor giants in globular clusters. Stars with V = 8 corresponding to a distance of about 4000 pc will be observable with short exposures at 2800 A.

Two hypotheses are proposed for explaining the mass-loss from red giants (Reimers, 1975): (a) acoustic waves from the convection zone provide the necessary energy for the escaping material; (b) radiation pressure on dust grains drives the expanding envelope. One could decide which of the two mechanism is operative by observing very metal-deficient stars where the second mechanism cannot be very efficient. UV observations will permit a more detailed study of the outer layers of binaries and give clues for explaining how the presence of a companion affects the energy balance, and why their chromospheres are more active than those of single stars.

Flare stars and T Tauri stars are examples of two classes of stars with very active chromospheres and coronas. X- and EUV-emissions have been observed from a few flare stars. No -UV spectroscopic observations have been made at high resolution. These objects, which are young, in part still contracting stars, will enable us to study chromospheres, coronas and winds in a very different range of masses and ages than the solar one.

The high spectral resolution will make it possible to study whether the interaction between star and interstellar medium consists only in mass-loss or if there is some evidence of accretion from the IS medium. This is an important point which needs to be studied. The high resolution will let us separate the various emission components.

Analogous problems are presented by the Herbig Haro nebular variables, which probably represent the massive counterparts of the Tauri stars.

<u>Chemical composition and chemical evolution of the galaxy</u>:
(a) Stars which are not appreciably evolved should reflect the chemical composition of the gas out of which they were formed. Hence the study of hot main-sequence stars both in galactic clusters, situated in different spiral arms and at different galactic longitudes, and in LMC and SMC is necessary and feasible. The study of F-G main sequence stars in globular clusters would be desirable, because of the high sensitivity and the high spatial resolution of ST. In the majority of cases, the chemical composition of members of globular clusters, because of the faintness even of the brighter non-evolved stars, is determined by observing their colors or low resolution spectra. However both these methods give ambiguous results. Cayrel de Strobel and Perrin found that (personal communication), once analyzed in detail, stars having the seven colors identical in the Geneva system (within 0.01 mag.) have not identical atmospheric parameters. A comparison of UV low resolution spectra (2 A) with computed synthetic spectra has been made by M. Burger (personal communication). It appears that the assumed microturbulence is more important than the chemical composition in determining the spectral features. For these reasons it would be highly desirable if the HRS could extend its spectral range to the visual.

We usually assume that all the stars of the same cluster have the same chemical composition. The high spatial resolution would allow us to verify this assumption, with important consequences for our ideas on star formation, by comparing the chemical composition of stars in peripheral parts of the cluster with those located in more densely populated regions. Preparatory work with the Faint Object Spectrograph will be necessary, in order to single out convenient representatives for the comparison.
(b) Stars which are appreciably evolved should show results of nuclear reactions in their atmospheres, like, e.g. hot stars which are members of globular clusters (hot horizontal branch stars, hot subdwarfs). There are about 25 globular clusters with stars brighter than $V = 17$ and bluer than $B-V = 0.0$, which could be observed with $R = 2\ 10^4$.

Bp, Ap, Am stars are non-evolved chemically-peculiar stars which are not satisfactorily explained by any theory. Previous observations in the UV range show that far UV spectra of Ap show strong differences from those of normal stars which present the same Balmer line profiles and energy distribution in the visual range (e.g. Leckrone, 1973; Aydin and Hack, 1978). Very precise measurements of the line intesities of some specific element are necessary for checking the predictions of different theories, such as diffusion or accretion. Several elements do not show measurable lines in the visual range (boron is not observable in any star; carbon, nitrogen, oxygen in Ap; iron group elements, heavy elements and rare earths in Bp). Several peculiar stars present complex profiles, periodically varying, suggesting a patchy structure of the photosphere. The variation is interpreted as due to the varying aspect of the star due to rotation. High resolution is requested in order to study the chemical composition in different patches, by resolving the complex line profiles.

Several hot halo stars present chemical peculiarities similar to those observed for the young non-evolved Ap stars. Very few high resolution studies have been made in the visual range and none in the UV. A detailed comparison of non-evolved and far-evolved Ap could help in understanding the origin of the chemical peculiarities.

References

Anderson, R., Henry, R.C., Moos, H.W., Linsky, J.L., 1978 Astroph. J. 226, 883
Aydin, C., Hack, M., 1978 Astron. Astroph. Suppl. 33, 27
Bernat, A.P., 1977, Astrph. J. 213, 756
Brandt, J.C., 1978 HRS Newsletter No. 1 (June 1, 1978)
Burger, M. 1977 personal communication
Cayrel de Strobel, G., Perrin, M.N., 1978 personal communication
Cruz-Gonzales, C., Recillas-Cruz, E., Costero, R., Peimbert, M., Torres-Peimbert, S., 1974, Revista Mexicana de Astron. Astrof. 1, 211
Dieter, N.H., 1965, Astron. J. 70, 552
Goy, G., 1973 Astron. Astroph. Suppl. 12, 277
Hulsbosch, A.N.M., Raimond, E., 1966 B.A.N. 18, 413
Hutchings, J.B., 1976 Astroph. J. 203, 438
Jenkins, E.B., Silk, J., Wallerstein, G., 1976 Astroph. J. Suppl. 32, 681
Jenkins, E.B., 1978 Astroph. J. 219, 845
Leckrone, D., 1973 Astroph. J. 185, 577
Liller, W., 1968 Astroph. J. 151, 589
McClintock, W., Henry, R.C., Linsky, J.L., Moos, H.W., 1978 Astroph. J. 225, 465
Muller, C.A., Raimond, E., Schwarz, U.J., Tolbert, C.R., 1966 B.A.N. Suppl. 1, 213
Münch, G., 1952 Publ. Astron. Soc. Pacific 64, 312
Reimers, D., 1975 in Problems in Stellar Atmospheres and Envelopes, edited by B. Baschek, W.H. Hegel, G. Traving, Springer-Verlag, p. 251
Reimers, D., 1977 Astron. Astroph. 57, 395
Shull, J.M., York, D.G., 1977 Astroph. J. 211, 803
Snow, T.P., Morton, D.C., 1976 Astroph. J. Suppl. 32, 429
Spitzer, L.Jr., 1956 Astroph. J. 124, 20
Van Den Bergh, S., Marscher, A.P., Terzian, Y., 1973 Astroph. J. Suppl. 26, 19
Vershuur, G.L., 1975 Annual Review of Astron. Astroph. 13, 257

J. AUDOUZE : In your presentation you suggested that the deuterium abundance can be determined from Space Telescope observations. I do not think that the wavelength range (λ< 1200 Å) of ST is suitable for such determination because the only transition available to ST is lyman α which is most generally awfully saturated. The interstellar D/H ratios measured with the Copernicus satellite have been performed at much lower wavelengths (around 910-920 Å).

M. HACK : It is possible (for nearby stars) because it has been done with Copernicus for a few nearby bright stars (see Ap.J. of Dec. 15, 1978, article by McClintock et al.)

I. APPENZELLER : Have you made an estimate of the possibility to observe stars in M31?

M. HACK : Only the brightest OB-type stars with absolute magnitude $\sim$-8 or brighter could be observable with the HRS in the low resolution mode - 2×10^4.

DENSITY AND METALLICITY GRADIENTS IN THE GALACTIC HALO

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ABSTRACT

Experience from extensive photometric studies demonstrates that the following problems require an extension of the observations of stars in the galactic halo beyond the observing limits of ground-based telescopes:

(i) the determination of the space distribution of field stars in selected directions out to the physical "boundary" of the galactic halo;
(ii) the determination of the luminosity functions of K- and M-stars of populations I and II necessary for halo mass estimates;
(iii) the determination of chemical gradients, i.e., changes of stellar metal abundances in the galactic halo as functions of the distance from the galactic plane or the galactic center.

The solution of these problems involves the following observations. RGU three-color photometry of faint halo stars down to corresponding UBV magnitudes $m_V \approx 24$ and $m_U \approx 26$; multi ($n \geqq 4$) -color photometry of star fields down to a corresponding magnitude $m_V \approx 25$, observed in a photometric system being designed for three-dimensional classification of stars of spectral types later than about K5; spectral scans of selected faint halo stars used for optimum design and calibration of the RGU and multi-color systems.

INTRODUCTION

The significance of the space telescope for galactic structure work is, of course, its ability to provide accurate information about very faint stars. Since the stars that we want to study in the galactic halo are faint <u>and</u> numerous, a logical approach consists in combining the potentials of the space telescope with those of stellar statistical methods applied to ground-based photometry.

In the following sections we will discuss the need for observations to be made with the space telescope in view of the results that have been obtained from the Basel halo survey, initiated by Becker (1965) almost fifteen years ago, and based on 48" Palomar-Schmidt plates taken in the RGU system.

1. DENSITY STRUCTURE

Statistically, halo stars have an ultraviolet excess, which causes a measurable displacement of their positions with respect to those of the normal disk stars in the two-color diagram of the RGU system. If the UV-excesses are interpreted as being due to metal deficiency as compared to the Hyades, then the absolute magnitudes of the halo stars can be determined by use of the blanketing vectors (Smith and Steinlin, 1964; Buser, 1979), and space densities can be computed. This procedure has been described in detail by Becker (1965).

Reliable space densities can be determined for halo stars with absolute G-magnitudes $3 \leqq M_G \leqq 8$. This means that, for a typical limiting magnitude $m_G \approx 19$ the intrinsically brightest stars are being surveyed at distances $r \approx 8$ kpc from the sun.

Figure 1 shows a preliminary synthesis of space densities observed in various directions lying in a plane perpendicular to the galactic plane (Fenkart, 1978). The absolute magnitudes of the stars involved have been confined to the interval $4 \leqq M_G \leqq 7$. The heavy lines connect points of equal space densities, illustrating the existence of density gradients and indicating a considerable flattening of the galactic halo.

To improve these results is largely a matter of extending the photoelectric scales down to fainter limiting magnitudes. For, at the faintest levels of apparent magnitude the present photographic photometry strongly depends on the extrapolations of the photoelectric sequences, notably in the ultraviolet. This may result in systematic errors mainly of the U-G colors, which in turn add to the difficulties in separating the populations and determining the absolute magnitudes of the halo and disk components among the intrinsically fainter stars.

The necessary improvement should go along with an extension of the present investigations toward the physical edge of the halo. This can be achieved by observing RGU-magnitudes down to $m_G \approx 25$ and $m_U \approx 26$ for a statistically significant number of stars in various selected fields.

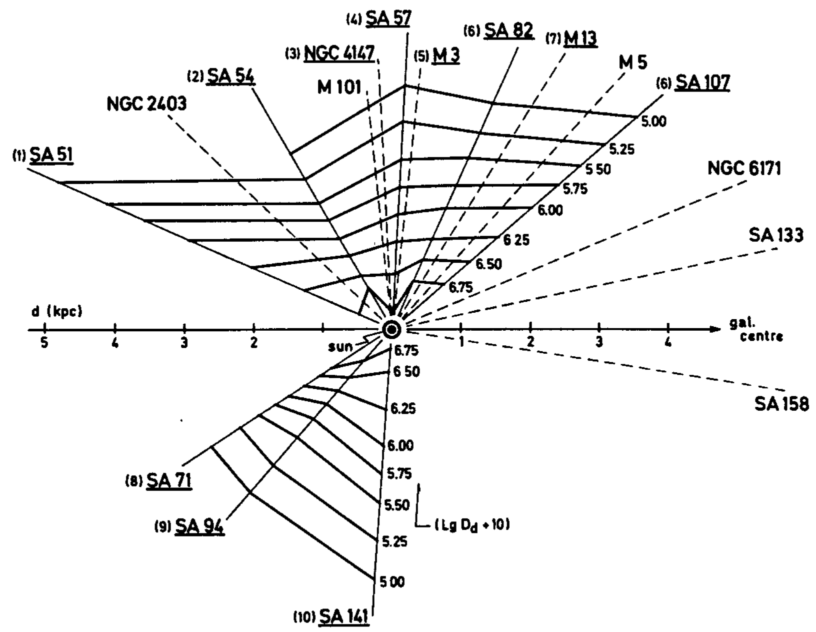

Fig. 1. Lines of equal space density in a plane perpendicular to the galactic equator and going through the galactic center and the sun.

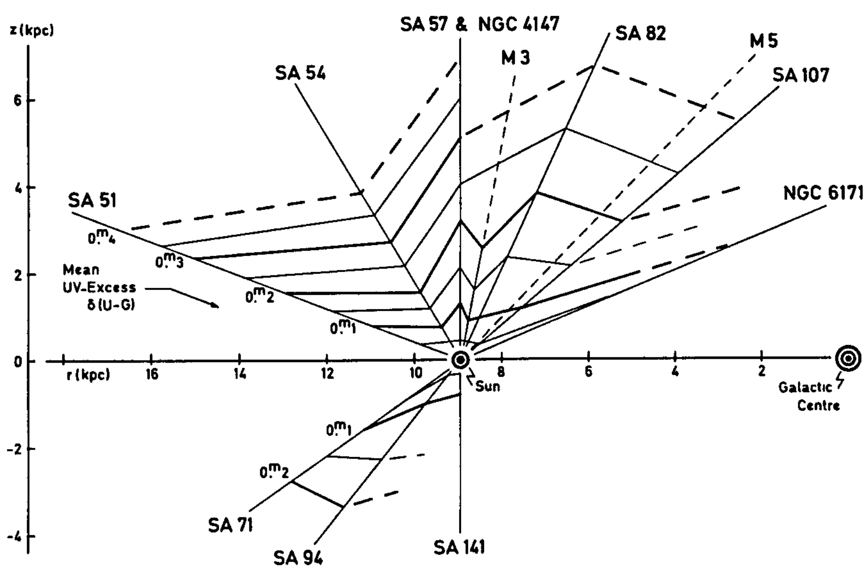

Fig. 2. Lines of equal mean ultraviolet excess of F8-G5 dwarf stars with $<M_G> = 5$. The lines are lying in the same plane as those of Fig. 1.

2. SPACE LIMIT AND OVERALL SHAPE

In the fractionated two-color diagrams for apparent magnitudes brighter than $m_G \approx 15$ the disk stars cover the whole main sequence with $M_G \geqq 3$. For decreasing apparent magnitudes these stars continuously disappear, beginning with the brightest absolute magnitudes. This progressing disappearance is caused by the space limit of the galactic disk beyond which, statistically, there are only halo stars left.

In the color-magnitude diagram this physical limit of the galactic disk corresponds to a (straight) line of constant distance (modulus). The stars on the brighter and redder side of this line are a mixture of disk and halo population, while those on the fainter and bluer side are almost exclusively of the halo population.

If the distance to the disk limit has thus been established by three-color photometry, then additional two-color photometry, preferrably in a very-wide band system such as the Johnson B, V-system, may be used to identify the halo stars at fainter limiting magnitudes.

This procedure has been applied by Becker (1967, 1970) in the analysis of two fields in SA 51 and SA 57, for which plates in B and V had been taken with the 200" Hale reflector in addition to the 48" Schmidt plates obtained in the RGU system. These analyses result in rough estimates of the halo space densities out to distances of about 20 kpc. The observations in the direction of the anti-center (SA 51) indicate that the space densities drop to zero at distances of the order of 35 kpc.

Thus, B, V-photometry down to $m_V \approx 25$ and $m_B \approx 26$ for a statistically significant number of stars observed in additional fields could produce the results necessary for the determination of the size and overall shape of the galactic halo.

3. CHEMICAL STRUCTURE

Figure 2 shows lines of equal UV-excesses for the stars observed in the Basel halo program. These contours have been constructed for the absolute magnitude interval $4.5 \leqq M_G \leqq 5.5$, i.e., late F- to G5-stars (Trefzger, 1979). This selection confines the sample to dwarfs and hence allows one to interpret the UV-excesses in terms of metal deficiencies, a UV-excess $\delta(U-G) \approx 0\overset{m}{.}4$ corresponding to [Fe/H] ≈ -2. The preliminary results of the figure indicate the existence of metallicity gradients resembling the density gradients of Figure 1 fairly closely.

Improving and extending these isoabundance contours to the farther reaches of the halo requires RGU three-color observations down to $m_U \approx 25$. For spectral types later than about K5 metallicity and luminosity effects on the colors have to be taken into account in a more elaborate manner than has been possible to the present time. In order to solve these problems we need spectral scans of faint stars with different metal abundances and luminosities, among which globular cluster main sequence stars and faint subdwarfs down to $m_V \approx 22$ and $m_U \approx 25$ are most important. In the present context, such scans would serve two purposes: first, to improve the calibration of the two-color diagram of the RGU system, and second, the design of a multi-color system suitable for three-dimensional classification of the reddest stars.

4. MASS

Fenkart (1977) has estimated upper and lower limits of the halo-to-disk mass ratio from the space densities and luminosity functions observed in a number of fields of the Basel halo program. The lower limit of this ratio has been based on the observed luminosity functions for the absolute magnitude interval $3 \leqq M_G \leqq 8$, while the upper limit includes a reasonable extrapolation of these functions down to $M_G = 16$.

The results thus obtained from purely photometric investigations can be considered an indispensible counterpart to dynamical determinations of the halo mass and halo mass distribution. It is therefore highly desirable to exhaust the potentials of photometric surveys more completely than has been possible so far. This implies, first, that the luminosity function of the halo stars should be known down to at least $M_G = 12$ in an extended solar neighborhood, and second, that space densities be derived for stars with $3 \leqq M_G \leqq 8$ and different metallicities out to distances of at least 12 kpc in various directions including the inner part of the halo. The observational requirements imposed by these goals can be met by the observing programs outlined in the previous sections.

This work was supported by the Swiss National Science Foundation.

REFERENCES

Becker, W.: 1965, Z. Astrophys. 62, 54.
Becker, W.: 1967, Z. Astrophys. 66, 404.
Becker, W.: 1970, Astron. Astrophys. 9, 204.
Buser, R.: 1979, in: Dudley Obs. Rep. No. 14, ed. A.G.D. Philip (in press).
Fenkart, R.P.: 1977, Astron. Astrophys. 56, 91.
Fenkart, R.P.: 1978, Recueil des Séminaires de l'Observatoire de Besançon.
Smith, L.L., and Steinlin, U.W.: 1964, Z. Astrophys. 58, 253.
Trefzger, Ch.: 1979, in preparation.

B.E.J. PAGEL : How many fields, requiring how much observing time, would be needed to make a reasonable impact on this programme?

R. BUSER : Three-color observations of at least eight or ten fields in the general directions of the galactic poles and the galactic center and anticenter would probably have the impact that we would hope for. This would require a total of about 30 2000-second exposure images.

J. AUDOUZE : Could you provide us with an upper limit of the density of the halo of our galaxy?

R. BUSER : The local value derived by Fenkart (1977) is $7.7 \times 10^{-4}\ \mathfrak{M}_{\odot} pc^{-3}$. Of course, we still know very little about the halo mass density in the inner part of the Galaxy.

OBSERVATIONS OF CLOSE BINARY STARS USING THE FAINT OBJECT CAMERA

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Introduction :

The photon-counting detector of the Faint Object Camera (FOC) with a present design at f/96 will yield a resolution of 0.022 arc sec per pixel. The camera will operate in the spectral range 120 - 800 nm and will have a large dynamic range, useful for the precision photometric measurements. Only the FOC oversamples the stellar image predicted for the Space Telescope. The central disc of the difraction image of the star has the minimum diameter for λ550 nm of six pixels. Thus, there is the possibility after the correction for photometric and geometric distortions to obtain a two-dimensional image intensity distribution of a single or very close double star. Therefore the FOC can provide vital information in the important field of binary research, because of its angular resolution and its capability to reach very faint objects.

Scientific objective :

One of the most obvious and fundamental contributions of double star astronomy to astrophysics is the determination of the absolute dimensions of stars : masses, radii and luminosities. The most important is the mass, binaries providing the only direct metod of mass determination. Most of our knowledge of the masses of stars less than one solar mass is derived from visual binaries in the solar neighbourhood. The masses of giant stars are still uncertain. A star of given mass can have very different luminosities in the course of its evolution, and the important relation between the three parameters mass, luminosity and age should be known as well as possible. Nevertheless, the empirical mass-luminosity relation of main-sequence stars is still an important function to which model calculations must conform, and its derivation depends almost solely upon close visual binary stars.

Modern speckle interferometric measurements have been made for about 200 very suitable and also very close visual binaries. Position angles and separations can be determined very accurately this way. However, the brightness difference, which is essential for the astrophysical interpretation of the results, can only be estimated in a crude way due to problems inherent in the technique. Using the area scanner technique it is possible to measure the difference in brightness with high degree of accuracy of binaries as close as 0.5 sec of arc (Rakos and al. 1978). Only the Space Telescope equiped with FOC will be able to carry out observations of significantly closer binaries with significantly greater magnitude differences.

A substantial number of astrometric and spectroscopic single line binaries is known, where a single high precision observation will yield the separation and the brightness difference of the two components. This immediately would allow ground based observations to be converted into individual masses and luminosities, for example the stars 61 Cyg, 70 Oph, Barnards Star, Ross 614 B, L 726-8, BD $20^{o}2465$, Ci 1244, Ci 2354 and many others.

In the endevour to obtain as complete as possible a picture of the distribution of the masses of stars, the study of invisible or unobserved companions has played an increasing role in recent years. These investigations have been particularly important in revealing masses in the range between planetary objects and stars. Especially spectroscopic variables of $a \sin i$ greater than 6×10^7 km are very suitable for such investigations. The problem of deriving the astrometric orbit is greatly simplified by the fact that the spectroscopic orbit already provides us with the period, the eccentricity, and the position of the star in the orbit. Thus, the solution merely requires the projection of an orbit of a given shape so as to best satisfy the astrometric data. A number of unresolved spectroscopic binaries of interest are the stars : 58 Per, V 367 Cyg, B 1074, 70 Oph A, 12 Com, 31 Cyg, α U. Ma.

Similar effort should be invested observing certain eclipsing binaries as VV Ceph, ζ Aur, RZ Oph and AR Pav.

Beside the very close binaries there are a large number of close double stars with known orbital elements or with differently evolved companions. The age of the individual components of a binary system can be assumed to be the same, so observations of the brightness difference in the far ultraviolet in addition to the observations in UBV and Strömgren systems can be compared to theoretical models of the stellar structure in an independent way. In particular, precise photoelectric photometry of magnetic stars in binary systems are of great interest for a theoretical explanation of the Ap phenomenon.

Data reduction techniques :

The experience and the extensive software for the reduction of area scanner measurements of double stars can be used for the reduction of proposed observations. After correcting the FOC frames for photometric and geometric distortion, we can mathematically project the two-dimensional intensity distribution onto a plane parallel to the line of separation to obtain the typical one-dimensional area scanner intensity distribution. As long as we restrict ourselves to binary systems, this involves no loss of information, however it facilitates greatly the data handling problem (Rakos et al.1978, Rakos 1974).

The accuracy of the observations depends on observing conditions resulting from tracking irregularities of the telescope, photon statistics and the optical quality of the stellar image in the used spectral region. Also the reduction method influences the accuracy of the results. The ideal observing conditions in space would allow the registration of intensity profiles of identical shape for both components of a binary, with the first component being just the scaled image of the profile of the second component.

If $\delta(x)$ represents the measured profile of the single star, r the brightness ratio of two component of a binary, than the combined double star profile will be the composite function

$$S(x) = \delta(x-p_1) + r\,\delta(x-p_2)$$

$p_2 - p_1 = d$ is the separation between the components (Dicks and Van Rooyen 1973).

The modulus of the Fourier transform of $S(x)$ is

$$M(\omega) = M_0(\omega)\sqrt{1 + 2r\cos 2\pi\omega d + r^2}$$

where $M_0(\omega)$ is the modulus of the transform of the single star profile $\delta(x)$.

Normalising the modulus ratio function to unity at zero spatial frequency ($\omega=0$) we get

$$R(\omega) = \frac{M(\omega)}{M_0(\omega)} = \frac{\sqrt{1 + 2r\cos 2\pi\omega d + r^2}}{1 + r}$$

for $\omega = 0.5\ d$ $R(\omega)$ passes through a minimum and has the value

$$R_{min} = \frac{1 - r}{1 + r} \quad \text{or} \quad \frac{r - 1}{r + 1}$$

and is a measure for the brightness difference of the two components.

Even for very close binaries, as close as $d=0.2\ W$ (W = width of the image profile, illustrated in Figure 1.) and the difference in brightness as large as 2.5 magnitudes, this reduction technique allows the accuracy greater than 0.01 magnitude (Michalke 1977). In the scale of the FOC this corresponds to the separation of only 0.02 sec of arc, as shown in Figure 1.

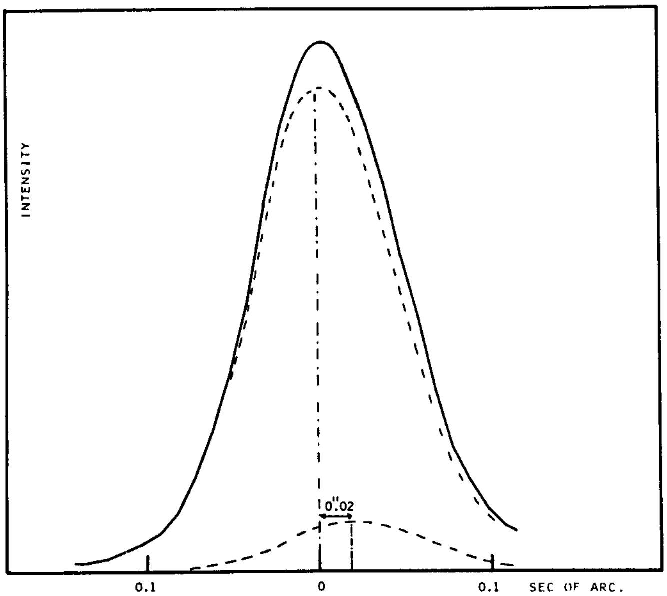

Figure 1. Dashed curves show resolved profiles of the binary components with the 2.5 magnitude difference and 0.02 sec of arc separation. Full curve corresponds to the double star profile as measured.

References : *Dicks, L., Van Rooyen E., 1973, Astrophys. & Space Sci. 22., 153.*
Michalke R., 1977, Dissertation Wien, Institute for Astronomy.
Rakos K.D., 1974, Pub. A. S. P. 86., 1007.
Rakos K.D. et al., 1978, I.A.U. Colloquium No. 48 Modern Astrometry, in print.

SPECTRAL CLASSIFICATION PROJECT

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Recent years have seen many detailed studies in the ultraviolet of individual stars. A large number of new facts have been discovered, many of them unexpected. Whenever such an analysis is made, at some point the author inevitably wants to go beyond the statement that such and such a phenomenon is observed, and wants to say something about the normalcy (or abnormalcy) of the phenomenon found, i.e. whether or not it is found in similar stars.

This is where difficulties start, and one feels uneasy because the exact meaning of "similar stars" is by no means as clear as one might think. It is worthwhile to analyze the question in some detail.

Forgetting the ultraviolet for a moment, let us suppose that we are working in the classic spectral region (λλ 3600-4800). There, when one asks for "similar stars," we answer by referring to stars of the same spectral classification (spectral type and luminosity class). This is done not merely out of habit, but because the spectral classification used is based upon the examination of the spectra of very large numbers of stars. Spectral types as given now were introduced in their present form by the Harvard astronomers at the beginning of the century. To establish the system, several tens of thousands of objects were examined. Similarly, the introduction of the luminosity classes in the Yerkes system, made in the forties, is based upon the examination of 10^4 or more spectra. Therefore, when one uses spectral classification, one is positioning a given object in a framework derived from several tens of thousands of objects. The classification of a group of stars as, say, F2 III, implies that all of them are similar, within the resolution used (typically 2A) and the spectral range considered (λλ 3600-4800). Obviously, when one considers the stars of the same classification (such as the F2 III stars referred to) at higher resolution, one cannot exclude the possibility that they might not be identical. For instance, lines belonging to less abundant elements, not seen at classification dispersion, might turn up in some but not in all the F2 III stars. A similar qualification applies to wavelength range; stars similar in one wavelength range are not necessarily identical in another.

If spectral types derived in the classic region are used to characterize stars in the ultraviolet region, one is overlooking what we have just said. Not only is there a consequent risk of errors, but also an artificial order is imposed upon observations, which might blind the observer to new results. Sometimes people argue that since stellar spectra are determined by physical parameters (temperature, surface gravity, and chemical composition) that do not depend upon the wavelength range, therefore the spectral type (derived from the classic region) can also be used to characterize the ultraviolet region. This argument could be right provided that we knew that only these three factors, and nothing else, determine the spectrum of the star.

Clearly, such a guarantee cannot be given, and therefore the whole question must be reexamined. This implies the establishment of a frame of reference in the ultraviolet, independent of that already established in the classic region. The point we want to emphasize is that there is no way of avoiding doing this.

Such a system was set up for the TDI/S68 experiment on the basis of 1500 spectra. The results can be seen in a series of four papers published by Cucchiaro et al. (1976,1977,1978,1978) and an atlas (Cucchiaro, Jaschek, and Jaschek, 1978). The resulting classifications were compared with those in the MK system, which is defined in the classic range, and one finding is that the systems fit in 85% of the cases. One would expect an overall agreement, but the resulting percentage shows that agreement is by no means perfect. So, for instance, a star may be peculiar in one system but normal in the other, or the luminosity may differ in the two systems, even taking into account the unavoidable statistical errors.

Since the spectral types in the classic region had to be taken from a variety of sources, part of the disagreement might be due to poor classifications. To examine this possibility, we observed at the Haute Provence Observatory, using a dispersion of 80 A/mm, about fifty stars with discrepant classifications. Our material shows conclusively that there are indeed disagreements, a fact which underlines the necessity of setting up a proper frame of reference.

The scheme set up for the TDI cannot, however, be definitive, because the resolving power available was too low (37 A). In a way, the TDI system is the equivalent in the ultraviolet of the Harvard system in the classic region. What we need is the equivalent of the Yerkes system, which requires a better resolution. We should consider the establishment of a proper ultraviolet frame of reference as one of the most urgent tasks for the future. Unless this is done, each star observed in that wavelength range will be a unique, isolated object, without clear relation to other stars. In view of the large variety of objects to be observed from Space Lab, a project of spectral classification is a priority project. In addition, since one can profit from the experience gained with the TDI, the number of stars required does not even need to be very large ($\sim 10^3$ objects).

BIBLIOGRAPHY

Cucchiaro A, Jaschek M, Jaschek C, and Macan-Hercot D, Part I (1976) A.A. Suppl. 26, 241.

Cucchiaro A, Jaschek M, Jaschek C, and Macan-Hercot D, Part II (1977) A.A. Suppl. 30, 71.

Cucchiaro A, Jaschek M, Jaschek C, and Macan-Hercot D, Part III (1978) A.A. Suppl. 33, 15.

Cucchiaro A, Jaschek M, Jaschek C, and Macan-Hercot D, Part IV (1978) A.A. Suppl. 35, 75.

Cucchiaro A, Jaschek M, and Jaschek C (1978) An Atlas of Ultraviolet Spectra. Liège and Strasbourg.

Minor Planet Observations Using the Faint Object Camera of the Space Telescope: Diameters, Surface Properties and Binary Nature.

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Abstract: Minor Planets have been observed in the last years for physical properties using photometry, polarimetry and IR-radiometry. It must be assumed generally that Asteroids are one of the most important clues for the understanding of the origin and evolution of our solar system.

Using the Faint Object Camera (FOC) of the Space Telescope it is possible to observe a large number of Asteroids directly. We propose to use the FOC with the high resolution down to 0.022 arcsec per pixel to examine Minor Planets with respect to (a) diameters and shapes, (b) surface and detail studies, (c) densities and (d) possible binary nature of selected Asteroids.

1. Introduction

The number of Minor Planets with known orbits was raised to 2050 in the Ephemerides of Minor Planets for 1979. The orbits of the Asteroids are aligned roughly between the orbits of the major planets Mars with a semimajor axis of a=1.52 AU and of Jupiter with a=5.20 AU. There are a few objects with exceptional orbits, closely approaching the earth, e.g. 1566 Icarus (a=1.08), 1620 Geographos (a=1.24) and 433 Eros (a=1.46). Outside of the orbit of Jupiter we know 944 Hidalgo (a=5.79, but with high excentricity), and recently 2060 Chiron at a=13.7 AU was detected.

From physical observations of the Asteroids by photometry and spectrophotometry we have developped a well defined picture of compositional types: C (carbonaceous, low albedo), S (stony metallic, high albedo), M (metallic), E (enstatic) and R (reddish)-type Asteroids, with an additional U-type group for unclassifiable objects These goups, correlated with their distribution in different orbital zones may be a basic clue to the understanding of the origin and evolution of the Asteroid belt and our solar system (Bowell et al.1978).

From combined IR-radiometry and polarimetry we know the diameters and albedos of about 200 Minor Planets (Morrison, 1977), from additional UBV photometry we can derive the diameters of a total of 400 objects (Bowell, 1977).

From high precision photoelectric photometry we know the light curves and light variations of about 200 Asteroids, together with their rotation periods - their spin rates - between two and 40 hours with a maximum around eight to ten hours. The light variations are mostly due to the irregular shapes and/or albedo differences on the surface of the objects,e.g. 1 Ceres appears to be nearly spherical, 1620 Geographos is like a cylindric cigar shape with an axial ratio of 1:6. Generally, the tendency to show irregular shapesincreases with decreasing diameters (Harris and Burns,1979, Schober, 1978, Tedesco and Zappalà, 1979).

2. Diameters of Minor Planets

The diameters of Minor Planets never have been measured successfully in a direct way. The only attempt was made using a micrometer at the telescope by Barnard (1902) with the following results, with modern values in brackets :

1 Ceres	770 km	(1003 km)
2 Pallas	490 km	(609 km)
3 Juno	190 km	(247 km)
4 Vesta	380 km	(538 km)

These more or less negative results are evident, considering the maximum appearent angular diameter of the largest Minor Planet 1 Ceres of only 0.7 arcsec, which is in the range of the best seeing conditions for ground based observations. Thus, good diamter measurements are today restricted to indirect methods: polarimetry, UBV photometry, IR-radiometry, but never accurate enough. Recently occultations of stars by Minor Planets have been used for more direct diameter measurements, but they cannot be predicted precisely enough and though the installation of a large observing network only lower limits for diameters can be established. And, of course, the irregularities of the shape cannot be measured for a complete rotation period.

In Table 1 we indicate the diameter D in km, with a range from 1 km up to 1000 km, and the semimajor axis of the orbit between 1.1 AU and 5.0 AU, where (a - 1 AU) is the resulting distance between the earth and the object at the time of opposition.

(a - 1 AU) \ D (km):	1	10	50	100	250	1000
0.1	0″.014	0.138	0.689	1.379	(3.447)	(13.788)
1.0	0.001	0.017	0.069	0.138	0.345	1.379
2.0	0.001	0.007	0.034	0.069	0.172	0.689
3.0	-	0.005	0.023	0.046	0.115	0.460
4.0	-	-	0.017	0.035	0.068	0.345

Table 1. Absolute and appearent diameters of Minor Planets

The results are the appearent diameters in seconds of arc. Of course, not all possible combinations do exist, e.g. no object of D = 1000 km with a=1.1 AU is known.

Table 2 shows the largest Minor Planets and two special objects with their physical characteristics: mean opposition magnitude m, semimajor axis a, diameter in km, the type, albedo in percent, rotation period and lightcurve amplitude.

	m	a-1AU	D(km)	type	alb.%	P^h	Ampl.
1 Ceres	7.4	1.77	1003	C	5.4	9.08	$0^m.04$
2 Pallas	8.5	1.77	609	U	7.4	7.88	0.12 - 0.15
3 Juno	9.6	1.67	247	S	15.1	7.21	0.15
4 Vesta	6.8	1.36	538	U	22.9	5.30	0.10 - 0.14
532 Herculina	11.0	1.77	150	S	10.0	9.41	0.08 - 0.18
624 Hector	15.0	4.12	40x110	U	28.0	6.92	0.10 - 1.10

Table 2. Physical characteristics of the largest Minor Planets and of two special Asteroids

As of today we know 14 Minor Planets with diameters larger than 250 km and 14 objects with diameters between 200 and 250 km (Table 3).

Name	D(km)	type	Name	D(km)	type
1 Ceres	1003	C	3 Juno	247	S
2 Pallas	609	U	324 Bamberga	246	C
4 Vesta	538	U	24 Themis	234	C
10 Hygiea	450	C	95 Arethusa	230	C
31 Euphrosyne	370	C	45 Eugenia	226	C
704 Interamnia	350	C	13 Egeria	224	C
511 Davida	323	C	19 Fortuna	215	C
65 Cybele	309	C	107 Camilla	211	C
52 Europa	289	C	88 Thisbe	210	C
451 Patientia	276	C	7 Iris	209	S
15 Eunomia	272	S	747 Winchester	205	C
16 Psyche	250	M	41 Daphne	204	C
48 Doris	250	C	6 Hebe	201	S
92 Undina	250	C	241 Germania	200	C
Asteroids with $D \geqslant 250$ km			Asteroids with $200 \leqslant D < 250$ km		

Table 3. Large Asteroids with $D \geqslant 200$ km
(Morrison, 1977)

The Minor Planets listed in Table 3 are roughly in a distance of their orbit with a semimajor axis of about 2 - 3 AU.

3. Observations of Minor Planets using the FOC of the Space Telescope

The specifications of the Faint Object Camera (FOC) of the Space Telescope (ST) are the following (Longair, 1979):

Field of view : 11 x 11 $(\text{arcsec})^2$

Max.angular resolution: 0.022 arcsec/pixel

Wavelength range: 120 - 800 nm, angular resolution depending on used wavelength

Photometric accuracy : 1 %

Focal ratio: f/48 and f/96 - we use f/96

Number of pixels : 500 x 500

Exposure time: up to 10 hours

Diameter and shape : From comparison of the tables we conclude that a large and sufficient number of Minor Planets can be studied with a spatial resolution of 0.02 arcsec per pixel. This includes the direct measurements of the diameters for many objects, the direct measurement of the shape, if the geometrical configuration is irregular, and the aspect variation due to the rotation of the object around its axis of lowest momentum, if several observations during the rotation period are obtained. By direct measurement of the diameters the scale of diameter derivations by other methods can be calibrated, as e.g. IR-diameters derived from a relative scale are much more precise than their absolute values.

Densities : If accurate masses are known (1 Ceres , Schubart,1974) using perturbation methods, and if additionally radii and geometric forms of an Asteroid are known, we shall be able to obtain really good values for the densities, until now only roughly known.

Surface studies : For the larger objects a detailed surface study with respect to craters and albedo variations on the surface can be carried out during a single rotational cycle. 1 Ceres rotates in $9^h.1$, the diameter is 1003 km and the maximum appearent diameter is 0.7 arcsec. A surface element of about 30 x 30 km^2 can be resolved directly with the pixel size of the FOC. The resolution can be improved with suitable deconvolution methods.
In addition, a polarimetric study can be carried out, as rough surface of the Asteroids is scattering light in a different way than a smooth layer. Polarisation measurements have been carried out from base ground , but are restricted in their accuracy, of course but changes of the polarisation have been found and are expected because of structured surface elements. Minimum polarisation for 1 Ceres is 0.7 %, for 2 Pallas 1.3 % and for 3 Juno 0.7 %.

Spin axis orientation : Further information can be obtained about the sense of rotation and the orientation of the spin axis in space if samples can be taken during a complete rotational cycle. The result will be available in a direct way, and no indirect conclusion will be necessary anymore. Orientationof spin axis is important for the theory of collision between Asteroids.

Binary Asteroids : A number of Asteroids is suspected to not consist of one single body, but of at least two. 624 Hector is one of those objects : if it is a single asteroid, the axial ratio must be at least 1 : 6. However, there are theoretical considerations in the past about a possible binary nature.
Recently observations of 532 Herculina occulting a star have indicated the existence of a possible satellite of 45 km at a distance of about 1000 km from 532 Herculina (D = 150 at a = 2.77 AU). A number of such objects is under discussion now, where the probability

to detect binaries under Asteroids is high if preselection will be done based on different methods as lightcurve investigations, period analysis and/or occultations. But of course, direct observations of such binary Asteroids will be easy to obtain using the FOC with its high resolution.

4. Final conclusions

We have shown that using the FOC of the ST a large variety of investigations of Minor Planets, very essential for our solar system and especially for the Asteroid belt can be carried out. Minor Planets play the role as tracers for the origin and evolution of the solar system, only comparable with comets, and it is assumed that they remained unchanged from the original condensation chemically, changed only by collision.

We emphasize and suggest to use the FOC of the ST to examine Minor Planets for their physical properties with respect to :

(a) Diameters and shapes
(b) Surface structure and details
(c) Densities
(d) Binary nature of selected Minor Planets.

REFERENCES

Bowell,E., Chapman,C.R., Gradie,J.C., Morrison,D., Zellner,B.:1978, Icarus 35, 313 .

Harris,A.W. and Burns, J.A.: 1979, Icarus, preprint .

Longair, M.S.: 1979, ESA/ESO workshop Geneva, this volume .

Morrison, D.: 1977, Icarus 31, 185 .

Schober, H.J.: 1978 , Astron.Astrophys.Suppl.31, 175 .

Schubart, J.: 1974, Astron.Astrophys.30, 289 .

Tedesco,E.F. and Zappalà, V.: 1979, Icarus, preprint .

Zellner,B. and Bowell,E.: 1977, in A.H.Delsemme (ed.),IAU Coll.39, Univ.of Toledo Press,pp. 185 .

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INTERSTELLAR MATTER AND GLOBULAR CLUSTERS

HII REGIONS AND RELATED PROBLEMS

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The HII regions are one of the most interesting object of observation because of their relation with the star formation problems. They are in general the best criteria to characterize the early stages of evolution of their associated stars and give evidence of others active events. HII regions are also the best spiral arms tracers.

Classification tool

For the ST, the HII regions will provide monochromatic criteria easy to recognize ever on the remote objects. As soon we detect in a distant galaxy some structures revealed by the HII region, we are capable to classified such type of spiral or irregular or some time a more exotic object. For the distant galaxies it can be, as we will see, a convenient means of classification.

Specific advantages in detection

For the observer, the HII regions have the main advantage, in spite of their relatively faint brightness, to be easy to discriminate. The astronomer can play on two very foundamental parameters, the monochromatic character of the emission and the extended source character. (Courtès, 1972).

The monochromatic emission exhibit usually a very narrow profile except for the Seyfert galaxies and for the integrated light of the violent events objects. This narrow profile allows the use of, narrow bandwidth, interference filter. The rate of rejection of the continuum light of the stars clouds and of the sky background can be almost perfect and the detection of the monochromatic light is favourised up to the maximum of possibilities of the collector and the detector.

The extended source character, gives for the very distant objects, a better chance of detection and allows a larger illumination of the detector owing to the use of high focal ratios.

The first advantage, the monochromaticity, will be correctly provided on the ST owing to the numerous interference or coloured filters foreseen by the projects of the Wide Field Camera and the Faint Object Camera.

The second advantage, the extended source character, will be not so favourised in the ST, the focal ratios remains very faint in the WFC and FOC. In fact, the photon counting detector system is supposed to be threshold free, practically noise free and linear. Then, this F number consideration is not so severe than in the use of photographic emulsion or noisy image tubes.

Improvement of detection in the visible spectral range

Except this last remark, the performances of the ST will be in the "visible" spectral range, very similar to the ground based telescope (GBT). The main improvement will be the space resolution ten times better, to observe the morphology, armorphus, circular, ring like of filamentous, some time star like, etc.. For example, the recent discovery by van den Bergh (1978) of a narrow inner filament in the Galaxy NGC 5128 will be perhaps generalized in others galaxies. In this last case, for a star like object, the light is concentrated to a surface hundred time smaller, the detection will reach an improvement of 5 magnitudes or a deep probe in space of a factor ten in distances.

HII regions in the distant galaxies

For the distant galaxies, the HII regions are still easely observable when the bright giant stars have already reached the limit magnitude of the telescope (for the GBT as well as for the ST). In the constant method of extrapolation often used in astrophysics, HII region are one of the best tool of very distant investigations. It is interesting to note the comparison of sensitivity of the optical detection and the radio detection (table 1). One see the advantage of the optical observation.

- TABLE I -

Sensitivity comparison Radio-Optics

Radiation	Galaxy	Extragalactic
Radio continuum	10 cm^{-6} pc	100 cm^{-6} pc
H recombination lines	200 cm^{-6} pc	2000 cm^{-6} pc
Hα emission high selectivity filters Fabry Perot interference technics	5 cm^{-6} pc	20 cm^{-6} pc

In the ST, this main qualities will be improved by the use of the UV and near IR wavelenght range owing to the elimination of the strong upper atmosphere emission. In UV, the main limitation of the integration time, the population II star clouds, will disapear almost completely below 2500 Å (except the difficult evaluation of the blue hot subdworfs). We can expect to detect the interstellar gases in emission even in the superimposition of galaxy bulges or nuclei.

Role of the coronograph mode of the FOC

In this last case, the coronographic mode of the FOC will provide a much better possibility of discovering this interstellar gases and non thermal emission like in NGC 4258 (Courtès et Cruvellier, 1961) very close to the bright nuclei of some galaxies. If one look the Hubble Atlas of galaxies, one realises the lack of information in the central parts of the galaxies not only because of their general overexposition, but for the fundamental reason of the strong contribution in the visible of the light given by the central bulge and some time the nucleus rich in populations II stars.

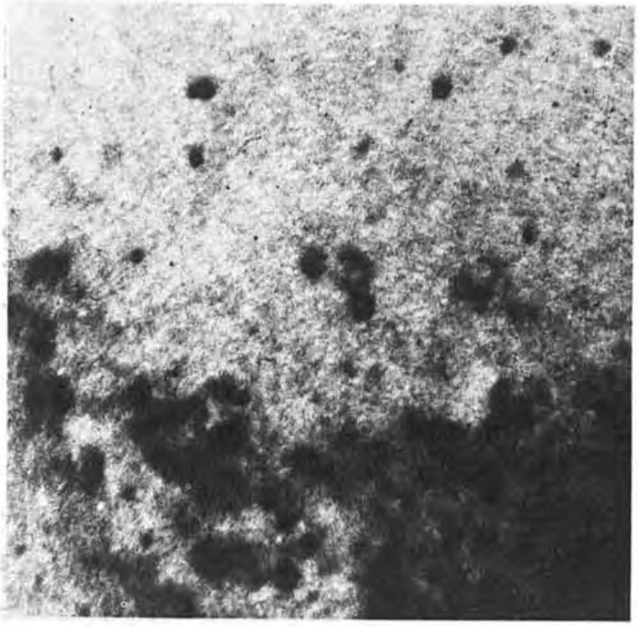
This kind of observation will provide the morphology on the repartition of the blue objects and will help to interprete the unforeseen UV flux discovered in galaxies (A.D. Code, 1969 ; Cruvellier et al., 1970 ; Deharveng et al., 1976).

HII regions in the spiral arms

In the arms, it will be possible to select between the different types of HII regions, especially between the condensed (classical Strömgreen Spheres), with their defined diameters and supernovae remnants.

The filamentary structures in this last case, will be recognized owing to the 0.1" resolution in the galaxies likely beyond the Local Group.

At the outer part of the arms, Bubble like HII regions, one of the best distance indicator reported first by de Vaucouleurs and more recently by Boulesteix et al. (1974) and Courtès (1977), will improve the distance scale much further. For example, some last unpublished detection (1977) of Bubble like HII regions in NGC 5128 by the Marseilles' group shows a case certainly at the limit of the 4 m class telescopes (the ESO 3,6 equiped with interference filter and Image Tube). NGC 5128 lies at 5 Mpc. If the ST equipment gives the same brightness detection performancies, the Bubble like distance indicator could be used up to 50 Mpc.

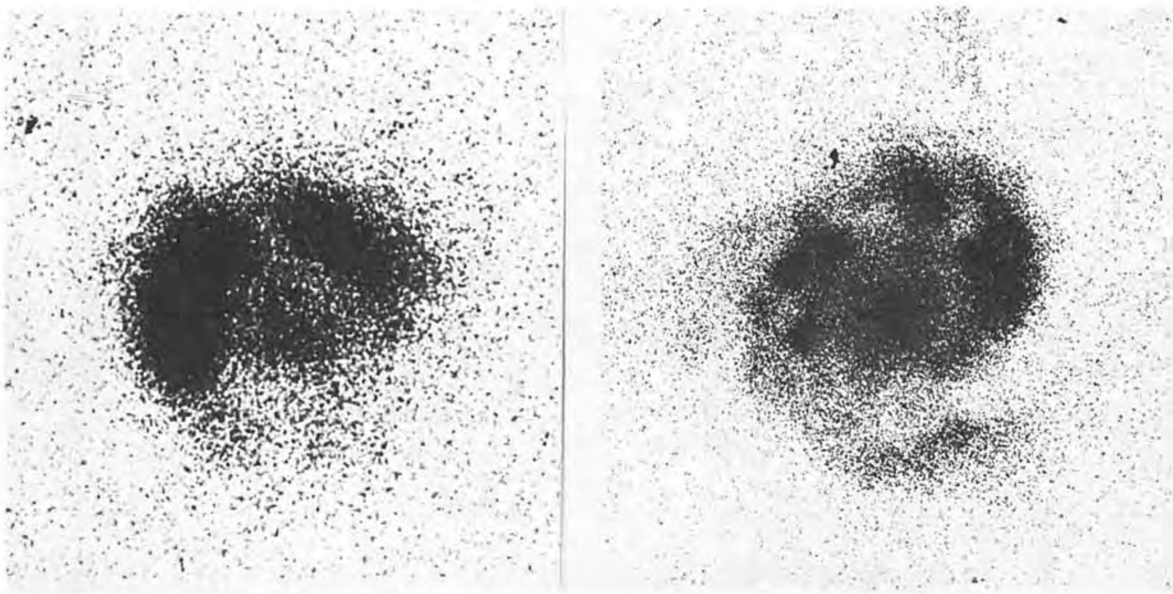


NGC 5128 Bubble like HII regions
Hα Interf. filter. RCA Tube - ESO 3,6 m Telescope (Georgelin and Comte, 1978)

Some HII regions have an exceptional brightness, they are often situated at the end or at the crossing of some branches of the spiral structures, they are another precious, but relatively poor reliable distance indicator. The 30 Doradus HII regions has a diameter of 1.3 Kpc similar HII regions should be detected in the remote galaxies. This distance indicator is better than no indicator at all.

HII regions in the central part

In the central parts, there is some peculiar HII regions of a similar exceptional brightness, one example in the "hot spots" of NGC 2997. The better resolution of the ST will allow to see on a larger number of galaxies what is the frequency of such features and their possible meaning as a stage of evolution of those galaxies.



Hα Interference Filter (Georgelin and Comte) — Continuum in B (Lautsen)

Central part of NGC 2997 - ESO 3,6 m Telescope - With a "bubble like" exceptional HII region.

Another kind of emission appears in the central parts, like the faint extended emission around the nucleus of M31, this peculiar large HII region has been observed spectrographically (G. Münch, 1960), but its shape and extension (about 1 Kpc radius) is not yet well known (Rubin and Ford, 1970) (Deharveng and Pellet, 1975) because of the very intense brightness of the integrated continua of the central stellar bulge of M31.

Recent results (Deharveng et al., 1976) show that in the center of this continuum an UV brightness is confined in a source of about 400 pc diameter.

The interpretation of the origin of the UV flux, early types stars or blue evolved halo-like stars can be verified only with better resolution of the light repartition, with, in case of the first interpretation (early types stars, Carruthers, 1978), their direct detection easy with the ST.

The Seyfert galaxies have a complex nuclei structure made of discrete clouds as it has been shows by M.F. Walker (1968).

Large scale filaments

Structures like the ones of M82, NGC 4258 possibly NGC 253 will be an important subject of observation as an evidence of violent events, detectable up to the nucleus owing the coronographic mode of the FOC.

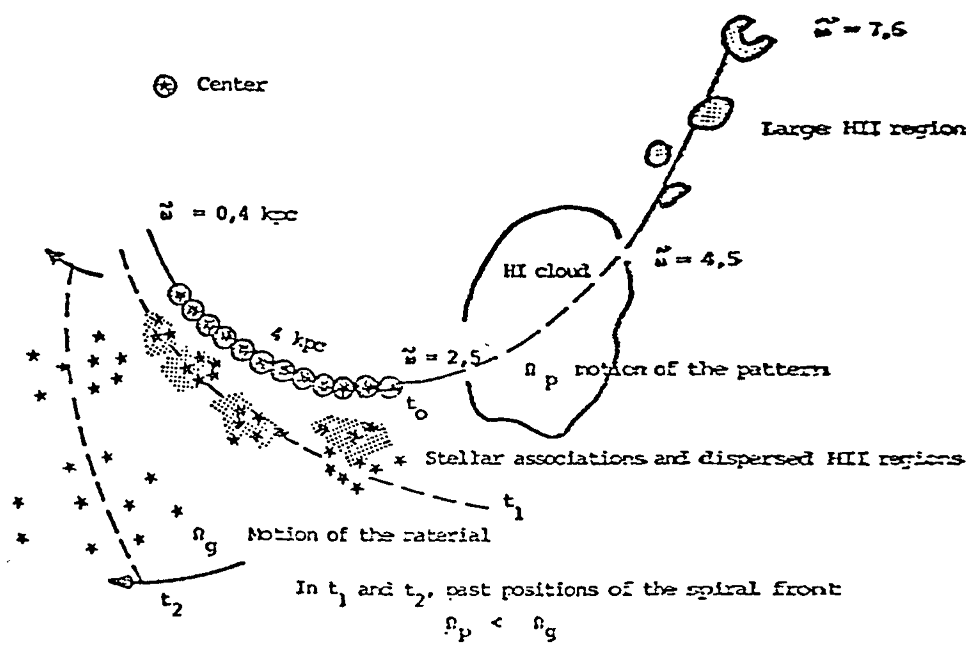
In the LMC, filaments originated from the Tarentula nebula are covering a large part of the LMC. Similar phenomenon are beyond the limit of resolving power in the others nearest irregular. Same remark can be made for the SNR's of the LMC and others irregulars.

Disk and arms monochromatic diffuse emission

The faint diffuse emission in the disk and in the arms, very extended concept of HII regions, suffers of a lack of resolving power, it is difficult to judge of the uniformity of the brightness, some filamentary or patchy structures are at the limit of the GBT in the nearest galaxies like M33 and M31 (Courtès, 1977). This morphology can be checked by the ST if the sensitivity for a so faint brightness (20 cm^{-6}pc) is reached (sufficient illumination of the detector at faint F ratios). The main interests of this morphology are the selection between recent phenomena revealed by the filamentary structures and "old" very regular repartition of the gas. Both in close relation with the, in locus, stars formation problems, and the in locus excitation by late blue stars or normal B stars beyond the limiting magnitudes of the GBT.

Arms and disk emission transitions, stars formation

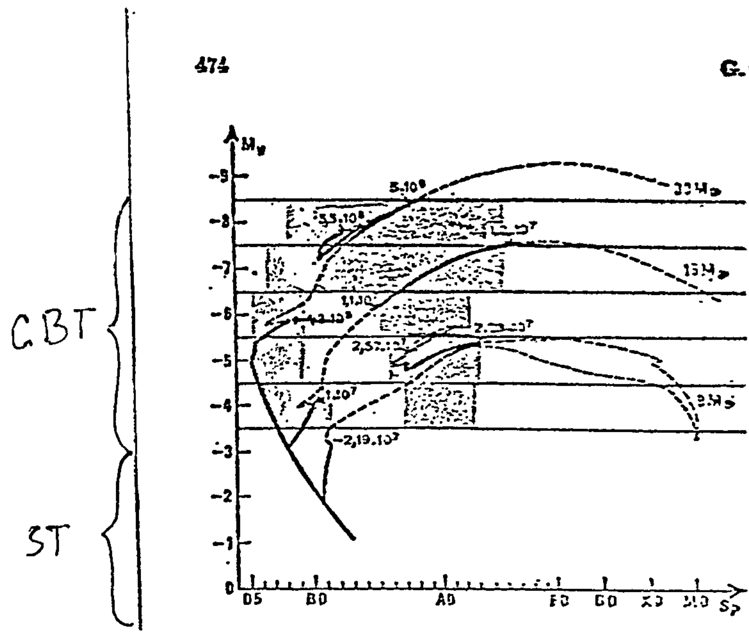
Since the first observation of the radial velocity gradient along the spiral pattern (Carranza et al., 1968) and the related theoretical works (Fujimoto, 1968 ; Robert, 1969 ; Shu et al., 1971 ; Contopoulos, 1972), a special attention has been focused on this evidence of star formation along the compression zone in this narrow front of velocities gradient (Courtès and Dubout-Crillon, 1971 ; Dubout-Crillon, 1977 ; Courtès, 1977) have tried to follow the star evolution from the spiral front up to the evolved star associations left behind after the crossing of the density waves.



Structure and motion of the southern spiral arm in M33.
From Courtès and Dubout-Crillon (1971) and Dubout-Crillon (1977)

The southern arm of M33 is one of the best example of this "stratigraphy" in age of the stars. Observation in UBV with the electronic camera and the 193 cm telescope of Haute Provence Observatory is limited in the star evolution diagramm down M = - 3,5.

Such a fundamental observation can be foreseen with the ST in reaching stars of smaller masses for M33 and the upper part of the diagram for more distant galaxies. If the ST reaches the $m_V = 25$ we shall observe in M33 down to $M_V < 0.5$, then the main sequence up to Ao type, the blue giants and all the red supergiants.



Evolution diagram from Iben and Stothers. The slow stages are indicated by dark curves. The hatched parts correspond to the place of this diagram in which one can find the observed blue stars.

The rich filters combination of ST can provide in the visible and in UV all the necessary information to follow the state of evolution of stars from their accurate multi-colour spectra photometry.

Physics of the gas

As Peimbert has already noted (Peimbert, 1975) the abundances of elements in galaxies will be obtained mainly from the line spectrometry of HII regions. The physics of the gas, known from the line intensity ratios, is very different from place to place and will be, in general, better understood when the ST will provide more informations from the exciting stars. For example, the dissymetry of the excitation between the North and South arms of M33 have had a beginning of explanation (Benvenuti et al., 1973 ; Pellet and Deharveng, 1970 ; Boulesteix et al., 1974 ; Comte and Monnet, 1974), owing to the statistics of 07 B1 stars in the North (low excitation) and the 03 07 stars in the South (stronger excitation).

A check on the fainter magnitudes and a better discrimination of individual stars and clusters will give a more precise interpretation. The present limit in M33 with the 193 cm telescope is 7 pc to be unable to discriminate a small cluster from an individual star.

Galactic HII regions

When one think about the ST one think first to the extragalactic programmes, but many problems about HII regions have to be solved with the maximum of space resolution. In the galaxy we have a large choice of very close HII regions at less than 500 pc. High resolution observations of HII regions have been very neglected but the best 1" resolution GBT results show a very fine structure with narrow filaments, small condensation of gas or dust, shock waves, etc.. See, for example in Orion nebula the ionization front and filaments (Courtès and Viton, 1965 ; G. Münch and Taylor, 1974). In this order of observation, the ST owing to its filters will select the morphological details in the different gas constituants. One of the new field of researches is the close relation will be the star - interstellar medium interaction, the coronographic mode of the FOC will provide, with narrow band interference filters, the best conditions of observation of those phenomena.

Present space observations of HII regions

Galactic HII regions

The space instrumentation has been, from the beginning, devoted to the stellar photometry and spectrography. The rare efforts to observe extended objects (galactic and extragalactic) are very recent. The Barnard Loop was observed from a french rocket owing to the LAS JANUS very wide field camera in the Balmer continuum (Courtès et al., 1975). During the Apollo 16 mission on the moon, the Schmidt telescope equiped with an electronic camera has given the first image (UV 1050-1600 Å) of the Cygnus Loop (G.R. Carruthers and T. Page, 1976).

Si III emissions ($\lambda = 1206$ Å) is interpreted by Carruthers from the previsions of Osterbrock (1963) as a possible main reason of brightness in the bandwidth of the filter. The energy emitted in the 1250-1600 Å spectral range is of the same order than Hα emission. This Cygnus Loop has been recently (october 1978) observed in a LAS Geneva Observatory balloon flight near 2000 Å by Sivan et al. (1979) with a Cassegrain flat field telescope. Always, from Osterbrock previsions, Sivan interpretes the emission caused by the excitation of Si III (1892 Å) and C III (1909 Å).

America nebula NGC 7000, observed during the same flight is definitly much fainter than the Cygnus Loop, this confirm the first evaluation of Carruthers.

Eta Carinae Nebula, ORI nebula, have been observed with the S 183 Skylab LAS experiment (Courtès et al., 1975).

Extragalactic HII regions

There has been a few experiments to obtain imagery of HII regions in the nearest galaxies. The first was made on the LMC owing to the Apollo 16 mission on the Moon (Carruthers and Page, 1972). The LAS S 183 Skylab experiment has given a good image of the Magellanic clouds, LMC and SMC (Courtès et al., 1975).

The second extragalactic imagery was made on the M31 Andromède nebula owing to the LAS FAUST program telescope (aperture 16 cm, focal ratio 1.1) (Deharveng et al., 1976) in the range 1400-1800 Å. Only the central part was detected on a diameter of 70 arc'seconde.

Similar observation with LAS S 183 Skylab experiment at 2500 Å shows the central parts with approximately the same diameter.

The last observation of Carruthers with the NRL Schmidt electrographic camera (Carruthers et al., 1978) shows the central parts but with a larger elongation in the direction of the major axis and the rich arm stars association NGC 206, but no detection of the gas in the spiral arms.

New observations (oct. 1978) owing to the LAS/Geneva Observatory balloon gondola Cassegrain Schmidt telescope, diameter 16 cm, F/2 show (Deharveng et al., 1979) the central part and all the spiral structure with the same morphology than the Hα survey at M31 (Pellet et al., 1978).

It is difficult before the complete analysis of the data to know the exact contribution of the early stars, the non thermal emission and the gas emission. According to the bandwidth used peaked at (2000 Å) the image of the arms is mainly due to Si III (1892 Å) and C III (1909 Å).

The arms are especially bright and this UV emissions appear to be a powerfull signal, certainly better than the [OII] and Hα emission, with the ST one can extrapolate the possibility of recognition of the spiral character on the most remote galaxies according to the performances such spiral arms structures could be theorically detected as soon they measure a width of 0.2".

The M31 arms are in UV emission about 2' wide, then one could recognize the spiral character on a remote galaxy up to a distance of 360 Mpc.

If one compares the brightness of the gas + population I images of LMC (Apollo 16) (Carruthers and Page, 1972) and Andromeda nebula (Deharveng et al., 1979), one sees that M31 is a pessimistic evaluation.

The Space Telescope will certainly recognize, owing to their HII regions, the classification types of the presently most distant observed galaxies.

B I B L I O G R A P H Y

BENVENUTI, P., ODORICO, S. d' and PEIMBERT, M., 1973
Astron. Astrophys., 28, 447

BERGH, S. van den, 1978
Astrophys. J., 226, L73, 122 B-9

BOULESTEIX, J., COURTES, G., LAVAL, A., MONNET G. and PETIT, H., 1974
Astron. Astrophys., 37, 33-48

CARRANZA, G., COURTES, G., GEORGELIN, Y., MONNET, G. and POURCELOT, A., 1968
Ann. Astrophys., 31, 63

CARRUTHERS, G.R. and PAGE, T.L., 1976
Astrophys. Journal, 205, 397-404

CARRUTHERS, G.R. and PAGE, T.L., 1972
Apollo 16, Preliminary Science Report (NASA SP-315) 13-1

CARRUTHERS, G.R., HECKATHORN, H.M. and OPAL, C.B., 1978
Astrophys. Journal, 225, 346-356

CODE, A.D., 1969
Publ. Astron. Soc. Pacific., 81, 475

COMTE, G. and MONNET, G., 1974
Astron. Astrophys., vol. 33, 161

CONTOPOULOS, G., 1972
The dynamics of spiral structure, Univ. of Maryland

COURTES, G. and CRUVELLIER, P., 1961
C.R. Acad. Sciences, t. 253, 218-220

COURTES, G. and DUBOUT-CRILLON, R., 1971
Annales Astrophys., 11, 468

COURTES, G., 1972
Vistas in Astronomy, Vol. 14, 81

COURTES, G., LAGET, M., SIVAN, J.P., VITON, M., VUILLEMIN, A. and ATKINS, H., 1975
Phil. Trans. R. Soc. Lond. A-279, 401-404

COURTES, G., 1977
Topics in Interstellar matter ; Hugo van Woerden, Ed., D. Reidel Publish. Cie, Dordrecht, Holland

COURTES, G., MAUCHERAT, A., MONNET, G. and SIMIEN, F., 1978
Astron. Astrophys., Suppl. 31, 439-461

CRUVELLIER, P., ROUSSIN, A. and VALERIO, Y., 1970
IAU Symp. 36, 130

DEHARVENG, J.M. and PELLET, A., 1970
Astron. Astrophys. 9, 181

DEHARVENG, J.M. and PELLET, A., 1975
Astron. Astrophys. 38, 15-28

DEHARVENG, J.M., LAGET, M., MONNET, G. and VUILLEMIN, A., 1976
Astron. Astrophys., 50, 371-375

DEHARVENG, J.M. et al., 1979
(in preparation)

DUBOUT-CRILLON, R., 1977
Astron. Astrophys. 56, 293-301

FUJIMOTO, M., 1968
IAU Symp. 29, 453 and Astrophys. Journal, 152, 391

MUNCH, G., 1960
Astrophys. Journal, 131, 250

MUNCH, G. and TAYLOR, K., 1974
Astrophys. Journal, 192, L93 -L95

OSTERBROCK, D.E., 1963
Planet. Space Sci., Vol. 11, 621-632

PEIMBERT, M., 1975
Ann. Review Astron. Astrophys., vol. 13, 113

PELLET, A., ASTIER, N., VIALE, A., COURTES, G., MAUCHERAT, A., MONNET, G. and SIMIEN, F., 1978
Astron. Astrophys., Suppl. 31, 439-461

ROBERTS, W.W., 1969
Astrophys. Journal, 158, 123

RUBIN, V.C., and FORD., W.K., 1970
Astrophys. J., 159, 379

SHU, F.H., STACHNIK, R.V., YOST, J.C., 1971
Astrophys. J., 166, 465

SIVAN, J.P. et al., 1979
(in preparation)

WALKER,M.F., 1968
Astrophys. Journal, 151, 71

THE INTEREST OF HIGH RESOLUTION OBSERVATIONS IN HII REGIONS: A NEW KIND OF CONDENSATIONS IN THE ORION NEBULA (1)

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Observatoire du Pic-du-Midi

Though it is one of the best studied, the Orion nebula remains an interesting object for the observer. Considering it is always worthwhile to go ahead in the research of improved spatial resolution, we have undertaken a program of two dimensional photometry with the aid of the Lallemand electronic camera at a place which has been considered for a long time to be a good seeing site, the Pic-du-Midi Observatory.

We present here a series of photographs of the core of the Orion Nebula, taken in several emission lines especially [OIII] λ 5007 Å Hα λ 6563 Å, and [N II] λ 6584 Å; but we have also got photographs in the following lines: Hβ λ 4861 Å, [S II] λ 6717 Å, [S II] λ 6731 Å, and in the continuum near λ 6440 Å. This material was obtained through narrow-band (10 Å) interference filters with S II photocathodes, and, with S 20 photocathodes, for the red part of the spectrum. It is the first time that the S 20 photocathode is associated with a Lallemand electronic camera.

A systematic investigation of the central part of the nebula (inside the trapezium and near it) allows us to distinguish between stars (several of them being already known) and "nebular condensations", highly ionized because they shine in the Hα, Hβ and [O III] lines but neither in the [N II] nor the [S II] lines. We have detected 6 of these condensations of a new type, the diameter of which does not exceed the measured stellar diameters on our best plates (FWHM = 1.4"). These condensations are shown to be neither something like Bok globules nor Herbig-Haro objects. A coincidence (within 2") with an infra red source (IRS 4), in one case, seems to be random rather than the sign of a physical association.

Using the spectrophotometric measurements of PEIMBERT and COSTERO (1969), we could calibrate our plates in the Hα, Hβ and [OIII] lines, and thus provide figures for the intensity of the six condensations in these lines. Then, assuming the simplified hypothesis of an homogeneous sphere of ionized gas, we calculate the electron density inside these condensations, assuming a standard electron temperature of 10 000 K; we find values between 1.5×10^5 cm^{-3} and 4.1×10^5 cm^{-3}. Nevertheless these figures must be considered as minima, since the measured diameters are maximum.

If we calculate the electron density from the [O III]/Hα ratio we find much higher values. The [O III]/Hα ratio goes down from 1.23 in the general nebular medium (the slit 8" x 120" of the Lick scanner used by PEIMBERT, with integration along the line of sight) to 0.54, 0.63, 0.75, 0.51 in the four condensations where it is possible to measure it without too great an uncertainty. However, the degree of ionization of oxygen is, at least, the same as it is in the general medium, and, more probably, higher than in the condensations. There is also no reason for the temperature to be lower inside, since there is, anyway, an increase of the electron density. Upon this basis, we calculate figures for this parameter and we find very high values: 2.2×10^6 to 3.5×10^6 cm^{-3}; from those, we calculate new values of the condensations diameters: 0.19" to 0.40".

Then, calculations of ionization and recombination show clearly that it is impossible to ionize thoroughly such a dense sphere even if it is only 0.19" (1.3×10^{15} cm) in diameter.

Finally, we propose that the condensations are, in fact, partially ionized globules, the inside being neutral, the ionization front penetrating inside, while the ionized matter becomes progressively diluted in the general medium. From the values of the electron density deduced from I (O III)/I(Hα) ratio, from the H_α flux and the thickness which can be ionized, we estimate the values R_i of the neutral globule and R_e of the ionized shell. This model, deduced from observational results, agrees well with the DYSON theoretical model (DYSON, 1968).

The time of evolution of such gravitationally stable globules is 2×10^4 to 8×10^4 years, which is compatible with the age of the Orion nebula. We think that the stars situated in the Orion nebula were born from globules not very different from these, but denser, so that the gravitational collapse could start.

It is evident that observations with the S.T. of such globules would be of great interest in order to have a better physical analysis.

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(1) paper presented after the review paper by Dr. G. COURTÈS on HII regions (Monday 12th, afternoon) - presentation by J.-L.VIDAL.

HIGHLY OBSCURED YOUNG STELLAR OBJECTS

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In recent years we have been investigating various star formation regions of high obscuration with the 1.2 m telescope on Calar Alto with the use of various auxiliary instruments. I would like to indicate here some of the problems one meets in dealing with objects of this kind and why they might be of interest for investigations with the Space Telescope.

We identify interesting objects by means of an infrared image-tube camera which is used as a survey instrument and enables us to take photographs at wavelengths of about 1 μm. With this camera we have seen sources in W3, M17 and other regions for the first time as they are inaccessible at shorter wavelengths or at least difficult to observe due to their faintness. Subsequent photometric and spectroscopic observations indicate that the majority of those are highly reddened early-type stars (Beetz et al., 1974, 1976; Cohen and Lewis, 1978).

The bipolar nebula S 106 = CRL 2584

One of our favourites during the past few months has been the compact HII region S 106, a bipolar nebula and well known IR source (CRL 2584) and I shall first of all refer to some new observations of this object made by Eiroa et al. (1979). Figure 1 contains a selection of photographs in $I \approx 0.95$ μm (left hand side) and $R \approx 0.70$ μm (right hand side) taken with the IR camera, the upper part showing exposures of short duration.

Hitherto the exciting source of S 106 has remained uncertain. In particular it was not clear whether the bright nebulous condensations which are to be seen on the photographs contain hot stars or

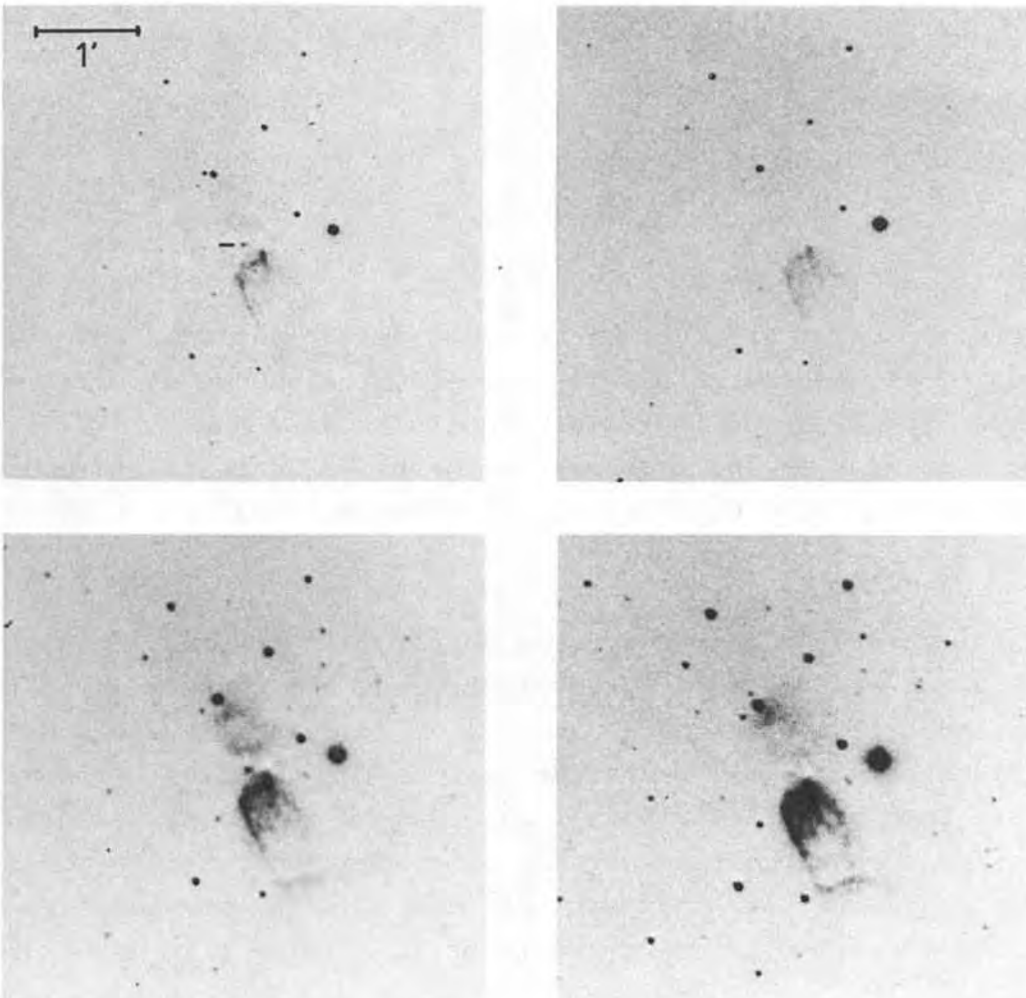

Figure 1: Photographs of S 106 in I (left-hand side) and R (right-hand side). North is at the top, East to the left. Upper part:short duration exposure (I 2 min, R 3 min), lower part: I 20 min, R 30 min. The stellar source is marked in the upper I photograph.

not. However, they even show up on our short exposures as diffuse knots, with appearance quite dissimilar to stellar images on the same photographs. We take this as an indication that no exciting stars are imbedded in these compact features which seem to be clumps of ionized gas and dust.

But the most interesting feature revealed by Figure 1 is the point-

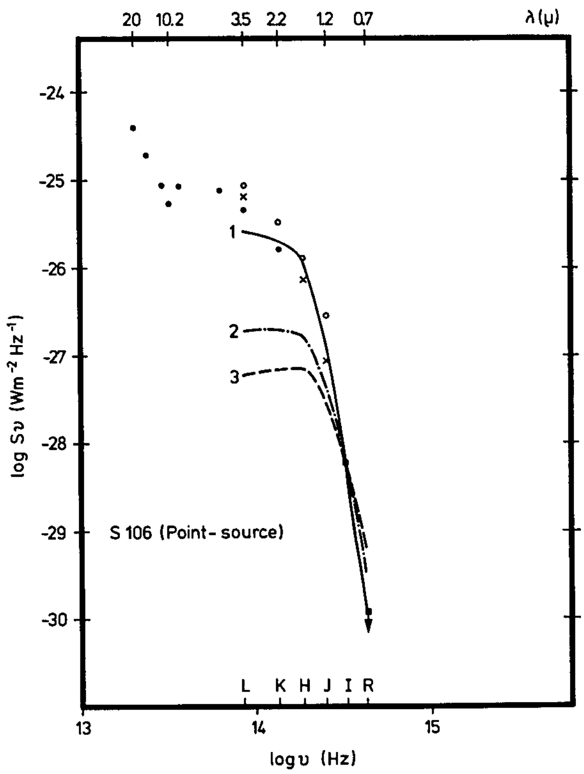

Figure 2: Energy spectrum of the stellar object. Observations of Allen and Penston o, Sibille et al. x, Pipher et al. • , Eiroa et al. ■. Curves correspond to different combinations of spectral type, extinction and distance. Curve 1: B O V, $A_V = 21^m$, r = 320 pc; 2 : O 5 V, $14^m.6$, 2.5 kpc; 3 : B O V, $11^m.8$, 8.25 kpc.

like object in the gap between the two lobes which can be seen distinctly on the I photographs only, even on those with only a few minutes exposure. This star lies near the peak intensity of the 3.5 μm map of Pipher et al. (1976) and coincides with their source 3. Figure 2 shows its energy spectrum on the basis of the flux densities determined by Allen and Penston (1976), Sibille et al.(1975) and Pipher et al. (1976) together with the I ($\approx 14^m.0$) and R ($\gtrsim 18^m.5$) values derived from our photographs. The steep decline of the energy curve towards shorter wavelengths is typical for highly obscured objects.

The three curves plotted represent various combinations of stellar spectral type, distance and extinction assuming a standard energy spectrum for the unreddened star and the normal interstellar reddening law. If one also takes into account the radio emission of S 106 (Israel and Felli, 1978) and its total IR luminosity, one can further narrow down the possible solutions for the point-source which we consider as the exciting star.

The observed source can be interpreted as a star of spectral type O9 or BO located near the centre of an absorbing disk of dust which is seen nearly edge-on separating the two nebulous lobes. The extinction follows as $A_V = 21^m$, the distance as about 500 pc. (Hitherto S 106 was assumed to be 2.3 kpc distant or more.) Towards the poles the extinction of the disk seems to be considerably lower than in its central plane, allowing stellar ultraviolet radiation to escape and to ionize the gas in the lobes. (A model of this type has already been proposed by Sibille et al.) The diameter of the disk is of the order of 0.1 pc, the mass of its dust is about 0.1 solar masses.

According to Lucas et al. (1978) S 106 is associated with an extended molecular cloud. This provides further evidence in favour of a young object, whereas others of similar shape, for instance the egg nebula, are known to represent an evolved stage. The bipolar appearance and the flatness of the absorbing disk suggest the influence of rotation. In fact Lucas et al. find a rotation of the molecular cloud about an axis which coincides with the direction perpendicular to the plane of the dust disk. On this basis we conclude that S 106 represents an early phase in the evolution of a single rotating star, the angular momentum of which appears to be closely related to the rotation of its parent cloud. Furthermore, the disk of dust with the obscured star in its centre might show us a preplanetary system.

This model is based on conventional assumptions (energy spectrum, reddening law) and it is by no means clear whether these are justified. As Figure 2 demonstrates we know at present very little about the stellar spectrum due to its faintness, and there is hardly any hope of obtaining detailed information on the blue and ultraviolet part by conventional methods.

IR emission - extinction law - polarization

Let me mention a few additional aspects of these highly obscured objects:

1.) Usually they are associated with IR emission, the observation of which may render information on their internal constitution. Measurements with spectral resolution superior to that of broad band photometry are required in this respect, but such measurements are presently available only for a very limited number of sources.

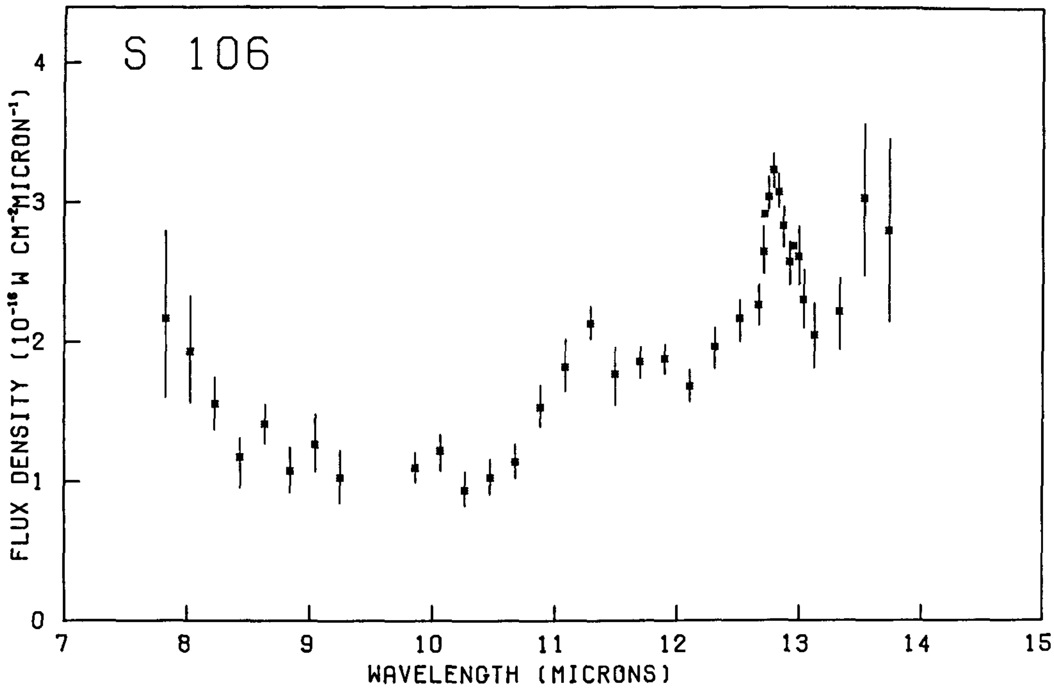

Figure 3: IR spectrum of S 106 according to Schulte i.d.B. and Hefele (1978)

Figure 3 contains the spectrum of S 106 between 8 and 13 μm according to the observations of Schulte i.d.B. and Hefele (1978) on Calar Alto with a circular variable filter of spectral resolution $\lambda/\Delta\lambda$ = 50. The field of view had a diameter of 25 arc sec and was centered on the northern lobe. Above a rather smooth dust continuum, with a relatively weak silicate absorption feature centered at 9.7 μm, one sees the Ne^+ fine structure line at 12.8 μm emitted by highly excited gas. The feature near 11.3 μm might be a mineral emission band. The interpretation of such spectra which, in a few cases, show additional emission lines apart from the one at 12.8 μm, is not far advanced.

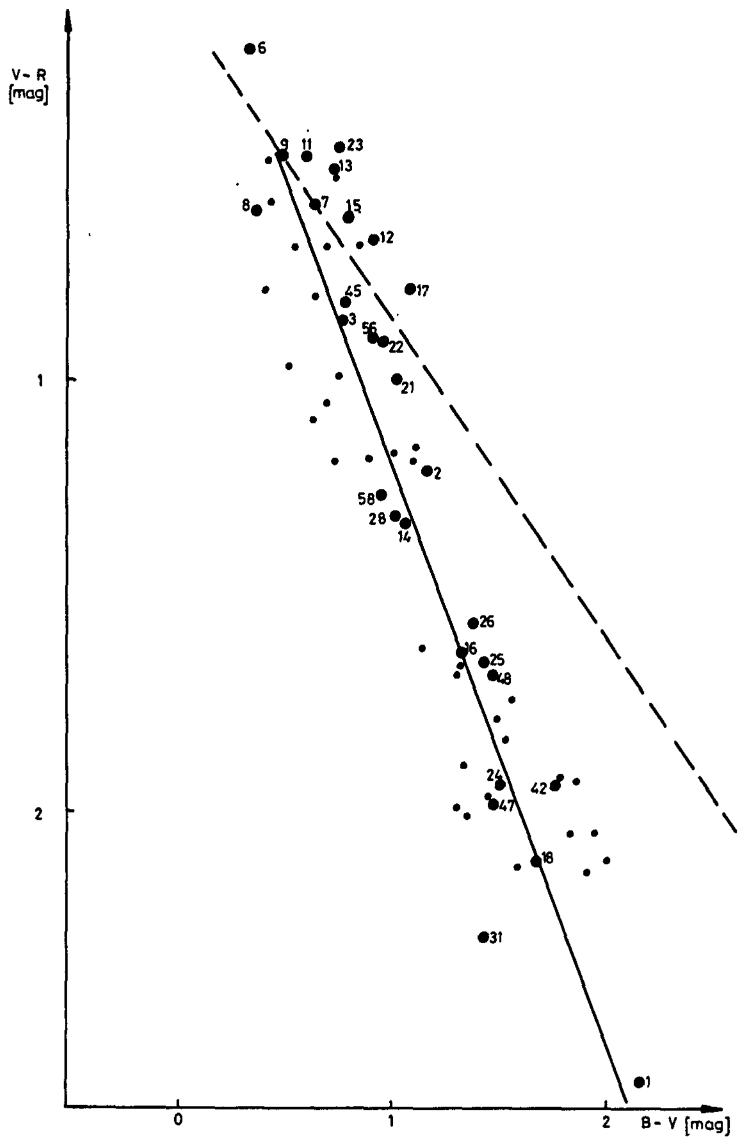

Figure 4: 2-colour-diagram of M17 stars according to Chini (1978). Reddening line of O5V star: - - -. Photoelectric magnitudes photographic

2.) Probing the dusty envelopes by observations of the obscured objects may reveal divergencies from the regular properties of interstellar matter. Figure 4 gives an example of this type: In M17 we identified a highly reddened cluster of early type stars (Beetz et al., 1976), several of which have been observed by Chini (1978) in order to derive improved photoelectric and photographic magnitudes.

Figure 4 shows a two-colour-diagram with the reddening line of an O5 star according to the normal extinction law. The measured M17 stars with extinction values A_V up to nearly 10^m exhibit a distinctly different behaviour corresponding to $R = A_V/E_{B-V} = 4.3$ in contrast to the normal value $R = 3.0$. As a result of the high extinction involved this anomaly can be determined here with a considerably higher degree of reliabality than in other cases of less obscured objects.

3.) Rather high amounts of linear polarization are found for a good deal of these highly obscured objects. Figure 5 demonstrates this for stars in M17. The data are from photoelectric observations in the visual by Schulz (1979) on Calar Alto again. The degree of polarization reaches 28 % here; a general alignment of the polarization vectors is obvious. Similar results have been derived in W3 (Schulz et al., 1978). Furthermore, strong polarization of compact IR sources has been reported by Dyck and Capps (1978). Another strongly polarized young IR source of high obscuration is the Becklin - Neugebauer object in Orion.

To interpret these findings in terms of the Davis-Greenstein mechanism (anisotropic extinction by elongated particles aligned in a magnetic field) is difficult. Elsässer and Staude (1978) proposed an alternative explanation, namely scattering by dust-grains and electrons in non-spherical circumstellar shells, and this brings me back again to disk-like configurations as observed in the case of S 106. This model assumes a central stellar source imbedded in a flat disk of dust and gas which is surrounded by an extended tenuous cloud. The optical thickness of the disk is supposed to be large in directions confined to its equator, but considerably less in the normal direction. An observer viewing the disk nearly edge-on will see highly polarized scattered light from the optically

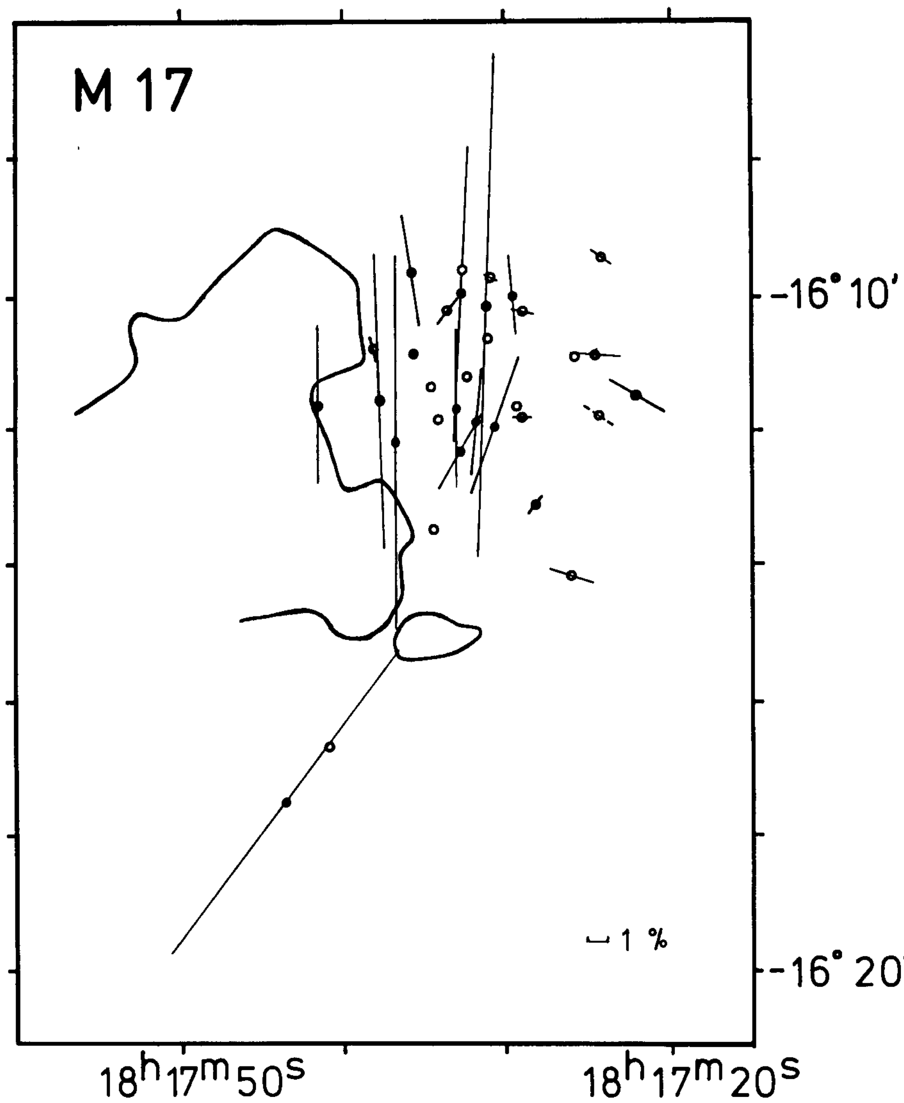

Figure 5: Polarization of M17 stars according to Schulz (1979). Members of M17 cluster ●, foreground stars o. The full line indicates visible nebular emission.

thin polar regions superposed on the strongly attenuated unpolarized direct light from the central star (Figure 6a). A compact circumstellar shell disrupted at the poles (Figure 6b) gives rise to the same polarization effects and may have a smaller diameter than the disk object of Figure 6a. In both cases the shape of the objects

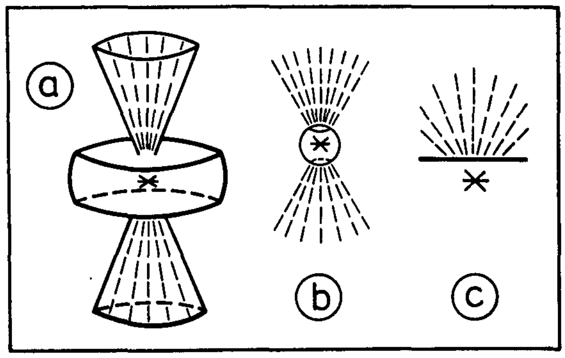

Figure 6: Configurations for explaining the polarization due to scattering, see text (Elsässer and Staude, 1978).

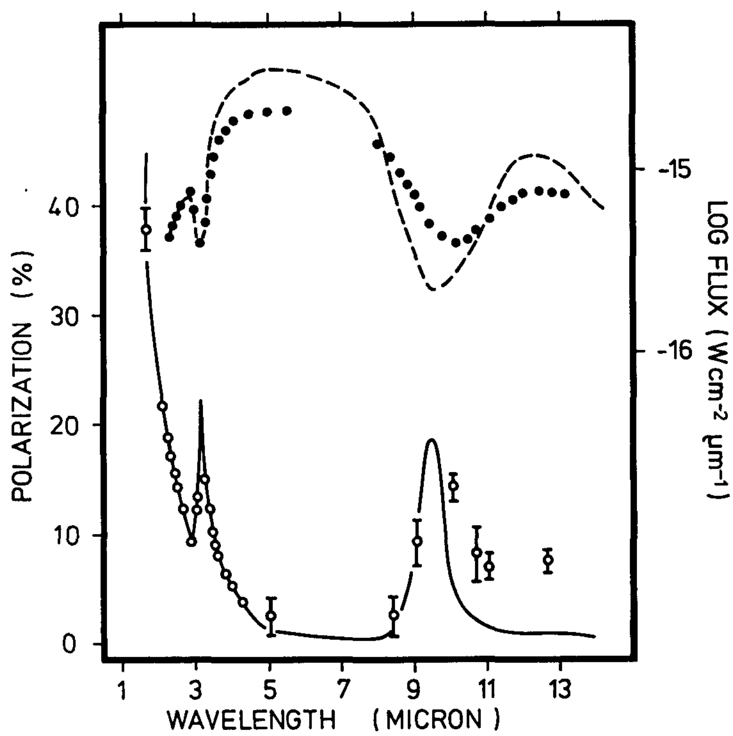

Figure 7: Flux and polarization for the Becklin - Neugebauer object. Observed quantities ● ● ● , o o o ; model - - -, —— (Elsässer and Staude, 1978).

suggests its relation to rotation. A further configuration is illustrated by Figure 6c: a star hidden behind a sharply bound obscuring edge is equivalent to the former cases with respect to the resulting polarization.

Figure 7 shows, according to Elsässer and Staude, flux values and the amount of polarization for the Becklin - Neugebauer object calculated for a model of type a in Figure 6. The results are in good agreement with the observational data. The parameters of the model are approximately the values derived by Becklin et al. (1973) for this source.

We do not believe that all of those highly polarized objects are to be interpreted along these lines. But this type of structure, seen in S 106 and other bipolar nebulae, may be characteristic of young rotating stars and, therefore, of a fundamental nature and deserving of further attention. For this reason one would like to know, above all, how frequently objects of this type occur in star formation regions. A survey of Neckel and Staude, presently in progress at our institute making use of the Palomar Sky Survey, has already shown that bipolar nebulae are more numerous than generally believed until now.

Conclusions

We still know little about the early phases of stellar evolution represented by the objects discussed here and characterised by the presence of dense circumstellar and interstellar shells still wrapping up these young stellar sources. In particular the significance of disk-like configurations is not clear (preplanetary systems?).

These objects are faint at visible and shorter wavelengths and their spectra may exhibit hitherto unknown and unaccessible features.Much observational work can certainly still be done with ground-based equipment. But the Space Telescope due to its fainter limiting magnitude, its high spatial resolution and its abilities in the short wavelength region, will be a powerful tool to obtain unique information on newly formed stars.

References

Allen, D.A., Penston, M.V.: 1975, Monthly Notices RAS 172, 245

Becklin, E.E., Neugebauer, G., Wynn-Williams, C.G.: 1973, Astrophys. J. (Letters) 182, L 7

Beetz, M., Elsässer, H., Weinberger, R.: 1974, Astron. Astrophys. 34, 335

Beetz, M., Elsässer, H., Poulakos, C., Weinberger, R.: 1976, Astron. Astrophys. 50, 41

Chini, R.: Thesis Heidelberg, 1978

Cohen, M., Lewis, R.R.: 1978, Monthly Notices RAS 184, 801

Dyck, H.M., Capps, R.W.: 1978, Astrophys. J. (Letters) 220, L 49

Eiroa, C., Elsässer, H., Lahulla, J.F.: 1979, Astron. Astrophys. (in press)

Elsässer, H., Staude, H.J.: 1978, Astron. Astrophys. 70, L 3

Israel, F.P., Felli, M.: 1978, Astron. Astrophys. 63, 325

Lucas, R., Le Sequéren, A.M., Kazès, I., Encrenaz, P.J.: 1978, Astron. Astrophys. 66, 155

Pipher, J.L. et al.: 1976, Astron. Astrophys. 51, 255

Schulte i.d.B., J.: Thesis Heidelberg, 1978

Schulz, A.: Thesis Heidelberg, 1979.

Schulz, A., Proetel, K., Schmidt, Th.: 1978, Astron. Astrophys. 64, L 13

Sibille, F., Bergeat, J., Lunel, M., Kandel, R.: 1975, Astron. Astrophys. 40, 441

OBSERVATIONS OF SUPERNOVA REMNANTS WITH SPACE TELESCOPES

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Introduction

The topic of supernova remnants can be divided in different ways according to taste. I have found it convenient to divide the subject matter into the following categories: 1. Extragalactic SNR's 2. Galactic and Magellanic Cloud SNR's 3. Pulsars.

However, much of what is said under the first category might apply in particular cases in the second category and vice versa.

In general I have avoided presenting detailed calculations to show that every suggested observation is eminently feasible. If what is presented here seems at times over-optimistic from the point of view of feasibility, perhaps it will provoke others to examine how the sought-after information might be obtained. But I rather think that here I have been conservative, and that the most exciting results will come from pushing the instrumentation to the absolute limits.

Extragalactic SNR.

1. Very Young SNR.

(a) Virtually nothing is known concerning the UV spectra of very young remnants with ages in the range 0 - several hundred days. Because we are only beginning to understand the visual spectra of SNR in this age range it is difficult to make strong predictions about what to expect in the UV. However should such a SN event occur (and it will) there is little doubt that astronomers with interests in this field will make strong claims to observe it in the UV.

(b) The youngest SNR in a fully "nebular" phase, Cas A, has an age of 300 years. Therefore a great gap in our knowledge exists at all wavelengths for the age range 300 days - 300 years. Spectroscopically the longest followed supernova is SN 1972e in NGC 5253 (Kirshner and Oke 1975), where observations were made 700 days after maximum light. Extrapolation of a typical light curve suggests that one might be able to follow such an object spectroscopically in both the UV and V with the LST to an age of 6 or 7 years. Although 6 years still falls far short of the 300 years for Cas A, such an object may have developed sufficiently far beyond its opaque stage to a nebular phase, that worthwhile spectral analyses will enable us to understand the physical situation in the ejected envelope, and to make reliable abundance determinations for material that is still in large part undiluted ejecta from the precursor star.

2. Older SNR.

(a) Detection in a systematic way of SNR's in galaxies in the distance range 2 - 20 Mpc could be made with the wide field camera and suitable filters, viz. Hα, [SII] and others. Galaxies closer than 2 Mpc or even more distant can be observed from the ground. (Danziger et al 1979). Within this distance range (i.e.20 Mpc) one finds a reasonable cross-section of later type galaxies, spirals and irregulars. A detailed survey of particular galaxian types might be compared with the results of statistics obtained from SN events observed up to the present time. It is left to the members of the audience to imagine the nature of the debate which will follow if there is not agreement. Utilizing the 2.7 arcminute field of the wide field camera one would require typically 9 or 10 exposures to cover a reasonable fraction of a galaxy.

(b) A follow-up program of UV and V spectroscopy of SNR's in the same distance interval seems feasible on the basis of recent results obtained for M33 (Danziger et al 1979) and M31. This spectroscopic information could be used to provide confirmatory evidence of identification as a SNR. In addition the spectroscopic data would prove valuable in checking results of abundance studies of the interstellar medium obtained from HII regions, which in general will be easier to observe than SNR's, though not necessarily for particular ions or elements. This checking is desirable because of the availability of better shock models and because the collisionally excited plasma of a SNR provides different physical conditions from those seen in HII regions.

(c) Direct imaging of SNR's in galaxies of the Local Group with the faint object camera could provide structural information in those objects which may be particularly interesting.

The possibility of making associated radio observations beyond the Local Group galaxies seems to be out of the question in the foreseeable future because of the very low flux levels expected (typically 2 - 3 mJy at 21 cm for SNR's in M33 obtained with the VLA by Goss et al 1979).

SNR's in the Galaxy and Magellanic Clouds.

1. Dynamical Studies of Nearby Remnants.

(a) Proper motion measurements of the filaments of nearby older SNR's Vela (500 pc), IC443 (500-1500 pc), S147 (<1000 pc) and the Cygnus Loop (800 pc) combined with ground-based radial velocity measurements would provide rather complete dynamical descriptions of these objects. Since 200 km/sec at a distance of 500 pc is 0.09"/year, and because differential radial velocities greater than 200 km/sec have been observed already in Vela, IC443 and Cygnus this is a feasible project. Such dynamical studies are important from the point of view of propagation of blast waves in the interstellar medium and particularly in the presence of density gradients.

This latter point is exemplified by the position of IC443 possibly near an HI and/or CO cloud complex. The impact of the blast wave on a dense cloud might be seen in the motions of the filaments in this region.

(b) The young SNR's in the galaxy with high velocity filaments, e.g. Cas A, may have been sufficiently studied from the ground (Kamper and van den Bergh 1976). However, young SNR's in the Large Magellanic Cloud, in particular N132D, might profitably be observed for filamentary proper motions since radial velocity measurements by Danziger and Dennefeld (1976) have yielded velocities greater than 4000 km/sec (0.017"/year at the distance of the LMC).

2. UV and V Spectroscopy.

The advent of detailed models of isothermally radiating shocks in the interstellar medium by Cox (1972), Dopita (1977) and

Raymond (1979) provides the basis for detailed interpretative work on the spectra of older SNR's. One can in principle use quantitative spectroscopic measurements in both wavelength regions to extract shock parameters such as propagation velocity and abundances in the filaments, which ought to reflect in general the abundances of the interstellar medium. Two advantages of the LST can be utilized for this work.

The UV spectrum of SNR's which will be accessible with the LST contains important strong lines (whose lower levels are in many cases ground state levels) of ions of such important elements as carbon, nitrogen, oxygen and silicon. The case of carbon is particularly important for abundance studies because no other suitable lines exist in the visual region. Models now exist for which the UV line strengths have been-calculated (see Dopita and Raymond above). There is both theoretical and observational evidence that some of these lines are stronger in collisionally excited gas than in photoionized gas, and hence SNR's may offer advantages over HII regions for some abundance studies. This might be asserted with even more conviction if SNR's were no more structurally complex than photoionized HII regions, but this is probably not the case. The stratification effects in SNR's are quite marked and require that many abundance determinations be model dependent.

This leads to the second advantage of the LST, its high spatial resolution. Because of stratification there seems to be some merit in trying to observe very small slabs of plasma in a SNR filament to ensure that one is sampling a homogeneous section. Such a technique is being more often employed nowadays for ground-based spectroscopy of planetary nebulae, where less severe stratification effects are known to exist.

(a) First priority objects might be the young SNR's, and even older ones where abundance anomalies appear to exist. Again as in the case of the very young SNR's discussed above, we desperately need direct observational evidence for element formation. If, as is generally thought, much of the newly synthesized material is released by SN explosions we have to observe it before it is diluted with the interstellar medium.

A sample of the SNR's in this category is given - see Kirshner (1978):-

Crab	- He abundance high, possibly other heavier elements also.
Cas A	- Oxygen and negligible hydrogen in the fast moving knots; nitrogen overabundant in the low velocity flocculi.
Kepler	- Nitrogen probably enhanced.
3C58	- Nitrogen probably enhanced.
Tycho	- Hydrogen only visible.
SN1006	- Hydrogen only visible.
Puppis A	- Nitrogen enormously enhanced.
N132D(LMC)	- Oxygen (and possibly neon) enhanced in high velocity filaments.

The type of results obtained from the UV may help us to decide whether we are looking at abundances in a circumstellar envelope ejected before the explosion, or material coming from deep inside the star, or simply peculiar (i.e. more extreme) excitation and ionization effects.

(b) Second priority objects might be the more normal looking SNR's.

The recent IUE observations of Benvenuti et al (1978) of the Cygnus Loop point to underabundance of carbon in the gas with the progressive return of carbon (which presumably had been preferentially absorbed into interstellar grains) to the gaseous phase by heating of the grains. These conclusions are so important for understanding the structure of interstellar grains that one is almost unjustified in calling this second priority.

(c) Spectroscopy or direct imaging with appropriate narrow band filters of older SNR's ought to be made to search for the theoretically predicted stratification effects resulting from the isothermal cooling behind the shock front. Cox (1972) and Dopita (1977) predict scale differences of $\sim$ 0.01 pc for zones of maximum emission of [OI], [OII] and [OIII], while Raymond (1979), presumably as a result of the inclusion of more physics (e.g. magnetic fields), obtains scale lengths an order of magnitude smaller. Since Vela is at a distance of 500 pc where 0.01 pc = 4", it is an obvious candidate for such observations in the UV and V. The main emphasis however must be on spatial resolution.

In practice these observations may be tricky to interpret because of aspect effects. Also in Vela (Danziger and Goss in preparation) one sees a dramatic difference in the type of spectrum (defined by [OIII]) on a scale of $\sim$ 10". There is both a high temperature spectrum not dissimilar to that observed by Miller (1974) as position 3 in the Cygnus Loop and a much lower temperature (and apparently more common) region 10" from it. In this case one cannot appeal simply to stratification effects predicted by models because the [OIII] lines are altogether too strong relative to Hβ to be accommodated by any of the models.

Other explanations at the moment remain semi-empirical or ad hoc.

Another observational experiment in the same class but with a different emphasis concerns the coronal line of [Fe XIV] at 5303 Å. Since the original reported discovery of this line in old SNR's with filter techniques, slit spectroscopy by Murdin et al (1977,78) has revealed this line in N49 and Puppis A. I do not dwell on this published work but instead mention that the λ5303 line in Puppis A while lying in a region of intense X-ray emission is concentrated also on an optical filament. Clark, Murdin and Zarnecki (to be published) find stratification between [NI], [OIII] and [FeXIV] on a scale of tens of arcseconds which might be consistent with a cool filament surrounded by a hot halo. Perhaps the LST does not offer an advantage in further mapping this SNR (at 2500 pc), but it will clearly be of value for working on such a program in the LMC.

(d) The problem of 2-photon emission may not be confined to HII regions and planetary nebulae. In an ionized gas of normal composition one would expect contributions to the visible continuum from b-f and f-f processes involving ions of hydrogen and helium. There is also a significant contribution from 2-photon emission from the 2S to 1S level of hydrogen. This emission has a peak emission at 2431 Å i.e. twice the wavelength of Lyman α. Direct proof of its existence has been difficult to obtain for the following reasons.

Most planetary nebulae where the surface brightness is high, have sufficiently high electron densities that the 2S state is collisionally depopulated. However in the Cygnus Loop (Miller 1974) and Vela (Danziger and Goss in preparation) one finds optical continuum emission that cannot be explained yet by processes other than enhanced 2-photon emission. This enhanced 2-photon emission would result from collisional population of the 2S level from the ground state, a process of much lower significance in a photoionized nebula. Since the enhancement is a factor of 2 or more, the chances of actually observing a maximum in these SNR's at 2431 Å are considerably enhanced. While such an observation ought to be done on planetary nebulae, for the reasons given above, SNR's may present a better opportunity for confirming the existence of a long-standing theoretical prediction in atomic physics. If the continuum is not explicable in this way then other processes must be identified.

The particular practical importance of understanding these and future UV observations lies in the fact that continuum observations provide the only direct practical way of determining the hydrogen recombination temperatures.

Pulsars

The following summary of optical data can be made for the Crab pulsar (P = 33 ms).

(a) The light curves are similar in all colours.

(b) Pulse shapes remain constant.

(c) Energy distributions for main and subpulse are similar.

(d) Strong linear polarisation exists but changes through the pulses from 20 percent at the leading edge, through 0 to 10 percent at the trailing edge. The plane of polarisation sweeps through 150° during 60° of rotation.

(e) Coincidence in arrival time of pulses at all wavelengths (γ-ray to radio) suggests a similar emission mechanism at all wavelengths.

For the Vela pulsar nothing is known concerning the first 4 points, and it is known that arrival times do not coincide at all wavelengths which therefore might suggest different emission mechanisms at different wavelengths (Wallace et al 1977).

The best chance of obtaining further more accurate information on the Vela pulsar lies with the LST. A calculation shows that if one divides the period of the Vela pulsar (89 ms) into 40 bins , 10 hours of observation with the photometer ought to give 3 percent accuracy for an average bin. One can then see what factor to multiply this by to get colours and polarisation. A significant advantage has been gained here with the LST by virtue of the lower sky brightness and the possibility of using small apertures (0.″7). Since we have only 2 optical pulsars, and since they appear to differ markedly in some respects, considerable observing time devoted to this project is justified if we really want the theoreticians to produce the correct electrodynamical theory.

A recent intriguing observation of both pulsars by Peterson et al (1978) suggests that there may be significant unpulsed radiation (or in the case of the Vela pulsar unresolved subpulses between the 2 main pulses). The colour of this radiation over as wide a baseline as is possible may be one of the few ways of understanding its nature and origin.

Conclusion

The programs discussed above are only a representative sample of the possibilities. Clearly the total is ambitious, if not too ambitious. It will be important that among those scientists working on supernova remnants an attempt be made to define priority programs so that at least the most significant projects have the possibility of being completed within the lifetime of the Large Space Telescope.

References

Benvenuti, P., D'Odorico, S., Dopita, M.A. 1979, Nature 277, 99.

Cox, D.P. 1972, Ap.J. 178, 143.

Danziger, I.J. and Dennefeld, M. 1976, Ap.J. 207, 394.

Danziger, I.J., Murdin, P.G., Clark, D.H., D'Odorico, S. 1979, M.N.R.A.S. 186, 555.

Dopita, M.A. 1977, Ap.J. Suppl. 33, 437.

Goss, W.M., Ekers, R.D., Danziger, I.J., Israel, F. 1979, M.N.R.A.S. to be submitted.

Kamper, K. and van den Bergh, S. 1976, Ap.J. Suppl. 32, 351.

Kirshner, R.P. and Oke, J.B. 1975, Ap.J. 200, 574.

Kirshner, R.P. 1978, Mem. Italian Ast. Soc. 49, 465.

Miller, J.S. 1974, Ap.J. 189, 239.

Murdin, P.G., Clark, D.H., Culhane, J.L. 1978, M.N.R.A.S. 183, 79P.

Murdin, P.G., Clark, D.H., Culhane, J.L. 1978, Mem. Italian Ast. Soc. 49, 583.

Peterson, B.A., Murdin, P.G., Wallace, P., Manchester,R.N., Penny, A.J., Jorden, A., Hartley, K.F., King, D. 1978, Nature 276, 475.

Raymond, J.C. 1979, Ap.J. Suppl. in press.

Wallace, P.T., Peterson, B.A., Murdin, P.G., Danziger, I.J., Manchester, R.N., Lyne, A.G., Goss, W.M., Smith, F.G., Disney, M.J., Hartley, K.F., Jones, D.H.P., Wellgate, G.W. 1977, Nature 266, 692.

SIGNIFICANCE OF ST OBSERVATIONS FOR KNOWLEDGE OF CARBON ABUNDANCE IN PLANETARY NEBULAE

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Abstract

The knowledge of carbon abundance in planetary nebulae and their central stars is very important for studies of stellar evolution and of chemical evolution in galaxies. This knowledge can be achieved by observation of the C III] 1907, 1909 A and the C IV 1548, 1550 lines complemented by UV observations of the nuclei. Information of this type in various galactic planetary nebulae is coming from the IUE NASA-ESA/UK satellite in operation since April, 1978. However the IUE satellite apparently is not able to observe a number of objects which are very important to the whole subject like the planetaries known to belong to the extreme population II and planetaries of very low surface brightness. The predictions concerning the carbon abundance in planetary nebulae as derived from stellar evolution theory are briefly presented. We wish to discuss the value of observations of these objects with the ST Telescope.

1. Introduction

Measurements of He and CNO abundances in planetary nebulae (PN) and their nuclei are very important for stellar evolution and chemical evolution of Galaxies. In fact: i) determination of chemical abundances in these nebular objects are believed to be in principle more accurate than those in normal stars, ii) we expect to observe material that has undergone mixing with chemically evolved matter, iii) PN are easily observed until the central regions of our Galaxy and are among the most promising candidates for knowledge of the chemical structure of the Galaxy, iv) hundreds of them have been detected by ground based telescopes in the Local Group Galaxies and more will be revealed by ST, even in more distant Galaxies, and their study is of great interest (cf. D'Odorico, Perinotto and Benvenuti, 1979).

Abundance of He, N and O of most of the known galactic PN can be obtained by ground based telescopes while for carbon this is not the case. Far UV observation of the nuclei are also essential for a most correct interpretation of the nebular spectrum as well as for establishing the characteristics of the progenitor stars.

In Section 2 we deal with the presently available information on the abundances of C (and He, N, O) in galactic planetary nebulae, while in Section 3 we briefly summarize the predictions of the stellar evolution theory. In the conclusions (Section 4) we underline the contribution that could be given by ST in this field.

2. Abundance of He and CNO in PN: observational aspects

The determination of the He abundance in PN rests on strong permitted He I and He II recombination lines and is considered rather accurate.

The mean of the errors associated with individual determinations is 9.5% (Kaler, 1978; 78 objects). The knowledge of the abundance of N and O rests mostly on lines collisionally excited by thermal electrons. Often these lines are forbidden transitions from excited states of the ground configuration of the various ions. As the nebulae are in general optically thin in these lines, the chemical abundance of the observed ions follows in a straightforward manner once the electron temperature and density distribution are known. Almost all available determinations come from this simplified procedure whose difficulties are: i) corrections for the contribution of unseen ions, and ii) oversimplified Ne, Te treatment (often we dispose only of Te from [OIII] and Ne from [OII]).

A more satisfactory method requires the solution of the equations of the ionization structure and thermal balance for each specific nebula with the following inputs: a) the ionizing flux of the central star, b) the geometry of the system, and c) the mass distribution, with chemical abundances as parameters. This method has been applied successfully to a very few objects (cf. Harrington, 1978 and references therein) but difficulties to reproduce the observed spectra in a number of cases have been noted (Aller, 1978). The limitation comes from the severe information required, particularly the frequency dependence of the ionizing flux from the central star. Even with this method problems remain for lines from low ionization potential ions in high excitation nebulae (cf. Harrington, 1978). Charge exchange reactions have been shown to be important in this frame (Williams, 1973; Perinotto, 1977; Pequignot et al., 1978), but conclusive answer waits for better knowledge of cross sections of various of these reactions.

Coming back to the simplified procedure, we note that problem i) is more severe for N, which is observed only in the stage N^+, and where the ionization correction suggested by Peimbert and Costero (1969) appears inadequate for PN with nuclei of log $T \lesssim 4.65$ (Kaler, 1969) and may be affected by charge exchange reactions (Perinotto, 1979). In the case of O the situation is more favourable and further its abundance is expected to vary very little for stellar evolutionary effects (cf. Sec. 3). The accuracy of its determination can then be inferred from the dispersion associated with a group of 29 PN carefully studied by Torres-Peimbert and Peimbert (1977), amounting to ~ 33%. As far as C is concerned, the available information is the most uncertain. There is presently a disagreement between the determinations based on faint permitted lines in the visible from C^+ (λ 4267, 3920) and C^{2+} (λ 4650) and the determinations making use of the strong resonance line of C^{3+} at λ 1550. The former determinations (Torres-Peimbert and Peimbert, 1977) are about one order of magnitude higher than the latter ones (Pottash et al., 1978). There are problems with the use of the permitted lines of C^{2+} , C^{3+} because of their weakness (intensities around $10^{-4} \div 10^{-3}$ of H_β) and because of uncertainties about the relative importance of the mechanisms able to produce these C lines (cf. Seaton, 1968; Leibowitz, 1972; Kaler, 1972; Grandi, 1976). There are difficulties also with the use of the strong λ1550 C^{3+} and λ1909 C^{2+}] lines. In the first one, which is a resonance line, the optical depth is certainly quite large. Thus the high extinction efficiency of dust in the far UV may cause an appreciable absorption of λ1550 photons and therefore an underestimate of the amount of C^{3+}. Since the same does not hold for the intercombination lines of C^{2+} at λ 1909, measurements of both C^{2+} and C^{3+} lines allow to evaluate the amount of this understimate.

In the case of NGC 7027, where both lines have been measured, and which is the most reddened PN, the underestimate is probably smaller than a factor of 4 (cf. Bohlin et al., 1975; Pottash et al., 1978). It is worth emphasizing that in order to have the total C abundance the contribution in form of grains must be added (cf. Panagia et al., 1977; Panagia, 1978).

In conclusion, while our knowledge of the He and O abundances in PN is relatively satisfactory, that of N is still poor and the one of C very poor. On the other hand C is expected to convey the most crucial information for stellar evolution theory (see next Section).

3. Abundance of He and CNO in PN: theoretical predictions

It is widely accepted that PN precursors are red giant stars with initial mass $M_i \lesssim 4\text{-}6\ M_\odot$, which have ascended the Asymptotic Giant Branch (AGB) burning hydrogen and helium in two shells. The rapid ejection of most of the hydrogen-rich envelope terminates the evolution along the AGB and forces the star to evolve toward the region of PN nuclei. Therefore, the chemical composition of PN is expected to be the same as that of the hydrogen-rich envelope at the moment of its ejection. The composition of the stellar envelope at the termination of the AGB evolution differs from the initial composition because various mixing episodes have dredged up nuclearly processed materials. Iben and Truran (1978, hereafter IT) list three phases of abundance variation at the surface. The first phase (first dredge-up) corresponds to the inward penetration of the convective envelope when stars reach the red giant branch for the first time. Correspondingly, nitrogen is enhanced at the expenses of carbon and, in low mass stars, helium is also enhanced by some 5-10%.

The second phase (second dredge-up) occurs in stars initially more massive than about 3 $M_\odot$, when, following the ignition of the helium-burning shell, the convective envelope penetrates into the helium core, dredging-up helium and nitrogen. Once again the surface abundance of N and He is enhanced while C is reduced.

The third phase (third dredge-up) occurs during the AGB evolution: following each helium-shell flash the inner boundary of the convective envelope penetrates into the inter-shell zone whose composition is mostly He and C . Correspondingly, the surface abundance of these elements is significantly enhanced. However, the amount of the enhancement depends on the envelope mass, which is affected by the assumed strength of the stellar wind (Fusi-Pecci and Renzini, 1975, 1976; IT). Further, the final envelope (nebular) composition depends on the envelope mass when envelope instability (and ejection) sets in, i.e. it depends on the function Me^{min} (Mc) giving the minimum envelope mass which is stably bound to a core mass Mc (= mass interior to the He-H discontinuity). Therefore, using the Reimers (1975) empirical mass loss rate for red giants, the nebular composition depends on the mass-loss parameter η (cf. Fusi-Pecci and Renzini, 1976; the same parameter being called α in IT) and on the function Me^{min} (Mc). We have computed the final envelope composition for stars with $1 \leq M_i \leq 8\ M_{\odot}$, using the analytic algorithms developed in IT implemented with the results of Sweigart and Gross (1978) for the He enhancement during the first dredge-up phase (cf. Fusi-Pecci, Renzini and Voli, 1979 for details). The results are shown in Fig.s 1 and 2, where, for

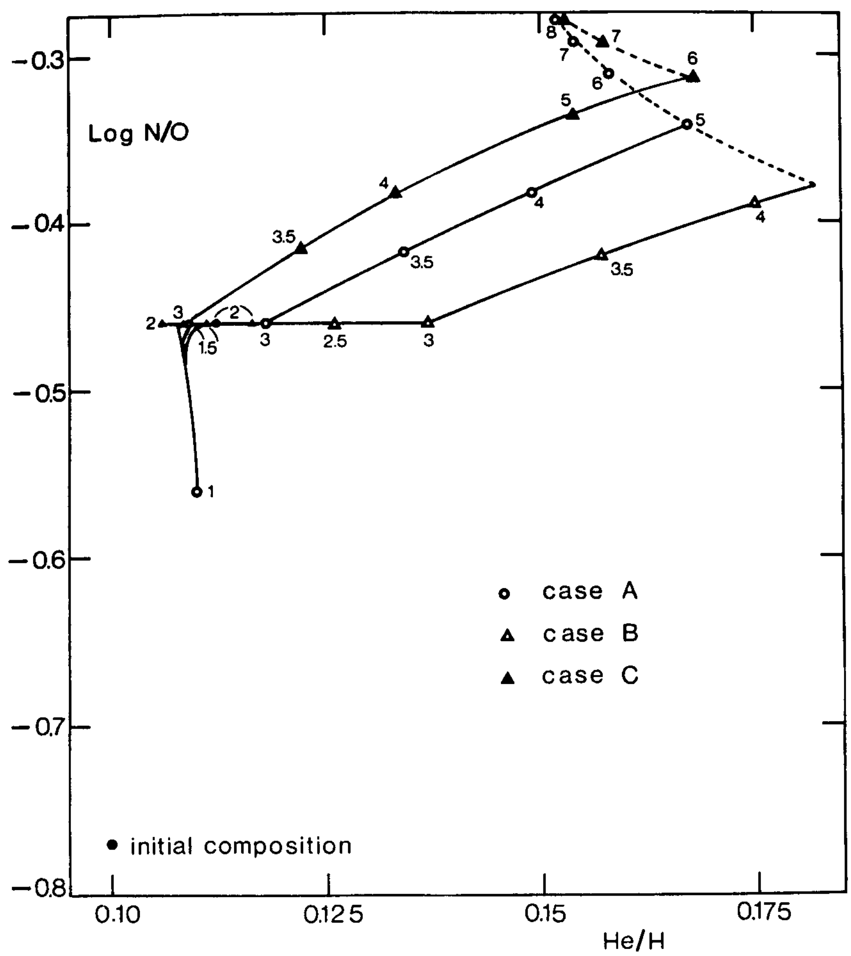

Fig. 1 - Abundance ratios N/O and He/H by numbers for the final envelope abundance in stars with initial mass between 1 and 8 Mo. Different cases refer to different assumptions concerning the mass loss processes (See Text). The filled circle marks the initial ratios. Mass symbols connected by dashed lines correspond to stars whose core exceeds 1.4 Mo and which are not expected to produce PN.

various initial masses, the number ratios N/O and C/O are reported as a function of He/H. Case A corresponds to the assumption $\eta = 1/3$ and Me^{min} (Mc) like in IT for $Mc \gtrsim 0.79\ M_\odot$ and analytically extended to $Me^{min} = 0.02\ M_\odot$ for $Mc = 0.5\ M_\odot$ (in order to account for the mass of the PN in the globular Cluster M15 ; cf. Peimbert, 1973). Case B refers to the assumptions $\eta = 1/3$ and Me^{min} (Mc) half that of case A. Case C corresponds to $\eta = 2/3$ and Me^{min} (Mc) like in case A. It is worth emphasizing that these results are also sensitive to the amount of dredge-up during the various phases, a quantity which (particularly for the third dredge-up) is still theoretically quite uncertain. Further, possible mixings of non-convective origin and possible burning within the convective envelope have been neglected.

Oxygen has been taken as reference element since in all cases its abundance varies by only a few percent with respect to the initial value. We have found that the contribution of the third dredge-up to the helium enhancement is in all cases larger than that of the second dredge-up. Kaler, Iben and Becker (1978) have compared theoretical and observed values of N/O and He/H for several PN. They have however neglected the contribution of the third dredge-up, which now appears to be substantial. Including the contribution of the third dredge-up the high values of He/H are more easily accounted for.

An inspection of Fig.s 1 and 2 shows that: i) carbon is the element whose abundance exhibits the larger variation as a function of the initial mass, ii) the correlation between C/O and He/H does not severely depend on the assumptions concerning

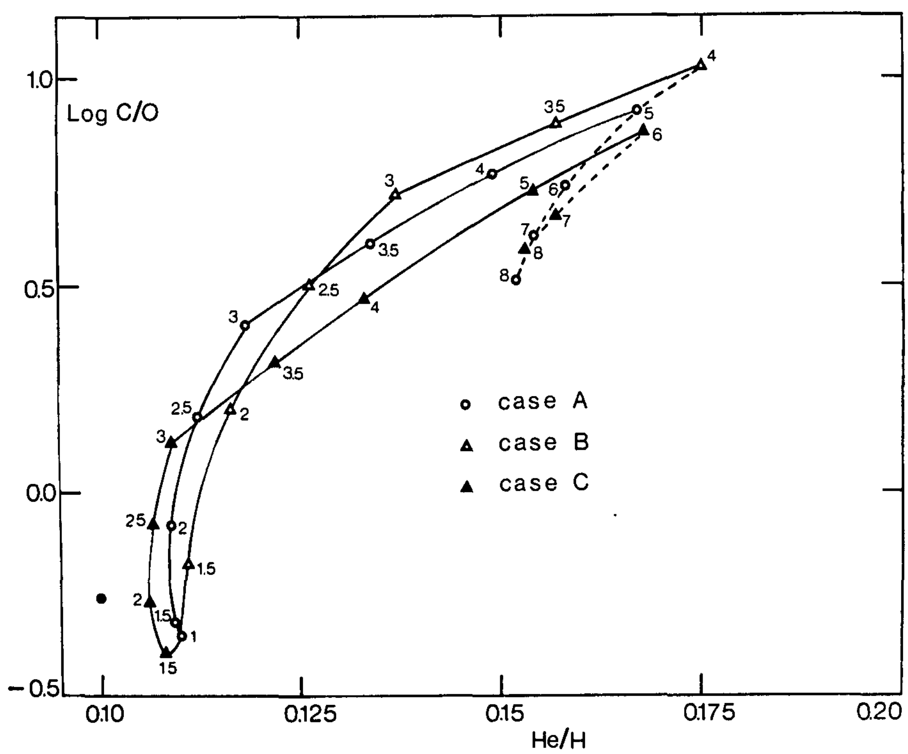

Fig. 2 - The same as Fig. 1 but for C/O vs. He/H.

the mass-loss processes, iii) the initial mass required to produce a given C or He overabundance crucially depends on the mass-loss assumptions.

The determination of C (as well as He, N and O) abundances of a fairly extended sample of PN will therefore provide decisive information on: i) the mass-loss rate during the red-giant phase, ii) the function Me^{min} (Mc) , which is relevant for the problem of the masses of PN , and iii) the behaviour of convective boundaries during stellar evolution. In order to achieve a wide consistency with the observations such information should be coupled with statistical considerations on the Mira variables period distribution (cf. Wood and Cahn, 1977) and on carbon stars (IT), since the frequency of these objects depends upon the same parameters η and Me^{min}(Mc). Further, nebular composition is expected to correlate with the location of the central star in the HR diagram (Renzini, 1979), extreme C, N and He enhancements being expected in faint, low surface brightness nebulae with hot and faint central stars. ST observations of PN and their nuclei will therefore provide a powerful check of current theory of advanced stellar evolution and important information on galactic chemical evolution.

4. ST observations of PN

From Figure 2 we see that low carbon nebulae are expected to be produced by stars with initial masses around 1 Mo, while more massive stars (up to 4 ÷ 6 M⊙) are expected to produce planetaries with the highest carbon abundance. On the other hand low mass PN nuclei spend their PN phase at high luminosity while massive PN nuclei are expected to be much fainter (Renzini, 1979).

Therefore we expect to find low carbon abundance in PN with bright nuclei (and especially in extreme Pop II PN) and high carbon abundance in PN with faint nuclei.

Actually we think that ST could give an important contribution allowing a close determination of the carbon abundance in the extreme Pop II PN on one hand and on the other hand the determination of C and (He, N, O) abundances at least in a number of PN with faint nuclei, low surface brightness. In Table 1 we show properties of the known galactic PN of extreme Pop II. While it would be quite difficult to observe the PN of Table 1 with IUE, especially K 648 (the one in M15), they are easily and much better observable with ST. The high resolving power of ST will permit a separate study of these PN and their nuclei and a determination of the filling factor, so providing for instance a better value of the nebular mass of K 648 . We recall that K 648 has the lowest N and O abundances so far measured in PN.

Moreover the determination of C (and He, N, O) abundances of an object in a globular duster is by itself of a great interest. Therefore the probable detection by ST of other PN in globular dusters is very important.

As far as the faint PN are concerned, we note that due to their relatively extendend angular diameters (13"÷ 1000" in the group of Abell, 1966) and very low surface brightness, the planned maximum slot of FOS (1 arcsec diameter) appears too

TABLE 1

PLANETARY NEBULAE OF EXTREME POPULATION II[a)]

Name	F(Hβ) (erg cm^{-2} sec^{-1})	c	diameter (arc seconds)	Estimated Relative Exposure λ 1909 A
{K 648 = 65-27 1	7.35-13[1]	0.16[2]	1.0[3]	1.0
49+88 1	2.63-13[1]	~0.043[4]	3.0±1.5[4]	~1.5
108-76 1	2.44-13[1]	0.22[1]	1÷2[5]	4.1

a) A probable PN (B~18÷19 mag) at the centre of M 15 (Peterson, 1976) and a PN at 3' from the globular duster NGC 6401, possibly associated with it (Peterson, 1977) might be added.

1) Hawley and Miller, 1978.
2) Peimbert, 1973.
3) O'Dell et al., 1964.
4) Miller, 1969.
5) Boeshaar and Bond, 1977.

small for optical observation of most of these nebulae. However, ST observations of the nuclei of all of these planetaries (which are almost reaching the white dwarf region) will provide a valuable piece of information for their accurate setting in the HR diagram and the determination of their surface composition.

References

Abell, G.O. 1966, Astrophys. J. 144, 259.

Aller, L.H. 1978, IAU Sympos. No. 76, "Planetary Nebulae", Y. Terzian Ed., D. Reidel Publ., Dordrecht, p. 225.

Boeshaar, G.O., Bond, H.E. 1977, Astrophys. J. 213, 421.

Bohlin, R.C., Marionni, P.A. and Stecher, T.P. 1975, Astrophys. J. 202, 415.

D'Odorico, S., Perinotto, M., Benvenuti, P. 1979, These proceedings.

Fusi-Pecci, F., Renzini, A. 1975, Mem. Soc. Roy. Sci. Liège, 6 Ser., 8, 383.

Fusi-Pecci, F., Renzini, A. 1976, Astron. Astrophys. 46, 447.

Fusi-Pecci, F., Renzini, A., Voli, M. 1979 (in preparation).

Grandi, S.A. 1976, Astrophys. J. 206, 658.

Harrington, J.P. 1978, IAU Sympos. No. 76, "Planetary Nebulae", Y. Terzian Ed., D. Reidel Publ., Dordrecht, p. 151.

Hawley, S.A. and Miller, S.J. 1978, Astrophys. J. 220, 609.

Iben, I. Jr., Truran, J.W. 1978, Astrophys. J. 220, 980.

Kaler, J.B. 1972, Astrophys. J. 173, 601.

Kaler, J.B. 1978, Astrophys. J. 226, 947.

Kaler, J.B. 1979, Astrophys. J. in press.

Kaler, J.B., Iben, I.Jr., Becker, S.A. 1978, Astrophys. J. Letters 224, L63.

Leibowitz, E.M. 1972, Mon. Not. R. Astr. Soc. 157, 97.

Miller, J.S. 1969, Astrophys. J. 157, 1215.

O'Dell, C.R., Peimbert, M. and Kinman, T.D. 1964, Astrophys. J. 140, 119.

Panagia, N. 1979, Proceedings of Workshop on "Chemical Inhomogeneities in the Galaxy", Frascati June 1978, Mem. S.A.It., in press.

Panagia, N., Bussoletti, E. and Blanco, A. 1977, in 'CNO Isotopes in Astrophysics', Ed. by J. Audouze, D. Reidel Publ., Dordrecht, p. 45.

Peimbert, M. 1973, Mem. Soc. Roy. Sci. Liège, 6^{e} Ser., 5, 307.

Peimbert, M. and Costero, R. 1969, Bol. Obs. Tonantzintla y Tacubaya 5, 3.

Pequignot, D., Aldrovandi, S.M.V., Stasinska, G. 1978, Astron. Astrophys. 63, 313.

Perinotto, M. 1977, Astron. Astrophys. 61, 247.

Perinotto, M. 1979, Proceedings of Workshop on "Chemical Inhomogeneities in the Galaxy", Frascati June 1978, Mem. S.A.It., in press.

Peterson, A.W. 1976, Astron. Astrophys. 53, 441.

Peterson, A.W. 1977, P.A.S.P. 89, 129.

Pottash, S.R., Wesselins, R.P. and van Duinen, R.J. 1978, Astron. Astrophys. 70, 629.

Reimers, D. 1975, Mem. Soc. Roy. Sci. Liège, 6^{e} Ser., 8, 369.

Renzini, A. 1979, Proceedings of IAU IV European Regional Meeting in Astronomy: Stars and Stellar Systems, Uppsala, in press.

Seaton, M.J. 1968, Mon. Not. R. Astr. Soc. 139, 129.

Sweigart, A.V., Gross, P.G. 1978, Astrophys. J. Suppl. 36, 405.

Torres-Peimbert, S. and Peimbert, M. 1977, Rev. Mex. Astron. y Astrophys. 2, 181.

Williams, R.E. 1973, Mon. Not. R. Astr. Soc. 164, 111.

Wood, P.R., Cahn, J.H. 1977, Astrophys. J. 211, 499.

R. VIOTTI : As you and Dr. Danziger have already pointed out, the ultraviolet spectrum is characterized by lines of C, N, O, Si, Al in different ionization stages, which may help in determining with good accuracy the relative abundance of these elements in diffuse objects. In particular one would have an estimate of the light-to-heavy element abundance which has important evolutionary consequences.

Furthermore, the presence of permitted (resonance) and density-dependent intercombination lines of C, N, O, Si (together with the different ionization stages) may help in overcoming the crucial problem of the physical structure of the field which is included in the aperture of the spectrograph, and the dependence of the derived abundances on the model.

M. PERINOTTO : We have restricted our attention here to He and CNO because they are among the most important and abundant elements in PN, but information on other elements is clearly also important. Regarding the second question, I must say that it is not yet clear which improvement may come from a careful and wider use of detailed models for deriving chemical abundances in PN. In my opinion this method is more satisfactory and should provide the best chemical abundance determinations.

B.E.J. PAGEL : There is other evidence concerning the relative abundances of C and O in planetary nebulae: this comes from infra-red spectral observations of the internal dust by D.K. Aitken and his colleagues, who are able to distinguish which of the two elements is the more abundant.

M. PERINOTTO : I agree of course about the importance of considering also the contribution of the dust content to the total chemical abundances of heavy elements in PN, an aspect that we omitted in our presentation.

GLOBULAR CLUSTERS

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1. WHERE GLOBULAR CLUSTERS?

No doubt that Globular Clusters are a very common component of present and past Universe. Observations tell us that GC's appear strongly connected with the halo of spiral galaxies or with elliptical galaxies, i.e. populating in both cases the spherical component of the galactic structures. Some 150 clusters have been found orbitating around our own Galaxy, a good many hundred in our spiral companion M 31 (= Andromeda), some thousand around the active elliptical M 87 (Racine 1968,1970) in the Virgo cluster, and many others around various galaxies e.g. in the Virgo cluster itself, in the Hidra I cluster (Smith and Weedman 1976) or in Fornax I (Dave and Dickens 1976).

Beyond such a clear association, GC's are widely represented also in minor components of the local group, like NGC 185 , a small (dEO) companion of M 31, or the "irregular" Magellanic Clouds and the dwarf spheroidal in Fornax. This latter occurrence appears of particular interest since dwarf spheroidal galaxies share with the large majority of Globular Clusters the nature of old self-gravitating systems of "Population II" stars. Both kinds of systems have, as a consequence, a large common problematic and we will include D Sph's in the following discussion, looking at these objects like a sort of intergalactic "super Globular Clusters". Like GC's, dwrfs spheroidals may be a common component of the Universe, as suggested e.g. by Karachentseva and Kostyuk (1974) fro the M 81 - M 82 group of galaxies.

Table 1 reports indicative distance moduli for some characteristic classes of clusters we are dealing with, Inspection of data from this table discloses how observational constraints have to be taken into account in such kind of problematic.

Objects	Characteristics	$V-M_V$	Other objects
NGC 6397	Our nearest GC	12^m	M 4
M 3	Typical well studied GGC	15^m	M 15,M 5,M 92
NGC 7006	"Outer halo" GGC	18^m	NGC 7492,Pal 11,Pal 13
Draco	Our nearest D Spher.	19^m	U Min
SMC+LMC	Very rich in GC	19^m	
NGC 2419	Remote G (?) GC	20^m	Pal 3,Pal 4
Fornax	The D Spher. with GC's	21^m	
M 31		25^m	NGC 205,NGC 147,NGC 185
M 87		30^m	Virgo Cl.,Fornax I Cl.

Table 1. Orientative distance moduli for GC's characterizing clas ses of distances.

Systems	M_V (System)	M_V(Br.Glob.)
M 31	-21.1	-10.9
Galaxy	-20.5:	-10.4
LMC	-18.5	- 9.8
NGC 205	-17.0	- 9.7
SMC	-16.8	- 9.4
NGC 185	-15.4	- 8.5
NGC 147	-14.6	- 7.7
Fornax	-13.0	- 8.5

Table 2. The integrated magnitude of the brightest GC compared with the magnitude of the parent galaxy for selected objects membering the local group (orientative values).

2. WHY GLOBULAR CLUSTERS ?

As far as the more general properties of GC's is concerned, it has been shown that the number of GC's looks as being at least partially correlated with the luminosity of the parent galaxy. A similar correlation has been found for the luminosity of the brightest GC (Hodge 1974) and the heavy elements abundance appears also correlated with galactic masses (van den Bergh 1978). With regard to the former point, Table 2 reports the integrated magnitude of the brightest GC for several objects in the local group. Along this line, there is no difficulty in understanding how GC's can provide useful indications on the distance of galaxies,supporting the evaluation of the Hubble constant.

Much more interesting, at least in some respects, is that the large majority of observed GC's show convincingly to be characterized by a sufficiently well defined evolutionary stage of cluster stars, i.e. by a sufficiently well defined point in the Y,Z,t space, being the previous quantities referred to the original chemical composition and to the age of actual evolving stars. The HR diagram location of cluster stars and the pulsational properties of RR Lyrae variables (when present) can be "decoded" in order to obtain information on the quoted parameters, giving in turn a great deal of informations on the history of matter in the Universe. Table 3 (to be read in connection with fig.1) reports a concise "atlas" of present theoretical constraints on the HR diagram location of GC stars, disclosing how many information can be obtained by handling the various kinds of photometric observations we are dealing with.

Spectroscopic observations add precious and direct informations on the original chemical composition and/or on the chemical variations induced by evolution. Both kinds of information are, of course, of invaluable interest , though some care must be used before to read the results in terms of chemical composition of the very proto-cluster clouds, since we cannot exclude "a priori" that

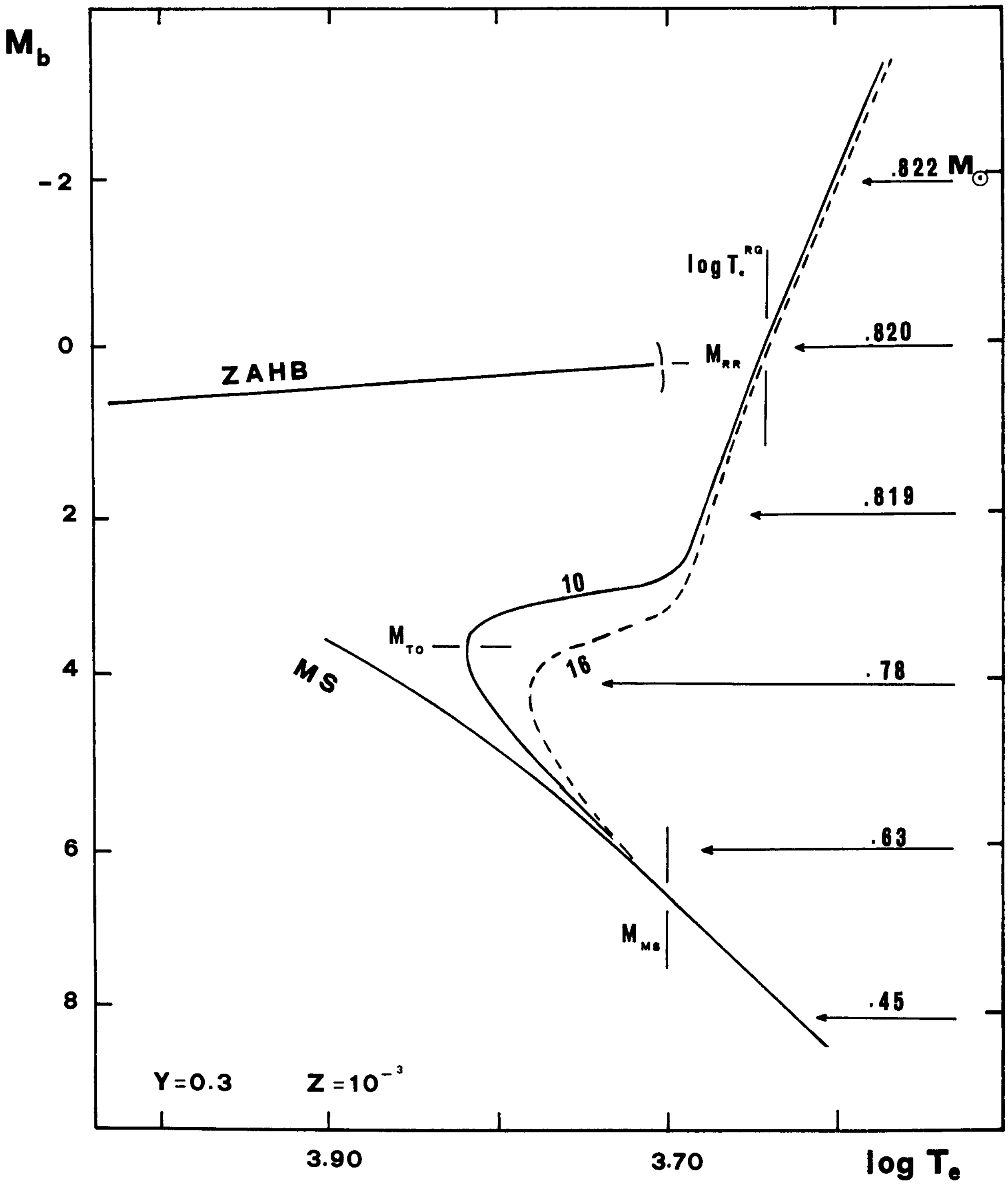

Fig.1:Theoretical cluster locus for the labelled original chemical composition and assuming a cluster age t=10 billion years.The masses of evolving stars are labelled on the right side.Evolutionary parameters discussed in Table 3 are shown,and the original MS is also reported. Dashed line discloses the expected variation of the cluster locus when passing to t=16 billion years.

T_e^{RG}= effective temperature of the Giant Branch at M_b=0

$$\partial \log T_e^{RG} / \partial \log Z \sim 0.03$$

$$\partial \log T_e^{RG} / \partial Y \sim -0.015$$

$$\partial \log T_e^{RG} / \partial t_9 \sim 0.001$$

M_{RR}= bolometric magnitude of HB at the luminosity of RR Lyrae

$$\partial M_{RR} / \partial \log Z \sim 0.15$$

$$\partial M_{RR} / \partial Y \sim -3.25$$

$$\partial M_{RR} / \partial t_9 \sim 0.02$$

M_{TO}= bolometric magnitude of Turn-Off point

$$\partial M_{TO} / \partial \log Z \sim 0.33$$

$$\partial M_{TO} / \partial Y \sim 1.5$$

$$\partial M_{TO} / \partial t_9 \sim 0.23$$

M_{MS}= bolometric magnitude of the Main Sequence at log T_e=3.70

$$\partial M_{MS} / \partial \log(Z+0.001) \sim -0.76$$

$$\partial M_{MS} / \partial Y \sim 3.$$

Table 3. Theoretical dependence of selected points of the cluster locus on the original abundance by mass of heavy elements (Z) or helium (Y) and on the cluster age in billion years (t_9).

some enrichment in heavy elements has been occurred within the proto-cluster before the starting of presently observed generation of stars.

Some general results of this kind of analysis are in general well known: galactic Globular Clusters show "family traits" which differ from those of GC's in Magellanic Clouds,dwarf spheroidal galaxies and M 31. A brilliant discussion on the consequences of this situation can be found in a recent paper by van den Bergh (1978).

One has finally to remember that characteristics of the HR diagrams are more or less reflected in the integrated colours of the clusters; in this way rough indications have been obtained on the cluster metallicity and/or the cluster age for a large set of galactic and extragalactic objects.

In the following we will discuss the impact of ST on the Globular cluster problematic, bearing in mind the above reported frame of photometrical and spectroscopical information ,on which a sufficiently well established system of theoretical interpretations has still been built.

3. ST:NEW GOALS FROM THE GAIN IN LIMITING MAGNITUDES

"Sic stantibus rebus" (i.e. on the basis of the previously quoted indications) there is no difficulty in understanding the tremendous impact of ST on GC problematic. In fig.2 we disclose the meaning of ST with regard to the "well studied" galactic globular cluster M 5, adopting as typical performances of ST the following crude assumptions:

i) Photometric information down to 28^m.

ii)Spectroscopic information : S1: $\Delta\lambda/\lambda = 10^{-2}$ down to 25^m.

S2: $\Delta\lambda/\lambda = 10^{-3}$ down to 22^m.

S3: $\Delta\lambda/\lambda = 5x10^{-5}$ down to 17^m.

The major point to be stressed out is that -as shown in fig.2 - we are facing not merely an improvement of present data,but the

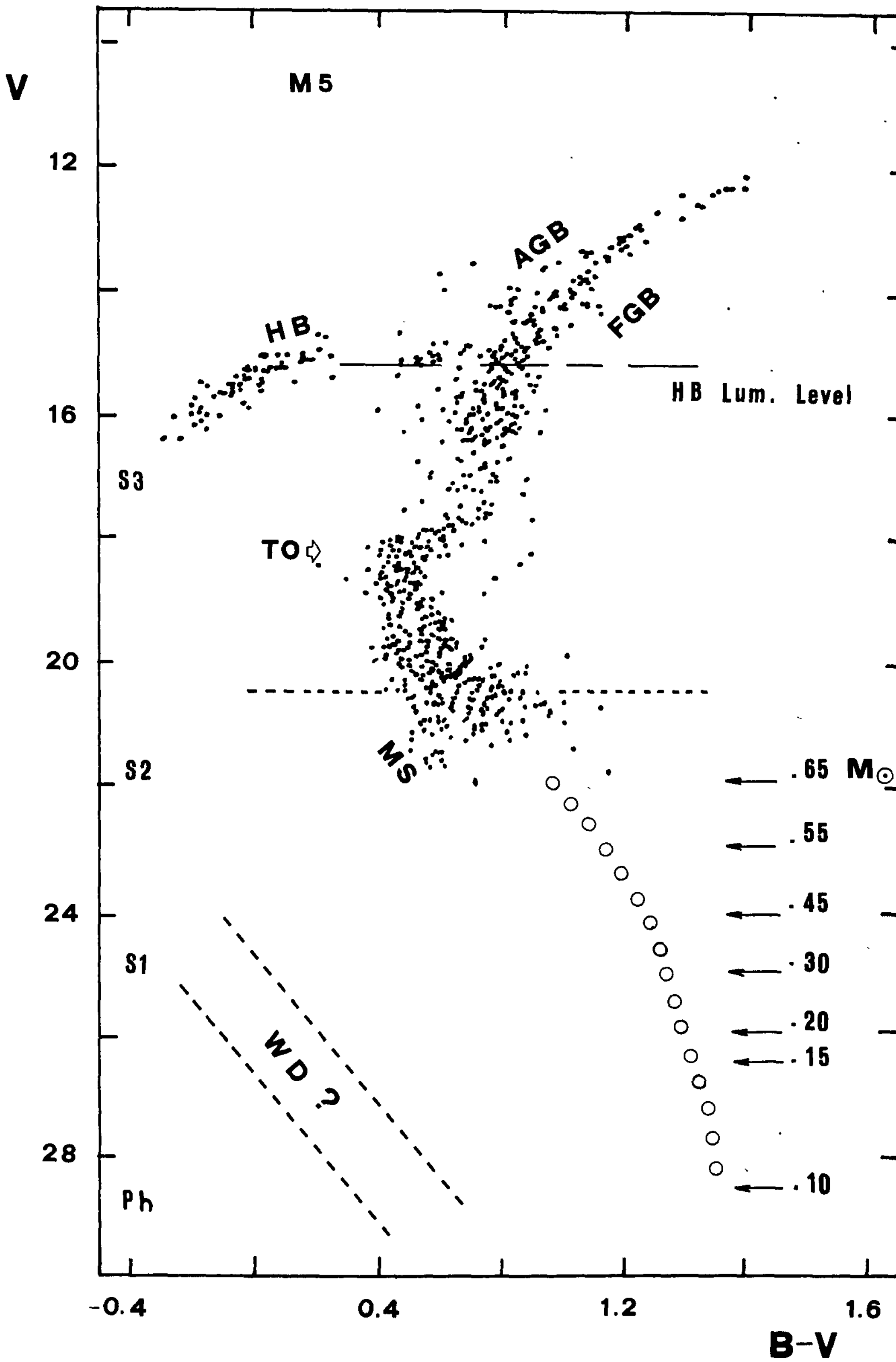

Fig.2: Presently available data on the "well studied" GC M5. Small circles report the expected location of MS stars, whose masses are labelled on the right side of the MS. The expected WD locus is also reported. Photometric (Ph) and spectroscopical limits (S1,S2,S3) are reported as labelled in section 3.

opening to a knowledge on which we have only hypotheses.

In particular we will achieve the first exhaustive informa tions on the main sequence in Globular Clusters: an evolutionary phase -maybe- not too much exciting from the point of view of people devoted to star evolution and, nevertheless, a key point to solve a lot of problems regarding the early evolution of stars in our Universe. What looks incredible is to realize that we will suddenly obtain information down to and -in some cases- below the limiting mass for H-ignition, so that one can reasonably expect to obtain from ST the first complete picture regarding star formation in the "old times" (provided that low mass stars are not escaped from the cluster!). Similar arguments hold for the probable,still undetected, population of cluster White Dwarfs.

The only way to give an idea on the consequences of such an improved knowledge is to list briefly some among the main points we will concerned with in the ST future:

a) The HR diagram location of MS's is a sufficiently well known function of (Y,Z) only (No time-No CNO abundances!). For a fixed temperature the luminosity is decreasing in increasing the original helium content Y. The contrary holds for the HB luminosity, so that comparison between the quoted evolutionary phases should be a sensitive indicator of original Y, independently of the cluster distance modulus (and giving also light on such a parameter). The amount of original heliu in Globular Clusters is a well known key-parameter, connected with the big-bang nucleosynthesis on one side and with the production of Pop.II heavy elements on the other side (Castellani 1978). A similar procedure, based on the difference in luminosity between HB and TO-point was suggested and used (Iben and Rood 1970); because TO-luminosity sensitively depends on the clus ter age, such a procedure is only able to give a relation Y(t) (see e.g. Caputo and Castellani 1975) in the assumption Z/Z_{CNO}=const.

b) The luminosity function along the MS is easily interpreted in terms of mass distribution. The mass function in different star generations is a crucial point in every investigation on the chemical evolution of our Galaxy. The constancy among different populations of Salpeter's mass function has been often challenged, but till now we have no clear observational indication whether or not the mass distribution of newly born stars is dependent on the chemical composition and/or the physical conditions of the interstellar medium. GC's will fix another point on the other side of time, i.e. at the very beginning of the Galaxy, giving light on such a problem (taken in the due account the problem of escaping stars).

c)Spectra of MS stars will answer the delicate question whether the chemical dishomogeneities found in the atmospheres of evolved stars in some Globular Clusters can be assumed as an indication of original dishomogeneities or, on the contrary, they are just an effect of mixing during evolution (see the discussion in Castellani 1977). Such a result will give light on the scenario from which GC's are born out and/or on the effect of evolution on atmospheric compositions.

d)High resolution spectra will give us a direct insight on the chemical composition of most primitive stars and -in particular- on the distribution of isotopes among the heavy elements. By the way, this will throw a new light on early mechanisms of nucleosynthesis,and it will help us in determining fundamental parameters for theoretical stellar evolution like the original amount of CNO

e)White Dwarfs in GC's will be observed (see fig.2) if luminosities and colours are in the range observed in WD's membering the galactic plane. In reality we have little doubts on the presence of WD's in GC's, though no definite ideas on the observational features of such kind of objects. A recent suggestion for very luminous WD's in NGC 6752 (Richer 1978) is anyway completely outside the range of theoretical expectations and ST will give a definite answer also to that question.

Informations contained in WD populations are of various kinds but they have a general common meaning: WD's are in some respects the debris of the evolutionary processes were active in the cluster for some 10^{10} years.As a consequence, they give invaluable informations on the past of the cluster. Decoding these informations will be more or less difficult; nevertheless we know that the characteristics of WD population do depend on primary questions like mass function of evolved stars, their internal structures and the amount of mass loss during the evolution. In the same time we expect that a complete and homogeneous sample of WD,whose oldest members began cooling 10^{10} years ago, will teach us a lot of physics as far as thermodynamic properties of degenerated and crystallized matter is concerned.

Beyond the previous sketch of the major goals of ST observations, there exist of course many other problems concerned with observations, and even more will be raised -I believe- just by the ST results. The previous points show,anyway, how the observations of the "well observed" clusters will disclose a completely new access to the history of galactic matter.

4. ST: THE GROWING RANGE OF EXPLORATION

The gain in the limiting magnitudes will enable us to push a detailed knowledge of GC systems far away beyond our own galactic structure. The meaning and the possibilities of such an extension can be understood relying on the following simple statements concerning classical (= old) GC's:
i) Clusters observed down to TO-point can give complete informations on the age and the original chemical composition, if and when a large sample of RR Lyrae is present (e.g. Castellani 1978). Otherwise, indeterminations on the original Y complicate the problem, though important results can be obtained at least about the origin of observed differences among clusters.
ii) Clusters observed down to HB can give informations on the original chemical composition, again if a consistent sample of

RR Lyrae is present. In any case HB features are well known indica tors of the evolutionary parameters; on this basis we were able to define general and interesting constraints for the evolution of our galactic halo. The slope and the location of the RG branch can give further informations on the cluster metallicity and (roughly) on the cluster age.

iii) Cluster integrated colours can be related to the metallicity, though age can play a relevant role.

iv) Spectra of individual giants and/or integrated spectra add independent informations on the metal content.

Bearing this crude picture in mind, one obtains from Table 4 a general information on the enlarged field of observation. It turns out that the theoretical frame and the interpretations at present based on few "well studied" clusters will be enlarged to a sample of -at least- some hundreds Globular Clusters membering our Galaxy, Dwarf Spheroidals and Magellanic Clouds. There is no diffi culty in preconizing that such an analysis will give definite light on what we are now guessing through extrapolations from the few M 3-like clusters we are able to analyze. The simple knowledge of TO luminosities will enable us to answer quite a lot of presently open questions.

The puzzling evidence for "young Globular Clusters" in the Magellanic Clouds adds a bit of suspense to the whole problem: it will be more difficult decoding the evolutionary informations from YGC's, nevertheless we are facing the exciting possibility to have axhaustive evolutionary samples (as GC's are!) not only for very old stars, but for various evolutionary stages. This means we will face a "prima facie" evidence for the whole evolutionary frame we are at present dealing with.

	W.D.				M.S.				T.O.				H.B.				R.G.				Integ.			
	Ph	S1	S2	S3	Ph	S1	S2	S3	Ph	S1	S2	S3	Ph	S1	S2	S3	Ph	S1	S2	S3	P	S1	S2	S3
NGC 6397	●	•			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
M 3	●				●	●	●		●	●	●		●	●	●	●	●	●	●	●	●	●	●	●
NGC 7006	•				●	●			●	●	●		●	●	●		●	●	●	●	●	●	●	●
DRACO-MC	•				●				●	●	●		●	●	●		●	●	●	●	●	●	●	●
NGC 2419					●	•			●	●			●	●	●		●	●	●		●	●	●	●
FORNAX					●				●	●			●	●	●		●	●	●		●	●	●	●
M 31					•				•				●	•			●	●			●	●	●	•
M 87																	●				●	●	•	
G.G.C.					○	○			□	○	○		☐	□	○		☐	☐	□	○	☐	☐	☐	○

within ST range ●

limiting objects •

☐ extensively observed

□ incomplete data

○ occasional informations

Table 4. Possible goals for ST in the field of Globular Clusters. Observable evolutionary parameters are reported for the various classes of distances indicated in Table 1. Available observations for Galactic Globular Clusters (GGC) are also sketched.
Photometric (Ph) and spectroscopic limits (S1,S2,S3) are reported as indicated in section 3.

5. THE GAIN IN ANGULAR RESOLUTION

A complete new field of investigations will be opened by ST thanks to the expected gain in angular resolution. With a resolving power ten times larger than ground based telescopes (i.e. of about 0".1) ST will enable us to look within the clusters, in the so called "forbidden" unresolved nuclei. Longair (1979) recently gave an impressive exemplification of what the improved ST resolution will mean for Globular Clusters.

It is not easy to guess how far in the cluster nuclei we will be able to go. Let us assume, for the sake of simplicity, that star density in the inner region of the cluster goes as r^{-2}, and then that the projected density goes as r^{-1}. On the basis of such a simple argument, one could expect that the mean separation between the stars goes as $r^{1/2}$ and then increasing the angular resolution by a factor of 10 the radius of the unresolved nucleus will be reduced to $\sim 10^{-2}$ of the present value.

Such an estimate can be assumed as a fair lower limit for the expected improvement with ST observations. Under "normal" circumstances we know that only in the outher region of the isothermic cluster core the density is decreasing as r^{-2}, whereas in the inner regions the density variation becomes more and more soft (see fig.3). This is not true if a massive black hole is present just at the center of the cluster, in which case the density around the BH goes as $r^{-7/4}$ (see e.g. Lightman and Shapiro 1978).

In any case we expect a large improvement in the observation of the inner structure of GC and certainly some well known clusters will be completely resolved in stars. One reason for such kind of observations is just the one quoted before: they can give light on the possible occurrence of massive BH and, in turn, on the origin of X-rays emission from some Globular Clusters. In the same time it will be possible to look more carefully into the possible occurrence of binary systems, an alternative hypothesis for X-ray sources (Katz 1975) and in any case an important datum to

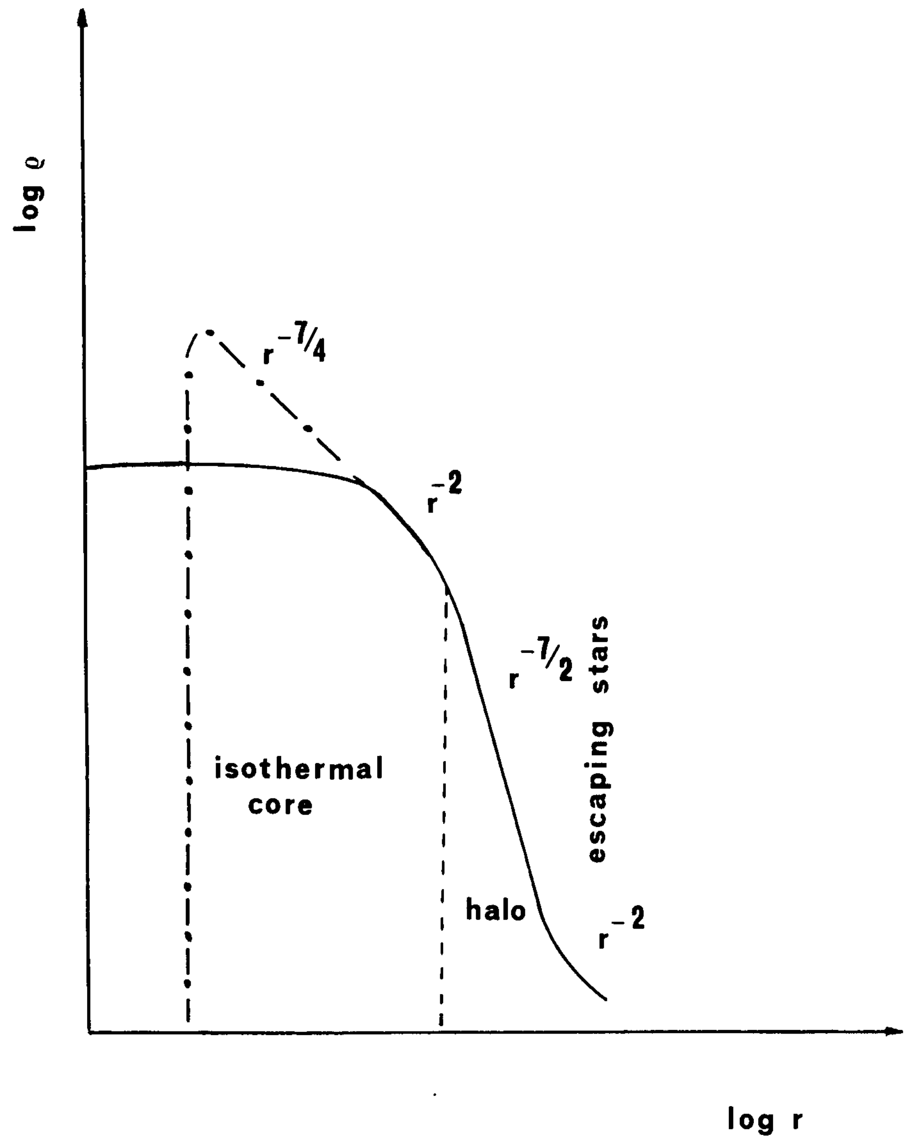

Fig.3: Schematic representation of stellar density as a function of radius in an isolated Globular Cluster (full line). In the presence of a massive central black hole the distribution is shifted following the dashed-dotted line. (From Lightman and Shapiro 1978)

understand the dynamical structure of the clusters.As is well known binary systems, if present, are expected to be concentrated toward the cluster center for simple dynamical reasons (i.e. equipartition of energy). In this context, it is worth to note that we may be able to pick up binary systems that could give information on the mass-luminosity relation and,as a consequence, on the original helium content of cluster members.

Let us finally mention that the knowledge of star distribution and of Doppler effects (i.e. radial velocities) throughout the cluster will certainly enable us to improve dramatically our understanding the dynamical evolution of GC's, an argument widely debated (Spitzer 1978) and strongly related to the past and the future evolution of our Galaxy.

A further exciting possibility is to have light on the suspected occurrence of "star populations" in some GC's. Changes of the evolutionary properties of stars with the cluster radius have been often suggested (e.g. Caputo and Castellani 1975) and recently discussed by Freeman (1978): the point is that the evolutionary stage and/or the integrated colour of the cluster seems to depend on the distance from the cluster center. If this is true, dynamical explanations (like re-distribution following mass-loss) are difficult to be believed and one is driven to speculate about age or chemical differences between cluster nucleus and cluster halo. A closer inspection of this problem may give us invaluable information on the chemical and dynamical evolution of the protocluster. Anyway, I share with many people the suspect that something odd may occur in the nucleus of GC's, and almost certainly many future topics will arise from unexpected discoveries. As an useful example, I would like to drive your attention on the class of information that can be obtained from the dynamical analysis of YGC, as studied by Geyer et al. (1979) for some clusters in LMC.

Distance	Ang.Diameter	Rank of distances
10 Kpc	10'	M 3
100 Kpc	1'	Draco
1 Mpc	6"	M 31
10 Mpc	0".6	M 101
20 Mpc	0".3	Virgo Cluster

Table 5. Orientative angular diameters of a M 3-like Globular cluster membering systems at various distances from the Sun.

6. FINAL REMARKS

In the previous sections some among the most obvious goals of ST with regard to GC's have been reported. Nevertheless one has to remember that, as recently stated by Greenstein (1977) " almost none of the major topics now dominating journals were 'expected' when their technology was developed". Some outstanding possibili_ ties are reported in the quoted paper by Greenstein. There exist intergalactic stars and will they be extremely metal poor? Do numerous faint halo stars exist at 50 Kpc as a galactic halo? Do any "zero metal star" ($Z < 10^{-5}$) exist?

There is no difficulty in extending such a list following the so many unknowns or indeterminations in our theories. What it looks clear to me is that ST could be devoted to such a problematic for a very long time without exhausting this subject. I, of course, cannot ask for a GCST (= Globular Cluster Space Telescope) though I am personally convinced that such an instrument would be among the most busy and useful instrument to be launched un space.

REFERENCES

Bahcall,J.N.,Ostriker,J.P.:1975,Nature,256,23

van den Bergh,S.:1978,Proc.NATO Conference on GC's (in print)

Caputo,F.,Castellani,V.:1975,Astrophys.Space Sci.38,39

" " :1975a,Mem.Soc.Astron.It.46,501

Castellani,V.:1977,Proc.IAU Coll."Chemical and Dynamical Evolution of our Galaxy"(E.Basinska,M.Mayor eds)p.133

" :1978,Proc.NATO Conference on GC's (in print)

Dave,J.A.,Dickens,R.J.:1976,Nature,263,395

Freeman,K.:1978,Proc.NATO Conference on GC's (in print)

Geyer,E.H.,Hopp,U.,Kiehl,M.,Witzigmann,S.:1979,Astron.Astrophys. (in print)

Greenstein,J.L.:1977,Proc.ESO Conf."Optical Telescope of the Future" p.525

Hodge,P.W.:1974,Pub.Astron.Soc.Pacific 86,289

Iben,I.Jr.,Rood,R.T.:1970,Astrophys.J.161,587

Karachentseva,V.E.,Kostyuk,I.P.:1974,Astrofizika,10,632

Katz,J.I.:1975,Nature,253,698

Lightman,A.P.,Shapiro,S.:1978,Rev.Mod.Physics 50,437

Longair,M.S.:1979,Quar.J.Roy.Astron.Soc. (in print)

Racine,R.J.:1968,J.R.Astron.Soc.Can.62,367

" :1970, ibid. 64,257

Richer,H.B.:1978,Astrophys.J.224,L9

Smith,M.G.,Weedman,D.W.:1976,Astrophys.J.205,709

Spitzer,L.:1978,Proc.NATO Conference on GC's (in print)

M. HACK : I agree that determination of chemical composition and isotope ratios in non evolved stars in galactic clusters is one of the most important problems; only HR spectroscopy can give a non ambiguous determination of metallic abundances. Unfortunately this will be impossible with the presently accepted configuration for the HRS; the visual range is not accessible, and only stars of spectral type F-G or later, brighter than V∿8 will be observable. It is a pity that we cannot fully exploit the high sensitivity and especially the high spatial resolution (0".3, which is the slit aperture of the HRS, against the 1" or worse which can be obtained from the ground) of ST for looking for possible chemical composition gradients in the cluster.

B.E.J. PAGEL : I believe you will have serious crowding problems in trying to observe individual HB stars in globular clusters of M31.

V. CASTELLANI : I hope your statement will turn out to be too pessimistic. In my talk I was concerned with the information we will in principle be able to derive from ST limiting magnitudes. Though itwill be difficult to obtain information on M31 stars, it will be worthwhile to make any possible effort to obtain individual observations of HB stars, as they are able to give us quite a lot of information on the evolutionary parameters of M31 clusters.

I. APPENZELLER : I certainly agree that high resolution spectrograms of GC stars, which allow to determine chemical abundances, would be very useful. However, I do not quite understand why the ST will for this particular type of observations be superior to observations with the existing larger ground based telescopes. The ST will (e.g.) have only about 20% of the light collecting power of the Mt. Palomar telescope and therefore I would expect that the Mt. Palomar telescope or similar large telescopes would provide higher resolutions or better signal-to-noise ratios for this type of observation.

V. CASTELLANI : This is of course a good point. As far as I understand, low R spectroscopy is the one able to open a new field of investigation, giving results comparable to and as useful as intermediate band photometry like the well-known DDO and also giving light on such kind of data. Nevertheless one may note that, as some people said during this meeting, clean high dispersion spectra obtained outside the atmosphere can be really useful for a better determination of the chemical distribution in population II stars.

E.H. GEYER : I am a bit concerned about the ground based observations on globular clusters which are put into the background. There are still so many observations in crowded field possible with the existing large telescopes for photometry (down to 23rd magnitude), spectroscopy (down to the 19th magnitude with $\Delta\lambda/\lambda \sim 10^{-3}$) and for the dynamic of g.cl. The Space Telescope should really be reserved for such observations which cannot be done by ground based telescopes. For example, I obtained last year a series of plates on ω Centauri with the new 2.5 m duPont telescope of the Hale Observatories for a search for main sequence variables (eclipsing binaries). The V- and B-plates have a limiting magnitude $> 22^m$, therefore main sequence stars of $M_V > 7^m$ are reached! To my surprise one can look through the cluster even in its center!

AN EXAMPLE OF THE INTEREST OF HIGH SPATIAL RESOLUTION PICTURES FOR THE STUDY OF GLOBULAR CLUSTERS

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1) Introduction

Obtaining the intensities in several passbands of individual stars in the inner parts of concentrated globular clusters is of great astrophysical interest. It provides with the knowledge of spatial distribution of stars having various physical properties.

Classical photometric systems (as U, B, V or narrows band systems) can be used; images through interference filters centered on absorption lines or bands (Mg b, C N, ...) or nebular emission lines (O |III|, ...) are also useful.

Such data allow the study of mass segregation (WOOLF 1964; KING 1975), the understanding of radial color variations and maybe the detection of chemical gradients (CHUN and FREEMAN 1979), or the understanding of the nature of the central condensation of X ray globular clusters such as Messier 15.

The inner parts of concentrated globular clusters are the more interesting because the dynamical effects are the most efficient. In counterpart, to disentangle each star contribution from the total intensity requires high spatial resolution. The critical part of the clusters implied in this study has an angular size typically smaller than half an arc minute. This is compatible with the field which will be analysed by the Faint Object Camera of the Space Telescope. We will see how the S.T. observations will help us in this problem through some results and limitations of a ground based study.

2) A ground based approach of the problem.

We are making a B and V survey of the central part of nine concentrated globular clusters (M 79, M 53, M 3, M 5, M 80 NGC 6440, M 15, M 2, M 30) with the F/15 Cassegrain focus of the one meter reflector of Pic du Midi Observatory. Photographic and electronographic imaging are involved. This survey shows that it is exceptional to obtain classic photometric plates with stars having a full width at half maximum smaller than 1.5 arc second. The two main well known limitations are the atmospheric seing and the photographic noise. Reducing them asks for two contradictory means : to shorten the exposure time, getting it below some seconds; to enlarge the image scale (i.e. the focal length). In addition, to improve chances of having atmospheric stability during the exposures, it is necessary to obtain numerous images in an observation. Electronographic technics which enable short exposures times and use plates of small graininess could be the most suitable for such studies; nevertheless, they are unable to give the great number of images required. Photometric quality can also suffer from shorter exposure times during which the spreading function cannot be made uniform on the field under study.

So, we have tried to obtain good resolution pictures independantly from the photometric ones. Then, we have used a thirty to forty five meters focal length and a single stage image tube. For bright clusters like M 5, M 3, M 15, M 2, unfiltered exposures (but with an atmospheric dispersion corrector) of about ten seconds have made it possible to improve spatial resolution by a factor of two or three, reaching 0.5 arc second. These pictures alone, of course, are inadequate for photometric purposes. Nevertheless, we are using them to know the positions of the stars that are measured on the B and V images. Finally, we are able to determine the magnitudes of stars that are not resolved on the photometric pictures. This method allows us to investigate the core of several bright concentrated globular clusters.

Fig. 1 shows the center of M 3 in a 98 x 74 arc second with a 0.5 arc second resolution. M 3 appears to be very concentrated according to PETERSON and KING (1975). Nevertheless, it seems completely resolved in stars.

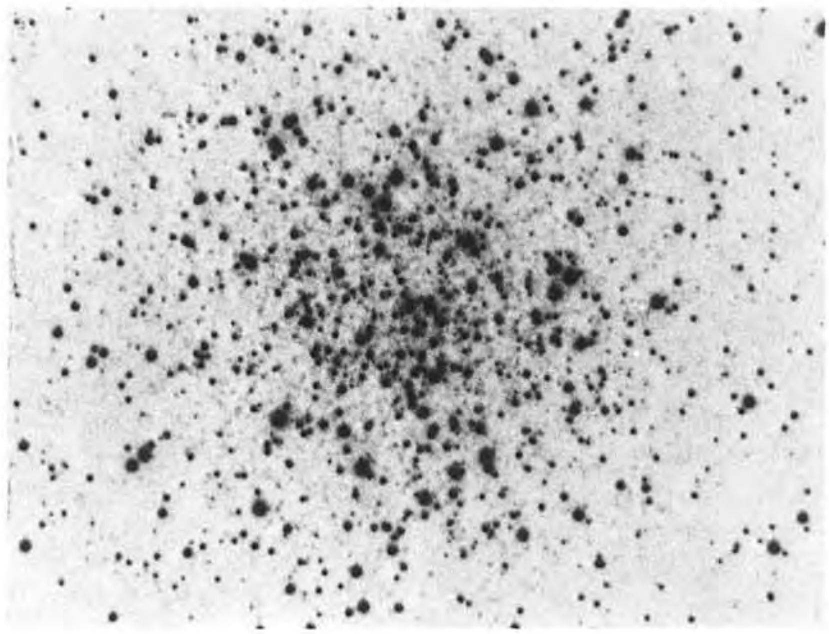

Fig. 1. The central part of M 3 within a 98" x 74" field.
North is towards the upper right.

The core of the X ray globular cluster M 15 reveals, in opposition, a 5 arc seconds diameter condensation that is not resolved in stars. This condensation is known to be responsible for a departure of the radial intensity curve from the isothermal profile (KING, 1975). A 0.7 arc second resolution electronographic picture shows several maxima (LEROY et al 1976) which may correspond to a beginning in resolution in several rather faint stars. A search for O|III| emission (AURIERE et al 1978) has shown us that the condensation did not seem to be associated with a planetary nebula (PETERSON 1976).

3) Conclusion for Space Telescope observations.

Ground based observations such as those roughly described above can help for choosing the Space Telescope targets for the problem discussed here.

The priority goes to the central part of condensed core clusters such as some of the X ray globular clusters. The galactic globular clusters will appear as bright objects for the F.O.C. so that even the faintest will be observed easily with narrow band filters.

For the bright ones, for which the core often overlaps the field of the F.O.C., ground based studies which are possible in this case with a good spatial resolution will be complementary . In counterpart, the knowledge of the real star structure of the clusters given by S.T. images will help to interpret ground based observations.

References.

AURIERE, M., LAQUES P., LEROY J.L. : 1978, Astron. Astrophys., 63, 341

CHUM M.S., FREEMAN K.C. : 1979, Astrophys. J, 227 93.

KING I.R. : 1975, in Dynamics of stellar systems, p. 99 Edited by A. HAYLI, D. Reidel Publishing Company, Dordrecht,Holland.

LEROY, J.L., AURIERE M., LAQUES, P. : 1976, Astron. Astrophys. 53, 227.

PETERSON, A.W. : 1976, Astron. Astrophys. 53, 441.

PETERSON, C.J., KING, I.R. : 1975, Astron. J. 80, 427

WOOLF, N.J. : 1964, Astrophys. J. 139, 1081.

WHAT CAN WE LEARN FROM THE ST OBSERVATIONS OF WHITE DWARFS IN GLOBULAR CLUSTERS?

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ABSTRACT:

ST will quite easily allow photometry of stellar objects down to $m_v \approx 26$. Using extant estimates of the white dwarf cooling times, the number of observable white dwarfs in a typical globular cluster is evaluated to be about 2.5 times the number of horizontal branch stars in the same cluster, i.e. several hundred white dwarfs should be found in the outer, uncrowded region of a cluster.

On the basis of the evolutionary theory of globular cluster stars, quite precise predictions can be made on the average mass and mass dispersion of white dwarfs in globular clusters: i.e. $M_{WD} = 0.5-0.53\ M_\odot$ and $\sigma(M_{WD}) \approx 0.004\ M_\odot$. From these values and from the Mass-Radius relation for degenerate stars the following predictions can be made: i) the intrinsic dispersion of the white dwarf sequence should be very small, being of the order of only $0^m.01$; ii) the uncertainty in the location of the WD sequence in the $(\log L - \log T_e)$ - diagram is only $\pm\ 0^m.03$. Using prediction ii) the relative distance moduli of various globular clusters could be determined with an uncertainty of $\pm\ 0^m.03$, i.e. with roughly a factor of 10 less than current estimates. As far as the determination of absolute distance moduli is concerned, the major uncertainty comes from the estimate of the effective temperature and bolometric correction of individual WD's, the uncertainty in the luminosity being $\delta \log L = 4\ \delta \log T_e$, where $\delta \log T_e$ is the uncertainty of T_e.

1. INTRODUCTION

Everybody agrees that globular clusters (G.C.) should be full of white dwarfs (WD). In a typical GC with $M=10^5 M_\odot$, there should be some 2×10^4 WD's. In most cases, these WD's are expected to be too faint for being detected by ground-based telescopes. Recent claims of WD's detection in the GC NGC 6752 (Richer, 1978 a,b) are probably unjustified, when allowance is made for the expected number of background QSO's (cf. Braccesi et al. 1979).

It is widely known that ST, reaching extremely faint objects, will allow photometry of WD's members of galactic GC's. The aim of this short communication is to show how the predictions of the stellar evolution theory of population II stars, in conjunction with ST observations, can be used to improve the distance determination of GC's. A few other miscellaneous topics are also discussed.

2. THEORETICAL PREDICTIONS

All presently evolving GC stars will terminate their evolution as Wd's. The mass $-M_{WD}-$ of these WD's is significantly smaller than the initial mass of the parent stars, because mass loss occurs during the red giant branch (RGB) and the asymptotic giant branch (AGB) evolutionary phases. Although the mass loss rate of red giants is observationally still uncertain, the comparison of theoretical and observational colour-magnitude diagrams allows a quite precise determination of the total amount of mass which is lost during the red giant phases. In fact, the observed morphologies of the horizontal branch (HB) of GC's indicate that about 0.2 $M_\odot$ is lost along the RGB phase (Rood, 1973; Renzini,1977), while another 0.1 $M_\odot$ is lost during the AGB phase (Renzini,1977). In this way M_{WD} is determined with fairly high accuracy, viz M_{WD}=0.50 ÷ 0.53 $M_\odot$. In fact, the maximum luminosity attained along the AGB crucially depends on the mass reached by the stellar core, which, in turns, is just M_{WD}. For $M_{WD} \lesssim 0.50\ M_\odot$ the AGB would not be populated in its upper part, while for $M_{WD} \gtrsim 0.53\ M_\odot$ a significant number of AGB stars should have luminosities in excess of the red giant tip luminosity (cf. Renzini, 1977). Therefore, only for M_{WD} within the indicated range the observed extension of the AGB in GC's is accounted for, and we can take

$$M_{WD} = 0.515 \pm 0.015\ M_\odot \qquad (1)$$

where the uncertainty allows for a possible trend of M_{WD} with the cluster metal abundance Z. It is worth emphasizing that M_{WD} is the mass of WD's which are forming <u>now</u>, while M_{WD} was higher in the past when the initial mass of dying stars was correspondingly higher.

A second important theoretical prediction concerns the expected dispersion $\sigma(M_{WD})$ of the mass of WD's which are now forming within one cluster. Rood (1973) has shown that the HB morphology is well reproduced with a dispersion in the mass of HB stars in one cluster $\sigma(M_{HB}) \approx 0.025\ M_\odot$. Mass loss during the subsequent AGB evolution has the effect of drastically reducing this mass spread in such a way that $\sigma(M_{WD}) \approx 1/6\ \sigma(M_{HB})$, or

$$\sigma(M_{WD}) \approx 0.004\ M_\odot \qquad (2)$$

(Renzini, 1977).

Let us now consider the implications of predictions (1) and (2) for the luminosity of GC white dwarfs. An analytical fit to the Hamada and Salpeter (1961) mass-radius relation for models of degenerate dwarfs gives:

$$R_{WD} = 9.128\text{x}10^{-3}\ M_{WD}^{-0.5434} \qquad (3)$$

where both R_{WD} and M_{WD} are in solar units.
This relation holds for $0.5 \leqslant M_{WD} \leqslant 0.6$. The WD luminosity (in solar units) is correspondingly given by

$$\log L = -19.124 + 4\log T_e - 1.087\ \log M_{WD} \qquad (4)$$

where T_e is the effective temperature.
At given effective temperature, an uncertainty $\delta \log M_{WD}$ in $\log M_{WD}$ implies an uncertainty in logL:

$$\delta \log L = -1.087\ \delta \log M_{WD} \qquad (5)$$

or, with $\delta \log M_{WD}$ from Eq.(1), $\delta \log L \approx 0.013$ and $\delta m_{bol} \approx 0.03$ mag. Therefore, the theoretical prediction (1) implies an uncertainty of only 0.03 mag. in the location in the (m_{bol}-$\log T_e$)-diagram of the WD cooling sequence of GC's.
In the same fashion, prediction (2) implies an intrinsic luminosity dispersion of the cooling sequence in one cluster of only 0.01 mag.

It is important to evaluate the expected number of WD's brighter than a given luminosity in a given GC. An analytical fit to the Sweeney (1976) cooling curve for M_{WD}=0.51 gives (for $\log t \lesssim 9.5$):

$$t \approx 2.6\times10^{6} L^{-0.79} \quad \text{(yrs.)} \tag{6}$$

where L is the WD luminosity (in solar units) and t is the time spent by the WD at luminosities higher than L. Eq.(6) can be written as:

$$t \approx 8.3\times10^{4}\times10^{0.32\,M_{bol}} = 8.3\times10^{4}\times10^{0.32(m_{bol}-\text{mod})} \tag{7}$$

where M_{bol} is the absolute WD bolometric magnitude, m_{bol} is the apparent bolometric magnitude (not corrected for absorption) and mod is the apparent distance modulus. It is worth referring the expected number of WD's to the number of a particular kind of stars whose lifetime is well known. HB stars are particularly appropriate, as their lifetime is 10^8 yr.s (cf. Renzini, 1977). Therefore, $R=N_{WD}(m_{bol})/N_{HB} = t(m_{bol})/10^8$, $N_{WD}(m_{bol})$ being the expected number of WD's brighter than m_{bol}. From Eq.(7) with mod=15 (appropriate for the cluster M3) we get the R values listed in table I which apply to both a cluster as a whole, or to any portion of it (provided segregation effects are small). By a simple scaling, table I can be used for any other value of the distance modulus, e.g. for the closest GC, NGC 6397, mod $\approx$ 12 and R=2.75 for m_{bol} = 23, and so on. It is worth emphasizing that table I represents the present theoretical expectations which can be used for planning the observational work with ST, the direct observation of WD's in GC's will actually provide the empirical WD luminosity function and cooling time.

Table I

m_{bol}	R
22	0.14
23	0.28
24	0.58
25	1.20
26	2.75
27	5.14
28	12.0

3. THE USE OF THE WD COOLING SEQUENCE FOR THE DISTANCE DETERMINATION OF GLOBULAR CLUSTERS.

Present estimates of the distance of galactic globular clusters are based upon the absolute magnitude of the RR Lyrae variables or on main-sequence fitting. These methods give conflicting results, and both are uncertain by some 0.25 mag. (cfr. Sandage, 1970). Conversely, as we have shown in the previous section, WD luminosity is affected by a much smaller uncertainty and WD's may provide a much better "standard candle" for distance determinations. In principle, using WD's the distance modulus of globular clusters could be determined with an uncertainty of only 0.03 mag. Among other advantages, the knowledge of the distance of GC's with this high accuracy, will allow: i) a reduction of the uncertainty in the cluster age by 3÷4 billion years, ii) a significant improvement in the determination of the helium abundance, and iii) the determination of the luminosity contribution to the Oosterhoff effect.

Let us now consider in some detail whether ST performances will allow a full use of the theoretical predictions presented in Section 2. With a photometric precision of 0.01 mag. (Longair, 1979) the Wide Field Camera (WFC) should allow a verification of prediction (2), at least for brightest WD's whose magnitude uncertainty is not limited by photon statistics. In this respect NGC 6397 appears to be the ideal object to study, being the closest GC. However, projection effects are in this case important: a dispersion of 0.007 mag. is in fact expected due to differences in the distance of cluster members (the cluster has a distance of 2.1 kpc and a diameter of ~ 15 pc).

The accuracy in the location of the WD sequence in a colour-magnitude diagram depends upon two factors, namely the photometric errors and the number of observed objects. It is worth emphasizing that the increase in the number of WD's with decreasing luminosity (cf. Eq. (7)) will almost completely compensate for the corresponding increase in the photometric error. Assuming that the photometric precision is 0.01 mag. at m_{bol}=22, it will be ~0.1 mag. at m_{bol}=26. From Table I one sees that for each WD at m_{bol}=22 we have 20 WD's down to m_{bol}=26. Therefore, assuming to have only one WD at m_{bol}=22, the precision in the location of the WD sequence at m_{bol}=26 is roughly $0.1/\sqrt{20}$ =0.02 mag., and it appears feasible to locate the WD sequence with a precision comparable with the theoretical uncertainty (~ 0.03 mag.). Obviously the choice of the filters should be made in such a way to optimize the photometric performance for stars in the expected range of WD effective temperatures (10 000 - 20 000 K). Since the accuracy of this method depends on the number of observed WD's, it is important to evaluate the expected number of observable WD's using the various ST cameras, for each particular cluster and for several distances from the cluster centre. For illustrative purpuses, we consider here the case of M3, bearing in mind that the figures given below will actually change dramatically in going to clusters with different central concentrations. Using the luminosity function given by Da Costa and Freeman (1976) and the radial stellar distribution given by Oort and van Herk (1959) we find the following numbers of stars per arcmin square at 0.'5 frm the cluster centre: a) N_{HB} =51, b) $N_{WB}(m_v < 26)$ =48, $N_{WD}(m_{bol} < 26)$=140; c) $N_{all\ stars}(m_v < 26)$= 32000. Correspondingly, the number of WD's brighter than m_v=26, in the field of the various ST cameras is respectively: 342 for the WFC, 63 for the PC, and 12 for the FOC (in the case of the maximum proposed aperture 44"x22") or 1.5 (for a 11"x11" field). Therefore, at the moment, the WFC or PC appear to be more appropriate, apart from specific problems the FOC could encounter in pointing a field with many bright (m_v < 16) stars. From the figures given above, one expects 228000 stellar images (with m_v<26) in the field of the WFC, or 11 pixels per stellar image (61 pixels in the case of the PC). However, bright stars will presumably disturb photometry of faint objects, correspondingly reducing the "clean" field, and some optimization in selecting camera and/or field should be made. In conclusion, it appears possible to get the required information within a reasonable ST observing time.

The relative distance modulus (with an accuracy of ~ 0.03 mag.) of any pair of unreddened clusters can be obtained in a very straightforward fashion: it suffices to fit the two WD sequences, like in the classic procedure of main-sequence fitting). It is worth noting that accurate relative distance determinations allow very precise estimates of the age and helium differences among GC's.

The situation is much more complex for the determination of the absolute distance scale, i.e. for the determination of the absolute modulus of one cluster. In fact, in order to apply Eq.(4) we need a very precise estimate of the WD effective temperature at a given colour. From Eq.(4), setting the uncertainty in luminosity introduced by the error in $\log T_e$ equal to that introduced by the uncertainty in $\log M_{WD}$ we get:

$$4\ \delta \log T_e = 1.087\ \delta \log M_{WD} \qquad (8)$$

or $\delta \log T_e = 0.003$, corresponding to 75 K at 10 000 K and 152 K at 20 000 K. Present uncertainties in the WD temperature scale are obviously much larger (Shipman, 1977, estimates an error of ~600 K). Spectrophotometric ST observations of field WD's coupled with more refined WD model atmospheres are therefore a prerequisite for the optimal use of this method.

4. MISCELLANEOUS TOPICS

Field WD's are classified into two main groups: DA WD's, with hydrogen atmospheres, and non-DA's, with helium atmospheres, and three-colour photometry can easily distinguish between them (cf. Weidemann, 1975). The relative occurrence of the two types in G.C.'s will shed light on the origin of this dichotomy.

If close binaries are present in G.C.'s in a significant number, and if during the evolution the two components coalesce as suggested by Webbink (1976), they will occupy a position in the HR diagram distinguishable from the normal stars locus only during three evolutionary phases. Namely, a) just after coalescence (as blue stragglers), b) during the upper AGB phase (as the brightest stars in the cluster), and c) during the WD phase, having a mass 0.1÷ 0.2 $M_{\odot}$ larger than normal WD's in the same cluster. Phase b) is very short lived, therefore the simultaneous observations of blue stragglers and WD's fainter than the normal sequence, will strongly support the binary origin of these objects and will allow an estimate of their frequency in G.C.'s.

We are indebted to C. Barbieri for providing us with information on ST instrumentations and to F. D'Antona for discussions.

REFERENCES

Braccesi, A., Zitelli,V., Bonoli,F., Formiggini,L. 1979 (preprint)
Da Costa, G.S., Freeman, K.C. 1976, Ap.J. 206, 128.
Hamada, T., Salpeter, E.E. 1961, Ap.J. 134, 683.
Longair,M.S. 1979, Q.J.R.A.S. (in press).
Oort, J.H., van Herk,G. 1959,B.A.N. 14, 299.
Renzini, A. 1977, Advanced Stages in Stellar Evolution, Ed.s P. Bouvier, A. Maeder, Geneva, p.149.
Richer, H.B. 1978a, Ap.J. Lett. 224, L9.
Richer, H.B. 1978b, Ap.J. Lett. 226, L157.
Rood, R.T. 1973, Ap.J. 184, 815.
Sandage, A.R. 1970, Ap.J. 162, 841.
Shipman, H.L. 1977, Ap.J. 213, 138.
Sweeney, M.A. 1976, A.A. 49, 375.
Webbink, R.F. 1976, Ap.J. 209, 829.
Weidemann, V. 1975, Problems in Stellar Atmospheres and envelopes, Ed.s B. Baschek, W.H. Kegel, G. Traving, Springer Verlag, p. 173.

The Use of ST for the Detection of Black Holes in Globular Cluster Cores

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About ten years ago the present author (Wyller 1970) raised the question of the existence of black holes as a central remnant in globular cluster cores after the initial protocluster cloud collapse. Some elementary considerations were given to possible observational consequences of such a hypothesis with particular emphasis on stellar velocity effects near the central black hole. The main conclusion in this respect was that the most significant velocity effects would occur inside a radius of one arc-second centered on the black hole. The observational tests would thus severely strain the capabilities of groundbased facilities and would in essence have to await spaceborne telescope facilities. Subsequently much more refined theoretical work has amply confirmed this conclusion, as we shall see.

Considerable impetus was given to further work theoretical and observational on this problem by the discovery in 1974 (Giacconi et al 1974) that several globular clusters are x-ray sources. Among various theories advanced to explained this x-ray emission was one which involved the assumption of a black hole in the center of the x-ray emitting globular cluster (Silk and Arons 1975, Bahcall and Ostriker 1975). Since then much theoretical work has been done on the stellar distribution around a massive black hole in a globular cluster, (Peebles 1972, Bahcall and Wolf 1976,77, Frank and Rees 1976, Lightman and Shapiro 1977, Young 1977 a,b, Ozernoy and Dokuchaev 1977, Ipser 1978 a; Shapiro and Marchant 1978; Cohn and Kulsrud 1978). The basic conclusion from this theoretical work is that a globular cluster with a central massive black hole should exhibit a steep central brightness profile and associated steep rise of the velocitydispersion profile. The expected significant rises in these quantities should occur inside a central radius of 1 arcsecond for a black hole of 1000 solar masses and a representative globular cluster distance of 10 kiloparsec.

Parallell with this theoretical activity considerable effort has also been spent on refined observations of the surface brightness distribution - - which relates to the stellar densitydistribution - in globular clusters and to some extent also on spectral velocity effects near the cluster center (see f.ex. Bahcall and Hausman 1977). Much of this observational work has centered on the globular cluster M15, which is an x-ray source. In 1976 Illingworth and Illingworth observed the surfacebrightness distribution of this cluster photoelectrically with a 24-inch telescope and a variety of apertures ranging from 10 to 185 arcseconds. Such aperture size is much too coarse for the detection of the steep nuclear brightness profile expected from current theoretical models. However improved observations of the brightness distribution in M15 have been made by Newell and O'Neil (1976) by electrographic means whereby they claim they were able to penetrate to 0.5 arcseconds from the centre. On the basis of this extended surfacebrightness distribution Newell, da Costa and Norris (1976) deduce a brightness excess in M15 inside a core with a true halfwidth of 2.7 arcseconds. Following model computations they attribute this brightness excess to a central massive black hole of about 800 solar masses.

On the other hand Illingworth and King (1977) from the same observational data and with model computations explain the central brightness peak as due to the gravitational effect of a group of neutronstars and dispense with the need for the assumption of a central black hole.

The observational material regarding the stellar velocitydispersions near the core center is not so well advanced. Spectral studies have been made by Illingworth (1976) and Newell, da Costa and Norris (ibid.) on the integrated core and the outer cluster regions. However the angular resolution in now way matches that of the surfacebrightness distributions. Observationally discriminating tests between the two hypothesis of a central group of neutronstars or a relatively massive black hole obviously require higher angular resolution than 1 arcsecond both in the mapping of the surface brightness distribution and in the velocitydispersions.

A most auspicious start on tackling in earnest the localization of a central brightness and velocity spike in an extended stellar system have been made by Young et al (1978) and Sargent et al. (1978) in their magnificent study of M87, a wellknown elliptical galaxy in many ways reminiscent of the globular cluster configurations but on a grander scale. Young et al. have mapped the surface brightness distribution in M87 with a SIT detector system on the Mt. Palomar 60-inch telescope and with a CCD detector on the 200-inch. At the center of M87 they have located a brightness spike smaller than 1.5 arcsecond in radius with a pixel size of 0.25 arcseconds in the CCD detector system. Sargent et al. have mapped the distribution of velocity dispersions across the nucleus of M87 with the Boksenberg Image Photon Counting System. Twenty spectra were recorded along a slitlength of 102 arcseconds with 5.4 arcsecond resolution. They find a velocity spike beginning with a velocity despersion of 350 km/sec at a radius of 1.5 arcseconds.

Both research groups from respective data, i.e. surfacebrightness and velocity dispersions, arrive at the conclusion that in the centre of M87 there resides a dark central mass of $5x10^9$ solar masses concentrated within a volume less 1.5 arcseconds = 110 parsecs. They do favour the hypothesis of a black hole but concede that with the inadequate spatial resolution inside a radius of 1.5 arcseconds their observations could also be fitted with a small compact group of neutronstars or white dwarfs. Both groups conclude that "the best hope for a dramatic improvement in the data lies with the Space Telescope which will offer an order of magnitude improvement in resolution" (Young et al. 1978 p. 729).

Fortunately one can say that the work of young et al. and Sargent et al. serves as a groundbased dress-rehearsal of some of the auxiliary instrumentations to be carried aloft by the ST in 1983. In the first Report by the Space Telescope Review Committee (circulated by the European Science Foundation in November 1978) one of the Space Telescope Scientific Instruments, the widefield/planetary camera, will be equipped with four CCD detector systems to be used in conjunction with the two optical systems. The widefield camera will have a field of view of 160x160 arcseconds (individual pixel size 0.1 arcseconds) and the planetary camera will have a field of view of 68.7x68.7 arcseconds and individual pixel sizes of 0.043 arcseconds. Each pixel will have a dynamic range of 15,000 and a signal to noise ratio of 450 per single exposure.

The ESA Faint Object Camera in its recently modified version will have a second optical path equipped with a spectrographic capability which in conjunction with the Boksenberg Image Photon Counting System will allow spectroscopic observations of extended objects while simultaneousle permitting spatial resolution of 0.1 arcsecond to be maintained along the 10 arcsecond slit.

One research objective for the wide field/planetary camera stated in the report is "observations at high resolution of luminosity profiles of galactic nuclei" but no mention is made of similar problems in globular clusters. The purpose of my presentation here today is to draw your attention to the fact that for a satisfactory resolution of the question whether or not black holes exist in globular cluster cores, the widefield/planetary camera and the faint object camera of the Space Telescope are uniquely suited.

R e f e r e n c e s

Bahcall, J.N. and Ostriker, J.P., 1975, Nature, 256, 23.

Bahcall, J.N. and Wolf, R.A., 1976, Ap.J., 209, 214.

Bahcall, J.N. and Wolf, R.A., 1977, Ap.J., 216, 883.
Bahcall, N.A. and Hausman, M.A., 1977, Ap.J., 213, 93.
Cohn, H. and Kulsrud, R.M., 1978, Ap.J., 226, 1087.
Frank, J. and Rees, M.J., 1976, M.N.R.A.S., 176, 633.
Giacconi, R., Murray, S., Gursky, H., Kellogg, E., Schreier, E., Matilsky,T., Koch, D. and Tananbaum, H., 1974, Ap.J., Suppl., 24, 37.
Illingworth, G., 1976, Ap.J. 204, 73.
Illingworth, G. and Illingworth, W., 1976, Ap.J., Suppl., 30, 227.
Illingworth, G. and King, I.R., 1977, Ap.J. Lett. 218, L109.
Ipser, J.R., 1978, Ap.J., 222, 976.
Lightman, A.P. and Shapiro, S.L., 1977, Ap.J. 211, 244.
Newell, B., da Costa, G.S. and Norris, J., 1976, Ap.J. Lett. 208, L55.
Newell, B. and O'Neil, E.J., 1976, in preparation.
Ozernoy, L.M. and Dokuchaev, V.I., 1977, preprint.
Peebles, P.J.E., 1972, Ap.J. 178, 371.
Sargent, W.L.W., Young, P.J., Boksenberg, A., Shortridge, K., Lynds, C.R. and Hartwick, F.D.A., 1978, Ap.J., 221, 731.
Shapiro, S.L. and Marchant, A.B., 1978, Ap.J., 225, 603.
Silk, J. and Arons, J., 1975, Ap.J. Lett., 200, L131.
Wyller, A.A., 1970, Ap.J. 160, 443.
Young, P.J., 1977a, Ap.J., 215, 36.
Young, P.J., 1977b, Ap.J., 217, 287.
Young, P.J., Westphal, J.A., Kristian, J., Wilson, C.P. and Landauer, F.P., 1978, Ap.J., 221, 721.

B.E.J. PAGEL : M31 also has a central brightness spike detected by STRATOSCOPE several years ago and it would be interesting to measure the central velocity dispersion with high spatial resolution. In this case the velocity dispersion is considerably smaller than in M87 and so one needs high resolution and therefore has to work in the u.v. I do not know how easy this will be. What is the velocity dispersion in the globular clusters?

A. WYLLER : Certainly, up till the 1 arcsec diameter of the nucleus, it should exceed 100 km/sec. But inside there you may have, according to the theoretical models, factors of 2 or 3.

NORMAL GALAXIES

THE MAGELLANIC CLOUDS

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INTRODUCTION

At the ESO symposium on the Magellanic Clouds in Santiago de Chile in March, 1969 (Muller 1971), part of the discussion concerned the possibilities that would exist when the second phase of the ESO construction programme was completed and the 3.6 m telescope was available for observations. Thus professor Strömgren discussed the applications of the uvby and Hβ photometry to the following problems in the Clouds:

1) The determination of ages of main- sequence stars of the spectral range B2 - B9 (-2.5 — M_V — $+ 0.5$; 16 — V — 20).
2) The determination of the chemical composition of these stars by locating the ZAMS in the [u - b] - β diagram.
3) The determination of metal contents of individual main sequence early F stars from the m_1 index (F0 - F5 : $+2.7$ — M_V — $+ 3.6$; 21.3 — V — 22.7).

The first two problems may be solved with the 3.6 m telescope: With a band width of about 200 Å the observations of a star of $V = 20$ with the 3.6 m telescope would result in a photocurrent amounting to about 20 photoelectrons per second. With a reasonable integration time, of 15 to 20 min, a photoelectric accuracy of 1 per cent and better would be achieved.

The third problem may not be economically attempted with the 3.6 m telescope, but is obviously within easy reach of the Space Telescope; its magnitude ranges (visual light) are + 3 to + 29 for the Wide Field Camera (WFC) and + 21 to + 29 for the Faint Object Camera (FOC) with their Image Photon Counting Systems (Longair 1979).

We are today about as close to the launching of the Space Telescope (ST) as ESO was, or believed it was, in 1969 to putting the 3.6 m telescope into action. It is then reasonable to plan the use of the ST for Magellanic Clouds investigations in the same way as plans were made for the 3.6 m telescope in 1969.

Many of the research programmes that one may foresee for the Magellanic Clouds with the aid of the Space Telescope (ST) are of a similar nature to those that may be planned for objects in the Galaxy. To this kind of programmes belongs for instance the analysis of UV spectra of the brightest stars in the Clouds, the OB supergiants, with the aid of the high resolution spectrograph. Others of this kind are easily found, for instance, among the specimen programmes listed by Longair (1979) for each of the planned scientific instruments. Looked upon in this way the Clouds have the disadvantage of being more than 50 kpc away, whereas the galactic objects of interest may have an average distance of possibly one kiloparsec. Expressed in magnitudes, and using the standard distance moduli of 18.6 for the LMC and 19.1 for the SMC, this difference may be less than 8 mag; the interstellar extinction in the galactic plane is certainly not less than A_V = 1 mag in most directions at that distance. With the large dynamic range of the instruments on the ST, all the known counterparts in the Clouds to galactic objects are available for investigations with the ST, others (white dwarfs) may never be observed there.

The Magellanic Clouds continue, of course, to have the advantage of offering us objects of all kinds at almost the same distance (a difference in m - M of 0.1 mag at the distance of the Clouds corresponds to a difference in distance of about 2.5 - 3 kpc), and at a distance that is not too large. Moreover, their evolutionary histories differ, and none is very similar to that of our Galaxy. In addition, they have, probably with the aid of our Galaxy, become strongly disturbed and produced the Magellanic Stream, the content of which is not very well known yet. It may consist only of hydrogen clouds, it may contain stars, globular clusters and even dwarf galaxies. In any case, the detailed studies that we expect to see carried out with the ST of the various populations and individual objects in the Clouds should contribute enormously to our understanding of the formation and evolution of stars and galaxies, perhaps more so than any other investigation of nearby or more remote objects.

In the following I will concentrate on those classes of objects in the Clouds which because of their faintness have hardly been touched upon previously and on a few problems particularly suited for the instrumentation of the ST.

THE FIELD STARS

The most obvious and the most appealing problem to many of us is the extension of the luminosity function in the Clouds to very faint stars. We will then be observing those faint objects which until now have at most been noticed as a disturbing background. It will certainly not be necessary to attempt to go all the way to the 29th magnitude immediately in sheer enthusiasm of being able to do so: a mere extension to V = 25 will take us below the turn-off point of the globular clusters in the Clouds, and it would give us the fundamental information about the main sequence field stars in the Clouds that we need so badly today.

It is important to select the high priority fields for the investigation of the luminosity function with great care. Both Clouds cover immense areas in the sky in relation to the fields of the ST cameras: The SMC has a diameter of at least 7°, the LMC the double or, if the halo is considered, probably of 24° (Westerlund 1974). The WFC has a maximum field of only 2.67 x 2.67 $arcmin^2$ and the FOC is limited to 11 x 11 $arcsec^2$. At the distance of the LMC 1' corresponds to 15 pc; the area covered by the WFC is then about 40 x 40 pc^2. This is less than the area covered by a small globular cluster or a small stellar association.

The sub- systems of the Clouds may perhaps still be adequately described in the way I presented them in Athens in 1972 (Westerlund 1974, Tables 4 and 5); each Cloud consisting of a Bar, a Central system and a Halo, and with the SMC having, in addition the Wing, and the LMC an extended Disc. The limiting magnitudes of the studies of these sub-systems have changed a little, naturally, but less than desired.

In the LMC two investigations of the luminosity functions of relatively faint stars in the field have recently been carried out; one, by Hardy (1977, 1978a, 1978b), deals with a number of small regions near the Bar; the other, by Butcher (1977) deals with a small area about 4 degrees north of the Bar.

Hardy finds that red giant stars dominate. There are clear indications that rather metal- rich Population II giants are most common, though a spread in metallicity is likely to exist. Low- metal giants are excluded, however. Further support for a rather strong Population II is found in the appearance of a horizontal- branch like feature near the limit of the investigation (at V = 19.1 ; limit of accurate photometry is V = 19.2). Using counts and brightness measurements Hardy confirms his previous conclusion that the Central System, near the Bar, contains only very old (80 %) and very young (20 %) stars. He finds this conclusion unlikely, however, mainly because there exist in the LMC intermediate-age clusters, and he proposes that also intermediate- age stars contribute to the bright resolved giant branch. Similar conclusions have been drawn by Tifft and Snell (1971) from photometric data of individual stars in a region near the Bar.

Butcher has carried out photometry to about V = 23 mag of stars in the field referred to above. In the interval 0 — M_V — + 4 he finds a rather pure main sequence with few red giant stars. The main sequence luminosity functions of the LMC at this position and of the cylindrically averaged solar neighbourhood differ in the way that the LMC function changes its slope at M_V = + 3; this is at one magnitude brighter than the change of the solar neighbourhood function. Butcher interprets this as resulting from a difference in the history of star formation of the two galaxies. He proposes that the bulk of star formation in the LMC began about 3 - 5 x 10^9 years ago, instead of 10 x 10^9 years ago as in the Galaxy.

There is, however, no clear reason not to assume that many of the main sequence blue stars observed by Butcher are much younger than he has estimated from the break in the luminosity function at M_V = + 3, and which he identified with the turnoff point of relatively old star clusters. If Butcher's colour - magnitude diagram is compared with Hodge's for virtually the same region, but for the brighter stars, we find a blue main sequence turning off at about V=16.5 (Hodge 1961b). We may then have a very young population here, and instead of a break in the luminosity function at M_V= +3, a change in the slope of the initial mass function, IMF (cf. the young globular clusters, below).

A comparison of Butcher's and Hardy's results shows that the number of red giants brighter than V = 19 has decreased appreciably from the Bar regions to 4^o North of the Bar (from about 10 to 2 per 48 x 48 $arcsec^2$), whereas the number of blue stars appears to be the same (but is very small and uncertain). Possibly more striking is the fact that no horisontal- branch stars appear in Butcher's region. Hardy (1978b) mentions that near NGC 2209, at 6 kpc from the Bar areas, the stellar population is very similar to the one observed by Butcher. Thus, it appears as if the Bar regions are dominated by old Population II stars, whereas the outer parts of the flat disc contain mainly a younger population. It is possible that there is a general lack of an extended halo population in the LMC; maybe there has not yet been time for the formation of a halo by the "tumbling together" of the globular clusters in the LMC (cf. Searle 1977). The few old globular clusters in the LMC may always have been too far apart to interact. For the lack of an extensive halo speaks also the fact that the RR Lyr stars in the region of NGC 1783 have a maximum scatter in distance of ± 2.4 kpc (Graham 1977), if the width of their apparent magnitude peak is interpreted solely as a distance spread. However, the RR Lyr stars in and near the globular cluster NGC 1841 may indicate that an extended halo exists which could have resulted from tidal interactions with our Galaxy (Kinman et al. 1976). The 3 "halo" RR Lyr stars there may, however, have their origin in the cluster and thus give no information about the existence fo an extended halo.

Also relevant in this connection is the lack of ab-type RR Lyr variables in the LMC with periods shorter than 0.45 days; this indicates that a prominent old disk population with high metallicity is absent (Graham 1977). This appears to contradict Hardy's conclusions that metal-rich Population II stars are common. - For a very metal-poor component in the LMC speaks also the composition of the planetary nebula found by Webster (1977) 45 arcsec from the center of the red globular cluster NGC 1852. In it nitrogen is between 10 and 20 times under-abundant relative to the solar neighbourhood. It may, however, be representative for the halo clusters, only, and have no relation to the disc population.

In the SMC a halo population appears to exist. The region around NGC 121, which has been studied by Tifft (1963) and Graham (1975), has a strong component of old Population II; it appears clear that no star formation has occurred in that area more recently than 10^9 years ago. On the Eastern side a halo population has been detected by Brück (1978) and further discussed by Brück and Marsōglu (1978). It extends to the East as far as the Wing (10.5 kpc) which is enveloped by it. From the distribution of stars in the colour- magnitude diagram the authors conclude that the halo has two components, one consisting of Population II stars and represented by the horisontal branch, at V = 19.5 mag; the other having an age of about 2 - 6 x 10^8 years and represented by the top of a main sequence with the turnoff point at about V = 20.5. The similarities between Tifft's diagram for the region of NGC 121 (1963) and the Eastern halo are referred to by the authors; it should be noted, however, that at least in Tifft's investigation the intermediate- age halo population lies far below the limit for accurate photometry. We feel that the interpretation of the lower part of the colour- magnitude diagrams should await further and more accurate photometry, so that sub-giants and blue main sequence stars may be identified and separated.

For the investigation of the disk and halo populations in the two Clouds with the ST a number of fields should be selected in such a way that the changes in the populations from a well defined centre and out towards the peripheral regions may be determined. It may be advisable to avoid fields near typical population objects, such as globular clusters, as there will otherwise always remain some doubt about the origin of identified objects. In the LMC some preference may be given to the "fossil" arm on the East side, now defined only by a number of intermediate- age carbon stars (Westerlund et al. 1978).

One should also bear in mind that much of the photometric material to be used for the investigation of the luminosity functions of the Clouds may be collected in the serendipidy mode. It appears evident that many luminous stars as well as HII regions, planetary nebulae and supernova remnants will be investigated with for instance the high-resolution spectrograph. Simultanesously, one may expect a photometric material to be collected, though the fields may not be as efficiently chosen as desirable.

We may ask if the small fields of the WFC and the FOC will give a sufficient number of stars for a reliable analysis of the luminosity functions in the various fields. From Butcher's data it appears likely that around 5 000 LMC members will be found in each field of 2.67 x 2.67 $arcmin^2$ brighter than V = 26 mag. In the 11 x 11 $arcsec^2$ field only about 25 stars may be found. A rough estimate of the galactic foreground stars to be expected in the WFC field leads to 30- 50 stars brighter than V = 28.5 ; this is based on Schmidt's luminosity function for a cylinder perpendicular to the galactic plane (Schmidt 1959).

Further preparations for the ST studies of the luminosity functions in the Magellanic Clouds are highly desirable though evidently not easily achieved. Accurate photometry below V = 22 mag is still full of difficulties (cf. Butcher 1977); the use of the kind of detectors planned for the ST should improve the ground-based results in the future. Very deep survey plates in the near infrared and in the blue should facilitate the choice of fields for the ST observations.

CLUSTERS AND ASSOCIATIONS

For the globular clusters in both Clouds many observations exist but the resulting picture must still be described as confusing. The main reason may be found in the difficulty of carrying out accurate photometry at sufficiently faint magnitudes. For a few clusters a limiting magnitude of about V = 22.5 has been reached (cf. Walker 1972) but it appears necessary to observe down to and below the turn- off point from the main sequence, i.e. to about V = 25. Then, hopefully, most of the outstanding questions should be settled.

For stellar associations and young open clusters the investigations have normally stopped at about V = 18, though some have reached V = 20 (Westerlund 1964). The luminosity function for the bright portion of these young objects is thus known; the extension to fainter magnitudes is desirable mainly for the determination of their Initial Mass Function.

There is a large number of open clusters having the top of their main sequence at about V = 17 and fainter. They are so far known only as catalogued objects, again due to the difficulty of carrying out accurate photometry of faint stars in the crowded fields of the Clouds. It is important to study these clusters in the outer as well as in the inner parts of each Cloud for completing the picture of the evolution that may result from the study of the field stars. The existing catalogues (cf. Hodge 1975) list a sufficient number of objects in all parts of the Clouds.

Particular interest should be paid to the so called young populous clusters in the LMC (Hodge 1961a). They have been discussed recently by Freeman (cf. Freeman 1977), who prefers to call them young globular clusters. These clusters have masses in the range 1 to 5 $\times 10^4$ solar masses and ages of 1 to 10 $\times 10^7$ years. Dynamically, they are similar to the old galactic globular clusters, which is interesting as they have not had time to have relaxed in the usual way. Their luminosity profiles indicate that they have relaxed; good fits are obtained to models giving excellent representation of the old galactic globular clusters. Interesting is also that about half of these young clusters are found in the outer parts of the LMC, where the H I density is very low. As their orbits are mainly circular, they must have formed in these low- density regions. In order to understand this the Initial Mass Functions of several of these clusters must be determined at least down to solar mass stars, i.e. to V > 23. There are indications that the IMF may be flat for these clusters (IMF : $dN/d(\log M) \sim M^{-x}$; Salpeter function x = 1.35).

Freeman compares the number of the very young LMC globulars, i.e. those with 0.1 < B-V < 0.3 and V < 10, with the number of those with 0.3 < B-V < 0.6. The latter have ages between 2 - 20 $\times 10^8$ years. If the clusters' IMFs are like the local LMF the 8 very young ones would correspond to 80 intermediate-age clusters. However, only 6 are known. This may be explained by the most recent burst of star formation being very vigorous (which I am inclined to subscribe to), but it appears also likely that the cluster IMFs are very flat, at least for the mass interval 3 to 1 solar masses.

From luminosity functions for six very young globulars Freeman finds that the mass functions have slopes varying from x = 0.2 to x = 2.5 in the mass range 6 - M - 1 $M_{\odot}$. No correlation appears to exist between the x-value and the properties of the cluster or of its environment. - It appears likely that many clusters have small or even negative x-values for the lower mass ranges.

The photometry of the young clusters to faint limiting magnitudes should be accompanied by a detailed investigation of the stellar distribution radially for stars down to a mass $\sim 1 M_{\odot}$. We should then be able to understand why these clusters appear to be relaxed; with the apparent star distribution it appears to be due to mean field relaxation in connection with the collaps phase of their formation.

Ultraviolet Observations of Clusters and Associations

The Naval Research Laboratory's Far-Ultraviolet Camera/Spectrograph was operated on the lunar surface during the Apollo 16 mission 21-23 April 1972. One field of view observed included the Large Magellanic Cloud. Direct imagery was carried out in the 1050 - 1600 Å and 1250- 1600 Å ranges, and spectrographic observations were performed in the 500 - 1600 and 1050- 1600 Å bands. An Atlas of the LMC in the far-ultraviolet has been prepared (Page and Carruthers 1978). Most of the individual sources have been identified with stellar associations or emission nebulae, but there are 85 unidentified objects which may be given some priority in planning further and higher resolution imagery as well as UV spectroscopy of objects in the Clouds. A careful ground-based investigation of the regions of these unidentified objects would be an important preparation, mainly in order to eliminate possible foreground objects that could not be identified with the help of the catalogues used by Page and Carruthers. The sizes of these objects are generally larger than the field of the WFC; the resolution at the place of the LMC in the frames was, however, of the order of 4 arcmin. - It is of interest to note that in the far ultraviolet the 30 Doradus nebula is not the brightest source. This distinction is taken by the nebula surrounding S Doradus.

The spectra obtained with the Apollo 16 Spectrograph have been briefly discussed by Carruthers and Page (1977) for some of the associations crossed by the slit. It is found that the intensity distribution corresponds to stellar models of about T_e = 30 000^{o} generally in agreement with groundbased photometry. (Also the spectra are integrations over about 4 arcmin.) These results have been verified by Henry et al. (1976) with a scanning photoelectric spectrometer on Apollo 17.

THE INTERSTELLAR MEDIUM

H II regions.

An excellent summary of the most recent results has been presented by Pagel et al. (1978) in connection with an analysis of their own rather extensive new data. Their investigations confirm the previous ones: oxygen is deficient by a factor of 4 in the SMC relative to the Orion nebula, while nitrogen is deficient relative to oxygen by a factor of about 4 in both Clouds. A spatial abundance gradient is small or absent in the LMC and conspicuously absent in the SMC. Average abundances in the two Clouds are similar to those found in M 33 and M 101 in zones having the same ratio of mass of gas relative to total mass.

It is of interest to note that the application of the spatial abundance gradient for the LMC found here would tend to favour the value of a metal abundance of NGC 2209 of [Fe/H] = - 0.5, as found by Gustafsson et al. (1977) by a re-analysis of the observations by Gascoigne et al. (1976). The latter had derived a value of [Fe/H] = - 1.2 for this intermediate-age populous cluster.

The near absence of a gradient is not surprising in the LMC where the H II regions all belong to the Central System which formed in the last burst of star formation, and,thus, with its interstellar content may be expected to be very homogeneous.

Planetary nebulae.

Again, an excellent summary is available (Webster 1977). Since the planetaries are believed to form from stars of about 1 to 4 solar masses, their distribution, chemical composition and ages should contribute to our knowledge about the old and intermediate- age population in the Clouds.

In the SMC the planetaries appear to concentrate towards the Bar. They do, however, show the same unexplained, division into two groups in radial velocities as other objects. Their excitation is generally low.

In the Large Cloud the planetaries are uniformly distributed over the whole area of the LMC with no concentration to the Bar. This is clearly not a selection effect. The distribution can be understood if the planetaries in the LMC originate from slightly more massive and younger stars than the bulk of the galactic planetaries. It should be noted that their spatial distribution to some extent is connected with their degree of excitation: the high- excited planetaries are found mostly in the preceding part whereas those of lower excitation are more evenly distributed.

The oxygen abundance of the planetaries in the LMC is about half that in Orion. In the SMC their oxygen abundance is still lower, about 1/3 of that in Orion. The He content is normal in each Cloud. The nitrogen abundances are uncertain; if they are higher than in the H II regions, enrichment has occurred in the stars. The very nitrogen- rich planetaries may come from more massive stars.

In each of the Clouds the mean planetary oxygen abundance is comparable with that of the H II regions in respective galaxy. Most of the chemical enrichment took place before the progenitors of the bright planetaries were formed. If this is true for the whole mass range, then the LMC underwent a very active time in star formation and element synthesis early in its history. According to Henize and Westerlund (1963) the SMC may have the same order of planetary nebulae per unit mass as the Galaxy; the LMC should be somewhat underabundant. Recently, Jacoby (1978) has investigated four small fields in the SMC to faint limiting magnitudes. As a result of this he considers the SMC too to be underabundant in planetaries as compared with the Galaxy. It appears likely that many faint planetary nebulae could be detected in the Clouds with ground-based telescopes. Such surveys would probably also reveal many resolved ones similar to the one found by Jacoby (1978), which would be important for establishing more definitely the total number of this class of objects.

Continued spectroscopic analysis of the planetary nebulae in both Clouds is highly desirable. With a resolution of 0.1 arcsec, i.e. 0.03 pc at the distance of the SMC, many planetaries should be resolved. One may hope that the central star may be seen in some of them.

The dust.

The existence of dust in a galaxy is usually indicated by the presence of dark nebulae. Its existence is also frequently observed as colour excesses of stars; this effect may be measured in several wavelength regions, from ultraviolet to infrared. A new important feature in the interstellar absorption law is the so called 2200 Å feature, attributed to small graphite spheres.

Mapping of the dark nebulae in the Clouds has been carried out by Hodge (1972, 1974) and by van den Bergh (1974). The two investigations agree well. Both deal by necessity with the central, star rich regions where the nebulae are clearly visible.

There is a conspicuous difference in the distribution of the dimensions of the dark nebulae in the SMC and the LMC. Not only are the SMC nebulae about half as large as those in the LMC, but they have also a narrower size distribution. The 30 per cent difference in distance will diminish the difference but not eliminate it. The SMC is more similar to the solar neighbourhood in this case. The densities of the nebulae appears to vary between 0.1 mag and over 1 mag.

In the SMC there is a reasonable agreement between the distribution of dark nebulae and the H I, whereas in the LMC most of the dust clouds appear to fall outside the rich H I regions. Only around and South of 30 Doradus is a high density of H I and dust nebulae obvious.

Some areas in the Wing of the SMC appear to be completely void of blue stars (Westerlund and Glaspey 1971). It is not known if this is caused by dust. Nandy et al. (1978) have observed a small amount of reddening in the NGC 456 region (where dark clouds have been identified); this is, however, much closer to the main body of the SMC than the Wing proper, and connected to pronounced emission nebulae.

One of the great advantages of the ST is that it will allow observations, direct and spectroscopic, in the far ultraviolet. A number of uv observations of the Clouds exist already from the Apollo missions and from the IUE. Particularly interesting for studying the dust content of the Clouds are those dealing with the 2200 Å feature.

Extensive data of the region of 30 Doradus were obtained with the Netherlands Astronomical Satellite (ANS) in the ultraviolet at wavelengths 1550, 1800, 2200, 2500 and 3295 Å with bandpass widths between 100 and 200 Å. The aperture used was 2.5 x 2.5 $arcmin^2$. From the observations of 5 associations near 30 Dor Borgman et al. (1975) concluded that the extinction law in (that part of) the LMC differed from the average extinction law in the solar neighbourhood. In particular, the extinction maximum near 2200 Å appeared to be absent. In a series of papers Borgman et al. (1977, 1978) and Koornneef (1978) reanalyzed the data, combining them with ground-based uvby photometry for a study of the general problem of interstellar extinction and stellar populations in the 30 Doradus region. Their results supported the previous conclusion of a deficiency in the absorption at 2200 Å of about a factor of 3 (on a logarithmic scale). However, Borgman (1978) has now derived ultraviolet intrinsic colours and absolute magnitudes of luminous early -type stars and has found that the anomalous behaviour of the UV extinction curve in the 2200 Å region in the 30 Doradus area may be explained as caused by the saturation of the ultraviolet colours to small apparent colour excesses, causing an apparent lowering of the 2200 Å feature, when the star cluster is embedded in dust. The extinction law may thus be the normal galactic one.

Several possible interpretations remain, however, and the problem may not be solved unless individual stars are observed and their spectral distribution analyzed in detail in the ultraviolet. For this, good colour- magnitude diagrams in passbands free from emission lines of the associations in the area are needed to faint limiting magnitudes. Also, a good spectral classification must be carried out in particular so that the O stars are all identified.

Another way of investigating the interstellar reddening law in the Clouds is to apply the technique frequently used in the Galaxy of comparing the flux distributions in the spectra of a reddened and an unreddened star. This has been done by Nandy and Morgan (1978) for two LMC stars between 1150 and 3200 Å, using IUE observations. The reddened B3I star Sk-69-108 is compared with the unreddened B0I star Sk-67-108 and a rather wide excess feature, extending from about 2 500 Å to 1 800 Å, is found in agreement with results for galactic objects.

Clearly, an accurate determination of the shape of the UV extinction curves in the LMC and in the SMC is important for our understanding of the interstellar medium in these galaxies. It should be done for individual objects over large parts of the Clouds.

UV observations of the SMC exist also already (Nandy et al. 1978). From absolute surface-brightness measurements in three wavebands centered on 1550, 2350 and 2740 Å with the Sky Survey Telescope (S2/68) in the TD-1 satellite they determined the colours ($m_{1550} - m_{2740}$) and ($m_{1550} - m_{2350}$) for six regions in the SMC. They concluded that there is a small amount of reddening in the observed part of the Wing (NGC 456-465) and that the ultraviolet extinction law in the SMC is similar to the galactic one.

By mapping the SMC in each of four wavebands centered on 1550, 1950, 2350 and 2740 Å they also determined the integrated magnitudes of the SMC. For an area of 12 deg^2 it is 2.47 mag at 2740 Å and 1.76 mag at 1550 Å. The integrated colours correspond to a galactic main-sequence B9 star. In the northern part of the Bar the spectral type is B6. Clearly, the ST will give more detailed information about the SMC stellar population as seen in ultraviolet light.

In a further investigation of the Wing of the SMC, at R.A. 2^h0^m, Dec.$-74\overset{\circ}{.}5$, Morgan and Nandy (1978) found the colours, integrated over the area (viewing slot is 12'x 17') to be similar to those of a galactic B9 - A0 star. The ultraviolet intensities are consistent with those predicted by visual star counts. The results are, however, rather uncertain due to a number of factors. Again observations of individual stars, spectroscopy or narrow- to intermediate -band filter imagery are desirable to determine the effects of the three components, the one, graphite, causing the peak at 2200 Å and those responsible for the absorption at visible and ultraviolet wavelengths.

Nandy et al. (1979) have carried out similar observations for regions around 30 Doradus and Henize 144 in the LMC, and for a comparison region in the SMC. Some of their assumptions appear uncertain, but we give nevertheless their conclusions:
(1) The observed ultraviolet colours for the region around 30 Doradus and Henize 144 are similar to those of a galactic main sequence B9 star.
(2) The apparent extinction laws for these regions using the observed luminosity function and a comparison region in the SMC are the same within the observational

errors.

(3) By considering a simple dust model it is shown that within the observational errors the interstellar extinction law for the two LMC regions at 2740, 2350, 1950 and 1550 Å is similar to that in our Galaxy.

It has been possible here to touch briefly only on a few of the fields of research where the Space Telescope may be expected to contribute heavily to solving the riddles of the Magellanic Clouds. I wish to finish by mentioning an important area, that of proper motions, which has so far been used only for eliminating foreground stars (Woolley 1963). Macchetto and Laurance (1977) have pointed out that at the distance of the Magellanic Clouds transverse velocities of about 50 km/sec will be measurable. The geometrical distances to the Clouds may be determined with a 10 per cent accuracy with the aid of the Faint Object Camera.

REFERENCES

Borgman,J.: 1978, Astron. Astrophys. 69, 245.

Borgman,J., van Duinen,R.J., Koornneef,J.: 1975, Astron. Astrophys. 40, 461.

Borgman.J., Danks,A.C.: 1977, Astron. Astrophys. 54, 41.

Borgman.J., Danks,A.C., Hartsuiker,J.W.: 1978, Astron. Astrophys. 69, 309.

Brück,M.T.: 1978, Astron. Astrophys. 68, 181.

Brück,M.T., Marşöglu,A.: 1978, Astron. Astrophys. 68, 193.

Butcher, H.: 1977, Astrophys. J. 216, 372.

Carruthers,G.R., Page,Th.: 1977, Astrophys. J. 211, 728.

Freeman,K.C.: 1977, The Evolution of Galaxies and Stellar Populations, p. 133, Eds. B.M.Tinsley and R.B.Larson, Yale Univ.Obs.

Gascoigne,S.C.B., Norris,J., Bessell,M.S., Hyland,A.R., Visvanathan.N.: 1976, Astrophys. J. 209, L 25.

Graham.J.A.: 1975, Publ. Astron. Soc. Pacific 87, 641.

Graham,J.A.: 1977, Publ. Astron. Soc. Pacific 89, 425.

Gustafsson,B., Bell,R.A., Hejlesen,R.M.: 1977, Astrophys. J. 216, L 7.

Hardy,E.: 1977, Astrophys. J. 211, 718.

Hardy,E.: 1978a, Publ.Astron.Soc. Pacific 90, 132.

Hardy,E.: 1978b, Astrophys. J. 223, 98.

Henize,K.G., Westerlund,B.E.: 1963, Astrophys. J. 137, 747.

Henry,R.C., Feldman,P.D., Fastie,W.G.: 1976, Astron. Astrophys. 53, 317.

Hodge,P.W.: 1961a, Astrophys. J. 133, 413.

Hodge,P.W.: 1961b, Astrophys. J. Suppl. Ser. 6, 235.

Hodge,P.W.: 1972, Publ. Astron. Soc. Pacific 84, 365.

Hodge,P.W.: 1974, Publ. Astron. Soc. Pacific 86, 263.

Hodge,P.W.: 1975, Irish Astron. J. 12, 77.

Jacoby,G.H.: 1978, Astrophys. J. 226, 540.

Kinman,T.D., Stryker,L.L., Hesser,J.E.: 1976, Publ. Astron. Soc. Pacific 88, 393.

Koornneef,J.: 1978, Astron. Astrophys. 64, 179.

Longair,M.: 1979, Q.J.R. Astron. Soc. in press.

Macchetto.F., Laurance,R.J.: 1977, ESA SN-126, The faint object camera, European Space Agency.

Morgan,D.H., Nandy,K.: 1978, Astron. Astrophys. 70, 785.

Muller,A.B. (ed.): 1971, The Magellanic Clouds, D.Reidel Publ. Co., Dordrecht.

Nandy,K., Morgan,D.H.: 1978, Nature 276, 478.

Nandy,K., Morgan.D.H., Carnochan,D.J.: 1978, Mon. Not. R. Astron. Soc. 184, 631.

Nandy,K., Morgan,D.H., Carnochan,D.J.: 1979, Mon.Not.R. Astron. Soc. in press.

Page,Th., Carruthers,G.R.: 1978, S201 Far- Ultraviolet Atlas of the Large Magellanic Cloud, Naval Research Lab.,Washington.

Pagel,B.E., Edmunds,M.G., Fosbury,R.A.E., Webster,B.L.: 1978, Mon.Not.R.Astron. Soc. 184, 569.

Schmidt,M.: 1959, Astrophys. J. 129, 243.

Searle,L.: 1977, The Evolution of Galaxies and Stellar Populations, p. 219, Eds. B.M. Tinsley and R.B. Larson, Yale Univ. Obs.

Tifft,W.G.: 1963, Mon.Not.R.Astron.Soc. 125, 199.

Tifft,W.G., Snell,Ch.M.: 1971, Mon.Not.R.Astron.Soc. 151, 365.

Van den Bergh,S.: 1974, Astrophys. J. 193, 63.

Walker,M.F.: 1972, Mon.Not.R.Astron. Soc. 156, 459.

Webster,B.L.: 1977, Publ. Astron. Soc. Pacific 88, 669.

Webster,B.L.: 1978, IAU Symp.No.76, Planetary Nebulae, p.11, Ed. Y.Terzian, D. Reidel Publ. Co., Dordrecht.

Westerlund,B.E.: 1961, Uppsala Astron. Obs. Ann. 5, No. 2.

Westerlund,B.E.: 1964, Mon. Not. R. Astron. Soc. 127, 429.

Westerlund,B.E.: 1974, Proc. First Europ. Astron. Meeting 3, 39, Eds. B. Barbanis, J.D. Hadjidemetriou, Springer-Verlag, Berlin.

Westerlund,B.E., Glaspey,J.: 1971, Astron. Astrophys. 10, 1.

Westerlund,B.E., Olander,N., Richer,H.B., Crabtree,D.R.: 1978, Astron. Astrophys. Suppl. Ser. 31, 61.

Woolley,R.v.d.R.: 1963, R.Obs. Bull. No. 66.

R.D. CANNON : It is very important to think hard about the calibration of photometric data on star systems in the Magellanic Clouds, so that the data can be compared with standard results on Galactic star clusters. It is not sufficient simply to be able to detect very faint stars, as is shown by the surprisingly slow progress of Magellanic Cloud studies since the commissioning of the new large optical telescopes in the south.

B.E. WESTERLUND : I agree completely. However, I think that we should also consider using the detectors that are planned for the ST also on the ground based telescopes. In this way, the calibration to faint limiting magnitudes may be achieved more easily.

H. VAN WOERDEN : Why do you think the RR Lyr stars in LMC are in the disk? A scatter of $\pm$ 0.1 mag in the RR Lyrae stars could be caused by a scatter of $\pm$ 5 per cent $\sim\pm 3$ kpc in distance. Would that not be reasonable for a LMC halo?

B.E. WESTERLUND : The dimensions of the halo, from its extension in the plane of the sky and defined by the old globular clusters, is of the order of 20 kpc.

STAR DENSITY DISTRIBUTION IN YOUNG AND OLD GLOBULAR CLUSTERS OF THE LARGE MAGELLANIC CLOUD.

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1. Introduction

In irregular- and Sc-spiral galaxies of the Local Group we observe two types of very populous spheroidal star clusters (Thackeray 1951, quoted by Baade; Hodge 1960, 1961). The first type is called "red", because the integrated colour index $(B-V)_i$ of them is larger than 0.65, and their brightest stars occupy the red giant region of the colour magnitude diagram in their majority. This cluster type is very similar or identical to the classical globular clusters of our Galaxy. Their stars are the representatives for the archaic stellar population with ages $>10^{10}$ years. The second type of populous clusters is completely unknown in giant spiral galaxies and are predominately observed in the Magellanic Clouds (MC). Since their $(B-V)_i$ is less than 0.25, and their brightest stars are blue supergiants and -main sequence stars, they are called "blue". Their stellar content must have an age which is certainly less than 10^8 years (Wooley, 1961). In their geometrical appearance they are indistinguishable from the red globular clusters.

The dynamical evolution of stellar systems is determined by two principal time scales. The one is the relaxation time T_R, which is the equipartition time scale for the kinematic energy by stellar encounters:

$$T_R \sim 8{,}8 \cdot 10^5 \cdot N^{1/2} \cdot R^{1/2} \cdot m^{-1/2} \cdot (\log N - 0.45)^{-1} \text{ years.}$$

Here are N the total number of stars, m their average mass, and R [pc] the mean radius of the system. For a typical globular cluster with $R \sim 15$ pc and $N \sim 2 \cdot 10^5$ T_R is about $3 \cdot 10^9$ years. The other fundamental time scale is the crossing time T_{cr}, which measures the average orbital period of an individual star in the gravitational field of the system:

$$T_{cr} \sim 9{,}4 \cdot 10^7 \cdot R^{3/2} \cdot M^{-1/2} \text{ years;}$$

$M = \Sigma m_i$ is the total mass of the system. T_{cr} is about $1.2 \cdot 10^7$ years for the quoted typical globular cluster. After the elapse of a few T_{cr} the stellar system settles into a quasistationary state, which can be described by a polytropic density distribution ("isothermal star gas sphere"), and which is altered by stellar encounters on the time scale of T_R. Therefore the young (blue) globular clusters of the MC's with ages comparable to their crossing time should show a star density distribution not too much different from their original state, when their star formation took place. In contrast, the red (old) populous clusters are already well relaxed, cluster individuality is washed out, and their originally less massive (unevolved) stars should begin to form a "halo".

As a pilot program we carried out star counts of two blue (NGC 1818, NGC 2004) and two red globular clusters (NGC 1806, NGC 1846) of the Large Magellanic Cloud (LMC) on B- and V-ESO Schmidt plates, to compare the star density distribution of these types of clusters. The limiting magnitude of the plates is close to 21^m. According to the distance modulus of $18\overset{m}{.}6$ for the LMC stars down to the absolute magnitude of $M_V \leq +2\overset{m}{.}2$ are included in the counts.

2. Observations and Reductions

Since both types of globular clusters of the LMC are in the same distance and are observed under the same identical conditions on the Schmidt plates, systematic errors of the star counts are minimized for the comparison of the cluster types. Of course, mainly effected are the counts in the central parts of the clusters (for details see Geyer et al., 1979).
The star counts where carried out by a "matrix method" by using an overlying square reseau. The matrix of the star counts have been added in lines and columns which lead to the strip count functions L(x), L(y). By polynomial least square fits for L(x), L(y) and subsequent determination of their maxima the geometrical cluster centers (x_o, y_o) results from which the radial dependance of the strip count function L(r) followed. Also R, the "mean" cluster radius has been determined accordingly. It is more or less defined by that distance from cluster center where L(r) becomes statistically indistinguishable from the surrounding star field.

The spatial star density D(r) of spherical clusters is given then by the well known Plummer-von Zeipel formula:

$$D(r) = - \frac{1}{2\pi \cdot r} \cdot \frac{d\,L(r)}{dr} \qquad (1).$$

As previously mentioned the cluster density distribution can be approximated by polytropic star gas spheres. We made use of the generalized Schuster law according to ten Bruggencate (1927) and Lohmann (1964, 1972):

$$D(r) = D_o \cdot (1 + r^2)^{-n}, \; n > o \qquad (2).$$

Here are D_o the central star density and n the "polytropic index". Equation (1) and (2) give for the strip count function L(r)

$$L(r) = \frac{\pi D_o}{1-n}\left[1-(1+r^2)^{1-n}\right] + L(o);\ n>1 \qquad (3),$$

which was used to determine n from the observed L(r) by successive least square fitting. For example, in figure 1 is shown such a least square fitting for NGC 1846.

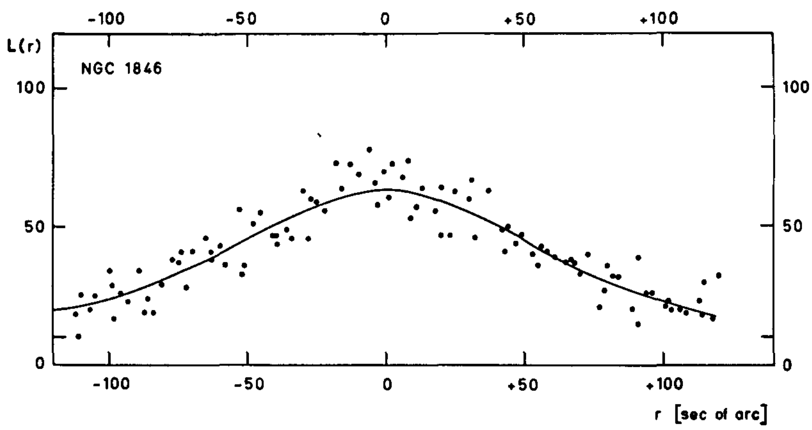

Figure 1: Observed strip count function L(r) versus distance from the cluster center for NGC 1846 from V-plate counts. The solid line is the least square fitting of equation (3) with n = 2.75 .

3. Results and Discussion

For all four globular clusters of the LMC, independently of their type, the best "polytropic index" turned out to be $n \sim 2.75$. This result confirms the quasistationary state of the clusters. Therefore these young globular clusters of the LMC must have been formed at least $>10^7$ years agoe.

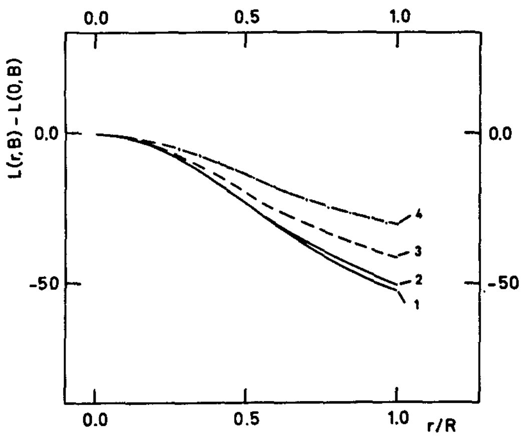

Figure 2: The relation L(r)-L(o) versus r/R for the observed clusters from B-plate counts. (1) NGC 1846; (2) NGC 1806;(3) NGC 1818;(4) NGC 2004.

Figure 2 gives a first comparison of the two types of globular clusters according equation (3). It clearly shows the identical behaviour of the red globular clusters, which seem to be well relaxed as was expected. On the other hand the blue clusters behave more or less as individuals.

Making use of the star counts on B- and V-plates we can define a "star density colour index" (SDCI) by equation (1):

$$\frac{D(r,B)-D(r,V)}{D(r,B)} = 1- \frac{dL(r,V)}{dL(r,B)} = \frac{d\left[L(r,B)-L(r,V)\right]}{dL(r,B)} \qquad (4);$$

which describes the spatial distribution of red and blue stars. Systematic counting errors which are inherent to L(r,B) and L(r,V) go in the same direction,and are once again removed according to (4).

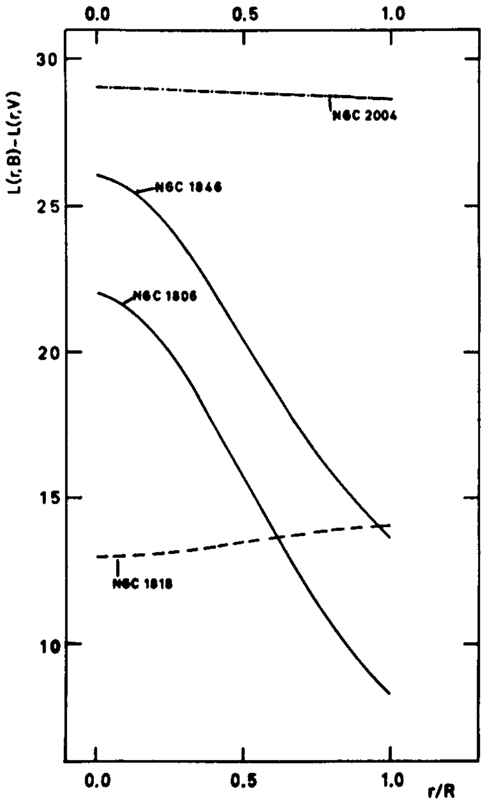

Figure 3: Relation between the difference L(r,B)-L(r,V) and r/R. Symbols as in figure 2.

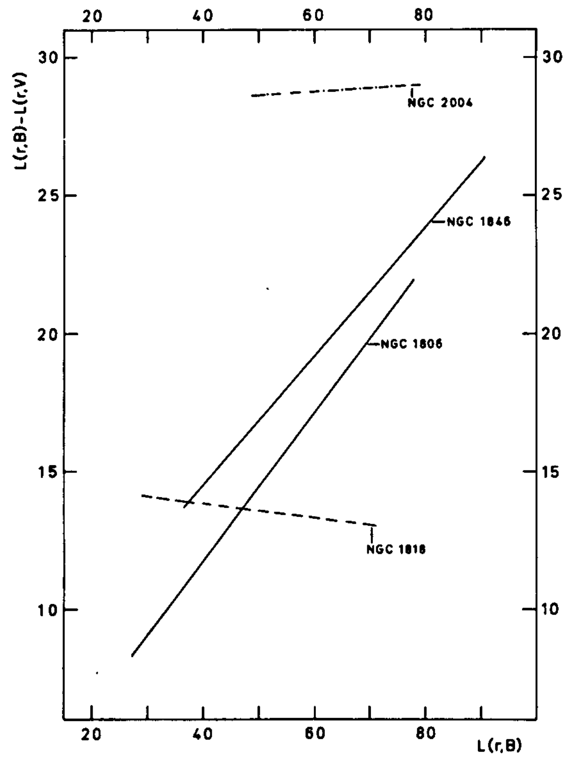

Figure 4: The relation L(r,B)-L(r,V) versus L(r,B).

In figures 3 and 4 are shown the functional dependence of L(r,B)- L(r,V) versus r/R and L(r,B) respectively. Here again the similarity for the two red clusters is striking. Figure 4 especially shows the fact that according to equation (4) and the Schuster law the relation is linear. Its slope is for the old clusters positive, whereas it is about zero for the young globular clusters.

Furtheron the radial distribution of the SCDI is indicative for the red clusters to have their blue stars more concentrated in their inner regions. On the other hand the distribution of the blue and red stars within the young clusters is more or less uniform.

Concerning the old globular clusters in the LMC the found star density distribution is similar to that in galactic globular clusters (King et al. 1968). Our finding that the blue stars are more concentrated towards the cluster center in the case of the old globular clusters in the LMC is indicating that these stars are originally more massive than their red giant and subgiant stars. Since the limiting magnitude of our investigation is restricting $M_V \leq 2^{m}.2$, these blue stars must be horizontal branch stars. As is known from stellar evolution horizontal branch stars are less massive than the stars of the first red giant branch in old globular clusters. Therefore the blue stars still "remember" dynamically their original mass.

4. Conclusion and Outlook

A next step for further investigations of the two types of globular clusters of the MC's is to derive reliable total cluster masses. This can be accomplished in a threefold way by ground based- and observations with the Space Telescope:

i) By the determination of the tidal radius of the clusters and the potential field at the clusters position in the relevant galaxy by the rotation curve. This was recently tried by Chun (1978).

ii) By the outlined star density distribution and the spatial brightness distribution, the latter of which is derived from surface photometry. Both distributions are interconnected via the luminosity function, and which yields the cluster mass by means of the mass-luminosity relation in the case of young clusters.

iii) By the determination of the velocity dispersion of the cluster stars and the application of the virial theorem.

In all cases the space telescope due to its enormous potentialities as far as resolution and limiting magnitudes are concerned certainly will give us the possibility to carry out such observations. It will render new insight for the formation and the dynamical evolution of globular clusters in galaxies.

References

Baade, W.: 1951, Publ. Obs. Univ. Michigan 10, 14.

Chun, M.S.: 1978, Astron. Journal 83, 1062.

Geyer, E.H., Hopp, U., Kiehl, M. and Witzigmann, S.: 1979 Astron. & Astrophys. in print.

Hodge, P.W.: 1960, Astrophys. Journal 131, 351.

Hodge, P.W.: 1961, Astrophys. Journal 133, 413.

King, J.R., Hedemann, E., Hodge, S.M.: 1968, Astron. Journal 73, 456.

Lohmann, W.: 1964, Zeitschr. f. Astrophys. 60, 43.

Lohmann, W.: 1972, Astron. Nachr. 294, 105.

Ten Bruggencate, P.: 1927, Sternhaufen, Springer-Verlag, Berlin, p. 38 ff.

v.d.R. Wooley, R.: 1960, Mon. Not. Roy. Astron. Soc. 120, 214.

THE STUDY OF GASEOUS NEBULAE IN GALAXIES WITH THE SPACE TELESCOPE

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Abstract

A number of problems are considered on the astrophysics of planetary nebulae, H II regions and supernova remnants and attention is given to areas where fundamental breakthroughs are expected with the Space Telescope. The relevance of observations above the atmosphere is discussed in detail for the following topics: distance scale and determination of individual masses of planetary nebulae, HR diagrams of ionizing stars in giant H II regions, giant ring nebulae in the Magellanic Clouds and their relation to energetic stellar winds from hot supergiants, ionization structure and chemical composition in supernova remnants.

INTRODUCTION

In this paper we outline a number of observing programs on gaseous nebulae in nearby galaxies for the Space Telescope. Section I deals with the planetary nebulae, section II with HII regions and related topics and section III with the supernova remnants (SNR). Ground based work on these objects is far from complete or stretched to the limits of present ground based techniques. However, there are areas where significant progress can be made only with observations with a powerful telescope which will fully exploit the advantages of the absence of the atmosphere. The programs discussed here cover a wide range of topics of quite different nature, but they have in common their relevance to the understanding of the structure, chemical composition and evolution of galaxies. Now that the initial enthusiasm for the QSO's and the multiform fauna of peculiar galaxies has somewhat faded out, astronomers realize that some of the most basic questions about the nature of the universe are investigated through a detailed study of the content of relatively nearby galaxies. Ad hoc ST observations will complement the systematic programs which will be carried out in this field with the most powerful ground based telescopes.

I. PLANETARY NEBULAE

The present knowledge on planetary nebulae in external galaxies has been summarized in Table 1 with emphasis on counts and chemical composition determinations. Systematic counts of planetary nebulae in nearby galaxies can be used to derive the relevance of disk population and to estimate the chemical enrichment of the interstellar medium due to these objects. Taking advantage of its high angular resolution, ST will complete the work carried out with ground-based telescopes in some of the galaxies of the Local Group to the fainter tail of the luminosity function of PN and will extend the identifications of PN in galaxies as far as 3 Mpc. Concerning the chemical composition, from data shown in Table 1 it is clear that differences both in helium and in the heavy element abundances are present in PN of different galaxies; in particular we notice a strong deficiency of O,N in the SMC relative to the LMC. We stress here the importance of the ST to determine the abundances of Carbon in extragalactic PN. This key element in nucleosynthesis processes has only weak permitted lines of C^+ and C^{++} in the visible, whose intensities are between 10^{-3} and 10^{-4} that of Hβ, but strong lines of C^+, C^{++} and C^{+++} in the 1200-3000 A wavelength region. For galactic planetaries, the weak lines in the visible have been measured (Torres-Peimbert and Peimbert, 1977). The same is true for the ultraviolet lines which have been observed in the brightest planetaries mainly with the IUE. For PN in external galaxies, the permitted lines of C^+ and C^{++} in the visible are expected to remain completely out of reach of any present or future ground telescope, but it will be possible to observe the strong UV lines with the ST.

We discuss now in a little more detail the importance of ST observations for problems related to the distance scale of planetary nebulae. As individual determinations of distances are available only for a few galactic PN, distance estimates of PN rest on statistical methods, either on the hypothesis of constant absolute magnitude of the nebulae (Zanstra, 1931) that essentially implies optical thickness of the nebula to the ionizing continuum of the central star and constant bolometric magnitude of the nucleus, or of constant mass of the ionized nebular shell (Minkowski and Aller, 1954; Shklowsky, 1956). Since the nuclei of PN move rapidly on the HR diagram toward the white dwarf region, the first method is unreliable if applied to PN in different evolutionary stages. The second method, which works for optically thin nebulae, is considered to provide reliable distances for a vast number of planetaries (e.g. Liller, 1978). It can be expressed by the formula:

$$d = C\,(M_n^2 \cdot \varepsilon)^{1/5}\, F(H\beta)^{-1/5}\, \phi^{-3/5} = k\, F(H\beta)^{-1/5}\, \phi^{-3/5}$$

where d is the distance, C a constant, M_n the mass of the nebula, ε the filling factor and ϕ the angular radius. Calibration of this method can be done using i) objects with individual determination of distance, ii) objects with known statistical parallaxes, iii) by assuming that the intrinsic brightness of the most luminous PN in the Magellanic Clouds and our Galaxy are the same (Seaton, 1968; Webster, 1969). Application of i) is made difficult by the small number of individual distance estimates. Presently the best distances of galactic planetary nebulae are those by Cudworth (1974) who used ii) and by Cahn and Kaler (1971) based on iii). The distances of Cudworth are larger by a factor of about 1.5. There are arguments in favour of the Cahn and Kaler distances (Liller, 1978) and of the Cudworth ones (Heap, 1978). This discrepancy implies a quite different estimate of the total number of planetaries in the local galaxy and even in the external ones with obvious consequences on the parameters which depend on this quantity. We propose to exploit the new capabilities of the ST, in particular imaging with an angular resolution of 0.1 arc sec, to determine the size, the filling factor and the flux of PN in Local Group galaxies. Table 2 shows the expected sizes of PN with linear radii 0.1 ÷ 0.6 pc, which is the range of optically thin PN in our Galaxy, when observed in nearby galaxies.

It is clear that PN cannot be resolved with ground based telescopes except for the largest ones in the MC (as confirmed by the recent work of Jacoby, 1978). With the ST Faint Object Camera and the Wide Field Camera, planetaries will be resolved in all the galaxies of the Local Group, with the complete population resolvable in the Magellanic Clouds. In these galaxies we will also observe

TABLE 2 Expected sizes of PN in nearby galaxies

Name	Type	Distance kpc	Angular Sizes arc sec
LMC	Ir I	52	0.4 ÷ 2.38
SMC	Ir I	63	0.33 ÷ 1.96
Fornax	E dwarf	170	0.12 ÷ 0.73
NGC 6822	Ir I	470	0.04 ÷ 0.26
M 31	Sb	670	0.03 ÷ 0.19

some structural details thus determining the filling factor. Because of the reduced galaxy background and higher resolving power in crowded fields, the accuracy of the F(Hβ) measurements should substantially improve relative to values from ground telescopes. Knowledge of these three quantities for a number of PN in the MC will permit the determination of individual masses of the nebular shells, a key parameter for late phases of stellar evolution and enrichment of the interstellar medium, and measure of the factor k and of its dispersion to clarify the problem of the distance scale of PN in our Galaxy.

II. H II REGIONS

There are quite a number of observational programs on H II regions to be carried out with the ST which are quite straightforward and have been mentioned since the birth of the project. Among the most important ones, we may mention the measure of diameters of H II regions at a distance 10 times larger than is now possible with the extension of the distance scale based on this method and spectro-photometric studies of H II regions in distant galaxies to widen our present knowledge of chemical composition variations. Here however we want to discuss two projects which are related to H II regions but concern also stellar and galactic evolution. The first is the determination of the HR diagram of the ionizing stars in the giant H II region NGC 604. This nebula is the brightest in the Sc galaxy M33 and in the Local Group galaxies is second only to 30 Dor in the LMC. Its flux at 1415 MHz is 3.6×10^{18} WHz^{-1}, 1/3 of 30 Dor, equal to W 51, the brightest galactic thermal source, and 10^{8} times brighter than Orion. It is a region where a high number of massive stars have been recently formed, similar to the giant H II complexes which are observed in Irregular and late Spirals and to the blue compact galaxies in the Zwicky lists (Sargent and Searle, 1972). These objects play an important role in our understanding of the chemical enrichment of galaxies as a function of their mass and H I content because they represent rather unevolved systems which go through a burst of star formation. In the models of chemical evolution of the galaxies which are built and compared with the observed abundances one of the key assumptions is the constancy with time of the initial mass function (IMF), which is usually computed from the observed star density in the solar neighbourhood and the theoretical lifetimes (Lequeux, 1979; Lequeux et al. 1979). The constancy of the IMF in the Local Group galaxies has been investigated by Lequeux (1979). No clear difference was detected but the data leave the possibility of variation from one galaxy to the other somewhat open. In particular there is a suggestion that the upper IMF might be richer in very massive stars in the MC and in M 33. A direct measurement of the magnitudes, B-V colour and possibly of the spectra of the stars associated with a giant H II region will permit the determination of the IMF free from contamination of evolved stars of the same spectral type. Lequeux (1979) points out the importance of this effect on the upper part of the IMF. The comparison of this IMF with the galactic value in the solar vicinity is important because in the two cases star formation should develop in rather different physical conditions.

The choice of NGC 604 instead of 30 Dor has some advantages. First, much work on the 30 Dor stars can be done with the telescopes of large diameter which came recently into operation in the southern hemisphere; second, the absorption in the central region of 30 Dor is rather patchy (see the photographs in Elliott et al. 1977) and on the average is 2 mag. from the comparison of the Hβ and radio continuum fluxes (Mills et al. 1978); third, 30 Dor may be a rather peculiar object (see its interpretation as the nucleus of the LMC, Schmidt-Kaler, 1975) and hence the HR diagram of the central cluster may be unusual. Fig. 1 shows a blue photograph of the core of NGC 604 obtained with a seeing of better than 1 arc sec. Conspicuous dust lanes are absent so that the bulk of the ionizing stars should be visible but for the crowding of the stellar images and the underlying nebulosity. Reddening as derived from the Balmer decrement is practically nil, but the comparison of the Hβ with the radio flux suggests an absorption of 1 mag_V (Melnick, 1979). By comparing the blue plate with V, R and Hα photographs, we have identified and numbered the brightest stars. Eye estimates of the B magnitudes were then obtained from three plates of excellent seeing quality for those stars which were not severely affected by crowding or

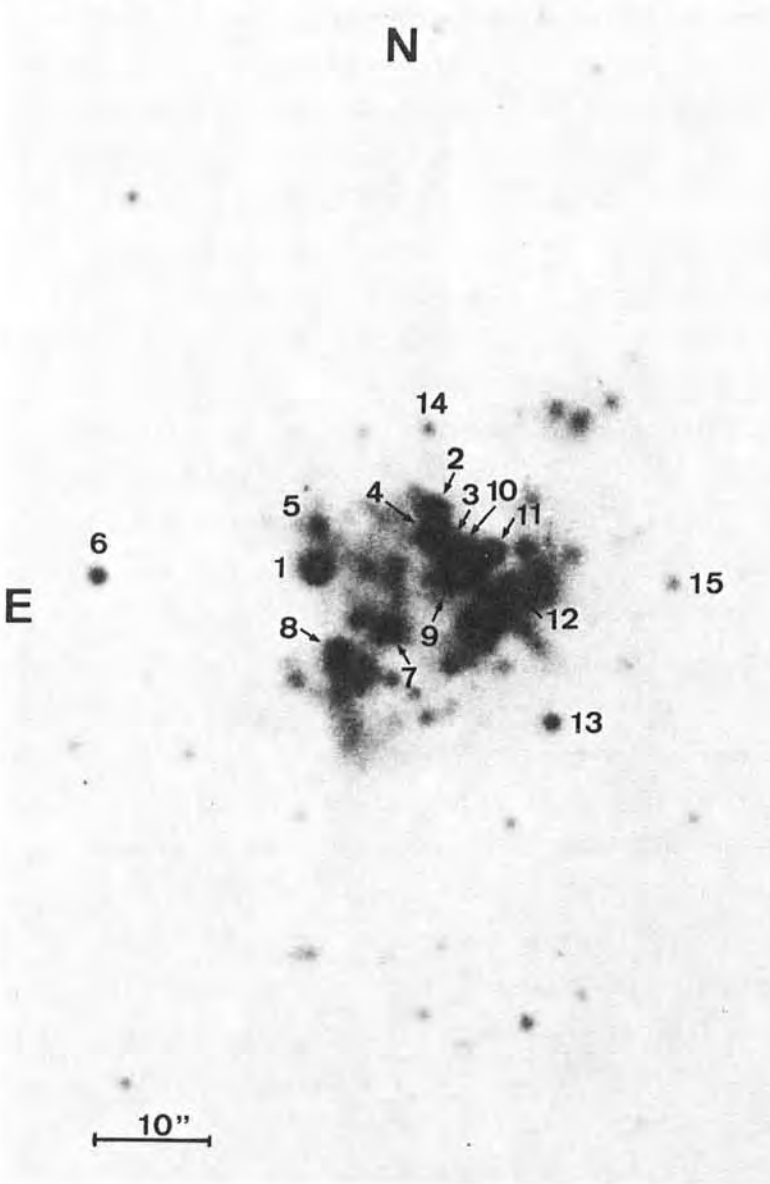

Fig. 1. Blue photograph of the central cluster in NGC 604 obtained with the Asiago 1.82 m telescope. Original scale 12 arc sec mm^{-1}. Limiting m_B = 21.

nebulosity (Benvenuti et al. 1979). The accuracy is 2-3 tenths of magnitude. Ten stars were measured with values between 16 and 19.1 m_B, which corresponds to -8.3 and -5.2 with no correction applied for extinction in the region. At present we have no information on the colours, but if, as seems likely, they are main sequence stars, at least three have spectral types earlier than O3 and masses larger than $60M_\odot$. It would be hazardous to draw any quantitative conclusion from this small sample of data. It is clear however that it would be possible to define the upper part of the IMF, a region which is poorly populated in the solar neighbourhood sample. With the ST cameras providing an angular resolution of 0.1 arc sec, the associated nebulosity would become 5 magnitudes fainter and the crowding of the stellar images much reduced. It should be possible to measure stars as faint as 23 mag, which is much brighter than ST capabilities but takes into account the presence of the background. With this value, it should be possible to derive the IMF to $M = 5\ M_\odot$. Note that one exposure of the Wide Field Camera would cover the whole region including reference stars which could be measured from the ground. 4 exposures with the FOC would be needed for the central cluster. The spectrographic option of the FOC would be very useful to obtain simultaneously spectra of several stars in the cluster.

A second project is centered on the nature of ring H II regions and on the associated O,B stars. The presence of giant ring nebulae with diameters from 50 to 500 parsecs was firstly remarked by Gum and de Vaucouleurs (1953). More recently they were observed by Georgelin (1971) in the Galaxy, by Davies et al. (1976) in the LMC and by Boulesteix et al. (1975) and Courtes (1977) in M33 and M 31. They seem to be a common feature of Irregulars and late Spirals. Two hypotheses are suggested for their origin: they could be the old remnants of SN explosions or the product of energetic stellar winds. Lasker (1977) discusses a few objects in the LMC and concludes that no discrimination is possible at this stage. Elliott et al. (1978) study the case of N 44 in the LMC and find some indication of the action of a stellar wind. If these regions are the result of mass loss from luminous main sequence stars in the interstellar medium, is their presence in late type galaxies an indication that the process is more effective for the stars in those galaxies? If we refer now to the case of the LMC, the theory seems to contradict this suggestion. The radiation pressure mechanism, which very likely is responsible for the stellar winds, depends on the abundance of heavy ions in the atmosphere, i.e. on the chemical composition. Several lines of evidence suggest that the Magellanic Clouds have a lower metal content than the Galaxy, so that, if differences should be found between stellar winds in galactic and MC supergiants, they should go in the direction of lower mass loss rate in the MC stars. On the other hand the Magellanic Clouds could be unusually rich in the upper part of the IMF where the mass loss process is more effective. Benvenuti et al. (1978) plan to observe O stars in the MC with the IUE to attempt a determination of the mass loss rate which could be compared with the values observed in hot stars in the Galaxy. A different mass loss rate would be relevant not only to the problem of the origin of the ring H II regions. It would modify the evolutionary tracks of the stars in the HR diagram and affect the other parameters which goes into the chemical evolution of the galaxy as a whole (Chiosi, in preparation). The OB stars in the Clouds can be observed only with the low dispersion camera of the IUE so that only a preliminary comparison with galactic observations will be possible. The High Resolution Spectrograph on the ST will provide the wavelength resolution required to determine the mass loss rates, thus giving a complete answer to the problems outlined here.

III. SUPERNOVA REMNANTS

Optical nebulosities associated with SNR are originated by cooling of matter which had been collisionally heated by a blast wave from the supernova explosion. After a few thousand years, we are observing essentially swept up interstellar medium, even if it cannot be excluded that fragments of the original explosion have maintained their identity also at a late stage. In the recent past, a considerable effort has been made to produce models for the physical processes in the cooling region in the approximation of a plane parallel shock (Cox, 1972; Dopita, 1976; Raymond, 1979; Shull and McKee, 1979). The models produce a set of emission line intensities which are a function of the expansion velocity, of the pre-shock density, of the transverse magnetic field and of the abundances of the main cooling elements. A best fit procedure with the observations permits the choice of a set of the parameters. While it is true that the plane parallel shock approximation is a rough simplification of the true physical conditions, the fit with the observations is convincing and determination of chemical abundances from SNR can provide a useful check of the abundances derived in H II regions. The first observations of UV spectra of filaments in the Cygnus Loop with the IUE (Benvenuti et al. 1979) show that the models were right in predicting that lines in the 1200-3000 A region would be a major source of cooling. The relative intensities point to an expansion velocity which agrees with the value obtained from the analysis of the visual spectrum.

The high angular resolution of the ST camera should make possible a test on the stratification predicted by the shock models. The swept up matter is collisionally ionized and reaches the maximum temperature immediately behind the shock surface. As the expansion goes on, the hot matter left behind cools down with different ions recombining at different distances from the front of the shock. Figure 2 shows the computed structure for the ions of Oxygen for a model by Raymond (1979). By observations of a sharp and isolated filament of a SNR in the light of emission lines from different ions of the same element, we should be able to measure the displacement of the different ions which is a function of the various parameters of the shock. Figure 2 shows that the separation between O^{++} and O^{o}, which give origin to the strong forbidden lines at 5007 and 6300 A respectively, could be resolved at the distance of the Cygnus Loop (1 kpc). Computations for other ions, e.g. those of Carbon, are much needed. Details on the proposed observations are given by Barbieri et al. (1978).

Until recently, SNR were known only in the Galaxy and in the Magellanic Clouds. Identifications were then obtained in M 33 (D'Odorico et al. 1978, Sabbadin 1978). D'Odorico (1978) showed that it will be possible to identify SNR in all the Local Group galaxies and has also reviewed the impact of SNR identification on SN statistics and on chemical composition determinations. Spectra of three SNR in M 33 have been obtained by Danziger et al. (1979). Spectrophotometry of a larger sample of remnants in that galaxy by Dopita et al. (1979) has shown that the abundances based on SNR substantially agree with the determinations from H II regions.

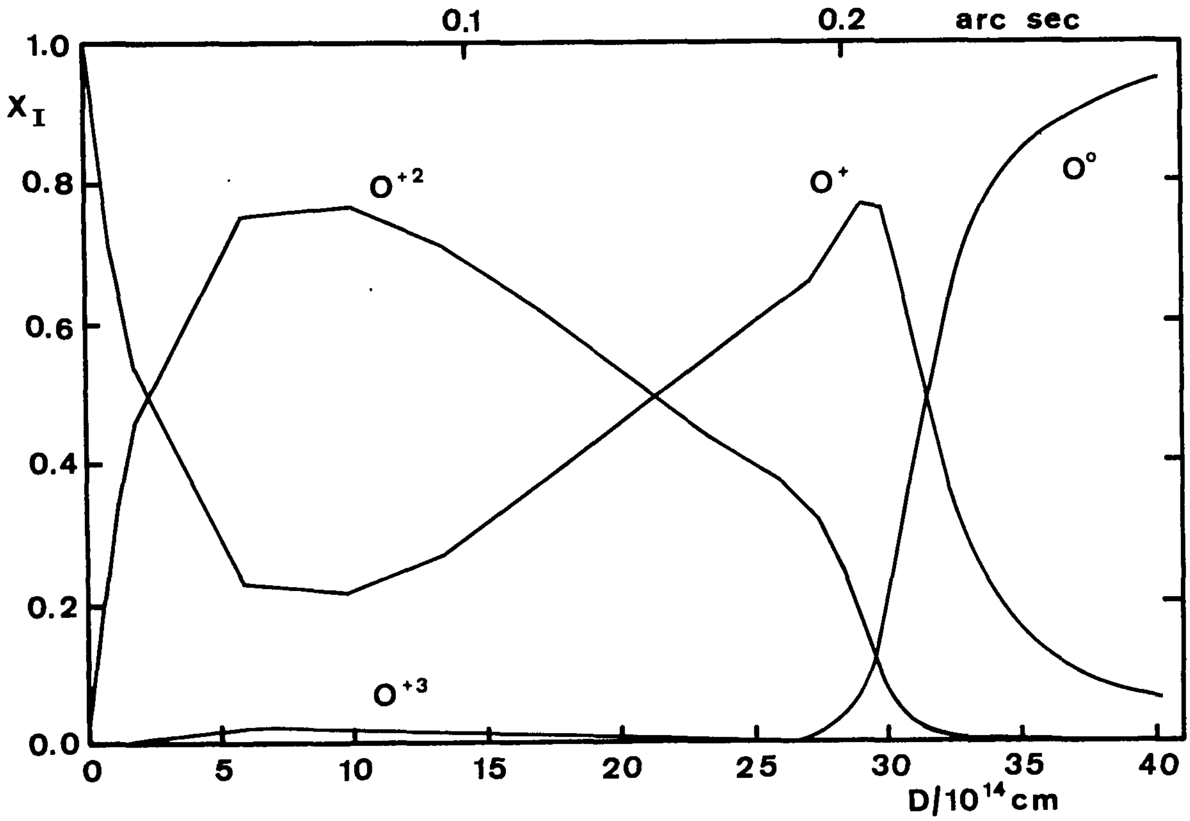

Fig. 2. Ionization fractions of Oxyger for model D of Raymond (1979) as a function of distance from the shock front. The computations have assumed a velocity of the shock of 81.5 km/sec, a pre-shock density of 10 cm^{-3} and cosmic abundances. The angular scale on the x-axis corresponds to a distance of 1 kpc (Cygnus Loop).

Moreover, the gradients in chemical composition across the galaxies which were derived from the H II regions, are proved to be real from the SNR observations which cannot be affected by a change in the spectra of the ionizing stars or dust content as the H II. The use of the ST will bring significant progress in at least two areas where ground observations cannot help: i) The nitrogen, sulphur and oxygen gradients across M 33 are known both from the H II regions and the SNR. As discussed in section 1, Carbon has only weak permitted lines in the visual. The UV lines require high temperatures to be excited and are not strong in H II regions. UV observations of PN and SNR represent the best way to estimate Carbon abundance (and gradient in the case of M 33) in external galaxies. These observations are well within the capability of the ST Faint

Object Spectrograph. ii) With the angular resolution of the Wide Field Camera it will be possible to complete the identifications in the crowded areas of Local Group galaxies and extend the work to galaxies as far as M 101. SNR could be identified with photographs taken in the light of C IV 1550 A or CIII| 1909 A and compared with continuum pictures. In the UV, H II regions have a dust scattered stellar spectrum and would show only in the continuum photographs. This criterion should be more effective than the comparison Hα/ |S II| which has been used so far with ground-based observations.

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REFERENCES

Barbieri C., Benvenuti P. and D'Odorico S. 1978, Trial observing proposal for the FOC, ESA, IST

Benvenuti P., Chiosi C., D'Odorico S. and Macchetto F. 1978, Proposal to ESA for IUE observations

Benvenuti P., D'Odorico S. and Dopita M.A. 1979, Nature 277,

Benvenuti P., D'Odorico S. and Dumontel M. 1979, preprint

Boulesteix J., Courtes G., Laval A., Monnet G. and Petit H. 1975 , ESO/SRC/CERN Conference on Programmes for Large Telescopes, A. Reiz edit. p.221

Cahn J.H. and Wyatt S.P., 1978, IAU Symp. No.76, Planetary Nebulae, Reidel Publ., Dordrecht, p.19.

Cahn, J.H. and Wyatt S.P., 1976, Astrophys.J. 210, 508.

Courtes, G., 1977, in Topics in Interstellar Matter, Reidel Publ., Dordrecht,209

Cox D.P., 1972, Astrophys.J. 178,143.

Cudworth K.M., 1974, Astrophys.J. 79,1384.

Danziger I.J., Dopita M.A., Hawarden T.G., Webster B.L., 1978, Astrophys.J. 220, 458.

Danziger I.J., Murdin P.G., Clark D.H. and D'Odorico S., 1979, M.N.R.A.S,in press

Davies R.D., Elliott K.H. and Meaburn J., 1976, Mem. Royal Astron. Soc., 81, 89.

D'Odorico S., Benvenuti P. and Sabbadin F., 1978, Astron. Astrophys. 63,63.

D'Odorico S., 1978, Mem. S.A.It. 49, 485.

Dopita M.A., 1976, Astrophys.J. 204, 395.

Dopita M.A., D'Odorico S. and Benvenuti P., 1979, in preparation.

Elliott K.H., Goudis C., Meaburn J. and Tebbutt N.J., 1977, Astron.Astrophys.55, 187.

Elliott K.H., Goudis C., Meaburn J. and Pickington J., 1978, Astrophys. and Space Science 55, 475.

Ford H.C., 1978, IAU Symp. No.76, Planetary Nebulae, Reidel Publ., Dordrecht,p.19.

Georgelin Y.P., 1971, Astron. Astrophys. 11,414.

Gum C.S. and de Vaucouleurs G., 1953, Obs. 73,152.

Jacoby G.H., 1978, Astrophys.J. 226,540.

Jenner D.C., Ford H.C., Jacoby G.H., 1979, Astrophys.J. 227,391.

Kaler J.B., 1978, Astrophys.J. 226,947.

Lambert D.L., 1978, M.N.R.A.S. 182,249.

Lasker B.M., 1977, Astrophys.J. 212,390.

Lequeux J., 1979, Astron. Astrophys. 71,1.

Lequeux J., 1979, Astron. Astrophys., submitted.

Lequeux J., Peimbert M., Rayo J.F., Serrano A. and Torres-Peimbert S., 1979, Astron.Astrophys., submitted.

Liller W., 1978, IAU Symp. No.26, Planetary Nebulae, Reidel Publ., Dordrecht,p.35.

Melnick J., 1979, Astron. Astrophys., in press.

Mills B.Y., Turtle A.J., Watkinson A., 1978, M.N.R.A.S. 185,263.

Minkowski R. and Aller L.H., 1954, Astrophys.J. 120,261.

Peimbert M. and Torres-Peimbert S., 1977, M.N.R.A.S. 179,217.

Raymond J.C., Astrophys.J. Suppl. Series, 1979 in press

Sabbadin F., 1978, preprint.

Sanduleak N., Mc Connell D.J., Davis Philip A.G., IAU Symp. No.76, page 64

Schmidt-Kaler, T., 1975, Proc. Symp. Mittelberg, HII regions and related topics, Springer Verlag, 484.

Searle L., Sargent W.L.W., 1972, Astrophys.J. 73,25.

Seaton M.J., 1968, Astrophys. Letters 2,55.

Shull M. and McKee C.K., 1979, Astrophys.J., in press.

Smith H.E., 1975, Astrophys.J. 199,205.

Shklowsky I.S., 1956, Soviet Astron. 33,222.

Torres-Peimbert S. and Peimbert M., 1977, Rev. Mex. Astron. Astrophys. 2,181.

Webster B.L., 1969, M.N.R.A.S. 143,79.

Webster B.L., 1978, IAU Symp. No.26, Planetary Nebulae, Reidel Publ., Dordrecht, p.11.

Zanstra H., 1931, Zs.f.A. 2,329.

TABLE 1

Planetary Nebulae in Galaxies

Galaxy	No. of discovered PN (1)	Estimated Population (1)			Chemical Abundances				Sources of the abundances
		Based on Cudworth (1974) distance scale		Based on Seaton (1968) scale	He	$Ox10^4$	$Nx10^5$	Number	
SMC	38	-	100	-	0.12	2.1	1.2	4	(2)
LMC	100	-	400	-	0.09	3.5	3.5	10	(2)
NGC 185	5	-		-	0.24	0.79	12.	1	(1)
NGC 205	22	57		220	-	-	-	-	-
NGC 147	5	-		-	-	-	-	-	-
M 31	307	7000		27000	-	-	-	-	-
M 32	21	88		340	0.10	-	-	1	(3)
Fornax	1	-		-	0.12	3.2	2.6	1	(4)
Galactic PN	1237	10000		38000	0.11	6.9	25.±20	-	(5)
Orion	-	-		-	0.10	5.6	5.8	-	(6)
Sun	-	-		-	-	8.3	9.8	-	(7)

NOTES:

1) The number of discovered PN are from Ford (1978) except for data relative to MC, from Sanduleak et al. (1978) and Jacoby (1978). Populations in NGC 205 and M 32 are from Ford (1978), in M 31 and the Galaxy from Cahn and Wyatt (1978, 1976), in the MC (independent of adopted scale) from Jacoby (1978)

2) Webster (1978). Objects of high excitation, strong [NII], that have He/H = 0.14, have been omitted

3) Jenner et al. (1978) 4) Danziger et al. (1978)

5) Kaler (1978) for helium (79PN) and Torres-Peimbert and Peimbert (1977) oxygen (29 PN) and nitrogen (21 PN)

6) Peimbert and Torres-Peimbert (1977). 7) Lambert (1978)

ST AND THE CHEMICAL EVOLUTION OF GALAXIES

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SUMMARY

Observations relevant to this topic include both abundances in different sorts of objects and data relating to the input assumptions underlying galactic evolutionary models such as stellar birth and death rates as a function of time and the initial mass function. Accordingly the proposals made here include the following: detailed study of the stellar population in the Magellanic Clouds near the oldest turnoff point from the main sequence, ultra-violet colorimetry of extragalactic globular clusters, spectra of galactic nuclei, interstellar absorption line spectroscopy in the disks and outer parts of spiral and irregular galaxies, surveys and spectroscopy of extragalactic planetary nebulae and supernova remnants, and studies of the stellar population in giant H II regions.

1. INTRODUCTION

Chemical evolution of galaxies is part of the wider problem of evolution of galaxies in general, so that there are few types of astronomical observation that are not relevant to it in some way. Accordingly, there will be considerable overlap between the present paper and others in this Workshop, but the present paper will concentrate on some particular observations that have occurred to me as being potentially useful ways to exploit the Space Telescope so as to advance our understanding of the origin and distribution of the elements.

The types of observation that are relevant to our problem include the following:-

1. Abundance peculiarities in evolved stars and their ejecta (e.g. planetary nebulae, novae, young supernova remnants) that may be feeding elements into the interstellar medium (ISM).

2. The present composition of the ISM in different parts of different galaxies as deduced from young stars, H II regions, mature supernova remnants and interstellar absorption lines.

3. The composition of the ISM in the past as deduced from older stars after allowing for the effects of their own evolution.

4. Data bearing on the various input assumptions of galactic chemical evolution models: advanced stages of stellar evolution, rates of star formation ($\dot{S}$), the initial mass function (IMF) and very many effects in interstellar and galactic dynamics (cf. Audouze and Tinsley 1976; Pagel 1979b).

I shall deal with these topics roughly in reverse order, but first take a brief look at the observations that one can expect to be able to carry out on objects at different distances.

2. POSSIBILITIES

Using the data supplied by the NASA Announcement of Opportunity and Longair (1979), I have made a rough assessment of the linear scales and the apparent and absolute visual magnitudes accessible to the Space Telescope at different resolving powers R in objects at different distances such as globular clusters, Magellanic clouds, M31 and the Virgo Cluster (Table 1). The basic underlying assumptions are that most of the light will be concentrated in a circle 0.2 arcsec in diameter and that the sky brightness is V = 23^m arcsec^{-2}, leading to a sky signal equivalent to one $26^m.5$ star per resolution element which can be measured to a precision of about 3 per cent in 10 hours. Judging by the luminosity function in a cylinder through the Sun at right angles to the galactic plane (Serrano 1978), this is also about the surface brightness of our Galaxy seen face-on at the Sun's radial distance, which imposes a further constraint on observations of distant galaxies, not only because of the surface brightness but also because of unwanted stars appearing in the typical resolution element; an estimate of the average number of such stars brighter than 30^m in parts of galaxies corresponding to the solar cylinder is provided in the last line of Table 1.

TABLE 1

A rough estimate of scales and absolute magnitudes accessible to the Space Telescope.

OBJECT	h,χ Per 6397 Cas A	GC	MCs Dra UMi	Fornax Leo	M31 M32 M33 6822	M 51 M101 Scl gp 5128	Virgo Cl
DIST KPC	2.4	10	60	200	700	4000	15000
m-M	12	15	19	21½	24½	28	31
"arc/pc	83	20	3.3	1	0.3	0.05	0.013
Mv							
V=15 R-10^5	3	0	-4	-6½	-9½	-13	-16
V=17 R=$2x10^4$	5	2	-2	-4½	-7½	-11	-14
V=20 R=1000	8	5	1	-1½	-4½	- 8	-11
V=22½ R=100	10½	7½	3½	1	-2	- 5½	- 8½
V=26 Brd ptm	14	11	7	4½	1½	- 2	- 5
V=29 Bare det.	17	14	10	7½	4½	1	- 2
n[$(0''.2)^2$] V ≤ 30 sol. cyl lum. fn.	$5x10^{-4}$	10^{-2}	0.1	1	3	6	3

3. HISTORY OF STAR FORMATION IN THE MAGELLANIC CLOUDS

The fundamental inputs into models for chemical evolution of galaxies include the history of past rates of star formation and the IMF. These can then be combined with a picture of the end-products of stellar evolution (Talbot and Arnett 1973; Chiosi and Caimmi 1979) to predict the degree of enrichment as a function of time and of the ratio of gas mass to total mass, and also to predict the statistical distribution of metallicities, all of which can in principle be observed, and the discrepancies then provide clues to possible departures from the assumptions made in simple models, eg Prompt Initial Enrichment, inhomogeneous collapse, inflow and outflow of gas etc.

The data on past star formation rates in our own neighbourhood are still not very satisfactory, but there is one striking fact that emerges from observation: there seems to be a definite upper limit to the ages of nearby disk stars corresponding to the age of NGC 188 (Wilson 1976), which is estimated by Demarque and McClure (1977) to be about 6 G yr. If the IMF is assumed to be smooth and invariable, then one can deduce its form by comparing the number of short-lived massive stars in the solar cylinder with the number of long-lived low-mass stars down to some lower mass limit to which observations are reasonably complete, and the data are then most readily fitted to the assumption that star formation has gone onat a fairly uniform rate since it began (Tinsley 1976; Mayor and Martinet 1977; Serrano 1978). Attempts to refine the picture further by counting giants and subgiants that have evolved from higher up the ZAMS than the lowest turnoff point (eg Neckel 1975) are hampered by inadequate precision in luminosities, but there is hope that astrometric projects such as HIPPARCOS and CARNAC will eventually provide adequate data for this type of investigation (Pagel 1979a; Connes 1979).

What happens in other galaxies? Some, like the Magellanic Clouds, are noted for their prominent young populations: OB associations, H II regions, blue globular clusters etc. (Westerlund 1970), but these do not give us the integrated effects over all of past history that are needed to test chemical evolution models. It is the "silent majority" of relatively faint stars near the oldest main-sequence turnoff point of the HR diagram that contains the information wanted for this purpose.

One interesting approach to this problem was the study of integrated colours of late-type galaxies by Searle, Sargent and Bagnuolo(1973) who adopted various reasonable IMFs and assumed different exponential decay rates for $\dot{S}$ and predicted U-B and B-V colours for Sc and Irr galaxies (cf also Larson and Tinsley 1978 and references therein). They concluded that all of their galaxies were of about the same age since star formation began, but that $\dot{S}$ had decayed at very different rates from one galaxy to another, corresponding to a range in colour from B-V = 0.4 ($\dot{S}$ = const.) to B-V = 0.9 (initial burst). On the other hand, many compact and Markarian galaxies are bluer than B-V = 0.3 and they suggested that these small systems are being caught during a sporadic fit of star formation that happens to be going on now and dominates the integrated light. The alternative that these systems are very young indeed was shown to be difficult to reconcile with the statistics of blue and red compact galaxies.

Recently Edmunds and Pagel (1978) suggested that effective ages of the stellar population in galaxies (which involve both the time when star formation began and the time-dependence of $\dot{S}$ thereafter) can be judged by looking at the abundance ratio N/O and cited the Magellanic Clouds as an example of a young system on grounds that they have a lower N/O ratio than objects in the solar neighbourhood. The same applies to some, at least, of the blue compact galaxies (Lequeux et al 1979), suggesting that they are also young, although not necessarily so extremely young as in the hypothesis dismissed above. For the Magellanic Clouds the youth hypothesis can readily be tested by using the ST, since precise photometry can be carried out down to $M_V \geq 5$, below the main sequence turnoff. Thus in the bar of the LMC, where the surface density (Pagel et al 1978) is comparable to that of the solar cylinder (ie $\sim 100 M_\odot\ pc^{-2}$), the Wide-Field Camera embraces a field of about $(50\ pc)^2$ without serious danger of overcrowding at the interesting magnitudes. I propose, therefore, that one should determine the lower envelope in the (V, B-V) plane in a few typical fields of both Clouds to find out when star formation began, trace the subsequent history of $\dot{S}$ by counting subgiant and giant stars emerging from higher turnoff points and examine the distribution of metallicity with age using (U, B, V) and DDO photometry.

Some evidence that the LMC stellar population is indeed effectively rather young is already available from a remarkable ground-based investigation at CTIO by Butcher (1977), who measured the luminosity function down to V=23 in a single LMC field of $(15\ pc)^2$ near an electronographic sequence by M F Walker and found, indeed, a break at a luminosity about 1^m brighter than in the solar neighbourhood. Butcher's limit is only 1^m brighter than I am suggesting for the ST, but in the latter case accurate magnitudes and colours can be measured in many fields without having to set up separate sequences affected by crowding and other problems as the earthbound ones are. In this way we would learn far more about chemical evolution, not only in the Magellanic Clouds, but also in our own Galaxy and in the blue compact galaxies, by testing several of the input assumptions to a high degree of precision.

4. EXTRAGALACTIC GLOBULAR CLUSTERS AND GALACTIC NUCLEI

The combination of u. v. capability and high spatial resolution makes the ST a uniquely powerful instrument for the study of globular clusters in our Galaxy and their constituent stars, but for the present purpose I shall concentrate on the possibility of studying extragalactic globular clusters. Something is already known about these from ground-based observations in the cases of M 31 (van den Bergh 1969; Spinrad and Schweizer 1972), M 87 (Racine et al. 1978) and M 49 = NGC 4472 (Harris and Petrie 1978) as well as the Fornax dwarf system (Hodge 1961) and, of course, the Magellanic Clouds.

Globular clusters in our own Galaxy display to a limited extent the large-scale radial abundance gradient that is characteristic of large ellipticals and the bulges of early-type spirals, the more metal-rich clusters being confined within 10 kpc or less from the centre (Bingham and Martin 1974; Woltjer 1975). This gradient can be interpreted as a consequence of inhomogeneous and differential collapse of stars and enriched gas during the formative stages (Larson 1974). Beyond 10 kpc, however, a range from about 1/10 to 1/200 of the solar metallicity is found over a very wide range of distances (Searle and Zinn 1978) and this result is attributed by Searle (1977, 1979) to star formation and enrichment under quite chaotic conditions in an overall state of free fall which in some ways mimics the results of the simple enrichment model (cf. Hartwick 1976).

What happens in other galaxies? In M 31 and M 87, unlike the case of our onw Galaxy, at least some globular clusters are found with moderately high metal abundances at all radial distances, and Spinrad and Schweizer found clusters in M 31 that apparently both are super-metal-rich and have strong blue horizontal branches. Evidently the ground-based observations can readily be extended by use of the Space Telescope, but the most significant advance in this case comes from the possibility of carrying out intermediate-band photometry in the ultra-violet. In the case of galactic globular clusters the possibilities have already been domonstrated by van Albada, de Boer and Dickens (1979), who used the ANS satellite to measure surface brightness at 1550, 1800, 2200, 2500 and 3300 Å.

At 1550 and 1800 Å the light is dominated by the horizontal branch, while at 2500 Å there are contributions from both HB stars and stars near the main-sequence turnoff, whose temperature can thus be measured, and λ 2200 gives a measurement of the reddening. Thus van Albada _et al_. were able to separate out two kinds of clusters with blue horizontal branches using C(18-25), the "droopy" horizontal branches with a long extension to very hot stars being brighter at λ1800 than the others; furthermore, using a metallicity index from ground-based observations, they were able to measure the turnoff ages of the clusters, recovering essentially the same range of ages as found by Demarque and McClure (1977) who applied similar models to different data.

For a typical galactic globular cluster, the 150 arc sec field of view of ANS corresponds to a diameter of about 3 pc, while the ST resolution of 0.2 arc sec corresponds to 2/3 pc and 15 pc at M 31 and in the Virgo cluster, respectively, so that the sizes of the accessible regions are quite comparable in the two cases. Clearly, then, the Space Telescope is capable of providing basic data on the ages, compositions and unobservable HR diagrams of extragalactic globular clusters out as far as the Virgo cluster, using simple colorimetric observations, and this would provide a splendid set of comparative data about the early evolution of galaxies covering a wide range of morphological types.

A somewhat related problem is that of the abundance gradients in galactic nuclei, notably in the case of M 31 for which Stratoscope surface photometry (Light _et al_. 1975) with 0.2 arc sec resolution reveals a central spike rather similar to that found more recently from ground-based observations in M87 and attributed to a massive black hole (Young _et al_. 1978; Sargent _et al_. 1978). However, there is no evidence at present for an increase in velocity dispersion at the centre of M 31 and the favoured model is of a dense cluster of stars torn away from globular clusters by dynamical friction (Tremaine _et al_. 1975). There are thus several reasons for wanting to make spectroscopic observations of the nucleus of M 31 (and many other galaxies, eg M 32, M 51, M 81, M 101, M 104, NGC 5128 etc, as well as M 87 itself) with a long slit and high spatial resolution. One reason is to get the rotation curve and velocity dispersion right into the nucleus so as to test the dynamical model (not easy to do in the ultra-violet), but there is a specific motive from the point of view of chemical evolution as well, which is to measure the fine details of the abundance and stellar population gradient. According to Spinrad, Smith and Taylor (1972), the CN strength in both M 31 and M 32 reaches a maximum about 2 arc sec or 7 pc out from the nucleus and diminishes as one goes further in, possibly (as Tremaine, Ostriker and Spitzer suggest) because of an increasing contribution from the debris of globular clusters. Alternatively, or additionally, there may be early-type stars present to account for the ionisation of the apparently nitrogen-rich gas that is seen in the nuclear regions of M31 (where there is already direct evidence for them from rocket observations; Carruthers _et al_. 1978), M51, M81 and other galaxies (Peimbert 1968; Alloin 1973). The nuclei are bright, e.g. that of M31 is brighter than 13^m arc sec^{-2} in V, and they should be easy objects for the long-slit spectrum facility of the FOC (see contributions by M.J. Disney and P. Crane in this volume) so that the population/abundance gradient and velocity dispersion can be measured with high spatial resolution."

5. STELLAR SPECTROSCOPY

The ST would have had interesting possibilities for high-resolution spectroscopy in the visible, as well as in the ultra-violet, because of its good spatial resolution, but the designers (perhaps wisely) have confined the field of operation of the High-resolution Spectrograph to the ultra-violet. Now I find it very difficult to estimate the potentialities of ultra-violet spectroscopy for stellar abundance determinations because so far it has contributed very little to this problem directly, although it has contributed indirectly through the provision of bolometric corrections and effective temperatures, and through revealing processes of mass loss from early-type stars which may modify the composition of the interstellar medium.

No doubt the next few years will bring new results on ultra-violet spectroscopy of hot stars from IUE, whereafter we shall be in a better position to discuss the possibilities. Many, of course, spring to mind: at high resolution, horizontal-branch stars, helium stars, peculiar B stars etc., and at lower resolution novae, WR stars and peculiar binaries; but it is not clear to me at the moment which particular set of observations would best use the unique capabilities of the Space Telescope to make a significant step forward in understanding the chemical evolution of galaxies by way of stellar abundances.

I can say a great deal more about interstellar lines, taking as a basis the fascinating information that has already been acquired, chiefly by the Princeton astronomers usung Copernicus (Spitzer and Jenkins 1975). This work has revealed a lot of things about the gas within about 1 kpc from the Sun: the depletion of heavy elements and the molecular and ionisation equilibrium in dense clouds; the interstellar deuterium abundance, absorption lines from H II regions and the existence of an unexpected pervasive component of coronal gas at a temperature of the order 5×10^5 K. Here again there will be many additional results from IUE and more specialised experiments in the next few years, extending the observations to greater column densities, high galactic latitudes, the vicinity of supernova remnants etc. The Space Telescope, with five times the maximum resolution and ten times the light grasp of Copernicus or IUE, is ideally adapted to extend these studies to external galaxies.

What can we expect to learn about the chemical evolution of galaxies from such studies? With a resolving power of 10^5, better spectra can be obtained than ever before in our own Galaxy and also for the brightest OB stars in the Magellanic Clouds; very many stars in the Clouds will be accessible with the Copernicus or IUE resolution of 2×10^4. Here it would be of interest to study the absorption lines of abundant elements and compare with the abundances that we think we already know from studies of emission lines from H II regions (Pagel et al. 1978). It would also be interesting to measure the deuterium abundance, especially in the Small Cloud where the degree of astration, as measured by the ratio of gas mass to total mass, is significantly smaller than in the Large Cloud or the solar neighbourhood: the difference in deuterium abundance (if any) would place limits on the total amount of gas that is ejected by a generation of stars in the course of its evolution.* Also it would be of importance to measure the relative amounts of molecular hydrogen and CO in the Clouds; radio observations have so far detected molecules in only one H II region of the Large Cloud, N 159 (Whiteoak and Gardner 1976). Finally, the Magellanic Clouds have the advantage that OB associations and supernova remnants therein are readily located in definite parts of the sky, so that it is relatively easy to investigate the relationship between them and any high-velocity and high-temperature gas that might be detected using lines like CIV and NV (OVI being inaccessible); a generalised galactic corona-chromosphere due to infalling intergalactic material, if present in our Galaxy, might well be absent in the case of the Clouds, whereas if supernova remnants and stellar wind bubbles are entirely responsible for heating and accelerating the gas, then they should be equally effective there.

* Specifically, in the absence of inflow, and in the instantaneous recycling approximation, the original abundance ratio D/H is cut down by a factor of $\mu^{\beta/(1-\beta)}$, where β is the total mass fraction of a generation of stars that is returned to the interstellar medium and μ the fraction of the system that is still in the form of gas.

Going somewhat further afield, there are many interesting problems concerning the interstellar material in galactic disks and halos that can be attacked by observing active galaxy nuclei and quasars through them, the classic case being the combination of NGC 3067 and 3C 232 (Boksenberg and Sargent 1978), where H I, Na I and Ca II were detected in absorption at a projected radial distance of 1.9 arc min or 11 kpc from the centre of NGC 3067, which translates into 40 kpc or $2\frac{1}{2}$ Holmberg radii if deprojected on to the plane of the galaxy. This raises in an extreme form the problem already presented by 21 cm observations of several galaxies, which show flat rotation curves (van der Kruit and Allen 1978) well out beyond the region where H II regions are seen (generally bounded by the de Vaucouleurs 25^m arc sec^{-2} isophote, or the co-rotation radius according to Roberts, Roberts and Shu 1975) and raise the question of invisible mass in halos; the Boksenberg and Sargent observations raise the additional question of why we see heavy elements so far out, where an extrapolation of the abundance gradient seen in our own Galaxy and several others (Pagel 1979b) would lead us to expect their abundance to be very small indeed. Perhaps, in fact, it is, and perhaps we are seeing a long path length through the halo. High-resolution ultra-violet observations with the ST should help us to find the answer, and they should be extended to other bright ($V < 18$) quasars and active galaxy nuclei to search for gas in our own and other identifiable galaxies and their surroundings. Conversely, by reducing the resolving power to 1000, we can reach fainter quasars, down to 20^m or so where there are sufficient numbers (say about 10 per square degree) to probe interstellar material in the larger galaxies, M 31, M 33, M 51, M 101 etc., both within and well beyond their easily visible disks. In these cases, incidentally, it would also be interesting to carry out stellar and surface photometry beyond the de Vaucouleurs radius using the Wide Field Camera, which could detect red giants (if present) out to M 31 and other local group members.

Another useful project related to interstellar gas is to look at horizontal-branch stars in the nearby dwarf systems Draco, Leo and Sculptor, which are accessible with a resolving power of 1000, and try to detect gas that may have been ejected by red giants and remained within the system.

6. EMISSION NEBULAE

My last topic comprises various sorts of emission nebulae: planetaries, supernova remnants and H II regions.

Planetary nebulae, with a typical size of a few tenths of a parsec, have now been detected from the ground in virtually all galaxies of the Local Group (Ford 1978), and there are several reasons why they are of particular interest. First, their statistics are of importance in relation to the stellar deathrate, and we also need to know the luminosities and effective temperatures of the central stars so as to fit them into the scheme of stellar evolution. Next they, or some of them, could be a significant source of enrichment of helium, carbon, nitrogen and s-process elements in the ISM, while their oxygen abundances (not believed to be affected by internal evolution in most cases) may help to indicate the composition of old or moderately old stellar populations in different parts of the universe. Planetaries are a very mixed bunch of objects (Peimbert 1978), and their compositions are apparently quite normal in some cases, but seem to show enhancements of helium, carbon and nitrogen in others; unfortunately there are significant differences between authors (and sometimes between inferences from different parts of one nebula; eg Czyzak and Aller 1979) and, in particular, the carbon abundances are still quite uncertain.

The ST can contribute significantly to all of these problems. To begin with, its high spatial resolution permits one to count planetary nebulae, identified with the aid of suitable filters in front of the WFC, in samples of the dense central regions of M 31, M 32, M 33 etc. These three galaxies already embrace a usefully wide range of stellar population types. Then their spectra can be measured with a resolving power of 1000 or so, giving the continuum and emission lines (if any) of the central star and quite adequate coverage of the nebular spectrum including the important C IV (1549) and C III] (1909) lines in the ultra-violet. Thus one can use planetary nebulae in different galaxies as constraints on the stellar death rate in the range of about 1 to 4 solar masses and estimate the resulting rate of enrichment; in some ways, also, the interpretation of the spectra is simplified (eg for luminosity and mass determination) because the distances are better known than for our own Galaxy.

Supernova remnants have a somewhat analogous significance to planetary nebulae, this time at the high-mass end of the IMF. Again their statistics are of importance in relation to the death-rate or birth-rate of massive stars, their ultra-violet spectra are of importance in tying down shock models and getting the carbon abundance and they have a twofold role in chemical evolution studies: young remnants like Cas A (Chevalier and Kirshner 1978) and N 132D in the LMC (Lasker 1978) show direct signs of nucleosynthesis while mature remnants bigger than a few tens of pc across and having a well-developed shell structure represent the composition of the interstellar medium in different parts of galaxies (Dopita et al. 1977). At the present time, extragalactic supernova remnants are less well known than planetary nebulae, having been detected with certainty only in the Magellanic Clouds (Mathewson and Clarke 1973) and M 33 (D'Odorico et al.1978) and with less certainty in M 31 (Kumar 1976).

The fresh young supernova remnants with enriched abundances are clearly excellent candidates for ultra-violet spectroscopy with the ST, while in external galaxies more mature remnants can be resolved as disks most of the way out to the Virgo cluster, and it seems likely that they can readily be distinguished from H II regions using u. v. line strengths, eg C IV and C III] which are prominent in the Cygnus Loop (Benvenuti et al. 1979). They should be quite plentiful in Scd and Irregular galaxies and perhaps still more so (relatively to the total mass) in the blue compact galaxies. The combination of ultra-violet with optical spectra should be especially helpful in tying down suitable shock models and in measuring the abundance of carbon in the ISM; this is a piece of information that would be of great importance in helping to understand the abundance gradients found for nitrogen and oxygen among H II regions in several galaxies where the N/O ratio is quite constant in any one galaxy but varies considerably from one galaxy to another (Edmunds and Pagel 1978; Pagel et al. 1979), and we believe nitrogen to be largely a primary nucleosynthesis product whose yield is a strong function of time since the bulk of star formation occurred. If we are right, then carbon should either increase with nitrogen or maintain a constant ratio to oxygen, whereas if nitrogen is secondary then its progenitor (carbon) should show signs of depletion when the nitrogen abundance is large.

What about H II regions themselves? Ground-based observations of them have revealed a great deal about the chemical evolution of galaxies: the existence of large-scale radial abundance gradients in some galaxies (Smith 1975; Shields and Searle 1978) but not in others, notably in cases like the Magellanic Clouds and the barred system NGC 1365 where there may be perturbations of orderly circular motion, and the peculiar behaviour of nitrogen referred to above (Pagel et al. 1979). Many H II regions are very luminous and large and can easily be observed from the ground in giant galaxies further away than the Virgo cluster, like NGC 1365, and their ultra-violet spectra, which will no doubt be helpful in the problem of choosing appropriate photo-ionisation models to represent them and derive better abundances, including that of carbon, will probably be studied in the very near future using IUE. A few data for Orion are already available from rocket observations (Stecher 1978). C IV and C III] have not been seen, probably because the degree of ionisation and the electron temperature are too small, but C II (λ 2323) has and it may be possible to derive a carbon abundance from it when used in conjunction with the optical recombination line λ 4267; but 4267 is too weak to have been seen in extra-galactic H II regions and therefore it would be of importance to study supernova remnants, though here there may be difficulties of another sort resulting from the shock model and the presence of depletion in at least the earlier recombination phases of the passage of the supernova shock (Benvenuti et al. 1979).

Where, then, do Space Telescope observations of H II regions come in? Evidently the spectra can be observed in both visible and u. v. (with a resolving power of 1000) at still greater distances and there are fringe benefits, eg in the near infra-red where atmospheric emission is a significant handicap in observing weak diagnostic lines, especially [O II] λ 7320, 7330, from the ground. However, it is not obvious to me that this is really vital, because enough H II regions are accessible that one can obtain a very fair sample of their systematic behaviour in different kinds of galaxies from ground-based observations with improved techniques and longer exposures. A more significant project, I think, would be to use the imaging capability of the ST with the Wide Field Camera, in the optical and ultra-violet, to make a detailed study of the stellar populations in some selected giant H II regions in, say, M 33 and thus study the luminosities and effective temperatures, and draw inferences about the IMF, of the exciting stars in regions with differing heavy-element abundances. The interesting point here is that, in galaxies with giant H II regions showing abundance gradients, like M 33, M 101 and NGC 300, there is very convincing evidence that the inward increase in abundances of heavy elements like oxygen is insufficient in itself to account for the excitation gradient measured by [O III]/Hβ or the equivalent width gradient of Hβ, and so Shields and Tinsley (1976) have postulated that hotter and possibly more massive stars are formed in regions where the heavy-element abundances are low, which is quite plausible on physical grounds. Alternatively, the maximum effective temperatures may be the same, but the ionising radiation increasingly attenuated by internal dust in H II regions with higher abundances (Sarazin 1976). It is difficult, if not impossible, to distinguish these two possibilities from ground-based observations, but if we could do so we should gain some important insight into the still largely unknown physics underlying the IMF with its implications for the yield of different elements from a generation of stars. With the ST this can almost certainly be done, because the range of effective temperatures involved, from about 38000K to 55000K (Shields and Searle 1978), would lead to very significant differences in colour index between, say, 1200 and 5500 Å, and this could be the most significant contribution of the ST to the interpretation of the spectra of H II regions and their consequences for galactic chemical evolution.

REFERENCES

Alloin, D. 1973, Astr. Astrophys., 27, 433.
Audouze, J., and Tinsley, B.M. 1976, Ann. Rev. Astr. Astrophys., 14, 43.
Benvenuti, P., D'Odorico, S., and Dopita, M.A. 1979, Nature, 277, 99.
Bingham, R.G., and Martin, W.L., 1974, Mon. Not. R. astr. Soc., 167, 137.
Boksenberg, A., and Sargent, W.L.W. 1978, Astrophys. J., 220, 42.
Butcher, H. 1977, Astrophys. J., 216, 372.
Carruthers, G.R., Heckathorn, H.M., and Opal, C.B. 1978, Astrophys. J., 255, 346.
Chevalier, R.A., and Kirshner, R.P., 1978, Astrophys. J., 219, 931.
Chiosi, C., and Caimmi, R. 1979, Astr. Astrophys., submitted.
Connes, P. 1979, ESA Colloquium on European Satellite Astrometry, in press.
Czyzak, S.J., and Aller, L.H. 1979, Mon. Not. R. astr. Soc., in press.
Demarque, P., and McClure, R.D. 1977, in The Evolution of Galaxies and Stellar Populations, ed B.M. Tinsley and R.B. Larson, Yale U. P., p.199.

D'Orico, S., Benvenuti, P., and Sabbadin, F. 1978, Astr. Astrophys., 63, 63.
Dopita, M.A., Mathewson, D.S., and Ford, V. 1977, Astrophys. J., 214, 179.
Edmunds, M.G., and Pagel, B.E.J. 1978, Mon. Not. R. Astr. Soc., 185, 77P
Ford, H.C. 1978, I.A.U. Symposium no 76: Planetary Nebulae, ed Y. Terzian, Reidel, p.17.
Harris, W.E., and Petrie, P.L. 1978, Astrophys. J., 223, 88.
Hartwick, F.D.A 1976, Astrophys. J., 209, 418
Hodge, P.W. 1961, Astr. J., 66, 83.
Kumar, K.C. 1976, Pub. Astr. Soc. Pacific, 88, 323.
Larson, R.B. 1974, Mon. Not. R. Astr. Soc., 166, 585.
Larson, R.B., and Tinsley, B.M. 1978, Astrophys. J., 219, 46.
Lasker, B.M 1978, Astrophys. J., 223, 109.
Lequeux, J., Peimbert, M., Serrano, A., Rayo, J.F., and Torres-Peimbert, S., 1979, Astr. Astrophys., submitted.
Light, E.S., Danielson, R.E., and Schwarzschild, M. 1975, Astrophys. J., 194, 257.
Longair, M.S. 1979, Quart. J. R. Astr. Soc., 21, in press.
Mathewson, D.S., and Clarke, J.N. 1973, Astrophys. J., 180, 275.
Mayor, M., and Martinet, L. 1977, Astr. Astrophys., 55, 221.
Neckel, H. 1975, Astr. Astrophys., 42, 379.
Pagel, B.E.J. 1979a, ESA Colloquium on European Satellite Astrometry, Padova, in press.
Pagel, B.E.J. 1979b, Chemical Evolution of Galaxies, in Stars and Star Systems: Fourth European Regional Meeting in Astronomy, Uppsala, ed. B Westerlund, in press.
Pagel, B.E.J., Edmunds, M.G., Fosbury, R.A.E., and Webster, B.L. 1978, Mon. Not. R. Astr. Soc., 184, 569.
Pagel, B.E.J., Edmunds, M.G., Blackwell, D.E., Chun, M.S., and Smith, G., 1979, Mon. Not. R. Astr. Soc., submitted.
Peimbert, M. 1968, Astrophys. J., 154, 33.
Peimbert, M. 1978, IAU Symposium no 76: Planetary Nebulae, ed. Y. Terzian, Reidel, p.215.
Racine, R., Oke, J.B., and Searle, L. 1978, Astrophys. J., 223, 82.
Roberts, M.S., Roberts, W.W., and Shu, F.H. 1975, Astrophys. J., 196, 381.
Sarazin, C.L. 1976, Astrophys. J., 208, 323.
Sargent, W.L.W., Young, P.J. Boksenberg, A., Shortridge, K., Lynds, C.R., and Hartwick, F.D.A. 1978. Astrophys. J., 221, 731.
Searle, L. 1977 in The Evolution of Galaxies and Stellar Populations, ed. B.M. Tinsley and R.B. Larson, Yale University Press, p. 219.
Searle, L. 1979, 22nd Liege Astrophysical Colloquium: Les Elements et leurs Isotopes dans l'Univers, in press.
Searle, L., Sargent, W.L.W., and Bagnuolo, W.G. 1973, Astrophys. J., 179, 427.
Searle, L., and Zinn, R. 1978, Astrophys. J., 225, 357.
Serrano, A. 1978, Thesis, Sussex University.
Shields, G., and Searle, L. 1978, Astrophys. J., 222, 821.
Shields, G., and Tinsley, B.M. 1976, Astrophys. J., 203, 66.
Smith, H.E. 1975, Astrophys. J., 199, 591.
Spinrad, H., and Schweizer, F. 1972, Astrophys. J., 171, 402.
Spinrad, H., Smith, H.E., and Taylor, D.J. 1972, Astrophys. J., 175, 649.
Spitzer, L. Jr. and Jenkins, E.B. 1975, Ann. Rev. Astr. Astrophys., 13, 133.
Stecher, T.P, 1978, in IAU Symposium no 76: Planetary Nebulae, ed. Y. Terzian, Reidel, p.122.
Talbot, R.J., and Arnett, W.D. 1973, Astrophys. J., 186, 51
Tinsley, B.M. 1976, Astrophys. J., 208, 797.
Tremaine, S.D., Ostriker, J.P., and Spitzer, L. Jr. 1975, Astrophys. J., 196, 407.
van Albada, T.S., de Boer, K.S., and Dickens, R.J. 1979, Astron. Astrophys., in press.
van den Bergh, S. 1969, Astrophys. J. Sup., 19, 145.

van der Kruit, P.C., and Allen, R.J. 1978, Ann. Rev. Astr. Astrophys., **16**, 103.
Westerlund, B. 1970, Vistas in Astron., **12**, 335.
Whiteoak, J. B., and Gardner, F.F. 1976, Mon. Not. R. Astr. Soc., **176**, 25P.
Wilson, O.C. 1976, Astrophys. J. **205**, 823.
Woltjer, L. 1975, Astr. Astrophys., **42**, 109.
Young, P.J., Westphal, J.A., Kristian, J., Wilson, C.P., and Landauer, F.P. 1978, Astrophys. J., **221**, 721.

J. AUDOUZE : It is because I agree with you that the measurement of the deuterium abundance in the Magellanic Clouds is of invaluable importance as far as cosmology and chemical evolution of galaxies are concerned that I stress again the point I made yesterday. It is extremely unlikely that this crucial observation can be made by Space Telescope because of wavelength range limitation ($\lambda > 1200$ Å) which is the most severe difficulty. Remember also that the deuterium abundance determinations in the solar neighbourhood with Copernicus are not trivial operations. Therefore Space Telescope does not appear to be suited to achieve this far more difficult detection concerning the Magellanic Clouds.

DYNAMICS OF GALAXIES

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1. INTRODUCTION

The fundamentals of the study of the dynamics of galaxies are the Liouville continuity equation which describes the behaviour of the particle distribution function in phase space (or a hydrodynamical equivalent for the case of a gaseous component) and Poisson's equation which links the density distribution and the gravitational potential field. The observational study of galactic dynamics involves therefore the measurement of the present characteristics of the distribution function and the use of these equations to explain in a consistent way the structure of galaxies. Ideally in observational studies the aim is to measure the space density, the distribution of particle masses and the first few moments of the distribution of velocity as a function of position in the system. In practice one is limited to the line-of-sight components of systematic motion and velocity dispersion and to light and colour distributions over the projected image on the sky. The resulting difficulties are well known and are among others: the separation of stellar populations to extract information on the actual three-dimensional distribution; conversion of light and colour distributions to mass-density distributions; effects of line-of-sight integration in velocity measurements and the separation between rotational and non-circular motions. Since these problems are fundamentally the same for ground-based and space observations they will not be further discussed, but it should be realized that their effects often seriously compromise the interpretation.

Clearly, measurements useful to galactic dynamics involve surface photometry (including measurements of colour distributions) and mapping of velocities and velocity dispersions. As has been often quoted the three main advantages of ST over ground-based optical astronomy are (1) the improved angular resolution, (2) the possibility of observing at UV-wavelengths and (3) the somewhat fainter sky-level in space, which results mainly from zodiacal light in the optical and diffuse galactic light in the UV. Since most dynamical investigations of galaxies study the systems on a large scale, the first point will be least advantageous for studies with ST. It is true that questions connected with the structure and dynamics close to galactic nuclei and the possible presence there of black holes (Sargent et al., 1978; Young et al., 1978) suggest observations realizable only through ST, but discussions of these will be left to other lectures in this workshop.

For surface photometry across galaxies, especially at very faint levels, the WFC will be most useful at all wavelengths. In this respect the possibility to measure reliable colours at fainter levels and in different wavelengths regimes is very important. As for spectroscopy ST has a few disadvantages compared to ground-based astronomy; in particular the absence of a spectroscopic mode with various resolution elements along a slit in the FOS and HRS. The inclusion of such an option in the spectroscopic mode of the FOC will certainly improve the flexibility of galactic research with ST, especially for central regions of galaxies or systems of small angular size (large redshift).

For most dynamical studies a wavelength resolution $\Delta\lambda/\lambda$ of 2×10^3 to 10^4 is required. The FOS therefore does not provide resolutions that make it particularly useful for kinematical studies. There are applications possible with the FOC spectroscopic mode, but it seems that often the resolution of the HRS is needed. This instrument has the disadvantage that one is restricted to observing in the UV. Many observations of importance are on absorption lines in older stellar components in galaxies (see below), which have spectral energy distributions like that of G- of K-type stars. So, in the first place the flux received is dropping fast relative to optical wavelengths, restricting observations to the longest wavelengths possible (say 2500 to 3000 Å). This should also be compared to the sky-background: the zodiacal light has an energy distribution not too different from that of the sun down to about 2000 Å (e.g. Pitz et al., 1978), but the Galactic background becomes very strong due to interstellar scattering of light from O and B stars in the Galactic disk. The effects can be small at high galactic latitudes, but irregularities and high-latitude reflection nebulosities (Sandage, 1976) should worry observers. Clearly, the UV is <u>not</u> very attractive for this kind of observation and for each individual project a choice has to be made based on a trade-off of wavelength regime, velocity resolution and exposure time between the HRS and the spectroscopic mode of the FOC.*

A discussion of observational programs for dynamical studies of galaxies unavoidable overlaps severely with one for evolutionary investigations. Many observations (except for the aspect of high velocity resolution) mentioned in the context of this talk are similar to those one would perform for the purpose of population synthesis or separation, and abundance determinations. This is fortunate since the whole field of research on galaxies - both observationally and theoretically - is moving towards a synthesis of dynamics, population structure, history of star-formation and chemical evolution (see e.g. Tinsley and Larson, 1977; Basinska-Grzesik and Mayor, 1977).

* At a resolution of 0".1 the surface brightness of globular clusters is sufficiently high to use the FOC with adequate S/N at distances up to that of the Virgo Clusters.

2. ELLIPTICAL GALAXIES AND SO's

The outstanding question at present in the field of dynamics of elliptical galaxies concerns their three-dimensional form (oblate, prolate or tri-axial spheroids) and the connected possible anisotropies in their internal kinematics. This matter developed after the discovery of the very low ratio of kinetic energy in rotation to that in random motion (e.g. Bertola and Capaccioli, 1975; Illingworth, 1977) and the resulting breakdown of dynamical models, which up till then were thought to be rather successful (e.g. Wilson, 1975). A recent review of the matter has been written by Binney (1978). The observational needs are in detailed surface photometry (e.g. axis ratios and orientation of isophotes at various radii) and mapping of systematic and random motions preferably over the whole face of the galaxies, but at least along the principal axes on the sky. Many observations of this kind - although often time-consuming - can very well be done from the ground and in particular most of the spectroscopic work is possible with large ground-based telescopes equipped with long-slit spectrographs and two-dimensional photon-counting detector arrays. It is actually to be expected that the most crucial observations will be done well before the launch of ST.

At this point it is worthwhile to consider the methods of velocity measurements in early-type galaxies from absorption lines. The most accurate and widely accepted method involves Fourier techniques in comparing the galaxy spectra with spectra of K-type giants (which in the optical most resemble the spectra of ellipticals) to find a radial velocity and a velocity dispersion. When the UV is used the method is in principle the same, even if the UV-spectra of elliptical galaxies are dominated by early G-type stars (as evident from spectrophotometry as in Boksenberg et al., 1978). The whole technique has been exhaustively discussed by Sargent et al. (1977, 1978). From their tests it appears that incorrect sky-subtraction can have a serious effect, which of course is most severe at faint light levels. The difficulties are connected with the absorption lines in the G-type (solar) spectrum of the zodiacal light, the photometric stability of the instrument and in particular the photometric quality of the sky during observing. This suggests that at faint light levels ST can in principle usefully improve over ground-based observations. Very long exposure times are often required. This and the difficulties with the UV will certainly restrict the application of this observing technique with the HRS. For larger velocity dispersions the FOC spectroscopic mode will be useful, especially to the extent that the observations are complementary to what can be done from the earth near the nuclei.

A second item of study in elliptical galaxies (except from the dynamics close to the centre) concerns the extended haloes of gE and cD systems in rich clusters (Oemler, 1976) and the question of the origin and dynamics of these systems (e.g.

the merging hypothesis; see Ostriker, 1977). A first necessary type of observation is to measure colours or preferably more direct indicators of metal abundance from low-resolution spectroscopy at faint light levels. This would indicate whether metallicity keeps declining with distance from the centre (Faber, 1977) or is typical for that in haloes of other cluster members - as would be expected on the merging hypothesis. Secondly, the velocity dispersion in the envelopes provides a strong test (Faber et al., 1977) since for the case of merging this property is expected to be comparable to that of the cluster as a whole or at least its core. This measurement is difficult from the earth (Faber et al., 1977). ST can in principle provide most necessary information with the WFC and the FOS or spectroscopic mode of the FOC, although again at the expense of long exposure times.

The study of the outer parts of ellipticals is also important in view of the unknown total masses of these systems and the "missing mass problem" in clusters of galaxies. For most elliptical galaxies, but in particular the gE's, their systems of globular clusters can be used to trace the density distribution and the internal velocity field. Recently Harris and Smith (1976) and Harris and Petrie (1978) have counted thousands of globulars in M87 and M49 - the brightest ellipticals in the Virgo cluster -, and have shown that their distribution is typical for the total population. The brightest globular clusters are already visible at visual magnitudes of about 20 and the angular sizes are less than 1 arcsec (at 20 Mpc this corresponds to 100 pc). On the ground seeing effects make the distinction between clusters and stars difficult, but with ST colour measurements with the WFC or exposures with the FOC and objective prisms could help very well in this respect. Only selected areas around galaxies can be studied, but that would not compromise the aims. Useful spectroscopic information can already be inferred using the FOC. Of course, such a program is also extremely important for studies of formation and chemical evolution (Racine et al., 1978).

Finally, I mention the problem of the origin of the SO-galaxies. Here the dynamics of both the spheroidal components (for which globular clusters might also be used) and the disk are to be investigated. If SO's are indeed spirals swept of their gas (e.g. Gunn and Gott, 1972; Faber and Gallagher, 1976) the disk dynamics should be similar to that of the stellar disks of late-type spiral galaxies. If SO's are distinct galaxy types resulting e.g. from the angular momentum distribution at the time of formation (Sandage et al., 1970), the disk dynamics (such as kinetic energy in random motion relative to rotation and the form of the rotation curve) would be strongly determined by the fact that the disk formed in the presence of a relatively much more massive spheroidal component. UV-photometry might reveal a minor young population if the sweeping was completed less than 10^9

years ago (Freeman, 1977). It is however not unlikely that most of this work can be done best using ground-based telescopes. ST might be complementary in particular in studying the spheroidal component.

3. SPIRAL GALAXIES

Most necessary velocity information on disks of spiral galaxies can probably be reliably obtained by ground-based optical and radio telescopes using optical emission lines and the 21-cm HI-line in the radio regime (van der Kruit and Allen, 1978). The needed information on the kinematics of the stellar disks (that is: through optical absorption lines) is most readily obtained with long-slit spectrographs and photon counting detectors on large ground-based telescopes. Of course very close to the centre the much improved spatial resolution of ST is essential, but this again is not discussed here. Also, the solution of the spiral structure problem (Toomre, 1977) and that of bars and oval distortions - at least as far as the kinematical aspect goes - is not dependent on the resolution offered by ST and is in any case probably best attacked by population separation and identification of star formation sites in spiral disks (Schweizer, 1976; Talbot et al., 1978) or by studies of large-scale kinematics (van der Kruit and Allen, 1978). As far as the aspect of star formation goes the UV photometry provided by ST could be of much help indeed, but it seems that the field of kinematics of inner disks (that is that part over which classical spiral structure is seen) of these systems is unlikely to be a major topic in astronomy with ST.

However, the situation is different with outer disks and spheroidal components. The first question is the extent of the disks; they seem to have rather steep fall-offs (below levels corresponding to a face-on brightness of $\sim$ 29 B-mag arcsec^{-2}) in surface photometry of edge-on systems (van der Kruit, 1978). Faint surface photometry at long wavelengths with the WFC can certainly add significantly to what can be done from the earth. There is evidence that the outer parts of the disks are made up of high M/L material. This result comes from the observation that rotation curves of spiral galaxies remain flat out to very large radii (Roberts and Whitehurst, 1975; Bosma, 1978). The resulting large mass at large radii is not necessarily confined to a disk, but Bosma and van der Kruit (1978) have argued that part - although probably not all - of the indicated radial increase in M/L to values around 300 is due to the disk material. This is based on the observed smooth appearance of the outer parts on deep optical plates, the redder colour in at least one system (van der Kruit, 1978) and the observed constancy with radius of hydrogen-to-total mass ratio (Bosma, 1978) combined with the well-known abundance gradients (e.g. Searle, 1971). However in spite of this indication we do lack the detailed knowledge necessary to separate disk and

and halo contributions to the mass distributions when interpreting rotation curves. A better knowledge of changes of stellar population with radius in the disks is required. Although we are currently studying the question using broad-band optical colours and by mapping of z-velocity dispersions in the HI (in face-on galaxies), surface photometry and spectrophotometry at faint light levels could put more stringent constraints on this.

Another problem concerns the possible existence of very massive haloes (e.g. Ostriker et al., 1974). A possible way of investigating this question observationally is through tracing the halo by its globular clusters. Their kinematics can put useful constraints on galaxy masses out to large radii (Sargent, 1977). In external systems mapping of the velocities of globular clusters at various projected radii enables one to distinguish between radial orbits and isotropic velocity dispersions - a problem which plagues the interpretation of the data in our Galaxy. The method will certainly be applied soon to M31 and possibly a few other nearby spirals using ground-based telescopes. Observations with ST of more distant systems will constitute an important extension of the test and the sample available, so that possible dependences of total mass on type, etc. can be investigated. At the same time these studies will give fundamental information concerning the history and formation of old galactic components (Searle and Zinn, 1978).

Finally, is there a possibility of directly observing the matter that makes up these hypothesized massive haloes? If they are made up of low-luminosity stars (M-dwarfs) the most promising wavelengths are of course in the IR. At optical wavelengths the measurements from ground-based surface photometry extend already to rather faint levels (Spinrad et al., 1978). ST can however improve on this in two respects when the WFC is used at optical and in particular near IR wavelengths on systems at somewhat larger redshift (smaller angular size). In the first place the limits can be pushed down in e.g. the I-band and secondly colour information to as faint limits as possible should give useful information on the stellar content of the spheroidal component. Of course by the time of ST launch IRAS will also have provided interesting data on the question of galactic haloes. Apart from the observations mentioned there is the possibility of studying the halo of our Galaxy from star counts at very faint levels in random positions whenever ST is observing, as has been described by the WFC proposal team.

4. CONCLUDING REMARKS

It will be clear from the discussion above that there will be somewhat limited use of ST in the field of the dynamics of galaxies, to a large extent due to the particular instrumentation. Of the important possibilities offered by ST we can mention the surface photometry and colour measurements at faint levels, the spatial mapping of systems of globular clusters well into the Virgo cluster and the spectroscopy at moderate resolution ($\Delta\lambda/\lambda \sim 2 \times 10^3$ to 10^4) of in particular extended older populations. It should at the same time be realized that the field will be a very active one on ground-based telescopes and ST will have the capability to perform some crucial observations - which cannot be done from earth - in the areas mentioned. In doing this ST will certainly be invaluable in stimulating further studies of the dynamics of galaxies.

REFERENCES

Basinska-Grzesik, E., Mayor, M. (editors) 1977, Chemical and Dynamical Evolution of our Galaxy (Geneva Obs.)
Bertola, F., Capaccioli, M. 1975, Ap. J. 200, 439
Binney, J. 1978, Comm. on Astrophys. (preprint)
Boksenberg, A. and 25 other authors 1978, Nature 275, 404
Bosma, A. 1978, Thesis (Univ. of Groningen)
Bosma, A., Kruit, P.C. van der 1978, Astron. Astrophys. (preprint)
Faber, S.M. 1977, In: Tinsley and Larson (op.cit), p. 157
Faber, S.M., Gallagher, J.S. 1976, Ap. J. 204, 365
Freeman, K.C. 1977, In: Tinsley and Larson (op.cit), p. 133
Gunn, J.E., Gott, R. 1972, Ap. J. 176, 1
Harris, W.E., Petrie, P.L. 1978, Ap. J. 223, 88
Harris, W.E., Smith, M.G. 1976, Ap. J. 207, 1036
Illingworth, G. 1977, Ap. J. 218, L43
Kruit, P.C. van der 1978, Astron. Astrophys. Suppl. (preprint)
Kruit, P.C. van der, Allen, R.J. 1978, Ann. Rev. Astron. Astrophys. 16, 103
Oemler, A.O. 1976, Ap. J. 209, 693
Ostriker, J.P. 1977, In: Tinsley and Larson (op.cit), p. 369
Ostriker, J.P., Peebles, P.J.E., Yahil, A. 1974, Ap. J. 193, L1
Pitz, E., Leinert, C., Schulz, A., Link, H. 1978, Astron. Astrophys. 69, 297
Racine, R., Oke, J.B., Searle, L. 1978, Ap. J. 223, 82
Roberts, M.S., Whitehurst, R.N. 1975, Ap. J. 201, 327
Sandage, A.R. 1976, Astron. J. 81, 954
Sandage, A.R., Freeman, K.C., Stokes, N.R. 1970, Ap. J. 160, 831
Sargent, W.L.W. 1977, In: Tinsley and Larson (op.cit), p. 427
Sargent, W.L.W., Schechter, P.L., Boksenberg, A., Shortridge, K. 1977, Ap. J. 212, 326
Sargent, W.L.W., Young, P.J., Boksenberg, A., Shortridge, K., Lynds, C.R., Hartwick, F.D.A. 1978, Ap. J. 221, 731
Schweizer, F. 1976, Ap. J. Suppl. 31, 313
Searle, L. 1971, Ap. J. 168, 327
Searle, L., Zinn, R. 1978, Ap. J. 225, 357
Spinrad, H., Ostriker, J.P., Stone, R.P.S., Chin, L-T.G., Bruzual A., G. 1978, Ap. J. 225, 56
Talbot, R.J., Jensen, E.B., Dufour, R.J. 1978, Ap. J. (preprint)
Tinsley, B.M., Larson, R.B. (editors) 1977, The Evolution of Galaxies and Stellar Populations (Yale Univ. Obs.)
Toomre, A. 1977, Ann. Rev. Astron. Astrophys. 15, 437
Wilson, C.P. 1975, Astron. J. 80, 175
Young, P.J., Westphal, J.A., Kristian, J., Wilson, C.P., Landauer, F.P. 1978, Ap. J. 221, 721

ASTRONOMICAL OPPORTUNITIES AND CONSTRAINTS OF THE FAINT OBJECT CAMERA

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Abstract

Two extragalactic programs are explored as possible uses of the ESA Faint Object Camera. The first deals with determining nuclear velocity dispersion in normal galaxies, and the second deals with using galaxy core radii for cosmological purposes. The emphasis is more on feasibility than on desirability. Therefore, realistic considerations of observing details have been included.

This paper will concentrate more on the use of space telescope rather than on any particular astronomical problem. Most of the papers presented here have dealt with the astronomy which might be done with only secondary emphasis on the actual realization of these astronomical goals with any particular ST instrument. The objective of this paper is thus to provide some examples of how to use the space telescope and specifically the ESA Faint Object Camera.

The relevant details of the Faint Object Camera are presented in Table 1. In deciding on whether or not to use the Faint Object Camera for a particular problem it is also useful to make a comparison with other ST instruments where there is some possible overlap. For imaging applications, the Faint Object Camera will have an advantage in speed over the Wide Field Camera at wavelengths less than about 4500 Å and for problems requiring deconvolution of the point spread function. The major disadvantages of FOC are its lack of red response and limited field of view. For spectroscopic applications comparison with the Faint Object Spectrograph is more difficult because the FOC spectroscopic capability is limited in wavelength coverage, and the instruments have different dispersions. However, it is probably safe to assume that the FOC and FOS will be competitive in speed in the regions where the FOC can observe. The FOC spectroscopic capability will be most effective for problems requiring spatial resolution perpendicular to the dispersion direction. The disadvantage of the FOC spectrograph will be its fixed spectral range and fixed slit width as well as possible problems from scattered light in the FOC optical train.

The remaining portions of the paper will be devoted to a discussion of selected observing programs, and their viability for ST and for the FOC. Table 1 shows the various observing modes in which the FOC could be used. Two hypothetical observing programs have been selected to illustrate typical use of the FOC and what may or may not be expected.

Velocity Dispersion in Elliptical Galaxies.

The scientific interest in this program comes from many sources. Probably the most popular is to verify if there are massive black holes in the nuclei of giant elliptical galaxies (Young et al. 1978, Sargent et al. 1978). The basic idea stems from the observations of M87 which indicate unexpected increases in both the velocity dispersion and the surface brightness in the

Table 1: Faint Object Camera Characteristics

Spectral Range	1200 Å - 6000 Å (QE > 5%) Hot Bialkali Photocathode	
Imaging Modes	f/96	11" x 11" field of view 16 bit pixels
		11" x 22" field of view 8 bit pixels
		0".022 x 0".022 pixels
		44 filters and prisms
		Coronographic mask
	f/48	22" x 22" field of view 16 bit pixels
		22" x 44" field of view 8 bit pixels
		0".044 x 0.044 pixels
		14 filters and prisms
Spectrographic mode	fixed grating in f/48 beam yielding 1.8 Å/pixel at 4000 Å	
	slit 0".1 x 10".0 fixed	
	slit width = 2.27 pixels	
	1^{st} order 5400 - 3600	
	2^{nd} order 2700 - 1800	
	3^{rd} order 1800 - 1200	
Time Resolved Imaging	500 ms time resolution.	

nuclear region of this object. However, more recent work (Davies, 1978) may indicate that this is a general phenomenon in the nuclear region and therefore similar data with higher spatial resolution will be required to get a better understanding of the dynamical conditions in "normal" galactic nuclei before the black hole hypothesis is verified.

This program would utilize the FOC in the spectrographic mode in the wavelength region from 4000-4500 Å. Operationally one compares the galaxy spectrum with the spectrum of a star of similar spectral characeristics to determine the broadening of the galaxy absorption lines (Sargent et al. 1976). The galaxy nucleus would be centered in the FOC spectrograph slit. Figure 1 shows the details of the FOC f/48 focal plane arrangement. Centering the galaxy nucleus already presents problems since we do not know the position of galaxy nuclei with the required precision. It will thus be necessary to take a preliminary high resolution photograph to determine the position of the nucleus. These exposures will have the additional advantage of providing a good estimate of the surface brightness in the nuclear region which will be useful in estimating the required exposure time.

Figure 1 shows the layout of the focal plane slit area of the FOC. The spectrograph will operate by moving a mirror into the normal optical path and reflecting this to the grating and then to the detector. This has the effect of imaging the slit onto the detector, as well as a portion of the normal field. There is some danger that scattered light from this region of the normal field will reduce to signal-to-noise in the spectra.

In order to accomplish this program it will be necessary to

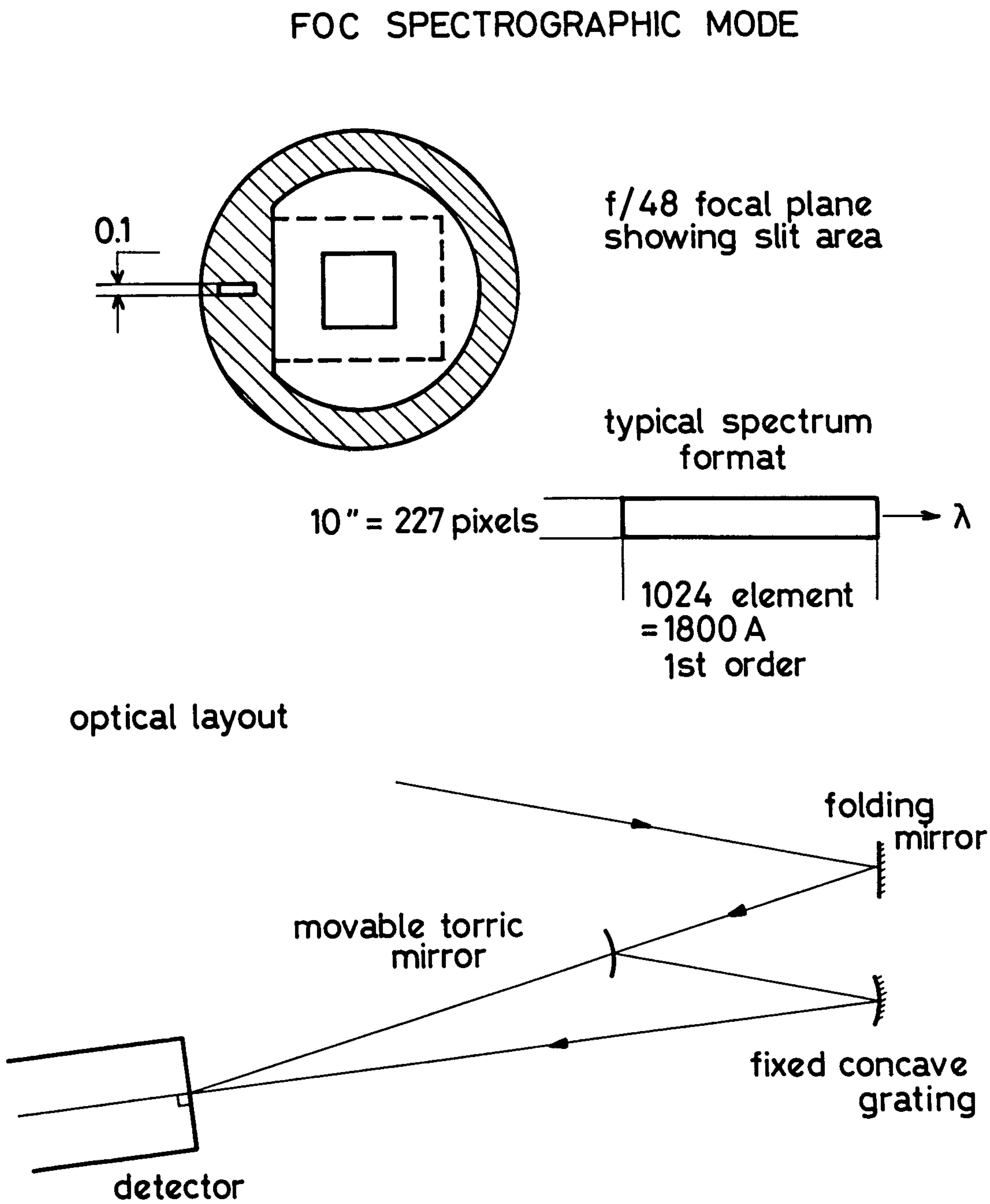

Figure 1: FOC Spectrographic Mode Focal Plane Layout.

determine velocity dispersions of the order of 150 km s^{-1} or greater. The FOC spectrograph provides 1.8 Å/pixel in the 1^{st} order at 4500 Å. The projected slit corresponds to 4.1 Å. A gaussian velocity profile of width corresponding to 150 km s^{-1} will be 4.5 Å wide. Thus the FOC spectrograph is well suited to this problem and will probably be useful for velocity dispersion somewhat smaller than 150 km s^{-1} perhaps to 120 km s^{-1}.

The total flux per detector pixel will be rather small and the exposure time will be rather long. If we take the typical central surface brightness of a galaxy to be SB_V = 16 mag/(arc sec)^2, and if we take the estimated counting rate to be 2 x $10^{6-0.4m_v}$ counts s^{-1} Å^{-1} we can combine this with the effective pixel size ($0\overset{''}{.}10$ x $0\overset{''}{.}044$) and the spectral range per pixel (1.8 Å) to determine the expected counting rate. Including an expected spectrograph efficiency of 0.45, the detected photon flux becomes 3. x 10^{-3} counts/sec /pixel. Typically between 10^5 and 10^6 total detected photons are needed to determine the velocity dispersion with optimum efficiency. If two pixels are summed along the slit then several hours of observation would be required to collect the appropriate amount of data. Since the core radii of galaxies are several seconds of arc across, and the surface brightness drops by only a factor of two at the core radius, the data all along the slit should be useful.

This program seems to be of great scientific importance and is one of the key uses that have been envisaged for the faint object camera spectrographic mode. However the photon budget is tight enough that it will take a major commitment even to do a few galaxies.

Galaxy Core Radii as a Cosmological Probe.

This program would attempt to use the core radii of galaxies as a standard of length in order to study the redshift dependence of measuring rods and from that determine the cosmological parameter q_o. Before using valuable space telescope time for this project, it would be necessary to determine the core radius distribution for elliptical galaxies in nearby clusters. Another by-product of this program would be to verify the $(1 + Z)^4$ dependence of surface brightness on redshift.

The brightness profile for galaxies will be modelled as $d(I_o\ \sigma,\ \varepsilon; r\theta)$ where I_o is a central surface brightness, σ is the core radius or some other characteristic length associated with the galaxies, and ε is the ellipticity. Photographs of galaxies will be analyzed to determine σ as well as the other parameters. Typical values of σ for nearby galaxies are about 0.5-1 kpc (Sandage, 1974). From this one can estimate the expected angular size at various redshifts. For standard cosmological models the angular size is given by

$$\theta(Z) = \frac{H_o\ (1 + Z)^2\ \sigma\ q_o^2}{C} \left[Zq_o + (q_o - 1)(\sqrt{2q_oZ+1} - 1)\right]^{-1}$$

where H_o = Hubble constant = 75 km $s^{-1}Mpc^{-1}$

q_o = deceleration parameter = ½

C = velocity of light = 3 x 10^5 cm s^{-1}

Z = redshift

For q_o = ½ and r = 1 kpc, the minimum radius is about 0.15 arc seconds. Since many galaxies will have core radius smaller than 1 kpc the actual scales of interest will more than likely be around 0.06 arc seconds or less.

Figure 2 shows a typical ST point spread function. Also

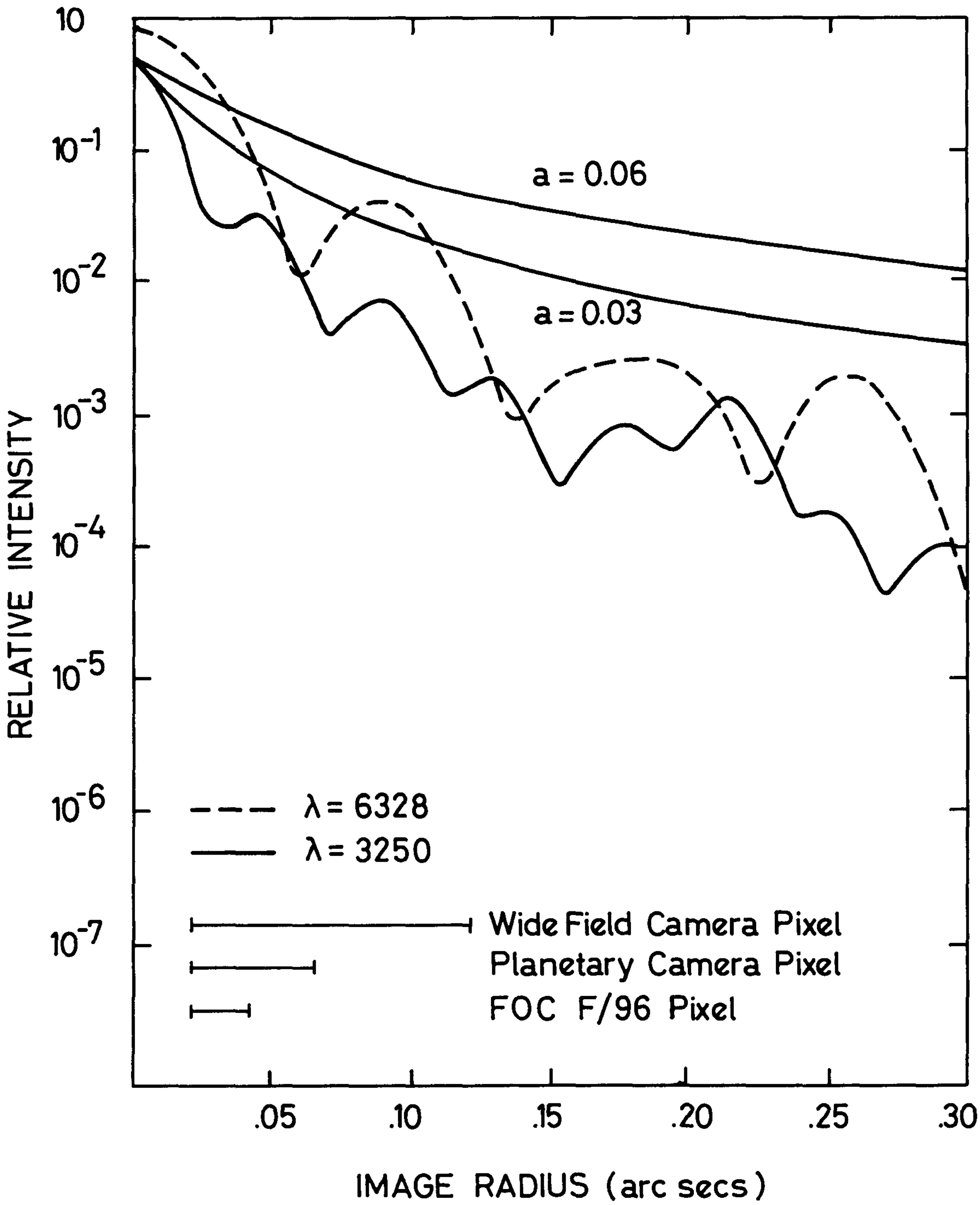

Figure 2: Optical Telescope Assembly Point Spread Functions and Galaxy Profiles. Point Spread Functions at $\lambda = 6328$ Å and $\lambda = 3250$ Å are shown as well as two probable galaxy profiles at $Z \cong 1$.

included are galaxy profiles of the Hubble type; $I(r) = I_o(1+{}^r/a)^{-2}$. Two profiles are plotted with a = 0"06 and a = 0"03. These will be well resolved by the ST optical system but may not be resolved by the shorter focal length cameras as can be seen by comparing the various pixel sizes shown in the lower part of the figure.

The f/96 beam of the FOC camera will provide enough spatial resolution to accurately determine the core radii and the limited field (11" x 11") will not be a limitation for this application. The trade offs between using the WF/PC in the Planetary Camera mode and the FOC f/96 beam will depend on several factors. The FOC will provide the highest spatial resolution on the ST, and this may prove to be the deciding factor even in the face of the higher quantum efficiency of the WF/PC. But this is not sure since galaxies at redshift of Z = 1 will have their light emitted at wavelengths of 3500 Å redshifted to 7000 Å at which point the sensitivity of the FOC is very low. The technical feasibility of this program will thus depend on some unanswered questions about the scale sizes and ultraviolet luminosity of galaxies.

The feasibility of this project from the scientific point of view may also be in doubt. We do not yet have a good understanding of the constancy of or range of values expected for the core radii of nearby galaxies. Even if we did know what to expect in nearby galaxies, we don't have a precise idea of what dynamical evolution might do to this. Nevertheless, the observations envisaged here will be useful in understanding these questions if not for cosmology.

Conclusions

Two observing programs of possible great impact on our understanding of the universe have been discussed. In spite of the fact that these observations look possible at first glance, there may be technical difficulties which will limit the results actually obtainable. It will then be necessary not only to do careful ground based preparatory observations, but also to think carefully about whether ST can do the job and if so, which instrument is optimum. And last, even if ST can do it, will the required time be available?

References

Davies R. 1978 ESO Seminar 23 January 1979 also, Cambridge University Thesis, 1979.

Sandage A. 1974 in Large Space Telescope - a New Tool for Science AIAA 12th Aerospace Sciences Meeting (Washington DC,January 1974)pp 19

Sargent W.L.W., Schechter P.L., Boksenberg A., and Shortridge K., 1977. Ap.J. 212, 326.

Sargent W.L.W., Young P.J., Boksenberg A., Shortridge K., Lynds C.R., and Hartwick F.D.A., 1978 Ap.J. 221, 731.

Young P.J., Westphal J.A., Kristian J., Wilson C.P., Landauer F.P., 1978 Ap.J. 221, 721.

ACTIVE GALAXIES

OBSERVATIONS OF RADIO GALAXIES AND OF NEBULOSITIES AROUND ACTIVE NUCLEI WITH THE SPACE TELESCOPE

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In this article, we examine what progress can be expected from observations with the Space Telescope in two areas of current astrophysical interest. The first topic is the determination of the Radio Luminosity Function of radio galaxies at large redshifts. The second topic is the investigation of the nebulosities of stars and/ or of ionized gas surrounding quasars and Seyfert nuclei.

I RADIO GALAXIES

A) The Determination of the Radio Luminosity Function at Large Redshifts.

Now that the local properties of this region of the Universe are rather well known, we wish to improve our knowledge and understanding of the evolution with cosmic time. How far into the past can we go from the ground? What can be the contribution of observations with the Space Telescope to the study of the evolution of the radio galaxy population?

It has been known for several years that the radio galaxy population evolves with time. Evidence for this evolution comes from the radio source counts. The source counts show that radio sources (i.e. radio emitting quasars and radio galaxies) were more luminous and/or more numerous in the past. By subtracting the contribution of quasars from the source counts, Schmidt (1972) showed that the radio galaxy population evolves with cosmic time, and that the evolution is strongest for the intrinsically powerful radio galaxies. The exact form of this luminosity dependent density evolution is not accurately known because it is difficult to predict accurately the contributions of quasars and ordinary galaxies to the total source counts. It is, therefore, important to directly determine the luminosity function of radio galaxies at various redshifts. This requires the definition of representative samples of the radio galaxy population at large distances and measurement of the redshifts of these distant radio galaxies.

Aside from the source counts, further evidence for the evolution of the radio galaxy population has recently been derived from new optical identifications made on very deep photographic plates (Laing et al. 1978; Grueff and Vigotti, 1978; de Ruiter, 1978). In Figure 1 taken from de Ruiter (1978) one can see that the density of radio galaxies derived from very distant radio galaxies - those of magnitudes m = 22 and 23.

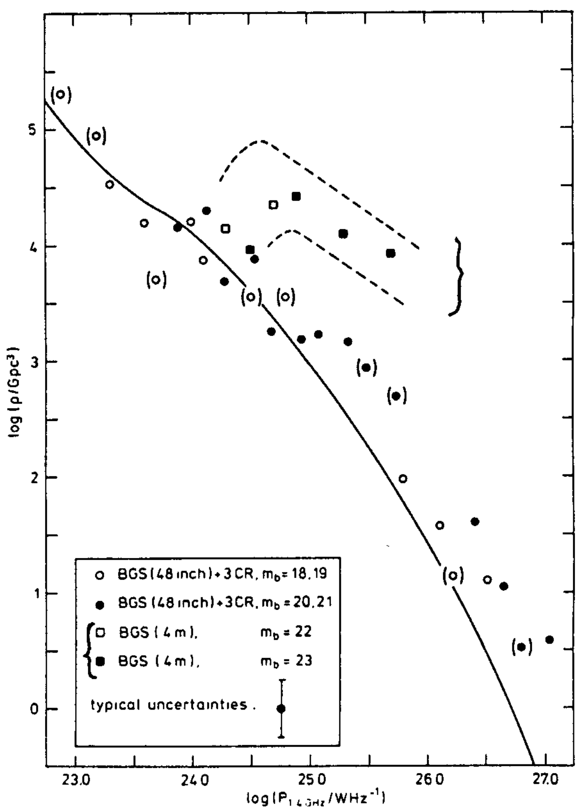

Figure 1. The radio luminosity function of galaxies. The evidence for density evolution of radio galaxies comes from the fact that the density determined from galaxies of magnitude 22 and 23 (squares) is 10 to 100 times larger than the density determined from galaxies of magnitudes 18 to 21 (dots) which are closer. It is assumed that M_b =-20.5. All these radio galaxies are in the same sample derived from the Westerbork Background Survey. Solid line: local radio luminosity function derived by Wall et al. 1977. For details see the thesis of de Ruiter (1978) from which this figure is taken.

(represented by squares) - is 10 to 100 times larger than the density of radio galaxies derived from the radio galaxies of magnitudes 18 to 21 which are relatively close by. Note that all these radio galaxies come from the same sample derived from the Westerbork Background Survey. It is clear that this sample contains radio galaxies at distances such that because of evolution, the luminosity function is substantially different from the local luminosity function (Meier et al. 1979). To determine the luminosity function at these large distances, we need the redshift of the radio galaxies identified with very faint galaxies. The question we wish to answer is how faint are the galaxies for which we can measure the redshift? At what redshift do observations with the Space Telescope become necessary? To find an answer to these questions we propose to go through the following exercise.

Let us consider a galaxy of magnitude $m_R = 22$ at $z = 0.8$ and suppose that we want to measure its redshift by fitting its energy distribution as observed through broad-band filters to the supposedly well-known energy distribution of a distant normal elliptical.† The exercise is done in the R band because it is where the break at 4000 A occurs for $z = 0.8$. Two cases are considered: In one case the observations are made from the ground with a hypothetical instrument similar to the Space Telescope and the Wide Field Camera but where one pixel represents one square arc second. In the second case the observations are made with the Space Telescope in orbit and the Wide Field Camera. The overall efficiency of the instrument is supposed to be 20% and the absorption by the atmosphere is neglected.

In the R band, the number of detected photons from a galaxy with $m_R = 22$ observed with the Space Telescope of effective area 4×10^4 cm^2 and efficiency 20% is 8. In the R band, the sky brightness above the atmosphere* is 3.5×10^{-18} erg s^{-1} cm^{-2} A^{-1} arc sec^{-2}; and the sky brightness on the ground is ~ 2.4 times as large; these figures converted into numbers of detected events <u>from the sky</u>, per second of time and per arc sec^2, are $n = 9$

† Here M_B is assumed to be constant and equal to -20.5

* Orbital night sky from atmospheric explorer C, corrected for bright stars. Reference: NASA Form 682, February 1976

above the atmosphere and n = 22 on the ground.

By using the surface brightness as a function of distance from center for M87 (Young et al. 1978) it can reasonably be assumed that 1/3 of the light received from a galaxy with $m_R = 22$ at z = 0.8 falls in one arc sec^2 (which corresponds to one pixel for the ground based observations) and 1/10 of the light from the same galaxy falls in the central 0.1 arc sec^2 of the image (which corresponds to the central 10 pixels in the case of the observations with the Wide Field Camera and the Space Telescope in orbit).

The number of counts due to thermal leakage per pixel per second is n' = 0.1 and the number of counts for the readout noise is 12*. The comparison between the two cases which we consider here, one corresponding to observations with the Wide Field Camera and the Space Telescope in orbit, the other corresponding to observations from the ground with a hypothetical instrument similar to the Space Telescope but where 1 pixel is one arc sec on the Wide Field Camera, can then be summarized as shown in Table 1.

From Table 1 it can be concluded that for measuring redshifts of distant galaxies up to z = 0.8 it is more efficient to use the hypothetical ground-based telescope considered above than the Space Telescope. The redshift limit is relevant only to broad-band photometry of the central region of distant galaxies with the aim of measuring their redshifts. If non-thermal continuum radiation modifies the energy distribution, the broad-band photometry method does not work but the redshift can be measured from the emission lines which are most likely to be present in the spectrum.

The actual value for the redshift limit discussed above depends on many factors: some geometrical like H and q_o, others physical like the optical luminosity evolution and possibly the surface brightness evolution. As our knowledge of more and more distant galaxies increases, the parameters used in this discussion should be modified accordingly. In any case, it is evident that exciting new results on the Luminosity Function of Radio Galaxies at fairly large redshifts can be obtained from the ground before ST flies.

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* Technical Proposal - Investigation Definition Team for Wide Field/ Planetary Camera.

TABLE 1

COMPARISON OF BROAD-BAND OBSERVATIONS OF A GALAXY WITH $m_R = 22$ AT $z = 0.8$, FROM THE GROUND AND FROM SPACE.

Ground based observations:

(one arc sec for one pixel)

Number of counts per arc sec^2 per second from galaxy $N = 3$

Number of counts per arc sec^2 per second from sky $n = 22$

Signal/Noise $= \dfrac{3}{\sqrt{22 + 3}} = 0.6$ in one second integration

S/N $= 19$ in 1000 seconds integration

Space Telescope observations:

(Only the 10 central pixels which receive 1/10 of the galaxy light and correspond to 0.1 arc sec^2 are considered here).

Number of detected events, per pixel, per second from galaxy $N = 0.08$

Number of detected events, per pixel, per second from sky $n = 0.09$

Number of detected events, per pixel, per second from thermal leakage $n' = 0.1$

Number of detected events, per pixel from readout noise $n'' = 12$

In 1000 seconds, Signal/Noise $= \dfrac{80}{\sqrt{80+90+100+144}} = 4$ for one pixel

In 1000 seconds, and on 10 pixels S/N $= 4\sqrt{10} = 13$

For redshift up to $z = 0.8$, it appears to be more efficient to use the ground-based telescope described in the text than to use the Space Telescope. This result holds only if the energy distribution of distant elliptical galaxies can be well determined and if, therefore, galaxy redshifts can be measured by broad-band photometry.

Finally it is stressed that the above calculation, summarized in Table 1, is not intended to be of a definitive character. It is proposed here as a guide and a simplified example for the feasibility study of a project.

B) Other Observations of Radio Galaxies.

1- Jets and Knots. At present, a dozen radio galaxies and quasars are known to have jets and knots located in the vicinity of the nucleus or pointing toward the nucleus. Table 2 lists those which were reported in publication at the time of the conference. The most interesting of these knots and jets are those emitting non-thermal continuum radiation in both the radio and the optical ranges because they can provide clues on the transfer of particles or energy from the nucleus outwards. The number of such objects will increase in the near future because of the availability of 1) very deep radio maps and 2) digital devices for direct imaging which make it possible to subtract the usually weak signal emitted by the jet from the strong background of the stellar population. Observations with the Space Telescope will further improve the situation; firstly because observing in the ultraviolet will increase the contrast of the non-thermal jet against the stellar population, and secondly because with an angular resolution 10 times better than on the ground it will be possible to follow the jets very close to the nucleus or to observe jets in distant galaxies or quasars.

2- Weak ultraviolet excess in nuclei of elliptical and spiral galaxies will be more easily measured from the Space Telescope than from the ground because of the improved angular resolution and the possibility of observing in the ultraviolet. The interest in observing weak ultraviolet excess in nuclei of galaxies is twofold. Firstly, in the case of spiral galaxies it makes it possible to determine the faint end of the luminosity function of Seyfert nuclei (Véron, 1978). Secondly, in the case of elliptical

TABLE 2

JETS NEAR NUCLEI OF RADIO GALAXIES AND QUASARS

Object	Detection	Extent angular	Extent linear (kpc)	References
M 87	Radio + opt.	22"	2	1
3C 273	Radio + opt.	20"	90	2
3C 66 B	Radio	50"	30	3
NGC 6251	Radio	3!4	100	4
NGC 5128≡Cen A	opt.,em.lines	13'	40	5
NGC 4552≡M 89	opt.	10'	35	6
NGC 7385≡2247+11	Radio + opt.,em.lines	20"	15	7
DA 240	opt.,em.lines	16"	17	8

$H = 50\ km\ s^{-1}\ Mpc^{-1}$

References: 1) Turland, 1975. 2) Greenstein and Schmidt, 1964. 3) Northover, 1973. 4) Waggett et al. 1977. 5) Blanco et al. 1975. 6) Malin, 1979. 7) Simkin and Ekers, 1979. 8) Burbidge et al. 1975.

galaxies, it allows us to see whether a weak flat spectrum radio source is accompanied by the presence of a weak non-thermal continuum source emitting in the visible and ultraviolet ranges and undetectable from the ground.

3- Relationship between the central radio source and the emission line region in radio galaxies. This is a complex problem with multiple facets. Much progress can be expected from optical and radio observations made with the same good angular resolution; for example with the Space Telescope and the Very Large Array. Here we consider only the particular case of NGC 1052 as one of many possible examples. The emission line spectrum of NGC 1052 is interpreted as produced by gas ionized and excited by shock waves (Koski and Osterbrock, 1976; Fosbury et al., 1978). On the other hand, it has been shown by Bell (1978) that radio emission can be produced by particles accelerated in shocks and this mechanism seems to work for supernova remnants. Combined radio and optical observations with the same scale of 0.1 arc sec will permit one to test whether this model of particle acceleration works also in the case of a galaxy like NGC 1052 by showing whether the radio emission and the emission lines originate in regions exactly coinciding.

II NEBULOSITIES AROUND ACTIVE NUCLEI

There are several types of nebulosities around active nuclei, i.e. around quasars and Seyfert nuclei. Some are the size of a galaxy and are formed by stars or by clouds of ionized gas. Others have dimensions less than 1 kpc. The different types of nebulosities present different astrophysical problems which will benefit to different degrees from observations with the Space Telescope.

The current questions raised by these nebulosities and the progress expected from Space Telescope observations are outlined as follows:

Table 3

NEBULOSITIES AROUND ACTIVE NUCLEI DISCUSSED IN THIS ARTICLE

A- <u>Small Nebulosities around Seyfert nuclei</u>

1- Region intermediate between broad line region and narrow line region: a region so far unexplored.

2- The narrow line region.

B- <u>Galactic Scale Nebulosities around Quasars</u>

1- Nebulosities of stars: underlying galaxies.

2- extended nebulosities of ionized gas.

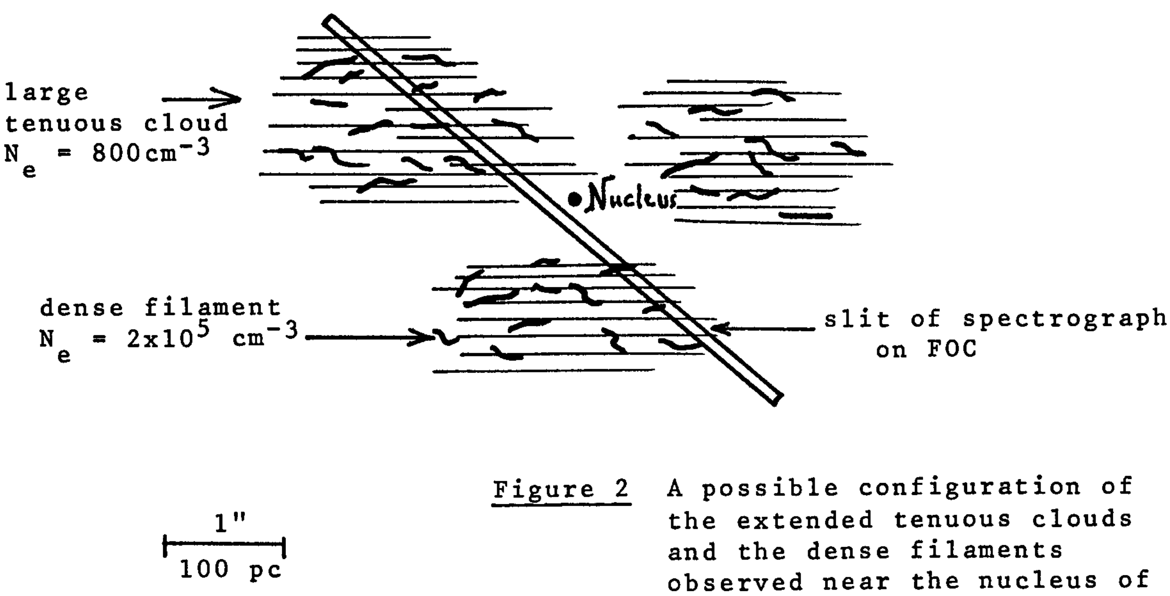

Figure 2 A possible configuration of the extended tenuous clouds and the dense filaments observed near the nucleus of NGC 1068. Other types of clouds are not shown. For details see text.

A) Nebulosities of small dimensions in active nuclei.

1- A new region so far unexplored. A new region which has not really been investigated so far will become observable with the Space Telescope in nearby Seyfert galaxies like NGC 4151. It is the region located outside the broad line region and very close to the center. The investigation of this intermediate region at 5 to 20 pc from the nucleus is very important for understanding 1) the mass loss from the broad line region and 2) the origin of the gas in the narrow line region. Because of the intense radiation field, the gas in this intermediate region can be highly ionized. Moreover, if the gas in this region is formed by debris lost by the broad line region it must have velocities intermediate between 10000 km s^{-1}, which is typical of the gas in the broad line region, and 1000 km s^{-1}, which is typical of the gas in the narrow line region; similarly its density must be intermediate between the densities of the narrow line and broad line regions, i.e. in the range 10^9 to 10^5 cm^{-3}. The physical conditions of the gas are difficult to predict because several factors affect them in opposite ways (e.g. the high photon density and the high gas density have opposite effects on the degree of ionization).

Much insight on the physical conditions in the intermediate region can be gained by studying emission lines corresponding to transitions from levels which are collisionally depopulated at high densities. The best example of such lines is [NeV]λ 1575 for which the critical density is 2×10^8 cm^{-3} (Harms et al. 1977). This line has been detected on the spectra of NGC 4151 taken with the IUE satellite (Boksenberg et al. 1978). The entrance aperture of the IUE spectrograph being 3 arc sec, the IUE spectra do not give any useful information on the location of the region emitting the NeV line, nor do they give information on the profile of the line because it appears in the wing of the very broad CIV line emitted by the broad line region. With the Space Telescope it will be possible to observe small regions 0".1 in diameter (or 7.5 pc at the distance of NGC 4151) and very close to the center. If the NeV line is found to be broader than the lines in the narrow line region, then it very probably comes from dense gas which has recently escaped the broad line region and is accumulating in the narrow line region.

2- The Narrow Line Region in Seyfert nuclei. This region has a typical dimension of 300 pc. Ground based observations show that it is inhomogeneous: Firstly, spectra taken with a high angular resolution and a high wavelength resolution (Walker, 1968; Ulrich, 1973) show that the narrow line region in NGC 1068 and NGC 4151 consists of a few large clouds which do not surround the nucleus completely. Secondly, from the spectrophotometry of the narrow line region, it is clear that these discrete clouds are themselves inhomogeneous, since with one value for the electron density it is impossible to reproduce the line intensity ratio. For example, in NGC 1068, Shields and Oke (1975) propose a model where there are dense filaments of thickness $\sim 10^{17}$ cm with $N_e = 2 \times 10^5$ cm^{-3} immersed in or adjacent to a tenuous region with $N_e = 800$ cm^{-3} which can have a dimension of 100 pc. At the distance of NGC 1068, 22 Mpc, 1 arc sec corresponds to 100 pc and with the Space Telescope, the relatively tenuous region will be resolved. It should thus be possible to obtain spectra of the tenuous region which are not contaminated by the dense filaments and also to correct spectra taken at the location of dense filaments from the contribution of the tenuous region.

Direct imaging of the central region through interference filters centered on different emission lines will give information on the distribution of the clouds with different densities. For example, it will be possible to verify the model of NGC 1068 proposed by Shields and Oke (1975) to explain the intensity of [OII] λ 3727. In this model a large fraction of the tenuous clouds at $N_e = 800$ cm^{-3} are located behind the dense clouds in relation to the central region emitting the non-thermal continuum.

To summarize, Space Telescope observations of the narrow line region in Seyfert nuclei will permit the exploration of inhomogeneities on scales 10 times finer than from the ground; these inhomogeneities being explored directly by direct imaging and long slit spectra, or being inferred from measurements of the line intensity ratios in regions 0.1 arc sec in diameter.

Finally, it is useful to remember the evident and important fact that when observing an extended object with the Space Telescope - for example the nuclear region of a nearby Seyfert galaxy - the number of photons per angular resolution element of dimension 0".1 is, on average, 100 times smaller than the number of photons in one square arc sec, which is the resolution element for ground based observations. Consequently, the regions of relatively low surface brightness, i.e. those of low electron density, will be very difficult to detect unless one adds the signal from several resolution elements. In contrast the small but very dense regions, as is probably the region emitting [NeV] λ 1575, will be easily observable.

B) Extended Nebulosities around Quasars.

1- Nebulosities of stars. At present one of the most important observational problems related to quasars is to search for an underlying galaxy associated with a quasar i.e. to search for a nebulosity which has the morphology and the absorption line spectrum of a galaxy and has the same redshift as the quasar. The larger the redshift of the quasar and of its nebulosity, the more significant the result for establishing unambiguously that quasars are in the nuclei of galaxies. Progress in this area is slow because the surface brightness of the nebulosities associated with quasars is very low. For example, the recent observation of the spectrum of the galaxy underlying the quasar 0837-12, which has a redshift $z = 0.2$, necessitated the use of some of the best equipment at present available for this type of observation - the IPCS developed by Dr. A. Boksenberg - and the Anglo Australian 4m telescope (Wehinger et al. 1978). With the Space Telescope, because of the high angular resolution, it will be possible to observe the nebulosities in quasars at larger redshifts. However, these observations will still be time consuming because the observations of the underlying galaxies will be done at essentially the same metric distance from the center as is done now from the ground for small redshift quasars.

More importantly, with the Cameras on board the Space

Telescope, it will be possible to determine the morphological types of the galaxies underlying quasars. This is an important observation even for quasars at modest redshift, z $\lesssim$ 0.5, because it will help us to understand the relationship between morphological type, radio properties and space density of radio galaxies and quasars. Radio galaxies with symetrical double radio structures and for which the morphological type is well determined are all elliptical galaxies: Are quasars with the same radio structures also in elliptical galaxies? The large majority of Seyfert nuclei are in spiral and SO galaxies which are weak radio emitters: Are radio quiet quasars also in spiral and SO galaxies?

2- Nebulosities of ionized gas. The benefit of space observations to the study of these nebulosities is not as evident as for the other nebulosities discussed in the previous sections; however it is useful to include them in this paper for the sake of completeness.

Extended nebulosities of ionized gas have been found associated with a number of quasars:

3C 48	z = 0.37	Wampler et al. 1975
4C 37.43	z = 0.37	Stockton, 1976
3C 249.1	z = 0.31	Richstone and Oke, 1977
AO 0235+164		Smith et al. 1977
III ZW2	z = 0.09	Green et al. 1978

The common features of these nebulosities are (i) dimensions between 10 and 40 kpc thus lying in the range of dimensions of galaxies. (ii) a large value for the [OIII] 5007/Hβ ratio indicating a high excitation very probably produced by the non-thermal continuum emitted by the quasar. The origin of these nebulosities is uncertain. Are they made of gas clouds ejected by the quasar? Are they formed by the gas normally found in the disk of a spiral galaxy but ionized and excited by the non-thermal source in the nucleus? Since these nebulosities have dimensions 3 to 10 arc sec, they can be studied from the ground and much progress can be made in this particular area before the Space Telescope is launched.

Acknowledgement. I would like to thank P.Crane for helpful discussions.

References

Bell, A.R. 1978, M.N.R.A.S. 182, 443

Blanco, V.M., Graham, J.A., Lasker, B.M. and Osmer, P.S. 1975, Ap.J. Letters 198, L63

Boksenberg et al. 1978, Nature, 275, 404, IUE Observations of Extragalactic Objects during the Commissioning Phase

Burbidge, E.M., Smith, H.E. and Burbidge, G.R. 1975, Ap.J. Letters 196, L137

Fosbury, R.A.E., Mebold, U., Goss, W.M. and Dopita, M.A. 1978, M.N.R.A.S. 183, 549

Green, R.F., Williams, T.B. and Morton, D.C. 1978, Ap.J. 226, 729

Greenstein, J.L. and Schmidt, M. 1964, Ap.J. 140, 1

Grueff, G. and Vigotti, M. 1977, Astr. Ap. 54, 475

Harms, R., Bartko, F., Beaver, E. and Ford, H. 1977, Investigation Definition Team; Faint Object Spectrograph for the Space Telescope.

Koski, A.T. and Osterbrock, D.E. 1976, Ap.J. Letters 203, L49

Laing, R.A., Longair, M.S., Riley, J.M., Kibblewhite,E.J. and Gunn, J.E. 1978, M.N.R.A.S. 184, 149

Malin, D.F. 1979, Nature 277, 279

Meier, D.L., Ulrich, M.-H., Fanti, R., Gioia, I. and Lari, C. 1979, Ap.J. April 1 (in press)

Northover, K.J.B. 1973, M.N.R.A.S. 165, 369

Richstone, D.O. and Oke, J.B. 1977, Ap.J. 213, 8

de Ruiter, H.R. 1978 Thesis, Leiden

Shields, G.A. and Oke, J.B. 1975, Ap.J. 197, 5

Simkin, S.M. and Ekers, R.D. 1979, Ap.J. 84, 56

Smith, H.E., Burbidge, E.M. and Junkkarinen, V.S. 1977, Ap.J. 218, 611

Stockton, A. 1976, Ap.J. Letters 205,L113

Turland, B.D. 1975, M.N.R.A.S. 170, 281

Ulrich, M.-H. 1973, Ap.J. 181, 51

Véron, P. 1978, preprint

Wagget, P.C., Warner, P.J. and Baldwin, J.E. 1977, M.N.R.A.S. 181, 465

Walker, M.F. 1968, Ap.J. 151, 71

Wall, J.V., Pearson, T.J. and Longair, M.S. 1977 in "Radio Astronomy and Cosmology", IAU Symp. No. 74, D.L. Jauncey, ed., D. Reidel, Dordrecht

Wampler, E.J., Robinson, L.B., Burbidge, E.M. and Baldwin, J.A. 1975, Ap.J. Letters 198, L49

Wehinger, P.A., Wychoff, S. and Boksenberg, A. 1978, preprint

Young, P.J., Westphal, J.A., Kristian, J., Wilson, C.P. and Landauer, F.P. 1978, Ap.J. 221, 721

M. S. LONGAIR: I make two comments on Dr. Ulrich's paper:

1. I agree that studies of the radio luminosity function are at a very intriguing stage. I would caution that there are many complications which should be taken into account. First, the identification percentages turn out to be a sensitive function of frequency. For example, M. Perryman (1979, in press) at Cambridge has shown that, in the deep radio surveys 5C6 and 7, the percentage of identification on deep 48-inch Schmidt plates is 40% for sources selected at 1.4 GHZ but is only 20% for objects selected at 408 MHZ. This difference can be attributed to sources with flat radio spectra, $\alpha \simeq 0.5 - 0.7$, being more readily identified in high frequency surveys. One can show that this result is consistent with the known correlation between low radio power (and hence "nearby" radio galaxies) and flat spectra. This result will strongly influence conclusions about changes in the radio luminosity function for galaxies. Second, the "standard" luminosity function for radio galaxies which was derived by Wall, Pearson and myself includes a substantial correction for cosmological evolution even at rather low radio luminosities. It is very important to take account of these corrections in comparing luminosity functions. I strongly recommend either, comparing observations with observations or using the same procedure (via a cosmological model incorporating strong cosmological evolution) for comparing the space densities of radio galaxies from surveys at different flux densities and frequencies.

2. Graham Hine and I (1979, in press) have found an interesting result of relevance to Dr. Ulrich's question concerning the relation between the radio and optical properties of nuclei. We have found that there is an excellent correlation between the ratio of the

radio luminosity of the central core to total radio luminosity and the width of the emission lines for those powerful extended 3CR radio galaxies with strong emission line spectra. Crudely speaking, the more activity in the nucleus, the greater the lines are broadened, either by turbulence or ejection resulting from that activity. This is evidence that there is indeed a close relation between the radio and optical properties of active nuclei, possibly of the type suggested by Dr. Ulrich.

M.-H. ULRICH: 1. We all agree that the study of the density evolution of radio galaxies must be based on samples all selected at the same - preferably low - frequency.

In figure 1, from H. de Ruiter's thesis, the evidence for the density evolution of radio galaxies comes from the fact that the density determined from radio galaxies of magnitudes 22 and 23 is 10 to 100 times larger than the density determined from radio galaxies of magnitudes 18 to 21 which are presumably closer. All these radio galaxies are in the same sample; this sample is derived from the Westerbork Background Survey. The local radio luminosity function derived by Wall, Pearson and Longair (1977, IAU Symposium No. 74) is given as an indication only.

2. Your result is very interesting. The relationship between radio and optical properties of radio galaxies and quasars is a very important and complex problem which is investigated by several groups (e.g. the recent results obtained by G. K. Miley and J. S. Miller, 1979, Ap.J. Letters 228, L55). I presented only one example; I chose it because in the case of NGC 1052, it is possible to resolve the emission line region and the radio region.

P.A. WEHINGER : Stockton, Wyckoff and I have secured absorption-line spectra of Markarian 205 ($z = 0.07$), which - depending who you talk to - is a quasar or a Seyfert galaxy.

ABOUT THE JET IN M 87.[1]

Jean-Luc NIETO asked me to present some results that he obtained with G. de Vaucouleurs from a study of the jet in M87.

After removing the galactic background, the jet presents a complex structure, presented in the slide No.1. This structure was decomposed in 11 knots with no continuous component, that is to say 3 knots more than in a previous study by de Vaucouleurs, Angione and Fraser in 1968. These new knots are located in the more confused part of the jet.

Their main result is that most of the knots are not stellar but have intrinsic structures and that their effective diameters are propertional to their distance to the center (slide No.2). This means that the matter is not only ejected but is also expanding in direct proportion to elapsed time since ejection.

The high resolution of the S.T. will allow us to confirm very highly the existence of the discrete structure of the jet, more particularly the reality of the 3 new knots and establish more firmly the relationship between the structure of the knots and the distance to the center. This will allow a better understanding of the physical phenomena involved in ejection of radio and optical matter.

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(1) by J.-L. NIETO, paper presented by J.-L. VIDAL (during the discussion of paper by M.-H. ULRICH, Wednesday 14th morning)

LONG SLIT SPECTROSCOPY WITH SPACE TELESCOPE

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INTRODUCTION

Long slit spectroscopy is an extremely valuable mode of operation on Earth based telescopes, making use, as it does, of both the spatial and spectral resolving powers of the instrument. Unfortunately the detectors chosen for the Faint Object Spectrograph and the High Resolution Spectrograph on Space Telescope, being a single line of individual diodes in each case, will render long slit work impossible. On the other hand the photon counting detector in the Faint Object Camera (F.O.C.) which is based on the Boksenberg I.P.C.S.[1], is ideal for long slit spectroscopy and has been much used in that mode on the Anglo Australian and other telescopes. Accordingly, the design team on the F.O.C. looked into the possibility of modifying the instrument slightly to include a long-slit spectroscopic option. We have found that, with very little modification, and at negligible expense to the other functions of the camera, we can include such a choice; but with one proviso. The proviso is that it be simple with none of the flexibilities such as changes in slit-width, grating angle, dispersion etc. normally available on the ground. This requires that the instrument be optimised for a certain scientific project, which we have chosen to be the spectroscopy of galactic nucleii. I would like to explain why we have chosen this project, what design parameters it leads to, and what are the expected performance and the foreseen limitations.

GALACTIC NUCLEI

Following Ambartzumian's[2] pioneering paper in the 1958 Solvay conference, we have come increasingly to the realization that galaxies may contain in their nuclei sources of radiation which can have outputs as much as 1,000 times as great as the whole remainder of the galaxy. The outputs may be variable on a timescale of days, indicating sizes of order 10^{16} cm or less, yet the secular lifetimes may be of the same order as galactic lifetimes, and in the ejection of radio jets 10^{8} years apart in time, but virtually identical in direction[3,4], we see evidence of considerable ordering and coherence.

The discovery of quasars in 1963 has led to extensive study of the properties of these nuclei but almost no understanding of the physical processes involved. It is widely accepted that massive bodies of order 10^{8} to 10^{9} solar masses are involved[5,6] and that sizes of around 10^{16} cm are to be expected.

From these nuclei emerge broad band non-thermal radiations stretching from the radio to the X-ray, and these can excite very strong optical line emission. These emission lines can have line widths as large as 30,000 km/sec in some Q.S.O.'s and Seyfert I's, be narrower than 200 km/sec in some radio galaxies, or be virtually absent as in the B.L. Lacertae objects. Beside the non-thermal radiation and gaseous emission lines, there is also an underlying stellar spectrum. Spectra of sufficient spatial and spectral resolution can be expected to tell us something of the physical and dynamical conditions close to these nucleii. What are the masses and binding energies involved? Do they rotate? Are the rotation axes aligned with other features such as the major optical or radio axes? Is mass being ejected? Are the abundances normal? How do the temperatures and densities vary as a function of radius? Is excitation by radiation, by particles, by shocks, or by what? Are dense dark bodies such as black holes involved? Is there infall? Are outlying regions affected? How far out does variability reach?

Some ground based work, much hampered by the poor spatial resolution set by seeing has already produced interesting results. For example, Lallemande et. al.[7] showed that the dense stellar nucleus of M31 rotates rapidly. Walker[8] has also shown that the emission lines in the nearby Seyfert NGC 1068 come from discrete high velocity clouds. Fosbury et. al.[9] have shown that the emission in the active elliptical NGC 1052 comes from an extended region well outside the nucleus. Disney et. al.[10,11] have found two radio galaxies with rapidly spinning gaseous discs in their cores. Miller et. al. have shown that emission in the quasar 3C 48 is extended. Simkin[12] has suggested, on the basis of her observations, that the core of at least one radio galaxy spins exactly about the radio axis. Sargent et. al.[13] have recently argued that the increase in velocity dispersion of the stars toward the centre of M87 indicates the presence there of a massive black hole.

All these observations indicate that data taken with the highest spatial and spectral resolution will be of great value in understanding the physics of nuclei, and such data can only be obtained by long slit spectra. For this reason we believe that the galactic nucleii problem alone justifies a long slit spectrographic mode on the Space Telescope, and it can go only on the F.O.C., which has the only suitable detector.

SPECTRAL RESOLUTION REQUIRED

Too low a spectral resolution will mean wastefully throwing information away. Too high a resolution will make it difficult to obtain enough photons, and reduce wavelength coverage.

One can calculate the required spectral resolution on dynamic grounds as follows. Consider a galaxy at distance D with a body of mass M in the nucleus. Then at distance R out the velocity will be given by an expression:

$$V^2/R \sim GM/R^2$$

We want to calculate the wavelength change $\Delta\lambda$ to be expected as we move one angular resolution element $\Delta\theta$ along the slit:

$$\frac{\Delta\lambda}{\Delta\theta} = \lambda \frac{\Delta v/c}{\Delta\theta} = \frac{\lambda}{c} \frac{\Delta v}{\Delta R/D} = \frac{D\lambda}{c} \cdot \frac{\Delta v}{\Delta R} .$$

Therefore $$\frac{\Delta\lambda/\lambda}{\Delta\theta} = \frac{D}{c} \frac{d}{dR} \left(\sqrt{\frac{GM}{R}}\right) = - \frac{D}{R^{3/2}} \sqrt{\frac{GM}{4c^2}}$$

Now let R correspond to n spatial resolution elements so that $R = n \cdot \Delta\theta \cdot D$, then

$$(\text{Resolution})^{-1} \equiv |\Delta\lambda/\lambda| = \frac{1}{n^{3/2}} \cdot \frac{1}{(\Delta\theta)^{\frac{1}{2}}} \cdot \frac{1}{D^{\frac{1}{2}}} \left(\frac{GM}{4c^2}\right)^{\frac{1}{2}}$$

For Space Telescope $\Delta\theta$ = 0.1 arc secs, take $M = 10^9 M_\odot$, we want n = 3 to 5 for enough information, and if we take D = 10 Mpc in order to include enough galaxies we find:

$$\Delta\lambda/\lambda = 2 \times 10^{-4} \Rightarrow 5{,}000 \text{ for resolution.}$$

Fortunately, the uncertain parameters M and D appear as square roots so a resolution of 5,000 is a very reasonable goal.

Since the highest resolution of the Faint Object Spectrograph is 10^3 and the lowest resolution on the High Resolution Spectrograph is 10^4, the F.O.C. specification conflicts with neither.

For reasons of simplicity in design we can afford only a single fixed grating which means that a working wavelength range must be chosen from the outset. We want to work on the closest galactic nucleii (< 20 Mpc) where the high angular resolution of S.T. translates into the highest spatial resolution, which means working at low redshifts. In addition, we want to work on strong narrow emission lines which will yield reasonable count rates - without undue astrophysical broadening. And in order not to waste observing time, we want to be certain in advance that such lines already exist in an object under study. All these considerations argue that the prime mode of observation should be centred round 5,000 Å, where the strong [OIII] lines at λ 4959 and λ 5007 are frequently present. In addition, this will give λ 4861 Hβ nearby in emission, and λ 5178 Mg I, a strong stellar absorption line, for velocity dispersion studies.

The F.O.C. works with one detector, the prime detector, at F/96 and the other at F/48. To keep the F/96 beam clear the spectrographic option must be sited at F/48, which means that the 25μ detector pixels are .044 arc seconds across and that only some 1,000 of them can be fitted across the detector head. With a resolution of 5,000 at 5,000 Å, this would require 2 pixels per Å and hence a total spectral average of only 500 Å at 5,000 Å, which we regard as too small. In the end we have compromised and set the resolution at 1.8 Å/pixel in the hope that the extra lines (and therefore photons) will mostly compensate for the formal loss of resolution, so that finally we can expect an effective velocity resolution of about 2,000. The projected slit is 4.2 Å wide.

The single grating then yields a range:

In 1st order = 3600 Å to 5400 Å.
In 2nd order = 1800 Å to 2700 Å.
In 3rd order = 1200 Å to 1800 Å.

The only gap is 2700 Å to 3600 Å, while the loss beyond 5400 Å is acceptable because the detector sensitivity is in any case falling away badly in the red. The orders will be separable by blocking filters in the filter wheel. Unfortunately it is very difficult to manufacture filters with good blocking in the visible but high UV transmission, so the performance in the UV with the filters in will be well down on that expected in the first order.

THE PHOTON BUDGET

The photon budget must be a worry because even at 1 arc sec resolution the surface brightness of normal galaxies is such that photons are hard to come by. To retain full spatial resolution, we want a slit only 0.1 arc sec wide, with resolution elements spaced 0.1 arc sec along it; thus the surface brightness per resolution element is reduced by 100 compared to the ground.

As a worst case, consider a canonical elliptical galaxy with a Hubble surface brightness law:

$$\sigma(r) = \frac{\sigma(0)}{(1 + \frac{r}{a})^2}$$

then for a typical gE galaxy $< \sigma(0) >$ = 16 V mag/sq.arc.sec. and $< a >$ = 100 pc. If we place such a galaxy at the distance of Virgo (20 Mpc) then $\sigma(\theta_r)$ the surface brightness as a function of angle θ_r out from the nucleus can be calculated. If we convolve this with the expected efficiency of the instrument then we find that the number of detected photons per spatial and spectral resolution element will at various angular radii out be given by Table I.

TABLE I

CALCULATED DETECTED PHOTON RATES PER SPECTRAL RESOLUTION ELEMENT PER SPATIAL ELEMENT FROM CANONICAL GALAXY

θ_r (arc sec)	r (pc)	Flux/sec x 10^3	Signal in 5 hours
0.1	10	8	144
0.3	30	6	108
0.6	60	4	72
1.0	100	2	36
3	300	.5	9
6	600	.2	4
10	1000		

Note that the object will be much brighter than the sky which will give only about 1 count per 5 hours per resolution area. Similarly, the dark count rate is expected to be very low and of order 1 x 10^{-5}/pixel/sec or about 1 x 10^{-4}/resolution element/sec, which is negligible. Observations are entirely dominated by object photon noise which means that very long observations can be added without loss of information.

The fluxes calculated in Table I are low, but by no means impossible, and they should be regarded as a minimum in most cases because:

(a) Active galaxies can be expected to have much higher fluxes in their nucleii. Nearby Seyferts typically have nuclear light $\sim 13^m$ coming from 1 arc sec^2 regions, though much of it may be non-thermal and therefore structureless.

(b) Most active galaxies have emission line fluxes 2 to 10 times the continuum values. 15% of all ellipticals and perhaps 90% of spirals have weak emission lines near their nucleii.

(c) Even for normal galaxies, the presently measured $\sigma(0)$s can only be minimum values set by atmospheric seeing, and there may be much brighter $\sigma(0)$s close in. The nucleii of the close-by galaxies M31 and M32 have $\sigma(0) \sim 12.5$ and this could be a common phenomenon.

(d) On the other hand, giant cD's tend to have $\sigma(0)$s lower than the average by 1 to 2 magnitudes, and these will be very difficult to observe without emission.

THE DESIGN (see Macchetto earlier in this volume)

The design consists of a movable mirror in the F/48 beam. The mirror, whose fail-safe position is out of the beam (therefore no spectroscopic mode if it fails) directs the beam off the tertiary on its way to the detector and sends it back off a diffraction grating and thence on to the detector. There are thus two more 'reflections' than the direct mode.

The slit, 10 sec of arc long by 0.1 arc sec wide, is fixed at the edge of the field of view of the F/48 camera. It cannot be rotated. However, the space-craft can be rolled plus or minus 30^o. For larger roll angles one will have to wait for 6 months of orbit to pass by.

There is no on-board wavelength calibration and this will have to be obtained using extended emission regions in the sky. Fortunately, in a space environment one expects the system to be stable enough for this to be possible. A typical galactic HII region should yield of order 0.1 photons/resolution element/sec in the stronger lines.

There is no on-board calibration lamp, which makes relative spectrophotometry more difficult.

The maximum detector head formats will be 1024 x 512 pixels x 8 bits or 1024 x 256 x 16.

Software will probably be provided to peak the signal where the positions of nucleii etc. are not sufficiently well-determined.

THE DATA

To give some idea of what the data will look like, Figures 1 and 2 show data I have taken with a very similar instrument and detector fitted to the Anglo Australian Telescope. Each shows the two emission lines λ 4959 and the stronger λ 5007 from the nucleii of two radio galaxies.

Figure 1 is from PKS 2048-57 (I 5063) which has a disc of highly excited gas 2 kpc in diameter rotating around the core of the galaxy. The total velocity difference across the disc is about 900 km/sec when the slit is (not in this figure) along its major axis. The spectra in both cases are about 1 arc sec apart in the vertical direction.

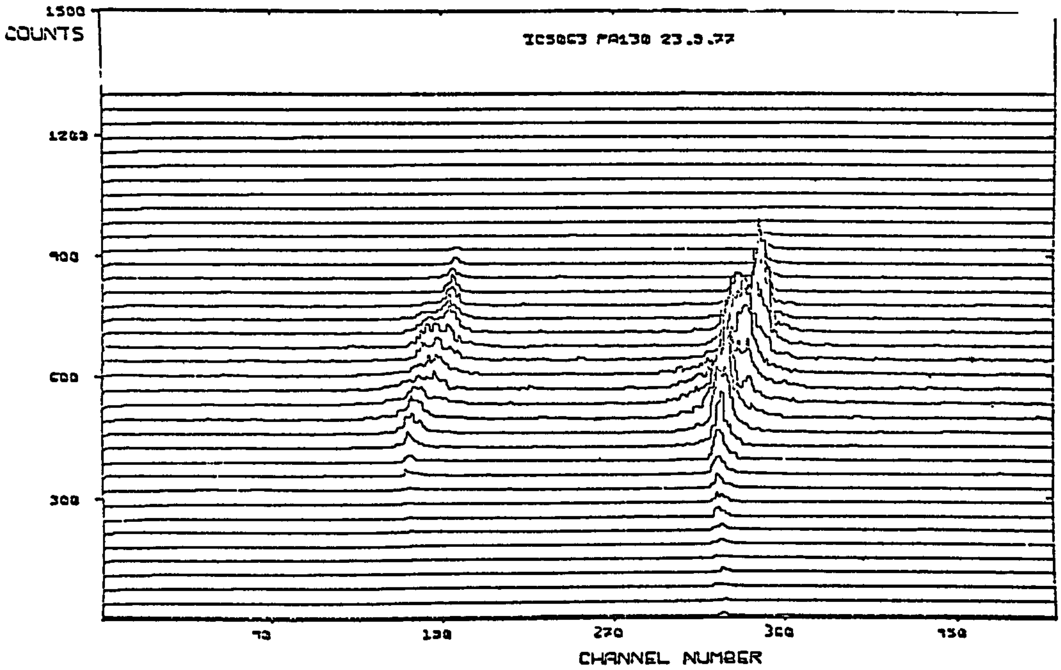

Figure 1.

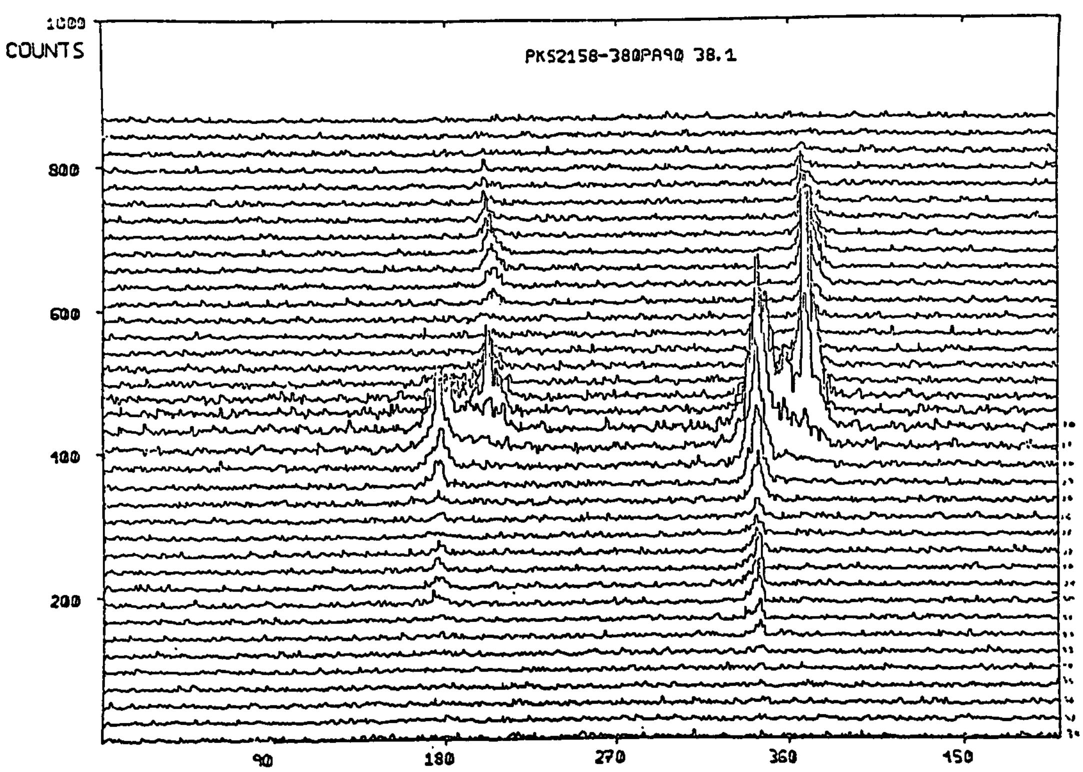

Figure 2.

Figure 2 is from PKS 2158-380, which is much more difficult to interpret, and speculations are left as an exercise for the reader.

ACKNOWLEDGEMENTS

The F.O.C. was designed by the E.S.A. project office in conjunction with the Instrument Science Team, of which I am but one member. The data shown in Figures 1 and 2 were taken in co-operation with Bob Fosbury, Mike Penston, and Andrew Wilson.

REFERENCES

1. Boksenberg, A., 1972, Proc. of E.S.O./C.E.R.N. conference: Auxiliary Instrumentation for Large Optical Telescopes, E.S.O., Geneva, 1972, p. 295.

2. Ambartsumian, V.A., 1958, Solvay Conf. Struct. Evolution Universe, 241, (Stoops R., Ed., Brussels).

3. Kellerman, et. al., 1975, Ap. J., 197, L113.

4. Readhead, et. al., 1978, Nature, 272, 131.

5. Burbidge, G.R., 1970, Ann. Rev. Astron. Astrophys., 8, 369.

6. Dibai, E.A., 1977, Sov. Astron. Lett., 3, 1.

7. Lallemande, et. al., 1960, P.A.S.P., 72, 76.

8. Walker, M.F., 1968, Ap. J., 151, 71.

9. Fosbury, et. al., 1978, M.N.R.A.S., 183, 459.

10. Disney, et. al., (in prep.).

11. Disney, et. al., (in prep.).

12. Simkin, S., 1978, Astron. and Astrophys., (in press).

13. Sargent, et. al., 1978, (preprint).

HIGH RESOLUTION IMAGERY & MEDIUM DISPERSION UV SPECTRA OF COMPACT PARTS IN PECULIAR GALAXIES, PARTICULARLY GIANT CLUMPY IRREGULARS.

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ABSTRACT: These last years, mainly in collaboration with C.Casini, we concentrated on the investigation of Markarian galaxies and more recently of Vorontsov-Vel'yaminov galaxies. We used statistical methods, 21-cm line neutral hydrogen observations, photographic or electronographic large scale plates, low and high dispersion optical spectrography and UV spectrography.
These investigations lead to topics for which we wish to obtain high resolution morphological data (with FOC) and UV medium dispersion spectra (with FOS) of high surface brightness parts of some of these objects. These topics are:
1- giant clumpy irregular galaxies; Sargent called the attention on the possibility of the existence of giant irregular galaxies. We proved their existence and singled out a class of "clumpy irregulars" characterized by UV excess radiation, a morphology made up of half a dozen high surface brightness clumps loosely scattered in a common envelope, and luminosities, dimensions and internal velocities larger than those of classical irregular galaxies. We have indications that these clumps may each be 50 times more massive than giant HII regions and be the locus of star formation on a tremendous scale.
FOC and FOS observations may provide interesting clues on the physical processes occuring in these galaxies which raise the question of whether they are a transient state in the galactic evolution- and if yes how it is produced and where from- or whether they form a different class of objects.
2- nests and chains of galaxies, galaxies peculiar as a whole, such as a "whorl", a giant double compact and a possible ex-BL Lac, and galaxies with internal peculiarities, such as double nuclei or linear strings of condensations.
FOC and FOS observations of these selected peculiar objects would bring valuable additional information on the physical processes occuring in them.

The map of figure 1 shows the structure of the irregular galaxy Markarian 325: half a dozen bright condensations scattered inside a common envelope. Similar morphologies have been observed for other Markarian galaxies: Ma 7, 8, 296, 297, 432. Note that these clumps do not belong to a multiple galactic nucleus, but are distributed over large distances.

These galaxies are bright, with absolute magnitudes from -18.9 to -21.1. They are large, with Holmberg diameters from 13 to 36 kpc. At last their 21-cm lines are wide, from 190 to 500 km s^{-1}, implying large internal velocities.

These properties, together with their UV excess (as Markarian galaxies), lead us to consider these irregulars as belonging to a peculiar class of galaxies, the <u>clumpy irregulars</u> (or <u>Ic</u>), which are giant and different with their morphology from classical irregulars.

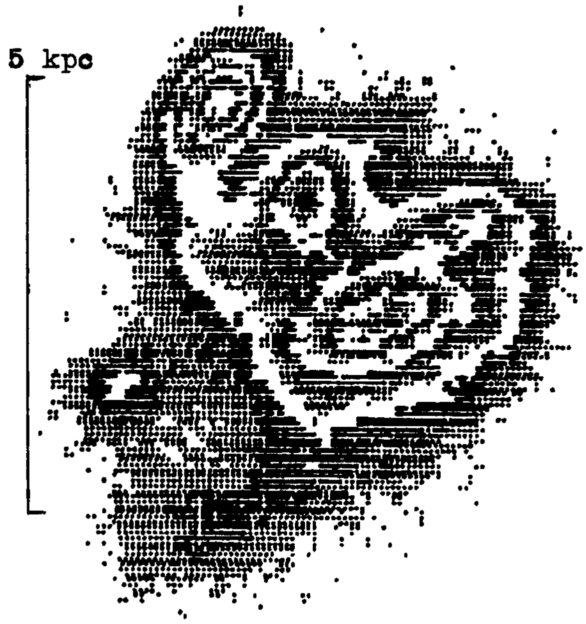

Figure 1: isodensity map of Markarian 325. 103aO plate, 23 min exposure, Cassegrain f/9 focus of the 182 cm Cima Ekar telescope. Density step 0.15.

We obtained spectra of the Ic Ma 296, of which figure 2 gives a map. Low dispersion spectra, taken at Steward Observatory, show Hα, Hβ, [OIII]λλ 4959, 5007 and [OII]λ 3727 in emission. The relative intensities correspond to a class 3-4 excitation. The high dispersion spectra of Hα from Haute Provence Observatory show a velocity gradient (figure 3).

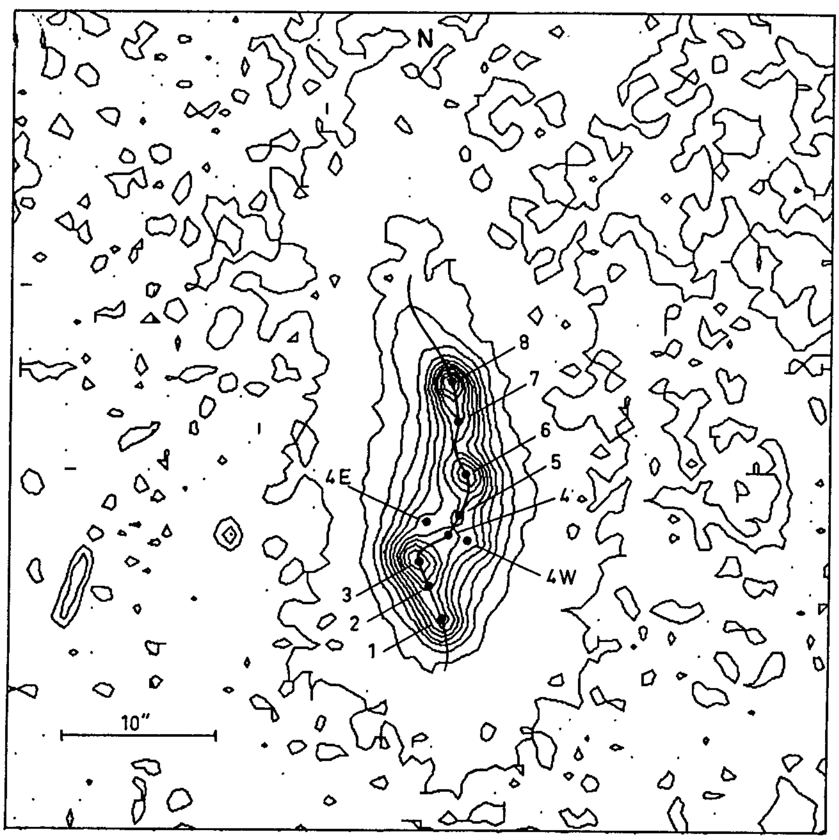

Figure 2: isodensity map of Ma 296. 193 cm Haute Provence Observatory electronograph, G5 emulsion, V filter, 60 min exposure.

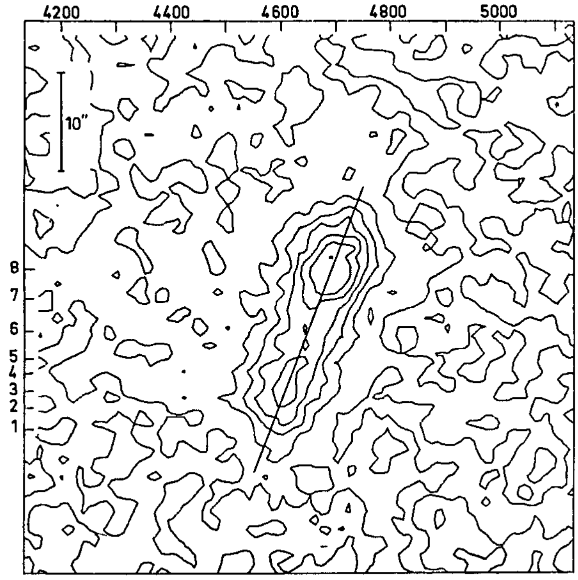

Figure 3: isodensity map of the Hα line of Ma 296. Horizontally are heliocentric velocities in km s^{-1}; the 10 arcsec bar gives the vertical scale and the 1-8 numbers the positions of the clumps as numbered in figure 2. Pellet spectrograph of the Haute Provence 193 cm telescope.

Using a simple spheroidal model this gradient gives for the total mass of the clumpy part an estimate $10^9 \odot$, which gives $1.4 \times 10^8 \odot$ per clump, or, for each, 50 times the mass of giant HII regions of the 30 Doradus or NGC 604 type.

The neutral hydrogen mass of Ma 296 is 3 times the total mass of the clumpy part; this implies that this hydrogen is more widely distributed than the optical part. This fact will be investigated with the Westerbork radiotelescope.

These clumps, with masses of the order of $10^8 \odot$, diameters of the order of 1 kpc, absolute magnitudes -16, a UV excess, a high surface brightness, emission lines and a number of half a dozen per Ic, raise the question of giant bursts of star formation and raise the problem of their triggering. Here it is out of question to invoke spiral arms.

We now work on the interpretation of IUE spectra of the Ic Ma 297.

It appears that giant clumpy irregular galaxies raise interesting questions on the origin and evolution of galaxies and that detailed morphology and UV spectrography of their clumps should be investigated. In case the clumps are indeed supergiant bursts of star formation they would be very interesting as models for primeval galaxies whose probable features have been extrapolated by Sunyaev, Tinsley and Meier from the much smaller Orion nebula.

For details on the nests, chains and peculiar galaxies we refer to our bibliography.

REFERENCES

Casini C., Heidmann J., 1976, Astron.Astrophys. 47, 371
Casini C., Heidmann J., Tarenghi M., 1979, Astron.Astrophys. 73, XX
Barbieri C., Casini C., Heidmann J., di Serego S., Zambon M., submitted to Astron.Astrophys.Supp.
Sunyaev R., Tinsley B., Meier D., 1978, Comments Astrophys. 7, 183

J. AUDOUZE : How many objects can be classified as clumpy irregular galaxies?

Is this number of objects expected to increase?

J. HEIDMANN : We know 6 of them now. They appear to be quite rare. With Barbieri we investigated galaxies from Vorontsov-Velyaminov's Second Atlas and found 2 possible Ic candidates.

Spectroscopy of Active Galaxies

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GENERAL

The Space Telescope offers basically two advantages over ground based telescopes:

(i) Improved spatial resolution

(ii) Greater spectral coverage.

This talk is mostly concerned with the second of these, reviewing a number of current research topics to which Space Telescope may be expected to contribute.

EMISSION LINES

Lines of high ionization species - eg.[FeXI] λ7892 (Grandi 1978) and [FeX] λ6374 (Penston, Fosbury, Wilson and Ward in preparation) - in Seyfert galaxies show different line profiles from lower ionization lines. It is anticipated that these lines emanate from a smaller region than other forbidden lines, probably one not resolved by Space Telescope.

Recent IUE data (Wilson, Carnochan and Gondhalekar, Nature, in press) show the continuum of Q2204-408, a quasar with Z = 3.18 continues to about 300 Å in the rest frame as a power law spectrum with $\alpha = -1.5$ ($f_\nu \propto \nu^\alpha$). Possible HeII λ304 emission is also reported. Plainly Space Telescope will obtain much better data on many more such objects.

Ultraviolet emission line ratios provide the opportunity to measure the reddenings, densities and temperatures of the nebulae in active galaxies. Examples of useful line ratios for these purposes are [OIII] λ2321 to λ4363, OIII] λ1663 to [OIII] λ4363 and SiII λ1817 to λ1190 respectively. In narrow line cases ratios of components of semi-forbidden lines may also be used for the density eg CIII] λ1907 to λ1909.

High dispersion observations (R $\sim 10^4$) will be possible for many active galaxies with Space Telescope. For example, NGC4151 would give spectra of high signal-to-noise in 15-30 minutes, compared with current rather low signal-to-noise data from an 8 hour IUE shift observation. Alternatively Space Telescope can work as faint as 17th magnitude at these dispersions.

Problems related to the anomalous Lα/Hβ found in 3C273 (Davidsen et al 1977) and other quasars Baldwin (1977) can be tackled. These include the recent claim by Netzer and Davidson (Mon. Not. R. Astr. Soc., in press) that the OI and HeII ratios λ1302 to λ8446 and λ1640 to λ4686 respectively are also discrepant.

ABSORPTION LINES

Active nuclei make excellent probes of interstellar media since compared to B-stars they possess no intrinsic absorption lines and can be seen to much greater distances!

They can be used to study the halo of our own galaxy as for example is shown by the absorption lines in 3C273 (Boksenberg et al 1978). With Space Telescope of course the ultraviolet resonance lines are accessible.

It is possible too that they can be used to probe intervening galaxies or clusters of galaxies in the same way that 3C232 has in the optical (Boksenberg and Sargent, 1978).

Absorption lines may also arise in the active galaxy itself as in the case of IC4329A which shows strong interstellar D-lines from that galaxy (Wilson and Penston, in preparation). This may also provide a means to test for the presence of λ2200 dust absorption at great distances.

Lastly the presence of absorption associated with the active nucleus itself may aid the interpretation of activities there. Examples where these kind of studies have already been made include NGC4151 (Boksenberg et al, 1978) and Mk231 (Boksenberg et al, 1977).

REFERENCES

Baldwin, J.A., 1977. Mon. Not. R. astr. Soc., 178, 67P.

Boksenberg, A., Carswell, R.F., Allen, D.A., Fosbury, R.A.E., Penston, M.V. and Sargent , W.L.W., 1977. Mon. Not. R. Astr. Soc., 178, 451.

Boksenberg, A., Snijders, M.A.J., Wilson, R., Benvenuti, P., Clavel, J., Macchetto, F., Penston, M.V., Boggess, A., Gull, T.R., Gondhalekar, P., Lane, A.L., Turnrose, B., Wu, C.C., Burton, W.M., Smith, A., Bertola, F., Capaccioli, M., Elvius, A.M., Fosbury, R., Tarenghi, M., Ulrich, M-H., Hackney, R.L., Jordan, C., Perola, C.G., Roeder, R.C. and Schmidt, M., 1978. Nature , 275, 404.

Boksenberg, A. and Sargent, W.L.W., 1978. Astrophys. J., 220, 42

Davidsen, A.F., Hartig, G.F. and Fastie, W.G., 1977. Nature, 269, 203.

Grandi, S., 1978. Astrophys. J., 221, 501.

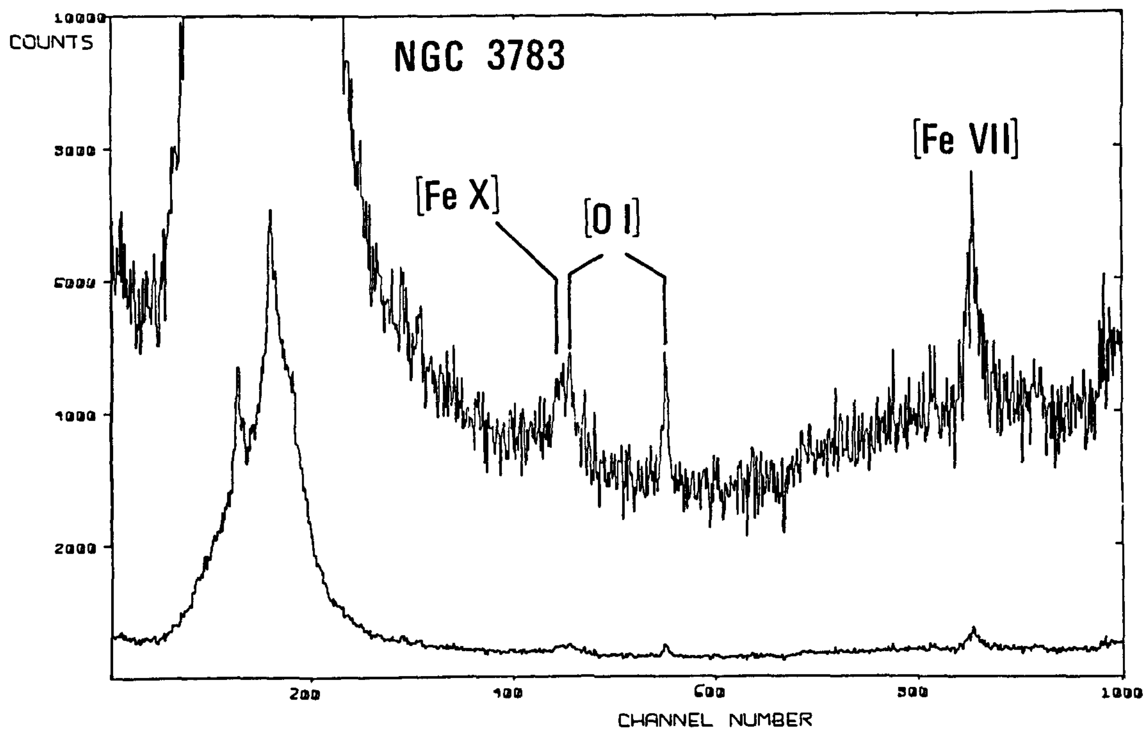

Fig. 1.

A spectrum of the southern Seyfert galaxy NGC 3783 obtained at the Anglo-Australian telescope. The data is plotted twice, once at ten times the scale of the other. Note the broad Hα line with [NII] on its red wing. The forbidden lines show a progression of increasing widths with increasing ionization as is shown by the identified [OI], [FeVII] and [FeX] lines. Possibly the [FeX] emitting region is intermediate between the usual "narrow-line" forbidden line and "broad-line" permitted line emission regions.

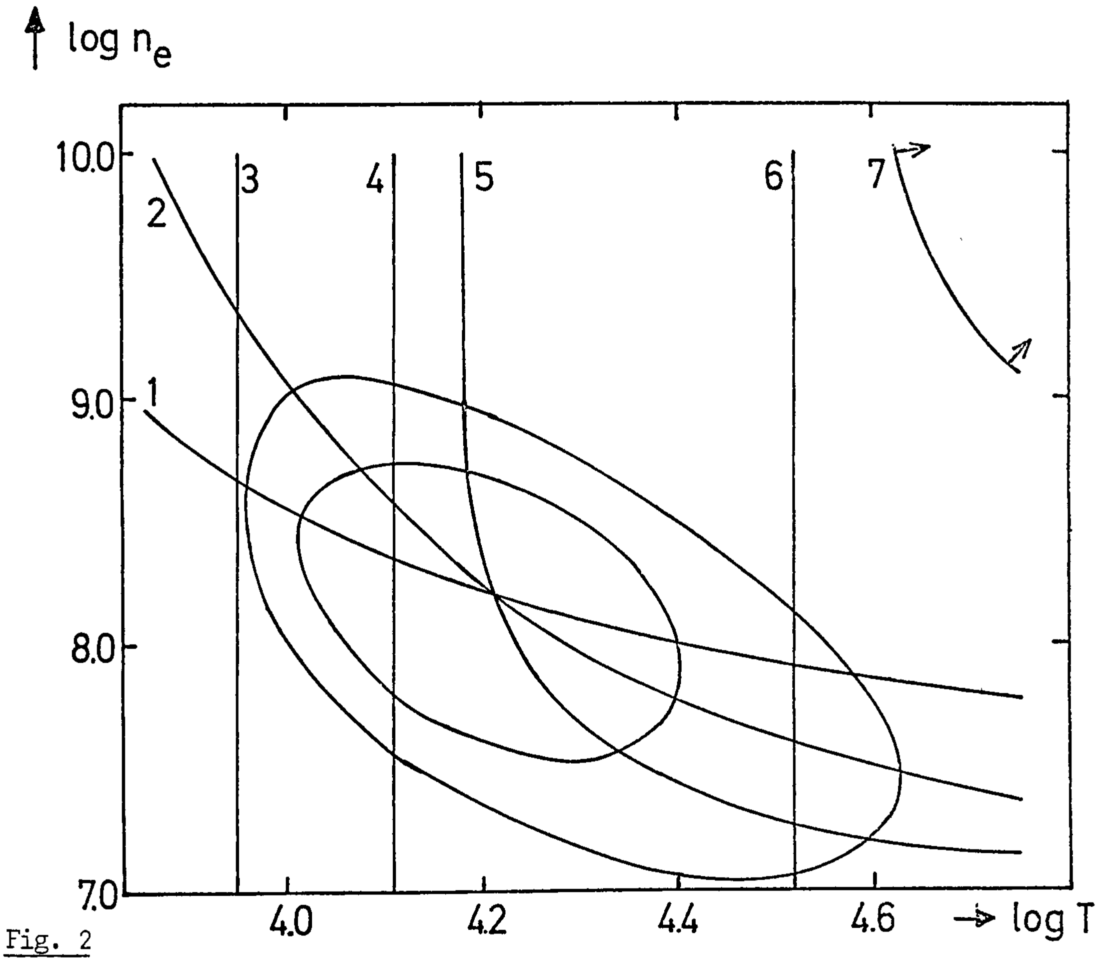

Fig. 2

The n_e - I plane for 3C273 from IUE emission line intensity ratios. The numbered curves define the loci at which various line ratios should hold their observed values. The closed ellipses are the 90 and 70 per cent confidence areas defined by the SiII and OIII line ratios after the parameter estimation methods used by X-ray astronomers.

Key to curve numbers:

1. OIII $\frac{1663}{4363}$, 2. OIII $\frac{1663}{5007+4959}$, 3. SiII $\frac{1530}{1190}$,

4. SiII $\frac{1530}{1262}$, 5. OIII $\frac{4363}{5007+4959}$, 6. SiII $\frac{1190}{1262}$,

and 7. the limit defined by the NeV ratio $\frac{1575}{3426}$.

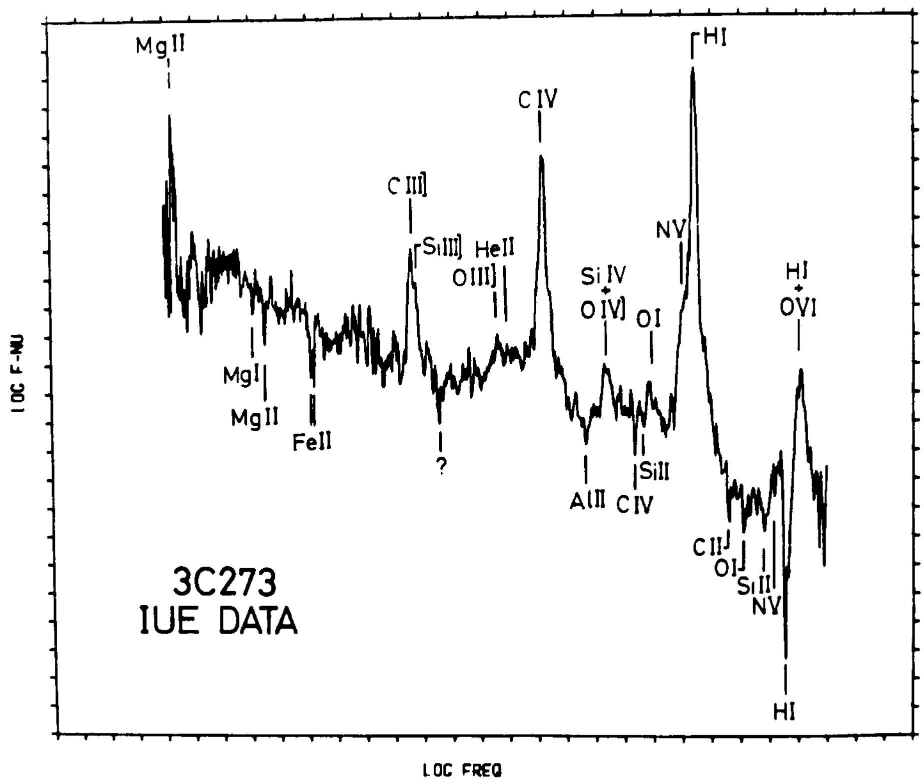

Fig. 3.

IUE data on the quasar 3C273 obtained by a collaboration of several extragalactic groups. The plotted spectrum represents the mean of many individual exposures. Note the strong absorption spectrum at zero redshift, probably originating in the halo of our galaxy. Note also the absence of strong FeII emission between CIII and MgII emissions - limits less than one hundreth of that expected from the optical emission and the branching ratios can be set.

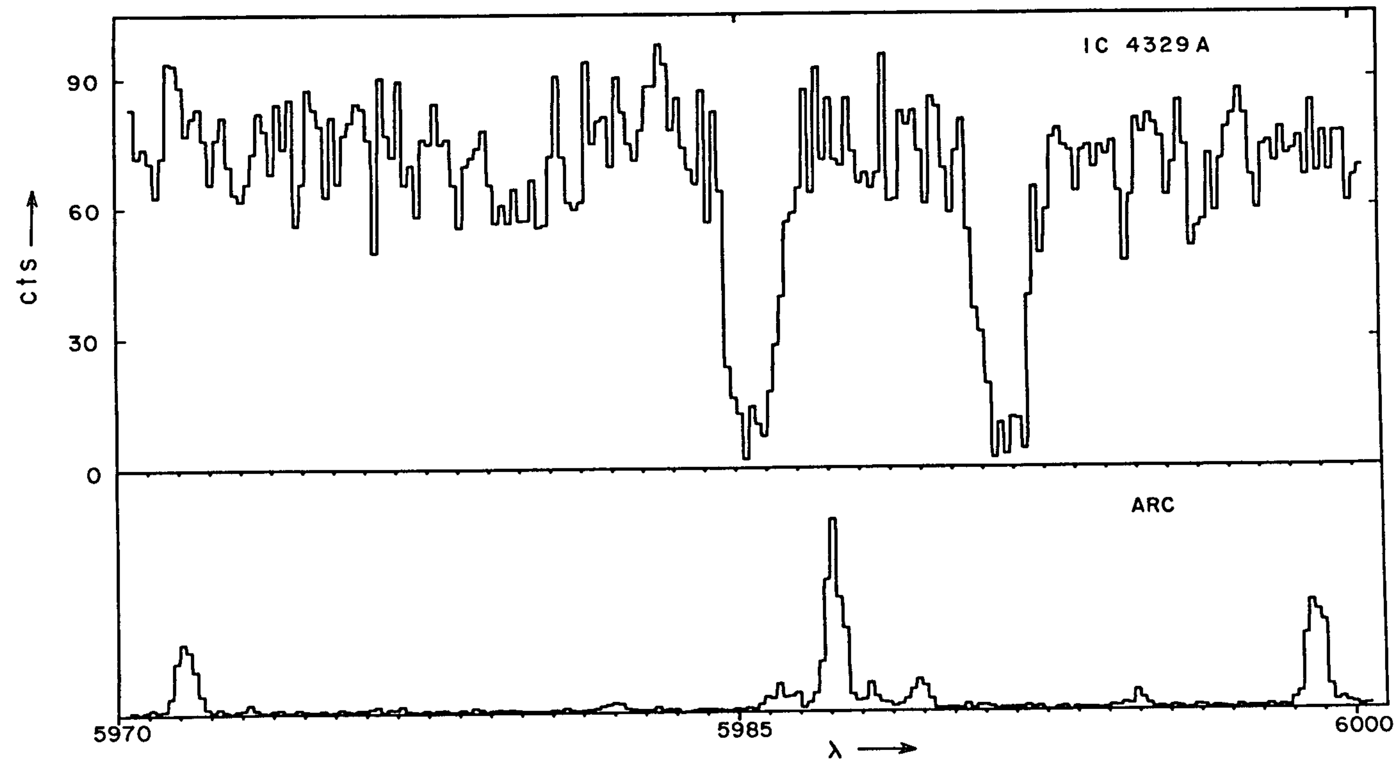

Fig. 4

The spectrum at 10 Å mm^{-1} of the 14th magnitude Seyfert galaxy IC4329A showing the D-lines in absorption. These D-lines have a redshift $z = 0.016140 \pm 0.000008$ and originate in the Seyfert galaxy. Note the equal equivalent widths indicating saturated lines which suggest $A_V \gtrsim 1.6$ magnitude. The lines are narrow (but resolved) and yield a surprisingly low velocity dispersion in the interstellar gas in IC 4329A with Stromgren's parameter $b = 9.8^{+2.2}_{-1.0}$ km s^{-1}, near its value in our galaxy.

P.A. WEHINGER : In many of the papers we have heard in the past three days, numerous speakers have required 10-hour integration times on ST to get spectra (or imaging data) of various faint objects. Since the typical integration time is limited to $\sim$ 2000 sec (or $\sim$ 30 minutes), how long will it take in practice to build up a 10-hour exposure of a single object?

C.R. O'DELL : The design requirements on ST are such that over a period of 24 hours one can come back to the same object as many times as one wants. So it should be possible to actually make observations over a continuous period of 24 hours, and then it becomes a question of how much of each orbit is useful. And the figure of about 2,000 seconds that was used on the first day is actually quite conservative. That would be an object essentially in the cpposite direction from the sun, and going anywhere but that area you would have a longer period.

ACTIVE GALAXIES at $z \gtrsim 0.5$

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LEIDEN OBSERVATORY

For several years a Leiden team has engaged in observational cosmology by means of radio source populations studies, using the Westerbork Synthesis Radio Telescope. This work has been published in dissertations (Katgert, 1977; de Ruiter, 1978) and a number of Astronomy and Astrophysics papers, listed at the end of this contribution. One rather intriguing result is the colour distribution as a function of apparent magnitude for galaxies identified with faint radio sources.

Consider our source samples, as summarized in the Table.

TABLE

The radio sample and the optical plates

SAMPLE	1	2	3
Radio Survey	BGS	BGS	3rdWbk
No.of Radio Sources	785	79	238
Plate	III a.J	III a.J	127-04
Telescope	Palomar 48"	KPNO 4m	Palomar 48"
lim. mag.	21.5	23.0	21.1
Percentage idents.			
Galaxies	11%	19%	19%
QSO's	10	22	7
Unclassified	7	6	8

Radio Flux Limit $S1.4 \gtrsim 5$ mJy

$H_o = 100 \quad q_o = 1 \quad M_b = -20.5 \quad M_r = -22.4$

The acquisition, reduction and identification of samples 1 and 2 on the one hand and of sample 3 on the other, were done independently, by different workers. The galaxy identifications were used to construct epoch-dependent radio luminosity functions (RLF). Since this requires distance determination and no redshifts are yet available, apparent magnitude was used as a distance indication, using the parameters given at the bottom of the table and applying the K-correction determined from the spectral energy distribution of elliptical galaxies as given by Pence (1976). The range of emitted luminosities is $P1.4GHz = 10^{23}$ to $10^{26.5}$ W Hz^{-1}.

One result, confirming and refining earlier findings, is the redshift-dependent number density evolution of radio sources: from $z = 0$ to $z \simeq 0.25$ there is little or no evidence for population evolution, but beyond that epoch the proper density increases rapidly, attaining enhancement factors ~30 for the most

* Now at ESO, Geneva.

powerful segment of the RLF. This result implies that either every giant elliptical was a strong radio source at $z \gtrsim 0.5$ or that these powerful radio sources were then associated with galaxies which are now more modest in *optical* luminosity.

A second result is the discrepancy noted when the RLF as determined from red plates was compared with that derived from blue plates. This discrepancy could be removed only by a z-dependent colour correction much more drastic than the K-correction implied by the adopted SED for giant ellipticals. Determining the colours of the identified galaxies using the PSS and the plate-material indicated in the table, this distribution does indeed show large departures from the standard $m_b - m_r$ vs. m_r. Its most striking feature is the blue excess of galaxies with $m_r \sim 19$ to 21, corresponding to $z \sim 0.42$ to 0.68; it amounts to two full magnitudes for a considerable fraction of the sample with $m_r \gtrsim 20$.

It is clear that our epoch is a very quiet one compared to the epoch corresponding to $z \sim 0.5 - 0.7$. We wish to know the origin of the blue excess and to discriminate between a nonthermal continuum and a large star formation burst. The former will be ultracompact and unresolved at 0".1; the region of star formation which contributes a luminosity corresponding to $M_b \sim -22$ is likely to be several kiloparsecs in extent and will therefore, at $z \sim 0.5$ have an angular size $\sim$1" easily resolved by the Wide Field Camera. Broadband 2D spectrophotometry will distinguish the alternative mentioned; if the blue excess is nonthermal continuum it may still have extended features and polarimetry will provide a further discriminant. Deep images of the WFC will show entire clusters, their galaxy colours and possibly some gross morphology as well. The deep radio surveys provide excellent search material for active galaxies and their surroundings at these epochs.

References

Katgert, P., 1975, Astron. Astrophys. 38, 87-104.

Katgert, P., 1977, Ph.D. Thesis, Leiden University.

Katgert, P. de Bruyn, A.G. and Willis, A.G., 1979, Astron. Astrophys. Suppl., in press.

Pence, W., 1976, Astrophys. J. 203, 39.

de Ruiter, H.R., Willis, A.G. and Arp, H.C., 1977, Astron. Astrophys. Suppl. 28, 211-293.

de Ruiter, H.R., 1978, Ph.D. Thesis, Leiden University.

Willis, A.G., Oosterbaan, C.F. and de Ruiter, H.R., 1976, Astron. Astrophys. Suppl. 25, 453-505.

Willis, A.G. and de Ruiter, H.R., 1977, Astron. Astrophys. Suppl. 29, 103-116.

COSMOLOGY

CLUSTERS OF GALAXIES

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A fundamental concept in modern cosmology is that the matter is uniformly distributed throughout the universe. This is true in an average computed over many thousands of galaxies. We know stars are concentrated in galaxies and their number into the space between galaxies is practically zero. The same situation seems to appear with galaxies. They are organized into clusters and the clusters tend to form superclusters with a very low density of galaxies in-between superclusters. The observational evidence of clustering is the result of few important surveys conducted with the 18 and 48 inch Schmidt telescopes at the Hale Observatory and the Lick Observatory survey using the 20 inch astrographic telescope. We have to imagine clusters or superclusters of galaxies as the "birthplace" for galaxy formation and the "home" of their evolution. Clusters are fundamental bricks of the universe and from the study of their distribution and evolution through time we have the best way to investigate the large scale structure of the universe and its history. Unfortunately only a very small number of clusters of galaxies have been studied in great detail. The discovery of a large number of X-ray sources identified with clusters of galaxies, the increase of spatial resolution and sensitivity in radio study, as well as a large number of theoretical studies have extraordinarily increased in the last few years the interest and the number of studies on clusters of galaxies.

The distribution of clusters of galaxies in the northern sky has been well studied from the examination of the National Geographic Society-Palomar Observatory Sky Survey by Zwicky et al (1961) and, for rich clusters of galaxies, by Abell (1958). Different groups have undertaken surveys of the southern sky on the ESO B sky survey, on the SRC-ESO sky survey, or on other wide field plates.

The existing surveys are exploring a very small volume of space, as a matter of fact the Abell cluster redshifts should be in the range of $0.22 < z < 0.20$.

The different properties of clusters of galaxies, such as richness, classification, galactic content, density profiles, size, luminosity function, dynamic evolution, masses, mass-to-light ratios, mass segregation, missing mass, X-ray and radio emission have been the subject of review papers in the recent years (Abell 1976, Bahcall 1977, van den Bergh 1977).

Clusters of galaxies will certainly be one of the important targets of ST but as well as for other areas of astronomical research there are limitations in the use of the ST. The basic problem of clusters of galaxies is that they are extended over large areas of sky. It is impossible to define a total "size" of galaxy clusters since the other envelope of a cluster does not exhibit a sharp edge. In literature it is possible to find different size definitions: the gravitational radius R_G, the core radius R_C, a "mean" or "effective" size, a halo size, and a dynamical size. These radii are used to describe different properties of clusters. As well as a "typical" diameter for a galaxy could be assumed to be 10 Kpc, we could think a galaxy cluster with a "typical" structure of about 10 Mpc in diameter, surrounded by a supercluster with a diameter of about 100 Mpc.

The angular size for an object of intrinsic linear diameter d is, in a homogeneous model of universe,

$$\theta = d\,\frac{H}{C}\;\frac{q^2(1+z)^2}{qz + (q-1)\;\left[(1+2qz)^{\frac{1}{2}}-1\right]}$$

where H is the Hubble constant, q is the deceleration parameter and z is the redshift of the object. Assuming $H = 75$ km sec^{-1} Mpc^{-1} and $q = 0.5$ Figure 1 presents the angular dimensions on the sky versus redshift of three typical linear dimensions used for clusters: 100 Mpc (supercluster), 3 Mpc (Abell radius) and 0.5 Mpc (core radius). In Figure 1 there are marked the typical field dimensions observable with a single exposure with a ground based telescopes: Schmidt telescope (6 x 6 degree field) prime focus of "4m class" telescopes plus triplet corrector (1 degree field) or single lens corrector (Gascoigne) (15 arcmin field diameter). It is also marked the maximum area covered by a single exposure by the WFC of ST (2.7x2.7 arcmin). From the inspection of Figure 1 it is evident the study of super-

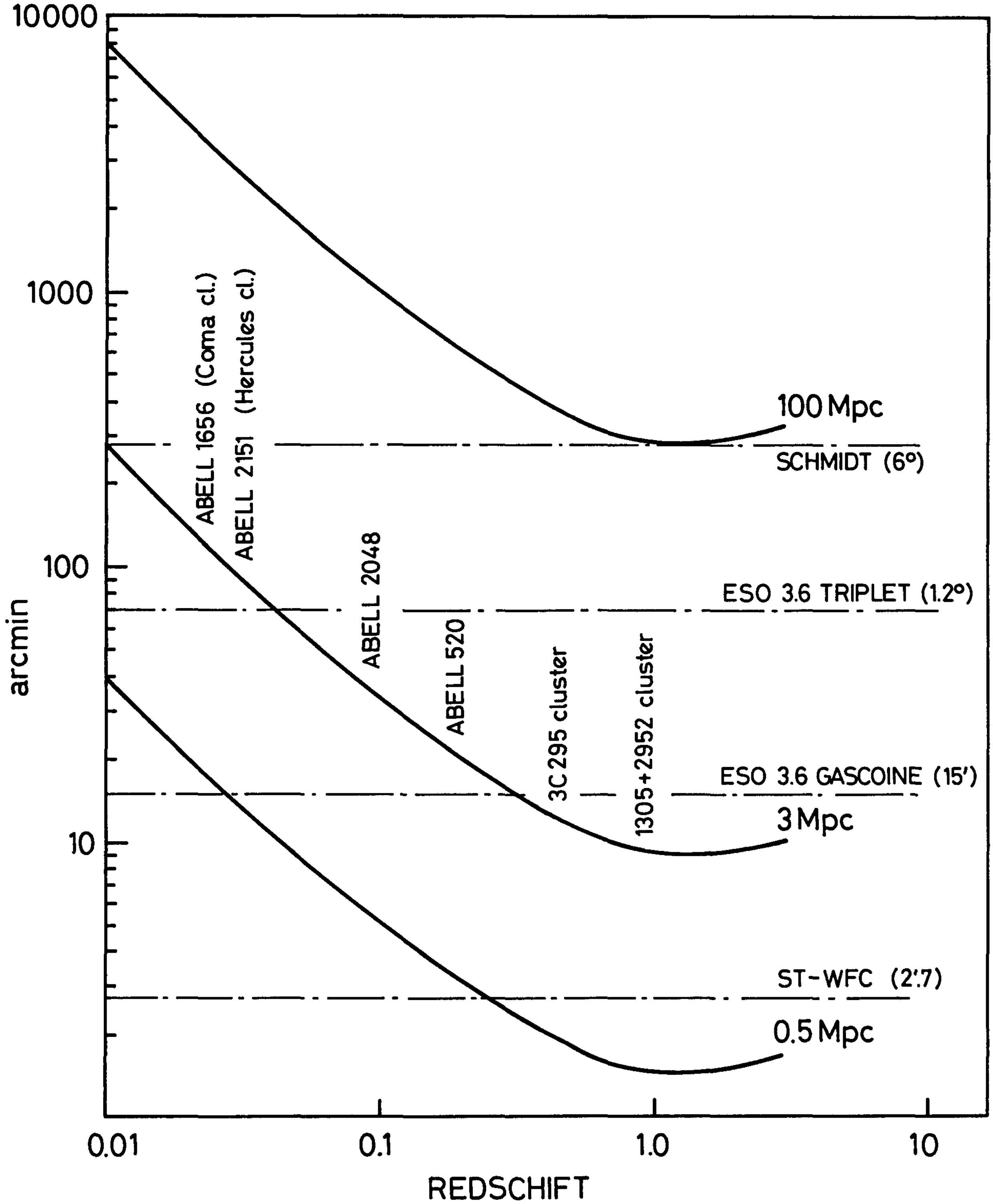
10000
1000
100
10
arcmin
0.01
0.1
1.0
10
REDSCHIFT
100 Mpc
SCHMIDT (6°)
ESO 3.6 TRIPLET (1.2°)
ESO 3.6 GASCOINE (15')
3 Mpc
ST-WFC (2'.7)
0.5 Mpc
ABELL 1656 (Coma cl.)
ABELL 2151 (Hercules cl.)
ABELL 2048
ABELL 520
3C 295 cluster
1305+2952 cluster

Fig 1

clusters of galaxies need few Schmidt plates, "4m" plates covering the region of clusters of galaxies inside an Abell radius at $z > 0.005$, and a ST picture is perfect to study the core radius region of clusters of galaxies with $z > 0.25$.
The following figures are a visual representation of the described situation. Figure 2 is the central part (16x20 arcmin) of the nearby cluster of galaxy Klemola 44 from a plate (IIIaJ + GG381 exp. 60) obtained at the prime focus of the Cerro Tololo 4m telescope. The cluster of galaxy Klemola 44 (see Maccaccaro et al 1977, and Chincarini et al 1978) detected as a X-ray source by Ariel V satellite and coinciding with a steep low frequency radio source has a mean redshift of $z = 0.0274$. The central portion is dominated by a cD galaxy and a superposed elliptical of rather high surface brightness. In the lower right corner of Figure 2 there is visible a clump of faint galaxies belonging to a background cluster with $z \sim 0.22$ (Chincarini & Tarenghi 1978, AAS Austin Meeting).
Figure 3a, 3b and Fig 4 are enlargements of Figure 2 relative to an area of 2.7x2.7 arcmin, or on the other hand three ST-WFC fields. The cD galaxy of Klemola 44 and the surrounding region could be very well studied with two pictures. The background cluster is at a distance at which it is possible to collect information over a large number of cluster members with a single exposure. From these considerations the study of clusters of galaxies with the ST has to be divided in two classes: nearby clusters $z < 0.3$ and distant clusters of galaxies $z > 0.3$.

Nearby Clusters

In the case of nearby clusters of galaxies ($z < 0.3$) the ST must be used to study individual members of the cluster. In particular ST will be of great advantage in the investigation of cepheid variable in the galaxies of Virgo cluster, globular clusters up to the distance of Coma and giant HII regions with diameter of 1000 pc will be resolved to a redshift of 0.05 (it is important to remember that Hercules cluster has $z \sim 0.03$). The imaging and spectra of galaxies of nearby clusters in the ultraviolet will provide a basic reference for comparison with systems at larger z. The study of distribution of surface brightness and colour of galaxies as a function of location of the galaxy within the cluster will be crucial to investigate for a number of physical processes such as

a) burst of star formation
b) inflow to the galactic center by metal rich gas
c) dynamical or thermal interactions within dense clusters with the intergalactic gas or direct collision between galaxies

The observations will be complementary to similar ones obtained with ground based telescopes.

Distant Clusters

A very attractive field of investigation with the ST will be the study of distant clusters of galaxies. The first problem is the discovery of such clusters. Up to now there are three methods commonly used:

a) special survey making maximum use of the deep plates now possible thanks to the new fine grain emulsions and the large field at prime focus of "4m class" telescopes
b) identification of radio sources
c) identification of high galactic latitude X-ray sources

With the ST it will be possible to take advantage of the so-called "serendipity mode". We have to remember that in a year of space telescope ($\sim$ 5000 orbits) it will be possible to get $\sim$ 2000 sets of long exposure pictures, collectively covering about 10 square degrees of sky. This area is large enough to contain a good number of distant clusters. It is known that down to $m_B \sim 24$ there are 10^4 galaxies per square degree, including about 3 rich clusters of galaxies. After the discovery it will start to study. The first step is the classification of the clusters and the individual galaxies. It will be possible to classify spiral galaxies to distances of $z \sim 0.3$ (where 0.1 sec is about 1Kpc) and to recognise galaxies of this type of even larger distance. Then it will be necessary to measure sizes, number density of galaxies, magnitudes, colours, and redshifts. This information will be used to study

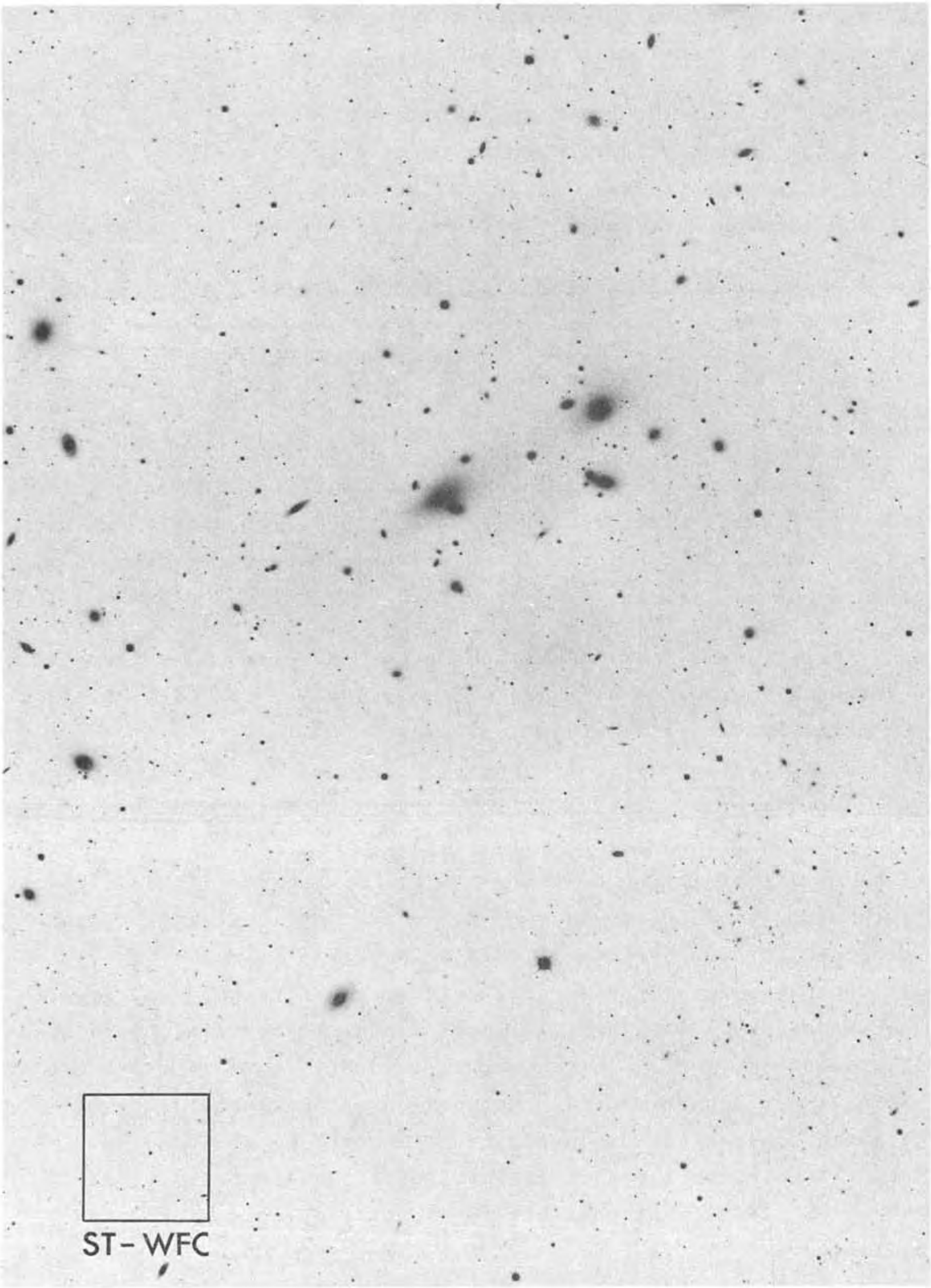

Fig 2

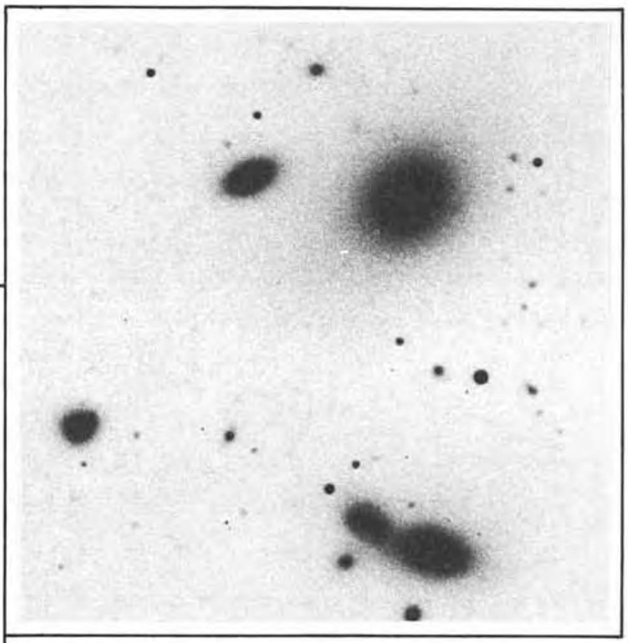

Fig 3b

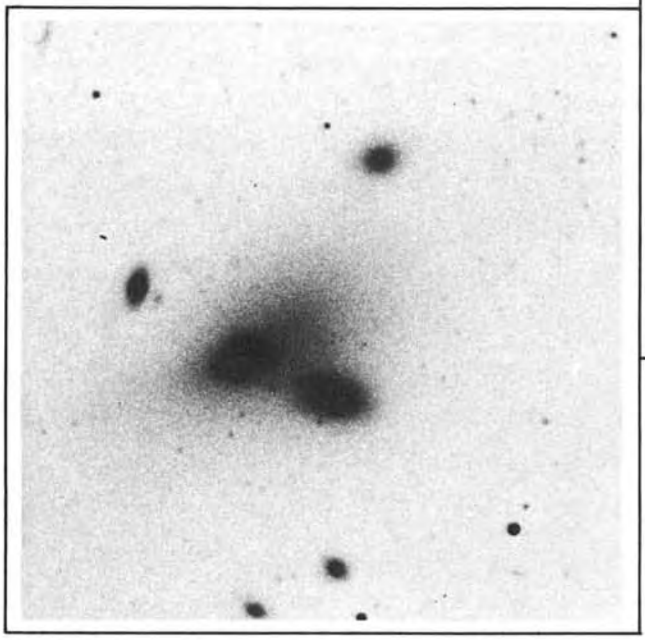

Fig 3a

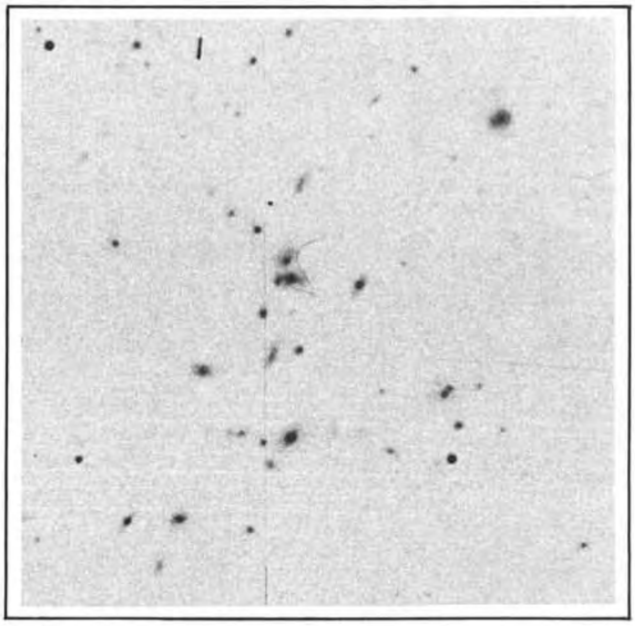

Fig 4

the problem of the evolution of galaxies inside clusters and of the clusters of galaxies as well.

Among the recent studies of this subject I would like to remember the study of Butcher and Oemler (1978) on "The evolution of galaxies in clusters", because of the importance of the results and because it is a perfect example of a possible existing work with ST. They have used a ISIT vidicon camera at the Cassegrain focus of Kitt Peak 2.1m telescope. Each frame is a square of 2.5x2.5 arcmin on the sky, practically equivalent to ST-WFC field. The system is able to reach m_V = 22 in 10 minutes. They did broad-band colour observations of giant clusters of galaxies at z $\sim$ 0.4. At this redshift the colour evolution of E galaxies is known to be small. One might expect to see more colour evolution for spiral galaxies or more spiral galaxies if SO-type galaxies are produced from spirals during cluster evolution. The study of nearby clusters shows there are very few blue galaxies in a compact (Coma-like) cluster. In the case of the two clusters of galaxies (Cl 0024+1654 and 3C295) studied by Butcher and Oemler, well known to be centrally condensed systems similar to the Coma Cluster, there are between one third and one half of the galaxies with the colours of spiral galaxies. The result needs confirmation over a larger sample to establish whether the effect is typical for the z $\sim$ 0.4 epoch and is a function of the cluster morphological type. The ST will be of great advantage because of the wide spectral range from UV to near IR and the space resolution. We need to determine whether these blue galaxies <u>are</u> really spiral and the population of compact clusters of galaxies at z $\sim$ 0.4 is similar to those of nearby spiral rich clusters like the Hercules cluster. Of course the ST will investigate the problem up to the highest possible redshifts.

Another aspect related to distant clusters of galaxies is the association between quasars or BL Lac objects and clusters of galaxies. The ST it the best tool for such investigation. The reason for studies of clusters of galaxies around QSO or BL Lac objects is not only the nature of the redshift of such objects but is the physics of the region around very luminous objects and the effects of the UV radiation on nearby galaxies. One of these possible cases is the BL Lac 3C66A studied by Butcher et al (1976). BL Lac objects are known to occur in elliptical galaxies and one might therefore expect to find these objects near the center of large, regular clusters of galaxies. 3C66A has an apparent magnitude $m_v \sim 15.4$ and on deep image tube plates there was clearly visible a swarm of faint objects nearby centered on the BL Lac object. From broad band photometry we suggest a redshift for the cluster $z = 0.37^{+0.07}_{-0.03}$. The spectrum of 3C66A shows a broad emission feature centered at 4044 Å (Miller et al 1978). If it is real and it is identified with Mg IIλ2800 the redshift is z = 0.044 and the possible association deserves more attention. If the redshift of 3C66A is correct the absolute visual magnitude is $M_v \sim -27.1$ and the total rest frame luminosity of the object is close to 10^{47} erg s^{-1}, which puts it among the more powerful QSO in total radiated power.

Conclusions

Although the small field is a limitation, ST must be used for the study of clusters of galaxies. The wide spectral range and high space resolution could be of great help in undertaking a number of fundamental problems such as:

a) is the luminosity function of the galaxies universal?
b) what is the missing mass?
c) how does the galaxy population change in cluster?
d) at what stage of the cluster formation was the intracluster gas produced? How much more massive were galaxies then?
e) are the clusters formed by gravitational clustering out of an already formed statistical sample of galaxies, or do large scale inhomogeneitis separate early in the history of the universe and form gaseous proto-clusters, which fragment and condens to form galaxies at substantially later epochs?

The answers to these questions will require a great collaborative effort between ground-based and space research. We have to remember that without a better understanding of the structure of nearby clusters it is risky to try to use their properties for clusters at cosmological distances accessible with the Space Telescope.

References

Abell, G.O. 1958 Astrophys.J. Supp.3,211

Abell, G.O. 1976, In "Galaxies and the Universe" ed. A. Sandage, M.Sandage, J. Kristian, Chicago University Press

Bahcall, N.A. Ann.Rev.Astron.Astrophys. 15,505

Butcher, M.R. and Oemler A, 1978 ApJ 219,18

Butcher, M.R. Oemler, A., Tapio,S. and Tarenghi, M. 1976 Ap.J. L 209,L11

Chincarini, G., Tarenghi, M. and Bettis, C. 1978 Ap.J 221,34

Maccacaro, T. Cooke, B.A., Ward, M.J, Penston, M.V. and Haynes, R.F., 1977 Month.Not.Roy.Astr.Soc. 180,465.

Miller, J.S., French, H.B, and Hawley, S.A. 1978, In "Pittsburgh Conference on BL Lac Objects", ed. A.M. Wolfe, University of Pittsburgh

Van den Bergh, S. 1977, Vistas of Astronomy 21,71.

Zwicky, F., Herzog, E. and Wild, P. 1961 "Catalogue of galaxies and clusters of galaxies", Calif.Institute of Technology

A. Vignato: What is your interpretation of the Butcher and Oemler B-V histogram for the galaxies of the two distant clusters studied by them (z = 0.39, 0.46)? Are the galaxies concentrated towards the centre, normal colour spiral galaxies or blue elliptical galaxies? There is some difficulty, in my opinion, to classify morphologically distant galaxies by means of ST images due to the low value of mag per arcsec achievable [22-23 mag/(arcsec)^2]

M. Tarenghi: There is a recent paper by Gisler (1979, Ap.J. 228,385) in which he tries to explain the Butcher and Oemler results. The stripping mechanism is analysed with respect to the rate of gas injected from evolving stars. The replenishment rate at different ages of the galaxies is studied as a function of initial star formation rate, initial mass function, and stellar mass loss function. Certainly the study of the colours as a function of distance from the cluster center is one of the future steps especially combined with the already mentioned "truth" morphologic classification.

Galaxy classification in distant clusters using the Space Telescope

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Abstract: Using the Faint Object Camera on the Space Telescope, the brightest galaxies in very distant clusters ($Z \lesssim 0.8$) can be classified morphologically.

The problem of galaxy evolution within clusters of galaxies has been revived recently by several observational papers. There is now increasing evidence indicating that galaxies within clusters evolve not only through dynamical interactions with their environment [1,2,3], but, if clusters are at a significant "look-back time", they even show the effects of normal stellar evolution, i.e. galaxies tend to be brighter and bluer [4,5,6]. The latter has been shown to be true for the brightest galaxies in distant clusters ($Z \lesssim 0.4$). On the other hand, the centrally located galaxies in nearby clusters are known to be ellipticals or SO's which are generally of older population. The question then arises whether the blue central galaxies found in distant clusters are not actually spirals! (At a later epoch these spirals may have interacted with individual galaxies and/or the primordial intergalactic medium to form SO's or even elliptical galaxies). It would be very useful if we could classify these distant central galaxies by the conventional visual inspection method. In this paper, we investigate the potential capability of the Space Telescope to classify galaxies at different redshifts.

Four parameters determine our ability to classify a galaxy:

(a) Its apparent size.

(b) Surface brightness.

(c) The minimum number of resolution elements needed in a particular classification system.

(d) The spatial resolution of the recording device.

The apparent size Θ_s of the brightest galaxy in a cluster is empirically related to the redshift through

$$\log\Theta_s = 0.986 \log cz + 5.331$$

which is valid[7] up to z = 0.461. Θ_s is the apparent isophotal diameter as measured visually on photographic plates in the V band. But this relation is also a good approximation for isophotal proper wavelengths as well. In the following we shall assume its validity beyond z = 0.461 (which would be equivalent to assuming a cosmological model with $q_o = +1$ for the deceleration parameter). From our experience with U.K. Schmidt plates we found that Θ_s as measured by Sandage is very close to the diameter where galaxies can be classified.

The surface brightness is proportional to $\left(\frac{1}{1+z}\right)^4$. Assuming a value of $\mu = 22$ mag/arcsec^2 as the minimum surface brightness of the most external isophote used to classify the brightest galaxy in the Virgo cluster (this is a highly conservative value), we get the normalised relation (assuming Z = 0.004 for Virgo)

$$\mu = 10 \log (1+z) + 22 \qquad (2)$$

(no K correction has been applied since at very high redshifts galaxies may have a very different image in the UV rest frame).

Now, if N is the minimum number of resolution elements needed to classify a galaxy in a classification system, and s is the size of each resolution element, then we shall be able to classify a galaxy <u>as small as</u>

$$\Theta_s \lesssim s\sqrt{N}$$

or, using equation (1a), at redshifts <u>up to</u>

$$\log cz_{max} \lesssim -1.014 \log s - 0.507 \log N + 5.407 \qquad (3)$$

which means that given N and s we can find the maximum z value where a reliable classification can still be made.

N is dependent on the classification system used. For example in the de Vaucouleurs[8] system $10^3 < N < 10^4$. On the other hand, the Hubble system need many fewer pixels since its subdivisions are wider. Furthermore, for our particular problem we need to classify galaxies only into spirals or (E + SO)'s and N can be further reduced. N will also depend on the plate scale: For an identical seeing disk of about 1.5 arcsec, galaxy images of about 10 arcsec in diameter can be classified on U.K. Schmidt telescope plates (67 arcsec/mm), while images as small as 6 arcsec were classified on a plate (18 arcsec/mm) taken on a 4-m telescope at CTIO. Assuming a pixel size of 1.5 arcsec, the number of resolution elements in each of the images will be $N \approx (\frac{10}{1.5})^2 = 45$ and $N \approx (\frac{6}{1.5})^2 = 16$ respectively. The Faint Object Camera on the Space Telescope has a larger F ratio, and N may be even reduced further.

Fig. 1 shows the relationships between s and z for N = 1000, 45, 16 as given in equation (3). The right hand scale presents the relation between μ and z as in (2). We see that given a particular seeing disk diameter s and a classifiction system (represented by N) we can determine the redshift of the brightest galaxy in a cluster that can still be classified (if its surface brightness is high enough). This graph can now be used to derive the potential capability of the ST. Some of its basic parameters as given by an ESA publication DP/PS(76)19 are:

Spatial resolution	0.1"
Spectral range	912 Å - 1 mm

S/N = 10 in 10 hours with a resolution of 0.25 arc sec on an extended source of 25 mag/arcsec^2

It can be seen from fig. 1 that for a seeing disk of 0.25 arcsec diameter we shall be able to classify the brightest galaxies up to $z \sim 0.8$ (The surface brightness will still be higher than 25 mag/arcsec^2). A larger focal ratio will improve the situation. Also a longer exposure time beyond 10 hours would improve the S/N and extend the range beyond z = 0.8. Since no K correction has been applied in equation (2) it is essential to observe the

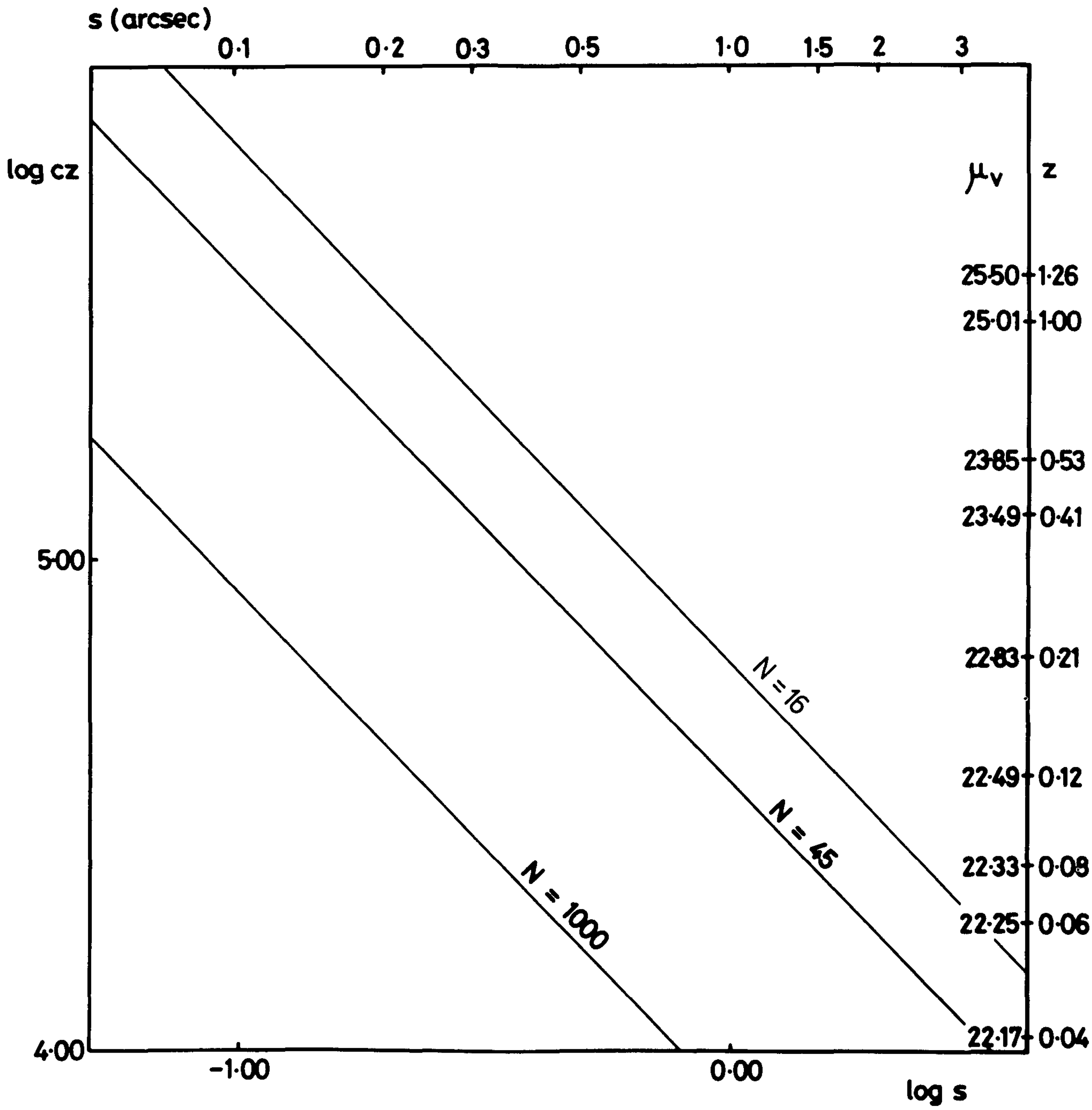

Fig. 1: The redshift z of the brightest galaxies in clusters that can still be classified morpholocially given the seeing s. The right hand scale shows also the surface brightness of an external isophote (see text) of a galaxy at each redshift.

clusters through the corresponding shifted bandwidths (if z is known). Thus under our estimates one may be able to classify those extremely interesting blue galaxies in the central regions of distant clusters.

It is also interesting to estimate the limits of large ground based telescopes for this problem. Assuming an average seeing disk of 1 arcsec diameter we shall be able to classify the brightest galaxies by the visual inspection method up to $z = 0.2$. Deconvolution methods may improve the image factor of 2 (see ref. 9) such that for $s \sim 0.5$ arcsec the upper limit for classification from ground based observations could be $z \sim 0.4$.

I thank Dr. H. Spinrad for letting me inspect his 4m telescope direct plate taken at CITO.

References

1) Melnick, J. and Sargent, W.L., Ap. J 215, 401. 1977.

2) Bahcall, N.A., Ap. J. 218, 693, 1977.

3) Tytler, D and Vidal N.V., MNRAS 182, 33P, 1978.

4) Kron, R., Spinrad, H. and King, I., Ap. J. 217, 251, 1977.

5) Kristian, J., Sandage, A. and Westphal, J.A., Ap. J. 221, 383, 1978.

6) Butcher, H., and Oemler, A., Ap. J. 219, 18, 1978.

7) Sandage, A., Ap. J. 173, 485, 1972.

8) Vaucouleurs, de, G., in Occasional Reports No. 1 of the ROE, 1977.

9) Arp, H., Lorre, J., Ap. J. 210, 58, 1976.

THE RELEVANCE OF THE SPACE TELESCOPE TO THE DISTRIBUTION OF GALAXIES

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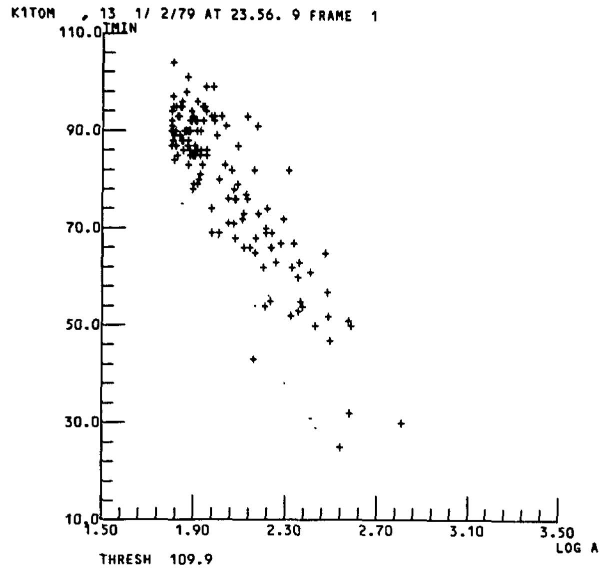
With the excellent seeing of the Space Telescope (ST), darker "night sky" and good signal to noise ratio, we shall be able to probe the "optical universe" deeper and so far back that it should then be possible to determine how it is changing with "cosmic time." The Durham group has now gained quite considerable experience in investigating deep galaxy samples with $z \sim 1/3$ and I fear that Groth's project of putting together many fields from the wide field camera (WFC) to study the distribution of galaxies as deep as the ST can probe will prove a difficult one. It is an exciting project and should be pursued, for it is a natural extension of the immense effort put into this field by Peebles and his collaborators in the U.S. and ourselves in Durham. For the galaxy correlation function, the difficulty of going very deep is the smallness of the amplitude, making it very susceptible to sensitivity variations across the field caused either by instrumental non-uniformity or, physically, by the presence of galactic and, perhaps, even extra-galactic absorbing clouds (Phillipps et al 1978). We, also, found that sampling problems became worse the deeper the sample. Indeed, even whole Schmidt plates give different results for the correlations on larger scales, $\gtrsim$ 10 Mpc.

There is, however, a more immediate and economical way of using the ST to investigate the distribution of galaxies and that is to help ground based telescopes themselves to effectively look deeper. The presence of measuring machines such as COSMOS at the Royal Observatory, Edinburgh, and APM at Cambridge and of the automatic reduction of PDS data on large computers or special purpose mini-computers is now providing a wealth of data off the excellent photographic plates that can now be taken. The first and most important step in the analysis is to separate stars from galaxies. For the fainter images the distinction necessarily becomes uncertain and the criterion somewhat arbitrary (MacGillivray et al 1976, Kron 1978). Fig. 1 shows a plot of images detected by COSMOS off a 6' x 6' area of a UK Schmidt plate , with the transmission corresponding to central intensity plotted against the area at threshold $\sim 25^{m}.2/\square''$. Fig. 2 is for an AAT plate, PDS measured and reduced by the software associated with the APM machine. Here an effective exponential profile slope is plotted against apparent magnitude. Referring to Fig. 1, we can by eye separate with certainty to a star magnitude of $m_B \stackrel{\sim}{\sim} 20^{m}.0$ (log A $\stackrel{\sim}{\sim}$ 2.0, A in units of 8μm x 8μm pixels) and with confidence to the fainter one of $\sim 20^{m}.5$ (log A $\stackrel{\sim}{\sim}$ 1.7). The ST can, obviously, help sharpen the criterion for this more mundane ground based work by offering us star/ galaxy identification to much fainter magnitudes. Theoretical angular diameter counts (Ellis, Fong and Phillipps 1977) indicate that for the Schmidt data, the log A = 2 position in Fig. 1 corresponds to the loss of galaxies through degradation of the image due to seeing. Calculations appropriate to the ST suggest that stars and galaxies can be separated to about $m_B \stackrel{\sim}{\sim} 24^{m}.5$. This easily meets the needs of work on photographic plates.

More interestingly, we would like an automated way of classifying according to morphological type the multitude of galaxies found; for example, on even a single Schmidt plate we detect more than 30,000 galaxies. This is an important task, for galaxies of different morphological types may well be distributed in space differently and, when we look very deep, their different evolutions will affect their distribution as projected on the sky. For ground based telescopes, structure is soon lost for the fainter and deeper galaxies, but we think it possible to separate types using colours and profiles. Again, some criteria like that used to star/galaxy separate are needed and, in determining them, the ST will be even more indispensable.

Fig. 1



COSMOS central transmissions vs. areas for a 6' x 6' area of a UK Schmidt plate. + denotes identification by eye as a galaxy and · as a star.

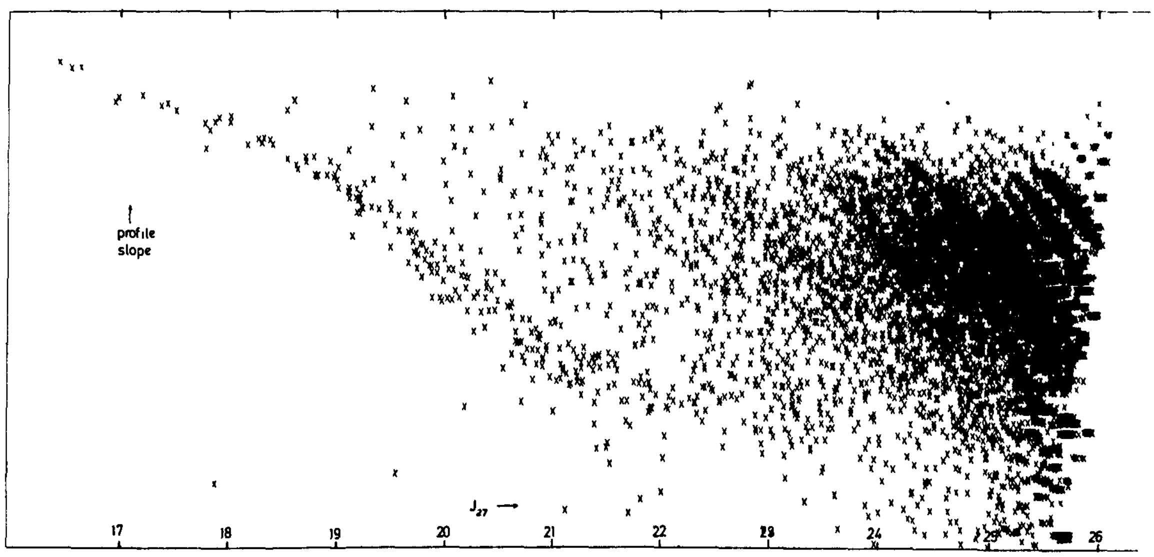


Fig. 2. Effective exponential slopes vs. magnitudes for APM data of an AAT plate.

Magnitudes are based on an uncertain blue magnitude of $23^m.0$ per $arcsec^2$ for the sky background. Present estimates, however, indicate a brighter sky $\sim 22^m.2 - 22^m.5$ per $arcsec^2$.

If we assume Freeman profiles for spiral and SO galaxies (Freeman 1971) and Abell-Mihalas profiles for galaxies (Abell and Mihalas 1966), then we can predict, for example, the central intensity vs. area plot. Fig. 3 shows this for ellipticals with $M_B = -20^m.9$ and Sbc spirals with $M_B = -21^m.1$. The decrease in intensity with area is caused by K-corrections (Pence 1976) and the $(1+z)^4$ factor difference between $d_A{}^2$ and $d_L{}^2$, where d_A and d_L are the angular diameter and luminosity distances. However, even with the small seeing of the ST, the degradation of elliptical profiles is substantial, as they are strongly peaked about the centre. To perform a simple calculation to estimate the effect on the central intensity, a "top hat" seeing with diameter 0.39" was applied and the effect is shown by the downward pointing arrows in Fig. 3. We assume that, for a measured image area large compared to the seeing, the profile is not rapidly varying near the threshold and expect then that the area is not much changed. Fig. 4 shows the result for a $\pm 4^m.0$ spread in the galaxy luminosity function. The calculation is, in fact, now being properly computed by Steve Phillipps, assuming a Gaussian form for the seeing. The results presented here would indicate that the simple measurement of profiles could well separate most galaxies into spirals/SO's or ellipticals and, used together with colours, could be a very powerful tool in the classification of morphological types.

It should be noted that no account has been taken in these computations of the complication of the profiles by the nuclei of spirals. (For further comment, see Ellis, Fong and Phillipps 1977). The calculations, however, do serve to illustrate the powerful usefulness of the determination of the distribution of galaxy profiles, another formidable task for the astronomer. But, if one can classify clearly galaxies using the ST, then it is within the capabilities of a measuring machine to determine smoothed profiles on a photographic plate. It is these smoothed profiles that are needed as standards for interpreting those of distant galaxies, as they will, in any case, be smoothed by the seeing present.

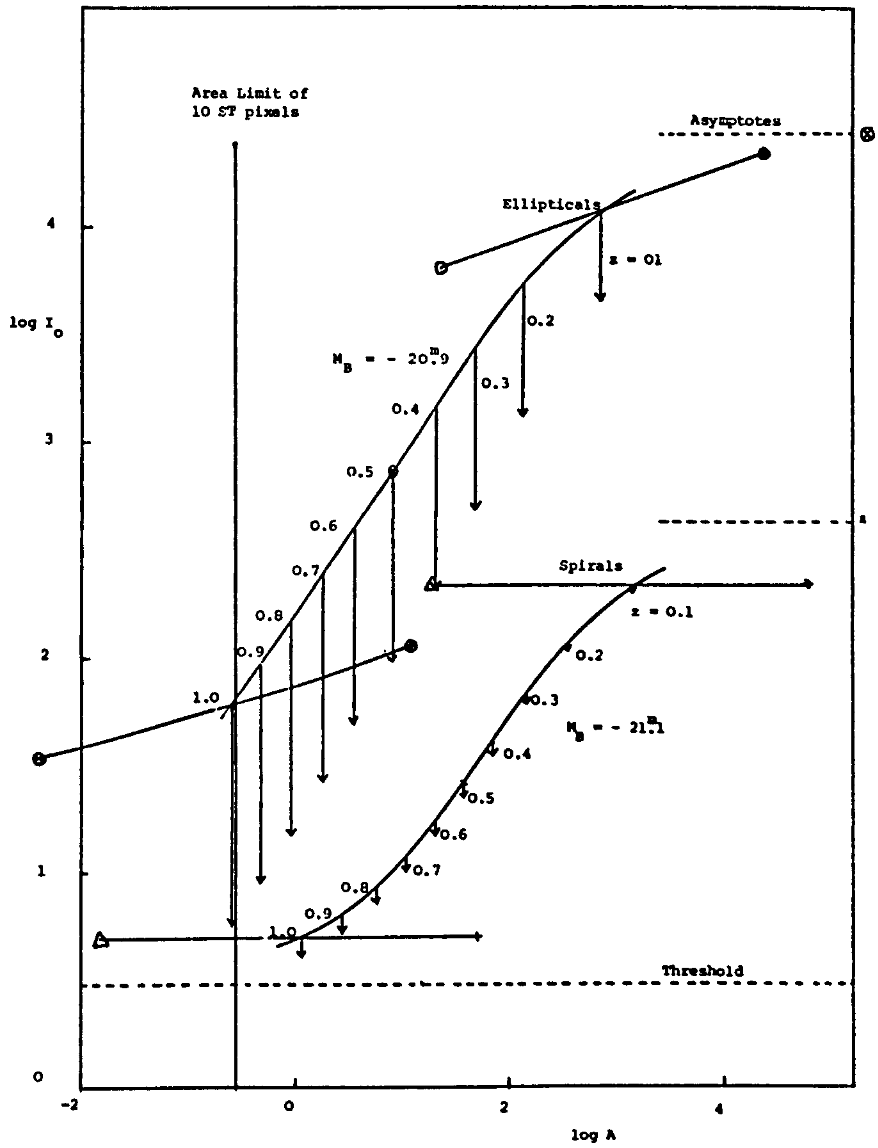


Figure 3

Predicted central intensities vs. areas. I_{sky} is normalised to 100 and m_{sky} taken to be $23^m.2$ with threshold at 3% of I_{sky}. The spread due to the luminosity function is indicated by the bars and the downward arrows give the degradation due to a "top-hat" seeing of 0.39". Points are labelled by their redshifts.

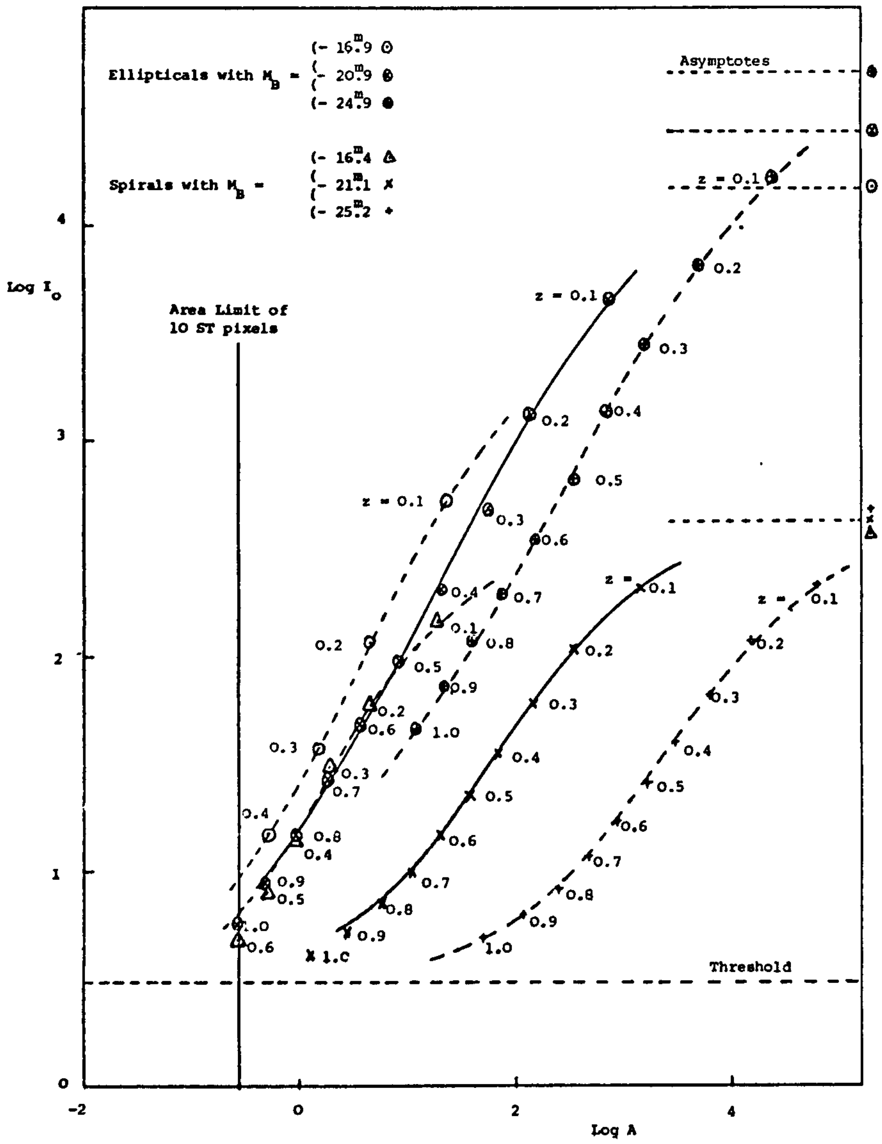


Figure 4

Predicted central intensities vs. areas with central intensities degraded by a "top-hat" seeing of 0.39". Same parameters as for Fig. 3. The curves for galaxies at the extreme ends of the luminosity function are also given.

The hope, then, is to use the WFC to classify images on one or more 3' x 3' fields within a larger field of interest, such as the South Galactic Pole, for which we have some excellent UK Schmidt plates that have already been processed by COSMOS and PDS and, soon, also by APM. They are plates that we have intensively studied and the results of our work is now being written up. The classification would then determine the boundaries separating images on plots such as Figs. 1 and 2 for the 3' x 3' fields and, by a simple process, be extended to the rest of the photographic plate: for a 48" Schmidt plate, this would classify all images in an unvignetted 4^{o} x 4^{o} area.

It is, further, impossible to give a correct cosmological interpretation of the results of the analysis of very deep galaxy samples unless the comparison distribution is extremely well determined. Perhaps, the most important elements of the distribution are the luminosity function and the K-corrections for the different types; for example, the ST is ideal for resolving the controversy over the UV spectrum of spiral galaxies. The ST offers the exciting prospect of looking very deeply into the universe, of making new and surprising discoveries. But, this is like looking at trees from the middle of the forest with a pair of very strong binoculars. To discover the large scale behaviour, we still need to determine the distribution nearby of normal galaxies and this is the quantitative scientific work the ST is well capable of doing. And this, I believe, would in the long term be the greater adventure, for we would then be in a very strong position to determine the evolution of galaxies and of clusters of galaxies, to deduce the space-time structure of the universe and lay a proper basis for a theory of the formation of galaxies. The nearby distribution of galaxies is a natural "standard" rule - at present, the only one - with which we may take the measure of the universe. I believe it to be an important scientific task to use the ST to help "calibrate" that rule.

REFERENCES

Abell, G.O. & Mihalas, D.M., 1966, Astr. J., 71, 635.

Ellis, R.S., Fong. R. & Phillipps, S., 1977, Mon. Not. R. astr. Soc., 181, 163.

Freeman, K.C., 1971, Astrophys. J., 160, 811.

Kron, R.G., 1978, Ph.D. Thesis, University of California, Berkeley.

MacGillivray, H.T., Martin, R., Pratt, N.M., Reddish, V.C., Seddon, H., Alexander, L.W.G., Walker, G.S. & Williams, P.R., 1976, Mon. Not. R. astr. Soc., 176, 265.

Pence, W., 1976, Astrophys. J., 203, 39.

Phillipps, S., Fong, R., Ellis, R.S., Fall, S.M. & MacGillivray, H.T., 1978, Mon. Not. R. astr. Soc., 182, 673.

Cosmology with the Space Telescope

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The Space Telescope collects about one optical photon per second from a 28^m object. On the other hand an optical photon has roughly a 70% chance to penetrate the atmosphere, where it is expected by considerably larger, ground-based collectors. This simple consideration shows that it is of paramount importance to make the best possible use of the specific advantages of the Space Telescope, i. e. of (1) the much higher resolving power and hence improved signal-to-noise ratio, (2) the increased range of accessible wavelengths, and (3) the somewhat reduced sky brightness (the actual gain depends on the wavelength).

In addition the very high cost of observing time with the Space Telescope ($\sim$ 4 $ sec^{-1}) requires that fundamental problems are tackled, which have no chance to be solved from the ground.

Cosmology is abundant of such fundamental problems which make heavy demands on the observations. Examples are:

- The epoch of galaxy formation (by observations of C-M diagrammes in different galaxies, the determination of the high-end redshift cut-off, and the detection of protogalaxies);
- The luminosity evolution of galaxies (by the Hubble diagramme and from galaxy counts at very faint levels);
- The luminosity and/or density evolution of radio galaxies and quasars (from counts of such objects if possible with known redshift);
- The dynamical evolution of clusters of galaxies (from the change of cluster properties with redshift).

In the following only a few specific problems are illustrated, viz. the determination of H_o, the mapping of the Hubble flow, the determination of q_o, and the nature of redshifts.

Nearly all of the cosmological programmes with ST pose a very serious problem: since it seems unlikely that ground-based observations shall provide finding lists of observable objects fainter than $\sim 24^m$, valuable time of ST has to be used, in spite of its extremely limited field of view, just to search and to detect such objects at fainter levels, where the performance of ST is a optimum. If it is proposed in the following to use ST for a search of distant objects (supernovae), it is therefore not as inappropriate as it may seem at first sight.

I. The Determination of H_O

The application of Cepheids, brightest stars, HII-regions, luminosity classes of spiral galaxies, globular clusters, the 21cm-line width/luminosity correlation, novae, supernovae, and other distance indicators has so far led to the result that $H_O = 50$. The error of that result is probably smaller than $\sim 20\%$, and in any case it is very likely that this error shall be substantially smaller by 1984, when ST will be launched.

The main error sources for the determination of H_O come presently from

1) Sampling errors (Malmquist bias and similar selection effects),
2) Uncertainties of the local calibration (since even the Hyades modulus is still uncertain at the 10% level, the calibration will be in no case better than 10%),
3) Patchiness of the galactic absorption (random variations of $\sim 0^m.2$ [cf. Sandage, 1976] shall introduce 10% errors for individual objects) and the additional problem for several distance indicators of absorption within the parent galaxy.
4) Deviations from an ideal Hubble flow (due to the random motions of field galaxies of ≤ 50 km s^{-1}, which is a nonnegligible effect for galaxies with recession velocities of ≤ 500 km s^{-1}, and to large-scale unisotropies [cf. Section II]).
5) Measuring errors and the intrinsic scatter of the distance indicators used.

In ground-based astronomy the effect of the errors under 3) to 5) can be reduced by a factor $\sqrt{n}$ by measuring the distances to n galaxies. Also the influence of the calibration error can be reduced by applying several kinds of distance indicators to obtain a mean value of H_O. This is the main reason why at present the mean value of H_O is known with higher accuracy than the distance of almost any individual galaxy. If in spite of this situation there is still considerable disagreement about the most likely value of H_0, it is almost entirely due to error source 1): neglect of or inadequate allowance for the Malmquist bias will always lead to values of H_0 which are systematically too large. There is no reason to hope that this error source, which is statistical in origin, will be remedied by ST.

From the above the consequences for ST are clear: presently known distance indicators cannot provide the distance to any individual galaxy with an accuracy of better than say 15% (because of 2) and 5)) and the corresponding value of H_0 shall carry (because of 3) and 4)) an even larger error. Therefore a fundamental improvement of the present situation can come only if also ST shall apply the method of averaging over n galaxies, which is extremely demanding on the necessary observing time. Three examples, involving RR Lyr stars, very red supergiants, and Cepheids, should illustrate the difficulty.

Photometry down to 20^m of RR Lyr stars has provided a distance modulus of $19^m.0$ for SMC (depending on assumptions about their absolute magnitude and internal absorption; Graham, 1975). Going to 27^m, requiring already 2000 sec of integration per exposure with the WFC of ST, would reach therefore to a distance modulus of $26^m.0$, corresponding to a mean recession velocity of 80 km s^{-1}. To obtain H_0 with a random error of 10% then requires, - assuming random motions of field galaxies of ~ 50 km s^{-1}, - the observation of RR Lyr stars in 40 galaxies, which is far in excess of the field galaxies known within that distance interval (Kraan-Korteweg and Tammann , 1979). In view of this obstacle it is not necessary to discuss the number of exposures necessary to derive periods and colours (to allow for internal absorption) and the systematic effect which the Local Group is expected to have on the Hubble flow of such local galaxies.

Baade and Swope (1963) have derived an apparent distance modulus of $24^m.8$ from the photometry of Cepheids down to 22^m; the internal accuracy of this distance determination is generally accepted to be $\sim 10\%$. Their result is based on 20 Pop. I Cepheids which were found in a outlying and hence rather absorption-free field of 12' radius. Therefore ST could reach by photometry to 27^m to a distance modulus of $29^m.8$, i.e. ten times more distant than M 31. At this distance the field of the WFC is only slightly larger than the M 31 field and one would consequently expect to find $\sim$ 25 Cepheids. Within the accessible distance range lies M 101 and its companions. While this galaxy is an important mile stone in the extragalactic distance scale (it is probably the nearest supergiant spiral) and its distance to within 10% of great interest, this single galaxy (or group of galaxies) is far from yielding an overall value of H_0 within the same accuracy. But already this modest aim is quite time-consuming: the WFC reaches 27^m within an accuracy of $0^m.07$ in ~ 2000 sec (Westphal et al., 1978); about 25 such exposures are needed to derive periods and additional ~ 5 exposures in a different colour are needed to control the effects of internal absorption and of the finite width of the instability strip. - This example demonstrates that a good Cepheid modulus for the Virgo cluster, - at roughly three times the distance of M 101, - may exceed already the possibilities of ST. In addition the accuracy of H_0 derived from a Virgo cluster modulus is limited by three factors: (1) the calibration error of the period luminosity-colour relation which, as already mentioned, amounts to ~ 10%; (2) the error of ± 60 km s^{-1} of the mean velocity of the Virgo cluster; and (3) the expected infall motion of the Local Group toward the Virgo cluster.

Very red supergiants have apparently in (late-type) galaxies a very stable maximum brightness of $M_V = -8^m.0$ and $M_B \geq -6^m.0$ (Sandage and Tammann, 1974; Humphreys, 1978), and because of their extreme colours they are easy to discover. At a velocity of $v_0 = 3250$ km s^{-1} they would appear at $V = 26^m$ and $B = 28^m$. Good V-photometry (± $0^m.06$) could be obtained in 1000 sec of integration, and since the B-magnitude is only needed to ensure that $(B-V) \geq 2^m.0$ about 2000 sec of integration in B are sufficient. The WFC covers at that distance the inner 25 kpc, i.e. essentially the whole optical spiral structure of even a large spiral galaxy and therefore almost the entire population of very red supergiants. From this it is clear that the very red supergiants are ideally suited for the WFC: they are still accessible at distances where whole spiral galaxies can be sampled.

The photometry of the very red supergiants in 50 galaxies would require 50 x 8000 sec or with three exposures per galaxy, - to obtain some control over the variability of these stars, - about 225 x 2000 sec of WFC time. This would yield a value of H_0, the error of which should be entirely determined by the calibration of the maximum luminosity of very red supergiants. Unfortunately this calibration, being still quite poor in our Galaxy, depends entirely on the counterparts in our neighbour galaxies, which automatically introduces a 10% error.

These examples seem to suggest that even an expenditure of the order of 100 x 2000 sec, corresponding to the useful ST time of roughly two weeks, cannot yield H_0 to an accuracy of better than 10%. Because this accuracy shall also be the aim of ground-based observations during the coming years, ST shall not be without competition in the determination of H_0. This is not to say, however, that ST shall have no influence on H_0: through galactic programmes the luminosity calibration of, e.g., Cepheids and RR Lyr stars shall almost automatically be improved (a programme, however, which could also be achieved by an astrometric satellite like HIPPARCOS), and via these variables the calibration uncertainty of secondary distance indicators in nearby galaxies could hopefully be reduced below 10%. This improvement would then perpetuate through the whole distance scale.

II. The Mapping of the Hubble Flow

The homogeneity and isotropy of the local expansion field or any deviations thereof have cosmological significance in several respects:

1) Knowledge of the relative flow pattern allows any individual determination of H_0 to be tied into the general field and such to be transformed from a locally relevant value into the global value of H_0.
2) The slow-down of the nearest galaxies outside of the Local Group yields a determination of its mass.
3) The variation of the expansion rate due to density fluctuations is directly related to the mean mass density in the universe (Sandage et al., 1972), and hence the observation $dv_0/d\rho$ leads directly to Ω (provided the visible mass reflects the true clumpiness of the total mass).
4) The presently suggested motion of the local standard of rest with respect to the 3 K background radiation (Smoot et al., 1977) raises the question as to the size of the co-moving volume, and the answer would only follow from a mapping of the Hubble flow.

It should be stressed that a meaningful mapping of the expansion field is obtained from only relative distances; the absolute value of H_0 is needed only as a scale factor. The limitations of the accuracy of H_0 due to calibration errors (as discussed in Section I) therefore do not apply for the determination of the local expansion field. Correspondingly the potentials of ST have here a more direct application.

From presently available data the Local Group seems to be non-expanding (Yahil et al., 1977). Deviations of the nearest field galaxies from an ideal Hubble flow are not yet detected. For field galaxies the deviations dH/H_0 seem to be ≤ 0.15 everywhere (Sandage and Tammann, 1975), and this upper limit holds even if the best known deviation from an ideal flow (Rubin et al., 1976) is taken at face value. Beyond $v_0 \approx 5000$ km s^{-1} this limit is well established by the Hubble diagramme of first-ranked cluster galaxies (Sandage and Hardy, 1973; Kristian et al., 1978; cf. also Weedman, 1976). Even in the neighbourhood of clusters the slow-down of the expansion seems quite moderate; in any case the peculiar motion of the Local Group toward the Virgo cluster centre is < 200 km s^{-1}, which already implies $\Omega << \Omega_{crit}$ (Tammann et al., 1979). Particularly a local motion of 600 km s^{-1} within the Local Supergalaxy seems impossible, and therefore the measured background anisotropy would require that a volume at least of the size of the Local Supergalaxy were co-moving. However, in the direction of this motion there is no obvious density enhancement, which could have induced it, and therefore the motion, - in spite of its unexpected size, - should perhaps be related to primordial currents (Yahil, 1978).

From this at least two applications for ST are obvious: (1) the relative distances of the roughly 20 galaxies with measurable redshifts near the periphery of the Local Group can be determined from RR Lyr stars with high accuracy. Because of the abundance of these variables a single field per galaxy should be sufficient. This field should be exposed several times to determine the periods and colours. The same project can be tackled from the ground using very red supergiants or Cepheids, but the advantages of RR Lyr are that they can be found in Pop. II and Pop. I galaxies and that they may well have an exceptionally small luminosity dispersion. (2) The very red supergiants $3000 \leq v_0 \leq 4000$ km s^{-1}, as discussed in Section I, could give relative distances to 50 or even 100 galaxies with errors of $\sim 10\%$, and these should give a solution of the motion of the local standard of rest to within ≤ 50 km s^{-1}. This would be significantly better than anything one could obtain from the ground for such a distant frame of reference, and would provide a much better understanding of the "local" expansion field and of the true nature of the anisotropy of the 3 K background radiation.

III. Supernovae, q_o, and the Nature of Redshifts

Present data suggest that SNe of Type I in E (and S0) galaxies are at maximum light very good standard candles. The observed magnitude dispersion amounts to $\Delta m_{pg} = 0^m.4$, but the true dispersion is certainly smaller and possibly vanishingly small (Tammann, 1978). SNe I in other types of galaxies suffer from internal absorption, as do SNe II, and they exhibit therefore a much wider luminosity scatter at maximum (cf. also Branch and Bettis, 1978).

Brightest cluster galaxies are known to undergo luminosity evolution which disqualifies them for the determination of q_o. Their rôle as standard candles could be taken over by SNe I in E/S0 galaxies, because the explosion of a Type I SN, whatever its origin may be, seems to be a physically well defined event, which is not expected to vary with time. However, SNe I are 3^m fainter at maximum than brightest cluster galaxies, and it is this property which makes them ideal objects for ST.

The potentials of SNe as cosmological probes are apparent from Table 1, where some of their relevant properties are compared with those of brightest cluster galaxies.

Before persuing the main line of our argument any further, it is important to investigate, if sufficient SNe I in E/S0 galaxies can be found at cosmologically useful distances, say at z = 0.5.

The SN Search: The faintest SN found so far from the ground has $\sim 20^m$. From this it is clear that SNe at 24^m, corresponding to the maximum magnitude at z = 0.5, must be searched with ST ! In that case one has to ask, where the highest SN I frequency per $(\text{arcmin})^2$ can be expected. This is clearly in rich clusters. These clusters have in addition the most welcome property of providing almost exclusively the subtype of SNe of interest here: with essentially only E and S0 galaxies these clusters cannot yield anything but absorption-free SNe I. There is yet another advantage to concentrate on clusters: if the parent galaxy of a SN happens to be too faint to obtain its redshift, - from the ground

Table 1

First-ranked Cluster Galaxies and SNe I in E/S0 Galaxies as Standard Candles

	First-ranked gal.	SNe I (in E/S0)
difficulty of surface photometry	yes	no
luminosity evolution	yes !	no
dynamical evolution	yes	no
selection effects (Malmquist bias)	yes	controllable [1)]
imperfect imaging of a realistic universe [2)]	yes	little
intergalactic absorption	yes	yes
M_V	$-23^m.2$	$-19^m.7$
$\sigma (M_V)$	$0^m.3$	$< 0^m.4$!
m_V (at z = 0.5)	$20^m.5$	24^m [3)]

1) At least in principle a comparison between expected and observed SN numbers yields the influence of any possible magnitude bias.

2) Cf. Zeldovich, 1964; Kantowski, 1969; Dyer and Roeder, 1973; Refsdal (1970). - In the absence of background the effect is negligible for the photometry of point sources.

3) The same K-correction is here assumed as for first-ranked cluster galaxies. Actually a smaller K-correction is expected for the hot SNe at maximum, and therefore 24^m is a safe fainter limit.

or from ST, - the cluster redshift can also be obtained from the brightest cluster members (which are several magnitudes brighter than the SN).

At z = 0.5 the field of the WFC corresponds to a circle of 0.64 Mpc radius. Within that radius a cluster like the Coma cluster contains $5 \cdot 10^{12}$ $L_\odot$ (Abell, 1975; Rood et al., 1972; King, 1972). The SN frequency in E/S0 galaxies amounts to 0.16 SNe $(10^{10} L_\odot)^{-1}$ $(100\ \mathrm{yr})^{-1}$ $(1 + z)^{-1}$ (Tammann, 1978), or to 0.5 SNe I per year per cluster at z = 0.5. (We make here the reasonable assumption that the SN I frequency has remained essentially the same during the last few billion years). An ST survey of 50 Coma-like clusters at z = 0.5 would therefore yield 25 SNe I per year with an estimated uncertainty of a factor 2.

From the standard B-light curve of SNe I (Barbon et al., 1973) one finds that a SN remains within 1^m of its maximum brightness for 25 (1 + z) days, i.e. at z = 0.5 it is brighter than 25^m for 38 days. About 40% of all SNe I with $m_B < 25^m$ discovered at z = 0.5 shall be at pre-maximum, for the remaining 60% the maximum B-magnitude can be restored within $\sim 0^m.2$ from the standard lightcurve. Very similar numbers would result if the V-magnitudes were considered. It is therefore sufficient if each cluster is searched down to 25^m once per month.

A 25^m object can be detected with the WFC with a signal-to-noise ratio of 7 within 100 sec of integration. The background noise of the parent galaxy shall reduce the photometric accuracy, especially in the inner regions, but it shall hardly affect the discovery chance. Therefore 12 100 sec-exposures of each of the 50 clusters, resulting in 25 sufficiently fresh SNe I, will require 30 x 2000 sec of actual observing time, which corresponds roughly to 4 days of telescope time. This is indeed a modest price for the goals described in the following.

The Hubble Diagramme of SNe:

The apparent magnitude of standard candles at z = 0.5 differs, after K-correction, by $0^m.25$ for the case $q_o = 0$ and $q_o = 0.5$ (Sandage, 1961). If the intrinsic magnitude dispersion of SNe I at maximum is $0^m.2$, it is therefore possible to distinguish with only six SNe between a Euclidean and an open universe at the 3 σ level. Even if the intrinsic dispersion were as high as

$0^m.4$ the same result could be obtained from 25 SNe.

It should be noted that the determination of q_o from the Hubble diagramme requires only apparent magnitudes (in addition to redshifts) and that it is therefore independent of H_o. However, it is not sufficient to have a number of SNe at $z = 0.5$ to determine the curvature of the Hubble line. Rather a number of SNe at small and intermediate redshifts with uniform photometry are needed in addition. The search for these additional SNe I in E/S0 galaxies shall turn out to be quite time-consuming, regardless if performed from the ground or with ST. The details of an optimum observing programme are still to be devised.

A minor difficulty is that at present the time-variable K-correction of SNe is not known. It would be important to obtain the ultraviolet spectra, possibly with IUE, of a nearby Type I SN during an interval of ~ 25 days around maximum light. This would also be important for the determination of the optimum wavelength of the precision photometry which must follow the discovery. This photometry, possibly performed with the FOC, is necessary to determine the exact phase and to inter- or extrapolate the maximum brightness.

SNe I as Non-Standard Candles:

It is a strange coincidence that a well-defined subgroup of SNe are not only the most nearly deal standard candles so far known, but that SNe also offer a magnificent chance to determine their distances in a fundamental way. By measuring the expansion velocity of their photosphere and their magnitude- and colour-change it is possible to apply the Baade-Wesselink method. This has been achieved already with remarkable success for SNe II (Kirshner and Kwan, 1974; and with a modified method Schurmann et al., 1979) and for SNe I (Branch and Patchett, 1973; Branch 1977a, 1977b).

It is clear that this method shall play a very important rôle in ground-based astronomy for further improvements of H_o from nearby SNe ($v_o \lesssim$ 10 000 km s^{-1}), once their atmospheres are fully understood. And these nearby SNe shall be equally important to prove that the method is free from systematical errors at a given state of the art.

With ST SNe shall still be accessible at $z = 0.5$, and if their distances can be well determined they shall be most important cosmological probes (Wagoner 1977, 1979; Schurmann et al., 1979; Colgate, 1978). Wagoner (1979) has worked out the details, how one obtains via the Baade-Wesselink method the proper-motion distance d_M, and from it q_o in first-order approximation:

$$q_o = \frac{2}{z} \left(1 - \frac{d_M H_o}{cz}\right) - 1 + 0(z^2)$$

This determination of q_o differs from that in the previous paragraph, where SNe I were treated as standard candles, in two principal ways: (1) the assumption of the SNe I phenomenon being the same now and then can be dropped; (2) a value of q_o follows from each SNe, and it is not necessary to have SNe at various values of z.

Presently the spectra of SNe II are better understood than those of SNe I, and the application of the Baade-Wesselink method seems easier for the former. One could therefore expect that SNe II were the most suitable objects for cosmology. However, there are three reasons why SNe I seem far more prospective: (1) SNe II are about 1^m fainter than SNe I (Tammann, 1978), and this difference is still increased by $\gtrsim 1^m$ by internal absorption if one compares SNe in spirals and in (absorption-free) E/S0s; (2) The absence of internal absorption of SNe I in E/S0s removes one unknown which otherwise has to be determined; (3) Although SNe II are in late-type spirals roughly three times more frequent per unit luminosity than SNe I in E/S0s, it would be extremely time-consuming to search with the small field of ST for the former, because spiral galaxies have a much weaker tendency to concentrate in rich clusters than E/S0 galaxies.

There remains a decisive problem for the application of the Baade-Wesselink method to SNe at z = 0.5: is it possible with ST to obtain a spectrum of an object say at $24^m.5$, which would yield the photospheric expansion velocity with sufficient accuracy? At a resolution of 100 the FOS takes about 3^h of integration for such an object. This is a reasonable amount of observing time, but the resolution may be insufficient. A resolution of 1000 would require a formal integration time of 30^h, which would lie at the very limit of feasability, because the many individual exposures needed would actually deteriorate the signal-to-noise ratio. On the other hand it was argued above that the adopted maximum

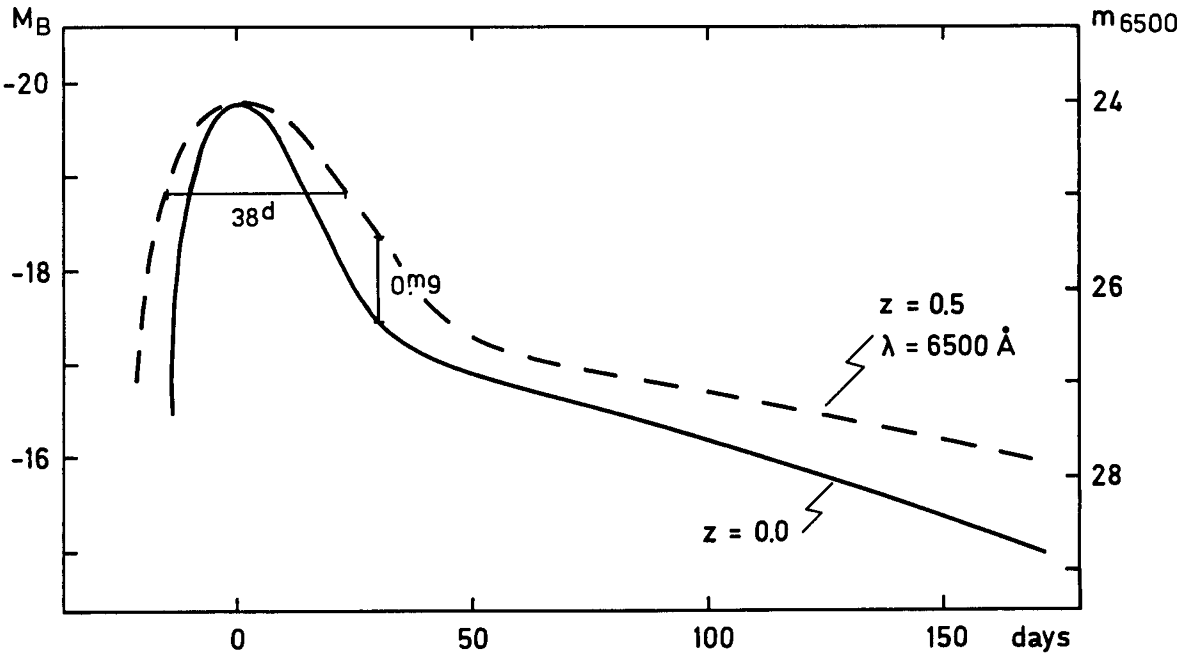

Fig. 1: The standard B-lightcurve of a SN I (full line) and the corresponding lightcurve at λ = 6500 Å for a SN I at z = 0.5 (dashed curve). The latter remains brighter than ~ 25^m, i.e. within 1^m from maximum, for 38^d. The two curves differ by $0^m.9$ 30^d after maximum.

brightness of 24^m of a SN I at z = 0.5 was probably too pessimistic. There remains therefore a realistic chance to complete the experiment with ST.

The Nature of Redshifts:

It is well known that the Doppler theory makes a specific prediction about the different dependence of metric and photometric diameters on z. A corresponding test with ST using the diameters of galaxies has been worked out by Sandage (1974).

An independent test is afforded by the standard lightcurve of SNe I. If the observed redshifts of galaxies are a Doppler effect then the time scale of the lightcurve of a SN at redshift z must be stretched by a factor of (1 + z). This is illustrated in Fig. 1, where the standard B-lightcurve of a SN I is shown (Barbon et al., 1973). Equally shown is the expected lightcurve of a SN I at z = 0.5 for a wavelength of 6500 Å, corresponding to the B-magnitude at z = 0.5. (The wavelength specification is necessary because the form of the lightcurve varies with λ). A local SN I declines during the first 30^d after maximum by $2^m.6$;

the observed standard deviation of this value is $\lesssim 0^m.6$. At z = 0.5 a SN I would decline by only $1^m.7$ during the same interval. By that time the SN would have reached m (6500 Å) $\approx 26^m$, the determination of which would require a still reasonable observing time with ST. A 3σ detection of the magnitude difference of $0^m.9$ would be provided by only six SNe I at z = 0.5, whose lightcurves were measured during a 30^d interval after maximum.

The conclusion is that ST shall be helpful for the determination of H_0, that it shall be very important for the mapping of the expansion field, and that it offers a unique chance to determine q_0 from SNe and to verify the Doppler nature of cosmological redshifts.

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References

Abell, G.O.1975, Stars and Stellar Systems, vol. 9, ed. A. and M. Sandage and J. Kristian (Chicago: University of Chicago Press), p. 601.

Baade, W., and Swope, H.H.1963, A.J. 68, 435.

Barbon, R., Ciatti, F., and Rosino, L.1973, Astron. Astrophys. 25, 241.

Branch, D. 1977a, In: Supernovae, ed. D.N.Schramm, Dordrecht: D. Reidel, p. 21.

Branch, D. 1977b, M.N. 179, 401.

Branch, D., and Bettis, C. 1978, A.J. 83, 224.

Branch, D., and Patchett, B., 1973, M.N. 161, 71.

Colgate, S.A. 1978, preprint.

Dyer, C.C., and Roeder, R.C.1973, Ap.J. Letters 180, L31.

Graham, J.A.1975, P.A.S.P. 87, 641.

Humphreys, R.M.1978, preprint.

Kantowski, R.1969, Ap.J. 155, 89.

King, I.R.1972, Ap.J. Letters 174, L123.

Kirshner, R.P., and Kwan, J.1974, Ap.J. 193, 27.

Kraan-Korteweg, R., and Tammann, G.A.1979, ESO Sci. Preprint No. 42.

Kristian, J., Sandage, A., and Westphal, J.A.1978, Ap.J. 221, 383.

Refsdal, S. 1970, Ap.J. 159, 357.

Rood, H.J., Page, T.L., Kintner, E.C., and King, I.R.1972, Ap.J. 175, 627.

Rubin, V.C., Thonnard, N., Ford, W.K.Jr., and Roberts, M.S.1976, A.J. 81, 719.

Sandage, A.1961, Ap.J. 133, 355.

Sandage, A.1974, Large Space Telescope - a New Tool for Science, ed. C.R. O'Dell, AIAA 12th Aerospace Science Meeting, p. 19.

Sandage, A.1976, A.J. 81, 954.

Sandage, A., and Hardy, E.1973, Ap.J. 183, 743.

Sandage, A., Tammann, G.A., and Hardy, E.1972, Ap.J. 172, 253.

Sandage, A., and Tammann, G.A.1974, Ap.J. 191, 603.

Sandage, A., and Tammann, G.A.1975, Ap.J. 196, 313.

Schurmann, S.R., Arnett, W.D., and Falk, S.W.1979, Ap.J., in press.

Smoot, G.F., Gorrenstein, M., and Muller, R.1977, Phys. Rev. Letts. 39, 898.

Tammann, G.A.1978, Mem. Soc. Astron. Italiana 49, 315.

Tammann, G.A., Yahil, A., and Sandage, A.1979, preprint.

Wagoner, R.V.1977, Ap.J. Letters 214, L5.

Wagoner, R. V. 1979, preprint.

Weedman, D. W. 1976, Ap. J. 203, 6.

Westphal, J. A. (and Co-Investigators) 1978, Technical Proposal, Wide Field/ Planetary Camera for Space Telescope, Pasadena: California Institute of Technology, p. 23.

Yahil, A. 1978, Talk presented at the Ninth Texas Symposium on Relativistic Astrophysics.

Yahil, A., Tammann, G. A., and Sandage A. 1977, Ap. J. 217, 903.

Zeldovich, Ya. B. 1964, Astron. Zh. 41, 19.

Discussion:

van Woerden: I was surprised about your statement that ST would have no advantages in our journey towards the Hubble constant. Don't you agree that the Sandage-Tammann steps on that journey are short, and the links on the distance scale therefore weak?

I should think then that ST, which reaches fainter magnitudes and smaller angular sizes, will allow each step to become much greater, so that the steps will strongly overlap and the links become strong.

Or do you think that the weakest link is between Cepheids and the next indicators (HII regions and brightest stars), and that it is very expensive to strengthen that link by observing more Cepheids to improve the calibration of the next indicators?

Tammann: It is indeed the expenditure of observing time which worries me, - and, of course, the limitations of any possible gains on the accuracy of H_0 due to the very local calibration. Once one shall have a good mapping of the expansion field out to a few thousand km s^{-1}, using only relative distances, it shall not be necessary anymore to reach distant galaxies for the determination of H_0. Possibly the best value of the scaling factor, and hence the global value H_0, would follow then from the distances of many, nearby field galaxies (say with $v_0 \lesssim 500$ km s^{-1}). For such a programme one may doubt whether the potentials of ground-based astronomy were already exhausted.

G L O B U L A R   C L U S T E R S   A S   D I S T A N C E   I N D I C A T O R S   F O R   G A L A X I E S

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INTRODUCTION

Although a number of observations and theoretical investigations with the purpose of determining the Hubble constant have been published, it is well known that the important questions of cosmology like: is the local expansion field quiet, homogeneous and isotropic are still under discussion. Sandage, Tammann and others have collected strong evidence that the above mentioned criteria are fulfilled and that the universe is therefore open. However, other evidence brought up in the literature is contradictory. To solve this discrepancy, astronomers have to improve observations and the theory of different distance indicators, especially those that can be used over a large distance scale.

Globular clusters can serve as such indicators to distances as far as about z = 0.1 where evolutionary effects very probably can still be neglected. Globular clusters will be investigated in the near future quite intensively, even if a Globular-Cluster-Space-Telescope, as demanded by Castellani in this workshop will not be launched.

According to present knowledge, the mean diameter of a galactic globular cluster is about 30 pc. Assuming a resolving power for the Space Telescope of 0.1" we will be able to discriminate a mean globular cluster from point sources at distances as far as 60 Mpc. The largest globular cluster in our galaxy (ω Cen), on the other hand, has a diameter of 150 pc. We can therefore expect to be able to identify the largest globular cluster in galaxies which are about 300 Mpc distant - provided they are bright enough. Of course we have assumed for this estimate that the population of globular clusters in our galaxy is typical for all the other galaxies.

As we will see later, the M_V of the brightest globular cluster seems to vary between -8 and -11 mag. Again, taking the design goal for the Faint Object Camera (m_V = 28 with a S/N of 6 within 10 hrs), it should be possible to do photometry of globular clusters at distances as far as 600 Mpc.

Homogeneous distances could be determined with Space Telescope observations of globular clusters within a distance ranging from our galaxy and the Virgo cluster to galaxy clusters at distances of about 500 Mpc. A further advantage would be a crosscheck with other distance indicators like the brightest members of galaxy clusters, H-II regions, 21 cm line widths, supernovae etc. However, to achieve this goal it is necessary to improve the calibration of some characteristic parameters of the globular cluster population and to determine first via ground based astronomy of nearby galaxies to what extent these parameters are universally constant, a function of the metallicity of the globular clusters and/or a function of the luminosity of the parent galaxy.

i) Luminosity function:
Hanes (1977 a and b) seems to have shown that the shape of the luminosity function of globular clusters is constant and of Gaussian shape with a (probably) constant intrinsic dispersion σ. However, his conclusions are essentially based on a comparison of globular clusters in our own galaxy, M 31 and M 87. He also found evidence that the globular cluster color function (population function) is constant for these three galaxies using Racines reddening free parameter $\mathcal{R}$. This finding, however, is contradicted by Racine et al. (1978) who measured the energy distribution of selected globular clusters and determined their line strength index L. The distribution of the abundance of globular clusters in M 87 proved to be the same as in M 31, but is different from that in our galaxy.

ii) Total number (N) of globular clusters of a galaxy:
Recently, de Vaucouleur (1970), Hodge (1974) and Wakamatsu (1977) have shown that $\log N$ is directly correlated with the luminosity of the central buldge of the parent spiral galaxy or the luminosity of the parent elliptical galaxy. This relation was calibrated on 8 galaxies in the Local Group and in 2 Virgo galaxies. However, Hanes (1977 c) pointed out that M 87 is overabundant by a factor of 3 in globular clusters when compared with other elliptical galaxies in the Virgo cluster. In any case, the determination of the background

and the photometry near the limit of the photographic technique seriously restricts the accuracy of the calibration of this parameter N .

iii) Mean magnitude of the globular cluster population ($\overline{M}_{GC}$) :
Hanes (1977 b) demonstrated that in four galaxies of the Local Group $\overline{M}_{GC}$ is about -6.85 with a σ of the normal distribution of 1.1 mag. This value agrees well with what is found for our galaxy ($\overline{M}_{GC}$ = -6.91 with a σ of 1.1 mag.). In addition, Hanes found that $\overline{m}_{GC}$ for seven Virgo galaxies are very similar. After all, $\overline{M}_{GC}$ seems to be the most reliable parameter for a distance determination, provided one is able to determine a luminosity function which is basically unbiased.

iv) Brightest globular cluster (M_{BGC}) :
The following table gives a list of M_{BGC} as a function of M_{Gal} for 8 galaxies, taken from Castellani (1979).

Name	M 31	Galaxy	LMC	NGC205	SMC	NGC185	NGC147	Fornax
M_{Gal}	-21.1	-20.5	-18.5	-17.0	-16.8	-15.4	-14.6	-13.0
M_{BGC}	-10.9	-10.4	- 9.8	- 9.7	- 9.4	- 8.5	- 7.7	- 8.5

A linear least squares regression results in:

$M_{BGC} = -3.39 + 0.35 \cdot M_{Gal}$

with a coefficient of determination of r = 0.92 which gives evidence for a relatively good fit (a perfect fit is characterized by r = 1). The main difficulty in using M_{BGC} as distance indicator is the danger of misidentification of the brightest globular cluster. An error of about 1 mag in the distance modulus can be introduced, if for example the fifth brightest globular cluster is mistaken as the brightest one. De Vaucouleur (1970), Hodge (1974) and Smith (1977) have discussed this problem and cite further references.

SPACE TELESCOPE AND GLOBULAR CLUSTERS IN GALAXIES

1) Due to the high spacial resolution of 0.1" of the Space Telescope it will be possible to discriminate globular clusters from field stars and galaxies.

2) Due to the much better photometric accuracy of the Space Telescope

for faint objects compared to ground based astronomy and the fainter limiting magnitude it will be possible to determine unbiased, or at least weakly biased, luminosity functions.

3) The high resolution and the excellent photometric property of the Space Telescope can be used to identify the brightest globular cluster with much better accuracy than is possible from the ground.

4) With the Faint Object Spectrograph it will be possible to investigate to what extent the metallicity of globular clusters changes from galaxy to galaxy and if there is any influence on $\overline{M}_{GC}$, M_{BGC} and the luminosity function of globular clusters.

5) The relation mentioned in ii) in this paper infers that there is a luminosity limit for a parent galaxy which has to be exceeded so that at least one globular cluster could develope. The current calibration put this limit at about $M_{Gal} = -13.0$. There are several galaxies in the Local Group which are close to this limit. It would be interesting to check these galaxies for globular clusters. If the limit proves to be real, any theory on the origin and evolution of galaxies would have to take this fact into account.

Concluding one can say that the Space Telescope can potentially increase our knowledge on globular cluster populations. It can be expected that quite a number of Wide Field Camera frames will be available for this project since the Wide Field Camera will continuously be operated when one of the other instruments on board the Space Telescope is used. Based on these frames, the Faint Object Camera can be efficiently used for detailed investigations. However, there is no doubt that much work still has to be done from the ground to provide a better fundament for a calibration of globular clusters as distance indicators in galaxies.

REFERENCES

Catsellani, V.: 1979, ESA-ESO Workshop on Astronomical Uses of the Space Telescope, Geneva, in press

Hanes, D.A.: 1977 a, Mon.Not.Roy.Astr.Soc. 179, 331

Hanes, D.A.: 1977 b, Mon.Not.Roy.Astr.Soc. 180, 309

Hanes, D.A.: 1977 c, IAU-Colloquium No. 37, CNRS Paris, 93

Hodge, P.W.: 1974, Publ.Astr.Soc.Pacific 86, 289
Racine, R., Oke, J.B., Searle, L.: 1978, Astrophys.Journal 223, 82
Smith, M.G.: 1977, IAU-Colloquium No. 37, CNRS Paris, 75
de Vaucouleur, G.: 1970, Astrophys.Journal 159, 435
Wakamatsu, K.: 1977, Publ.Astr.Soc.Pacific 89, 504

SPECIAL TECHNIQUES
AND OTHER SPACE PROJECTS

IMAGE RESTORATION OF ST PHOTOGRAPHS

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Abstract:

According to the NASA announcement the ST will be diffraction-limited at about 600 nm and longer wavelengths but not at short UV wavelengths. At 150 nm the 70 % encircled energy radius is predicted to be about 0.16 arc-seconds for the 0.075λwavefront error system and about 0.10 arc-seconds for the 0.05λwavefront error system (optimistic estimate). The diffraction limit of a 2.4 m - telescope would be at 150 nm about 0.015 arc seconds, however. Therefore, image deconvolution techniques should be used for improving the spatial resolution of ST photographs down to about 0.015 arc-seconds. We plan to apply deconvolution techniques to photos of active nuclei and similar compact objects making use of experiences in image restoration.

Two steps are necessary to obtain an aberration-free image:

(A) to record a sequence of photographs that contains complete information about the object - although in encoded form

(B) to decode (deconvolve) by means of suitable image restoration methods

We will propose a new concept to collect (step A) enough information in order to be able later to decode (step B) successfully. It is investigated the deconvolution for various classes of ST photographs (each class is selected such that holes in the spatial frequency domain are avoided):

1. deconvolution of a diffraction-limited image from one ST photograph
2. deconvolution from a sequence of photos recorded at different rotation angles of the ST
3. deconvolution from a sequence of defocused ST photos
4. deconvolution from photos recorded at different off-axis positions in the focal plane

A laboratory simulation of the second method is shown.

1. Introduction

Two levels of the optical performance of the ST are discussed: 0.05λ and 0.075λ wavefront error. In the NASA announcement the point spread functions (PSF) and the encircled energy functions (EEF) for the 0.075λ and 0.05λ system (optimistic estimate) are given. Only the 0.075λ performance is assured by NASA. The optical performance is described for wavelengths down to 121.5 nm. A plot of radius of 70 % encircled energy versus wavelength shows that the ST is diffraction-limited for wavelengths longer than 630 nm, but not for UV wavelengths. At 150 nm, for example, the radius of 70% encircled energy is about 0.10 arc-seconds for the 0.05λ system and 0.16 arc-seconds for the 0.075λ system. This means that the radius of 70 % encircled energy is at 150 nm much larger than the radius of the theoretical point spread function (Airy pattern) of an (aberration-free) 2.4 m - telescope. The angular radius R_o of the Airy pattern (angular distance from the center to the first zero) is given by $R_o = 1.22\lambda/D$, where λ denotes the wavelength and D the diameter of the aperture. The angular radius of the Airy pattern is about 0.015 arc-seconds for D = 2.4 m and λ = 150 nm. In fig. 1 the size of the Airy pattern of a 2.4 m - telescope at 150 nm and the radius of 70 % encircled energy for the ST are compared (same scale for all drawings). Fig. 1 illustrates that the ST is not diffraction-limited.

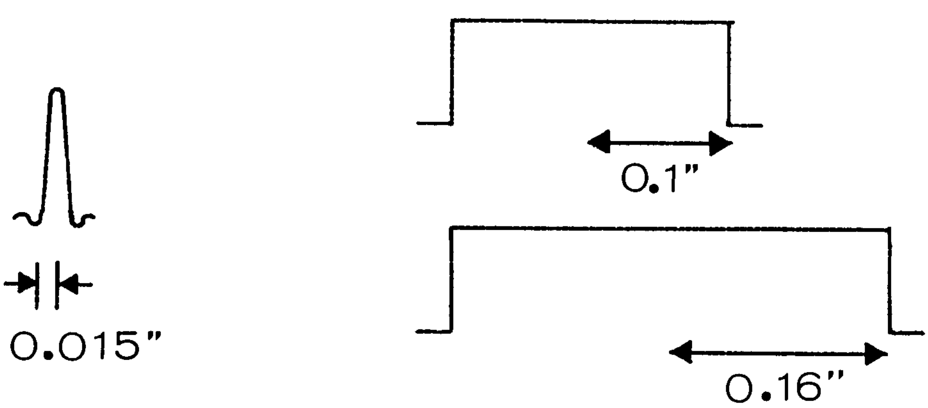


Fig. 1 Comparison of the point spread function of an aberration-free 2.4 m - telescope at 150 nm and the predicted radii of 70 % encircled energy of the ST.

Although the ST is not diffraction-limited at 150nm, we believe that diffraction-limited images can be deconvolved. In order to study the possibilities for deconvolution, we simulatedaberration degraded images. A 2.4m-telescope with 0.1 to 0.2 seconds of arc aberrations (EER) was simulated. From such aberration degraded images diffraction-limited images were reconstructed (see fig.2). These experiments are described in the next chapter.

2. Deconvolution of aberration degraded images

We simulated in the laboratory aberration degraded images of an object consisting of a point source and a triple star (see fig.3). The distances in the triple system were chosen smaller than the diameter of the aberration degraded images, which are shown in fig.2. From these 9 aberration degraded images the high resolution (diffraction-limited) image of the triple star shown at the bottom was deconvolved. The deconvolution of the complete 4-star system would be possible too, but this would yield no additional information. One can see in fig.2, that the structure of the aberration was not changed during the experiment. The interference pattern caused by aberrations was rotated only. This was achieved by rotating the simulated ST. We will now describe this experiment in more details.

The intensity distribution $I(x,y;\varphi_n)$ of one of the discussed aberration degraded images can be described by the usual space-invariant, incoherent imaging equation.

$$I(x,y;\varphi_n) = O(x,y) * P(x,y;\varphi_n), \tag{1}$$

where $O(x,y)$ describes the object intensity distribution, $P(x,y;\varphi_n)$ the point spread function of the n-th recorded image and $*$ denotes convolution. We assume, that the ST can be rotated and $P(x,y;\varphi_n)$ denotes the photograph recorded at a rotation angle φ_n. Such a rotation does not change the fine structure of the point spread function P, but only the orientation. The advantage of such a rotation of P is the fact that the zeros of the optical transfer function (=Fourier transform of P) will change their position in the Fourier space. In other words, the rotation enables us to

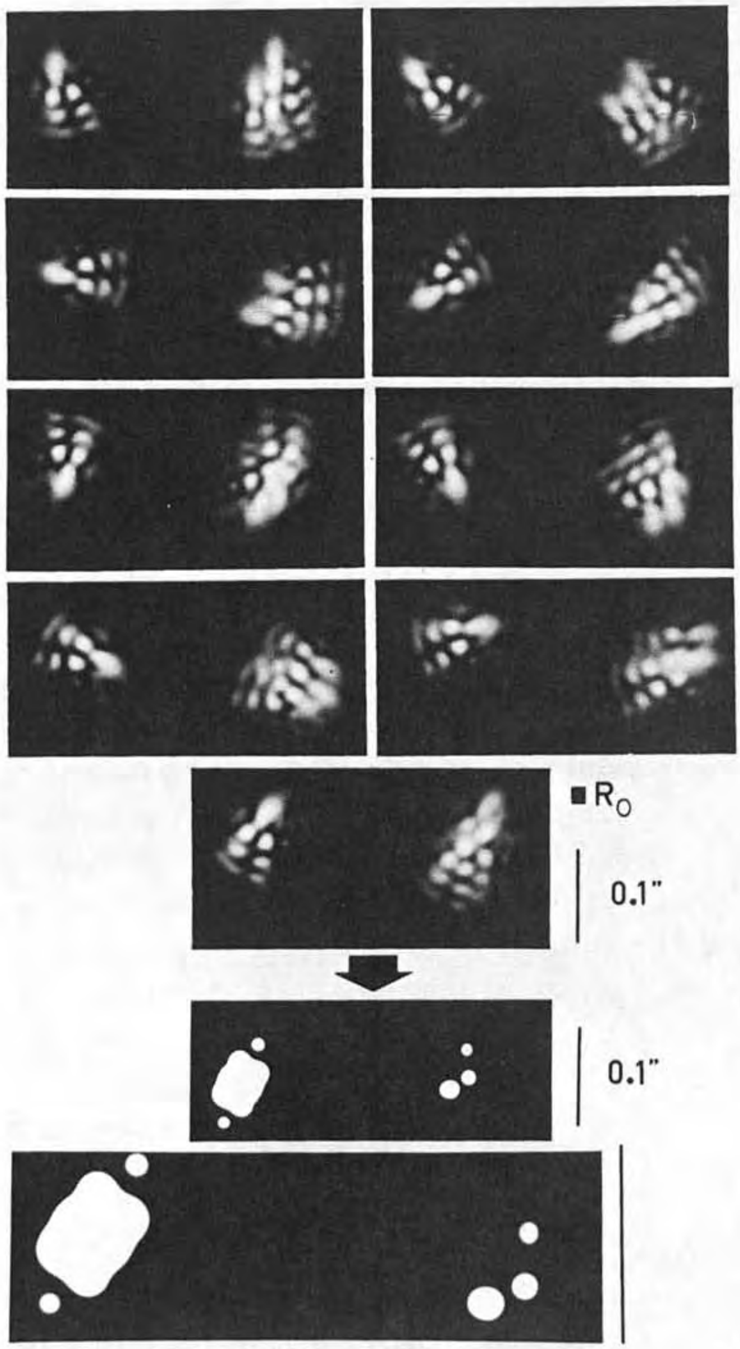


Fig. 2 Laboratory deconvolution experiment. The high resolution (diffraction-limited) image of the triple star (at the bottom) was reconstructed from the nine shown aberration degraded photographs $I(x,y;\varphi_n)$ (φ_n = 0°, 40°, 80° ... 320°)

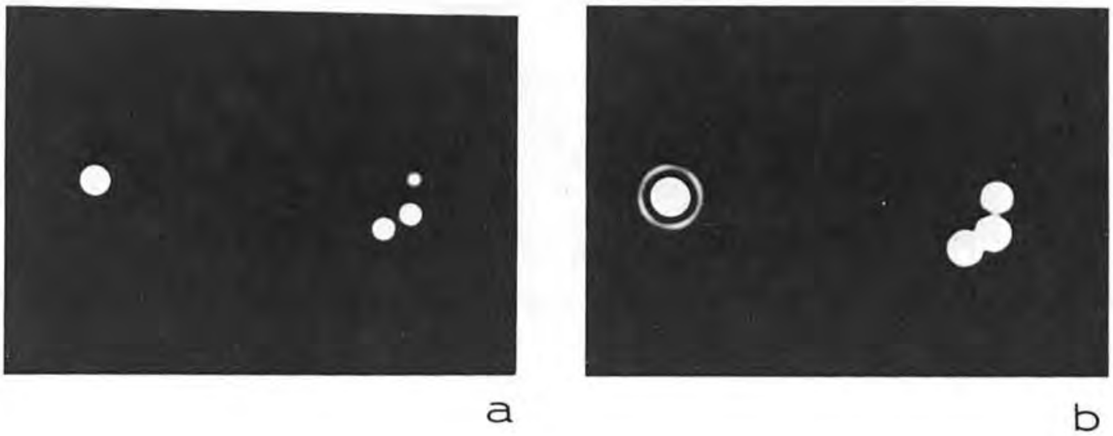


Fig. 3 Laboratory object of a point source and a triple star. The ring around the star on the left-handside of 3b is the first diffraction ring of the Airy pattern. This Airy pattern shows, that the separations in the triple system are near to the diffraction limit.

measure the object power spectrum at all spatial frequencies in the Fourier plane.

From the aberration degraded photographs $I(x,y;\varphi_n)$ an image of $O(x,y)$ can be reconstructed by standard deconvolution technique, if the single point spread functions $P(x,y;\varphi_n)$ are known. In our experiment of fig.2 these point spread functions $P(x,y;\varphi_n)$ are known, because the aberration degraded images of the point source on the left-hand side in the nine photographs $I(x,y;\varphi_n)$ represent the point spread functions. Inverse filtering (deconvolution) and averaging yields

$$O(x,y) \approx \sum_{n=1}^{N} FT^{-1}\{FT[I(x,y;\varphi_n)] \; / \; FT[P(x,y;\varphi_n)]\} \qquad (2)$$

where FT and FT^{-1} denotes the Fourier transform and inverse Fourier transform operator. The term $\{...\}$ is defined to be zero for spatial frequencies where $FT[P] = 0$ (in the spirit of Wiener filtering). Averaging of N inverse filtering experiments is advantageous because of holes in the transfer functions $FT[P(x,y;\varphi_n)]$. At such positions of the Fourier plane no information of the object power spectrum FT[O(x,y)] is available, if one uses only one I and P (i.e. N = 1). On the other hand we want to point out that deconvolution from one photograph $I(x,y;\varphi_n)$ is possible, but the signal to noise ratio is lower. For illustration in fig.4 the power spectrum of one photograph $I(x,y;\varphi_n)$ and the average power spectrum of 9 aberration degraded images is shown (4-star object shown in fig.3). Up to now we discussed inverse filtering. Of course the application of more sophisticated techniques such as Wiener filtering and Cannon filtering (see /1) can be sometimes advantageous.

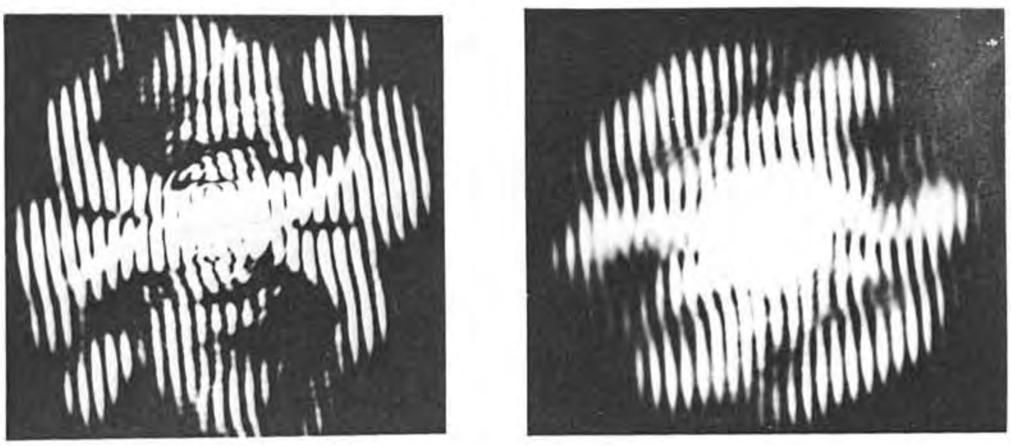


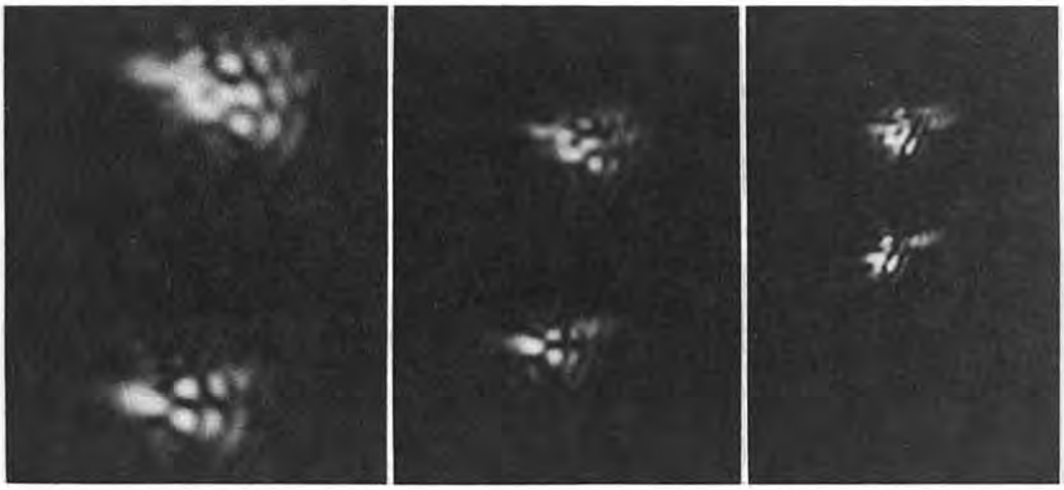
Fig. 4 Average power spectrum $\sum_{n=1}^{N} |FT[I(x,y;\varphi_n)]|^2$ for N=1 (left) and 9 . Some zeros in the power spectrum on the left-hand side are caused by the zeros in the transfer function FT[P] . These zeros can be avoided by using more than one φ_n.

The deconvolution (inverse filtering) shown in fig.2 can be performed in different ways. One can perform the deconvolution described in equation (4)directly with a digital computer. Another possibility is to deconvolve by autocorrelating the aberration degraded images. The produced average autocorrelation of the 4-star system would contain a real diffraction-limited image of the desired triple system, because one of the terms in this average autocorrelation is the average crosscorrelation of the aberration degraded images of the point source and the aberration degraded images of the triple star. This technique was applied in the experiment of fig.2. This technique is similar to Labeyrie's speckle interferometry /2/ and to speckle holography technique /3-6/ Other canditate methods for image deconvolution are inverse filtering (as described earlier), Wiener filtering and Cannon filtering.

For the deconvolution process it is necessary to know the single point spread functions $P(x,y;\varphi_n)$. These can be measured easily, if there is an unresolvable star together with the object, which is investigated, within the field of the camera. Probably this is fulfilled in most cases due to the limiting magnitude of the space telescope. If there is no suitable point source in the same field as the object, then one can also use a point source outside the object field, after changing the direction of the telescope.

Up to now we discussed the case that the point spread function $P(x,y)$ is changed by rotation (only the orientation was changed, not the fine structure). However, there are yet other possibilities to change the point spread functions as discussed already in the abstract. Changing the point spread functions $P(x,y)$ is necessary in order to change the position of the zeros of the transfer function $FT[P(x,y)]$ as discussed already. A very comfortable way for taking photographs with different point spread functions is to <u>record the photographs at different off-axis positions</u>. However, in order to use this technique it is necessary that the point spread function (caused by aberrations) of the telescope is space variant. Up to now we have not yet checked the space variance of the ST point spread function, but we will investigate this point.

Another possibility for <u>changing the point spread function is defocusing</u>. Fig.5 illustrates the dependence of the fine structure in the point spread function on the defocus. This fine structure change can be understood in the following way. The bright spots in the aberration degraded photographs (for example in fig.2) are three-dimensional interference maxima. They can be regarded as speckles produced from a low number of scatterers (aberrations).Ordinary speckles have a lateral diameter (in the focal plane) of λF, where λ is the wavelength of light and F is the stop number, and a longitudinal extension (parallel to the optical axis) of about λF^2 (/7/ and /8/). In the case of F $\approx$ 100 and λ = 200nm the speckle length is about 2mm. These three-dimensional interference maxima (speckles) have a statistical distribution in space. Therefore one can change the fine structure of the point spread function by defocusing (see /8/ fig.1 and 2). This fine structure change by defocusing is also illustrated in fig.5.



z_o z_1 z_2

Fig. 5 This photograph shows the focusing dependence of the point spread function of the simulated ST used in the experiment of fig.2.

Finally, we want to discuss the application of the faint object camera (FOC) for our method. At f/96 the pixel size will be 0.022". At 300 nm the pixel size is fine enough to achieve diffraction-limited resolution (i.e. 0.03") with the described method. For shorter wavelengths (150 nm) and higher resolution (down to 0.015") we would like to be able to switch from f/96 to f/200 or f/500, preferable. In our opinion, the optical flexibility of the FOC would be much increased if f/48, f/96, and f/500 would be available.

References:

/1/ H.C. Adrews and B.R. Hunt, Digital Image Restoration Prentice-Hall Signal Processing Series, Prentice-Hall, INC., Englewood Cliffs, New Jersey 07632 (1977)

/2/ A. Labeyrie, Astron. Astrophys. 6, 85 (1970)

/3/ C.Y.C. Liu and A.W. Lohmann, Opt. Commun. 8, 372 (1973)

/4/ R.H.T. Bates, P.T. Gough, P.J. Napier, Astron. Astrophys. 22, 319 (1973)

/5/ G.P. Weigelt, Optik 43, 111 (1975)

/6/ G.P. Weigelt, Appl. Opt. 17, 2660 (1978)

/7/ J.W. Goodman, in: Laser Speckle and Related Phenomena (Ed. J.C. Dainty), Springer-Verlag, Berlin-Heidelberg-New York (1975)

/8/ G.P. Weigelt and B. Stoffregen, Optik 48, 399 (1977)

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CORONAGRAPHY ON STARLIKE OBJECTS WITH THE SPACE TELESCOPE : EXPERIMENTAL SIMULATION AND EXPECTED PERFORMANCE.

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SUMMARY

The high angular resolution of the Space Telescope gives a strong interest to a coronagraph in order to observe the nearest faint structures surrounding a bright starlike object (stars with planets or shells, nuclei of galaxies, underlying galaxies).

An experimental simulation with diffraction limited optics and a Lyot system is described. Presented results show the possibility of detection of $2\ 10^{-7}$ relative intensity features at 1 Arc second of the bright source.

A coronagraph of this type will be implemented in the Faint Object Camera.

The high resolution of the Space Telescope, expected to be diffraction limited, the absence of atmosphere and consequently of seeing and sky scattering, lead to observe the nearest faint structures close to a bright starlike object.
A well known goal is the detection of a planet near a star, where the ratio of luminosity could be about 10^{-9} at 1" (second of arc). But many other objects can be considered, such as the coronae of Wolf-Rayet or redgiant stars, the proximity of bright nuclei of galaxies, or the surrounding nebulosities of quasars.

In such observations, one must avoid saturation or damage of the detector, and also reduce the stray light produced inside the telescope mainly by 2 phenomena for the small field of view to be considered here (about 2" around the bright source) :
- First, the diffraction by the edges of the obstructed aperture, giving an average of 10^{-5} at 1" in the visible. This edge effect can be reduced with a coronagraphic Lyot-type system, as was exposed by Bonneau, Josse and Labeyrie (1975).

- Secondly, the scattering from middle-scale wavefront errors given by the Space Telescope mirrors. According to a statistical model by KenKnight (1977), it could be an order of magnitude stronger than the edge effect, but the model is severe and this should be considered as an upper limit. Active optics or interferometers are necessary for a correction of this phenomenon, which is presently under experimental investigation at our laboratory in Marseille.

Anyway, only a Lyot-type system will be implemented in the Faint Object Camera (fig . 1). It is composed of 2 removable masks inserted in f/96 imaging mode : a 0.6" diameter focal mask occulting the Airy pattern up to the third ring at ST focus, and a Lyot apodizer stopping in a relayed pupil plane the residual diffracted light. Of course, for field sources, the Lyot stop acts as the aperture diaphragm and diffracts as usual ; the energy loss was lower than 20 % in any case in the following.

To realize the expected performance of this device, we have set up an experimental simulation whose apparatus is given in fig. 2 : an illuminated pinhole simulates a star ; internal reflections in a glass cube give satellites 1.3 10^{-3} and 2.0 10^{-6} in relative intensity. Diffusion by the cube was checked afterwards to be neglectable. A common 200-mm focal length cemented doublet is diaphragmed at f/24 by a 0.37 diameter obstructed pupil. It gives a good diffraction pattern whose size defines the scale in second of arc, as it will be at ST focus. Two spherical mirrors magnify the image to a f/96 aperture with the diffraction resolution. Both focal occultor and Lyot apodizer can be inserted in the beam.

Fig. 3 - shows three exposures with increasing illuminations taken at f/96 in white light. The focal mask only is ON. Its diameter is 0.75". One can see the 1.3 10^{-3} satellite whose (simulated) distance from center is 0.65". The 2.0 10^{-6} satellite at 1.3" is not clearly apparent. Pseudoradial structures on the most exposed picture are due to minute irregularities of the aperture diaphragm.

Fig. 4 - shows the remaining starlight distribution in the reimaged pupil plane when the focal mask is ON. Most of the energy is located along the contours of the aperture (see Miyamoto, 1964) and is stopped by the Lyot apodiser. The fringe along spiders will be relatively thinner in the actual F.O.C. pupil plane. Parasite Newton rings in the lower quadrant are probably due to interferences inside the cemented doublet.

Fig. 5a - illustrates the efficiency of the Lyot stop which is OFF on upper and ON on lower part (the focal mask is of course ON on both). The diffracted light intensity is reduced by a factor of 10 to 15 on the whole field.

Fig. 5b - is an (unfortunately reversed) enlargement of lower part of Fig. 5a. The 2 10^{-6} satellite is at lower left and its first diffraction ring of approximatively 2 10^{-7} relative intensity (16.7 magnitudes) is detected. Half way between the 2 10^{-6} satellite and the center, the 1.3 10^{-3} satellite saturates the emulsion and can be guessed by its spider diffraction spikes.

Fig 6 - is an image similar to that of figure 5b, but here, the used focal mask is composed of 2 crossing wires 160 µm, or 0.57" in diameter ; the shape of the Lyot stop was adapted. The resulting contrast is much better : the reduction of the stray light reaches a factor of about 50 on a vertical line ; but the available field close to the center is smaller.

We have also tested the coronagraph with a photon-counting television camera. Fig. 7 and Fig. 8 show the camera set up at f/96 focus and the acquisition, real time processing and display system. A detailed description of it can be found in Cenalmor et al. (1978).
The 1.3 10^{-3} satellite was blocked near the cube to avoid supplementary light and the coronagraphic masks were the same as in Fig. 5b. A 10000 s exposure was taken at 433 nm, which makes the first dark ring radius comparable to the pixel size (43 µm), leading to a satellite width of 2 pixels.

Fig. 9 is a rough display of the image.
Fig. 10 gives color coded isophotes : the first level was choosen at the top value of the 2 10^{-6} satellite (138 counts on one pixel). The background average is 6 counts by pixel far from the star. A profile across the image at satellite height shows the contrast of the detection.

Assuming a sky background added to detector noise of 4 10^{-3} counts/pixel/s and 1.5 $10^{9-m_V/2.5}$ detected photons/s (see R.J. Laurance) with the f/96 , 50 µm pixel imaging mode of the Faint Object Camera, an image similar to Fig. 10 would be obtained in 1500 s on a bright star of m_V = 10 and its companion of m_V = 24.2 at an angular separation of 1.3".

In conclusion, the performance of the coronagraphic system in the Faint Object Camera will depend strongly on the optical quality of the Space Telescope.
In the best conditions, it can reduce the stray diffracted light by a factor 50 (4.2 mag.) and allows by direct imaging the detection of 2 10^{-7} (16.7 mag.) relative intensity features at an angular separation of 1 arc second from a bright starlike object. The detection limit of F.O.C. being m_V = 29, the coronagraph should be useful for bright sources up to m_V = 17.

REFERENCES

D. Bonneau, M. Josse and A. Labeyrie
Lock-in image substraction : detectability of circumstellar planets with the Space Telescope.
Image Processing Techniques in Astronomy, 1975, p. 403
(Ed. de Jager and H. Nieuwenhuijzen).

V. Cenalmor, Ph. L. Lamy, J.M. Perrin and T. Nguyen-Trong
Photon counting and analog television systems with digital real time image processing and display.
Astron. Astrophys. 69, 411 (1978).

C.E. KenKnight
Methods of detecting extrasolar planets.
Icarus, 30, 422 (1977).

R.J. Laurance
Internal ESTEC working paper n° 1038.

K. Miyamoto
Effect of boundary diffraction wave in coronagraph.
J.O.S.A. 54, 1105 (1964).

M.V. PENSTON : After the coronograph has removed most of the light from the bright source the image looks most peculiar; can one still measure the separation of the bright and faint sources accurately?

N. MAURON : Yes, using residual diffracted light from the spiders or the axis of symmetry in the image.

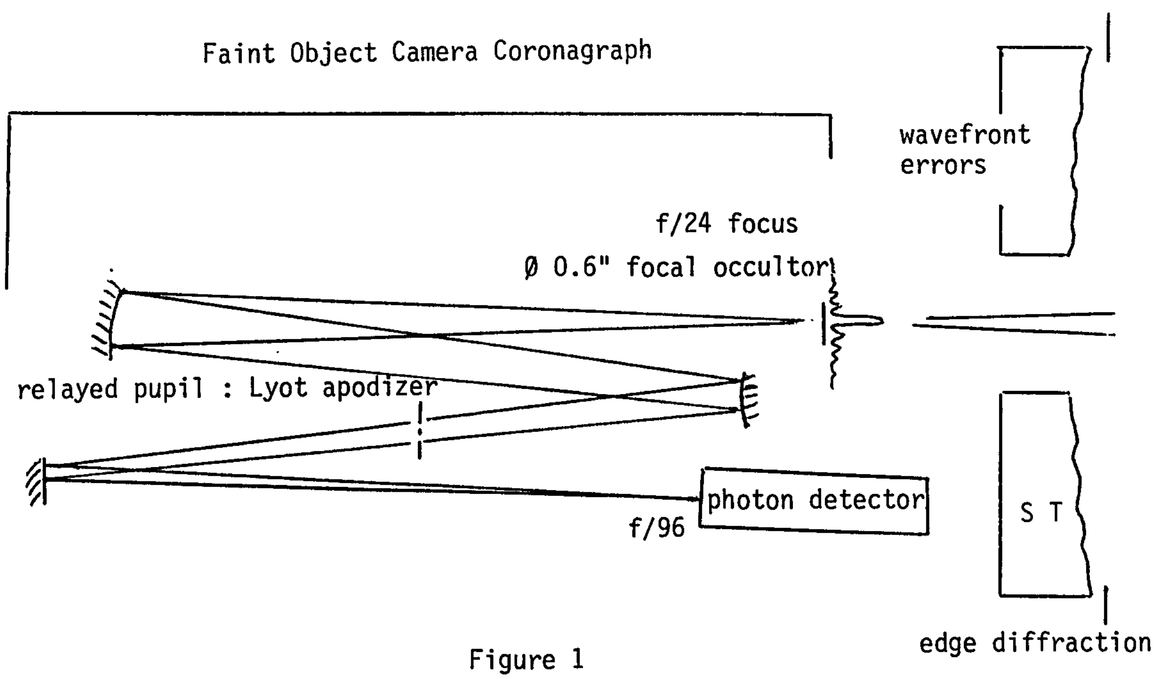

Figure 1

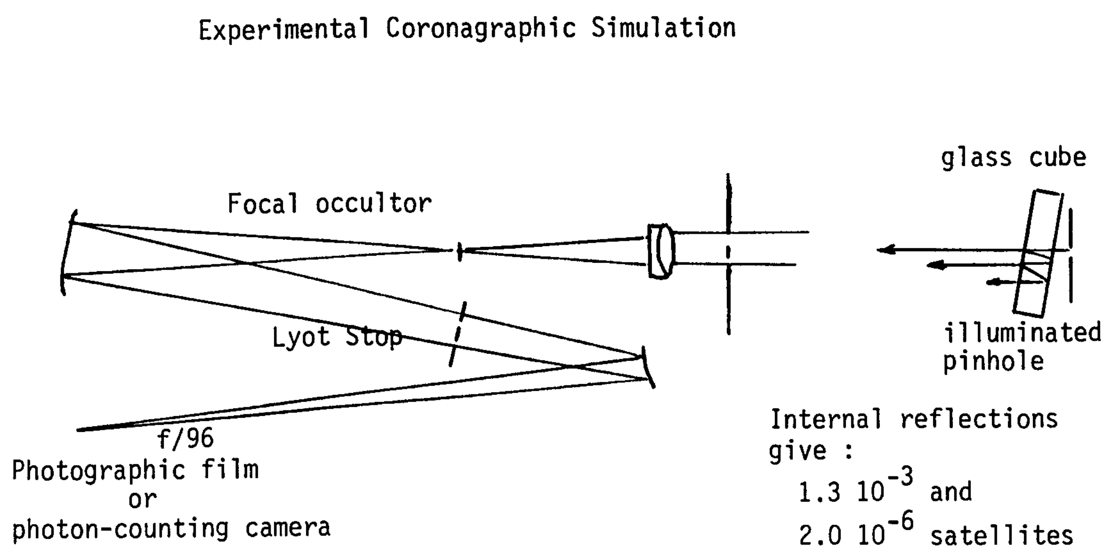

Figure 2

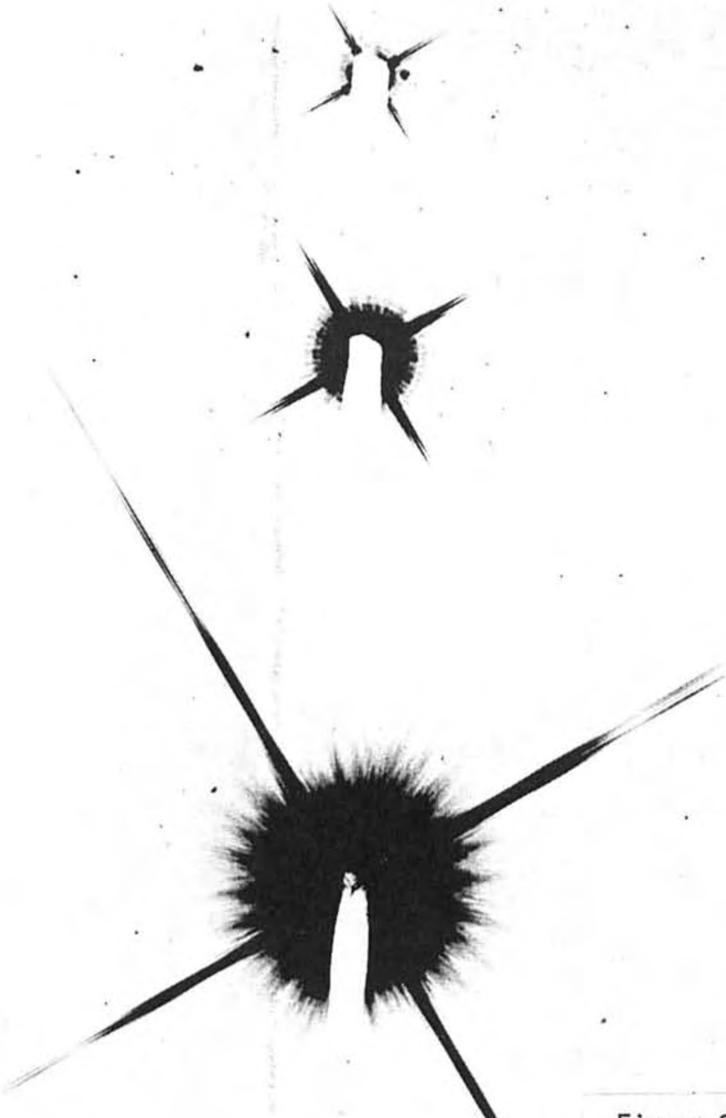

Figure 3

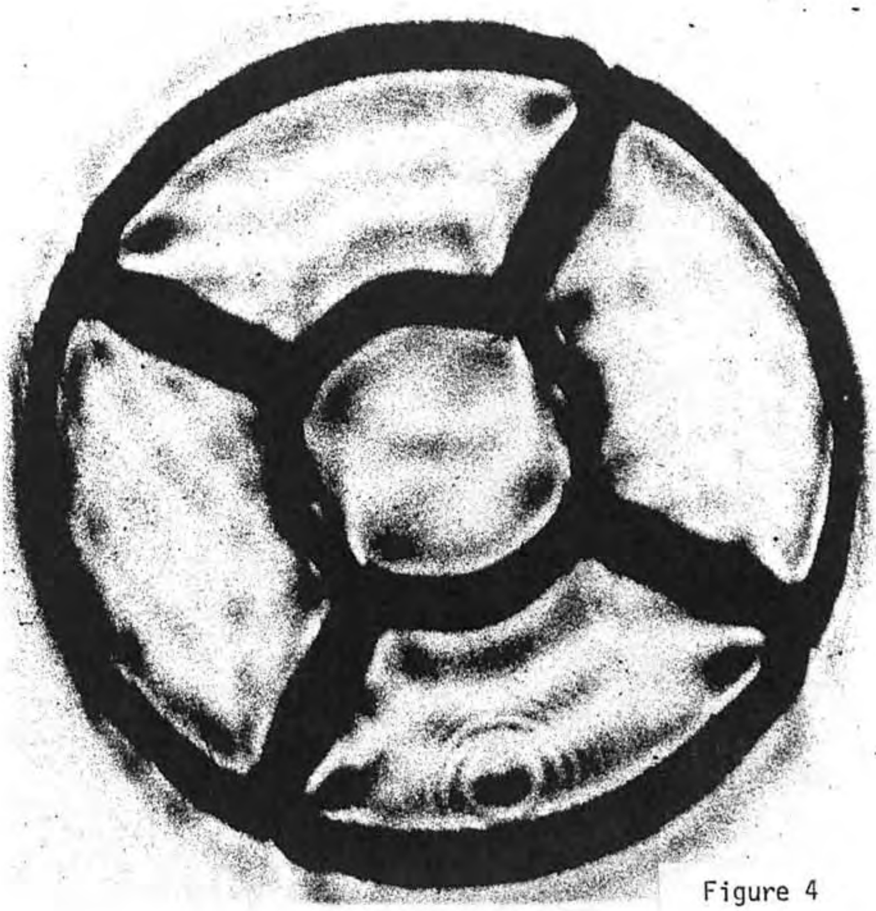

Figure 4

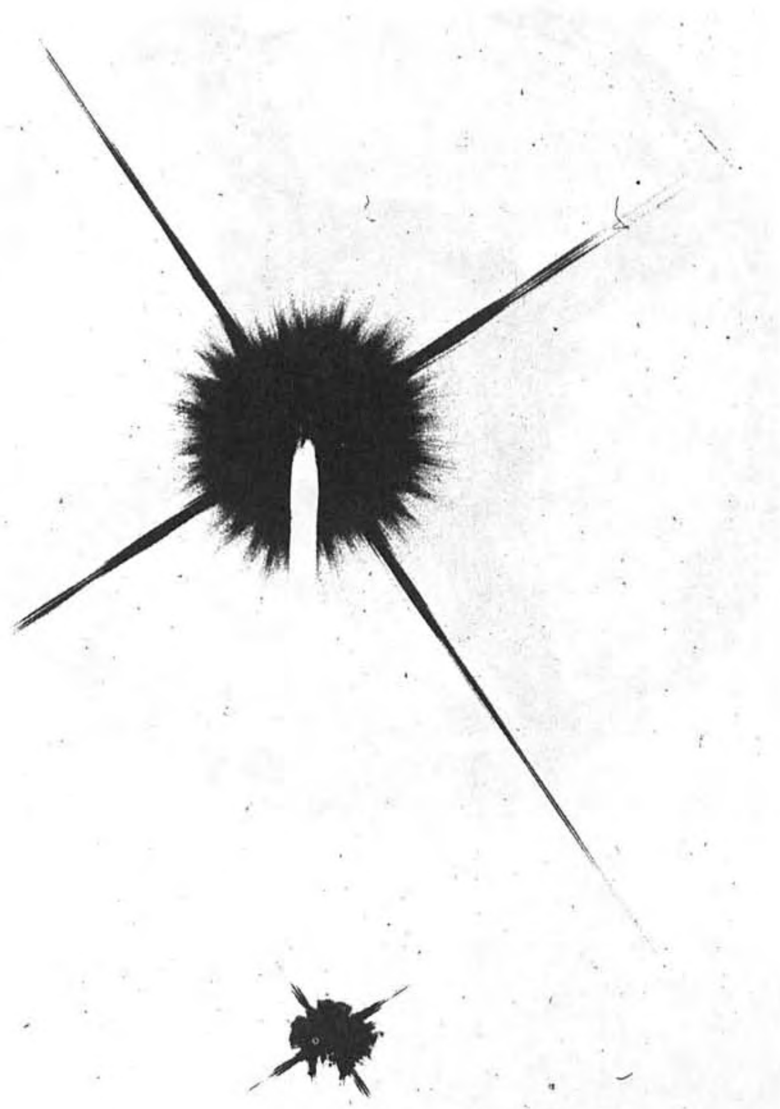

Figure 5a

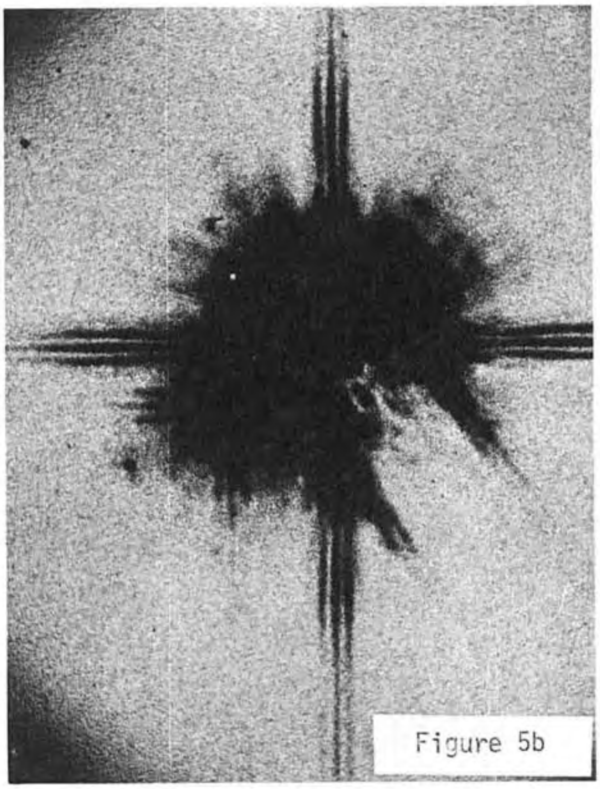

Figure 5b

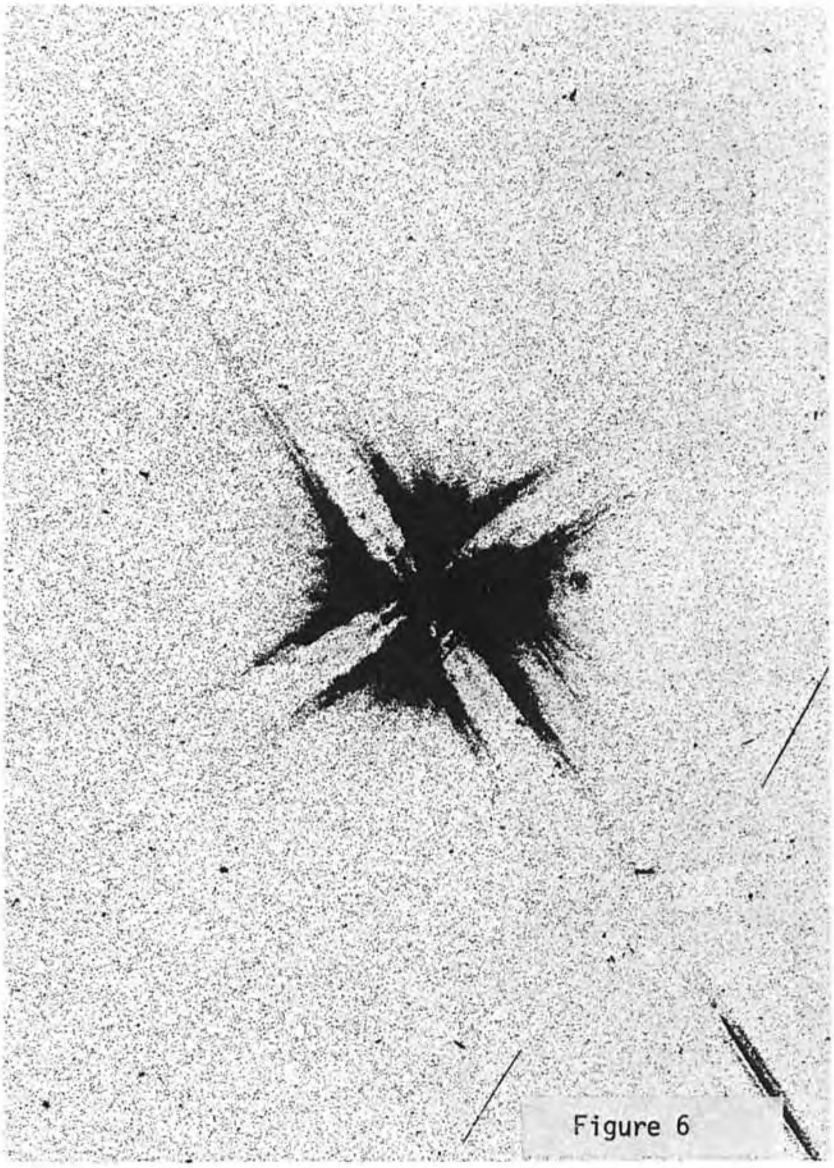

Figure 6

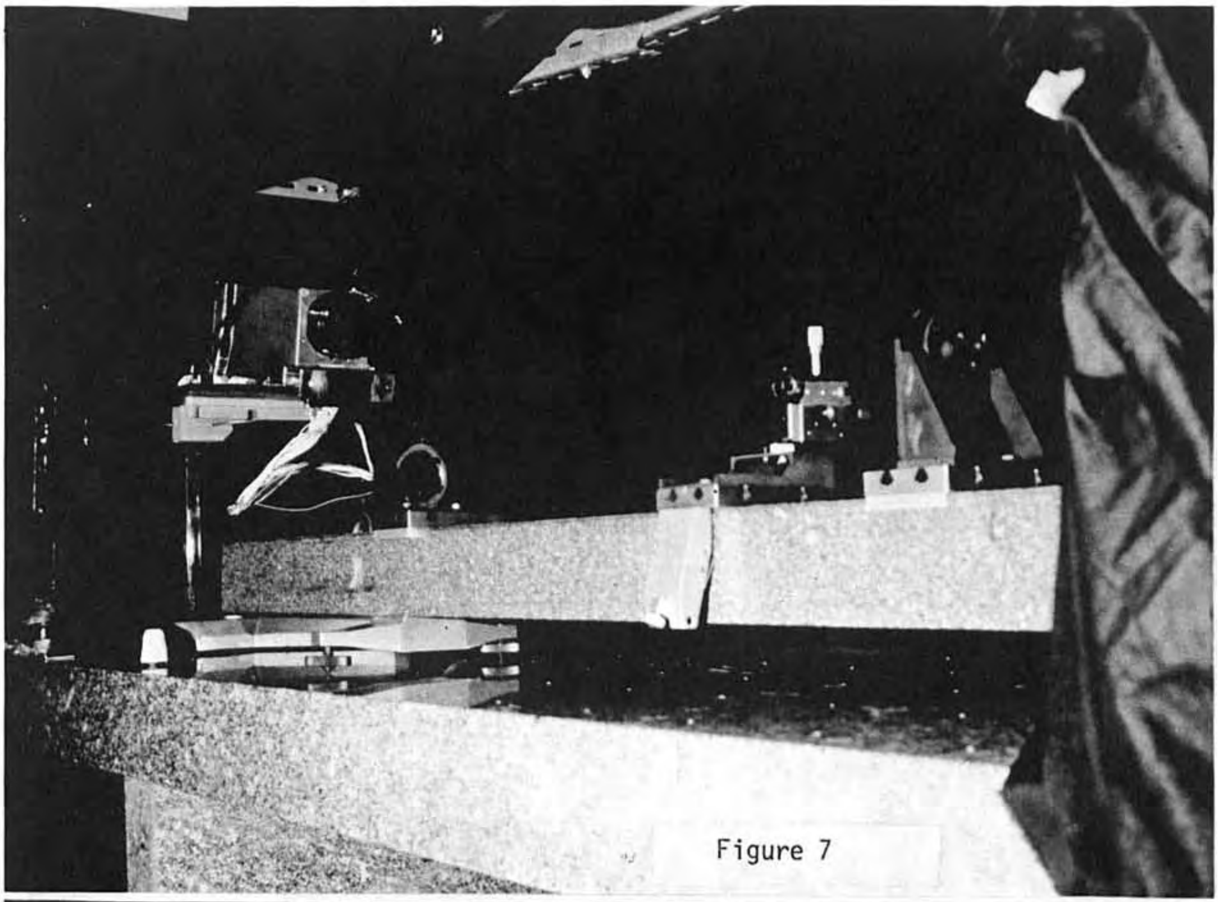

Figure 7

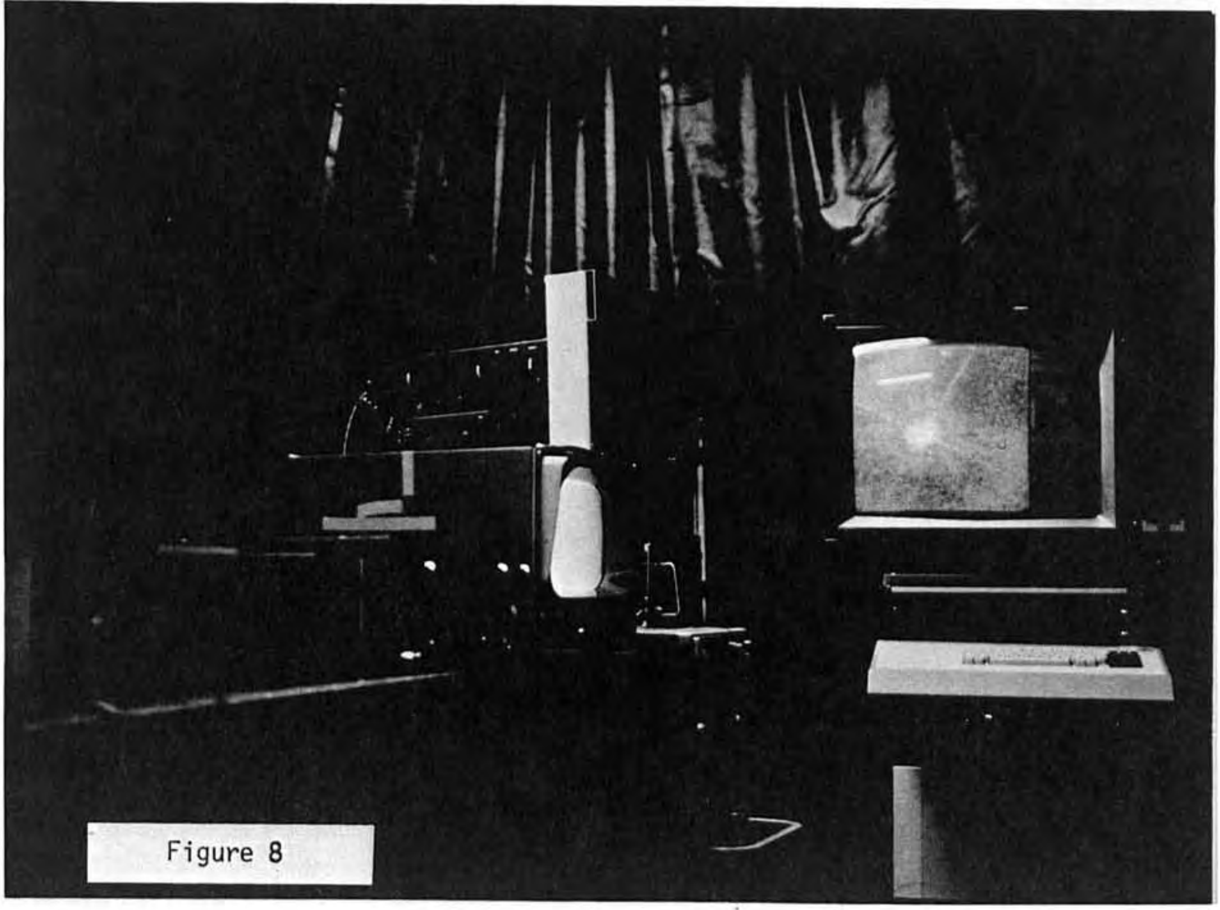

Figure 8

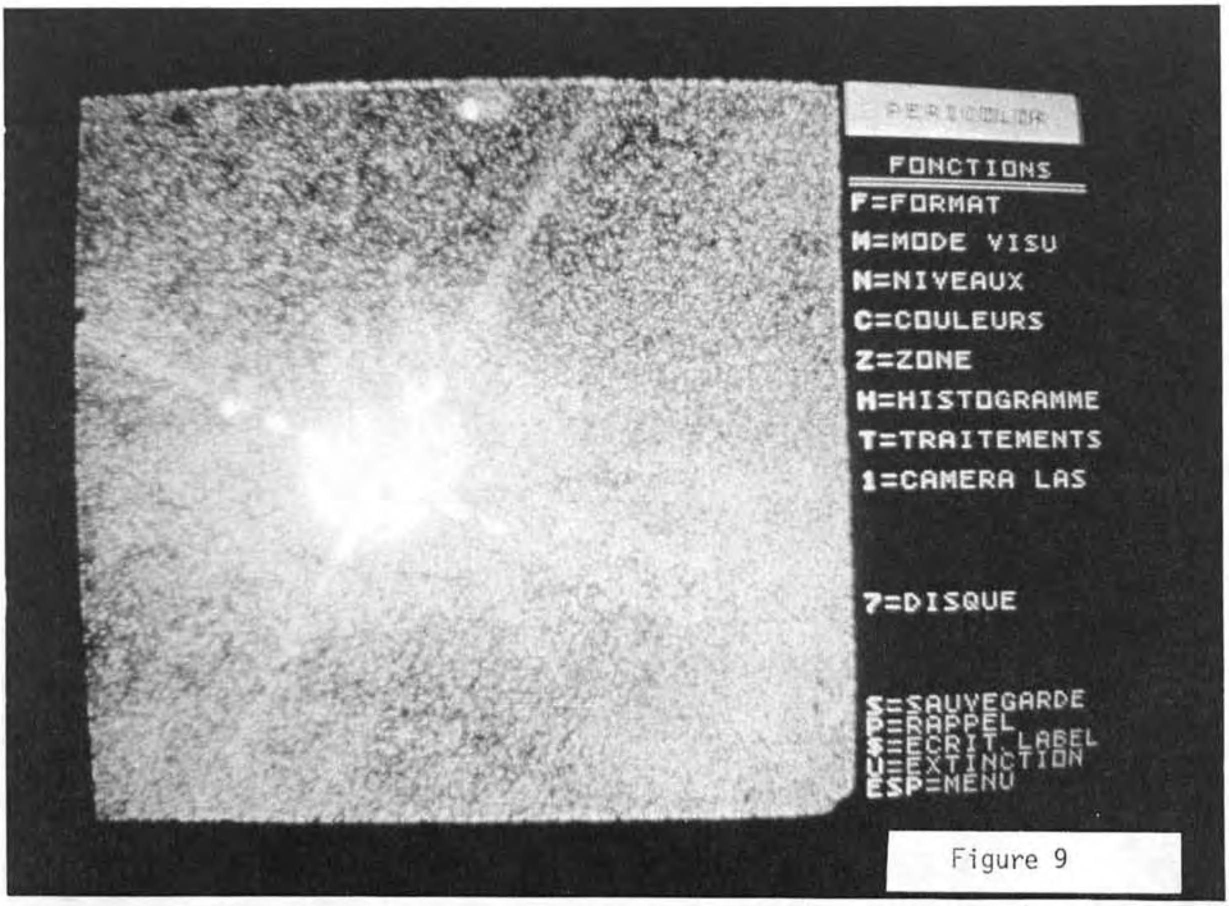

Figure 9

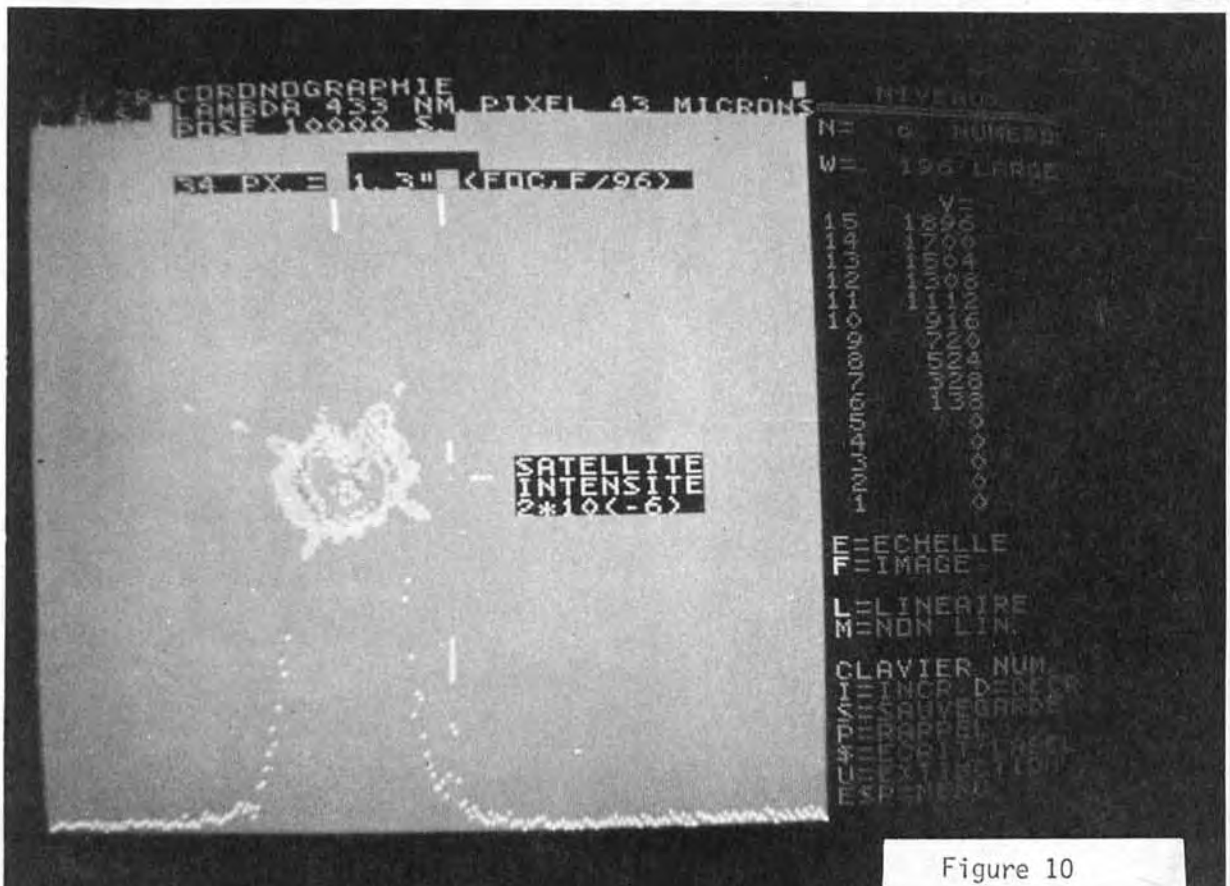

Figure 10

THE SPACELAB WIDE ANGLE TELESCOPE (SWAT)

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ABSTRACT

A NASA Science Workshop has recently recommended the incorporation in the space astronomy programme of a fast wide angle telescope that will be capable of imaging to the darker sky limit and in the ultraviolet wavelength region available above the atmosphere. The telescope (SWAT) will have a resolution comparable to that of large ground-based Schmidt telescopes and a field of at least five degrees. A number of astrophysically important investigations can only be accomplished with such a telescope, e.g. detection of hidden, hot objects like hot white dwarfs and subdwarfs in stellar binary systems and energetic regions in globular clusters and galaxy nuclei. It will permit unique studies of the UV-morphology of extended objects and allow discovery of very faint extensions, halos, jets and filaments in galaxies. It will contribute to the investigation of dust in the Milky Way and in other galaxies and, with an objective prism, spectra of very faint objects can be obtained.

The history of astronomy has repeatedly shown the great value of having large telescopes and wide angle cameras at the same observing site (Palomar, La Silla, Tololo, Siding Spring). The SWAT will provide an invaluable service in localizing objects for further study with the narrow-field Space Telescope. An ultraviolet survey of a (substantial) part of the sky will be a very important complement to large-scale ground-based surveys (e.g. Palomar, ESO (B), ESO/SRC).

I. INTRODUCTION

The main advantages of orbiting telescopes over ground-based telescopes are the possibility to observe in wavelength regions not accessible from below the atmosphere, the improved angular resolution due to the absence of atmospheric turbulence and the lower sky background. For these reasons, the Space Telescope will be able to observe objects which - because of their faintness and/or spectral energy distribution - can not be observed with the presently available telescopes on the ground.

Nevertheless, the first objects to be studied with the ST will necessarily be those which are already well-known, and which have been investigated extensively from the ground. However, it is clear that there are many other objects of interest to the ST that are not known at present and which can only be discovered from space. An important problem therefore remains how to assure that the ST is provided with exhaustive observing lists of potentially significant objects.

In view of the limited time available at the ST, and since it is in any case very inefficient to use this narrow-field telescope to search for objects (except in the serendipity mode), it must be supported by other space telescopes. Several instruments offer interesting possibilities in this connection. In this paper, however, we shall only discuss the proposed Spacelab Wide Angle Telescope (SWAT) which has recently been recommended for incorporation in the space astronomy programme by a NASA Science Workshop that was established in 1978. The design parameters are shown in Table 1 and are further discussed in section II.

A strong scientific case has been built for a fast wide-angle instrument like the SWAT, to be flown on Space Shuttle Extended Missions at about the same time as the ST (1983 and onwards). The SWAT would offer a unique possibility for discovering objects, not before known from ground-based observations, which could subsequently be further explored with the ST. Note, that the sky area covered by one SWAT frame (5^o) is 10.000 times that of the ST "Wide Field Camera" (3'). In addition, SWAT, with its tremendous information-gathering capability, would be an astronomical telescope of great potential all by itself, and would provide the astronomical community with an extremely valuable set of reference data (in UV as well as in IR) in the form of surveys of (substantial) parts of the sky.

The interest of the astronomical community in a wide field survey from space is well testified by the setting-up (in 1976) within

IAU Commission 28 of an ad hoc Working Group on Extragalactic Surveys From Space (Chairman : R. Barbon).

A clear historical parallel to the future ST-SWAT collaboration exists on the ground in the form of the Palomar 5 m telescope and the Palomar 48-inch Schmidt telescope. Without the support of the other,

TABLE 1. PRELIMINARY SWAT DESIGN PARAMETERS

TELESCOPE APERTURE	:	0.7 TO 1.0 METER
FOCAL RATIO	:	F/3
OPTICAL SYSTEM	:	ALL REFLECTING SCHMIDT (ARS), CF. FIGURE 1.
SCALE	:	~ 100"/MM
FIELD	:	~ 5^{o} CIRCULAR
RESOLUTION	:	≤ 1" AT FIELD CENTER, ~2" AT EDGE, OR BETTER
SPECTRAL REGION	:	1100 - 11000 A
DETECTORS	:	ELECTROGRAPHIC IN UV IMAGE INTENSIFIER IN IR (DIRECT PHOTOGRAPHY)
EXPOSURE TIME	:	UP TO 30 MINUTES
LIMITING MAGNITUDE	:	V ~ 26^{m}, OR 0.7 μJY (UNREDDENED B0 STAR IN FAR-UV AT 5σ S/N-RATIO
STABILIZATION	:	SPACELAB INSTRUMENT POINTING SYSTEM (IPS)

neither of these would ever have been able to contribute as efficiently to the advance of astronomy. The Palomar example was recently followed up in Australia (the 4 m AAT and the 48-inch SRC Schmidt telescope) and in Chile (the 4m Tololo telescope and the Curtis Schmidt ; the 3.6 m ESO telescope and the 1m Schmidt at La Silla). The experiences at these observatories have repeatedly confirmed the importance of having large and wide-angle telescopes on the same site.

The National Geographic Society-Palomar Observatory Sky Survey was published in the second half of the 1950ies, covering the sky north of -30^{o} declination. As a continuation, the ESO/SRC Sky Survey of the Southern Sky, which is now being produced with the ESO and SRC Schmidt telescopes, will show the part of the sky south of -20^{o} declination. We shall therefore soon have the entire sky covered by very deep, two-colour sky atlases ($m_B > 21$; $m_R > 20$).

One of the main objectives of the SWAT project is to obtain a similar coverage in the wavebands not accessible from the ground. The intercomparison of future, very deep ultraviolet and/or infrared surveys and existing ground-based blue/red surveys will offer unique possibilities for detection of certain classes of objects and for a preliminary astrophysical investigation of otherwise "normal" objects.

Previous limited sky survey projects in the UV have been excellently reviewed by Carruthers (1978). Among the more important projects should be mentioned the OAO-2 Celescope (in 1968) that covered 10% of the sky, in $2^{o} \times 2^{o}$ fields with a limiting magnitude of about 10^{m} (Davis et al., 1973). The Naval Research Laboratory S201 project (Carruthers, 1973) which was deployed on the lunar surface by the Apollo 16 crew in 1972, obtained ten spectacular 20^{o} field photographs, including one of the Large Magellanic Cloud. The S019 experiment (O'Callagan et al.,1977) on Skylab (1973-1974) provided objective prism spectra of stars brighter than 6^{m} and the S183 experiment, also on Skylab, performed a limited ultraviolet survey for the Marseille Observatory and the Laboratory for Space Astronomy in Marseille. The UV Sky Survey Telescope on the TD-1 satellite (Boksenberg et al., 1973) observed about 3000 stars brighter than 10^{m} to 11^{m} and measured their UV colours. The ORION-2 experiment was flown on SOYUZ-13 (Gurzadian, 1976) and obtained low-dispersion spectra of more than 3000 stars, down to 13^m.

Large numbers of ultraviolet observations of individual objects have also been obtained with the five-channel UV spectrophotometer, on-board the Netherlands Astronomical Satellite (ANS) and, more recently, the International Ultraviolet Explorer (IUE) observed the UV spectra of stars, nebulae and galaxies.

On the basis of these (limited) UV surveys, many objects have been found which are unexpectedly bright in the UV. It is possible to draw the following firm conclusion : the sky as seen in the Far-UV (below 2000 Å) is not a simple extrapolation of the ground-accessible Near-UV (3000-4000 Å).

The SWAT project represents a very significant step forward, as compared to earlier UV-surveys, in terms of angular resolution, limiting magnitude and, most probably, sky coverage. For a better appreciation of its scientific potential, we first discuss the technical data and then the main scientific objectives, although it must be kept in mind that the design parameters of SWAT are a function of the research goals. Further details are given in the "Preliminary Report of the SWAT Science Workshop", NASA, March 1979.

II. TECHNICAL DATA FOR SWAT

Preliminary technical data for the SWAT project are summarized in Table 1. It should be emphasized that the technical feasability study has not yet been finished, but few changes of the main parameters are expected.

It is proposed to use a f/3 All Reflecting Schmidt system (ARS), as shown in Fig. 1. It will give a definition of about 1" (100% energy circle) at the center of the field, falling off to about 2" at a distance of 2^o from the center. Very recent optical studies have indicated the possibility of improving the resolution, perhaps by a factor of two. The advantage of the All Reflecting Schmidt is that it can be used for all wavelengths (1100 Å - 11000 Å). The focal plane is curved and attention must be given to the problem of fitting the detector cathode. Another optical system, the All-Reflecting Baker Schmidt (BTS), has a flat focal plane, but is less promising, because of lower resolution and a large central obscu-

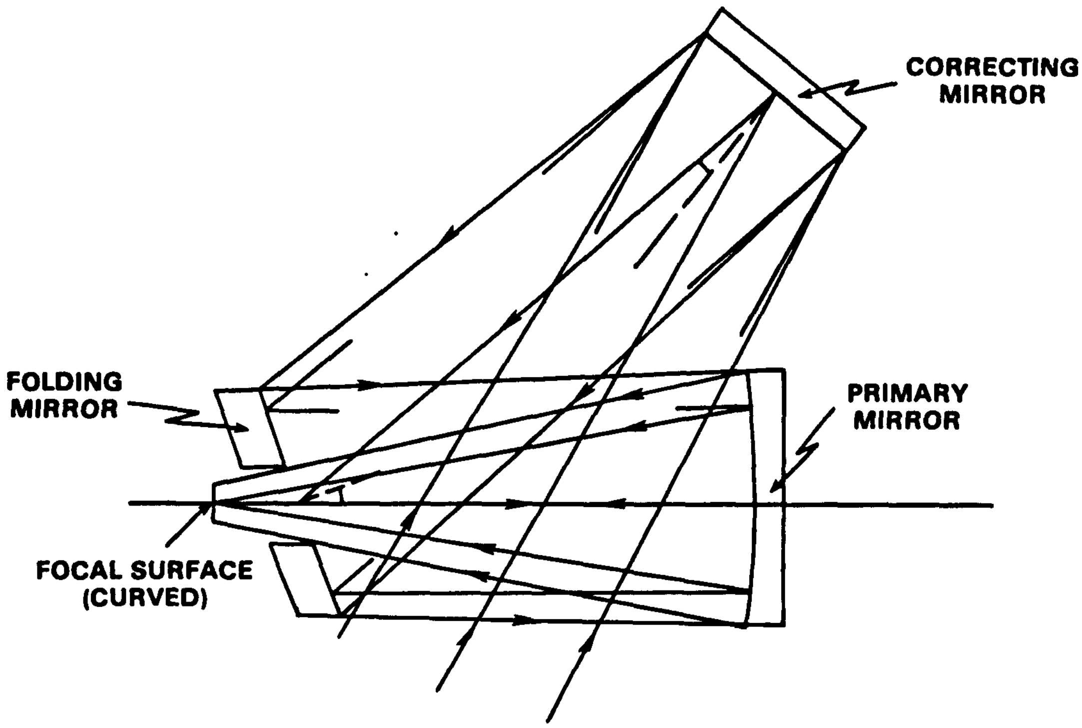

Fig. 1 Folded All-Reflecting Schmidt design for f/3.0 and 4°0 field of view.

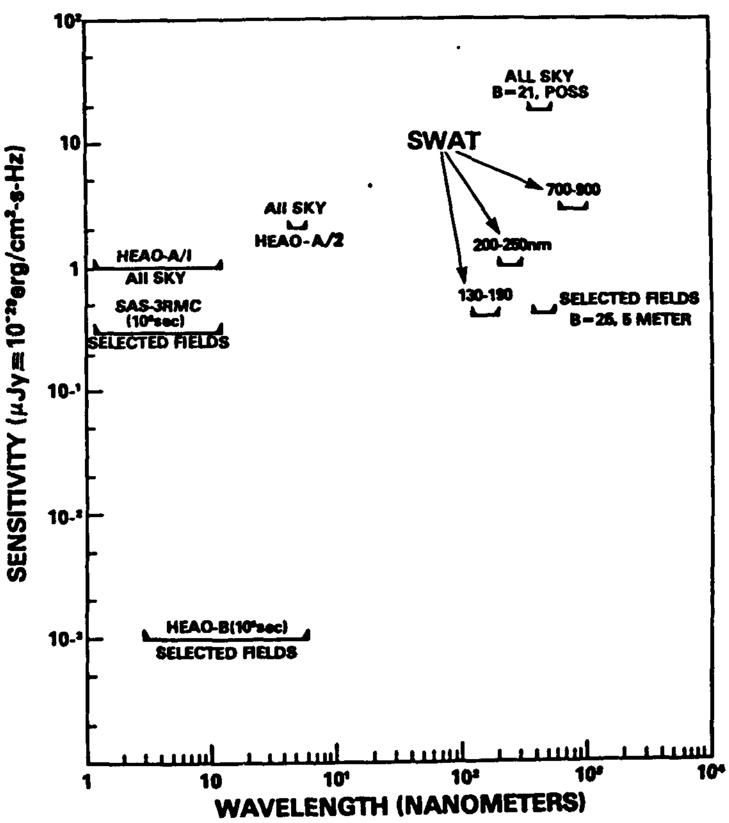

Fig. 2

Sensitivity of SWAT compared to other surveys.

ration by the secondary mirror.

With a scale of approximately 100"/min, a 5^{o} field would correspond to 18 cm. The electrographic camera, which is now being developed at the Naval Research Laboratory by Carruthers is expected soon to be available in a corresponding size. Other possible detectors are image intensifiers, and photographic films. It is expected that the Far-UV limiting magnitude will correspond to V = 26 (spectral type BO) and that due to the lower sky background, detection of extended features is possible at a level of 1^{m} fainter than what can be reached from the ground (cf. Fig.2). For these figures a maximum exposure time has been taken as 30 min, which is equal to the dark time during one Spacelab orbital revolution. Shorter exposures may be made on the bright side.

The idea of a deep photographic survey from Spacelab has been pushed within Europe by an Italian group (Barbon et al., 1977, and Barbon et al., 1978). A 20 cm All Reflecting Schmidt telescope has recently been successfully constructed and tested at the Padova Observatory (Bertola et al., 1979). Nearly all technological requirements for SWAT are state-of-art, but further development is needed in the detector field.

SWAT would use portions of two pallets on the NASA Space Shuttle and would be flown on missions, lasting from 7 to 30 days, at a nominal altitude of 300 km. The exposed films will be developed in a conventional way. The possibility of making the photographs available in the form of an atlas, as film or glass copies, is being studied.

The SWAT photographs will be calibrated and can be measured quantitatively with presently available, fast, scanning microphotometers.

III. MAIN SCIENTIFIC OBJECTIVES

In addition to providing astronomers with the possibility of comparing photographs of the sky in various wavelength regions, SWAT

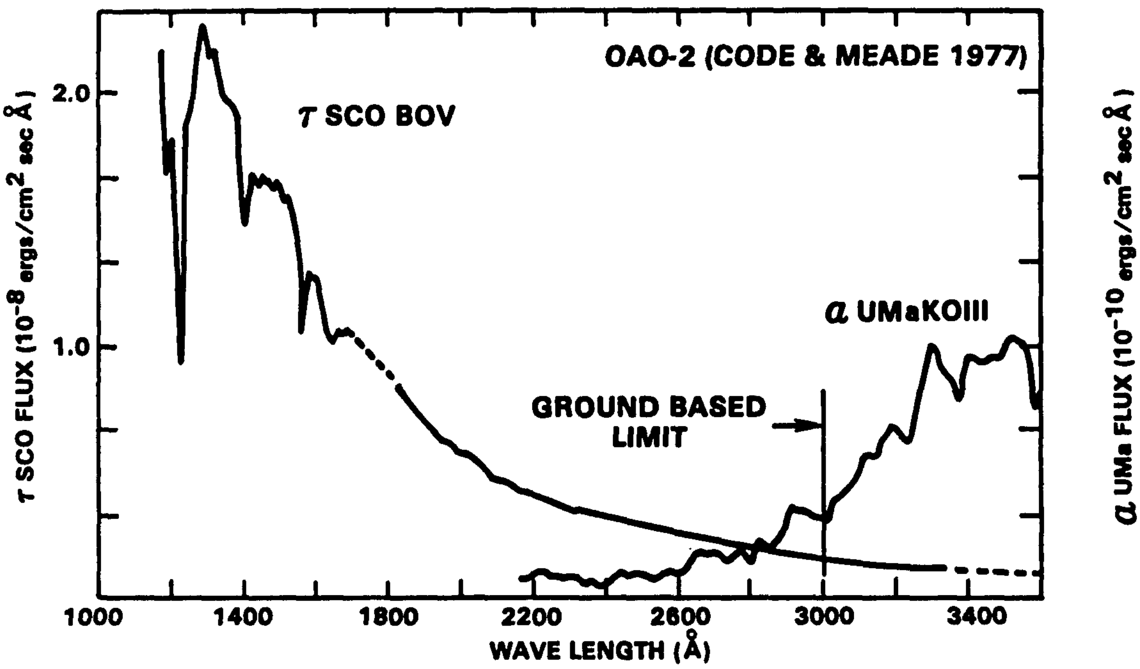

Fig. 3 Hot star and cool star flux distributions in the UV.

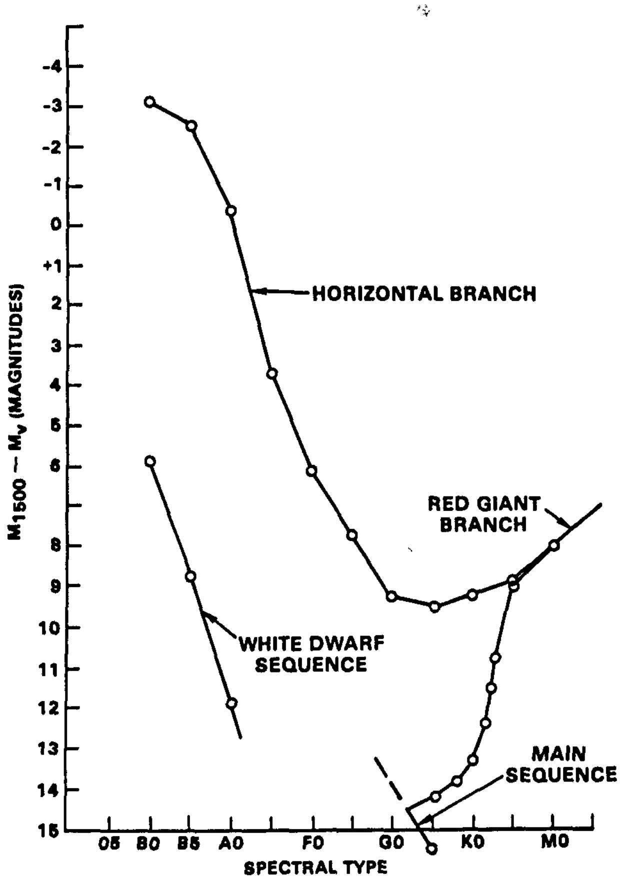

Fig. 4

UV HR-diagram for Pop II (M_λ = 1500 - V from ANS observations) will have a direct impact on the following astronomical fields, as identified by the NASA SWAT Science Workshop :

1)- Hidden Hot Objects, e.g. in star groups, globular clusters and galaxies
2)- UV-morphology of galaxies
3)- Dust in the Milky Way and in other galaxies (extinction and scattering)
4)- The study of faint extended objects, like nebulae and extensions to galaxies and galaxy clusters
5)- Emission line objects, by means of objective prism or grating spectra
6)- Extended solar system objects (comets and planets)

SWAT will be uniquely suited for the large-scale exploration of these areas,most of which can not be done with other space telescopes or from the ground. The NASA Workshop enumerated further areas of research with SWAT, for which it is a very useful instrument, but which may also, to some extent, be carried out with other instruments. The objectives are summarized in the Preliminary Report of the SWAT Science Workshop.

III.1. Hidden hot objects

Fig. 3 shows the observed spectral distribution of a KO III and a BO V star. Whereas the cooler star has virtually all of its energy longwards of the atmospheric cut-off at 3000 Å, only a very little part of that of the hot star is emitted in the atmospheric window. Earlier UV surveys have shown many cases of hot stars, in particular white dwarfs and subdwarfs, which were first detected in the UV due to "masking" by a nearby, colder star. An example is the star HD 149499B, a 100.000 K^o white dwarf, which is the secondary component in a binary system of which the primary is a KO V star. The hot component was first seen on S019 photos.

The UV HR-diagram for a population II globular cluster is shown in Fig. 4. It is obvious that a wide-field picture of such an object will provide important information on the population of the horizontal branch and therefore on the metallicity. Likewise, the detection of white dwarfs in the nearer galactic clusters is of great importance

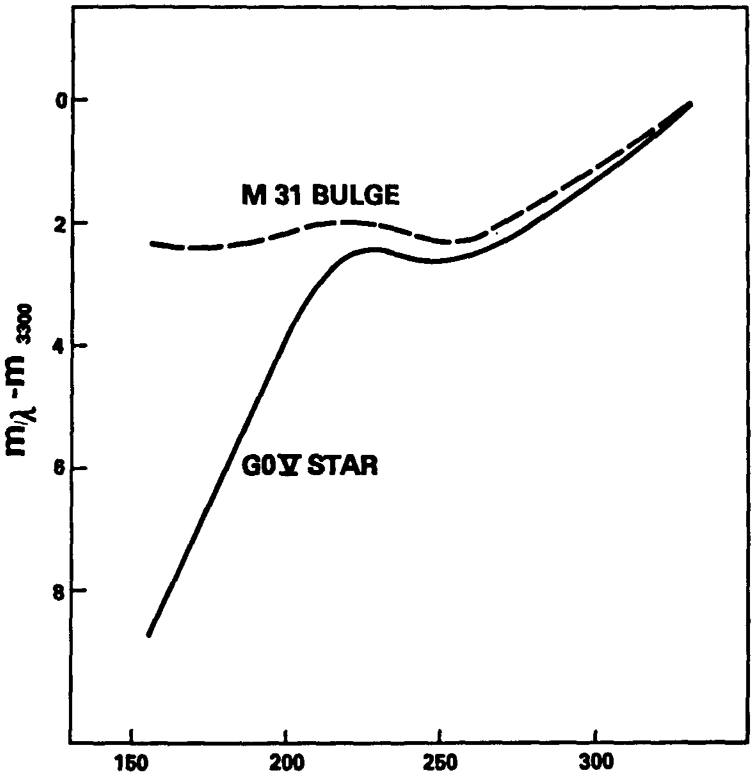

Fig. 5

UV flux distributions of the nucleus of M31 vrs. a G0V star.

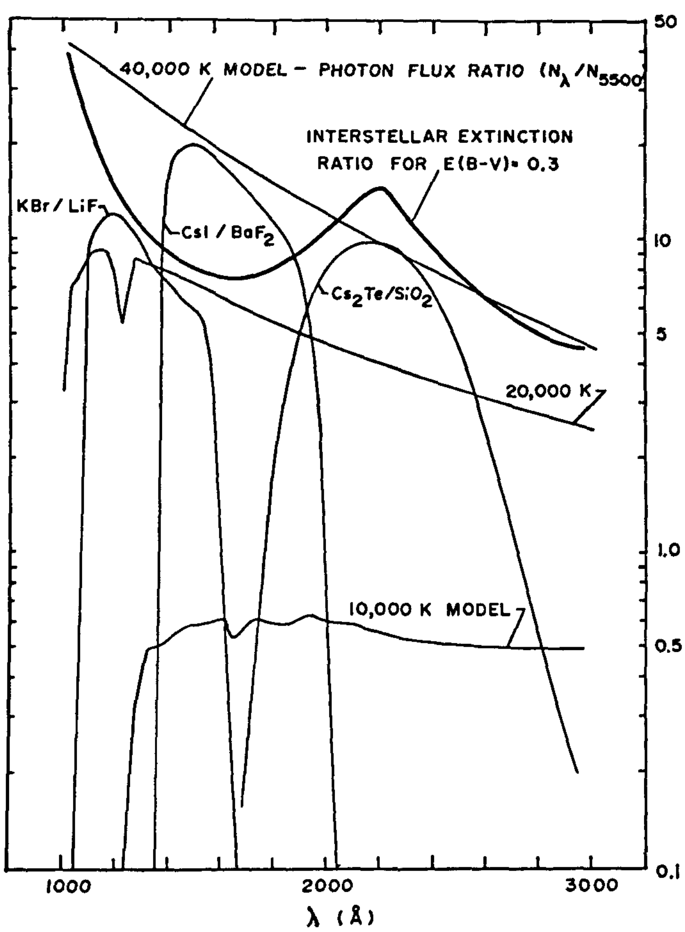

Fig. 7

Comparison of intrinsic stellar flux distributions with the average interstellar extinction. Also shown are three spectral bandpasses for photocathode-substrate window combinations (NRL).

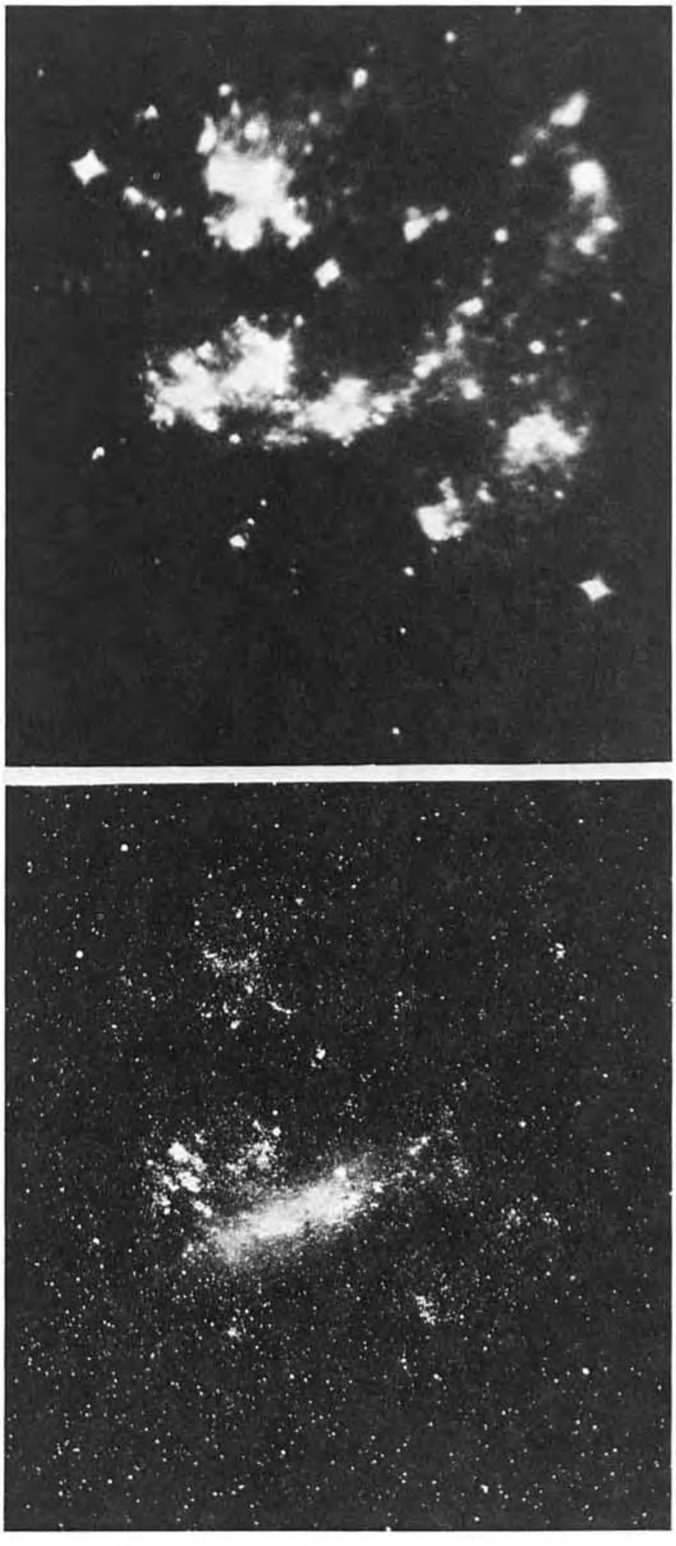

Fig. 6

The Large Magellanic Cloud, photographed in UV (upper) and V (lower). UV photo from the S201 experiment with bandpass 1250 - 1600 A; courtesy G. Carruthers. V photo from Lick Observatory.

for the determination of the stellar death rate in a supposedly uniform stellar sample and thus of the Initial Mass Function.

Quite apart from galaxies with active nuclei, seemingly normal galaxies may show a considerable UV-excess. Fig. 5 shows the normalized spectral distribution of the bulge of M31. Whereas it fairly closely approximates that of a GO V star in the near UV, it has a strong UV excess below 2000 Å. SWAT will provide hundreds or thousands of UV galaxy images in a single picture.

III. 2. UV morphology of galaxies

As an example of the tremendous difference in the appearance of a galaxy in different colours, we show in Fig. 6 the Large Magellanic Cloud, as seen in the far UV and in visual light (Carruthers, 1978). The UV picture was made during the Apollo 16 Lunar Mission and shows the distribution of hot objects in the LMC. The hot stars delineate areas of current star formation and can therefore be used in a straightforward verification of the various theories of spiral arm formation. It is furthermore of obvious significance to learn where and how often bursts of star formation take place and in which (types of) galaxies they occur. This can only be efficiently done with a wide-field camera like SWAT.

III. 3. Dust

In all cases where it has been possible to measure the extinction by interstellar dust, over a large spectral region, it has been found that it increases drastically towards the UV and that it shows a maximum around 2200 Å, the origin of which is still not known. Furthermore far-UV photographs have shown that the dust albedo is much higher than in the visual spectral region. Reflection nebulae are therefore optimally detected on UV photographs, also because they are often associated with hot stars and thus illuminated by a large UV photon flux.

The extinction maximum allows a separation of stellar temperatures and the extinction, because of the apparent "blueing" shortwards of 2200 Å. A technically feasible 3-colour filter system is shown in Fig. 7.

The observation of a large sample of galaxies with SWAT will provide new insights in the distribution of dust and thus into the formation of stars within galaxies and to the evolution of galaxies in general.

III.4. Faint extended objects

The decreased brightness of the sky above the atmosphere, in particular in the IR, will allow the fast focal ratio SWAT to reach a surface intensity fainter than can be observed with ground based telescopes (cf. Fig.8). It will therefore be possible to observe very faint features like faint jets and filaments extending from the nuclei of active galaxies ; faint extensions to galaxies and bridges in interacting systems ; possible, extended halos to giant galaxies and intergalactic matter in clusters of galaxies ; very faint dwarf galaxies and low surface brightness galaxies, and faint nebulosity in high galactic latitudes.

The study of these features with SWAT will obviously be of great importance for the understanding of the evolution of galaxies (M/L ratio and Mass Function) as well as of cosmological significance (missing mass).

III. 5. Emission line objects

The combination of a wide-angle telescope with an objective prism or grating has long been known as one of the most efficient information-gathering astronomical instruments. Several important spectral surveys have been carried out on the basis of relatively few plates (i.e. requiring a modest amount of telescope time) and the recent improvements in the sensitivity of photographic plates have made it possible to reach very faint limiting magnitudes, even with Schmidt telescopes of moderate aperture. The tremendous potential has been impressively demonstrated by the discovery of hundreds of quasars on a single SRC 48-inch Schmidt plate (for a review, cf. Smith, 1978).

For the SWAT, one can either use a UV transmitting prism mosaic, f.inst. of CaF_2 blanks, which are now available up to about 15 - 20 cm diameter, or an objective diffraction grating used in reflection. It is also possible to use a grism in front of the detector.

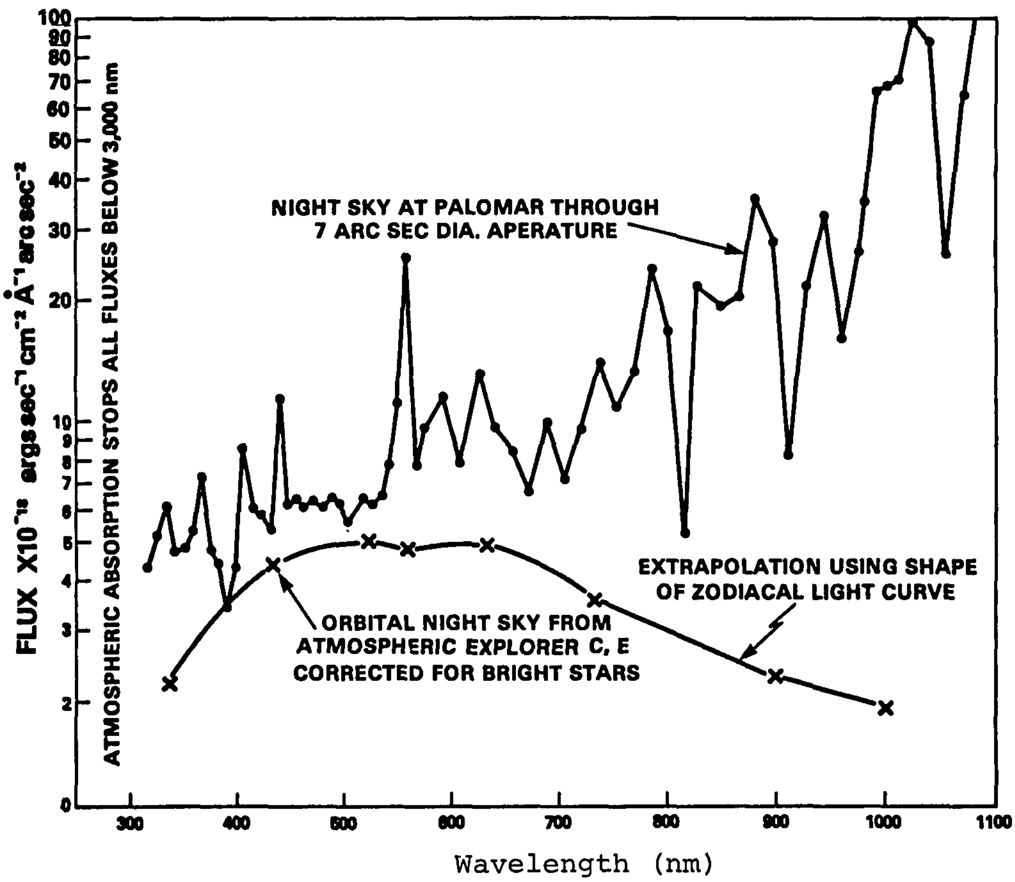

Fig. 8 The night sky from ground and orbit.

Most of the resonance lines of the common elements are in the UV, and SWAT clearly has an enormous potential for discovery of peculiar objects as well as classification of normal ones.

III. 6. Solar system observations

Among the solar system objects which can advantageously be observed with SWAT, comets and planets are the most important. The spatial mapping of atomic species and simple molecules in and around cometary comae and the detection and measurements of common elements around planets and their satellites is of great interest.

III.7. Other spectral regions

Because of the SWAT all-reflecting optical system, it is equally suited for observations of other pass-bands, for instance in the near IR. Due to the hydroxyl emission, there is an even greater gain in the IR in sky brightness (cf. Fig. 8), and very faint objects can be studied by means of IR detectors. Among the many possible applications, a search for very high redshift quasars is of particular interest.

IV. CONCLUSIONS

The ST will imply a significant step forward in angular resolution and limiting magnitude. The SWAT will provide efficient and complementary support to the ST. With a limiting magnitude like the large ground based telescopes and a wide field, SWAT can survey a large part of the sky in spectral regions that cannot be efficiently studied from ground. It will therefore detect a vast number of hitherto unknown objects of astrophysical importance which can later be studied in detail with the ST and frequently also with telescopes on the ground. The comparison between SWAT photographs in the UV and existing ground based sky surveys will greatly enhance our knowledge of the distribution of thermal and non-thermal objects in the Milky Way and in other galaxies.

We feel that the incorporation in the space astronomy programme of SWAT will have a profound impact on many frontline research areas in astronomy and urge that the necessary steps be taken to ensure that the SWAT project is realized with a launch date as early as technically possible. In view of the many possible applications of this basic astronomical tool, it would obviously be of great importance to establish a broad international cooperation within the frame of the SWAT Project.

ACKNOWLEDGEMENTS

The scientific and technical definition of the SWAT Project is a result of the joint efforts of the members of the NASA SWAT Science Workshop.

REFERENCES

Barbon, R., Benacchio, L., Bertola, F., Cappacioli, M., Cosmovici, C.B., Maffei, P., Strafella, F., 1977, "Deep Survey from Spacelab", ESA Colloquium on Long Term Scientific Planning, Trieste.

Barbon, R., Benacchio, L., Bertola, F., Cappacioli, M., Cosmovici, C.B., Maffei, P., 1978, "New Instrumentation for Space Astronomy", edit. K. Van der Hucht and J.S. Vaiana, 1978, p.3

Bertola, F., Ortolani, S., Zen, R., 1979, in Proceedings of Colloquium on European Satellite Astrometry, eds. C. Barbieri and P.L. Bernacca, 101

Boksenberg, A., Evans, R.G., Fowler, R.G., Gardner, I.S.K., Houziaux, L., Humphries, C.M., Jamar, C., Macau, D., Malaise, D., Monfils, A., Nandy, K., Thompson, G.I., Wilson, R., Wroe, H., 1973, Mon. Not.R. Astr. Soc., 163, 291

Carruthers, G.R., 1973, Applied Optics, 12, 2501

Carruthers, G.R., 1978, Space Sci. Instr., 4, 3

Code, A.D., Meade, M.R., 1977, Wisconsin Astrop., No. 30

Davis, R.J., Deutschman, W.A., Haramundanis, K.L., 1973, Celescope Catalog of Ultraviolet Stellar Observations, Smithsonian Institution Press, Washington

Gurzadian, G.A., 1976, in Proceedings of the Third European Astronomical Meeting, Ed. E.K. Kharadze, Publishing House, "Metsniereba", Tbilisi, 33.

O'Callaghan, F.G., Henize, K.G., Wray, J.D., 1977, Applied Optics, 16, 973

Smith, M.G., 1978, Vistas in Astronomy, 22, 321

P.R. WESSELIUS: 1. Looking out to m_{uv} = 25 to 26 does not necessarily mean that you can look farther out than the POSS. You are much more bothered by interstellar extinction in the ultraviolet.
2. The extinction law varies much in the UV partly because of its normalization in the visual.

G. COURTES: There has been already some UV (2500 Å) survey of the sky -

1°/ Rockets L.A.S.* wide field camera (1967) 80° x 120° up to the m_e = 10

2°/ Skylab L.A.S. S 183 camera (1973) m_e = 12

3°/ Balloon L.A.S. - GENEVA-OBS. (1978) UV(2000 Å) m_e = 12

M 31 and Cygnus Loop observations - (CIII and SiIII lines)

Two new surveys are accepted on the first Spacelab Mission -

1°/ The Very Wide Field Camera V.W.F.C. from L.A.S. - field 60° - 3 bandwidths and a grating mode -

F1 = λ 1500 Å

F2 = λ 2000 Å

F3 = λ 2800 Å

Nebular spectrograph - Δλ = 1300 - 1800 Å slit 10° field x 0,6°

2°/ The FAUST experiment - LAS + Berkeley University.

Δλ = 1350 - 1600 Å M_e = 17 field 6°.

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MOTIONS IN OUR GALAXY FROM SPACE TELESCOPE AND HIPPARCOS OBSERVATIONS

P. LACROUTE

Hipparcos, the E.S.A. project for space astrometry will allow the accurate determinations of parallaxes, positions and proper motions in a very consistent system for at least 100 000 stars, up to m = 11. The absolute rotation of the resultant reference system will remain unknown. It does not matter for the parallaxes, they are absolute. But the use of the proper motions is often dependent on the precision of our knowledge of the absolute rotation Hipparcos system.

HIPPARCOS HOPED-FOR RESULTS

The E.S.A. project is able to allow the proper motions with incertitude $2{,}3.10^{-3}$"/y on 100 000 stars at m < 11 (case A). With a second launch, 10 years after, the incertitudes decrease to 3.10^{-4}"/y (case A').

But Hipparcos is again in process. If we succeed in the elimination of jitter on the attitudes, through the use of dynamical smoothing we obtain better results of more numerous stars. Table I shows the results of a programme of 200 000 stars. Although this method is not now certainly feasible we study also this case (case B) and the case of two launches (case B').

Table I

RANDOM ERRORS ON THE PROPER MOTIONS (UNIT $.10^{-3}$"/y)

INCERTITUDES ON THE POSITIONS IN BRACKETS (UNIT $.10^{-3}$")

Case		A	A'	Case		B	B'
m < 7	(1.6)	2.3	0.3	m < 6	(0.3)	0.4	0.05
7 à 11	(1.6)	2.3	0.3	7	(0.5)	0.7	0.09
11 à 12	(1.8)	2.6	0.4	8	(0.7)	1.0	0.13
				9	(1.0)	1.4	0.18
				10	(1.8)	2.5	0.33
				11	(2.9)	4.1	0.53
				12	(4.6)	6.5	0.84

In the Hipparcos system the errors on the proper motions are a little correlated between the very neighbouring stars. We have a kind of local systematic error. They are included in the random errors. However the reduction of the errors on an average of stars is not so good as on completely independent measures. In case A and A' on an extensive cluster like the Hyades, we can decrease only by a factor 4 the error of the mean motion ; only by a factor 2 on a compact cluster (E.S.A., OP/PS (78) 13). In case B and B' the local systematic errors, and not the statistic of photons, limit the precision on the bright stars. These systematic errors are independent to 2 degrees of distance. On an extensive cluster it is possible to divide the errors by 2 on an average. On a compact cluster it is unfeasible to obtain smaller errors than on a bright star.

In table I all the errors are only mean errors. The comparison between the cases A and the cases B is difficult because in the programme A on 100 000 stars, more time is given to the faint stars in order to obtain about the same accuracy on all the stars, and that is necessary with regard to the adopted process. The results in cases B are computed observing each star during 4 sec. on the 20 sec. of transit. That gives the possibility to observe 200 000 stars or more. That gives also the possibility to decrease the incertitudes by about a factor 2 on some sparse selected stars. But we never obtain incertitudes below these given on bright stars.

USES OF HIPPARCOS PROPER MOTIONS

The Hipparcos system will be very consistent. Also all the stars contribute to the definition of the system. The incertitude on the rotation definition is in spite of the local systematic errors about :

Case	A	A'	B	B'
	10^{-5}"/y	$1,4.10^{-6}$"/y	4.10^{-6}"/y	6.10^{-7}"/y

The study of each star with an adequate absolute precision is unfeasible, consequently we can not study the absolute rotation with these precisions.

Also we have to consider the real needs for the practical uses of Hipparcos proper motions. In each case of use we accept conventionally errors coming from the error of absolute rotation of the system if they are half of the random errors in the system.

In table II we give the acceptable errors on the absolute rotation concerning the uses on individual stars, on clusters and the statistical uses.

In the case of use on clusters the correlations between the results on neighbouring stars are taken in account. The statistical uses are always disturbed by the random individual velocities of the stars. For instance a transverse velocity of 20 km/sec. gives a proper motion of $0{,}044''/y$ at 100 parsecs, and $0{,}0044''/y$ at 1 000 parsecs. Also the random errors of the Hipparcos proper motions are very often uselessly small for the statistical uses. Their precisions are only useful on the far stars. In order to obtain precise statistical results we need large samples. Concerning the statistical uses of proper motions, the advantage of the Hipparcos results relatively to the present data, will be essentially the elimination of the local systematic errors because these errors remain on the averages. We can discriminate a direct use of the Hipparcos results, and an indirect use eliminating the local systematic errors on the present proper motions. The statistical efficacy of the indirect use is certainly better because we increase the number of the stars in the samples, but it is difficult to give now an estimation. Also we study here only some direct uses.

An error on the absolute rotation is without effect on the statistical parallaxes from the dispersions of the proper motions.

The absolute rotation disturbs the secular parallaxes coming from the particular velocity of the sun, but only in so far as the given weight to the samples is dissymetrical relatively to this velocity.

Certainly the study of the law of differential galactic rotation is the most sensitive to an error of the absolute rotation. For instance we find completely this error on the B Oort'term. From the Hipparcos results the precision will be limited by the number of stars. Accepting the densities in stars by Allen, on interstellar absorption of 1,8 magnitude by kiloparsec, using all the stars at $m < 10$, at distance smaller than 200 parsecs from the galactic plan, and at distances between 200 and 1 500 parsecs from the sun, using so about 50 000 stars, it is possible to obtain B with an incertitude $3.10^{-5}''/y$. The incertitude is the same in all the cases because the error comes from the too small number of useful stars, and not from the incertitudes on the Hipparcos proper motions. Certainly it is possible to improve the results by the indirect use of the proper motions. Now the different B term values agree at about $4.10^{-4}''/y$. But we have to add the incertitude coming from the precession, probably a little smaller than $10^{-3}''/y$.

Table II

WANTED INCERTITUDES ON THE ABSOLUTE ROTATION

(1/2 OF THE USEFUL RANDOM ERRORS). Unit "/y

Case	A	A'	B	B'
Use on one star	$1,15.10^{-3}$	$1,5.10^{-4}$	$3,5.10^{-4}$	$4,5.10^{-5}$
Use on a cluster	3.10^{-4}	4.10^{-5}	4.10^{-5}	$2,2.10^{-5}$
Statistical determination of B	$1,5\ .10^{-5}$	$1,5.10^{-5}$	$1,5.10^{-5}$	$1,5.10^{-5}$

DETERMINATION OF THE ABSOLUTE ROTATION

It is tempting to establish a connection between the Hipparcos system and the very far objects certainly without significant proper motions. The possibility to observe the most distant objects by radio techniques and to build thus an absolute reference system suggests at first sight to establish a connection between the radio system and the optical system. That is the purpose of the methods I and II.

METHOD I

A.N. Argue (Cambridge) sent to the E.S.A. a proposal by photographic connection. Around each object of the radio system a photographic plate taken through a big telescope give an image of the object (faint, m ∿ 18), and a lot of about 20 stars near the magnitudes 10 to 13 on one square degree. The Hipparcos system is able to allow the positions of these stars with incertitudes smaller than 0"01. Measurements on the plates are possible with incertitudes of the order 0"05. With some plates it seems possible to obtain the positions of the radio objects on the Hipparcos system with errors of the order 0"03, the same order as the random errors of these objects on the radio absolute system.

By this way using a desired system of 100 radio sources, measuring at distances 10 years, it seems possible to obtain the absolute rotation of the Hipparcos system with an incertitude 4.10^{-4}"/y.

That seems really possible but we use photographic comparisons between objects of very different magnitudes, 12 and 18. In spite of many feasible precautions, we know the difficulties on the Lick programme and the method seems not absolutely safe.

Otherwise we accept that the radio and the optical positions are the same. On the quasars that is often not the case.

METHOD II

In order to avoid the doubtful photographic comparisons and the eventual discordance of the radio and photographic positions, we can establish the best possible proper motions in the radio system on the emitting radio stars. Afterwards we compare these absolute proper motions with the Hipparcos proper motions on the same stars. Now we have 12 radio stars (Walter. Space astrometry. E.S.R.O. SP - 108. 1975). Even if we are very optimistic on the incertitudes of the absolute motions of these stars the precision is limited by the incertitudes of the Hipparcos proper motions on such a small number of stars.

But otherwise the whole of the absolute proper motions of the radio stars cannot transmit a better precision than the definition of the radio system itself. B. Elsmore gave at the I.A.V. colloquium n° 48 a list of positions for 28 sources. This system gives a rotation definition with incertitiude 3.10^{-4}"/y on 10 years, and $1,5.10^{-4}$"/y on 20 years. It is possible to hope for some progress on the absolute radio system, but not very important progress because of the dimensions, the variabilities and the too small number of good radio-sources. Perhaps a gain in weight by a factor of 3 is possible. Table III shows the different causes of limitations.

Table III (Unit "/y)

	A	A'	B	B'
Limitation by Hipparcos proper motions in case of 12 bright radio stars	3.10^{-4}	10^{-4}	$2,5.10^{-4}$	$3,2.10^{-5}$
Limitation by the present quality of the radio system	3.10^{-4}	$1,5.10^{-4}$	3.10^{-4}	$1,5.10^{-4}$

METHOD III

The Hipparcos system will be really a new type of system much more consistent than the present systems. Each comparison gives information valid for the whole. Also we can save the building of a radio system and proceed to a direct comparison between the Hipparcos system and the far objects. The Hipparcos positions are very precise, the use of the space-telescope is useful in order to obtain a precision of the same order on the comparisons. As well we use only optical positions and the photoelectric methods on the space-telescope are safer than photographic methods for comparison between objects of such different magnitudes (around 11 and 17).

SPACE-TELESCOPE WORK

From a paper by Jefferys (European Satellite Astrometry Padova, June 1978, and private letter) it seems that the space-telescope is able to yield the relative positions of 10 stars of magnitudes 10 to 17 on his field (270 square arc minutes) in 10 minutes of time with an accuracy of 0,002 arc seconds. In our case we have to consider only one faint far object and a few stars (probably two) around m = 11. The time, 10 minutes, will be good enough.

The work of the space-telescope certainly begins before the launch of Hipparcos. Probably we have 10 years in hand between beginning and the time when the Hipparcos results will be ready. If we use in the future a second launch of astrometric satellite 10 years later we have in hand a space of time of 20 years for measurements on the space-telescope.

To save time on the space-telescope also we consider only the obtained results from one measurement at the beginning and one measurement at the end of the spaces of time. However some more measurements are necessary on some objects in order to check the validity of these objects.

So starting from measurements with incertitudes 0,002" we obtain from two measurements on 10 years the proper motions of the far objects on the Hipparcos system with an incertitude of $0{,}002\ \frac{\sqrt{2}}{10} = 0{,}28.10^{-3}{}''/y$.

ERRORS COMING FROM HIPPARCOS

We need at least two stars on the field around the far object. The field is small. We give below the probabilities to have one star in function of the magnitudes far from the galactic plane.

m	10-10,5	10,5-11	11-11,5	11,5-12	12-12,5	12,5-13
Probability	0,100	0,159	0,237	0,364	0,534	0,794
Cumulated		0,259	0,496	0,860	1,394	2,188

In function of the accepted magnitude limit the part of the far objects is really useful, and the accuracy of the Hipparcos system changes. In order to evaluate the accuracy, the improvements relative to Table I are limited to a factor $1/\sqrt{2{,}5}$, and only for the cases B and B' because the two stars are too near. However some more improvements are possible at high ecliptic latitude.

Limit magnitude	Part of far objects useful
m < 11	1 on 8
m < 12	1 on 2

INCERTITUDES OF INFORMATION WITH ONE FAR OBJECT (Unit "/y)

Case	A	A'	B	B'
m = 11	$2{,}8.10^{-3}$	$0{,}4.10^{-3}$	$2{,}6.10^{-3}$	$0{,}37.10^{-3}$
m = 12	$4{,}5.10^{-3}$	$0{,}6.10^{-3}$	$4{,}0.10^{-3}$	$0{,}55.10^{-3}$

If we select the far objects by the condition m < 11 for the stars around, using 100 far objects, the incertitude on the three components of the absolute rotation will be about :

Case	A	A'	B	B'
	$2{,}8.10^{-4}$	$4{,}1.10^{-5}$	$2{,}2.10^{-4}$	$3{,}6.10^{-5}$

Increasing the number of far objects we can improve freely the results.

CHOICE OF THE FAR OBJECTS

The above computed incertitudes are bigger than the wanted incertitudes in order to use the Hipparcos proper motions in good conditions. Also we have an interest in increasing the number of the far objects in so far as we have enough time on the space-telescope.

Concerning the quasars, a study by J. Lequeux shows that we can hope for 17 quasars by steradian at m < 17 and with noticeable radio emission. So we hope for about 200 quasar candidates on the sky, but only 25 with 2 magnitude 11 stars on the same field. Also we want to add the Q.S.O. The detection of the Q.S.O. by optical method is difficult because using the values of U-B and U-V in order to detect the very blue objects, it is only for the magnitudes bigger than 16,5 that we avoid the giant blue stars of the galactic halo. Concerning the numbers we have in hand only statistical results of samples smaller than 50 square degrees. From a paper of H. Steppe, P. Veron and M.P. Veron (preprint E.S.O. no 40) we can hope for about 2 400 Q.S.O. (m < 17) on the sky. From another paper including objects with small redshifts by A. Braccesi, V. Zibelli, R. Bonoli and L. Formiggini (preprint) we can hope for 2 000 objects (m < 17) on the sky. So we can hope for about 300 useful far objects (stars m < 11).

But we are far from knowing all these objects and their coordinates.

OTHER PERHAPS POSSIBLE USE OF THE SPACE-TELESCOPE

We remark that in 10 years the errors coming from the Hippcarcos system are preponderant. Then we accept a small increase in the errors coming from the comparison by means of the space-telescope. It seems that the space-telescope will be able to work on fainter far objects giving in the same integration time a slightly bigger error. We accept 0,002 $\sqrt{2,52}$ on m = 18 instead of 0,002" on m = 17.

Moving the limit from m = 17 to m = 18 the number of the far objects increases by a factor of 3 for the quasars and 7 for the Q.S.O. objects. Also we can hope for about 16 000 objects. Above all the identification of the Q.S.O. will be much easier. It will be easy to select from the large number of the far objects those with nearest convenient stars.

In order to show the influence of the magnitudes on the far objects and on the stars we give below the total incertitude of one piece of information on one far object.

Table IV

INCERTITUDE FROM ONE FAR OBJECT (UNIT 10^{-3}"/Y)

m stars	10	11	12	10	11	12
		Case A			Case B	
m = 17	2,3	2,8	4,5	1,6	2,6	4,0
m = 18	2,3	2,8	4,5	1,6	2,6	4,0
m = 19	2,4	2,9	4,5	1,7	2,7	4,1
		Case A'			Case B'	
m = 17	0,33	0,39	0,60	0,26	0,37	0,55
m = 18	0,37	0,42	0,63	0,31	0,41	0,58
m = 19	0,47	0,51	0,69	0,42	0,50	0,64

Table IV shows the small influence of an increase of the incertitudes on the comparison by the space-telescope.

CONCLUSION

By means of methods I and II the incertitudes on the absolute radio system limit the accuracy. Also the incertitudes on the photographic comparison in method I, and the too small number of radio stars in method II limit the improvements of accuracy.

Method III gives now slightly better results, but especially prepares better results for the future. That is particularly important if, as is probable, we obtain from new satellites better results on a little fainter stars. Then we have to begin the measurements with the space-telescope since the beginning of its work.

However it will be useful to use all the methods for checking.

HIPPARCOS AND THE SPACE TELESCOPE

Astrophysical implications of two complementary astrometric projects.

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Abstract

The ESA project of an European Astrometric Satellite, Hipparcos, (HIgh Precision PARallax COllecting Satellite) will provide the astronomical community with a fantastic amount of data: 100 000 stars measured in trigonometric parallaxes and proper motions with respective maximum error of 0".002 and 0.002"/year, which means 100 000 stars with a very accurate determination of the absolute magnitude. It is impossible to review all the consequences of such a renewal in the basic data on stellar physics and galactic astrophysics. The main ones are underlined here: test of stellar evolution and internal structure theories, detailed structure of the HR diagram, almost perfect statistical representation of the solar neighborhood (mass and luminosity functions, age and velocity distributions) and therefore a major improvement in the knowledge of the chemical and dynamical evolution of our galaxy and of the cosmic distance scale.

The astrometric programs of Hipparcos and the Space Telescope are complementary not only from a purely astrometric point of view but also for their astrophysical implications. The astrometric point of view is studied by Professor Lacroute in this workshop. With regard to astrophysical applications the same main complementary features are to be considered: the Space Telescope will perform a limited number of measurements mainly on selected faint stars in narrow fields while the main results of Hipparcos will be a complete survey up to $m_B \sim 9$ and very accurate measurements of the brightest stars ($m_B < 6$). The basic set of observations of Hipparcos will be extended by the Space Telescope to fainter and / or more distant stars.

I - Introduction

Up to now the astrometry was one of the few fields of astronomy where the possibilities offered by space observations had not yet been employed. There are now two quite different approaches to Space Astrometry, the European Astrometry Satellite "Hipparcos" and the Space Telescope. Nevertheless it has to be kept in mind that the main impact of these two missions will be their astrophysical applications.

II - Hipparcos and the Space Telescope

"Hipparcos" is an acronym for HIgh Precision PARallax COllecting Satellite. This underlines the very large possibilities of this satellite in the measurement of trigonometric parallaxes. It is also the name of the first Greek astronomer who have measured a parallax (that of the moon) and made a star catalogue (800 stars). Groundbased observations of trigonometric parallaxes represent a strenuous and difficult work and this explains the small number and poor precision of existing measurements. Trigonometric parallaxes are available for about 8 000 stars but only 5% of them are known with a relative accuracy better than 10%. These data are affected by important systematic errors and by three very serious biases: high proper motion, very nearby and dwarf stars later than A0 are favored. Only five giant stars are measured with an accuracy better than 20% and no main sequence star earlier than A0 (Turon Lacarrieu 1975, Heck 1977, Upgren 1977).

This poor situation will be drastically improved by Hipparcos. The positions, parallaxes and proper motions of 100 000 stars will be determined with a very high accuracy. The feasability study performed by ESA has proven that a 2.5 years Hipparcos mission will provide a maximum mean error of $\pm 0\farcs002$ for absolute parallax measurements and of $\pm 0.002''$/year for proper motion measurements for stars brighter than $m_B = 12$. It seems even possible to reach $0\farcs0003$ for the brightest stars ($m_B < 6$). Two salient and original features of Hipparcos will allow this fundamental improvement. First, the basic principle itself which is to measure with great precision the angular distance of pairs of stars separated by a large angle, close to 70°. This very high accuracy, homogeneous over the whole sphere (this is impossible to obtain from groundbased observations), will permit a major improvement in the quality of the astrometric reference system. Second, the possibility of a systematic survey up to a given magnitude (say 9; to be defined in the observation program) is crucial for a perfect and unbiased representation of the solar neighborhood. For more details, the reader is referred to ESRO Colloquium on Space Astrometry (1974), Report on Phase A Study (1978), ESA Colloquium on European Astrometric Satellite (1978).

The possibilities of the Space Telescope are quite different. The principal astrometric instrument is one of the three fine guidance sensor when it operates in an astrometric mode. In addition, three other instruments have possible astrometric uses: the high speed photometer, the wide field camera and the faint object camera (Jefferys 1978). With the high resolution and precise pointing stability of the Space Telescope, it will be possible to measure relative positions of stars to a predicted accuracy of ±0".002. The fine guidance system should cover a brightness range m_V=10 to 17 with a photometric precision of 1% or better. By increasing the integration time, it may be possible to reach the 20th magnitude. It should be possible to measure ten 17th magnitude stars in ten minutes. The Space Telescope is perfectly designed to measure the relative positions of stars which lie within the field of view of one of the fine guidance sensors, which means a significant improvement of relative astrometry for preselected very faint objects over small fields. Another promising kind of observation will be the measurement of positions and proper motions of a small number of well-observed fundamental stars, or stars observed by Hipparcos (Lacroute, this workshop), relative to quasars. This would serve two purposes: 1) determine the rotation-free Hipparcos reference system by means of quasars, and 2) convert the relative proper motions and parallaxes obtained with the Space Telescope in other fields to absolute ones.

III - The absolute luminosity calibration

Three major improvements are expected from Hipparcos and the Space Telescope parallax measurements. First, the high accuracy of these measurements will considerably increase the volume of space investigated with precision around the sun. Second, this fundamental method of distance determination, and hence of absolute luminosity determination, will be extended to almost all types of stars. Hipparcos will allow to reach very bright but rare stars which are of the utmost importance for the determination of the cosmic distance scale, such as blue giants (about 50 of them are nearer than 500 pc), supergiants ($\sim$ 30 nearer than 500 pc), Cepheids (12 nearer than 500 pc) and RR-Lyrae (4 nearer than 500 pc). Space Telescope will on the contrary extend the measurements towards the very faint end of the main-sequence: red dwarfs and subdwarfs, and also white dwarfs. Third, Hipparcos will provide the first sample of parallax measurements without any bias towards high proper motion stars. These improvements will translate directly into a better knowledge of luminosities and masses, which are perhaps the two most fundamental parameters necessary in interpreting the physics of an object.

IV - Stellar physics

The main consequences of this much precise luminosity calibration which will extend over all spectral types are first to be found in stellar physics.

1 - Theories of internal structure and stellar evolution require precise experimental absolute magnitudes to be tested. A much spread range of spectral types will be available as well as a certain number of some special kinds of objects: very metal-poor stars; blue horizontal branch stars; planetary nebulae, the distances and absolute magnitudes of which are very difficult to estimate by non-geometrical methods (20 of them are nearer than 500 pc, 9 of which are accessible with Hipparcos for absolute parallax measurements). Measurements of binary stars, especially with the Space Telescope are also very important for the study of the late evolution of stars.

2 - Linear stellar radii

An important by-product of precise distance measurements will be the accurate determination of linear radii for stars with known angular diameters.

3 - Detailed structure of the HR-diagram

The much more accurate determination of the absolute magnitudes will allow a detailed study of all the regions of the HR-diagram: B and Be sequences; A and Am sequences; study of F to K subgiant, dwarf and subdwarf stars to search for a possible influence of the helium and heavy element content over the position in the HR-diagram; subdwarf stars, planetary nebulae, white dwarf sequences. (Programs to be realized either by Hipparcos for bright stars or by the Space Telescope for fainter stars). A direct consequence of such a better knowledge of stellar position in the HR-diagram will be a better estimation of the stellar ages (in the region of the HR-diagram where the age determination is possible).

4 - Binaries

Precise orbit measurements will be possible with the Space Telescope. Observations of "visual" orbits for some spectroscopic binaries not resolved from the ground would increase the available data on stellar masses.

In addition, a significant number of stars will be observed for the detection of faint and possibly even planetary companions.

5 - Improved calibration of period-luminosity relations for Cepheids and Mira-type variable stars. The importance of the calibration of Cepheids is again underlined here because of its straightforward repercussion on the determination of the cosmic distance scale and more precisely of the Hubble constant.

V - Structure and evolution of our galaxy

The precise knowledge at one and the same time of the parallax and proper motion of such a large variety of astronomical objects offers the opportunity of a giant leap forwards in galactic studies. Spatial and kinematical distributions of the different types of stars could be studied both as functions of distance to the galactic center and/or the galactic plane and of ages. The survey by Hipparcos will also allow a much better statistical estimation of the mass and luminosity functions in the solar neighborhood. This observational basis is necessary for investigations concerning the kinematical, dynamical and chemical evolution of galaxies (C. Turon Lacarrieu 1978).

The study of galactic clusters is of the utmost importance in all these investigations. They are fundamental steps in the distance calibration. Ten of them are within 300 pc from the sun (among them the Hyades, Pleiades, Praesepe, Coma...) and their brightest stars are accessible to Hipparcos. This implies an absolute determination of their distance and even, for the Hyades, a three-dimensional picture of the cluster. Their faintest stars (lower main-sequence stars and white dwarfs) will be studied by the Space Telescope. The great accuracy of its proper motion measurements for these very faint stars will provide answers about membership, mass segregation, internal motions... This will have important consequences in main-sequence fitting: instead of fitting every cluster to the Hyades main-sequence, ten clusters will be available with different ages and chemical composition. This will have important repercussions in distance and age determinations.

VI - Cosmic distance scale and cosmology

The cosmic distance scale, a really basic tool for our knowledge of the Universe, will be drastically improved by Hipparcos. Observations with the satellite will allow:

- Proper motion and absolute parallax measurements of large star samples.
- Precise distance determinations for a sufficient number of galactic clusters including the Hyades.
- Accurate luminosity calibration of photometric and spectroscopic indices.
- First trigonometric parallaxe measurements of some primary distance indicators (blue supergiants, RR-Lyrae, Cepheids).

The Space Telescope will provide much valuable information about the lower main sequence stars of galactic clusters and about the subdwarf sequence. This last one is very important for the distance scale calibration of population II stars as the globular cluster main sequences are fitted to it. (Observations to be made especially with the Wide Field Camera).

VII - Other applications

1 - Giant planet satellites

Important information about the interiors of the giant planets will be provided by much precise orbit determination of their satellites. From the 22 satellites of Jupiter and Saturn, 14 will be observable by Hipparcos. It would be interesting to follow the other ones with the Space Telescope.

2 - Gravitational deflection of the light

The gravitational deflection of the light could be observed by Hipparcos using the sun as the large body. It is possible to measure this effect from 50 to 130° from the sun with a good precision.

Using Jupiter as the large body, the effect might be statistically detectable by Hipparcos and by the Space Telescope.

VIII- Conclusion

As written by Jefferys (1978) "the weaknesses of the Space Telescope as an astrometric instrument lie in just those areas where Hipparcos has its strengths" and reciprocally. Therefore, it is very important to plan coordinated observing programs "so that the maximum scientific advantages can be obtained from both observatories".

Up to now, a large number of stellar, galactic and cosmological studies are standing upon a very small number of observational data as a pyramid upon its head. The coordination of these two observatories will provide a much reliable and steady basis for all these astrophysical researchs.

References

ESA Colloquium on European Satellite Astrometry, Padova, 5-7 June 1978.

ESRO Colloquium on Space Astrometry, Frascati, 1975, ed. T.D. Nguyen and B.T. Battrick, ESRO SP. 108.

A. Heck, 1978, Vistas in Astronomy 22 221.

W.H. Jefferys, 1978, ESA Colloquium, Padova.

Report on Phase A study: "Space Astrometry, Hipparcos", ESA, DP/PS (78) 13. 1978.

C. Turon Lacarrieu, 1975, Space Astrometry, Frascati.

C. Turon Lacarrieu, 1978, ESA Colloquium, Padova.

A.R. Upgren, 1977, Vistas in Astronomy 21 241.