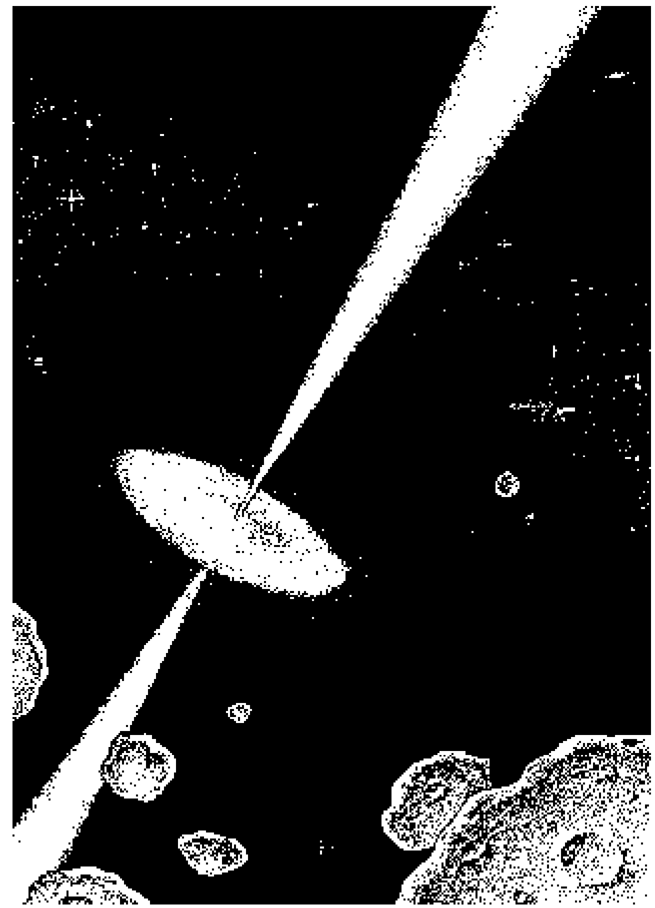
Astronomy 102: Black Holes, Time Warps, and the Large-Scale Structure of the Universe

What do black holes, wormholes, time warps, spacetime curvature, hyperspace and the Big Bang have in common?

- ❑ Explanations with their origins in Einstein's theories: the **special theory of relativity** (1905) and the **general theory of relativity** (1915).

This semester we will discuss all of these exotic phenomena, mostly qualititatively, in the context of Einstein's theories.

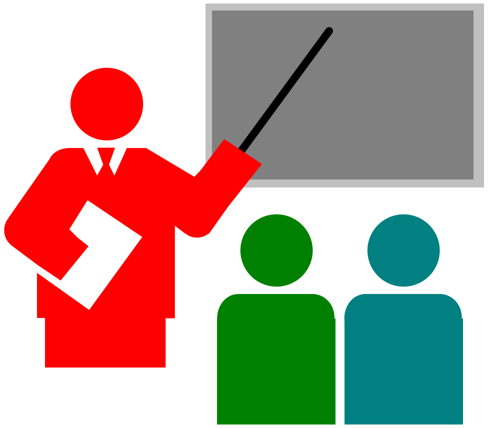


Artist's conception of the quasar 3C273, from Thorne, *Black holes and time warps.*

Human and printed features of Astronomy 102

People:

- **Dan Watson**, professor
- **Adam Kubik**, first-year graduate student, teaching assistant
- **Michael Greene**, third-year undergraduate, teaching assistant



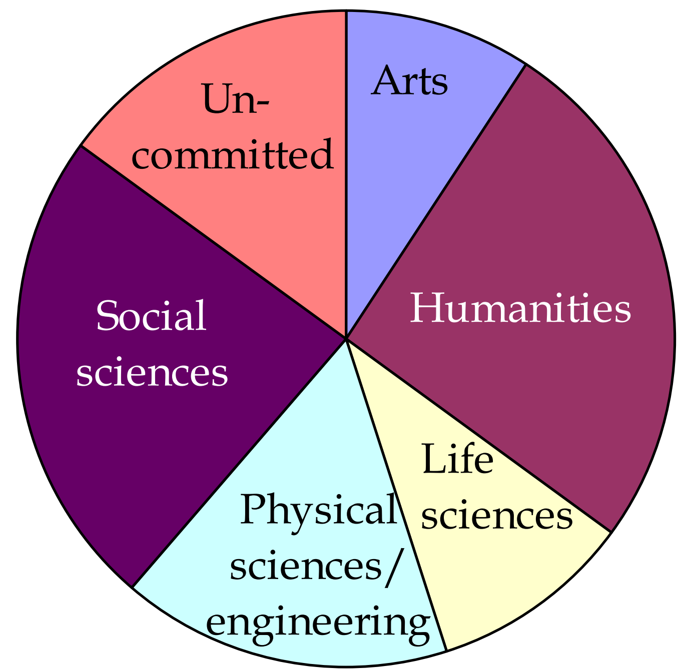
Textbooks (one required, three recommended):

- Kip S. Thorne, *Black holes and time warps* (1994).
- Michael A. Seeds, *Foundations of astronomy* (1998). Also used in AST 105 and AST 104.
- Stephen Hawking, *A brief history of time* (1988).
- Joseph Silk, *The Big Bang* (1989).

Our primary goals in teaching Astronomy 102

- to **demystify** black holes, the Big Bang, and relativity, to enable you to evaluate critically the things you read about them in the press and in popular science and science-fiction literature;
- to provide you with a glimpse of the processes by which scientific theories are conceived and advanced in general.

Astronomy 102, Spring 2000

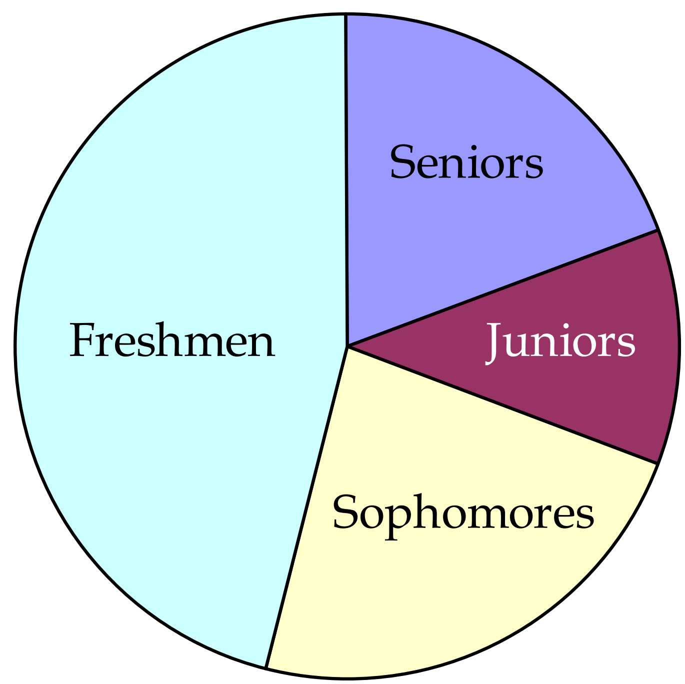


In doing so we aim primarily at **non-science majors.**

Our primary goals in teaching Astronomy 102 (continued)

We hope that by the end of the course you will understand and retain enough to be able to offer correct explanations of black holes and such to your friends and family, and that you will retain a permanent, basic understanding of "how science works."

Astronomy 102, Spring 2000

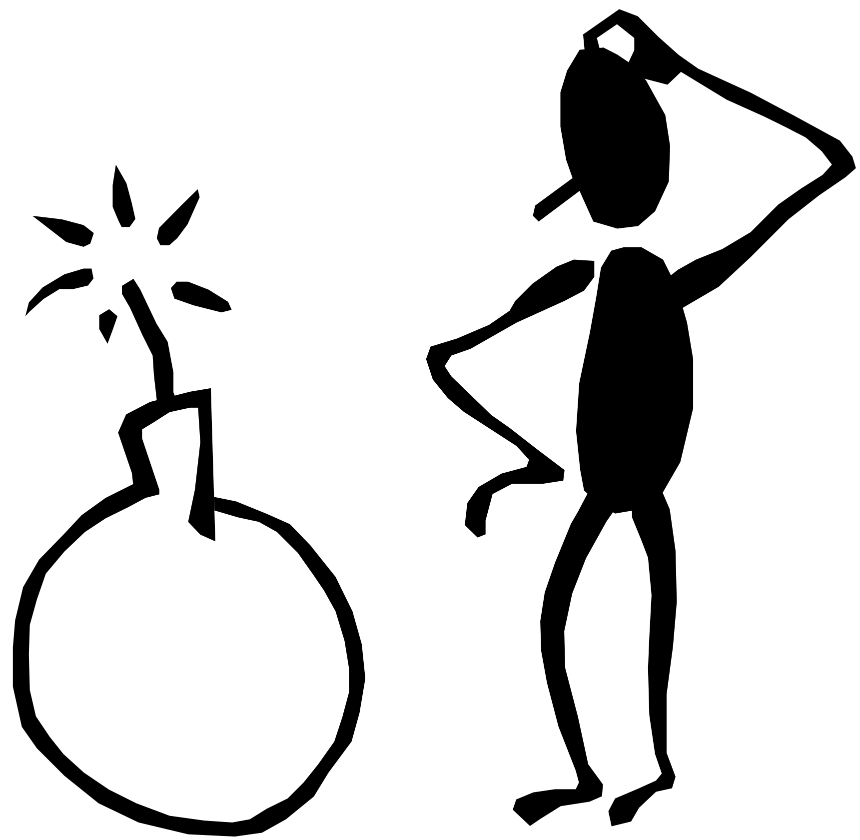


Electronic features of Astronomy 102

- **Computer-projected lectures**, for greater ease in presentation of diagrams, astronomical images and computer simulations, and for on-line accessibility on our...
- **World Wide Web site**, including all lecture presentations, practice exams, much more.
- **E-mail list server**, a forum for the class to communicate easily and at all hours with the instructors and each other.
- Computer-assisted personalized homework assignments using **WeBWorK**, to enable instant feedback, self-correction and student interaction on homework problems, and to free the instructors from grading, to spend more time with the students.

Onerous features of Astronomy 102

- The minimum of mathematics required to tell our story (but no less than the minimum!).
- Six homework problem sets, all using WeBWorK.
  - Seven if you count the first, ungraded, “test” homework. More on this in a minute.
- Three exams (but no *comprehensive* final exam).
- Grades (but on a straight scale, not a curve).

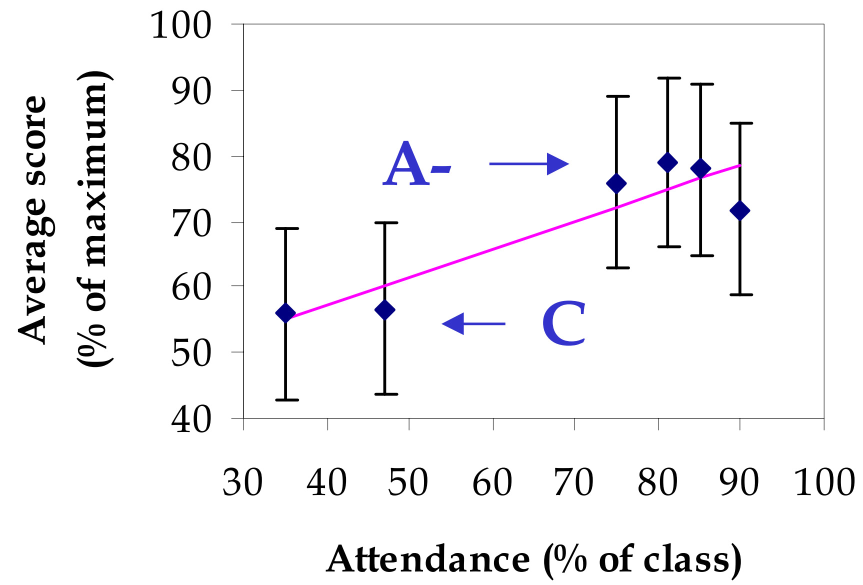


90% of success is showing up.

- Woody Allen

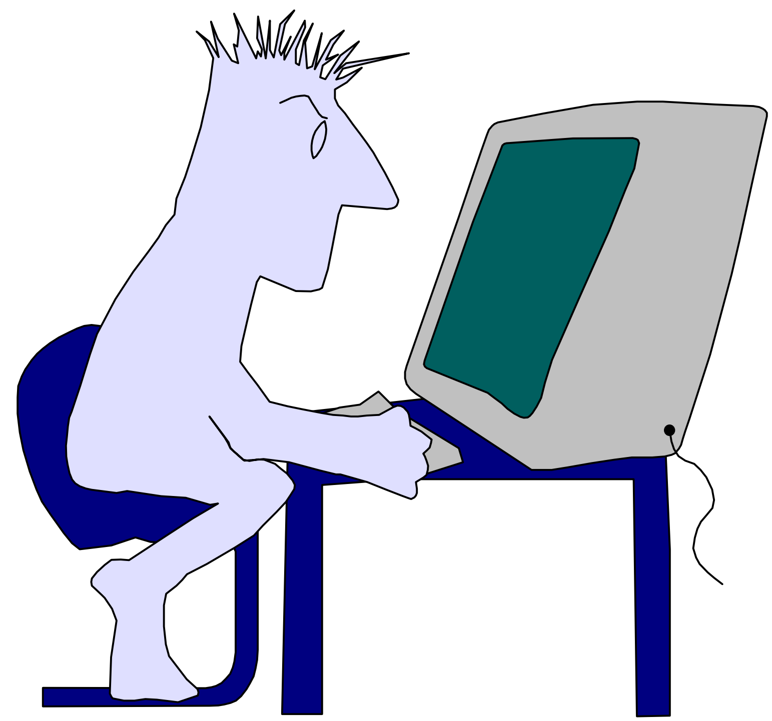
All members of the class are expected to attend all of the lectures, and encouraged to attend one recitation per week.

This is for your own good! You will very probably get a better grade if you go to class, as is demonstrated by these average test score and average attendance data from past AST 102 classes.



Your first homework assignment is due on Tuesday morning, 8AM.

Don't worry; you already know all the answers, and it won't be graded anyway.



- ❑ It's available now. Check your e-mail for a password you'll need to get your assignment.
- ❑ The point of this exercise is to make sure everybody can log into and out of the system successfully, before we have to do it for real.
- ❑ While you're at it, print today's and Tuesday's lecture notes.

Mid-Lecture Break

This will be a regular feature of Astronomy 102 lectures.

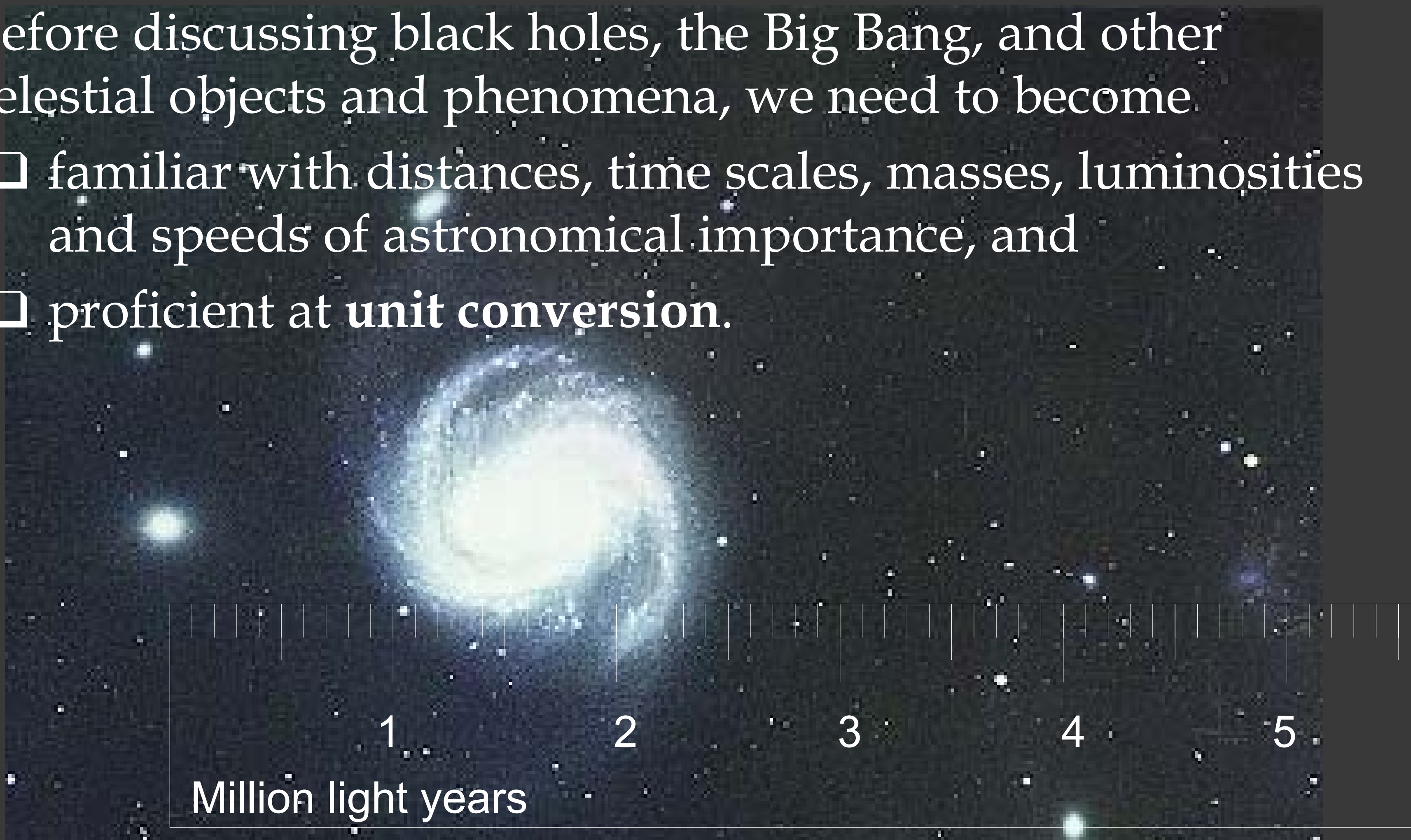
Please review the course syllabus, fill out the Astronomy 102 Background Survey, and gather your questions on them to ask at the end of the break. Choose a recitation, too.

Image: wide-field view of the Orion Nebula, by David Malin (Anglo-Australian Observatory).

Today in Astronomy 102: How big is that?

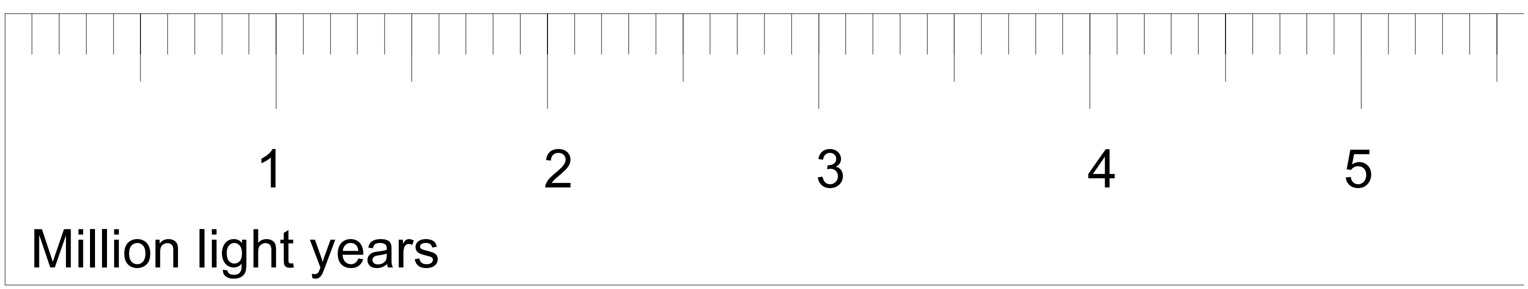
Before discussing black holes, the Big Bang, and other celestial objects and phenomena, we need to become

- familiar with distances, time scales, masses, luminosities and speeds of astronomical importance, and
- proficient at **unit conversion**.



The "how big is that?" sheet

For convenience, we have circulated copies of a summary - **the "how big is that?" sheet** - of the unit-conversion factors and typical dimensions of importance in astronomy. Keep it handy while you read the textbooks or work on the homework.



Sizes in astronomy

Sizes of important astronomical objects exhibit such a great range that fixed-decimal-point number notation isn't practical.

Object		Diameter in:		
	centimeters	kilometers	miles	light years
Hydrogen atom	0.0000000106	0.000000000000106	0.000000000000065	0.0000000000000000000000000112
Human hair	0.008	0.00000008	0.00000005	0.0000000000000000000085
Penny	1.9	0.000019	0.000012	0.0000000000000000020
Rochester	2,000,000	20	12	0.0000000000021
Earth	1,274,200,000	12,742	7,865	0.0000000013
Moon	347,640,000	3,476	2,146	0.0000000004
Jupiter	14,260,000,000	142,600	88,025	0.000000015
Sun	139,198,000,000	1,391,980	859,247	0.00000015
Milky Way galaxy	160,000,000,000,000,000,000,000	1,600,000,000,000,000,000	987,654,320,987,654,000	169,133

Sizes and distances in astronomy

Thus we use **scientific notation**:

	centimeters	kilometers	miles	light years
Diameter of a hydrogen atom	1.1×10^{-8}	1.1×10^{-13}	6.5×10^{-14}	1.1×10^{-26}
Diameter of a human hair	8.0×10^{-3}	8.0×10^{-8}	4.9×10^{-8}	8.5×10^{-21}
Diameter of a penny	1.9×10^{0}	2.0×10^{-5}	1.2×10^{-5}	2.1×10^{-18}
Diameter of Rochester	2.0×10^{6}	2.0×10^{1}	1.2×10^{1}	2.1×10^{-12}
Diameter of the Earth	1.3×10^{9}	1.3×10^{4}	7.9×10^{3}	1.3×10^{-9}
Diameter of the Moon	3.5×10^{8}	3.5×10^{3}	2.1×10^{3}	3.7×10^{-10}
Diameter of Jupiter	1.4×10^{10}	1.4×10^{5}	8.8×10^{4}	1.5×10^{-8}
Diameter of the Sun	1.4×10^{11}	1.4×10^{6}	8.6×10^{5}	1.5×10^{-7}
Diameter of the Milky Way galaxy	1.6×10^{23}	1.6×10^{18}	9.9×10^{17}	1.7×10^{5}
Distance to Buffalo	1.0×10^{7}	1.0×10^{2}	6.2×10^{1}	1.1×10^{-11}
Distance to the Moon	3.8×10^{10}	3.8×10^{5}	2.4×10^{5}	4.1×10^{-8}
Distance to the Sun	1.5×10^{13}	1.5×10^{8}	9.2×10^{7}	1.6×10^{-5}
Distance to the next nearest star, α Centauri	3.8×10^{18}	3.8×10^{13}	2.3×10^{13}	4.0×10^{0}
Distance to the center of the Milky Way	2.6×10^{22}	2.6×10^{17}	1.6×10^{17}	2.7×10^{4}
Distance to the nearest galaxy	1.6×10^{23}	1.6×10^{18}	9.9×10^{17}	1.7×10^{5}

Sizes and distances in astronomy

Typically we also use different units for different scales:

	centimeters	kilometers	miles	light years
Diameter of a hydrogen atom	1.1×10^{-9}			
Diameter of a human hair	8.0×10^{-3}			
Diameter of a penny	1.9			
Diameter of Rochester	2.0×10^{6}	20	12	
Diameter of the Earth	1.3×10^{9}	1.3×10^{4}	7.9×10^{3}	
Diameter of the Moon	3.5×10^{8}	3.5×10^{3}	2.1×10^{3}	
Diameter of Jupiter	1.4×10^{10}	1.4×10^{5}	8.8×10^{4}	
Diameter of the Sun	1.4×10^{11}	1.4×10^{6}	8.6×10^{5}	
Diameter of the Milky Way galaxy	1.6×10^{23}			1.7×10^{5}
Distance to Buffalo	1.0×10^{7}	100	62	
Distance to the Moon	3.8×10^{10}	3.8×10^{5}	2.4×10^{5}	
Distance to the Sun	1.5×10^{13}	1.5×10^{8}	9.2×10^{7}	
Distance to the next nearest star, α Centauri	3.8×10^{18}			4
Distance to the center of the Milky Way	2.6×10^{22}			2.7×10^{4}
Distance to the nearest galaxy	1.6×10^{23}			1.7×10^{5}

Typical lengths and important conversions

- Diameter of normal stars: millions of *kilometers* (km)
- Distance between stars in a galaxy: a few *light-years* (ly)
- Diameter of normal galaxies: tens of *kilo-light-years* (kLy)
- Distances between galaxies: a *million light-years* (Mly)
- 1 ly = 9.46×10^{12} km = 9.46×10^{17} cm
- 1 km = 10^5 cm; 1 kly = 10^3 ly; 1 Mly = 10^3 kly = 10^6 ly.

Example: The Andromeda nebula (a galaxy a lot like our Milky Way) lies at a distance D = 0.5 Mly. How many centimeters is that?

$$D = 0.5\ \text{Mly} \times \frac{10^6\ \text{ly}}{1\ \text{Mly}} \times \frac{9.46 \times 10^{17}\ \text{cm}}{1\ \text{ly}} = 4.7 \times 10^{23}\ \text{cm}$$

More detail on Unit Conversion

Previous example: repeated multiplication by 1. One may *always* multiply anything by 1 without changing its real value.

The unit conversions always give a couple of useful forms of 1. Take, for example, the conversion 1 ly = $9.46\text{x}10^{17}$ cm:

$$\frac{9.46\times10^{17}\ \text{cm}}{1\ \text{ly}} = 1 = \frac{1\ \text{ly}}{9.46\times10^{17}\ \text{cm}}$$

Choose forms of 1 that cancel out the units you want to get rid of, and that insert the units to which you wish to convert. This sometimes takes repeated multiplication by 1, as in the previous example:

$$D = 0.5\ \text{Mly} \times \frac{10^{6}\ \text{ly}}{1\ \text{Mly}} \times \frac{9.46\times10^{17}\ \text{cm}}{1\ \text{ly}} = 4.7\times10^{23}\ \text{cm}$$