AST 301: What you will have to learn and get used to

1. Basic types of objects in the universe

Planets, stars, galaxies, a few things inbetween--look through your textbook soon!

You will have to learn:

a. Basic properties of these objects--basically whatever we can measure: how bright, surface temperature, distance, …

b. How "we" determine those properties from observations…of what? Light is basically all we get, since we can never visit. (That's why chapters 3 and 4 are so important.)

c. *Theories* for their origin and evolution that can match the observations in a and b. These involve various physical processes that you will have to understand, but only superficially.

2. Units of measurement

Astronomical unit AU, parsec (roughly: average distance between stars) for distances; degree or (most commonly) arcsecond (will return to this because it occurs all through the course), scientific notation (see below).

3. A few fundamental physical "laws"

Kepler's laws, Newton's laws, blackbody radiation laws ⇒ understand these and your troubles are over!). This is where we will spend most time for first exam.

The math isn't so important as understanding the ideas behind them.

Suggestions for getting started:

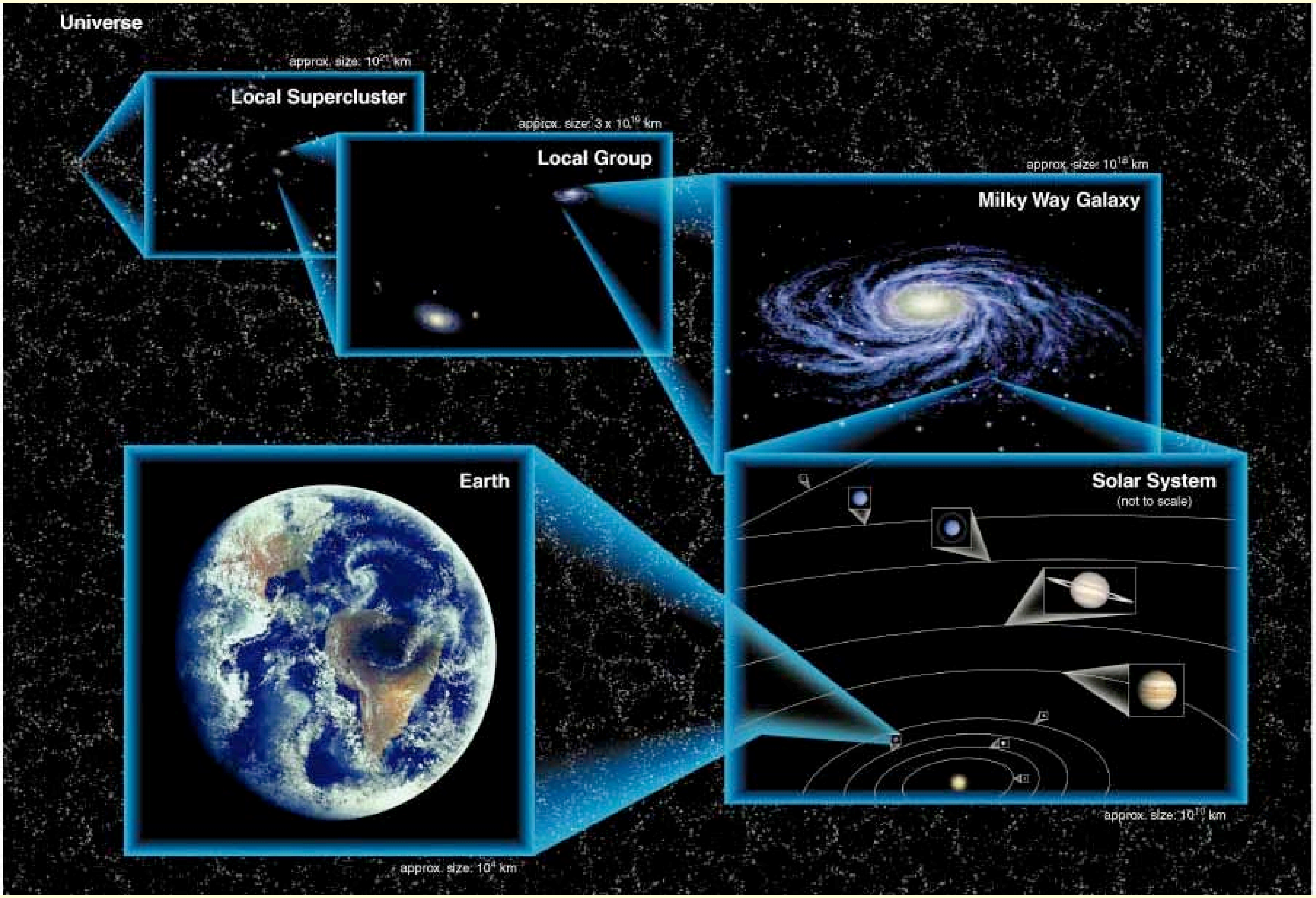
- **These preliminaries are important: Use new terminology often enough so that you are fully adjusted and comfortable with it well before any exam. There is no way to adjust to terminology in a few days: You have to encounter it and use it as frequently as possible. Examples: inverse-square law, arcsecond, blackbody radiation, types of stars and galaxies,… The list will run into the 100s.**

- **In astronomy, there is a huge range of size, mass, distance, and other scales that you will encounter, from atoms to planets to galaxies. Now is a good time to see if you can guess a typical value for the sizes of these various objects. Then try to look them up in the book, a good chance to skim through your textbook.**
  Don't worry about meters, inches, yards, or any everyday unit of measurement--we will have to define some new yardsticks (e.g. AU, light year, parsec, Megaparsec, for distances and sizes…). One of the most important has to do with angular size--understand it now and avoid later frustration--examples in class.

  You don't have to know them *numerically*, except in a very rough way (I'll explain in class and with examples).

- **Scientific notation** for very large and small numbers (**read Appendix 1** in text).
  Examples: 3×10^6 = 3 million, 4×10^{-3} = 0.004, a speck of dust is about 10^{-4} times as large as your fingertip. *You will continuously encounter this notation in the textbook, so become comfortable with it now* (even though I won't ask you to manipulate them on exams). Just get used to it—try writing down a few yourself—e.g. two million, 3 one-thousandths, …Here is one that you might see again: **How much larger in size is a typical galaxy than a typical star?**

Range of size scales in the universe requires the use of a variety of units of distance--
kilometer (km), astronomical unit (AU), parsec (pc), kiloparsec (kpc), megaparsec (Mpc)



Units of length, size, mass, ... *Defined just for convenience*

First, realize that the units we use in measuring anything are usually just for convenience. You don't give the distance from Austin to New York in inches, or your age in seconds, or your height in miles.

Example: For distance or size, we could use "microns" for light waves or for dust particles, "centimeters" or "inches" for everyday objects, "light years" or "parsecs" for stars, "megaparsecs" for galaxies.

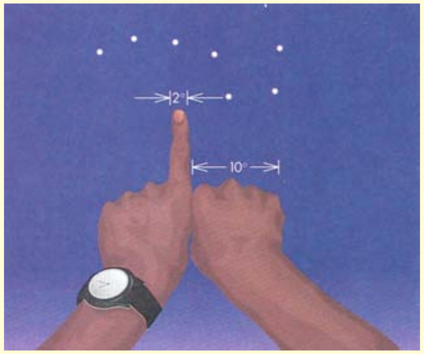
This is really nothing--you just have to get used to it! Keep thinking about it for a while and soon it will be second nature. There are absolutely no new ideas here.

Appendix 2 in the textbook goes over some of this; just skim it now and use it for future reference if you become confused about units. But we will only be using a few units in this class, so it shouldn't cause any problem.

Another (important) example: it is convenient to state the masses of astronomical objects in units of the Sun's mass, e.g. "200 solar masses" or "200 M_{sun}" instead of writing "4 x 10^{35} grams." The mass of many galaxies (including our own) is in the range 10^9 to 10^{12} solar masses, so you can see there is no escaping scientific notation, even if we use a convenient unit. The range of properties of astronomical objects is just too large.

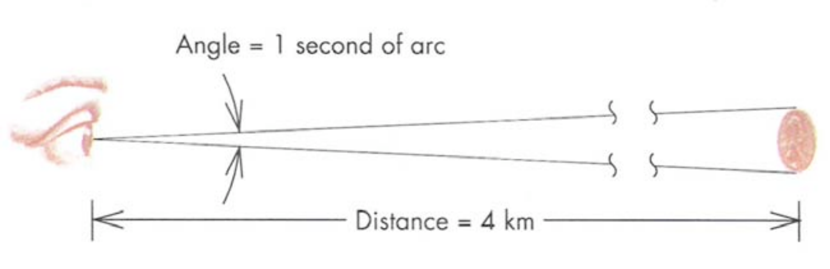
Angular measure (box, p. 11) –degree, arcminute, arcsecond (especially important). *Most astronomy today commonly breaks the "arcsecond barrier"* imposed by our own Earth's atmosphere. (This effect, called "scintillation," is due to the turbulence in the Earth's atmosphere, which makes stars "twinkle." We return to it in Ch.5) *This is usually a difficult unit for students to get used to,* This is one of those things that will return to haunt you over and over. Angular measure using "*arcsecond*" terminology will occur in many places throughout the course (first in connection with "parallax").

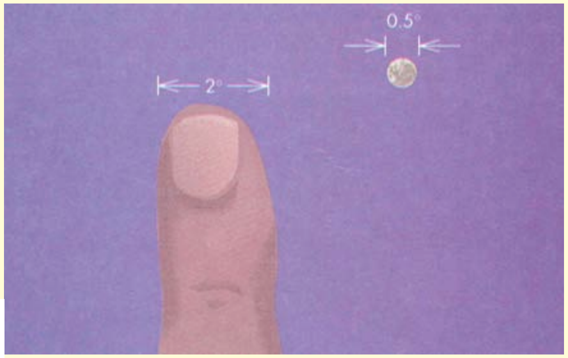
The term for the smallest angular size at which you can distinguish objects is called "**angular resolution**," a phrase you will encounter frequently. Learn it now! You can remember what resolution means by keeping in mind that poor resolution is like being very nearsighted—everything looks blurry. What is the angular resolution of an extremely nearsighted person? What do you think the angular resolution of your eyes are? Look around!



One Second of Arc

A penny at a distance of 4 km (2.5 miles) has an angular diameter of 1 second of arc.





Constellations: These are just apparent groupings of stars in the sky; they are (usually) not physically associated, and could be at very different distances (see Orion example).

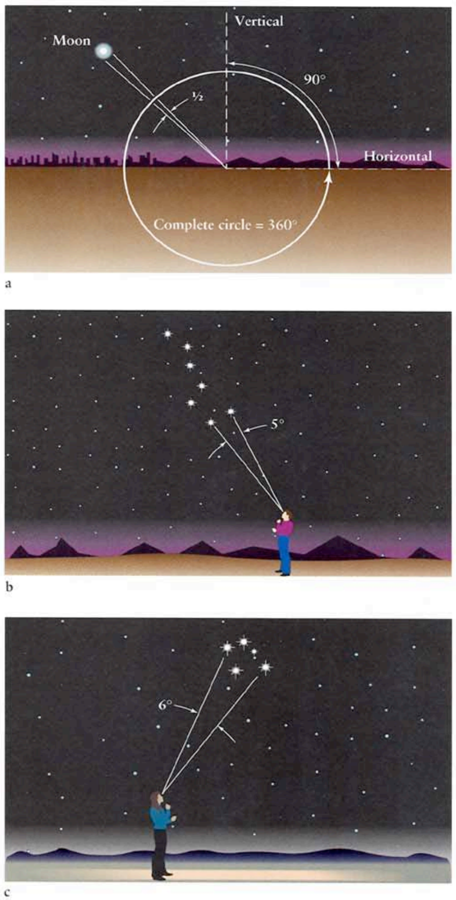
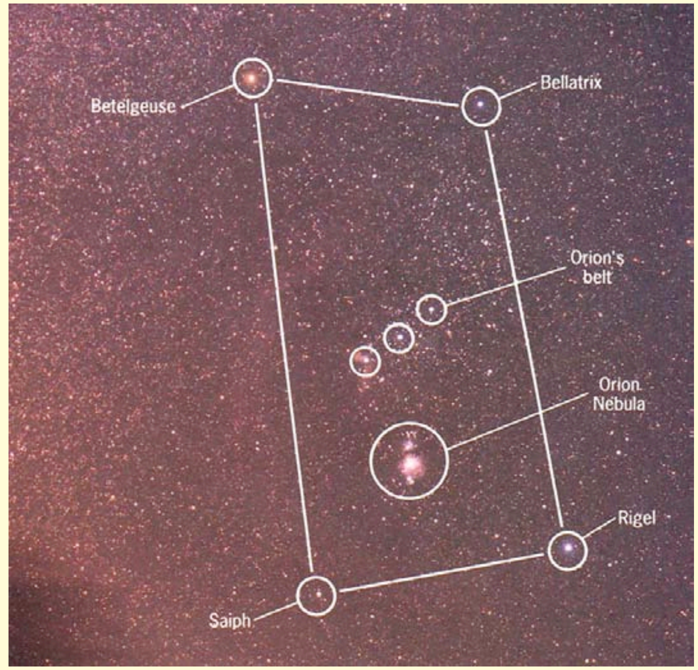
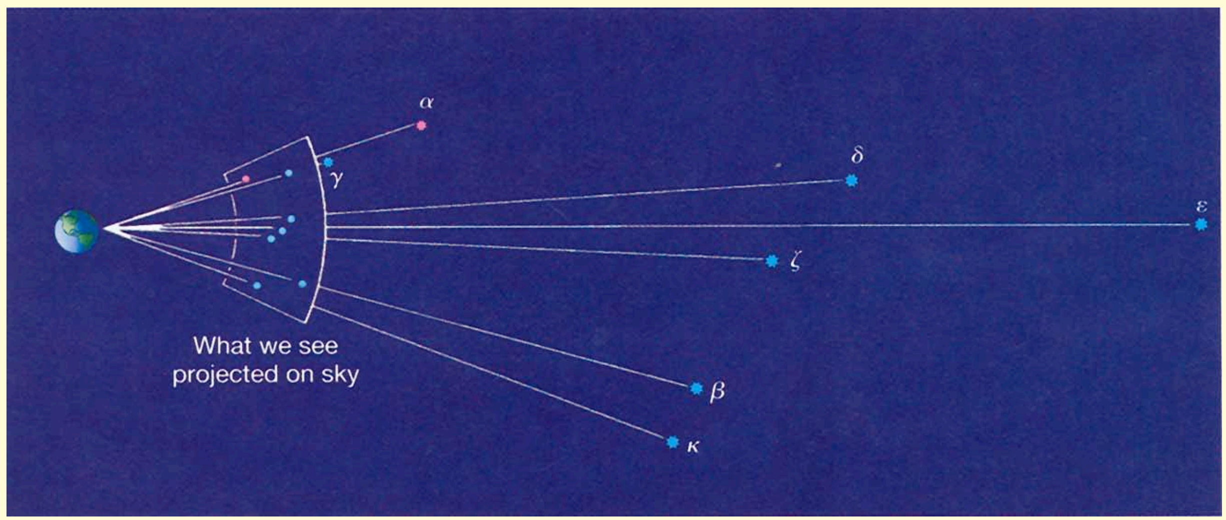


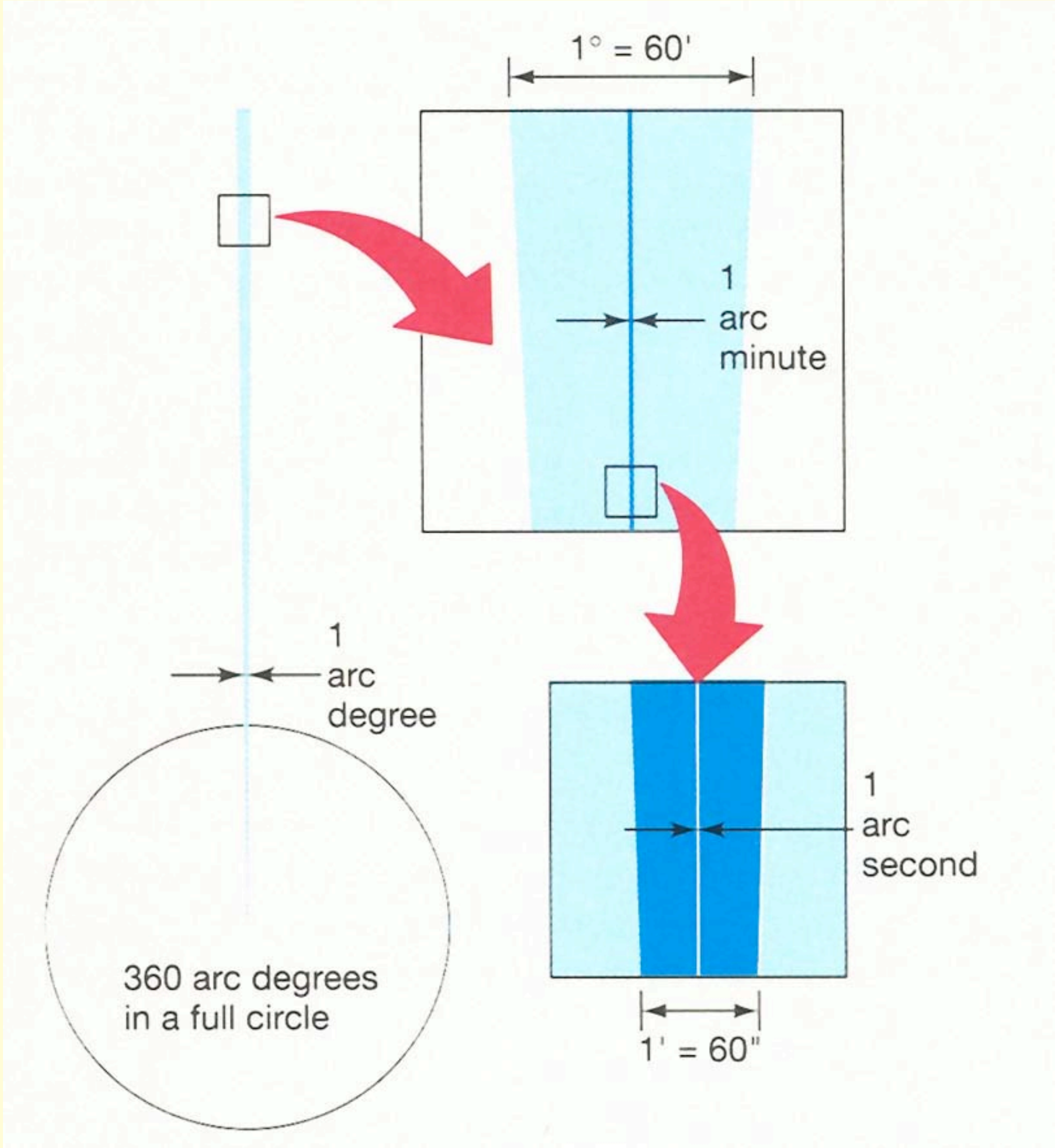
Figure 1-9

Angles and Angular Measure **(a)** Angles are measured in degrees (°). There are 360° in a complete circle and 90° in a right angle. For example, the angle between the vertical direction (directly above you) and the horizontal direction (toward the horizon) is 90°. The angular diameter of the full moon in the sky is about ½°. **(b)** The Big Dipper is an easily recognized grouping of seven bright stars, visible from anywhere in the northern hemisphere. The angular distance between the two pointer stars at the front of the Big Dipper is about 5°, roughly ten times the angular diameter of the Moon. **(c)** The four bright stars that make up the Southern Cross can be seen from anywhere in the southern hemisphere. The angular distance between the stars at the top and bottom of the cross is about 6°.





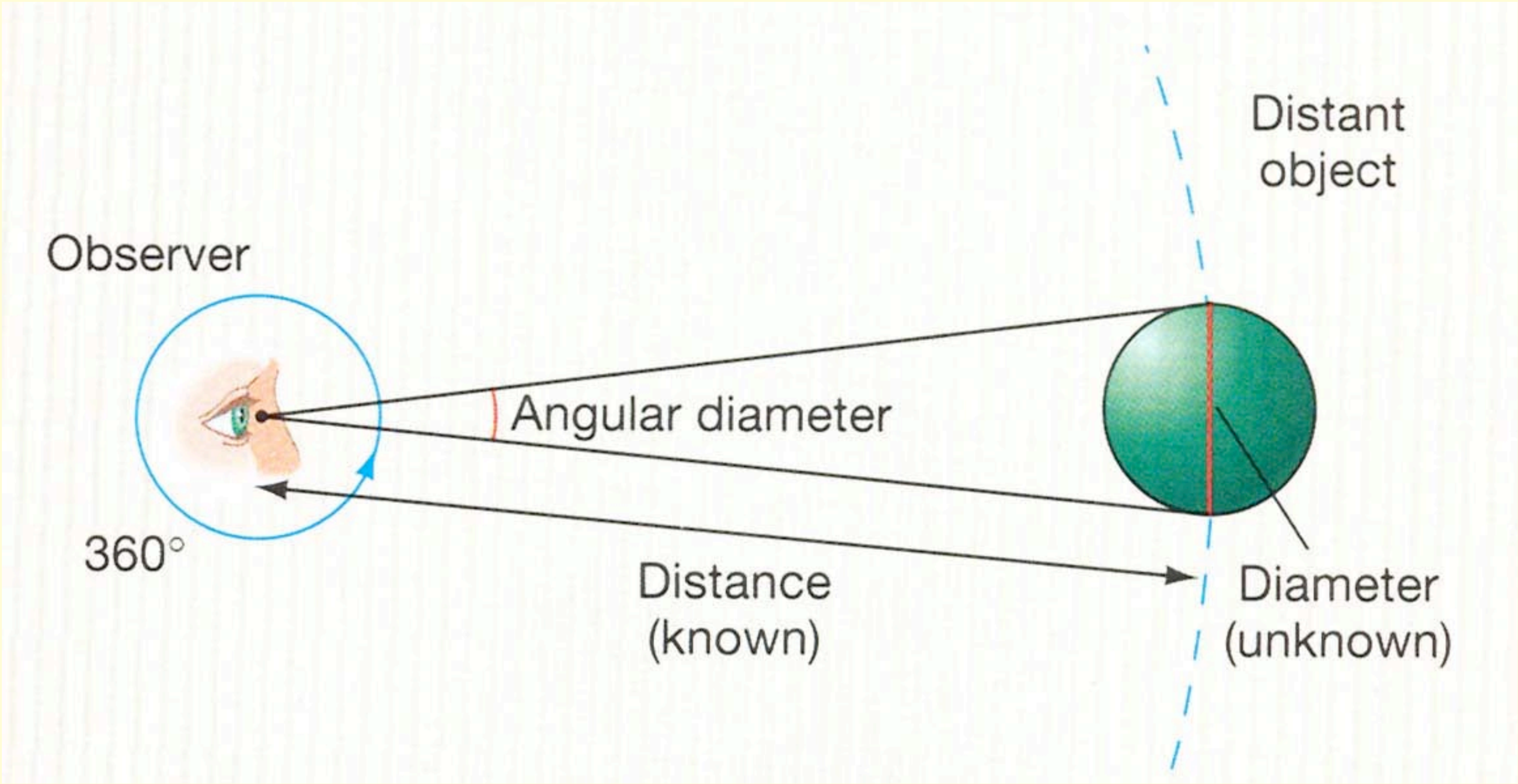
Angular measure--illustration from your textbook.



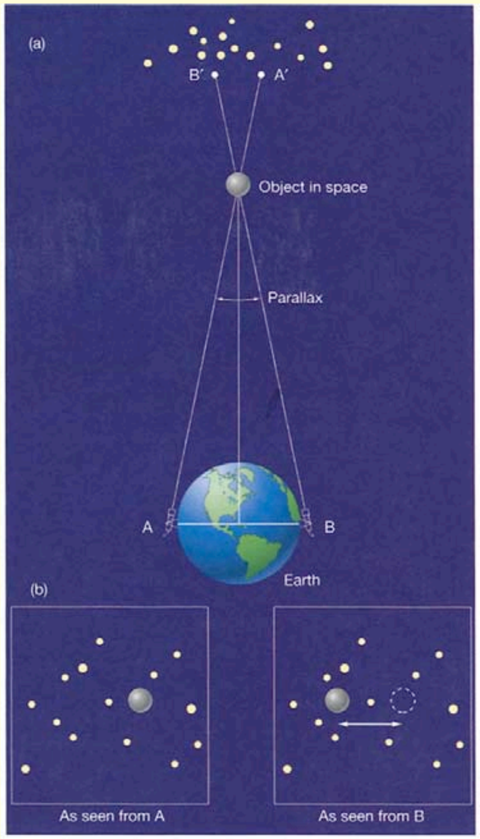
Angular diameter of an object --notice how you could get the distance of the object if you knew its size, or its size if you knew its distance. The formula is

diameter = distance x angular diameter (in "radians")

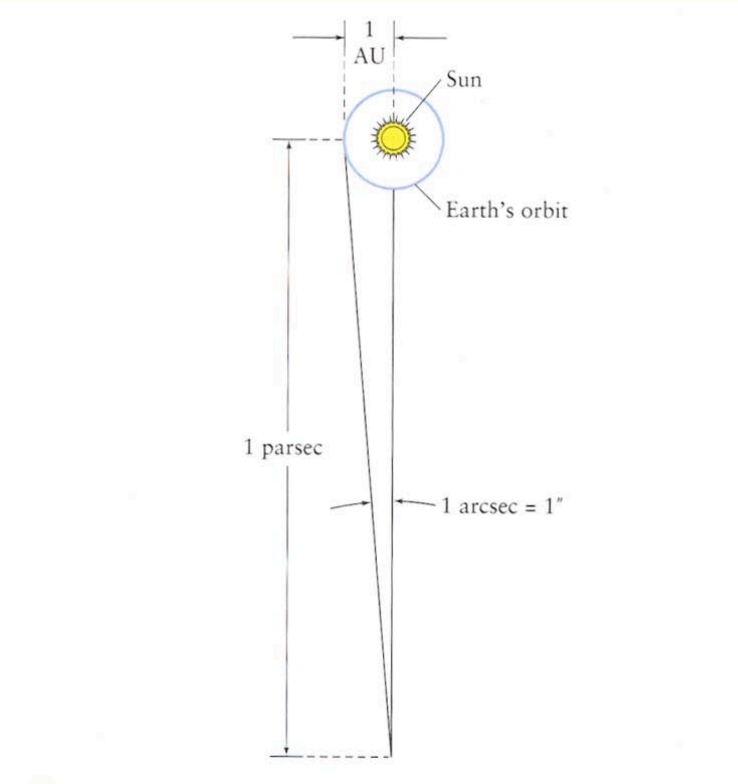
But if you can't "resolve" the object, , then you can't use this method at all (e.g. for stars--try to understand why we can't "resolve" the surface of a star). Make sure you understand what this means!



Distances from **Parallax** Angle (sec. 1.7 in text)



▲ **FIGURE 1.31 Parallax** (a) This imaginary triangle extends from Earth to a nearby object in space (such as a planet). The group of stars at the top represents a background field of very distant stars. (b) Hypothetical photographs of the same star field showing the nearby object's apparent displacement, or shift, relative to the distant, undisplaced stars.



A Parsec The parsec, a unit of length commonly used by astronomers, is equal to 3.26 light-years. The parsec is defined as the distance at which 1 AU perpendicular to the observer's line of sight subtends an angle of 1 arcsec.

Left: Parallax using diameter of Earth. Understand why baseline is too small for stellar distances.

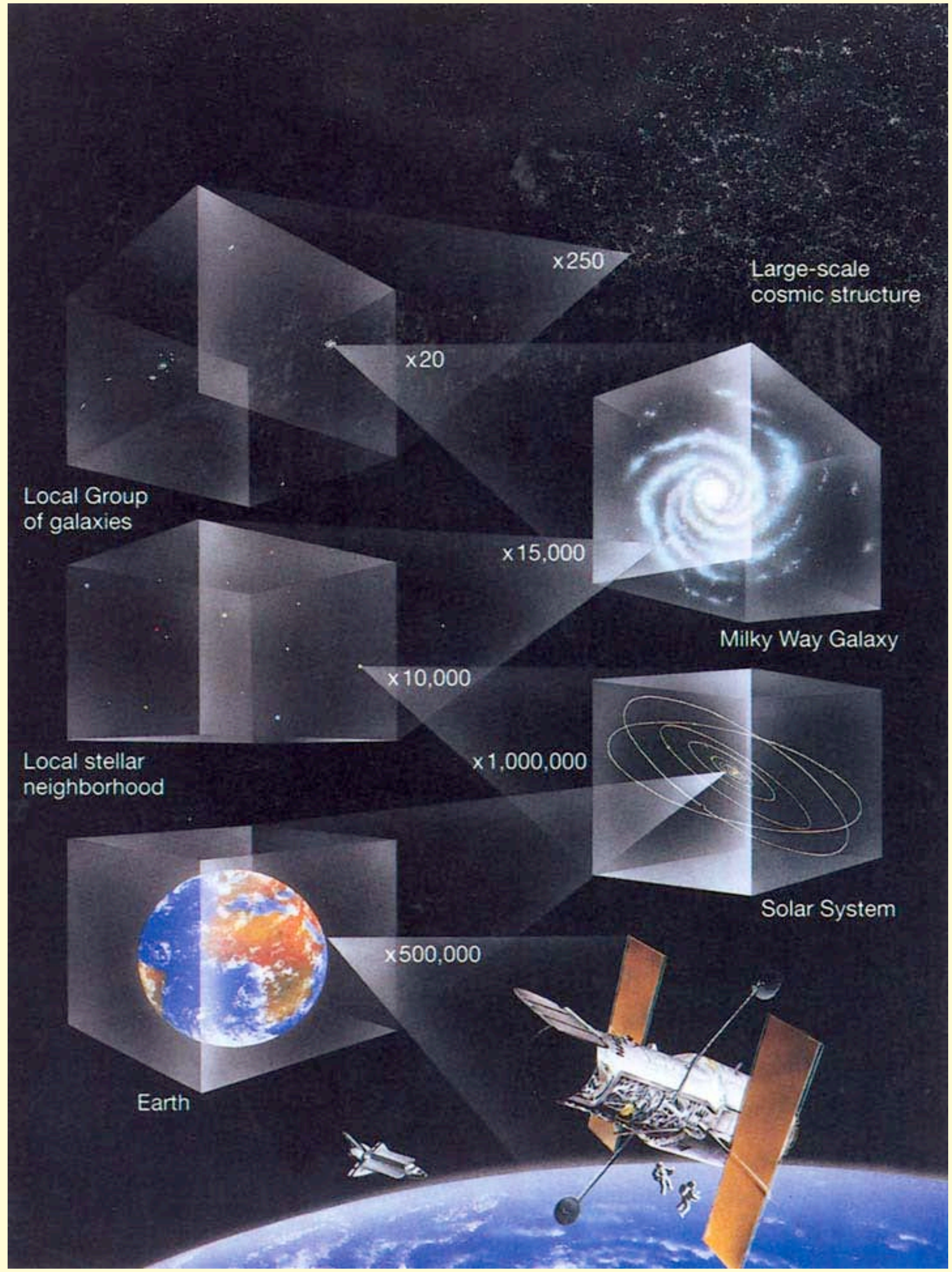
Right: Parallax using 1AU→ defines the unit of distance called a "**parsec**" (for distance of object whose <u>par</u>allax is one <u>sec</u>ond of arc (one arcsec). This is abbreviated pc, as in "That star is 6.3 pc away."

Distances and sizes in the universe

The measurement of distances to stars by parallax is the first step in a long line of methods to learn about the scale of the universe at larger and larger distances.

We can only use parallax for nearest ~ few 100 pc (because stars more distant than that have parallaxes so small that they can't be measured (yet), even from space. Be able to explain this!
Much of the rest of the book is taken up with devising other trickier methods to get distances, with astonishing results…

What we end up with is an amazing range of sizes and distances of various objects in the universe, as shown in the illustration to the right (from your text; good idea to stare at it a while). But parallax is only the first step.

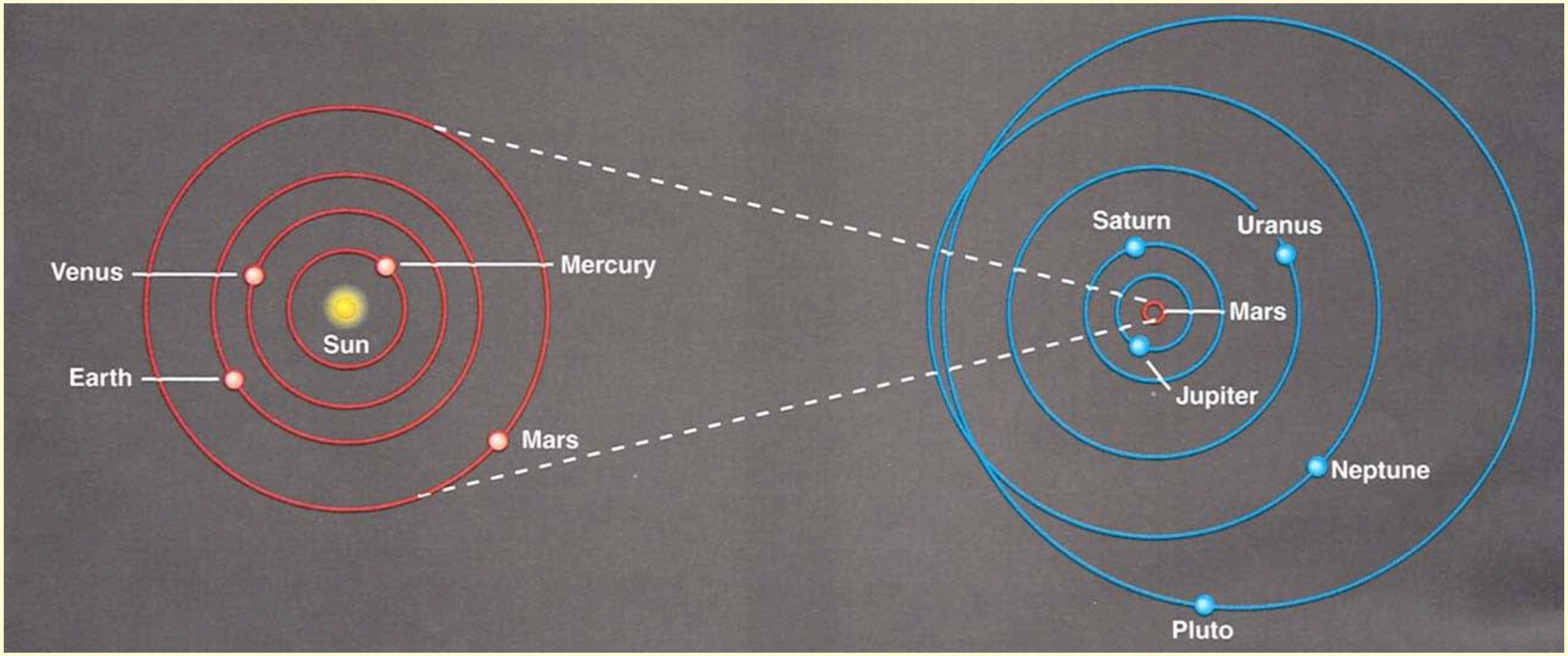


Distances: We'll return to parallax in more detail later in the course: for now you should just get the basic idea, and how it relates to the unit of distance called "*parsec*."

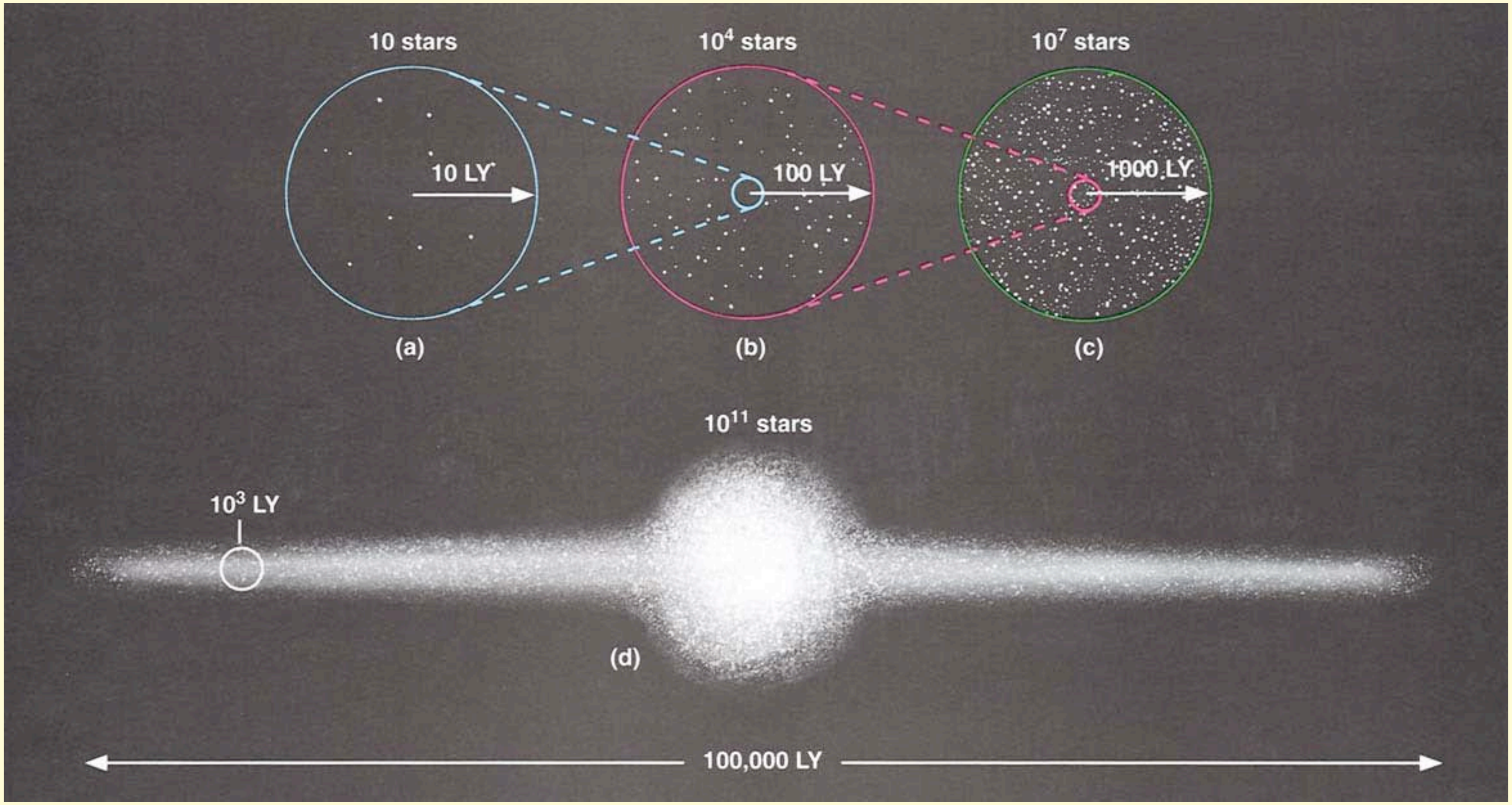
Nearest stars are about 1 pc (a few light years) away. This is also the average distance between neighboring stars in most galaxies. It is a number that you should remember.

Size of our Galaxy and many others is about 10,000 pc, and the distances between galaxies range from millions (Mpc) to billions of pc (1000 Mpc—make sure you are comfortable with what this means--see preceding figure again).

For distances in the solar system, see sec. 2.6. Average distance from Earth to Sun defined as "*astronomical unit*" (1AU) (~ 10^{-3} pc), size of our solar system ~ 100 AU.



As we move out from the solar system to see the nearest stars, the scale of distances expands enormously--100AU is *tiny* compared to the average distances between stars, and nearly infinitesimal compared to the sizes of galaxies or larger structures in the universe.



Geocentric vs. heliocentric models (sec. 2.2-2.4)

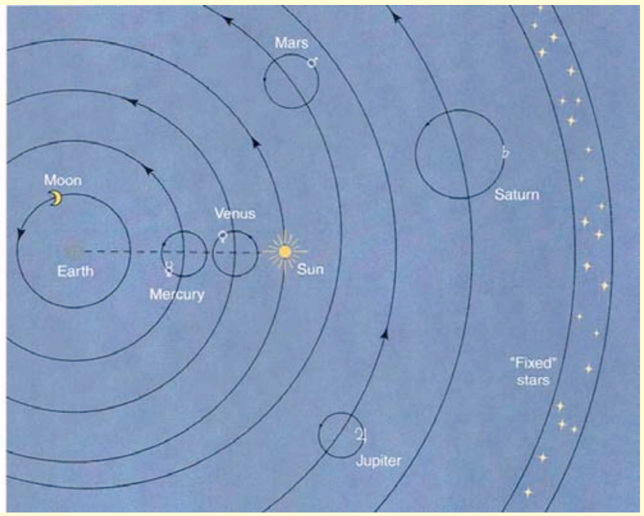
The important historical progression is the following:

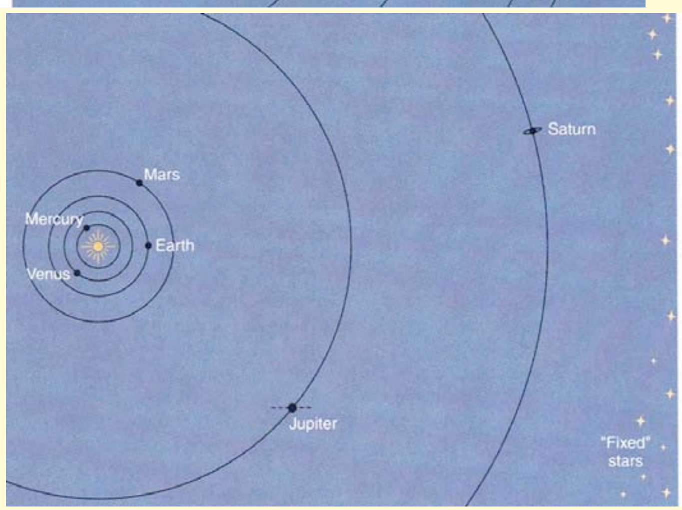
Ptolemy (~140 AD) … Copernicus (~1500 AD), Galileo (~1600), Tycho Brahe, Kepler (2.5), Newton (2.6).

It is important to recognize the change in world view brought about by:

- Geocentric model (Ptolemy, epicycles, planets and Sun orbit Earth)
- Heliocentric model (Copernicus, planets orbit Sun)

The solar system as conceived by Ptolemaic astronomers between about 100 and 1500. Ptolemaic astronomers made rough predictions of planetary motions, using a theory in which the Sun and other planets moved in circular orbits around a stationary, central Earth. Superimposed on the larger orbits were smaller circular motions called epicycles, introduced to try to make the theory more accurate.





The solar system as it might have been conceived around 1700, at the end of the Copernican revolution. The diagram shows the orbits of the 10 known planets to true scale. The view is correct except that the outermost planets (Uranus, Neptune, and Pluto) and the asteroids had not yet been discovered. Compare with Figure 3–2 to see the change from the Ptolemaic view.

Kepler's Laws

Empirical, based on observations; NOT a theory (in the sense of Newton's laws).
So they are "laws" in the sense of formulas that express some regularity or correlation, but they don't *explain* the observed phenomena in terms of something more basic (e.g. laws of motion, gravity--that waited for Newton)

1. Orbits of planets are *ellipses* (not circles), with Sun at one focus.

Must get used to terms *period* (time for one orbit), *semimajor axis* ("size" of orbit), eccentricity (how "elongated" the orbit is), *perihelion* (position of smallest distance to Sun), *aphelion* (position of greatest distance to Sun)

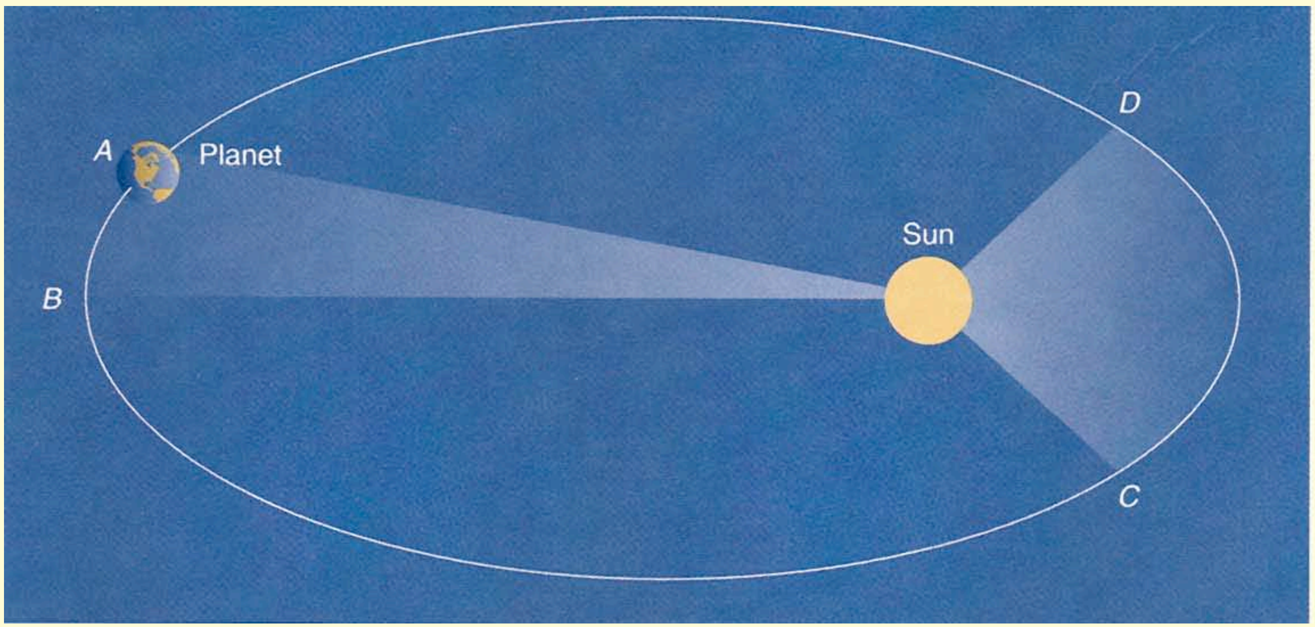
Examples: comets, planets: Why do you think these have such different *eccentricities* ?

Escaping from the assumption of perfect circles for orbits was a major leap, one that even Copernicus was unwilling to take. This is an important example of how strongly a preconception in the form of a belief can rule our thought.

Kepler's 2nd law:

2. Equal areas swept out in equal times; i.e. <u>planet moves faster when closer to the sun.</u>

Good example: comets (very eccentric orbits, explained in class).



Kepler's second law of planetary motion. The orbit sweeps out an ellipse where an imaginary line connecting the planet to the Sun sweeps out equal areas in equal time intervals. The time taken to move from *A* to *B* equals the time taken to move from *C* to *D*. In other words, planets travel faster when they are close to the Sun and more slowly when they are far from the Sun. The true planet orbits are much closer to circles, and the speed only changes by a small percentage along the orbit.

Kepler's 3rd law: Square of the period "P" is proportional to the cube of the semimajor axis "a"

$$P^2 = a^3$$

when P is expressed in Earth years and "a" is in units of A.U. (astronomical unit; average distance from Earth to Sun). (This is about as difficult as the math gets in this class.)

(Absolute size of A.U. unit determined from radar observations of Venus and Mercury, and other methods--see textbook. In case you care, it is about 1.5×10^{13} cm.)

⇒ **Kepler's 3rd law, as modified by Newton (see below), will be a cornerstone of much of this course, because it allows us to estimate masses of astronomical objects (e.g. masses of stars, galaxies, the existence of black holes and the mysterious "dark matter").** It is important that you see why it makes sense after we discuss gravity.

Example: The planet Saturn has a period of about 30 years; how far is it from the Sun?

NEXT: Newton's laws of motion and gravity. Read in textbook by Friday.

Kepler's third law of planetary motion. The period of a planet's orbit increases with increasing distance from the Sun. Planets discovered after the invention of the telescope obey this law, too. Notice that according to Kepler's law, planets can have properties that place them *anywhere* on this curve. The planets of the solar system have a particular pattern in their spacing from the Sun.