AST 301
Introduction to Astronomy

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AST 301 (Lacy), course website

Topics for this week

Describe the reactions in the proton-proton chain.

How does Einstein's equation, $E = m c^2$, help explain how nuclear reactions generate energy?

Describe how neutrinos allow us to observe the interior of the Sun, and say what was found.

Describe the ideas of thermal and hydrostatic equilibrium for a star.

How are flux (or apparent brightness), luminosity, and distance of a star related?

How do we measure flux and distance of a star?

How do we measure temperatures and masses of stars?

How do we use the Hertzsprung-Russell diagram to make sense of the temperatures and luminosities of stars?

Equilibriums in stars

The idea of thermal equilibrium said that the Earth must radiate as much energy into space as it absorbs in sunlight. Otherwise it would change temperature.

For a star to be in thermal equilibrium, it must radiate as much energy into space as it is generating by nuclear fusion.

Stars are also in hydrostatic equilibrium.

For a star to be in hydrostatic equilibrium, the pressure at any point in the star must be right to support the weight of what's above that point.

Pressure is the force per unit area that a gas exerts on its surroundings.

Gas properties

Temperature is a measure of how much energy of motion gas atoms have (how fast they move).

Pressure is the force the gas atoms exert on their surrounding as they bounce off of the walls.

Pressure is proportional to the number of atoms in the box (actually the density, or number of atoms per unit volume).

Pressure is also proportional to the temperature of the gas (because fast moving atoms hit the walls harder and more often).

Squeezing a gas increases both its density and its temperature.

Gravity makes the gas settle toward the bottom of the box, so the pressure is higher toward the bottom.

This is an example of hydrostatic equilibrium.

More on hydrostatic equilibrium

We usually describe hydrostatic equilibrium by saying that the pressure at any point in a star must be right to support the weight of what's above that point.

What if the pressure was too high inside a star?

The star will expand, which decreases the pressure, until pressure is right to support the weight.

This happens quickly, in about an hour.

More on thermal equilibrium

When a star is in thermal equilibrium, the rate of energy generation by fusion equals the rate of energy loss by radiation from the surface of the star.

The rate of fusion depends strongly on temperature, because the protons must be moving fast to get close enough together so they can be attracted by the strong force before their electrical repulsion pushes them apart.

If the center of a star is too hot, fusion will run faster than energy is being radiated from the surface.

But the high temperature will cause high pressure, which will cause the star to expand. And since the star is a gas, when it expands it cools.

So fusion slows down.

Until its rate is right to generate the energy lost by radiation.

Measuring properties of stars

What properties of stars can we measure?

Flux or apparent brightness (Watts/m^2)

Distance (km or parsecs)

Luminosity or absolute brightness (Watts)

Mass (kg or solar masses)

(surface) Temperature (K)

Composition

What else?

Flux or Apparent Brightness

The flux of a star is the power in the light from that star that would hit a 1 m^2 area facing the star.

To measure a star's flux, we use a telescope to collect light from the star, measure the power in the light we collect, and the divide the power by the collecting area of the telescope. (A bigger telescope will collect more light. We don't want the flux to depend on what telescope we use to measure it.)

The flux of a star depends on how much light it emits and on how far we are from that star.

We've defined flux so it doesn't depend on what telescope we use, but it does depend on where the telescope is.

Parallax and Distance

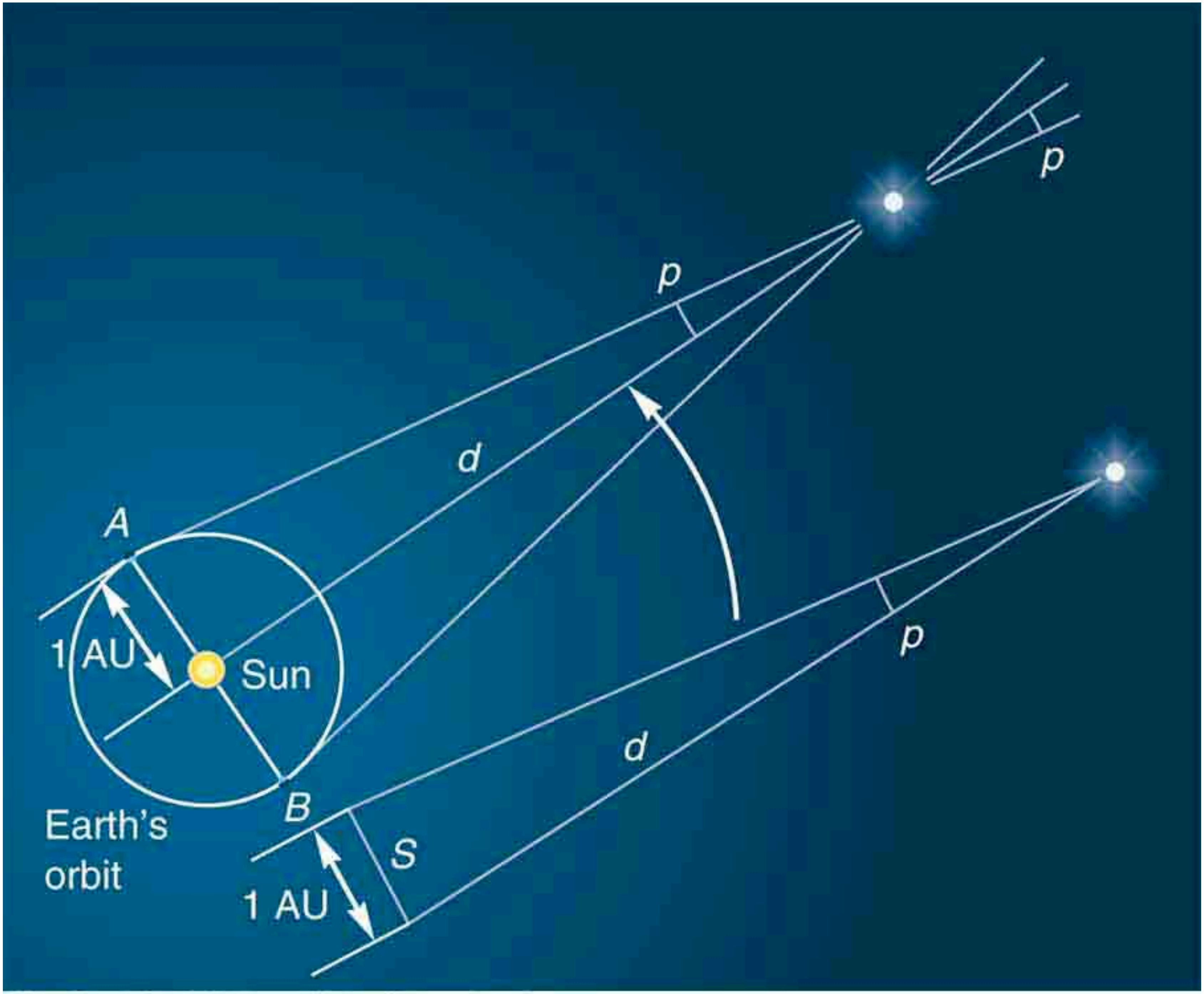
You judge the distance to objects (depth perception) from the fact that your two eyes view an object from two different locations, so have to look in different directions to look at an object.

The different direction to an object from different positions is called parallax.

Astronomers use the change in the direction to a star during a year, as the Earth orbits around the Sun, to judge the distance to the star.

Nearer stars have bigger parallaxes, or

parallax α 1 / distance


p
p
d
A
1 AU
Sun
B
d
p
Earth's
orbit
S
1 AU

Stellar parallax

Astronomers use a unit for distance called the parsec (abbreviated pc) so that a star at a distance of 1 pc has a parallax of 1 arcsecond (1/60 of 1/60 of 1^o).

1 pc is approximately 3 light-years or 200,000 AU

What is the parallax of a star with a distance of 2 pc?

A. ½ arcsecond

B. 2 arcseconds

C. 10^2 arcseconds

D. 10^{-2} arcseconds

Stellar parallax

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parallax α 1/distance, so if you increase the distance from

1 pc to 2 pc, the parallax decreases by a factor of 2, from 1 arcsecond to ½ arcsecond.

p = 1/d if you measure p in arcseconds and d in parsecs.

Another question

What is the distance to a star with a parallax of 0.1 arcseconds?

A. 0.1 pc

B. 1 pc

C. 10 pc

Apparent brightness

How bright a star appears is determined by how much light from that star enters your eye.

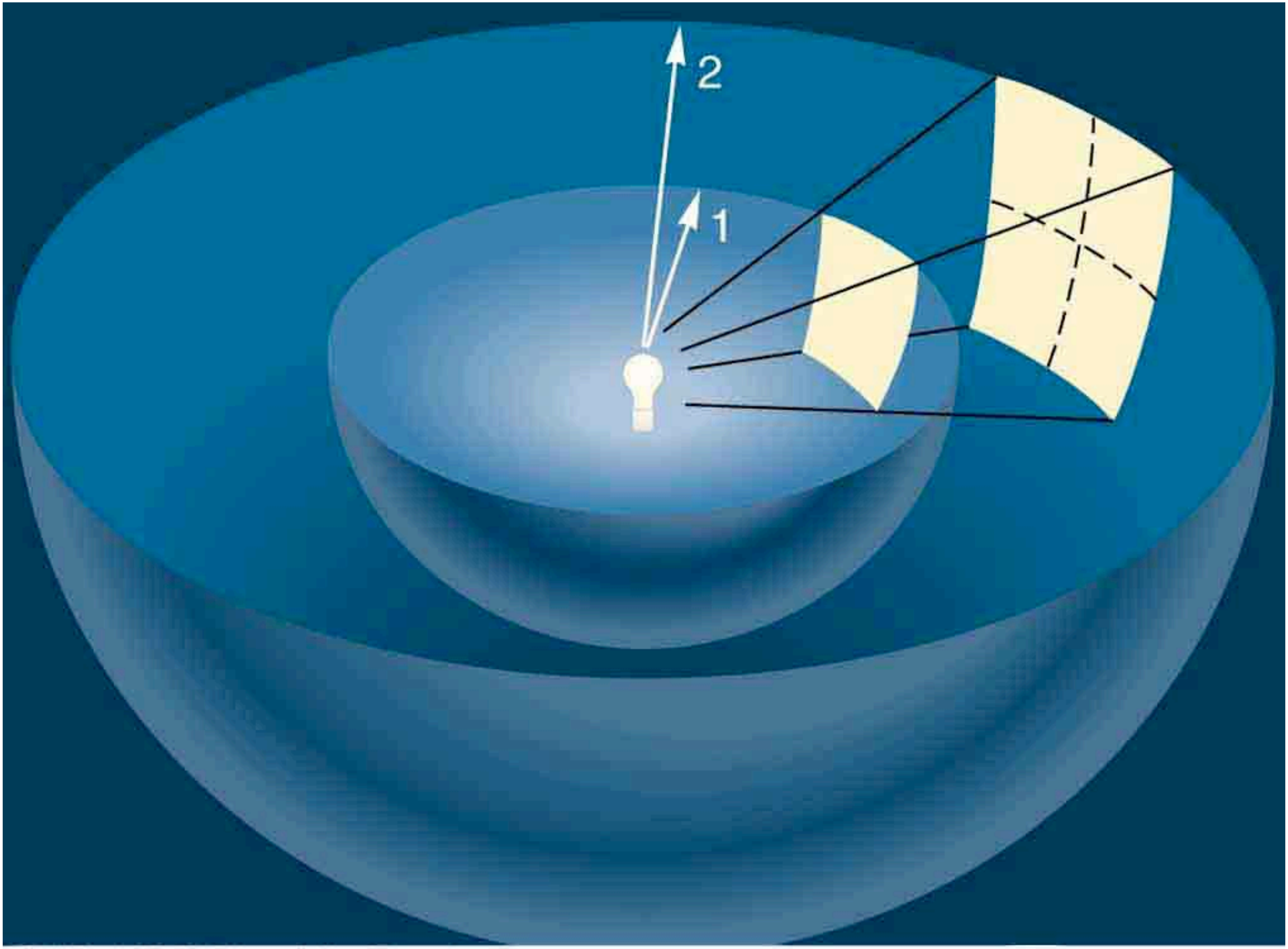
That is given by the product of the area of your pupil and the light power per unit area reaching you from the star.

We refer to the power per unit area as the flux or apparent brightness of the star.

Flux = Power / Area

You can calculate the flux of light from a star by dividing the power emitted by the star by the area it has spread over by the time it gets to you.

Because all areas vary as the square of the size of the object, the area the light has spread over varies as the square of the distance it has traveled.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Flux or Apparent Brightness

In traveling a distance of 1 pc from a star, light spreads out over some area.

When the light has traveled a distance of 2 pc from the star, it has spread out over 4 times as much area.

Since the flux of starlight is the power emitted divided by the area it has spread over, the flux is 4 times smaller 2 pc from the star than it is at 1 pc.

The formula is: Flux α 1 / distance^2

Or if the stars we are comparing have different luminosities (power emitted), the formula becomes:

Flux α Luminosity / distance^2

Quiz

Sirius and Vega are very similar stars.

They emit about the same amount of light power.

But Vega is about 3 times farther from us than Sirius is.

Which star appears brighter?

A. Sirius

B. Vega

How many times brighter?

A. 3

B. 6

C. 9

D. 1/9

Combine parallax and brightness

Spica and Canopus emit about the same amount of power.

Spica has a parallax of .005 arcsec and Canopus has a parallax of .01 arcsec.

How do Spica and Canopus compare in apparent brightness?

Work it out and compare answers with your neighbors.

Hint: first figure out how they compare in distance, and then figure out how that affects their brightnesses

Combine parallax and brightness

Canopus has twice the parallax of Spica.

Since distance α 1 / parallax, Spica must be at twice the distance of Canopus. (The numbers are 100 pc and 200 pc, but you don't need to know that.)

The more distant star (Spica) appears fainter.

Since it is twice as distant as Canopus, it appears 4 times fainter, or ¼ as bright.

We could use the magnitude system to describe how much fainter Spica is than Canopus, but I prefer to talk about fluxes instead of magnitudes.

Masses of Stars

The gravitational force of the Sun keeps the planets in orbit around it.

The force of the Sun's gravity is proportional to the mass of the Sun, and so the speeds of the planets as they orbit the Sun depend on the mass of the Sun.

Newton's generalization of Kepler's 3rd law says:

$$P^2 = a^3 / (M_1 + M_2)$$

where P is the time to orbit, measured in years,

a is the size of the planet's orbit, measured in AU,

and $M_1 + M_2$ is the sum of the two masses, measured in solar masses.

Masses of stars

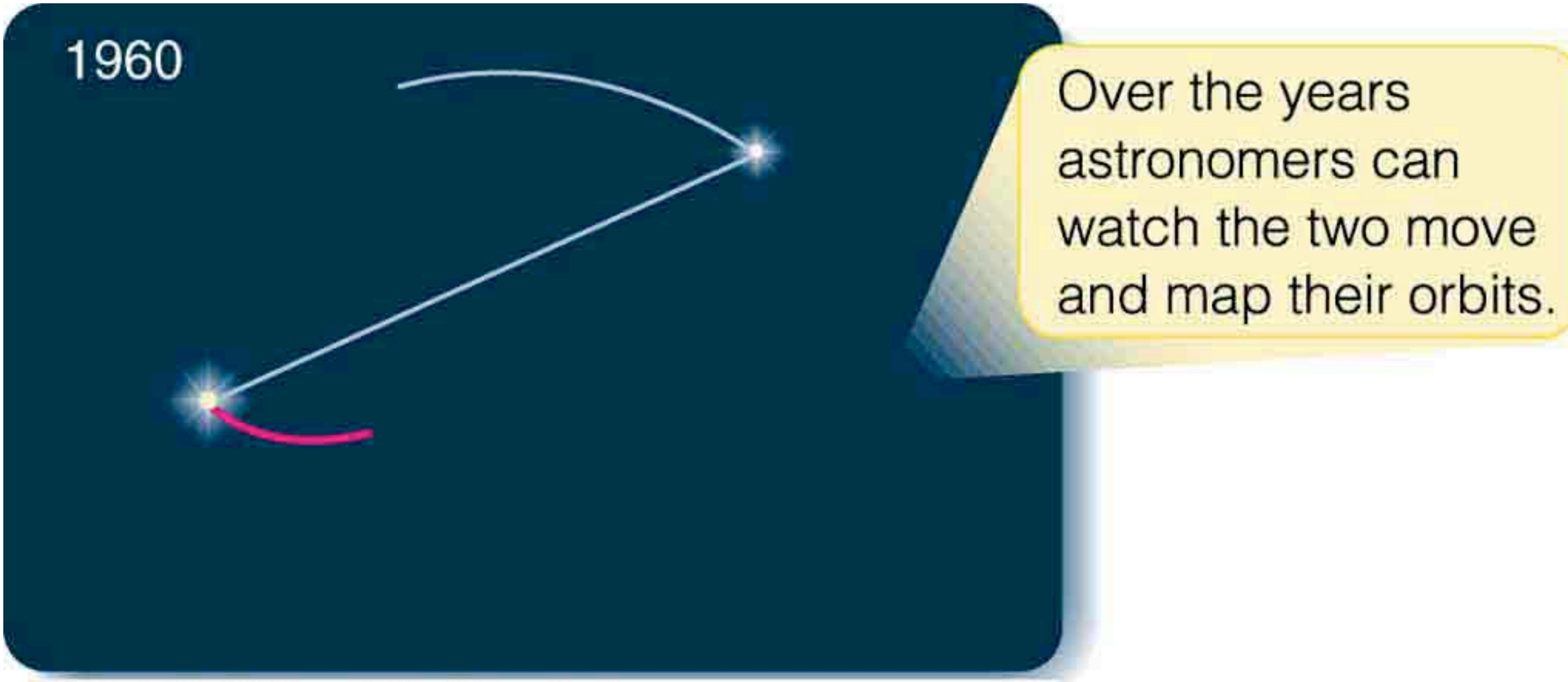
It is difficult to see planets orbiting other stars, but we can see stars orbiting other stars.

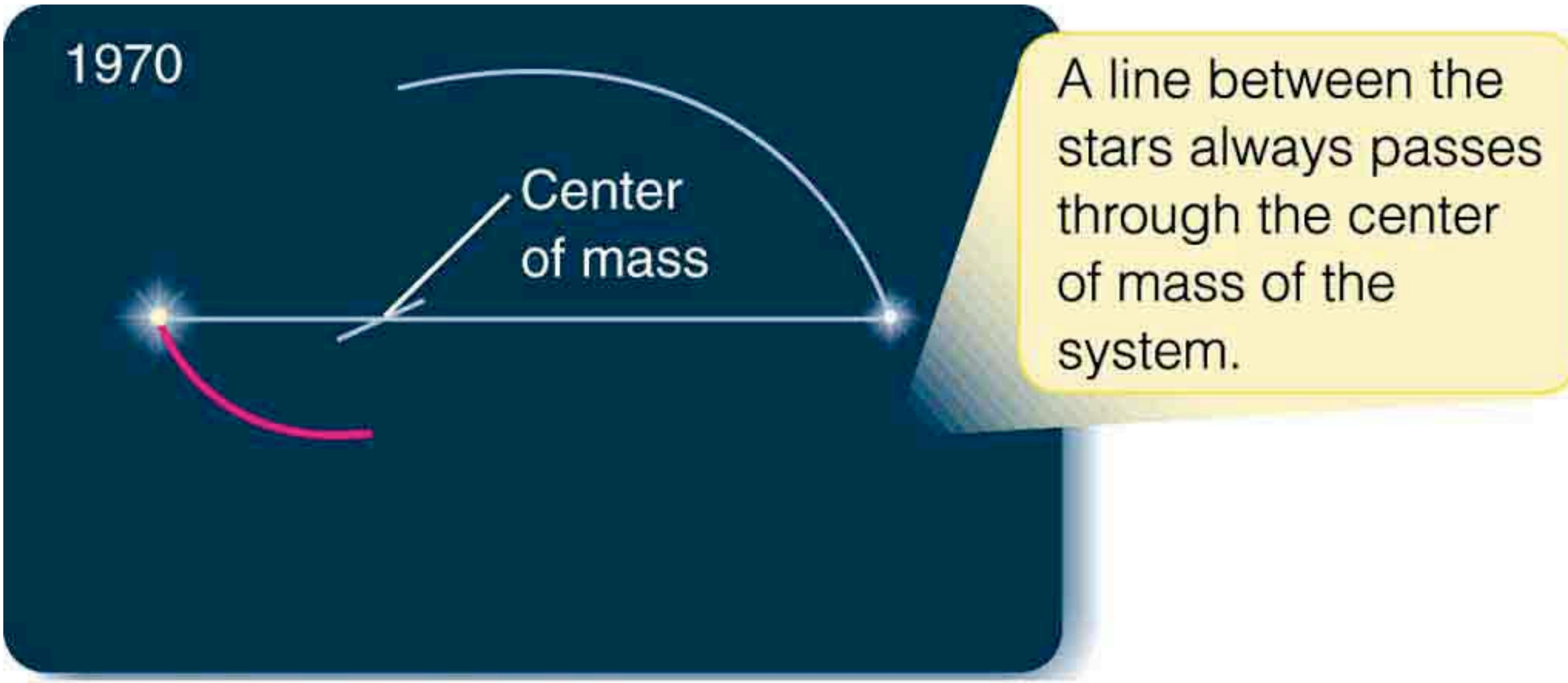
By measuring the periods and sizes of the orbits we can calculate the masses of the stars.

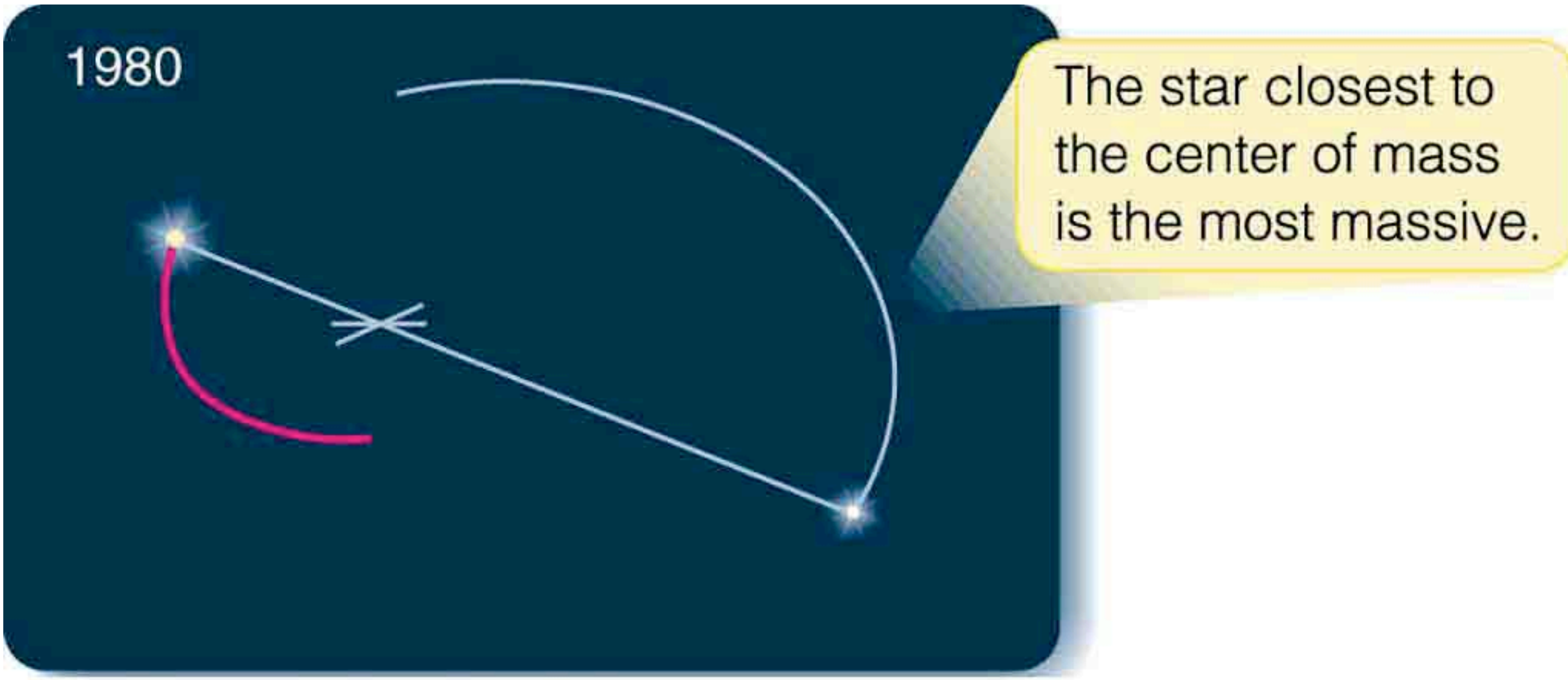
If $P^2 = a^3 / (M_1 + M_2)$, $M_1 + M_2 = a^3 / P^2$

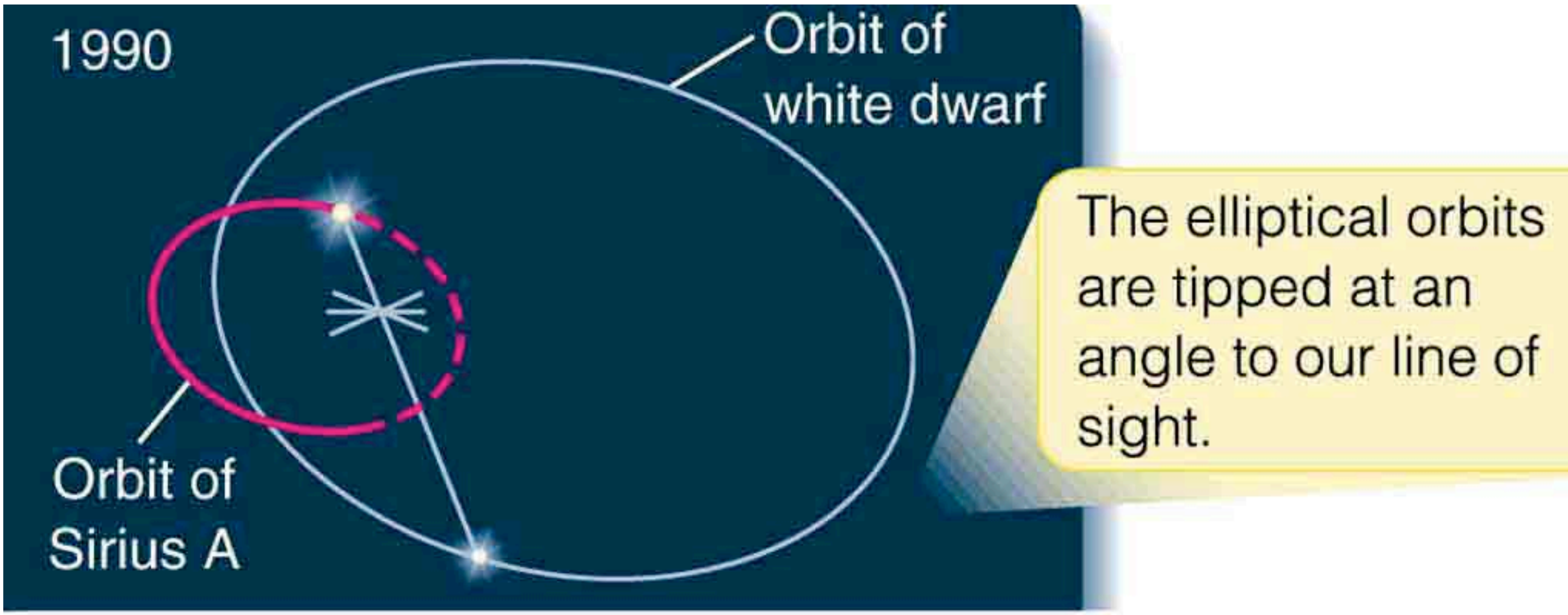
This mass in the formula is the sum of the masses of the two stars. If we observe the motions of both stars we can find out the mass of each star.

a is the average distance between the two stars.


1960
Over the years astronomers can watch the two move and map their orbits.


1970
Center
of mass
A line between the stars always passes through the center of mass of the system.


1980
The star closest to the center of mass is the most massive.


1990
Orbit of
white dwarf
The elliptical orbits
are tipped at an
angle to our line of
sight.
Orbit of
Sirius A