Math Review

- $1 / 0.001 = 1000$
- $1000 \times 1000 = 1000000$
- $10^3 \times 10^3 = (10^3)^2 = 10^6$

Math

- $10^2 \times 10^5 =$

A) 10^3

B) 10^4

C) 10^{10}

D) 10^{14}

E) 10^7


Picture by Mila Zinkova

Parallax and Distance

Astronomy 1120:
Stars and Galaxies
Adam Ginsburg &
Devin Silvia
July 13, 2010

Learning Goals

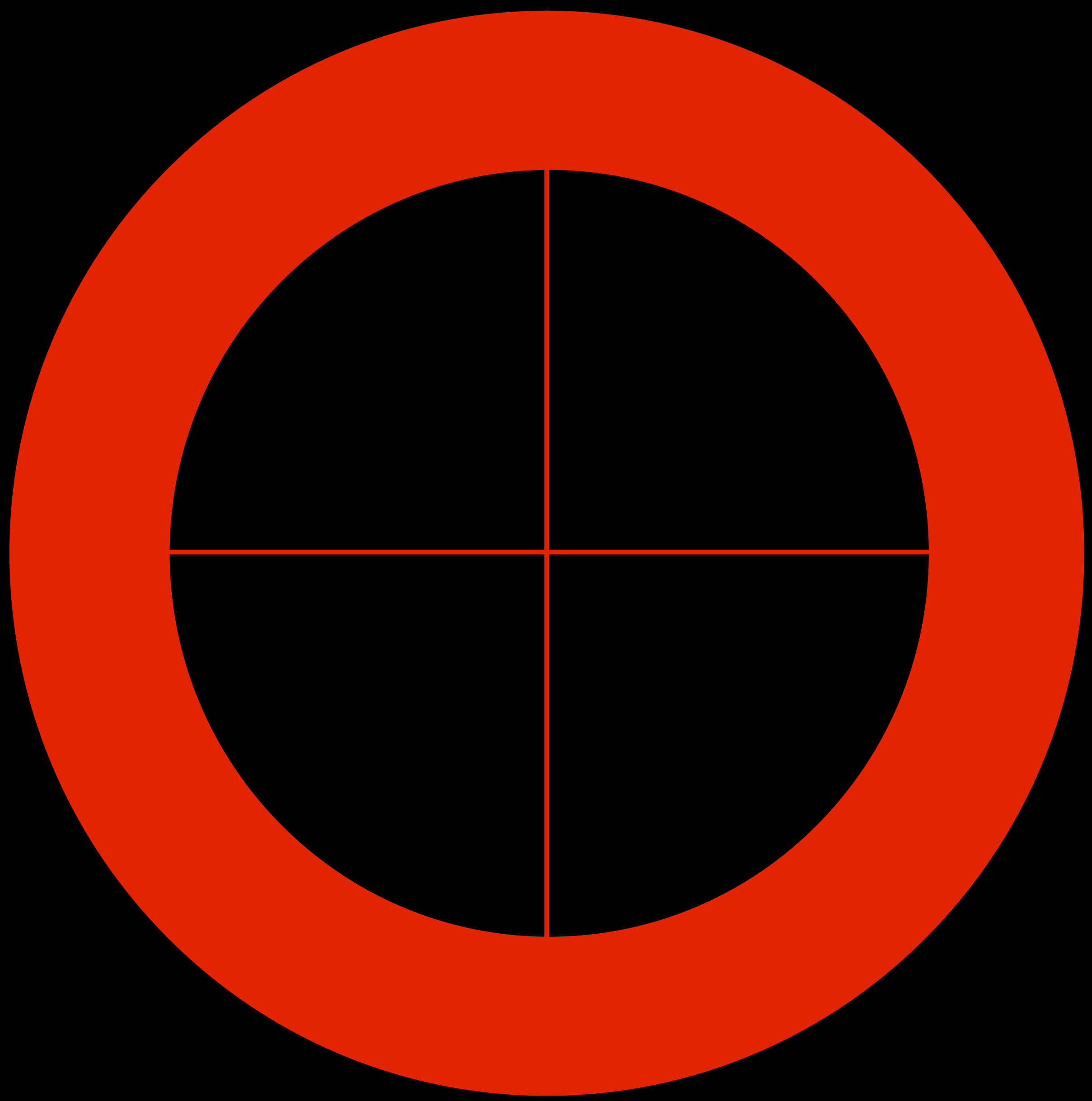
- Why is it important to know how far something is?
- How can astronomers measure distance?
- Definitions: arcsecond, parsec

A little history

- Up through the 1920's, it was not known whether Galaxies like Andromeda were nebulae within our own galaxy or independent, enormous groupings very far away
    - The big uncertainty was the distance: because it is so far away, we can't resolve individual stars in Andromeda, so it just looks like fuzz
- If Andromeda had turned out to be a nebula within the Milky Way, it would be at least 100 times smaller, or $(100)^3 = 1{,}000{,}000$ times less massive!

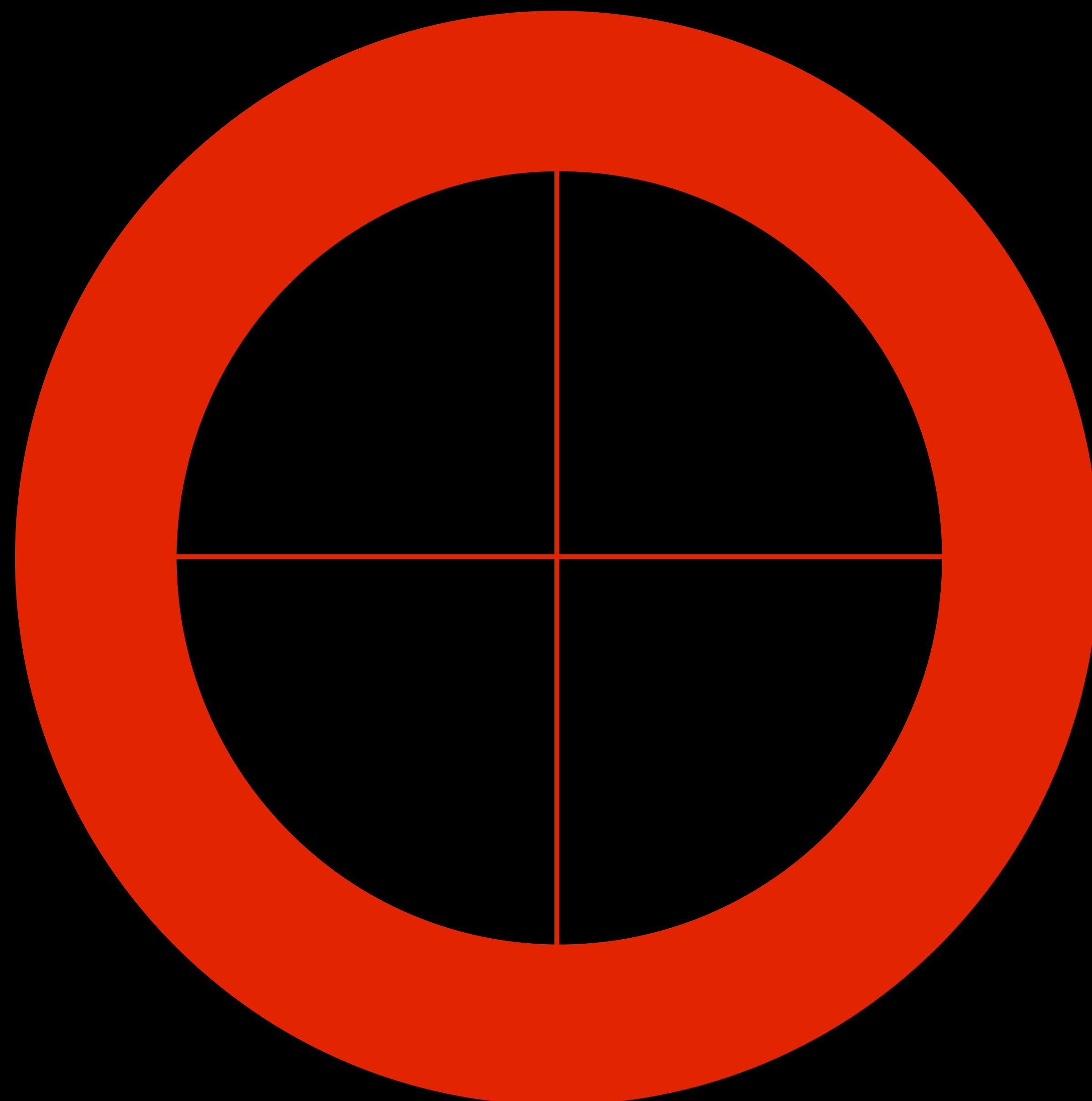
Parallax Demo

- Stick your thumb out at the target
- Close one eye, then the other



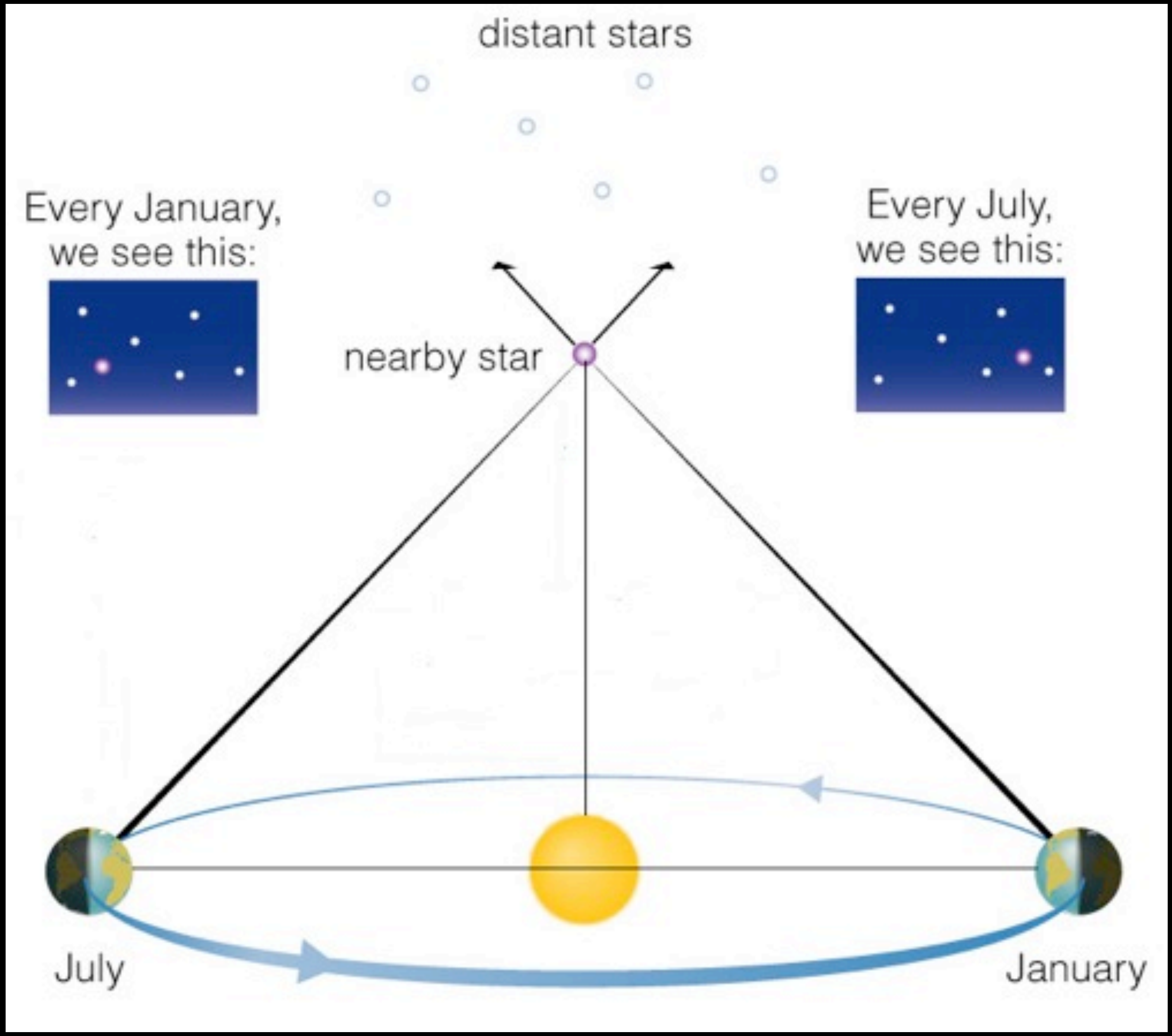
Parallax Demo

- Move your thumb closer to your eye
- Does the parallactic angle change?



Stellar Parallax

- As the Earth moves around the Sun, nearby stars will appear to move relative to “fixed” background stars



Measuring Parallax

- If an object appears to move relative to a fixed background, where is it?

A) closer than the background

B) further than the background

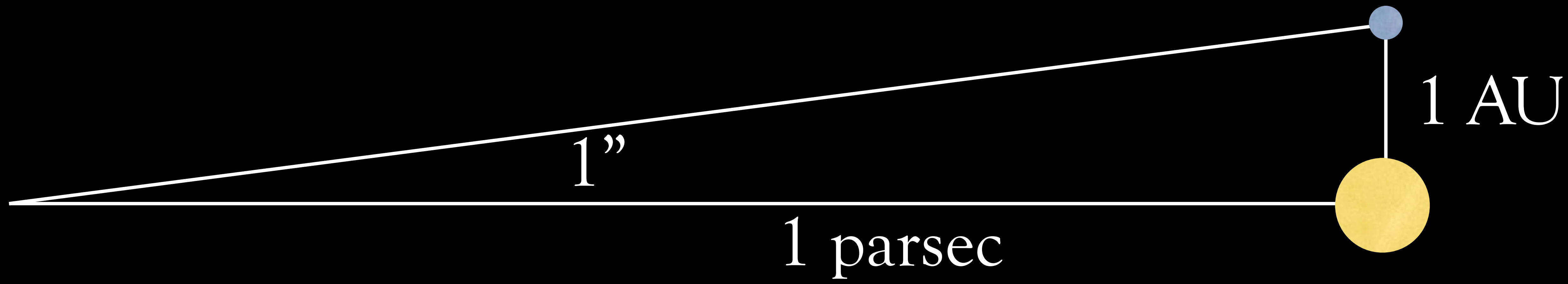
C) you can't tell

Measuring Angle

- There are 360 degrees in a circle
- 60 arcminutes (‘) in a degree
- 60 arcseconds (“) in an arcminute
  - or 3600 arcseconds in a degree
- Your thumb held out at arm’s length is about 2 degrees (it should cover the sun or moon completely)

Measuring Parallax

- The “Parsec” is a unit of distance
  - Parallax Arcsecond
  - If the apparent motion of a star is 1 arcsecond, its distance is 1 parsec (3.26 light-years, or 19 trillion = 19 x 10^{12} miles)
    - A star 10 parsecs away has a parallax of 0.1”



Parallax

- A star has a parallax of 0.01” (10 milli-arcseconds). How far away is it?

A) 0.01 parsecs

B) 0.1 parsecs

C) 1 parsec

D) 10 parsecs

E) 100 parsecs

Parallax

- A star has a parallax of 0.01” (10 milli-arcseconds). How far away is it?
  E) 100 parsecs
- 100 pc = 1/(0.01 arcseconds)
- The nearest 100 stars are within about 7 pc, or 22 light-years. There are 380 known stars within 10 parsecs (32.6 ly)

http://www.nova.org/~sol/solcom/stars/pc10.htm

Parsecs and Light-Years

- The parsec is a unit based on the geometry of the Solar System
- The Light-Year is based on the constant speed of light: it is the distance light travels in 1 year
  - A light-second is 186,000 miles
  - Light can travel around the Earth 7.5 times per second

The Millenium Falcon

Kessel run in 12 parsecs? Nope.

Parsecs are a unit of distance, not time!

The closest stars

- After the sun, the closest stars are Proxima and Alpha Centauri, which are at a distance of 1.3 pc (4 ly)
  - Their parallax is <1” (arcsecond)
    - recall that ground-based telescopes have a resolution of ~1” because of the atmosphere
  - *Parallax is hard to measure!*

Travel Time

- Spacecraft launched from Earth using chemical rockets travel around 5 km/s (12,000 mph). How long would it take a satellite to reach Alpha Centauri, which is 4 light-years away, at that speed?
  (don't calculate, just guess what you think sounds reasonable. Hint: the speed of light is 300,000 km/s)

A) 4 years

B) 400 years

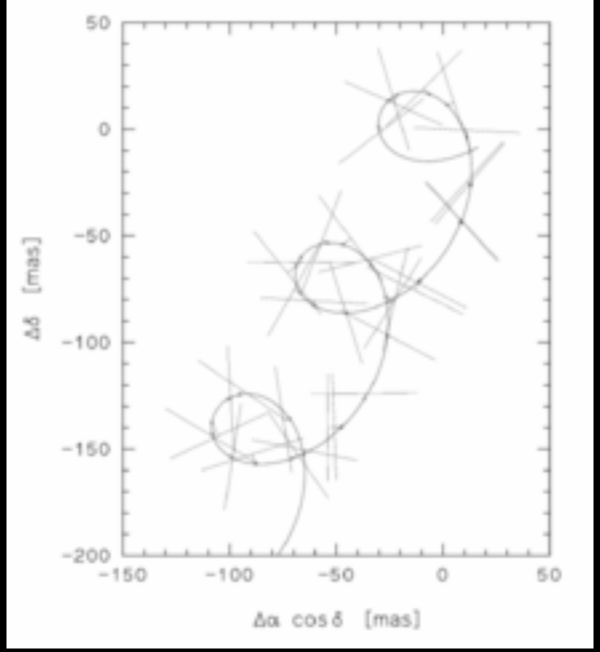
C) 240,000 years

D) 24 million years

E) 1 billion years

Astrometry & Parallax

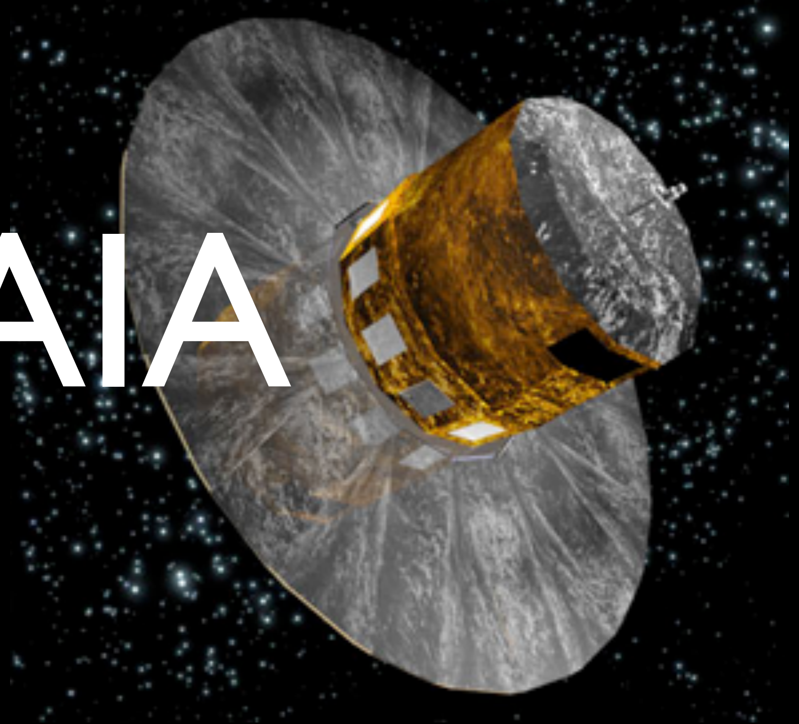
- The measurement of positions of objects is known as astrometry
- Precise astrometry is needed to get parallax measurements, but is also useful for measuring proper motion, which is the tangential motion of an object on the sky
- Astrometry + Doppler Shift gives full 3D velocity information
- Astrometry + Parallax gives full 3D location information



Hipparcos

- Since astrometric precision from the ground is limited, we used a satellite called Hipparcos to measure parallaxes towards stars within 3300 light-years of the sun
- It observed 120,000 stars with 0.001” accuracy

VLBI and GAIA



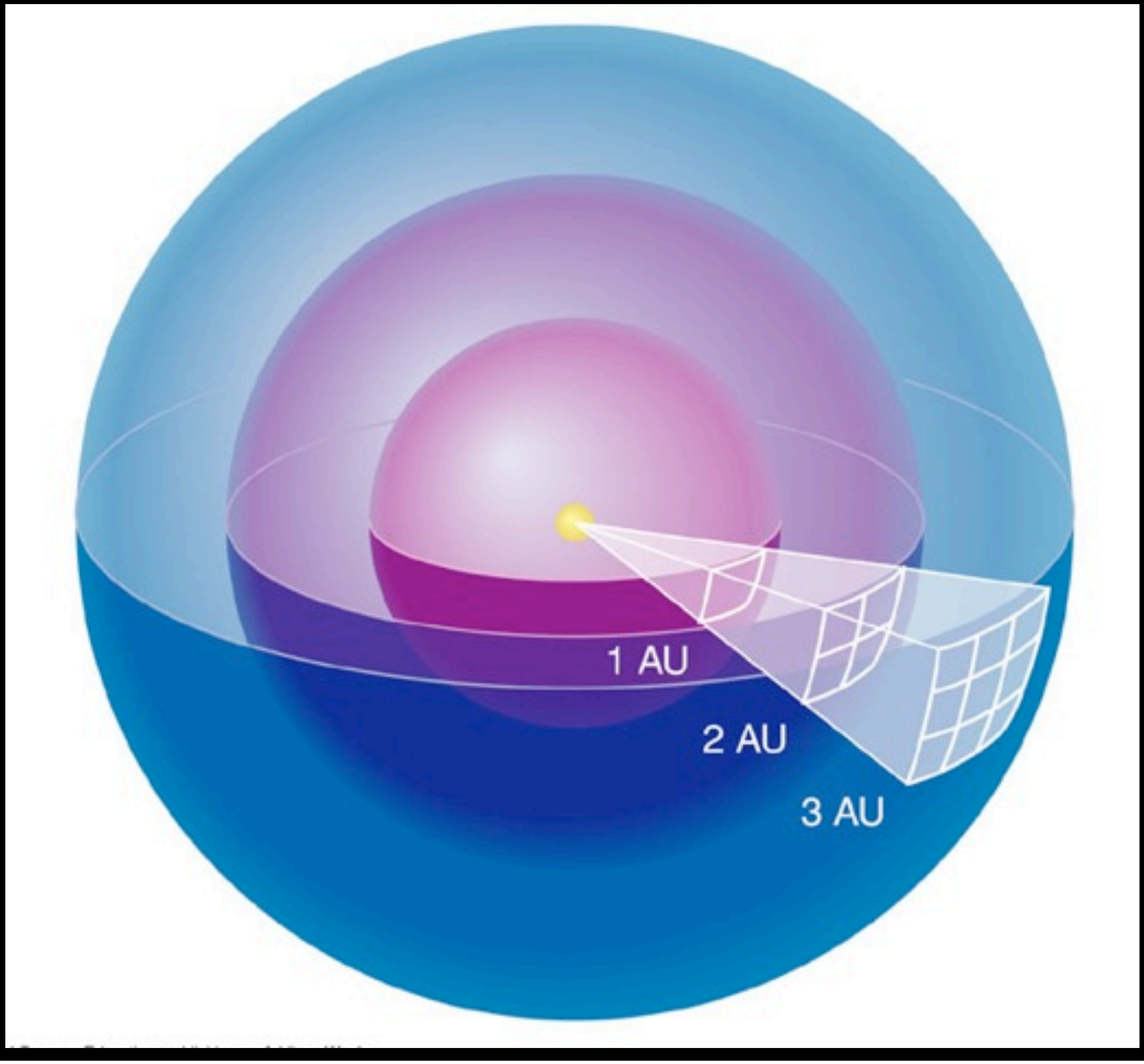
- Very Long Baseline Interferometry allows resolutions of ~10 micro-arcseconds (0.00001"), so distances to some special objects called masers can be measured throughout the galaxy

- GAIA is a new astrometric satellite that will launch in 2012 and measure stellar parallaxes to millions of stars with ~20 micro-arcsecond accuracy

Stop: Tutorial Time

- Page 35: The Parsec

Distance past Parallax



$$\text{Apparent Brightness} = \frac{Luminosity}{4\pi \cdot distance^2}$$

Luminosity ➤ Distance

- If you know exactly how bright a source is and how bright it appears, you can say how far away it is

$$\mathbf{F = L / 4 \pi d^2}$$

Brightness & Distance

- Spica is about 3x further away than Canopus, but is the same luminosity. Which star is brighter, and by how much?

A) Spica, 3x

B) Spica, 9x

C) Canopus, 3x

D) Canopus, 9x

E) They are the same brightness

Brightness & Distance

- Spica is about 3x further away than Canopus, but is the same luminosity. Which star is brighter, and by how much?

D) Canopus, 9x

$L_{Spica} = L_{Canopus} \qquad d_{Spica} = 3\ d_{Canopus}$

$F_{Spica} = L_{Spica} / 4\ \pi\ d_{Spica}^2$

$F_{Canopus} = L_{Canopus} / 4\ \pi\ d_{Canopus}^2$

Substitution:

$F_{Spica} = L_{Canopus} / 4\ \pi\ (3\ d_{Canopus})^2 = 1/9\ F_{Canopus}$

or $F_{Canopus} = 9\ F_{Spica}$

Brightness & Distance

- Becrux and Deneb have the same brightness, but Deneb is 9x more luminous. Which is closer, and by how much?

A) Deneb, 3x

B) Deneb, 9x

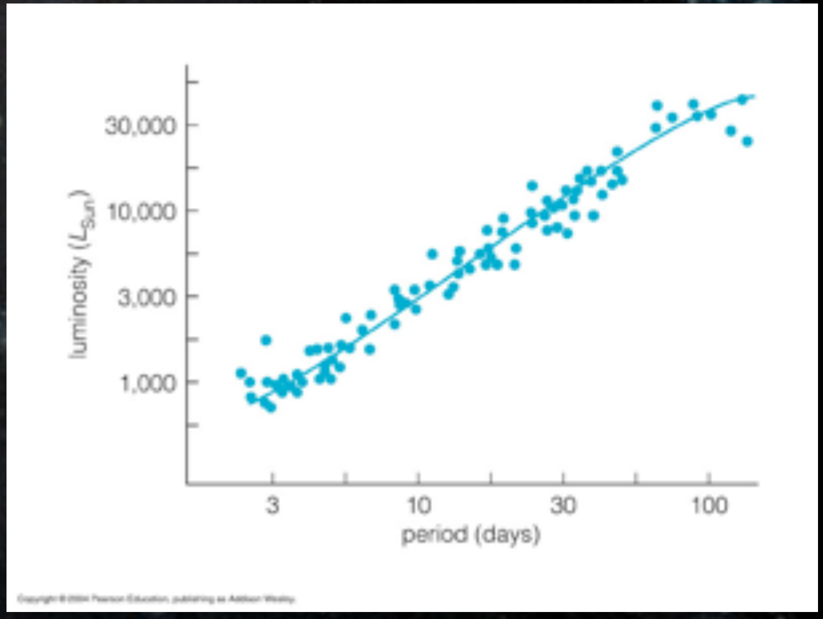
C) Becrux, 3x

D) Becrux, 9x

E) They are at the same distance

Measuring Luminosity

- More details in stellar classification, but...
- There are special stars called Cepheid Variables that follow a period-luminosity relationship
- Luckily, these stars are very large and very bright - we can use them to measure the distance to other galaxies
- The trick is that we use timing measurements to get the luminosity and imaging to get the brightness

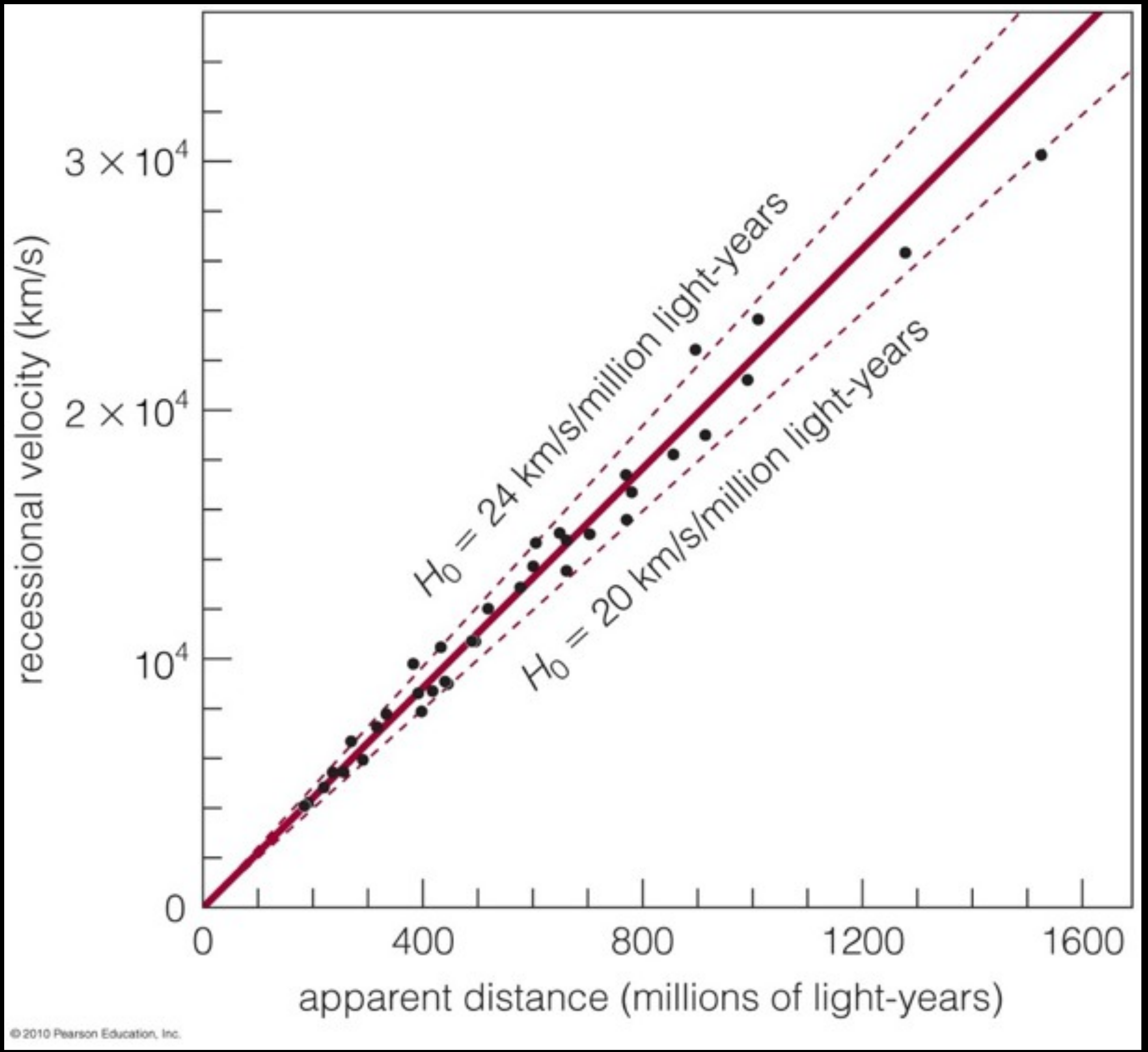


Cepheid Period-Luminosity Relation

- The luminosity of Cepheids is directly measured using parallax distances:
- $F = L / 4 \pi d^2$
- Timing measurements show that luminosity and pulsation period are related

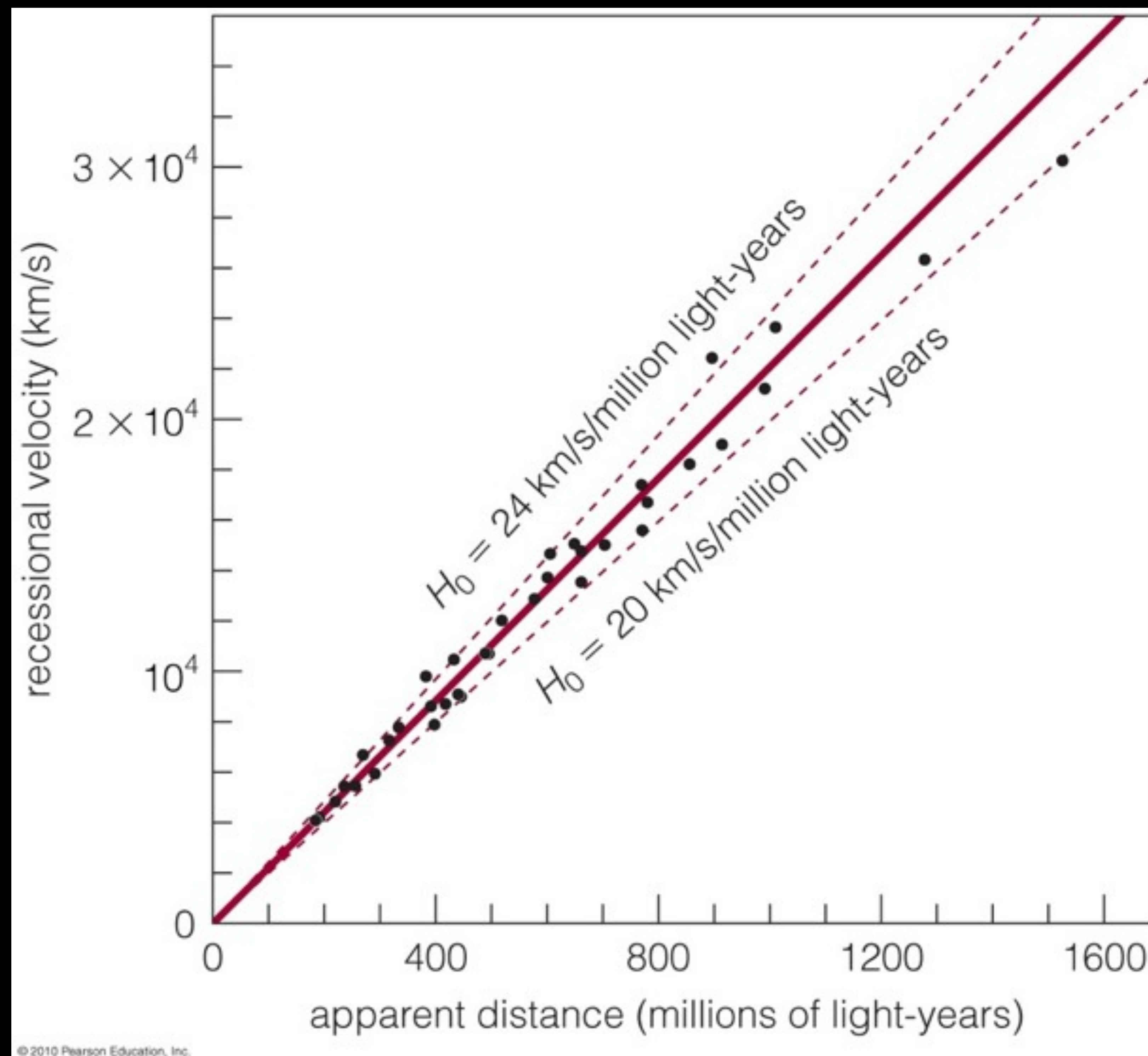
Distance past Cepheids

- Hubble's Law: More distant galaxies are moving away faster
- Doppler Shift and Distance are correlated!



Distance past Cepheids

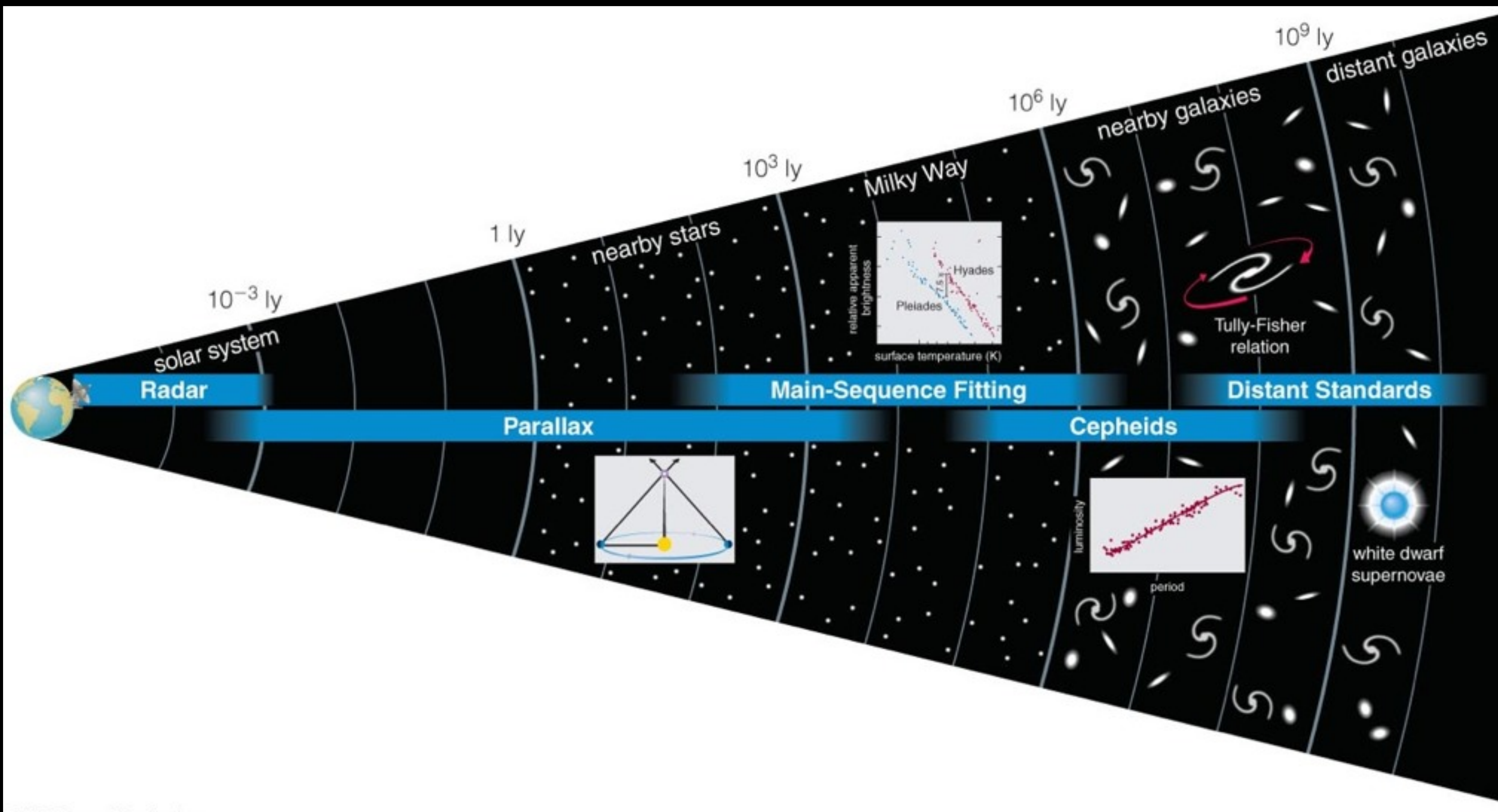
- Cepheids are used to determine the distance to galaxies, and spectroscopy is used to measure the doppler shift
- We use multiple observational methods to infer distances we can't directly measure



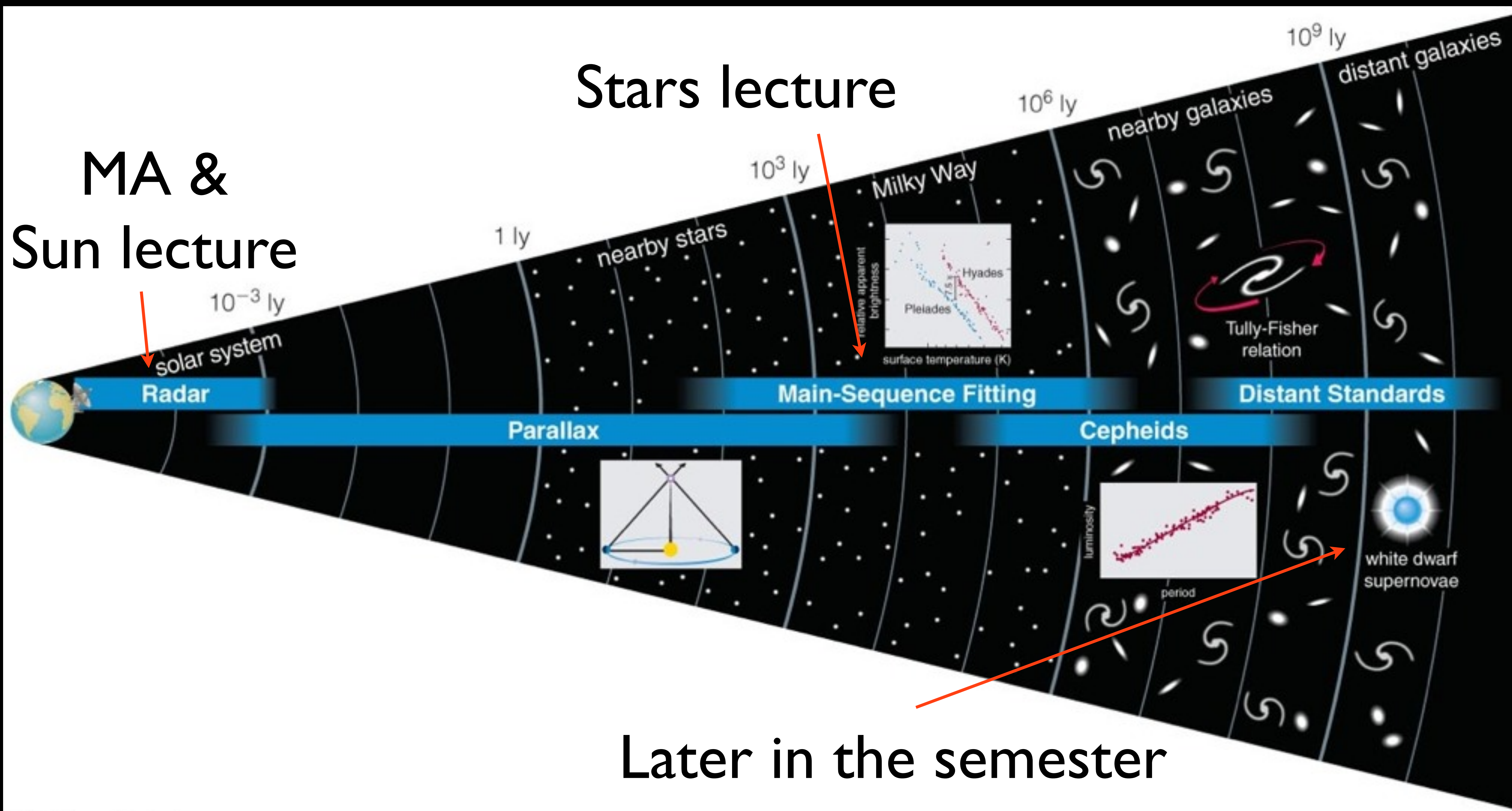
Process of Science: Empirical Law

- Parallax is simply geometry; it can easily be verified by experiments in every-day life
- The Cepheid Period-Luminosity relation and Hubble's Law are "Empirical Laws": we observe that they are true for many objects, and assume they are true for all similar objects
  - Empirical Laws can easily be disproved if counterexamples are discovered

The Distance Ladder



The Distance Ladder



Distance

Can we use parallax to measure the distance to galaxies?

A) Yes, Very Long Baseline Interferometry can do it

B) No, they are too faint

C) No, they are too far away

Distance

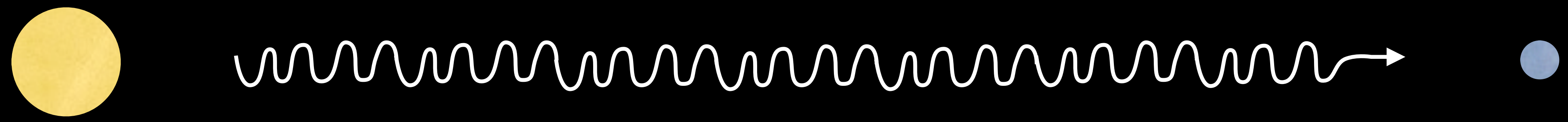
Can we use parallax to measure the distance to galaxies?

C) No, they are too far away

The closest galaxy, Andromeda, is at a distance of 720 kiloparsecs, or a parallax of 1.4 micro-arcseconds, which is about 10x smaller than modern telescopes can measure

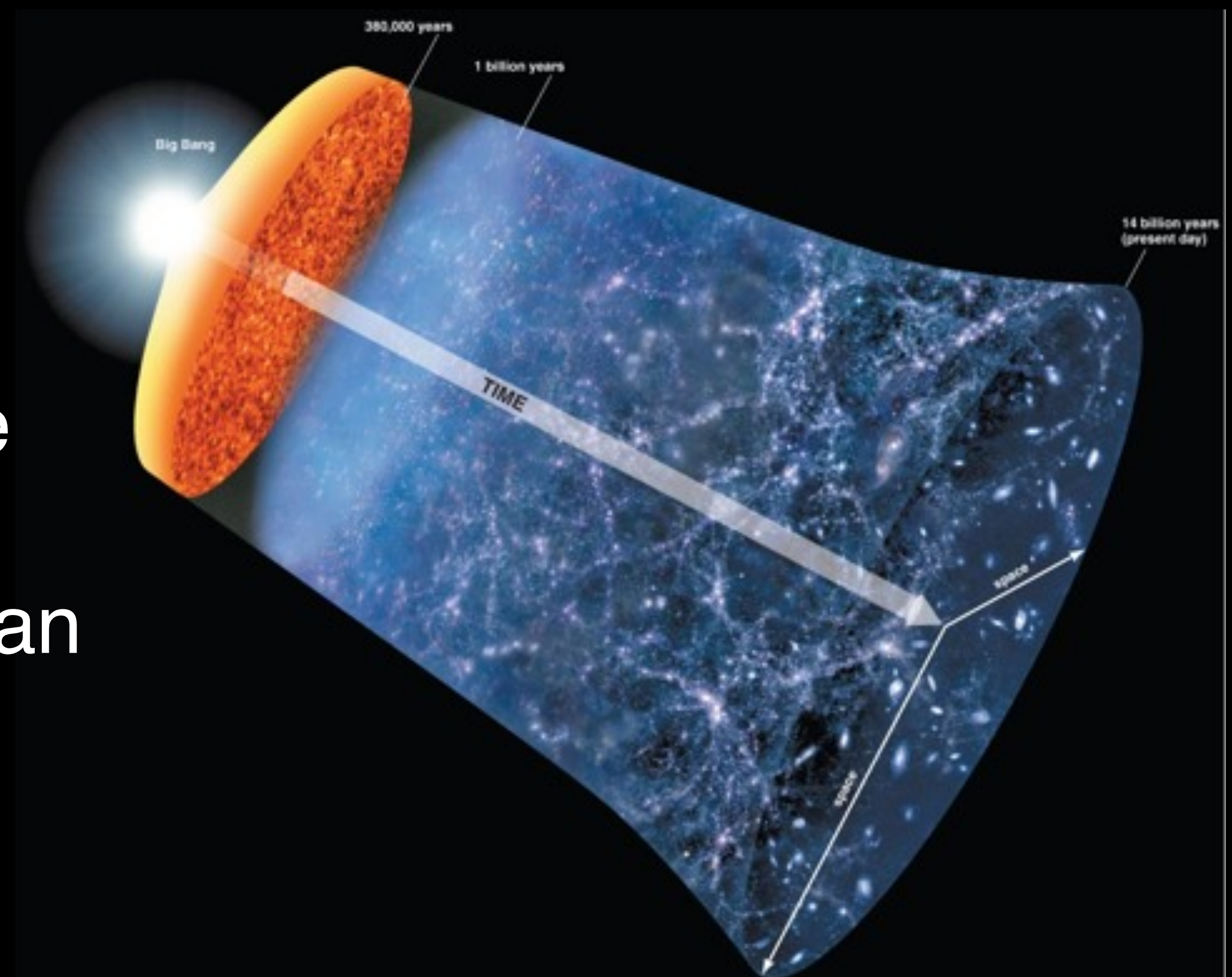
Distance and Time

- A light-year is a measure of distance
- But because it takes light 1 year to travel a light-year, we are looking *back in time* when we look at distant objects
- The sun's light we see on Earth escaped its surface 8 minutes ago



Look-back time

- The center of our Galaxy is ~24,000 light-years away, so any light from the galactic center was emitted before the written human history began
- The nearest galaxy, Andromeda, is 2.5 million light-years away
- Millions of galaxies have been observed at ages >5 billion years, older than the Sun



What time is it?

- Even though the light we see was emitted a long time ago, we talk about objects in space as they appear now - we talk about things in terms of the time we receive their light

Look-back time

- What light can we see now that was emitted around the time dinosaurs ruled the earth?

A) Light from nearby planets

B) Light from nearby stars

C) Light from far away stars in the center of the Milky Way

D) Light from moderate-distance galaxies

E) Light from the beginning of the universe

Learning Goals Revisited

- Why is it important to know how far something is?
  - Need distance to determine size and other properties
- How can astronomers measure distance?
  - Parallax and many bootstrap methods

Lecture Tutorial

- Page 39: Parallax and Distance


Tomorrow:
THE SUN