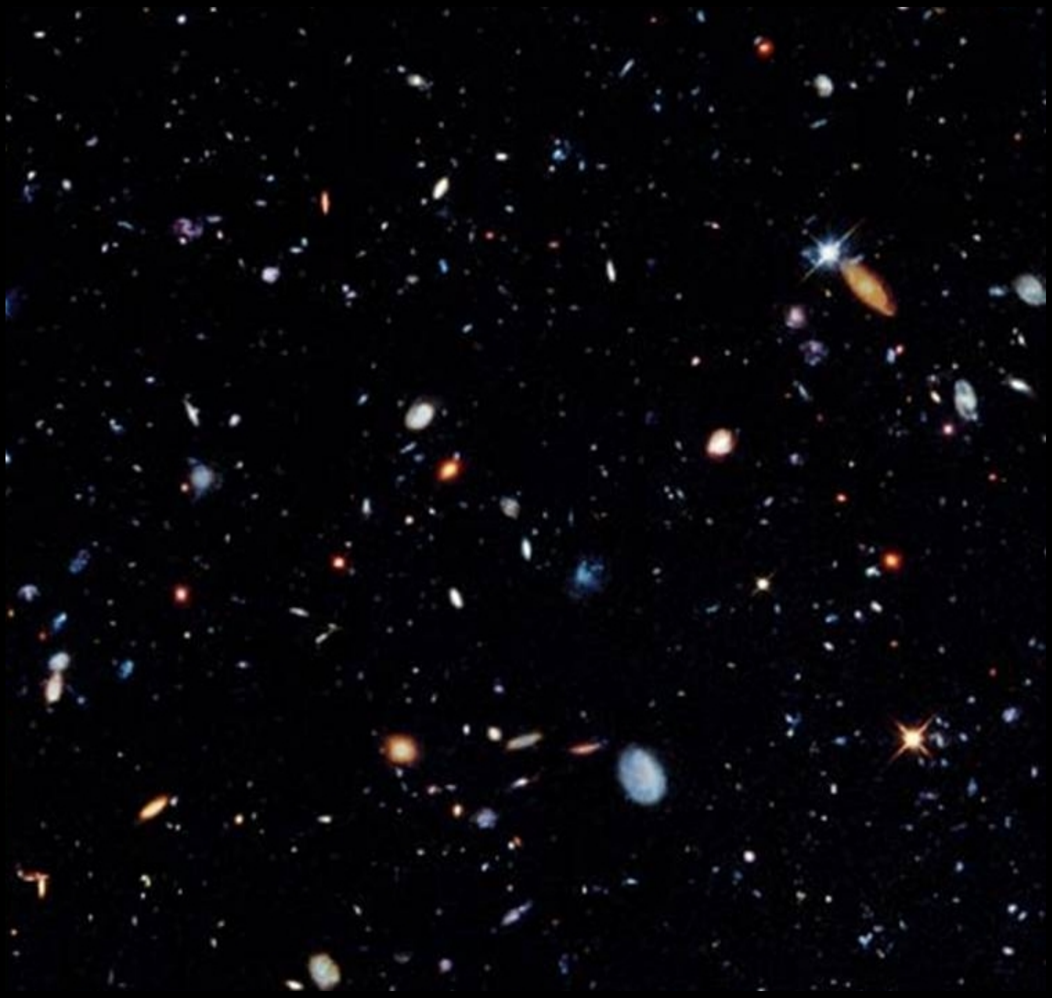
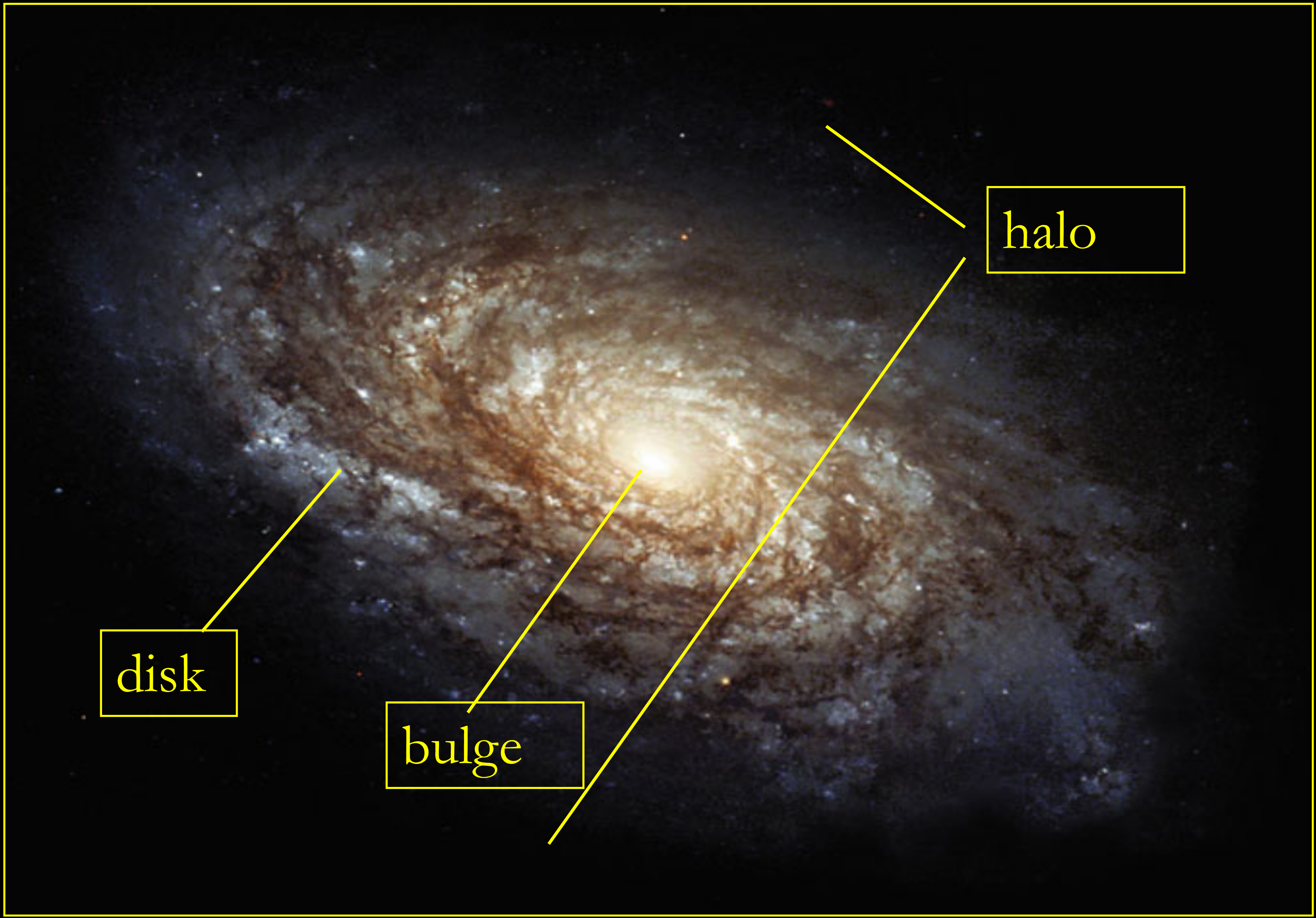
Lecture 22: Galaxies & Distances

What are the three major types of galaxies?



1. Spiral galaxies



Spiral galaxies

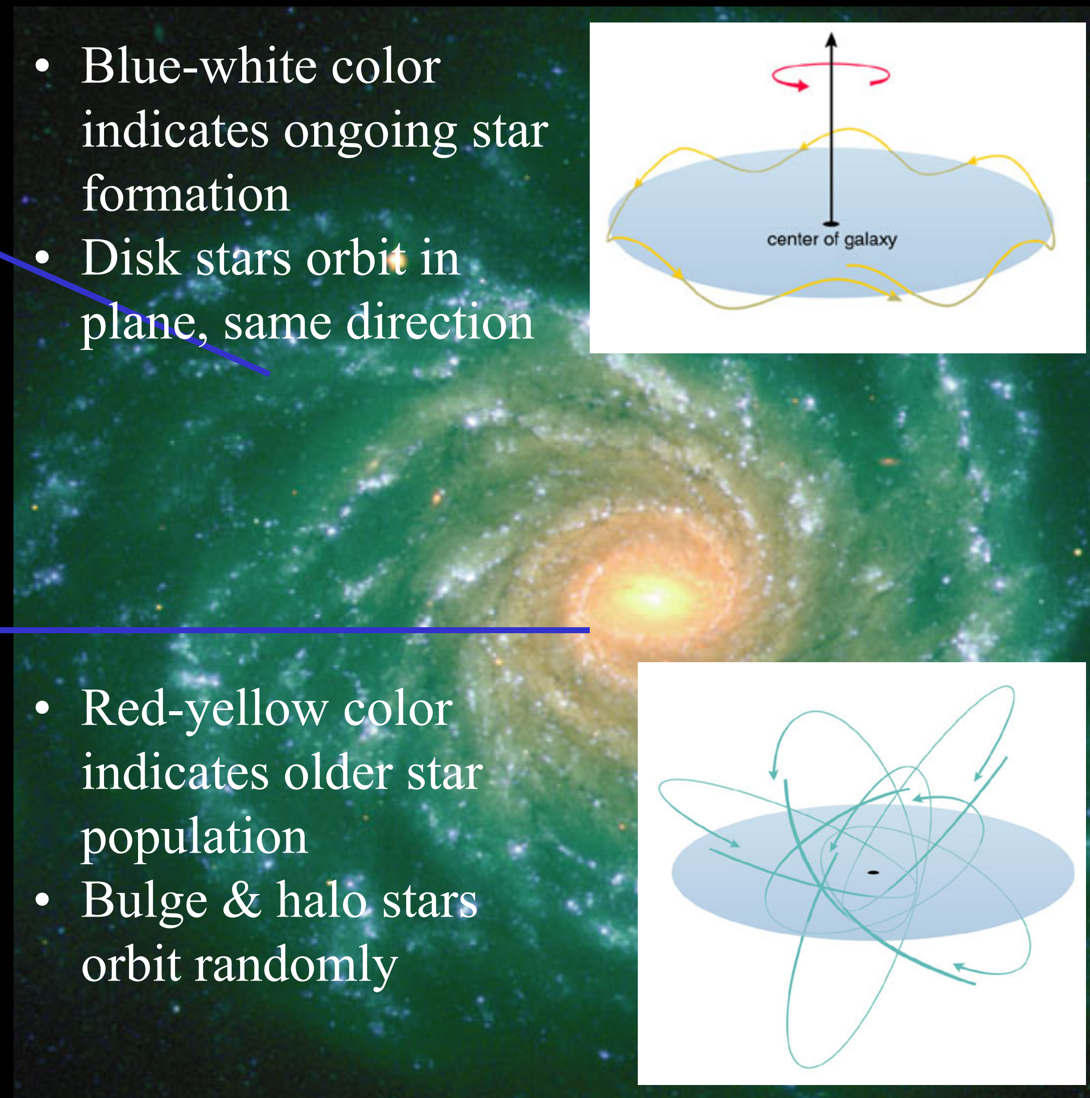
Bulge and halo: cooler stars, few gas clouds

Disk: stars of all temperatures, many gas clouds

Spiral galaxies

Disk:
stars of *all ages*,
many gas clouds

Bulge and halo,
old stars,
few gas clouds



- Blue-white color indicates ongoing star formation
- Disk stars orbit in plane, same direction

- Red-yellow color indicates older star population
- Bulge & halo stars orbit randomly

Barred Spiral Galaxy:

Has a bar of stars across the bulge

Think/Pair/Share

Why does ongoing star formation lead to a blue-white appearance in a spiral galaxy's arms?

A. There aren't any red or yellow stars.
B. Young blue stars outshine others.
C. Gas in the disk scatters blue light.
D. Most stars become white dwarfs.

Think/Pair/Share

Why does ongoing star formation lead to a blue-white appearance in a spiral galaxy's arms?

A. There aren't any red or yellow stars
B. Young blue stars outshine others
C. Gas in the disk scatters blue light
D. Most stars become white dwarfs

2. Elliptical galaxies

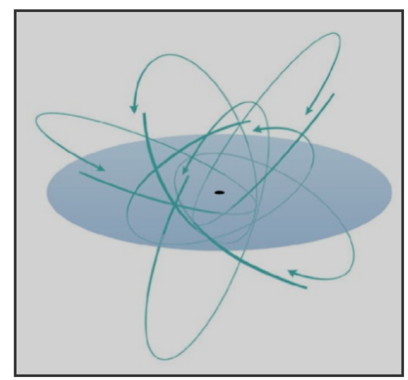
Elliptical Galaxy:

- All spheroidal component, virtually no disk component
- Little or no gas for star formation
- Vast majority are small but some are giants

Elliptical galaxies

Elliptical Galaxy:

Red-yellow color indicates older star population (II), little star formation



Random orbits of stars

Elliptical or Spiral?

Lenticular Galaxy:

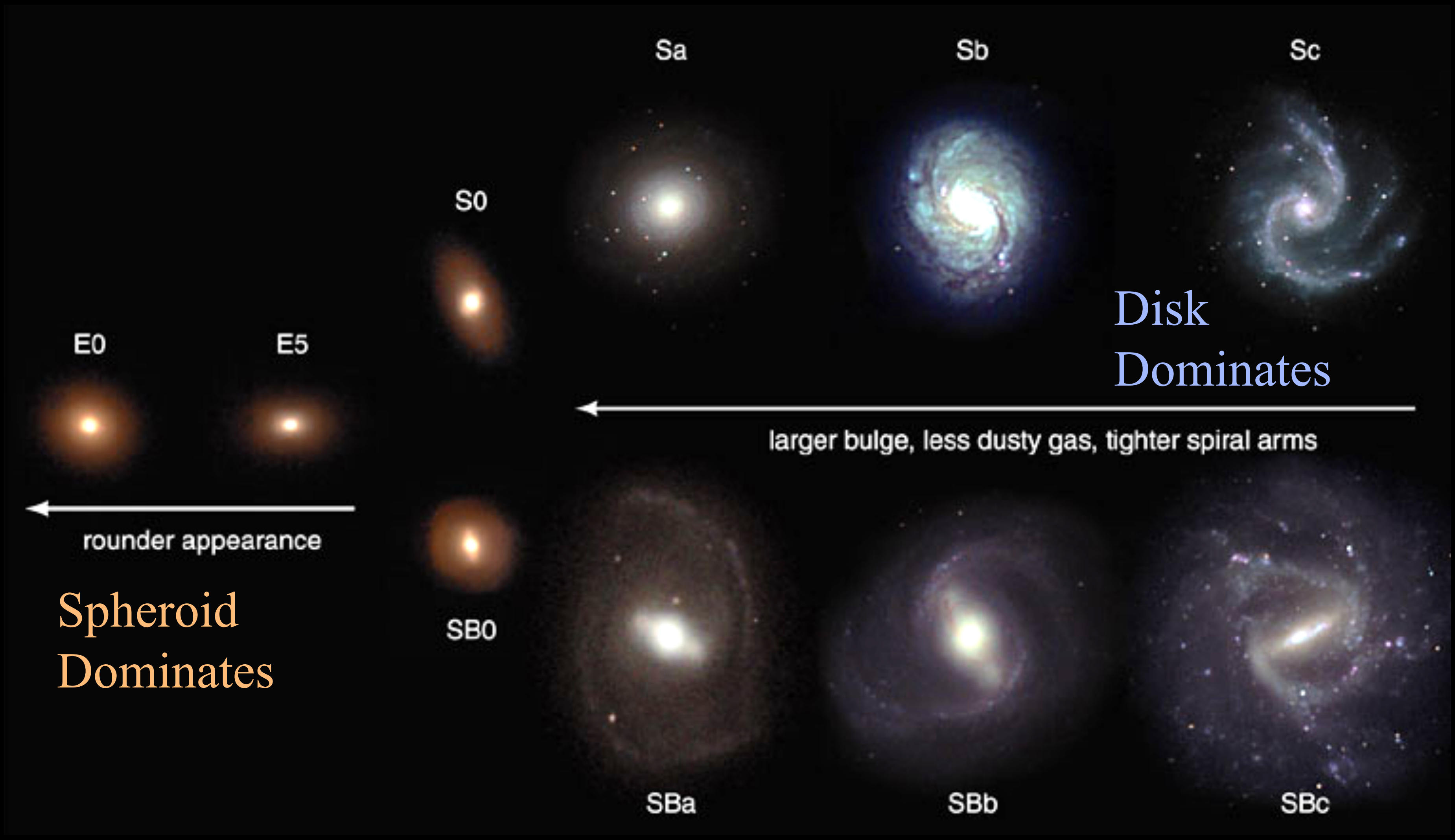
•Has a disk like a spiral galaxy but much less dusty gas
•No discernible arms
•Intermediate between spiral and elliptical)

3. Irregular Galaxy:

Neither spiral nor elliptical

Blue-white color and emission nebulae indicate ongoing star formation.

Hubble's galaxy classes



Disk Dominates

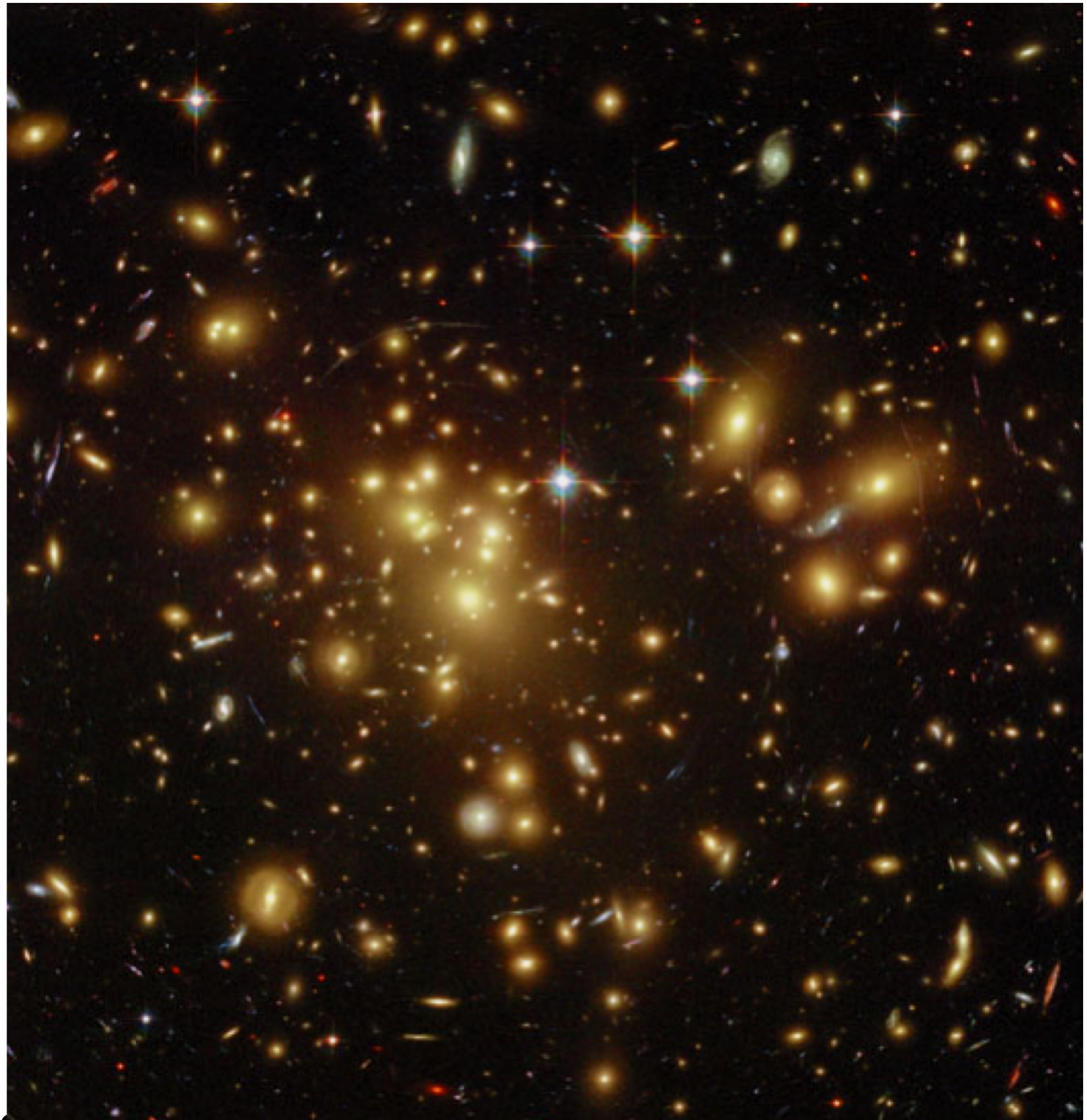
Spheroid Dominates

How are galaxies grouped together?

How are galaxies grouped together?

Spiral galaxies are often found in ***groups*** of galaxies (up to a few dozen galaxies per group).

How are galaxies grouped together?



Elliptical galaxies are much more common in huge ***clusters*** of galaxies (hundreds to thousands of galaxies).

What have we learned?

Begin 3 minute review

What have we learned?

What are the three major types of galaxies?

Spiral galaxies, **elliptical** galaxies, and **irregular** galaxies.

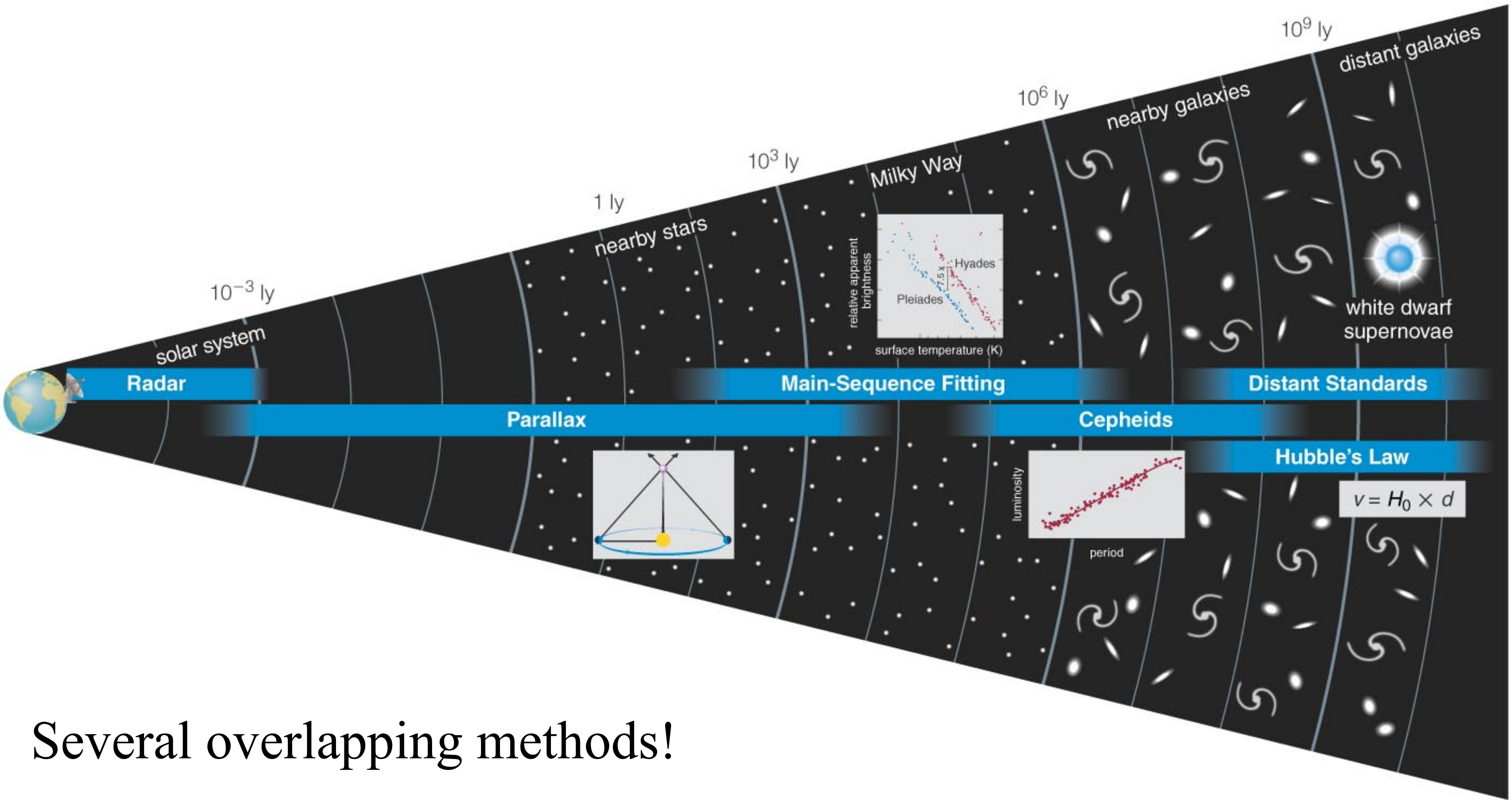
Spirals have both disk and spheroidal components; ellipticals have no disk.

How are galaxies grouped together?

Spiral galaxies tend to collect into **groups** of up to a few dozen galaxies.

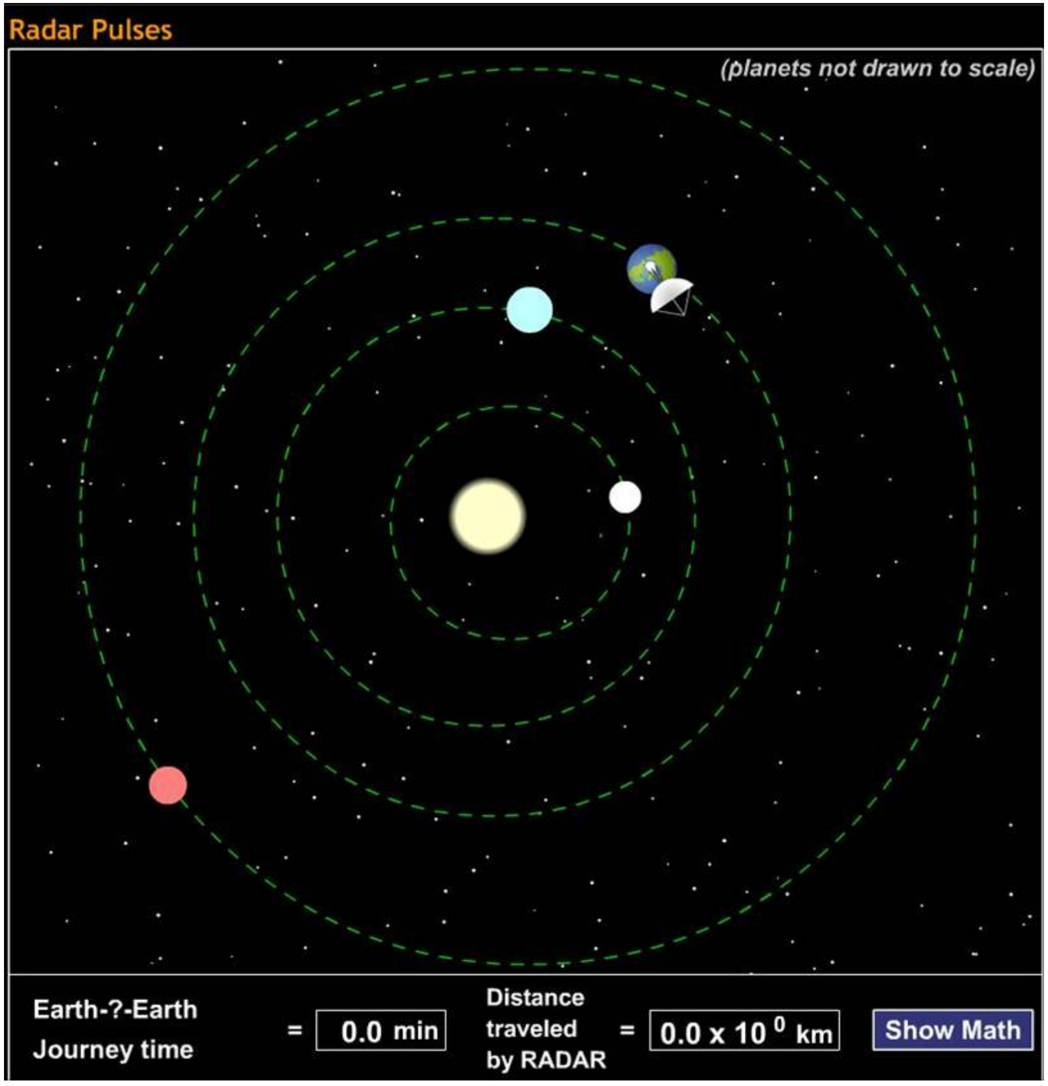
Elliptical galaxies are more common in large **clusters** containing hundreds to thousands of galaxies.

How do we measure **distances** to galaxies?



Several overlapping methods!

Measuring distances

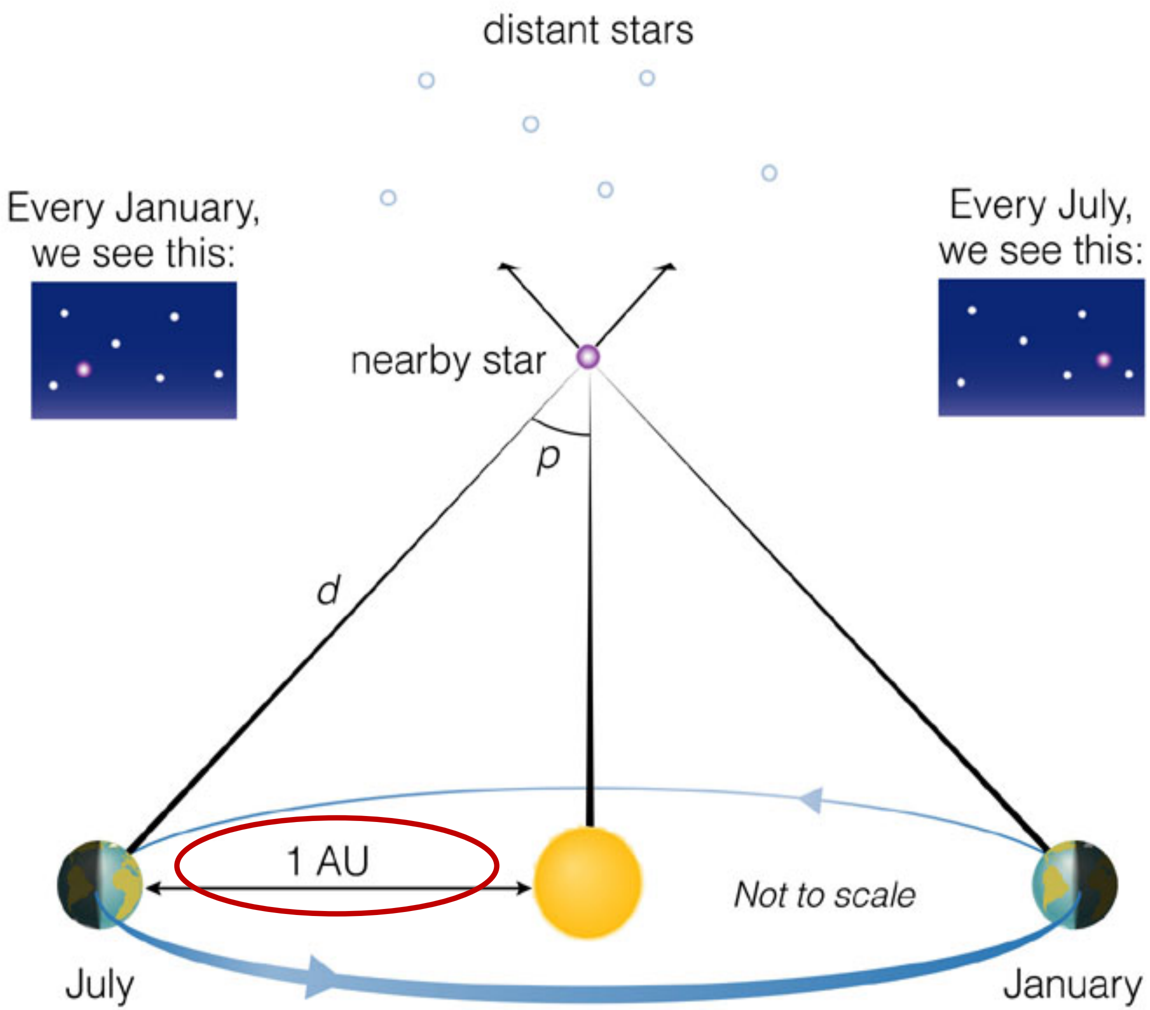


Step 1

Determine size of the AU.

- Transit of planet
- Radar

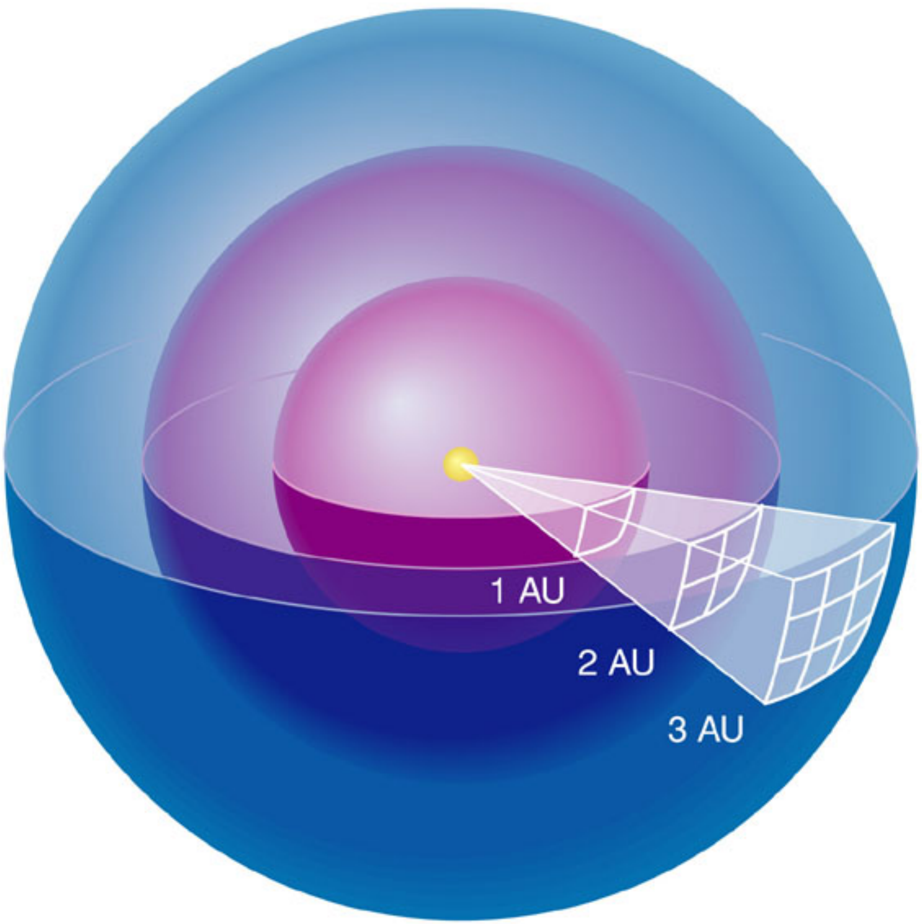
Measuring distances



Step 2

Determine distances of stars out to a few hundred light-years using **parallax** (knowing the AU from our solar system)

Inverse-square law



- Luminosity passing through each sphere is the same

Area of sphere = $4\pi\,(\text{radius})^2$

- Divide luminosity by area to get brightness

- **Inverse square law of light** can give distance

Inverse-square law of light

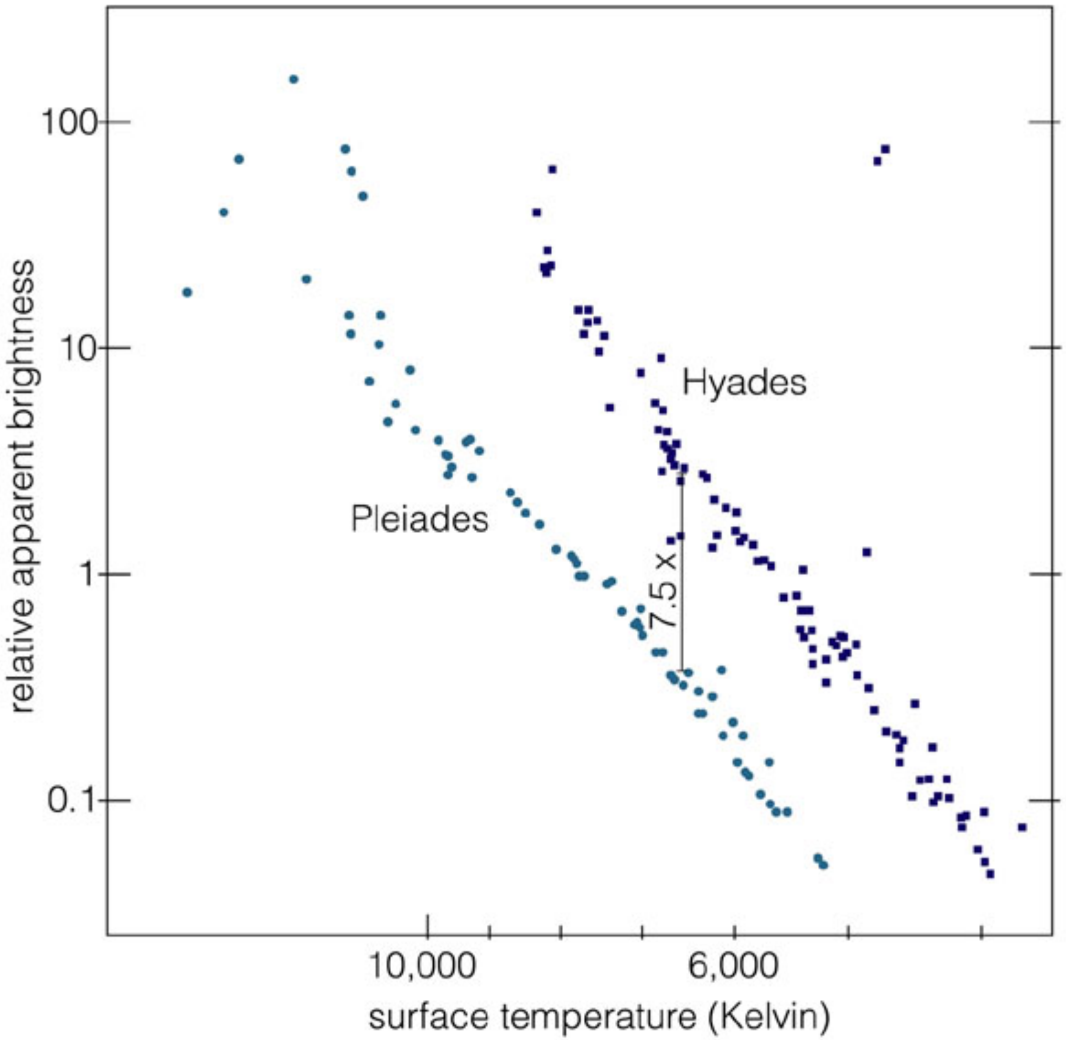
The relationship between apparent brightness and luminosity depends on distance:

$$\text{Brightness} = \frac{\text{Luminosity}}{4\pi\,(\text{distance})^2}$$

We can determine a star's distance if we know its luminosity and can measure its apparent brightness:

$$\textbf{Distance} = \sqrt{\frac{\text{Luminosity}}{4\pi \times \text{Brightness}}}$$

Measuring distances



Step 3

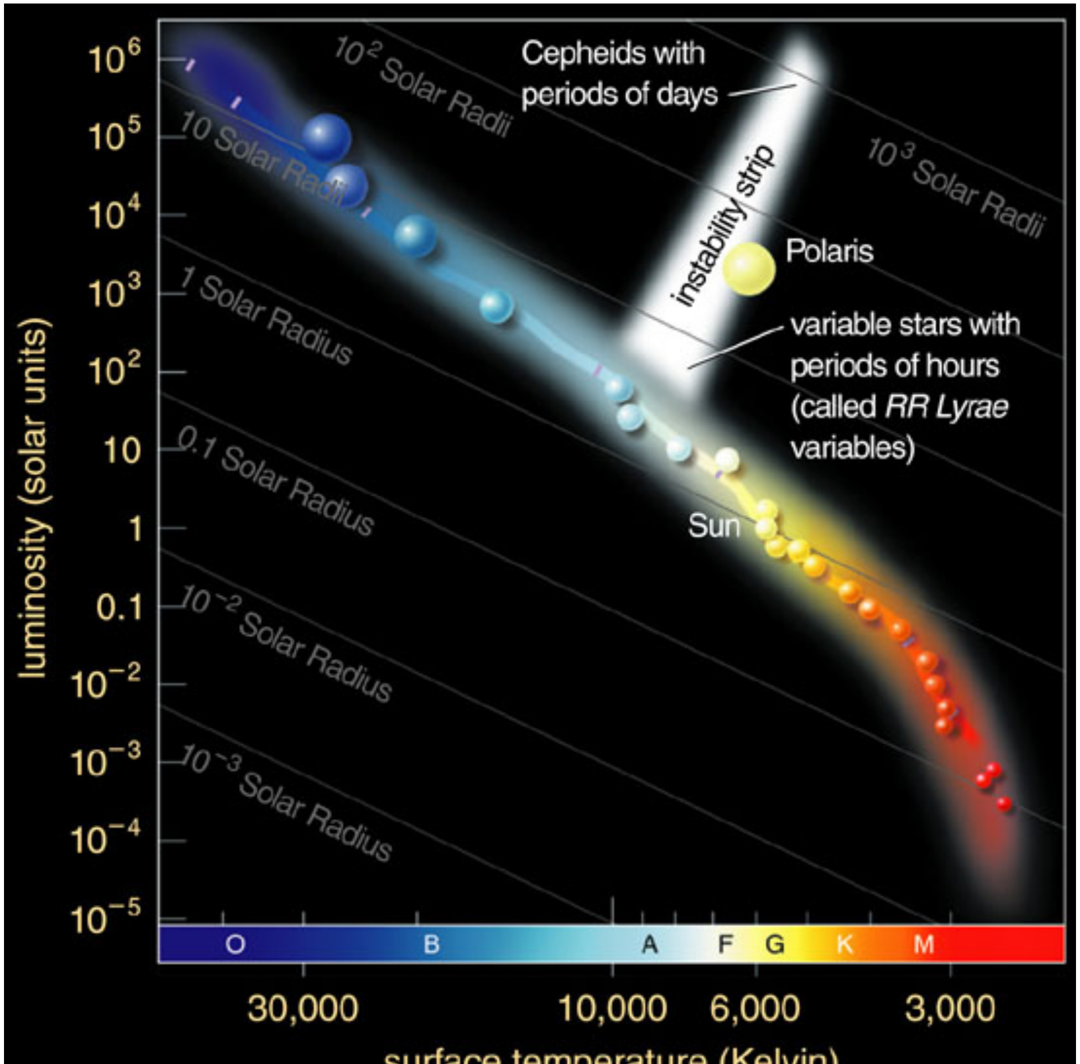
Main sequence fitting:

• *We measure the distance to Hyades cluster with parallax*, plot its MS as standard
• All main sequence stars of a spectral class have same luminosity
• *Apparent* brightness of another star cluster's main sequence tells us its distance: dimmer = more distant!

Measuring distances

Knowing the actual luminosity of stars in a cluster, we can determine its distance using its **apparent brightness** and **inverse-square law**

Standard candles

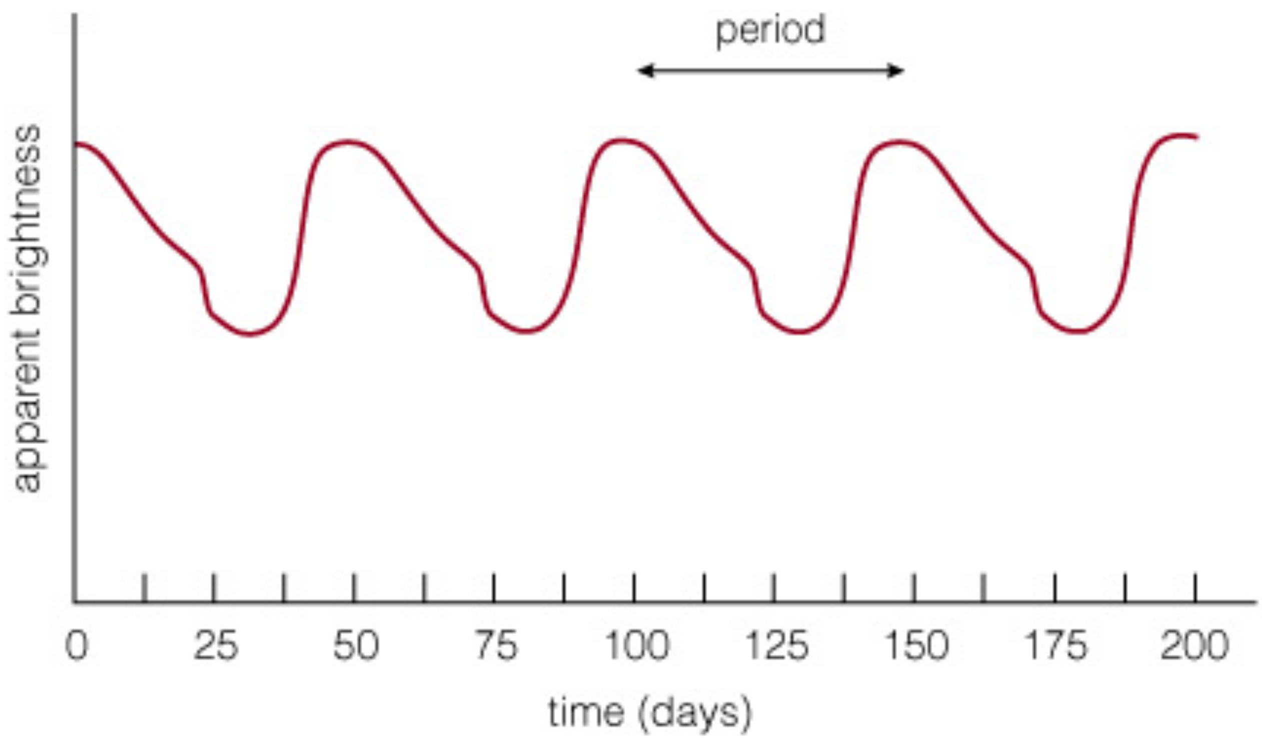


A ***standard candle*** is an object whose luminosity is known and can be used to determine its distance.

Cepheid variable stars

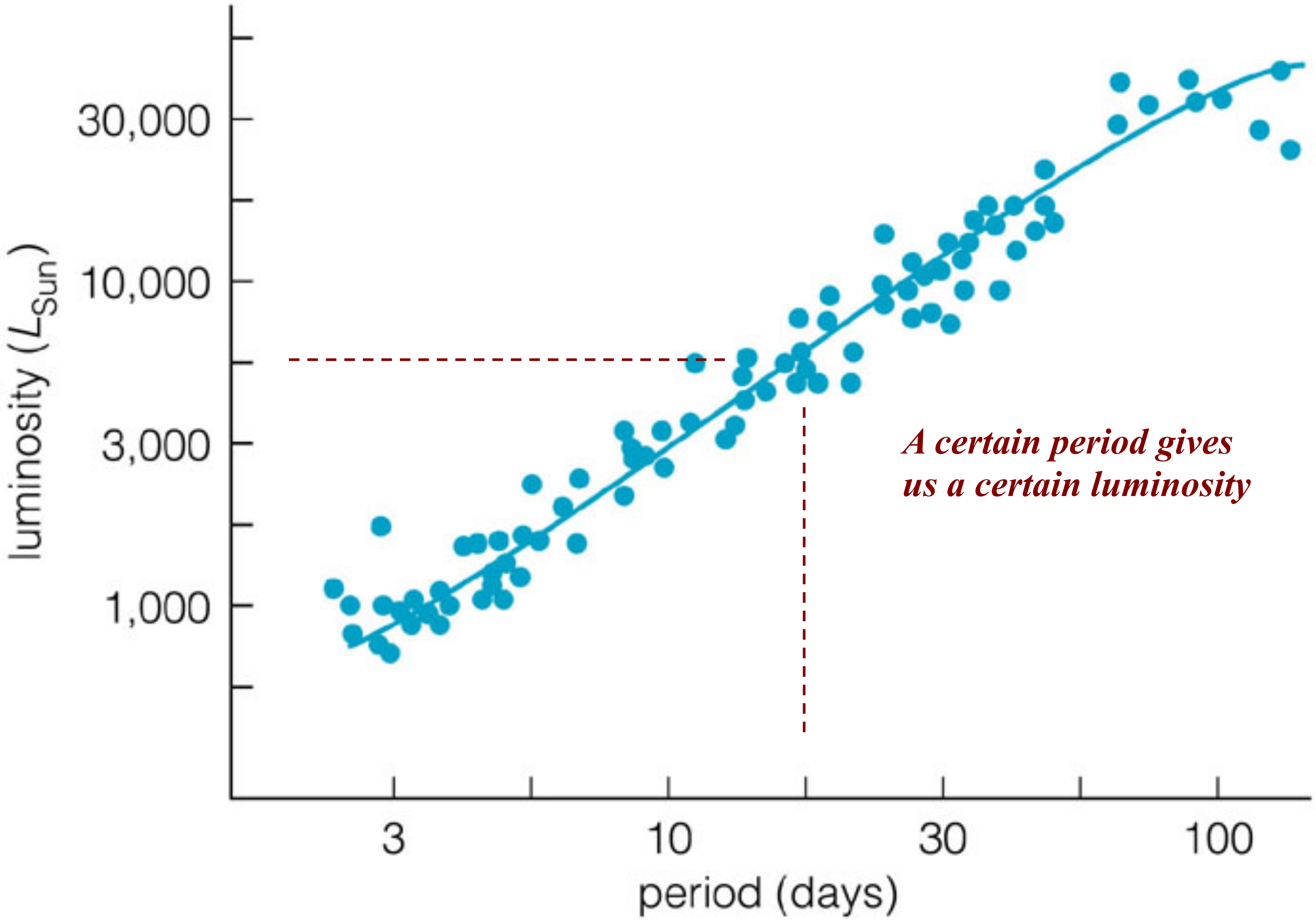
- highly luminous
- can be seen to great distances
- make excellent standard candles

Cepheid Variable Stars



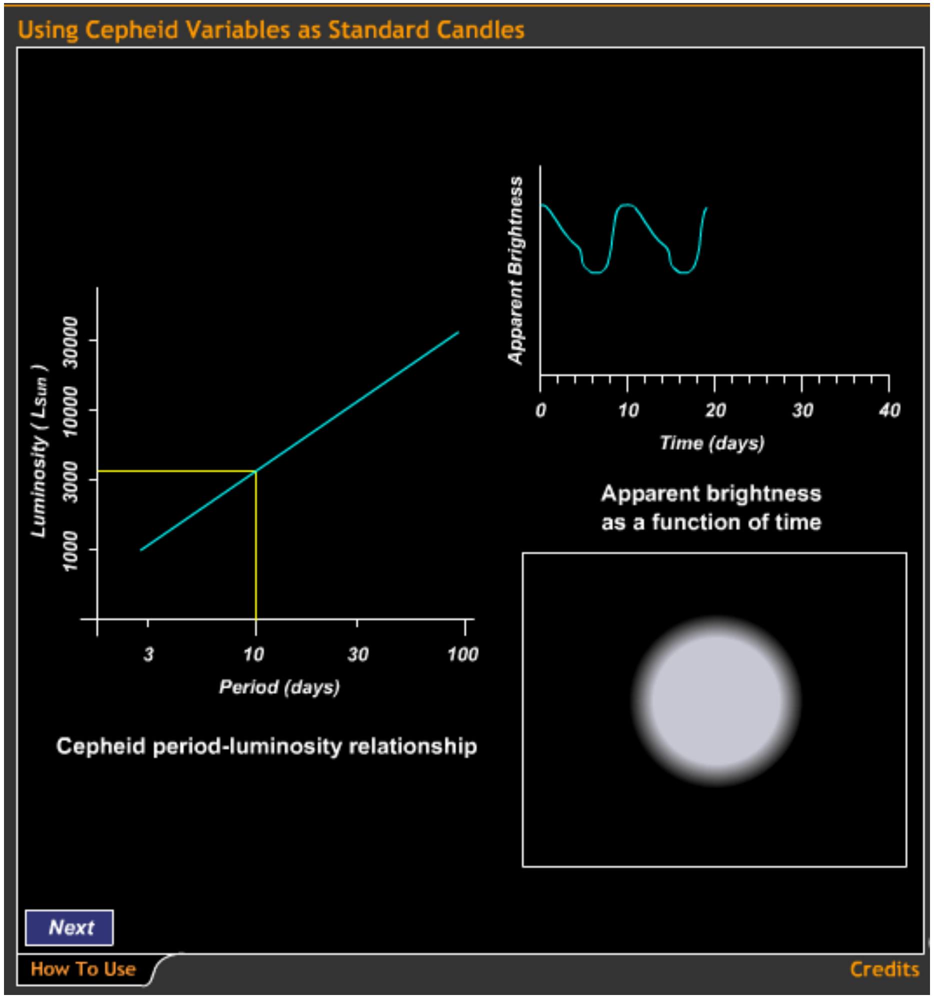
The light curve of this *Cepheid variable star* shows that its brightness alternately rises and falls over a 50-day period.

Period-luminosity relation



Cepheid variable stars with longer periods have greater luminosities.

Period-luminosity relation



Step 4

*Because the period of a **Cepheid variable** star tells us its luminosity,* we can use these stars as standard candles with the inverse square law to determine distance.

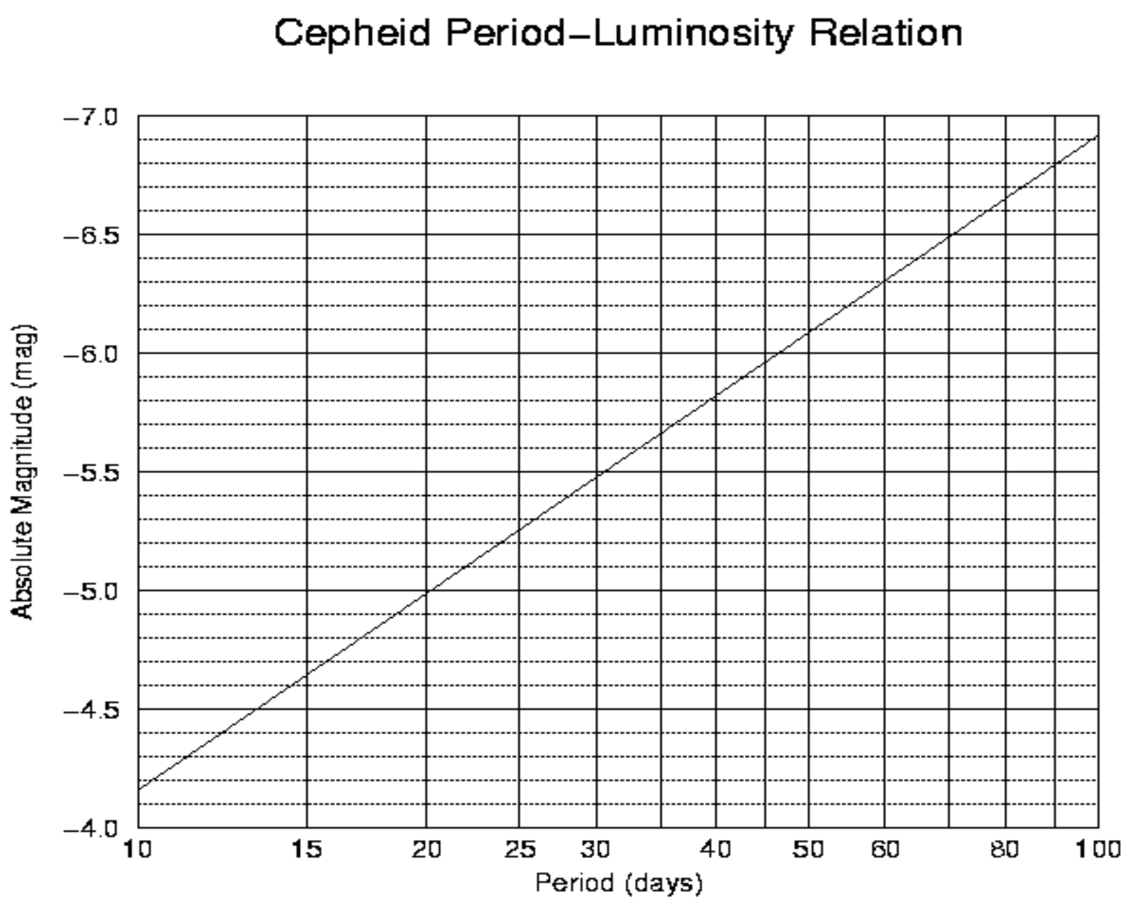
PLAY Using Cepheid Variables as Standard Candles

Measuring Astronomical Distances

We can use the period of a Cepheid to determine its absolute magnitude (M) (**related to luminosity**). The distance to the star can then be calculated using the following formula:

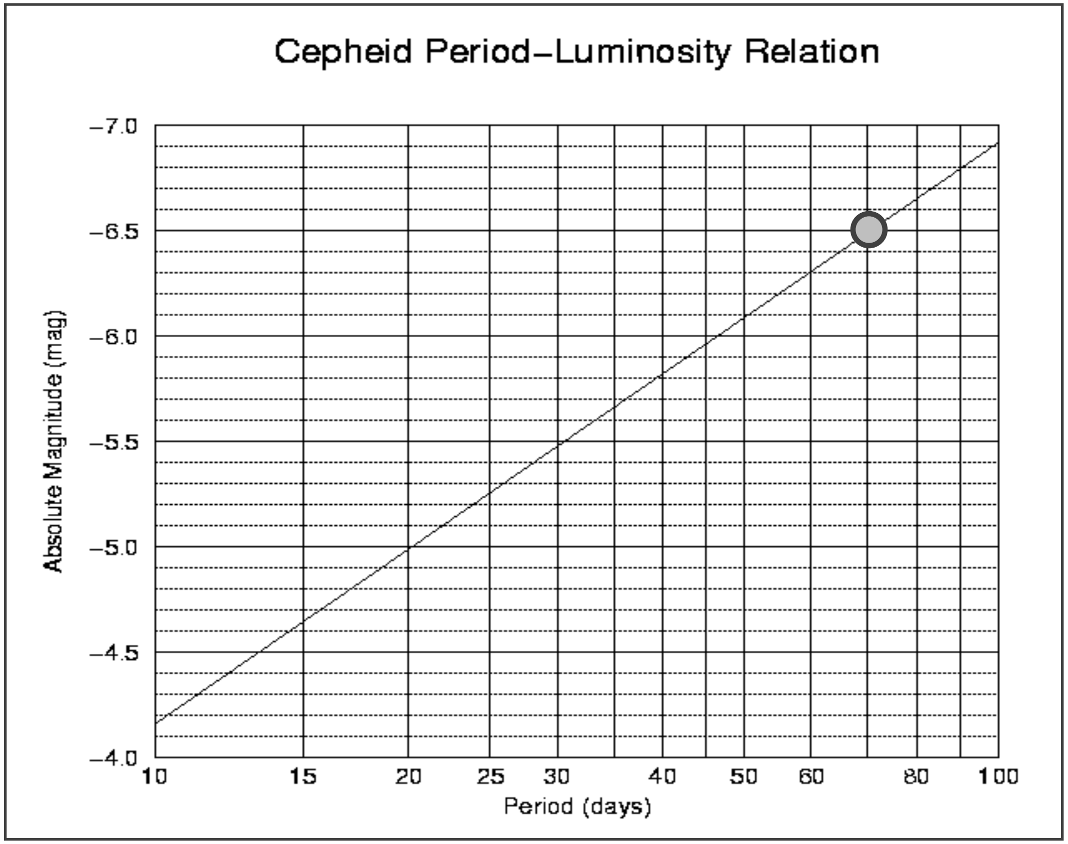
$$\mathbf{d = 10^{[(m-M)+5]/5}}$$

where distance (d) is in pc (1 pc = 3.26 ly), **m** is the apparent magnitude and **M** the absolute magnitude.



Measuring Astronomical Distances

Calculating Cepheid variable distances



1. Measure apparent magnitude m = **18.1**
2. Determine *period* :

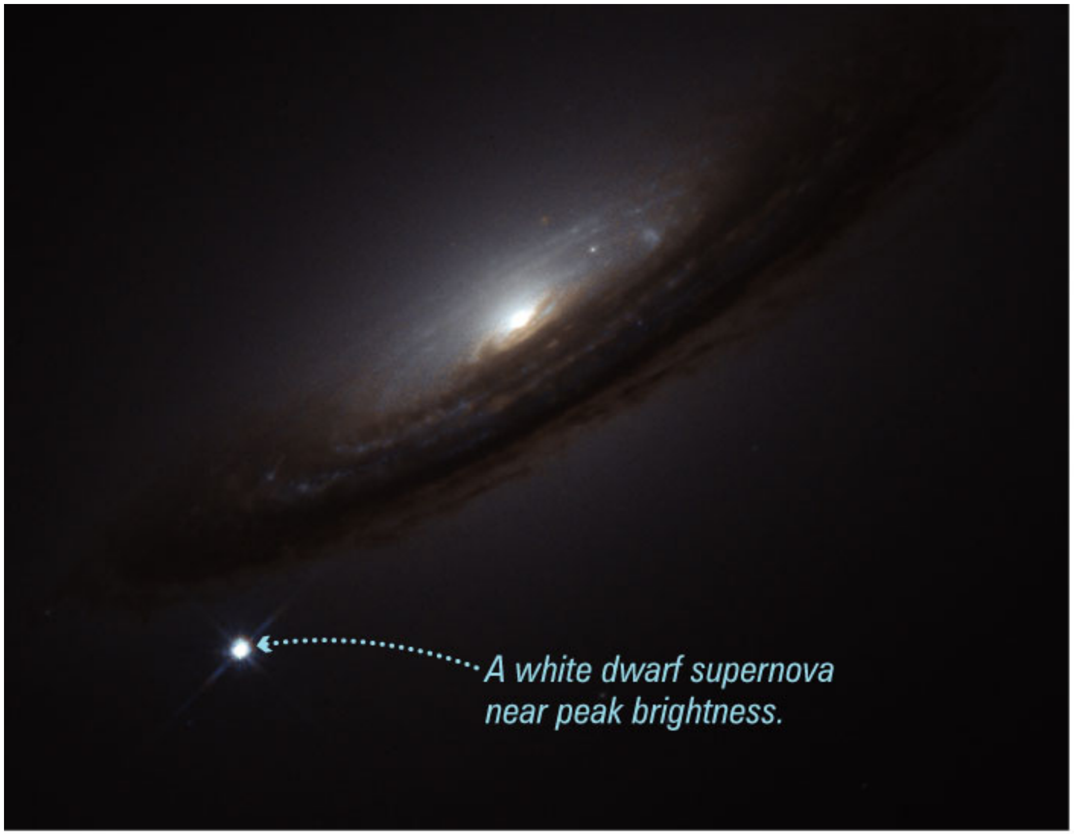
   p = 70 days
3. Find *absolute magnitude* M using chart:

   M = -6.5
4. Calculate *distance modulus* :

   $\Delta m = m - M = 24.6$
5. Determine *distance*:

$$\text{distance} = 10^{[(m-M)+5]/5}$$
$$= 10^{5.92}$$
$$= 835{,}000 \text{ pc}$$

Other standard candles



• White-dwarf supernovae (Type I) can also be used as standard candles.

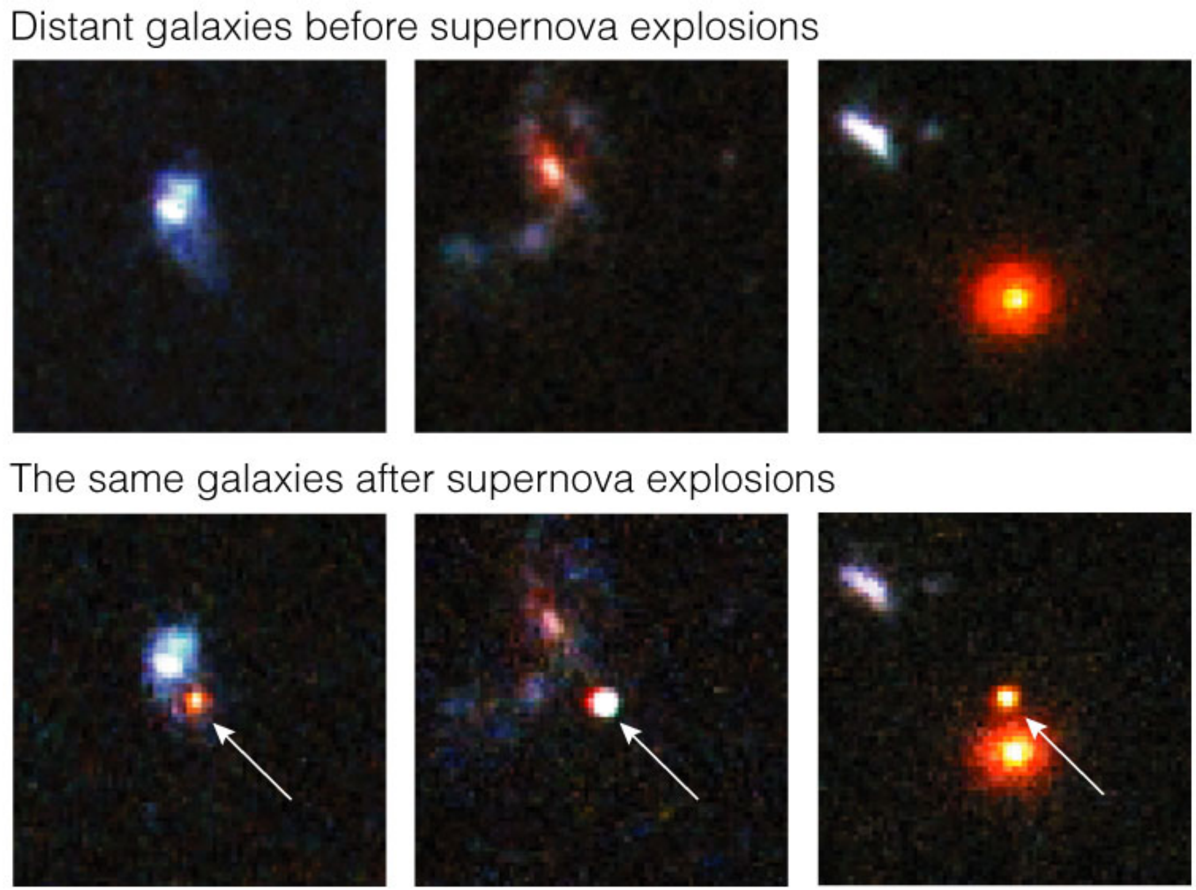
• **All have same luminosity** (10^9 L_{Sun}) - same mass stars exploding in same way

PLAY Using White-Dwarf Supernova as Standard Candles

Type Ia supernovae

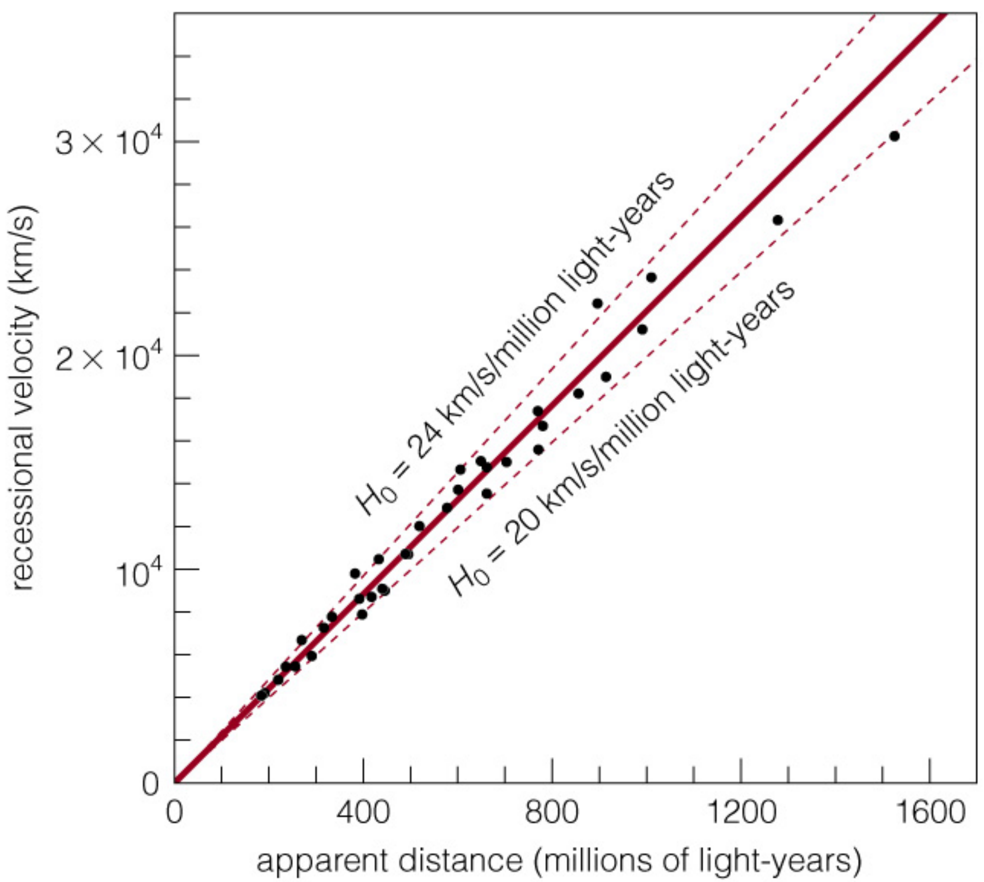
Step 5

Apparent brightness (and inverse square law) of a **white-dwarf supernova** tells us the distance to its galaxy (up to 10 billion light-years).

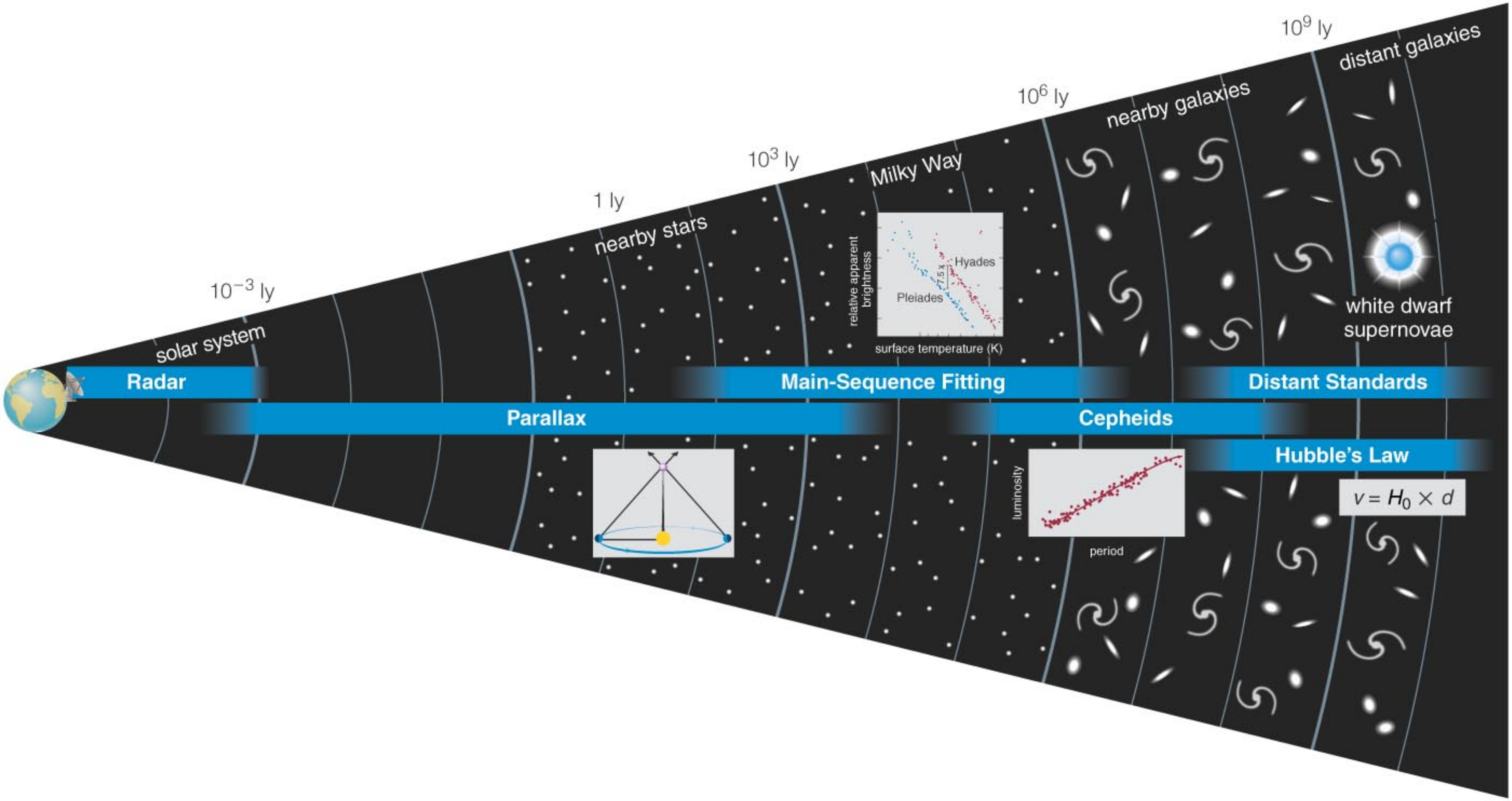


Measuring distances

Hubble's law: H_0 = velocity / distance



We measure galaxy distances using a chain of interdependent techniques.



What have we learned?

Begin 3 minute review

What have we learned?

How do we measure the distances to galaxies?

The distance-measurement chain begins with (1) **measuring the AU** within our solar system.

The distance-measurement chain continues with (2) **parallax** measurements to nearby stars.

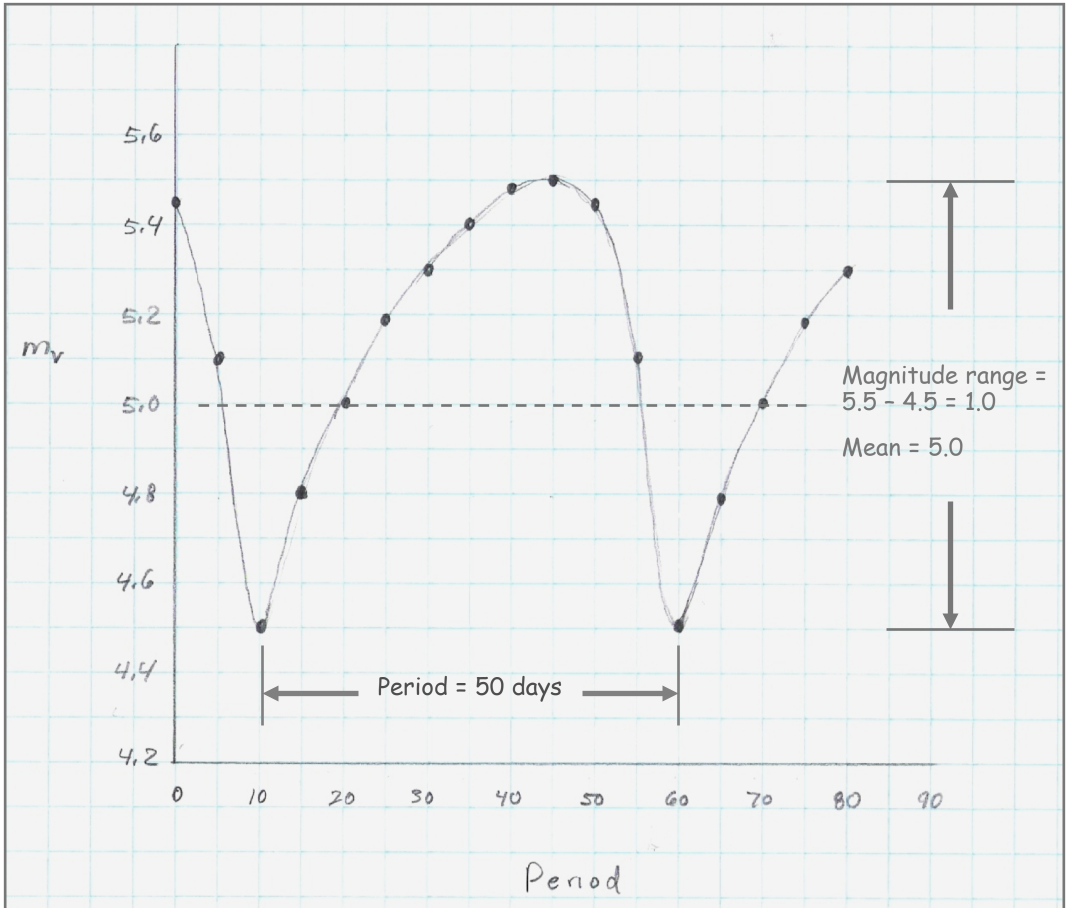
Using parallax and (3) the relationship between luminosity, distance, and brightness, we can find distances to clusters using **main-sequence fitting**.

Knowing stellar distances we can calibrate a series of standard candles such as (4) **Cepheid variables**.

We can measure distances up to 10 billion light-years using (5) **white dwarf supernovae** as standard candles.

Measuring Astronomical Distances

Calculating Cepheid variable distances



1. Plot observed magnitudes over time on graph
2. Determine *period* from graph:

   p = 50 days

3. Determine mean *apparent magnitude* from range:

   m = 5.0

4. Calculate *absolute magnitude* of Cepheid using **formula:**

   M = - 2.8 log (50 days) – 1.43 = **- 6.2**

5. Calculate *distance modulus* :

   Δm = **m – M = 11.2**

6. Determine *distance*:

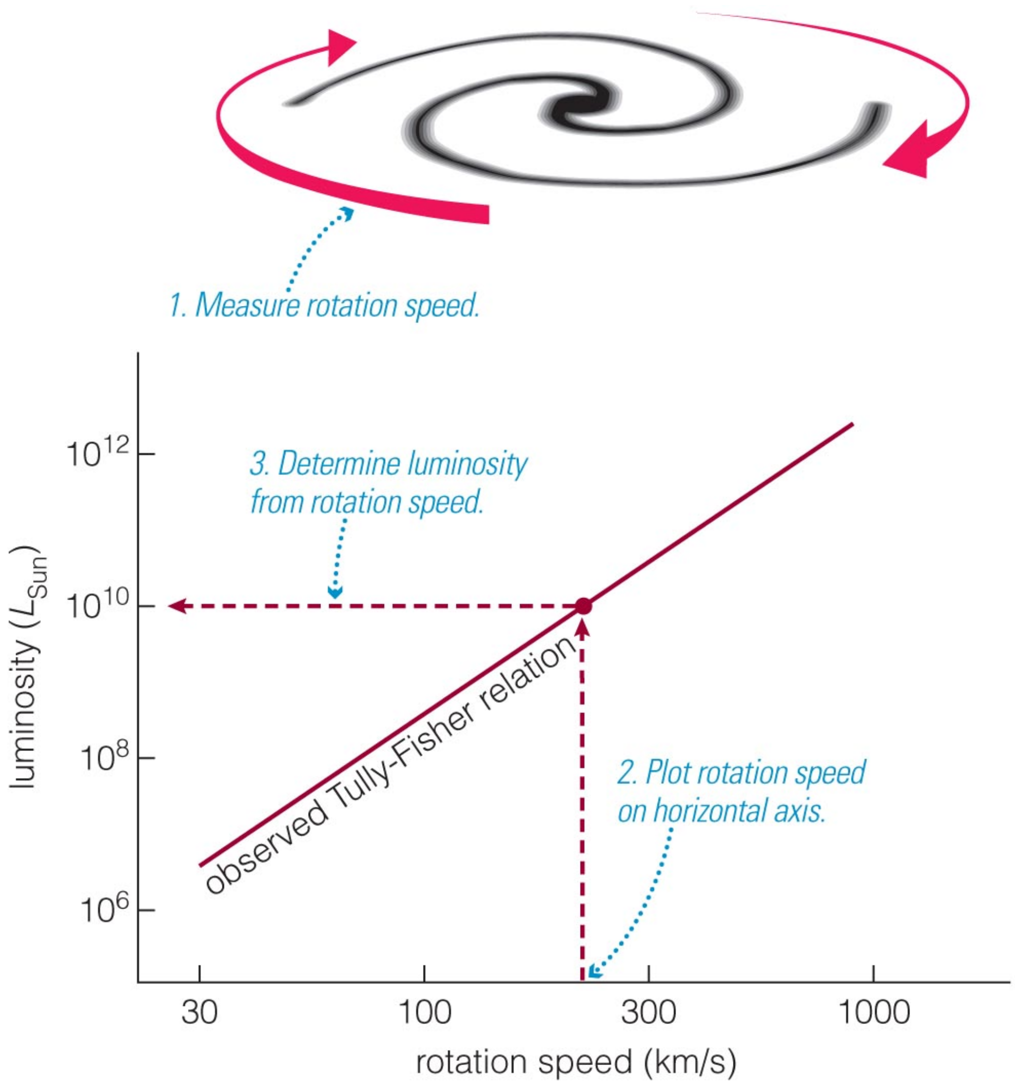
   m – M = 5 log (dist / 10 parsec)

   11.2 / 5 = log (dist / 10 parsec)

   174 = dist / 10 parsec

   1740 parsec = distance

Measuring distances



Tully-Fisher Relation

Entire galaxies can also be used as standard candles because **a galaxy's luminosity is related to its rotation speed.**