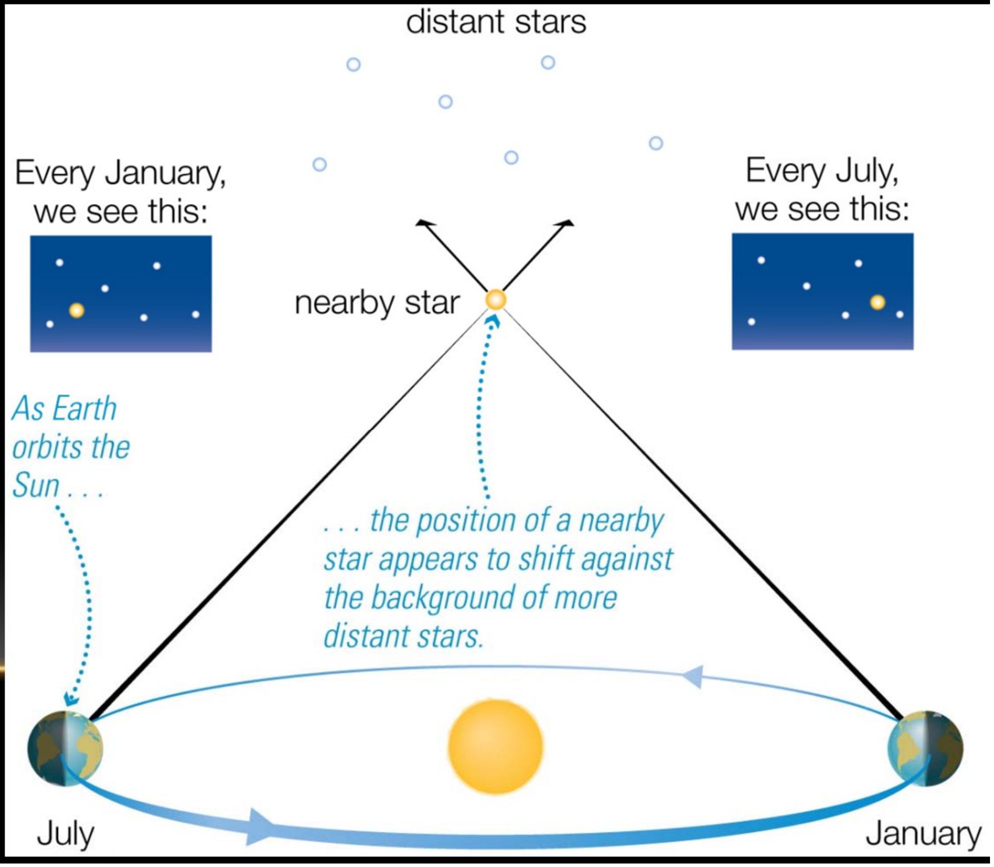
# DISTANCE

PLAY

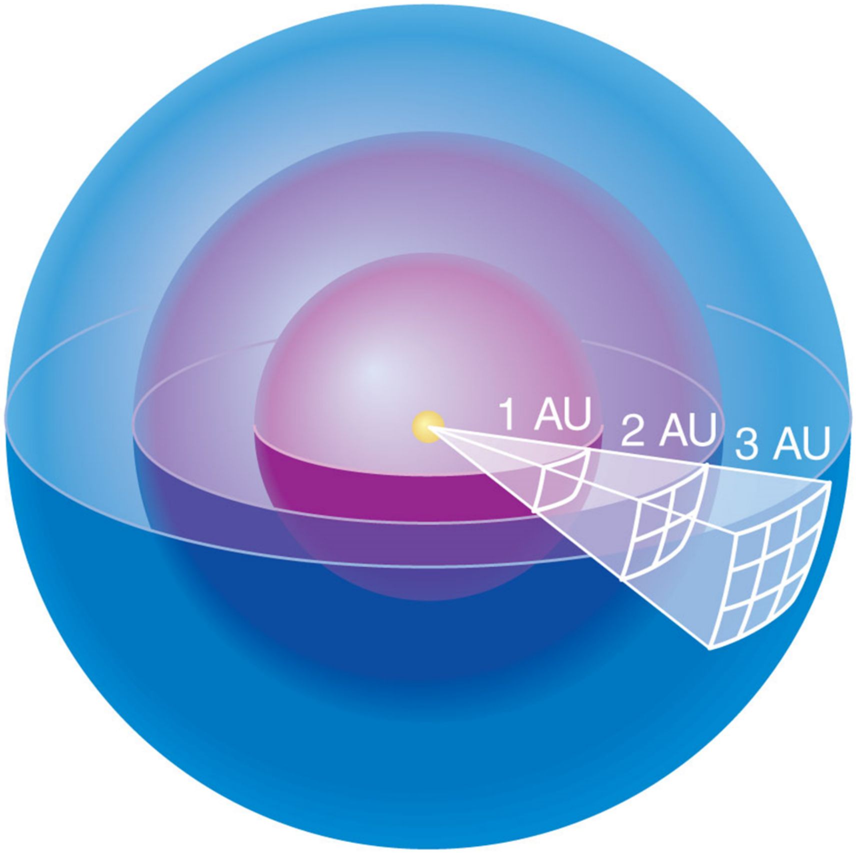
- Can just radar around our solar system PLAY
- With Stars, we saw:
  - Close by: parallax: knowing size of Earth's orbit, compare apparent motion of stars as we orbit



# DISTANCE

- Further out, "spectroscopic parallax" (*ie*, how luminous is that star's spectral type really compared to what we see)

$$\text{Brightness} = \frac{\text{Luminosity}}{4 \pi r^2}$$



# MAIN SEQUENCE FITTING

- Same idea, with a whole cluster of stars at a time

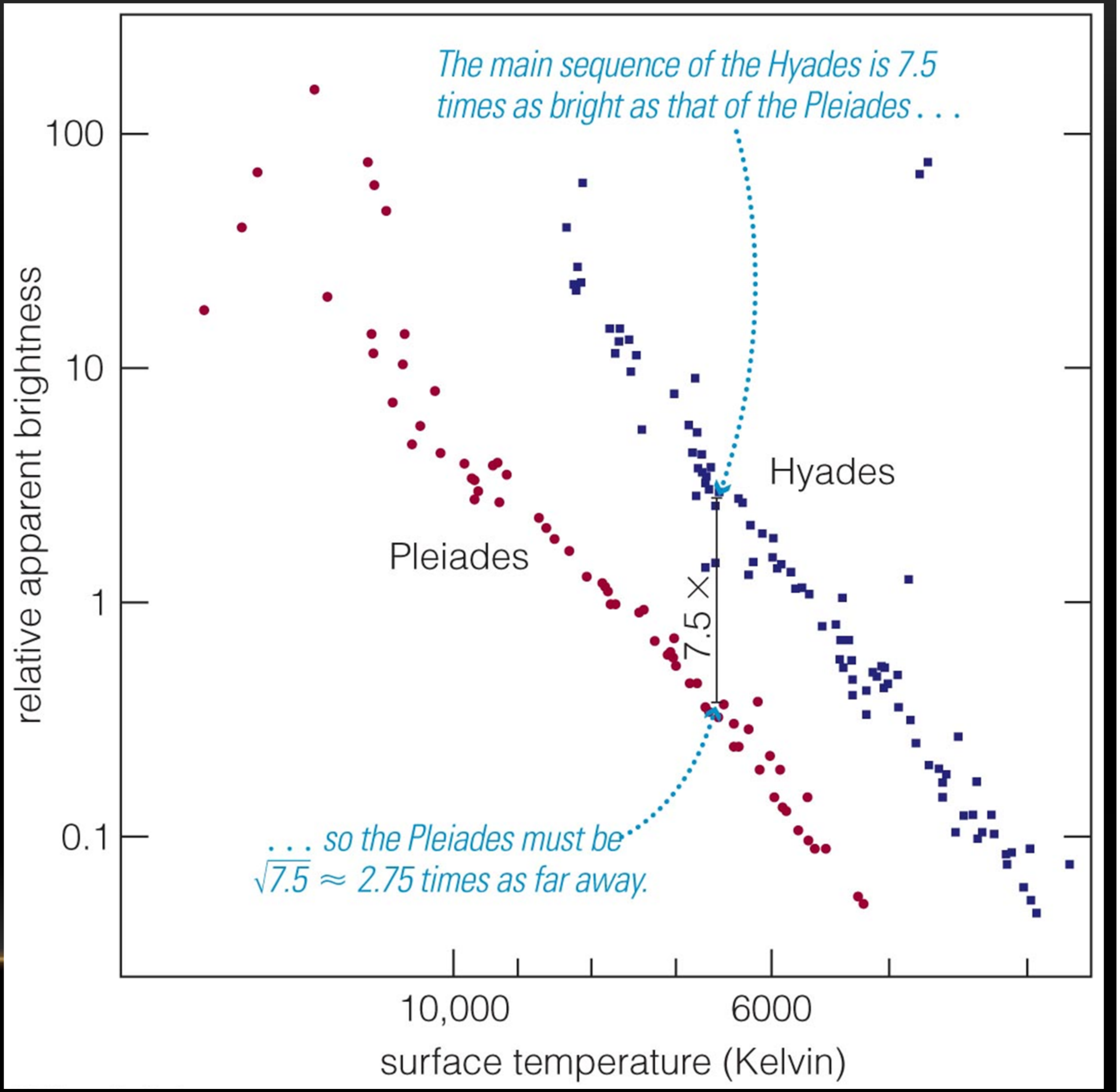



Fig.16.10

# STANDARD CANDLES

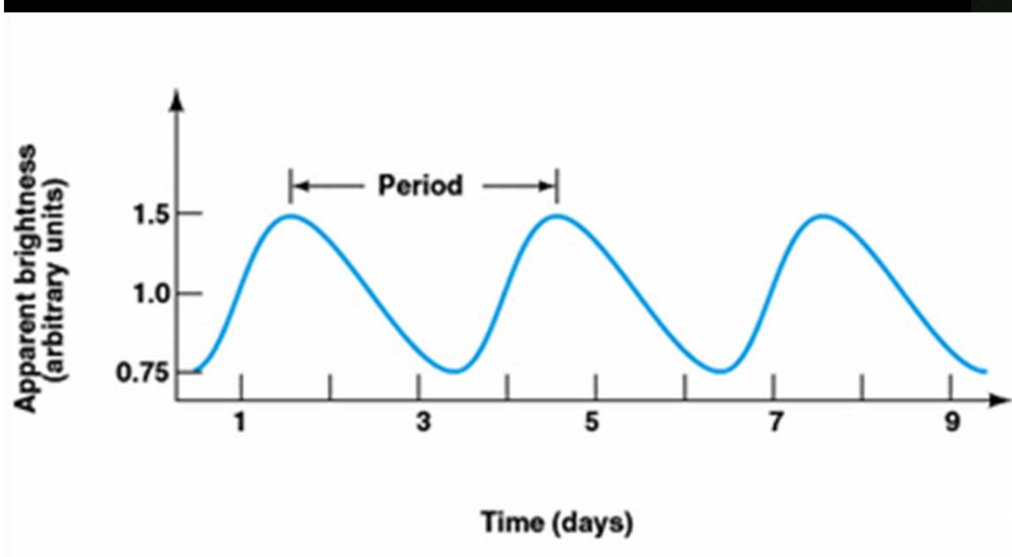
- Much of Distance Finding involves finding things that we know how luminous they really are
  - So we can play that $1/4\pi r^2$ game to calculate how far away they are based on how bright they appear to us
- Like “what’s the luminosity of that spectral type of star” or “that whole main sequence is 7.5 times too dim”

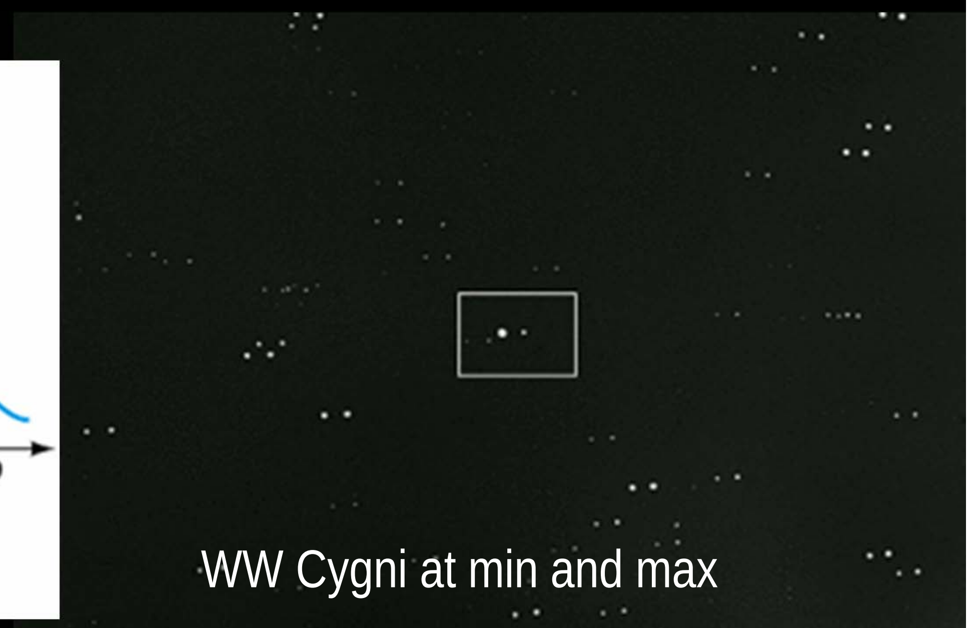
# VARIABLE STARS

- A Variable Star is one which changes its brightness
  - Most stars (including the Sun) do this to one degree or another
- Algol was such a star
  - An Eclipsing Variable
  - Changes caused by one star occulting the other
- Other stars vary by changing their size
  - Radius pulsates in and out as measured via the Doppler effect

# CEPHEID VARIABLES

- Named after the first such star identified, δ Cephei
- Bright, pulsating supergiant stars
- All have a "light curve" which looks something like this:

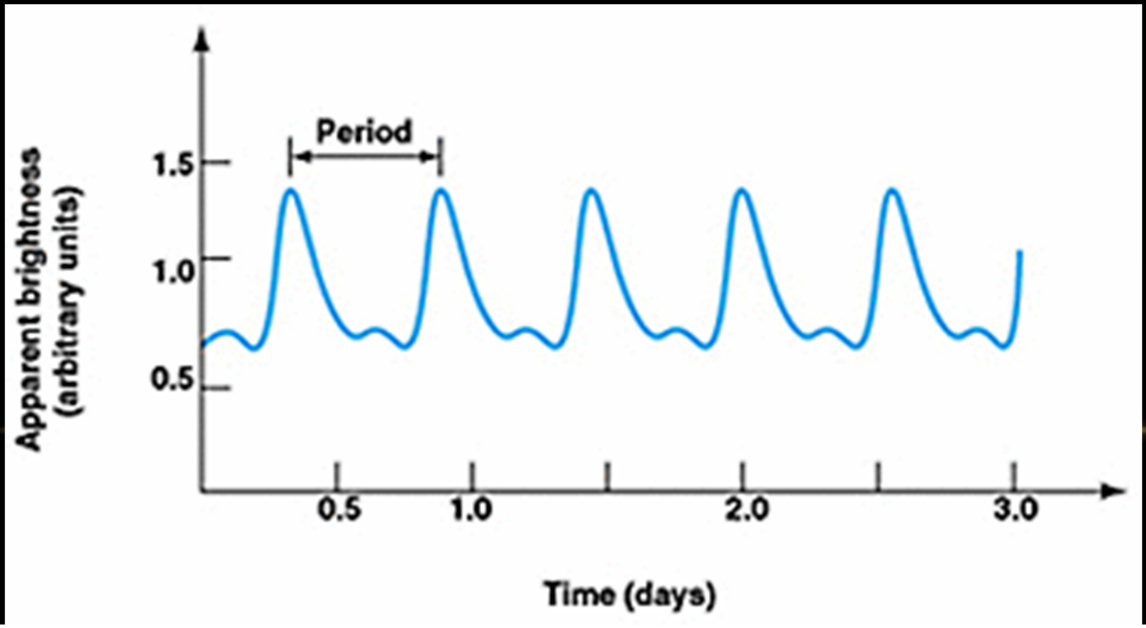


WW Cygni at min and max

# RR LYRAE STARS

- Named after the the star RR Lyrae
- A bright, pulsating giant star
- They have a regular, repeating light curve too:



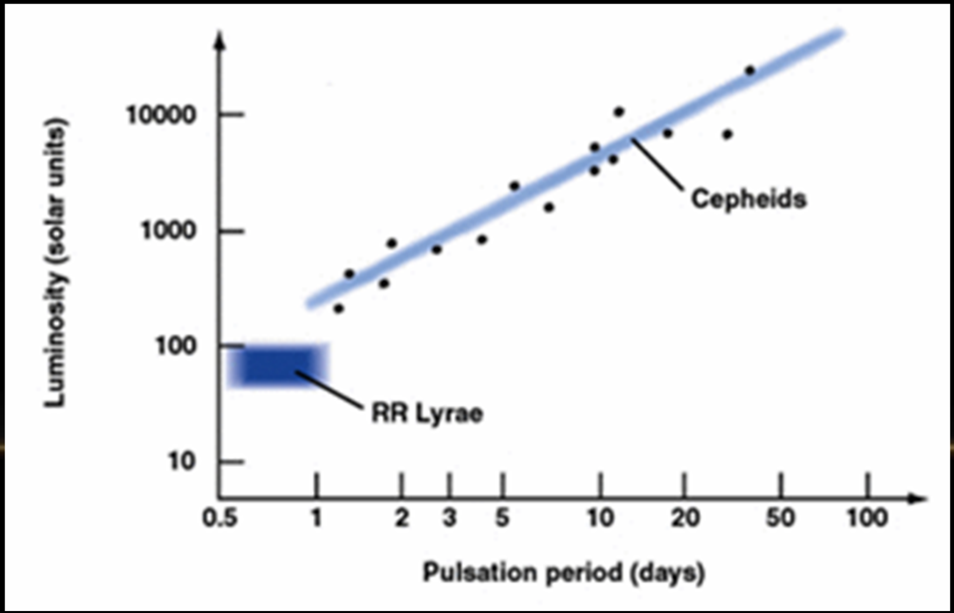
# MAGELLENIC CEPHEIDS

- The Magellenic Clouds are small galaxies near to us
  - So the stars in them are all about the same distance from us
- In 1912, Henrietta Leavitt noticed that the 25 Cepheid variables she found there had periods related to their brightness
  - Longer periods, brighter stars

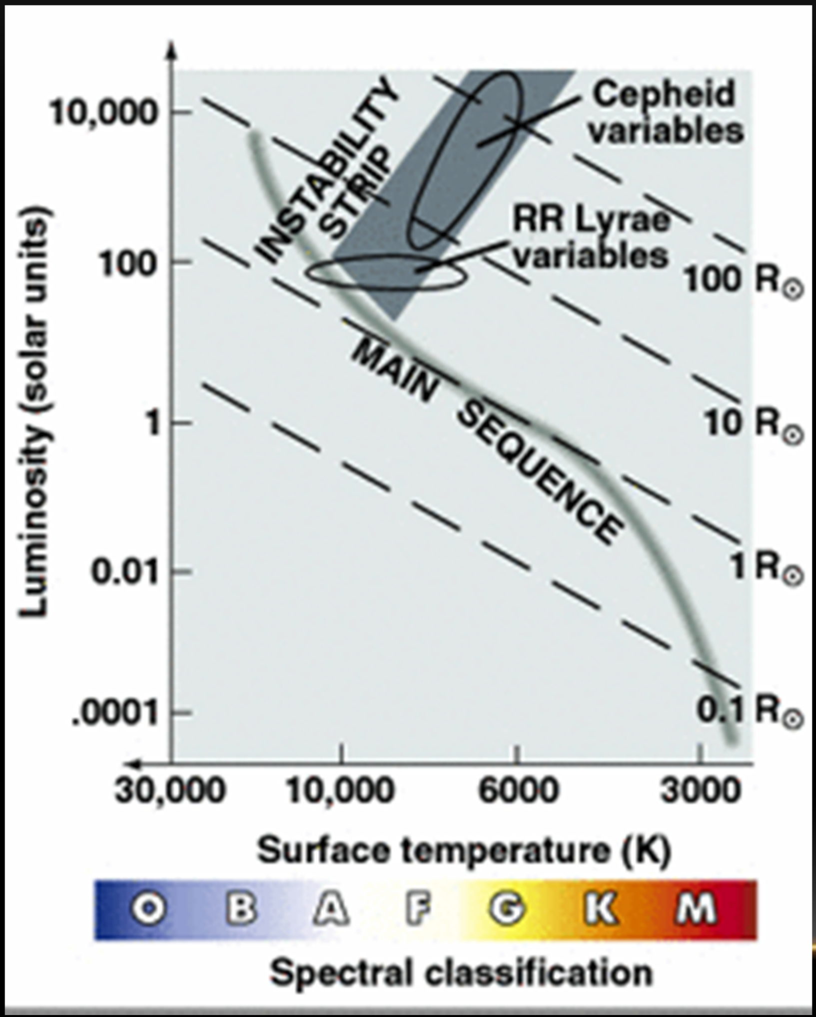
# PERIOD-LUMINOSITY RELATION

- Since all these stars were about the same distance, that meant that long period Cepheids have a higher Luminosity
- So, find a Cepheid, measure its period, learn its real Luminosity
- Then, see how dim it appears to us – calculate distance!

(RR Lyrae work in a similar way)



# INSTABILITY STRIP

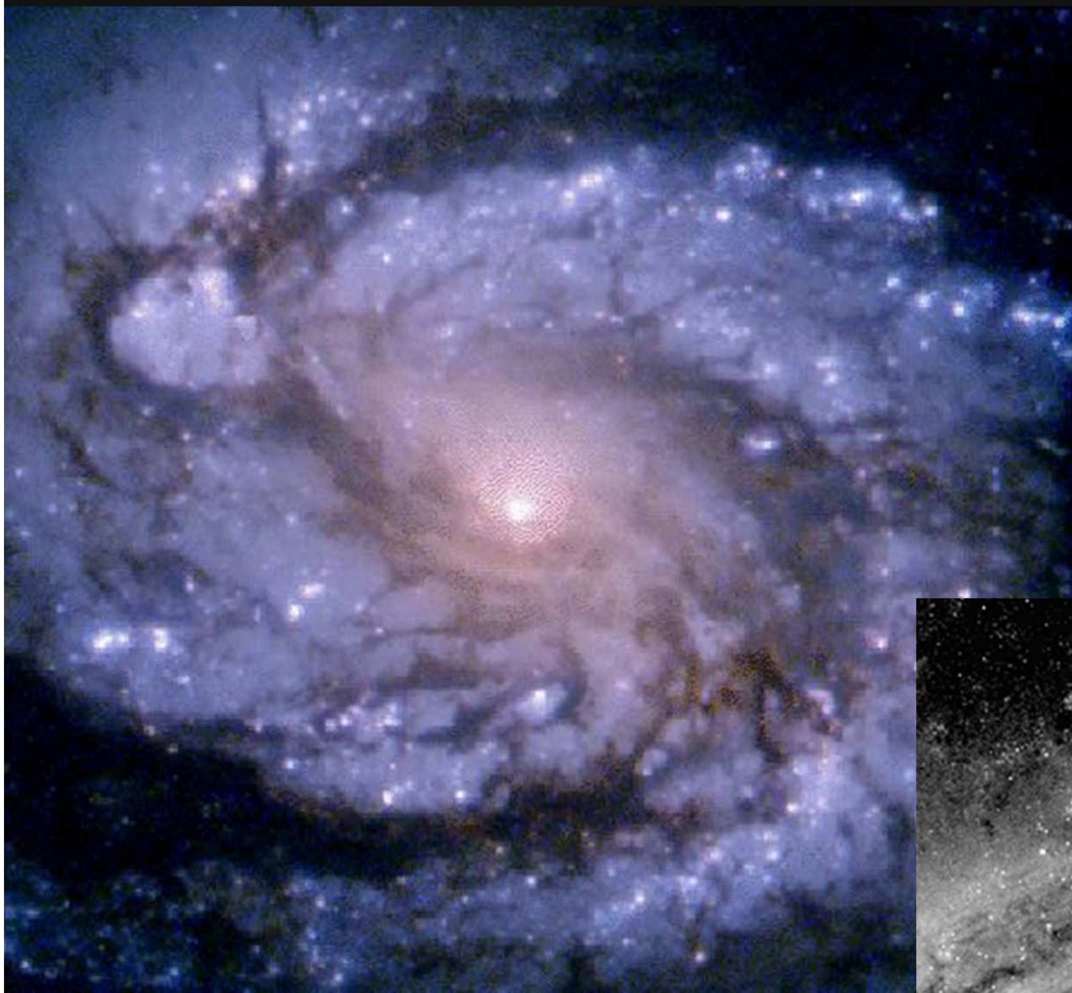



- When located on the HR Diagram, these stars are in a similar place
  - Called the “Instability Strip” since stars there are busy pulsing
- These stars are extremely useful to find distances
  - Bright, can see from far away
  - Measure period, learn their distance!

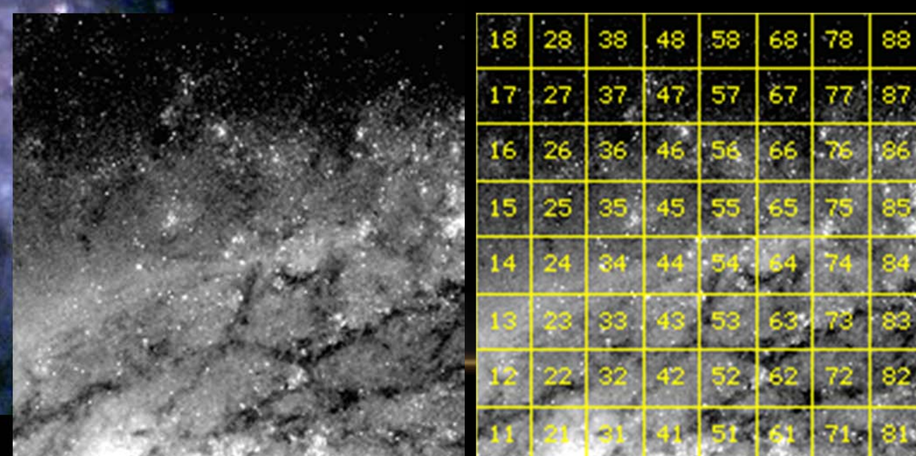
# LONGER DISTANCES

- For nearby (< 200 million ly) galaxies, we can pick out individual Cepheids
- Use period-luminosity relation and apparent magnitude to calculate distance
- Study these galaxies carefully, find out absolute magnitudes of other bright things

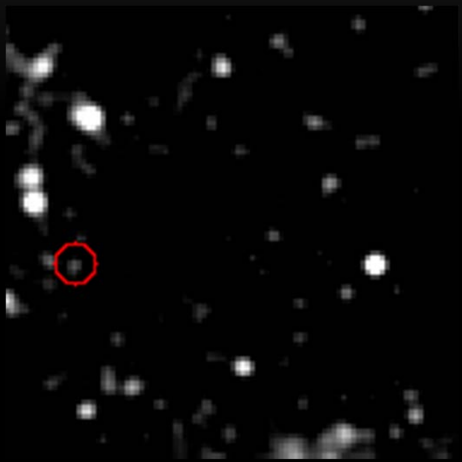
# DETERMINING THE DISTANCE

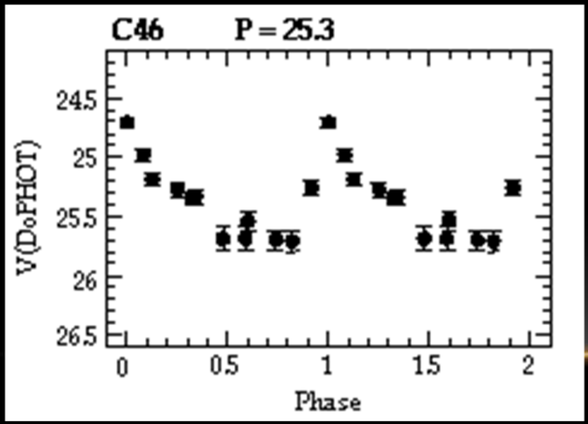


- M100 is a spiral galaxy
- Take a closeup, divide it into sections



# FIND THE CEPHEIDS






- Compare pictures from many nights
- Look for variable stars, plot their light curves
- Identify Cepheids from shape of curve
- Measure period, learn Luminosity, calculate distance

PLAY

# OTHER STANDARD CANDLES

- Things like planetary nebulae, novae, bright O and B stars, globular clusters are measured when nearby
- Compare absolute magnitudes of such objects at known distances with apparent magnitudes of similar things at unknown distances
- Find the distance to the host galaxy

# FARTHER AWAY

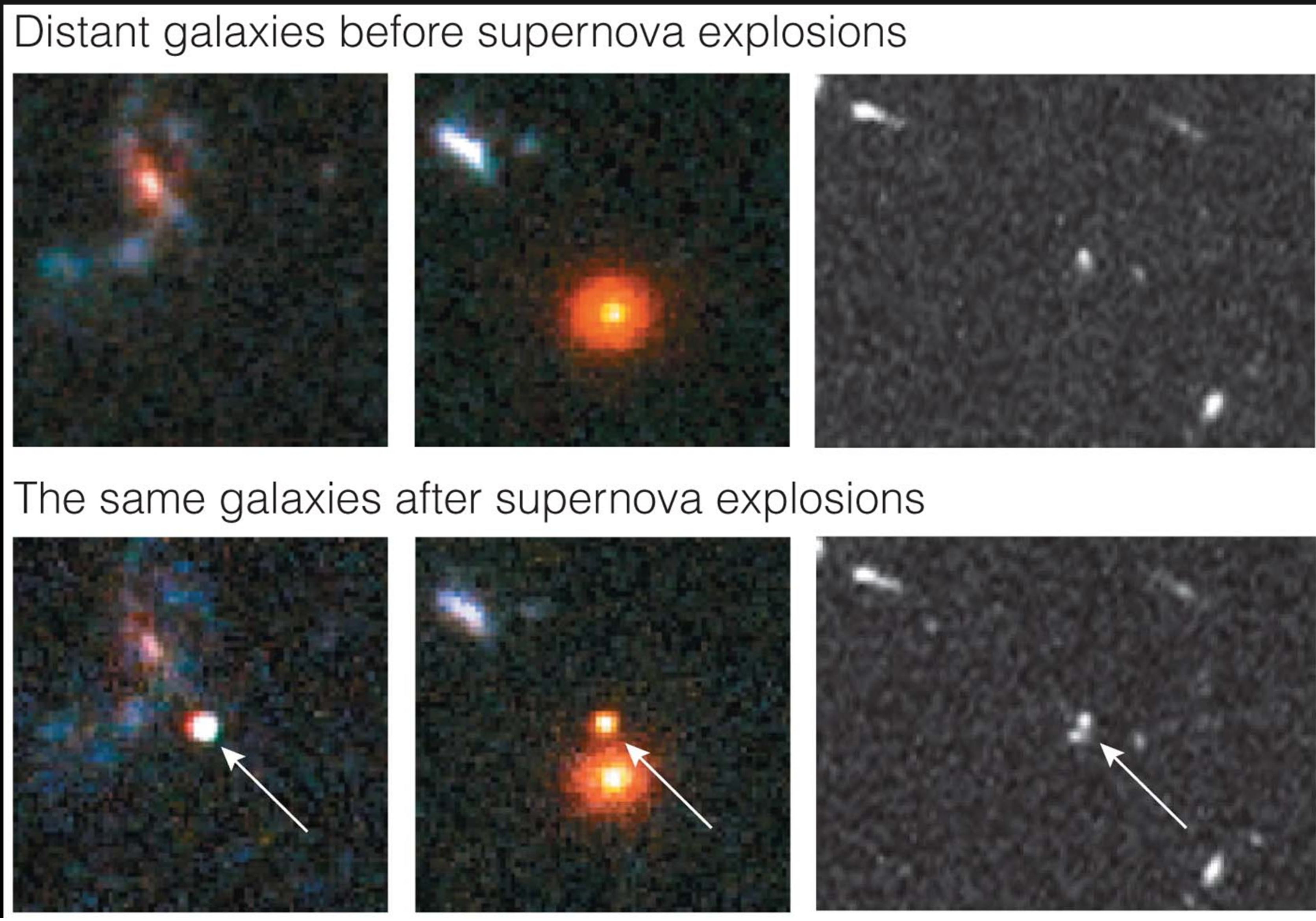
- Use the galaxies themselves!
- For example, we know how bright Sb galaxies are if close by
- Compare to how bright further ones seem, calculate the unknown distance
  - Care must be taken to choose really similarly shaped galaxies! *(this doesn't work as well as "Spectroscopic Parallax" does for stars*)
- Tully-Fisher relation
  - Spiral galaxy rotation speeds are proportional to their brightness: more mass, more speed, more brightness
  - Measure rotation speed, you have an idea of how bright it should be

# REALLY FAR AWAY

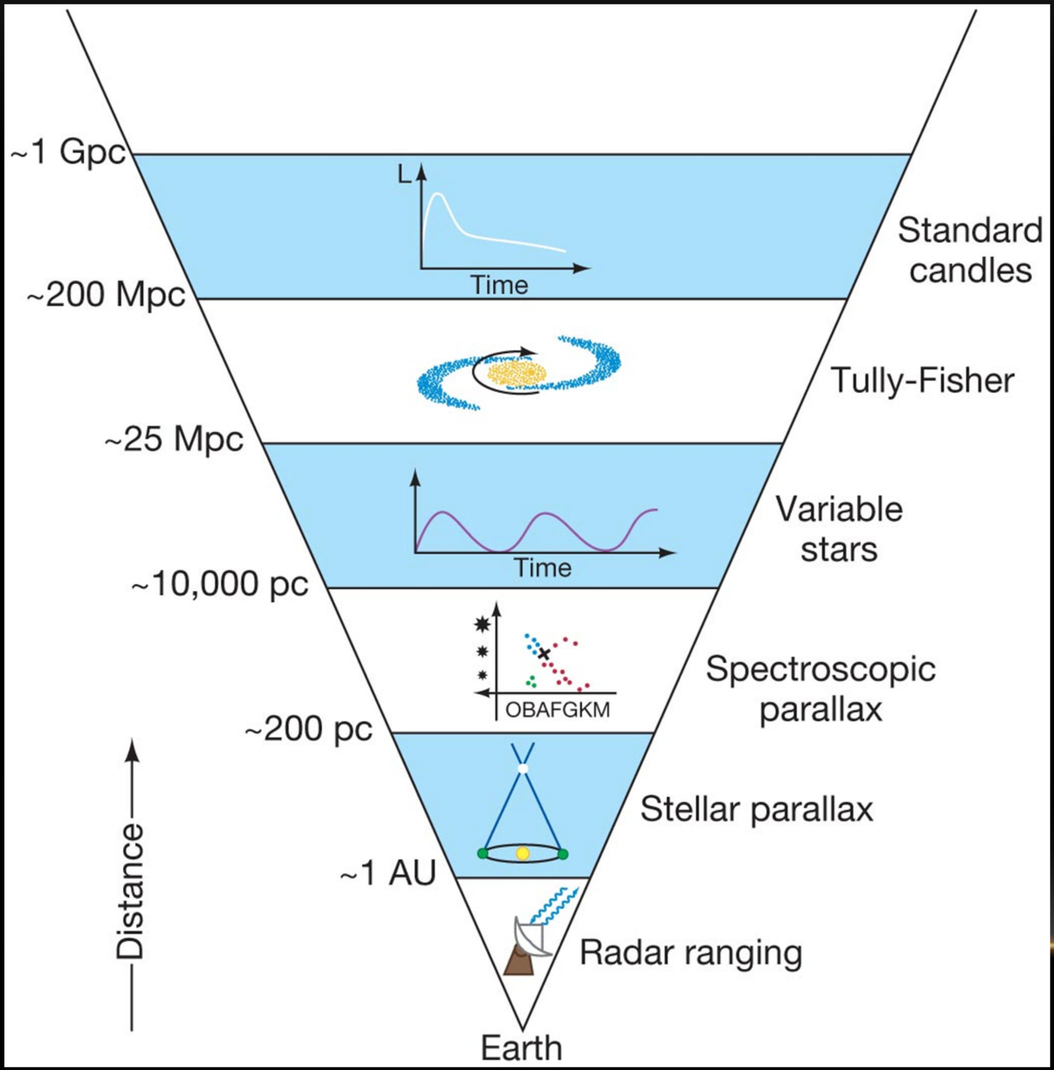
- SN Ia can be seen to the edge of the observable universe
  - If one happens in a galaxy we can calculate the distance
  - All SN Ia have a similar absolute luminosity: they are all white dwarfs getting the last straw that broke the 1.4 $M_{\odot}$ camel's back

# REALLY FAR AWAY

Fig.16.13

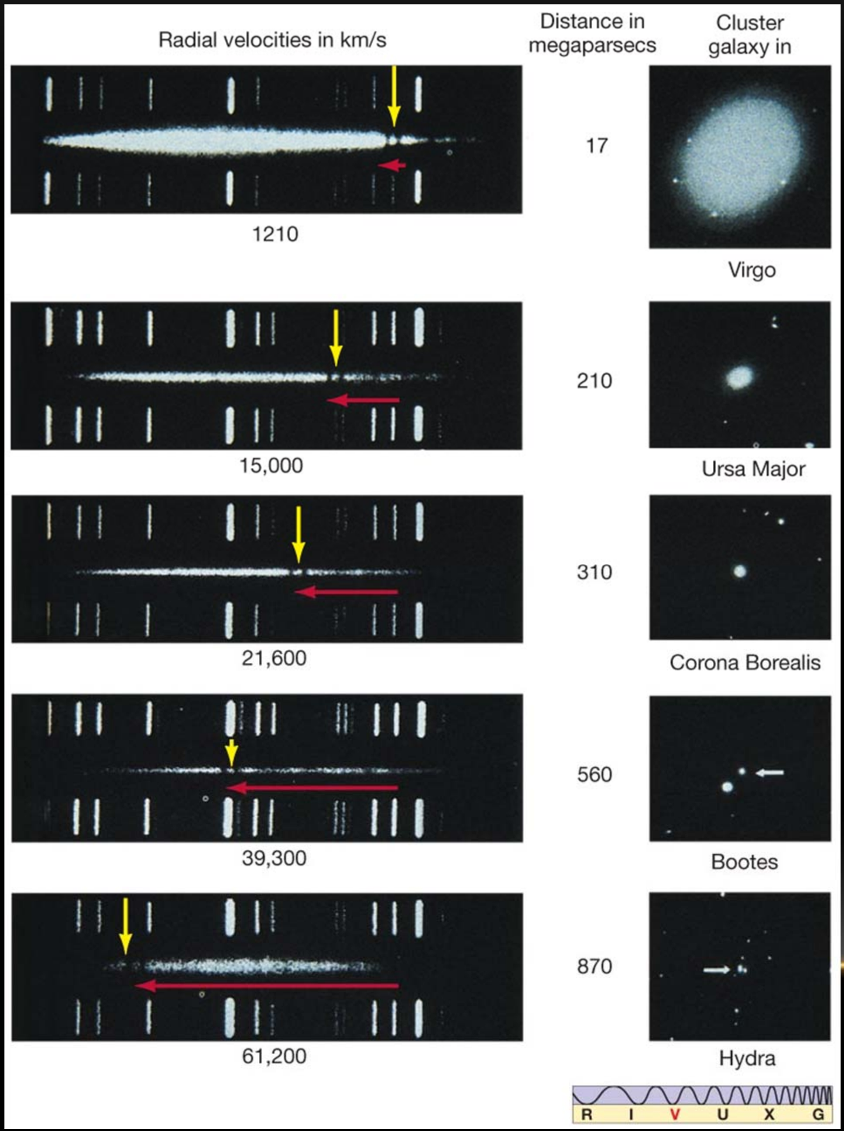


# THE DISTANCE LADDER




- Different techniques for distance measuring
- From near to far
- The nearer things are, the more accurate the methods
- But all work surprisingly well

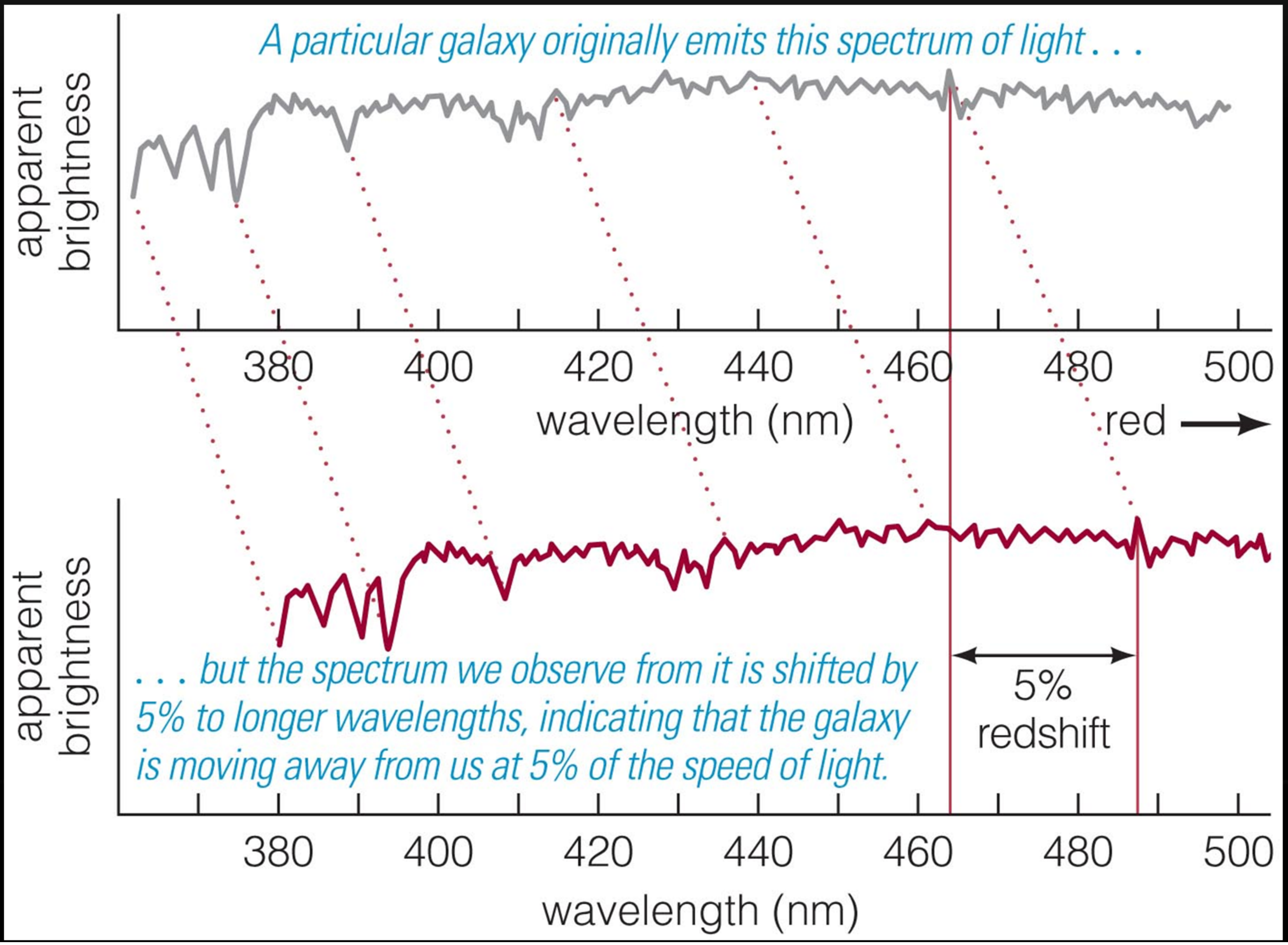
# RADIAL VELOCITY




- Spectral absorption lines are seen in the galaxy's spectrum
  - From the stars and gas
- The faster the galaxy moves away, the more those lines are Doppler shifted to the red

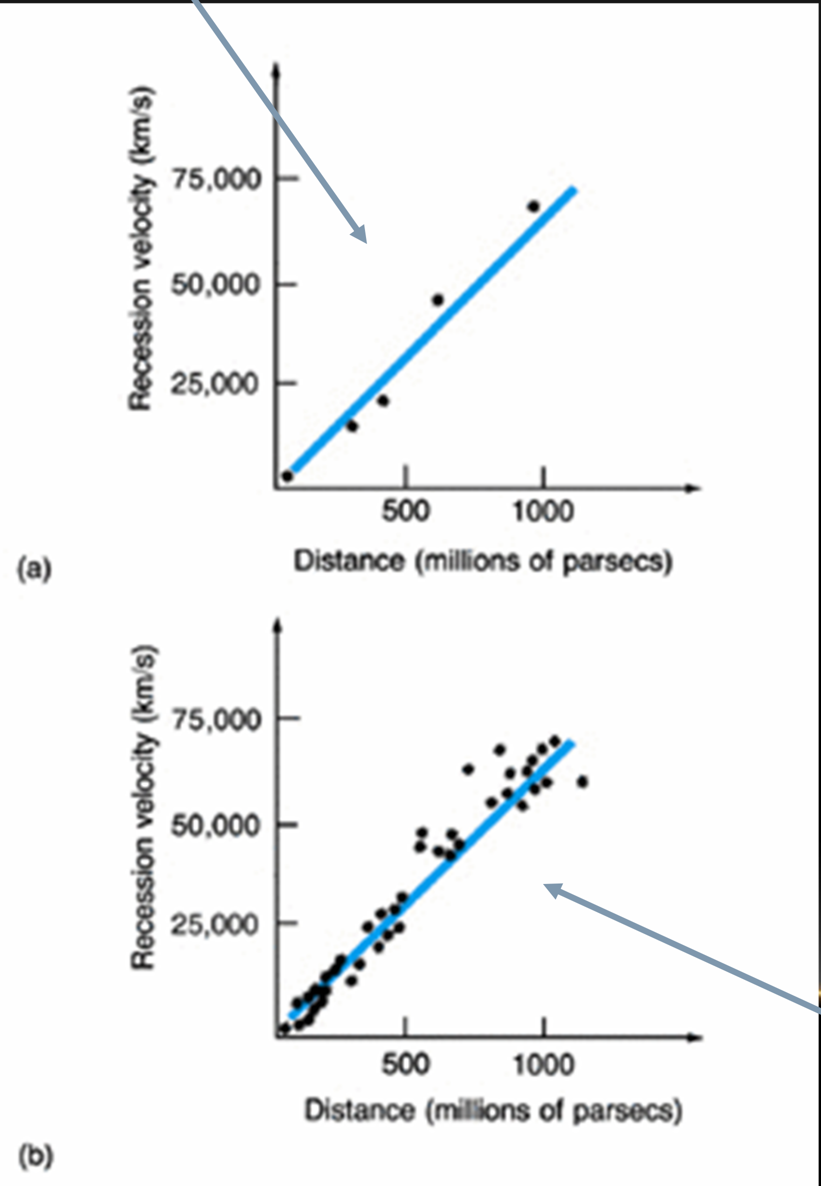
# RADIAL VELOCITY

Fig.16.15



# THE HUBBLE LAW

5 galaxies
from prev. page




- In 1924, Hubble also finds that a galaxy's distance and velocity away from us are related
  - Farther galaxies move away faster

Lots of galaxies

PLAY

# CHECK THIS OUT TO REALLY FAR

- Using white dwarf (type Ia) Supernovae

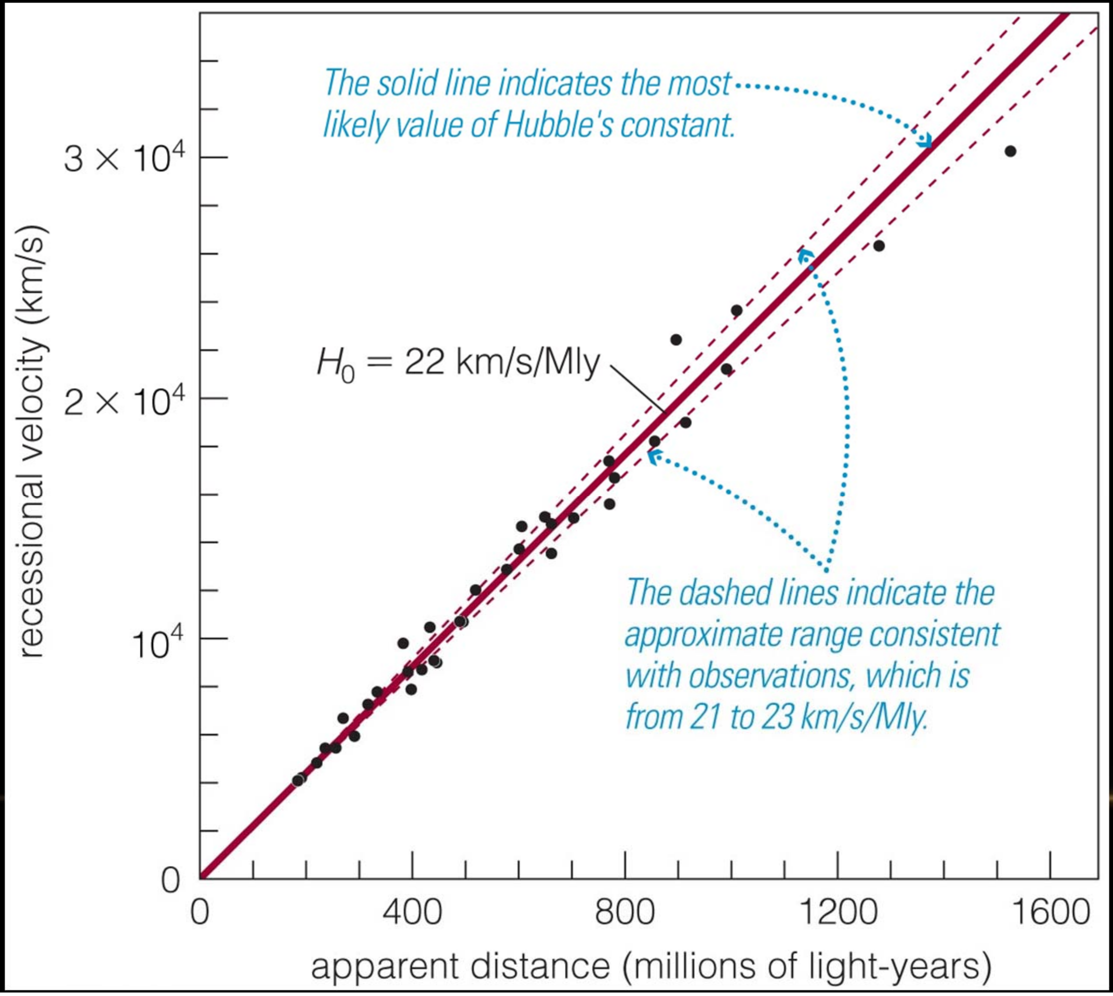
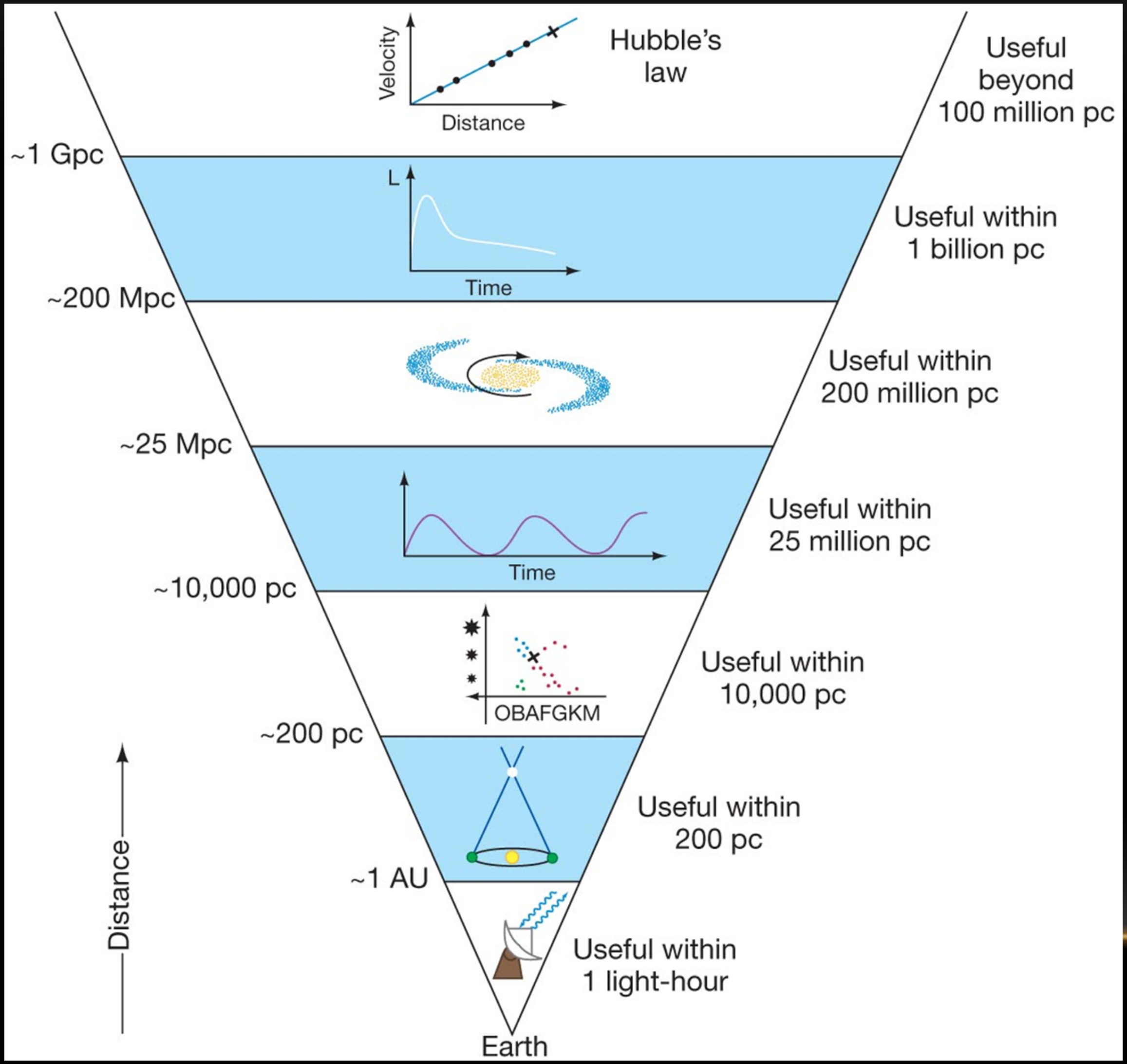



Fig.16.16

# THE HUBBLE LAW

- Caused by expanding universe (more in Ch.17, “Cosmology”)
- Can use that straight line
  - $v = H_0 d$
  - to find distances of really far away things
  - $H_0$ = 70 km/s/Mpc (*or 22 km/s/Mly*)

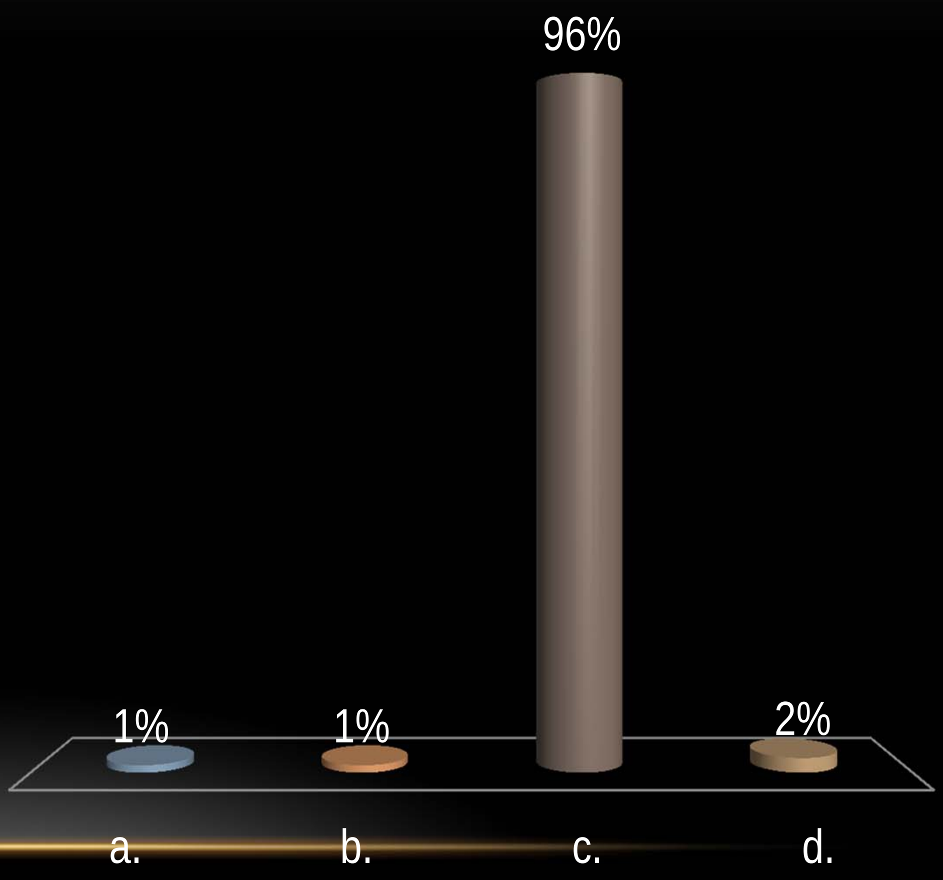
# THE DISTANCE LADDER




- Use the Hubble Law itself to figure out the most distant distances

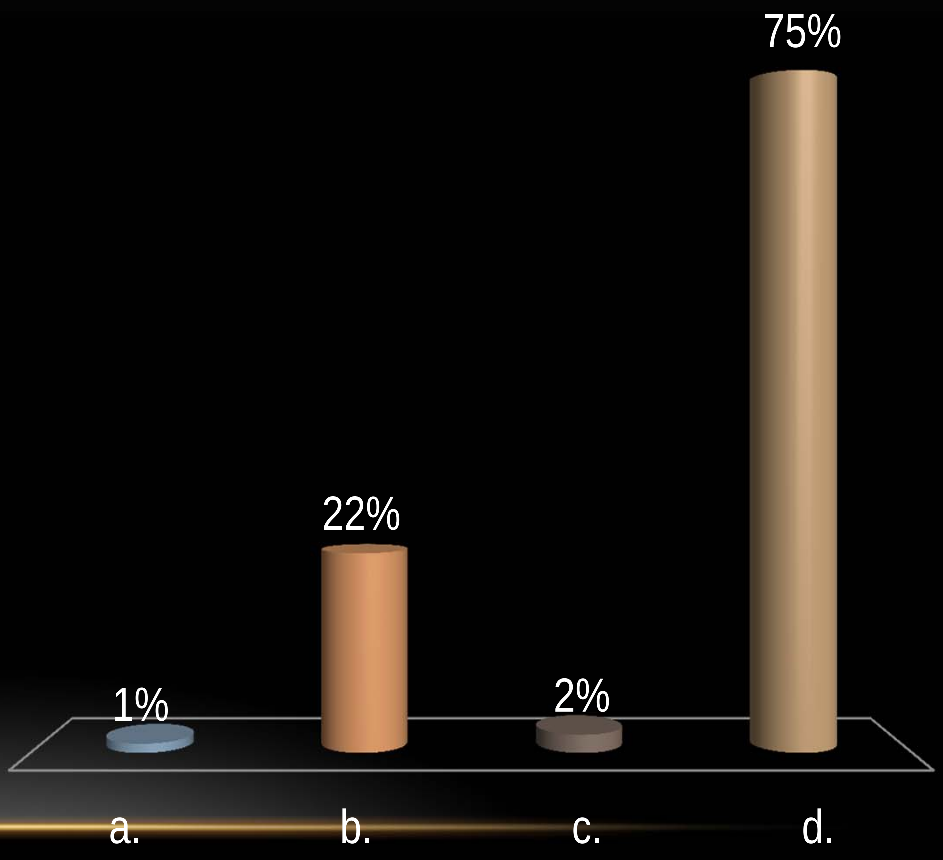
YOUR FRIEND LEAVES YOUR HOUSE. SHE LATER CALLS YOU ON HER CELL PHONE, SAYING THAT SHE'S BEEN DRIVING AT 60 MILES AN HOUR DIRECTLY AWAY FROM YOU THE WHOLE TIME AND IS NOW 60 MILES AWAY. HOW LONG HAS SHE BEEN GONE?

a. 1 minute
b. 30 minutes
c. 60 minutes ✔
d. 120 minutes



YOU OBSERVE A GALAXY MOVING AWAY FROM YOU AT 0.1 LIGHT-YEARS PER YEAR, AND IT IS NOW 1.4 BILLION LIGHT-YEARS AWAY FROM YOU. HOW LONG HAS IT TAKEN TO GET THERE?

a. 1 million years
b. 14 million years
c. 10 billion years
✓ d. 14 billion years



# DISTANCES AND AGE OF THE UNIVERSE

- Hubble's constant tells us the age of the universe because it relates velocities and distances of all galaxies.
  - Age = distance/velocity
  - That's ~ $1/H_0$

PLAY

# WHY ARE THINGS FLYING APART?

- Either we're the center and everything is flying away from us, or the whole place is expanding
- The expansion rate appears to be the same everywhere in space.
- The universe has no center and no edge (as far as we can tell).

PLAY

# EXPANDING UNIVERSE

Fig.16.18