Announcements

- Today: Start with galaxies
  → start reading Chapter 14
- November 12, 8-9pm: Stargazing

Astronomy in the news

Source: http://www.eso.org/public/news/eso1432/

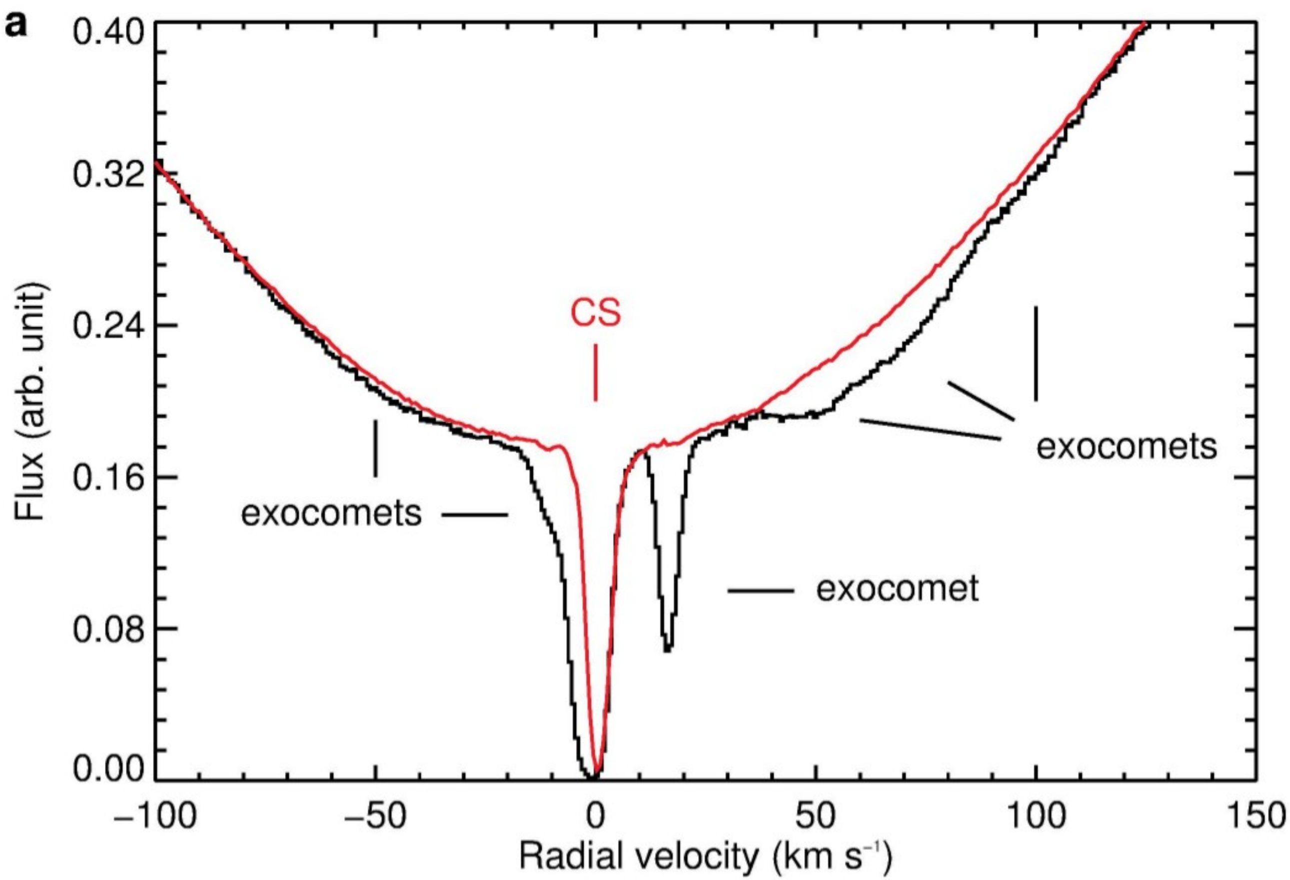
Exocomets around β Pictoris

- Beta Pictoris is a young star located about 63 light-years from the Sun. It is only about 20 million years old and is surrounded by a huge disc of material — a very active young planetary system where gas and dust are produced by the evaporation of comets and the collisions of asteroids.
- For almost 30 years astronomers have seen subtle changes in the light from Beta Pictoris that were thought to be caused by the passage of comets in front of the star itself. **Comets are small bodies of a few kilometres in size, but they are rich in ices, which evaporate when they approach their star, producing gigantic tails of gas and dust that can absorb some of the light passing through them.** The dim light from the exocomets is swamped by the light of the brilliant star so they cannot be imaged directly from Earth.
- To study the Beta Pictoris exocomets, the team analysed **more than 1000 observations** obtained between 2003 and 2011 with the HARPS instrument on the ESO 3.6-metre telescope at the La Silla Observatory in Chile.
- The researchers selected a sample of **493 different exocomets**. Some exocomets were observed several times and for a few hours. Careful analysis provided measurements of the speed and the size of the gas clouds. Some of the orbital properties of each of these exocomets, such as the shape and the orientation of the orbit and the distance to the star, could also be deduced.

Exocomets around β Pictoris

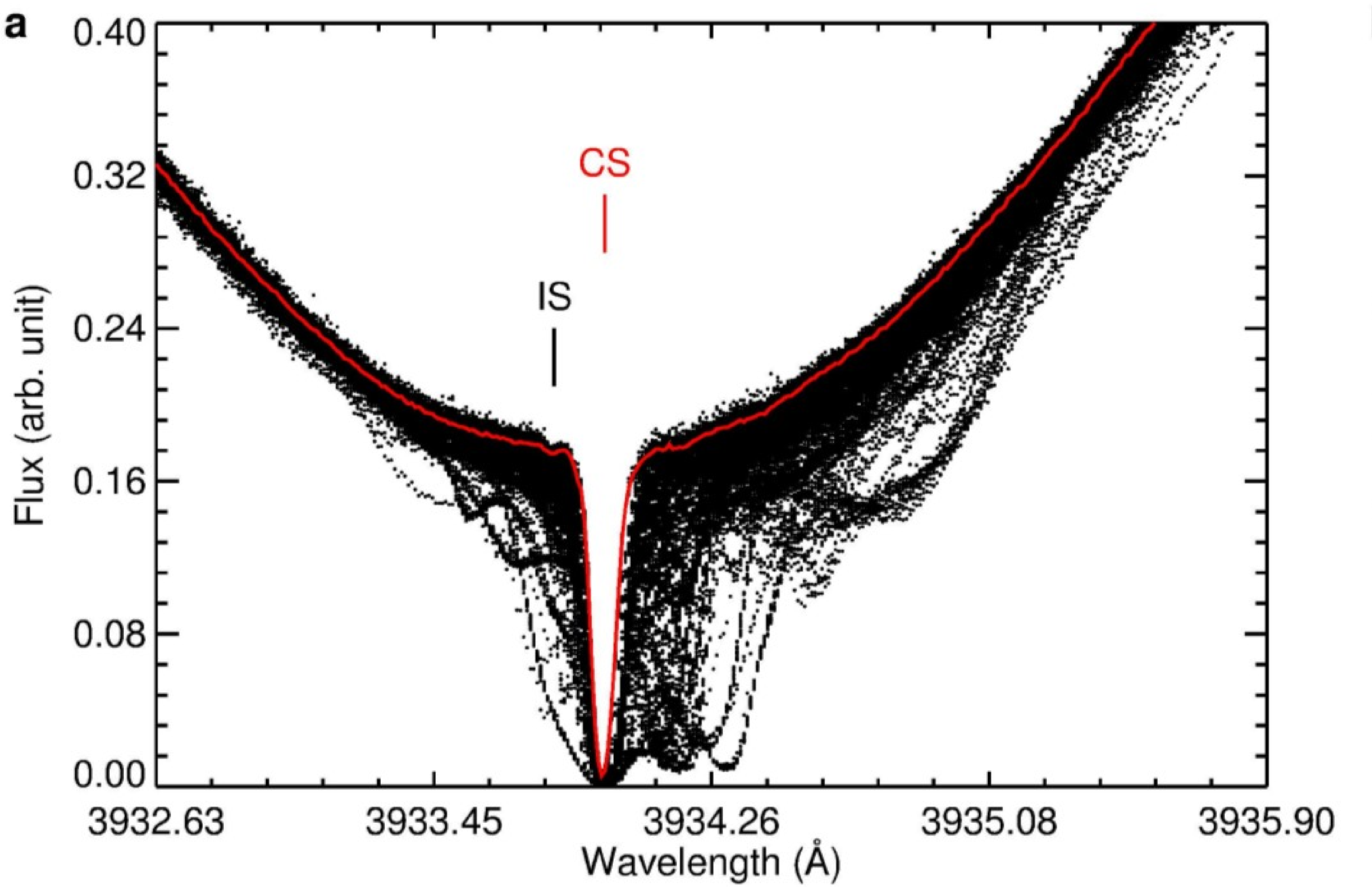
- This analysis of several hundreds of exocomets in a single exo-planetary system is unique. It revealed the presence of two distinct families of exocomets: one family of old exocomets whose orbits are controlled by a massive planet, and another family, probably arising from the recent breakdown of one or a few bigger objects. Different families of comets also exist in the Solar System.
- The exocomets of the first family have a variety of orbits and show a rather weak activity with low production rates of gas and dust. This suggests that these comets have exhausted their supplies of ices during their multiple passages close to Beta Pictoris.
- The exocomets of the second family are much more active and are also on nearly identical orbits. This suggests that the members of the second family all arise from the same origin: probably the breakdown of a larger object whose fragments are on an orbit grazing the star Beta Pictoris.
- “For the first time a statistical study has determined the physics and orbits for a large number of exocomets. This work provides a remarkable look at the mechanisms that were at work in the Solar System just after its formation 4.5 billion years ago.”

The science behind the press release



The authors took many many spectra of the central star, zooming in on a particular absorption line of calcium. What they find are the signature of the star and a circumstellar disk (labeled CS in the plot), plus many other features that are highly variable. Each comet basically produces a small transit signature, very much like extrasolar planets produce transits when they move across the star's disk.

The science behind the press release



By observing the star repeatedly you can track these comet transits and study their nature in more detail, in particular their orbital sizes (from the transit timing).

Galaxies

read Chapter 14

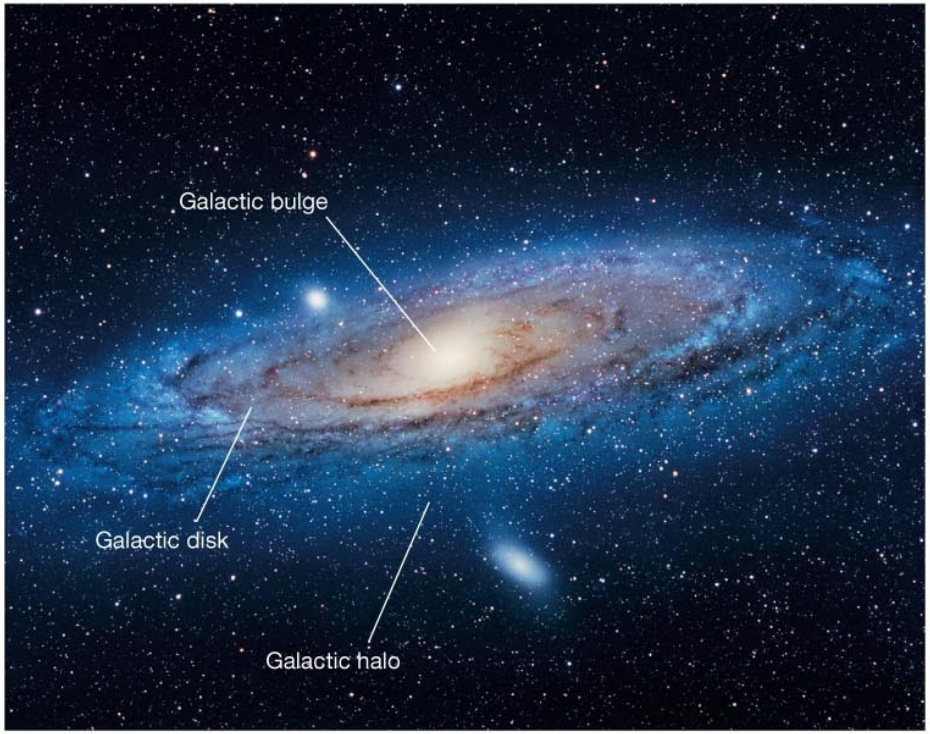
What is a galaxy?

A galaxy is a huge collection of stars that is isolated in space and held together by gravity.

We happen to live in one called the Milky Way Galaxy or just the Galaxy (with a capital “G”)

This is a picture of the Whirlpool galaxy – not the Milky Way

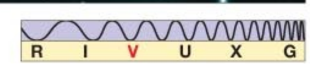
The Milky Way



(a)

(b)

(c)



Our Galaxy is a spiral galaxy. Here are three similar galaxies.

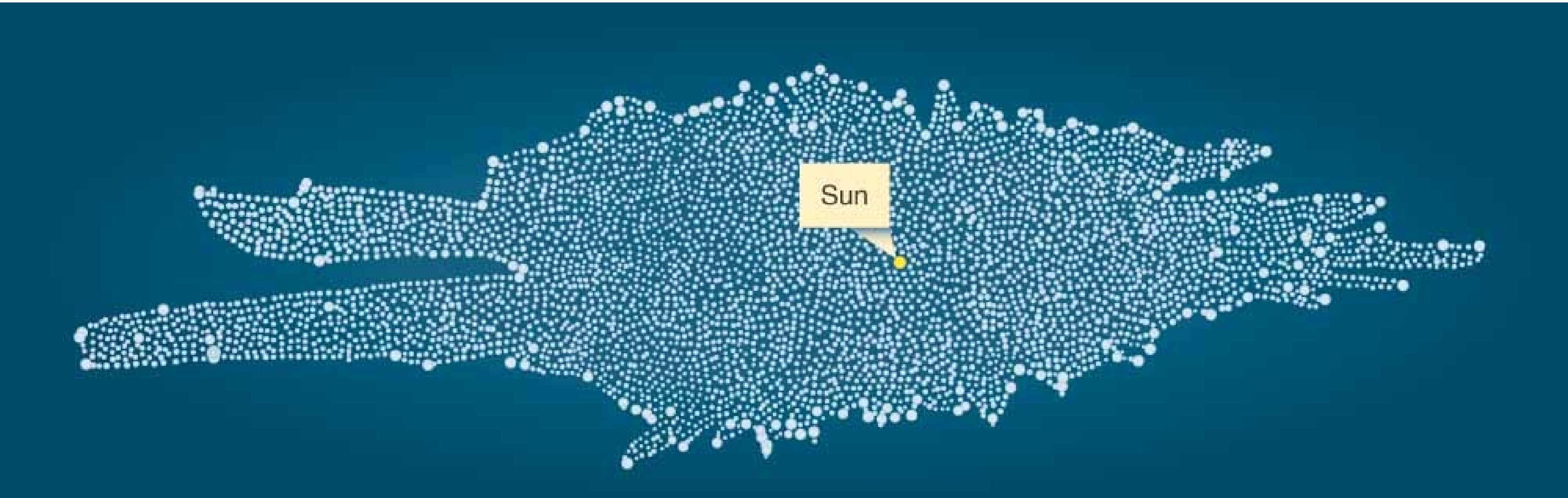
How do we know that the Galaxy looks like this?

Count the number of stars in different directions

William Herschel first did this in 1756 and discovered that the galaxy looks like a disk

Note that the Sun is in the center of the disk

This is not right! Sun is not at the center, and Herschel didn't know that most of the light is blocked by dust, especially toward center of Galaxy



The new distance ladder

William Herschel didn’t have a way to measure distances to stars, so he just assumed that the stars are uniformly distributed

The real revolution in the study of our Galaxy (and other galaxies) came from building up the next rung of the **distance ladder with the use of variable stars**

Recall that the distance ladder is our collection of methods for measuring distances to astronomical objects: ladder because each step builds on the one before

Review of the distance ladder

1) Radar ranging to find distances to nearest planets and the AU.

2) Parallax for distances to the closest stars.
The Hipparcos satellite extends the range of parallax to over 200 pc or about 700 ly, but beyond that, the parallax angle is still too small to be seen.

3) To measure the distance to stars beyond this one can use standard candles, objects whose luminosity is known. That is, if you know the luminosity of a candle, or a light bulb or a star, you can find its distance by measuring its brightness: the farther away it is, the smaller its apparent brightness: The energy is spread out over a sphere of area $4\pi d^2$, with d the distance to the star, giving the relations that we have used:

luminosity = apparent brightness x $4\pi d^2$

Standard Candles

The first standard candles we encountered were main sequence stars.

The H-R diagram tells you the luminosity of each spectral type of main sequence star.

To find the distance to a main sequence star,

1) From its spectral type, find its luminosity
2) From its luminosity and its apparent brightness find its distance

Using main sequence stars as standard candles (spectroscopic parallax), one can find distances to stars anywhere one can see them in our galaxy, more than 30,000 ly or 10,000 pc away

Standard Candles: Variable stars

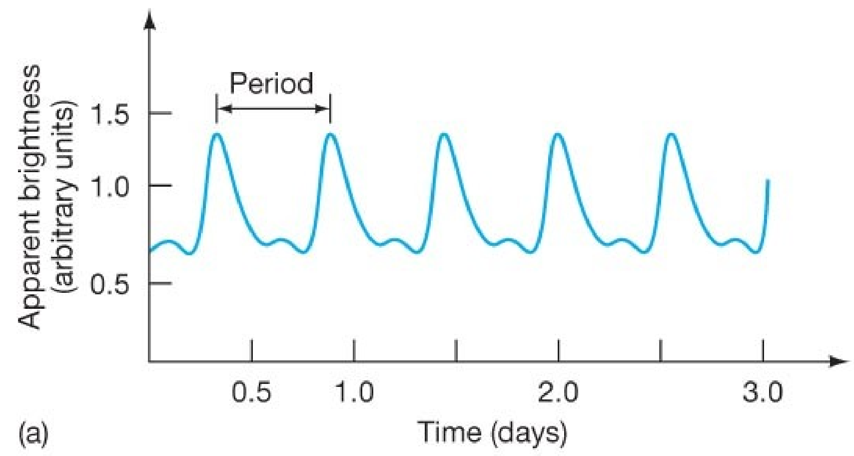
All stars oscillate. Oscillations are long sound waves, and the oscillation time is the time it takes sound to cross the star.

Large stars, like large bells, oscillate more slowly than small stars. Late in their evolution, bright stars have, for a short time, unusually large oscillations.

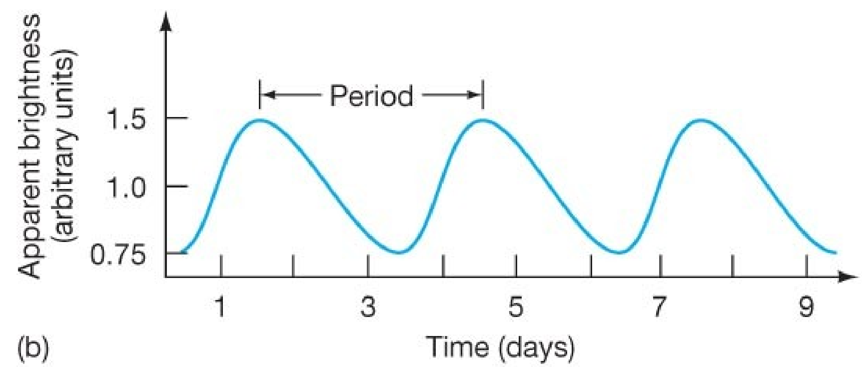
- Stars that take between 1-100 days to pulsate are call **Cepheids**.
- Stars that take less than 1 day are call **RR Lyrae** stars.
- Stars that take longer than 100 days are called **Mira variables**.

Variable Stars

The upper plot is an RR Lyrae star. All such stars have essentially the same luminosity curve, with periods from 0.5 to 1 day.



The lower plot is a **Cepheid variable**; Cepheid periods range from about 1 to 100 days.



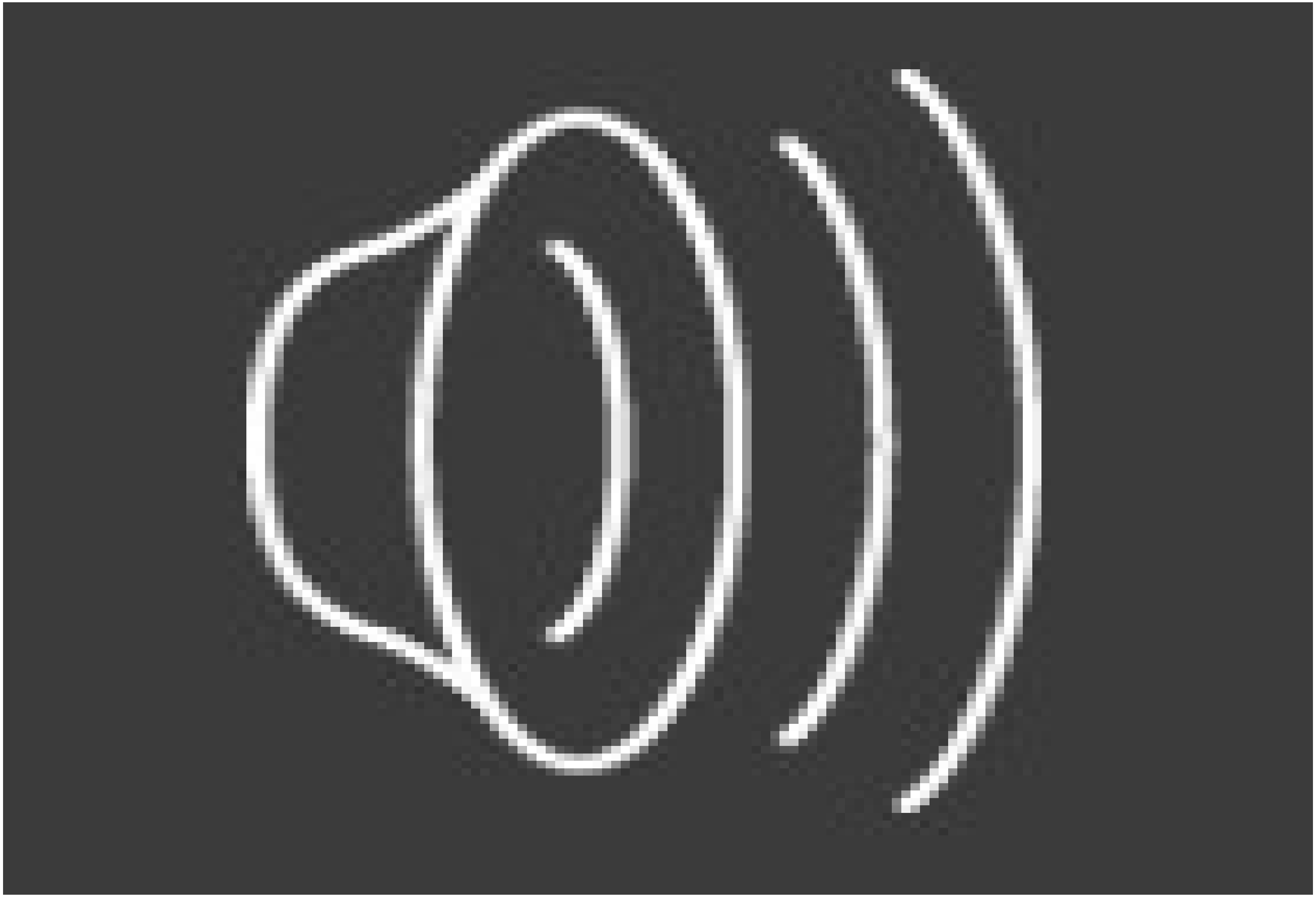
Variable Stars

Late in a star's evolution, its oscillations can become unstable, growing enormously, and greatly changing the brightness of the star each oscillation

The larger a star is, the longer its period of oscillation

This is a Mira variable star at its faintest and at its brightest.

Cepheid Variables



Leavitt's period-luminosity relation

Because large stars are brighter than small stars, there should be a relation between the period and luminosity of oscillating stars: **Stars with longer periods should be larger and brighter than stars with shorter periods.**

The larger a star is, the longer its period of oscillation.

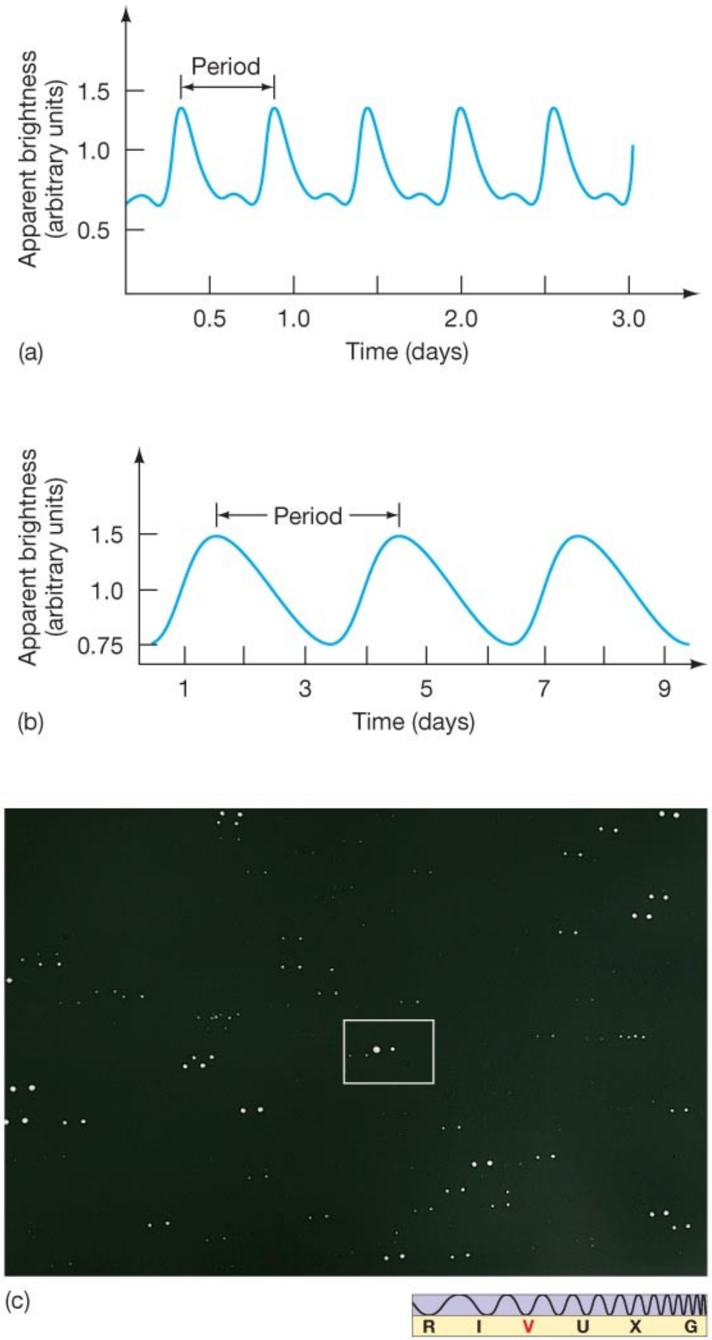
Henrietta Leavitt showed that this was true for Cepheid variables, looking at a set of variable stars in the Magellanic clouds in order to see stars at the same distance.

Henrietta Leavitt discovered the period-luminosity relation for Cepheids

The relation makes each Cepheid into a standard candle: a light source whose luminosity is known, once the period is measured.

Henrietta Leavitt

Henrietta Leavitt measured the relation between period and luminosity for variable stars with long periods (1-60 days), called Cepheids

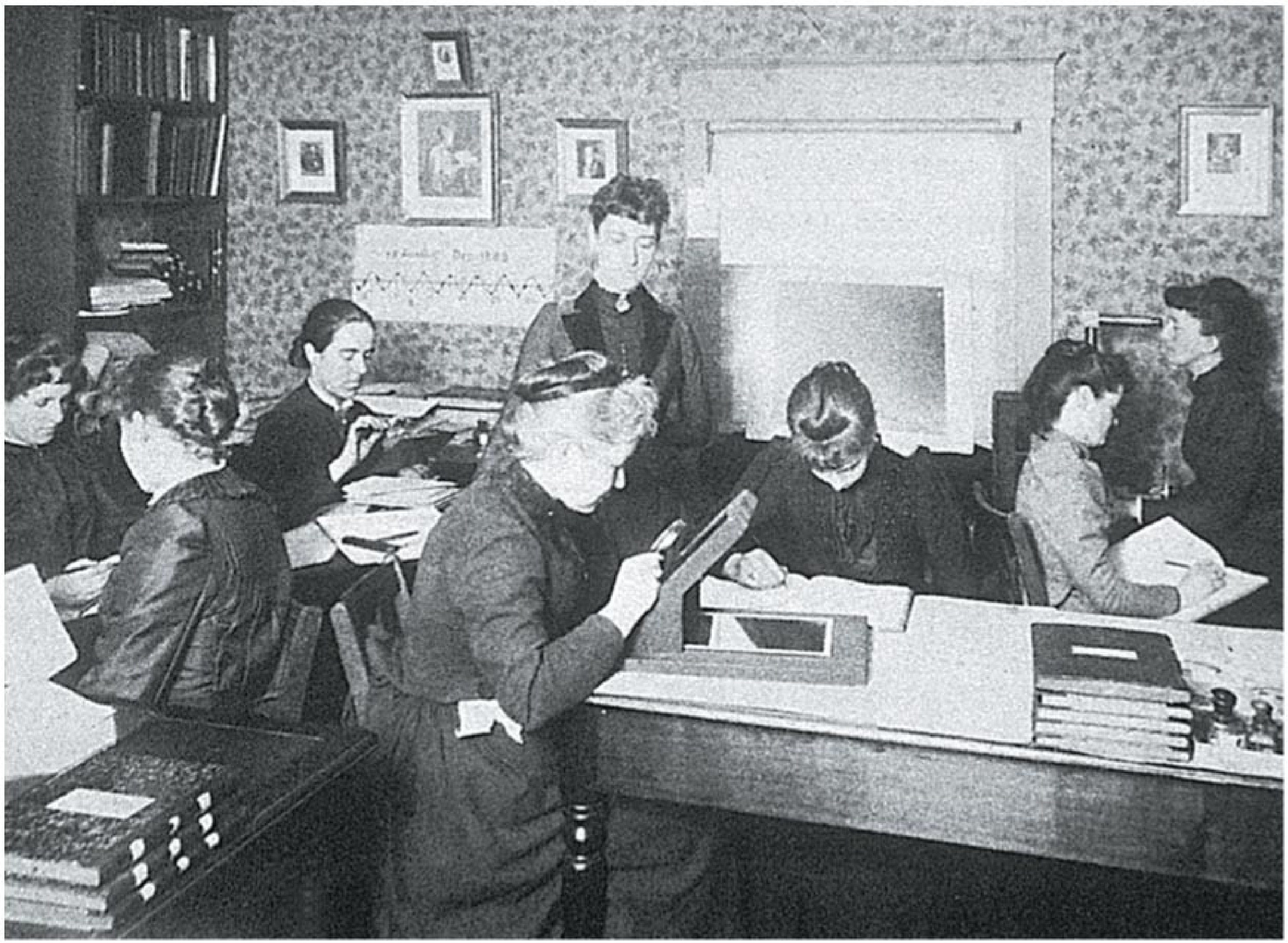


RR Lyrae

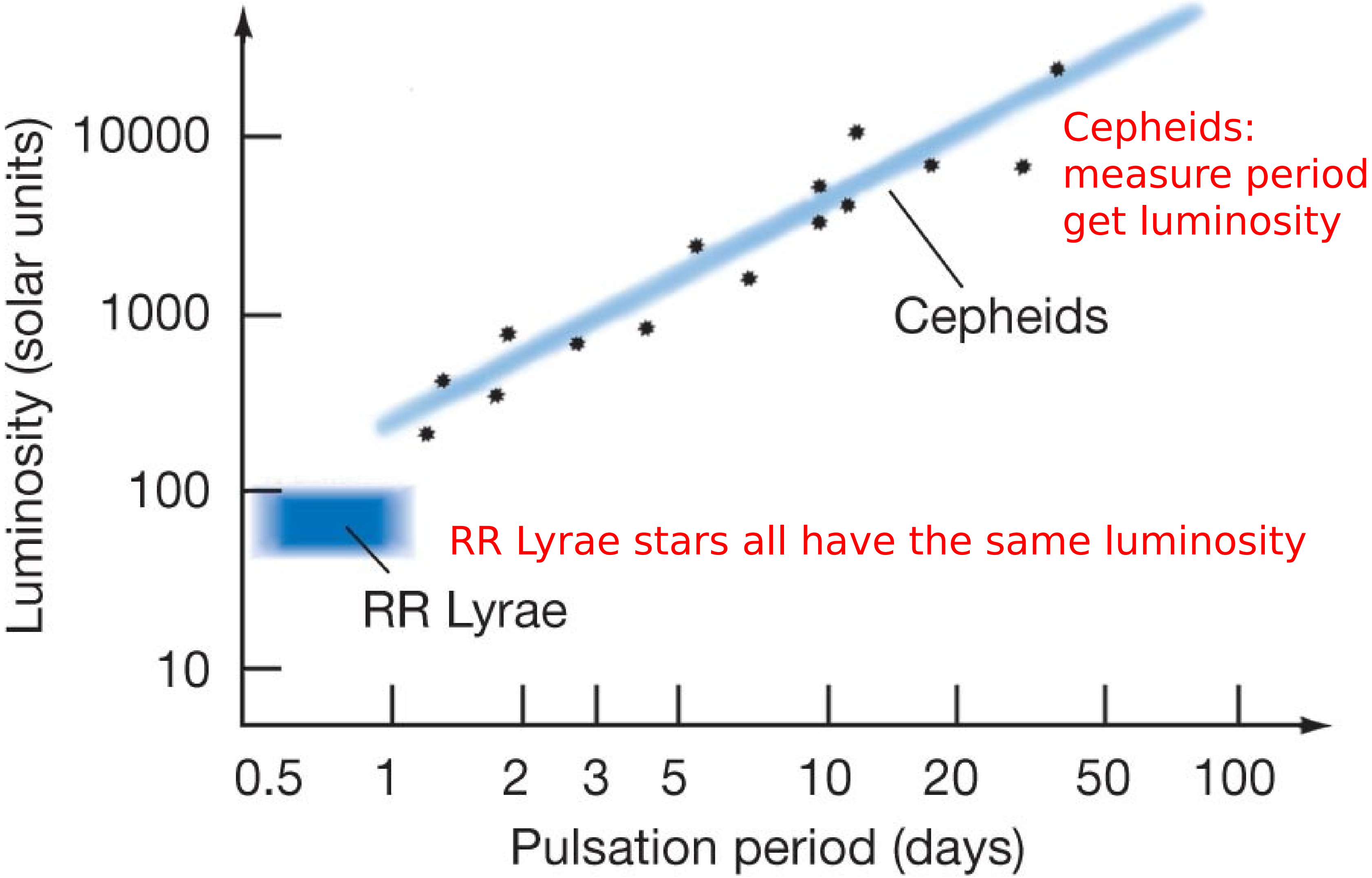
Cepheid

Cepheid—two displaced images taken at different times

Leavitt was part of a group of women “computers” that looked over many thousands of plates and included Annie Jump Cannon in Harvard College Observatory



Leavitt's Period-Luminosity Relation for Cepheid Variable Stars



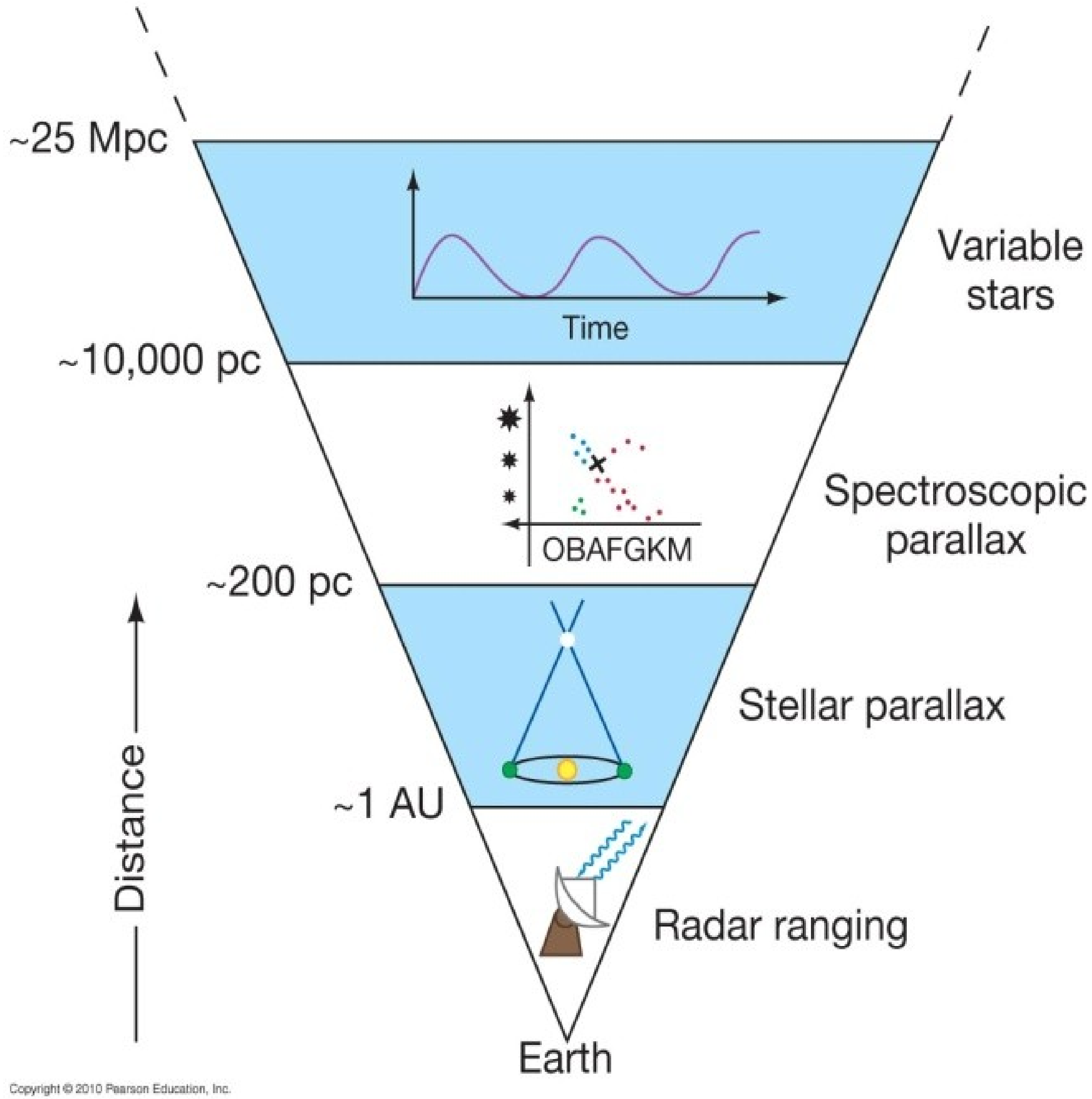
Cepheids as standard candles

A Cepheid variable can be used as a standard candle:

1) Find its luminosity by measuring its period
2) Measure its apparent brightness and deduce its distance from the 1/r2 formula

Summary of the distance ladder

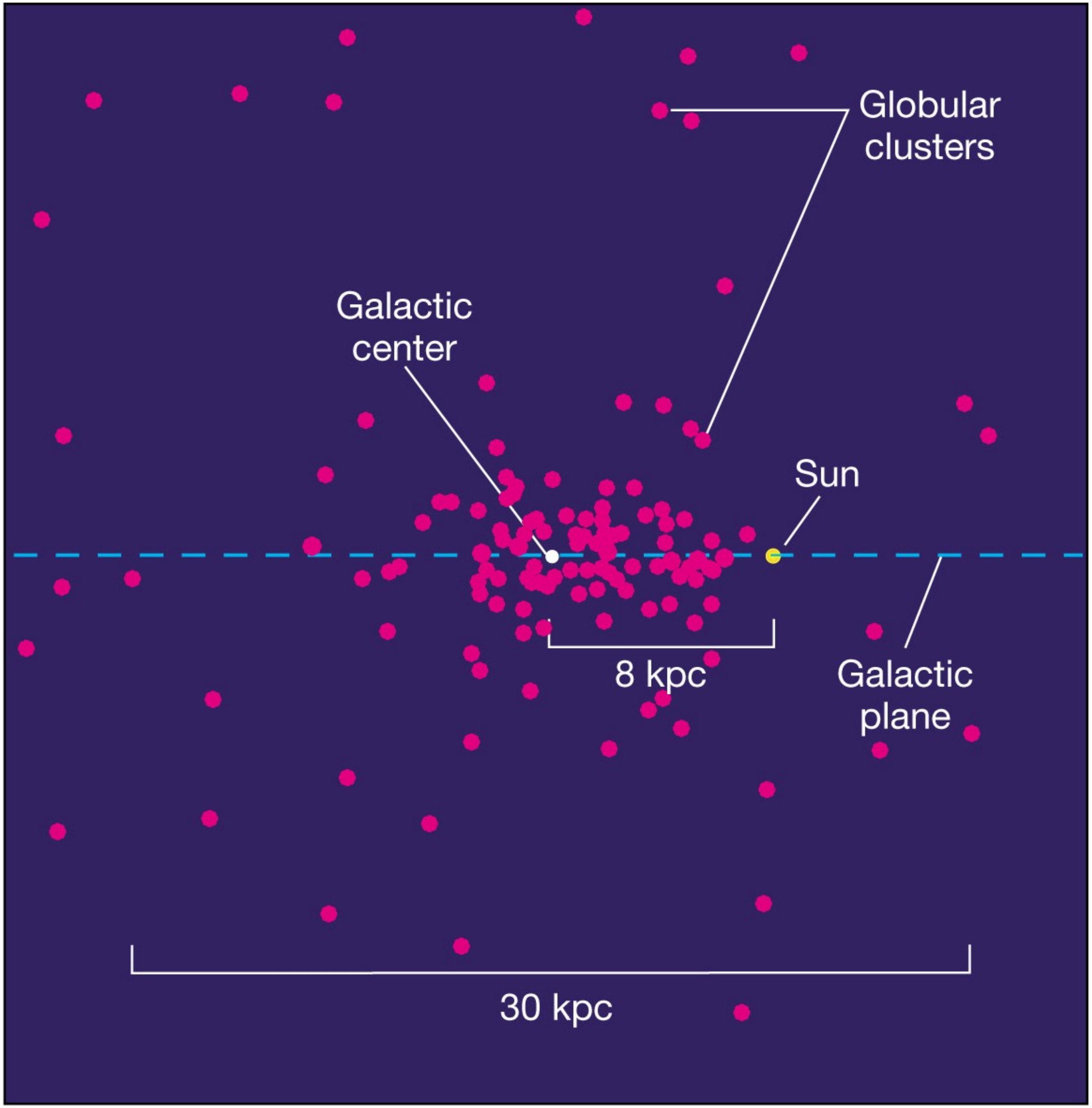
- Use radar bouncing to find distances to Mars and Venus and so to find 1 AU
- Knowing 1 AU → use parallax to find the distance to stars within a few thousand light-years
- Knowing the distance to these stars, find the luminosity of main sequence stars.
  → Using main-sequence stars as standard candles, find the distance to stars throughout our galaxy.
- Knowing the distance to clusters of stars in the galaxy, find the luminosity of Cepheid variables.
  → Using Cepheid variables as standard candles, find the distance to galaxies outside the Milky Way.


~25 Mpc
Variable stars
Time
~10,000 pc
Spectroscopic parallax
OBAFGKM
~200 pc
Stellar parallax
~1 AU
Radar ranging
Distance
Earth

Size of the Milky Way

- With variable stars as the standard candle, the size of the Milky Way can now be found
- Harlow Shapley in 1917 found the distances to distant globular clusters using these variable stars
- By assuming that the most distant globular clusters lie near the outside of the Milky Way, he found the extent of the Milky Way's halo
- And by noting that there are more globular clusters on one side of the sky than the other, he deduced that the Sun is not at the center of the Milky Way (globular clusters lie outside the disk of the galaxy, so they are less obscured by dust) and found the direction to the Galactic Center

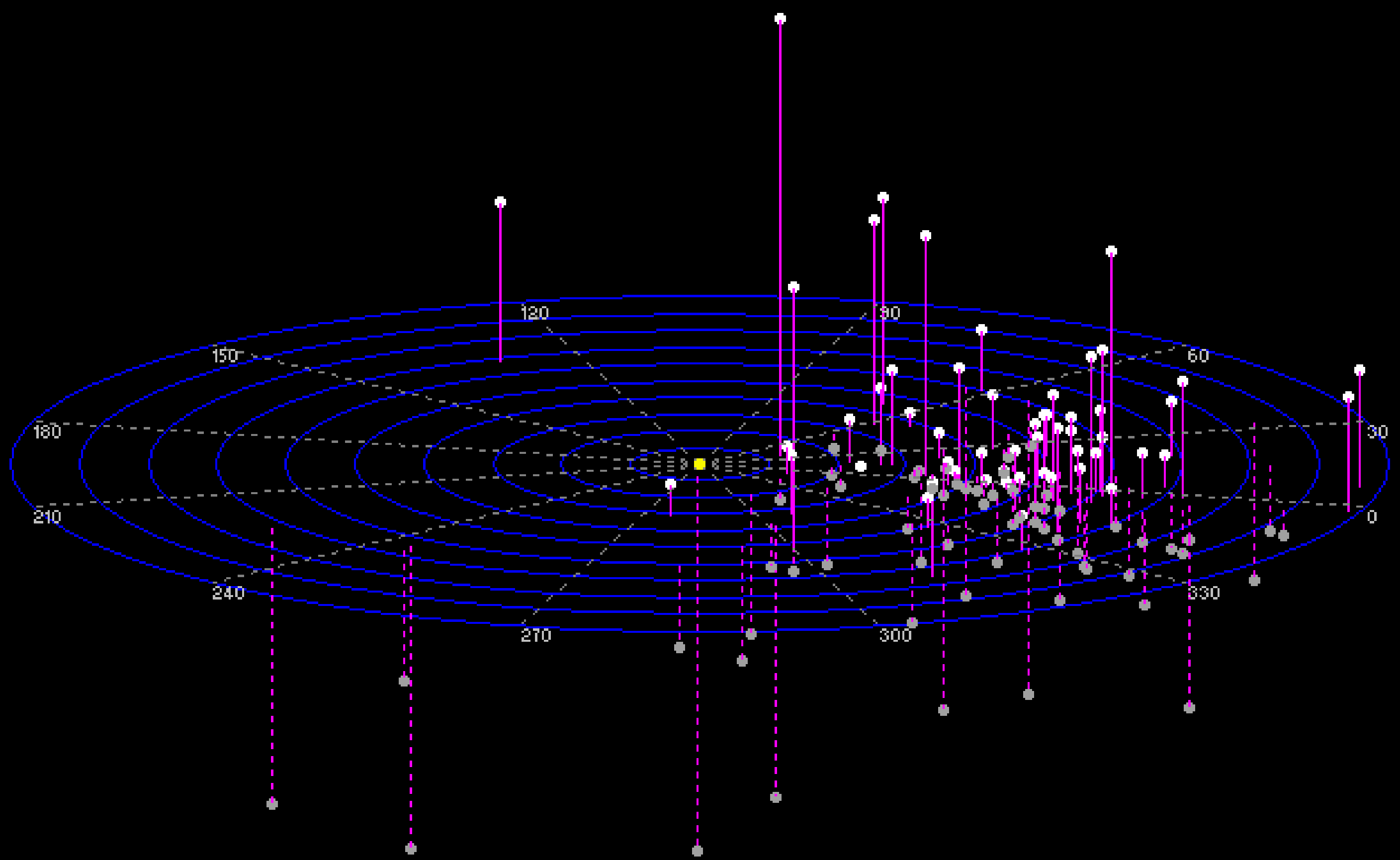
Globular
Cluster
M107


Globular
clusters
Galactic
center
Sun
8 kpc
Galactic
plane
30 kpc

The 116 globular clusters within 50,000 LY of the Sun

Sun centric (galactic longitude and latitude)

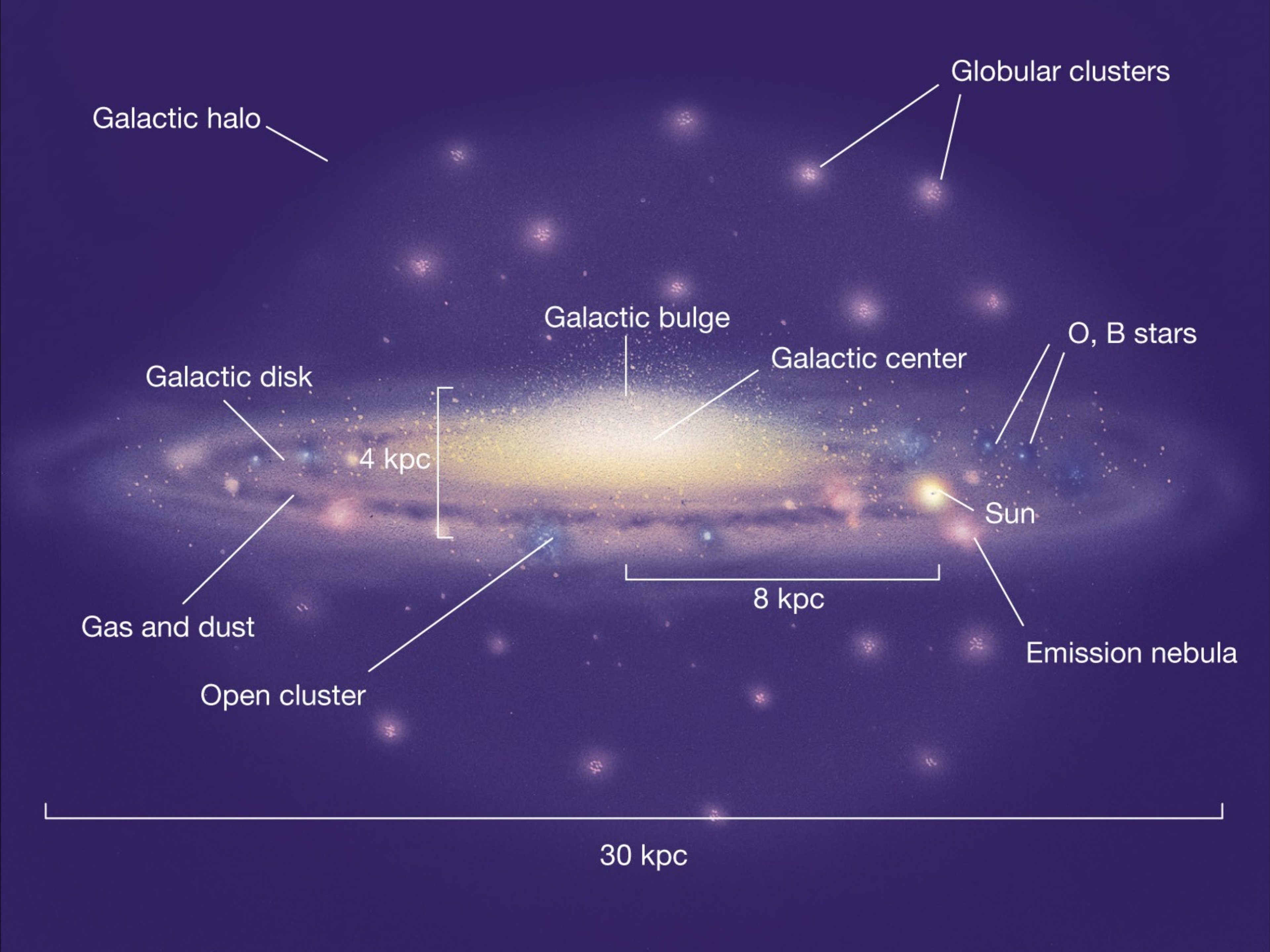
5,000 LY



Source: http://calgary.rasc.ca/globulars.htm

Data from William E. Harris, McMaster University
http://www.physics.mcmaster.ca/Globular.html

3D Diagram by Larry McNish


Globular clusters
Galactic halo
Galactic bulge
O, B stars
Galactic center
Galactic disk
4 kpc
Sun
8 kpc
Gas and dust
Emission nebula
Open cluster
30 kpc