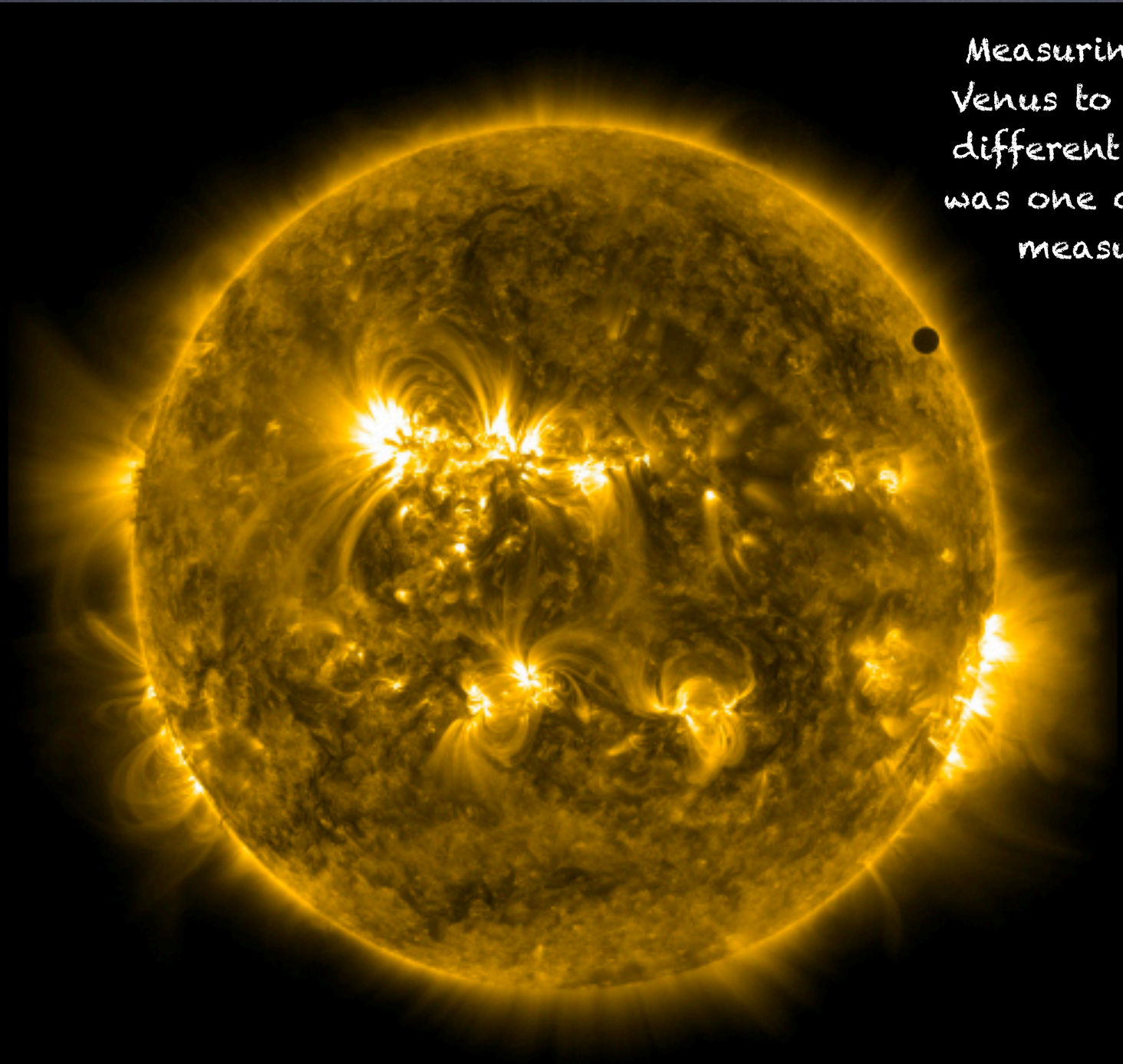
Celestial Distances

Chapter 19

Stellar Distances

- It is actually rather hard to measure distances to stars. That may seem surprising since distance is usually easy to measure, but that is for things we can travel to.
- Since stellar distances are so large there is no possibility of traveling there, nor of bouncing light off of a source and waiting for it to return. Determining the distances to stars is hard.

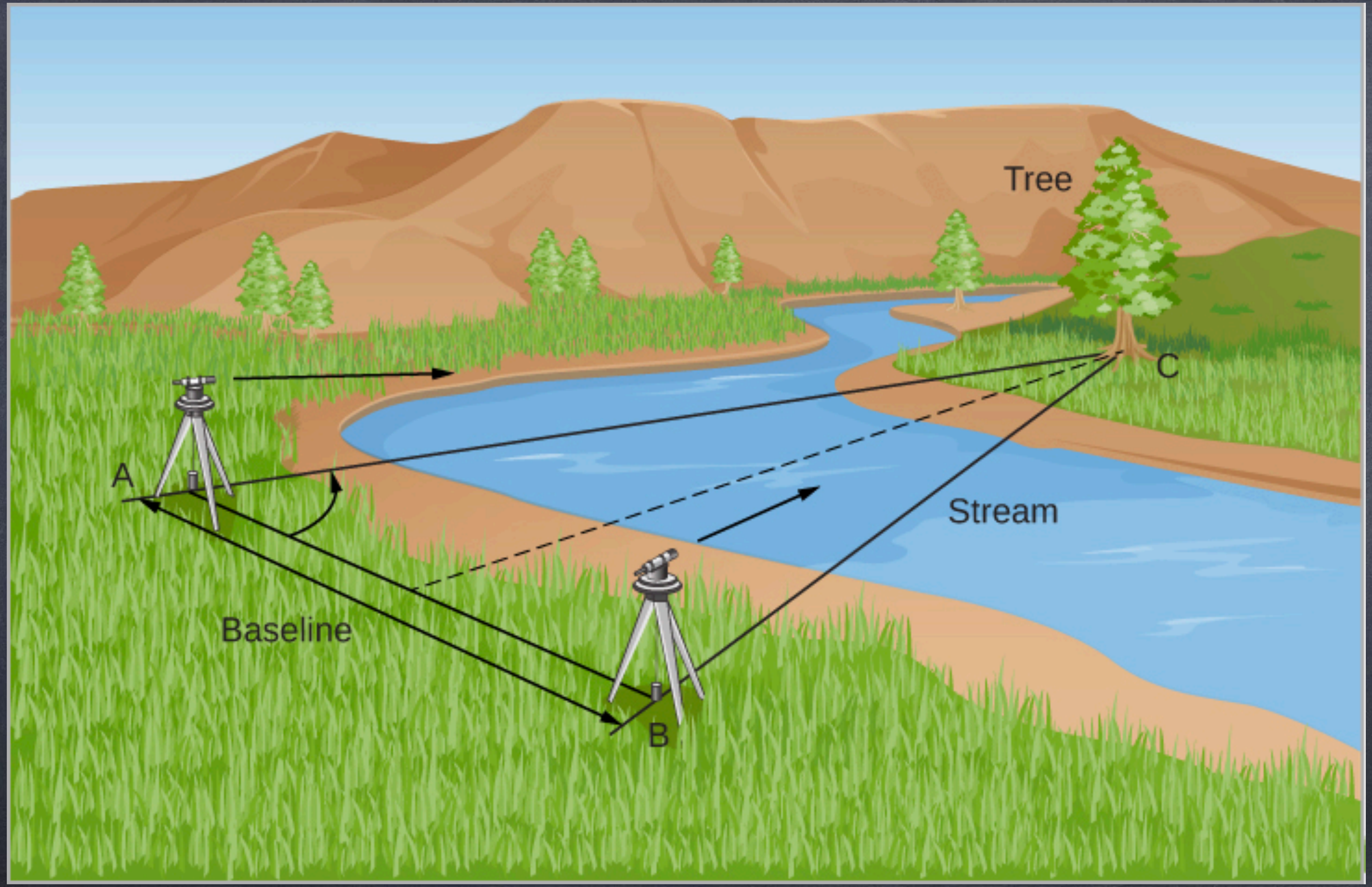


Measuring the time it took Venus to cross the sun from different latitudes on Earth was one of the early ways to measure its distance.

- Now days we can pretty easily measure the distances to objects in the solar system using radar.
- Radio waves are emitted from Earth make it to the planet and then bounce back. We time how long it takes.
- Since we know the speed of light, $c = 3 \times 10^5$ km/s, the time gives us the distance.
- 1AU is 1.5×10^8 km, takes light 500s to travel. Thus the light travel time to the edges of the solar system, 30AU is $30 \times 500s = 15{,}000s$ or 4.16 hours.
- However, the nearest star is 4.3 light years away so it would take 8.6 years for a single to bounce back if we could detect it.

Triangulation in Space

- The main way to measure distances in space is using triangulation.
- This is the method used by surveyors on Earth to measure distance.
- The concept is to measure an angle from one location, then move to a different location and measure the angle to the same thing. The change in angle gives you the distance.
- For astronomical observations to move to a different location we just have to wait 6 months and the Earth has moved 2AU or 300 million km.


Tree
C
A
Stream
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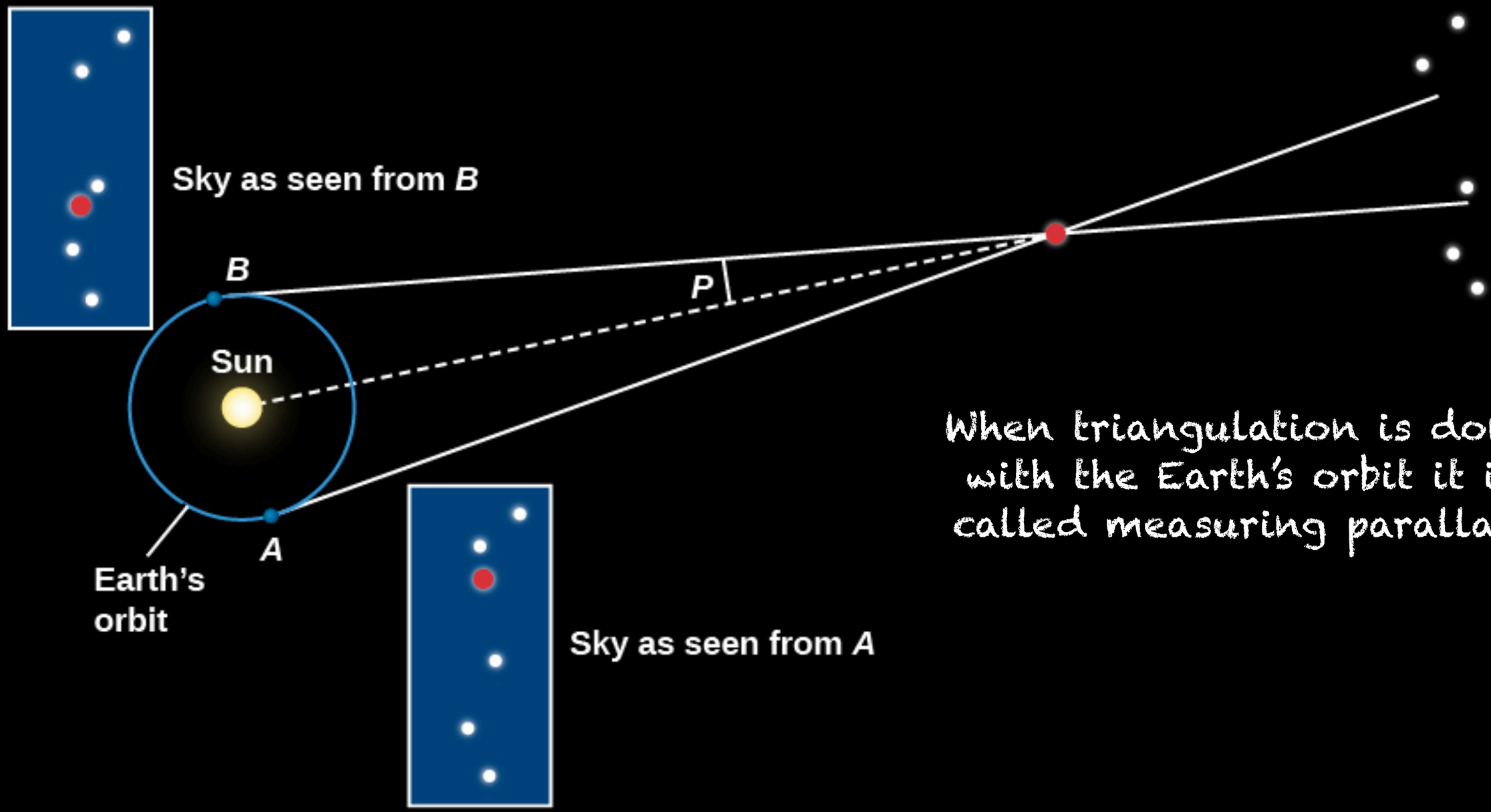
B



When triangulation is done with the Earth's orbit it is called measuring parallax.

Measuring Parallax

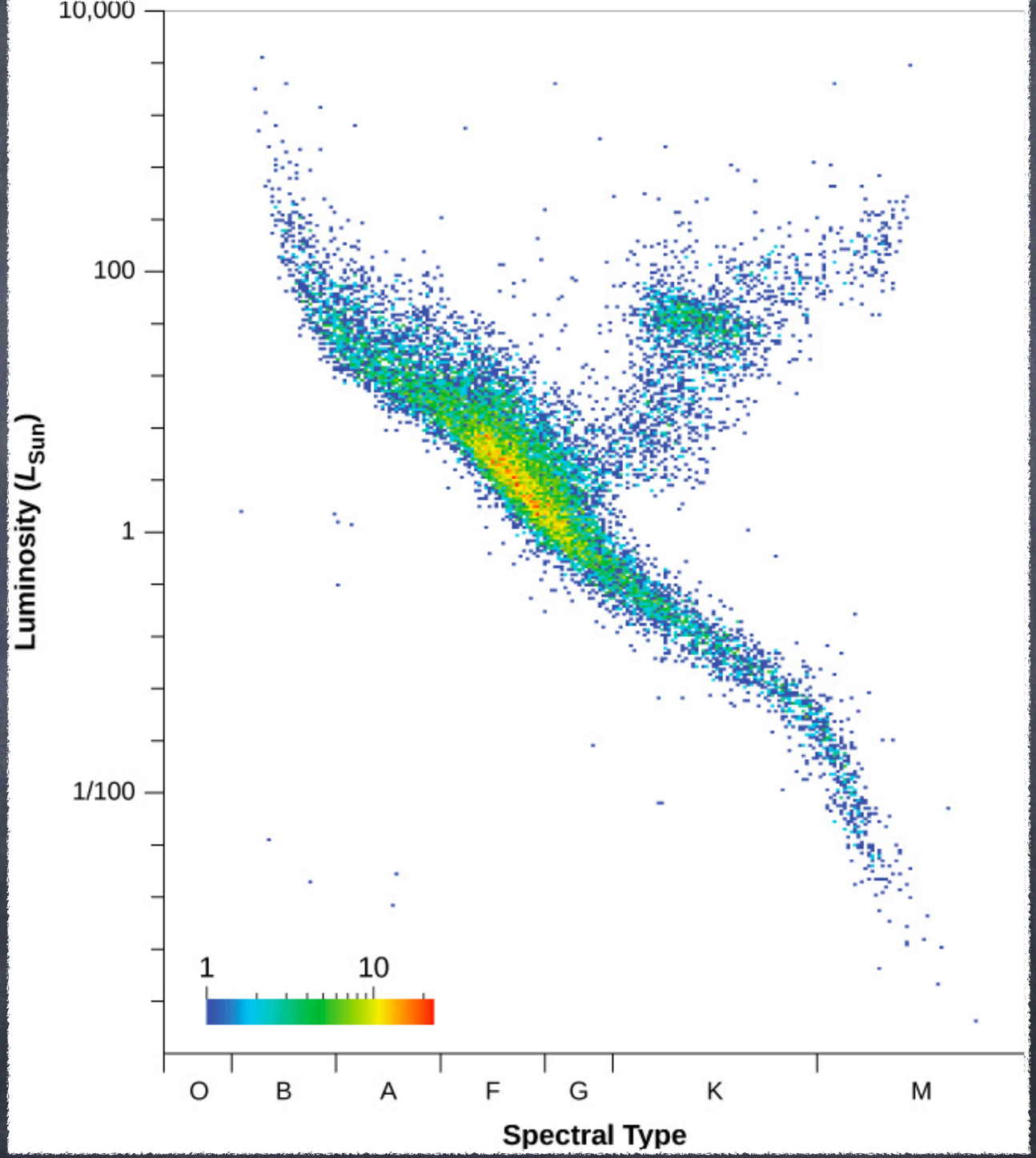
- Parallax is a good way to measure distances, but it is rather hard. The closest stars have parallaxes of 1 arcsecond, which is the width of a hair at arms length.
- In addition, the atmosphere causes stars to twinkle which varies their location by about 1 arc second (0.5 under the best conditions). So measuring the parallax for stars from the ground is extremely challenging.

Measuring Parallax

- Since parallax is the main way astronomers measure distance they came up with a new unit of distance that works well with parallax. This unit is the parsec and it is close to 3.3 light years.
- The advantage of the parsec is that if you know an objects parallax then the distance in parsecs is just:

distance [parsec] = 1/parallax [arcsecond]

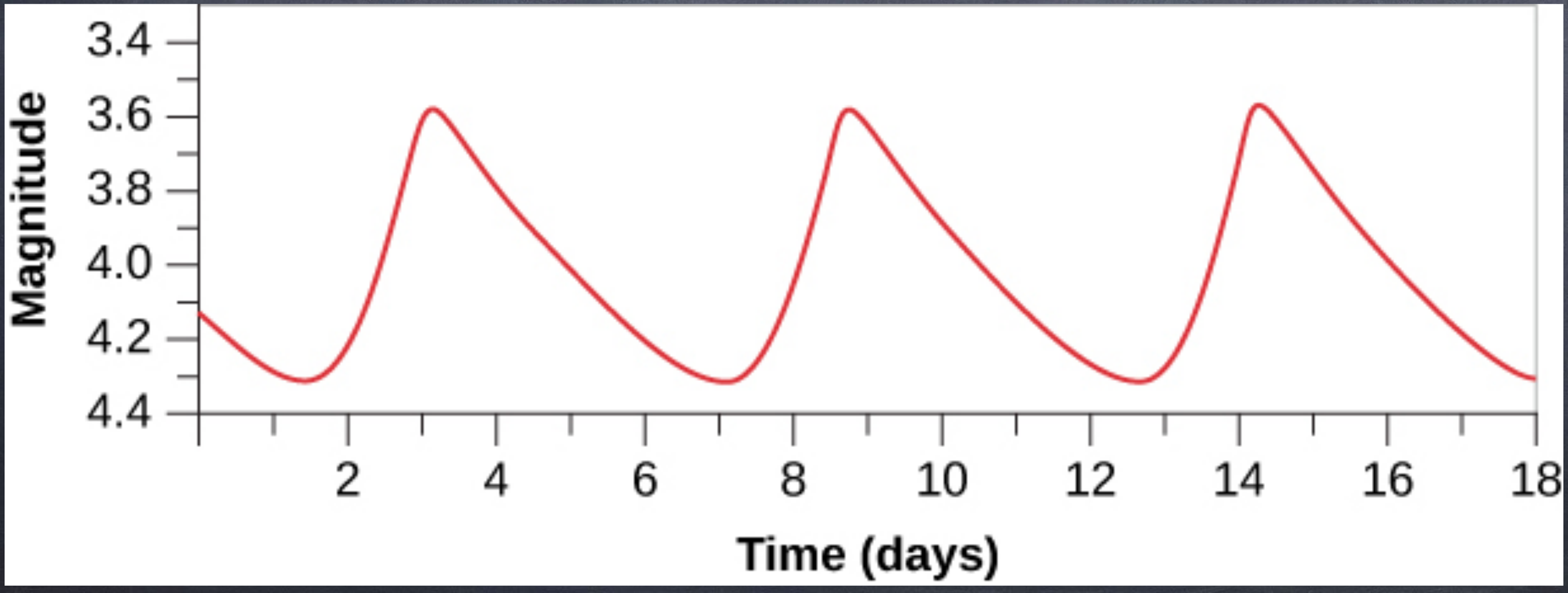
- Today the issue of measuring distances to stars has been solved by using special space missions designed to get incredible high angular accuracy.
- The mission Hipparcos launched in 1989 started this getting parallaxes to thousands of stars with accuracies of 10%-20%.
- The successor mission, Gaia, was launched in 2013 and has an accuracy of a few millionths of an arcsecond. It has measured distances to a billion stars as far as 30,000 light years away.



Variable Stars

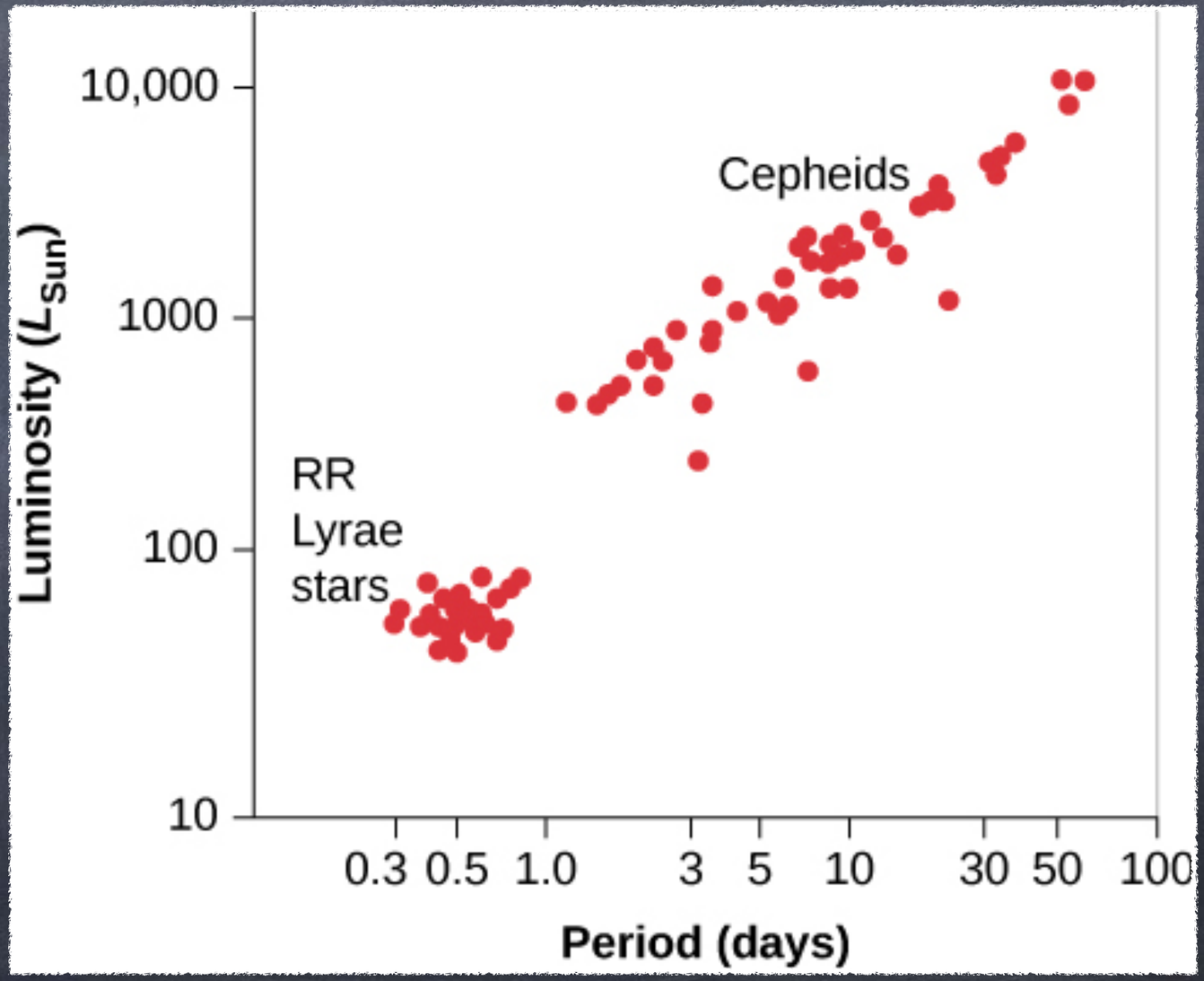
- Even if we can measure parallaxes to most of the stars in our galaxy, we are still far from measuring the distances to objects outside our galaxy.
- The main way we measure distances to nearby galaxies is by using variable stars. These are stars whose luminosity oscillates in a stead pattern.
- Most importantly, measuring the period of the oscillations allows one to estimate their luminosities and thus determine thier distances.

Pulsating variable stars change their luminosity because they are getting bigger and then smaller. The size of the star can change by 10%-20% which is a change in brightness by as much as 50%.



RR Lyrae and Cepheids

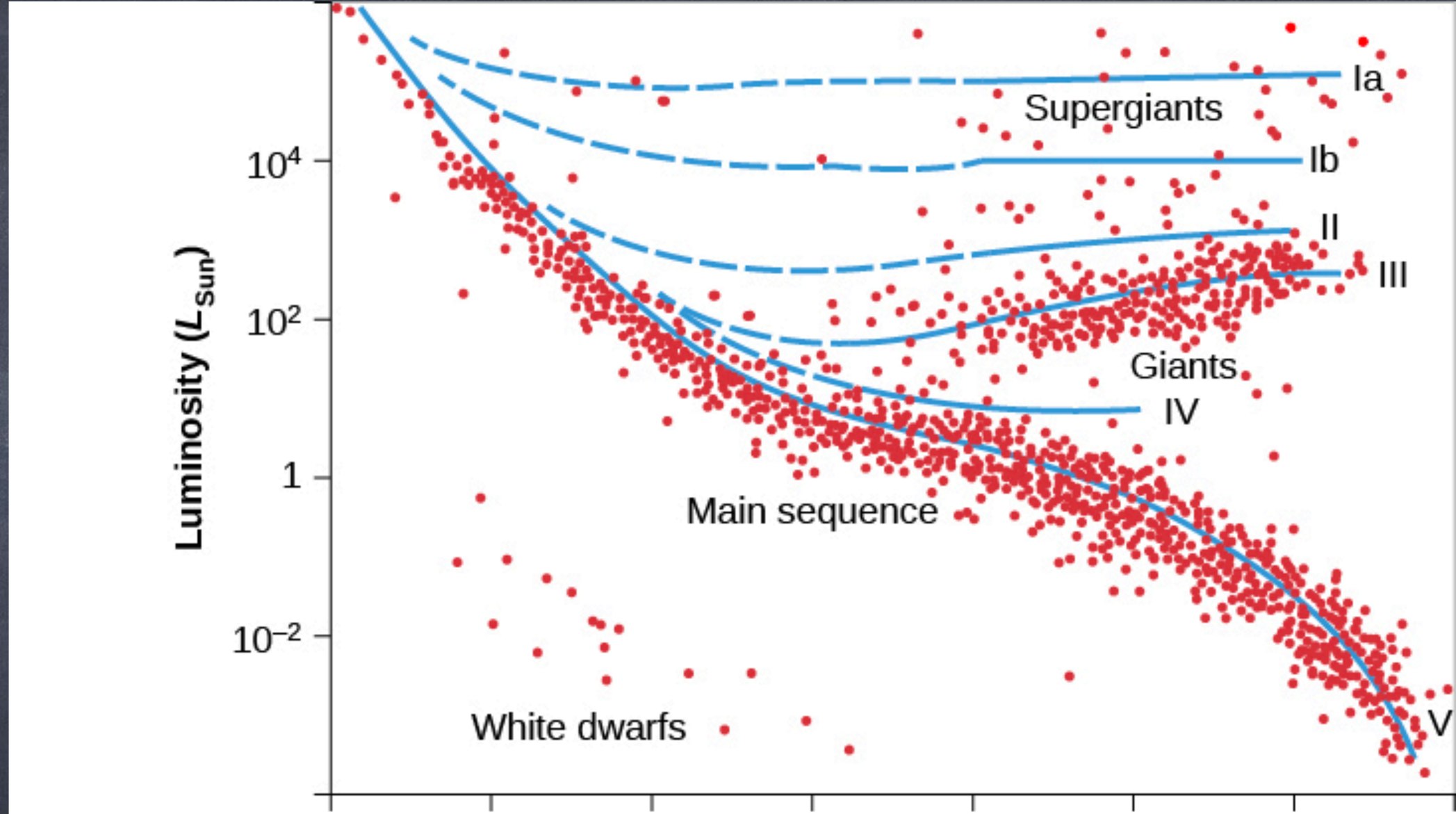
- Measuring the pulsation time for these stars gives a good measure of their luminosity.
- Measuring their apparent brightness thus tells you their distance.
- They are also very luminous so can be seen from far away.
- The only problem with these stars for finding distances is that they are rare.



Spectral Type Distance

- An alternative method of getting distances is to use the HR diagram.
- Like the period-luminosity relation for pulsating variables, the HR diagram gives us luminosity as a function of temperature.
- However, stars at a given temperature can have many luminosities. One also needs to know the pressure on the star to determine if the star is main sequence or a giant.
- This method works okay, but only gives distances that are accurate to about 25%. But it works for every star for which you can take spectra.

Knowing the temperature and the pressure for a star one can estimate its luminosity.



Distance Range

Method	Range
Parallax	4-30,000 light years (1pc-10kpc)
RR Lyra Stars	300,000 light years (100kpc)
HR Diagram	1,200,000 light years (0.4Mpc)
Cephiod Stars	60,000,000 light years (20Mpc)