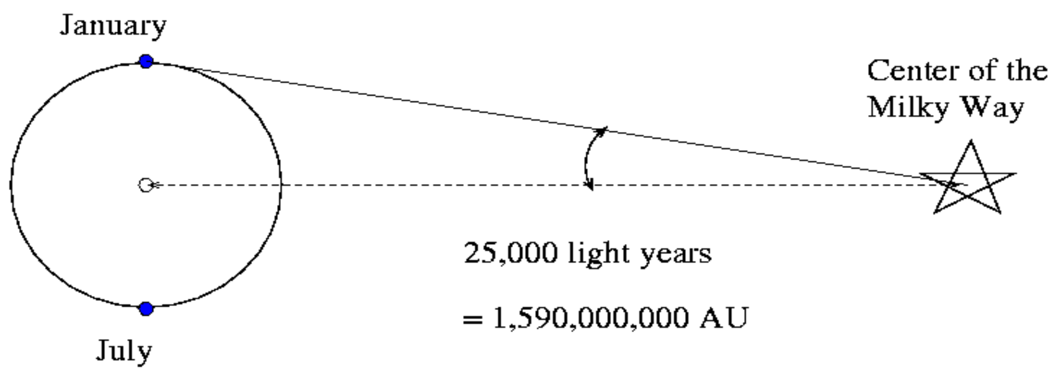
Pulsating Stars and the size of the Milky Way

If you look in your textbook on page 309, you'll see a diagram of the Milky Way Galaxy. It indicates that the disk is about 75,000 light years across, and the Sun is about 25,000 light years from the center of the bulge. How do we know these dimensions?

Is it possible to use parallax to measure the distance to the center of the Milky Way? The best parallax measurements from the Hipparcos satellite are around 0.003 arcseconds, or 8 x 10^(-7) degrees. Let's see ....



Q: How large would the parallax angle be?

Hmmmm. Parallax won't do the job.

You can observe clusters of stars, and use the HR diagram of each cluster to estimate its distance. But what if you want to know the distance on a finer scale, in between clusters?

In some circumstances, astronomers can use individual stars as **standard candles** to measure distances across the galaxy. A "standard candle" is simply an object of known luminosity. If we know the total power emitted by a star, or, equivalently, we know its absolute magnitude, then it may be used as a standard candle. Finding distances with standard candles is easy:

1. we know the intrinsic luminosity (absolute magnitude) ...

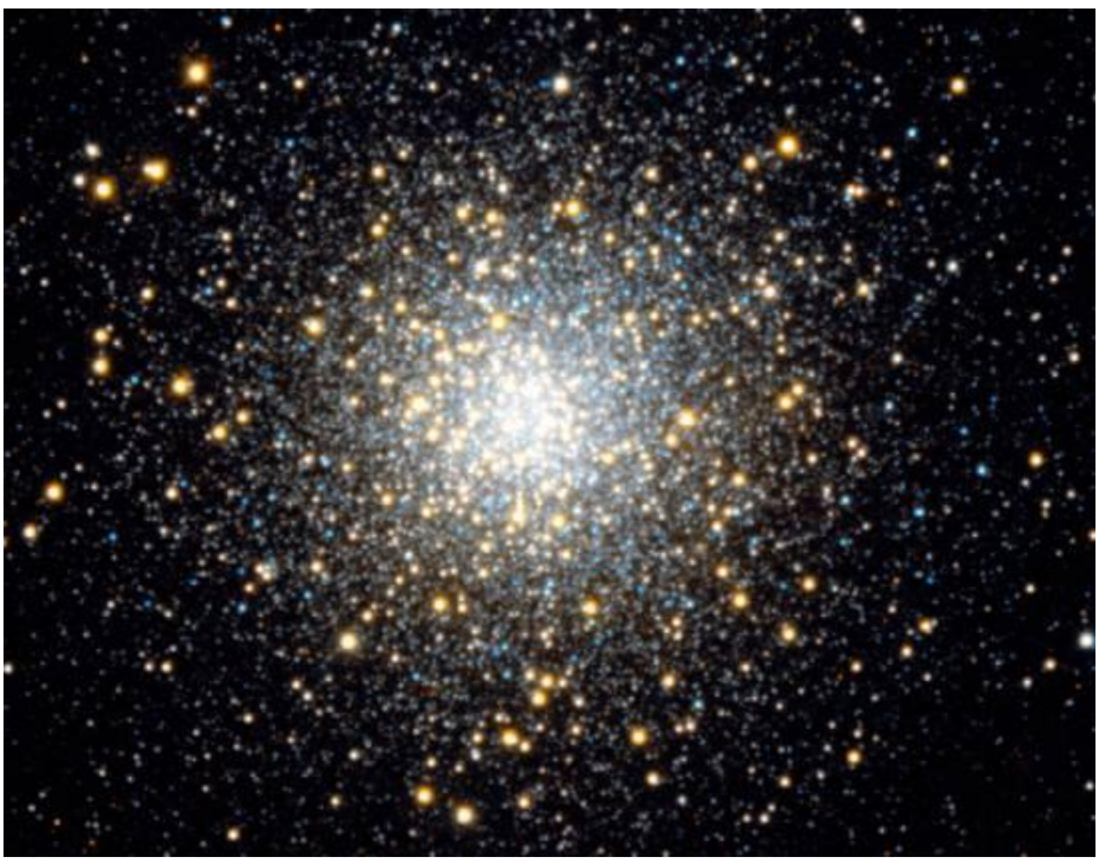
2. we observe it in the sky and measure its apparent brightness (apparent magnitude)
3. apply the inverse square law, or the magnitude-distance equation, to find the distance

So, all we need is some type of star we can use as a standard candle. Fortunately, Nature has provided two types of stars which are easy to recognize, and easy to use.

- RR Lyrae stars
- Cepheid stars

RR Lyrae stars

If you take a single picture of a distant cluster of stars, you see ... a bunch of stars.



You can measure the brightness of each star in the cluster. Then you have a bunch of numbers ....

But if you take a second picture of the cluster, and then a third, and then another, and another, and another, and measure the brightness of all the stars in all the pictures, THEN you discover something interesting:

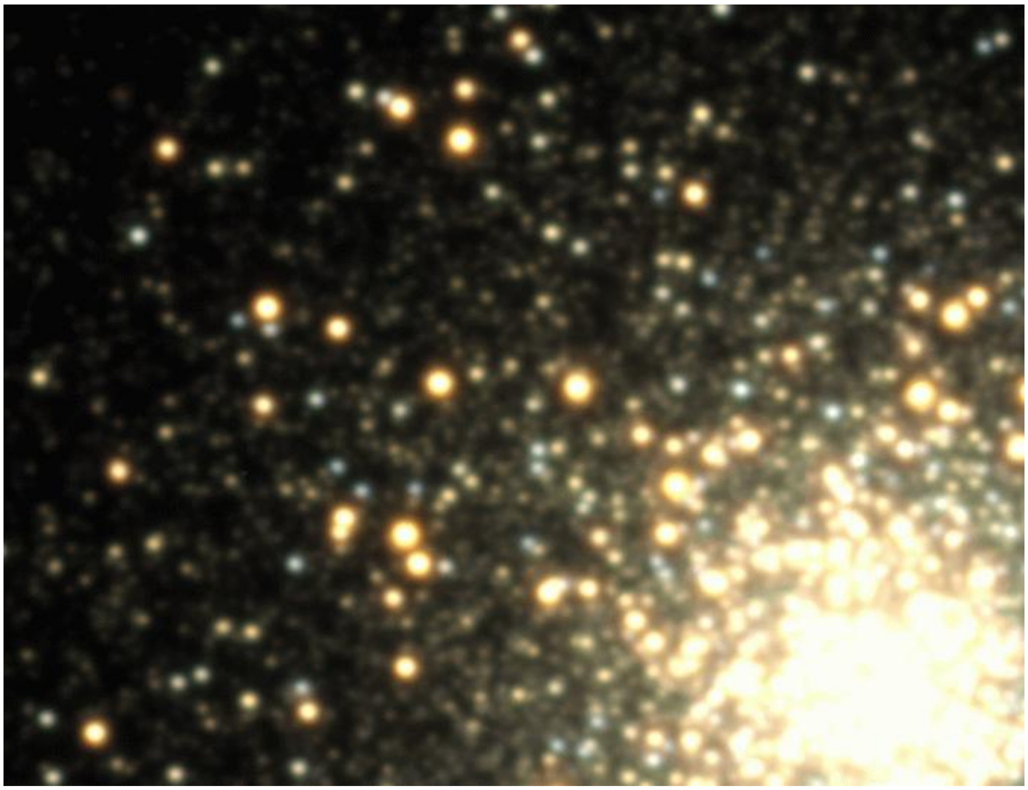
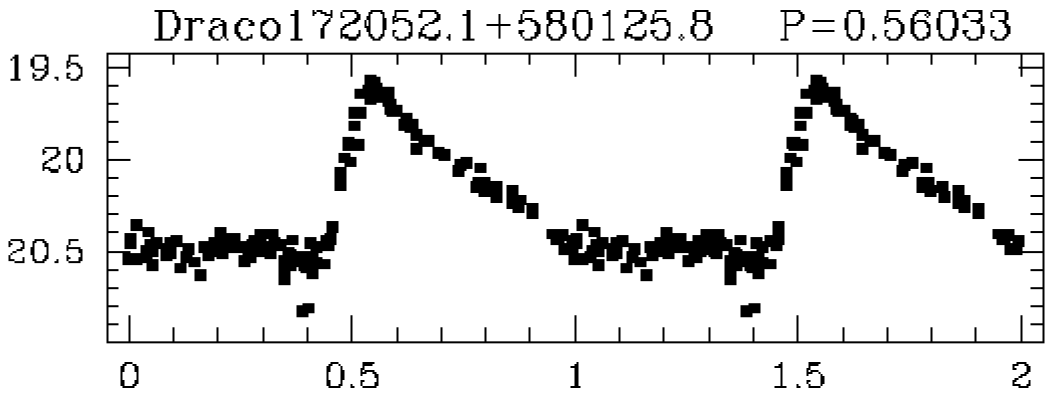


Image courtesy of J. Hartman and K. Stanek (Harvard CFA)

Most of the stars remain the same brightness all the time, but a small fraction vary, growing brighter and fainter, brighter and fainter.

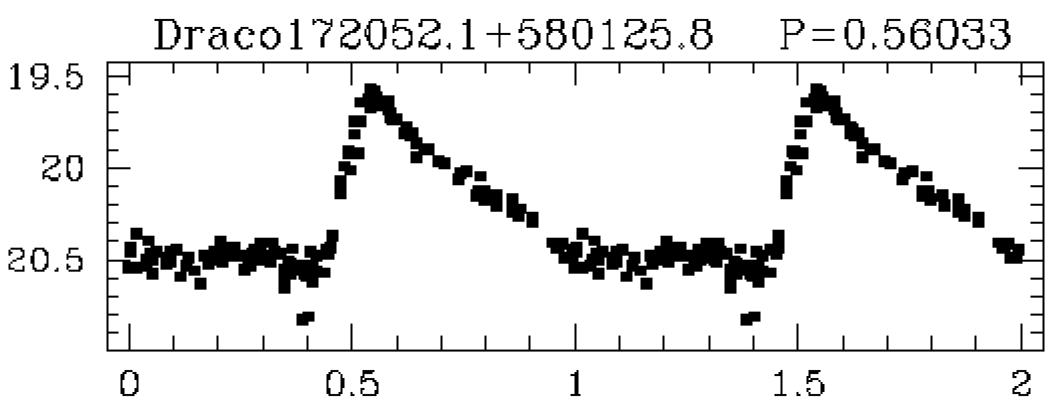


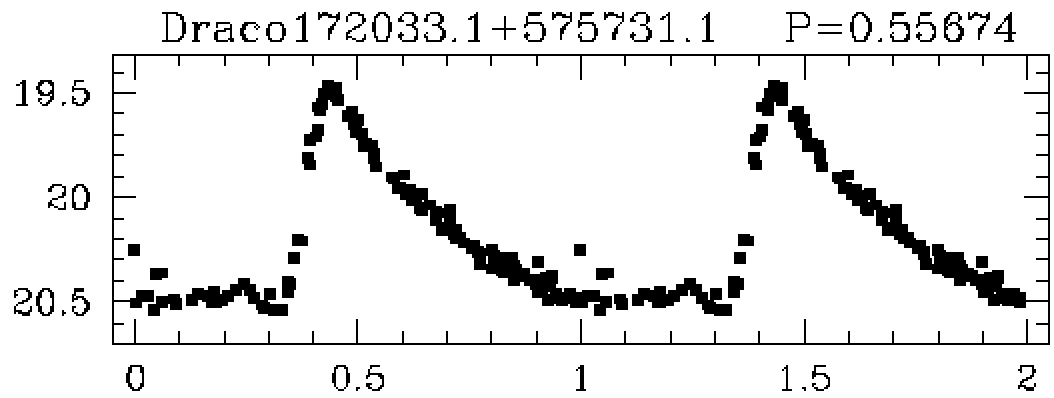
Many of these variable stars have a set of common features:

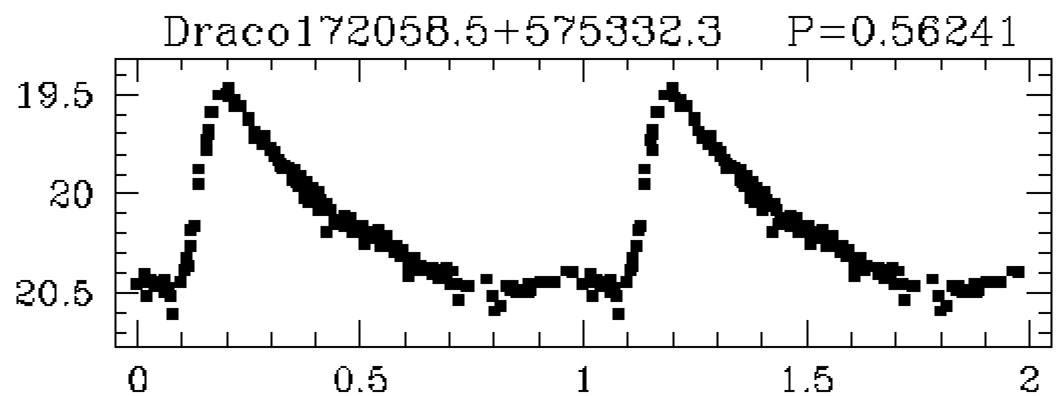
- a pattern of "sharp rise, gradual decline" in brightness
- a period of about half a day
- an amplitude of about 1 magnitude
- a color which indicates temperatures slightly hotter than the Sun

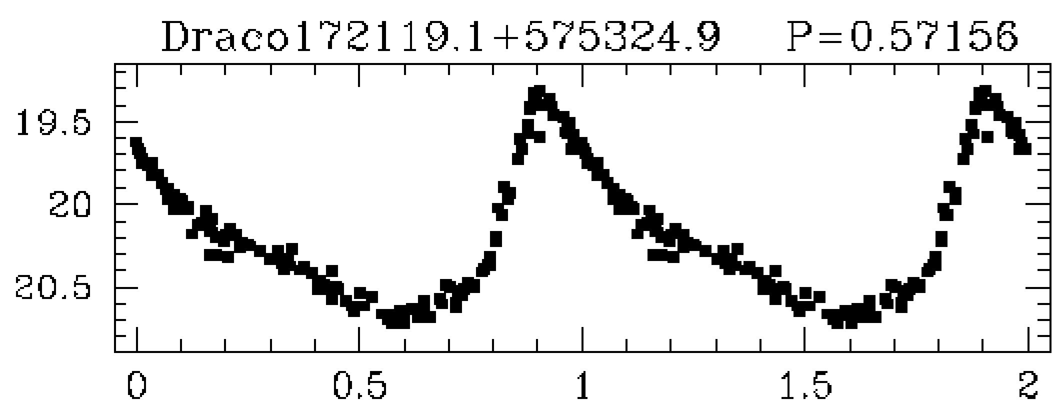
We call this class of variable star **RR Lyraes**, after one particular member, the star RR in the constellation of Lyra.

Oh, and one more thing they have in common: they all produce roughly the same power. Look at the magnitudes of a set of RR Lyrae stars in a cluster called Draco (taken from a paper by Bonanos et al.):









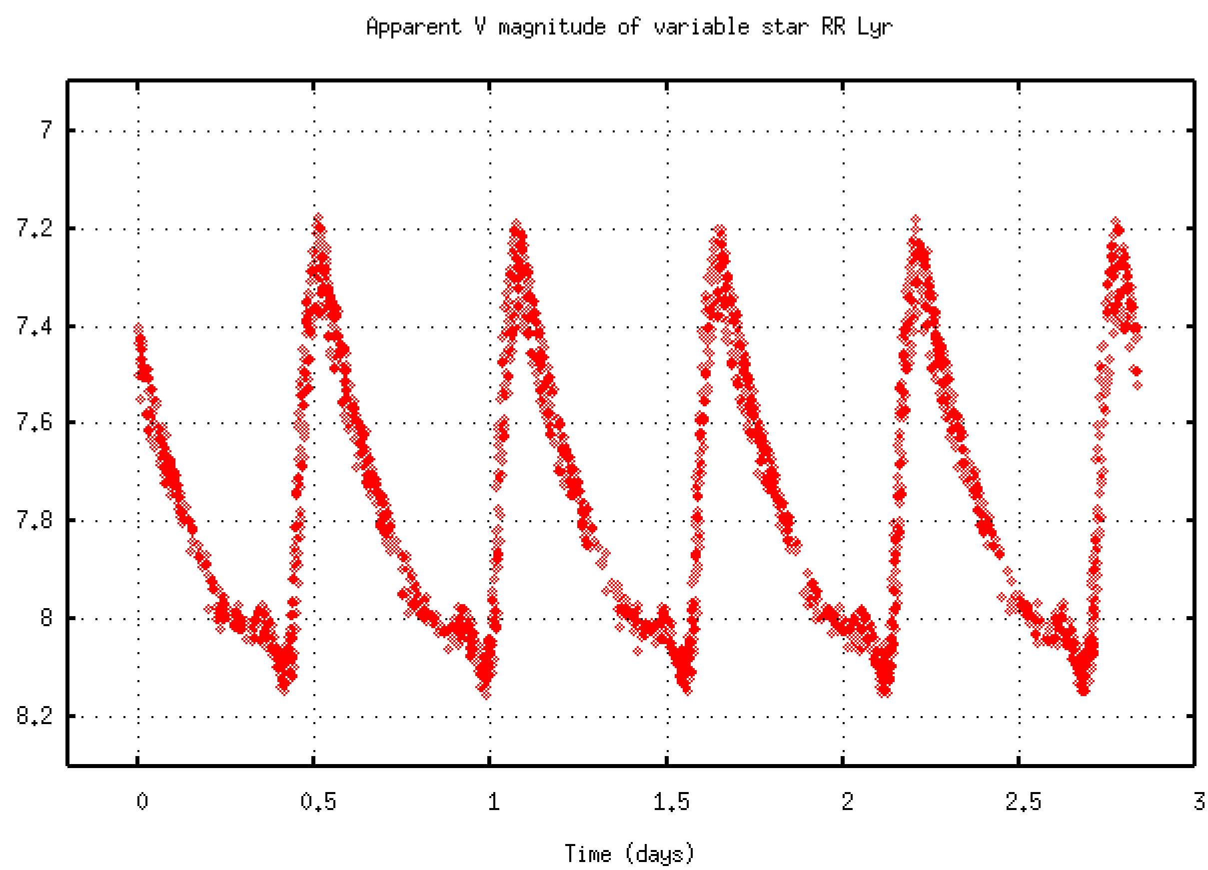
If they emit the same amount of light, then we can use them as standard candles. All we need to do is find out their absolute luminosity, and then we're set. It turns out that RR Lyrae stars are significantly brighter than the Sun. To a rough approximation, we can say they all have

RR Lyrae stars: (average) absolute mag M = 0.6

Their colors vary as they pulse, but typically lie between (B−V) = +0.20 and (B−V) = +0.50.

Q: Where do RR Lyrae stars fall on the HR diagram?

So, using this absolute magnitude, and the equation on page 312 of your textbook, can you figure out how far away from Earth the star RR Lyrae is?

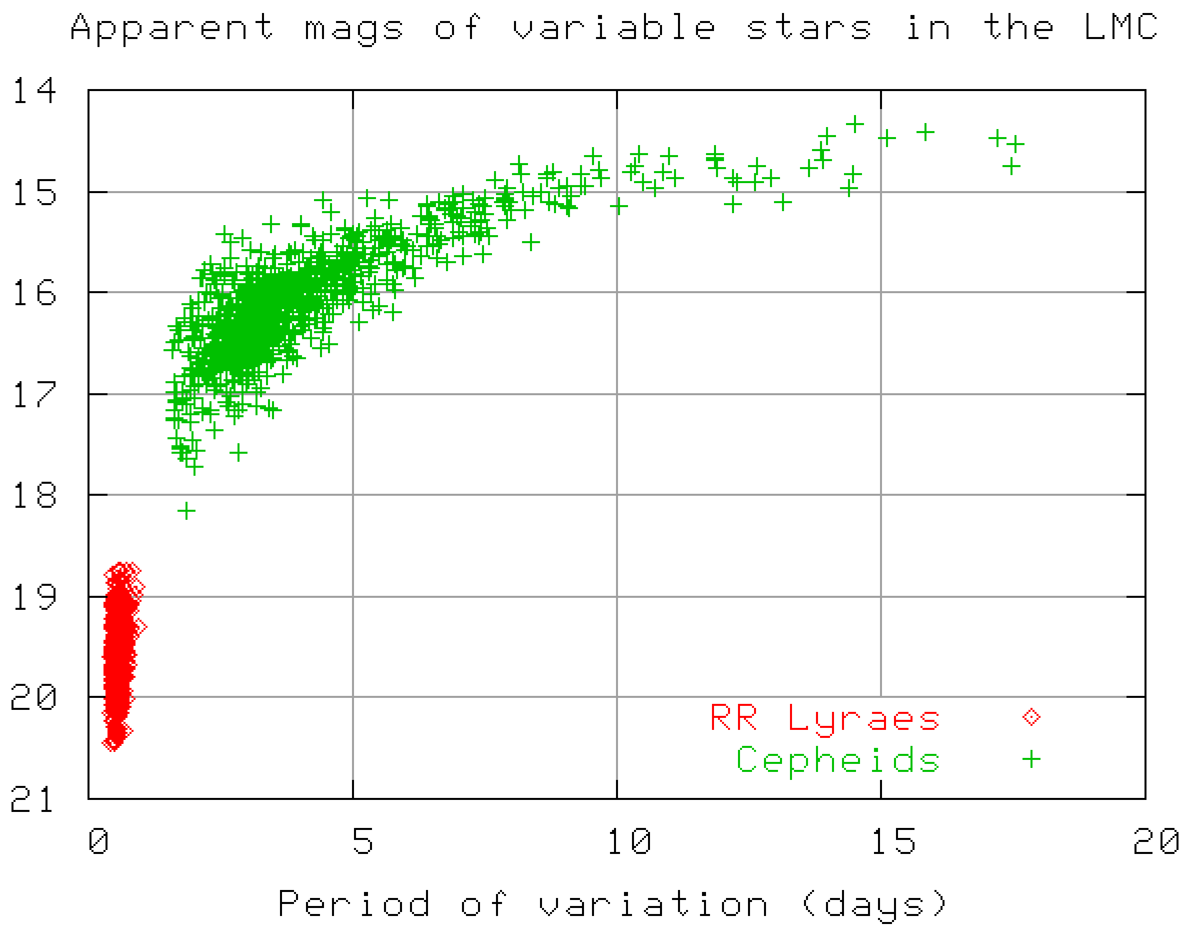


Cepheid variables

Cepheids are another class of variable stars which may be used as standard candles. They are both better and worse than RR Lyrae stars:

- better, because they are much brighter, and can be seen at greater distances
- worse, because they don't all have the same absolute magnitude

Hey! How can we use Cepheids as standard candles if they don't all have the same luminosity? Well, take a look at this diagram; it shows the apparent magnitude of stars in a distance cluster called the LMC, plotted as a function of their period.

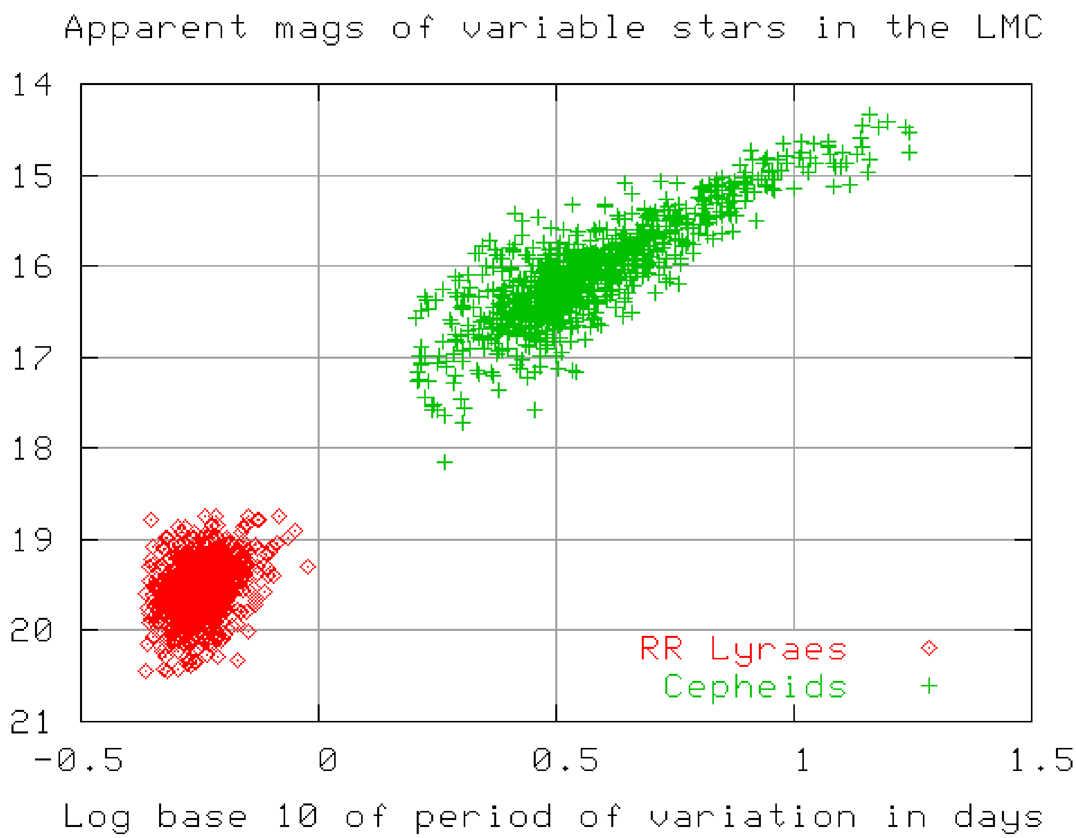


Thanks to the MACHO group

Notice two things:

- Cepheids have a wide range of periods, unlike RR Lyrae stars
- Cepheids have a wide range of magnitudes, unlike RR Lyrae stars

However, there is a saving grace: the absolute magnitude of a Cepheid variable star is correlated with its period. Longer periods mean more powerful stars. This is especially clear if one plots the magnitude of stars against the logarithm of their periods:



It is possible to make a simple equation which will predict the absolute magnitude of a Cepheid star, given its period. One analysis suggests

Cepheids: (average) absolute V mag M = -1.0 - 2.8 * log(Period)

The colors of Cepheids cover quite a range, due to their wide range of masses and their variations as they pulse; to a rough approximation, they span (B-V) = +0.5 to +1.0.

Q: Where do Cepheid stars of period P = 10 days fall on the HR diagram?

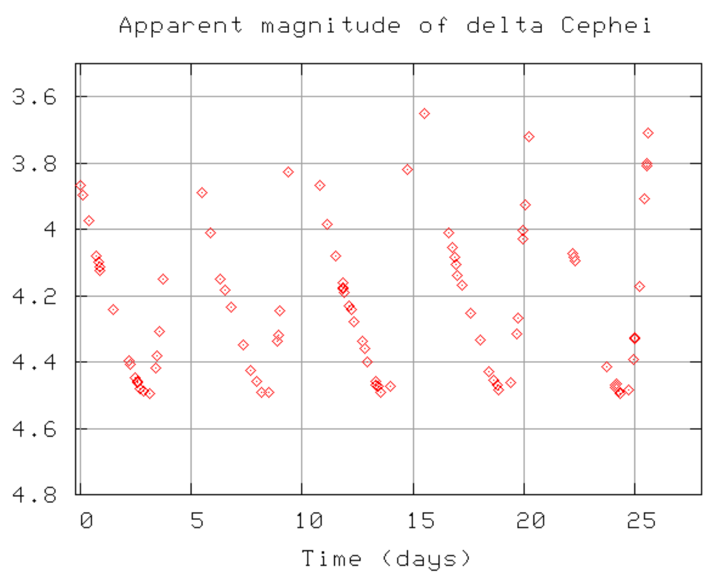
Q: Where do Cepheid stars of period P = 100 days fall on the HR diagram?

So, all you have to do is

1. take repeated pictures of a field
2. find Cepheid stars, based on their periodic variations
3. measure their periods and apparent magnitudes
4. calculate their absolute magnitudes
5. use the distance-magnitude equation to find their distance

It's a bit more work than for RR Lyrae stars, but since Cepheids are brighter, you can use them to measure greater distances.

Give it a try: below are some measurements of one Cepheid star (delta Cephei, the prototype of its class). Can you figure out its distance away from the Earth?



Using variable stars to find the size of the Milky Way

So, how can we use these variable stars to find the size of the Milky Way? Suppose that we want to measure the distance between the Earth and the center of the galaxy. All we have to do is take pictures of the center of the Milky Way, find some Cepheids or RR Lyrae stars, and ...

We can't see ANYTHING at the center of the Milky Way! Clouds of dust and gas block our view!

Source: http://spiff.rit.edu/classes/phys230/lectures/mw_size/mw_size.html