NAME:___________________________

VARIABLE STARS

What will you learn in this Lab?

This lab will cover three of the main types of variable stars that we observe in our night sky: RR Lyrae stars, Cepheid variable stars and Eclipsing Binary stars. After discussing how these stars are manifest in terms of their light curves, you will be asked to take a series of provided data and determine for yourselves which stars are which types and from there derive their particular properties.

What do I need to bring to the Class with me to do this Lab?

For this lab you will need:
- A copy of this lab script
- A pencil
- A scientific calculator

Introduction:

Not all the stars in the heavens have a constant appearance. Many of them change their apparent brightness over time. The nature of these variations can tell us much about the star itself, how far away it is and some other physical properties of the object.

RR Lyrae Stars

RR Lyrae stars are a special type of star that physically pulsate (in other words, stars get bigger and smaller) to cause the apparent change in brightness that we see from Earth. The pulsation comes from the fact that the star itself has entered an internally unstable state in its evolutionary history. This phase causes the star to "bounce" or oscillate back and forth across a stable size and brightness becoming alternately too large and fainter, and then too small and brighter.

Since the conditions for this type of behavior are so explicit, the absolute magnitude, M, of these stars does not vary much and is typically right around +0.5 magnitude. Such stars can be used as "standard candles" – if you know how bright it is intrinsically, then by measuring its brightness (its apparent magnitude, m) you can determine its distance.

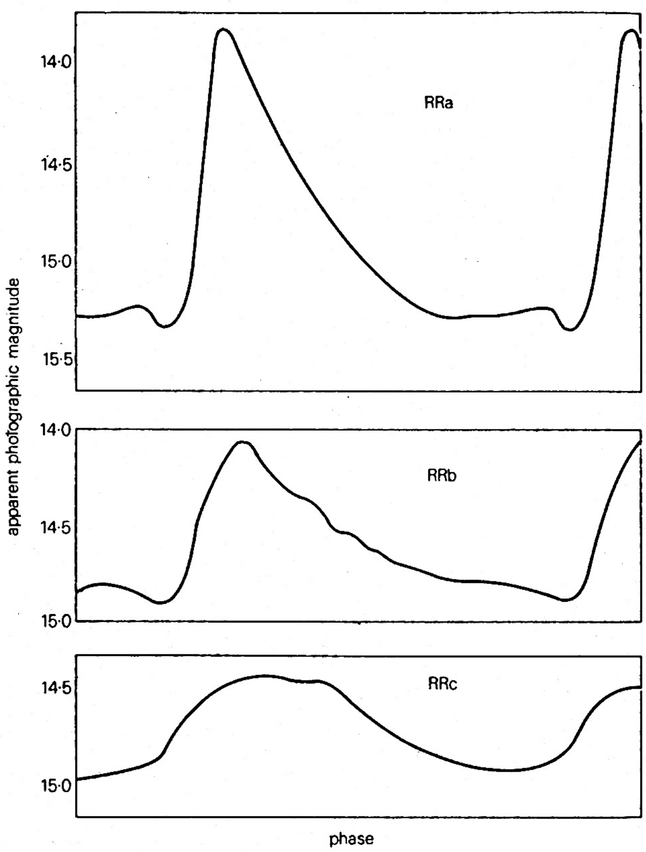


Figure 1

The equation for this calculation is:

$$m - M = 5\log_{10}\left(\frac{d}{10}\right) = 5\log_{10}(d) - 5$$

where d is the distance of the star measured in parsecs. 1 parsec = 3.26 light years = 3.09×10^{16} m.

When the brightness of a star is tracked over a period of time, a plot of the changes in brightness on a graph is called a *light-curve*. In the case of RR Lyrae stars, the shapes are determined by different types of pulsation – either whole or partial contracting.

Cepheid Stars

These are similar to RR Lyrae stars in that they oscillate in size and shape to provide the changes in brightness we see. However, Cepheids (named after the first one found: δ Cepheus) are much bigger and brighter stars than RR Lyrae stars. Cepheid stars also obey a period-luminosity relation that predicts that a star of a given period of oscillation has a certain intrinsic brightness, but that stars of different period have differing brightnesses. This is a remarkable result – it means that how fast a star changes in size and brightness is affected by how absolutely bright that star is. There are actually two types of Cepheids, but we will deal with only the brighter ones – Type I's.

The period of a variable star is found simply by measuring the time between the same parts of the light curve:

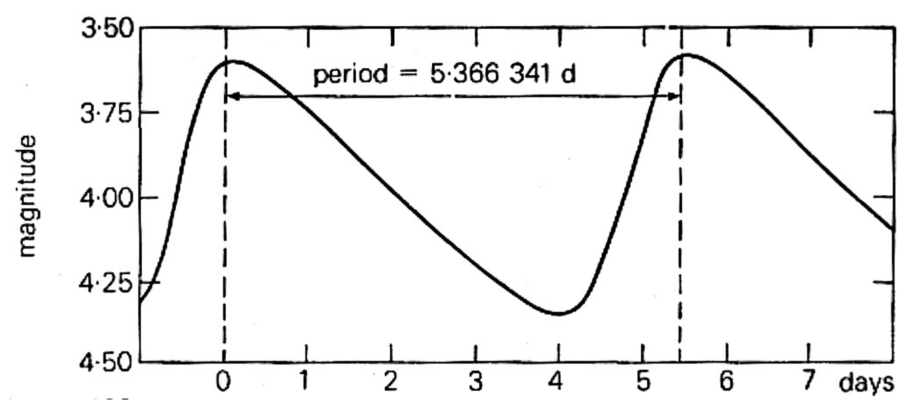


Figure 2

The final piece to this puzzle is the nature of the period-luminosity relation, shown below:

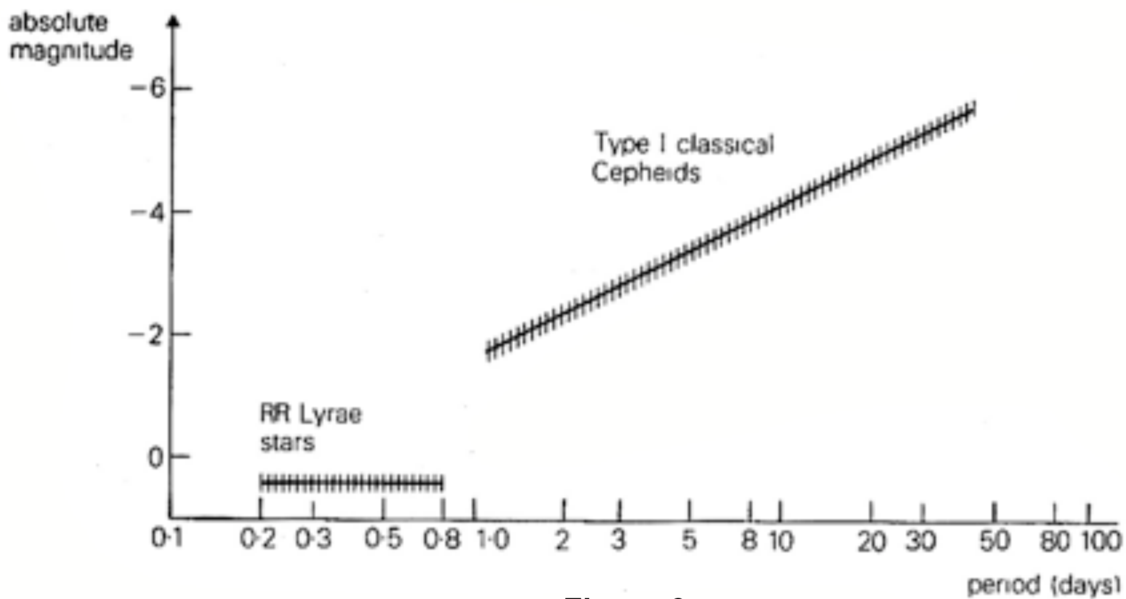


Figure 3

Therefore, if you can measure the period of a Cepheid variable star, you can determine how intrinsically bright it is, and thus the distance to the star. Note that the main difference between Cepheids and RR Lyrae stars is how long the period is – with the latter always having a period less than a day, and the former always being more than a day.

Why they pulsate – the Instability Strip

Both RR Lyrae stars and Cepheids pulsate because of a change in the internal structure of the star as it evolves. This state is actually well-defined on an H-R diagram and is called the "instability strip" as shown below. Also shown are the various locations you will find the types of variables stars that exist, and not just the ones we deal with in this lab. (Note: Type 2 Cepheids obey the period-luminosity relation, they're just a lot fainter – hence the parallel second track on the diagram above.)

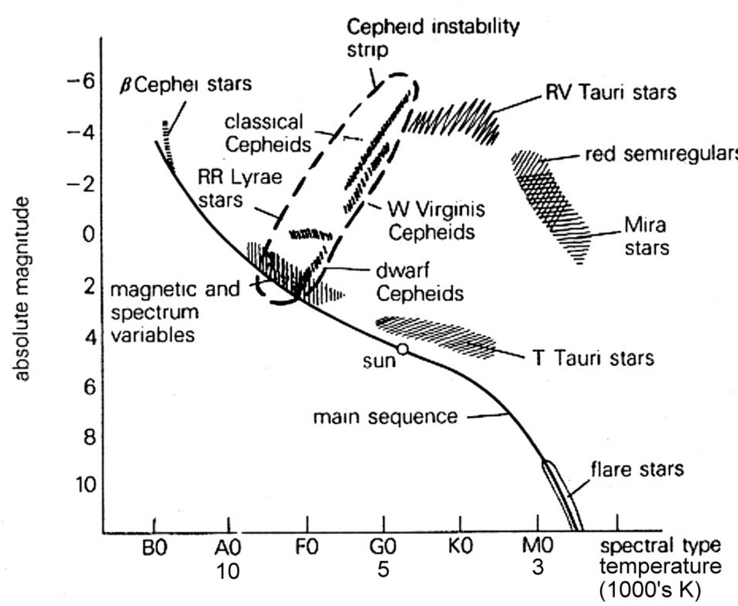


Figure 4

Eclipsing Binaries

The final category of commonly observed variable stars is eclipsing binaries. These are pairs of stars that orbit very closely with each other, in some cases sharing a common outer envelope of gas. What makes them unique from our point of view is that their orbital plane is seen almost edge on, so the two stars take turns eclipsing the light from the other star. As such the light curve seen from these objects obeys certain rules that tell us information about the stars involved.

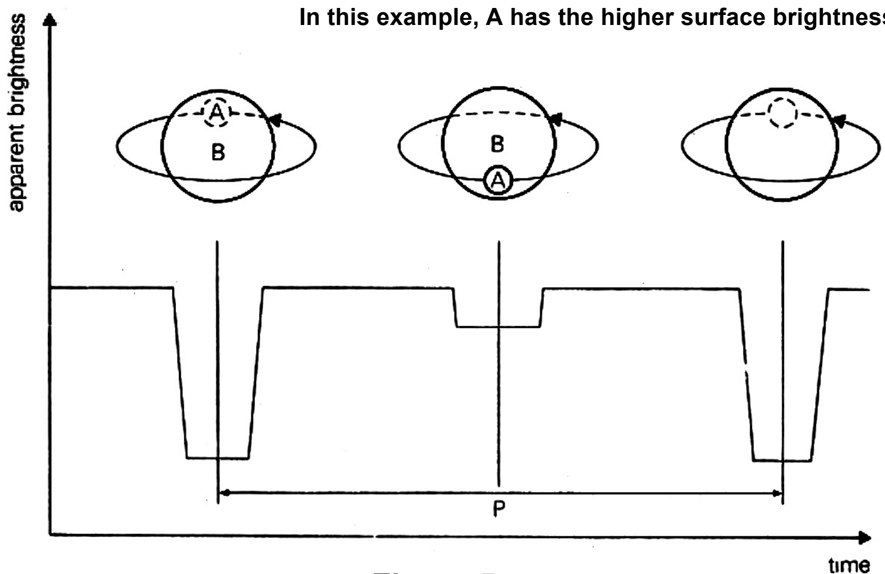


Figure 5

An eclipsing binary usually consists of two stars: one large with a low surface brightness, and another small but very bright. As the stars orbit one another, the smaller star is alternately visible and invisible. When both stars are visible the brightest light level is seen (Star A and Star B). When the small star is obscured, the light level drops to that of the larger star alone. Thus, the light curve tells us how bright the larger star (Star B) is. As the small bright star moves in front of the larger dimmer star, the light level drops to a combination of both the small star (Star A) and part of the larger star (Star B). **The amount of time each trough lasts also tells us something about the relative sizes of the two stars**.

The light curve shown is somewhat idealized, but you can see that it looks very different from the other ones you've seen. Again, the period of the system is measured between the peaks (or troughs) of the light curve. However in the case of Eclipsing Binaries we do not know the absolute brightness of the stars and additional information has to be obtained by other means including radial velocity measurements and spectra of the stars to know their exact type and mass to resolve the actual distance to the object. This particular method is of current interest because if you replace the smaller star with an orbiting planet, this is exactly the technique used to find exoplanets and determine their size and mass relative to the central star.

Procedure

Now you are going to put all this knowledge into play. First, answer the following questions about the different types of variable stars:

Q1. Consider the following properties: period, absolute magnitude, average apparent magnitude of an individual star, distance to the object, size of star

a. Which of the above properties can NOT be determined for an RR Lyrae star (there is only one)?

b. Which of the above properties can NOT be determined for a Cepheid variable star (only one)?

Q2. Consider the following properties: period, absolute magnitude, average apparent magnitude of an individual star, distance to the object, relative size of the stars

a. Which of the above properties can NOT be determined for an eclipsing binary system (there are two)?

Q3. We are going to give you light curve data acquired from a variety of sources, and you are going to use the information above to figure out what type of variable star each one is, and derive whatever properties for each object you can. Don't be intimidated – this is exactly what astronomers who study variable stars do all the time. Study each one carefully – some of the details are not as obvious as you might think.

Using your answers to the previous questions, fill out the table on the next page.

Note 1: Some of the cells in this table will remain empty when you are done.

Note 2: the period – luminosity relationship for variable stars indicates their *average* luminosity ⇒ average absolute magnitude ⇒ average apparent magnitude.

Note 3: If there is only one star, refer to it as "star A." **In some cases there may not be a "star A+B."**

Light curve	Variable type	Period (days)	Absolute mag (from Fig. 3)	Apparent avg mag of star A or B	Apparent magnitude of star A+B	Distance (parsecs)
1						
2						
3						
4						
5						
6						
7						
8						

Q4. What is the main difference between RR Lyrae stars and Type 1 Cepheids?

Q5. What are the other differences?

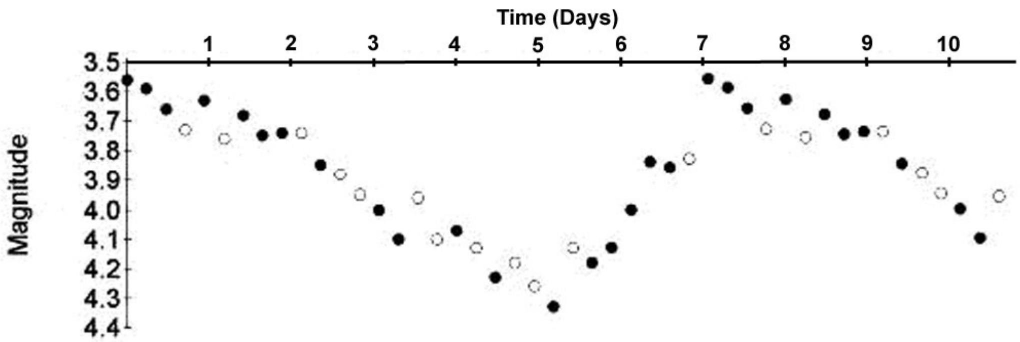
Q6. What can we determine from eclipsing binaries from the *length* of time for each dip in brightness?

Q7. Which of the two stars has the brighter surface per unit area – the larger or smaller one? How can you tell?

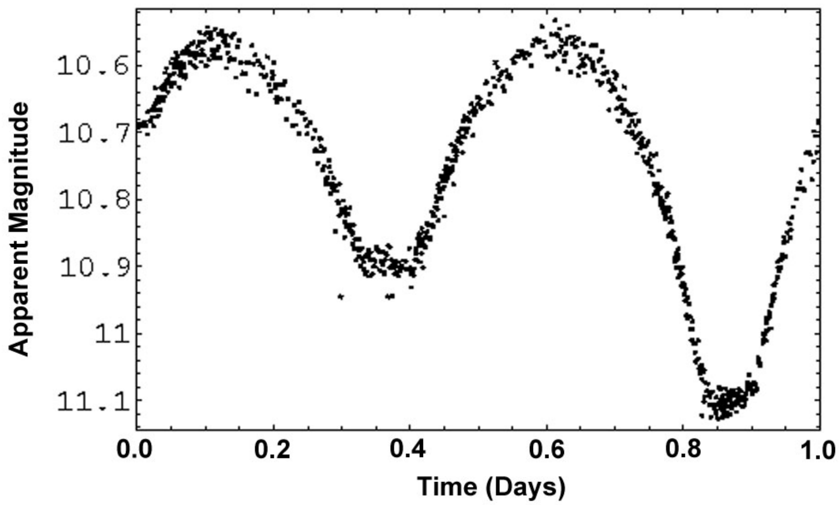
Q8. Which can you see farther away, RR Lyrae or Cepheid variable stars? Why?

Summarize what you have learned in tonight's lab:

ALL MAGNITUDES ARE APPARENT



1.



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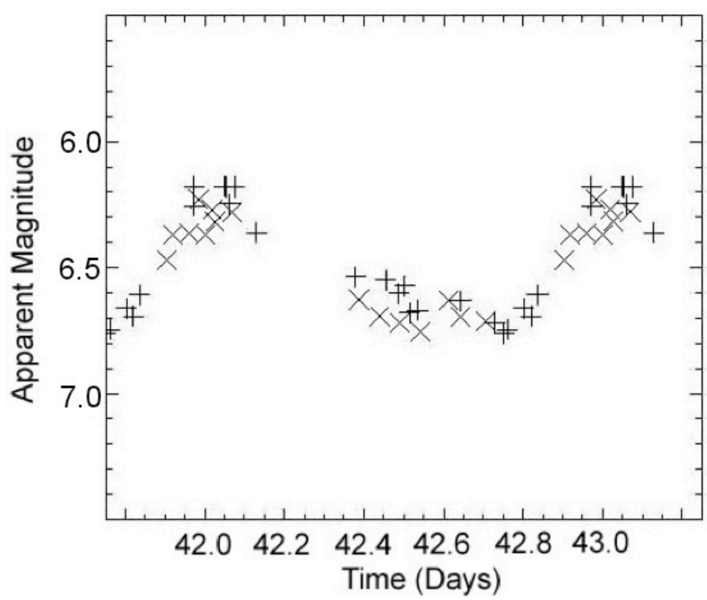

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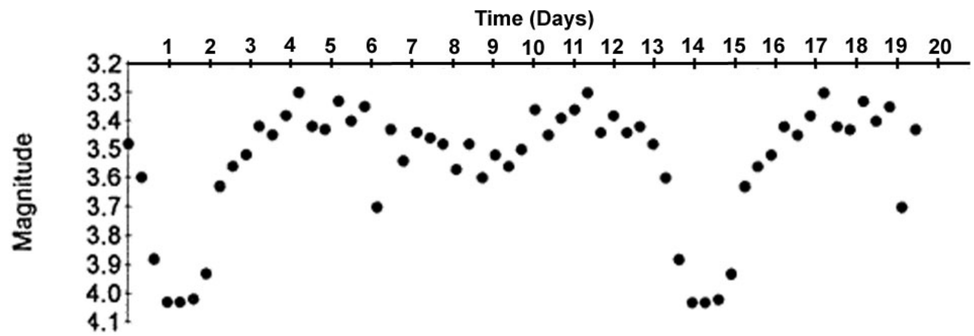
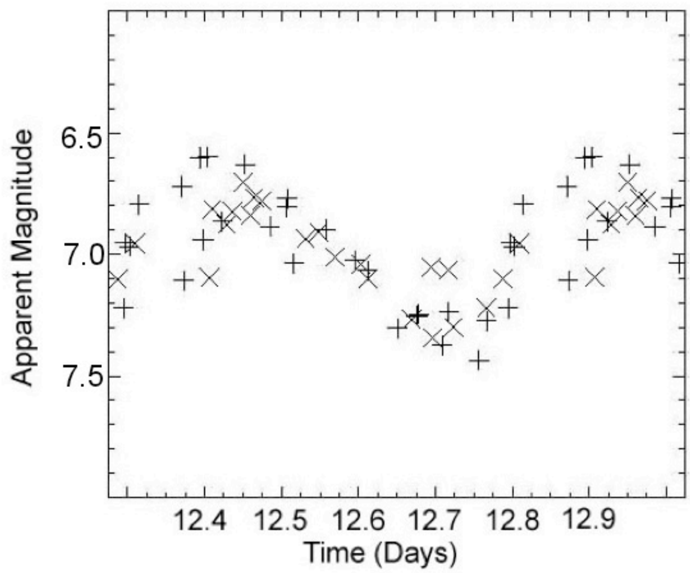
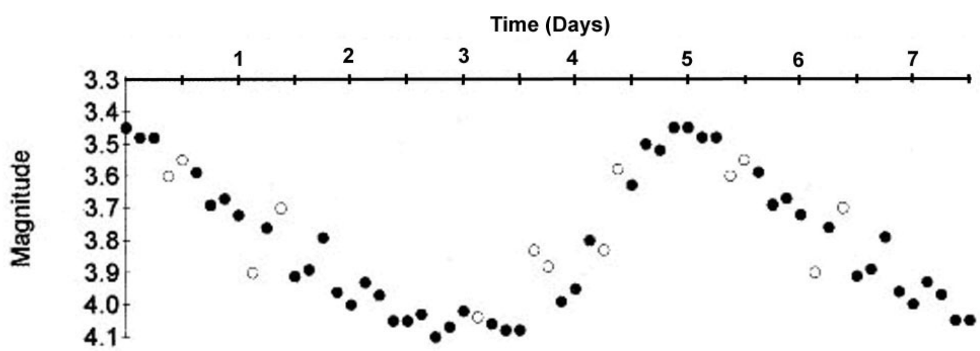

Time (Days)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Magnitude
3.2 3.3 3.4 3.5 3.6 3.7 3.8 3.9 4.0 4.1

4.

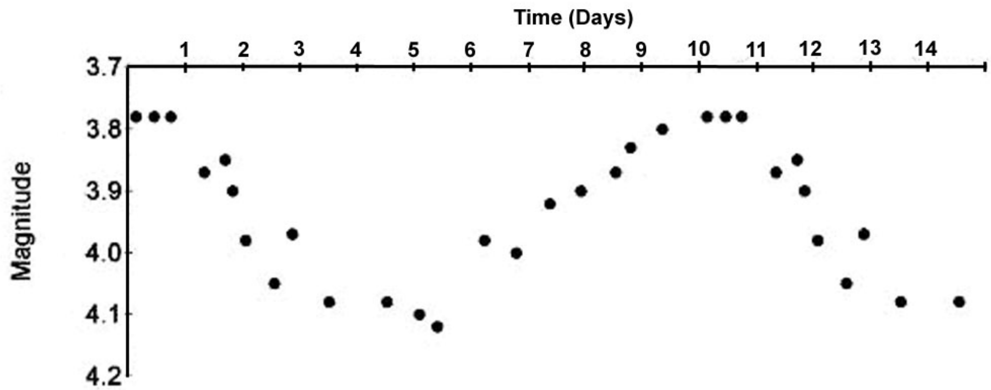

Apparent Magnitude
6.5 7.0 7.5
12.4 12.5 12.6 12.7 12.8 12.9
Time (Days)

5.

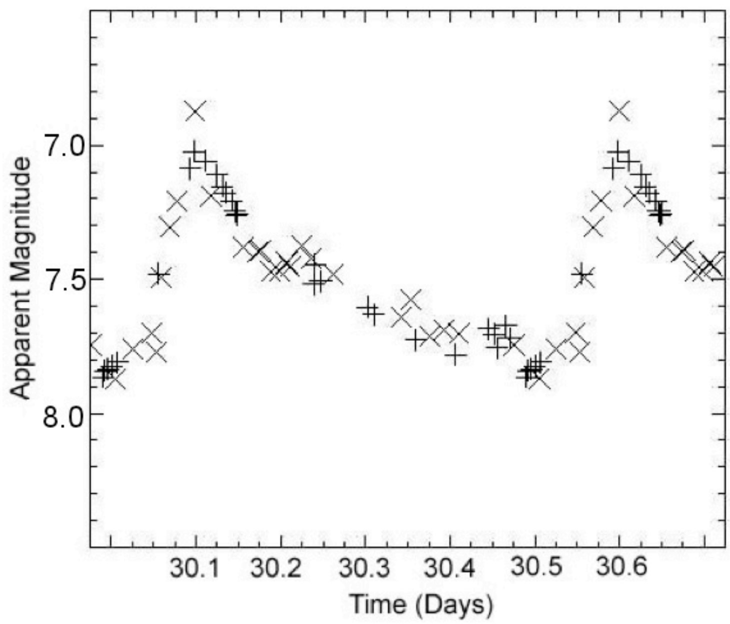

Time (Days)
1 2 3 4 5 6 7
Magnitude
3.3 3.4 3.5 3.6 3.7 3.8 3.9 4.0 4.1

6.

7.


Time (Days)
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Magnitude
3.7 3.8 3.9 4.0 4.1 4.2

8.


Apparent Magnitude
7.0 7.5 8.0
30.1 30.2 30.3 30.4 30.5 30.6
Time (Days)