# Observing a Variable Star – Interpreting the Data
# COSMOS Astronomy Project, Summer 2004

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By now you've used the eclipse experiment to learn about how the light will vary from different eclipsing systems, and made the conclusion that our star, *SZ Her*, probably is a system of two stars eclipsing each other. Such a system is not surprisingly called an *eclipsing binary star*. Now is a good time to learn some more about binary stars, but a lot of it you guys have already figured out so it will refresh your memory.

## 1 What is an eclipsing binary star?

Stars frequently come in pairs or groups, held together by their gravity. A pair of stars orbiting each other is called a binary star. It's like the solar system, except that one of the planets is another star. If the two stars are far apart we can usually see them as two separate stars, and if we wait long enough (on the order of hundreds or thousands of years) we can see the two stars moving around each other. If the two stars are close enough, we will see them as a single star in the telescope, but often we can still figure out that there's actually two stars there by watching the Doppler effect as one star comes towards us and the other star moves away.

An eclipsing binary star is what we get when the orbit of the two stars is arranged in such a way that one star will pass in front of the other as seen from the Earth. When this happens, the star will appear to get dimmer and then brighter again, since we can only see one of the two stars for a period of time. By watching how the brightness of the system changes with time, we can learn a lot about the two stars and how they orbit each other.

And not only will you use your observations to try to figure out what the star system looks like, you will also report them to the American Association of Variable Star Observers, AAVSO, so your observations will be used by professional astronomers to learn more about how these stars work!

## 2 Describing the Star System

As you've already explored in the eclipse experiment, the way the light varies depends on a lot of different things: how large the stars are, how far apart they are, how they orbit each other, and so on. From now on we will use a computer program to calculate the light curve from a particular star for you, but in order for you to know what you're doing, you need to understand how we describe the binary star system.

To describe an eclipsing binary star system, there are a number of parameters (at least six) that have to be specified. You should recognize all of them from the eclipse experiment, but astronomers use them in a slightly different way so they are all described here. If it seems

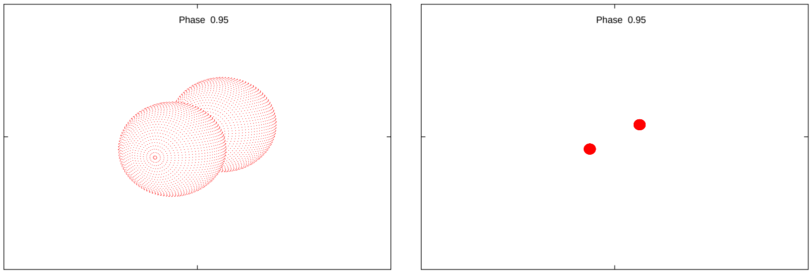



Figure 1: How large the stars are can make the difference between having an eclipse and not. The large stars on the left eclipse each other, but the small stars on the right do not.

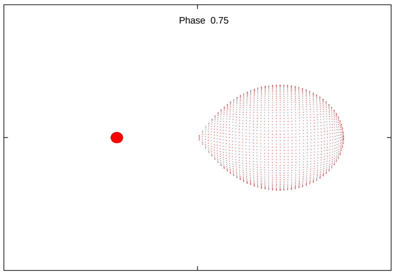



Figure 2: If a star is very large, the gravitational force from the other star will pull it out into a teardrop shape.

overwhelming, don't worry. You will get to play with the computer program to see what they all do, and your project advisor will be happy to explain it to you in more detail.

The simplest ones are the *mass ratio*, the mass of the first star divided by the mass of the second star, and the *inclination* of the orbit. The inclination describes whether we're seeing the orbit from the side, so that the stars will pass directly in front of each other, or from the top where we will just see the stars moving around each other, never one in front of the other. In order for a star to be an eclipsing binary, we have to see the orbit pretty much from the side, which means that the inclination has to be close to $90\,\deg$ .

The sizes of the stars, relative to how far they are apart, will also matter. If the stars are small and far away, they will only appear to be in front of each other for a small part in their orbit, but if they're so large they almost touch, one will almost always appear to be in front of the other. Look at Figure 1. The stars to the left are large, and the first star is eclipsing the second, while the small stars on the right seen from the same viewpoint are not eclipsing each other.

If a star is very large, the gravitational pull from the other star will distort its shape. The part of the star that is closest to the other star will be pulled more strongly, and the star will have a teardrop-like shape, like in Figure 2. If the star is very large, gas can actually be pulled completely off from the star and fall onto the smaller star.

A good way to think about the binary star system is to imagine two lakes, separated by a ridge. In this case, there are three possibilities:

- The water level in both lakes is well below the level of the ridge. This is like having two small, well-separated, stars.
- One of the lakes reaches up to the lowest point on the ridge, and water overflows into the other lake. This is like one star being so large that gas is pulled off of the large star onto

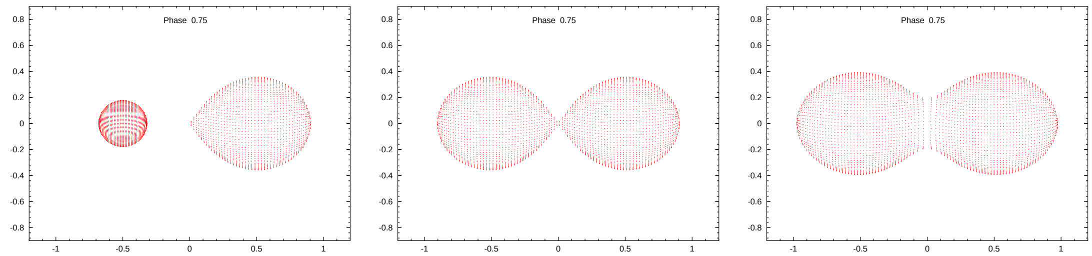



Figure 3: The size of the star can be expressed by the "Roche lobe filling factor", which tells you how large the star is compared to how large it can be before gas starts to get pulled off of the star. In the figure on the left, the smaller star has a Roche lobe filling factor of 0.5, while the larger star has a Roche lobe filling factor of 1.0. This means that the large star is just big enough for gas to fall onto the smaller star. In the middle figure, both stars have a Roche lobe filling factor of 1.0, so they just barely touch in the middle. In the figure on the right, the stars have a Roche lobe filling factor larger than one, so they have actually merged into a single object.

the small one.

- Both lakes overflow the ridge and form one single lake, with a waist in the middle. In this case the stars are so large that they actually touch and form one bowling-pin-shaped object.

The largest size that a star can have in the binary star system is given by something called the "Roche lobe", an imaginary, teardrop-shaped surface in the space around the star. Once the star grows to fill its Roche lobe, gas will start to fall onto the other star. In the computer program we will use, the size of the star is expressed by a quantity called "the Roche lobe filling factor". If the Roche lobe filling factor is 1.0, the star is just about as big as it can be without overflowing onto the other star. If the filling factor is 0.5, the star is half that size, and if it's larger than 1.0, the stars have merged into one. Figure 3 may make things clearer.

The *temperatures* of the two stars also affect the light. Hotter stars shine more brightly, so when they are eclipsed the loss of light will be greater than when the cooler star is eclipsed. This effect was very visible in the eclipse experiment when you had two bulb of different brightness. Cool stars have a red color, while hotter stars are whiter, so the system will actually appear to change color as well, and since we observed *SZ Her* using both the B and V filters, we will be able to check for that.

To reiterate, the six basic parameters are: mass ratio, inclination, Roche lobe filling factor, and temperature. The Roche lobe filling factor and the temperature have to be specified for both stars, giving six parameters.

As you may have gathered by now, figuring out exactly how the light changes as a function of time is not easy. Fortunately, you will have a computer program called "Nightfall" to do all this for you. You can play with the different parameters, see what the stars look like and how they affect the light curve, and your task is to see if you can figure out how to reproduce the light curve that you observed!

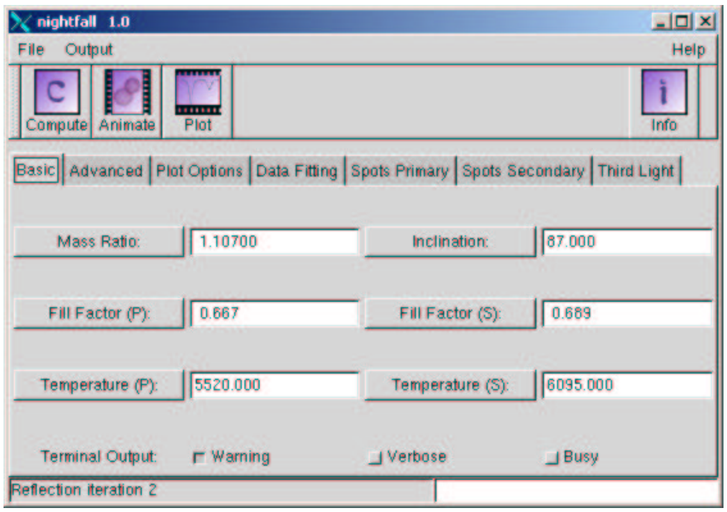
## 3 How to Use Nightfall

Nightfall, the program which calculates the light curve for you, is pretty easy to use. There are many options to play with, though, so it might take a little while to understand what is going on. Here's an overview of how to use it. There is also a user manual that you can look at if you want, or feel free to ask your advisor for help.

## 3.1 Overview

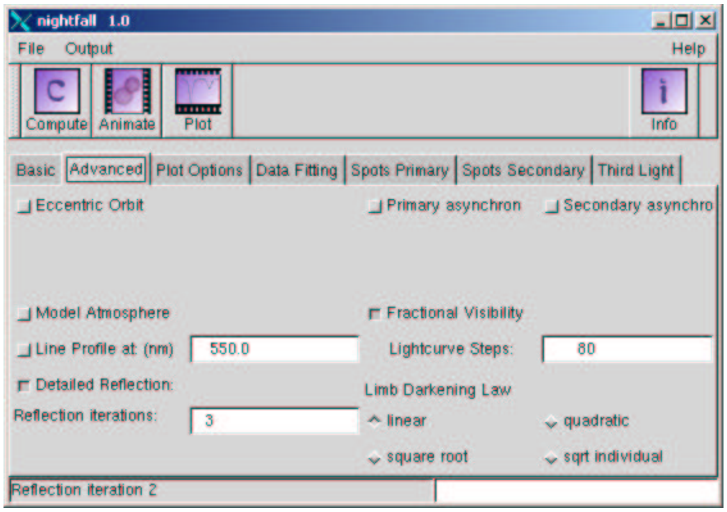
Nightfall has two main windows, you enter the parameters in the first one, and you get the results plotted in the other one. There are four big buttons on top, labeled Compute, Animate, Plot and Info.

- Compute is used to calculate the light curve when you have set the parameters you want.
- Animate is an on/off switch. If it's "on", the program will show you a little animation of what the system looks like when you press the Compute button (which makes it really slow...)
- Plot is used to plot the light curve after pressing the Compute button.
- Info brings up a help window which tells you what the different options are and what they do.

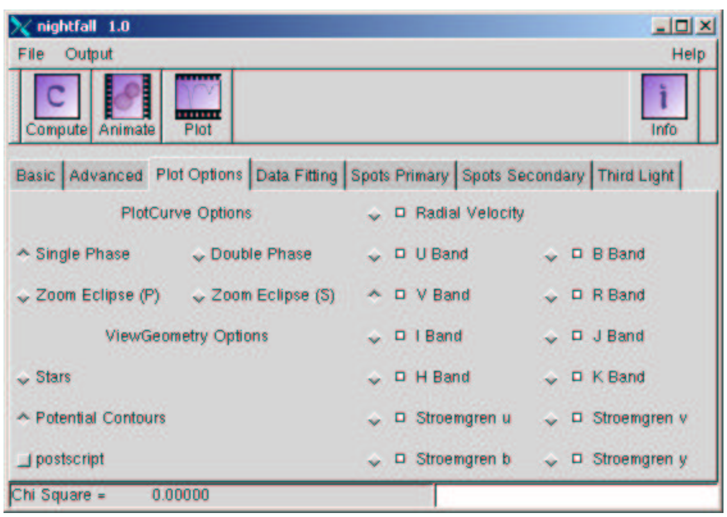



Below those buttons is a row of little tabs that bring up different options. You will probably only need to use the four first ones, labeled Basic, Advanced, Plot Options and Data Fitting.

- Basic contains the basic settings for the binary star system: the mass ratio, the inclination angle, the Roche lobe fill factor (of both the primary and secondary star) and the temperature (again for both stars). There are also three small buttons on the bottom of the window. The most useful one is probably "Warning", which will tell you when you're using settings that are suspect.

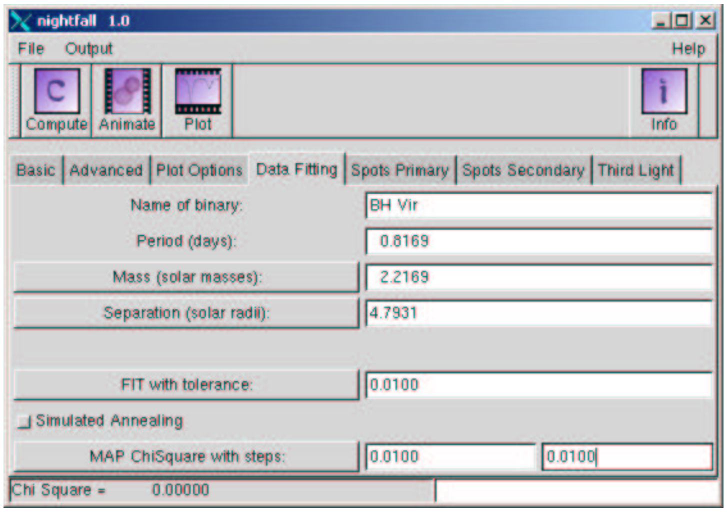



- Advanced contains more advanced settings that we haven't talked about so far. Some of the things you can set here:
  - Eccentric Orbit allows you to set the stars to orbit on an ellipse, so they get closer together and then further apart. This makes the calculation go very slowly, so don't set it unless you absolutely need to. Your advisor will tell you if that's the case.
  - Light Curve Steps controls how accurately the program will calculate the light curve. More steps means a more accurate light curve, but also takes longer time. Leave it at 80 unless your advisor tells you to.
  - Detailed Reflection controls how accurately the program computes light from one star that is reflected off of the other star. If the stars are large and almost touch, this needs to be turned on in order for the light curve to be accurate. If warnings are turned on in the Basic settings, the program will warn you if you are not using detailed reflection when you should.



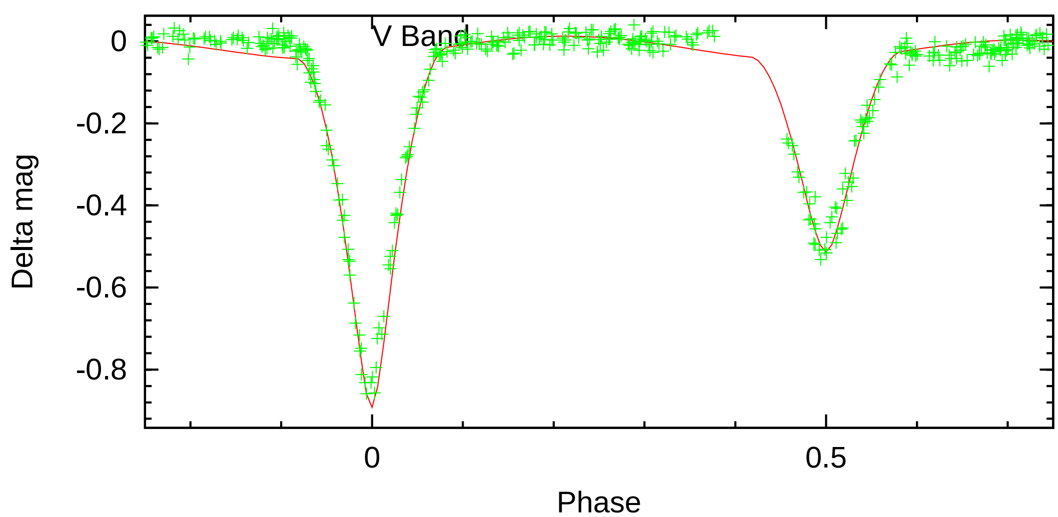

- Plot Options contains options for how the program will plot the results.
  - PlotCurve Options determines how the program will plot the light curve. Single phase plots a single revolution, double phase plots two orbits, and zoom eclipse shows a magnified view of the eclipse portion of the light curve.

– To the right there are a number of buttons labeled "U Band", "V Band", and so on. This determines what kind of light of the light curve describes. If it's set to "V Band", light curve is for green light, "B Band" is for blue light, and so on. If the two stars have different temperature, looking in different colors will give different light curves. We have observations in both V and B, so you will you have to use both of these. (The little white squares next to the labels will contain a little cross for the colors we have data for.)




- Data Fitting contains options that have to do with trying to have the computer program figure out by itself what the star looks like. This doesn't work so well, so most likely we won't try that.

There are also two menus on top of the window. "File" is used to load and save data. "Open data file" is used to load an observed light curve, like the one we got from the telescope. Once the light curve is loaded, the observations will show up along with the computed light curve, so it's easy to compare the two. The program will also tell you the difference between the observed light curve and the computed one, and this should be as close to zero as possible. The example below shows the light curve for another star, *BH Vir*. The computed light curve is the red line, and the observations are the green points.



"Save configuration" is used to save the parameters you have come up with, and "open config file" is used to load it again. This is useful if you want to continue playing with the settings you have tomorrow.

The "Output" menu contains different options for output. The most useful one is "StarView", which shows a little picture of the star system, and lets you look at it from different directions to see what's going on. (StarView made the images that are on the front page of this manual.)

### 3.2 Figuring out the Right Parameters

So, now your assignment is to figure out what the parameters are in order to make the light curve look like the one from *SZ Her* that we observed. How do we do that? Start by loading the data file that contains your observations. (Your advisor has prepared this file so it looks the way Nightfall wants it to.) Use the "Open data file" in the "File" menu to load the file. When you plot the light curve now, our observations will be plotted along with the computed light curve. They probably don't agree very well...

Try changing one of the parameters, press the "compute" button and then "plot", to see how that changed the light curve. If it looks more like the one we observed, try changing it a little more in the same direction. If it looks worse, try going in the other direction. Play this game with the basic parameters: mass ratio, inclination angle, Roche lobe fill factor and temperature.

If you get stuck, your project advisor will be happy to give you some tips. Also, when you have gotten a light curve that looks pretty good, you can try having the computer figure out the exact values of the parameters by itself. This is kind of complicated, so your project advisor will help you when you get to that stage. (Also, the computer is *very* slow at figuring this out, so you should start it when you are ready to leave and do something else.)

When you think you have figured out the answer, you can compare to the results that other people have gotten, and see if you agree. Your advisor will also help you save a picture of what the stars look like, that you can use in your presentation.

## 4 Publication

The coolest part of this project may be that your results will actually be used by astronomers who are working to understand eclipsing binary stars. The American Association of Variable Star Observers (AAVSO) collects observations from hundreds of people all over the world, and these observations are then forwarded to scientists that can use them.

Specifically, what they are looking for is accurate measurements of at what times the stars are at minimum brightness. The rotation of eclipsing binary star systems slows down over time, by some very complicated mechanisms, and to study this you need many, many measurements of the falling and rising brightness of the stars, spread out over a long time.

Once you have completed the analysis, and you have a light curve, you will send this to the AAVSO. Your advisor will prepare the data file so that it's in the right format, and you will then report it in an e-mail to them.

If you're interested in finding out more about variable stars and how to observe them, you can check out the AAVSO Web site at www.aavso.org – you *don't* have to have a super advanced telescope like the one we used here. With training and experience you can make useful observations just using your eye and a pair of binoculars.