

## Light Curves and What They Can Tell Us

A light curve is a graph which shows the brightness of an object over a period of time. In the study of objects which change their brightness over time, such as novae, supernovae, and variable stars, the light curve is a simple but valuable tool to a scientist. A sample light curve is shown in Figure 1. The light curve is the graph, or plot, generated from the following data:

Date	Brightness (Magnitude)	Date	Brightness (Magnitude)
April 21	9.2	June 20	8.7
April 27	9.3	June 26	8.3
May 3	9.7	July 2	8.6
May 9	9.9	July 8	9.1
May 15	9.6	July 14	9.1
May 21	9.8	July 20	9.2
May 27	9.9	July 26	9.5
June 2	9.7	Aug 1	9.9
June 8	9.1	Aug 7	9.7
June 14	8.8	Aug 13	9.7

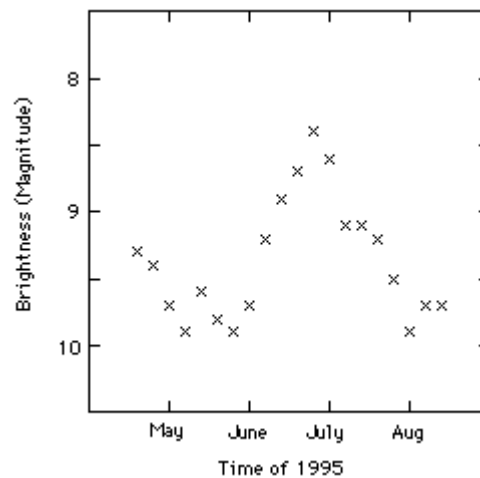


Figure 1

The plot shows the brightness of a certain astronomical object viewed through a telescope every 6 days over the course of a few months. This gives us a light curve of the object we have measured. But light curves can be generated for any measure of brightness which is repeated over and over in time. So, if I measured the number of X-rays being emitted by a star during every second for an hour, I could generate a light curve from my observations. Astronomers call these plots light curves because it is usually some part of the electromagnetic spectrum that we measure as a function of time and use to help us understand our universe.

How do we use light curves to tell us something useful?

The record of changes in brightness that a light curve provides can help astronomers understand processes at work within the star (or stellar system) and identify specific categories (or classes) of stellar events. For example,

once a light curve has been made for a certain stellar object, it can be compared to standard light curves to help identify the type of object being studied.

If the light curve you measured looked like Figure 2, then you could identify your object as an eclipsing binary star. We can also tell from this light curve that it takes 10 days for one of the stars in the binary to orbit completely around the other. Astronomers would say "the orbital period of the binary system is 10 days."

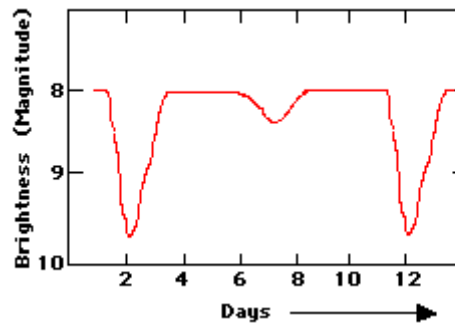


Figure 2

If the light curve looked like Figure 3, scientists would know that this signals the death of a star by a massive explosion called a supernova!

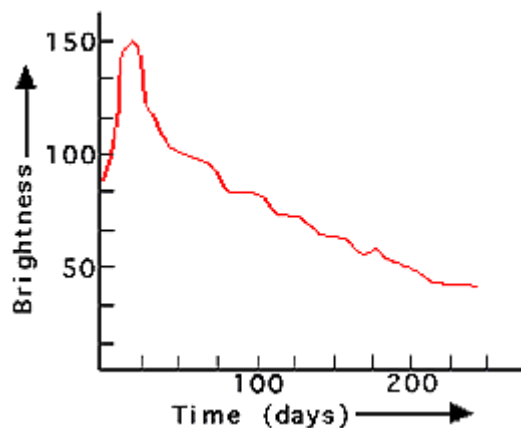


Figure 3

### Tools for All Astronomers

Because most of the objects that astronomers observe are so far away, we cannot touch them - observing the light that they emit is often the only means we have of understanding them. Studying the light that comes from a source can tell us a great deal about what kind of object it is - we can measure the energy of the light coming from the source, we can measure the amount of light coming from the source, and we can make an image of the source. If we graph the amount of light having different energies, we can make a spectrum. We can also measure the brightness of the source over time, making what is called a light curve. By making an image of the source, we see what it looks like.

The concept of an image is probably the most familiar - telescopes like the Hubble Space Telescope produce many beautiful images. But images can also be made using light we can't see with our eyes - such as infrared or ultraviolet. Graphical data, like spectra and light curves, are very valuable to astronomers as well. Among other things, a spectrum can give us information about an object's composition, mass, and motion. A

light curve can analyze short-term or long-term changes in the brightness of a source - useful for bursting objects, binary systems of stars, and pulsars.

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A light curve is a graph of intensity over time. Such a graph is made by counting the number of photons coming from a source over a period of time. For example, by counting the number of X-rays being emitted by a star every second for an hour, you could generate a light curve from your observations. Your light curve would tell you how bright your source is and the amount of time it remained at that brightness. A graph similar to a light curve can be generated for any physical measurement which is repeated over and over in time.

([http://heasarc.gsfc.nasa.gov/docs/xte/learning\\_center/universe/light\\_curves.html](http://heasarc.gsfc.nasa.gov/docs/xte/learning_center/universe/light_curves.html))

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What are X-ray Binaries?

Binary star systems contain two stars that orbit around their common center of mass. Many of the stars in our galaxy are part of a binary system. A special class of binary stars is the X-ray binaries, so-called because they emit X-rays. X-ray binaries are made up of a normal star and a collapsed star (a white dwarf, neutron star, or black hole).

(<http://heasarc.gsfc.nasa.gov/docs/objects/binaries/binariestext.html>)

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#### Compact Binary Quantization?

Compact binaries, consisting of a "normal" low mass star and a compact object (either a neutron star or black hole), are among the brightest X-ray sources in the sky, and also among the most active X-ray emitting objects, switching from faint states to bright states, apparently irregularly. Now, thanks to continuous monitoring with the All Sky Monitor (ASM) on the Rossi X-ray Timing Explorer (RXTE), astronomers Padi Boyd and Alan Smale have discovered an underlying pattern in the apparently random variations in X-ray brightness for 3 important compact binaries. Boyd and Smale found that the number of days between low points of emission can, for each source, be described as a series of integer multiples of some fundamental underlying number. For example, the neutron star binary Cygnus X-2 has an orbital period of 9.8 days. Boyd and Smale found that the time between minimum X-ray brightness is always a whole-number multiple of 9.8 days -- for example 77.7 days, 58.8 days or 49 days, which are 8, 6 and 5 times 9.8. However the multiple that will come next cannot be predicted. Boyd and Smale also looked at 2 black hole binary systems, Cygnus X-3 and LMC X-3, and found that while some integer multiple relation did exist for these systems, the integer multiple was not related to the orbital period.

([http://heasarc.gsfc.nasa.gov/docs/objects/heapow/archive/compact\\_objects/lmxb\\_asm\\_numerology.html](http://heasarc.gsfc.nasa.gov/docs/objects/heapow/archive/compact_objects/lmxb_asm_numerology.html))

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[http://imagine.gsfc.nasa.gov/docs/ask\\_astro/binary.html](http://imagine.gsfc.nasa.gov/docs/ask_astro/binary.html)

The Question

I have a couple of questions for you on binary stars. I would just like to know how the stars got their name "Binary," which scientist discovered them, and why people find them so interesting.

The Answer ([http://imagine.gsfc.nasa.gov/docs/ask\\_astro/answers/980202a.html](http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/980202a.html))

'Binary' just means having two parts, and you will find it used in many places (whenever there are two of something) and not just in connection with stars. The English astronomer William Herschel coined the term binary star, after an investigation in the 1790s of stars that appear close together in the sky showed that many were indeed pairs of stars traveling together. Binary stars are very important in astronomy, because a lot of things which are hard to discover when stars are on their own can be easily measured when two are together.

When two things are close together, they affect each other in many ways, and we can learn a lot from those effects. For example, two stars close together exert a gravitational pull on each other changing the way they move. By measuring their movements very carefully we can often figure out how much material is in each star - how heavy it is.

The Question

How can binary stars be detected even when a telescope like HST can't even see them together?

The Answer ([http://imagine.gsfc.nasa.gov/docs/ask\\_astro/answers/980330d.html](http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/980330d.html))

There are stars called spectroscopic binaries that are detected when a spectrum is seen to contain two sets of lines which move slightly relative to each other, in step with the two stars' movement about their common center of gravity. If we are roughly in the plane of the binary orbit, we will see first one set of lines slightly blue shifted and the other slightly red shifted (as one star moves towards us and the other away) and then the opposite effect (after another 180 degrees of mutual revolution). If the two stars are similar the two sets of lines will be similar, but if the stars are quite different the lines will be too.

The Question

What percentage of the stars are binary systems?

The Answer ([http://imagine.gsfc.nasa.gov/docs/ask\\_astro/answers/980402c.html](http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/980402c.html))

Somebody once said that "2 out of every 3 stars are in a binary". Seriously, the fraction is very high, but it's difficult to be precise, because it's difficult to prove that a certain star is definitely single. Of the stars nearest to the Sun, about half are known to be in multiple systems.

The Question

Binary stars are popular in science fiction. Star Wars' Tatooine, for example.

I'm wondering about the orbit of a planet around binary stars. Is it possible?

Would the greater combined mass of two stars be more likely to pull in surrounding material, hence making the formation of planets less likely in a binary system?

Would the combined heat and radiation from binary stars mean that habitable planets would have to have a VERY large orbital radius?

The Answer ([http://imagine.gsfc.nasa.gov/docs/ask\\_astro/answers/980122c.html](http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/980122c.html))

There are stable orbits for planets in binary star systems. There are various stability criteria which say when an orbit is stable. One such criteria (and I don't know the actual numbers) says that if all orbits are circular and the stars are the same size, then the planet must orbit one of them at less than /some fraction/ of the inter-star distance, or must orbit both combined at more than /whatever/ times the inter-star distance. Figure-eight orbits are unstable, and can eject the planet from the system.

If you have two Sun-like stars at the center of the system, a planet would be the same temperature as Earth if it were at  $\sqrt{2} = 1.4$  astronomical units away, rather than Earth's 1 AU. This distance is closer than Mars's orbit (1.6 AU). Most stars are dimmer than our Sun, so the orbit could be even smaller.

The high energy astronomers at NASA don't know much about this subject, so we asked an expert: Eric Mamajek of Pennsylvania State University:

The solar-like stars 16 Cygni B and 55 Cancri A have been found to have Jupiter-size extrasolar planets orbiting them. So we do have indirect proof, through Doppler spectroscopy methods (Marcy & Butler, SFSU, Lick Observatory), that planets indeed form in binary systems.

The formation mechanisms for forming stars and planets are very different. Planets require accretion to form, specifically accretion in a protoplanetary disk around a young star. Stars can form from the collapse of a molecular cloud core on their own, however planets can only form in the disk around a star. (Pulsar planets are likely formed "posthumously" around pulsars, and are a different beast all together). The main problem with forming planets in multiple star systems is dynamic ejection... stars can simply toss planetesimals out of the system all together (or even accrete them). An example of this is the Kirkwood gaps in the asteroid belt where Jupiter doesn't allow asteroids to exist in certain orbits, and conversely it "shepherds" asteroids in to certain other orbits. A companion star would have a similar effect, except there would be a lot less "shepherding" orbits. The vast majority of binary stars have eccentric orbits. It is difficult for bodies to exist in a system with two very massive bodies in an eccentric orbit. They can only exist very close to each star, or very far from both stars.

An excellent example in the lines of the Tatooine example is the nearby solar-like stars Alpha Centauri A and B. They orbit each other at an average distance of 23 AU, however the eccentricities of each orbit bring them to as close to 11 AU and as far as 35 AU. Numerical simulations by Paul Weigert at University of Toronto have shown that each star has a "safe zone" about 3 AU in radius in which planets could safely survive for billions of years. Objects placed further out from each star than about 3 AU are dynamically ejected in a matter of millions of years or less. Alpha Cen A is about 1.5 times as luminous as our Sun, and Alpha Cen B is about .45 times as luminous as our Sun, and if you do the simple physics, one can see that a "habitable zone" exists around BOTH stars within the 3 AU dynamic "safe zone." Indeed, it could be possible that BOTH Alpha Cen A and B have planets conducive to life. Theoretical models age them anywhere from 3-8 Gyr... plenty of time for life to develop if the planets have the right conditions...

#### The Question

I'm curious about why there is such a large percentage of binary star systems. What are the best theories about the reason for this? Are there any websites you would recommend to research this?

The Answer ([http://imagine.gsfc.nasa.gov/docs/ask\\_astro/answers/990321a.html](http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/990321a.html))

A major barrier to star formation is angular momentum. A gas cloud collapsing to form stars can convert its angular momentum into the rotation of the stars, both as individuals and as members of larger groups rotating about a common center of mass. The binary stars tend to gain energy (i.e. become closer together and shorten their periods) through collisions with single stars in dense stellar environments, thus making it more difficult for single stars to form.

#### The Question

How are binary star systems formed?

The Answer ([http://imagine.gsfc.nasa.gov/docs/ask\\_astro/answers/010330b.html](http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/010330b.html))

This is a very good question and, perhaps much to your surprise, this can be a hot topic for a debate among astronomers.

In essence, a binary-star system emerges out of a cloud of gaseous material collapsing and forming more than a single star at the same time in a small proximity. This type of a collapsing event does not necessarily form only two stars -- it can form more than two, but it all depends on their unique environment in which stars form.

Also it is most unlikely for a single star to capture another star in a typical stellar space. When two stars encounter, they tend to swing by each other and almost never captures one to another by their own gravitational field. We are not going to explain why it is so, but you will need more than two stars (in fact, many stars) to do just that. Some cases of binary-capture may have been seen in a place like globular clusters where a million of stars are found in a very tiny volume of space.

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One amateur-astronomy organization has helped professionals by observing stars since 1911. The American Association of Variable Star Observers (AAVSO) monitors variable stars, which vary due to explosions, eclipses, pulsation and rotation. By supplying data for light curves -- graphs that plot brightness changes over time -- amateurs have allowed professional astronomers to test their models of how variable stars work.

\*\*\*Monday, May 29

By 10 o'clock, the constellation Lyra the Lyre hangs well above the eastern horizon. The pattern consists primarily of its brightest star, Vega, trailed by a parallelogram of four stars, which form the body of the mythical harp of Orpheus. As you look at this parallelogram, note the two easternmost stars, and in particular the one that lies furthest south of the two.

This is Beta Lyrae, also known as Sheliak, an eclipsing variable star that fluctuates a little over a magnitude from 3.45 to 4.36 every 13 days (or, to be as accurate as possible, every 12.939637 days). Being an eclipsing variable, Beta Lyrae itself does not vary intrinsically, rather it is periodically occulted by a fainter companion.

When the companion passes between brighter Beta and Earth, it dims the light of the brighter star. The period from minimum to minimum marks the orbital period of the companion.

Fortuitously, there is an easy way to calibrate Beta's maximum and minimum magnitudes. As you study the star from night to night, compare its brightness to Sulafat (Gamma Lyrae), which lies to Beta's left (or north), and Zeta Lyrae, which lies above Beta, nearest Vega. At its brightest, Beta should be only slightly fainter than Sulafat and at its dimmest it should equal Zeta.

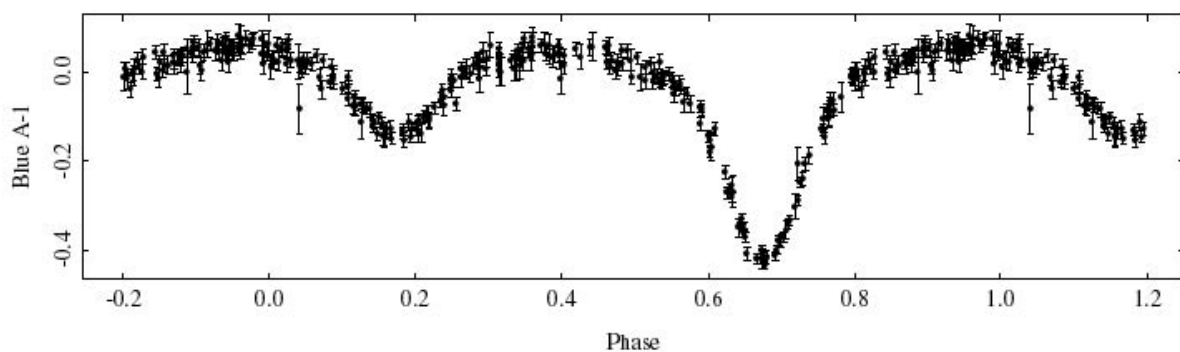
([http://www.space.com/scienceastronomy/astronomy/skywatch\\_000529.html](http://www.space.com/scienceastronomy/astronomy/skywatch_000529.html))

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(<http://www.physics.sfasu.edu/astro/binstar.html>)

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Eclipsing binaries consist of two stars orbiting each other in a conformation relative to the observer such that brightness variability occurs as one star passes in front of the other in turn; as the stars may be of different brightness, the drop in light flux depends on which star is in the front. These stars have periods of between 3 hours and 24 years, although 0.5 to 10 days is the most common range. The light curve from an eclipsing binary is shown in the next figure:



The brightness changes in the remaining classes of periodic variables is caused by periodic pulsation (contraction and expansion) of the stars and their outer layers.

(<http://stat-www.berkeley.edu/users/rice/UBCWorkshop/>)

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<http://www.physics.sfasu.edu/astro/binstar.html>

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We present solutions of recent new photometric observations of the eclipsing binary EF Boo and of the eclipsing and spectroscopic binary CN And. Radial velocities are incorporated into the solution for CN And. Absolute dimensions are determined for CN And and estimated for EF Boo. For EF Boo, no solutions have been published prior to this paper. We find that an over-contact configuration with a dark spot on either of the two stars fits the observations well. We successfully model CN And as a marginally contact system. The shape of its light curve is dominated by a large dark spot on the more massive component. Reliable absolute dimensions are determined for this system for the first time. (<http://www.aas.org/publications/baas/v32n4/aas197/329.htm>)

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<http://www.ta3.sk/caosp/Eedition/FullTexts/vol31no1/pp5-12.pdf>

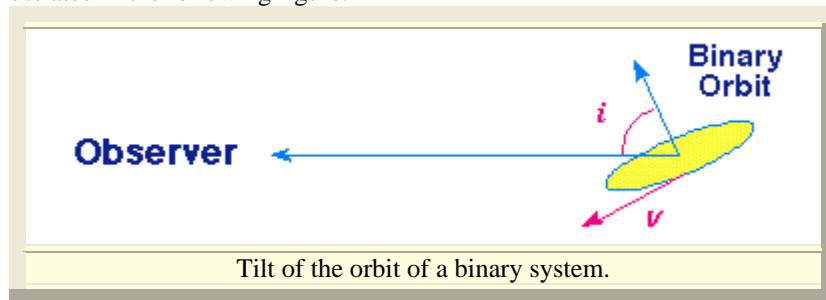
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## ECLIPSING BINARIES

If in a binary star system the orbits are oriented so that one star can pass in front of the other as we view the system, we say that the binary is an eclipsing binary. In some cases, this can lead to significant variations in the light output of the system.

### Orbital Orientation in Binary Systems

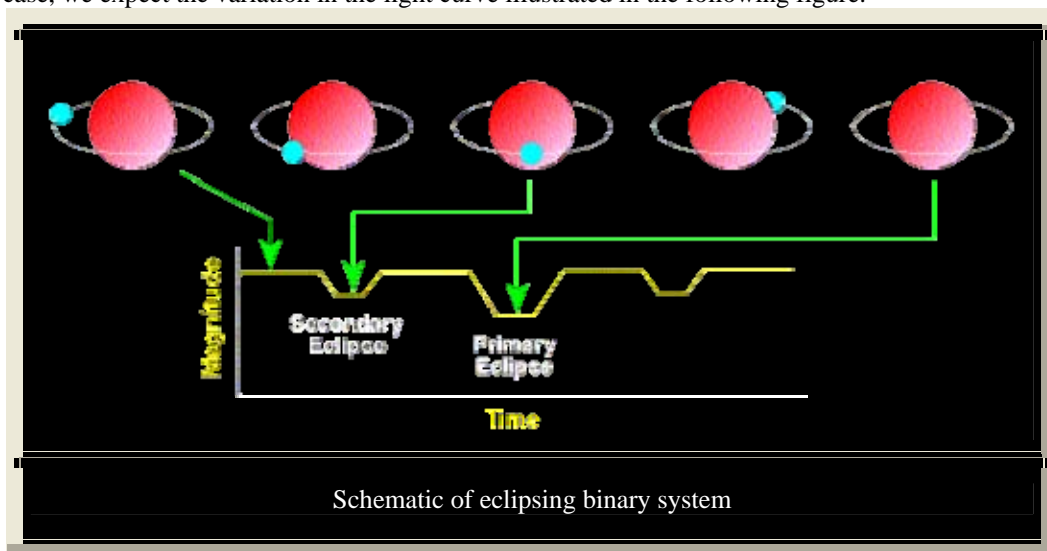
As we have noted, binary star systems can have different orientations of their orbital planes with respect to our line of sight, as illustrated in the following figure.



If the angle  $i$  is sufficiently close to 90 degrees, the two stars can eclipse each other as they revolve around their common center of mass.

### Light Curve for Eclipsing Binaries

In that case, we expect the variation in the light curve illustrated in the following figure.

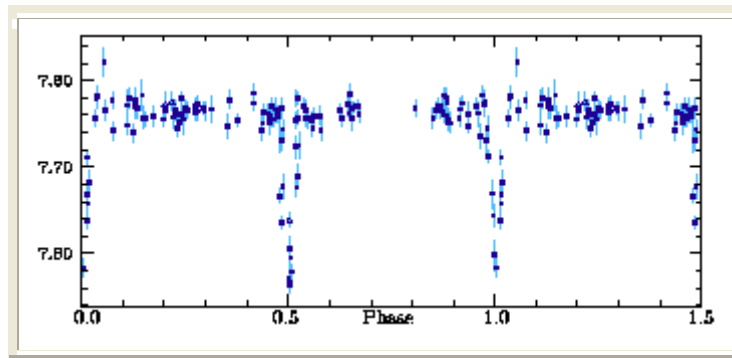


Twice in each orbit, we expect dips in the light output (notice that this is true independent of whether we can distinguish the two stars visually from each other). The duration, detailed shape, and depth of these dips will depend on the details of the orbital inclination to our line of sight, and to the sizes and detailed features of the two stars.

In the preceding illustration the smaller blue star is assumed to emit more light per unit surface area than the larger red star. Thus, the light output is dimmed most when the blue star is eclipsed (this is called the primary eclipse) and is dimmed less when the red star is eclipsed (this is called the secondary eclipse).

#### Light Curve of Eclipsing Binary Discovered by Hipparcos

The following image shows a light curve measured by the Hipparchos satellite. HIP 53806 (HD 95492, V359 Vel).



This star is of spectral type B9V. It varies between about 7.58 and 7.84 magnitudes, with a period of 4.5350 days. It is classified as an Algol-type eclipsing binary. (The very sharp dips in light output are characteristic of this type of eclipsing variable.) Hipparcos found 343 previously unknown eclipsing binaries; this is one of them.