Determining Properties of the Eclipsing Binary CV Boo Using Differential Photometry

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Introduction: What are Eclipsing Binaries?

Some Basic Binary Facts:

- Binary stars are the only stars outside the solar system whose masses have been directly and accurately determined.
- There are 4 types of binary stars: optical doubles, visual doubles, spectroscopic binaries, and eclipsing binaries.
- It is believed that the majority of the stars in the universe are probably part of a stellar system of two or more stars

Fig. 1 – Spectroscopic Binary

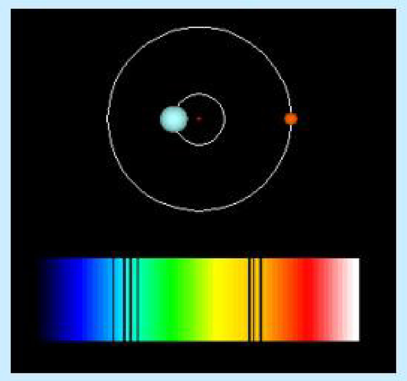
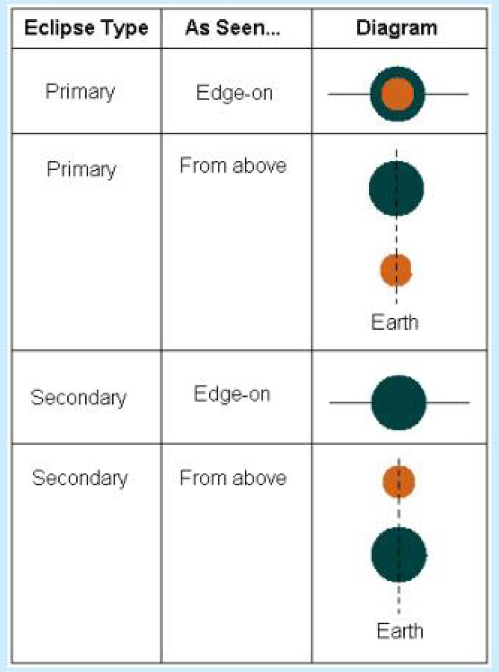


Fig. 2 – Eclipsing Binary



Above: as the phase changes, spectral lines will shift back and forth, indicating a spectroscopic binary.

Right: what an eclipsing binary looks like during a primary and secondary eclipse.

Why Studying Eclipsing Binaries is Important: As mentioned above, multiple star systems are the norm – learning about these systems is a good indicator of how most stars spend their lifetimes. Eclipsing binaries make determining characteristics of these stars – from mass to age, and many things in between – rather simple. These data then are very useful for testing current stellar evolution theory.

Objective: Eclipsing Binary CV Boo

CV Boo is a dim star in the constellation Bootes. Its magnitude was found to vary with time, and therefore put into a variable star category. Interestingly, its magnitude varied periodically. Because there were two instances of a sharp decrease in brightness during one period, it was discovered to be an eclipsing binary – these decreases in brightness were due to the two eclipses that occur during one period.

Scientists began to observe eclipsing binaries early in the 20th century using photographic plates. This technique resulted in very inaccurate periods of these stars, many of which are still recorded that way today. New photometric techniques allow for not only an accurate period to be determined, but other properties of the stellar system, as well.

The goal of this project is to determine the properties of the two stars in CV Boo using differential photometry in order to add to our knowledge of eclipsing binaries and stellar evolution.

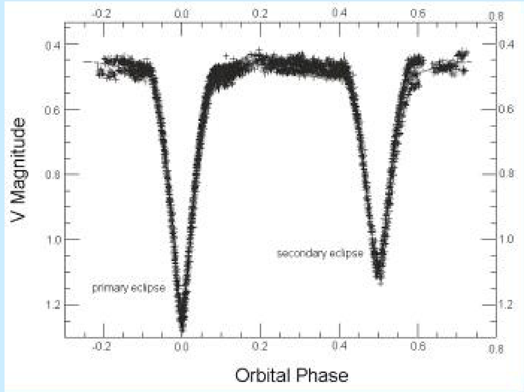
Methodology: Light Curve Analysis

What is a light curve, anyway? A light curve is the magnitude of an object plotted as a function of its orbital period. For an eclipsing binary, the light curve looks like that in Fig. 3 below, where the deepest valley occurs at the primary eclipse and the more shallow one at the secondary eclipse

Some factors that effect the shape of a light curve:

1. Center of mass
2. Eccentricity and longitude of periastron
3. Inclination
4. Luminosity, mass, radii, and temperature of each star
5. Shape of the orbits (circular vs. elliptical)

Fig. 3 – The light curve of CV Boo



Plotting the Light Curve of CV Boo

Before a light curve can be plotted, the data must be collected. Images of CV Boo had been taken over the course of the year in 2002. These are raw images, the sky as seen through the Johnson V filter. The following programs written by Dr. Lacy were then used for the indicated reason:

Measure – to measure the magnitudes of the CV Boo with respect to its comparison star, the difference in magnitude between the comparison and check stars, and plot this data as a function of time. Examples of these plots are located in Fig. 4 below.

New Minima – to determine the date of minimum for a given night.

Dates of Minima – to determine CV Boo's period and its uncertainty. A sample image is located in Fig. 5 below.

Fig. 4 – Plot from *Measure*

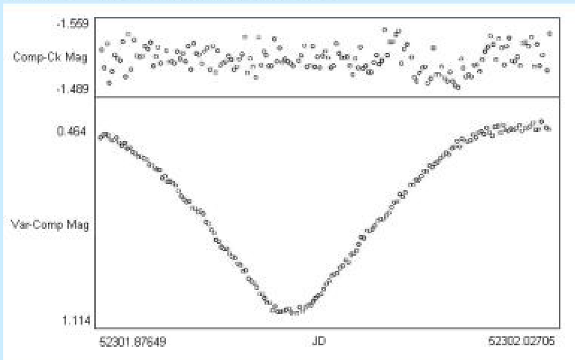
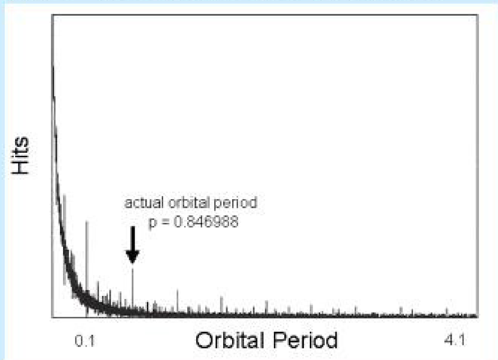


Fig. 5 – Plot from *Dates of Minima*



To plot the light curve, the program EBOP was used. The user must give EBOP the photometric data and as many known parameters as possible. When running, EBOP will test various numbers in the unknown parameters until its theoretical plot looks almost identical to the data given to it. These parameters include the following, among a few others:

- Ratio of radii
- Orbital Inclination
- Eccentricity
- Limb-darkening coefficients of primary and secondary
- Gravity-darkening coefficients of primary and secondary
- Mass ratio
- Third light
- Luminosity scaling factor
- Orbital period

Fig. 6 – Limb darkening

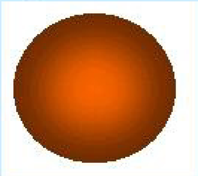
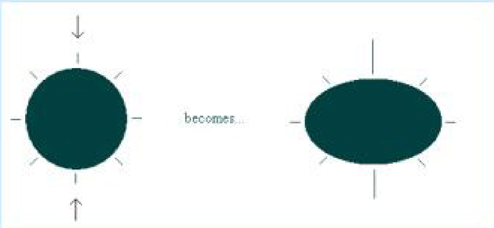


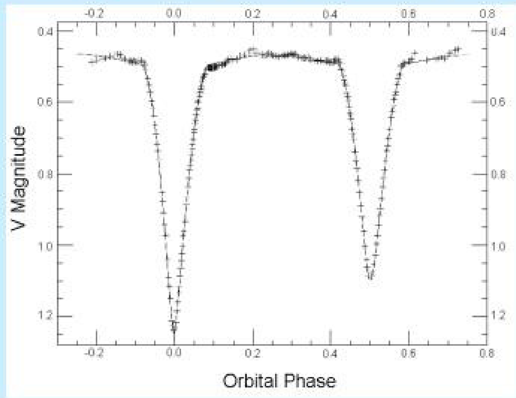
Fig. 7 – Gravity darkening



Results: EBOP and MRLcalc

Fig. 3 (shown to the left) is the light curve generated by EBOP for all of the data points. There are so many points that the theoretical line cannot be seen. The points were then normalized and run through EBOP again. This produced the light curve in Fig. 4 below. What was nearly 4000 points is now roughly only 1000 points – the graph looks nicer and it is far easier to see the theoretical line.

Fig. 8 – Light curve of normalized data



The data that was unknown and left for EBOP to determine is now known. The program MRLcalc was then given such data as that which follows, and calculated additional properties of the stellar system:

- Relative radii, temperature, and visual surface brightness of the primary and secondary
- Orbital inclination
- Eccentricity

Meet CV Boo…

Fig. 9 – Properties of CV Boo, some as they compare to our Sun

Property	CV Boo
inclination	87.24 deg
period	0.846988 days

Property	CV Boo - P	CV Boo - S	Our Sun
mass	1.028 solar units	0.974 solar units	1.989 x 10^33 g
radius	1.290 solar units	1.163 solar units	695,000 km
surface temp	5916 K	5780 K	5770 K
log surface gravity	4.229 (cgs units)	4.295 (cgs units)	4.437 (cgs units)
log luminosity	0.265 solar units	0.134 solar units	0 solar units
limb darkening	0.6939	0.6939	0.6310
gravity darkening	0.3440	0.3440	—
V surface brightness	3.762	3.746	—
RV semi-amplitude	137.8	145.5	—

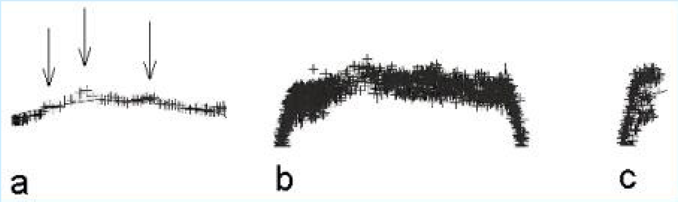
CV Boo is a star very similar to our own Sun. The temperature, surface gravity, etc. are nearly the same. Therefore, if the ages are similar (the Sun is approximately 4.5 billion years old), then they should be at about the same place in their evolution. If the Sun is younger, it will eventually age to be very much like CV Boo's stars.

Possible Future Work

There is still much to be explored regarding eclipsing binary stars. Focusing on CV Boo, there are a couple of things that need to be explored:

1. Note the shape of the light curve when the stars are not in eclipse (enlarged in Fig. 10a below) and the thickness of this same segment when all data points are present (Fig. 10b). Also, the magnitude was different at the same time of the phase on different nights (Fig. 10c).

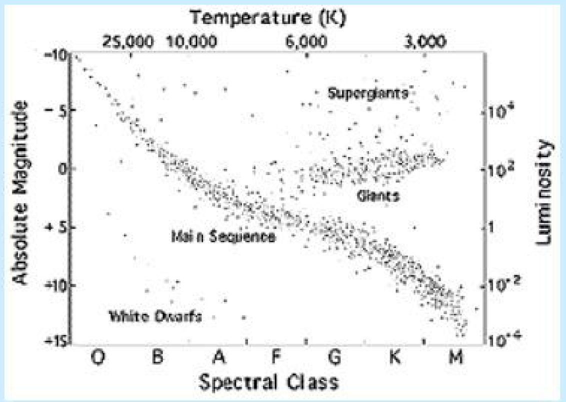
Fig. 10 – Anomalies on CV Boo's light curves



This is all quite possibly due to star spots on the surface the primary and/or the secondary star. Over time, this can be monitored to possibly determine which star(s) the star spots are on, how large they are, and how frequently they occur.

2. Also of interest is the age of CV Boo. Knowing its properties, it can be determined by comparing these properties to theoretical work done by Claret, Schaller, and others in the 1990s. By determining its age, CV Boo's place on the H-R diagram can be found. This would aid to our knowledge of stellar evolution.

Fig. 11 – H-R Diagram



3. Using our data, the ephemeris has been determined to be:

$$\text{HJD Min I} = 2452332.85631 + 0.846988n$$

This formula can be used to predict future eclipses. A list of theoretical eclipse dates and times has already been generated. Several primary and secondary eclipses will be occur at a time and place in the sky where they can be observed using the telescope at the University of Arkansas in Fayetteville. Later this summer, weather permitting, an eclipse will either not be observed and prove our data wrong, or will (most likely) be observed and confirm our ephemeris as being correct.