Solutions to the Light Curve of UV Psc

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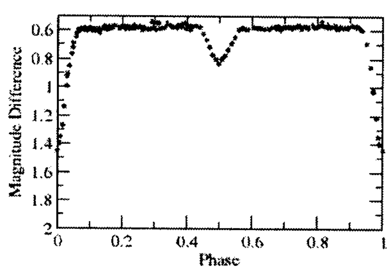
I graphed a light curve of the RS CVn eclipsing binary star system UV Psc using archival photometric data. I then used modeling programs to make models that attempt to best fit the data on the light curve. From these models, I was able to determine many parameters about UV Psc.

Introduction

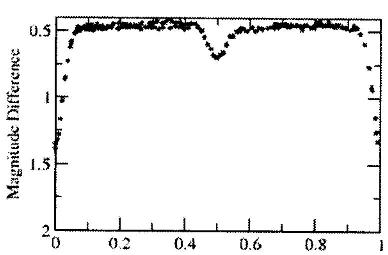
UV Piscium is an RS CVn eclipsing binary star system located in the constellation Pisces. It lies around 63 parsecs away from Earth and has an orbital period of 0.861 days. I am analyzing the changes in brightness of UV Psc due to the eclipses by graphing these changes in brightness as a light curve. RS CVn systems like UV Psc have stars with active chromospheres which make their light curves interesting to study. Since the light curve of can change over time, it is important to compare past observations with modern ones. Models then are made of the light curve which can tell us many things about the stars that make up the UV Psc system. Also by studying binary star systems such as UV Psc, we can better overall understand stellar evolution.

Figure 1: Light curves for the y, b, & v filters

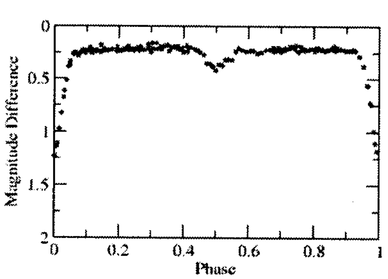
y-filter



b-filter



v-filter



Observations and Reduction

Twelve nights of photometric data for UV Psc were taken at the Mount Laguna Observatory's 16 inch telescope between the dates of September 6 and December 14, 1980. These observations were carried out by Frank Allan Greenwood, Jr. and were taken using a photomultiplier tube. Differential photometry was used to measure the changes in brightness of UV Psc. These readings were taken through the Strömgren set of yellow, blue, violet, and ultraviolet filters. The light curve for each filter represents the magnitude difference between UV Psc and the non-variable comparison star as a function of time. The light curves have been phase folded and phase=1 corresponds to the orbital period of UV Psc which is about 0.861 days. I transcribed Greenwood's tables of photometric data onto the computer. Because the orbital period of RS Cvn star systems can vary, the time of primary minima in Greenwood's observations did not match phase=0. I had to calculate a new ephemeris in order to correct the phase shift in the observations. This phase shift happened because RS Cvn star systems like UV Psc can show changes in their orbital period. Using the method of Kwee, I found the times of primary and secondary minima. With the new Heliocentric Julian Date (HJD) of the primary minima from Kwee, I used a the ephemeris

$$\text{HJD of primary minima} = 44526.745205 + (0.8610477 * E)$$

in a Fortran program I wrote to correct for this phase variation. This discrepancy in phase corresponds very well to the changes in UV Psc's orbital period as discussed by Shengbang et al. (1999).

After graphing the light curves, the ultraviolet filter was determined to have too much scatter and has not been included in the analysis. Also, the first four days of observations were removed in order to further reduce variation and scatter in the data.

Analysis

In order to analyze the data for UV Psc, I used two computer programs. The first program I used was Wilson-Divinney (Wilson 1992). The second program was Eclipsing Light Curve Code (ELC) created by Orosz & Hauschildt (2000). Both programs attempt to create models of binary star systems. The programs then compare their models to the data from UV Psc to see how well the models fit the light curve. By creating good models, many parameters about the UV Psc star system can be determined.

Figure 2: Wilson-Devinney Model Fit

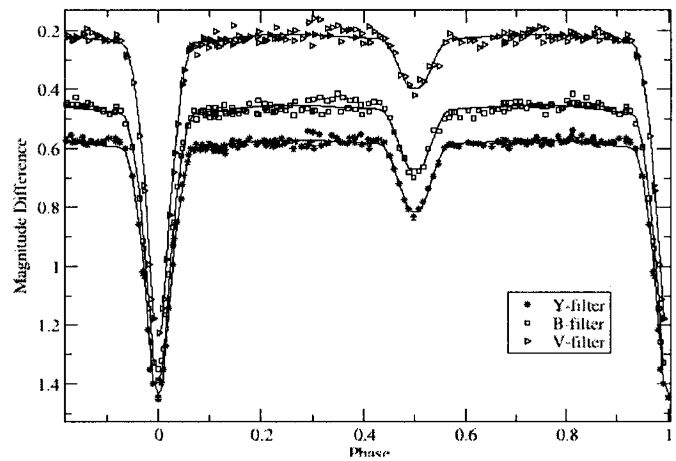
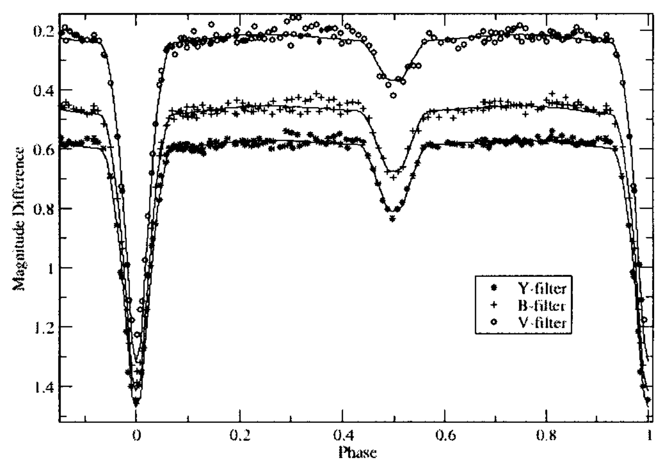


Figure 3: ELC Model Fit



The first model I created with Wilson-Divinney had the orbital inclination of UV Psc set to 83 degrees. Using the grid approach, I tried different inclinations, and 83 degrees had the smallest error. In this model, the secondary star of UV Psc had a larger radius then the primary star. This meant the secondary star had to be an evolved sub-giant. More massive stars evolve faster then less massive stars, so having the more massive primary star less evolved then the secondary star presented a problem with this model. Also, the inclination of 83 degrees conflicted with other published inclinations for this system, which mainly fall around 89 degrees. I then created another model with Wilson-Devinney which had the inclination set to 89 degrees and the radius of the secondary star smaller then the primary. In this model, both stars lie on the main sequence so the secondary star is not more evolved then the primary. To investigate which model is the one more likely to be correct, I consulted a paper by Kjurkchieva, et al. (2005) which investigated the rotational velocity of both stars in the UV Psc system. By studying the rotational broadening of the Fe 1 spectral line, they found that the primary star was spinning with a velocity of 63 ± 1.4 km/sec and the secondary star spinning with a velocity of 53.3 ± km/sec. Assuming that both stars in UV Psc are tidally locked, the primary star must have a larger radius then the secondary if it has a greater rotational velocity. If the primary has a larger radius then the secondary, the secondary is not an evolved sub-giant, so both stars lie on the main sequence. Because of this, I decided to go with my second model which has both stars of UV Psc on the main sequence and the system at an inclination of 89 degrees.

Table 1: Wilson-Devinney results

	Primary Star	Secondary Star
Inclination	89.05°	
Mass Ratio	0.775	
Separation	4.61 $R_{\odot}$	
Temperature	5800 K	4783 K
Mass	1 $M_{\odot}$	0.78 $M_{\odot}$
Gravitational Potential	4.9616	5.3701
Albedo	0.382	0.65
Radii	1.11 $R_{\odot}$	0.84 $R_{\odot}$
Gravity Darkening	0.25	0.25
Luminosity y-filter	82.46%	17.54%
Luminosity b-filter	84.75%	15.25%
Luminosity v-filter	87.68%	12.32%
Limb Darkening y-filter	0.605	0.766
Limb Darkening b-filter	0.705	0.887
Limb Darkening v-filter	0.801	0.994

Table 2: ELC results

	Primary Star	Secondary Star
Inclination	89.815°	
Mass Ratio	0.73	
Separation	4.757 $R_{\odot}$	
Temperature	5800 K	4803 K
Mass	1.128 $M_{\odot}$	0.823 $M_{\odot}$
Fills	0.2461	0.1861
Albedo	0.4	0.6
Radii	1.149 $R_{\odot}$	0.874 $R_{\odot}$
Gravity Darkening	0.08	0.08

It is clear from looking at the light curve that neither star in UV Psc has filled their Roche lobe so the system is detached. There is little sign of any major ellipsoidal motion in the time between eclipses. The results from Wilson-Devinney were taken using mode 2, which is the mode for detached binary star systems. I used linear limb darkening law which was taken from Van Hamme (1993). The results from Wilson-Devinney can be found in Table 1. The model fit can be seen in Figure 2, showing how the line from the model fits the data in the light curve.

Similar parameters were obtained using ELC. The results of which can be found in Table 2. Linear limb darkening law with the same parameters as those used in Wilson-Devinney was also used for ELC. Figure 3 shows the ELC model fit to the data on the light curve. Figures 4 and 5 both show how the ELC model fits the primary and secondary eclipses.

It should be noted that these results are not set in stone and the data may warrant further analysis in the future. The O-C plots for both Wilson-Devinney and ELC can be seen in Figures 6 and 7. Both plots show each of the three filters used in the light curve. Although both models are very similar, the differences between them most likely stem from the differing mass ratios that each modeling program used in its calculations.

Figure 4:

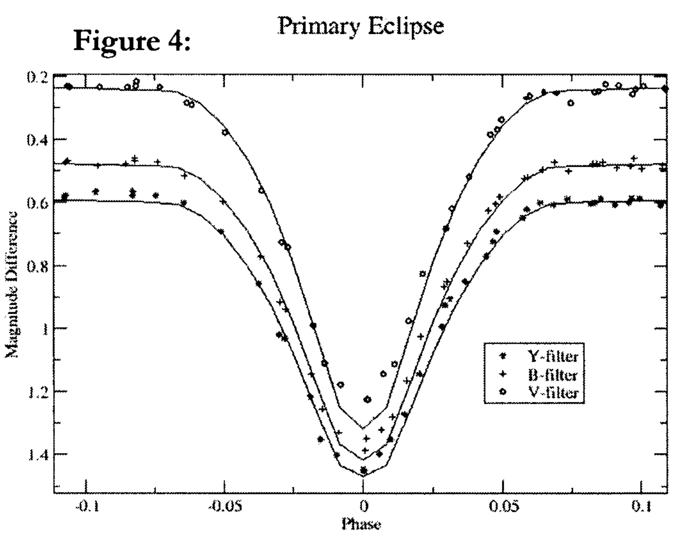


Figure 5:

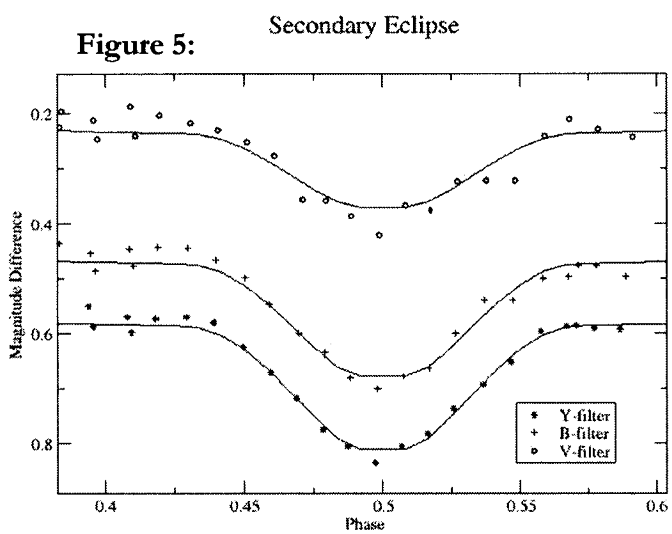


Figure 6: Wilson-Devinney Model O-C

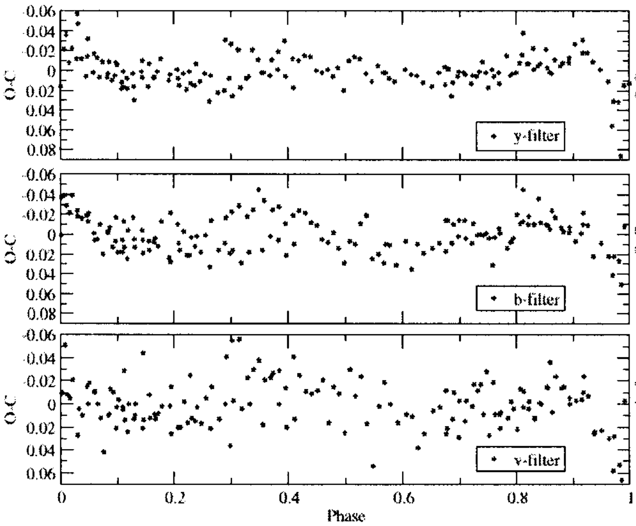
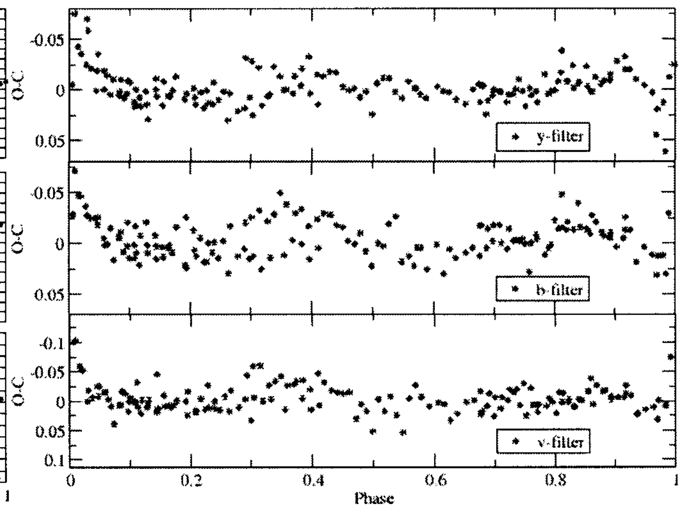


Figure 7: ELC Model O-C



Conclusions

Both of these models show that both stars do not fill their Roche lobes, making UV Psc a detached binary star system. Since neither star fills its Roche lobe, there is virtually no mass transfer between the two stars. Without mass transfer, each star must evolve separately. Both the primary and secondary stars appear to lie on the main sequence with mass, temperature, and radius of the primary star being very similar to our own Sun. The results from my models agree well with what other astronomers have determined about UV Psc.

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