A Photometric Study of the Eclipsing Binary Star UV Lyncis

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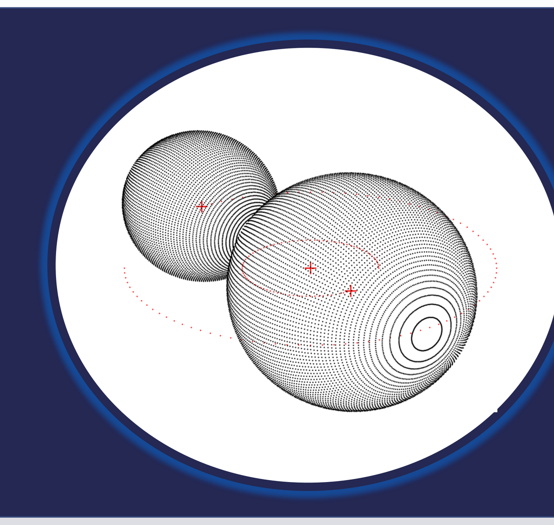


Introduction

The study of binary star systems is one of the primary means of measuring stellar properties. The target of this research was the eclipsing binary star UV Lyncis located in the northern constellation Lynx. It has an orbital period of just 10 hours. These stars are in contact physically and share a common atmosphere. A photometric study was undertaken to obtain high quality light curves which could then be analyzed with a light curve synthesis program. When combined with spectroscopic measurements this analysis was used to determine the physical properties of the individual stars including masses, luminosities and temperatures. In addition, a period study was made to look for evidence of mass streaming between the stars.

Observations

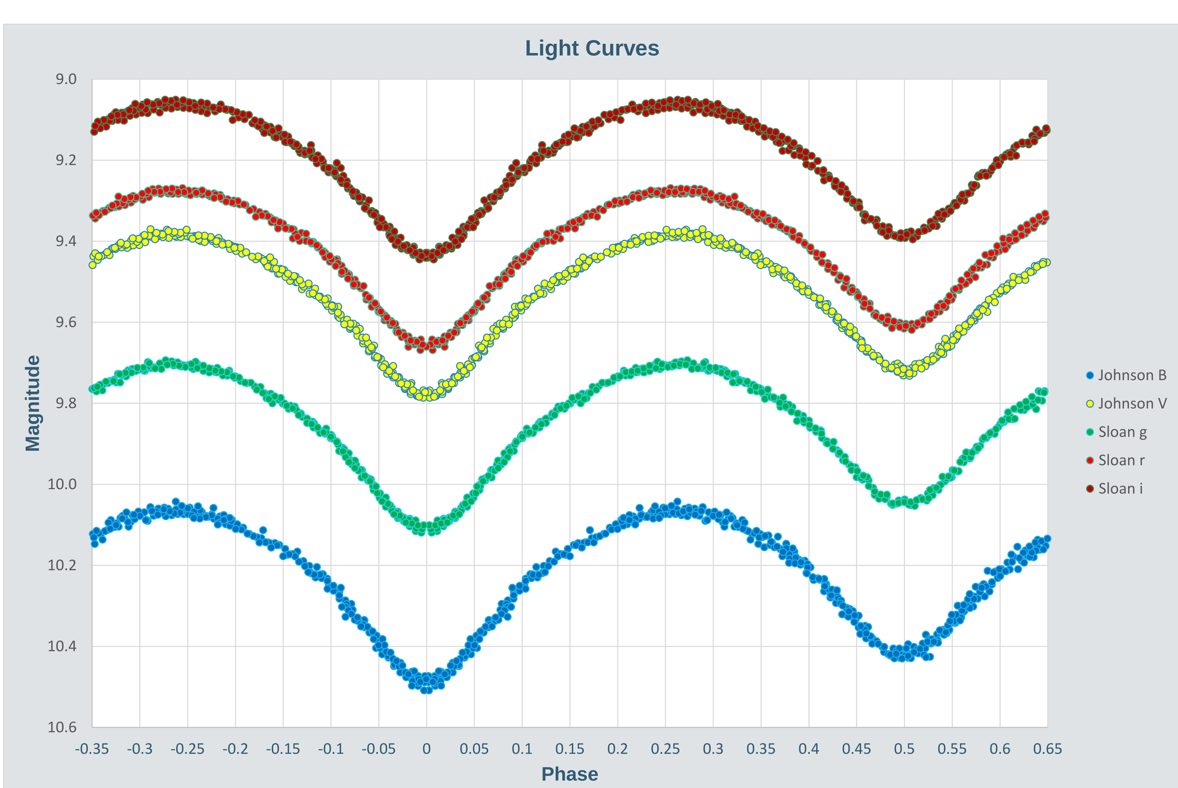
Photometric data was collected at the Waffelow Creek Observatory during 8 nights in February and March 2014. A 0.3 meter robotic telescope and a science imager equipped with a KAF-6303E CCD cooled to -30°C were used for the observations. This telescope worked autonomously each night, taking images serially in 5 standard bandpasses (colors), Johnson B and V and Sloan g′, r′, and i′. A total of 3051 images were acquired. The magnitudes (brightness) of the same four stars in each image were determined from the measured fluxes, two comparison stars, a check star and UV Lyncis. Using MIRA[1] software the images were first calibrated, sky background subtracted and then brightness in standard magnitudes computed. The brightness of UV Lyncis was measured by differencing the instrument magnitude of that star with the constant comparison stars using

$$V_{ins} - C_{ins} = -2.5\,log\left(\frac{Flux_{var}}{Flux_{comp}}\right),$$

where V_{ins} and C_{ins} are the instrumental magnitudes of the variable and comparison. The standard magnitude was then computed with

$$V_{std} = (V_{ins} - C_{ins}) + C_{std}$$

where C_{std} is the standard magnitude of the comparison. Standard magnitudes for the comparison and check stars were taken from APASS[2]. The comparison stars were found to be constant on all nights and the check star's magnitude agreed very well with APASS photometry. Each image also contained a precise time of observation in Heliocentric Julian Days (HJD). The time of each observation was converted into orbital phase (0 to 1) so that all the observations could be folded into a single light curve, one for each bandpass. An orbital phase of 0.0 is the time of primary eclipse and 0.5 is the time of secondary eclipse. The resulting light curves show the flux is constantly changing at all phases. This is characteristic of a W UMa type binary where the stars have ellipsoidal shapes.

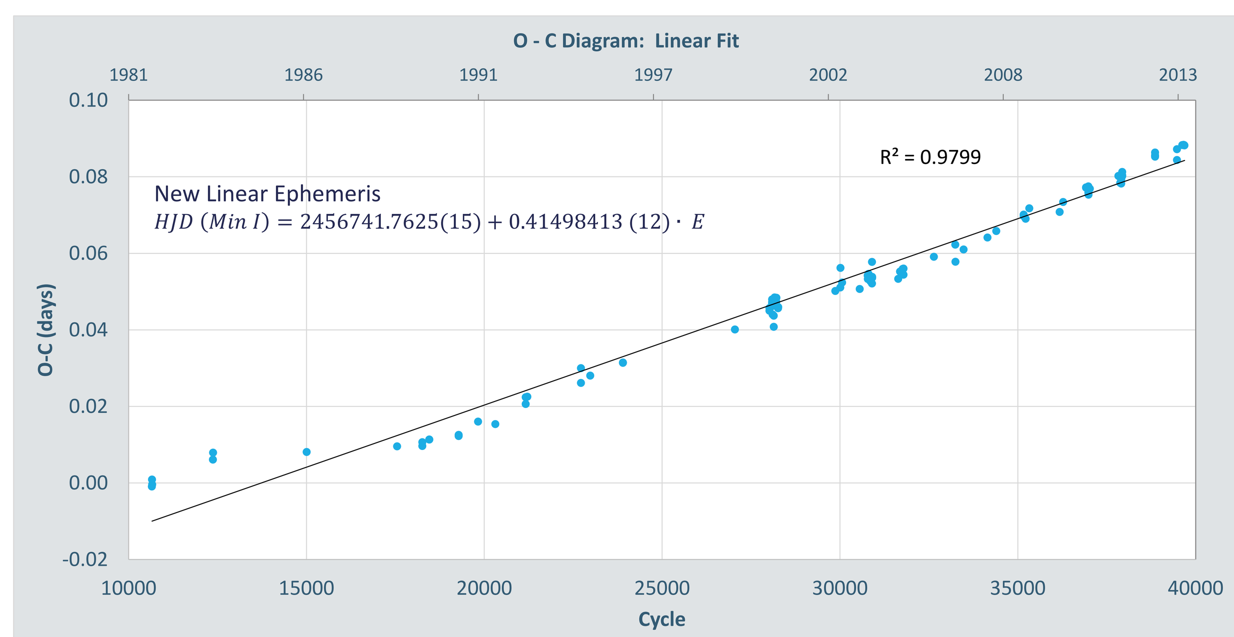


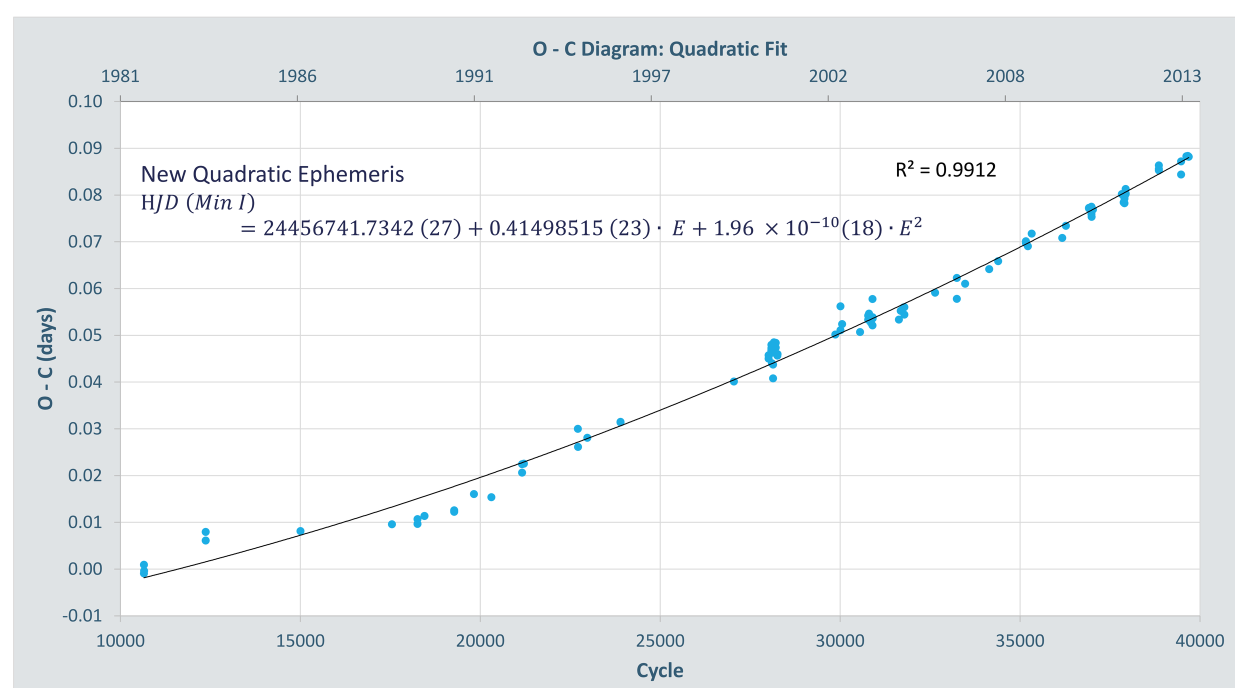
Period Study

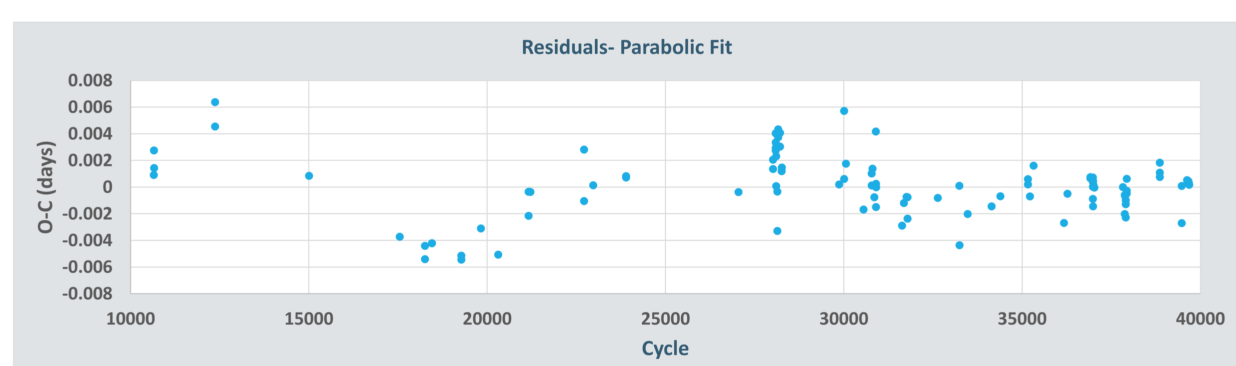
The orbital period of a binary star can provide important clues as to their evolution. If a primary or secondary eclipse occurs on a given night, then a precise time of minimum can be determined from the light curve. In this study 5 times of minimum light were measured using the K-W[3] method. A literature search uncovered 101 additional photoelectric and CCD minima going back to 1981. The starting ephemeris used to predict the HJD of a primary eclipse was taken from the work of Markworth and Michaels[4].

$$HJD\ (Min\ I) = 2440271.5021 + 0.41498088 \cdot E$$

The first light element is the time of primary eclipse, the second light element is the orbital period in days and E is the cycle count (number of completed orbits). Using this ephemeris, a predicted time of minima was computed and compared to the observed minima by calculating the residuals (O - C). The results of a linear and quadratic regression analysis to these data were used to calculate new ephemerides shown in the O - C diagrams below. The standard errors are in parenthesis. These new ephemerides will provide a more accurate prediction of future eclipse minima. The superior fit of the quadratic solution indicates the orbital period is very slowly increasing which confirms findings of two previous studies by Vanko[5] and Xiaobinand[6]. Mass transfer from the less massive secondary star to the more massive primary star causes the system center of mass to slowly shift toward the more massive star. This results in a slowly increasing orbital period. The period change is very small, 0.62±0.06 seconds per century.





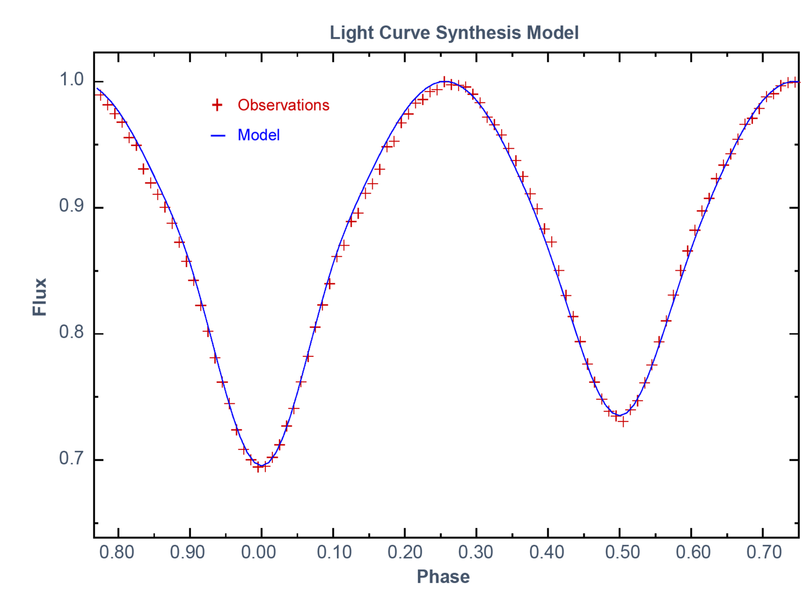


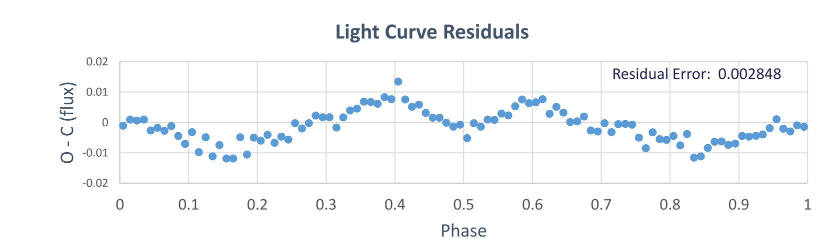
Light Curve Modeling

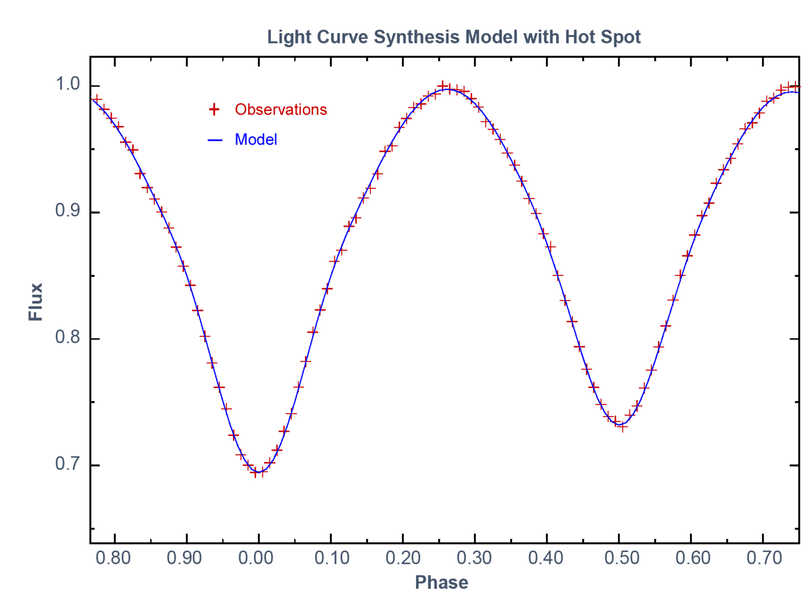
This star system was modeled with the light curve synthesis program ***Binary Maker 3***[7] (BM3). The light curves of this study were combined with the spectroscopic data of Rucinski[8] to determine the absolute eclipsing binary parameters. UV Lyncis was modeled as an overcontact system by varying the following parameters.

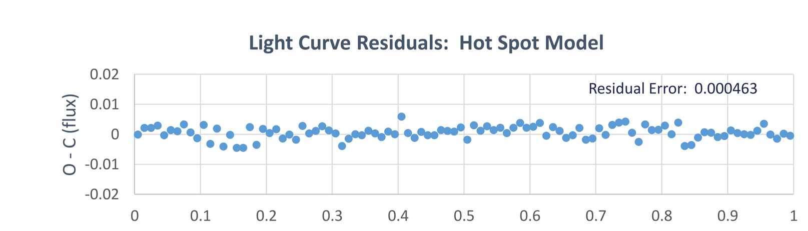
- **inclination (i)** – Tilt of orbital plane with respect to an Earth observer
- **mass ratio (q)** - Mass ratio is normally the less massive star (M_2) divided by the more massive star (M_1) but since the less massive star in the UV Lyncis system was the hotter star the inverse mass ratio was used.
- **modified potential (Ω)** – Surface of equal gravitational potential within which orbiting material is gravitationally bound to the star. Ω combined with mass ratio fully describes the surface structure of synchronously rotating, circular orbit binary stars.
- **fillout factor (f)** – Represents the degree of overcontact of a component within a binary system
- **temperature (T)** – Effective temperature of each star in Kelvin

Additional parameters held fixed at their theoretical values were gravity brightening, limb darkening and bolometric albedo. The mass ratio (q) of this system was held fixed as well since it been determined from the radial velocity measurements of Rucinski[4]. Before modeling, each dataset was binned by phase to improve accuracy. The bin size was set to 0.01 which provided 100 data points for each light curve. With the parameter values entered, BM3 computes a synthetic light. The program displays the results graphically with the synthetic light curve overlaid on the observed data points for analysis. Using an iterative procedure the parameters were adjusted, a new light curve generated and the results examined for an improved fit. The result of the first solution attempt using the Visual (V) bandpass data is shown to the right. Even though the synthetic light curve fits the data reasonably well, the residuals plot shows an almost sinusoidal pattern. This indicates a hot or cool spot(s) is most likely located on the surface of one or possibly both stars. The excess light on either side of secondary minimum, at phase 0.5, suggests a slightly hotter region may exist on the cooler and larger star near the contact point. Using the spot function of BM3, a single hot spot was modeled on the larger star. This again was an iterative procedure. The spot parameters adjusted were latitude and longitude, size and temperature. The final solution is shown to the right. The residual error was considerably lower when compared to the first solution. The flat distribution of the residuals indicates the star system was well modeled through its entire orbit. Solutions were obtained using the light curves from each of the other bandpasses as well. Those solutions gave very similar results.



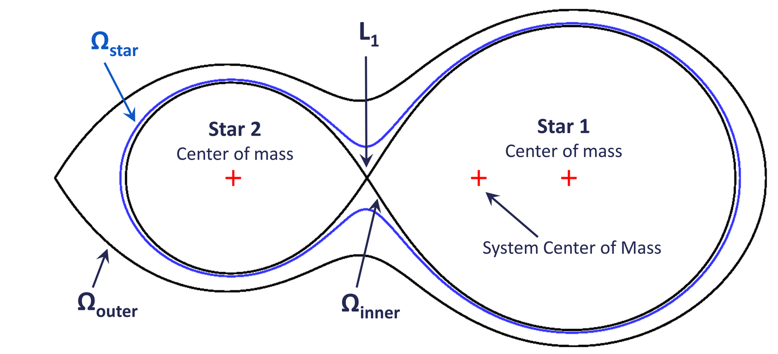


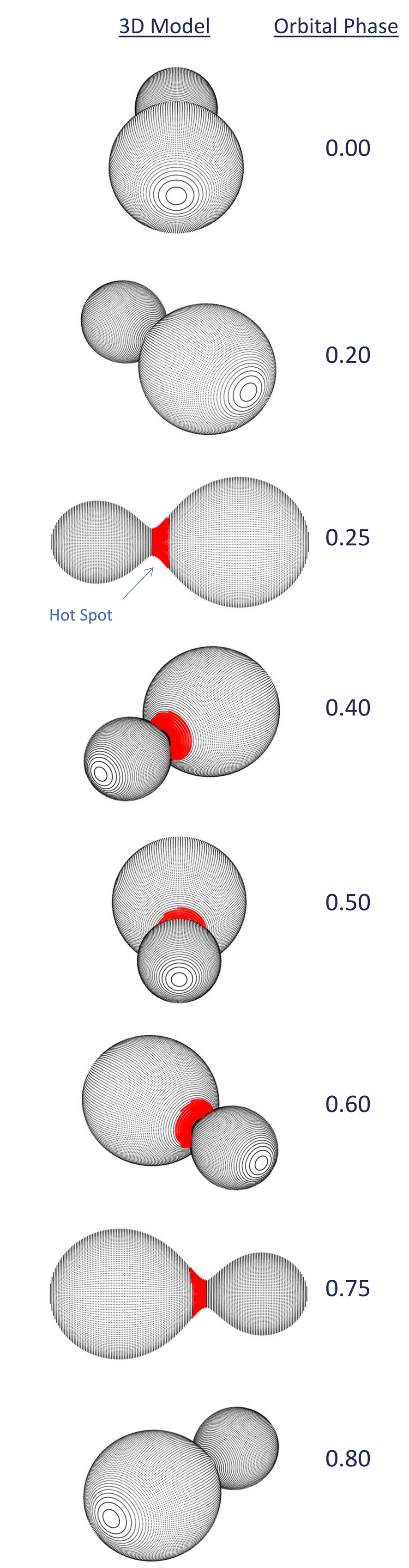




Conclusions, Absolute Parameters and 3D Model

The light curve synthesis solution confirms UV Lyncis as a member of the W UMa class of interacting eclipsing binary stars. The equipotential surface for UV Lyncis is shown in the diagram below (blue). This accurately depicts the surfaces and shapes of the two stars. The modeled surface potential (Ω) indicates UV Lyncis is an overcontact system. Its surface is 18.5% from filling the space between the inner (Ω_{inner}) and outer (Ω_{outer}) Roche equipotential surfaces. Ω_{outer} is the limit of stability for a binary system. Mass transfer is occurring through the Lagrangian L_1 point and is causing the slow increase in orbital period. This matter transfer may contribute to impact heating in the region of the modeled hot spot on the cooler larger star (Star 1).





Light Curve Solution Parameters

Mass Ratio	2.725	
$\Omega_1 = \Omega_2$	6.135951	
Ω_{inner}	6.249607	
Ω_{outer}	5.635248	
Fillout $f_1 = f_2$	0.185	
Inclination	66.4°	
	Star 1	Star 2
Surface Area	2.917164	1.186668
Luminosity	0.6691	0.3309
Temperature (Kelvin)	6090	6385
Gravity Coefficient	0.320	0.320
Limb Darkening	0.611	0.611
Reflection	0.500	0.500
Spot Parameters		
Co-Latitude	90.0°	--
Longitude	2.0°	--
Spot Radius	19.6°	--
Temperature Factor	1.08 (+487 K)	--

Absolute Parameters

	Star 1	Star 2
Mass	1.37 $M_\odot$	0.50 $M_\odot$
Mean Radius	9.62×10^7 km 1.38 $R_\odot$	6.15×10^7 km 0.88 $R_\odot$
Mean Density	0.75 gm/cm^3	1.59 gm/cm^3
Luminosity	1.47 $L_\odot$	0.72 $L_\odot$
Distance	120 ±18 parsecs or 390 ly	
Eccentricity of Orbit	0.0 (circular orbit)	
Semi-Major Axis of Orbit	2.01×10^6 km or 2.88 $R_\odot$	
Rate of Mass Transfer	1.93×10^{-10} $M_\odot$/day	

* $L_\odot$ - Solar Luminosities, $R_\odot$ - Solar Radii, $M_\odot$ - Solar Masses

References

[1] Mira Pro Ultimate, www.mirametrics.com/mira_pro_ue.htm
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[3] Kwee K.K., van Woerden H., 1956, BAN, 12, 327.
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[7] Binary Maker 3, www.binarymaker.com
[8] Rucinski, S.M., Lu, W.: 1999, Astron. J. 118, 2451.