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A Study On NN Serpentine Binary Star System*

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ABSTRACT

A duo of stars revolving around a common center of mass is observed over the span of 4 hours during which a red dwarf completely eclipses the target white dwarf star. I aim to analyze its behavior over this time as its light curve presents a distinct loss of flux of about 0.04992 mag. Using this, properties of both the target and eclipsing star of the binary star system are found and compared. The host star's mass is found to be around 4.527 times larger than its partner star, as that star orbits the outer path at a velocity of $v = 338$ km/s.

1. INTRODUCTION

There is an astronomical phenomena known as a binary star system. This is when two stars revolve around a common center of mass. This particular binary system is called NN Serpentis, which consists of a white dwarf with a mass of 0.535 $\pm 0.012 M_\odot$ and a red dwarf with a mass of 0.111 $\pm 0.004 M_\odot$ (Parsons (2010)) revolving around a center of mass. Moreover, the red dwarf with lower mass will revolve closer to the common center, as the white dwarf will revolve on the outer path. It is a distance of 1670 ly (512 pc) from Earth (Parsons (2010)). The location of the double star is RA 15h:52m:56.131s and DEC +12°54' 44.68". In the data provided by LCO, we will be able to extract a light curve that displays one of the stars eclipsing the other due to its orbit.

It is observed that certain factors like gravitational waves and magnetic braking inflict drag on the motion of the two stars, causing the stars to lose angular momentum and draw closer together over time. This type of binary system is known as a Post-Common Envelope Binary star system (PCEBs). Because of such factors involved in the binary system's orbit, it results in slightly lower periods of rotation. This paper will briefly describe its motion quantitatively by using calculations of distance, orbital period, and mass. Below displays a figure of the reference target star.

2. OBSERVATIONS

The telescope used is called 1m008, located at the McDonald Observatory in Fort Davis, Texas, USA. 1m008 is a 1.0-meter telescope with an altitude limit of approximately 15°with an hour-angle limit of ± 4.6 hours.

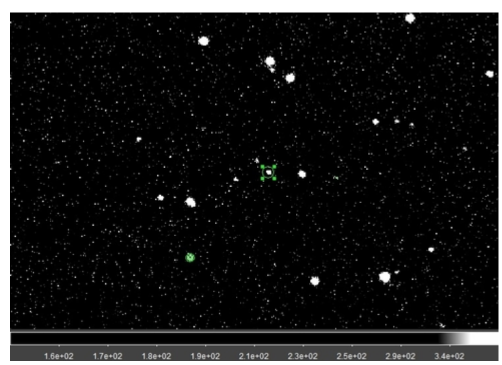

Figure 1: The target star that becomes eclipsed due to orbiting partner star

3. METHODS

3.1. *Photometry*

The photometry was extracted using AstroImageJ software, where I separated the B and V filter images by noticing that the file names were different with each filter. When separated, I was able to find the target star and create an aperture profile for each filter and mark its neighboring stars to find the target's relative flux (see Figures 2 and 3). Although very faint, several reference images provided by M. Navaroli (Wikimedia Commons) were used to help determine where the star's location was, along with using the RA and DEC coordinates read in SAO DS9. Therefore, figure 4 shows light curves for both B and V filter sets and are plotted alongside each other, with the V filter data showing a more distinct light curve fluctuation. This is because of the abundance of V filter data compared to the lack of B filter data. As

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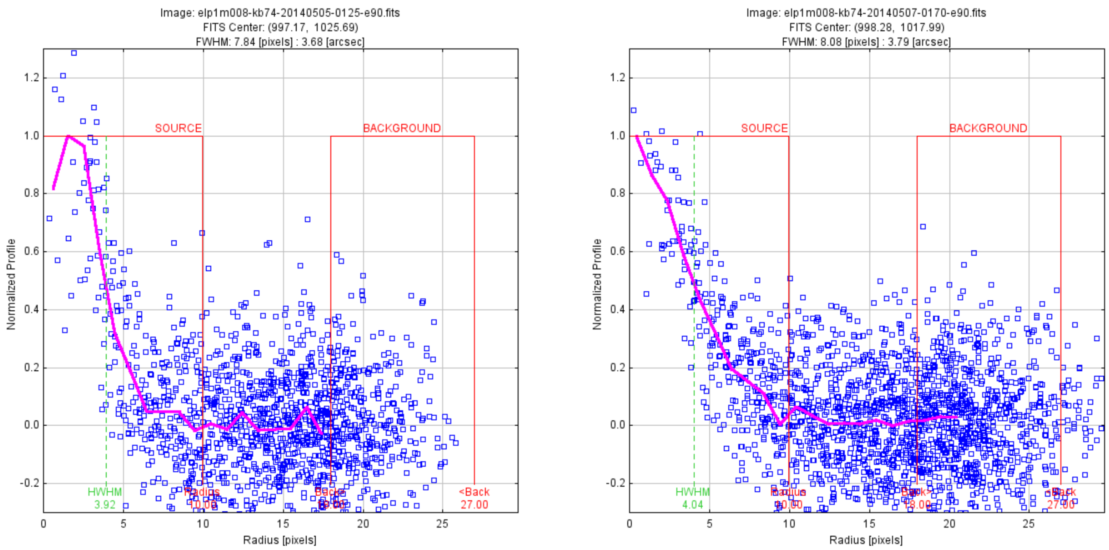

Figure 2: Aperture profiles for B filter (left) and V filter (right) observations

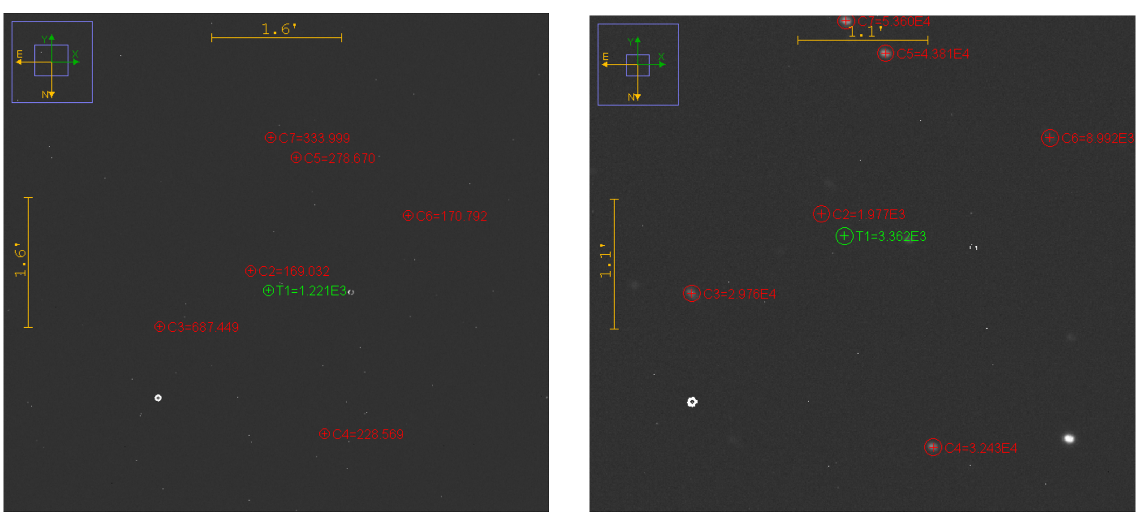

Figure 3: Targets used for B filter and V filter light curves

a result, the B filter light curve showed no sign of a change in flux of the target star, so it was discarded.

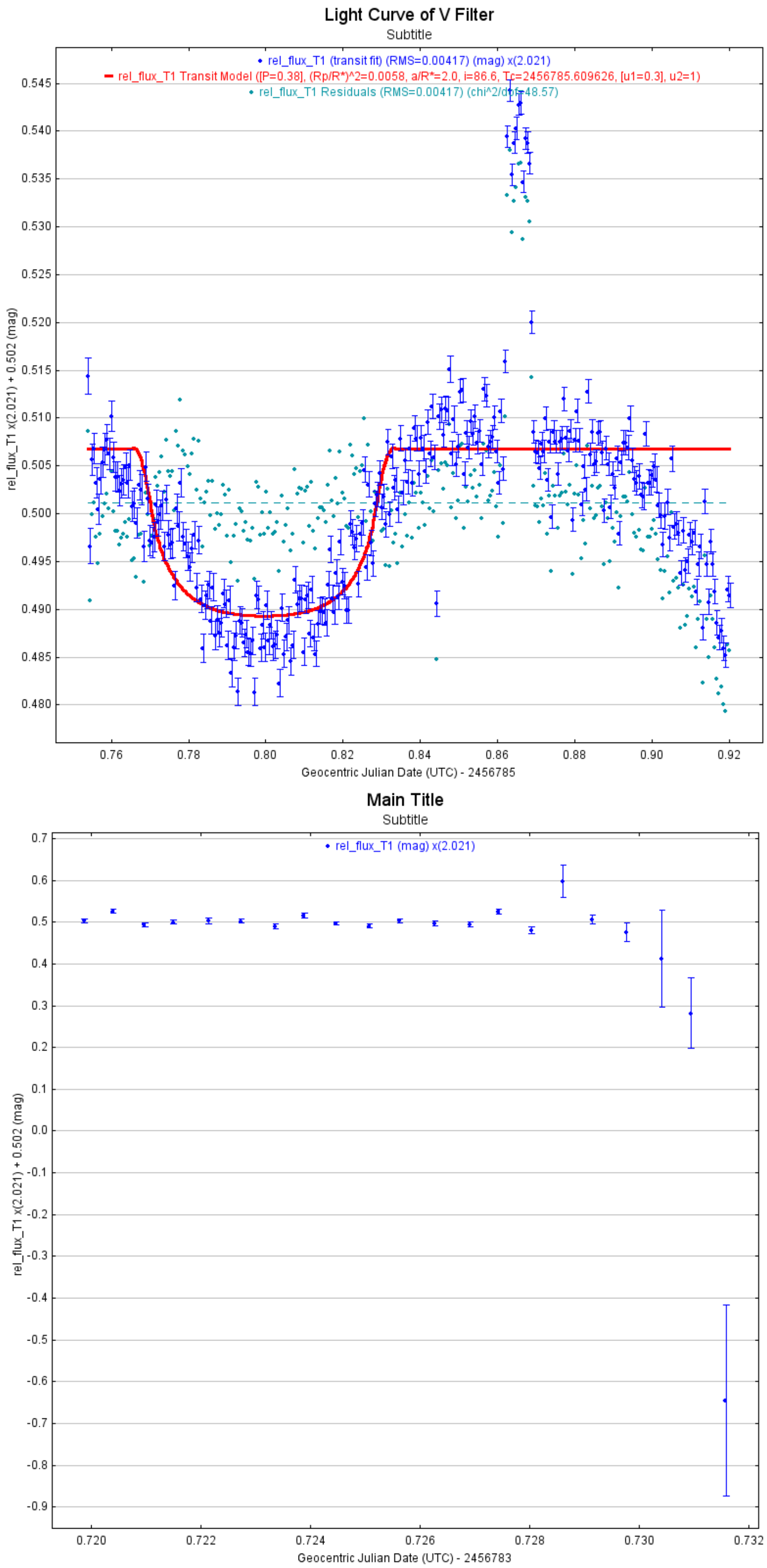

Figure 4: Comparing B and V filter light curves

3.2. *Calculating Relative Radius*

Radius to the eclipsed star was calculated using the equation:

$$\frac{\Delta F}{F} = (\frac{R_e}{R_*})^2$$

where ΔF is the change in observed flux of the target star in NN Ser, F the observed flux, R_e is the radius of the eclipsing star, and R_* is the radius of the inner eclipsed star. For this, the change in flux was found by subtracting the lowest point of the dip in flux from the middle point of flux, i.e. the observed flux, F. This ratio was then used to find the relative radii of the two stars.

3.3. *The Period of the Eclipse*

The period of the eclipsing star's orbit is important because it describes how quickly each star is revolving around the center of mass. By utilizing the change in flux observed in the light curve, I was able to easily estimate the period of orbit by correlating the time at which the dip in the light curve occurred and when it ended. Because the light curve displayed a peak and a valley, I estimated the period P to equal the time correlated to the width of the peak and valley.

For all time-related calculations, the x-axis was measured in Geocentric Julian Time (UTC), so some simple conversions were performed to normal calendar date and time (UTC), but no timezone conversions were needed since only the change in time in between fluxes were relevant to this study.

3.4. *Target Star Magnitude*

Extracting the light curve gives information that can be valuable to finding the relative brightness of the host star. By analyzing the curve's observed apparent magnitude, and using the distance measured to the star (in parsecs) (citation), I was able to calculate the absolute magnitude using the distance modulus:

$$m - M = 5log(d) - 5$$

where m is the apparent magnitude, M is the absolute magnitude, and d is the distance from Earth to NN Ser in parsecs. The reason why another distance measurement is used is because it was impossible to measure the distance given the data without the parallax angle.

3.5. *Calculating the Semi-Major Axis and Orbital Velocity*

After calculating many basic yet crucial properties of the binary system, it is possible to calculate its motion. By doing so, I will demonstrate an analysis of other factors that are involved in its motion, such as drag.

The period of the orbit is proportional to the system's semi-major axis by Kepler's Third Law. Therefore, the ratio of the two is equal to a constant, namely:

$$\frac{a^3}{P^2} = \frac{G(M_* + M_e)}{4\pi^2} \tag{1}$$

where G is the gravitational constant, a is the semi-major axis, P is the period of the orbit, and M_* and M_e are the masses of the host and eclipsing star, respectively. Rearranging the equation and solving for a gives us the value of the semi-major axis, or the distance separating orbiting star from the center of the orbit.

Using the value for the semi-major axis and the orbital period P, we can also compute the orbital velocity (assuming a circular orbit) with $v = \frac{2\pi a}{P}$.

4. DISPLAYING MATHEMATICS AND RESULTS

4.1. *Calculating Radii of the Double Stars*

Recall that the ratio of the difference of the observed flux and the observed non-eclipsed flux is:

$$\frac{\Delta F}{F} = (\frac{R_e}{R_*})^2 \tag{2}$$

where $\frac{\Delta F}{F} = \frac{0.5061-0.4814}{0.5061}$. The change in flux is interpreted as the difference of $\frac{\partial F}{\partial t} = 0$ and the local minima of the curve. Taking the square root of the result gives us:

$$\sqrt{\frac{0.5061 - 0.4814}{0.5061}} = \frac{R_e}{R_*} = \sqrt{0.0488} \tag{3}$$

Rearranging the left-hand side of (3), we can see that the radius of the eclipsed target star is ≈ 4.527 times larger than its partner star.

4.2. *Calculating Orbital Motion*

To analyze different orbital properties of this system, I began with calculating the orbital period. This is because it was information that could easily be analyzed from the extracted photometry. The value of the orbital period is shown to be the curve from 2456785.76 to 2456785.8949, or about 11,646 seconds (0.135 days).

Now, computing the semi-major axis of the orbiting star is a simple calculation. Since $P^2 \propto a^3$, it leads us to understand that the ratio of the two is equal to a constant, shown in Equation (1). Solving for a, we get:

$$a^3 = \frac{G(M_* + M_e)P^2}{4\pi^2} \Rightarrow a = (\frac{G(M_* + M_e)P^2}{4\pi^2})^{\frac{1}{3}} \tag{4}$$

Finishing this calculation gives a value of $a = 6.26 \times 10^8$m at the time of orbit. Additionally, we can include another simple calculation for the orbital velocity:

$$v = \frac{2\pi a}{P} \approx 3.38 \times 10^5 m/s$$

4.3. *Calculating Magnitudes*

Lastly, calculating the apparent and absolute magnitudes (m and M, respectively) only involves one simple equation: the distance modulus:

$$M = m - (5log(d) - 5) = -8.366 \tag{5}$$

5. ANALYSIS

The targets for B and V filters had to be selected identically because of how the target's flux is actually relative flux, i.e. relative to the target stars nearby. However, the aperture profiles used to process the light curves in each filter are not identical, obviously, because of several different instrumentation and time-dependent factors like changing environments. The resulting curves are not remotely similar in the least, though, meaning that the B filter either did not process the target's signal or there simply was not enough data taken with that filter. The former can allow us to infer that the star system itself is closer to a blue color, which implies a much hotter surface (Parsons (2012)). This information is accurate, as the binary star system itself contains a white dwarf, which is known to be much hotter than most stars in the universe. We can rule out any type of Doppler shift because, in order for the host star to be eclipsed, it must be moving perpendicular relative to its axis pointing towards Earth.

In calculating the relative masses of the double star system, the value of 4.527 is actually really accurate, as the error difference between the calculated relative value and the provided value is $\approx 6.1\%$.

The absolute magnitude calculation seems to be incorrect, as the known value of the absolute and apparent magnitudes of NN Ser are 8.1 *mag* and 16.5 *mag* respectively (citation). The value calculated here is brighter than most stars in the universe!

After calculating the orbital velocity, it can be said that any external force acting on it must be extremely strong in order to slow the orbit any amount.

5.1. *Error*

The light curves for both filters show clear discrepancies, in opposite directions. A possible and very likely source of error is a disruption by its host galaxy or our own, as no external background subtraction was performed except by the photometry software itself. Additionally, the large error in the V filter light curve appears to happen right at a peak in the curve. This infers that either the peak was not supposed to happen, or that the 1-meter telescope malfunctioned at this time of observation. In contrast, the error in the B filter light curve happens at the very end of the observation run, which could also imply another instrumentation or calibration error.

The line of best fit did not consider the supposed peak in the curve, mainly because the software did not allow for it (as the line after the transit it really straight). However, like mentioned previously, it was not worth analyzing since there was an abundance of errors at that time.

6. CONCLUSION

The light curves led us to discover many properties of the host star of NN Ser, such as mass, temperature, and its size. Compared to its partner star, it proved to be about 4.527 times more massive, inferring that it contains the inner orbit of the binary star system.

More importantly, there was a distinct dip in the curve, showing a very clear transit caused by its partner star. It was discovered that the orbital speed was equal to 338 km/s, much less than the known average velocity of binary stars at around 700 km/s (Fienberg (2006)).

7. ACKNOWLEDGMENTS

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I hope to write more in the future.

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