Lab Report

Predicting and Analyzing Time of Conjunction of an Eclipsing Binary Star, V*RR Nor

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1 Objective

In this experiment, the goal is to further develop astronomical observing skills, especially photometry, by using standard astronomy software (TOPCAT, AstroImageJ, Cartes Du Ciel, AstroPy, Lightkurve) to observe a chosen eclipsing binary star (EB). Using the iTelescope network, a target star is imaged over the course of its eclipse and multi-aperture photometry is used to create a light curve (LC). Analyzing the light curve can yield the time of conjunction which can be compared to predictions and the established literature.

2 Procedure

This lab consisted of several steps: pre-observation filtering and selection, observation planning, post-observation analysis and conclusions. Firstly, TOPCAT was used to filter through *TESS Eclipsing Binary Stars. Sector 1-26.* Prsa et al. 2022 to select a candidate target. Then, Cartes Du Ciel was used to verify the possibility of observation and to generate the plan for the iTelescope network. Lastly, the obtained images were analyzed using Python and several Astronomy oriented libraries. Note: All equatorial coordinates are given in J2000.

2.1 TOPCAT Filtering & Conjunction Prediction

To find a candidate for this experiment, TOPCAT was used to filter through a TESS catalogue. Several criteria were filtered, namely the equatorial coordinates, the magnitude, the period and the depth of the primary eclipse. It was chosen before hand to use a telescope in the southern hemisphere to narrow the search down. Thus, the Declinations were restricted between 30°N to 90°S. Similarly, the Right Ascension was limited between 140° and 260° as this range corresponded to the night time in mid May. For observational purposes, the magnitude was limited to anything brighter than the 12th Mag, and because of the sensitivity of the CCD, primary eclipse depth values below 0.3 Mag were rejected. Lastly, to allow for multiple observations if necessary and to guarantee a short eclipse, only candidates with a period shorted than 2 days were included. Out of the starting 4584 candidates, only 5 were left. Finally, to choose a target, each EB was viewed in EASky 5.0.2 to ascertain whether the field of view was crowded or not. Ultimately, TIC 41561453, also known as V* RR Nor was selected as the best candidate for observation.

Cartes du Ciel, also known as Skychart was used to investigate the observational characteristics of the target. On the 18th of May, the possible observation night, RR Nor transited at 23h34m05 (UTC+10) with an altitude of 65°53 as seen by the Siding Spring Observatory.

As the goal of the experiment was to observe the EB at the moment on primary conjunction, this time had to be estimated. The next time of conjunction was predicted using the EB's period and epoch. To calculate when the next eclipse was, the following calculation was performed:

$$t_{predicted} = P \times \lceil (t_{now} - t_0)/P \rceil \quad (1)$$

Target	RA (°)	DEC (°)	TMag	Period (d)	Epoch (JD)
RR Nor	228.1396393	-55.3136541	10.194	1.5137671	2452500.463

Table 1: Characteristics of RR Nor. Taken from TESS Catalogue and Prsa et al. 2022

Date	Observed from	Coordinates	Predicted Conj.	Transit
18/05/2023	Siding Spring, AUS	31° 16' 24" S 149° 03' 52"E	20:08:15	23:34:05

Table 2: Observation data. All times are given in Observatory local time (UTC+10)

Where t_{next}, t_{now} and t_0 are the times of next conjunction, current time and epoch respectively in Julian Days and P is the Period in Julian Days. $\lceil x \rceil$ is the ceiling operator. The next predicted conjunction would occur at UTC: 2023-05-18 10:08:15.69 or JD: 2460082.9224039. As seen by the Siding Spring Observatory, this would occur at UTC+10: 2023-05-18 20:08:15.69 which would be close to its time of transit.

2.2 T17 Telescope Programming

Telescope T17 was selected from the Siding Spring Observatory because of its relative low cost and its wide array of band filters. Since TESS uses a V (Visual) band filter, the same was selected for our observation. Since the goal of this experiment is to observe and record the time of conjunction using aperture photometry, observation should be planned around the predicted time from equation 1. Approximately 1H of observing was planned starting 30m before the predicted time of conjunction at 19:30 UTC+10, with 60 frames to be captured.

3 Data

The data collected by the T17 telescope consists of 120 FIT files, 60 calibrated and 60 raw. Only the calibrated files were used for the analysis. The calibrated frames were assembled into a stack and processed through AstroImageJ. First they were individually plate solved using a key from Nova Astrometry after which they were aligned and comparison stars were selected. These stars would work as standards to calibrate the magnitude of the target. The different comparison and target stars can be seen in figure 4.

Three different kinds of light-curves were generated during the analysis. The first, figure 5, shows the apparent magnitude over the course of the observation of a comparison star which was assigned its V band magnitude from SIMBAD. The second, figure 6, shows the apparent V magnitude of a control target (a target who's magnitude was calculated relative to the comparison stars) during the observation. The last, figure 7, shows the apparent V magnitude of the target, RR Nor.

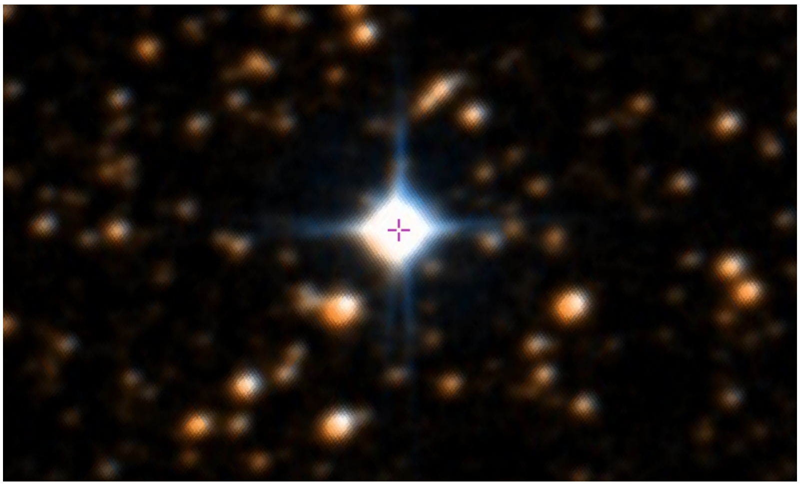

Figure 1: Star-field of RR Nor in ESASky.

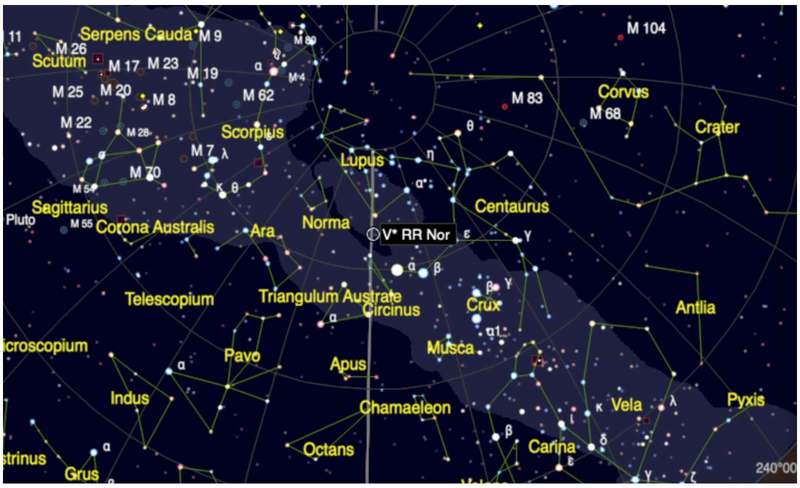

Figure 2: V*RR Nor in the Australian sky on Cartes du Ciel at time of observation.

Instrument Package

CCD: FLI ProLine PL4710
QE: 94% Peak (Near IR)
Full Well: 100,000 e- Non Anti-Blooming Gate (NABG)
Gain: 1.23 e- ADU-1
Dark Current: <0.2 e- /pixel/sec. @ -45° C
Readout Noise at 20 kHz: 2.0 e- rms
Pixel Size: 13um Square
Resolution: 0.92 arcsec/pixel
Sensor: E2V CCD47-10-1-109 Deep Depletion Fused Silica
Cooling: -35C default
Array: 1024 x 1024 pixels
FOV: 15.5 x 15.5 arcmin

Figure 3: Technical Information of T17 Telescope. See more on iTelescope

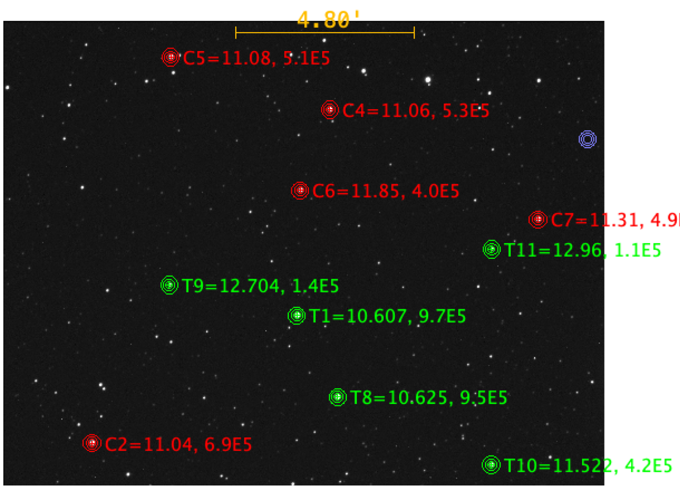

Figure 4: Slice of stack showing comparison stars (red) and target stars (green) with RR Nor as T1.

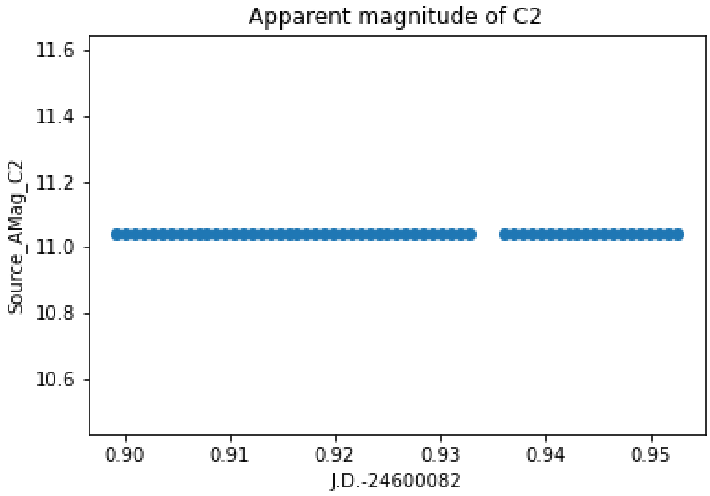

Figure 5: Magnitude light-curve of comparison star C2.

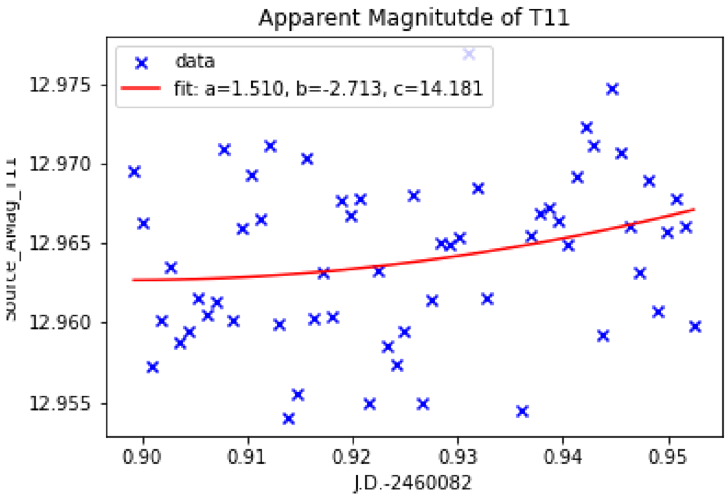

Figure 6: Magnitude light-curve of control target T11.

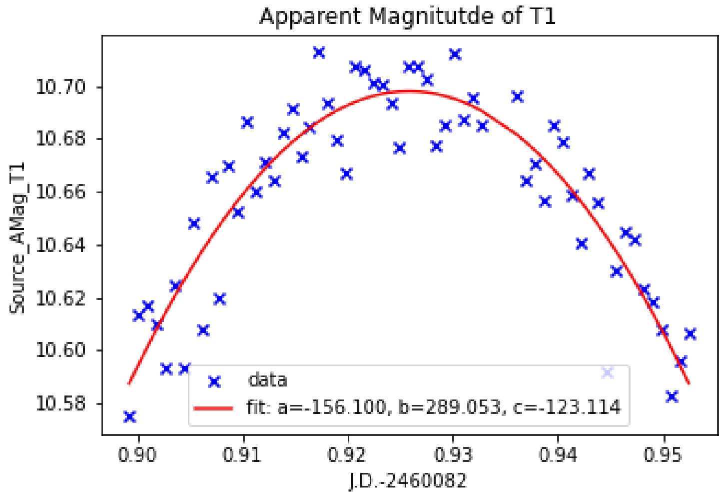

Figure 7: Magnitude light-curve of target RR Nor.

4 Analysis

4.1 Calibrated vs. Raw FITs

The calibration takes three main sources of image noise of out the final science image. Firstly, the bias frame is a 0 second image to the signal due to readout process only. Secondly, the dark frame is an image over a long exposure time but with no light to pickup on any signal due to thermal noise. Lastly, the flat frame is an image of an even illumination source that reveals pixel-to-pixel variation in system response. Together, these frames can be combined to remove as much instrumental noise recorded by the CCD and yield a calibrated science image which can be used for photometry. For more information on calibration see section 4 of the AAVSO Photometry Guide *AAVSO Guide to CCD/CMOS Photometry with Monochrome Cameras* 2022. The reason only the calibrated FIT files were used for analysis is because iTelescope handles the calibration for science images directly. It also provides the raw files along with the calibration frames for calibrations, although doing this is both redundant and time consuming.

4.2 Multi-Aperture Photometry

To analyze the 60 calibrated frames and obtain figures 5, 6 and 7, multi-aperture photometry was performed in AstroImageJ (AIJ). To do this, an appropriate aperture was made, such that the inner radius fully included the target star. A radius of 10 pixels was selected. After plate solving all the slices, the setting of centering the aperture based on RA/DEC coordinates was selected. Six comparison stars were selected and their magnitudes were looked up on SIMBAD and entered in AIJ. Then the target stars were selected and the multi-aperture process was launched. For each frame, the pixel counts within all the apertures were recorded, and using the comparison star's magnitude, these counts were translated to apparent magnitudes. Finally, the measurements were exported as a .csv file

	Julian Date	UTC
Predicted	2460082.9224	2023-05-18 10:08:15.69
Observed	2460082.9258	2023-05-18 10:13:14.45
Difference	0.0034 JD	4.979 min

Table 3: Results of analysis. Observed vs. Predicted times of conjunction.

and analyzed in Python using Numpy, Matplotlb and Lightkurve packages. To access the analysis code as well as the calibrated FIT frames, see GitHub.

There is little extrapolation available from this data set, as it only contains a partial light-curve. However, we can estimate the magnitude drop observed and compare it to the literature. In figure 7, a drop of the order 0.1 Mag can be observed compared to a recorded drop of 0.497 Mag in the TESS catalogue. This makes sense as only a part of the eclipse was observed.

4.3 Observed Conjunction and Curve Fitting

The light curve of RR Nor in figure 7 shows a clear eclipse-like trend, wherein the magnitude increases (the flux of light decreases), peaks, and then decreases. However, the control target star's light curve (figure 6) doesn't show a clear trend but rather random fluctuations of small order. Therefore, we can rule out that this observation is due to an atmospheric effects and conclude it is indeed an eclipse.

Since the observation occurred only 1 hour around conjunction, the base magnitude of the target was not observed and a light curve could not be fit the data. Instead, the peak of the eclipse was approximated as a 2nd order polynomial which could be solved to yield the time of conjunction. Indeed, the time of conjunction corresponds the roots of the derivative of the polynomial fit:

$$\begin{aligned} 2 \cdot a \cdot x + b &= 0 \\ -2 \cdot 156.1 \cdot t_{observed} + 289.053 &= 0 \\ t_{observed} &= \frac{289.053}{2 \cdot 156.1} \end{aligned} \tag{2}$$

Equation 2 yield $t_{observed} = 2460082.925861764$, or in UTC 2023-05-18 10:13:14.45. See table 4 for a comparison between observed and predicted times of conjunction.

Finally, the observation made in this experiment can be compared to the established literature form Kreiner 2004. In figure 8, our observation is added as a red cross to the O-C plot. This observation matches previous ones and confirms the period and epoch are accurate enough for prediction of future eclipses.

5 Conclusion

In conclusion, using the iTelescope network, the complementary astronomical software and TESS data, we attempted to predict the time of conjunction of an eclipsing binary

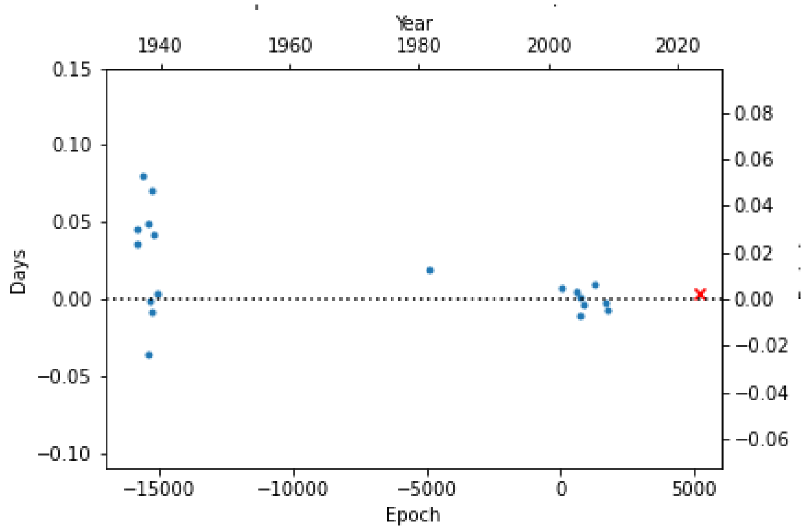

Figure 8: O-C plot of RR Nor with our observation added as red x. From Kreiner 2004

star system and observe it around that time. We successfully acquired a partial light curve centered around the time of conjunction, which allowed us the extract the observed time of conjunction and compare it the predicted time of conjunction based on the period and epoch from Kreiner 2004 with a small error of 5 minutes.

Thanks to the photometry capabilities of AstroImageJ we managed to rule out the possibility that the observed eclipse-like light-curve was due to atmospheric or other effects, by comparing different star's light-curves.

Ultimately, we contributed to the current literature on a specific EB, RR Nor, by adding our observation and prediction to Acta Astronomica Vol. 53. Further observation of RR Nor before and after conjunction could yield a full light-curve which could be fit to investigate intrinsic properties of the star system such as the system mass, rotation velocity or even be used as a standard candle for cosmology McVean et al. 1997.

References

AAVSO Guide to CCD/CMOS Photometry with Monochrome Cameras (2022). (Visited on 05/25/2023).

Kreiner, J.M. (2004). *Acta Astronomica*. Vol. 54, pp. 207–210.

McVean, J R et al. (June 1997). "Analyses of the Light Curves of the Eclipsing Binaries in the Globular Cluster M71". In: *THE ASTROPHYSICAL JOURNAL* 481, pp. 782–794. DOI: 10.1086/304067. (Visited on 05/25/2023).

Prsa, Andrej et al. (Jan. 2022). "TESS Eclipsing Binary Stars. I. Short-cadence Observations of 4584 Eclipsing Binaries in Sectors 1–26". In: *Astrophysical Journal Supplement Series* 258, pp. 16–16. DOI: 10.3847/1538-4365/ac324a. (Visited on 05/01/2023).