Deciphering Multiple Observations of V480 Lyrae

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Abstract Existing and new observations of the variable V480 Lyr are examined and analyzed. This study utilized a 25-cm Schmidt-Cassegrain Telescope (SCT) to observe multiple cycles of the star and obtain new *BVRI*-band photometry. These new observations, when combined with other published observational data, allowed the determination of multiple period values for the variable. From this multi-period behavior, and from an examination of other intrinsic parameters, there is evidence that V480 Lyr could be classified as an RV Tauri type star, which differs from earlier classifications.

1. Introduction

V480 Lyr is listed in the *General Catalogue of Variable Stars* (GCVS; Sternberg Astron. Inst. 2009) as an eclipsing binary (β Lyr type). This designation is based on the initial work of H. Gessner (Gessner 1983), who produced a partial light curve and postulated that the variable was an EB type with a period of approximately 100 days. The Gessner light curve is quite sparse and is shown in Figure 1. The initial demonstration phase of the Robotic Optical Transient Search Experiment (ROTSE 1) from 1998 produced a *V*-band set of data for V480 Lyr that was interpreted as the variable being a Cepheid, with a period of 44.5 days (Akerlof *et al.* 2000). This interpretation has been repeated in several other publications (Samus *et al.* 2003; Schmidt *et al.* 2007). Analysis of subsequent ROTSE data and new observations of this star by the author in 2007 and 2008 called into question the accuracy of this interpretation and period.

2. Observations

All observations by the author were made using a Meade LX200 10-inch (0.25m) telescope, with a Starlight Xpress MX 716 CCD camera, which has a 550 × 720 pixel array. One-minute exposures were taken at an *f*-ratio of 6.3 (for an effective field of view of approximately 12 × 16 arc minutes) with standard *BVRI* photometric filters. Five contiguous one-minute exposures were averaged to produce a single data point during the time-series observations.

Typical seeing conditions for this low-altitude site were between 3.5 and 4.5 arc seconds FWHM for each image. The air mass for observations ranged from 1.01 through 1.45. All exposures were dark current- and bias-subtracted, and also flat-fielded (using twilight sky flats) according to established procedures. The software tool AIP4WIN (Berry and Burnell 2000) was utilized to make photometric measurements.

The *B, V, I,* and *R* photometric data were calibrated with measurements taken from Tycho observations of comparison and field stars (Høg *et al.* 2000) corrected to the Johnson-Cousins system. Zero points were then determined from the comparison star photometry and applied to photometry of V480 Lyr using AIP4WIN, to produce standardized *B–V*, *V–R*, and *V–I* measurements. The calculated photometric error of observations of the variable star was at or below 0.03 magnitude in all bands.

V480 Lyr was observed from JD 2454263.706 to 2454382.608 (2007 June 12 to 2007 October 9) and from JD 2454632.705 to 2454726.632 (2008 June 15 to 2008 September 17).

All exposures of V480 Lyr included two comparison stars, GSC 3130-1721 and GSC 3130-1779, whose *BVRI* magnitudes are shown in Table 1. To ensure that the comparison stars were not variable, the difference between GSC 3130-1721 and GSC 3130-1779 was also measured for each exposure. The standard deviation of the *V*-band magnitude difference of these two comparison stars over all observations was found to be 0.017 magnitude.

The position determined for V480 Lyr was R.A. (2000.0) $18^h 40^m 23^s$, Dec. (2000.0) +43° 56' 21", based upon the reference coordinates in the *USNO-A2.0 Catalog.* It very closely matches the position generated from the SIMBAD website (FK5 2000.0 coordinates: R.A. $18^h 40^m 23^s$, Dec.+43° 26' 22" or the coordinates in the GCVS.

3. Analysis

Inspection of the 2007 and 2008 observations by the author (Figure 2) shows an alternating pattern of shallow and deep minima for this variable. This pattern is also apparent from an examination of additional data on V480 Lyr from the ROTSE project from JD 2452473 through 2452706 (2002 17 July to 2003 9 March) shown in Figure 3 (available through the Northern Sky Variability Survey, Woźniak 2004). The light curve of V480 Lyr clearly is not that of a typical type 1 Cepheid, nor an eclipsing binary, but the alternating pattern of minima, together with the varying depth of shallow minima, may indicate that V480 Lyr may be a RV Tauri-type star.

There are a number of published papers on RV Tauri stars and their respective behavior. In general, the visual light curves of RV Tauri stars have alternating deep and shallow minima, and have periods between 30 and 150 days (Sterken and Jaschek 1996). Pollard *et al.* (1996) list a number of characteristics for determining a star's inclusion in the RV Tauri class of variable stars. While Pollard *et al.* list a total of nine characteristics, some are only applicable to their comparison of a group of RV Tauri stars. Hence, the applicable characteristics to a single star, and this paper, can be summarized as follows:

a) there are alternating deep and shallow minima in the light and color curves;

b) secondary minima depths are more variable than primary minima depths;

c) a mean phase lag exists between the color index and light curves;

d) during extremely deep pulsations, the photometric colors get very blue; and

e) the shorter period RVa subclass exhibits a constant mean magnitude.

RV Tauri stars are known to be giant and supergiant stars, having masses close to that the Sun, spectral types at maximum ranging from early F to late G or early K, and most have low metal abundances. RV Tauri stars are known to be strong infrared sources, and some observations have shown that RV Tauri stars have substantial amounts of dust surrounding them (Wallerstein 2002).

4. Period determination

Because of the alternating shallow and deep minima of RV Tauri stars, the usual method of determining the period from adjacent minima cannot be used. The established convention for these types of stars places the primary, or deeper minimum at phase 0.0, and the secondary, or more shallow, minimum at phase 0.5. Additionally, the "formal," or double, period is defined to be the time between deep minima and the "fundamental," or single, period is time between successive minima.

A well known explanation for the alternating shallow and deep minima of RV Tauri stars (Takeuti and Petersen 1983) suggests a 2:1 resonance exists between the fundamental mode and the first overtone vibrations of an RV Tauri star.

To examine this hypothesis for V480 Lyr, the 2007 and 2008 *V*-band observations by the author, together with the 2002 and 2003 *V*-band ROTSE data, were entered into the software program PERANSO (Vanmunster 2007). Utilizing the PDM (Phase Dispersion Minimization) period determination tool, two periods were readily apparent. One period is the primary ("formal") period at 104.2 ± 0.6 d and is shown in Figure 4. A second significant period is seen at 52.09 ± 0.2 d and is shown in Figure 5. These two periods have a period ratio consistent with the 2:1 resonance model.

While these two periods were pre-whitened, the PDM tool did not reveal any other significant periods beyond those within the margin of error for each period found earlier.

It is noted that the interval between the two primary minima observed in 2007 and in 2008 (Figure 2) is 312 days, or three times the "formal" period of 104 days.

As an additional check on the two periods determined, a self correlation analysis was conducted (Percy *et al.* 2003). This analysis also revealed the 52- and 104-day periods previously determined.

5. Color index and light curves

Light curves for the *BVRI* photometry are shown in Figure 6. Each curve shows the typical primary and secondary minima and is phased to the 104.2-day period. The differences between maxima and the two minima are listed in Table 2. The deepest primary minima occur in the *B* band (1.48 magnitudes), while the deepest secondary minima occur in the *R* band (0.61 magnitude). The ratio of magnitude change in primary to secondary minima is approximately 3:1 for the *B* and *V* bands, and approximately 2:1 for the *R* and *I* bands.

A comparison of mean *V*-band magnitude was made using the ROTSE 1 data and data from the author. For the available data, the V480 Lyr mean magnitude is remarkably constant at *V* mag = 12.68, varying only 0.17 magnitude from this on one instance (circa JD 2451444.00).

The *B–V*, *V–I*, and *V–R* color indices compared with the *V*-band light curve are shown in Figure 7. Examination of these indices shows alternating deeper and shallow minima similar to the *BVRI* light curves, although not at the same amplitude. Also of note is that the *B–V* phase changes precede the *V*-band phase changes by approximately 0.15 phase. The color curves are typically bluer (smaller numbers) at phases around 0.15 and phase 0.60 (on the rising branch of the light curve), which is not unexpected in an RV Tauri star, possibly due to shock-related features. The colors are reddest (largest numbers) at phase around 0.95–1.0, when V480 Lyr is faintest.

6. Conclusions

New photometry of V480 Lyr has been obtained, and when combined with previously published data, shows that V480 Lyr meets many of the published characteristics of an RV Tauri type star. V480 Lyr shows an alternating pattern of shallow and deep minima, and the two periods (104.2 days and 52.09 days) show the characteristic 2:1 ratio for RV Tauri stars. The color indices show a phase lag with the single color curves, the primary minima is very deep in the blue band, and the mean magnitude of all pulsations is constant, at 12.68 magnitude.

The lack of many shallow minima in the 2002 and 2003 ROTSE 1 data may present a problem in being confident in the conclusion that V480 Lyr is a RV Tauri star, although the ROTSE 1 data are essentially *R*-band photometry, and the depths of alternating minima are not as significant at redder wavelengths. Still, additional *V*-band observations will be necessary to provide such confidence or suggest an alternative classification.

7. Acknowledgements

This research has made use of the SIMBAD database, operated at Centre de Données astronomiques de Strasbourg, and the GCVS databases, operated by the Sternberg Astronomical Institute, Moscow, Russia. This research has also made use of the website and associated material from various "Variable Stars of the Season" articles from the AAVSO.

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Table 1. The magnitudes of V480 Lyr comparison stars from observations by the author in 2008.

Comparison Stars	*B*	*V*	*R*	*I*
GSC 3130-1721	11.49 ± 0.03	10.95 ± 0.03	10.67 ± 0.03	10.41 ± 0.03
GSC 3130-1779	13.95 ± 0.03	13.09 ± 0.03	12.88 ± 0.03	12.57 ± 0.03

Table 2. The magnitude differences between the maxima and the primary and secondary minima from *BVRI* photometry of V480 Lyr by the author in 2008.

Band	*Max–Min (Primary)*	*Max–Min (Secondary)*
B	1.48	0.42
V	1.41	0.50
R	1.09	0.61
I	0.95	0.57

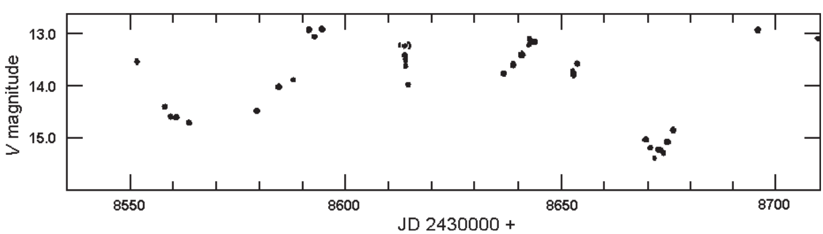

Figure 1. An early light curve for V480 Lyr from Gessner (1983).

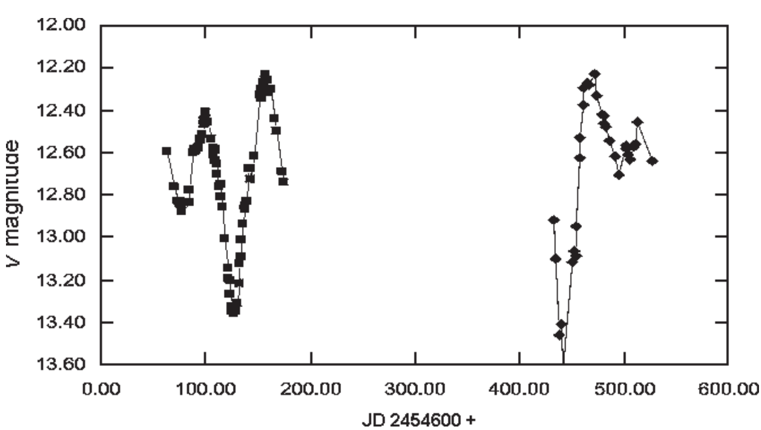

Figure 2. The *V* magnitude of V480 Lyr from observations by the author in 2007 (squares) and 2008 (diamonds).

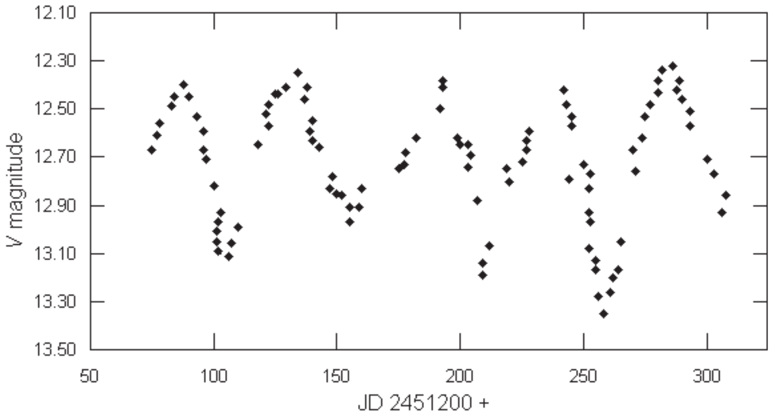

Figure 3. The *V* magnitude of V480 Lyr in 2002 and 2003 from the Northern Sky Variability Survey (Woźniak 2004).

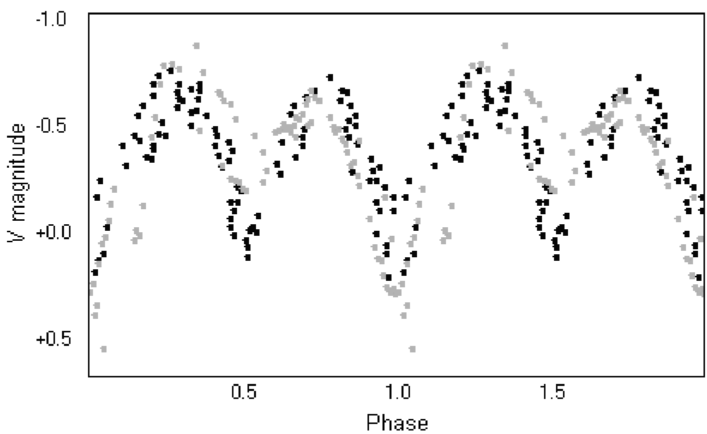

Figure 4: The *V* data for V480 Lyr phased with the primary (formal) 104.2-day period. These data are from observations by the author in 2007 and 2008 (gray dots), and from the Northern Sky Variability Survey in 2002 and 2003 (black dots).

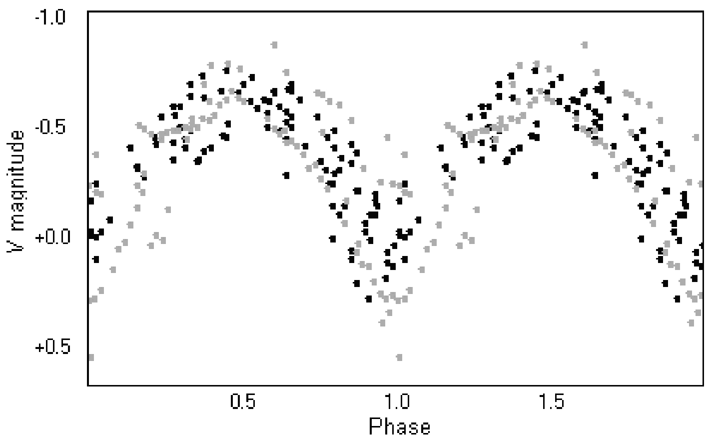

Figure 5: The *V* data for V480 Lyr phased with the second significant period of 52.09 days. These data are from observations by the author in 2007 and 2008 (gray dots), and from the Northern Sky Variability Survey in 2002 and 2003 (black dots).

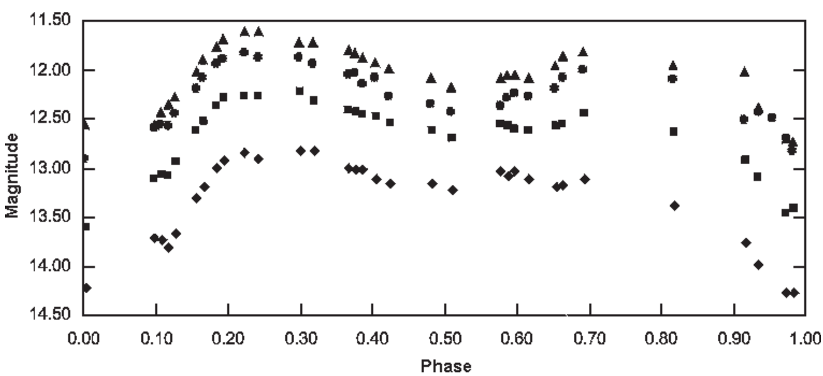

Figure 6. The new photometry of V480 Lyr from observations by the author in 2008: *B* (diamonds), *V* (squares), *R* (dots), and *I* (triangles).

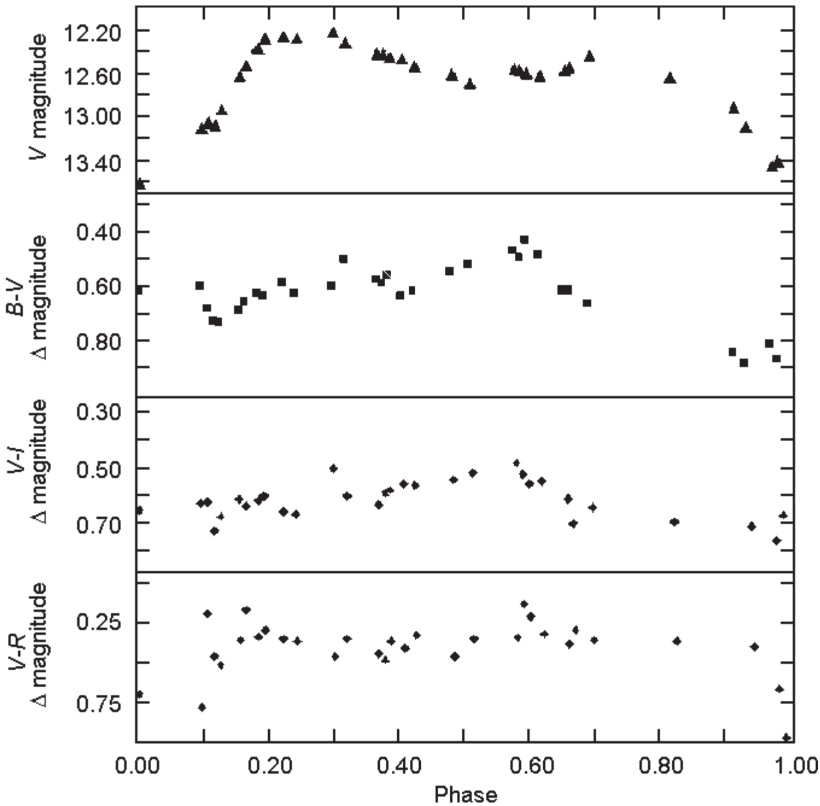

Figure 7. New photometry of V480 Lyr from the author in 2008, comparing the *V* light curve with the *B–V*, *V–I*, and *V–R* color indices.