Photometry of V578 Monocerotis

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Abstract V578 Monocerotis (= HDE 259135), a member of the galactic cluster NGC 2244, is an eclipsing binary containing two early B-type stars with a period of 2.4048 days. From early photometric observations of V578 Mon obtained by the author, and from data by D. S. Hall's collaborators (Anon. 1995), both the orbital period, noted above, and an apsidal motion period of about 30.4 years was determined. The current study is a summary of all the *UBV* photometric data obtained by the author from 1962 through the 2005–2006 season. The purposes of this study were to obtain an improved orbital period of this eclipsing binary, to determine a better estimate of the apsidal motion period, and to search for any light curve changes over time.

1. Introduction

The photometric variations of HDE 259135 (= V578 Mon) were accidentally discovered during a *uvby*-β study of the galactic open cluster NGC 2244 (Hardie 1970; Heiser 1977). The star was noted, from only two radial velocity observations, as a possible variable by Hayford (1932). Morgan *et al.* (1965) in their spectral type study of the stars in NGC 2244 noted that spectra of HDE 259135 (B0.5V) showed double lines. The double lined nature was verified by spectra obtained at the Kitt Peak National Observatory (KPNO) by Heiser (1972). Radial velocities from these spectra and the early photometry led to the first period determination of 2.420 days. From the variety of photometric observations of V578 Mon obtained by the author and by D. S. Hall's collaborators (Anon. 1995), an apsidal motion period of approximately 30 years was estimated. A detailed study of the physical properties of the system was undertaken by Hensberge *et al.* (2000).

The current study is a summary of all the photometric data obtained by the author, from 1962 through the 2005–2006 season, at various observatories: Dyer Observatory (DO), Kitt Peak National Observatory (KPNO), and the Vanderbilt-Tennessee State University (TSU) 16-inch (APT) at Fairborn Observatory. The purposes of this study were (i) to obtain an improved orbital period of this eclipsing binary, (ii) to determine a better estimate of the apsidal motion period, and (iii) to show the light curve changes over time.

2. Observations

The author's photometric *UBV* data can be divided into three sets based on the observational epochs and the different observatories.

(i) 1962–1970 (HJD 2437698 to HJD 2440703) at DO; 1–2 observations per night.

(ii) 1967–1983 (HJD 2439503 to HJD 2445703) at KPNO; 1–3 observations per night.

(iii) 1994–2006 (HJD 2449638 to HJD 2453842) at APT; continuous observations on some predicted minima nights, and many nights with single observations.

All the data are in differential form, in the sense "variable – comparison." Virtually every night also had check star observations, in the sense "comparison – check." The comparison star, from Johnson's study of NGC 2244 (1962), was HD 46106 (= Johnson 5 type B1V) and the check star was either HD 46149 (= Johnson 4 type O8.5V), or HD 46223 (= Johnson 3 type O5e). Table 1 is a summary of the average observational errors from the differential check star observations at the different epochs and observatories.

3. Analysis

3.1. Times of minimum and period determination

The sporadic nature of the differential *B* data collected at DO and at KPNO resulted in a number of times when there were values that appeared to be near a minimum of the light variation. These minimal values of ΔB, listed in Table 2, indicated a probable orbital period for V578 Mon of about 2.408 days, which was later confirmed by the work of Hall and his collaborators (Anon. 1995). This period, together with the arbitrarily chosen KPNO HJD 2443158.8443 time of minimum, was used to predict times of minima for the observations undertaken with the APT. Differential *BV* data obtained at the APT resulted in six additional times of primary minimum, also listed in Table 2, as well as a number of times of secondary minimum. All the times of minima from the APT data were determined using the method of Kwee and van Woerden (1956).

The ΔB times of minimum were used in the following manner to determine a significantly better orbital period for V578 Mon: The two times of minima, HJD 2443158.84434 (KPNO) and HJD 2451554.77106 (APT), were separately iterated using trial periods until the sum of the $(O–C)^2$ was minimized for all fourteen values of the primary minima determined from the ΔB measurements. These results are 2.40848475 days (KPNO) and 2.40847965 days (APT), which gives an average period of 2.4084822 ± 0.0000026 days. This period was used with an epoch of HJD 2451554.77106 ± 0.00057 to calculate all the phases of

the light variations of V578 Mon from 1962 to 2006.

The apsidal motion period was determined by measuring (O–C)' deviations from thirteen times of primary minima around epoch HJD 2451554.77106. Least square fits were made to data over the range of cycles –6000 to –3000 and –1000 to +1000, giving slopes, shown in Figure 1, of 0.000055 ± 0.000010 and 0.000054 ± 0.000005, respectively. Since these two estimates are identical within their uncertainties, one can calculate the HJD's of each set at their (O–C)' values of 0.0. The difference of these HJD's is about 10,517 days. A similar analysis, using the deviations from epoch HJD 2443158.84434, gives a difference of about 11,680 days. Averaging these two differences results in an apsidal period of about 30.4 years, which is in good agreement with the value quoted by Hall and his collaborators (Anon. 1995).

3.2. Light curves

All DO and KPNO differential Δ*B* data are shown in Figure 2. Observations around primary minimum, near phase 0.07, indicate that the 1973 to 1978 data occur at slightly later phases than those of 1968 to 1971. On the other hand, the data from 1973 to 1978 at secondary minimum, near phase 0.54, occur at slightly earlier phases than observations from 1968 to 1971. Observations outside of eclipse show a post-primary shoulder from phase 0.13 to 0.20, then a slight increase to a maximum phase near 0.3 with no shoulder going into secondary eclipse, and then a very slight rise from phase 0.6 to 0.95. These outside-of-eclipse observations indicate that there are effects due to the ellipsoidal nature of the two stars, limb darkening, or reflection effects from the more luminous star onto the less luminous star.

The average *UBV* color indices at each minimum of the DO and KPNO observations are shown in Table 3. These colors indicate that the more luminous star is somewhat hotter than the less luminous star.

The APT observations around primary and secondary minima show variations indicative of apsidal motion. Figure 3a shows the variations in Δ*B* at primary minimum for the seasons of 1994/1995/1996 (=94/95/96), 1999/2000, and 2005/2006. The light curves show the primary minimum depth *increasing with time* and *increasing in phase* from the 94/95/96 observations to the 2005/2006 observations. Figure 3b shows the variations in Δ*B* at secondary minimum for the seasons of 94/95/96, 1999/2000, and 2005/2006. At secondary minimum both the depths and the phases are *decreasing with time*. The changes at the minima over the APT 11–12-year time interval lends support to the apsidal period of 30.4 years determined above in section 3.1.

4. Summary

The very long baseline of these observations of V578 Mon underscores the value of acquiring and analyzing data obtained over long time periods. The *UBV*

observations of this binary, obtained from 1962 to 2006, were used to determine a more significant orbital period. Color changes at minimum light indicate that the primary has a somewhat higher surface temperature than the secondary. Changes in the light at minima support the presence of an apsidal motion period of about 30.4 years. A further analysis of these observations has been undertaken by Garcia *et al.* (2010).

5. Acknowledgements

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Table 1. Average errors, in magnitudes, from V578 Mon check star observations.

Observatory	*Errors in* ΔV	*Errors in* ΔB	*Errors in* ΔU
DO	±0.004	±0.007	±0.004
KPNO	±0.004	±0.004	±0.004
APT	±0.002	±0.001	—

Table 2. HJD times of minima of V578 Mon.

Year	*Observatory*	*Time of Minimum*	*Time of Min. Error*	ΔB *value*
1962*	DO	2437698.7496	± 0.0002	0.778
1962*	DO	2437739.6617	± 0.0002	0.773
1969*	DO	2440292.6882	± 0.0002	0.786
1973*	KPNO	2442014.83162	± 0.0002	0.808
1973*	KPNO	2442043.70033	± 0.0002	0.817
1976*	KPNO	2443105.90927	± 0.0002	0.790
1977*	KPNO	2443158.84434	± 0.0002	0.795
1977*	KPNO	2443488.86693	± 0.0002	0.788
1995#	APT	2449738.75624	± 0.00085	0.762
1995#	APT	2449750.79842	± 0.00152	0.762
2000#	APT	2451554.77106	± 0.00057	0.791
2005#	APT	2453712.83465	± 0.00076	0.799
2005#	APT	2453724.87717	± 0.00063	0.799
2005#	APT	2453741.73648	± 0.00111	0.800

* *Time of minimum is the observation time of the "minimal"* ΔB *measures.*
\# *Time of minimum is from Kwee and van Woerden (1956) analyses.*

Table 3. Differential *UBV* color indices of V578 Mon at minima.

Type	Δ *(*B – V*)*	Δ *(*U – B*)*
Primary	0.046 ± 0.002	0.030 ± 0.002
Secondary	0.045 ± 0.003	0.026 ± 0.006

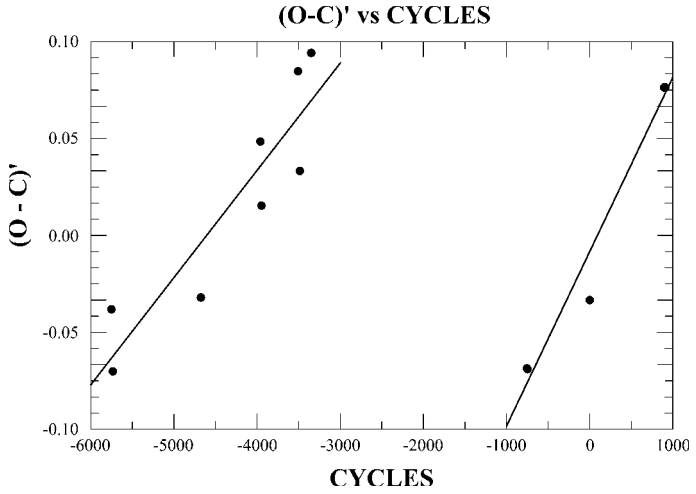

Figure 1. V578 Mon, deviations of the Table 2 times of minimum light as a function of the number of cycles, from the epoch HJD 2451554.77106.

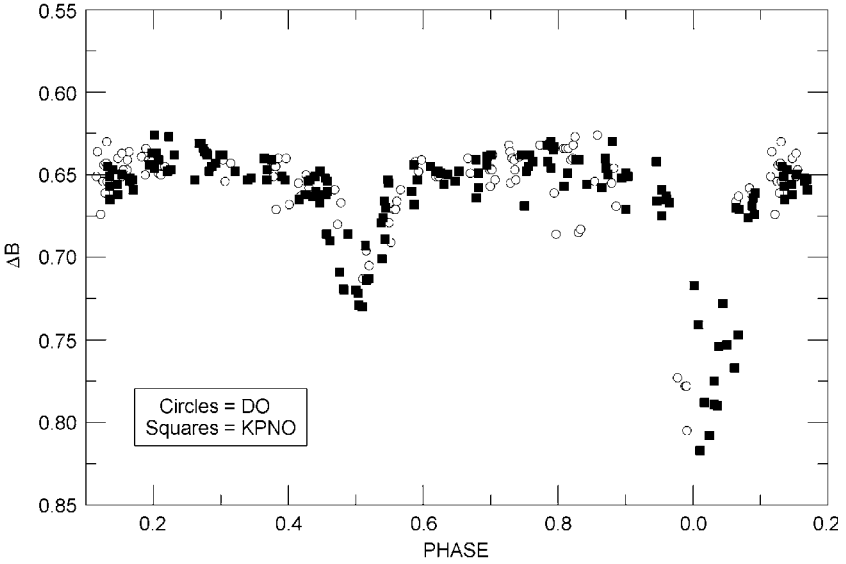

Figure 2. The differential *B* light curve for V578 Mon using the DO and KPNO data from 1968 through 1983.

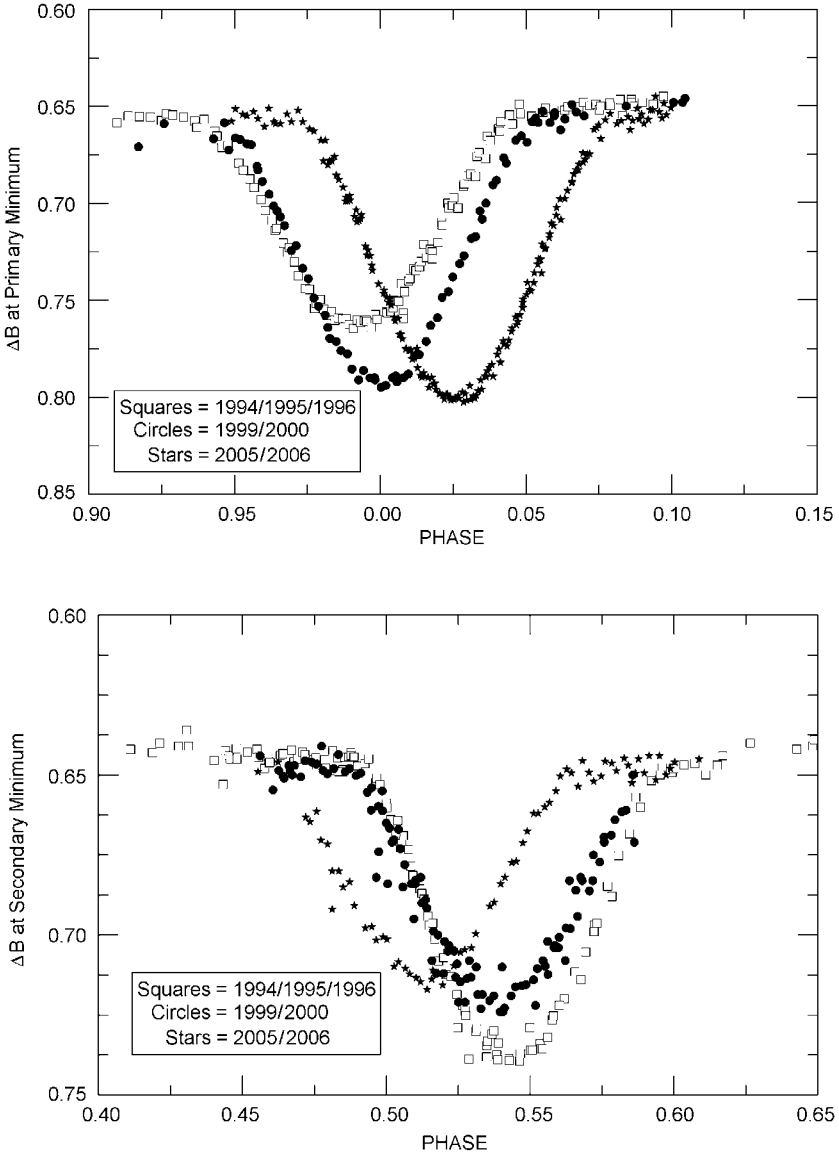

Figure 3. The APT differential *B* light curves around primary (top graph) and secondary (bottom graph) minimum for V578 Mon from 1994/1995/1996, 1999/2000, and 2005/2006. The curves show the increase in depth and phase over the indicated observing sessions.