Discovery of Pulsating Components in the Southern Eclipsing Binary Systems AW Velorum, HM Puppis, and TT Horologii

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Abstract Eclipsing binary stars with pulsating components are especially valuable for studies of stellar evolution. We have discovered that three eclipsing binary stars in the southern sky have a pulsating component with oscillations similar to those of δ Scuti stars. The systems are: AW Velorum, HM Puppis, and TT Horologii. Their spectral types were determined as A7 for AW Vel and HM Pup and F0-F2 for TT Hor. The dominant pulsation frequencies are 15–38 cycles per day with amplitudes of 10–60 millimagnitudes.

1. Introduction

The interiors of stars cannot be observed directly, but they can be studied by observing and interpreting the frequency spectra of pulsating stars. This is the field of asteroseismology. In recent years there has been great interest in single δ Scuti stars, which pulsate with typical frequencies of 20–50 cycles per day. Such pulsating stars may also be found in eclipsing binary systems where the absolute masses and sizes of the two components can be determined accurately from radial velocity spectrometry and eclipse photometry. This information can only be derived indirectly for single δ Scuti stars. Furthermore, the passage of the secondary star in front of the primary during a primary eclipse provides a spatial filter, accentuating or repressing the visibility of different pulsation modes. Accordingly, the study of δ Scuti stars in binary systems yields considerably more information than for isolated δ Scuti stars (see for example

Creevey *et al.* 2011; Liakos *et al.* 2012; Mkrtichian *et al.* 2004; Soydugan *et al.* 2006).

Two types of binary systems with pulsating components are recognized:

a) detached systems, in which both stars do not fill their Roche lobes and thus there is no mass exchange; the pulsator is a typical δ Scuti star. Such systems are at an early stage of binary evolution, where neither component has evolved away from the main sequence to swell to the sub-giant stage and fill its Roche lobe, thus initiating mass transfer. These types of systems are traditionally classified as EA/DSCT.

b) semi-detached systems, in which the (primary) pulsating component is undergoing mass accretion from the larger secondary that has filled its Roche lobe. Its properties and evolutionary history are considerably different from isolated δ Scuti stars. These types of eclipsing Algol (EA) binaries are classified as oscillating EA systems (oEA) (Mkrtichian *et al.* 2002, 2004).

The Southern Eclipsing Binaries Programme of Variable Stars South is a multi-purpose and ongoing campaign to observe and analyze bright eclipsing binary stars accessible to Southern Hemisphere observers. Despite their importance and ease of observation, many of them have not been observed in detail since their discovery, and many more require follow-up work to extend and check existing studies (Richards 2013). During studies to obtain accurate eclipse timings and update ephemeris elements, we have found that AW Vel, HM Pup, and TT Hor each contain a component with short periodic oscillations in magnitude. In this paper, we provide a brief summary of their properties. Further observations are in progress and are planned to obtain full light curves and radial velocities.

None of the three eclipsing binaries that we report on here were listed by Soydugan *et al.* (2006) in their catalogue as candidates for eclipsing binaries with δ Scuti components.

2. Observations and analysis

2.1. Time series photometry

The instruments used for photometry were a 350-mm Meade Schmidt-Cassegrain with a SBIG ST8 CCD camera (Streamer), a 356-mm Celestron Edge HD 1400 aplanatic Schmidt Cassegrain with a Moravian G3-6303 CCD camera (Moriarty), and a 410-mm RCOS Ritchey-Chrétien with an Apogee U9 CCD camera (Richards). All imaging was done with Johnson V filters. The images were reduced using aperture photometry; details of the comparison stars are given in Table 1. The resulting magnitude data are un-transformed.

Examples of primary and secondary eclipses of each target are shown in the figures.

The ephemeris light elements were updated from the data available from the GCVS and AAVSO/VSX. Times of minima were determined using the Kwee and van Woerden algorithm or Polynomial fit in PERANSO, with at least three minima analysed for each system (Vanmunster 2013). A linear regression analysis was applied to obtain improved light elements and errors. Pulsation frequencies were analysed after subtraction of the eclipse curves using Fourier methods in PERIOD04 (Lenz and Breger 2005).

2.2. Spectra

The spectra of TT Hor were obtained using an Lhires spectrograph with 150 g/mm grating on a 280-mm SCT, with an Atik 314L CCD, giving a resolution of 10 Angstroms (R=590) (Heathcote). Spectra of AW Vel and HM Pup were obtained with a LISA spectrograph on a Celestron C11 SCT using a SBIG ST8XME CCD with a resolution of R = 900 and a S/N of approximately 50 (Bohlsen). Each spectrum was calibrated using a neon calibration light.

The spectra were compared to known standards in the MK Spectral classification system with a resolution of 3.6 Angstroms from the Dark Sky Observatory at the Appalachian State University (Gray 2013). The accuracy of the spectral types that we determined was limited by the resolution and the S/N of equipment and observing sites.

3. Results and discussion

3.1. AW Vel

AW Vel (V mag. = 10.7, P = 1.9924566 days) is an EA system with a 1.54-magnitude primary eclipse and a 0.05-magnitude secondary eclipse. Oscillations similar to those of δ Scuti stars were most apparent during the secondary eclipse (Figure 1). The oscillations were also observed in the out-of-eclipse sections of the light curve, but less apparent during the primary eclipse (Figure 2). This may be due to a spatial filtering effect as discussed by Mrktichian *et al.* (2002). The dominant frequency was 15.2 ± 0.3 cycles/day with an amplitude of 58 ± 1 millimagnitudes (Table 2); other frequencies were not significant. We determined the combined spectral type to be A7 (Table 2). This can be taken as the spectral type of the primary, as the shallow secondary eclipse indicates that the luminosity of the secondary component is relatively weak. The spectral type of A7 lies at the hot end of the intersection of the instability strip and the main sequence. In the catalogue of Svechnikov and Kuznetsova (1990), it is recorded as a semi-detached system with spectral types as (A4)+[G2IV].

3.2. HM Pup

HM Pup (V mag. = 10.9, P = 2.589715 days) is an EA system with a very deep, flat-bottomed (total) primary eclipse to V magnitude 14.2 and a weak 0.05-magnitude secondary eclipse. Uneclipsed portions of the light curve are slightly convex. The primary eclipse lasts for about 43 minutes, during which no oscillations were apparent (Figure 3). Oscillations similar to those of δ Scuti stars were recorded during the intervals between eclipses and during the secondary eclipse (Figures 4, 5). The amplitude of the pulsations was small, in summation no greater than 20 millimagnitudes (mmag.) when the maxima were in phase with each other, as seen in an out-of-eclipse portion of the light curve. Analysis of the secondary eclipses and the out-of-eclipse phases showed the dominant frequency to be 31.9 ± 1.2 cycles/day with an amplitude of 10 ± 4 mmag. A second frequency of 38.0 ± 0.4 cycles/day had an amplitude of 6 ± 2 mmag. Other frequencies could be extracted from the data, but were unreliable given the limits of detection for our instruments. We determined that the spectral type for HM Pup is A7 (Table 2), whereas Svechnikov and Kuznetsova (1990) show it as (A2)+[G6IV] and semi-detached.

3.3. TT Hor

TT Hor (V mag. = 11.0, P = 2.6082044 days) is an EA system with a 0.65-magnitude primary eclipse and a very weak 0.03-magnitude secondary eclipse. The system shows oscillations during the primary eclipses, as well as in the secondary eclipses and the intervals between eclipses (Figures 6a, 7a, 8). The amplitudes of the pulsations varied during the eclipse cycle, but were greater during the primary eclipses. For example, on HJD 2456267 the oscillations had a greater amplitude before and during the primary minimum than after it (Figure 6b), whereas on HJD 2456280, the oscillation amplitude was greater after the primary eclipse (Figure 7b). The same primary eclipse (HJD 2456280) was recorded from two different locations and the pattern of oscillations was identical, indicating that these were not due to equipment or differences in seeing conditions. The frequency analysis showed pulsations with several frequencies. The dominant frequency was 38.7 ± 0.4 cycles/day, with two others of 33.4 ± 0.7 and 42.3 ± 0.3 cycles/day (Table 2). We determined the spectral type of TT Hor to be in the range of F0–F2 (Table 2), whereas Svechnikov and Kuznetsova (1990) catalogued it as (A2)+[G6IV)] and semi-detached.

4. Conclusions

The pulsating components of eclipsing binary systems are usually the brighter, primary, components of the systems, as evidenced by the data in the catalogue of Soydugan *et al.* (2006), where the primary component was the pulsator in 23 of 25 confirmed eclipsing binaries with an oscillating component. Our photometric data for these three systems indicate that the primary components are the pulsators. Furthermore, the spectral classifications indicate that the primaries are in the instability strip of the H-R diagram. Whether all three can be classified as semi-detached is not certain. In the case of TT Hor, the amplitudes of the oscillations during the (partial) primary eclipse were greater than those observed during the secondary eclipses and in the intervals between the eclipses. We suggest that the observed amplitude changes during the primary eclipses were due to beating between the frequencies noted above. A spatial filtering effect may also be present.

As our data shown in Figure 5 indicate that the light curve of HM Pup is not flat, we conclude that it is most likely to be an oEA system as defined by Mkrtichian *et al.* (2002). Although ASAS data (Pojmański 1997) indicate that the three targets have substantially flat light curves between eclipses, there is considerable scatter in those observations. We are planning more detailed observations to determine the precise shape of the full light curves in several pass bands for these systems.

The spectral types that we determined for these stars are the first record of their actual spectra and differ from those given in the catalogue of Svechnikov and Kuznetsova (1990). Their designations were inferred from statistical analysis of data given in GCVS IV and are, therefore, approximate.

Additional photometric studies combined with radial velocity measurements are needed for a better understanding of each of these targets.

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Table 1. Photometry and updated ephemeris elements of AW Vel, HM Pup, and TT Hor. The numbers of primary minima with accurate timings that were used to calculate new periods are shown for each star.

Parameter	*AW Vel*	*HM Pup*	*TT Hor*
Comparison star	GSC 7671 1482	GSC 8124 0271	GSC 8059 0284
Magnitude (V)	10.459	10.905	10.755
Epoch (HJD)	2456274.15028	2455991.0535	2456267.0770
Epoch error	0.0003135	0.00193	0.004035
No. of primary minima	6	2	3
Period (days)	1.9924566	2.589715	2.6082044
Period error	0.0000037	0.000002	0.000607

Table 2. Oscillation parameters and spectral types of AW Vel, HM Pup, and TT Hor. The oscillation frequencies are cycles/day and the amplitude of the dominant frequency is in millimagnitudes.

Parameter	*AW Vel*	*HM Pup*	*TT Hor*
Oscillation Frequency 1	15.2 ± 0.3	31.9 ± 1.2	38.7 ± 0.4
Oscillation Frequency 2	—	38.0 ± 0.4	33.4 ± 0.7
Oscillation Frequency 3	—	—	42.3 ± 0.3
Oscillation Amplitude 1	58 ± 1	10 ± 4	20 ± 4
Oscillation Amplitude 2	—	6 ± 2	10 ± 2
Oscillation Amplitude 3	—	—	14 ± 2
Spectral Type	A7	A7	F0-F2

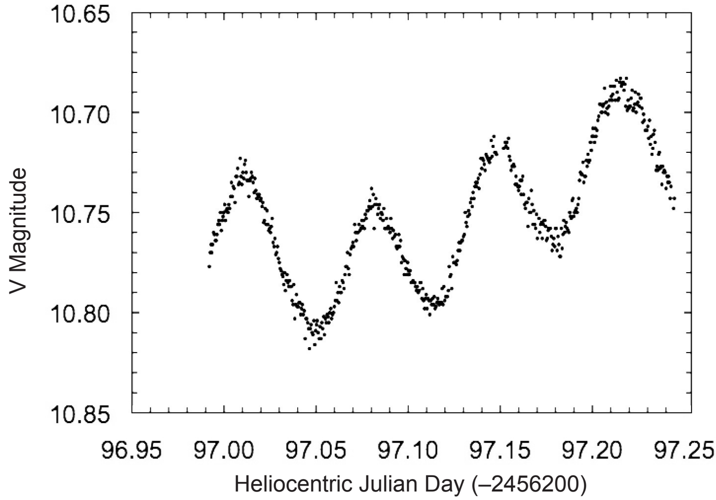

Figure 1. A secondary eclipse of AW Vel, with oscillations of 50–70 millimagnitudes.

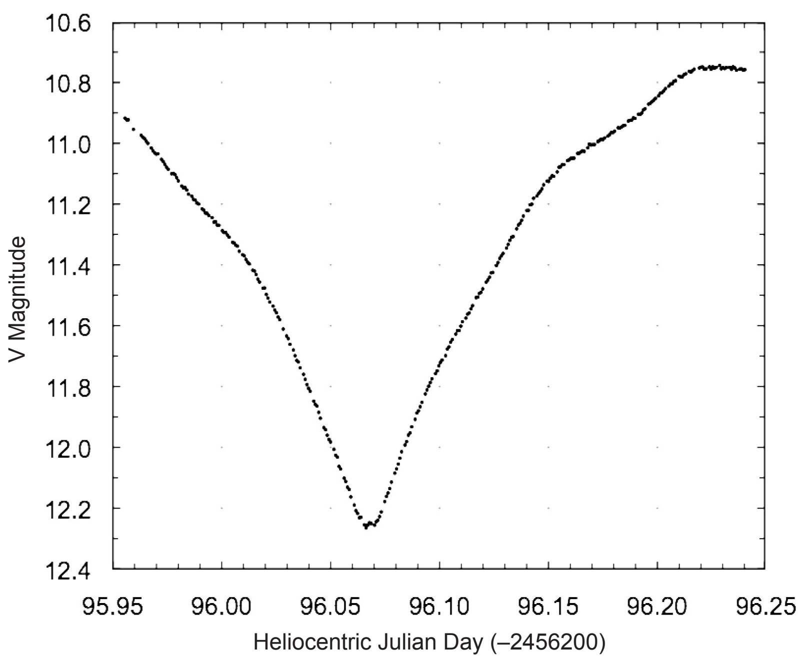

Figure 2. A primary eclipse of AW Vel.

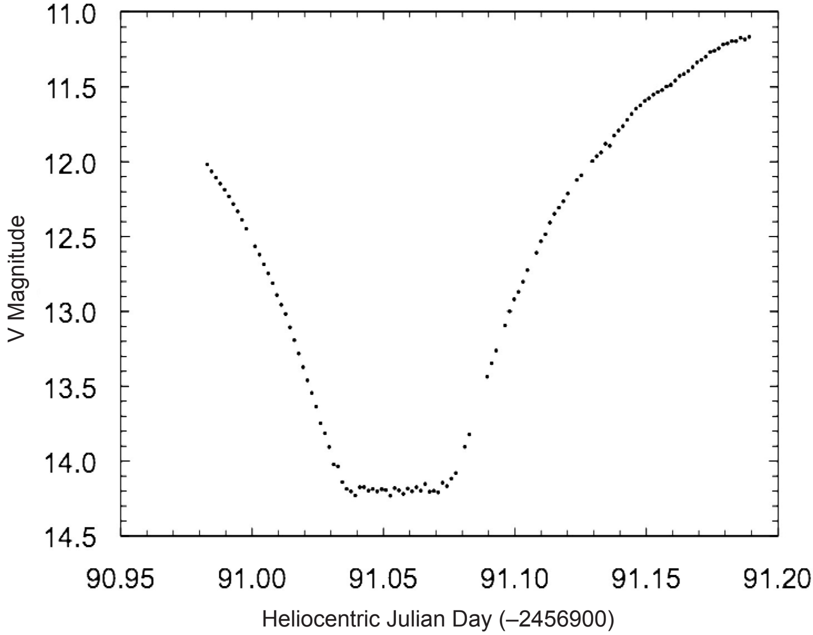

Figure 3. A primary eclipse of HM Pup.

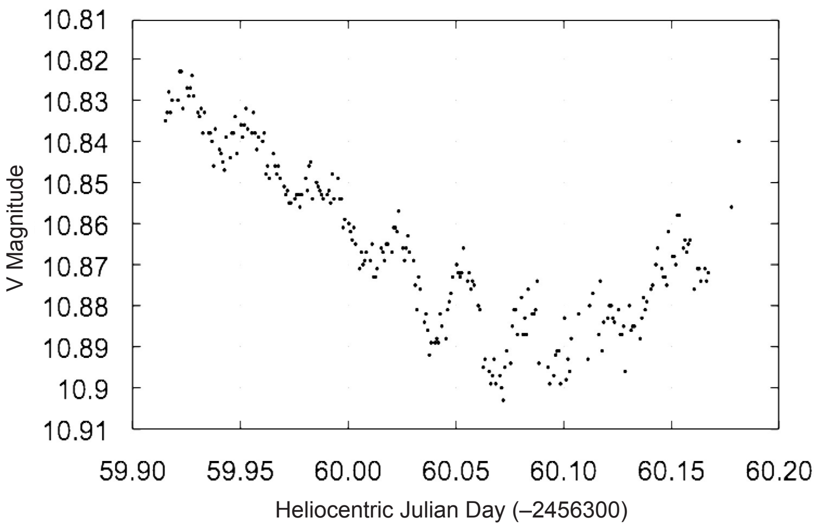

Figure 4. A secondary eclipse of HM Pup with oscillations of 20–30 mmag.

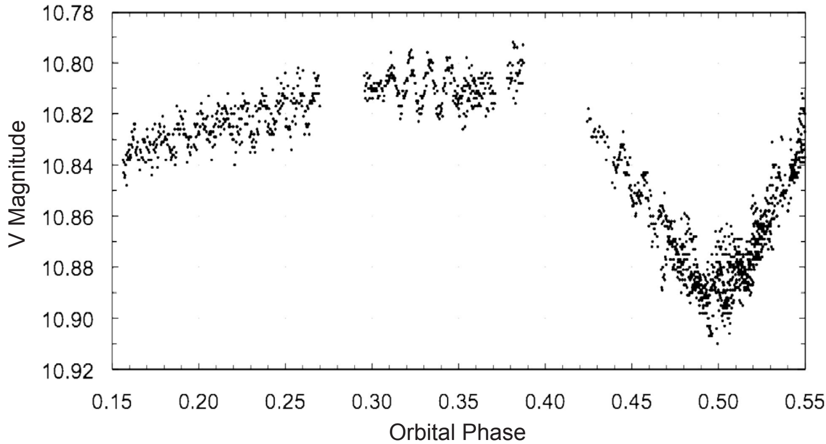

Figure 5. A portion of the phased light curve of HM Pup showing the oscillations during the secondary eclipse and the interval between eclipses.

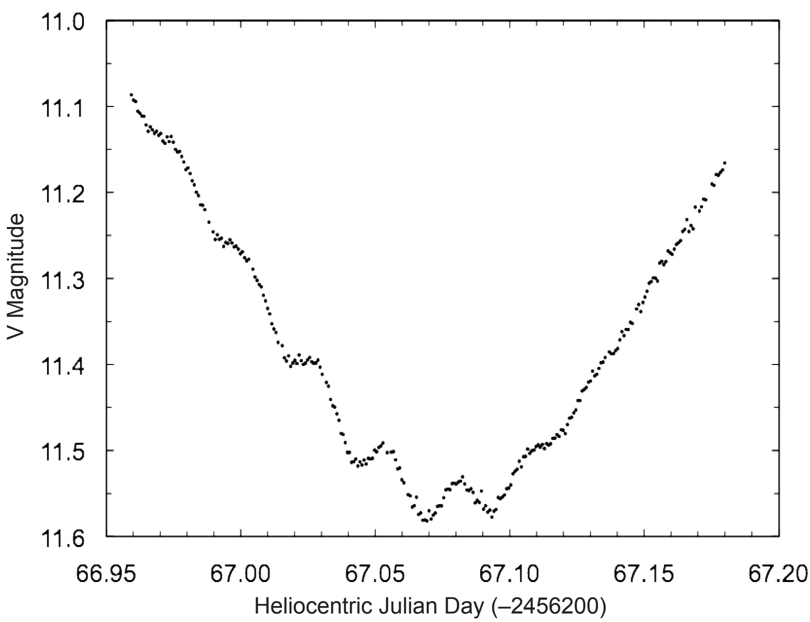

Figure 6a. A primary eclipse of TT Hor with oscillations apparent in the descending phase and at the minimum of the eclipse.

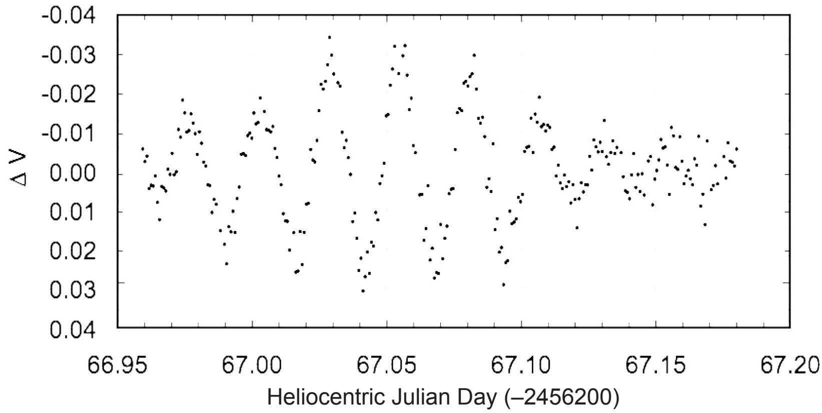

Figure 6b. Oscillations during the primary eclipse of TT Hor in Figure 6a with the primary eclipse light curve subtracted.

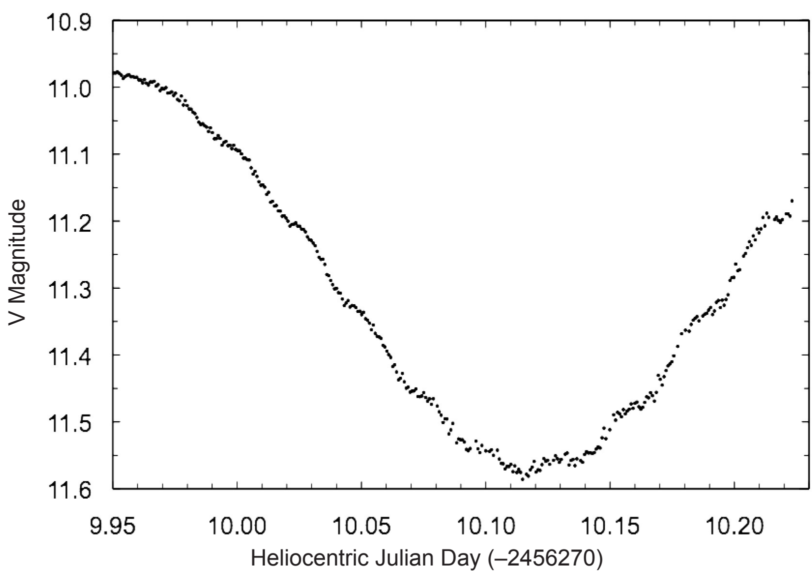

Figure 7a. A primary eclipse of TT Hor 70 days later than that shown in Figure 6, with oscillations more prominent on the ascending phase of the light curve than observed earlier.

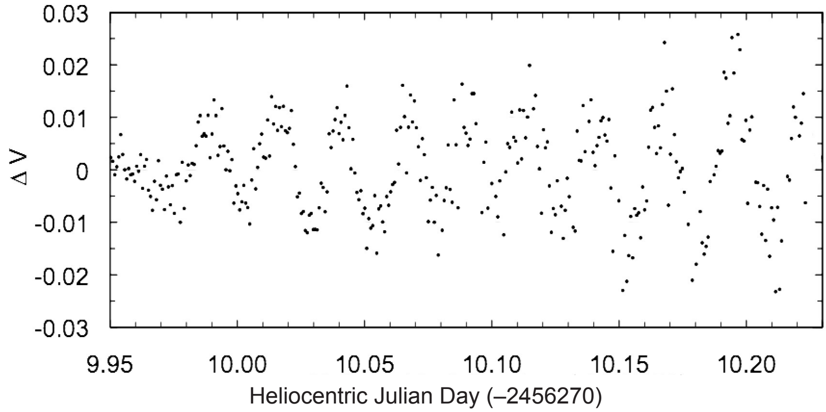

Figure 7b. Oscillations during the primary eclipse of TT Hor in Figure 7a with the primary eclipse light curve subtracted.

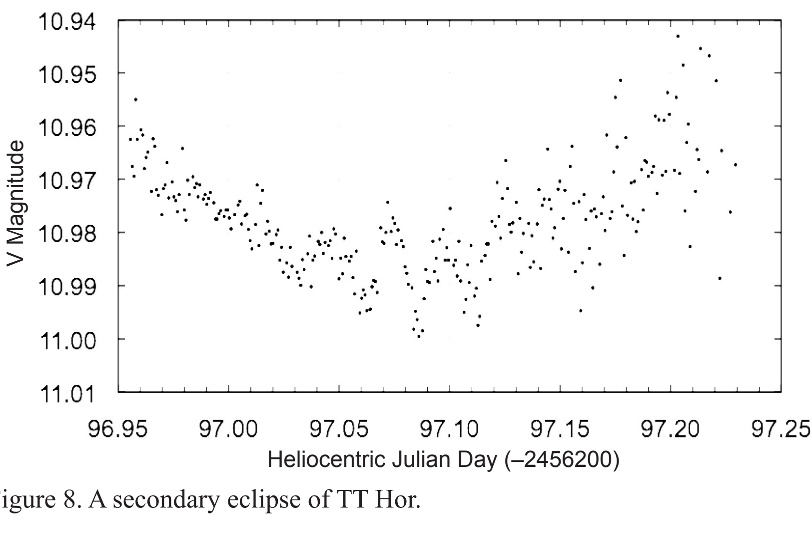

Figure 8. A secondary eclipse of TT Hor.