

V345 Lacertae: TESS Eclipse Timings and the Apsidal Drift of the Secondary Minimum

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Abstract

V345 Lac (TIC 421726141) is an eccentric eclipsing binary. TESS 120-second photometry in Sectors 56, 57, 76, 77, 83, and 84 gives 20 primary and 17 secondary minima. A linear fit to the primaries yields $P = 7.4919092 \pm 0.0000043$ days, within 0.3 seconds of the sidereal period 7.49190587 days found by Wolf et al. (2019). The secondary minimum falls at phase 0.358, which measures $e \cos \omega = -0.223$ and matches their elements $e = 0.260$ and $\omega = 208.3^\circ$. From Sectors 56–57 to Sectors 83–84 the primary-to-secondary interval lengthens by 7.2 minutes, a rate of 3.6 ± 0.4 minutes per year. Their apsidal rate predicts 3.4 minutes per year. A light-time delay shifts both minima together and does not change the interval, so this drift is the apsidal motion. Residuals of the primaries about the linear ephemeris scatter by 1.1 minutes. A two-year primary diagram does not separate their apsidal period, $U = 1580 \pm 610$ yr, from their 23.9-year light-time orbit.

1. Introduction

Eclipsing binaries with eccentric orbits are valuable laboratories for testing stellar structure and evolution models through the study of apsidal motion (the precession of the line of apsides). The rate of apsidal advance is sensitive to the internal structure constants of the component stars and can also include contributions from general relativity and third-body effects (e.g., Giménez 2006; Bulut & Demircan 2007).

V345 Lacertae (GSC 03986-02900, FL 3354, TIC 421726141) is a detached eclipsing binary with $V \approx 11.3$. Wolf et al. (2004) list the spectrum as B8. Wolf et al. (2019) describe the star as B5V, the type carried by SIMBAD from Reed (2003). The orbit is eccentric. The current photometric and timing solution is Wolf et al. (2019): $e = 0.260$, $\omega = 208.3^\circ \pm 1.4^\circ$, an apsidal period $U = 1580 \pm 610$ yr, and a third body on a 23.9 ± 0.8 yr orbit whose light-time semi-amplitude is 0.0150 ± 0.0005 days (about 22 minutes).

We time the eclipses in six TESS sectors observed from 2022 to 2024 and compare the period, the phase of secondary minimum, and the change in the primary-to-secondary interval with that solution. The times are a modern epoch on the published sidereal period.

2. Literature Review

Wolf et al. (2004) derived $e \approx 0.46$ and an apsidal period $U = 7000 \pm 700$ yr from ground-based minima. Bulut (2013) obtained a longer period, $U = 14240 \pm 2800$ yr, and a larger eccentricity, $e = 0.73 \pm 0.12$. Wolf et al. (2019) solved the ASAS-SN light curve with PHOEBE. They found $e = 0.26 \pm 0.01$, $i = 87.0^\circ$, temperatures 9300 K and 9105 ± 195 K, and a V-band light ratio of 53% to 47%. On the long O–C diagram the same paper gives $\dot{\omega} = 0.227 \pm 0.090$ deg/yr, $\omega_0 = 208.3^\circ \pm 1.4^\circ$, and $U = 1580 \pm 610$ yr, together with the light-time orbit quoted above. Their sidereal period is $P_s = 7.49190587 \pm 0.00000012$ days. The GCVS period 7.491862 days is the older photographic ephemeris.

Two years is a short arc of both the 1580-year apsidal cycle and the 24-year light-time orbit. Once a straight line is removed, both effects are absorbed into the period. The primary-to-secondary separation behaves differently. Apsidal motion changes it, because the argument of periastron moves the two conjunctions by different amounts. A light-time delay moves the whole binary and cancels in the difference.

The TESS times test those two predictions directly: the sidereal period, and the rate of change of the eclipse separation.

3. Observations and Data Analysis

3.1 TESS Data

We used the TESS Science Processing Operations Center 120-second PDCSAP light curves of TIC 421726141 in Sectors 56, 57, 76, 77, 83, and 84. Quality flag zero leaves 103,548 cadences from BTJD 2825.3 to 3610.3. BTJD is barycentric Julian date in the TDB time scale minus 2457000. Each sector was divided by the median of its out-of-eclipse flux. The July reduction reached these same sectors through the lightcurve package and the Multimodal Universe HATS catalog.

The normalization for each sector is the median of the quality-zero samples more than 0.35 day from every minimum. Depths and the phase curve use those normalized samples with no additional sigma clip.

3.2 Eclipse Detection and Classification

Eclipse minima are the analytic vertices of a quadratic fitted to the samples below 0.93 of the normalized flux. The vertex is the time at which the derivative is zero.

These are the same vertices listed in the July draft. A time was kept when the PDCSAP curve shows an eclipse there. Four entries from that draft, at BTJD 2839.237, 3577.423, 3595.110, and 3609.737, fall on flat light and are dropped. One primary, near BTJD 2866.03, lies in a 0.22-day gap at the end of a data segment in Sector 57 and was not timed. Primary and secondary follow the Wolf et al. (2019) primary ephemeris. In the TESS bandpass the secondary is the deeper eclipse, so the depth does not identify which conjunction is which.

3.3 Orbital Period Determination

The period is the least-squares line $T = T_0 + P E$ through the primary times. Cycle numbers are counted with a seed period of 7.491906 days. Every retained primary falls on an integer cycle.

- A linear ephemeris fitted to the primary minima.
- The mean primary-to-secondary interval, and a straight-line fit of that interval against time.

For an inclination near 90° the secondary minimum is displaced from phase 0.5 by $(2/\pi) e \cos \omega$, to first order in the eccentricity. Here ω is the argument of periastron of the primary, and phase is measured from primary minimum. The product $e \cos \omega$ is the quantity the eclipse times measure. The eccentricity itself comes from the light curve.

3.4 O-C Analysis

O-C residuals of the primaries are measured from the linear ephemeris above. The interval fit is separate. Because a light-time delay is common to both minima, a slope in the interval is an apsidal signal.

4. Results

4.1 Eclipse Detection

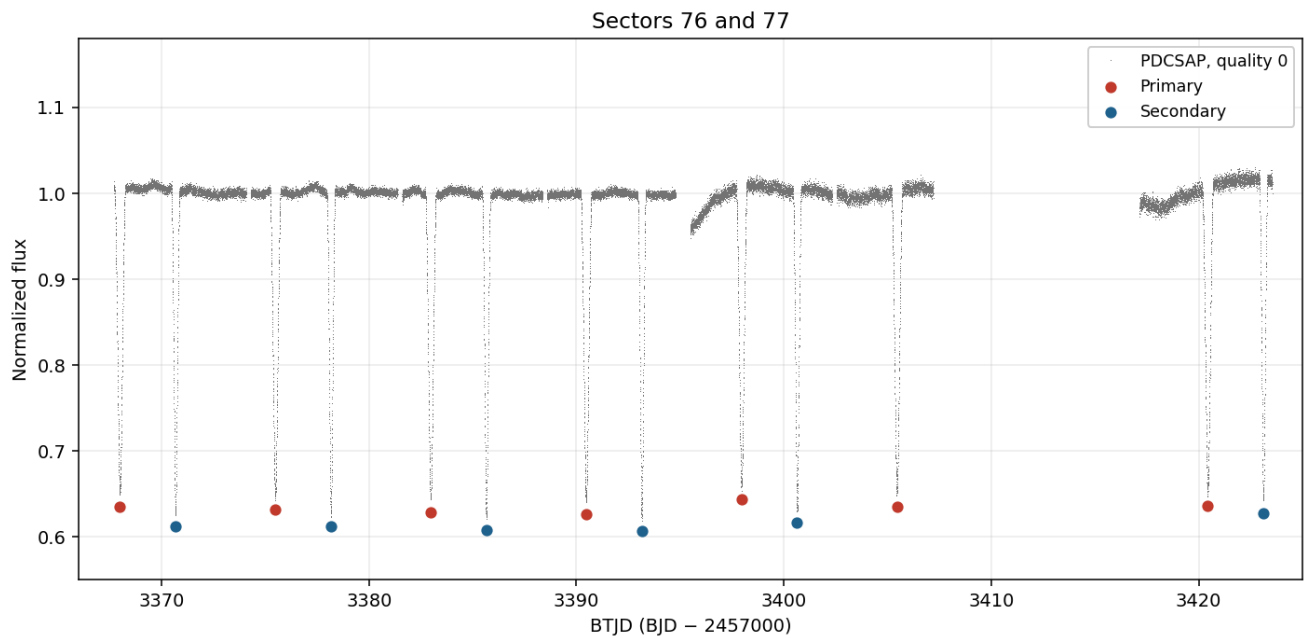
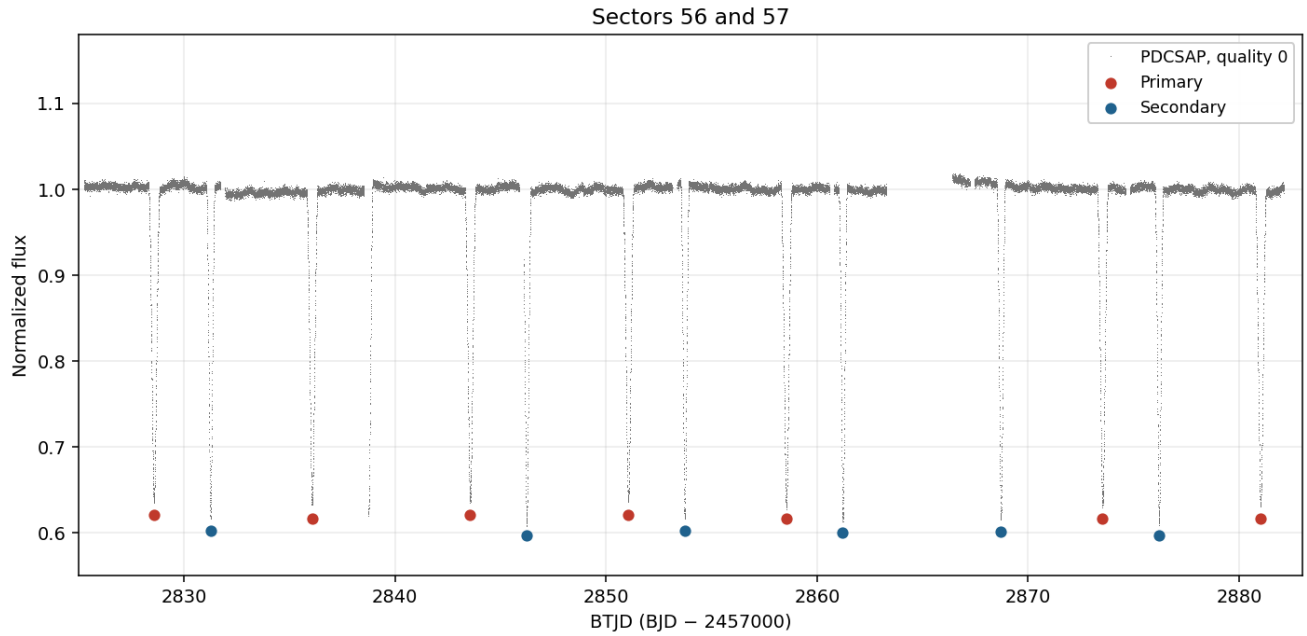
The six sectors contain 20 complete primary eclipses and 17 complete secondary eclipses. The bottom of a primary reaches 0.64 of the out-of-eclipse flux, and the bottom of a secondary reaches 0.62, each value an average of the eight lowest samples within 0.04 day of the minimum. The two eclipses are partial and of similar depth, as expected for a pair with nearly equal temperatures and radii at $i \approx 87^\circ$ (Wolf et al. 2019). The secondary is the deeper minimum at every epoch away from the Sector 77 gap. Figures 1–3 show the three pairs of sectors. The vertical scale runs down through the eclipse bottoms.

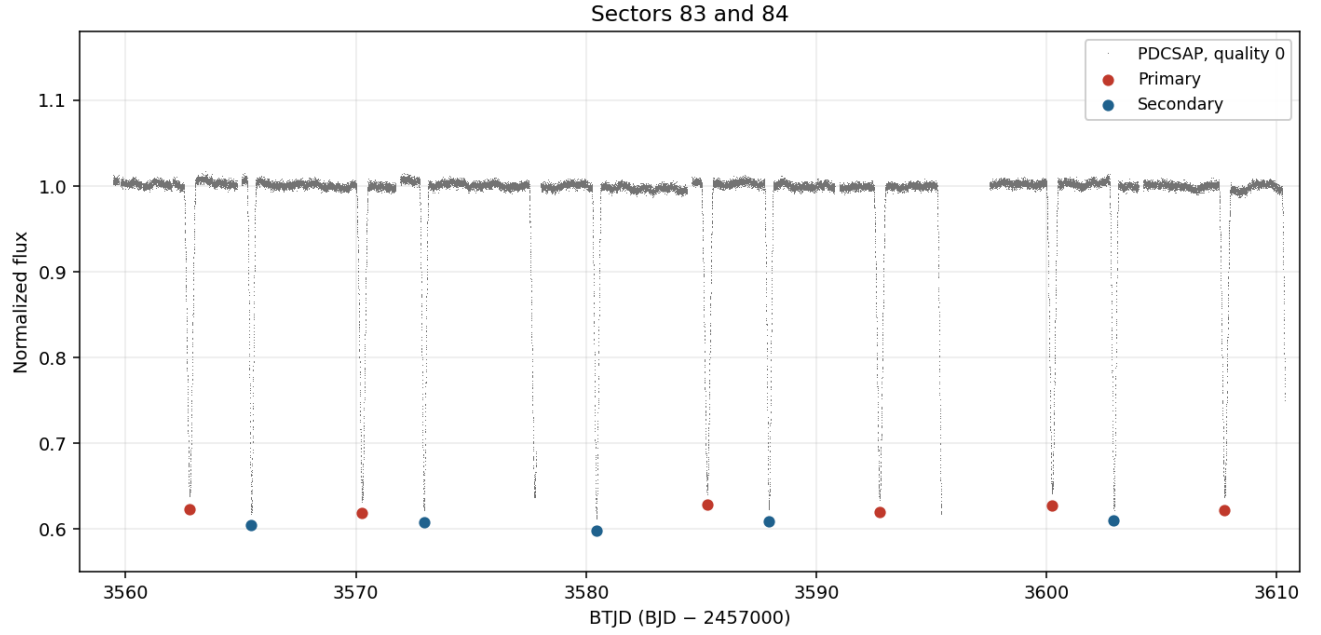
Red marks sit under primary minima and blue marks under secondary minima.

Sector boundaries and gaps

Sector 76 ends at BTJD 3394.8 and Sector 77 begins at BTJD 3395.5. For the first day and a half of Sector 77 the continuum is about 5% faint, then returns to the sector median. Cadences are missing from BTJD 3410 to 3417, which removes one primary. After that gap the continuum runs about 1.5% bright. The primary at BTJD 3420.429 falls in that bright stretch. Its residual is -3.3 minutes, and it is the only primary residual larger than 2 minutes. The eclipses on either side of these stretches were timed. The missing minimum inside BTJD 3410–3417 was not.

TESS pixels are 21 arcseconds on a side, and the aperture covers several of them. The few-percent offsets at the sector boundary and after the downlink gap are the size of a background or pointing residual. They are far smaller than either eclipse.





4.2 Orbital Period

The primary ephemeris is $\text{Min I} = \text{BTJD } 2828.5708 \pm 0.0003 + 7.4919092 \pm 0.0000043 \text{ E}$, with $E = 0$ at the first TESS primary. The root-mean-square residual of all 20 primaries is 1.1 minutes. Leaving out BTJD 3420.429 lowers the scatter to 0.8 minutes and changes P by less than the quoted uncertainty. This period is 0.3 seconds longer than $P_s = 7.49190587$ days. It is 4.1 seconds longer than the GCVS period 7.491862 days.

Fifteen primary-to-secondary pairs have a mean separation of 2.6815 days at the middle of the time series, which is phase 0.3579. The first-order relation then gives $e \cos \omega = -0.223$. Integrating Kepler's equation at $i = 90^\circ$ with the Wolf et al. (2019) elements $e = 0.260$ and $\omega = 208.3^\circ$ places the secondary at phase 0.354. The TESS phase lies inside the range allowed by their uncertainties on e and ω . With those elements, primary conjunction is at true anomaly -118° and secondary conjunction is at $+62^\circ$. Periastron falls at phase 0.25, between the eclipses and closer to the secondary. The star–star separation is 1.06 a at primary conjunction and 0.83 a at secondary conjunction, so the partial eclipse nearer periastron is the deeper one. The interval is growing. The five pairs in Sectors 56–57 average 2.6785 days, and the four pairs in Sectors 83–84 average 2.6835 days. The difference is 7.2 minutes over 1.99 years, or 3.6 ± 0.4 minutes per year. Differentiating $e \cos \omega$ at the published rate $\dot{\omega} = 0.227 \text{ deg/yr}$ predicts 3.4 minutes per year. The measured drift and that prediction agree. The Sector 76–77 pairs fall between the two clumps, on the same line.

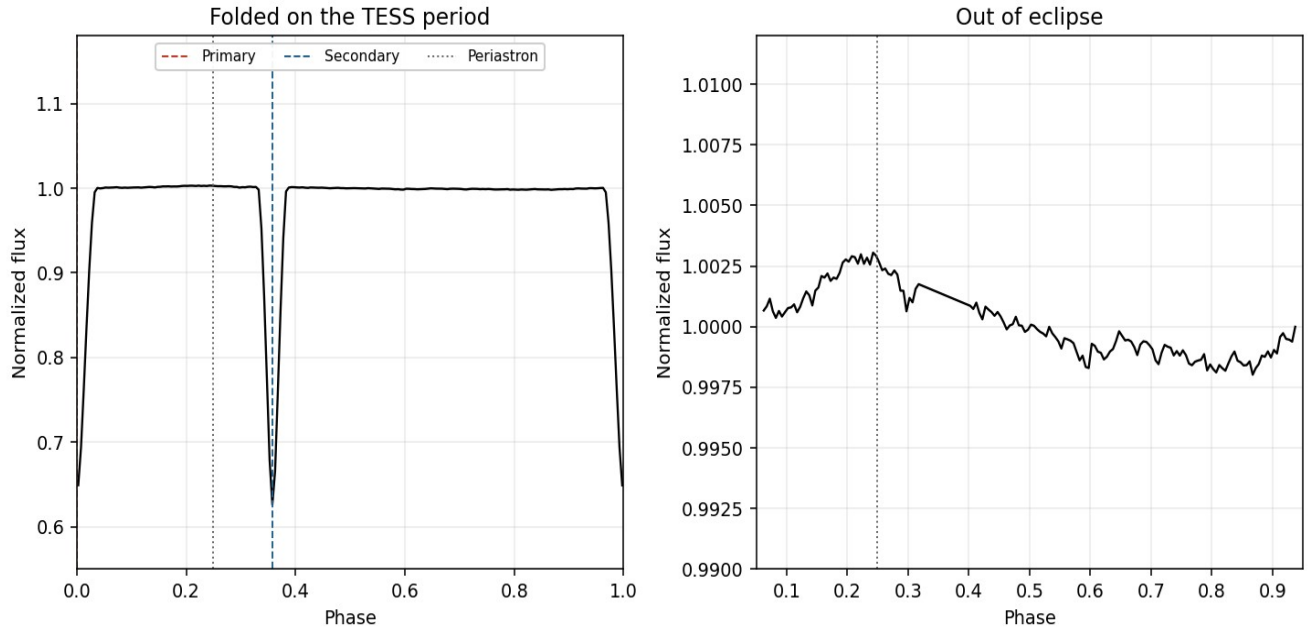
4.3 Eclipse depths and the phase curve

Figure 4 folds the quality-zero photometry on the ephemeris above, with primary minimum at phase 0. Secondary minimum is at phase 0.358. Outside eclipse, the binned flux on the side of the orbit that contains periastron (phases 0.10–0.30) sits 0.3% above the flux on the opposite side. Periastron and one quadrature both fall near phase 0.25, so ellipsoidal distortion and reflection land on the same phases. The published temperatures differ by about 200 K. We report the amplitude and do not split it into the two effects.

The mean primary-to-secondary interval is 2.682 days and the return from secondary to the next primary is 4.810 days. For a circular orbit both intervals would be 3.746 days.

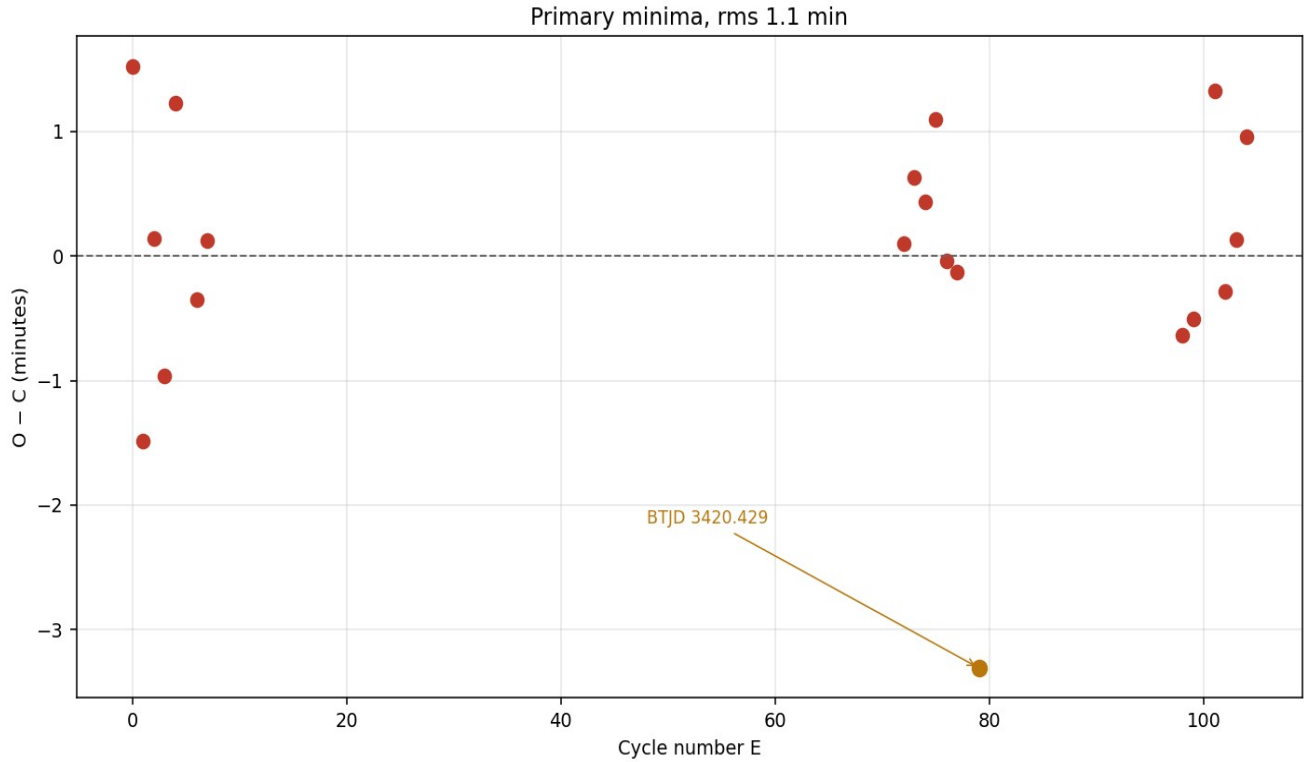
4.4 Out-of-eclipse variability

A Lomb–Scargle periodogram of the points more than 0.30 day from every minimum peaks at the orbital period. The normalized power is 0.13. Neighboring peaks near 7.3 and 7.8 days are the window pattern of six short sectors separated by long gaps. Power at $P/3 = 2.497$ days is 0.01. That signal is the third harmonic of the orbit. The out-of-eclipse scatter is 0.6%. These light curves do not yield a second period that could be assigned to rotation.



4.5 Primary O–C diagram

Figure 5 shows the primary residuals about the TESS line. The scatter is 1.1 minutes. The amber point is BTJD 3420.429, at -3.3 minutes, in the bright stretch that follows the Sector 77 gap. Curvature from an apsidal period of 1580 years is a few hundredths of a minute over this baseline. The 23.9-year light-time orbit, with a semi-amplitude of 0.015 days, can bend a two-year arc by about two minutes, which is the size of the scatter, and the linear part of that bend is absorbed into P . Referred to the Wolf et al. (2019) CCD minimum at HJD 2458097.9333 and to P_s , these primaries fall 11 minutes late with the same 1.1-minute scatter and no additional slope. The zero-point includes the difference between HJD and BJD_TDB and whatever light-time accumulated between 2018 and 2022. This baseline does not separate those two contributions.



4.6 Eclipse counts

The ephemeris uses 20 primary minima. The primary at BTJD 2836.062 is a normal eclipse in the middle of Sector 56 and is included. Seventeen secondary minima are timed. The gap at BTJD 2866 takes one primary. The gap at BTJD 3410–3417 takes another.

5. Discussion

The TESS period agrees with the Wolf et al. (2019) sidereal period to 0.3 seconds, inside our uncertainty of 0.4 seconds. Their period remains the more precise of the two, because it rests on a baseline of decades. The secondary phase gives $e \cos \omega = -0.223$, which is the timing consequence of their $e = 0.260$ and $\omega = 208.3^\circ$. The new measurement is the lengthening of the primary-to-secondary interval, 3.6 ± 0.4 minutes per year, against the 3.4 minutes per year implied by their ω . That comparison is independent of the light-time orbit. It is a check of the apsidal rate, and the two numbers agree, so these data do not call for a new value of U .

The primary O–C diagram is a poor tool for that test on a two-year baseline. Both the apsidal advance and the light-time orbit are nearly linear here, and the fitted period takes up the slope. The flat residuals are the expected result for $U = 1580 \pm 610$ yr and for a 24-year orbit of 22-minute amplitude. They do not distinguish those two periods, and they do not revive the older 7,000-year and 14,000-year values, which Wolf et al. (2019) replaced.

The secondary eclipse is slightly deeper than the primary in this bandpass. With $\omega \approx 208^\circ$ the secondary is the conjunction closer to periastron, where a partial eclipse covers more of the facing star. The depth ordering follows from that geometry and from the nearly equal surface brightnesses. Changes of a few

hundredths in the eclipse bottom, from sector to sector, remain available for spots or for residual background in the 21-arcsecond TESS pixels. The periodogram does not supply a rotation period.

6. Conclusions

Six TESS sectors give 20 primary and 17 secondary times for V345 Lac. The ephemeris is $\text{Min I} = \text{BTJD } 2828.5708(3) + 7.4919092(43) \text{ E}$. Secondary minimum lies at phase 0.358, so $e \cos \omega = -0.223$, in agreement with $e = 0.260$ and $\omega = 208.3^\circ$ from Wolf et al. (2019). The primary-to-secondary interval increases by 3.6 ± 0.4 minutes per year, matching the 3.4 minutes per year predicted by their apsidal elements. The times are a modern epoch for the long-baseline O–C solution of that paper.

The primary residuals over these two years scatter by about one minute. That diagram is consistent with the published apsidal period and with the published light-time orbit, and it is too short to measure either one on its own.

Acknowledgements

This work uses the public TESS data products of the Science Processing Operations Center. The July reduction was carried out with *lightkurve* and with the Multimodal Universe HATS catalog on Hugging Face. We are grateful to Grok, built by xAI, for help with the original reduction and with the October 7, 2026 revision of the timings, the depths, and the interval drift.

The interest in V345 Lac originated in the early 1990s when the first author spent several months observing at Braeside Observatory in Flagstaff, Arizona, under the guidance of Dr. Dan Caton (Appalachian State University). Attempting to obtain full light curves was extremely challenging because the ~ 7.5 -day eclipse interval meant that every other eclipse occurred during daylight, and the subsequent eclipse often began near sunrise. Despite persistent efforts, the data from those nights were ultimately lost. This early experience sparked a long-term interest in the system. The availability of high-quality TESS photometry decades later finally allows us to complete the study that began at Braeside.

References

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Appendix

Table 1. Primary minima. BTJD is $\text{BJD}_{\text{TDB}} - 2457000$. O-C is measured from $\text{Min I} = \text{BTJD } 2828.5708 + 7.4919092 \text{ E}$. The scatter is 1.1 minutes, so the trailing digits of each time are finer than the uncertainty of a single minimum.

BTJD E O-C (min)

2828.571838 0 +1.5
2836.061654 1 -1.5
2843.554694 2 +0.1
2851.045839 3 -1.0
2858.539266 4 +1.2
2873.521989 6 -0.4
2881.014230 7 +0.1
3367.988308 72 +0.1
3375.480586 73 +0.6
3382.972358 74 +0.4
3390.464730 75 +1.1
3397.955848 76 -0.0
3405.447694 77 -0.1
3420.429305 79 -3.3 after the Sector 77 gap
3562.777436 98 -0.6
3570.269434 99 -0.5
3585.254526 101 +1.3
3592.745315 102 -0.3
3600.237516 103 +0.1
3607.729997 104 +1.0

Table 2. Complete minima. Primary and secondary follow Wolf et al. (2019). Four times in the July list that sit on flat light are omitted.

BTJD label

2828.571838 primary
2831.248837 secondary
2836.061654 primary
2843.554694 primary
2846.233632 secondary
2851.045839 primary
2853.725169 secondary
2858.539266 primary
2861.217086 secondary
2868.709370 secondary
2873.521989 primary

2876.201646 secondary
2881.014230 primary
3367.988308 primary
3370.671290 secondary
3375.480586 primary
3378.162139 secondary
3382.972358 primary
3385.654088 secondary
3390.464730 primary
3393.146198 secondary
3397.955848 primary
3400.638671 secondary
3405.447694 primary
3420.429305 primary
3423.114527 secondary
3562.777436 primary
3565.460818 secondary
3570.269434 primary
3572.953716 secondary
3580.444679 secondary
3585.254526 primary
3587.937370 secondary
3592.745315 primary
3600.237516 primary
3602.921153 secondary
3607.729997 primary
2866.03 primary lost in a 0.22-day gap
3410–3417 primary lost in the Sector 77 gap