Search for the Binary Period in the Recent Nova V1369 Cen Using TESS and Small Ground Telescopes

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Introduction

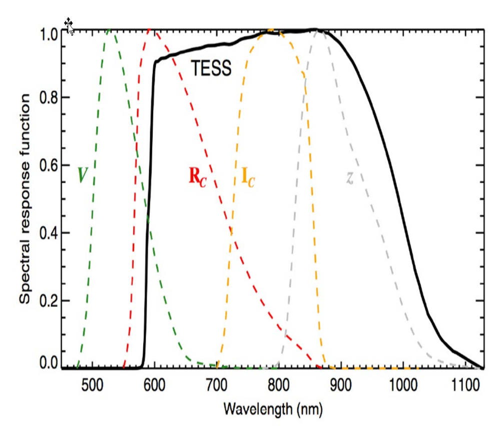
Novae are thermonuclear runaways on the surfaces on white dwarf stars, accreting in close binary systems. Outside of outburst, many resemble cataclysmic variables (CVs), and most CVs likely undergo nova outbursts. To make sense of the sheer variety of nova types, we seek to understand the underlying binary systems (as characterized by orbital period, inclination, masses, magnetic field, etc.) in a variety of novae.

Here we report on a search for the orbital period of a recent nova, V1369 Cen (N Cen 2013). One of the brightest novae of the current millennium, V1369 Cen was a slow, dust-forming novae that is currently in the nebular phase. In this phase, the envelope is optically-thin, and the underlying binary system is, in principle, observable.

We report on an analysis of TESS (Transiting Exoplanet Survey Satellite) and ground-based photometry of V1369 Cen, from 5.4 to 7.4 years after outburst. During this time the V magnitude of the nova faded from about 13.4 to 13.7. We identified likely periods in both sets of data, but the interpretation is complicated by the fact that the two periods are mutually incompatible.

Comparison of TESS and Ground Images

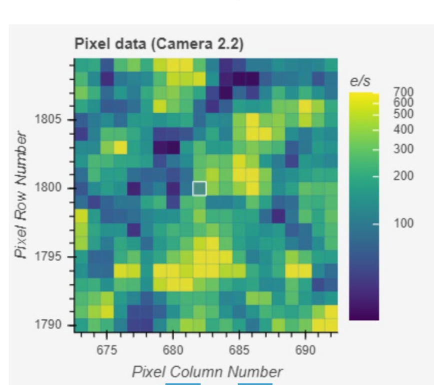
	TESS	Planewave 17" CDK (T50)
FOV	24°x96° (Cutout images analyzed were 20x20 pixels = 7x7 arc minutes)	16.19x15.74 arc minutes
Pixel size	21 arc sec	0.92 arc sec
Image Exposure Time	30 minutes	2 minutes
Duration of Time Series	27 days (with one day break)	17 nights over 15 months, 2-8 hour times series
Time of observations	JD 2458596-2458623 (April 22, 2019 - May 19, 2019)	JD 2458878-2459331 (January 29, 2020 – April 26,2021)
Filter	TESS 600-1000 nm	I (Cousins)
Measurement errors	~0.006 magnitude	~0.01 magnitude

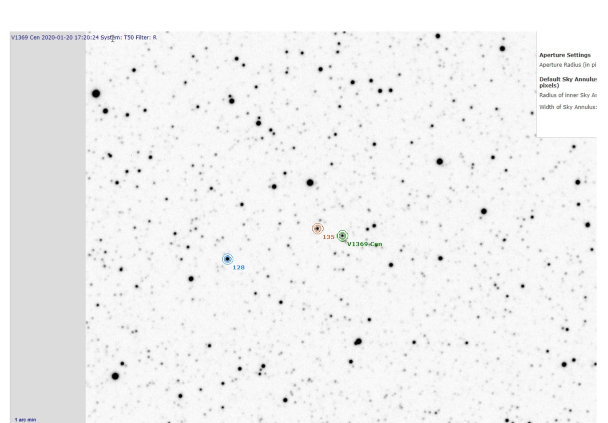


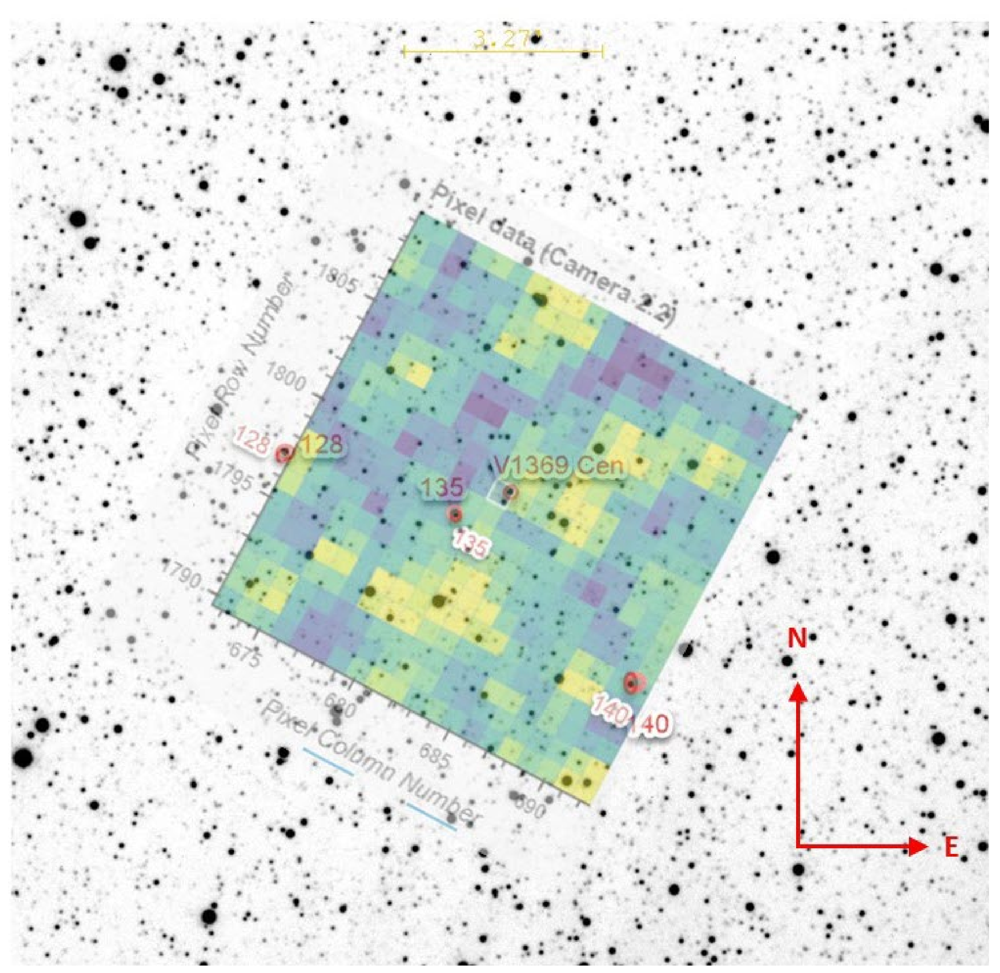
TESS and T50 (PlaneWave 17" CDK) Images

A TESS image is shown below (upper left). This 20x20 pixel image is 7 arcmin on a side. The large (21x21 arcsec) pixels in the Full Frame Images (FFI) make for poor image quality by typical optical standards. The spatial resolution of about 42 arcsec smears out a lot of detail. But being above the atmosphere provides a very stable observing platform.

A 16x16 arcmin T50 image (I band) is shown below left, and the two are superposed in the right image. The TESS image is not suitable for target identification except for the very brightest targets. The TESS project supplies an astrometric solution for the images, so we know to a fraction of a pixel where the target is located within the TESS image.







Data Analysis

TESS observed V1369 Cen for 27 days, between Julian Days (JD) 58596-58623, with a 1 day gap in the middle. TESS observed continuously with a 30 minute cadence (1425 second integration per readout). We used Full Frame Imager (FFI) data. There were 1179 independent images; 307 had background more than 10 sigma above the median background.

We downloaded a 40x40 pixel cutout from the STScI MAST archive using the TESScut software (Brasseur et al 2019). We extracted the counts from the image using aperture photometry within a 1.5 pixel radius of the source position. The background was taken to be the median of the pixel values in the full image after excluding all bright sources. TESS measures electron fluxes in a CCD detector; we convert these to instrumental magnitudes (-2.5 log_10[counts/sec]). TESS has a very red bandpass which corresponds roughly to a sum of R+I bands; we later convert to astronomical magnitudes by scaling to I-band magnitudes from simultaneous AAVSO observations. We independently used the lightkurve software from the Lightkurve Collaboration (2018) to extract the TESS light curve from the single pixel centered on V1369 Cen.

We followed up with 17 nights of time-series ground observations over 15 months (JDs 58878-59331), using a Planewave 17" CDK telescope (T50) located at Siding Spring, Australia.

We subjected the data to independent periodogram analyses, one using the Scargle algorithm as implemented in IDL, and the other using the Peranso (V 3.0.3.0 www.peranso.com) software. The independent analyses agree. The TESS data show a clear 0.15654 day sinusoidal modulation. The ground-based data suggest a somewhat longer 0.16477 day modulation, but with significant aliasing. The amplitude of the modulation was initially about 0.01~mag, but it decreased significantly with time.

Figure 5 shows the TESS light curve. The first three days of each thirteen day observing cycle, denoted in the figure by the open circles, are the times of high background. The Lomb-Scargle periodogram (Figure 6) finds the peak period to be 0.15655 +/- 0.00012 days. The data folded on this period are shown in Figure 7. This period has no significant aliasing, because the data are nearly continuous for about 180 periods. The period is present in both the full data set and the low background data alone.

The T50 data was analyzed similarly. All observations were included. Figures 8 ,9, and 10 show the lightcurve, periodogram, and phased plot. The most significant period is 0.16477 +/- 0.000024 days. The amplitude of the variation seems to be decreasing with time, and the period is not detected at all epochs. Further analysis is continuing.

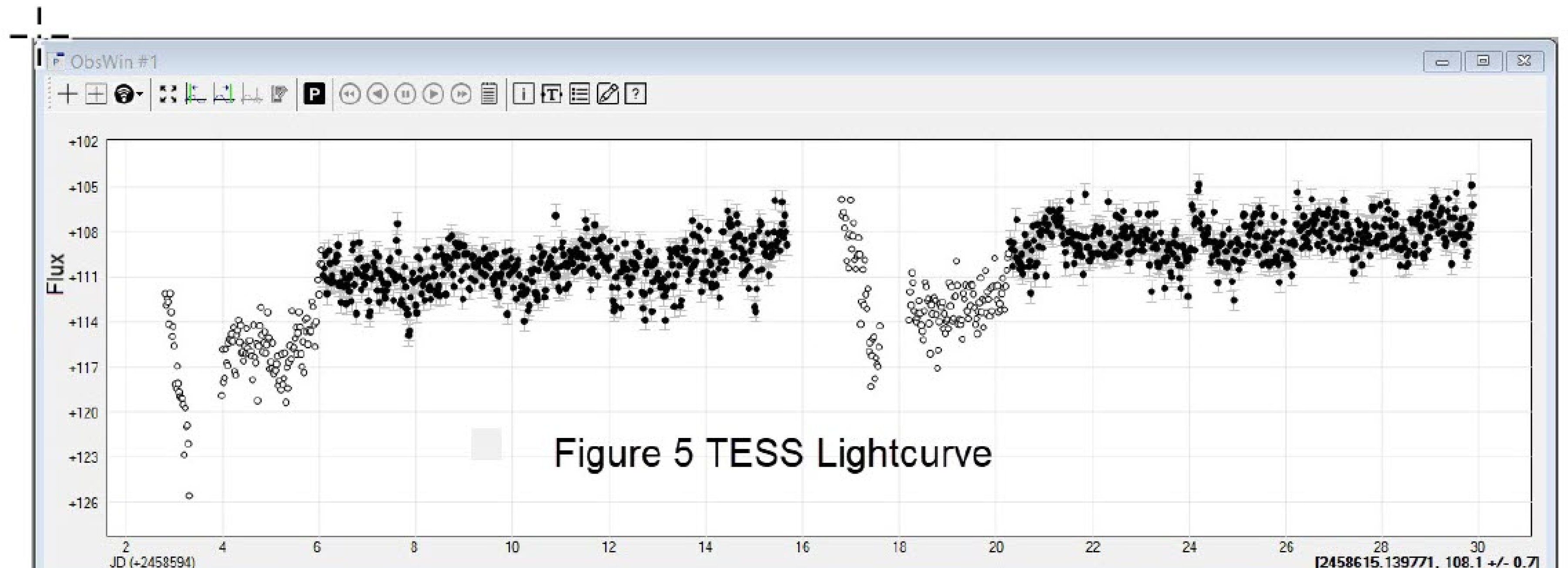


Figure 5 TESS Lightcurve

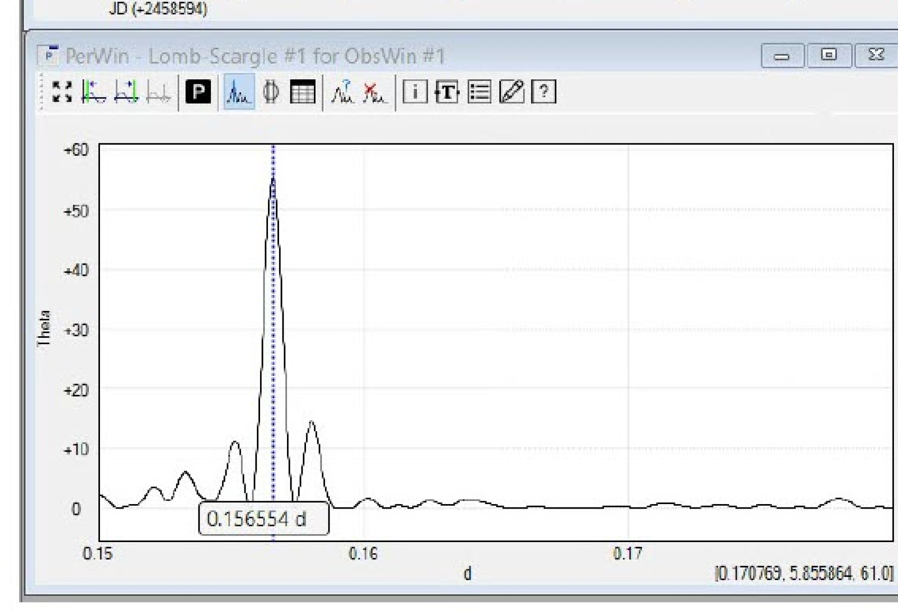


Figure 6 - Lomb-Scargle Periodogram using TESS Data

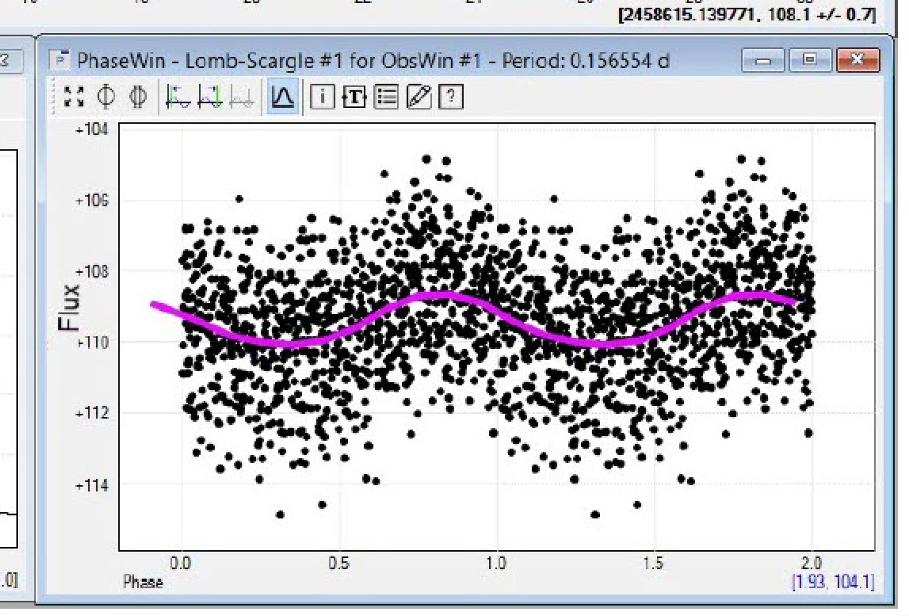


Figure 7 Phase Diagram using TESS data

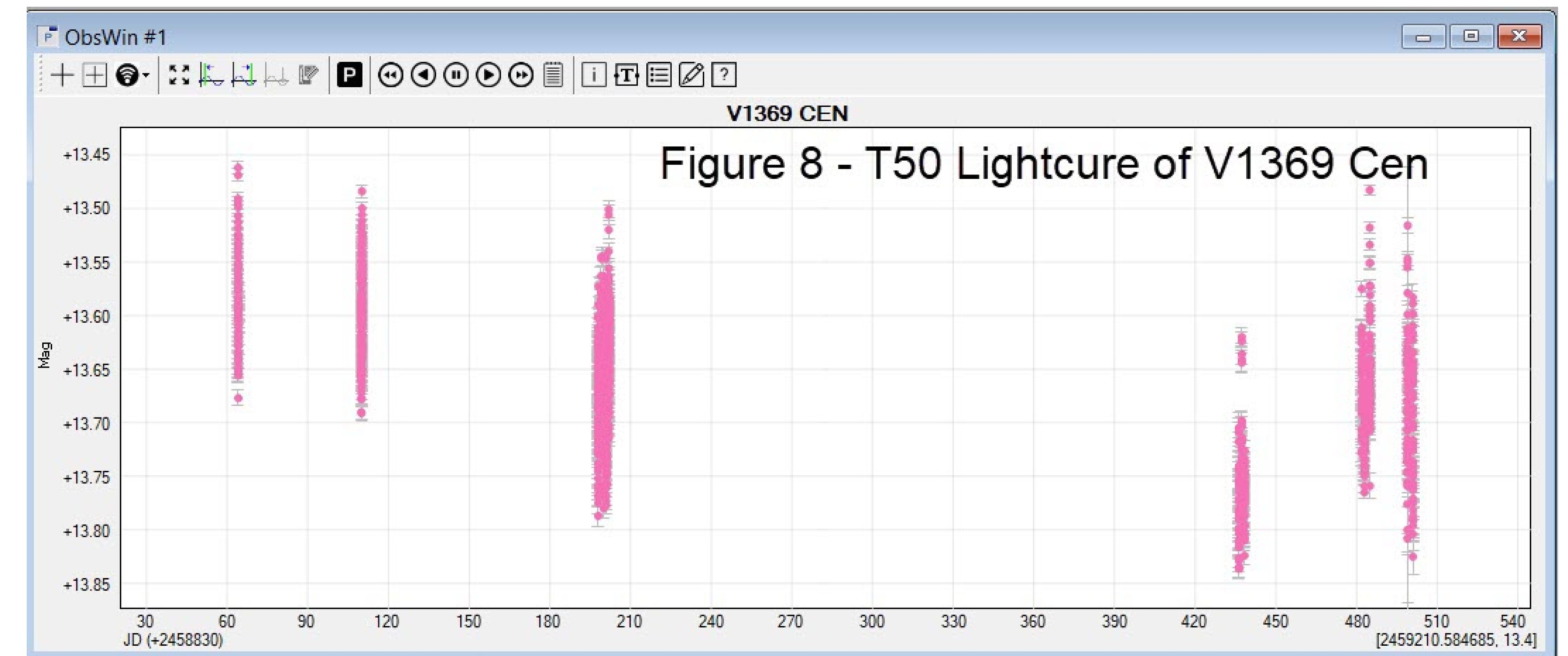


Figure 8 - T50 Lightcure of V1369 Cen

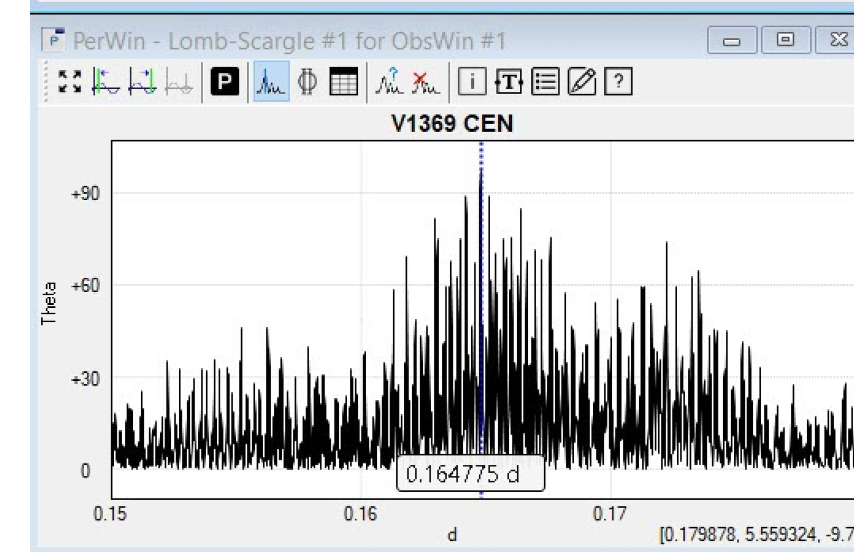


Figure 9 - Lomb-Scargle Periodogram using T50 Data

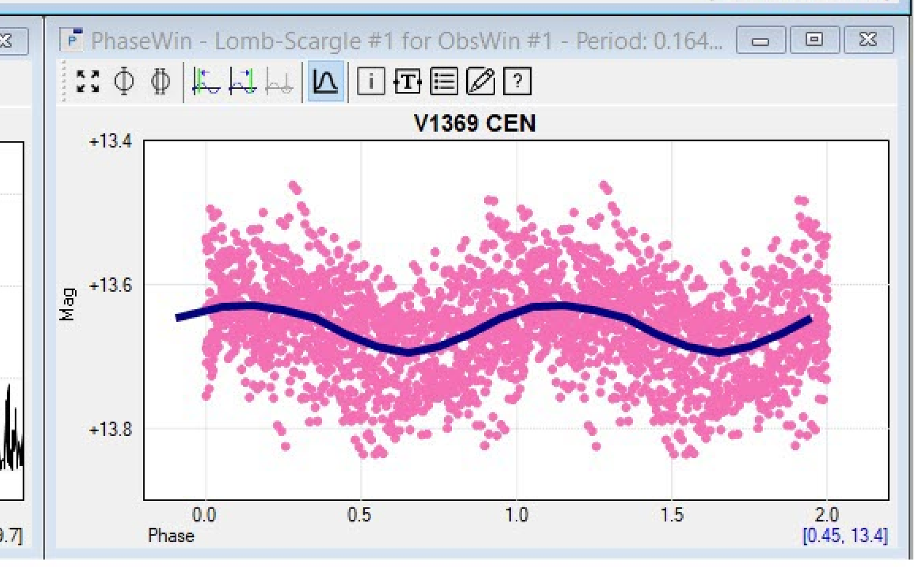


Figure 10 - Phase Diagram using T50 Data

We have detected two periods which differ by 5% in the V1369 Cen system. The modulation, within the uncertainties, is a simple sinusoid, as might be expected from an ellipsoidal variation or rotational modulation. The source of the period is not firmly known, but the variability, both in period and amplitude, suggests that it is related to the accretion disk. The period is likely close to the orbital period of the binary system.

While TESS is a powerful tool for determining short stellar periods, because the continuous cadence greatly diminishes the aliasing arising from short observing windows, TESS is severely limited for this kind of focused investigation because it cannot observe targets on demand, and because its poor spatial resolution can lead to significant source confusion.

The ground-based observations are difficult - one must invest a full night to obtain 1-2 periods, and obtain data for a number of successive nights (or from a spread of longitudes) to beat down the aliasing. But had we only the TESS light curve, we might be confident that we knew the orbital period. The ground-based follow-on shows that this would have been a premature conclusion. The synergies between the ground and space observations raise important astrophysical questions.

We urge members of the AAVSO who have appropriate instrumentation to consider undertaking time-series observations of post-novae, to study the reformation and evolution of the accretion disk in these systems as they approach quiescence.

References

This research made use of Peranso (https://www.cbabelgium.com/peranso/), a light curve and period analysis software; Lightkurve, (Lightkurve docs — Lightkurve), a Python package for Kepler and TESS data analysis. (Lightkurve Collaboration, 2018); AIP4WIN (AIP4Win@groups.io | Home), a Windows astronomical image processing software program, and Astropy, (http://www.astropy.org), a community-developed core Python package for Astronomy.

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