Photometry of Algol Type (EA) Eclipsing Binaries with Delta Scuti Pulsating Components

Abstract:

Thirty six Algol-type (EA) binaries were discovered by Hipparcos in 1997. According to their (B-V) color and spectral types, these systems are approximately located in the instability strip of the Hertzsprung-Russell diagram. Other than the Hipparcos photometry, these binaries have not been routinely observed. In this study, the thirty six Algol-type eclipsing binaries discovered by Hipparcos will be studied incorporating photometry from the Transiting Exoplanet Survey Satellite (TESS). Of the thirty six binaries, thirty one have complete TESS photometry files, while the remaining five have only FFI (Full Frame Images) with no corresponding photometry files. These five binaries utilize photometry from ASAS-SN to produce light curves. From these light curves, periodograms are produced, yielding the pulsation spectrum frequency structure of the binary system. This pulsation spectra clearly shows the behavior of the Delta Scuti component of the binary systems. Additionally, the period analysis and resulting orbital phase plot for the eclipsing binaries are presented. This study will begin with six of the thirty six Algol-type (EA) binary systems, presenting light curves, pulsation spectra, period analyses, and orbital phase plots for each. The remaining thirty will be presented in future studies.

Introduction and Background

Thirty six Algol-type (EA) binaries were discovered by Hipparcos in 1997. According to their (B-V) color and spectral types, these systems are approximately located in the instability strip of the Hertzsprung-Russell diagram. As discussed in Soydugan, E., et al., (2006), these thirty six binaries are part of a larger catalog of 197 close eclipsing binaries (71 detached and 90 semidetached) with at least one of the components located in the Delta Scuti region of the Cepheid instability strip. Hinzel, D., 2025, studied TESS observations of the detached eclipsing binary V477 Cygni (Table 3 of Soydugan, E., et al., 2006) which included a heartbeat structure due to tidal effects, as well as the possible existence of a third companion, likely a compact object (a white dwarf). Other than the Hipparcos photometry, these binaries have not been routinely observed. These thirty six binaries are indicated in Table 5 of Soydugan, E., et al (2006). Table 5 does not show the equivalent TIC (TESS Input Catalog) designation from which photometry for this study was obtained. The TIC designators were obtained by crossmatching the binary name (e.g., V342 And) from the SIMBAD Astronomical Database and are indicated in the individual plots shown herein (e.g., TIC 440003271). AAVSO VSX links are shown in blue for each binary in the light curve plot. It should be noted that this study is primarily to present the TESS photometry of these thirty six

Algol-type (EA) binary systems, not the detailed analysis of any particular system at this time.

Methods

This study looks at eclipsing Algol-type (EA) binaries with a Delta Scuti pulsator as one of the members of the system. The light curve and the periodogram are analyzed from TESS photometry data contained in the Mikulski Archive for Space Telescopes (MAST; StScI 2024). All of the TESS photometry files were downloaded and a light curve was generated by the American Association of Variable Star Observers (AAVSO) VStar software (Benn, D. 2012, Algorithms + Observations = VStar, Journal of the AAVSO (JAAVSO), v40, n2, pp.852-866). Prior to mode identification of pulsation mode frequencies (or periods), the frequencies themselves must be extracted by assembling time-series data of the star's observable surface properties. Such time-series data can be obtained from time-series photometry with the periodic variability of the star's brightness as a function of time. This is the star's light curve. To extract pulsation mode frequencies, it is common practice to employ Fourier analysis, specifically Discrete Fourier Transforms (DFTs) for unevenly sampled time series or a Lomb-Scargle periodogram (Scargle, 1982). The frequency spectrum is calculated up to the Nyquist frequency, defined as: F (Nyquist) = $1/2\Delta t$ where Δt is the cadence of the time series. Once the frequency spectrum has been calculated, peaks are noted that are statistically significant and represent pulsation mode frequencies based on satisfying a significance criterion. This is the periodogram. The data is analyzed with VStar. Specifically, Fourier analysis of the combined photometric data is performed to yield a detailed periodogram for the Delta Scuti pulsator from which frequencies, periodicities, and other variations can potentially be identified. VStar utilizes the Date Compensated Discrete Fourier Transform (DCDFT) algorithm (Ferraz-Mello, 1981) to produce a power spectrum, a period range, and a resolution. The Date Compensated DFT compensates for gaps in the data, which is common for variable star observations. The resulting analysis can include one or more periods, one or more harmonics, one or more subharmonics, and other frequency products that may be due to nonlinear processes in the star. These can be selected to create a model that can also include a polynomial function that is used as a smoothing mechanism to capture key aspects of the data set without all the noise and fine fluctuations. When a model is created, it is subtracted from observations in the series to yield a second series called a residual. The residuals can also be analyzed to look for other signals (frequencies/periods) in a process called pre-whitening. Periodicities and other potential variations are analyzed utilizing TESS photometry, models are created from the photometry, mean series are computed, and residuals are analyzed to obtain all possible variations. These are shown in the period analysis and pulsation spectrum plots for each binary system.

Analysis and Results

Figures 1-24 below show the light curve, period analysis, pulsation spectrum, and phase plot of V342 And, CU Tuc, BH Scl, V773 Cas, DP Cet, and V405 Cep. The TESS Input Catalog (TIC) designation is shown as well as the link to the AAVSO VSX file on each binary system. Of particular interest is the pulsation spectrum of each binary, showing a periodic frequency structure. The spectral components of each are harmonics of the lowest frequency component, i.e., for V342 And, the lowest frequency shown is f = 0.76198 (Figure 2). The higher frequencies are 2f = 1.51466, 3f = 2.2766, etc. All binary systems have a similar frequency/comb pulsation structure.

For the orbital phase of each binary system, there is disagreement with some of the orbital data presented in Soydugan, E., et al., (2006), Table 5, Column 5, Porb(d). Given the old (1997) and limited observation data shown in Table 5, it will be assumed that the orbital data presented herein is correct.

V 342 And (TIC 440003271)

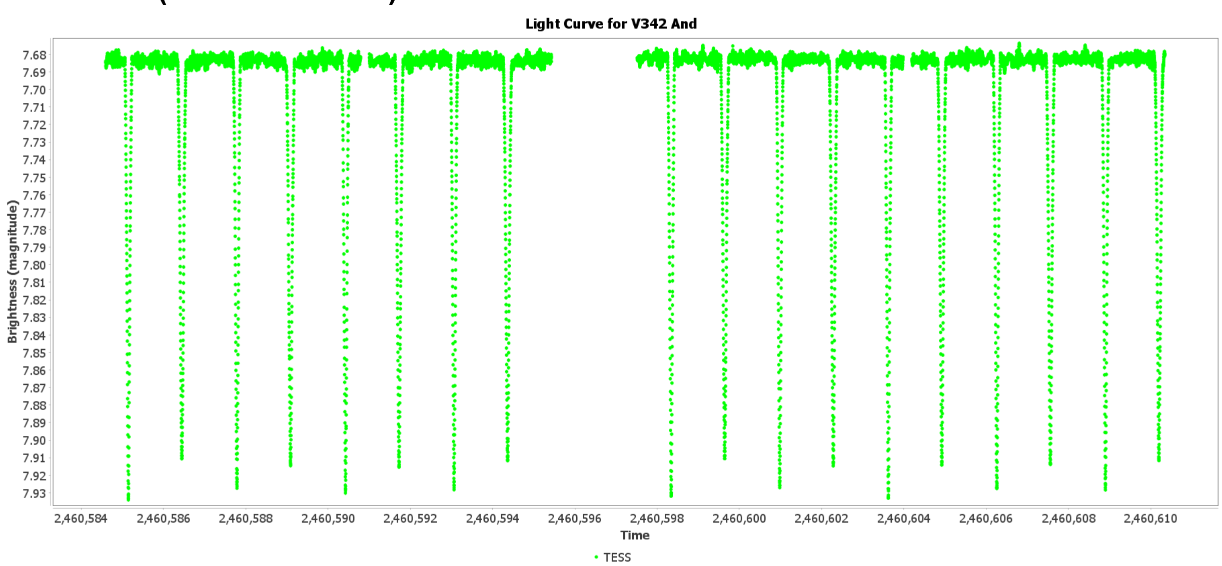

Figure 1: Light Curve

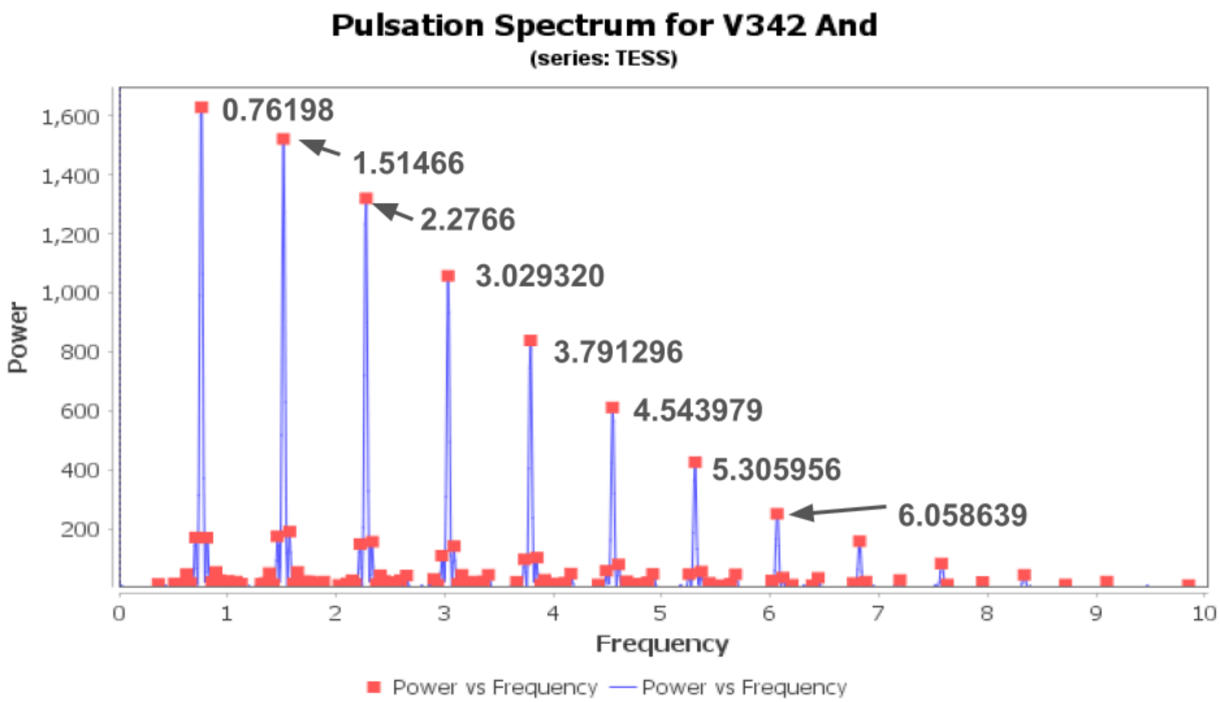

Figure 2: Pulsation Spectrum

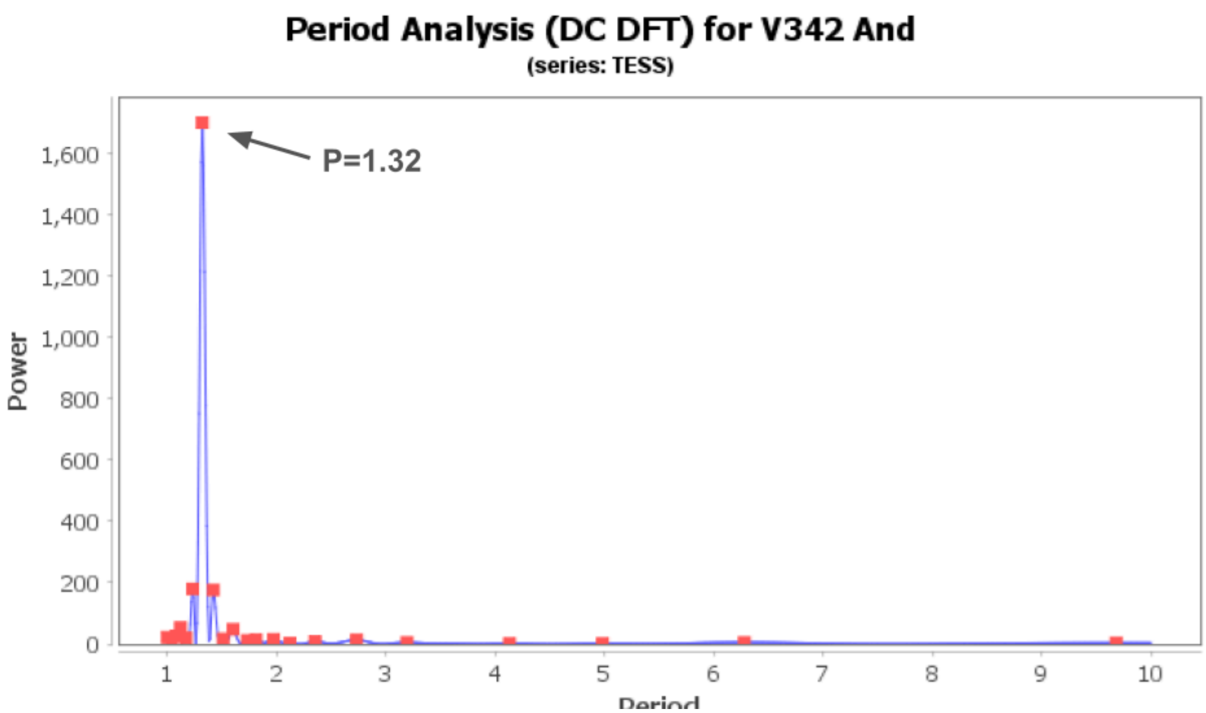

Figure 3: Period Analysis

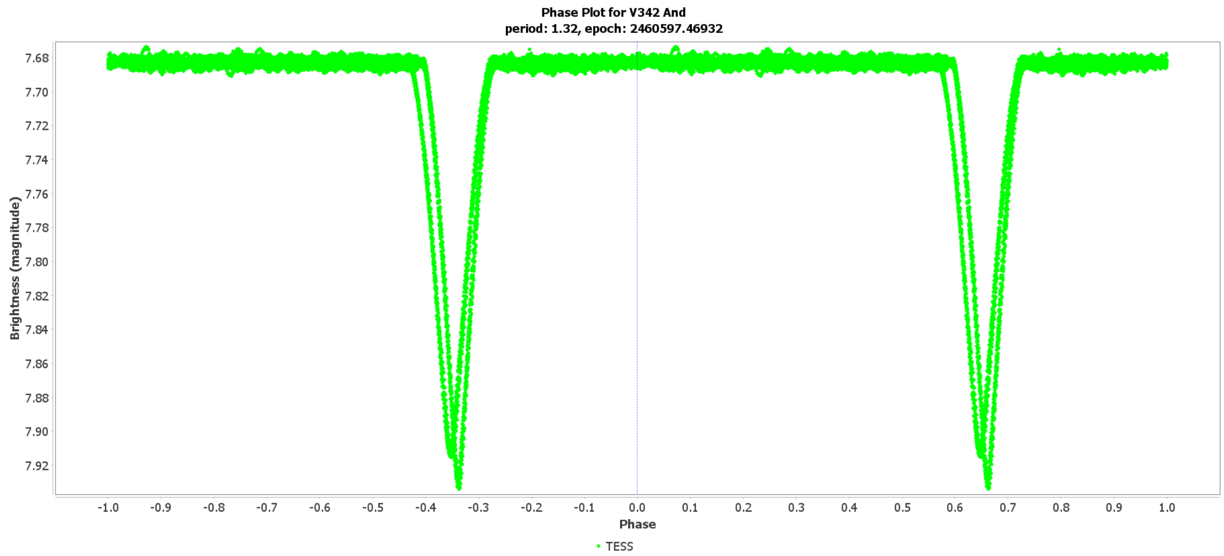

Figure 4: Phase Plot

CU Tuc (TIC 234491752)

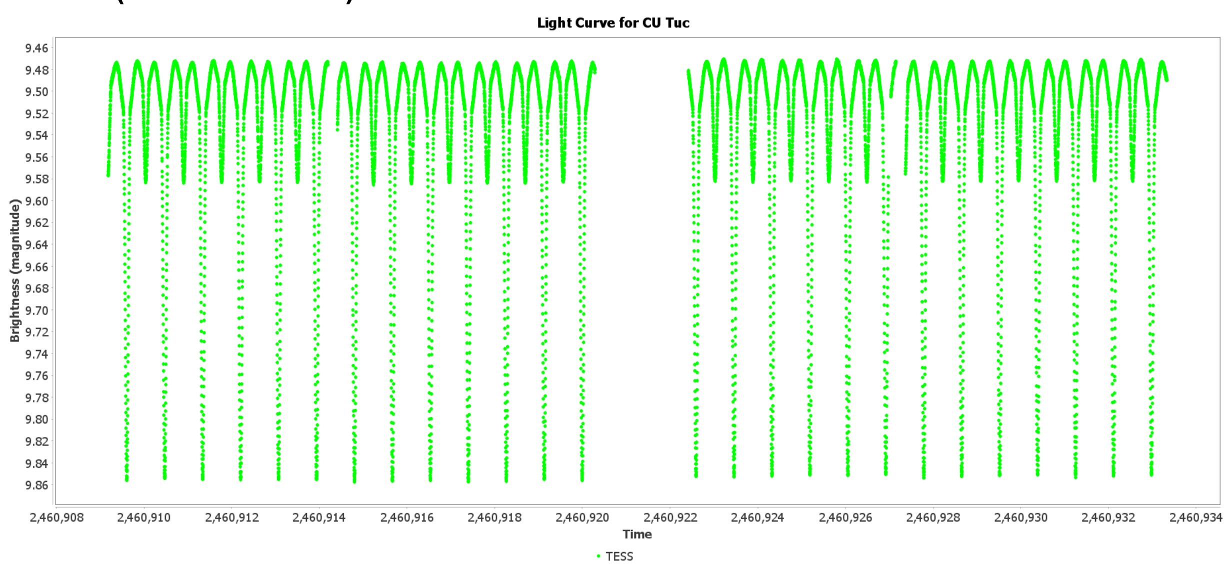

Figure 5: Light Curve

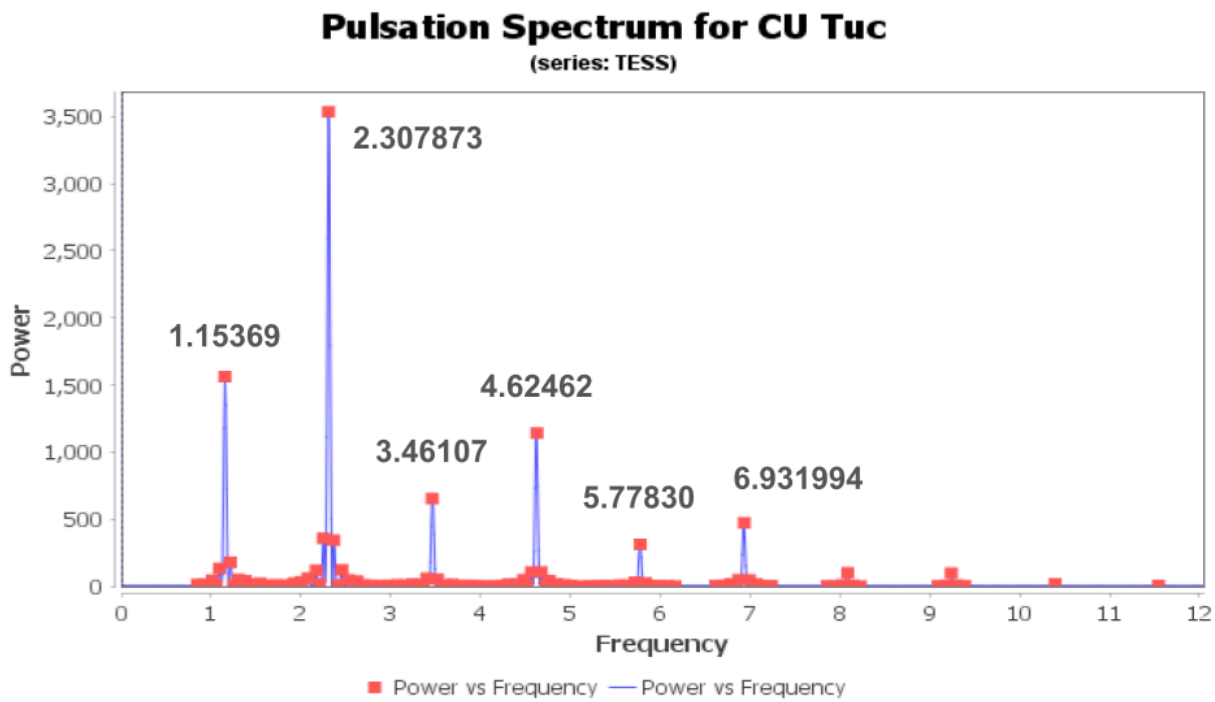

Figure 6: Pulsation Spectrum

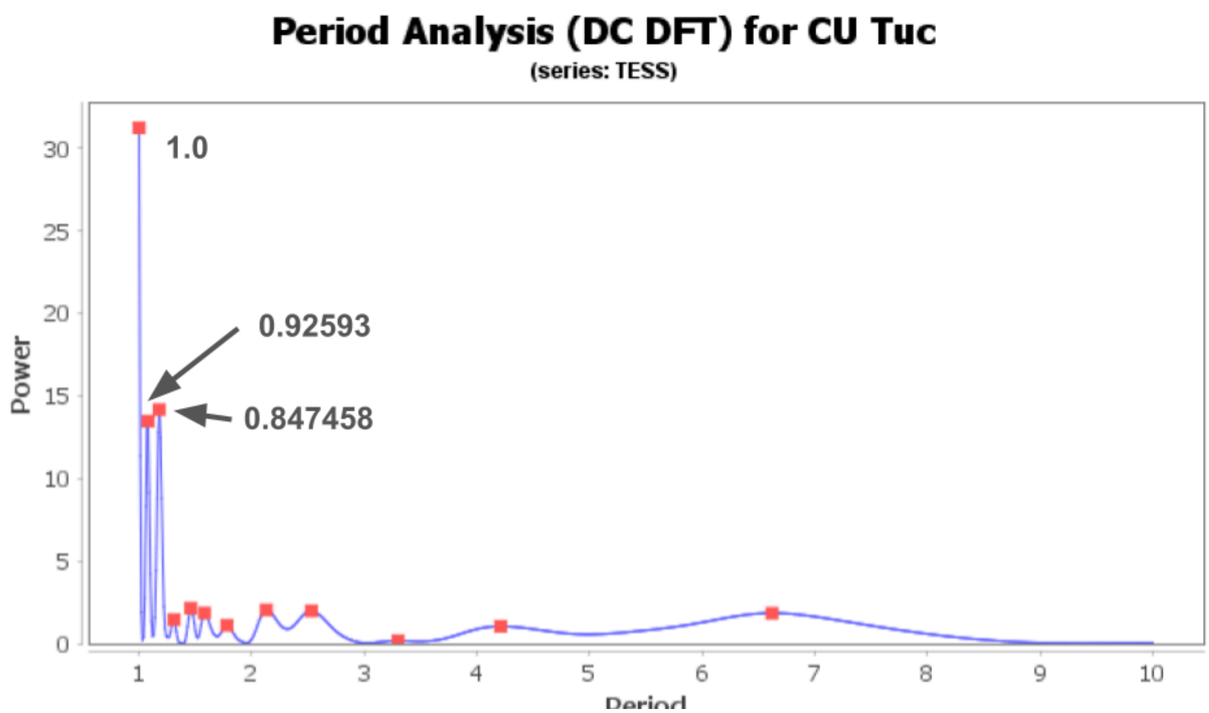

Figure 7: Period Analysis

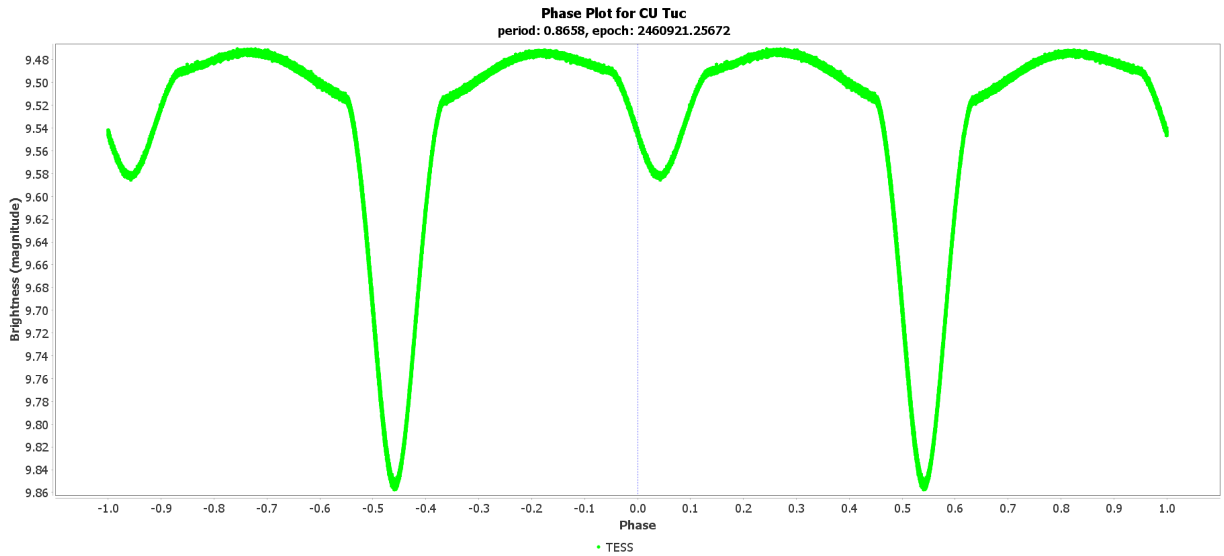

Figure 8: Phase Plot

BH Scl (TIC 97467902)

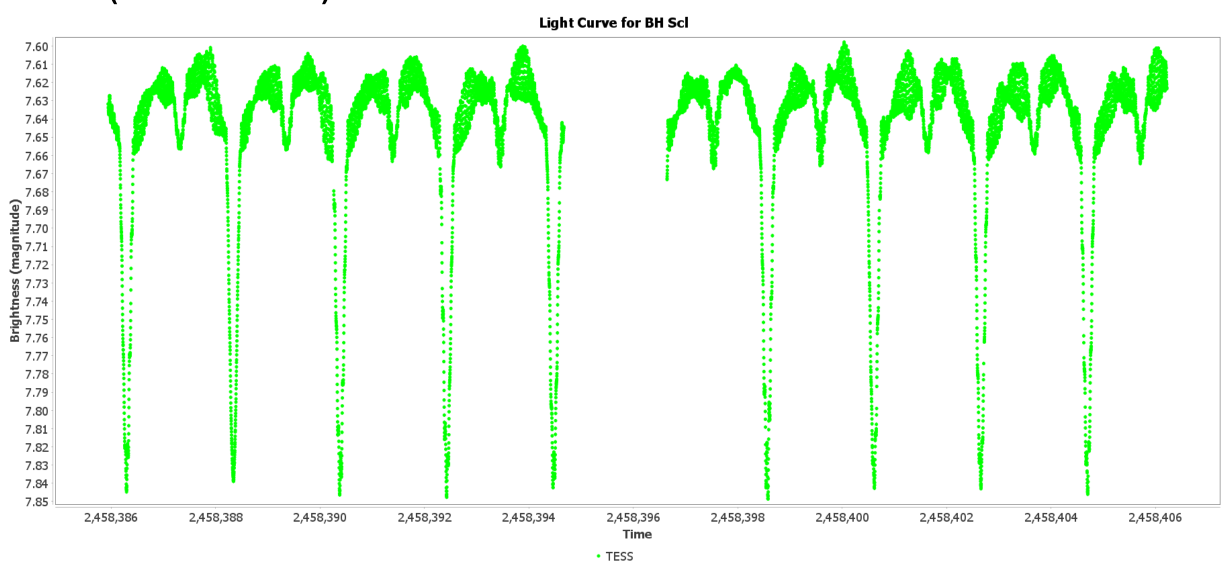

Figure 9: Light Curve

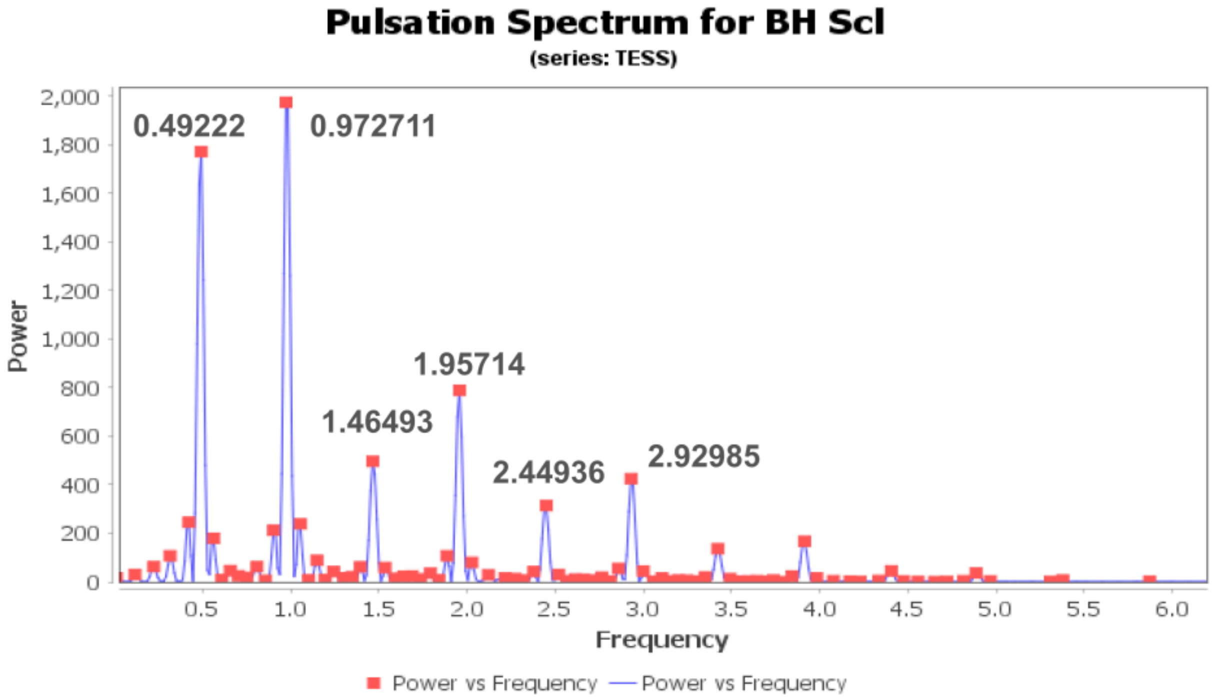

Figure 10: Pulsation Spectrum

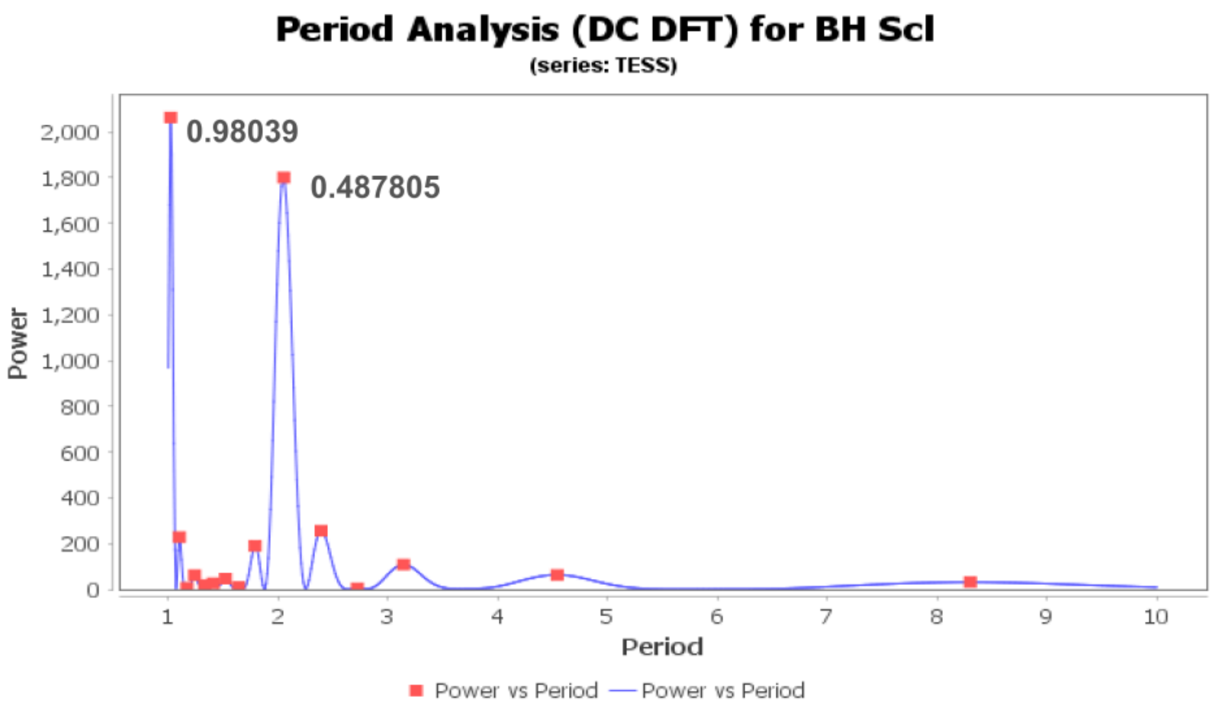

Figure 11: Period Analysis

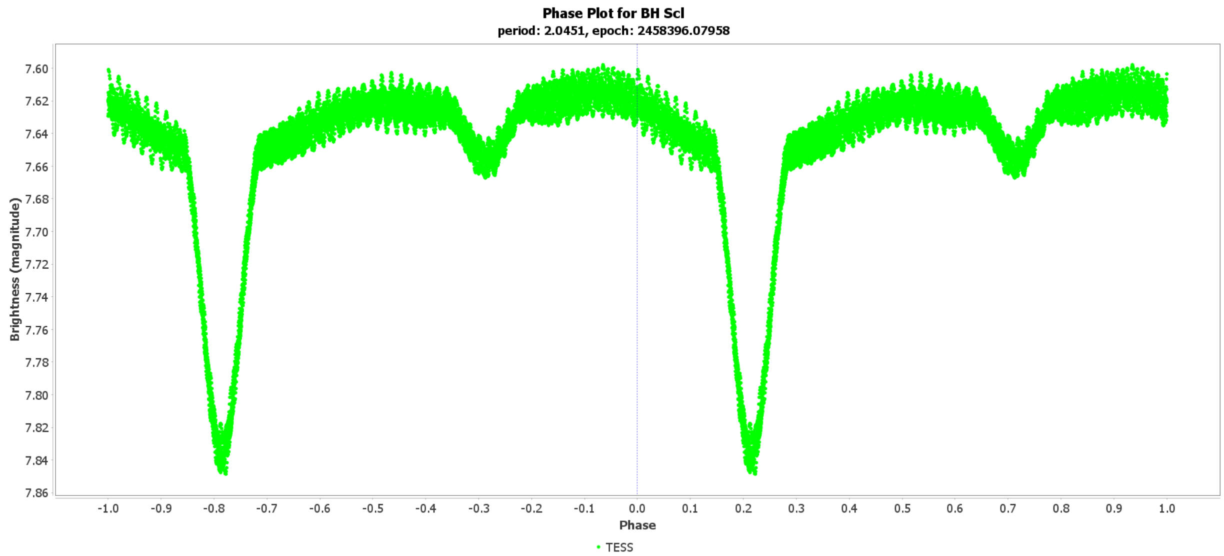

Figure 12: Phase Plot

V773 Cas (TIC 71847068)

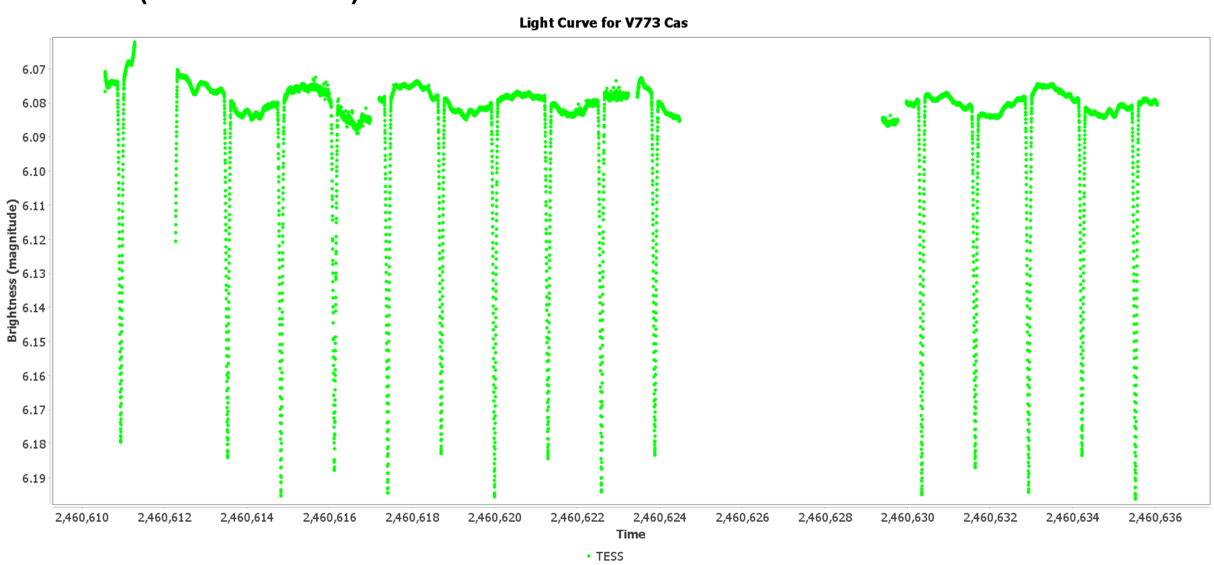

Figure 13: Light Curve

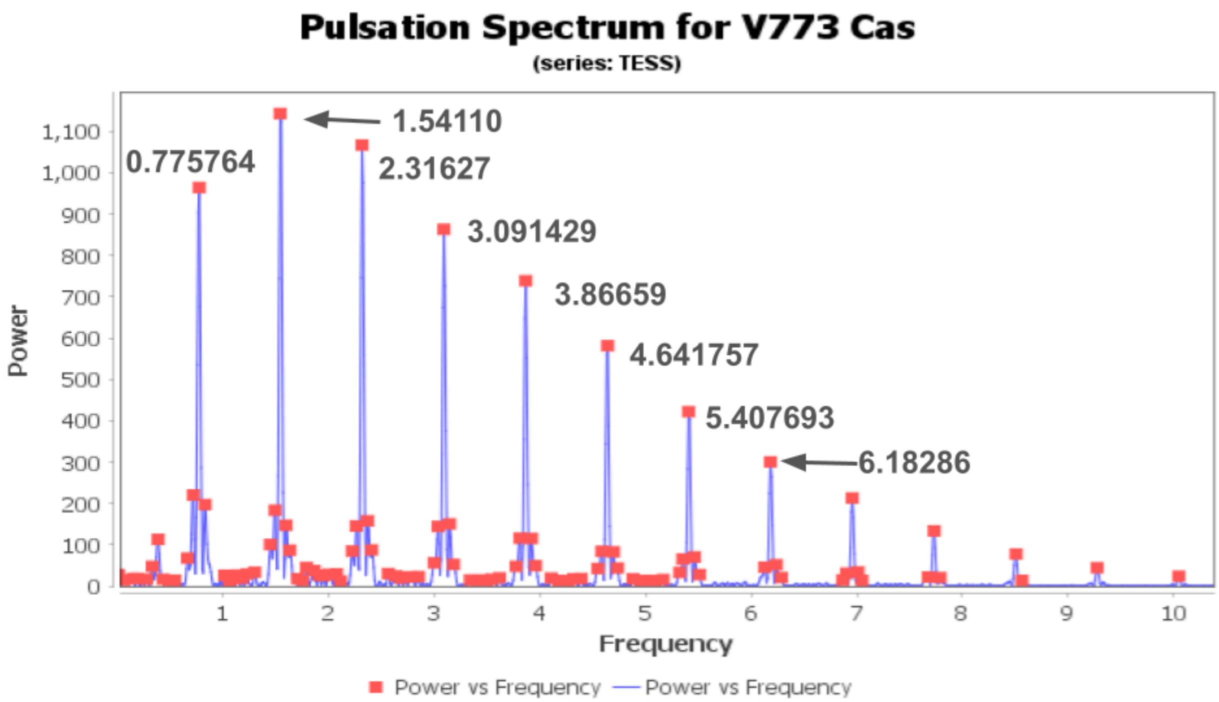

Figure 14: Pulsation Spectrum

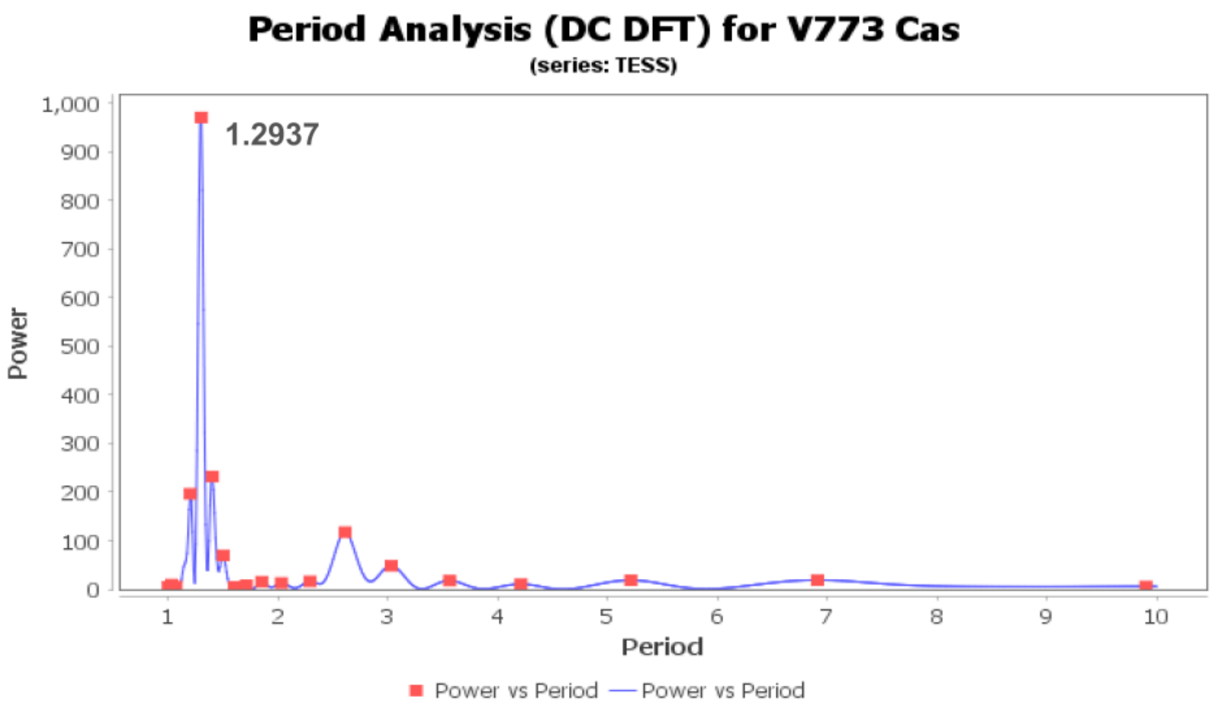

Figure 15: Period Analysis

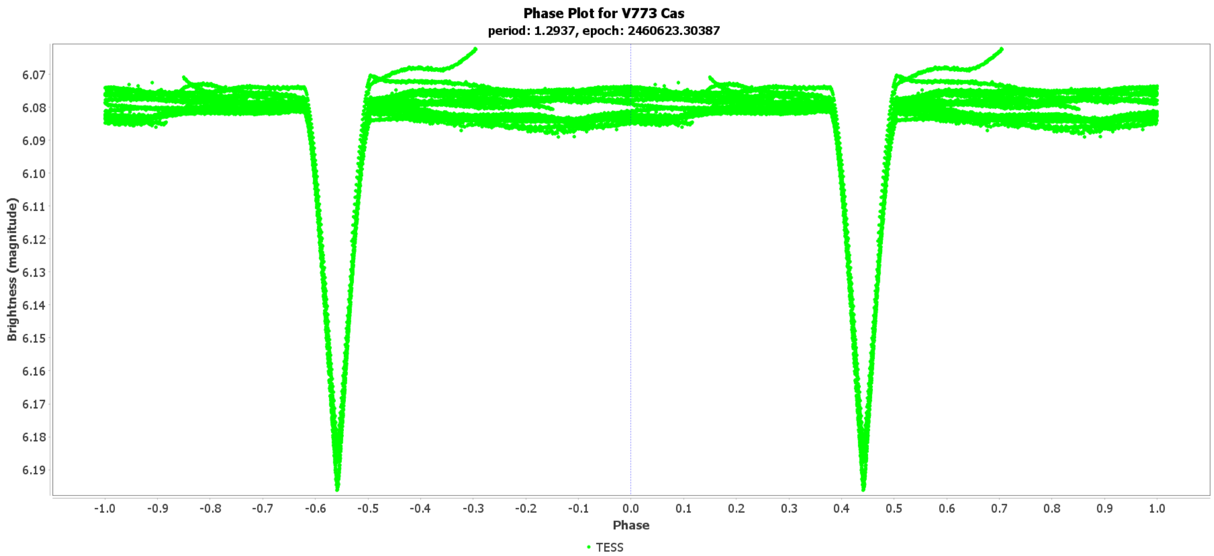

Figure 16: Phase Plot

DP Cet (TIC 270371961)

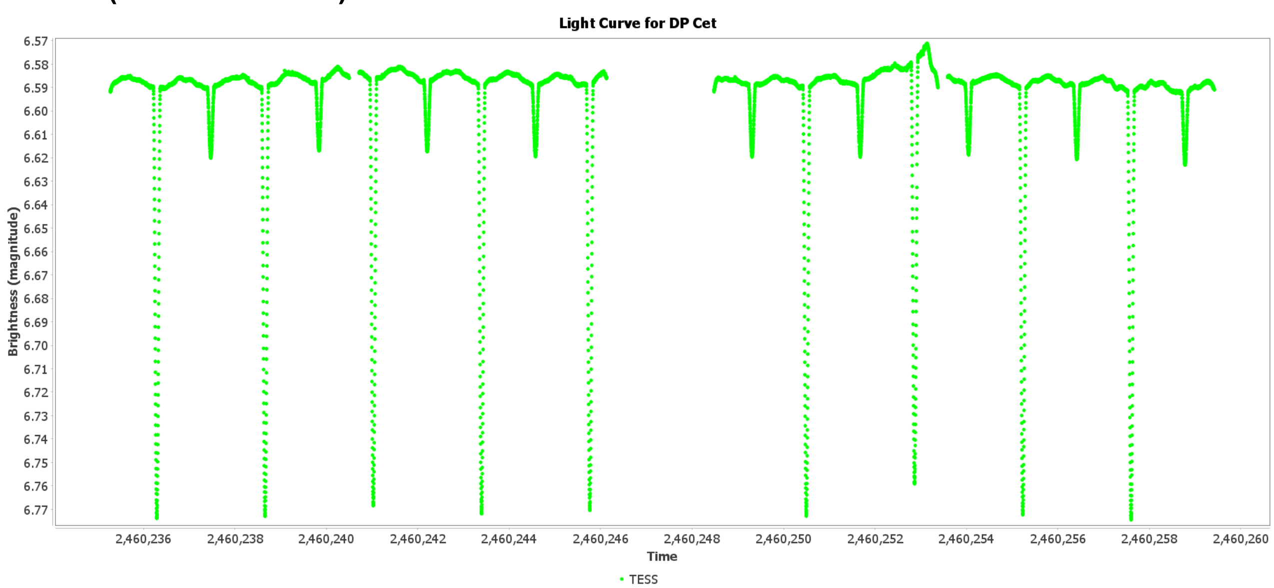

Figure 17: Light Curve

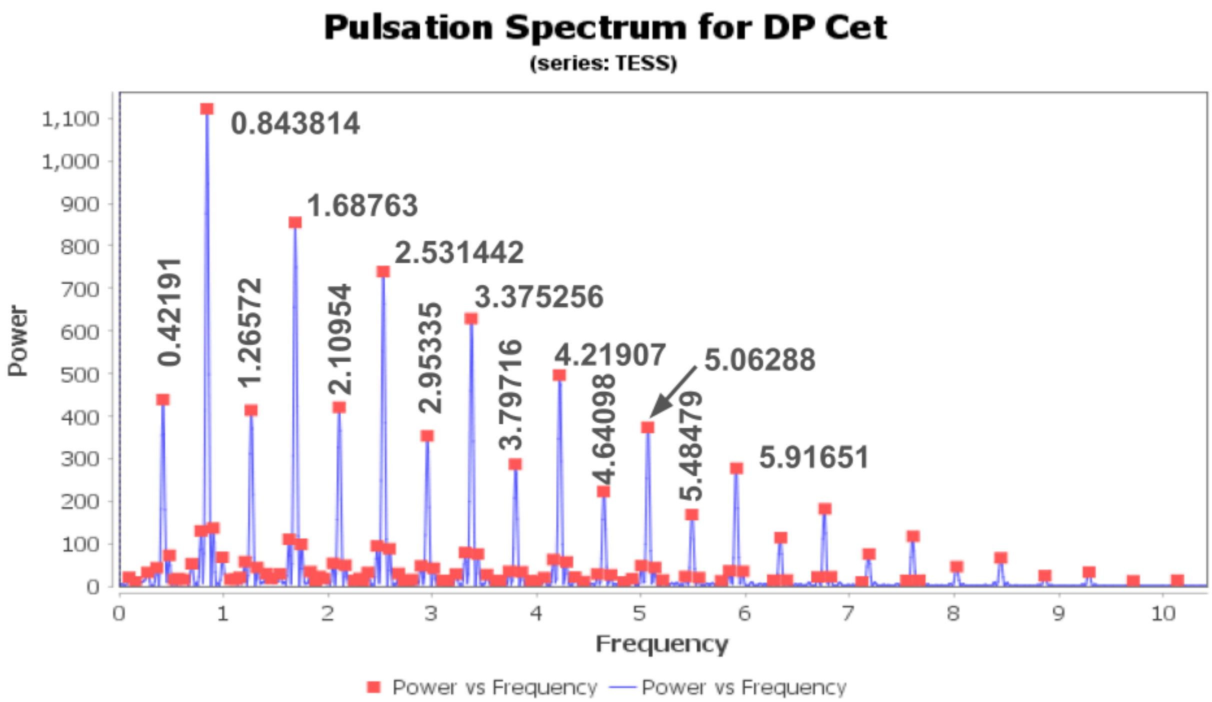

Figure 18: Pulsation Spectrum

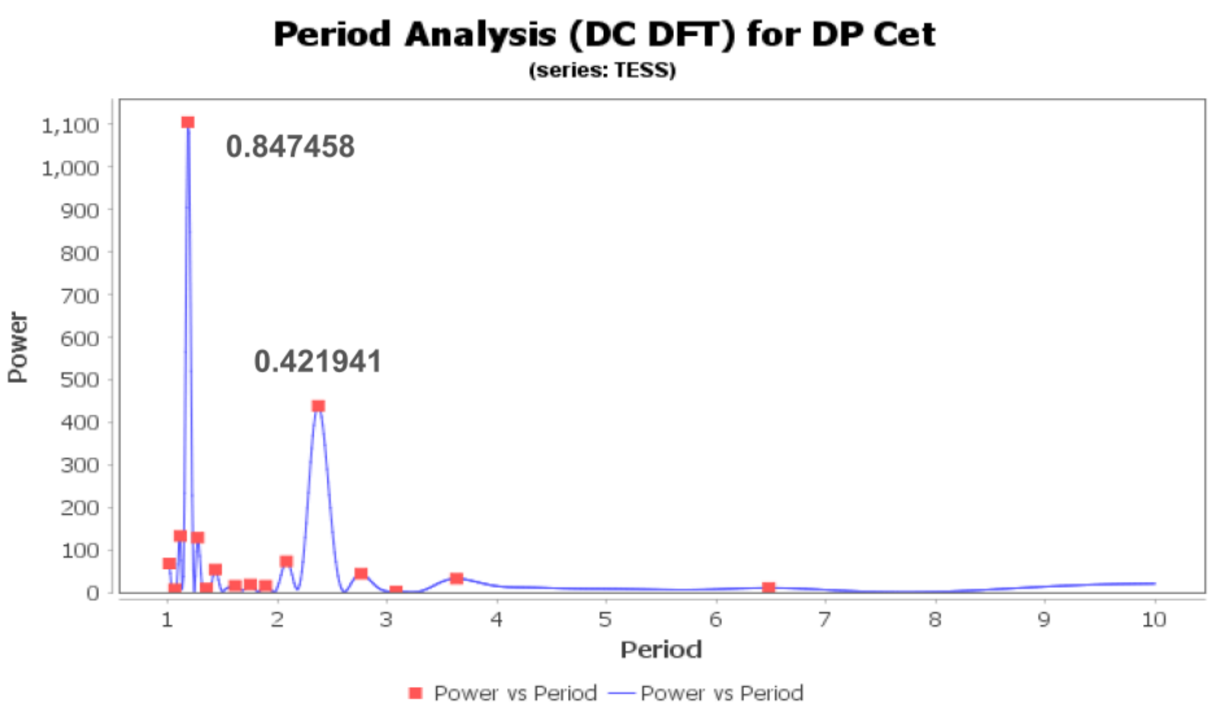

Figure 19: Period Analysis

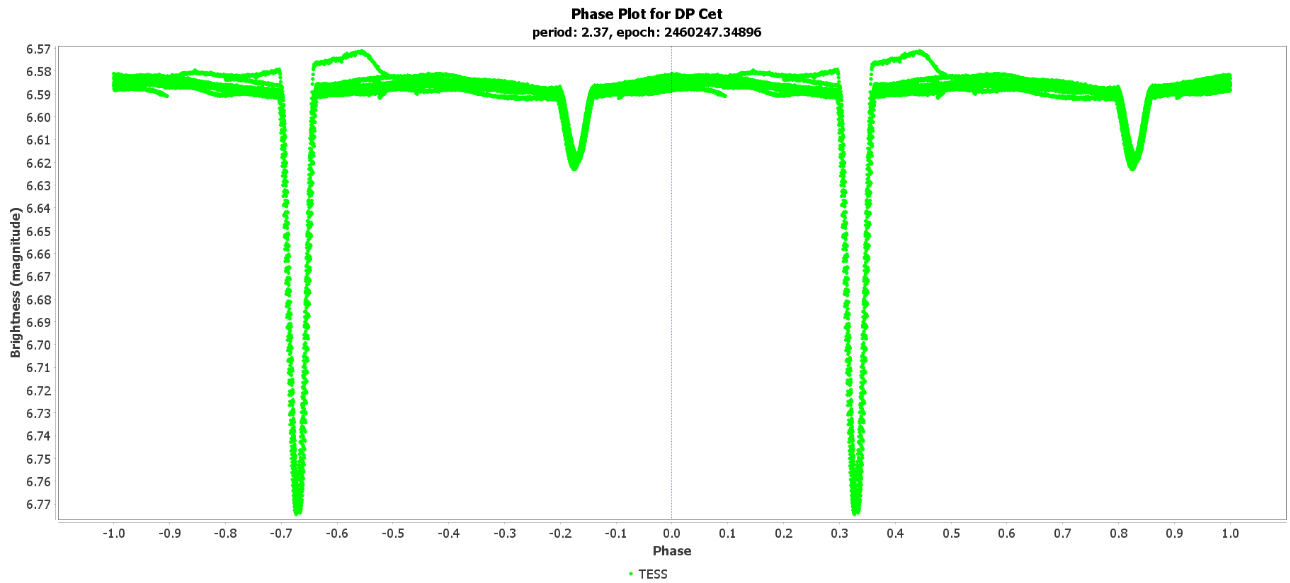

Figure 20: Phase Plot

V405 Cep (TIC 401498844)

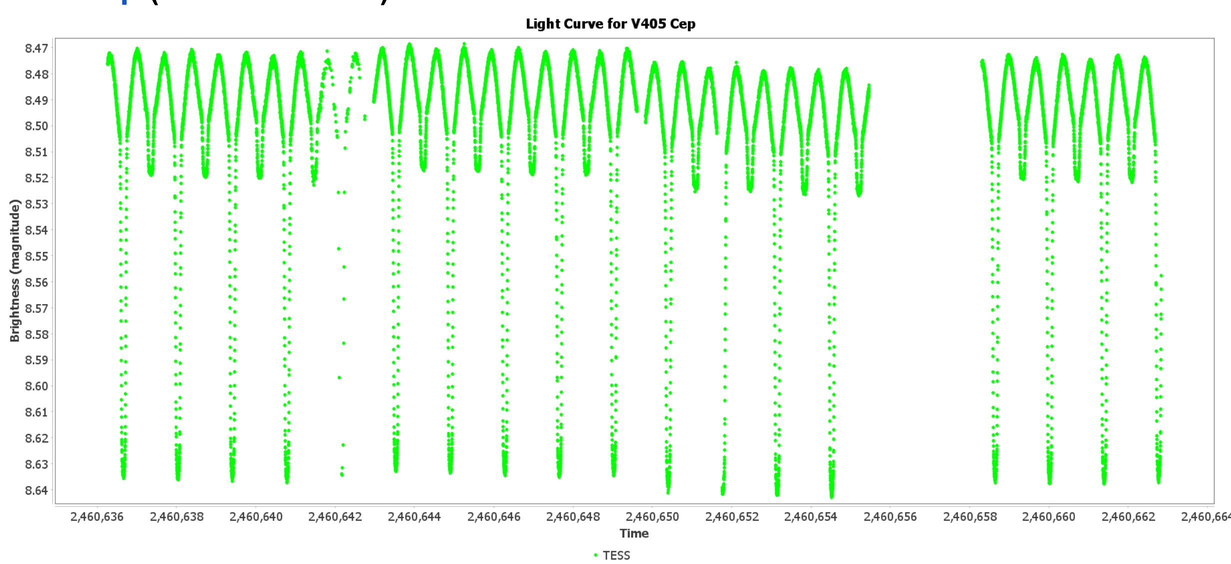

Figure 21: Light Curve

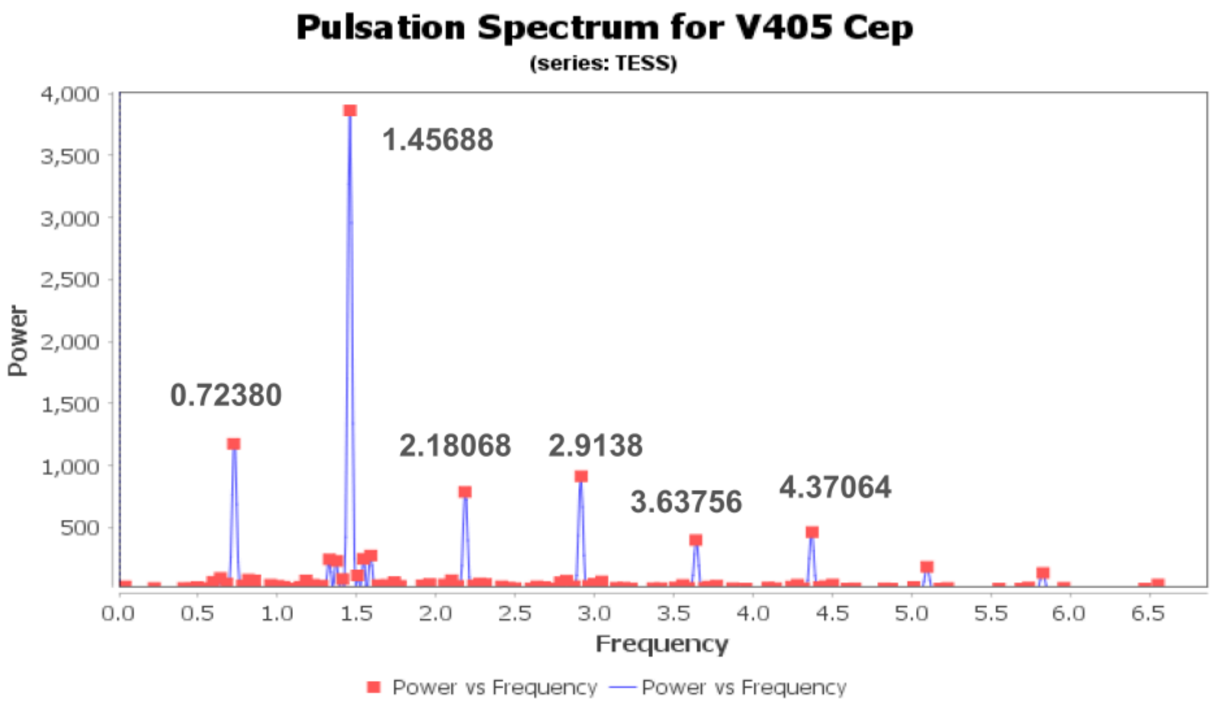

Figure 22: Pulsation Spectrum

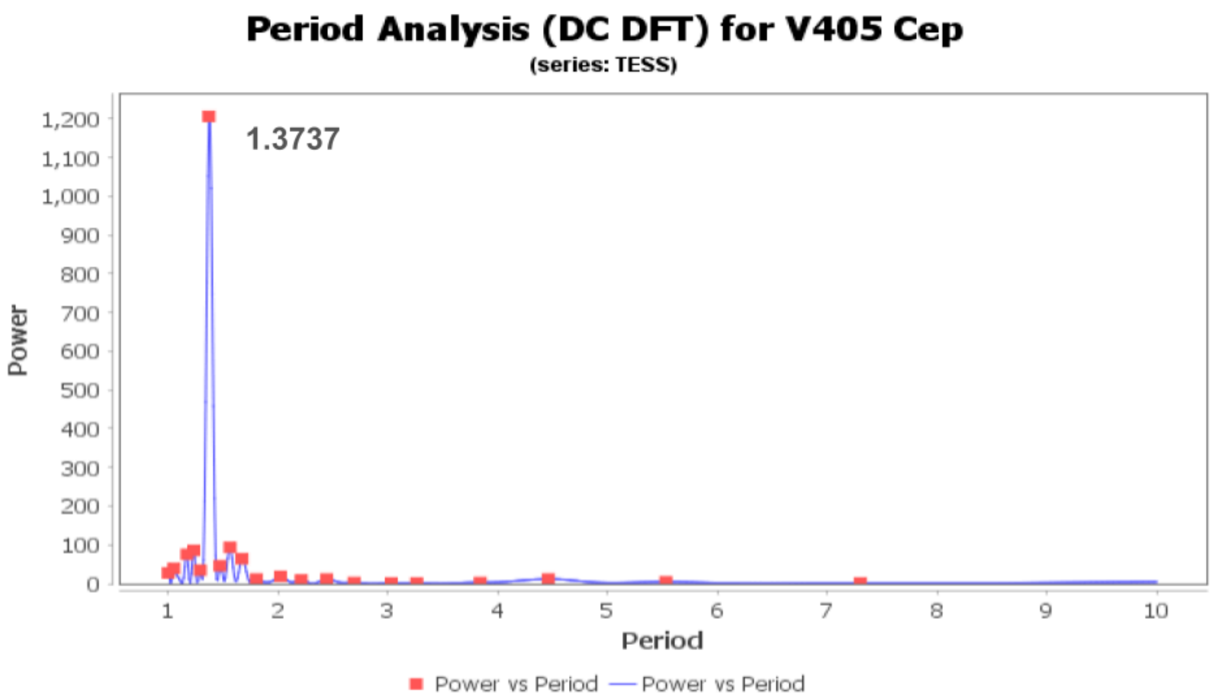

Figure 23: Period Analysis

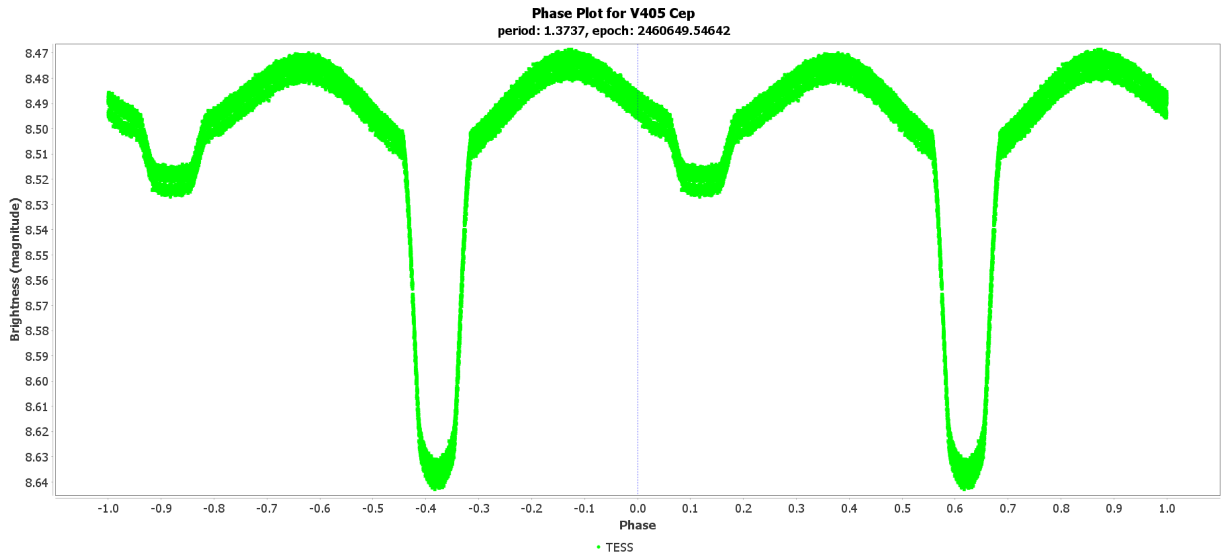

Figure 24: Phase Plot

Discussion

The mechanism of the δ-Scuti pulsator is complex. Stellar pulsation modes directly probe a star's internal structure, including interior physical conditions and transport processes. The self-excited resonant pulsation modes of a star represent small perturbations to the hydrostatic equilibrium structure. Each pulsation is a standing wave with unique geometry, frequency, and pulsation signal structure including harmonics, subharmonics, and signal higher order products that reflect nonlinear processes within the star. The frequencies can be separated into radial and angular components. Radial components are characterized by a radial order n, describing the number of interior shells acting as resonant cavities. Each resonant cavity supports a characteristic vibration mode. Angular components are characterized by an angular degree l, and an azimuthal order m, that describes the number of surface nodal lines. There are two main pulsation excitation mechanisms. The first is a stochastic mechanism that operates within large convective envelopes. Turbulent convection continually drives and damps the resonant frequencies of the star. These produce radial order pressure modes within certain frequency ranges determined by the resonant cavity. The second main pulsation excitement mechanism is a heat-engine mechanism in which mechanical work is converted to heat. This heats the various zones and causes them to expand. After expanding, the radiation is able to flow through the zones which releases the heat so the layers cool down and contract again. This periodic expansion-contraction cycle allows heat from the star to be converted into mechanical work and excite pulsations. Additionally, if the star is rapidly spinning, gravity can be important as a restoring force, resulting in additional frequencies and pulsation modes.

Conclusions

This study has presented the analysis of TESS photometry for six EA Algol type eclipsing binaries with Delta Scuti pulsating components. A light curve, pulsation spectrum, period analysis, and orbital phase plot were generated for each. The pulsation spectrum for each system shows an harmonic or comb-like structure. The remaining thirty binary systems will be presented in future studies.

References

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