Transiting Exoplanet Survey Satellite (TESS) Observations of Pulsations in 36 Delta Scuti Stars

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Abstract: The Transiting Exoplanet Survey Satellite (TESS) observed pulsations in 36 Delta Scuti stars in the instability strip of the Pleiades open cluster. TESS is producing high-precision, rapid-cadence light curves over most of the sky, opening up new possibilities for studying large samples of Delta Scuti stars. Using time-series photometry data from TESS contained in the Mikulski Archive for Space Telescopes (MAST) database, light curves and periodograms are examined in detail to extract frequency/period relations among the pulsations. In this study, one of the 36 Delta Scuti candidates is examined in detail, specifically TIC 402366726, showing a complex frequency/period structure. The TIC 402366726 frequency structure seems to exhibit a modulation reminiscent of that incorporated in radio frequency communications systems such as pulse or phase shift key modulation as well as amplitude modulation as seen in the light curve. The remaining 35 Delta Scuti candidates will be studied in detail in future presentations.

Introduction and Background

Bedding, T. R., et al., 2023, studied 89 A- and F-type members of the Pleiades open cluster. Using time-series photometry from the NASA Transiting Exoplanet Survey Satellite (TESS), they discovered Delta Scuti pulsations in 36 stars. Additionally, Hinzel, D.H., 2025, studied TESS observations of eclipsing binary V477 Cygni which included a Delta Scuti pulsator as one of its components. TESS is producing high-precision, rapid-cadence light curves over most of the sky, opening up new possibilities for studying large samples of Delta Scuti stars. TESS observations are made in 27 day sectors. The observations of the 36 objects in the Pleiades cluster were made in the fourth year of the mission in Sectors 42-44 (August 20 to November 6, 2021). The TESS observations incorporate a 120 second cadence for all objects. All 89 members of the Pleiades open cluster, including the 36 Delta Scuti pulsators, are summarized in Table 1 of Bedding, T. R., et al., 2023. All objects are assigned a TESS Input Catalog (TIC) designation number, but Table 1 also lists common names for each star such as HD 23156, V624 Tau, etc. In this study, one of the 36 Delta Scuti candidates is examined in detail, specifically TIC 402366726, showing a complex frequency/period structure. The TIC 402366726 frequency structure seems to exhibit a modulation reminiscent of that incorporated in radio frequency communications systems such as pulse or phase shift key modulation as well as amplitude modulation as seen in the light curve. The remaining 35 Delta Scuti candidates will be studied in detail in future presentations.

Methods

This study looks at TIC 402366726 which is a Delta Scuti pulsator. The light curve and the periodogram are analyzed from TESS photometry data contained in the Mikulski Archive for Space Telescopes (MAST). 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, and one or more subharmonics. 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.

Analysis and Results

Figure 1 shows the light curve (1), periodogram resulting from analysis of the light curve (2), and a close-in view of the primary pulsation of frequency 34.881567 (3). As seen in the periodogram, the spectrum of TIC 402366726 is complex. There are five frequencies/periods that significantly contribute to the complex signal structure. These are, in order of signal strength: 1) the primary pulsation frequency of 34.881567, 2) 37.88329, 3) 37.911297, 4) 22.16511, and 5) 18.37444. Visual inspection of the light curve seems to indicate an amplitude modulation. The periodogram, centered on the primary pulsation frequency of 34.881567, shows sidebands that seem to exhibit a modulation reminiscent of that incorporated in radio frequency communications systems such as pulse or phase shift key modulation. The other four signal frequencies show similar modulation sidebands.

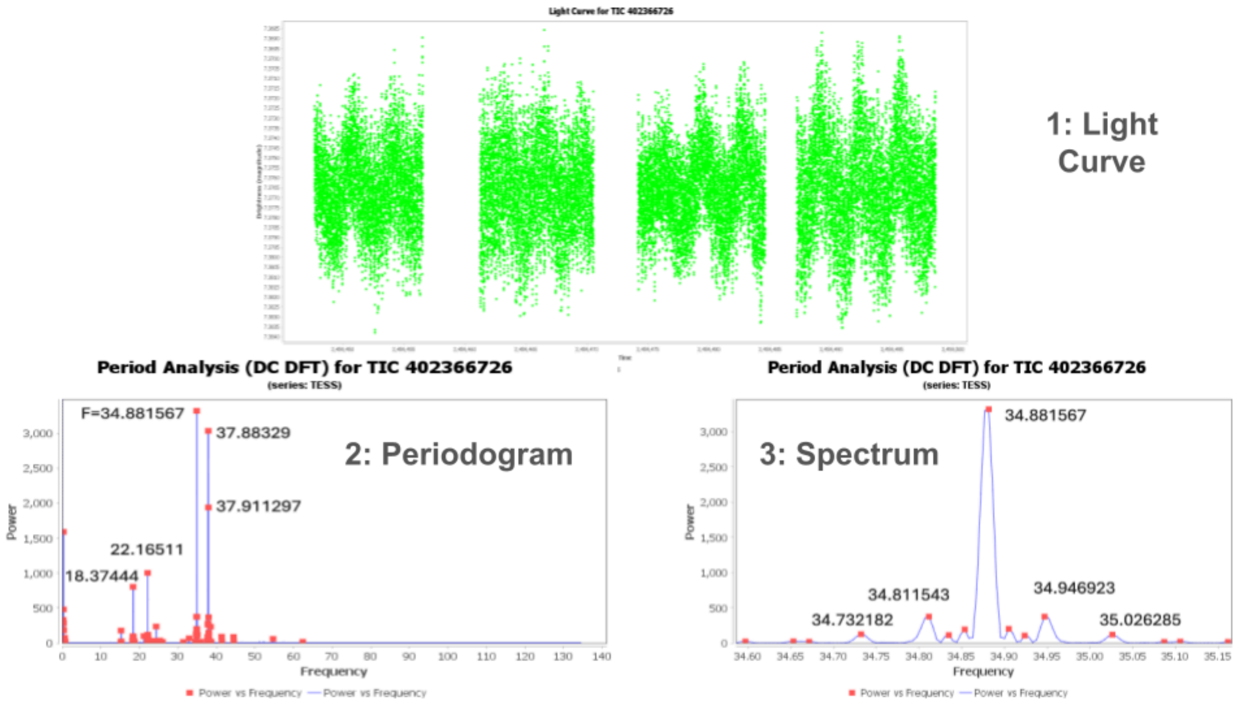

Figure 1: TIC 402366726 Light Curve, Periodogram, and Spectrum

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

The Transiting Exoplanet Survey Satellite (TESS) observed pulsations in 36 Delta Scuti stars in the instability strip of the Pleiades open cluster. Using time-series photometry data from TESS contained in the Mikulski Archive for Space Telescopes (MAST) database, light curves and periodograms are examined in detail to extract frequency/period relations among the pulsations. In this study, one of the 36 Delta Scuti candidates is examined in detail, specifically TIC 402366726, showing a complex period/frequency structure. The TIC 402366726 frequency structure seems to exhibit a modulation reminiscent of that incorporated in radio frequency communications systems such as pulse or phase shift key modulation as well as amplitude modulation as seen in the light curve. The remaining 35 Delta Scuti candidates will be studied in detail in future presentations.

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