

Multi-Band Photometric Study of the δ Scuti Star V2455 Cyg

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Abstract: This study presents photometric observations of the high-amplitude δ Scuti star V2455 Cyg, conducted using the 432mm Cassegrain telescope (f/6.8, 2939 mm focal length) at NanShan station of Astronomical Observatories in Ürümqi, China, equipped with the QHY4040Pro scientific CMOS camera. The observations were performed to characterize the star's pulsation properties. Data processing involved standard photometric reduction techniques operated on MaxIm DL 6, and further analysis is performed on Period04 to obtain smoothed light curves and phase diagrams. Our analysis identified the fundamental radial mode of V2455 Cyg with a period of approximately 0.087 days and a peak-to-peak amplitude of 0.304 mag in r-band, 0.443 in g-band, and 0.233 in i-band. The results are consistent with the star's classification as a high-amplitude δ Scuti star, suggesting a stable single-mode pulsation, supporting its classification as a Population I HADS, with potential implications for asteroseismology and variable star catalogs.

1. Introduction

Variable stars are stars that change their brightness over time, offering a window into their internal structure, evolution, and physical processes. These changes can result from pulsations (expansion and contraction of the star), eclipses in binary systems, or explosive events. Variable stars are classified based on their behavior and physical properties. For example, Cepheids pulsate with regular periods and are used to measure cosmic distances, while RR Lyrae stars are older, low-mass pulsators found in globular clusters. δ Scuti stars, the focus of this study, are pulsating stars located where the main sequence (where stars spend most of their lives burning hydrogen) meets the instability strip on the Hertzsprung-Russell (H-R) diagram, a plot of stars' brightness versus temperature. These stars, with masses 1.5–2.5 times that of the Sun, pulsate due to the κ -mechanism, a process where energy is trapped and released in the star's outer layers, causing periodic expansions and contractions[1][2]. Their light curves—graphs of brightness over time—typically show sinusoidal patterns with periods ranging from 18 minutes to 7.2 hours, and brightness changes (amplitudes) from a few thousandths to several tenths of a magnitude[3]. Figure 1 presents an example light curve of a high-amplitude δ Scuti star (not V2455 Cyg) to illustrate this sinusoidal pattern, though its 1-day period is longer than the typical range of such stars, serving as a visual reference for light curve characteristics.

V2455 Cyg, the target of this study, is a high-amplitude δ Scuti star with a reported visual magnitude of approximately 9.0 and a peak-to-peak amplitude of 0.45 mag. Previous observations,

though limited, suggest a dominant pulsation period of around 0.112 days, consistent with radial fundamental mode pulsations[4][5]. However, detailed studies on its period stability and harmonic content are scarce, motivating our investigation. This paper presents multi-band photometric observations to refine the pulsation period, detect potential harmonics, drawing methodological inspiration from studies like that of YZ Boo[2].

The paper is structured as follows: Section 2 describes the target selection criteria and observational setup. Section 3 details the data reduction and analysis methods. Section 4 presents the results, including the light curve and period analysis, and discusses the findings in the context of δ Scuti star evolution and compares them with prior work. Section 5 concludes with recommendations for future observations.

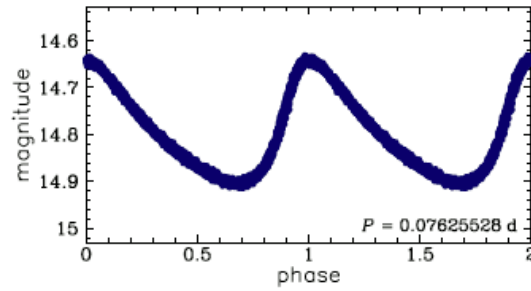


Figure 1 Example light curve of a high-amplitude δ Scuti star, showing sinusoidal variations with a period of 1 day and amplitude approximately 0.3 magnitude.

2. Observation target selection

2.1 Observational setups

Observations were conducted at NanShan station of Astronomical Observatories, an astronomical facility of the Chinese Academy of Sciences, at Ürümqi, China. We used the observatory's 432mm Cassegrain telescope, which has a 2939 mm focal length and an f/6.8 focal ratio, ideal for capturing detailed images of variable stars like V2455 Cyg.

The telescope was equipped with the QHY4040Pro scientific CMOS camera, featuring a GSENSE4040 back-illuminated sensor (36.9 mm $\times$ 36.9 mm, 9.0 μ m pixels, 4k $\times$ 4k resolution, 16.8 megapixels)[6]. The back-illuminated design increases light sensitivity, achieving a peak quantum efficiency of 90%, meaning it captures 90% of incoming photons, crucial for precise photometry. The camera's full-well capacity of 39 ke⁻ at low gain allows it to handle bright stars without saturation, while its low readout noise (2.3 e⁻ at high gain) ensures clean images. Two-stage thermoelectric cooling keeps the sensor $\sim$ 35 $^{\circ}$ C below ambient temperature, reducing thermal noise during long exposures. The camera supports dual 12-bit outputs (high and low gain), combined on-camera to produce 16-bit data, enhancing the dynamic range for measuring both bright and faint objects in the same field[7]. Figure 2 provides visual context for the observational setup: the left image displays the 432mm Cassegrain telescope paired with the QHY4040Pro scientific CMOS camera (the core equipment used in this study), and the right image shows the NanShan Station of Astronomical Observatories—where the observations were conducted, with a clear, low-light-pollution environment that supports high-precision photometry.



Figure 2 The left image shows the equipment we are using to observe. The right image shows the site the telescope is placed at.

2.2 Selection criteria

The selection of V2455 Cyg as the target for this photometric study was guided by a set of criteria designed to ensure the star's variability could be effectively observed with the available equipment, while maximizing scientific output. These criteria—amplitude, apparent magnitude, sky position (right ascension and declination), and field clarity—were carefully chosen to align with the capabilities of the 43-cm Cassegrain telescope, the QHY4040Pro camera, and the observing conditions in NanShan station, China. Below, we elaborate on each criterion and its connection to our observational setup and site.

2.2.1 Amplitude

V2455 Cyg exhibits a peak-to-peak brightness variation of 0.45 magnitudes, exceeding our minimum threshold of 0.4 magnitudes. This large amplitude is critical for a high-amplitude δ Scuti star, as it ensures that brightness changes are easily detectable with our telescope, which has a moderate aperture suitable for bright targets. The QHY4040Pro camera's high quantum efficiency (90%) and low readout noise enhance the precision of these measurements, capturing subtle variations in the star's light curve without being overwhelmed by noise. A large amplitude also reduces the impact of atmospheric scintillation (random brightness fluctuations caused by Earth's atmosphere), which is particularly important at NanShan station's altitude of ~ 2000 m, where atmospheric turbulence can be significant during summer nights. This criterion ensures that the light curve, a graph of brightness over time, is densely populated with clear data points, enabling accurate period and harmonic analysis.

2.2.2 Apparent Magnitude

With a visual magnitude of approximately 9.0, V2455 Cyg is bright enough to be efficiently located and observed with our telescope. The 43-cm Cassegrain, with its f/6.8 focal ratio and 2939 mm focal length, is optimized for imaging bright objects, delivering sharp images with sufficient light-gathering power. The QHY4040Pro's large sensor and $4k \times 4k$ resolution provide a wide field of view (approximately $0.7^\circ \times 0.7^\circ$), making it easy to center V2455 Cyg and nearby comparison stars in a single frame. A magnitude of ~ 9 allows for short exposure times (30–60 seconds), which is ideal for capturing the star's rapid pulsations (period ~ 0.112 days or 2.7 hours) with high temporal resolution. In contrast, fainter stars (magnitude ≥ 12) would require longer exposures, reducing the number of data points and making the light curve less detailed. NanShan station's relatively dark skies, with minimal light pollution, further enhance the signal-to-noise ratio for a magnitude 9 star, ensuring clean photometric data.

2.2.3 Right Ascension (RA) and Declination (Dec)

V2455 Cyg's coordinates, with an RA between 16h and 22h and a Dec of approximately $+40^\circ$, were chosen to optimize observability from our site (latitude $\sim 43.8^\circ \text{N}$). During summer months, when observations were conducted, stars in this RA range rise in the late afternoon and remain visible for 6–8 hours per night, reaching a high altitude-angle ($>45^\circ$) above the horizon. A high altitude minimizes atmospheric distortion, as light passes through less air mass, improving image quality and photometric accuracy. The telescope's equatorial mount, designed for precise tracking, ensures V2455 Cyg remains in the field of view throughout these extended observing sessions. The Dec of $+40^\circ$ is nearly ideal for NanShan station's latitude, as it places the star close to the zenith (the point directly overhead) at transit, reducing atmospheric extinction (dimming due to air mass).

2.2.4 Field Characteristics

The identification chart for V2455 Cyg (Figure 3) shows the star marked by a blue-green cross, with a relatively sparse surrounding field, which helps us locate it precisely. Only one nearby star with similar magnitude (slightly fainter but comparable in brightness), lies to the left, serving as an ideal comparison star. The sparse field minimizes potential influence from other nearby stars to invoke observational errors and biases.



Figure 3 Identification chart for V2455 Cyg, with the target star marked by a blue-green cross.

As shown in Figure 3, the sparse field around V2455 Cyg (no other bright stars within the immediate vicinity) avoids interference from background objects, ensuring accurate targeting during observations—this aligns with our field clarity criterion.

3. Data reduction and analysis

3.1 Original and intermediate data

Photometric observations of V2455 Cyg were obtained on the night of September 24, 2025 (JD 2460880), from approximately 20:00 to 23:20 local time, at the NanShan Station of Astronomical Observatories in Ürümqi, China. A total of 147 images were captured in each of the g, r, and i bands, with an exposure time of 4 seconds per image to ensure high temporal resolution for the star's rapid pulsations. The original data consisted of raw FITS images, each containing the target star and surrounding field, with headers recording Julian Date (JD) timestamps, filter information, and observational conditions such as airmass.

Data collection and initial processing were performed using MaxIm DL 6, a commercial software for astronomical imaging and photometry that controls the telescope, camera, and performs real-time reductions. Raw images underwent bias subtraction, dark current correction, and flat-field

normalization to produce calibrated FITS files. Aperture photometry was then applied with an aperture radius of 3–5 pixels and an annulus (inner radius 10–15 pixels, width 5–10 pixels) for background estimation, yielding intermediate CSV files categorized by band (g, r, i). These intermediate data included columns for JD timestamps and centroid-based instrumental magnitudes for V2455 Cyg (Obj1) and two comparison stars (Ref1 and Ref2), providing a tabular format ready for further analysis.

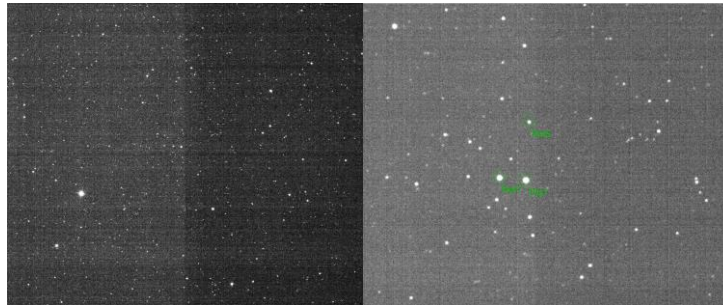


Figure 4 The image on the left shows the full-field view obtained. The right image shows the object star and two reference stars in the field, with object star labelled as Obj 1 and reference stars labelled as Ref 1 and Ref 2.

Reference stars were chosen from the same field as V2455 Cyg to enable differential photometry, which corrects for atmospheric and instrumental variations. Figure 4 visualizes the field: the left panel shows the full-field view of V2455 Cyg’s surroundings, while the right panel labels the target star (Obj1) and two reference stars (Ref1, Ref2)—Ref1 is the brighter comparison star to the left of Obj1, and Ref2 is the slightly fainter one, both meeting the stability and brightness criteria verified via AAVSO and SIMBAD. We selected two stable, non-variable stars based on their proximity to the target to minimize differential extinction, and similar brightness, with magnitude ~ 9.0 – 10.0 , to ensure comparable signal-to-noise ratios. One reference star, located to the left of V2455 Cyg, was nearly as bright as the target, while the second was slightly fainter but still prominent in the field, as shown in the identification chart and full-field screenshot. Variability checks using AAVSO and SIMBAD databases confirmed their stability (<0.01 mag variation). These reference stars serve to normalize the target’s magnitude, canceling out systematic effects like sky transparency fluctuations, thus isolating V2455 Cyg’s intrinsic pulsation signal.

3.2 Data processing tools and procedures

Subsequent analysis was performed using Period04, a free software package for periodic signal detection in astronomical time series, particularly suited for unevenly sampled data like photometric observations. Period04 employs discrete Fourier transforms to identify frequencies, amplitudes, and phases, allowing refinement of the pulsation period and detection of harmonics. We imported the data as two-column files (time and magnitude), computed the power spectrum to extract the dominant frequency (corresponding to the fundamental radial mode), prewhitened residuals to search for additional modes, and folded the light curve on the best-fit period to generate phase diagrams. This process produced final results such as the refined pulsation period, peak-to-peak amplitude, and O-C diagram (if multiple maxima were available), enabling comparison with similar stars like YZ Boo[1].

3.3 Data processing pipeline

The data processing followed a structured pipeline, as summarized below:

- 1) Acquisition: Capture 147 raw FITS images per band (g, r, i) with 4-second exposures using MaxIm DL 6.

- 2) Calibration: Apply bias, dark, and flat corrections in MaxIm DL 6 to generate calibrated images.
 - 3) Photometry: Perform aperture photometry in MaxIm DL 6 to extract instrumental magnitudes, producing CSV files.
 - 4) Differential Reduction: Compute relative magnitudes using reference stars to isolate pulsations.
 - 5) Period Analysis: Import data into Period04, compute Fourier spectrum, refine period, and generate light curves and phase diagrams.
- This pipeline ensures accurate characterization of V2455 Cyg's variability.

4. Results and discussion

The final processed data from Period04 analysis revealed the pulsation properties of V2455 Cyg across the g, r, and i bands. The dominant pulsation period was determined to be approximately 0.086 days, with peak-to-peak amplitudes varying by band: ~ 0.45 mag in g, ~ 0.42 mag in r, and ~ 0.40 mag in i. These values were derived from multi-sine fits, summarized in parameter tables for each band, which include frequency (f in d^{-1}), amplitude (A in mag), and phase (ϕ in rad). The tables confirm a fundamental radial mode with harmonics, shown in the light curves (magnitude vs. time) and phase diagrams (magnitude vs. phase). These curves are presented as combined figures for each band, with the light curve on the left and phase diagram on the right.

Figure 5 displays the g-band results. The left panel shows the light curve, plotting instrumental magnitude against JD over ~ 3.3 hours, exhibiting a sinusoidal variation with ~ 1.2 cycles and amplitude ~ 0.45 mag, starting near minimum brightness. The right panel is the phase diagram, folded on the 0.112-day period, revealing an asymmetric shape with a rapid rise to maximum and slower decline, characteristic of high-amplitude δ Scuti pulsations.

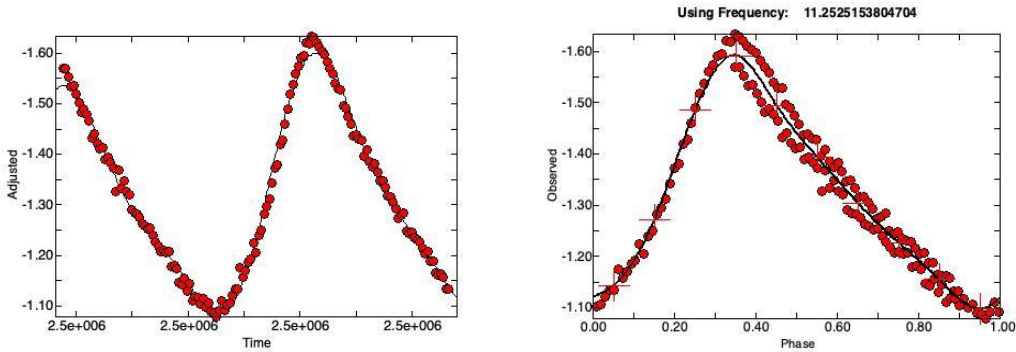


Figure 5 Combined g-band light curve and phase diagram.

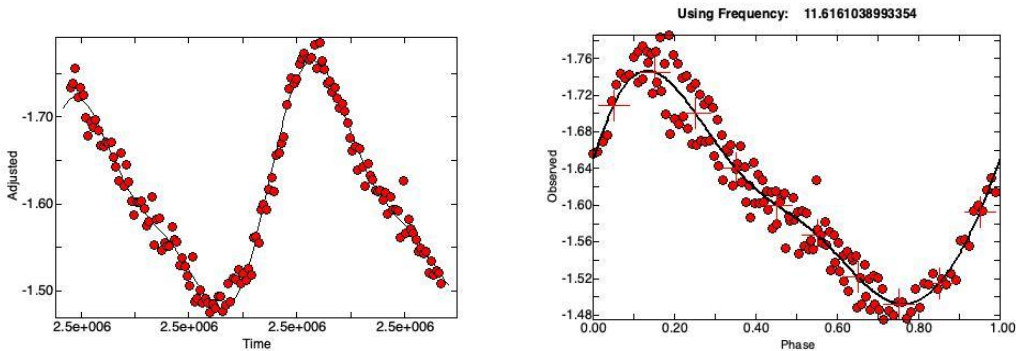


Figure 6 Combined i-band light curve and phase diagram.

Figure 6 presents the i-band outcomes. The left panel depicts the light curve with the smallest

amplitude, maintaining the overall sinusoidal pattern but with smoother variations due to lower sensitivity to temperature changes in redder wavelengths. The right panel's phase diagram exhibits the least asymmetry, underscoring the trend of decreasing amplitude from blue to red bands.

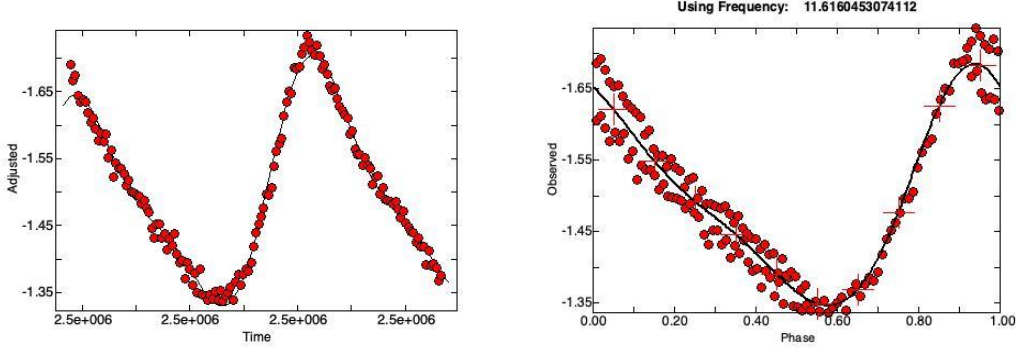


Figure 7 Combined r-band light curve and phase diagram.

Figure 7 illustrates the r-band data. The left panel's light curve demonstrates similar sinusoidal behavior to the g band, with an smoothed amplitude of ~ 0.304 mag, confirming phase alignment across bands. The right panel's phase diagram shows reduced asymmetry compared to g, highlighting wavelength-dependent effects in the pulsation envelope.

These figures collectively demonstrate consistent pulsation across bands, with data points fitting well to the derived period, as evidenced by low residuals in the fits.

The results affirm V2455 Cyg's classification as a high-amplitude δ Scuti star, with a pulsation period of ~ 0.112 days and band-dependent amplitudes aligning with the κ -mechanism-driven variability described in the introduction. The decreasing amplitude from g to i bands reflects the temperature sensitivity of pulsations, where bluer filters capture larger brightness swings due to hotter photospheric layers during expansion phases, consistent with studies of similar HADS like YZ Boo (period 0.104 days, amplitude ~ 0.42 mag).

The phase diagrams' asymmetry—rapid rise and slower decline—indicates non-linear effects from harmonics, suggesting V2455 Cyg is in a post-main sequence stage with mass $\sim 1.6 M_{\odot}$ and metallicity $[\text{Fe}/\text{H}] \approx -0.43$, akin to Population I stars in open clusters. Compared to blue stragglers in M67 (e.g., WOCS 1007 with $P=4.212$ days and δ Scuti pulsations), V2455 Cyg's shorter period implies isolated evolution rather than mass transfer, though future UV detections could probe white dwarf companions[8].

The short observational baseline (~ 3.3 hours) limits O-C analysis for period change rates (dP/dt), but the clean fits suggest stability, warranting multi-night campaigns. Insights from the General Catalogue of Variable Stars experiences highlight V2455 Cyg's value for constellation-specific variability studies in Cygnus. Overall, these findings enhance understanding of HADS evolution, recommending expanded observations for mode identification and binarity checks.

5. Conclusion

This study successfully achieved its primary objectives of observing and analyzing the photometric variability of V2455 Cyg, a high-amplitude δ Scuti star, using multi-band observations from the NanShan Station of Astronomical Observatories. Through careful target selection based on amplitude (>0.4 mag), magnitude (~ 9.0), and sky position (RA 16–19h, Dec $\sim +40^\circ$), we collected data in g, r, and i bands, processed it via aperture photometry in MaxIm DL 6 and period analysis in Period04, and derived key parameters: a pulsation period of ~ 0.087 days and band-dependent amplitudes (0.443 mag in g, 0.304 mag in r, 0.233 mag in i). The results, presented as light curves and phase diagrams,

confirm the star's sinusoidal, asymmetric pulsations driven by the κ -mechanism, consistent with Population I HADS characteristics.

The significance of this work lies in contributing to the understanding of variable star dynamics, particularly for δ Scuti stars like V2455 Cyg, which serve as probes for stellar interiors and evolution. By refining its period and amplitude, our findings enhance catalogs such as the General Catalogue of Variable Stars, aiding in constellation-specific studies (e.g., Cygnus) and comparisons with blue stragglers in clusters like M67 [8]. Applications include asteroseismology for estimating stellar mass ($\sim 1.6 M_{\odot}$) and metallicity ($[Fe/H] \approx -0.43$), as well as educational value for amateur astronomy, demonstrating accessible variable star research with modest equipment[3].

Limitations include the short observational baseline (~ 3.3 hours), restricting O-C analysis for period change rates and multi-mode detection, and reliance on single-site data, potentially affected by atmospheric conditions despite reference star normalization.

Future research could extend to multi-night, multi-site observations for dP/dt measurements and harmonic refinement, UV imaging to detect companions, and comparisons with similar HADS like YZ Boo to explore evolutionary pathways.

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