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First and Comprehensive Study of V0757 Pup : γ–Dor Pulsator in Detached Eclipsing Binary

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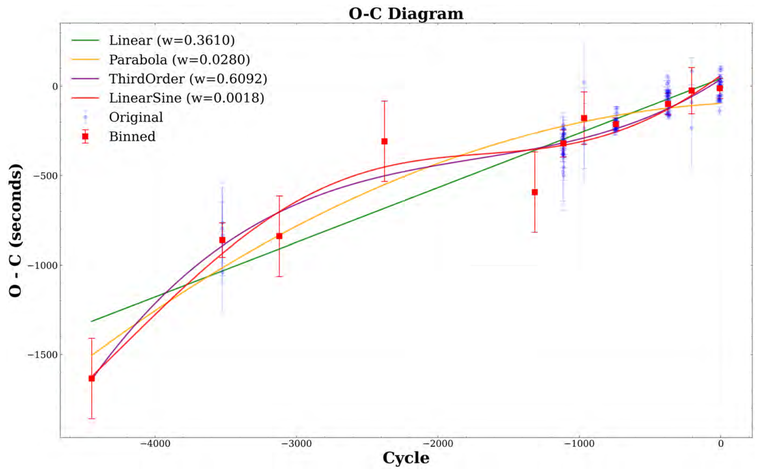


INTRODUCTION

The study specifically of γ-Doradus pulsators in eclipsing binaries, **which quite rare** with total < 50 systems has been fully analyzed, offers a unique opportunity to **combine the geometric precision** of binary analysis with **the internal diagnostics of asteroseismology** as the fitted physical and orbital parameters through binarity analysis can reduces the degeneracy presents in seismic modelling of single stars.

In this work, we presented **the first comprehensive analysis** of V0757 Pup, previously catalogued as eclipsing binary in GCVS, but now **confirmed to also exhibit γ-doradus pulsation**, enabled by high-precision photometry of space telescope. Our dataset combines photometry and spectroscopy. For photometry, we used TESS TPFs (Sectors 7, 34, 61, and 88) and ground-based data from the Thai Robotic Telescopes network (TRT-net). We also conducted spectroscopic observations using the 2.4m Thai National Telescope (TNT) equipped with the MRES instrument, with spectral resolution of 16,000-19,000.

ECLIPSE TIMING VARIATION



From four TESS sectors and ground-based observation using TRT, we obtained a total of 105 time of minima measured using the bisector method. Adding additional data from the OC gateway, we managed to compute an O-C profile spanning more than 24 years in total. We then fitted this O-C profile using four established models following Deeg et al. (2008). To account for uneven data density, the fitting is performed on the seasonal average value of the data and then evaluated using AIC.

The third-order polynomial model provided the highest statistical support, suggesting a slowly varying line-of-sight acceleration, whereas the linear and quadratic models were inconsistent with the period changes observed across individual TESS sectors. A sinusoidal model—potentially indicating a third body or magnetic cycle—was strongly disfavored, though remaining physically plausible.

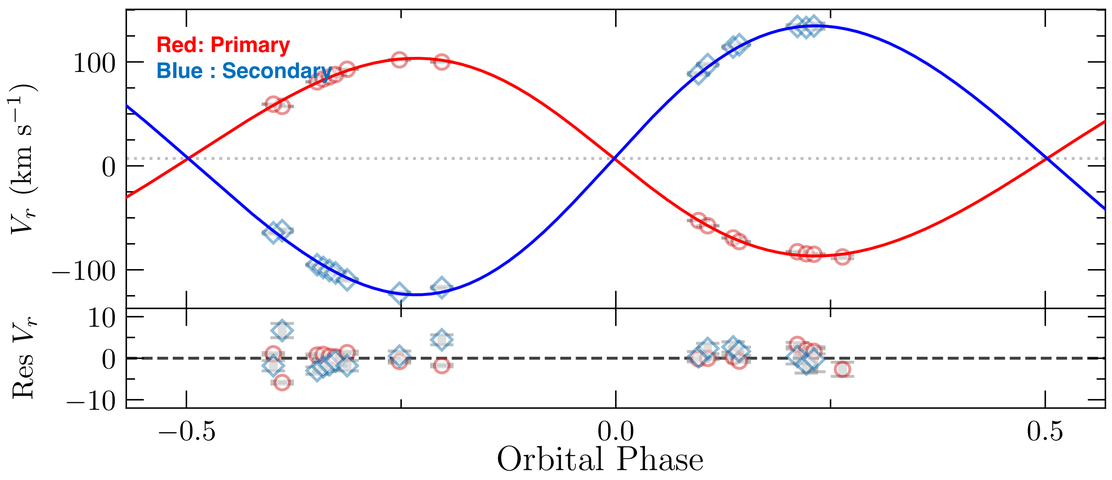
New updated Ephemeris

$$T_{\mathrm{minI}}[\mathrm{BTJD}] = 60717.769303(13) + 1^{d}.9891(64)$$

SPECTROSCOPIC ANALYSIS

RADIAL VELOCITY MEASUREMENT & FITTING

Least Squares Deconvolution (LSD, Donati et al. 1997, MNRAS, 291, 658) was performed to derive radial velocity. Extracted LSD profiles were then further fitted with rotational broadening function to decompose true radial (v_r) and rotational velocity ($v \sin i$) for each primary and secondary components. Radial velocities then were inputted into `PyWD2015` program for the determination of orbital parameter under the assumption rotational-to-orbital velocity ratio of both components to be 1.



INTERSTELLAR REDDENING ESTIMATION

We utilized high-quality MRES spectra to estimate the interstellar extinction towards V0757 Pup by separating the interstellar sodium doublet lines (Na I D) from the stellar components. Using multi-Gaussian fitting across 13 spectra, we measured average equivalent widths of 84.53 ± 19.72 mÅ and 129.42 ± 14.54 mÅ for the D_1 and D_2 lines, respectively. By applying the empirical relationships established by Poznanski et al. (2012, MNRAS, 426, 1465) through Monte Carlo simulations, we derived a consistent reddening parameter of $E(B-V) \approx 0.025$ mag

To validate this result, we compared it with various photometric dust maps. While the standard 2D Galactic Dust Map (Schlafly & Finkbeiner, 2011, ApJ, 737, 103) yielded a significantly higher value of 0.291 mag, applying a distance correction for the system's proximity (~352 pc) reduced this estimate to ~0.05 mag. This corrected value aligns well with our spectroscopic measurement, as well as with values from the TESS Input Catalogue (0.040 mag) and the 3D Dust Mapping project (~0.02 mag, Green et al. 2019, ApJ, 887, 93), confirming a low level of interstellar extinction along the line of sight.

PHOTOMETRIC ANALYSIS

TESS LIGHT CURVE MODELLING

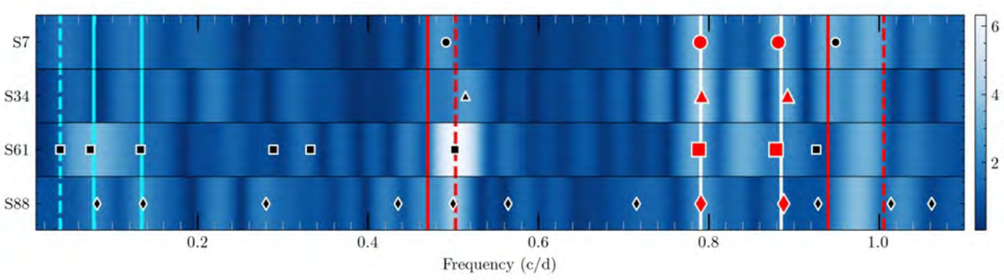
TESS light curve that had been corrected and cleaned against TESS spacecraft movement and were then fitted using `PyWD2015` software (Güzel & Özdarcan, 2020, CAOSP, 50, 535). Our fitted parameter (other than fitted orbital parameters from RV fit) included $e, P, dP/dt, i, T_2, \Omega_1, \Omega_2, L_1$ with T_1 set fixed from our spectroscopic analysis value and L_2 being derived from T_2. Gravity brightening and albedo value used were assuming convective outer layers and limb-darkening coefficients were set to be automatically interpolated. Residuals light curve exhibited consistent patterns not caused by binarity but instead due to pulsation of the primary stars.

LIGHT CURVE RESIDUAL ANALYSIS

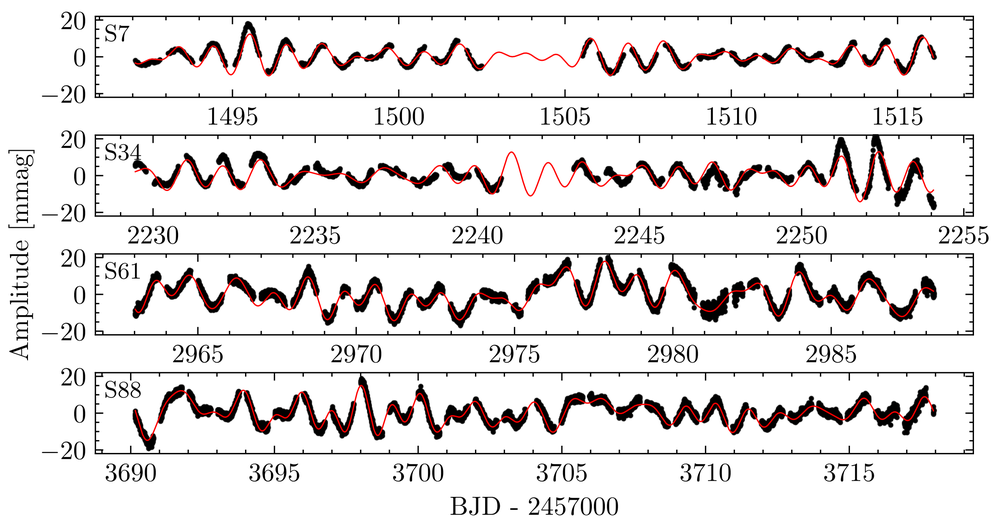
Multimode frequency analysis were done on the residual light curve and by choosing only signals with $\mathrm{SNR} \geq 4$, we were able to obtain multiple frequencies for every single TESS sectors. After the identification of dominant frequencies, there was then a need further categorization to discern original, combination, orbital, rotational or artefact frequencies.

$$f_k = a \cdot f_1 + b \cdot f_2 + c \cdot f_{orb} + d \cdot f_{rot} + e \cdot f_{scat}$$

We identified a total of only 2 original pulsation frequencies ($f_1 = 0.79$ c/d, $Q_1 = 0.68$ and $f_2 = 0.89$ c/d, $Q_2 = 0.61$ while the rest were either combination frequency or due to orbital or rotational modulation. Our derived pulsational constants are consistent with typical *g*-mode pulsations (Grigahcène et al. 2010, ApJL, 713, L192; Uytterhoeven et al. 2011, A&A, 534, A125)

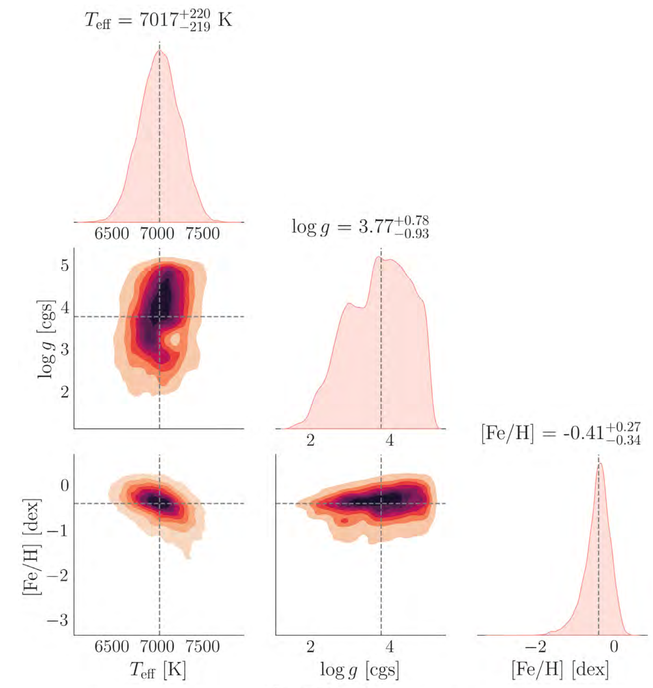


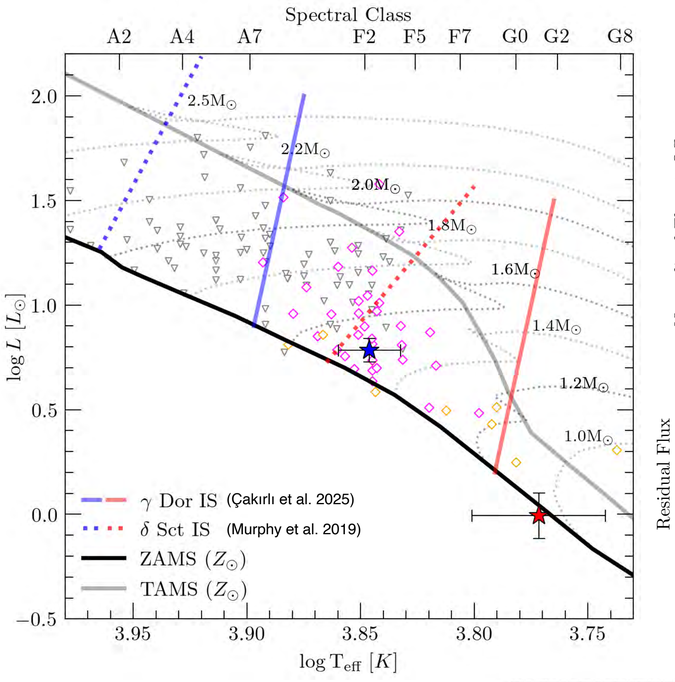
The periodogram of each sector is plotted as a heatmap, with the color map representing amplitudes in mmag. Red-filled points with solid white lines indicate pulsation independent frequencies, while black-filled points represent combination or non-independent frequencies of the V0757 Pup primary component. We have marked the orbital and rotational frequencies and their harmonics with dashed and solid red lines, respectively. Cyan solid and dashed lines represent artefact signals due to scattering around the mid-TESS observational window.

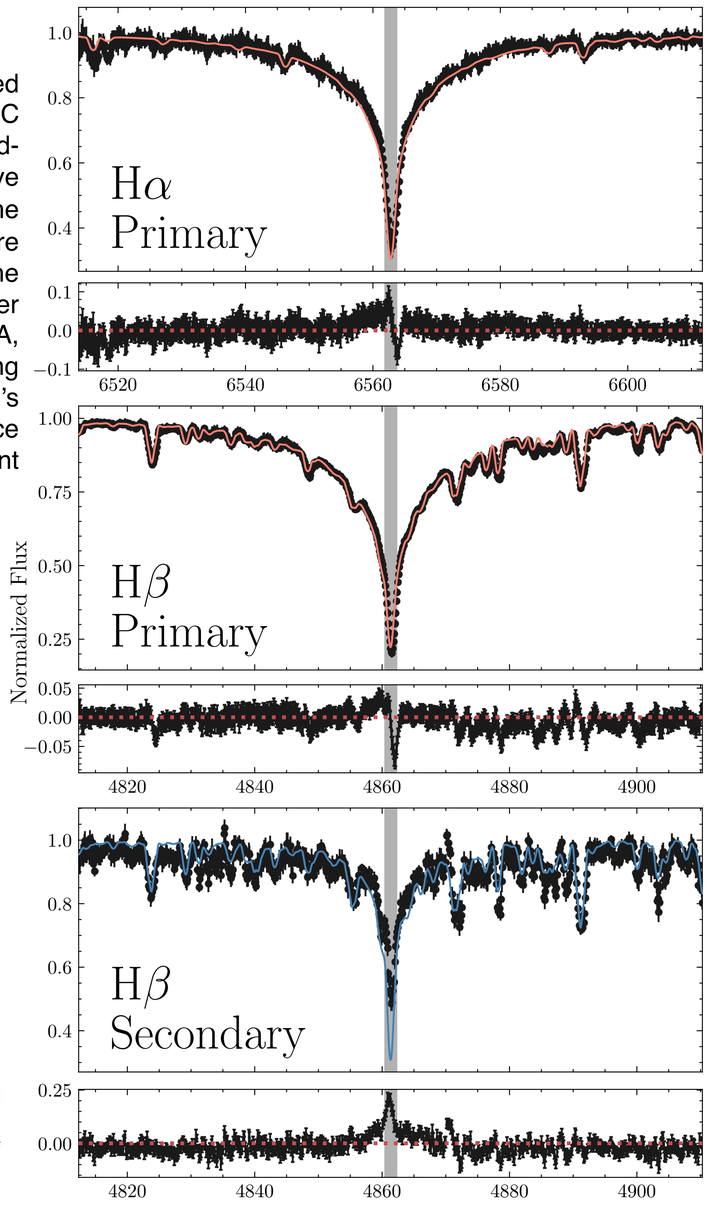


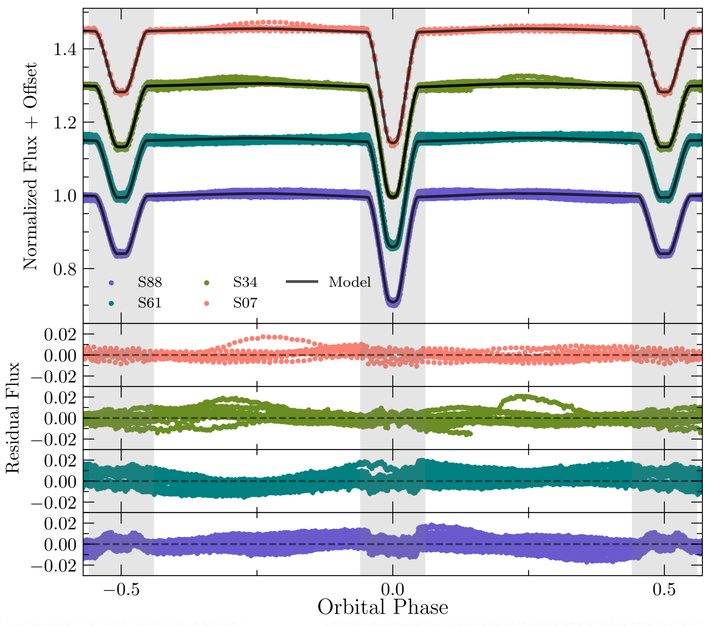
STELLAR PARAMETERS DETERMINATION

For estimate temperature precisely, we performed spectral modelling (`FDBINARY`: Ilijic et al. 2004, ASPC Vol. 318, 111–113), on each component's normalized-disentangled spectra. By utilizing the $T_{\mathrm{eff}} - \log g$ sensitive Balmer H_α and H_β lines' broadened wings and some other additional corrections (such as non-LTE), we were able to determine the atmospheric parameters using the 1D MARCS model atmosphere and the radiative transfer code `TurbospectrumNLTE` (Gerber et al. 2023, A&A, 669, A43) which were then further optimized using MCMC sampling. We obtained effective primary star's temperature to be around 200 K higher and surface gravity 0.3 dex lower compared to previous measurement under single star assumption by TESS and *Gaia* DR3.



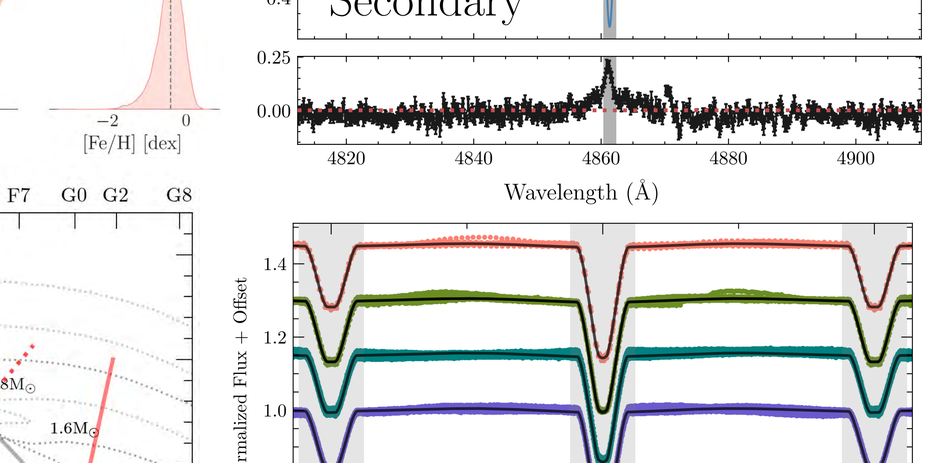






Absolute parameters of V0757 Pup

Parameters [unit]	Primary	Secondary
$T_{\mathrm{eff,\,spec}}$ [K]	7017^{+220}_{-219}	5911^{+399}_{-501}
$T_{\mathrm{eff,\,LC}}$ [K]	(fixed)	5899 ± 18
$T_{\mathrm{eff,\,SED}}$ [K]	6708^{+218}_{-160}	5643^{+451}_{-712}
$\log g_{\mathrm{spec}}$ [cgs]	$3.77^{+0.78}_{-0.93}$	$3.60^{+0.93}_{-1.08}$
$\log g_{\mathrm{phot}}$ [cgs]	4.12 ± 0.02	4.47 ± 0.09
$[\mathrm{Fe/H}]_{\mathrm{spec,\,NLTE}}$ [dex]	$-0.41^{+0.27}_{-0.34}$	$-0.60^{+0.31}_{-0.36}$
$[\mathrm{Fe/H}]_{\mathrm{evol,\,LTE}}$ [dex]	$-0.28^{+0.10}_{-0.10}$	$-0.16^{+0.21}_{-0.23}$
$v \sin i$ [km s^{-1}]	39.8 ± 2.5	29.6 ± 2.8
M [$M_\odot$]	1.341 ± 0.025	0.986 ± 0.033
R [$R_\odot$]	1.674 ± 0.026	0.952 ± 0.096
L [$L_\odot$]	6.09 ± 0.79	0.98 ± 0.25
M_{bol} [mag]	2.79 ± 0.74	4.77 ± 1.65
log Age [yr]	$9.32^{+0.03}_{-0.02}$	



EVOLUTIONARY STATUS

Based on simple single star assumed `MESA` evolutionary tracks, V0757 Pup is determined to be a main-sequence system with an estimated age of ~2.0 Gyr, despite a minor metallicity offset likely caused by current spectral data limitations. The primary component is evolving toward the Red Giant Branch and is predicted to fill its Roche lobe in ~1 Gyr. At that stage, the system will undergo a major transformation from a detached to a semi-detached binary as mass transfer begins, and the primary star will exit the γ Doradus instability strip.

ACKNOWLEDGEMENT

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