MODERN ASTRONOMY: FROM THE EARLY UNIVERSE TO EXOPLANETS AND BLACK HOLES

Frequency analysis of Gamma Doradus variables observed by TESS

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Abstract. We present a frequency analysis of γ Dor variables based on the TESS photometric data: among 35 objects, period spacing patterns were found in five stars TIC 235680293, TIC 235682463, TIC 416401558, TIC 232620739 and TIC 406927322. We estimate their near-core rotation and make an assumption about the pulsation modes. Also three objects TIC 75784209, TIC 318837103, and TIC 309662501 show pulsations in p-modes and g-modes simultaneously, and we identify them as δ Sct–γ Dor.

Keywords: asteroseismology; stars: oscillations (including pulsations), rotation

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1 Introduction

Asteroseismology is the field of astronomy that studies the internal structure of pulsating stars by analyzing their frequency spectrum. Measuring pulsation frequencies requires high-precision photometry, and the data must be continuous in time. The launch of space missions such as Convection Rotation and Planetary Transits (Auvergne et al. 2009), BRIght Target Explorer (Weiss et al. 2014), Kepler (Borucki et al. 2010) and Transiting Exoplanet Survey Satellite (Ricker et al. 2015) made a significant contribution to the development of asteroseismology.

Gamma Doradus variables (γ Dor) are stars that exhibit pulsations in gravitational modes (g-modes) or Rossby modes (r-modes). They are main sequence objects of late A or early F spectral class with the masses of $1.4 < M < 1.9\,M_\odot$ and the pulsation periods from 0.3 days to 4 days (Kaye et al. 1999); g-modes and r-modes are most sensitive to internal stellar structure, so studying γ Dor stars allows us to probe their near-core regions. An asteroseismological instrument such as the period spacing patterns (ΔP–P relation) allows us to identify pulsation modes and measure the near-core rotation rate.

2 Search for period spacing patterns

To search for period spacing patterns, 35 γ Dor stars observed by TESS telescope in more than 20 sectors were selected. This made it possible to achieve high frequency resolution, since the distance between the pulsation periods can reach $0.001\,\mathrm{d}^{-1}$.

The frequencies were determined using the `Period04` (Deeming 1975; Kurtz 1985), which implements two methods: the nonlinear least squares method and the discrete Fourier transform for inhomogeneous time series. As a result, period spacing patterns are observed in five objects: TIC 235680293, TIC 235682463, TIC 416401558, TIC 232620739 and TIC 406927322. All five objects were identified by Skarka et al. (2022) as γ Dor stars. The slope (Σ) of the ΔP–P is directly proportional to the near-core rotation rate. TIC 235680293, TIC 235682463 and TIC 416401558 demonstrate a downward trend (prograde modes; $m > 0$; e.g. Fig. 1) with $\Sigma = -0.048 \pm 0.002$; -0.0264 ± 0.0007 and -0.0368 ± 0.0006 respectively, while TIC 232620739 and TIC 406927322 demonstrate an upward trend (retrograde modes; $m < 0$; e.g., Fig. 2) with $\Sigma = 0.0657 \pm 0.0005$ and 0.067 ± 0.001 respectively. Using the empirical calibration from Li et al. (2019), we were able to estimate the near-core rotation rates and identify the pulsation modes (Table 1).

Also we found three objects TIC 75784209, TIC 318837103, and TIC 309662501, which have frequencies in the p-mode pulsation region ($P < 0.25$ days) as well—therefore we identified them as δ Sct–γ Dor hybrids. Such objects are of great interest for asteroseismology, as they allow us to study both the inner and outer regions of the star.

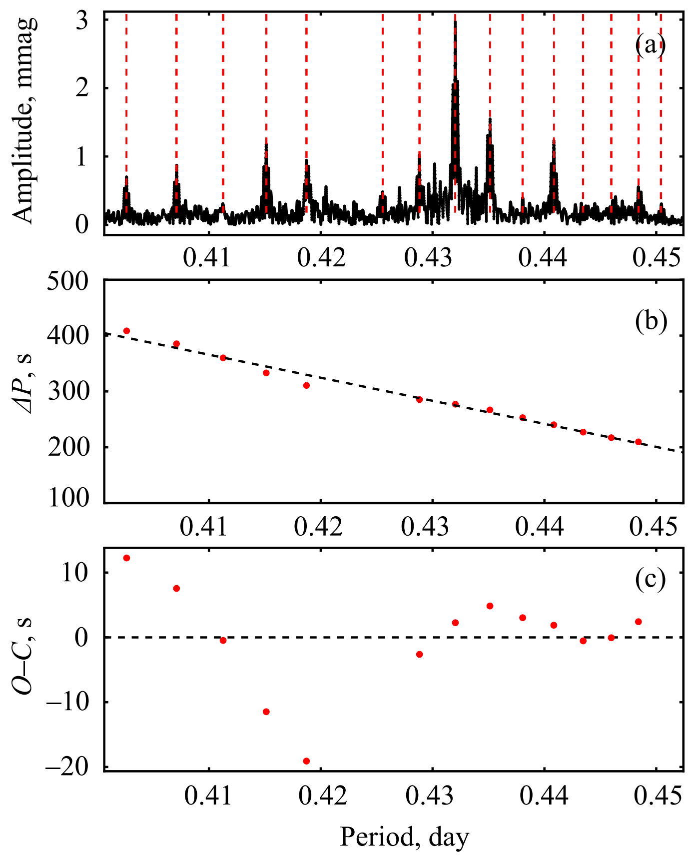

Fig. 1. The period spacing patterns of TIC 235680293. Panel (a): the amplitude spectrum (black line) and peaks with $S/N > 4$ (dashed lines). Panel (b): the period spacing patterns (red dots) and linear approximation with the slope $\Sigma = -0.048 \pm 0.002$ (dashed line). Panel (c): $O-C$ diagram.

3 Summary

Among 35 γ Dor stars with more than 20 TESS observation sectors, we found period spacing patterns in five objects: TIC 232620739, TIC 235680293, TIC 235682463, TIC 406927322, TIC 416401558, the period spacing patterns were found and their slope Σ, $\langle P \rangle$, $\langle \Delta P \rangle$ was determined—the values that allowed us to identify the pulsation modes and the near-core rotation rate (see Table 1), relying on the empirical cal-

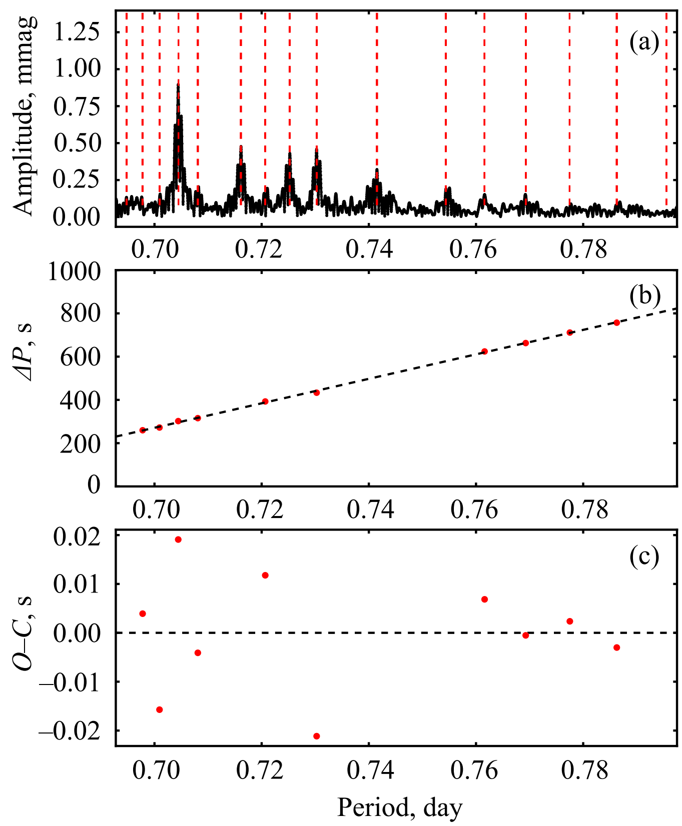

Fig. 2. Same as Fig. 1, but for TIC 232620739. The slope $\Sigma = -0.0657 \pm 0.0005$.

Table 1. The results of the period spacing patterns analysis for five objects. Σ represents the slope of ΔP–P relation; $\langle P \rangle$ is average period; $\langle \Delta P \rangle$ denotes the average period spacing; l is angular degree (only for g-modes); k for r-modes; m is azimuthal order; $f_{\rm rot}$ represents near-core rotation rate.

TIC number	Σ	$\langle P \rangle$ day	$\langle \Delta P \rangle$ s	l	k	m	$f_{\rm rot}$ day^{-1}
232620739	0.0657(5)	0.7	470		−2	−1	1.7
235680293	−0.048(2)	0.4	290	1		1	1.2
235682463	−0.0264(7)	0.8	890	1		1	0.5
406927322	0.067(1)	0.7	370		−2	−1	1.8
416401558	−0.0368(6)	0.5	260	1		1	0.9

ibration calculated by Li et al. (2019). Three objects TIC 75784209, TIC 309662501, TIC 318837103 exhibit pulsations in different modes: p-modes ($P < 0.25$ days) and g-modes. They are identified as δ Sct–γ Dor hybrids.

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