Asteroseismology of hot pre-white dwarf stars observed with TESS: discovery of new GW Vir stars

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Abstract

We present the discovery of two new GW Vir stars, TIC 333432673 and TIC 095332541. We have derived atmospheric parameters for both stars by fitting synthetic spectra to the newly obtained low to intermediate resolution SOAR/GOODMAN for TIC 333432673 and INT/IDS for TIC 095332541 spectra. The determined atmospheric parameters show that TIC 333432673 and TIC 095332541 are identical in terms of surface temperature and surface gravity ($T_{\rm eff} = 120,000 \pm 10,000$ K and $\log g = 7.5 \pm 0.5$) and they are only different regarding the surface C and He abundance. The analysis of the TESS light curves of TIC 333432673 and TIC 095332541 reveals the presence of several oscillations with periods ranging from 350 to 500 s associated to typical gravity (g)-modes. We searched for patterns of uniform period spacings in order to constrain the stellar mass of the stars, and employed the individual observed periods to search for a representative seismological model. Using the high-quality data collected by the *TESS* space mission and follow-up spectroscopy, we have been able to discover and characterize two new GW Vir stars.

Spectroscopic analysis

For the spectral analysis, we used a grid of line-blanketed non-local thermodynamic equilibrium (non-LTE) model atmospheres consisting of H, He, and C as introduced by [5]. The spectra of both stars exhibit lines exclusively from He II and C IV. Oxygen, which is usually the most abundant element after He and C in PG1159 stars, and nitrogen, which is found as trace element in some PG1159 stars, might be detectable in spectra of better resolution and signal-to-noise ratio. There are no hints of the presence of hydrogen in the spectra, which refers the absence of a nebulae and therefore these two GW Vir stars are classified as DOV stars. The model fits are displayed in Fig. 1.

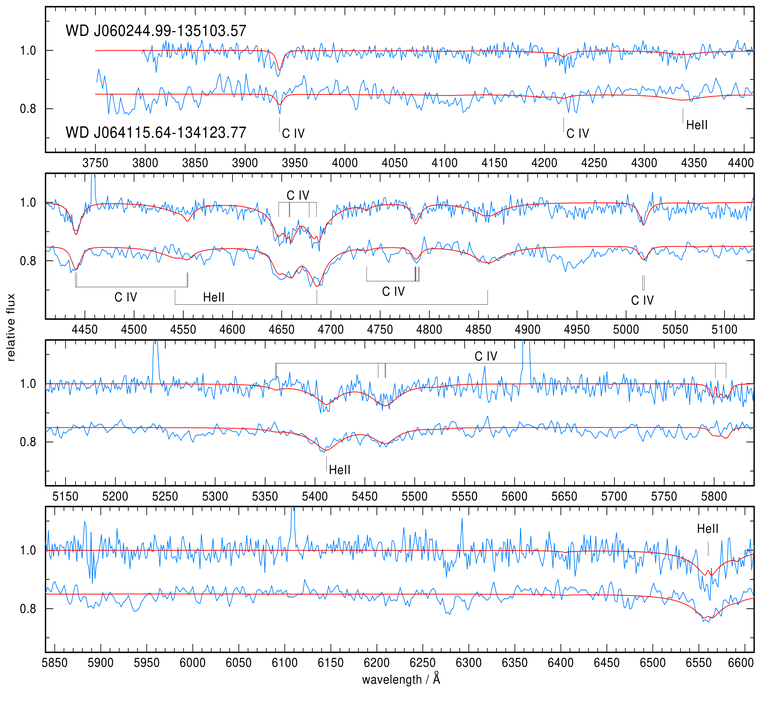

Figure 1: Optical spectra of the two new GW Vir stars. Overplotted are the best-fit models. Identifications of He II and C IV lines are marked.

Asteroseismology

In the asymptotic limit of stellar pulsations, i.e., for large radial orders ($k \gg \ell$), g modes of consecutive radial order in WDs and pre-WDs are approximately uniformly spaced in period [3]. The asymptotic period spacing is given by $\Delta\Pi_\ell^a = \Pi_0/\sqrt{\ell(\ell+1)}$, $\Delta\Pi_\ell^a$, Π_0 being a constant defined as $\Pi_0 = 2\pi^2\left[\int_{r_1}^{r_2}\frac{N}{r}dr\right]^{-1}$, where N is the Brunt-Väisälä frequency [4]. The pulsation spectrum is displayed in units of period in Fig. 2 with the expected locations of the $\ell = 1$ modes for even period spacing indicated.

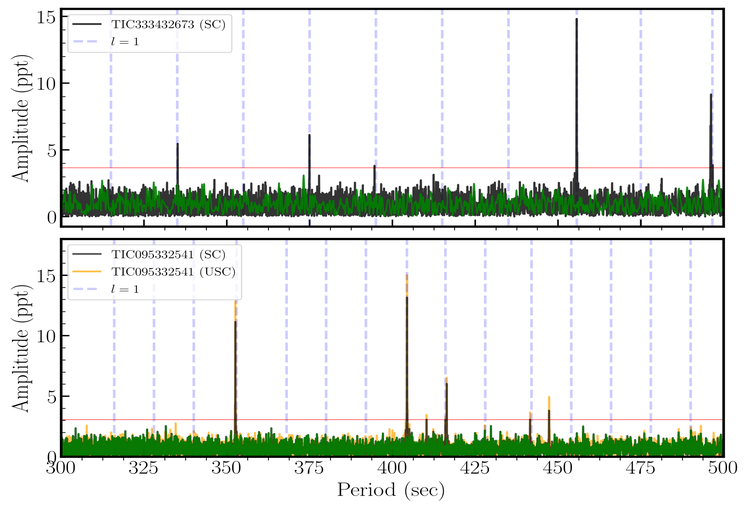

Figure 2: Pulsation spectrum in period space with the dotted vertical lines indicating the expected locations of $\ell = 1$ modes from the asymptotic pulsation theory.

A set of post-AGB evolutionary sequences computed with the LPCODE evolutionary code [1] were followed through the very late thermal pulse (VLTP) and the resulting born-again episode that give rise to the H-deficient, He-, C- and O-rich composition characteristic of PG 1159 stars. In Fig. 3, we compared the period spacing of ~ 20.19 s with the $\overline{\Delta\Pi_k}$ in terms of $T_{\rm eff}$ for all the masses.

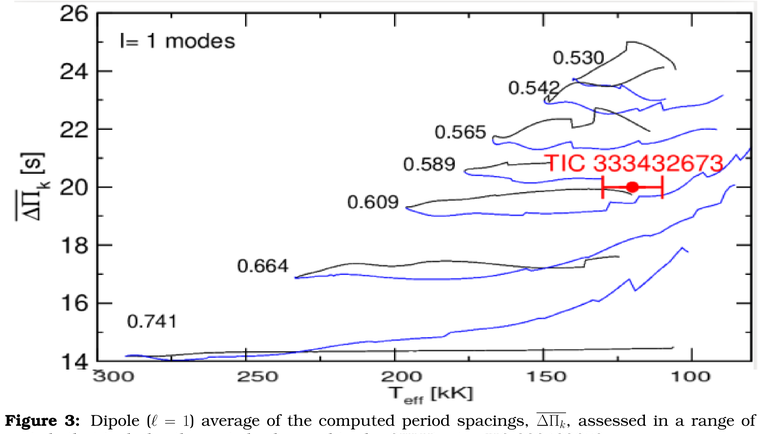

Figure 3: Dipole ($\ell = 1$) average of the computed period spacings, $\overline{\Delta\Pi_k}$, assessed in a range of periods that includes the periods observed in the GW Vir star TIC 333432673.

Results and conclusions

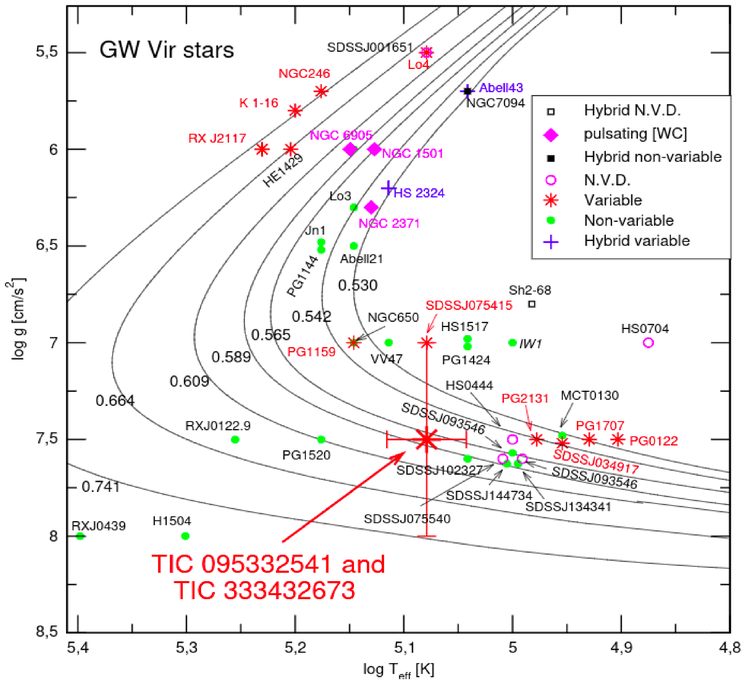

Figure 4: The already known variable and non-variable PG 1159 stars and variable [WCE] stars from [2]. The location of the two new GW Vir stars TIC 333432673 and TIC 095332541 is emphasized with a large red star symbol with error bars.

In Fig. 4 we show the evolutionary tracks of PG 1159 stars in the $\log T_{\rm eff}$ vs. $\log g$ plane. We have carried out an asteroseismological investigation on both GW Vir stars employing fully evolutionary models of PG 1159 stars.

- On the basis of PG 1159 evolutionary tracks, we derived a spectroscopic mass of $M_\star = 0.58^{+0.16}_{-0.08}\,M_\odot$ for both stars.
- Our asteroseismological analysis of TIC 333432673 allowed us to find a constant period spacing compatible with a stellar mass $M_\star \sim 0.60 - 0.61\,M_\odot$, and an asteroseismological model for this star with a stellar mass $M_\star = 0.589 \pm 0.020\,M_\odot$.
- Unfortunately, we have not been able to put constraints on the stellar mass and distance of TIC 095332541 with our asteroseismological tools.

References

[1] L. G. Althaus, A. M. Serenelli, J. A. Panei, A. H. Córsico, E. García-Berro, and C. G. Scóccola. The formation and evolution of hydrogen-deficient post-AGB white dwarfs: The emerging chemical profile and the expectations for the PG 1159-DB-DQ evolutionary connection. *A&A*, 435:631–648, May 2005.

[2] Alejandro H. Córsico, Leandro G. Althaus, Marcelo M. Miller Bertolami, and S. O. Kepler. Pulsating white dwarfs: new insights. *The Astronomy and Astrophysics Review*, 27(1), Sep 2019.

[3] M. Tassoul. Asymptotic approximations for stellar nonradial pulsations. *ApJS*, 43:469–490, August 1980.

[4] W. Unno, Y. Osaki, H. Ando, H. Saio, and H. Shibahashi. *Nonradial oscillations of stars*. 1989.

[5] K. Werner, T. Rauch, and S. O. Kepler. New hydrogen-deficient (pre-) white dwarfs in the Sloan Digital Sky Survey Data Release 10. *A&A*, 564:A53, April 2014.