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Discovery of 25 new DAVs

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Abstract. White dwarf stars are the end point of evolution of 95-98% of all stars. As they cool down, they pass through three instability strips: DOVs (200 000-70 000 K), DBVs (26 000-22 000K), and DAVs (12 300-10 800K). The study of pulsating white dwarf stars allows us to constrain their internal structures, as each periodicity is an independent measurement of its interior. We report the discovery of 25 new DAVs, using the telescopes at OPD, the SOAR telescope, and McDonald observatory. We selected our candidates from SDSS and SPY, based on their effective temperature from optical spectra. Being able to observe stars at larger distances, we can probe a different population of WDs and thus progenitors. In our discovery light curves, we identified between 2 and 9 periodicities, ranging from 250 to 1200s. Follow up observations of these new variables will allow us to study their internal structure.

Key words. Stars: white dwarfs – Stars: variables – Stars: oscillations

1. Introduction

As white dwarf stars cool, they pass through three instability strips, depending on their temperatures, atmospheric composition, and the element that drives pulsation: C and/or O (DOVs), He (DBVs), or H (DAVs or ZZ Cetis). Observationally, the DA instability strip ranges in effective temperature ($T_{\rm eff}$) from 12 270 to 10 850 K (Bergeron et al. 2004, 2005, Mukadam et al. 2004). While Bergeron's instability strip is pure, Mukadam et al. (2004) and Mullally et al. (2005) did not detected evidence of variability from a considerable number of stars inside the instability strip, questioning its purity, but their effective temperatures are based on lower signal–to–noise spectra than Bergeron's.

As pulsations are global, the asteroseismological studies of white dwarf stars allows us to constrain their internal structure, as each periodicity is an independent measurement of their interior, to measure the stellar mass (Winget et al. 1990, Bradley & Winget 1994) and even to constrain the value of the $C^{12}(\alpha,\gamma)O^{16}$ cross section (e.g. Metcalfe 2003), which can only be measured in a terrestrial laboratory at energy levels eight orders of magnitude higher. Furthermore, the cooling time scales of DAVs (Kepler et al. 2000, Mukadam et al. 2003) can be used to calibrate the age of the galactic morphological components (Winget et al. 1987, Hansen et al. 2002), by observing field stars, open and globular clusters up to magnitudes

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that include the turnoff of the white dwarf cooling sequence.

Pulsating white dwarf stars are also important to study the phenomena of physics at high densities, like crystallization (Winget et al. 1997, Montgomery et al. 2003, Metcalfe 2004). We can also test, through pulsating white dwarf stars, neutrino cooling (Kawaler et al. 1986, Winget et al. 2004) and axion emission models (Córsico et al. 2001, Kepler 2004, Kim et al. 2005). Both particles can be created in the white dwarf cores and consequently, have to be taken into account in the cooling process.

Quasar surveys, like SDSS (Sloan Digital Sky Survey), HE (Hamburg ESO) and 2dF (Two Degree Field), are increasing the number of spectroscopically identified white dwarf stars, as quasars and white dwarf stars have similar colors. As these new white dwarf stars are fainter than those previously known, their study will sample stars from the thin and thick disk, and a wider range of metallicity.

Mukadam et al. (2004) show that at least 90% of SDSS candidates with $12\,000 \geq T_{\rm eff} \geq 11\,000$ K are pulsators. They selected the candidates from $T_{\rm eff}$ derived from fitting the total optical spectra, not only the H lines, as shown by Kleinman et al. (2004). Mukadam et al. (2004) and Mullally et al. (2005) used the 2.1-meter telescope at McDonald Observatory with a prime focus camera to discovered 46 new ZZ Cetis. This is the same criterion we used to select our candidates from SDSS.

The progenitors of the more distant white dwarf stars may have different metallicity and the white dwarf stars may be distinct from the close by counterparts. Considering that white dwarf stars are the progenitors of SN Ia, the study of their chemical composition, not only in the atmosphere but also in the inner structure, is crucial if we are to use SN Ia as standard candles.

In this paper, we report the discovery of twenty-five new pulsators, from our candidate list from SDSS and HE. The future seismological studies of these new pulsators will allow us to constrain the stellar evolution of different populations.

2. Observations and reductions

We observed our candidates at Observatório Pico dos Dias, LNA, in Brazil, using a 1.6 m and 0.6 m telescope, at the 4.1 m SOAR telescope, in Chile, and at the 2.1 m telescope at McDonald observatory, in U.S.A., with the prime focus Argos camera. At the 1.6 m and 2.1 m telescopes, we used a frame transfer CCD, while with the others, we had CCDs with readout times from 6 to 7.5 s.

We use time series photometry to look for variability, comparing the targets with the other stars in the same field, in order to compensate for sky fluctuations and thin cirrus.

For extractions, we used the IRAF scripts hsp, developed by Antonio Kanaan, based on weighted aperture photometry. In our reduction generated light curves from 1 to 3 times the seeing. All light curves are Fourier transformed and we select the photometric aperture by choosing either the lowest noise level or the highest SNR in the Fourier transform.

The criterion to determine which peaks are real in the discrete FT is to adopt an amplitude limit so that a peak exceeding it due to noise has only a probability 1/1000 (false alarm probability).

We looked for pulsations in the known range of ZZ Ceti, from 70s to 1500s, which are listed in Table 1. The uncertainties in frequency are, on average, 123μHz, equivalent to 1s at P$\sim$100s.

3. New variables

In Table 1, we list $T_{\rm eff}$ and $\log g$ derived from the optical spectra, as well as their main periodicity.

Combining these twenty-five new ZZ Cetis with the previously known pulsators, we see a well defined instability strip in Fig 1. The triangles (SDSS candidates only) and circles represent the previously known pulsators and the squares, the new ones. It is important to point out that this is not an homogeneous sample, as the previous determinations of $T_{\rm eff}$ and $\log g$ were obtained with different model grids (e.g. Bergeron et al. 2004, Koester & Allard 2000), and different methods – line profile vs.

Table 1. Properties of new ZZ Cetis

Name	g	$T_{\rm eff}$ (K)	$\log g$	Main Periodicity
HE 0031-5525	15.94	11476±31	7.65±0.018	330 s@2.5 mma
WD 0249-0100	19.08	11057±109	8.31±0.095	1045 s@10.9 mma
WD 0825+0329	17.48	11801±105	8.33±0.044	481 s@4.5 mma
WD 0843+0431	17.93	11250±63	8.18±0.044	373 s@10.43 mma
WD 0851+0605	17.08	11306±48	8.11 ±0.029	326 s@22.4 mma
WD 0911+0310	18.41	11634±126	8.11±0.084	347 s@17.4 mma
WD 0917+0926	18.09	11341±64	8.15±0.044	289 s@16.1 mma
WD 1106+0115	18.37	10990±62	8.09±0.049	822 s@12.2 mma
WD 1216+0922	18.56	11293±109	8.29±0.078	823s@45.2 mma
WD 1218+0042	18.71	11123±93	8.16±0.068	258 s@16 mma
WD 1222-0243	16.74	11398±44	8.35±0.026	396 s@22.0 mma
WD 1255+0211	19.09	11385±154	8.16±0.106	897 s@31.7 mma
WD 1257+0124	18.65	11523±158	8.36±0.087	906 @47.5 mma
WD 1301+0107	16.30	11099±34	8.11±0.023	879 s@13 mma
WD 1310-0159	17.67	10992±65	7.92±0.049	280 s@6.6 mma
WD 1337+0104	18.57	11533±156	8.55±0.085	797 s@10.2 mma
WD 1408+0445	17.93	10938±64	8.06±0.044	849 s@24.3 mma
WD 1533-0206	16.62	11354±38	8.20±0.024	261 s@5.3 mma
WD 1618-0023	19.26	10855±164	8.16±0.12	644 s@5.5 mma
WD 1641+3521	19.04	11230±158	8.43±0.099	773 s@30.9 mma
WD 2128-0007	17.97	11439±101	8.29±0.071	302 s@17.1 mma
WD 2135-0743	18.59	11188±117	7.67±0.089	565 s@49.8 mma
WD 2153-0731	18.45	11929±127	8.07±0.056	210 s@5.5 mma
WD 2231+1346	18.63	11084±102	7.95±0.065	627 s@26.3 mma
WD 2307-0847	18.83	11055±107	8.19±0.087	1212 s@25.6 mma

whole spectra fitting (Kleinman et al. 2004), but the instability strip is restricted to a narrow range of temperature 12 270 K $\geq T_{\rm eff} \geq$ 10 850 K. There is one cooler star from Mukadam et al. (2004), around 10 300 K, which is not in this range. Even though this star is cooler than red edge of the instability strip, according to Mukadam et al., its detected periods indicate it as a hot DAV. Our fit of the SDSS spectrum line profiles result in a temperature of 10 686±100 K and using the whole spectrum, we obtained 10 866±100 K, placing the star in the red edge of the instability strip.

The temperatures derived from SDSS optical spectra have external uncertainties larger than 300 K, as demonstrated from their duplicate spectra. In this sense, we conclude our observations are still consistent with a pure instability strip, but it does not exclude possible contaminations, as the strip covers only ∼ 1000 K. To solve this problem, we need spectra with SNR≥50 to achieve $\sigma_{T_{eff}} \leq 200$ K and to re-observe the stars which do not show variability in the literature to decrease their detection limits to below 4mma.

Our results are mapping not only the blue edge, but also the red edge of the instability strip. We discovered a pulsating star, J161837.2-002302.7, with $T_{\rm eff}$ and periodicities characteristics of the red edge, even though it is a low amplitude pulsator. This star will be extremely important to study why the ZZ Cetis will stop pulsate at $T_{\rm eff} \sim 10850$.

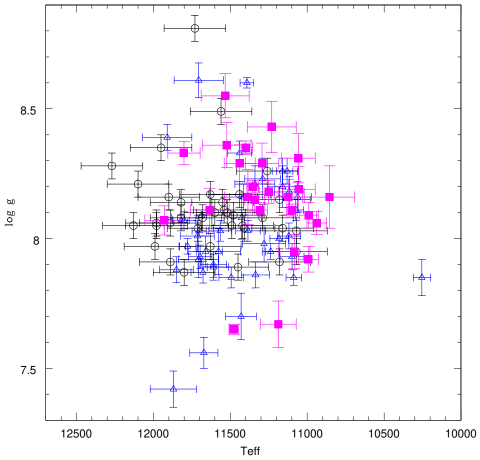

Fig. 1. The updated instability strip including all 100 known ZZ Cetis. The open circles are the stars described in Bergeron et al. (2004), the triangles are the pulsators discovered by Mukadam et al. (2004) and Mullally et al. (2005), and the squares are the twenty-fine new ZZ Cetis presented in this paper.

4. Conclusions

We report the discovery of twenty-five new pulsating DA stars, totaling now 100 known variables, all in the narrow range of temperature 12 270 K ≥ $T_{\rm eff}$ ≥ 10 850 K corresponding to the partial ionization of hydrogen and development of a sub-surface convection zone.

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