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New Pulsating ZZ Ceti Stars

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Abstract. Over the last four years the number of known pulsating DA white dwarf stars increased from 32 to a total of 147; 87 are white dwarf stars identified by the Sloan Digital Sky Survey and selected from fits of synthetic spectra from model atmospheres to the $S/N < 30$ optical spectra. With time series photometric observations at the SOAR 4.1m telescope, we found 42 new pulsators, extending the instability strip in terms of effective temperature and surface gravity, but mainly in terms of very low amplitude pulsators. The discovery of 1.5 mma pulsators raises the necessity to re-observe all stars previously classified as non-pulsators close to or inside the instability strip, as their detection limits, in general, were above 3 mma. The real extent of the instability strip and its possible contamination with non-pulsators, specially at the borders, are still open questions.

1. Introduction

White dwarfs with hydrogen atmospheres comprise at least 83% of all known spectroscopically identified white dwarf stars. Observationally, they start to pulsate when they cool down to around $T_{\text{eff}} \simeq 12300$ K, defining the ZZ Ceti instability strip. The position of this strip has a small dependency on the stellar mass, such that more massive stars start to pulsate at an effective temperature slightly higher than less massive stars. According to the current best models, pulsations start when the hydrogen partial ionization zone at the bottom of a very shallow convection zone reaches a thermal timescale around 100 s. The partial ionization zone has higher opacity than the hotter ionized state, hindering the energy transport and the star starts to pulsate in non-radial g-modes. At the blue edge of the instability strip, we observe low amplitude pulsating stars with periods close to the 100 s thermal timescale and showing fractional amplitudes of the order of a few mili-modulation-amplitude (mma) (Winget and Kepler 2008). Theory predicts that, as the convection zones deepens with the subsequent cooling, the thermal timescale increases and the pulsation periods and average pulsation amplitude also increases. This is in agreement with the observations of cooler stars, that pulsate with higher amplitudes and longer periods. After cooling by $\simeq 1500$ K, the models show that the surface convection layer becomes so large that pulsations subside. Mukadam et al. (2004b, 2006) and Castanheira et al. (2007) have detected stars with small amplitudes close to the red edge of the instability strip, sampling the stage when stars are stopping to pulsate.

2. SDSS Variables

In 2004 Kleinman (2004) started to identify a few thousand new white dwarf stars with the Sloan Digital Sky Survey (SDSS) and to measure their effective temperature and surface gravity by

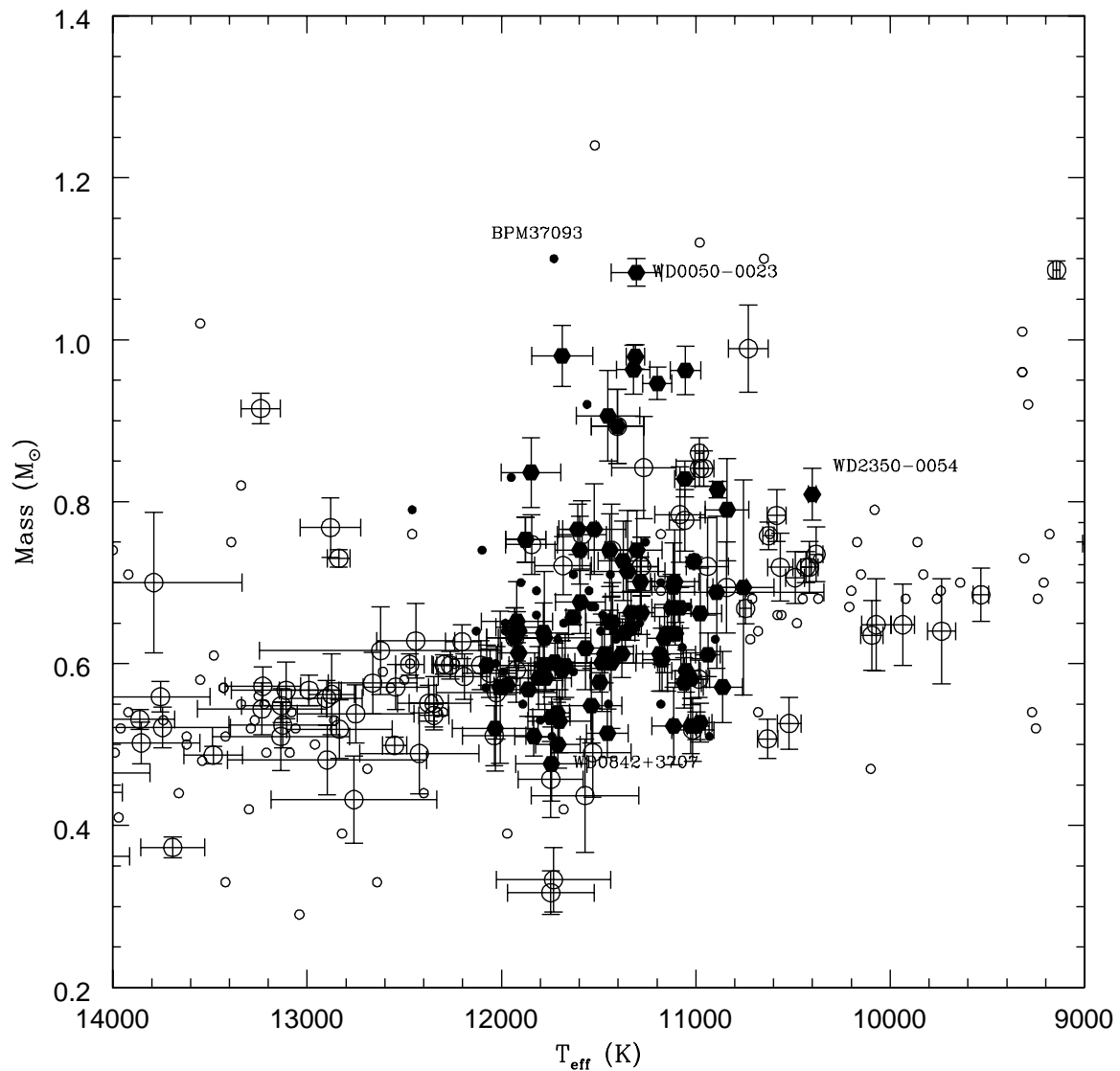


Figure 1. The ZZ Ceti instability strip showing variables as filled circles and non-variables as open circles. The cooler variable SDSS J235040.74-005430.8, with $T_{\text{eff}} = 10\,370 \pm 20$ K from two independent spectra, remains a challenge to explain. The smaller points are from the bright sample of Gianninas et al (2006). Most of the stars for which previous studies did not detect pulsations had limits around 5 mma, but our discovery of pulsators with amplitudes as low as 1.5 mma requires they all be re-observed to lower the detection limits.

fitting the signal-to-noise rate ≤ 30 optical spectra to synthetic spectra calculated from model atmospheres by Koester (2008). Mukadam (2004a), Mullally (2005), Kepler(2005), Castanheira et al (2006), (2007) selected the stars with effective temperature close to the ZZ Ceti instability strip from these SDSS candidates and obtained time series photometry using CCD cameras on the 2.1 m telescope at McDonald Observatory, the 1.6 m telescope at Observatório Pico dos Dias, and the 4.1 m telescope SOAR, to search for variability. They found that that most stars with temperatures in the range $12\,300\text{ K} \leq T_{\text{eff}} \leq 10800\text{ K}$ do pulsate. Some of the new pulsators show pulsations with fractional amplitudes of only 1.5 mma.

3. Results and Discussion

We have continued this search with the 4.1 m telescope SOAR using white dwarf candidates selected by Scot Kleinman and Atsuko Nitta from the subsequent SDSS data releases (Eisenstein et al 2006, Adelman-McCarthy 2007, 2008) and their fits to new and improved synthetic spectra by Detlev Koester. We discovered low amplitude pulsations in stars previously classified as Not-Observed-to-Vary by Mukadam (2004a) and Mullally et al. (2005), because with a larger telescope we could reach smaller amplitude limits and find previously undetected pulsations, as in Castanheira et al (2007).

Kepler et al. (2006) obtained $S/N \geq 70$ optical spectra of a few of the white dwarfs discovered by the SDSS to compare with the low S/N SDSS spectra and demonstrated the internal uncertainties from SDSS spectra are underestimated, but only by $\Delta T_{\text{eff}} \simeq 320\text{ K}$, and $\Delta \log g \simeq 0.24\text{ dex}$. We have continued to observe other stars with Gemini over the last two years and obtain similar results.

Our main goal has been to use the observed pulsation modes to measure the structure of the white dwarfs through seismology (Kim et al 2008, Castanheira et al. 2008). We also aim to determine if pulsation is a normal stage that all white dwarf stars pass as they cool down (Gianninas et al. 2005, 2006, 2007, Castanheira et al 2007). As the detection limit for pulsations in previous studies were larger than the now known lowest amplitude pulsator, we do not know at present if there are non-pulsators inside the instability strip or even the real extent of the instability strip.

The discovery of a substantial number of pulsators is necessary to map the instability strip, not only with T_{eff} , but also in terms of its mass dependency. Our discoveries of massive pulsators, shown in Figure 1, are steps towards such coverage. ZZ Ceti stars are useful tools in the study of high density physics, specially considering that the massive pulsators crystallize inside the DAV instability strip (Kanaan et al 2005).

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