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Asteroseismological Investigations of Pulsating White Dwarf Stars

Theses of the PhD Dissertation

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1 Introduction

White dwarfs represent the final evolutionary stage of $\approx 98\%$ of the stars. By the investigation of their interiors we can find the clue to the previous steps of stellar evolution, use them as cosmic laboratories and measure the age of the stellar population they are belonging to.

Some of them show light variations on time scales of minutes. We can find them in well-defined regions of the Hertzsprung–Russell-diagram, and they can be classified in three major groups: DAV (ZZ Ceti), DBV (V777 Her) and GW Vir stars. The most populous one is that of ZZ Ceti, $\approx 80\%$ of the known pulsating white dwarfs belong to this group. Contrary to DBVs and GW Vir stars, DAVs has a thin hydrogen layer above the helium one. These stars have some hydrogen left in spite of the effective mass loss processes that occured on the asymptotic giant branch.

All of the white dwarf pulsators show nonradial g-mode pulsation. In the case of DBVs and DAVs the excitation mechanism is the so-called convective driving and it is in connection with the partially ionization of helium or hydrogen, too. The internal structure of the pulsating white dwarfs is representative of the white dwarfs as a whole group. Asteroseismological investigations of these stars give the chance to determine their main physical parameters, and learn their internal structure and the physical processes that take place inside.

2 Scientific goals

One of my aim is to observe the selected white dwarf pulsators over at least a whole season, determine the precise values of the pulsational frequencies and perform asteroseismological investigations of the targets using the normal modes of pulsation. By utilizing white dwarf models I can give constraints on the helium and hydrogen layer masses, test the possibility of mode trapping phenomenon and determine the asteroseismological distances of the stars.

The investigation of short-term amplitude (and possibly frequency) variabilities is also one of the scientific goals. Short-term variations of the pulsational modes' amplitudes (on weeks-to-months timescale) are common features among cool DBV, cool DAV and Planetary Nebula Nucleus Variable (PNNV) stars. Possible explanations of the variations could be convection/pulsation interactions, non-linear mode coupling and beating of modes, including the effect of unresolved (such as rotational split) frequencies. The latter can easily be tested by our data sets.

3 Methods

My theses summarize the results obtained on three ZZ Ceti stars with similar main pulsational behaviour. In two cases we made observations at Piszkés-tető (the mountain station of Konkoly Observatory) with the 1-m RCC telescope and CCD. In the case of the third object I used literature period values.

The reduction of raw CCD frames was performed by the standard routines of IRAF[1] („Image Reduction and Analysis Facility”). For the aperture photometry of stars I used the IRAF/DAOPHOT program package. To determine the pulsational frequencies of a given object I performed Fourier analyses of the individual nights, data subsets and the whole data set.

I carried out Monte Carlo simulations on synthetic light curves to give the errors of the frequency values. Also using synthetic light curves but with different noise levels I tested the determinability of the frequencies and gave more realistic error ranges for them. I wrote specific scripts for these purposes.

I performed tests for the possible sources of the amplitude variations observed. With synthetic data sets I simulated the effect of closely spaced rotationally split frequencies.

I used the White Dwarf Evolution (and pulsation) Code (WDEC; Bischoff-Kim, Montgomery & Winget 2008, ApJ, 675, 1512) to generate equilibrium white dwarf models and build model grids by varying either five or four main physical parameters. Knowing the pulsation modes' period values I could compare them with the calculated ones. Considering their differences, the atmospheric parameters determined by spectroscopy and the l values of modes expected I selected the „favoured” models. With these models I could give constraints on the helium and

[1] http://iraf.noao.edu

hydrogen layer masses.

I investigated the possibility of mode trapping using period spacing diagrams. The period distribution of white dwarfs displays regularity, this fact gives the high research potential to these stars. Deviations from the uniform spacing could denote mode trapping; minima in the period spacing diagrams correspond to modes trapped by the hydrogen or helium layer.

4 Theses

1. In the case of KUV 02464+3239 and GD 154 I could determine five and two new pulsation modes by our observations, respectively. It was allowed by the medium-long time base of the observations. The extended number of modes gave the potential to perform the asteroseismological investigations of these stars with model grids. [2]

2. I carried out the detailed study of the pulsation's non-linear features in the light curve of KUV 02464+3239. This star is representative of the cooler ZZ Ceti stars and has a strongly non-sinusoidal light curve shape. Using light curve segments I found harmonic and near-subharmonic peaks in their Fourier spectra. Investigations of the quality of light curve fits generated with the pulsation modes only also showed that the dynamics of the star is dominated by non-linear processes. [1, 3]

3. In the case of KUV 02464+3239 and GD 154 the Fourier analyses of the individual nights and longer data subsets revealed remarkable amplitude variations on a time-scale of weeks. The tests, using synthetic light curves and period values of KUV 02464+3239, showed that although closely spaced, large amplitude frequencies in certain phase relations can cause apparent variations, real changes in the energy content of modes seem to be plausible. [2]

4. I gave constraints on the hydrogen and helium layer masses of the three stars. The selected models have the following mass values: $M_{\mathrm{H,KUV02464}} = 2.5 \times 10^{-5} - 6.3 \times 10^{-6}\, M_*$, $M_{\mathrm{H,GD244}} \approx 10^{-5}$ or $10^{-6}\, M_*$ and $M_{\mathrm{H,GD154}}$

$\approx 10^{-7}$ or $10^{-11}\,M_*$. For the helium layer mass of KUV 02464+3239 and GD 154 the investigations imply that $M_{\mathrm{He}} = 10^{-2}\,M_*$ is the preferred value. Effective temperature and $\log g$ (stellar mass) values of the best models support the spectroscopic ones, only the seismic mass of GD 154 seems a bit far from the expected one. [2, 4]

5. By further investigations of the best-fitting models I calculated two stars' asteroseismological distance. The values obtained for KUV 02464+3239 and GD 154 are $\approx$ 70 and 44 parsec, respectively.

   Using period spacing diagrams of their selected models I concluded that the high amplitude of some modes can be the result of mode trapping, but it is not required. [2]

5 Conclusions

In the framework of my PhD researches I could achieve the stated scientific goals. Investigations of medium-long data sets open new possibilities in white dwarf research. With the longer-term (at least one observing season-long) monitoring of target stars we get the chance to determine new pulsation frequencies. In the case of rarely observed object or stars having only few known modes this is necessary for their asteroseismological investigations.

I showed that variations on time scales shorter than the evolutionary ones can be detected and investigated by our data sets.

My results demonstrated that the selected models can reproduce the observed periodicities with high accuracy while their masses and effective temperatures are close to the spectroscopic values. The investigations support other authors' results on the presence of ZZ Ceti hydrogen layers thinner than the expected $10^{-4}\,M_*$ given by evolutionary calculations. My results also support the „canonical" $M_{\mathrm{He}} = 10^{-2}\,M_*$ value and confirm that with more shorter period (low-order) modes we can give stronger constraints on M_{H}.

Using the known luminosities of the selected models I could calculate the asteroseismological parallax of some targets. This demonstrated the unique opportunity to determine the distance of a star by asteroseismological method.

Publications related to the theses

1. *More frequencies of KUV 02464+3239*
   Zs. Bognár, M. Paparó, A. Már, Gy. Kerekes, P. Pápics, L. Molnár, E. Plachy, N. Sztankó, E. Bokor
   2007, *Astronomische Nachrichten*, **328**, 845

2. *Characterizing the pulsations of the ZZ Ceti star KUV 02464+3239*
   Zs. Bognár, M. Paparó, P. A. Bradley, A. Bischoff-Kim
   2009, *Monthly Notices of the Royal Astronomical Society*, **399**, 1954

3. *Light Curve Patterns and Seismology of a White Dwarf with Complex Pulsation*
   Zs. Bognár, M. Paparó, P. A. Bradley, A. Bischoff-Kim
   2009, *American Institute of Physics Conference Proceedings*, **1170**, 625

4. *GD 244: asteroseismology of a pulsator in the middle of the ZZ Ceti instability strip*
   Zs. Bognár, M. Paparó
   2010, *American Institute of Physics Conference Proceedings*, **1273**, 504

Other related publications

5. *Monitoring of the cool ZZ Ceti star PG 2303+243*
   E. Pakštiene, J.-E. Solheim, G. Handler, B. Steininger, F. Rodler, M. Paparo, **Z. Bognar**, R. Patterson, M. Reed
   2007, *Proceedings of IAU Symposium #239*, 382

6. *GD 99 – an unusual, rarely observed DAV white dwarf*
   Zs. Bognár, M. Paparó, B. Steininger, G. Virághalmy
   2007, *Communications in Asteroseismology*, **150**, 251

7. *Preliminary Results in White Dwarf Research by a New Group*
   M. Paparó, E. Plachy, L. Molnár, P. I. Pápics, **Zs. Bognár**, N. Sztankó, Gy. Kerekes, A. Már, E. Bokor
   2008, *Communications in Asteroseismology*, **154**, 59

8. *2006 Whole Earth Telescope Observations of GD358: A New Look at the Prototype DBV*
J. L. Provencal, M. H. Montgomery, A. Kanaan, ..., **Zs. Bognar** et al.
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9. *Preliminary XCOV26 results for EC14012-1446*
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2009, *Journal of Physics: Conference Series*, **172**, 012061

10. *Pulsational Mapping of Calcium Across the Surface of a White Dwarf*
S. E. Thompson, M. H. Montgomery, T. von Hippel, ..., **Zs. Bognár** et al.
2010, *The Astrophysical Journal*, **714**, 296

11. *The period and amplitude changes in the coolest GW Virginis variable star (PG 1159-type) PG 0122+200*
G. Vauclair, J.-N. Fu, J.-E. Solheim, S.-L. Kim, N. Dolez, M. Chevreton, L. Chen, M. A. Wood, I. M. Silver, **Zs. Bognár**, M. Paparó, A. H. Córsico
2011, *Astronomy & Astrophysics*, **528**, A5

12. *The cool ZZ Ceti star PG 2303+243: Observations and analysis of variability in 2004*
E. Pakštiene, J.-E. Solheim, G. Handler, M. Reed, **Zs. Bognár**, F. Rodler, M. Paparó, J. Zdanavičius, B. Steininger, G. Wolf
2011, *Monthly Notices of the Royal Astronomical Society*, accepted for publication