Baltic Astronomy, vol. 9, 113–118, 2000.

TIME-RESOLVED SPECTROSCOPY OF BPM 37093 AND PG 1336-018

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Received October 15, 1999

Abstract. We present time-resolved spectroscopy of two pulsating stars using VLT UT1. Primary aim is an identification of the pulsation modes from the wavelength dependency of the amplitudes. A mode identification is the prerequisite to make full use of the photometric data obtained for asteroseismologic studies.

Key words: stars: white dwarfs, subdwarfs, oscillators, individual: PG 1336−018, BPM 37093

1. INTRODUCTION

Asteroseismology of pulsating white dwarfs and pre-white dwarfs has proven to be an extremely valuable tool to directly investigate stellar interiors. The observational approach is the recording of the light variations caused by the temperature variations induced by the non-radial pulsations. The variation of the temperature over the stellar surface can be described by spherical harmonics. Since a distant observer only sees the variations averaged over the surface, the observed modes are reduced to those with low latitudinal wave number ℓ.

Exploring the seismologic data as diagnostics for the stellar interior requires the unambiguous mode identification, mainly the latitudinal wave number ℓ. Mode identification from photometric data is obtained by matching the theoretical mode pattern (pulsation frequencies and frequency spacings) obtained from stellar models with the observed ones. That works reliably in the case of stars with rich pulsation frequencies (e.g. PG 1159-035, Winget et al. 1991) but is very difficult or even fails in the case of stars with few observed pulsation frequencies (like in the case of PG 1336-018 and BPM 37093), since the theoretical modes are much more numerous than the observed ones. In this case, an alternative identification is required employing the spectral dependence of the pulsating amplitude. The brightness distribution according to the spherical harmonics causes cancellation effects. Since limb darkening is wavelength dependent (increasing towards higher wavelength), the cancellation effects of different ℓ-modes are also wavelength dependent because the spatial distribution over the surface differs thus reducing the cancellation effect for higher ℓ-modes. This procedure is independent of the stellar pulsation models employed for the analysis of the photometric data.

Matching the wavelength dependent amplitude variations as well as the time-resolved spectral information reveals the brightness distribution and thus the wave number ℓ. This procedure has first been used using broad band colors and an analytic limb darkening law by Robinson et al. (1982) demonstrating the non-radial nature of the pulsations in ZZ Ceti stars. More advanced approaches, employing white dwarf atmospheric models by Koester, have been undertaken e.g. by Robinson et al. (1995), Nitta et al. (1998) and Väth et al. (1997).

2. OBSERVATIONS

The short pulsation periods require short exposure times. A reasonable S/N ratio for each spectrum therefore requires a large telescope. We used the VLT UT1 telescope equipped with the FORS1 spectrograph for that project. The observing time (April 14, 1999) was coordinated with XCOV 17 in order to make use of the much longer time basis of the WET data ensuring a more precise mode frequency determination. The grism 600B+12 covers the spectral range from about 3800 to 6000 Å, covering the Balmer lines from Hβ to H9. The read-out time was reduced by using the four-channel read-out mode and a 2×2 binning resulting in a spectral resolution of about 10 Å. The original plan to perform a small off-set along the slit after each exposure and read the CCD only after many single exposures failed due to the instrument software. The efficiency was therefore much lower than expected, resulting in a ratio of exposure time to cycle time of only 1/3. The efficiency of the instrument was also affected by severe contamination of the CCD surface due to problems with the CCD dewar. Additionally, the reflectivity of the main mirror was down to 80 % and we lost two hours observing time because of start-up problems with the active optics of the main mirror.

Primary target was BPM 37093, a ZZ Ceti star (Kanaan et al. 1992, Koester & Allard 2000, Nitta et al. 2000, Kanaan et al. 2000). ZZ Ceti stars are variable hydrogen rich white dwarfs with effective temperatures near 13 000 K. This star stands out of the group of ZZ Ceti stars due to its exceptionally high mass (1.01 $M_{\odot}$)and therefore is the ideal candidate to check the current status of the crystallization theory by its influence on the pulsation frequencies. Up to now, crystallization theory could not be tested directly, despite of its astrophysical importance. Uncertainties in the theory and the extent of crystallization is the major uncertainty in the determination of the age of cool white dwarfs, which are important indicators for the age of the galactic disk. Determination of the latitudinal wave number ℓ of the non–radial modes via the spectral variation of the amplitude will allow to determine the crystallized mass fraction of BPM 37093.

Secondary target was one member of the newly discovered class of EC 14026 stars (pulsating sdB stars, Kilkenny et al. 1997), namely PG 1336-018 (Kilkenny et al. 1998). PG 1336-018 is an eclipsing binary composed of a sdB primary and a M4 – M5 secondary with a very short orbital period of 2.4 h. The light curve shows partial eclipses, the system is remarkably similar (except for the addition of pulsations) to the previously unique system HW Vir (Wood et al. 1993). Spectroscopic analyses have revealed that sdB stars are extreme horizontal branch stars (Heber 1986), their origin, however, is still unclear and strongly debated. Subluminous B stars dominate the populations of faint blue stars and are found both in the old disk (field sdBs) and in the halo populations (globular cluster members). Evidence has accumulated that sdB stars are the most likely source for the "UV upturn phenomenon" observed in elliptical galaxies and galaxy bulges (Greggio & Renzini 1990). The fundamental aim is the discrimination between radial and non-radial pulsations, which is still not clear for the whole class of EC 14026 stars.

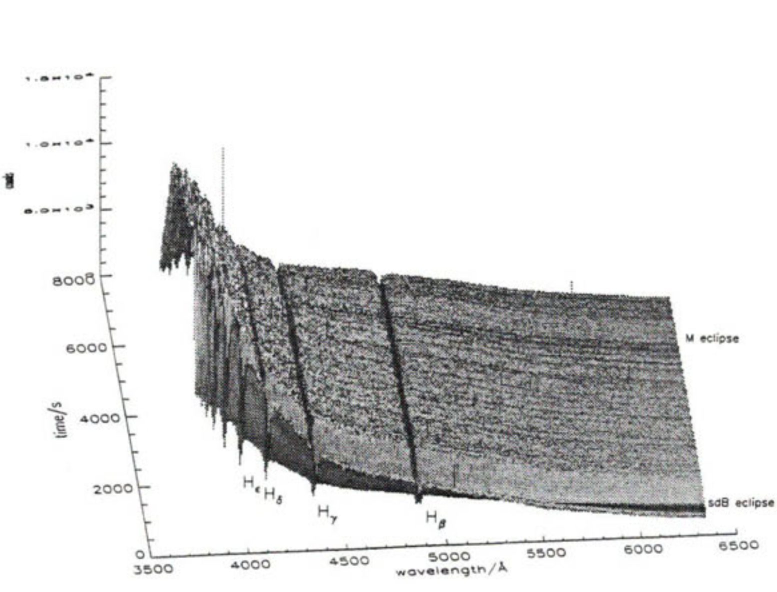

Fig. 1. The time-resolved spectra of PG 1336-018

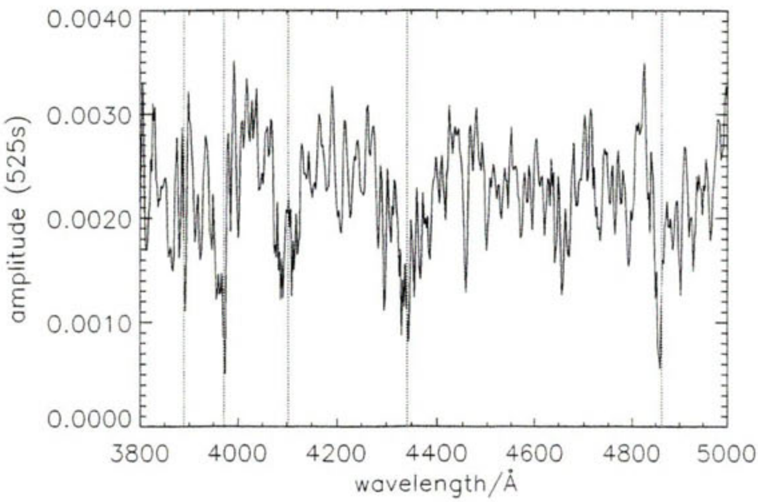

Fig. 2. Wavelength-dependent amplitude in BPM 37093. The wavelengths of the Balmer lines, where the amplitude significantly changes, are marked by vertical lines

3. RESULTS

As an example, Fig. 1 shows the time resolved spectroscopy of PG 1336-018. The eclipses of the sdB and the cool companion star can be clearly seen. Also visible is the flux variation due to the pulsation of sdB star. We performed a multi-period fit for each individual spectrum using the periods detected during the WET run as constraints. We tried several fitting procedures and found the genetic algorithm `pikaia` (Charbonneau 1995) to produce the most stable results. The amplitudes of the pulsation modes versus the wavelength (Fig. 2) can then be compared with theoretical predictions (Fig. 3). As obvious from the comparison the S/N is far too low to allow a ℓ determination. We therefore have to admit that the primary aim of this project could not be achieved for BPM 37093. Theoretical predictions of the wavelength dependency of the pulsation amplitude for PG 1336-018 from sdB model atmospheres remain to be calculated. Since PG 1336-018 is about a magnitude brighter than BPM 37093 the situation might be slightly better in that case.

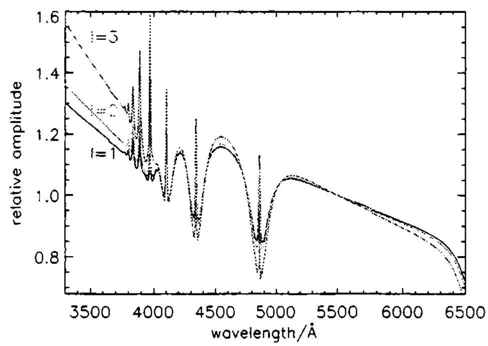

Fig. 3. Theoretical predictions of wavelength-dependent amplitudes in BPM 37093 for different spherical harmonic indices ℓ normalized to 5500 Å.

We also inspected the spectral change over the orbital period in PG 1336-018. In the blue optical wavelength range covered by our spectra no sign of any spectral feature from the cool companion can be detected. The very low orbital separation together with the huge difference in effective temperatures of about a factor of 10 probably produces an iso-thermal atmosphere on the illuminated hemisphere of the secondary. Even in the eclipse of the hot primary this star still dominates the optical spectrum due to the large difference in visual magnitude and the relatively low inclination (81°, Kilkenny et al. 1998).

ACKNOWLEDGMENTS. This project is based on observations collected at the European Southern Observatory, Chile (ESO N° 63.H-0363). S.D. and U.H. acknowledge support by NATO ARW and IITAP (UNESCO) funds.

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