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Letter to the Editor

BPM 24754: A new Southern ZZ Ceti star[*]

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Abstract. We report the discovery of a new long–period ZZ Ceti star through the analysis of photometric time series gathered on 7 nights between 1995 and 1996. The light curve displays a periodic variation with a period of $\sim$ 18 min in white light and the frequency analysis reveals a low frequency peak at $\sim$ 0.92 mHz with an amplitude varying from 0.007 to 0.025 mag present every night. BPM 24754 is the 28th known ZZ Ceti star and it has the second longest period. We have also determined its atmospheric parameters using line profile fitting and its mass using white dwarf evolutionary models. BPM 24754 has $T_{\rm eff}$ = 12,900 $\pm$ 320 K, $\log g$ = 8.04 $\pm$ 0.08, and M = 0.63 $\pm$ 0.04 $M_\odot$. We compare its $T_{\rm eff}$ in relation to the ZZ Ceti instability strip.

Key words: stars: individual: BPM 24754 – stars: variables: other – stars: oscillations – stars: fundamental parameters – white dwarfs

1. Introduction

ZZ Ceti or DAV stars are normal DA white dwarfs (pure H atmospheres) which show light variations produced by non–radial g-mode pulsations caused by convective driving (Brick-hill 1991) in the hydrogen partial ionization zone. All pulsating DA stars are found between $T_{\rm eff}$ = 11,160 K and 12,460 K (Bergeron et al. 1995) on the white dwarf cooling sequence, and this narrow strip is known as the ZZ Ceti instability strip. The

ZZ Ceti stars are mutliperiodic and therefore the astereoseismological study of this class can provide a detailed understanding of white dwarf structure and evolution (Kleinman et al. 1994; Pfeiffer et al. 1996). The ZZ Ceti stars have also been used to estimate the evolutionary time of these stars on the white dwarf cooling sequence (Kepler et al. 1991). By using the theoretical age–luminosity relation to interpret the observed white dwarf luminosity function it is possible to obtain a minimum age for the local Galactic disk (Winget et al. 1987; Wood 1995; Oswalt et al. 1996). The Whole Earth Telescope (WET; Nather et al. 1990) has proved to be a powerful tool for probing the structure of variable stars using temporal spectroscopy of complex light curves – see e.g. Kepler & Bradley (1995) and references therein for a review on white dwarf seismology – and the discovery of new targets for future seismological studies is important to increase our knowledge of stellar structure and evolution.

Bradley (1995) lists 24 known ZZ Ceti stars and recently Vauclair et al. (1997) and Jordan et al. (1997) discovered 3 new DAV stars increasing the number of known ZZ Ceti stars to 27. Of all known ZZ Ceti stars only seven are in the Southern hemisphere, indicating the especially incomplete surveying for Southern ZZ Ceti stars. Therefore, we have selected all DA white dwarf stars from the McCook & Sion (1987) catalogue with colors near or within the ranges $0.16 \leq B - V \leq 0.25$ (Fontaine et al. 1982), $0.038 \leq b - y \leq 0.092$ (Fontaine et al. 1985), and $-0.45 \leq G - R \leq -0.35$ (Greenstein 1982), to monitor for variability.

For the past 10 years there has been a serious search to find which stellar parameters are sufficient to place a variable star in the ZZ Ceti instability strip. Originally, it was believed that $T_{\rm eff}$ was the unique parameter since all then known DA stars inside the instability strip were variable (Fontaine et al. 1985). However, Dolez et al. (1991), Kepler and Nelan (1993), Kepler et al. (1995), and recently Giovannini (1996) found several non-variable DA stars inside the strip; these results indicate another parameter should distinguish between variables and non-variables, or that the instability strip is not "pure". Using the theoretical results by Bradley & Winget (1994) that the blue

Table 1. Journal of observations at LNA

Run	Date (UT)	Start time (UT)	Length (h)	Integration time (s)
ro074	8/29/95	00:41:50	1.9	5
ro077	8/29/95	22:11:20	3.4	5
ro086	7/09/96	02:50:20	1.5	5
ro089	7/10/96	23:39:10	2.2	5
ro093	7/13/96	01:19:20	4.1	10
ro096	7/14/96	00:53:40	4.5	10
ro100	7/16/96	01:01:00	4.0	10

edge temperature of the ZZ Ceti instability strip depends on the stellar mass, Kanaan (1996) showed that the observations agree.

Using the colors as indicators, we have already discovered one DAV, BPM 37093 (Kanaan et al. 1992), the most massive known DAV at 1.09 $M_\odot$ (Bergeron et al. 1995), and now this paper reports the second DAV star discovered, BPM 24754. It was originally selected by its color and later we determined its T_{eff} and log g spectroscopically. In the meantime, extensive time series photometry was obtained and during two observing runs we found it to vary.

In this paper, we show the light curves, their Fourier spectra, and we also determine the fundamental parameters [T_{eff}, log g, mass] of BPM 24754. Finally, we discuss its location in relation to the observed ZZ Ceti instability strip.

2. Observations

BPM 24754 is listed in the McCook & Sion (1987) catalogue as WD 1714–547 with 1950 coordinates $\alpha = 17^h14^m48^s$ and $\delta = -54°44^{'}$, with $V = 15.6$, $B - V = 0.27$, $b - y = 0.070$, and a spectral type of DA7. Its finding chart can be found in Luyten (1949) under the name L 269–72. Time series photometry and spectroscopic observations of BPM 24754 are reported here.

The time series photometry was obtained at the Laboratório Nacional de Astrofísica (LNA)/CNPq, Brazil, in 1995 August and 1996 July using the two–star Texas Photometer (Nather 1973) attached to the 1.6 m telescope. In both channels we used Hamamatsu blue–sensitive photomultipliers with no filter to maximize the signal–to–noise ratio. A total of 21.6 hours of data during 7 nights were gathered on BPM 24754. The journal of observations is presented in Table 1. Sky measurements were made about every $\sim$ 40 min in both channels. The standard data reduction as described by Nather et al. (1990) was applied to light curves: sky subtraction by interpolation, extinction correction, and normalization to mean intensity. The resulting time series are in units of fractional intensity (mi) relative to the mean intensity of the star (mi $\equiv \Delta I/\langle I \rangle$, i.e., 1 mi corresponds to variation of 100%.). The seven time series are plotted in Fig. 1.

The spectroscopic observations were carried out at the Cerro Tololo Inter-American Observatory (CTIO) in 1995 August. We used a Cassegrain Spectrograph on the 1.5 m telescope with a
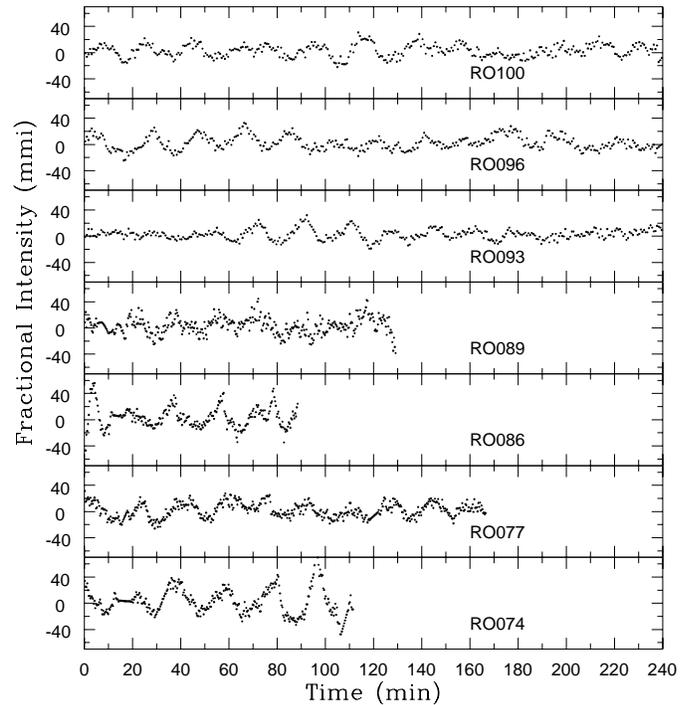
Fig. 1. Time series. Fractional intensity vs. time in minutes.

300 ℓ/mm grating and a 250 arcsec–wide slit. This configuration provided a spectral resolution of $\sim$ 8 Å. Because high signal–to–noise spectroscopy is necessary to determine the atmospheric parameters with a precision of 200 – 300 K in T_{eff}, we observed the star for 2 hours in 6 exposures of 20 min. After flux calibrating each frame, the spectra were co–added and the resulting spectrum is shown in Fig. 2.

3. Time series and frequency analysis

Inspecting the time series in Fig. 1 we can identify a periodic light variation in all curves with a period of $\sim$ 18 min and amplitude varying from $\sim$ 10 mmi (run ro093) to $\sim$ 70 mmi (run ro074). The time series of the comparison star which was observed in channel two do not display any periodic light variation. Moreover, it is noteworthy that the regular light variation was detected both in 1995 and in 1996, i.e., we can state that this variation is not due to transparency or sky variations. We can also see on run ro093 what seems to be beating between pulsations with closely spaced frequencies. The time series shown in Fig. 1 therefore strongly suggests that BPM 24754 has a multiperiodic light curve. Obviously, this periodic light variation must appear in the amplitude spectrum as a peak at the corresponding frequency.

We analysed the time series of fractional intensity using the well-known Fourier Transform method. The Deeming (1975) algorithm was applied and a frequency spectrum was obtained. The output Fourier spectrum is in units of amplitude modulation (ma), we therefore call it an amplitude spectrum. We calculated these spectra for each run separately and the results are shown
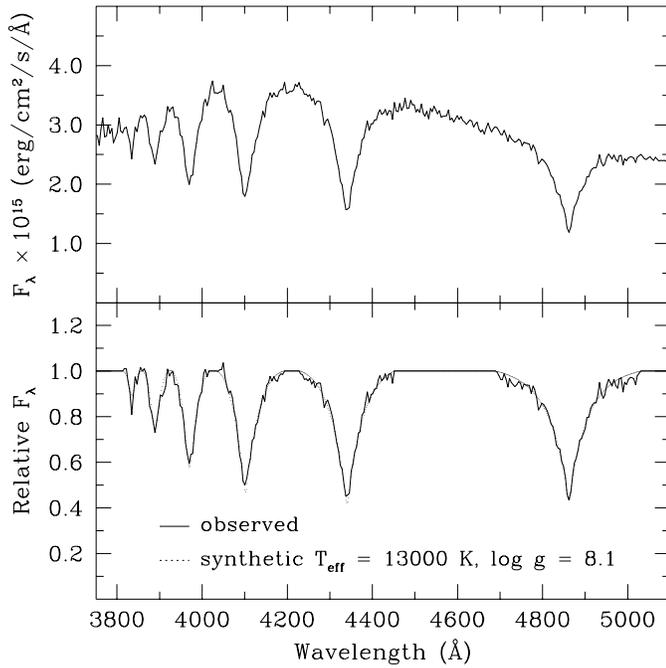
Fig. 2. Top: optical spectrum. Bottom: line profile fitting. Comparison of the observed optical lines with the closest synthetic spectrum (dotted). Both spectra are normalized to continuum.

Table 2. Observed frequencies and amplitudes

Run	Frequency (mHz)	Period (min)	Amplitude (ma)	Δm (mag)
ro074	0.85 ± 0.15	19.6	0.0226	0.025
ro077	0.95 ± 0.08	17.5	0.0091	0.010
ro086	0.92 ± 0.19	18.1	0.0132	0.014
ro089	1.02 ± 0.13	16.3	0.0077	0.008
ro093	0.91 ± 0.07	18.3	0.0061	0.007
ro096	0.89 ± 0.06	18.7	0.0063	0.007
ro100	0.89 ± 0.07	18.7	0.0067	0.007

in Fig. 3. The frequency range spans from 0.1 to 5.0 mHz and the amplitude varies from 0 to 9 mma or 25 mma (ro074). We clearly note in Fig. 3 the presence of the same peak in every spectra with a frequency around 0.92 mHz or a period of $\sim$ 18 min – confirming the light variation period displayed by light curves (Fig. 1). Table 2 shows the observed frequencies and the corresponding period for the largest amplitude peak. The different frequencies and amplitude of this peak can be caused by the presence of other smaller amplitude pulsations, beating of closely spaced frequencies, and the spectral resolution – approximately the inverse of the data length.

4. Discussion

From our reported photometric observations we conclude that BPM 24754 is a pulsator. It has the second longest period ($\sim$ 18 min) but its amplitude, between 0.007 and 0.025 mag, is
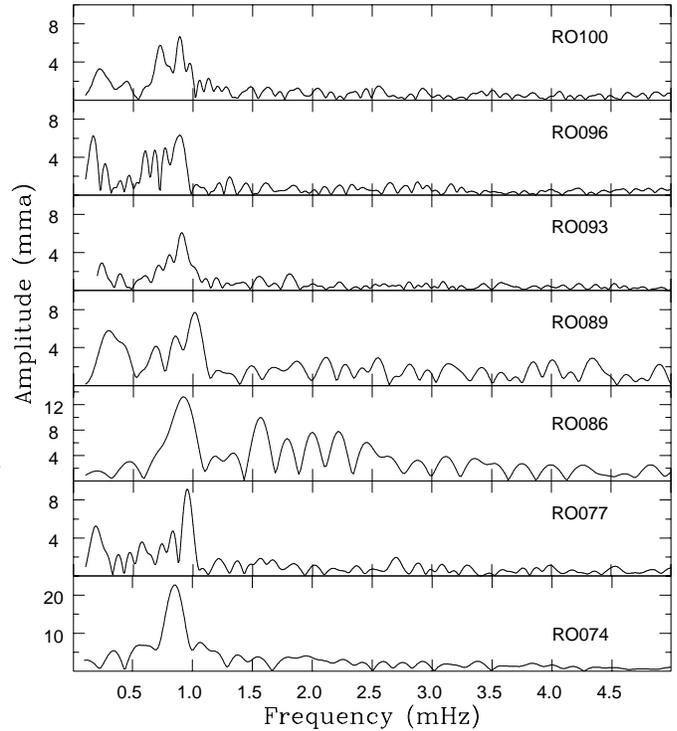

Fig. 3. Amplitude spectra. Fractional amplitude vs. frequency in mHz.

smaller than some other ZZ Ceti stars. Therefore, BPM 24754 does not fit the period–amplitude relation – the longer the mean period, the larger the mean amplitude (Fontaine & Winget 1987; Clemens 1993). As BPM 24754 is probably multiperiodic, additional time series photometry are needed to get more information on its amplitude spectrum. Clemens (1993) also showed that both period and amplitude increase monotonically with decreasing temperature, consistent with theory. Then, where is BPM 24754 in relation to the instability strip? To answer this question, we determine its atmospheric parameters [$T_{\rm eff}$, $\log g$] through synthetic spectra produced by the ML1/α = 2 model atmospheres of Koester et al. (1994). The atmospheric parameters for BPM 24754 were determined using the same fitting technique as described by Bergeron et al. (1992) that compare only the Balmer line profiles between observed and synthetic spectra. In this case we used six lines: H_β to H_9 and the best synthetic spectrum fit to BPM 24754 is shown in Fig. 2. The values derived for BPM 24754 are: $T_{\rm eff}$ = 12,900 $\pm$ 320 K and $\log g$ = 8.04 $\pm$ 0.08. With these atmospheric parameters, we interpolate the white dwarf evolutionary models of Wood (1995), which have "thick" hydrogen layers of $10^{-4}M_\star$, and derive a mass of $0.63 \pm 0.04 M_\odot$. This effective temperature places it outside the ZZ Ceti instability strip limits as determined by Bergeron et al. (1995) who used both optical and UV spectra and ML2/α = 0.6 models[1]. We also recall that $T_{\rm eff}$ determina-

[1] However, if we compare our results to those by Bergeron et al. (1995) which were obtained using only the optical spectrum and ML2 models (their Table 2), BPM 24754 falls inside the ZZ Ceti instability strip.

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tion is very uncertain for DAV stars. Koester & Vauclair (1997) show that even for well–studied DAV stars, e.g. GD 165, the determination of T_{eff} from recent years can differ by 2600 K. Moreover, Bergeron et al. (1995) and Koester & Vauclair (1997) show that one can only get consistent solutions by fitting both optical and UV spectra simultaneously. At present, we have only the optical spectra at hand and therefore our conclusions may change if UV spectra become available.

5. Summary

Below we summarize our conclusions:

1) BPM 24754 is the 28th ZZ Ceti star with a period of $\sim$ 18 min and amplitude between 0.007 and 0.025 mag. It has the second longest period;

2) It does not fit the period–amplitude relation;

3) The amplitude spectrum indicates a multiperiodic light curve;

4) We need to gather extra single site data to better interpret its amplitude spectrum;

5) The fundamental parameters are: $T_{\mathrm{eff}} = 12,900 \pm 320$ K, $\log g = 8.04 \pm 0.08$, and $M = 0.63 \pm 0.04\ M_{\odot}$;

6) The T_{eff} is hotter than the blue edge of the observed ZZ Ceti instability strip;

7) We need a UV spectrum to obtain a consistent solution for T_{eff} and $\log g$.

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