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Asteroseismology of new pulsating white dwarfs

R. S. Stobie,[1] D. O'Donoghue,[2] R. Ashley,[2] C. Koen,[1] A. Chen[2] and D. Kilkenny[1]

[1] *South African Astronomical Observatory, PO Box 9, Observatory 7935, Cape, South Africa*

[2] *Department of Astronomy, University of Cape Town, Rondebosch 7700, Cape, South Africa*

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ABSTRACT

The discovery of another large-amplitude ZZ Ceti star in the Edinburgh–Cape Blue Object Survey is announced. The light curve is non-sinusoidal, with a peak-to-peak variation ranging from 0.08 to 0.30 mag in white light. Frequency analysis of four nights of high-speed photometry reveals a similar frequency structure, with power at 1.382, 1.639, 1.885 and 2.507 mHz present on every night. There is evidence that the power at these frequencies is not constant, indicating the presence of multiple close frequencies. The frequency pattern fits that of other ZZ Ceti stars, supporting the evidence for a small range in total mass and hydrogen layer mass in pulsating DA white dwarfs. Possible mode identifications for this star, and for a previously announced pulsating DA white dwarf, are given.

Key words: stars: individual: EC14012 – 1446 – stars: oscillations – white dwarfs.

1 INTRODUCTION

The ZZ Ceti stars are a class of pulsating DA white dwarfs (DAV) stars. The light variations result from non-radial gravity-mode pulsations driven by an instability in the hydrogen partial ionization zone. The instability strip is delineated by a narrow temperature range of $11\,000 < T_{\rm eff} < 13\,000$ K on the white dwarf sequence, and it is suspected that most, and perhaps even all, hydrogen-rich DA white dwarfs will pulsate as they evolve to lower temperatures and pass through this temperature range. Thus the properties of the ZZ Ceti stars, which have been described by Fontaine et al. (1982) and Winget (1988), are typical of most white dwarfs. Such stars are therefore vital in the quest to obtain a detailed understanding of white dwarfs. Because of their multiperiodic nature, they are natural targets for asteroseismological investigation.

Of the 23 known ZZ Ceti stars listed by Bradley (1993), only six have negative declinations, indicating the great incompleteness in the search for such objects in the southern hemisphere. The Edinburgh–Cape Blue Object Survey is a potential source of candidate degenerate pulsators (Stobie et al. 1992). The blue stellar objects are identified from COSMOS scans of U and B plates taken with the UK Schmidt Telescope. Follow-up photometry and spectroscopy are being obtained at the South African Astronomical Observatory (SAAO) to classify and determine the nature of each blue stellar object. Currently, over 190 DA white dwarfs have been identified, of which the majority are not in existing catalogues (O'Donoghue et al. 1993). From these white dwarfs, we have selected stars with $B-V$ colours near or within the range $0.15 < B-V < 0.25$ to monitor for variability. The first variable white dwarf to be discovered by the Edinburgh–Cape Survey was discussed by Stobie et al. (1993). This paper describes the second ZZ Ceti star to be discovered in the Edinburgh–Cape Survey, and extracts asteroseismological data for both stars.

2 OBSERVATIONS

EC14012 – 1446 has 1950 coordinates $14^{\rm h}01^{\rm m}14\overset{\rm s}{.}4$, $-14°46'47''$, accurate to 1 arcsec. Its colours are $V=15.67$, $B=0.17$ and $U-B=-0.52$. It is not in the catalogue of spectroscopically identified white dwarfs (McCook & Sion 1987). Spectra with a resolution of 3 Å and covering 3400–5200 Å, taken with the SAAO 1.9-m telescope and the Intensified Reticon Photon Counting Spectrograph, clearly identify EC14012 – 1446 as a classical DA white dwarf. Use of the above photometry and the scale defined by McCook & Sion (1987) gives it a classification of DA5.

Intensive photometry was obtained with the SAAO 1.0-m telescope using the St Andrews Photometer, and with the SAAO 0.75-m telescope using the University of Cape Town Photometer. The observing log is listed in Table 1. Observations were obtained in white light with blue-sensitive photomultiplier tubes and with a time resolution of 10 s. Offset guiding enabled continuous monitoring of the programme star, except for occasional interruptions (about every ~30 min) to obtain sky measurements. A cubic spline fitted to the sky values was interpolated to subtract the sky from the

stellar readings. The data were then corrected for extinction using mean coefficients applicable to Sutherland, and normalized by the mean intensity during the run. The resulting time series is therefore in units of differential magnitudes relative to the mean brightness of the star. Portions of each of the four light curves are plotted in Fig. 1.

3 FREQUENCY ANALYSIS

The four light curves were analysed for their component frequencies using the periodogram technique of Balona (1983). The periodograms for all four nights are shown in Fig. 2. At very low frequencies ($f < 0.2$ mHz), the power is primarily due to long-term drifts in the data caused by variations in extinction not matching the mean extinction correction. For the range of frequencies 0.2 to 10 mHz, we have extracted the component frequencies listed in Table 2. The procedure was to select the highest amplitude term and pre-whiten the data by the best-fitting sinusoid at this frequency. The residuals were then searched for further frequencies until the highest amplitude terms were not significantly above the noise. With all identified frequencies on a given night, a simultaneous fit was carried out to all frequencies, and the resultant amplitudes are listed in Table 2.

It is unusual in DAV stars for so many frequencies to be identified above the noise from a single night's observation. On all nights at least six frequencies, and in one case nine frequencies, have been isolated. The identification of these frequencies is shown in Table 2. The non-sinusoidal nature of the oscillations leads to the presence of the first harmonic

Table 1. Observing log of EC14012 − 1446.

telescope	photometer	starting time HJD2440000 +	integration (s)	length of run (h)
1.0m	StAP	9510.21495	10	5.4
0.75m	UCTP	9516.26519	10	3.1
0.75m	UCTP	9517.21906	10	5.4
1.0m	StAP	9539.21952	10	4.0

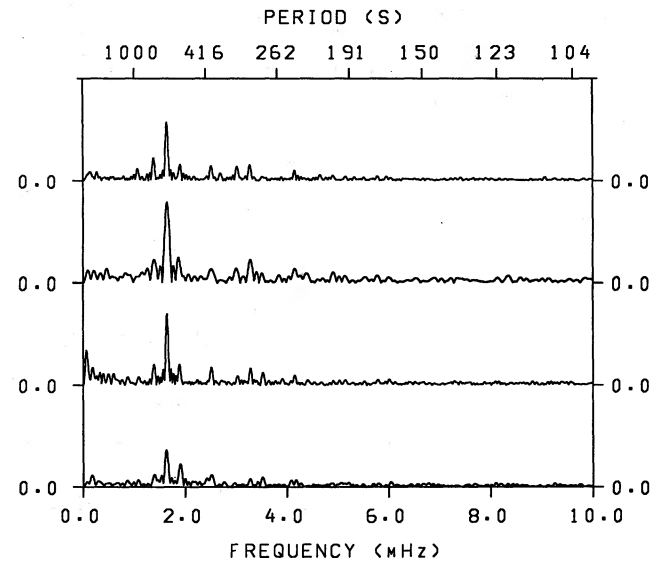

Figure 2. Amplitude periodograms of EC14012 − 1446 on four nights. The abscissa covers the frequency range 0–10 mHz. The amplitude scale of each panel is 0–0.1 mag.

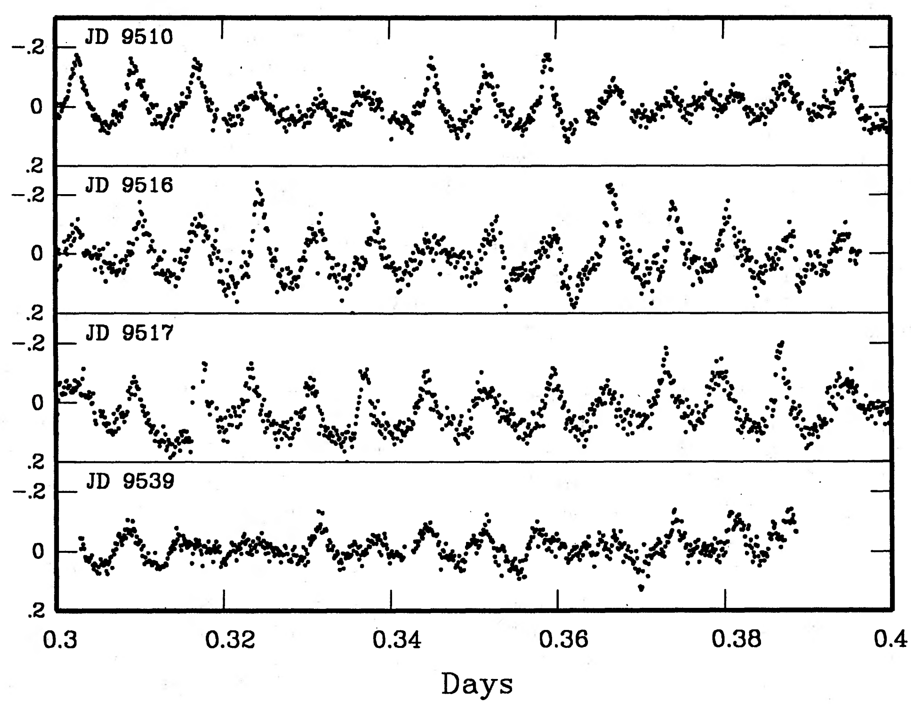

Figure 1. White light observations of EC14012 − 1446. Only a portion of each night's observations is displayed. The ordinate is in differential magnitude units relative to zero mean intensity for the whole night.

Table 2. Frequencies present in EC14012 − 1446.

identification	frequency (mHz)	period (s)	amplitude* JD9510	JD9516	JD9517	JD9539
f_1	1.639	610	0.057	0.077	0.070	0.036
f_2	1.382	724	0.021	0.022	0.020	0.011
$2f_1$	3.271	306	0.014	0.022	0.016	-
f_3	1.885	530	0.015	0.017	0.018	0.024
f_4	2.507	399	0.013	0.013	0.017	0.011
f_1+f_2	3.020	331	0.012	-	0.010	-
f_5	1.067	937	0.011	-	-	-
f_1+f_4	4.149	241	0.010	0.013	0.010	0.007
f_1-f_2	0.259	3857	0.009	-	-	-
f_1+f_3	3.522	284	-	-	0.012	0.009

*The error in the amplitude is typically 0.002.

$2f_1$ of the f_1 frequency. Many of the frequencies are cross-terms, e.g. f_1+f_2, f_1-f_2, etc., caused by the interaction of the modes with each other in the pulsating envelope of the star (Brickhill 1992).

There is clear evidence of variable amplitude, at least for the f_1 and f_2 terms. The typical error in amplitude is 0.002 mag, and the amplitudes on different nights of the f_1 term (e.g. 0.077 on JD 9516 and 0.036 on JD 9539) differ by 20σ. On the basis of intensive campaigns on other pulsating white dwarfs, these variable amplitudes are probably caused by a close frequency multiplet that is presently unresolved (Robinson, Nather & McGraw 1976).

4 DISCUSSION

The asteroseismological understanding of individual DAV stars has long been elusive, for two principal reasons: (i) the low-amplitude pulsators do not reveal sufficient modes to enable analysis; (ii) the large-amplitude pulsators have power spectra which change radically on many time-scales. Recently, however, Clemens (1993) has shown that progress can be made by considering the DAV stars as a group rather than as individuals. Clemens showed that the hottest DAVs have the shortest periods and smallest amplitudes. Also, both period and amplitude increase monotonically with decreasing temperature, consistent with theory. A remarkable result has been the striking similarities in the power spectra of all the DAV stars, which is interpreted as evidence for a very small range of total mass and hydrogen layer mass amongst these stars.

In the case of a multiperiodic star, the characteristic period of pulsation must be defined. Clemens (1993) defined this as the weighted mean period, where the weights are assigned according to the power in each mode. The total pulsation power may apparently vary from night to night (e.g. caused by beating of close frequencies), in which case the observed maximum power is taken as the total pulsation power. With these definitions, both EC23487 − 2424 (Stobie et al. 1993) and EC14012 − 1446 fit the correlation between total power and weighted mean period (fig. 4 of Clemens 1993). Although no independent temperature determination is available for either star, it is predicted, on the basis of their large amplitudes and long periods, that both stars are on the low-temperature side of the instability strip.

EC14012 − 1446 shows a remarkable similarity to the period structure of G29−38, based on the Whole Earth Telescope (WET) observations (Winget et al. 1990), although the period structure of G29−38 appears to have changed from that of the original discovery observations of McGraw & Robinson (1975). The WET campaign reveals the dominant frequency at 1.626 mHz with amplitude 0.06 mag, similar to EC14012 − 1446, and also frequencies near 1.38, 2.50 and 3.27 mHz as observed in EC14012 − 1446.

Considering the DAVs as a group, Clemens (1993) demonstrated that the periods present form a highly non-random distribution in period space with strong clustering near preferred values. EC14012 − 1446 fits this pattern, especially for the periods at 610 and 399 s which fall exactly where there already are strong groupings. On the basis of the shorter period DAVs, Clemens (1993) has identified the modes as principally $l=1$ modes, with the group near 400 s corresponding to $l=1$, $k=6$. More recently, Clemens (private communication) has indicated that Bradley's models predict that a 0.58-$M_\odot$ model at $T_e=13\,000$ K has its $l=1$, $k=11$ mode at 615.4 s, while a 0.65-$M_\odot$ model at $T_e=12\,590$ K has its $l=1$, $k=12$ mode at 616.0 s. The models otherwise have identical properties. Thus there is an ambiguity in model space regarding unique mode identification for EC14012 − 1446. Based on the fact that ~57 s is the approximate period spacing between consecutive k-values for average-mass DAV stars, this leads to the following mode identifications for EC14012 − 1446: $P=399$ s, $k=7$ or 8; $P=530$ s, $k=9$ or 10; $P=610$ s, $k=11$ or 12; $P=724$ s, $k=13$ or 14 (all with $l=1$). On this basis, we can also tentatively identify modes observed in EC23487 − 2424 (Stobie et al. 1993) as $P=804$ s, $k=14$ or 15; $P=868$ s, $k=15$ or 16; and $P=993$ s, $k=17$ or 18 (all with $l=1$). Because these two DAV stars fit the pattern observed in the other DAV pulsators, these results are interpreted as evidence that the DAV stars are remarkably homogeneous as a group, with similar total masses and similar hydrogen layer masses ($M \sim 10^{-4}\ M_*$).

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