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Preliminary XCOV26 Results for EC14012-1446

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Abstract.
EC14012-1446 is a hydrogen atmosphere (DA) white dwarf pulsator. Its rich pulsation spectrum displays a range of excited modes with complex multiplet structure, in addition to numerous combination frequencies. In April 2008, EC14012-1446 was the primary target of XCOV26. We obtained over 300 hrs of nearly continuous high speed photometry with the goal of using the nonlinear pulse shapes to empirically determine the parameters of the convection zone. The Fourier transform (FT) of the light curve contains power between 1000 to 4000 μHz, with the dominant peak at 1234 μHz. We find 13 independent frequencies distributed in 8 modes, as well as a myriad of combination frequencies. In the following, we present preliminary results and lay the groundwork for future investigation leading to light curve fitting of EC14012-1446.

1. Introduction

Every star will meet one of three ends as it approaches the limits of its evolution. If the star is massive, the events triggered by the exhaustion of fuel in the stellar core will lead to a black hole. If the star is of intermediate mass, the product will be a neutron star. If the star is low mass, a definition that includes over 90% of all stars currently on the main sequence, the end product will be an electron-degenerate white dwarf.

White dwarfs play important roles in our understanding of the Galaxy and the universe. The structure and composition of white dwarfs contain records of stages of stellar evolution. The chemical evolution of the Galaxy is traced through the generations of stars formed from contaminated material ejected by pre-white dwarfs as they evolve through the planetary nebula phase. The white dwarf mass distribution and the luminosity function are used to examine the Galaxy's overall formation history. Type I supernovae, in which an accreting white dwarf undergoes a thermonuclear event, are used as distance indicators demonstrating the acceleration of the universe.

Asteroseismology allows us to peer beneath the photospheres of white dwarf stars and reveal the secrets of their interior structure and composition. Pulsating white dwarfs are only unique in their temperatures, as any white dwarf cools, it passes through temperature regimes where oscillations may be excited. The oscillations reveal information about basic physical parameters, such as mass, rotation rate, internal transition profiles, and compositional structure. This information (see for example: Nather et al. 1990; Winget et al. 1991; Winget et al. 1994; Kepler et al. 2000; Kanaan et al. 2005; Provencal et al. 2008) can be applied to the white dwarf

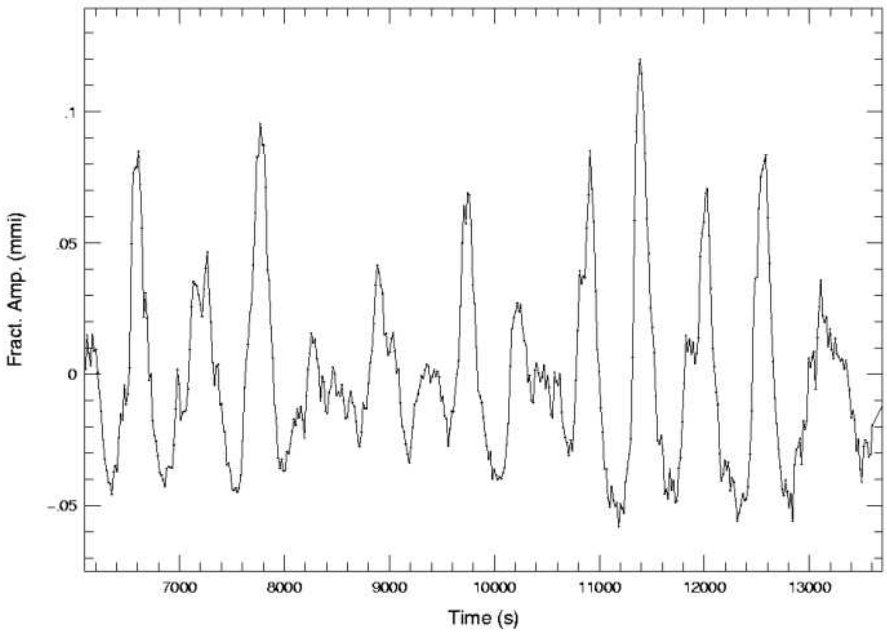

Figure 1. A portion of EC14012-1446-s light curve obtained with SOAR, demonstrating the light curve quality required for Montgomery's fitting technique. The complete light curve can be seen at www.physics.udel.edu/darc.

population as a whole, providing important constraints on a wide range of fields of astrophysical importance.

Asteroseismology is now expanding its focus to attack the fundamental physical process of convection. Convection is one of the largest sources of theoretical uncertainties in our understanding of stars and other natural phenomena. Montgomery (2005) shows how precise observations of variable star light curves can be used to observationally derive the depth of the pulsator's convection zone and its sensitivity to changes in temperature. The Whole Earth Telescope and the Delaware Asteroseismic Research Center are currently conducting a project to map convection across the white dwarf instability strips. The criteria for selecting candidate objects include nonlinear pulsations and a fairly bright target. The ZZ Ceti EC14012-1446 was chosen as a primary target for XCOV26 in April 2008 based on its suitability as a candidate for light curve fitting. In the following, we present the resulting data set, our preliminary analysis of the the light curves and Fourier transforms (FTs), and list the identified frequencies. Our discussion will lay the groundwork for the success of convective light curve fitting with EC14012-1446.

2. Observations

XCOV26 spanned March 25 - April 18 2008, with the densest coverage occurring April 1-14. Our goals were twofold for EC14012-1446: provide accurate frequency identifications, and obtain several nights of very high signal to noise light curves to be combined with the frequency information as required for light curve fitting. Over 20 telescopes participated in the complete run, including SOAR (4 m) and SALT (10 m). EC14012-1446 was the primary target. This DAV ($T_{eff} = 11,300$ K (Koester et al. 2001)) is a multiperiodic high amplitude pulsator discovered by

Table 1. EC14012-1446 Journal of Site Observations

Telescope	Instrument	Length
Hawaii 2.2 m	CCD	6.2
SAAO 1.0 m	CCD	77
Tenerife 0.8 m	CCD	6
McDonald 2.1 m	CCD	32
Loia 1.52 m	CCD	1.1
CTIO 0.9 m	CCD	70
SOAR 4.1 m	CCD	30
SARA 1.0 m	CCD	8
SALT 10.0 m	CCD	2.4
Mt. John 1 m	CCD	6.6
BOAO 1.8 m	CCD	20
Lulin 1.0 m	CCD	10
KPNO 2.1 m	CCD	15
LAS Cumbres 2.0 m	CCD	20
Mt. Abu 1.2 m	CCD	4

Stobie et al. (1995) and observed extensively by Hander et al. (2008). Over 146,000 data points were obtained during XCOV26 by 24 telescopes distributed around the globe, achieving over 80% coverage during the central 5 days of the run. The Journal of Observations for EC14012-1446 is given in Table 1. In the interest of space, we present the total observing time for each site, rather than the individual run names. The individual runs can be found at www.physics.udel.edu/darc.

A goal of all Whole Earth Telescope (WET) runs is to obtain as uniform a data set as possible. XCOV26 was the first full WET run comprised solely of CCD photometers. We minimize bandpass issues by using CCDs with similar detectors and equipping each CCD with a BG40 or S8612 filter to normalize wavelength response and reduce extinction effects. Details of instruments and cycle times can be found at www.physics.udel.edu/darc. We followed the reduction procedures outlined in Provencal et al. (2008). Each reduced light curve consists of a list of times and fractional intensities. Finally, we combined the individual light curves to produce the complete data set. Figure 1 shows a light curve obtained by the SOAR telescope. We obtained 5 nights of SOAR observations and ≈2 hrs of SALT observations. These lightcurves easily achieve the signal to noise required by Montgomery's technique.

3. The Fourier Transform

The XCOV26 Fourier Transform (FT) is given in Figure 2. Following the guidelines and procedures outlined in Provencal et al. (2008), we identify a total of 70 frequencies, including 13 independent frequencies distributed in 10 modes and numerous combination frequencies (Table 2). The main frequencies are at 1633.905 and 1887.405 μHz. We find most of the modes to contain a single dominant frequency. Only the 1887.405 μHz mode exhibits triplet structure, with a splitting of 3.8 μHz. The remaining multiplet splittings do not conform to the predictions of frequency splitting in the limit of slow rotation. We do not find and so cannot confirm the multiplet splittings from Handler et al. (2008).

However, the period spacings provide some information. The two dominant modes, at 1633.905 and 1887.405 μHz, are separated in period by 82 seconds, indicating that these are not consecutive radial overtones. EC14012-1446's mode distribution is difficult to understand

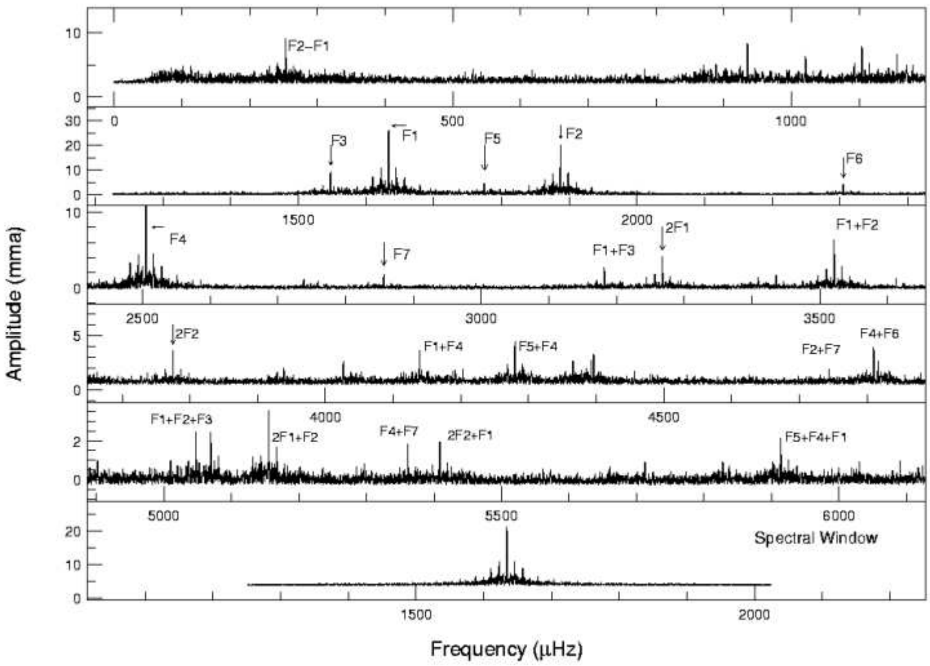

Figure 2. XCOV26 Fourier Transform of EC14012-1446. We find 13 independent frequencies distributed in 8 modes, as well as numerous combination frequencies. The spectral window is given in the last panel.

assuming consecutive overtones of a single l value. We do find some early indications of period spacings of ≈34 seconds, as well as ≈20 seconds. Based on these indications, and given the limitations on log g imposed by spectroscopic evidence, we believe that EC14012-1446's FT contains a mixture of l=1 and l=2 modes. Detailed identifications are still underway.

Handler et al. (2008) reports that EC14012-1445's pulsation modes undergo amplitude and frequency variation similar to that reported in the pulsating DBV GD358 (Provencal et al. 2008). Figure 3 shows EC14012-1446's FTs from 2004, 2007, and XCOV26 (2008). In both stars, the modes with higher radial overtones (higher frequency) show pronounced amplitude variability accompanied by frequency changes. Note in particular the slight frequency shift associated with the 1633 μHz mode, the complete disappearance of power at 1300 and 1400 μHz in the 2008 FT, and the overall lower amplitudes present in the 2008 FT.

Our goal of light curve fitting to determine convective parameters requires that we understand EC14012-1446's stability over the length of XCOV26. We divided the data set into two equal chunks and calculating the FT of each chunk (Figure 4). For the dominant peaks, the frequencies are consistent to within measurement error and the amplitudes remain stable to within 3σ. The differences between each FT are explained by variation in window structure and resolution from chunk to chunk. We are confident that EC14012-1446 was fairly stable over the length of XCOV26.

4. Conclusions

The 2008 XCOV26 observations were obtained with the goal of using EC14012-1446's nonlinear lightcurve to characterize its convection zone. XCOV26 reached both of its observational goals,

Table 2. Table of Independent Frequencies

ID	Frequency (μHz)	Amplitude (mma)
F3	1548.144 ± 0.001	7.9 ± 0.1
	1521.570 ± 0.002	2.2 ± 0.2
F1	1633.905 ± 0.001	25.6 ± 0.1
	1624.017 ± 0.003	3.1 ± 0.2
F5	1775.168 ± 0.002	4.5 ± 0.2
F2	1883.601 ± 0.003	1.6 ± 0.2
	1887.405 ± 0.001	20.6 ± 0.1
	1891.141 ± 0.002	3.7 ± 0.2
F6	2304.730 ± 0.001	4.0 ± 0.1
F4	2504.896 ± 0.001	12.7 ± 0.1
	2508.062 ± 0.002	2.1 ± 0.2
F8	2738.108 ± 0.002	1.2 ± 0.2
F7	2856.161 ± 0.002	2.0 ± 0.2

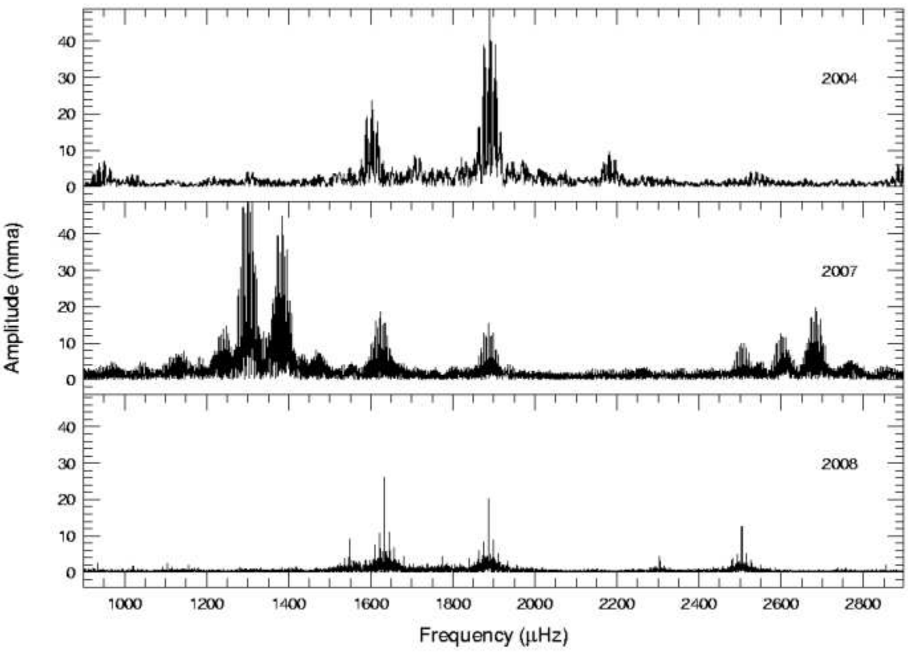

Figure 3. FTs of EC14012-1446 from 2004, 2007, and 2008. EC14012-1446 displays frequency and amplitude changes similar to GD358.

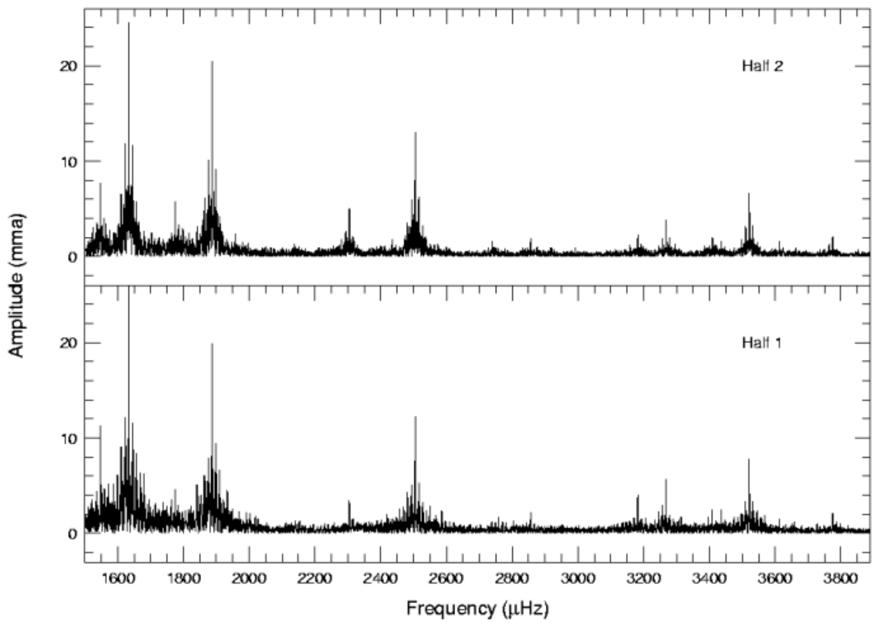

Figure 4. FTs of EC14012-1446 during the first half of XCOV26 (top panel) and second half (bottom panel). EC14012-1446 was fairly stable of the length of the run.

providing us with accurate frequencies for EC14012-1146 and obtaining several nights of high signal to noise light curves suitable for light curve fitting. Our asteroseismic analysis of this data set is still in its early stages, but promises to reveal a great deal of interesting information about EC14012-1446's pulsational behavior. We have identified over 70 frequencies present in the FT, with 13 independent frequencies distributed in 8 modes. While our identifications parallel the results of Handler et al. (2008), EC14012-1446 presented a somewhat different appearance during XCOV26. We find most modes to be dominated by a single frequency and lacking clear triplet structure. In addition, the period spacings seem to indicate that EC14012-1446 pulsates with both l=1 and l=2 modes. These results complicate the l and m identifications necessary for light curve fitting. We are proceeding along a number of fronts, including an examination of the combination frequencies and an analysis of period spacings for all of EC14012-1446's excited modes.

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