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The observational search for tidally tipped pulsation axes in subdwarf B stars

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Abstract. We attempt to interpret frequencies detected in PG 1336-018 with those of a pulsator in which the pulsation axis is influenced by tidal forces and continually points toward the companion. PG 1336-018 is in a close eclibpsing binary with a period of about 2 hours. It was observed by the Whole Earth Telescope in the spring of 2001.

Key words. Stars: pulsating – Stars: asteroseismology – Stars: Binary – Individual: PG1336-018

1. Introduction

In order for asteroseismology to discern the internal conditions of variable stars, the pulsation "mode" as represented mathematically by spherical harmonics with quantum numbers n (sometimes designated k), ℓ, and m, must be identified. For nonradial, multimode pulsating stars, pulsation periods, frequencies and/or the spacings between them are used to discern the spherical harmonics (see for example Winget et al. 1991). These *known* modes are then matched to models that are additionally constrained by non-asteroseismic observations; typically $T_{\rm eff}$ and log g from spectroscopy. Within such constraints, the model that most closely reproduces the observed pulsation periods (or period spacing) for the proper modes is inferred to be the correct one. Occasionally, such models can be confirmed by independent measurements (Reed et al. 2004, Reed, Kawaler, & O'Brien 2000, Kawaler 1999). Unfortunately, more often than not, it is impossible to uniquely identify the spherical harmonics and asteroseismology cannot be applied to obtain a unique conclusion.

Several methods are being pursued to observationally constrain the spherical harmonics including time-series spectroscopy (included in these proceedings are papers by Mathys et al.; and Sachkiv et al.) and multicolor photometry. Our contribution is to use tidal forces in close binaries.

Analogous to the oblique pulsator model described by Kurtz (1992) that has been successfully applied to roAp stars, tidal forces may impact pulsations by inclining the spherical harmonics towards the companion. PG 1336+018 is an sdBV star with an ~M5 companion in a 2.4 hour eclipsing binary during which the companion covers about half of the pulsator (Kilkenny et al., 1998). As the pulsation geometry should align with the strongest force, a measure of the likelihood of the pulsation axis to point at the companion is the ra-

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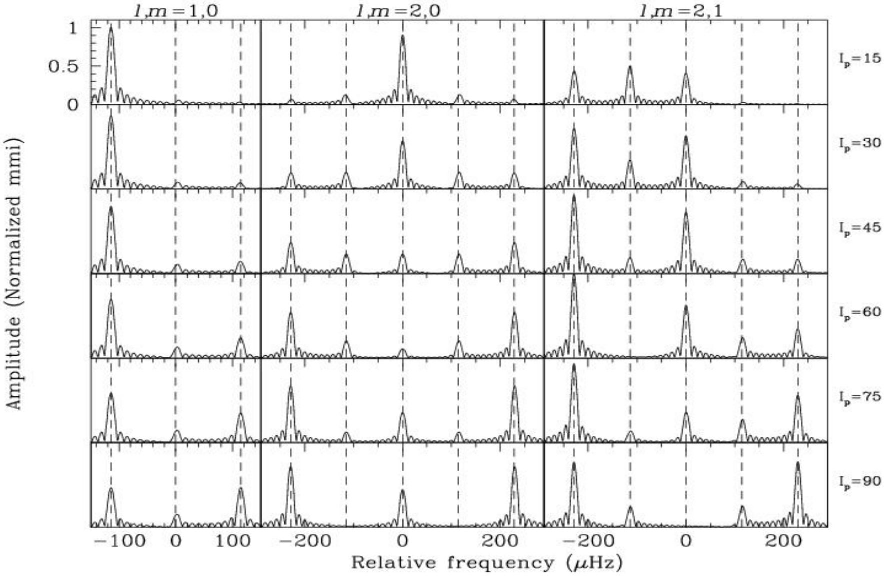

Fig. 1. Fourier transorms of simulated data for PG 1336 for varying degrees of inclined pulsation axes (I_p) for three pulsation modes. The dashed lines indicate the input frequency (at 0) and orbital splittings.

tio of the tidal to centrifugal acceleration. For PG 1336+018, this ratio is 1:2, so we might expect the inclination (I_p) to be intermediate between the two forces.

2. What do we expect to see?

We have previously discussed our simulations to determine the impact on pulsations for a pulsation axis that points at the companion and precesses with the orbital period (Reed, Brondel, & Kawaler 2005; Reed, Kawaler, & Kleinman 2001). For the simulations in this paper, we used pulsation and orbital periods appropriate for PG 1336, allowed the pulsation axis to range from 0 to 90^o compared to the rotation/binary axis, which was set to 81^o, as observed. Figure 1 shows Fourier transforms (FTs) of these simulations for several pulsation modes with varying pulsation geometries. For each panel of the figure, we have taken the FT of a simlated lightcurve with a single input frequency (at 0 μHz), 10 s time steps, and total duraction of about 10 orbital cycles (about a day). All of the pulsation modes shown appear essentially normal until the pulsation inclination exceeds about 60^o. Note that for all of the modes shown, the original, input frequency is not detected for some orientations. This is because the phase of pulsation changes over the orbital period as we observe opposite sides of the star. These opposite phases serve to cancel the input frequency. If the lightcurve is properly divided into regions of like phase for an individual pulsation mode, the central, input frequency is recovered. For the particular modes shown in Fig. 1, we would not expect to see indications of a tipped pulsation axis unless the axis is tipped at least 60^o.

3. What did we really see?

The data reductions were completed in two ways: The complete data set (CDS) was examined for peaks spaced like the simulations in Fig. 1 and the phase-separated data (PSD) for ℓ = 1, 2, and 3 (all m values) were examined for new peaks. Phases were also calculated for

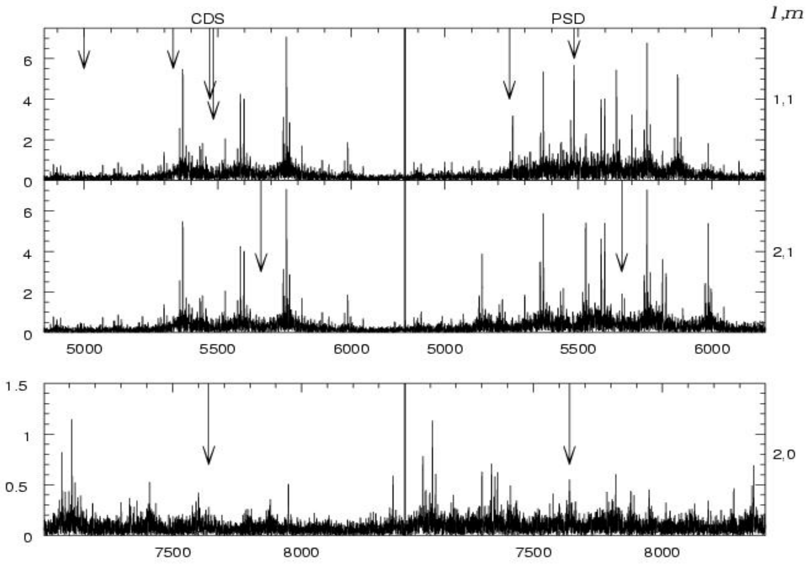

Fig. 2. FTs of the complete data set (CDS; left panels) and phase-separated data (PSD) for the indicated modes (right panels). Inverted arrows in left panels indicate where peaks would be expected in the PSD sets based on splittings in the CDS while those in the right panels indicate which are actually detected.

all the peaks in the PSD sets and examined for 180^o separations.

The left panel of Fig. 2 shows FTs of the CDS (the top 2 panels are the same). Anytime we see a splitting of $2 \times f_{orb}$ (shown in the top panel of Fig. 2), it is an indication of a tipped $\ell = 1$ mode, while splittings of $4 \times f_{orb}$ (shown in the bottom two panels of Fig. 2) indicate either $\ell = 2$ or $\ell,m = 4,1$ modes. The central frequency of such splittings are indicated by inverted arrows in Fig. 2. These indicate where new peaks should appear in properly split PSD sets.

The complete data were also divided into regions of like phases for various plusation modes. Frequencies that match between the two phase sets are then examined to see if they 1) are detected in the complete data or only in the phased data; 2) at a frequency expected if not in the complete data; and/or 4) differ in phase by 180^o as expected. The results are shown in the right panels of Fig. 2 for the three modes for which we believe we have a detection.

4. Conclusions

We have examined data from Xcov 21 to look for indications of tidally modified pulsations and have discovered four likely candidates. Of the two new peaks in the $\ell,m = 1,\ 1$ (top right panel of Fig. 2) PSD sets, the peak at 5485 μHz fits all 3 criteria while the peak at 5212 μHz fits 2 of the 3 criteria (it was not predicted from the CDS). Interestingly, these two new peaks are separated by $2 \times f_{orb}$. The $\ell,m = 2,0$ peak detected at 7620 μHz also fits all 3 criteria for a tidally tipped pulsation mode as does the $\ell,m = 2,1$ peak at 5660 μHz although its amplitude is very low (but would it switch phase if produced by aliasing?).

All of the modes attributed as tipped pulsations require $I_p \geq 60^o$. However, $\ell,m = 1,\ 0$ modes that would be observable at even modest inclinations are not detected. Additionally, we have to wonder why we only detect a single $\ell,m = 2,1$ when there should be two. Another complicating factor is that the four modes we have identified as inclined pulsators, only account for six CDS frequencies. This leaves ≈ 20 frequencies unidentified (albeit, mostly at low amplitudes).

Further investigations will attempt to use the eclipses with the identified tipped modes to place constraints on the actual pulsation inclination.

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