Simulating colour variations in pulsating sdB stars

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Abstract

We combine a grid of high-resolution theoretical intensity spectra with simulated non-radially pulsating stellar surfaces for a variety of pulsation modes. These are used to simulate the light curves in a number of photometric pass bands. We attempt to provide diagnostics for identifying the modes in pulsating sdB stars KPD2109+4401 and HS0039+4302.

Introduction

Mode identification in nonradially pulsating stars is a major issue to be settled. A number of workers (see cf. Stamford & Watson 1981; Watson 1988) have attempted to solve this problem through analysing photometric colour variations. In recent years some of the subdwarf B stars have been discovered to pulsate with many frequencies. They offer an oppurtunity to perform asteroseismic analysis provided their modes are identified. The usual method for mode identification is to obtain the theoretical amplitude ratios and compare these with observations. The theoretical methods mainly involve modelling the flux variations on the surface to obtain the corresponding disk integrated quantities in various photometric pass bands. But this also involves the introduction of nonadiabatic ad hoc parameters (Watson 1988) which is not always desirable. Here we try to provide diagnostics to identify the modes of oscillations in these stars by numerically simulating the colour variations through theoretically generated disk integrated spectra thereby avoiding photometric modelling.
We take two subdwarf B stars KPD 2109+4401 and HS0039+4302. KPD2109+4401 was dicovered independently by Billeres et al.(1998) and Koen(1998). KPD2109+4401 exhibits about seven periods closely spaced between 180s to 200s. It was also a target of high speed spectroscopy(Jeffery & Pollacco 2000) and they found velocity amplitudes of just over 2km/s for two modes of the star. HS0039+4302 was discovered to pulsate by Ostensen et al.(2001). It pulsates in about four frequencies with the periods between 180s to 195s.

Intensity Spectra

Theoretical intensity spectra were calculated for a range of model atmospheres chosen to match approximately the observed properties of KPD 2109+4401 and HS0039+4302. The model atmospheres were calculated using STERNE (Jeffery et al. 2003) on a grid $T_{\rm eff}$ = 28 000(1 000)36 000K, $\log g$ = 5.5(0.1)6.0, a He/H ratio of 0.1 by number and [Fe/H] = −1. The intensity spectra were computed using SPECTRUM v3 (Jeffery 2003), in the wavelength range 2900 – 7500 Å, using 6 angles $\mu = 0.(0.2)1.0$. Typically 25000 metal lines and all H and He lines would be included in the spectral synthesis. (In fact, the high-order members of the Balmer series are not currently treated in the code; we omitted the wavelength range 3650 – 3800 Angstrom from the final analysis).

Simulation of colours

BRUCE (Townsend 1997) was used to simulate the surface of non-radially pulsating stars; of particular importance for us are the temperature and gravity distributions across the visible hemisphere. For the characteristic models we adopted a polar $T_{\rm eff}$ = 32 000K and $\log g$ = 5.8 appropriate for comparison with KPD2901+4401 (Heber 2000) and HS0039+4302 (Edelmann et al. 2003), polar inclination 60° and 30°, equatorial rotation velocity 10 km/s. Simulations were carried out for pulsation models with (l, m) = (0,0),(1,0),(1,1),(2,0),(2,1),(2,2),(3,0),(3,1),(3,2),(3,3). The amplitude for each pulsation was defined to be 10 km/s in velocity. These surface models were convolved with the intensity spectra using KYLIE (Townsend 1997) in order to obtain disk-integrated fluxes as a function of time for a given pulsation mode. We converted these spectra into the Sloan digital sky survey photometric system(SDSS) (Fukugita 1996) by convolving the fluxes with filter functions for u',g',r' filters (Fig 1). We then obtained simulated light curves for each of the filters. Figure 2 shows the simulated light curve for a l=1,m=0 mode for KPD2109+4401 at polar inclination angle of 60°.

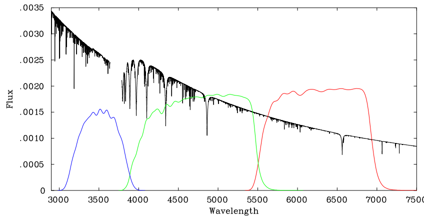

Fig 1. Theoretical flux spectrum for $T_{\rm eff}$ = 32 000K, $\log g$ = 5.8 and [Fe/H] = −1 in then wavelength region 2900 – 7500 Å. The SDSS filter response function for u',g',r' are superimposed.

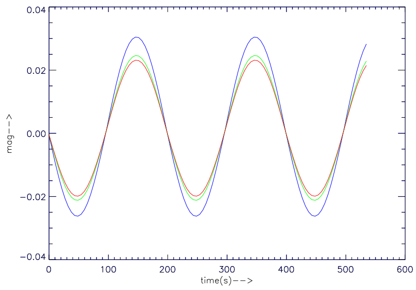

Fig 2. The light curve for l=1,m=0 mode for KPD2109+4401 at polar inclination angle of 60°. The amplitude of u' filter is the greatest followed by g' and r' and there is no phase difference

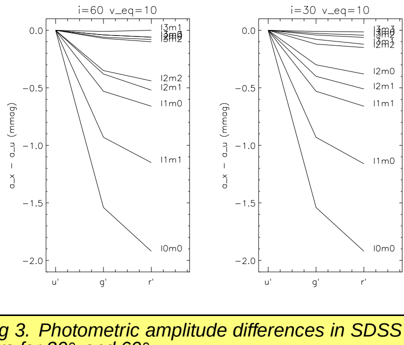

Fig 3. Photometric amplitude differences in SDSS filters for 30° and 60°

Analysis

The total amplitude depends on the amplitude of the oscillation and not on the mode. we use difference in amplitudes $a_{x'} - a_{u'}$ where $a_{x'}$ indicates amplitudes of green and red colours and $a_{u'}$ is the amplitude of the u' filter. From the light curves,we calculated the photometric amplitudes for each filter for two polar inclination angles at 30° and 60° (Fig 3) and obtained the amplitude differences $a_{g'} - a_{u'}$ and $a_{r'} - a_{u'}$ (see table 1). As expected, Figure 3 demonstrates the largest difference between $a_{u'}$ and $a_{g'}$ for low order (l = 0,1) modes; that the $a_{g'} - a_{u'}$ variation is generally smaller than $a_{r'} - a_{u'}$. The inclination angle seems to be an important factor in discriminating between modes of the same spherical degree. We note that there are no phase differences between the various pass bands (see Figure 1).

Table 1. Amplitude differences for various modes $a_{g'} - a_{u'}$ and $a_{r'} - a_{u'}$. ($a_{g'} - a_{u'} \equiv g'/u'$) and ($a_{r'} - a_{u'} \equiv r'/u'$).

		i = 60°		i = 30°	
l	m	g'/u'	r'/u'	g'/u'	r'/u'
0	0	-0.0154	-0.0332	-0.0154	-0.0193
1	0	-0.0053	-0.0660	-0.0092	-0.0115
1	1	-0.0093	-0.0115	-0.0053	-0.0066
2	0	-0.0006	-0.0008	-0.0029	-0.0037
2	1	-0.0036	-0.0052	-0.0040	-0.0051
2	2	-0.0035	-0.0042	-0.0011	-0.0014
3	0	-0.0004	-0.0006	-0.0003	-0.0004
3	1	-0.0001	-0.0000	-0.0008	-0.0012
3	2	-0.0007	-0.0010	-0.0004	-0.0006
3	3	-0.0004	-0.0000	-0.0000	-0.0001

Conclusion

We have combined a theoretical grid of spectra with that of simulated non-radially pulsating stellar surfaces appropriate to two subdwarf B stars KPD 2109+4401 and HS0039+4302. We numerically simulated light curves which were obtained after suitably convolving the theoretical fluxes with the filter functions in Sloan digital sky survey system. We find that there are no phase differences between the pass bands. We also find that the inclination angle between the polar axis and line of sight is an important diagnostic for identifying modes as it can be a discriminating factor between modes of the same spherical degree.

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