SPECTROSCOPIC NON-ADIABATIC DIAGRAMS FOR MULTIMODAL PULSATING STARS

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ABSTRACT. Recently we proposed a new method of mode identification based on spectroscopic nonadiabatic diagrams (Cugier & Daszyńska 2001, As.Ap., 377, 113). Our results are for β Cephei models. These diagram involve the amplitude ratios and phase differences calculated from various oscillating parameters measured from line profiles. We found that the spectroscopic observables are especially useful to determine m values. In this paper we investigate the case of multimodal pulsating models.

Key words: Stars: variable: β Cephei, multiperiodic; Line: profiles, Pulsation: mode identification.

1. Introduction

In many β Cephei stars we observe more than one excited mode of pulsation. The mode identification in the multiperiodic variables is of great importance, because the richer spectra of oscillation frequencies constrain potentially much stronger the stellar properties. Unfortunately the frequency spectra of B type stars are spare, in comparison to the Sun or some white dwarfs, and we need more sophisticated method to derive three quantum numbers, which characterise a given mode of oscillation.

In previous papers we proposed the method of mode identification in β Cephei stars based on the constructing diagrams with amplitude ratios and phase differences derived from various line profile parameters (Cugier & Daszyńska 2001, Daszyńska & Cugier 2001). We adopted the term ***spectroscopic nonadiabatic observables*** for these quantities. The properties of these observables were investigated from calculated time series of theoretical line profiles of Si III 455.26 nm for Main Sequence stellar models with a mass of 10 $M_\odot$. All unstable modes were considered in the limit of the single mode of oscillation. In this paper we study the multimode case.

The plan of the paper is as follows. In Section 2 we describe the method of calculations. The results for a MS stellar model of 10 $M_\odot$ with three unstable modes excited simultaneously are given in Section 3.

2. Model calculations

We calculated time series of Si III 455.26 nm line profiles for the 10 $M_\odot$ stellar model of log $T_{\rm eff}$ = 4.3693 and log g = 3.9137. We used results of linear nonadiabatic calculations of Dziembowski & Pamyatnykh (1993), as well as the line blanketed models of stellar atmospheres of Kurucz (1996), see Cugier & Daszyńska (2001) for details. We selected three modes with the periods: $P_1 = 0.^d11846$, $P_2 = 0.^d15633$ and $P_3 = 0.^d17112$, and assumed the corresponding amplitudes of the radius variations of $\varepsilon = 0.015$, $\varepsilon = 0.005$ and $\varepsilon = 0.003$, respectively. The (ℓ, m)-values are $\ell = 0$ for P_1, $\ell = 2, m = +2$ for P_2 and $\ell = 1, m = -1$ for P_3.

The data contain 3000 line profiles calculated at equally distant time points with the step of 0.005 day. From these line profiles we measured several characteristics including residual intensities measured at the deepest point of the normalized line profiles ($F_{\rm min}$), radial velocities corresponding to $F_{\rm min}$ ($V_{\rm min}$), equivalent widths (EW), full width at the half of maximum ($FWHM$), radial velocities corresponding to FWHM ($V_{\rm hm}$), line intensities at $\lambda_0 = 455.26$ nm (F_{λ_0}) and line intensities at $\lambda_1 = \lambda_0 - 0.05$ nm (F_{λ_1}). The data span an interval of 15 days.

Now, we search frequency spectra of these time series. For this purpose we compute the least-squares (LS) power spectra using Jerzykiewicz's computing code, which is based on the well-known method of Lomb (1976). The computations were carried out with the step of 0.001 cycles day^{-1}. The results were searched for the maximum values of the power, p(f), over frequency interval up to 30 cycles day^{-1}. The frequency responsible for the highest value of the power was found. After prewhitening with this frequency, we repeated the calculations. In some cases the periodogram analysis reveals the presence of many mixed frequencies in addition to the primary frequencies of modes of oscillations. Finally, for a given set of frequencies we calculated synthetic curves, which fit the best, in the sense of LS, the measured quantities as a function of time.

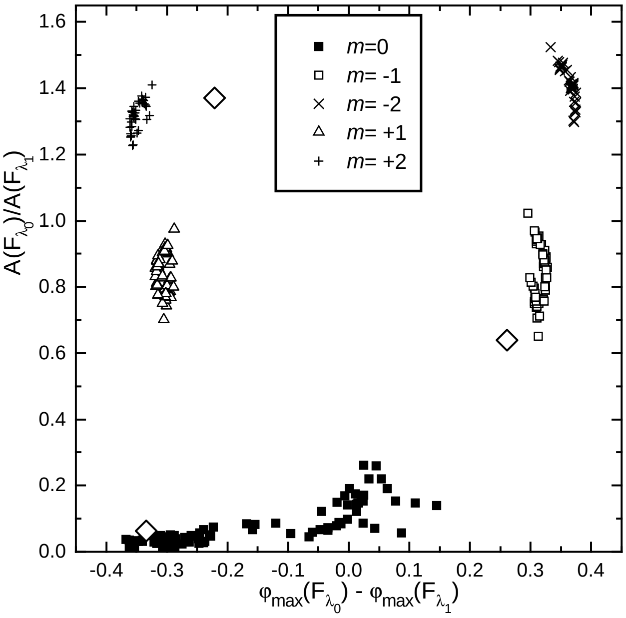

Figure 1: The amplitude ratio *vs.* phase difference for the monochromatic fluxes F_{λ_0} and F_{λ_0}. Modes with different m are marked by various symbols. Big diamonds represent modes retrieved from theoretical calculation for multiperiodic model.

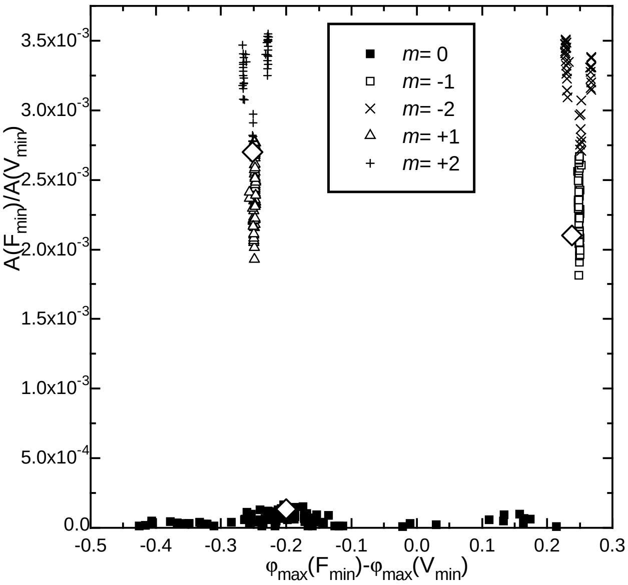

Figure 2: The same as in Fig. 1, but for $F_{\min}$ and $V_{\min}$.

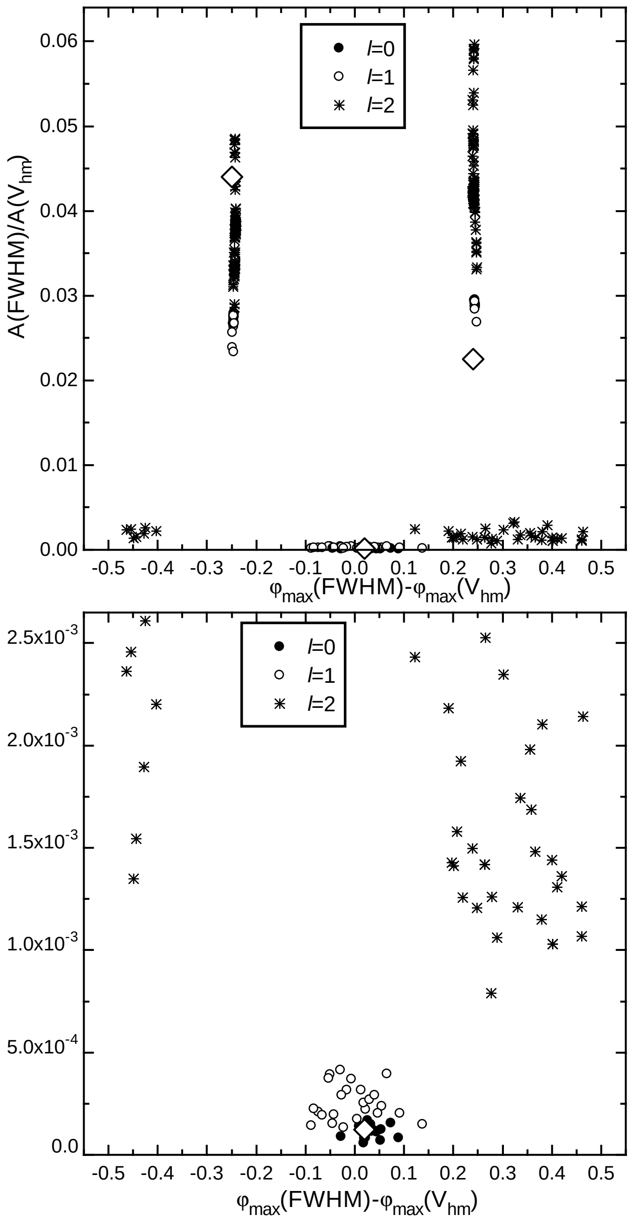

Figure 3: The spectroscopic diagram for the pair $(FWHM, V_{\rm hm})$. Here modes are marked by various symbols with respect to harmonic degree. In the top panel there are all unstable modes with $\ell = 0, 1, 2$, and in the bottom one only zonal modes ($m = 0$).

3. Mode identification for multiperiodic β Cep star

Having frequencies, amplitudes and phases as described in Sect. 2, we constructed various spectroscopic nonadiabatic diagrams in order to check whether it is possible to retrieve the quantum numbers for the modes of oscillations. In Figure 1 we plot the diagram $A(F_{\lambda_0})/A(F_{\lambda_0})$ *vs.* $\varphi(F_{\lambda_0}) - \varphi(F_{\lambda_1})$. Big diamonds are assigned to the three modes studied in this paper. Here we also show all unstable modes with $\ell = 0, 1, 2, m = -\ell, ..., +\ell$ for Main sequence models with the mass of 10 $M_\odot$, at the selected epoch of evolution taken from Cugier & Daszyńska (2001). The modes with different azimuthal order are marked by various symbols. As we can see, the radial mode ($\ell = 0, m = 0$) is in proper place. In the case of the left two modes, ($\ell = 2, m = +2$), ($\ell = 1, m = -1$), we have a good location as far as the amplitude ratio is concerned, but in the values of phase difference they are a little misplaced.

Another example is for the observables $F_{\rm min}$ and $V_{\rm min}$.

Figure 3 illustrates the possibility of deriving the harmonic degree. It turned out that the diagram employing FWHM and radial velocity corresponding to it, $V_{\rm hm}$, is the best to obtain this quantum number. In Figure 3 we show the location our modes on this diagram, where various symbols are for different ℓ-values. As previously the modes obtained from the "multiperiodic" calculation are marked by big diamonds. In this case we have problem only with the mode of ($\ell = 2, m = +2$), because it is located at the joint of two regions: with $m = +1$ and with $m = +2$.

More detailed discussion will be given in a future paper.

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