On the determination of the rotational period of δ Sct stars

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ABSTRACT

We call attention on the possibility of determining the rotational period of a nonradial pulsating star by combining photometric and spectroscopic techniques. The periods are obtained for three δ Sct stars, i.e. X Cae, BV Cir and HD 2724.

1. Mode identification in nonradial pulsating stars

During a pulsational cycle, photometric and spectroscopic variations are induced. In presence of nonradial oscillations (as in the relevant asteroseismologic targets), modelling them is not an easy task. When performing photometric measurements, high-degree modes generate cancellation effects (i.e. equivalent areas moving forward and backward with respect to the observer) and no flux variation is detectable over the noise level. However, the Doppler effect makes these modes spectroscopically detectable: the line profiles define a monodimensional map of the stellar disk and the moving features generate variations. This is the most obvious reason for which photometry and spectroscopy must be used together to obtain a complete pulsational scenario of a nonradial pulsating star, but it also demonstrates the complexity of the matter.

Moreover, to give an asteroseismologic picture of a star doesn't only mean identifying frequencies, but also typifying the excited modes, i.e. providing the spherical harmonic degree ℓ and the azimuthal order m.

Photometric ground-based techniques rely on the fact that the relative amplitudes and phases at different wavelengths depends on ℓ. A review of the possibilities offered by this approach is described by Garrido (2000): excited modes with $\ell \leq 4$ can be identified by this method.

Line profile variations give far more information. In addition to local variations of the radial velocity, a nonradial pulsation causes periodic changes in local temperature and gravity and these effects contribute to the line profile variations. Balona (1987) and Aerts et al. (1992) applied the method of the moments to perform mode identification. As in the case of the photometric approach, this technique is very suitable for low-degree modes, since the moments are quantities derived from integration on the whole line profile.

Independent constraints on mode typing and detection of higher degree ℓ modes can be obtained from the analysis of the time series of the individual pixels defining the line profiles. Fig. 1 shows the amplitudes and phases of the detected modes across the profile of the 4508 Å line in the spectrum of BV Cir. This star's frequency spectrum is very rich in high-degree modes (Mantegazza et al. 2001); the phase plots of the 13.85, 14.95, 15.80, 16.44 and 17.28 c d^{-1} terms are their fingerprints.

It is possible to estimate the ℓ, m parameters of the detected modes by modelling the variations observed on the line profile shape. The technique adopted to separate the contributions of the different modes to the

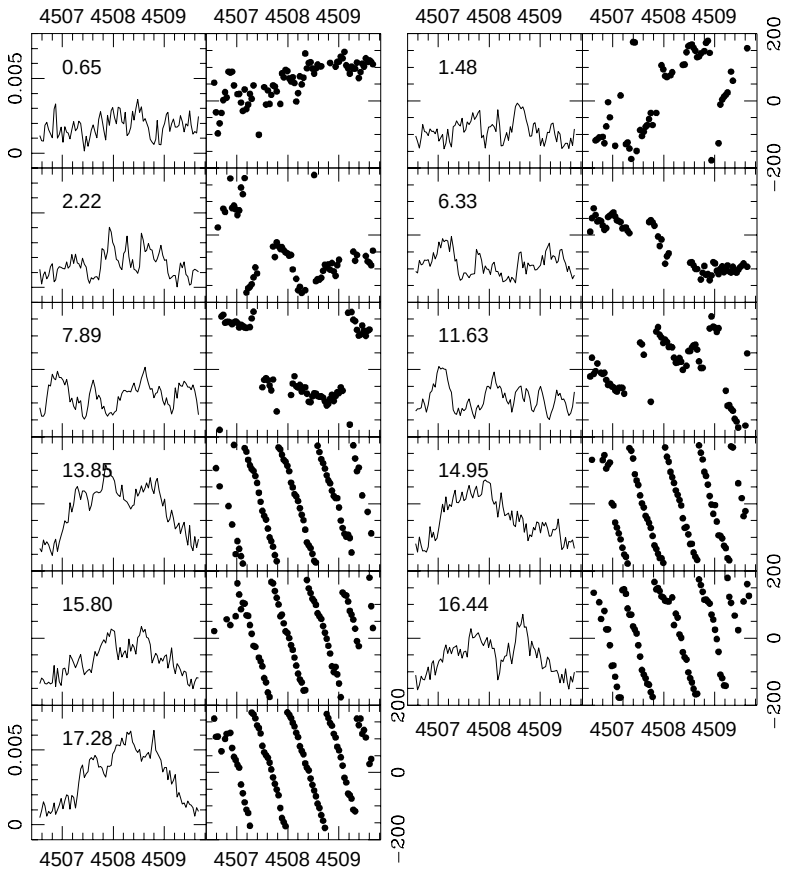

Fig. 1.— Amplitude (left column of panels) and phase (right column of panels) variations of the modes spectroscopically detected on BV Cir. Amplitudes are in units of continuum intensity; phases are in degrees. The frequency of each mode is reported (in c d^{-1}) in the amplitude panels.

global observed line profile variations is described by Mantegazza (2000), who also describes how to fit the observed variations with a theoretical model, computed by using dedicated software (Balona 2000).

2. The determination of the rotational period

In the past years, we have been making a particular effort to observe, photometrically and spectroscopically, some δ Scuti stars, which constitute a good target for asteroseismology. We analyzed the data by using the line profile fitting technique. The best fitting modes are selected according to a "discriminant" which describes how well the candidate mode reproduces spectroscopic, light and colour variations. The ultimate goal was to propose a reliable mode typing. However, we would like to emphasize an intermediate point which deserves attention. For some modes the discriminant is sensitive to the inclination

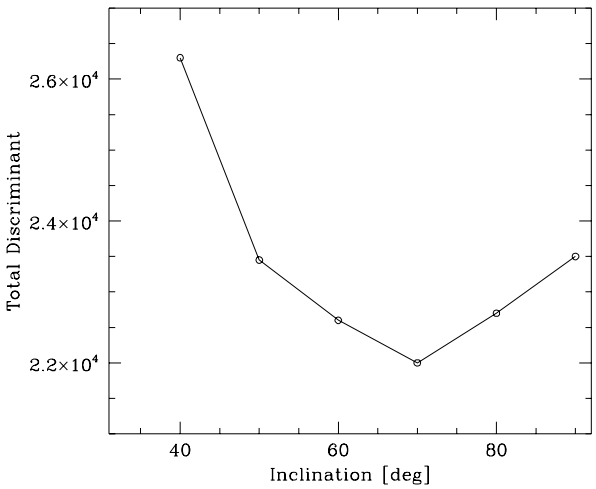

Fig. 2.— Total Discriminant (in arbitrary units) in function of the inclination angle for the spectroscopic observations of X Cae. A value of $70^o \pm 10^o$ can be proposed.

of the rotational axis. Hence, the best fitting procedure allows us to calculate a total discriminant as a function of the inclination angle i which minimum value can fix this angle. In the case of X Cae the result is very impressive (Fig. 2; Mantegazza et al. 2000).

In the same way, we obtained estimates of the i angle also in the case of HD 2724 (Mantegazza & Poretti 1999) and BV Cir (Mantegazza et al. 2001). The analysis of high-resolution spectrograms yields a very accurate value of the projected rotational velocity $v \sin\ i$, and therefore the velocity v can be determined. Multicolor photometry (Strömgren and Geneva systems) was used to derive such stellar parameters as $\log g$, $T_{\rm eff}$, while the HIPPARCOS parallaxes supply accurate M_V values. Since the radius R of the star can also be inferred from these quantities, we have the opportunity to calculate the rotational period of the star. Uncertainties are of the order of $\pm$0.3 d, maybe too large for detailed analysis, but very helpful to yield independent cross checks. Tab. 1 summarizes the process and results.

Star	v sin i [km s^{-1}]	i [deg]	v [km s^{-1}]	Radius [R$_\odot$]	Rotational Period [d]
BB Phe	83.0	70	88	4.7	2.7
X Cae	69.0	70	73	3.4	2.4
BV Cir	96.5	55	117	3.6	1.6

Table 1: Rotational period of some δ Sct stars as derived from combined photometry and spectroscopy.

3. Practical implications

We have described how the determination of the rotational period is accessible, using combined photometry and spectroscopy, in presence of nonradial modes.

When considering ground-based observations, having an estimate of the rotational period is the only way to test the rôle played by the rotational splitting. Unfortunately, the matching of theoretical models is not always feasible as the number of detected frequencies is seldom greater than 20 (multisite campaigns).

In the case of interest here, i.e. continuous high-precision space observations, the number of detected frequencies is expected to increase dramatically. It is known that rotation breaks the degeneracy on m and splits ℓ modes in multiplets, whose symmetry is in turn destroyed by quadratic terms (involving rotation). Moreover, effects of distortion (non-spherically symmetric shape of the star) and of degenerate coupling can be important even at moderate rotation periods (Goupil 2000). As a consequence, a method making the rotational period a quantity we can determine from observations can greatly help us to decipher the multiplet patterns and, in turn, to make steps toward asteroseismological models of δ Sct stars. Of course, an improvement of the period determination is necessary to match the inputs requested by the theoreticians. That can be done with a more continuous spectroscopic survey (after target selection) and from a more accurate calibration of stellar parameters (as derived from multicolor photometry and high-resolution spectra).

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