β Cephei stars and SPBs: excited modes in exciting stars

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ABSTRACT

In this contribution, we first recall some important properties of pulsating early-type B stars. Then, we discuss the relationship between the photometric variability and $v \sin i$, as well as the occurrence of ℓ values in β Cephei stars. We conclude by giving two examples of multiplets in β Cephei stars.

1. Some properties of early-type B stars

Some of the important properties of β Cephei stars and Slowly Pulsating B Stars are summarized in the following table.

β Cephei Stars	**Slowly Pulsating B Stars**
Periods: 3 to 8 hours	Periods: 1 to 3 days
Mono + Multi-periodic	Multi-periodic
Radial + nonRadial	nonRadial
p-modes	g-modes
Number: $\geq$ 100	Number: $\geq$ 100

As one can see, the main observational difference between the two classes of pulsating stars is the pulsation period. This leads to a different observing strategy with ground-based telescopes. For example, making a measurement every 20 minutes is useful for a β Cephei star but not for an SPB. For the latter class, the time spread of observations is more important because they show very long beat periods, and it can take months or even a year to cover them. Concerning these beat periods, we like to emphasize that observing SPBs in the exoplanet field of COROT could be very promising, precisely because of the long observing period so that the complete frequency set can be disentangled.

The position of both classes in the HR diagram is shown in Fig. 1. The β Cephei stars are situated in the upper instability strip, while the SPBs are situated in the lower instability strip. We would like to note that about 90% of the SPBs in this strip were discovered by Hipparcos.

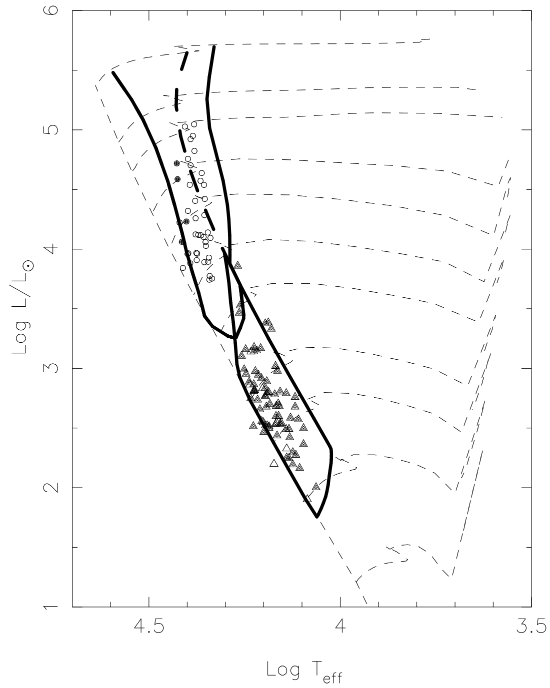

Fig. 1.— A Hertzsprung-Russell diagram showing the instability strips of the β Cephei stars and the SPBs as computed by Pamyatnykh (1997) for $X = 0.7$ and $Z = 0.02$.

2. Needed: Space-Based Photometry

In Fig. 2 we show a time series of high-resolution spectra of a silicon line of the β Cephei star λ Scorpii. The time-averaged line profile is shown in the bottom panel. This mean profile was subtracted from each of the measured spectra, and the residual spectra are shown in grey scales. Time is running up. The bright spots are shallower than the mean profile, the dark spots are deeper than the mean profile. The moving bumps are easily seen. λ Scorpii is an example of a star where the spectroscopic data reveal a richer pulsational behaviour than the ground-based photometry because the accuracy of the latter is not good enough. Disentangling the frequency spectrum with spectroscopy, however, turns out to be very difficult since the time span of such data is most often limited to a few nights. Because we are currently often pushing the limits of ground-based photometry, we encounter more and more of these cases, for which line profile variations reveal more variability than photometry. High-accuracy satellite data, uninterrupted during several weeks, could mean a real breakthrough in these cases.

3. Photometric variability versus *v* sin *i*

Is there an observed relation between the photometric variability and the $v \sin i$ of β Cephei stars? To find out, we searched in the Hipparcos catalogue for the photometric datasets of β Cephei stars, and searched in the literature for $v \sin i$. About 75 stars were retained. For these stars the outliers were removed from the photometric data, and the peak-to-peak photometric variability in millimagnitude was computed. The

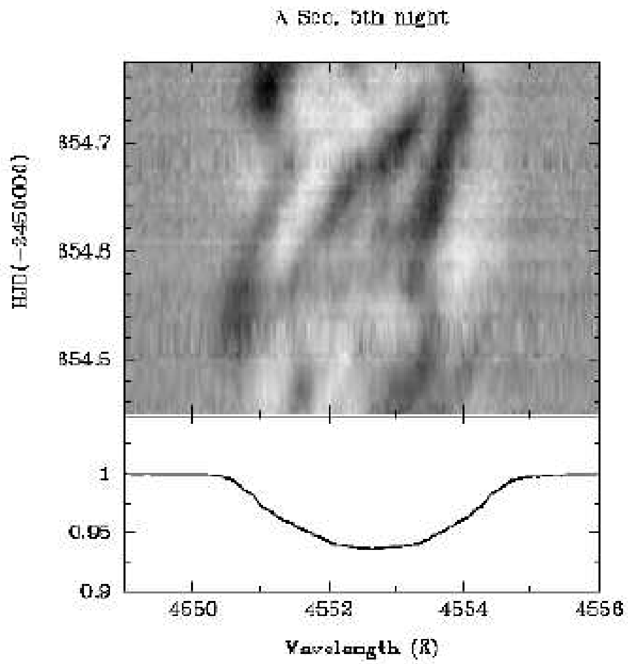

Fig. 2.— A greyscale diagram of the β Cephei star λ Scorpii.

result is shown in Fig. 3. The lonely datapoint at about 200 mmag is BW Vulpeculae which is the only β Cephei star which is known to pulsate nonlinearly. Clearly, most stars fall in a quite homogenous rectangle between $v \sin i = 0$ km/s and $v \sin i \approx 220$ km/s. Our result does not necessarily prove that rotation inhibits pulsation (as is often claimed in the literature), since there are many other explanations possible. Perhaps there *are* simply much less rapidly rotating B stars than intermediatly and slowly rotating B stars. Schrijvers (1999) published a large unbiased sample of observed stars with spectral type between B0 and B3. Only 10% of his sample appears to rotate faster than $v \sin i$ = 220 km/s. Also, the more rapid the star rotates, the broader its spectral lines are, and the more difficult it is to establish a reliable $v \sin i$ or to confirm it as a β Cephei star. Moreover, perhaps the most rapidly rotating B stars are Be stars, so that they are not in our list of confirmed β Cephei stars.

4. ℓ values of β Cephei stars

Do some pulsational degrees ℓ occur observationally significantly more often than others? A sample of 31 β Cephei stars was studied in Leuven by D. Heynderickx in an attempt to answer this question. The stars were intensively observed photometrically, and the identification was done by comparing the observed ratio of photometric amplitudes in different bands, with the theoretical ones (see Heynderickx et al., 1994). The result is shown in the following table.

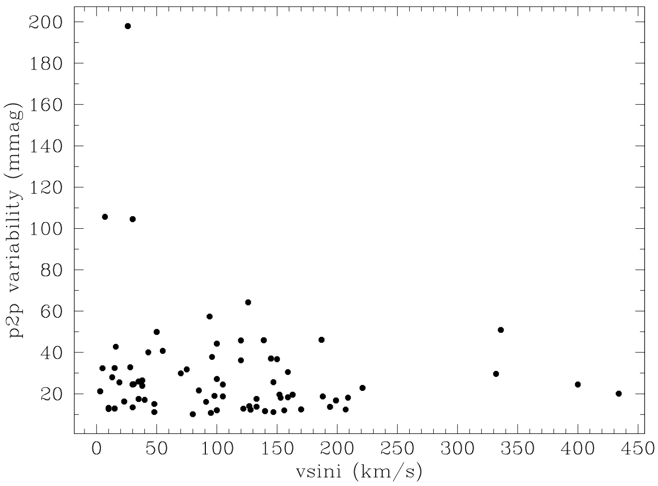

Fig. 3.— The peak-to-peak Hipparcos photometric variability versus $v \sin i$ of some β Cephei stars.

ℓ	$N_{\rm obs}$
0	17
1	11
2	15
3	0
4	6

$N_{\rm obs}$ is the number of observed modes with that particular ℓ; of course, some stars exhibit several modes at the same time. It turns out that the radial mode occurs most frequently, followed not by $\ell = 1$ but by $\ell = 2$. $\ell = 1$ is only the third most observed degree. The fact that $\ell = 4$ occurs much less is to be expected since the higher the degree ℓ the lower the photometric amplitude will be, so that a bias is introduced. The fact that no modes with $\ell = 3$ are observed is curious, but not totally surprising. Several authors (e. g., Stamford & Watson, 1981) remarked that $\ell = 3$ is more difficult to find with photometry than $\ell = 0, 1, 2, 4$. Moreover, some of the $\ell = 3$ modes may be misclassified. We should also not forget that the model used by Heynderickx et al. (1994) was developed for nonrotating stars only. Nevertheless, it *is* peculiar that no mode *at all* is observed with $\ell = 3$. This is certainly worth future investigation. Mode identifications based on spectroscopic data do sometimes result in $\ell = 3$ modes.

5. Multiplets in β Cephei Stars

Do β Cephei stars show interesting frequency multiplets? This is where COROT comes in! But we do already have evidence for multiplets for a few stars from ground-based photometry. We chose to give two examples: 12 Lacertae and β Cephei. Their frequency multiplets are shown in Figs. 4 and 5. Challenging

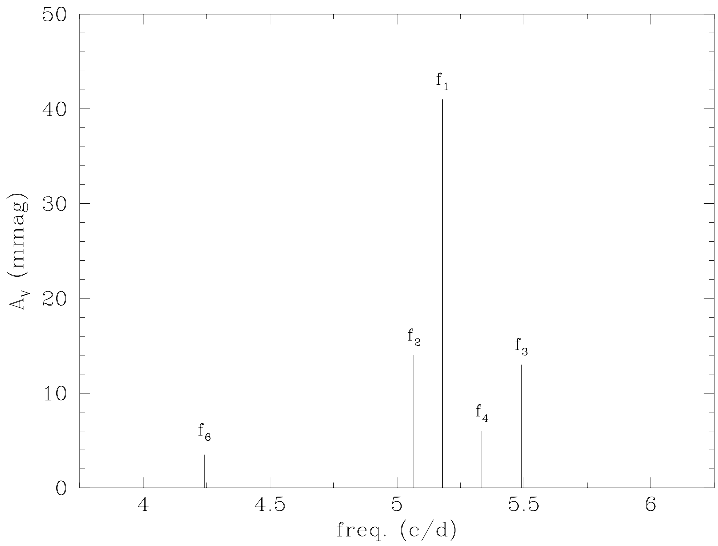

Fig. 4.— The frequency multiplet of the β Cephei star 12 Lacertae.

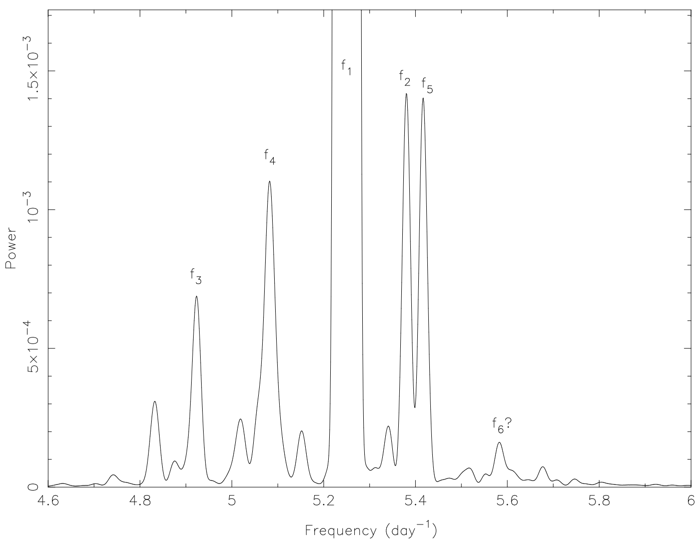

Fig. 5.— The frequency multiplet of the prototype star β Cephei.

about the multiplet of 12 Lac is the triplet f_1,f_3 and f_4, which is exactly equidistant to within observational error. We refer to Dziembowski & Jerzykiewicz (1999) for a detailed discussion. It turns out difficult to model this exact equidistance theoretically. A possible explanation could be nonlinear phase locking.

β Cephei is the prototype star, but at the same time an exception since it is the only β Cephei star in which a magnetic field is detected. This magnetic field causes the frequency multiplet shown in Fig. 5. This multiplet was successfully modeled by Shibahashi & Aerts (2000) with the oblique pulsator model.

6. Conclusion

β Cephei stars and SPBs are an unexploited goldmine of asteroseismological information. B stars provide a unique opportunity to look into massive stars, i. e., the future supernovae which will chemically enrich our Milky Way, and SPBs which exhibite g-modes provide us literally a deep insight in their internal structure.

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