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A Hare and Hound in a BAG: Asteroseismology of β Cephei stars

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Abstract

Several members of the COROT Seismology Working Group (SWG) have performed several "hare-and-hound" exercises to prepare the data exploitation of the mission in the past few years. These exercises consist in reproducing a theoretical model on the basis of a light curve obtained from a frequency spectrum computed from an "unknown" theoretical model of a solar-like or a δ Scuti star. Members of the BAG (Belgian Asteroseismology Group) have now shown that such an exercise in the mass range of β Cephei stars is extremely convincing, making these stars excellent targets for asteroseismology space missions.

Asteroseismology has recently become a very interesting way to probe the interior of stars, and hence, learn more about the physics of stellar interiors. The Sun has been extensively studied, both from the ground and from space. The pulsations of other stars are being observed from the ground, e.g., α Cen (Bouchy & Carrier 2002), 16 Lac (Lehmann et al. 2001, Aerts et al. 2003a), HD129929 (Aerts et al. 2003b). One of the first satellites which will be launched to observe from space the pulsations of stars other than the Sun is the European COROT satellite. COROT will observe some 50 stars for long uninterrupted

times of about 150 days, while several other stars will be observed for shorter times.

In order to carefully choose the targets which will be observed for 150 days, the COROT SWG has undertaken a series of "hare-and-hound" exercises. In such an exercise, one group of people makes up a star within a given error box in the HR-diagram and calculates the oscillation frequencies of that star. Another group transforms the oscillation spectrum into a light curve, given the specifications of the COROT instrument. A third group analyzes the light curve and extracts frequencies. A fourth group then performs a seismic analysis of the star. These useful exercises have been going on within the COROT SWG for several months, considering each time solar-type oscillations in solar-type and δ Scuti stars.

β Cephei stars are massive main sequence stars, of about 9 to 12 solar masses. Their structure is very simple: a rather large convective core surrounded by a radiative envelope. There is no convective envelope. Their metallicity is probably not far from the solar metallicity. They can be described by few parameters: the mass M, the hydrogen mass fraction X, the metallicity Z, the core overshooting parameter α_{ov}, and any quantity related to the evolutionary stage, such as the age. These stars are excited through the κ mechanism in the iron opacity bump around 200,000K. They exhibit f, g and p modes of oscillation, but only the low-degree and low-order modes are excited. Furthermore, their spectrum of frequencies is rather sparse.

Recently, very interesting results have been obtained for β Cephei stars observed from the ground. For the star 16 Lac, three frequencies of well-identified modes are known with very high precision, allowing a rather precise determination of its mass and metallicity. The number of modes identified was however too low to constrain the overshooting parameter (Thoul et al. 2003). The star HD129929 was observed for 20 years, and six frequencies were obtained with high precision. The seismic analysis of that star was performed, and very strong constraints were obtained for its mass, metallicity, and overshooting parameter. In addition, since several multiplets were detected, it was possible to rule out a rigid rotation of its envelope (Aerts et al. 2003b) These encouraging results prove that it is indeed very interesting to study the pulsations of β Cephei stars in full detail.

This is why the BAG (Belgian Asteroseimology Group) decided to perform a "hare-and-hound" exercise for β Cephei stars. The major groups involved in this exercise were the "Leuven group" and the "Liège group", but other teams were also involved. The Leuven team used the Warsaw-New Jersey evolution code and Dziembowski's oscillation code while the Liège team used the stellar evolution code CLES (Code Liègeois d'Evolution Stellaire) and its own oscillation code MAD. The Liège group produced a star (HH1), while the

Leuven group produced another one (HH2), both within a given error box in the HR diagram ($\log T_{\rm eff} = [4.34, 4.36]$ and $\log g = [3.70, 3.90]$). Each group transmitted the oscillation frequencies of their star to data analysis experts who produced a light curve using the COROT instrumental and orbital specifications. Each light curve was then transmitted to the other team who had to extract the oscillation frequencies and perform a seismic analysis of the star. It is important to point out that the models were produced and analyzed using different stellar evolution and oscillation codes.

The outcome of these two hare-and-hound exercises was presented at the 4th COROT Week in Marseille (June 2003). The details of the exercise and the figures can be found in the PowerPoint file of the presentation, on the BAG WebSite

`http://www.asteroseismology.be/B_Stars.ppt`

We give here only the main conclusions of the exercise. The first conclusion is that there is only one possible identification for the modes observed, due to the sparse nature of the oscillation spectrum. In both case (HH1 and HH2) all the excited modes were correctly identified. We have to stress, however, that slow rotation was assumed when determining the oscillation frequency spectra from the chosen model. This is realistic, as most well-studied β Cephei stars indeed have low $v \sin i$ (Aerts & De Cat 2003). It is necessary to resolve the multiplets in order to know the frequencies of the axisymmetric modes. Fitting one frequency fixes the age of the model. Fitting additional frequencies gives information on the other parameters. The splittings in the multiplets give valuable information on the internal rotation law of the star. In the case of HH2, it was possible to differentiate between two models which differed only through the value of the metallicity using an $l = 5$ mode. Such modes have lower amplitudes and cannot be observed from the ground.

The results of the HH2 exercise are shown in Fig.1, where the acceptable output models are compared to the input model. As seen in this figure, through the seismic analysis we were able to get the mass of the model star with a relative accuracy of 1.5% (!), the metallicity Z with a relative accuracy of 10%, and the overshooting parameter with a relative accuracy of 10%. The least constrained parameter was the hydrogen mass fraction. Similar results were obtained for the HH1 exercise. We also compared the frequencies extracted from the light curve to the original frequencies, both for HH1 and for HH2. In both cases, the frequencies were recovered with a relative accuracy of about 10^{-4}.

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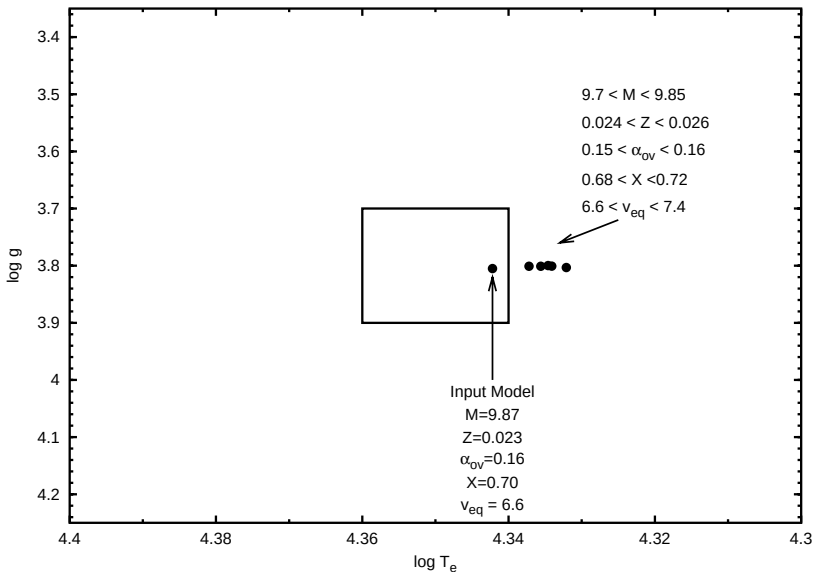

Figure 1: Results of the HH2 exercise

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References

Aerts, C., De Cat, P. 2003, Space Science Reviews 105, 453

Aerts, C., Lehmann, H., Briquet, M., Scuflaire, R., Dupret, M. A., De Ridder, J., Thoul, A. 2003a, A&A 399, 639

Aerts, C., Thoul, A., Daszynska, J., Scuflaire, R., Waelkens, C., Dupret, M.-A., Niemczura, E., Noels, A. 2003b, Science 29, May 2003, (10.1126/science.1084993)

Bouchy, F., Carrier, F. 2002, A&A 390, 205

Lehmann, H., Harmanec, P., Aerts, C., Bozic, H., Eenens, P., Hildebrandt, G., Holmgren, D., Mathias, P., Scholz, G., Slechta, M., Yang, S. 2001, A&A 367, 236

Thoul, A., Aerts, C., Dupret, M.-A., Scuflaire, R., Korotin, S.A., Egorova, I.A., Andrievsky, S.M., Lehmann, H., Briquet, M., De Ridder, J., Noels, A. 2003, A&A, in press