Instability domains of $\delta$ Scuti and Slowly Pulsating B stars: How will the CoRoT satellite help to determine the limits?

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Abstract

This work is intended to illustrate the possibilities offered by the CoRoT satellite observations to study the different instability strips, and through them, physical processes and specific features of stellar interiors.

The CoRoT space mission (Baglin A. et al. 2002), launched on December 27th 2006, has been developed and is operated by CNES, with the contribution of Austria, Belgium, Brasil, ESA, Germany and Spain. It enables us to observe oscillations from stars down to a noise level of less than a ppm, much lower than the limit usually obtained from the ground. During the nominal duration of the mission, about 6 long runs (~ 150 d each) and 6 short runs (~ 20 d each) will take place (CoRoT Book, 2006). Only 2 long runs and 1 short run are illustrated in this study. This means that the number of available targets will have more than tripled by the end of the mission.

These data might help testing the “purity” of the instability strips (i.e. the presence/absence of photometrically constant stars within) and lead to the discovery of new classes of pulsating stars (Degroote et al 2008). We address this problem in the frame of the B and A main sequence stars.

Observations and variability detection

The CoRoT mission has 2 main scientific programs: stellar seismology and search for extrasolar planets. Onboard the satellite are 4 CCDs dedicated to science. Two of them are optimized for seismology (seismofield) and permit the observation of 5 stars each during a run of the satellite. The other two are optimized for the exo-planet search (exofield) and can process up to 6000 stars each. The main difference is that the CCDs for the seismofield handle stars...
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Figure 1: \( \delta \) Scuti-like pulsators from the Initial Run of observations for the exofield (IR01). The diagram shows the theoretical red edge and blue edge (Dupret et al., 2004). The size of the symbols is scaled to the amplitude of the most prominent frequency and ranges from 300 to 30000 ppm (Kaiser, A., private Communication).

with magnitude \( m_V \in [5.4, 9.5] \) with a 1s time-sampling, while those for the exoplanet-search are dedicated to stars with \( m_V \in [10.5, 16] \) with a much lower time sampling (i.e. 512s). For the study at hand, both fields have their own importance as the seismofield offers data with a very low noise level while the large number of stars observed in the exofield allows statistical studies.

Figures 1 and 2 represent HR diagrams related to CoRoT exofield and seismofield observations respectively. In both figures the blue and red edges of the \( \delta \) Scuti instability strips are plotted and figure 2 also shows the red edge of the SPB stars instability strip. Those edges are sensitive to different physical processes, which are developed below.

Figure 1 illustrates the above-mentioned great interest of the exofield for statistics. It features approximately 100 \( \delta \) Scuti stars extracted from the observations of the Initial Run (IR01) in the exofield.

Figure 2 summarizes the results of the variability analysis we conducted on 19 A and B stars observed in the CoRoT seismofield during the first runs of observations. The point size is proportional to the amplitude of the star's observed variations. Known eclipsing binaries have been plotted with empty squares, and CoRoT data, in addition to ground-based complementary observations, will enable us to improve the quality of the binarity parameters as well as discriminate between binarity-related variations and possible pulsations.

Results and Discussion

We describe here the main characteristics of the classes of pulsating stars studied here and the associated results. Table 1 summarizes the parameters and results for these stars, divided into categories each associated with their typical frequency domains.
B stars: SPB stars and Be stars

Slowly pulsating B stars are variable mid-B-type \((B3-B8)\) with periods in the range of 0.5 to 9 days \((\sim 3-20 \mu \text{Hz})\) and g-mode pulsations are reported to be the cause of their variability. Be stars are still on the main sequence or close to it, rapidly rotating, and surrounded by a disk. Early types are close to the \(\beta\) Cephei part of the HR diagram, while later types have pulsational characteristics similar to that of SPB stars. The red edge of the SPB instability strip \((IS)\) is essentially sensitive to the abundance of iron-group elements \((\text{Dziembowski et al. } 1993, \text{Miglio et al. } 2007a)\) and while the accumulation of iron modifies it as shown in Miglio et al. \(2007b\), a quantitative physical justification remains to be found.

All the studied stars in these classes clearly show variability in the expected frequency range. Among them are low amplitude \((\text{less than } 100 \text{ ppm})\) pulsators that could be detected thanks to the low noise-level \((\text{estimated in the power spectrum in areas free of signal close to the frequency range of interest})\) of the seismology field (see Table 1). Note the presence of a \(\beta\) Cephei star in this sample \((\text{HD}180642/\text{B1.5III-III})\), which is also clearly pulsating in its frequency domain \((\text{up to a few } 100 \mu \text{Hz})\). However, its position in figure 2 should not be trusted yet due to a log(L/L_0) value which is clearly underestimated.

A stars: \(\delta\) Scuti stars

\(\delta\) Scuti stars have masses between 1.5 and 2.5 M_\odot and usually pulsate with periods of a few hours \((f = 50 \mu \text{Hz} \text{ to } 600 \mu \text{Hz})\). The \(\kappa\) mechanism, associated with the opacity bump
of Hell, is responsible for the variability of those stars. The red edge of the \( \delta \) Scuti IS can be attributed to the coupling between oscillations and convection. The position of the blue edge, however, is dependent on the abundance of Helium inside the star and the position of the resulting opacity bump.

Eight stars correspond to this class and most of them did show photometric variability. However, this small sample also revealed a few stars with no identified variability down to the 1 ppm level within the \( \delta \) Scuti theoretical IS. They are plotted as diamonds in the HR diagram of Fig. 2 and ongoing research will allow better determination of their parameters. This will enable us to confirm their positions relative to the blue border of the IS. Indeed, firm values of \( T_{\text{eff}} \) and \( M_V \), along with determination of their \( \text{vsini} \) and chemical abundances will help answering the questions about the occurrence of variability in the IS and physical parameters ruling it.

**Conclusions**

This preliminary work is intended to stress the potential of the CoRoT satellite to probe the existing limits between the different types of excitations and variations. To this purpose, the exoplanet field is of utter importance as it contains the greater numbers of stars. The seismology field, however, with very low detection limits and precise individual stellar parameters will bring valuable complementary information.

On one hand, our results show that all B-stars considered here are found variable. At this stage, variability due to e.g. ellipsoidal distortion cannot be rejected, but if confirmed, these results would suggest that the pulsation mechanisms in these stars can be apprehended with
a limited amount of parameters.

On the other hand, we found A-stars that are constant down to the ppm level. This will help assessing which parameters, and beyond them which physical processes, are needed to understand the pulsational instability in this domain of the HR diagram.

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