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CoRoT's view on the variability of O stars: new theoretical challenges

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Abstract. The CoRoT satellite reveals diverse causes of intrinsic variability in a sample of 6 O-type stars: β Cep-like pulsation modes in HD 46202 and HD 47129, sun-like oscillations in HD 46149, and red noise in the hottest targets observed (HD 46150, HD 46223, and HD 46966). A preliminary comparison with stellar models points out several shortcomings and questions to be resolved. An excitation problem is encountered for HD 46202. The physical cause of the existence of red noise is unknown, and the reasons why a behaviour is observed in some targets and not in other ones have not been investigated yet. That requires an in-depth description of the outer layers of the objects. In addition, a fine tuning of the asteroseismic modelling is needed for all three stars with stellar pulsation detected.

1. Context

As part of the asteroseismology programme, 6 O-type stars were observed by CoRoT during the second short run SRa02 (duration of 34 days at a time sampling of 32 seconds) pointing towards the anticenter of the Galaxy. The objects – HD 46149, HD 46150, HD 46202, HD 46223, HD 46966 and HD 47129 – belong to the young open cluster NGC 2244 inside the Rosette nebula and to the surrounding association Mon OB2. They cover spectral types between O4 and O9. All 6 light curves were analysed using standard methods of frequency analysis. We refer to Blomme et al. (2011a), Briquet et al. (2011), Degroote et al. (2010) and Mahy et al. (2011) for detailed studies of the space white-light photometry complemented by ground-based data. A summary of the results presented in these papers is given in Blomme et al. (2011b). Here we focus on the pulsational variability and underline the theoretical challenges brought by CoRoT.

2. Observational results

Stellar pulsations are detected in three O-type objects of the CoRoT sample. Typical β Cep-like pulsations with frequencies between 0.5 and 5 d^{-1} are observed in the O9 V star HD 46202. After removing the orbital period ($P_{orb} = 14.39625$ d) of the binary system HD 47129 (O8 III/I + O7.5 V/III), significant frequencies most probably due to non-radial pulsations are found below 6 d^{-1}. After removing a long period signal (among which a rotation period of 11.8 days), a prominent frequency spacing of 0.48$\pm$0.02 d^{-1} is detected between 3 and 13 d^{-1} for the binary HD 46149 with an O8 V component. The members of this spacing cannot be traced throughout the entire observing run, suggesting a stochastic nature of the modes whose average lifetime is about 3.5 days. The three hotter stars (HD 46223 (O4 V), HD 46150 (O5.5 V) and HD 46966 (O8 V)) show no evidence of periodicities associated to pulsations but rather their light curves are dominated by red noise whose origin is not instrumental.

3. Comparison with theoretical predictions: problems encountered and discussion

For HD 46202, standard CLÉS models (Scuflaire et al. 2008) can reproduce the frequency spectrum observed by CoRoT, allowing to give constraints on the mass and core overshooting parameter of the star (see Briquet et al. 2011). However, there is a discrepancy amounting to 0.24 dex between the $\log g$-value of the best-fitting models and the $\log g$-value determined by spectroscopy. Another important problem is that none of the observed frequencies is predicted to be excited by non-adiabatic MAD computations (Dupret et al. 2002) for an appropriate metallicity Z and opacities currently used in stellar modelling. This excitation problem is similar to those reported in the literature for other β Cephei stars (e.g., Dziembowski & Pamyatnykh 2008), and an increase of opacities in the driving region might be a solution. However, the problem is more acute for HD 46202 than for other β Cephei stars as none of the observed modes is predicted to be excited for the former, while only few of the observed frequencies are missing among the excited ones for the latter. A plausible explanation for the case of HD 46202 is that the star is a fast rotator, which would require new stellar modelling and excitation computations. It could also resolve the current discrepancy between the spectroscopic and asteroseismic $\log g$.

The pulsation modes detected in HD 46149 have a different nature from those observed in HD 46202. They resemble stochastically excited solar-like oscillations that fulfill an échelle diagram (see Degroote et al. 2010) and can be excited by turbulent convection induced by the iron opacity bump located in the upper layers of massive stars (Cantiello et al. 2009, Belkacem et al. 2010). By considering a characteristic spacing between $\ell = 0, 1$ modes in stellar models, there is a good agreement between the location of the observed and theoretical ridges of the échelle diagram but, at low frequencies, the model frequencies deviate significantly from the observed frequencies. A fine tuning of the interior models is needed to obtain a better match.

In order to evaluate the various excitation mechanisms at work in O-type stars in the main-sequence phase but also in view of determining the currently unknown physical cause of the red noise observed in the three hotter objects, an in-depth exploration of the physics in the outer layers is indispensable. Several hypotheses are possible to explain the presence of red noise: is it related to the existence of a sub-surface convection zone (Cantiello et al. 2009), due to granulation or yet to another phenomenon? In any case, this effect seems to appear only in the hottest O stars since such a behaviour is not observed in HD 46202 nor in HD 46149, and is much less prominent in HD 47129.

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