Magnetic Fields throughout Stellar Evolution
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Combining magnetic and seismic studies to constrain processes in massive stars

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Abstract. The presence of pulsations influences the local parameters at the surface of massive stars and thus it modifies the Zeeman magnetic signatures. Therefore it makes the characterisation of a magnetic field in pulsating stars more difficult and the characterisation of pulsations is thus required for the study of magnetic massive stars. Conversely, the presence of a magnetic field can inhibit differential rotation and mixing in massive stars and thus provides important constraints for seismic modelling based on pulsation studies. As a consequence, it is necessary to combine spectropolarimetric and seismic studies for all massive classical pulsators. Below we show examples of such combined studies and the interplay between physical processes.

Keywords. stars: early-type, stars: magnetic fields, stars: oscillations (including pulsations)

1. Modelling oblique magnetic dipoles with pulsations

β Cep is a magnetic pulsating star. It hosts a radial pulsation mode as well as non-radial pulsations of lower amplitude. The line profiles in its spectrum therefore show mainly variations with the pulsation periods in addition to the Zeeman broadening due to the magnetic field. Measurements of the magnetic field in Stokes V clearly show both variations due to the pulsations and the Zeeman signatures of its field. Therefore it is mandatory to take pulsations into account when trying to determine the magnetic field configuration and strength from the Stokes profiles.

For the first time we thus modelled the intensity and Stokes V profiles of a magnetic massive star, β Cep, taking into account its pulsations with the new Phoebe 2.0 code (see Fig. 1), and we compared the results with a standard oblique dipole model without pulsations. Without pulsations we find $\mathrm{i} = 89°$, $\beta = 51°$, $\mathrm{B_{pol}} = 389$ G, while with pulsations our preliminary results are $\mathrm{i} = 70°$, $\beta = 50°$, $\mathrm{B_{pol}} = 276$ G. In particular, the resulting field strength seems significantly lower when taking pulsations into account.

2. Taking magnetism into account in seismic studies

The impact of a fossil magnetic field on rotation and mixing can be estimated following two theoretical criteria: (1) the Spruit criterion (Spruit 1999): Above a critical strength, the magnetic field freezes differential rotation and mixing, and the field stays oblique. Otherwise the structure adjusts to a symmetric configuration by rotational smoothing;

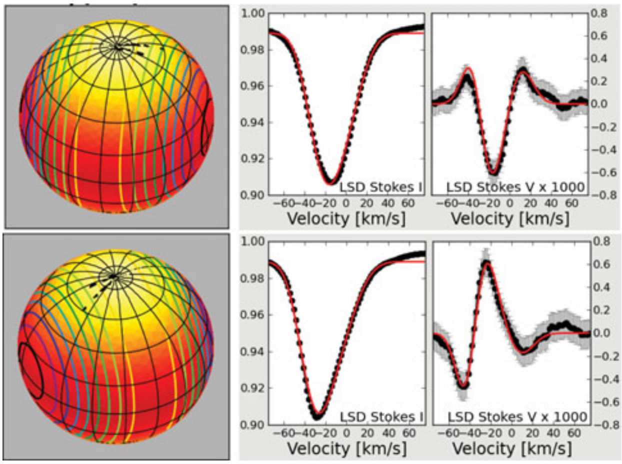

Figure 1. Examples of the modelled surface (left), LSD Stokes I (middle) and V (right) profiles of β Cep fitted with pulsations and magnetic field, at two different phases.

(2) the Zahn criterion (Zahn 2011, Mathis & Zahn 2005): The Lorentz force removes differential rotation along poloidal field lines above a certain field strength and thus removes mixing.

For the magnetic pulsating B star V2052 Oph, the Spruit and Zahn critical field strengths are $B_{crit} = 40$ G and 70 G, respectively. In this star, the measured polar field strength is $B_{pol} = 400$ G (Neiner *et al.* 2012). Therefore we expect no mixing in V2052 Oph. Indeed, a seismic model of the pulsations of V2052 Oph shows no overshoot in this star (Briquet *et al.* 2012). This example shows how a magnetic field study can provide constraints for seismic modelling.

A magnetic field also produces splitting of the pulsation modes and a modification of the amplitude of the pulsation modes. The split multiplet depends both on the strength of the field and on its obliquity (see Shibahashi & Aerts 2000). No magnetic splitting has been identified so far in massive stars. However, the observation with CoRoT of regular splittings in the hybrid B pulsator HD 43317 (Papics *et al.* 2012) and the recent discovery of a magnetic field in this star (Briquet *et al.* 2013) make it an ideal candidate.

3. Conclusions

It is crucial to take pulsations into account when modelling the magnetic field strength and configuration in pulsating massive stars. Moreover, knowing this magnetic configuration provides important constraints on seismic modelling, in particular it constraints the mixing, differential rotation and identification of the modes.

References

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