Massive Stars Near and Far
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Can we detect deep axisymmetric toroidal magnetic fields in stars?

Hachem Dhouib[1], Stéphane Mathis[1], Lisa Bugnet[2], Timothy Van Reeth[3] and Conny Aerts[3,4,5]

[1]Université Paris Cité, Université Paris-Saclay, CEA, CNRS, Astrophysique, Instrumentation et Modélisation Paris-Saclay, F-91191, Gif-sur-Yvette, France
email: hachem.dhouib@cea.fr

[2]Flatiron Institute, Simons Foundation, 162 Fifth Ave, New York, NY 10010, USA

[3]Institute of Astronomy, KU Leuven, Celestijnenlaan 200D, 3001 Leuven, Belgium

[4]Department of Astrophysics, IMAPP, Radboud University Nijmegen, PO Box 9010, 6500 GL Nijmegen, the Netherlands

[5]Max Planck Institute for Astronomy, Koenigstuhl 17, 69117 Heidelberg, Germany

Abstract. The current angular momentum (AM) transport models fail to reproduce asterosieimic observations. One of the best candidates to explain this discrepancy is the magnetic field in radiative zones with its various possible topologies, for instance axisymmetric toroidal magnetic field. If such azimuthal field is strong enough, the Tayler's instability could occur which induces a magnetic torque that allows a very efficient transport of AM and could trigger dynamo action in radiative layers. If such important field does not emerge at the surface, spectropolarimetry is blind. In this case, the only way to detect and characterise the field is by using magneto-asteroseismology. It consists in searching for the characteristic signatures of magnetic field in the observed frequency spectra of stellar oscillations.

Keywords. stars: early-type, stars: interiors, stars: magnetic fields

1. Introduction

Asteroseismology has revealed the existence of a strong extraction of angular momentum (AM) operating in stars. One of the plausible candidates to efficiently carry AM is the magnetic field in stellar radiative zones. Since the seminal work by Spruit (2002), a strong interest has been devoted to axisymmetric toroidal magnetic fields. He suggested that such field could trigger a dynamo action in stably stratified layers (the way the dynamo loop is closed has been debated in Zahn et al. (2007) and Fuller et al. (2019)) and that the resulting magnetic torque allows a very efficient transport of AM. However if such field is present in the radiative envelope but does not emerge at the stellar surface, spectropolarimetry will not be able to detect it. Thus, the key question to answer is how they can be detected and characterised. The only diagnostic tool that we have to address this problem is magneto-asteroseismology (Neiner et al. 2015; Mathis et al. 2021). It consists of searching for magnetic signatures in the stellar oscillations frequency spectrum. We here study the impact of general axisymmetric toroidal magnetic fields on gravito-inertial modes in a non-perturbative way. These modes are the oscillations that propagate in rotating stellar radiative zones under the combined action of the buoyancy force and the Coriolis acceleration. In the magnetised case, these modes become magneto-gravito-inertial modes (MGIM) because of the Lorentz force.

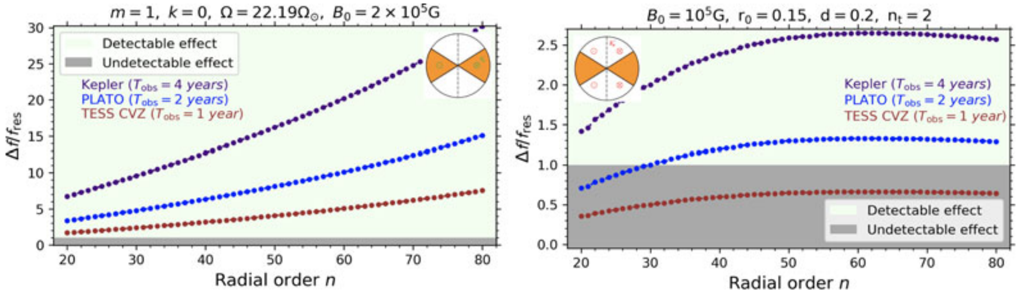

Figure 1. Detectability of the signature of an equatorial (left) and hemispheric (right) toroidal magnetic field on the $\{k=0, m=1\}$ mode as a function of the radial order n using a $1.6M_\odot$ γ Dor model near ZAMS.

2. Magnetic TAR

We generalise the traditional approximation of rotation (TAR) which is intensively used in asteroseismology for the study of low-frequency waves propagating in strongly stratified zones (e.g. Lee & Saio 1997). This approximation allows us to neglect the vertical component of the Coriolis acceleration along the stratification direction because it is dominated by the buoyancy force. The TAR, in its standard version, relies mainly on three assumptions. First, the rotation is assumed to be uniform. Second, the star is assumed to be spherical. Finally, the magnetic field is neglected. To introduce magnetic effects, we derive the magnetic TAR, which includes a general axisymmetric toroidal magnetic field (with a general 2D profile of the Alfvén frequency ω_A) in a non-perturbative way and a general 2D differential rotation Ω. Using this formalism we derive a new generalisation of the Laplace tidal equation (Laplace 1799). The derivation of the generalised magnetic Laplace tidal equation can be found in Dhouib et al. (2022).

As a proof of concept, we applied this new formalism to representative stellar models of typical γ Dor stars during their main-sequence evolution. We choose to investigate the impact of two different configurations of toroidal magnetic field. The first one is an equatorial field localised near the equator. The second is a hemispheric field composed of two magnetic distributions localised in the Northern and Southern hemispheres and vanishing at the equator. As we can see in Fig. 1, the effect of an equatorial magnetic field is in principle largely detectable for all radial orders using nominal TESS CVZ, *Kepler* and PLATO light curves. In opposite, the detection becomes much harder for hemispheric fields because gravito-inertial modes can be equatorially trapped.

3. Conclusion

The inclusion of magnetic effects in stellar oscillation theory and seismic forward modelling will provide important observational constraints on the theory of transport processes in stellar interiors. This would lead to breakthrough in our understanding of the evolution and the magnetism of stars.

Supplementary material

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S1743921322002617.

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