Simulation of Interfero-Polarimetric Observations for Magnetic Stars

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**Abstract.** We propose to use the Spectro-Polarimetric INterferometry (SPIN) technique to resolve complex magnetic field structures on stellar surfaces (Vakili et al., this volume). To define well the observables of this new technique, we apply it first to a model Ap star. These numerical simulations allow us to illustrate the SPIN capabilities for detecting and constraining magnetic fields. Finally, the SPIN signal of β CrB is calculated: we show how the two most recent models proposed by Bagnulo et al. (2000) can be disentangled by SPIN observations.

1. **Introduction**

Adding a polarimeter at the combined focus of a stellar interferometer opens new prospects for studying stellar polarisation phenomena such as scattering processes in extended atmospheres and in circumstellar envelopes around hot

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(O, B, Be) stars or magnetism in numerous kinds of objects (Chesneau et al. 2000). In practice, we measure the fringe signal inside linearly and/or circularly polarised components over a spectral range (Chesneau et al., this volume). For each wavelength and each polarisation, we measure a fringe contrast (or visibility $V$) and a fringe position (also called fringe phase $\Phi$). The complex spectral power spectrum (Fourier transform) of the object brightness is thus sampled at spatial frequencies $B/\lambda$ where $B$ stands for the interferometric baseline projected on the sky and $\lambda$ for the wavelength. Whereas $V$ is sensitive to angular diameter variations, $\Phi$ is directly related to the photocentre displacement of the object. The latter observable, besides when it is recorded across a spectral range in a differential mode, is a powerful means for constraining magnetic field topology of Ap/Bp stars (Rousselet-Perraut et al. 2000).

2. A model Ap star

To illustrate the SPIN capabilities, we compute a model Ap star by assuming a dipolar magnetic field topology, a Voigt profile broadened by the Doppler shift due to the stellar rotation, a Zeeman splitting in a triplet pattern and a uniform distribution of the metallic elements over the stellar disk, which reduces our application to iron lines for which local abundance variations are far smaller than for rare earths, manganese, silicon (see Sect. 5.).

3. SPIN capabilities

The SPIN capabilities have been analysed in detail by Rousselet-Perraut et al. (2000). In the following, we illustrate them within the context of the existing French GI2T Interferometer (Mourard et al. 2000) and the European VLTI array under construction (Glindemann et al. 2000). We consider a spectral resolution $\mathcal{R} = 30 000$ and a baseline length $B$ equal to 50 m (GI2T), 100 m and 200 m (VLTI). The baseline orientation $\psi$ can vary with respect to the stellar coordinate system. The numerical simulations clearly show that:

- SPIN can provide independent constraints on the axial inclination $i$ (angle between the rotation axis and the line of sight) and the obliquity $\beta$ (angle between the rotation axis and the magnetic dipole axis) since the average fringe phase $\Phi_{mean}$ and the maximal variation of the fringe phase $\Delta \Phi$ along the stellar phase vary in opposition versus $i$ and versus $\beta$: the small variations of $\Delta \Phi$ correspond to high inclinations and/or to small obliquities whereas the small $\Phi_{mean}$ correspond to small inclinations and/or to high obliquities. As a rule, rotational Doppler effect tends to reduce these phase variations over a stellar period by a factor 2 to 4 according to the magnetic field geometry. However, stellar rotation can also magnify the SPIN signal, especially in the case of the pole-on dipole.

- Given the strong sensitivity of the fringe phase to anti-symmetric configurations of intensity maps, the SPIN signal can be a powerful means for detecting small fields. Polar fields as small as 100 G can thus be detected with baselines of 200 m or spectral resolutions of 60 000 (Fig. 1).
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Figure 1. Differential circular visibility (left) and fringe phase (right) between the two central pixels for an equator-on dipole vs. polar field $B_{pol}$ ($g=2$). $R = 30000$ (top) or $60000$ (bottom). $B = 50$ m (dash-dot), 100 m (dash) or 200 m (solid). Circles are for illustration only.

Figure 2. Parameters of the two models of magnetic field topology for $\beta$CrB (from Bagnulo et al. 2000).

Figure 3. Fringe phase in the Fe I line (6430.844) versus the stellar phase (left) and the baseline orientation (right) for the Model 1 (solid line) and the Model 2 (dashed line).
4. Application to β CrB

We consider the magnetic field configurations described by Bagnulo et al. (2000): superposition of a dipole and a (non-linear) quadrupole centred on the star, with the parameters given in Fig. 2. We also assume an angular diameter of 1 mas and a rotational velocity \( v \sin i \) of 3.5 km/s. The fringe phases in the Fe I \( \lambda 6430.8 \) line are obviously different for the two models (Fig. 3). In particular, the phase variations versus stellar phase and versus baseline orientation are in antiphase for the two models and the whole variation amplitude equals 2.6° for Model 1 and reaches 4.6° for Model 2.

5. Conclusion and perspectives

Numerical simulations indicate promising capabilities of the SPIN technique, which will be validated by observations with the GI2T. Further simulations are foreseen for hydrogen lines using the formalism of Brillant, Mathys, & Stehlé (1998) and to explore the effect of abundance inhomogeneities on the SPIN signal. Finally this novel technique will be more powerful on future optical arrays (VLTI, CHARA, . . . ), in a first step, with phase closure information and inversion techniques (Jankov et al. 2001) and, in the medium term, with highly resolved polarised images of stellar surfaces and environments. We also emphasise that the SPIN technique can obviously be applied to other classes of objects where various physical mechanisms can be at play at the same time.

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References