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The magnetic properties of Am stars

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Abstract. We present the results of a spectropolarimetric study of three Am stars: β UMa, θ Leo and Alhena. Two of the three stars of this study showed peculiar magnetic signatures with prominent positive lobes, like the one of Sirius A, that are not expected in the standard theory of the Zeeman effect. Alhena, contrary to Sirius A, β UMa and θ Leo, exhibits normal signatures. The follow-up spectropolarimetric observations of Alhena allowed us to determine the magnetic properties of this star.

Key words: stars: magnetic fields – stars: early-type – stars: chemically peculiar

1. Introduction

Magnetic fields play an important role in the evolution of intermediate-mass stars. Until recently, among this kind of stars, the chemically peculiar Ap/Bp stars were the only known magnetic stars. The topology of the fields in these stars is quite simple (usually mostly a dipole) and the strength is above 300 G. This vision of the magnetic fields in intermediate-mass stars was disrupted by the discovery of an ultra-weak magnetic field (longitudinal magnetic field below 1 Gauss) at the surface of the fast rotating normal star Vega (Lignières et al., 2009; Petit et al., 2010) and raised the question of the existence of such kind of magnetic field in all intermediate-mass stars that do not host a strong magnetic field.

A first weak signature was discovered in the Stokes V profiles of the Am star (i.e. chemically peculiar stars showing metallic lines), Sirius A (Petit et al., 2011). However, the observed signature in circular polarization exhibits a prominent positive lobe. This signature shape is not expected in the normal Zeeman theory. Therefore, the peculiar signature in the polarized profile remained a puzzle and required further investigation.

As a consequence, we observed three other Am stars with ultra-high precision spectropolarimetry: β UMa, θ Leo and Alhena. Detecting ultra-weak fields in Am stars is challenging due to the weakness of the expected signatures. The three objects are early A-type targets and have similar stellar parameters.

The targets were observed with the Narval spectropolarimeter, installed at the 2-meter Bernard Lyot Telescope (TBL) at the summit of Pic du Midi Observatory in the French Pyrénées. We used the polarimetry mode to measure circular polarization (Stokes V).

2. Magnetic analysis

To test whether the stars are magnetic, we applied the Least-Squares Deconvolution (LSD) technique (Donati et al., 1997) on each spectra using a line list adapted for each star.

For β UMa and θ Leo, we did not obtained a detection in the individual LSD profiles. To further improve the signal-to-noise ratio, we thus co-added all LSD profiles of each star, resulting in one single averaged LSD profile. The Stokes profiles of β UMa and θ Leo display peculiar signatures with a prominent positive lobe (see Fig. 1) similar to the signatures of Sirius A. This kind of signatures is not expected in the normal Zeeman theory, and required investigations to confirm or refute the magnetic origin of these signatures. For β UMa and θ Leo, we demonstrated thanks to several tests that the peculiar signatures are due to a magnetic field (see Blazère et al. 2016 for more details).

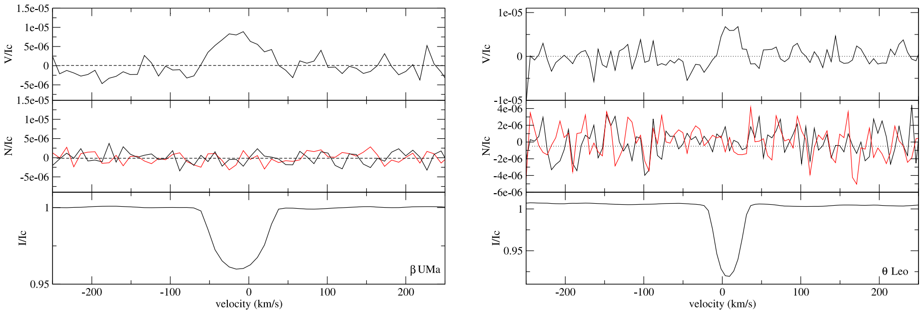

Figure 1. Co-added LSD profiles in Stokes I (bottom) and V (top). The two available "null" control parameters Null1 and Null2 are shown in the middle panel. *Left*: β UMa observations. *Right:* Same figure for θ Leo. Taken from Blazère et al. (2016)

For Alhena, contrary to β UMa and θ Leo, we obtain magnetic detections in the individual LSD profiles. The Stokes V profiles exhibit normal Zeeman

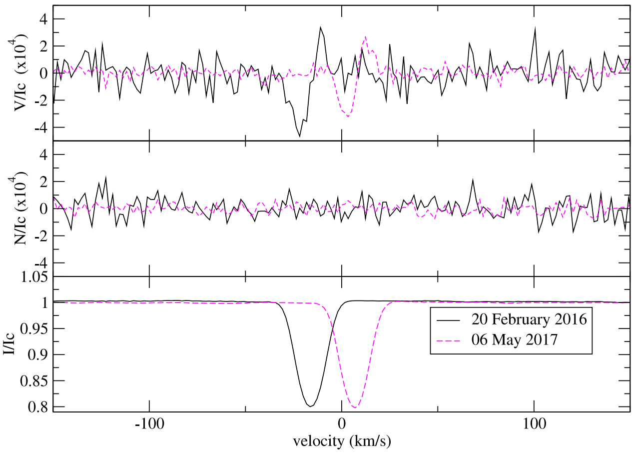

Figure 2. Example of LSD profiles in Stokes I (bottom), Stokes V (top), and "null" polarization (center) for two different nights of observations. All profiles are normalized to the intensity continuum level.

signatures for each night of observations. Examples of the LSD profiles are shown in Fig. 2. It is the first detection of normal signatures at the surface of an Am star.

The longitudinal field values (B_l) of Alhena were calculated thanks to the centre-of-gravity method (Rees & Semel, 1979). The longitudinal magnetic field is negative for each night of observations with values between -10 G and -3 G.

The Stokes V signatures were modelled using an oblique rotator model, assuming a dipole for the magnetic field of Alhena and a rotational period of 8.975 days (see Blazère et al. in prep. for more details). The best fit corresponds to an inclination of $22.8\pm4.1°$, an obliquity angle of $34.1\pm3.4°$, and a dipolar field strength of 32.4 ± 1.7 G.

Figure 3 shows the comparison between the observed and the best fit synthetic LSD V profiles for all observations. The model matches quite well the Stokes V profiles but it is not perfect. This difference between the model and the observations can be due to a more complex field than a dipole or due to non-rotational variations of the magnetic field or of the line profiles.

The magnetic map at the surface of Alhena was reconstructed thanks to the Zeeman-Doppler Imaging technique (ZDI, Donati & Brown 1997; see Fig. 4). The reconstructed field is compatible with a dipole. The surface differential rotation of Alhena was measured, following the method developed by Petit et al. (2002) that assumed a simplified solar rotation law. A differential rotation was detected at the surface of Alhena (Fig. 5).

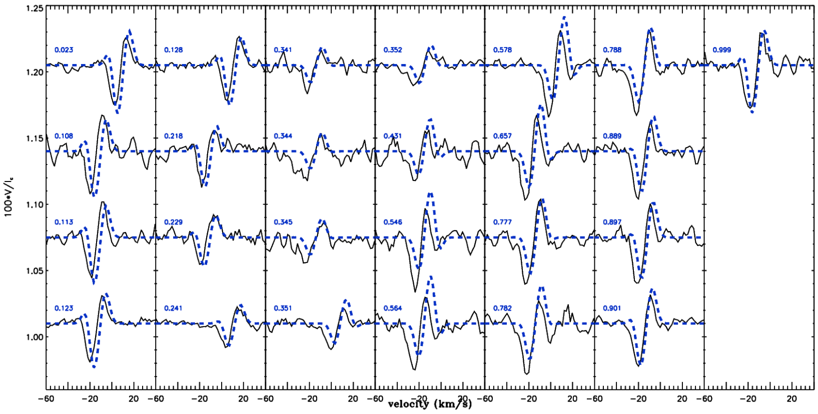

Figure 3. Best dipolar model fit (blue) of the observed Stokes V profiles (black) of Alhena. The blue numbers correspond to the rotational phase.

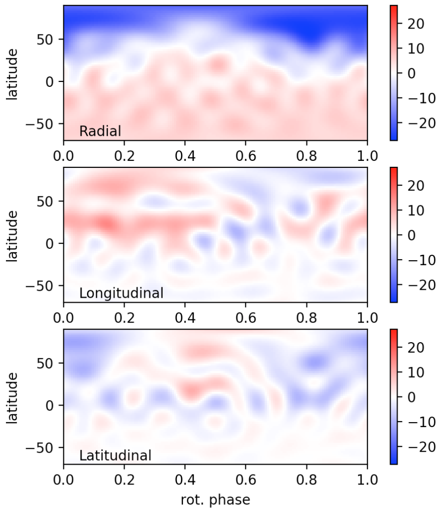

Figure 4. Magnetic map of Alhena. The three panels illustrate the field components in spherical coordinates (top: radial, center: azimuthal, and bottom: meridional). The magnetic field strength (colour scale) is expressed in Gauss.

3. Conclusion

Only four Am stars were observed with the required precision to detect ultra-weak magnetic fields, and all of them indeed host a weak magnetic field. Three of them (Sirius A, β UMa and θ Leo) show peculiar magnetic signatures with a prominent positive lobe and one star (Alhena) shows a normal Zeeman signature. The preliminary explanation for the peculiar signatures observed in most Am stars is a combination of a vertical gradient in velocity and in magnetic

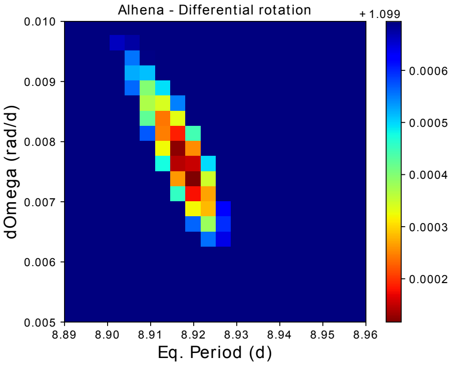

Figure 5. Surface differential rotation of Alhena.

field in the surface layers of the stars. This explanation is sustained by the fact that these Am stars have a high microturbulence and host a superficial layer of convection. The Am star that hosts a normal signature (Alhena) has a lower microturbulence compared to the other Am stars. Its microturbulence is close to the one of Vega, which also displays a normal signature. Alhena hosts a weak magnetic field with a dipolar strength of $\sim 30\,$G. However this value is higher than the one of Vega. Finally, we discovered for the first time a differential rotation at the surface of a magnetic intermediate-mass star.

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