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A NEW FAMILY OF MAGNETIC STARS: THE AM STARS

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Abstract.
We presented the discovery of an ultra-weak field in three Am stars, β UMa, θ Leo, and Alhena, thanks to ultra-deep spectropolarimetric observations. Two of the three stars of this study shown 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, show normal signatures. These detections of ultra-weak fields in Am stars suggest the existence of a new family of magnetic intermediate-mass stars: the Am stars. However the various shapes of the signatures required further observation to identify the physical processes at work in these stars. A preliminary explanation is based on microturbulence.

Keywords: Stars: magnetic fields,

1 Introduction

Magnetic fields play an important role in the evolution of intermediate-mass stars. However, the properties of these magnetic hot stars are still poorly understood. About 10% of intermediate mass stars are found to be strongly magnetic with a longitudinal magnetic field in excess of 100 G (Aurière et al. 2007).

A first ultra-weak magnetic field was discovered on the normal A star Vega (Lignières et al. 2009). The magnetic maps constructed thanks to Zeeman Doppler Imaging (ZDI) show a magnetic spot close to the pole. This discovery raises the question of the existence of ultra-weak magnetic fields in the $\sim$ 90% of stars that do not host a strong field.

A first weakly magnetic Am star (i.e. chemically peculiar stars showing metallic lines), Sirius A, was discovered by Petit et al. (2011). However, the observed signature in circular polarization is not of null integral over the line profile as in other intermediate-mass stars, since the Stokes V line profile exhibits a positive lobe dominating the profile. This signature shape is not expected in the normal Zeeman theory. Therefore, the abnormal shape of the polarized profile remained a puzzle and required further investigation.

As a consequence, we observed three Am stars: β UMa, θ Leo, and Alhena. Detecting ultra-weak fields in Am stars is challenging due to the weakness of the expected signatures. The fundamental parameters of all targets are presented in Table 1. The three objects are early A-type targets and have similar stellar parameters.

2 Observations

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).

We obtained 149 spectra of β Uma collected in 2010 and 2011, 171 spectra of θ Leo collected in 2012, 2013, and 2014 and 20 spectra of Alhena gathered in October 2014 and between September 2015 and April 2016 in the frame of the BritePol project (see Neiner et al. 2015).

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Table 1. Fundamental parameters of β UMa, θ Leo and Alhena

	β UMa	θ Leo	Alhena	Sirius A
spectral type	A1Vm	A2Vm	A2Vm	A1Vm
$T_{\rm eff}$ (K)	9600^a	9350^b	9260^e	9900
log g	3.6^a	3.83^c	3.65^b	4.33
Mass $M_\odot$	2.7 ^{d}	2.7 M^d	2.5 ^{d}	2.12
Radius $R_\odot$	3.9 ± 0.1 ^{d}	3 ^{a}	4.3	1.7 ^{a}
Microturbulence	$2.0\text{-}2.65^e$	$2.1\text{-}2.4^d$	$1.0\text{-}1.4^d$	$1.8\text{-}2.0^f$

[a] Boyajian et al. (2012) [d] Adelman et al. (2015)
[b] Smith & Dworetsky (1993) [e] Adelman (2014)
[c] Monier (2005) [f] Landstreet (2011)

3 Data Analysis

To test whether the stars are magnetic, we applied the well-known and commonly used Least-Squares Deconvolution (LSD) technique (Donati et al. 1997) on each spectra and computed LSD pseudo line profiles from all available photospheric lines. The line-lists used for LSD were created from a list of lines extracted from the VALD data base (Piskunov et al. 1995; Kupka & Ryabchikova 1999) using the respective effective temperature and log g of each star (Table 1). We removed the H lines, the lines blended with the H lines and the lines that are not visible in the spectra.

For β UMa and θ Leo, we did not obtain detection in the individual LSD profiles. To further improve the signal-to-noise ratio, we then co-added all LSD profiles of this star, resulting in one single averaged LSD profile for each star. The result are shown in Fig. 1.

The Stokes profiles of the 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 infirm 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. 2016b for more details).

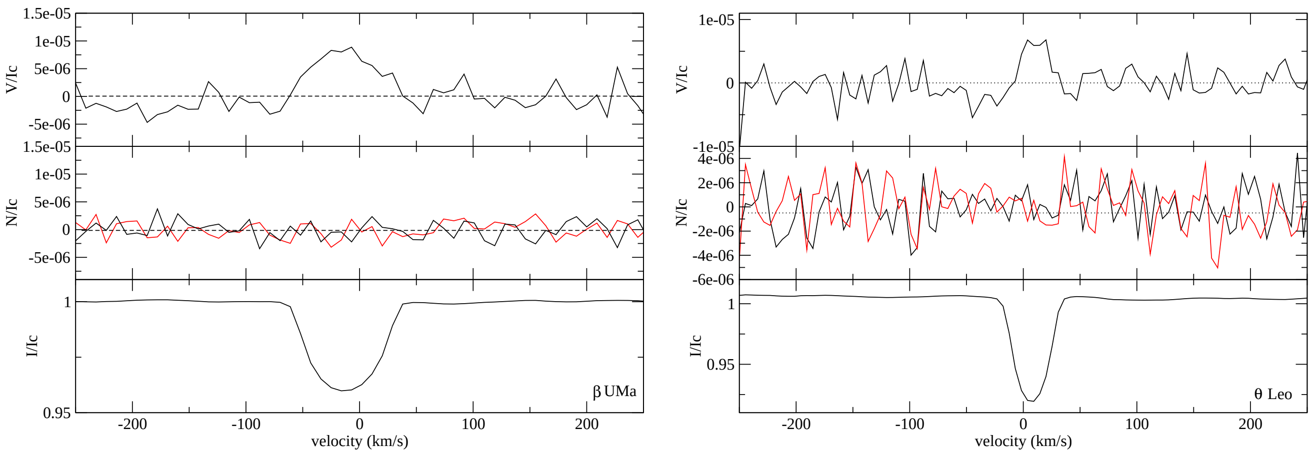

Fig. 1. Co-added LSD profiles in Stokes I (bottom) and V (top). The two available "null" control parameters Null1 and Null2 are shown in the middle panel. Top: β UMa observations. Bottom: Same figure for θ Leo. All profiles are normalized to the continuum level. Taken from Blazère et al. (2016b)

For Alhena, contrary for β UMa and θ Leo, we obtain detections in the individual LSD profiles. Examples of the LSD profiles are shown in Fig. 2. The shape of the Stokes V signatures is as expected in the standard Zeeman theory, like the one of Vega, and change slightly with time (see Blazère et al. 2016a for more details). The measured longitudinal magnetic fields is between -5 G and -10 G, which implies a minimal dipolar field strength of ∼30 G. That is weak but higher than the one of Vega (∼ 7 G, Petit et al. 2010).

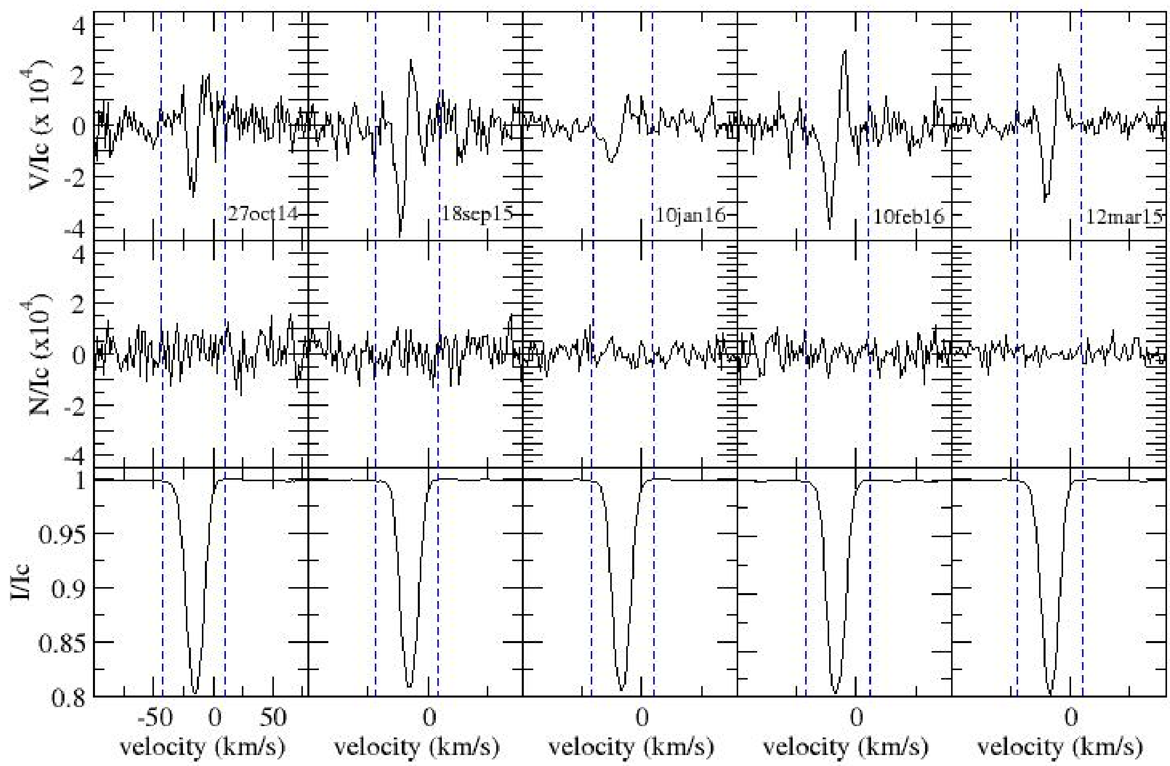

Fig. 2. Example of LSD profiles in Stokes I (bottom), Stokes V (top), and "null" polarization (center) for different nights of Alhena observations. All profiles are normalized to the continuum level.

4 Conclusion

Only 4 Am stars were observed with the required precision to detect ultra-weak magnetic fields, and all of them host a weak magnetic field. These stars belong to a new family of magnetic stars: the magnetic Am stars. 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 gradient in velocity and in magnetic field. 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. Therefore, microturbulence could be an explanation for the peculiar versus normal signatures in Am stars. All Am stars observed so far have similar spectral parameters (temperature, mass, radius, metallicity,...), they are hot and their Am character is weak. Observing cooler Am stars and stronger Am stars could help us to understand the physical processes that produce the peculiar signatures and determine if the amplitude and shape of the magnetic signatures depend on particular stellar parameters.

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References

Adelman, S. J. 2014, PASP, 126, 505
Adelman, S. J., Gulliver, A. F., & Kaewkornmaung, P. 2015, PASP, 127, 340
Aurière, M., Wade, G. A., Silvester, J., et al. 2007, A&A, 475, 1053
Blazère, A., Neiner, C., & Petit, P. 2016a, MNRAS
Blazère, A., Petit, P., Lignières, F., et al. 2016b, A&A, 586, A97
Boyajian, T. S., McAlister, H. A., van Belle, G., et al. 2012, ApJ, 746, 101
Donati, J.-F., Semel, M., Carter, B. D., Rees, D. E., & Collier Cameron, A. 1997, MNRAS, 291, 658
Kupka, F. & Ryabchikova, T. A. 1999, Publications de l'Observatoire Astronomique de Beograd, 65, 223
Landstreet, J. D. 2011, A&A, 528, A132
Lignières, F., Petit, P., Böhm, T., & Aurière, M. 2009, A&A, 500, L41
Monier, R. 2005, A&A, 442, 563
Neiner, C., Grunhut, J., Leroy, B., De Becker, M., & Rauw, G. 2015, A&A, 575, A66
Petit, P., Lignières, F., Aurière, M., et al. 2011, A&A, 532, L13
Petit, P., Lignières, F., Wade, G. A., et al. 2010, A&A, 523, A41
Piskunov, N. E., Kupka, F., Ryabchikova, T. A., Weiss, W. W., & Jeffery, C. S. 1995, A&AS, 112, 525
Smith, K. C. & Dworetsky, M. M. 1993, A&A, 274, 335