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ULTRA-WEAK MAGNETIC FIELDS IN AM STARS: β UMA AND θ LEO

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Abstract. An extremely weak circularly-polarized signature was recently discovered in spectral lines of the chemically peculiar Am star Sirius A (Petit et al. 2011). This signal was interpreted as a Zeeman signature related to a sub-gauss longitudinal magnetic field, constituting the first detection of a surface magnetic field in an Am star. We present here ultra-deep spectropolarimetric observations of two other bright Am stars, β UMa and θ Leo, observed with the NARVAL spectropolarimeter. The line profiles of the two stars display circularly-polarized signatures similar in shape to the observations gathered for Sirius A. These new detections suggest that very weak magnetic fields may be present in the photospheres of a significant fraction of intermediate-mass stars, although the strongly asymmetric Zeeman signatures measured so far in Am stars (featuring a prominent positive lobe and no detected negative lobe) are not expected in the standard theory of the Zeeman effect.

Keywords: Stars: magnetic field, Stars: chemically peculiar

1 Introduction

Magnetic fields play an important role in the evolution of hot stars (O, B and A stars). However, the origin and even the basic properties of hot star magnetic fields are still poorly understood. About 7% of hot stars are found to be strongly magnetic with a longitudinal magnetic field in excess of 100 G (Wade et al. 2013). But recently, a sub-gauss longitudinal magnetic field has been discovered in the normal A star Vega (Lignières et al. 2009). This detection raises the question of the ubiquity of magnetic fields in objects belonging to this mass domain. In 2011, another polarimetric signal was detected in the bright Am star Sirius A (Petit et al. 2011). For this object, the polarized signature in circular polarization is not of null integral over the line profile as in other massive stars, since the Stokes V line profile exhibits a positive lobe dominating over the negative one (in amplitude and area). Here, we present the results of a magnetic field search carried out for two other bright Am stars: β UMa and θ Leo. The fundamental parameters of both targets are presented in Table 1. The Am stars are chemically peculiar stars exhibiting overabundances of iron-group elements such as zinc, strontium, zirconium and barium and deficiencies of others such as calcium and scandium. Most Am stars also feature low projected rotational velocities, as compared to normal A stars (Abt 2009).

2 Data analysis

Data were taken with the NARVAL spectropolarimeter. Narval is operated at the 2-meter Bernard Lyot Telescope (TBL), at the summit of Pic du Midi in the French Pyrénées. This fibre-fed spectropolarimeter was especially designed and optimized to detect stellar surface magnetic fields through the polarization they generate in photospheric lines and provides complete coverage of the optical spectrum from 3700 to 10500 Å on 40 echelle orders with a spectral resolution of 65000.

β UMa was observed in March/April 2010 and March/April 2011, while observations of θ Leo were collected in January/March/April 2012, March/April 2013 and May 2014 (see Table 2).

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Table 1. Fundamental parameters of β UMa and θ Leo

	β UMa	θ Leo
spectral type	A1V	A2V
T_{eff}	9600 K^a	9350 K^b
log g	3.83^c	3.65^b
Mass	2.7 $M_\odot^d$	2.5 $M_\odot^d$
Radius	3 $R_\odot^a$	4.3 $R_\odot^a$
vsini	23 km/s^e	46 km/s^e

[a] Boyajian et al. (2012) [c] Monier (2005)
[b] Smith & Dworetsky (1993) [d] Wyatt et al. (2007)
[e] Royer et al. (2002)

Table 2. Journal of observations

date	mid-HJD	star	T_{exp} (s)
17mar10	2455273.52016	β UMa	16 × 4 × 107
06apr10	2455293.41173	β UMa	17 × 4 × 107
10apr10	2455297.44406	β UMa	19 × 4 × 107
11apr10	2455298.39660	β UMa	19 × 4 × 107
25mar11	2455646.42619	β UMa	25 × 4 × 107
31mar11	2455652.50367	β UMa	25 × 4 × 107
02apr11	2455654.37913	β UMa	03 × 4 × 107
04apr11	2455656.46150	β UMa	24 × 4 × 107
22jan12	2455949.64440	θ Leo	05 × 4 × 180
23jan12	2455950.62844	θ Leo	05 × 4 × 180
24jan12	2455951.62417	θ Leo	05 × 4 × 180
25jan12	2455952.64032	θ Leo	05 × 4 × 180
14mar12	2456001.57862	θ Leo	05 × 4 × 180
15mar12	2456002.52449	θ Leo	10 × 4 × 180
24mar12	2456011.52572	θ Leo	05 × 4 × 180
25mar12	2456012.50225	θ Leo	05 × 4 × 180
27mar12	2456013.39956	θ Leo	10 × 4 × 180
21mar13	2456373.48791	θ Leo	09 × 4 × 180
23mar13	2456375.46496	θ Leo	09 × 4 × 180
16apr13	2456399.44433	θ Leo	09 × 4 × 180
17apr13	2456400.49237	θ Leo	09 × 4 × 180
22apr13	2456405.51179	θ Leo	09 × 4 × 180
23apr13	2456406.45400	θ Leo	09 × 4 × 180
24apr13	2456407.50188	θ Leo	09 × 4 × 180
14apr14	2456762.44478	θ Leo	05 × 4 × 180
07may14	2456785.40762	θ Leo	05 × 4 × 180
08may14	2456786.41135	θ Leo	05 × 4 × 180
09may14	2456787.41580	θ Leo	05 × 4 × 180
14may14	2456792.47117	θ Leo	05 × 4 × 180
15may14	2456793.41300	θ Leo	05 × 4 × 180

To test whether β UMa and θ Leo are magnetic, we applied the well-known and commonly used Least-Squares Deconvolution (LSD) technique (Donati et al. 1997) on each spectrum of both stars and computed LSD pseudo line profiles from all available photospheric lines. The line lists used are 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 both stars (Table 1). To further improve the signal-to-noise ratio, we then coadded all LSD profiles of each star, resulting in one single averaged LSD profile for each target. The result are shown in Figure 1.

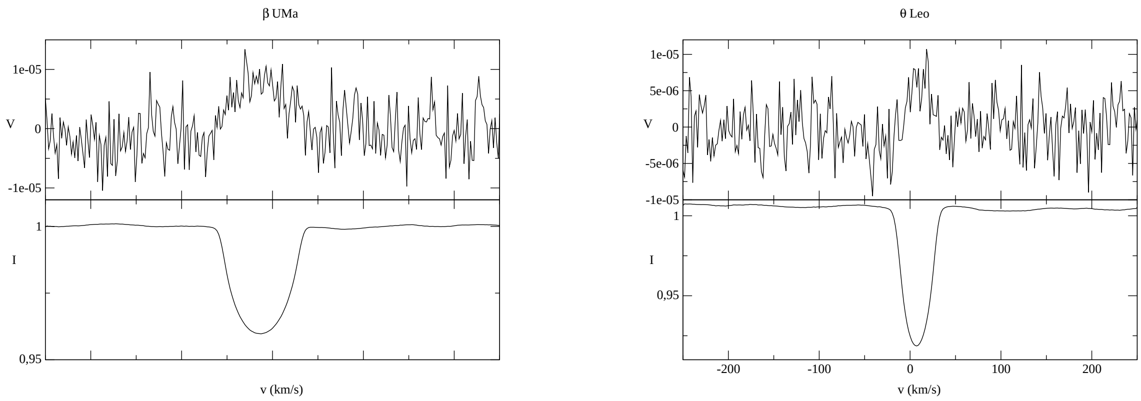

Fig. 1. Left: normalized Stokes I and V averaged LSD profiles for β UMa. Right: same figure for θ Leo.

3 Results

The line profiles of the two stars display circularly-polarized signatures similar in shape (see Figure 1) to the observations previously gathered for Sirius A. We have also separately coadded LSD profiles for each observing year (not shown here) to evaluate the temporal stability of this signal, concluding that the signatures are stable over the time-span of our observations.

4 Conclusions

These new detections may be interpreted to suggest that sub-gauss magnetic fields are present in the photosphere of a significant fraction of intermediate-mass stars, although the strongly asymmetric Zeeman signatures measured so far in Am stars (featuring a prominent positive lobe and essentially no negative lobe) are not expected in the standard theory of the Zeeman effect (see possible interpretations in Petit et al. 2011). New observations are currently being carried out to gain a better statistics of the prevalence of weak magnetic fields in intermediate-mass stars and evaluate the impact of various stellar parameters on the Vega-like magnetism.

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