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THE MAGNETIC PROPERTIES OF THE AM STAR ALHENA

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Abstract. Alhena (γ Gem) is a bright magnetic Am star that exhibit normal Zeeman signature with a positive and negative lobe, contrary to all previously studied Am stars that show the presence of ultra-weak (sub-Gauss) fields with peculiar Zeeman signatures with an unexpected prominent positive lobe.

We present here the result of the follow-up observations of Alhena, thanks to very high signal-to-noise data obtained with the spectropolarimeter Narval. Thanks to this data, we determine the magnetic properties of Alhena.

Keywords: stars: magnetic field – stars: early-type – stars: individual: Alhena

1 Introduction

Until recently, among the intermediate-mass stars the only known magnetic stars were the chemically peculiar Ap/Bp stars. These stars exhibit strong magnetic fields ($B_d \geq 300$ G) and the structure of the field is quite simple (usually mostly a dipole). 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) changed this vision of the magnetic fields in intermediate-mass stars and raised the question of the existence of such kind of magnetic field in intermediate-mass stars that do not host a strong magnetic field.

In addition, ultra-weak magnetic fields have been detected in four Am stars: Sirius A (Petit et al. 2011), β UMa and θ Leo (Blazère et al. 2016b), and Alhena (Blazère et al. 2016a). The first three stars exhibit peculiar Zeeman signatures in circular polarization with a prominent positive lobe. Blazère et al. (2016b) demonstrated that this kind of ultra-weak signature have a magnetic origin, although they were not expected in the standard Zeeman effect theory. Alhena is the only Am stars that exhibit normal Zeeman signatures similar to the one of Vega. The difference between the field of Alhena and the other Am stars is puzzling. In particular, Alhena has very similar stellar parameters to θ Leo that exhibit peculiar signatures.

Alhena is a well known bright spectroscopic binary composed of a subgiant A0IVm star (Gray 2014) and a cool G star (Thalmann et al. 2014). Drummond (2014) measured the orbital elements of the binary thanks to interferometry and found a orbital period of 12.63 years with a high eccentricity (e=0.89).

2 Spectropolarimetric measurements

2.1 Observations

In the frame of the BRITE spectropolarimetric survey (Neiner et al. 2016), new observations of Alhena wer obtained with the Narval spectropolarimeter (Aurière 2003), in circular polarization mode (Stokes V). Narval is a high-resolution spectropolarimeter, very efficient to detect stellar magnetic fields thanks to the polarization they generate in photospheric spectral lines, installed at the 2-meter Bernard Lyot Telescope (TBL) at the summit of Pic du Midi in the French Pyrénées. Alhena was observed in total 25 times, once on October 27, 2014, 20 times between September 2015 and April 2016, and 5 times in April/May 2017. The journal of observations is provided in Table 1.

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Table 1. Journal of 25 observations of Alhena indicating the date of observation, Heliocentric Julian Date at the middle of the observations (mid-HJD - 2450000), the number of sequences and exposure time in seconds, the mean S/N of the intensity spectrum at ∼500 nm, the longitudinal magnetic field of Alhena A (B_l), and null (N) measurements with their respective error bars, and magnetic detection status (DD = Definite Detection, MD = Marginal Detection).

#	date	mid-HJD	$T_{\rm exp}$ (s)	S/N	$B_l \pm \sigma B_l$ (G)	N$\pm\sigma$N (G)	Detection
1	27 Oct. 14	6958.6531	4 × 25	986	-3.72±2.25	-1.36 ±2.25	DD
2	18 Sep. 15	7284.6954	4 × 35	1016	-6.50±2.33	2.17±2.31	DD
3	19 Sep. 15	7285.6944	4 × 35	1093	-6.58±2.12	-1.90±2.12	DD
4	20 Oct. 15	7304.7204	4 × 35	1152	-10.34±2.06	0.54±2.06	DD
5	09 Oct. 15	7305.7266	4 × 35	1194	-6.32±1.99	-2.03±1.99	DD
6	10 Oct. 15	7306.7104	4 × 35	961	-6.50±2.42	1.72±2.43	DD
7	14 Oct. 15	7310.5895	4 × 35	938	-8.61±2.46	-2.83±2.43	DD
8	20 Oct. 15	7316.6682	4 × 35	832	-9.45±2.87	-1.94±2.85	DD
9	30 Oct. 15	7326.7289	4 × 35	1157	-6.68±2.24	0.17±2.24	DD
10	31 Oct. 15	7327.7354	4 × 35	1149	-5.43±2.06	3.32±2.04	MD
11	09 Nov. 15	7336.7300	4 × 35	935	-10.01±2.54	-1.77±2.52	MD
12	16 Nov. 15	7343.6352	4 × 35	917	-3.79±2.49	0.14±2.49	DD
13	01 Dec. 15	7358.6118	4 × 35	951	-4.53±2.47	-0.40±2.47	DD
14	06 Dec. 15	7363.6642	4 × 35	1320	-6.65±1.79	0.15±1.79	DD
15	11 Dec. 15	7368.6264	4 × 35	1170	-6.66±2.00	-2.08±2.02	DD
16	17 Dec. 15	7374.6085	4 × 35	1057	-7.19±2.38	1.15±2.39	DD
17	20 Jan. 16	7408.6078	3 × 4 × 42	2246	-8.08±1.05	1.03± 1.05	DD
18	20 Feb. 16	7439.4452	3 × 4 × 42	1323	-8.31±1.78	0.51±1.78	DD
19	20 Mar. 16	7460.4035	3 × 4 × 42	2307	-5.15±0.98	-0.16±0.98	DD
20	06 Apr. 16	7485.3300	3 × 4 × 42	2173	-8.82±1.89	1.09±1.90	DD
21	20 Apr. 17	7864.3198	3 × 4 × 42	1028	-5.15±1.40	-2.14±1.40	DD
22	21 Apr. 17	7865.3263	3 × 4 × 42	1346	-5.15±1.02	0.28±1.02	DD
23	22 Apr. 17	7866.3196	3 × 4 × 42	1203	-6.12±1.11	-0.25±1.11	DD
24	03 May 17	7877.3349	3 × 4 × 42	1141	-8.49±1.27	-0.64±1.27	DD
25	07 May 17	7881.3275	3 × 4 × 42	1347	-5.59±1.05	0.11±1.05	DD

2.2 Magnetic measurements

We applied the well-known and commonly used Least-Squares Deconvolution (LSD) technique (Donati et al. 1997) on each individual spectrum, using a mask containing 1052 spectral lines.

Thank to this mask, we extracted LSD Stokes I and V profiles for each observations as well as the null (N) polarization profiles to check for spurious signatures. Normal Zeeman signatures with positive and negative lobe are clearly seen for all nights.

Using the centre-of-gravity method (Rees & Semel 1979), we calculated the longitudinal field value (B_l) of Alhena. The values of the longitudinal magnetic field are all negative and vary between -10 G and -3 G, with typical error bars below 3 G. The values extracted from the N profiles are compatible with 0 G within 3σN, where σN is the error on N. The result are summarized in Table 1 for each night of observations.

Due to the binarity, the LSD I profiles taken in 2017 are shifted (see Fig. 1) compared to the ones taken in 2015/2016. The signature in the Stokes V profile follows this shift in radial velocity, confirming that it is the primary (the Am star) that is magnetic.

3 Magnetic modeling

3.1 Stokes V modeling

We modeled the Stokes V signatures thanks to the oblique rotator model, assuming that the magnetic field of Alhena A is a dipole and that the rotational period is 8.975 days as determined thanks to the variation of equivalent width of the LSD I profiles (see Blazère et al. in prep. for more details).

We calculated a grid of Stokes V profiles for each phase of observation by varying the five free parameters: the inclination i, the obliquity angle β, the dipolar magnetic field B_d, a phase shift ϕ, and the off-centering

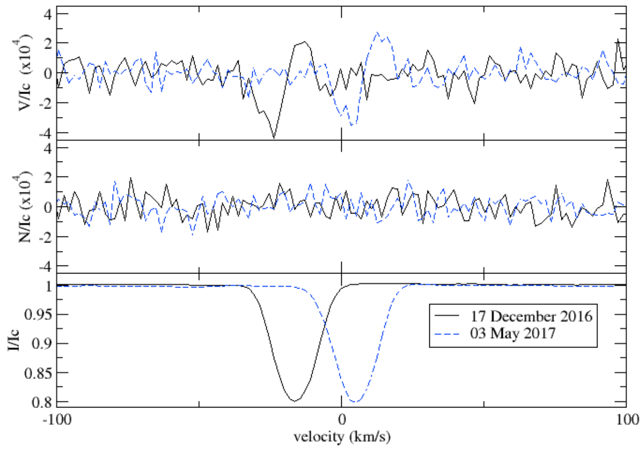

Fig. 1. Example of LSD Stokes I (bottom), Stokes V (top), and null N (middle) profiles for two different nights of observation.

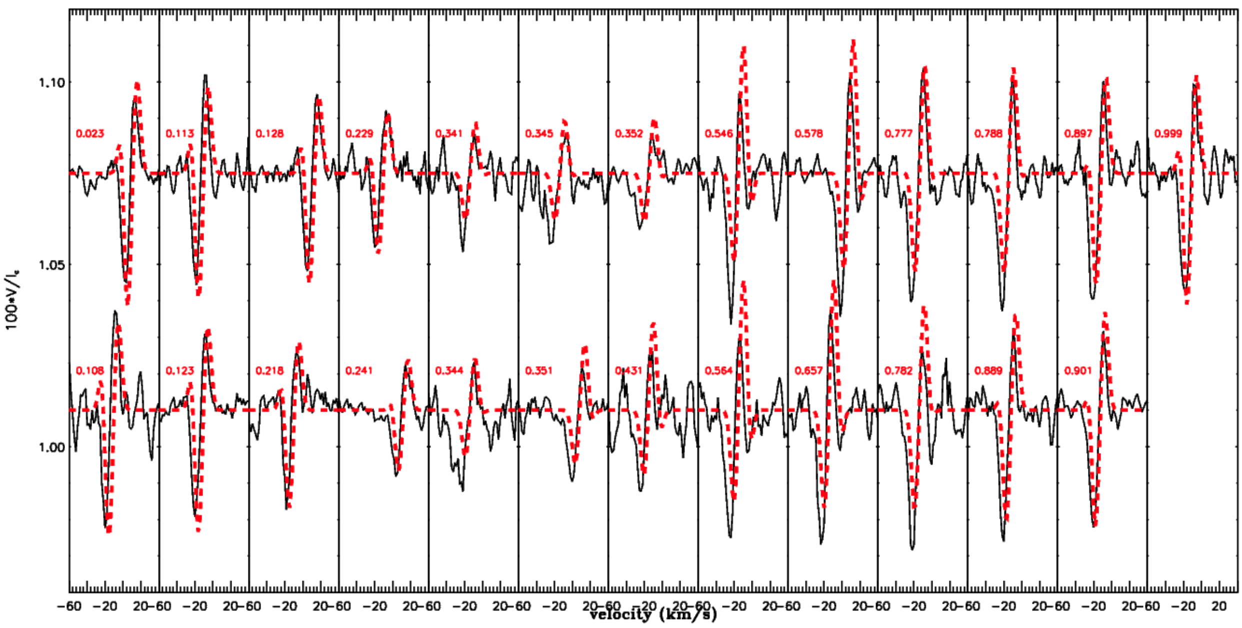

Fig. 2. Best dipolar model fit (red) of the observed Stokes V profiles (black) of Alhena A. The red numbers correspond to the rotational phase.

distance d_d of the dipole with respect to the center of the star (d_d=0 for a centred dipole and d_d=1 if the center of the dipole is at the surface of the star). We obtained the best fit of all observations simultaneously by applying a χ^2 minimization (for more details see Alecian et al. 2008). The best fit is obtained for i=22.8±4.1°, β=34.1±3.4°, ϕ=0.201±0.013, B_{pol}=32.4±1.7G and d_d=0.007±0.014, where the error bars correspond to a 3σ confidence level.

The comparison between the observed and the best synthetic LSD Stokes V profiles for all observations is shown in Figure 2. The model fits quite well the Stokes V profiles. Nevertheless, the fit does not match perfectly with the observations, suggesting that the structure of the magnetic field is more complex than a dipole or that some variability of the magnetic field or line profile exist.

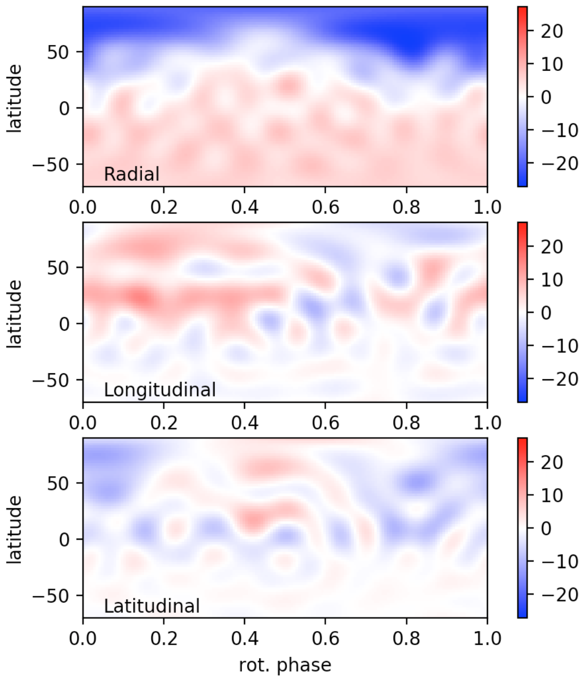

Fig. 3. Magnetic map of Alhena A. The three panels illustrate the field components in spherical coordinates (top: radial, center: azimuthal, and bottom: meridional). The magnetic field strength (colour scale) is expressed in Gauss.

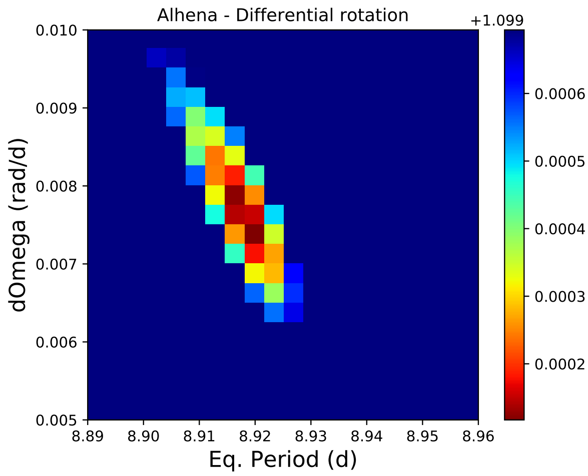

Fig. 4. Surface differential rotation of Alhena A.

3.2 Zeeman-Doppler Imaging

We reconstruct the magnetic map at the surface of Alhena A using the Zeeman-Doppler Imaging technique (ZDI, Donati & Brown 1997). The map of the magnetic field is shown in Fig. 3. We find that the field has a simple configuration, compatible with a dipole and we find a rotational period of 8.97 days close to the one determined with the equivalent width variations. We can also measure the surface differential rotation of the star using the method developed by Petit et al. (2002), assuming a simplified solar rotation law. We detect differential rotation at the surface of Alhena A (Fig. 4).

4 Conclusions

Alhena A is the first Am star that exhibit normal Zeeman signatures contrary to the other studied Am stars that exhibit peculiar signatures. We found a rotational period of $\sim$ 8.97 days and a dipolar strength of $\sim$ 30 G. This value is weak compared to the strong magnetic fields of Ap/Bp stars. However it is higher than the one of Vega. It is also the first discovery of surface differential rotation on a magnetic intermediate-mass star.

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