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Letter to the Editor

Magnetic field detection in the bright A0-type supergiant HD 92207★

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ABSTRACT

Context. Recent developments in observational techniques and theories revealed the potential significance of magnetic fields for stellar structure, evolution, and circumstellar environment. At present, the distribution of magnetic field strengths in massive stars from the zero-age main sequence to more evolved stages, which would shed light on the origin of the magnetic field, has not been studied.
Aims. We searched for the presence of a magnetic field in the visually brightest early A-type supergiant HD 92207.
Methods. Observations were obtained using the low-resolution spectropolarimetric mode of FORS 2 (FOcal Reducer low dispersion Spectrograph) mounted on the 8 m Antu telescope of the VLT. For the mean longitudinal magnetic field measurements, we applied a linear regression analysis in two ways: using only the absorption hydrogen Balmer lines or using the entire spectrum including all available absorption lines.
Results. A mean longitudinal magnetic field at a significance level of more than 3σ was detected in two out of three observations distributed over about one year. It is one of the rare cases where a field of about a few hundred Gauss is detected in an early A-type supergiant. All line profiles in the spectra of HD 92207 undergo distinct variations in radial velocities and intensities, probably caused by previously detected non-radial pulsations.

Key words. stars: early-type – stars: individual: HD 92207 – stars: magnetic field – stars: kinematics and dynamics – stars: variables: general

1. Introduction

The photometrically and spectroscopically variable bright A0 supergiant star HD 92207 is of particular interest for spectropolarimetric studies. It has been monitored for several years in the *uvby*-Strömgren system by Sterken (1983) and spectroscopically by Kaufer et al. (1996, 1997), who found cyclical changes of the brightness and substantial profile changes for metal lines and at Hα. The periods derived from Strömgren photometry of HD 92207 coincide with the periods detected in radial velocities. Kaufer et al. (1997) suggested that the observed photometric and Hα line variations are the result of a corotating structure in the wind, which they considered to be in the star's equatorial plane. Furthermore, their study of the line profile variations revealed clear pulsation-like structures, indicating the presence of non-radial pulsations.

Ignace et al. (2009) measured linear polarisation in the spectra of this star on seven different nights, spanning approximately three months in time. For the continuum polarisation, the authors explored a spiral-shaped wind density enhancement in the equatorial plane of the star, in line with the suggestion of Kaufer et al. (1997) that the observed photometric and Hα line variations are the result of a corotating structure in the wind. On the other hand, the authors reported that the polarisation across the Hα line on any given night is typically different from the degree and position angle of the polarisation in the continuum. These night-to-night variations in the Hα polarisation are hard to understand in terms of the spiral structure that was considered for the continuum polarisation.

The most recent determination of the atmospheric parameters was carried out by Przybilla et al. (2006), who also determined elemental abundances for over 20 chemical species. Their results indicate a modest enrichment of nitrogen with an N/C abundance ratio of 0.83. According to Przybilla & Nieva (2011), mixing signatures with $N/C > 0.8$ in B-type main-sequence stars indicate a possible magnetic nature. However, it is not clear whether for the early A-type supergiant HD 92207 the mixing signature is in line with predictions of evolutionary models.

A search for the presence of magnetic fields was previously conducted only in very few early A-type supergiants. Scholz & Gerth (1981) measured a mean longitudinal magnetic field in the range of a few hundred Gauss to up to 2 kG in the A2Iab supergiant ν Cep. No magnetic field detection was achieved in six early A-type supergiants in the study of Verdugo et al. (2005) using the MuSiCoS spectrograph, with measurement accuracies between a few Gauss for α Cyg and up to 300 G for V819 Cas. Grunhut et al. (2010) obtained spectropolarimetric observations with ESPaDOnS for η Leo and α Cyg at single epochs with a

★ Based on observations obtained at the European Southern Observatory (Prgs. 074.D-0008(B), 078.D-0330(A), 087.D-0049(A), and 088.D-0425(A)).

Table 1. Magnetic field measurements of HD 92207 using FORS 2. All quoted errors are 1σ uncertainties.

MJD	$\langle B_z\rangle_{\rm all}$ [G]	$\langle B_z\rangle_{\rm hyd}$ [G]	S/N
55 688.168	-384 ± 42	-402 ± 52	2020
55 936.341	145 ± 38	157 ± 51	1942
56 018.224	17 ± 48	49 ± 64	1783

similar result as Verdugo et al. In the last two studies, least-squares deconvolution (LSD) was used in the analysis.

In the present work we discuss magnetic field measurements based on spectropolarimetric observations acquired during 2011 and 2012 with the multi-mode instrument FORS 2 installed at the 8 m Antu telescope of the VLT.

2. Magnetic field measurements

The FORS 2 observations were obtained in May 2011 in visitor mode with blue optimised E2V chips and in January and April 2012 with red optimised MIT chips in service mode. We used a slit width of $0\farcs4$ in May 2011, and $0\farcs5$ in 2012, and the GRISM 600B to achieve a spectral resolving power of about 1600 to 2000. A detailed description of the assessment of the longitudinal magnetic field measurements using FORS 1/2 is presented in our previous work (e.g. Hubrig et al. 2004a,b, and references therein). The mean longitudinal magnetic field, $\langle B_z\rangle$, was derived using

$$\frac{V}{I} = -\frac{g_{\rm eff} e \lambda^2}{4\pi m_{\rm e} c^2}\ \frac{1}{I}\ \frac{{\rm d}I}{{\rm d}\lambda} \langle B_z\rangle,$$

where V is the Stokes parameter that measures the circular polarisation, I is the intensity in the unpolarised spectrum, $g_{\rm eff}$ is the effective Landé factor, e is the electron charge, λ is the wavelength, $m_{\rm e}$ the electron mass, c the speed of light, ${\rm d}I/{\rm d}\lambda$ is the derivative of Stokes I, and $\langle B_z\rangle$ is the mean longitudinal magnetic field.

The mean longitudinal magnetic field was measured in two ways: using only the absorption hydrogen Balmer lines or using the entire spectrum including all available absorption lines. Two spectral regions were excluded from the measurements: one is related to the spectral region containing the Hβ line because the high-resolution spectra of this star show a contamination of this line by emission. The second spectral region excluded from the measurements is the region $\lambda\lambda$3957–3975. In this region Hϵ is blended with the Ca II H line. In addition, an inspection of the spectra obtained with the blue optimised chip reveals the presence of instrumental artifacts at wavelengths close to the Ca II K and Hϵ lines.

The results from our three measurements are presented in Table 1, together with the modified Julian date of mid-exposure and the obtained signal-to-noise ratio. Field detections at a 3σ significance level were achieved on the nights in May 2011 and in January 2012. No significant fields were detected in null spectra calculated using the formalism described by Bagnulo et al. (2009). A few examples of Stokes I, Stokes V, and null spectra in a wavelength region containing low-number Balmer lines and the Ca doublet lines are presented in Fig. 1.

Since the rotation period of HD 92207 is unknown, rotation phases for the magnetic field observations cannot be calculated. Przybilla et al. (2006) determined for HD 92207 $T_{\rm eff}$ = 9500 ± 200 K. and $v \sin i$ = 30 ± 5 km s^{-1}. As the supergiant HD 92207 belongs to the cluster NGC 3324 at a high probability (see Sect. 4), we use the cluster distance to calculate

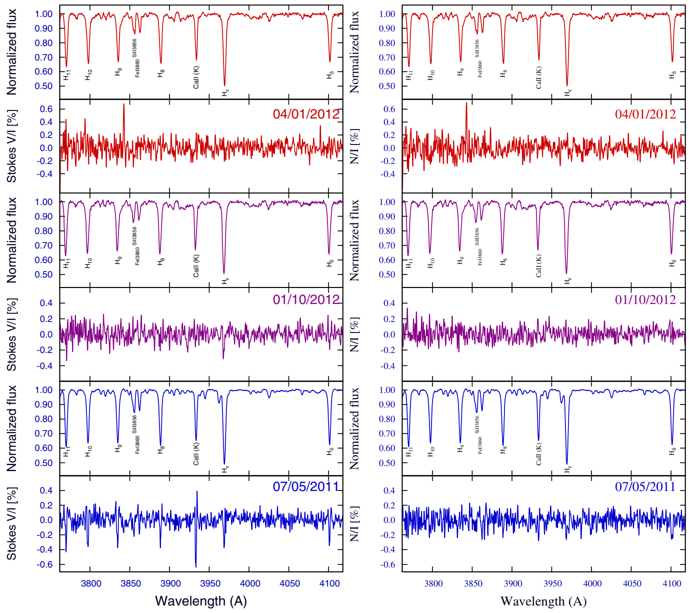

Fig. 1. *Left panel:* Stokes I and V spectra in a spectral region containing low-number Balmer lines and the Ca doublet lines at three epochs. *Right panel:* Stokes I and null spectra in the same spectral region.

the stellar luminosity $\log(L/L_\odot)$ = 5.15. Using this luminosity value and $T_{\rm eff}$ = 9500 ± 200 K, we calculate the stellar radius $R = 139.1 \pm 5.9\,R_\odot$. With the value $v \sin i$ = 30 ± 5 km s^{-1}, we estimate the rotation period $P_{\rm rot} \le 235 \pm 36$ d.

3. Spectral variability

In the Stokes I spectra obtained on three different epochs we detect distinct line profile variations of all spectral lines that are caused by non-radial pulsations. In Fig. 2 we display the behaviour of the Balmer lines, showing in particular asymmetric line profiles in observations obtained in 2012.

Since the spectroscopic monitoring of HD 92207 was carried out by Kaufer et al. (1997) more than fifteen years ago, we decided to study the spectrum variability over the last seven years and added our own seven FORS 1 observations obtained in 2007 and one FEROS spectrum ($R = \lambda/\Delta\lambda \approx 48\,000$) observed in 2004 on La Silla that we retrieved from the ESO archive. Furthermore, we used one EBASIM spectrum ($R = \lambda/\Delta\lambda \approx 20\,000$) obtained in 2006 in CASLEO in Argentina. Radial velocities were calculated by the cross-correlation technique using the synthetic template of the BLUERED database (Bertone et al. 2008) for appropriate temperature and gravity. For FEROS and EBASIM spectra the spectral resolution was degraded in order to be able to compare these spectra with the low-resolution FORS 1/2 spectra. The radial velocity measurements are presented in Table 2.

Furthermore, we obtained radial velocities of individual lines to evaluate potential differences between the various chemical elements in the spectrum. Our recent FORS 2 spectra were obtained with GRISM 600B, while previous FORS 1 observations were carried out using GRISM 600R. For this reason, we were able to study the spectral line variability only in the overlapping spectral region from 4670 to 6200 Å. We find that the lines of the elements Fe, Cr, and Si show very similar behaviour. The radial velocities determined from the He I λ 5876 line are only slightly higher than those for the metal lines, while the Balmer line Hβ shows a velocity that is systematically lower than the

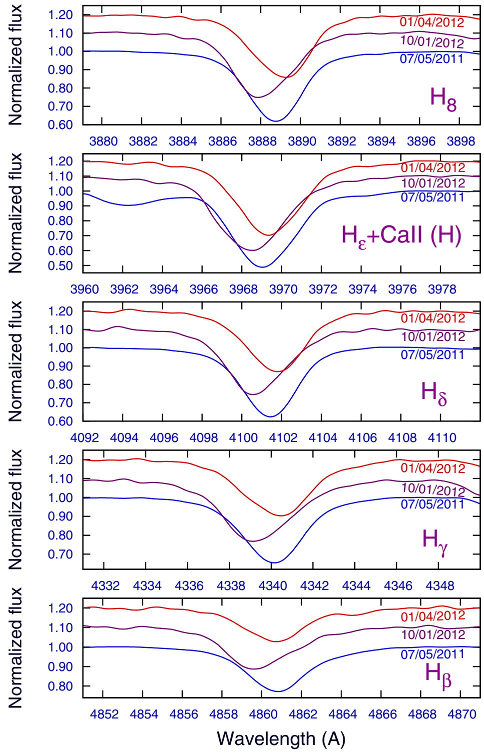

Fig. 2. Examples of the behaviour of the Balmer lines in the spectra of HD 92207 on the three epochs with available longitudinal magnetic field measurements. The strongest magnetic field of about a few hundred Gauss is detected in spectra obtained on May 7, 2011 with rather symmetrical line profiles. Spectra are vertically shifted for clarity.

Table 2. Radial velocity measurements of all available spectra of HD 92207.

Instrument	MJD	RV [km s^{-1}]
FEROS	53 362.2559	-17.97 ± 5.21
EBASIM	53 804.2025	-22.12 ± 0.15
FORS 1	54 106.3558	0.98 ± 8.40
FORS 1	54 155.1911	30.22 ± 7.17
FORS 1	54 157.1142	42.67 ± 7.65
FORS 1	54 158.1192	44.86 ± 8.13
FORS 1	54 170.2936	-6.50 ± 7.94
FORS 1	54 184.1649	9.97 ± 7.80
FORS 1	54 185.1539	15.62 ± 7.99
FORS 2	55 688.1707	-38.19 ± 9.50
FORS 2	55 936.3410	-68.86 ± 9.62
FORS 2	56 018.5269	-12.36 ± 8.07

values obtained from the metal lines. The measured radial velocities for the metals, the He I λ 5876 line and for Hβ are presented in Fig. 3. For comparison, in the left panel of the figure we show the radial velocity measurements obtained in the past by Kaufer et al. (1997). Interestingly, while the measurements at high resolution with FEROS and EBASIM show results more or less similar to those obtained by Kaufer et al., radial velocities obtained with FORS 1/2 show a high dispersion and appear to be mostly positive in 2007 and negative in 2011/2012. At present, it is not clear to us whether this behaviour can be explained by the presence of a companion to HD 92207.

A few examples of line profile variability caused by non-radial pulsation for different elements are presented in Fig. 4 in the upper panel. In the lower panel of the same figure we show the line intensity variations in the spectra corrected for the pulsational radial velocity shifts. The strongest intensity variations are detected in the Hβ line profile and in the profiles of Fe II lines.

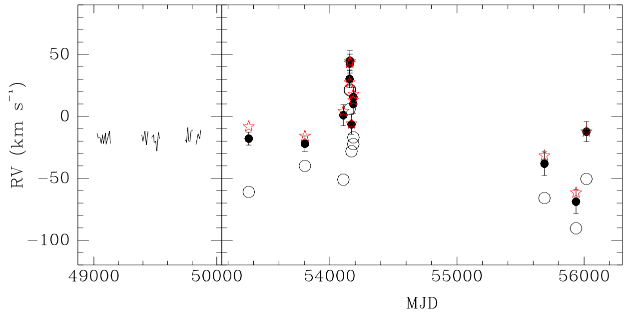

Fig. 3. Radial velocity variations in the studied spectra. In the *left panel* previous radial velocity measurements by Kaufer et al. (1997) are presented. In the *right panel* different symbols indicate the measurements on the Cr II, Fe II, and Si II lines (filled circles), open stars stand for the measurements using the He I λ5876 line and the open circles for the measurements using the Hβ line.

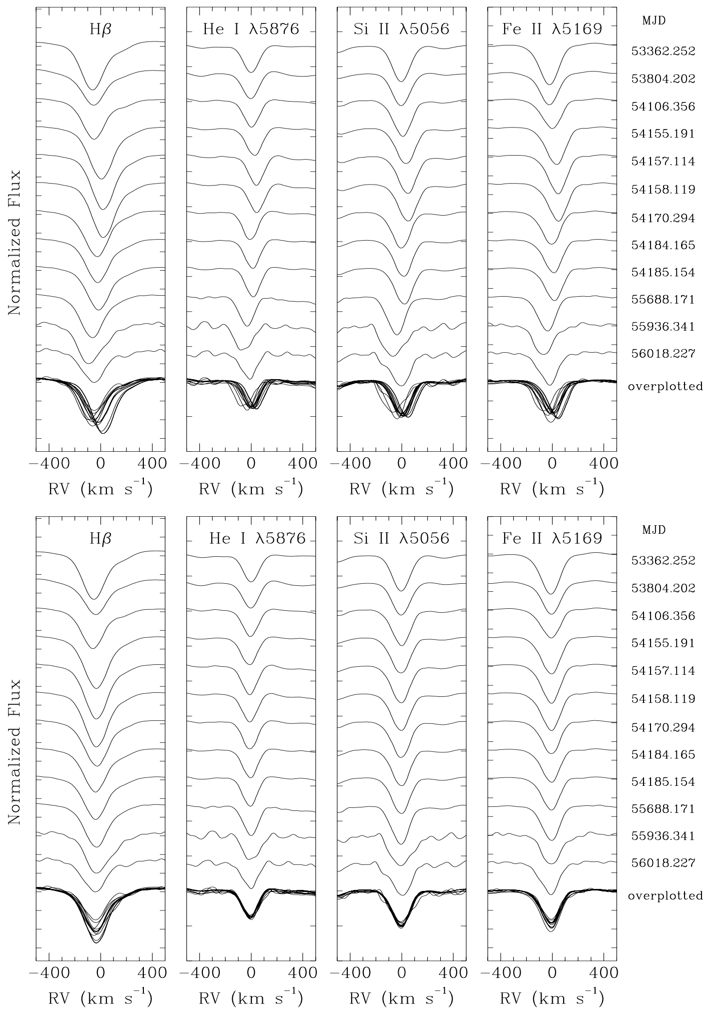

Fig. 4. Behaviour of line profiles belonging to different elements in the spectra of HD 92207 on twelve different nights. *Upper panel*: a few examples of line profile variability caused by non-radial pulsations for different elements. Note the small differences in the pulsation behaviour of the line profiles between Hβ and He, Si, and Fe lines. *Lower panel*: changes in the line intensities for different elements in the spectra corrected for the pulsational radial velocity shifts.

Table 3. Astrometric and kinematic characteristics of HD 92207 and the cluster NGC 3324.

Name	l [deg]	b [deg]	PMx [mas/yr]	PMy [mas/yr]	RV [km s^{-1}]	π [mas]	$P_{\rm kin}$ [%]	$P_{\rm phot}$ [%]
HD 92207	286.29	−0.26	-7.18 ± 0.79	3.43 ± 0.66	−10.0	-0.16 ± 0.33	87	100
Cl NGC 3324	286.29	−10.19	-7.81 ± 0.63	3.77 ± 0.65	−8.5			

Table 4. Space velocities with respect to the Galactic open cluster system (SV$_{\rm C}$) and the corresponding Galactic velocity components.

Name	Spectral type	M_V [mag]	$(B-V)_0$ [mag]	Distance [pc]	X [pc]	Y [pc]	Z [pc]	SV$_{\rm C}$ [km s^{-1}]	U [km s^{-1}]	V [km s^{-1}]	W [km s^{-1}]
HD 92207	A0Iae	−7.2	+0.01		+645	−2209	10	77 ± 13	-76 ± 8	-3 ± 5	1 ± 8
Cl NGC 3324				2301	+643	−2209	13	84 ± 11	-84 ± 7	-6 ± 5	1 ± 8

4. Discussion

At present, the distribution of magnetic field strengths in massive stars from the zero-age main sequence (ZAMS) to more evolved stages, which would shed light on the origin of the magnetic field, has not been studied. A few years ago Cantiello et al. (2009) suggested the presence of a sub-surface convective dynamo in the iron convective zones of massive stars. These authors showed that the extent of such zones increases when the stellar envelope expands and becomes cooler, i.e. it becomes more prominent for high-luminosity stars. Future monitoring of the behaviour of the magnetic field of HD 92207 will be very valuable to identify whether it is dynamo-generated or is a fossil field created during or shortly after star formation.

Previous kinematical studies of magnetic massive stars showed that a significant fraction of these stars can be considered to be candidate runaway stars (e.g. Hubrig et al. 2011a,b,c). Based on the work of Kharchenko et al. (2005) and Kharchenko & Röser (2009), the supergiant HD 92207 belongs with a high probability to the open cluster NGC 3324 at the age log $t = 6.72$ that is located at a distance of 2.3 kpc. The values for the positions, proper motions, radial velocities, parallaxes, and the kinematic and photometric probability for cluster membership are presented in Table 3, together with cluster parameters. The calculated space velocities and their Galactic rectangular components are presented in Table 4. Spectral type, corresponding absolute visual magnitude and $(B-V)_0$ on the ZAMS are listed in Cols. 2 to 4. The spectral class–colour–absolute magnitude calibration was based on Straizys (1992). The errors in M_V and $(B-V)_0$ were assumed to be 0.5 and 0.01 mag, respectively. The distances and rectangular galactic coordinates X, Y, and Z with respect to the Galactic plane are shown in Cols. 5–8. Space velocities with respect to the Galactic open cluster system (see Kharchenko et al. 2005) and the corresponding Galactic velocity components are listed in Cols. 9 to 12. The cluster NGC 3324 is located in the Galactic plane in the Carina star-forming region and shows kinematical characterictics typical for the thin disk. A search for a magnetic field was carried out in another member of this cluster, the O-type star HD 92206. According to Hubrig et al. (in prep.), this star also shows a magnetic field. Certainly, additional kinematical studies of magnetic massive stars are urgently needed to constrain the conditions controlling the presence of magnetic fields.

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