Magnetic fields in OB-type stars from the study of open clusters of different age and the field

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Abstract: Important effects induced by magnetic fields in massive stars are suggested by recent models and observations. However, the origin of these magnetic fields remains unknown. At present, only very few magnetic O-type stars are known to belong to clusters, whereas the other magnetic O-type stars are field stars. We report here on our recent spectropolarimetric studies of magnetic fields in OB-type stars in clusters and in the field.

Observations: Our spectropolarimetric studies of a sample of massive O and B-type stars in clusters and in the field were carried out using FORS2 at the VLT and the SOFIN echelle spectropolarimeter at the 2.56m Nordic Optical Telescope. The major goal of the study was to build trustworthy statistics on the occurrence of magnetic fields in massive stars. This is critical to answer the principal question of the possible origin of such fields.

Results for O-type stars: During the observations with FORS2 in May 2010, we were able to detect among the studied 35 massive O-type stars nine stars with mean longitudinal magnetic fields in the range from 80 to 400 Gauss. Among the stars with magnetic field detections, five stars are members of open clusters, which are tracing the Sagittarius-Carina arm, and four stars are field stars. The ages of the clusters containing magnetic O-type stars range from *log t*=6.70 to *log t*=7.17 (Kharchenko et al. 2005, A&A 438,1163). Surprisingly, a kinematical study of the field O-type stars with detected magnetic fields indicates that some of them can be considered as candidate runaway stars. Since this indication can be in some way related to the origin of magnetic fields in massive stars, we carried out calculations of space velocities of O-type stars with previously published magnetic fields. Two stars, HD 36879 (Hubrig et al. 2008, A&A 490, 793) and HD 57682 (Grunhut et al. 2009, MNRAS 400, 94) were already identified as candidate runaway stars in the past (e.g. de Wit et al. 2004, A&A 425, 937; Comeron et al. 1998, A&A 330, 975). For the star θ^1 OriC, the study of Stahl et al. (2008, A&A 487, 323) indicates that this star is moving rapidly away from the Orion molecular Cloud and its host cluster. The space velocities and the Galactic rectangular components were calculated for the remaining seven O-type stars with published magnetic fields: HD 108 (Martins et al. 2010, MNRAS 407, 1423; Hubrig et al. 2010, AN 331, 781), HD 37742 (Bouret et al. 2008, MNRAS 389, 75), HD 148937, HD 152408, HD 155806, HD 164794 (Hubrig et al. 2008, A&A 490, 793), and HD 191612 (Donati et al. 2006, MNRAS 365, 6; Hubrig et al. 2010, AN 331, 781). The stellar positions and parameters (Kharchenko 2001, KPCB 17, 409), and the results of the calculations are presented in Tables 1 and 2.

Only two stars, HD 155806 and HD 164794, with the lowest space velocities, are likely members of clusters, namely Sco OB4 and NGC 6530, respectively. HD 155806 is also classified as an Oe star, probably representing the higher mass analogues of classical Be stars. The star HD 164794 is a spectroscopic double-lined system, known as emitting non-thermal radio-emission, probably associated with colliding winds (Rauw et al. 2005, Proceedings of a JENAM workshop). The Of?p star HD 148937 is surrounded by the circumstellar nebula NGC 6164-6165 and it is assumed that this nebula has been ejected during an LBV-like event (Leitherer & Chavarria, 1987, A&A 175, 208). The stars HD 108, HD 152408, and HD 191612 are moving with rather high velocities, from 50 km/s to 94 km/s, suggesting that they all can be considered as candidate runaway stars. In summary, the results of our kinematical study of O-type stars indicate that the presence of a magnetic field is more frequently detected in candidate runaway stars than in stars belonging to clusters or associations.

Table 1. HD numbers, stellar positions, proper motions, radial velocities, parallaxes, and magnitudes of magnetic O-type stars.

HD number	l [deg]	b [deg]	PMx [mas/yr]	PMy [mas/yr]	RV [km s^{-1}]	π [mas]	B [mag]	V [mag]
108	117.9221	1.2470	−5.12±1.11	−1.15±0.93	−62.0	−0.01±0.84	7.505±0.007	7.375±0.007
37742	206.4522	−16.5852	3.99±0.74	2.52±0.40	45.5	3.99±0.79	1.798±0.005	1.898±0.004
148937	336.3614	−0.2124	0.80±1.42	−5.12±1.15	−33.1	0.82±1.30	7.058±0.010	6.757±0.009
152408	344.0789	1.4969	−1.21±1.11	−2.28±0.82	−56.5	0.35±0.75	5.946±0.004	5.807±0.008
155806	352.5859	2.8883	0.35±1.00	−2.02±0.50	10.9	0.65±0.76	5.559±0.004	5.613±0.005
164794	6.0090	−1.2050	1.92±1.19	−0.40±0.99	−12.0	0.66±1.00	5.940±0.005	5.933±0.005
191612	72.9871	+1.4565	−3.26±0.96	−6.65±1.02	−5.2	0.13±0.74	8.035±0.009	7.821±0.009

Table 2. Space velocities with respect to the Galactic open clusters system (SV_O), with respect to the LSR (SV_{LSR}), and with respect to the Sun (SV_S), and the corresponding Galactic velocity components.

HD number	Spectral Type	M_V [mag]	$(B-V)_0$ [mag]	dist [pc]	X [pc]	Y [pc]	Z [pc]	SV_O [km s^{-1}]	U [km s^{-1}]	V [km s^{-1}]	W [km s^{-1}]
108	O6.5 V	−5.3	−0.32	2510	−1175	2217	74	94±19	93±12	−15±7	2±12
37742	O9.7 Iab	−6.5	−0.24	391	−335	−187	−91	52±6	−51±5	−7±2	2±1
148937	O7 V	−5.2	−0.32	1043	958	−413	16	31±11	−27±6	10±6	−12±6
152408	O8 Iab	−6.7	−0.30	1694	1629	−464	64	50±13	−50±6	7±3	1±3
155806	O7.5 III	−5.7	−0.32	1251	1239	−161	82	19±9	19±6	1±5	0±4
164794	O5 I	−7.2	−0.33	2615	2600	275	−55	24±21	−3±6	17±14	−15±14
191612	O7 V	−5.2	−0.32	1874	548	1792	67	71±14	70±10	−11±5	0±9

HD number	SV_{LSR} [km s^{-1}]	U [km s^{-1}]	V [km s^{-1}]	W [km s^{-1}]	SV_S [km s^{-1}]	U [km s^{-1}]	V [km s^{-1}]	W [km s^{-1}]
108	96±13	95±11	−15±7	3±12	87±13	84±11	−25±7	−4±12
37742	51±5	−50±4	−7±2	2±1	45±5	−41±4	−19±2	−4±1
148937	30±11	−25±5	10±6	−12±6	41±10	−37±5	−1±6	−19±6
152408	49±12	−48±5	3±3	1±3	60±12	−59±5	−4±7	−5±3
155806	21±3	21±5	2±5	0±4	16±3	10±4	−9±4	−7±4
164794	24±20	−2±5	18±14	−15±14	27±20	−13±5	5±13	−22±13
191612	73±14	72±9	−11±5	0±9	65±13	61±8	−23±5	−7±9

Results for B-type stars: Our surveys of the massive B-type stars in the last years revealed the presence of magnetic fields in about two dozens of β Cephei and Slowly Pulsating Stars. In 2006, using low-resolution FORS1 polarimetric spectra, we announced that the star ξ^1 CMa possesses the strongest magnetic field among the β Cephei stars (Hubrig et al. 2006, MNRAS 369, 61). The slight variability of the field was also recently confirmed by high-resolution SOFIN observations separated by one year ($\langle B_z \rangle$= +386±39G and $\langle B_z \rangle$=+297±26G). In Fig. 1 (left panel) we present SOFIN Stokes *I* and *V* spectra of this star. A few months ago additional FORS2 observations obtained in service mode allowed us to determine the rotation period (see Fig. 1, right panel) and the magnetic field geometry of this star (Hubrig et al. 2010, submitted). The new high-resolution SOFIN observations also confirmed the presence of magnetic fields in the massive O-type stars HD 36879, 15 Mon, and 9 Sgr, previously detected with low-resolution FORS2 observations. The first kinematical assessment of massive B-type stars with magnetic fields shows that most of them are field stars and only very few magnetic B-type stars belong to clusters or associations. We note, however, that the sample of stars with detected magnetic fields is still rather small and a study of a larger sample is urgently needed to confirm the low occurrence frequency of magnetic massive stars in clusters and associations.

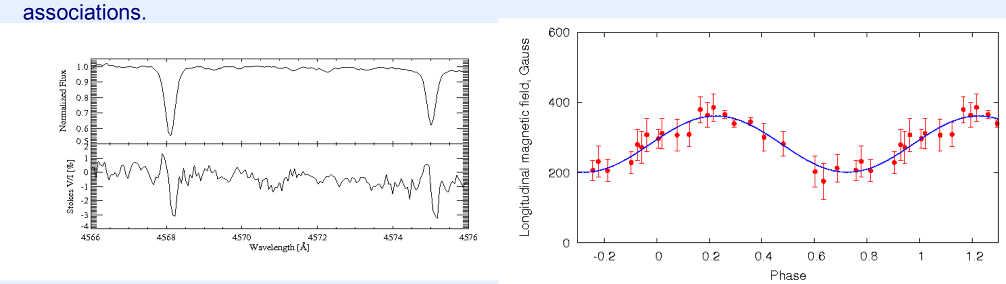

Fig. 1. *Left:* SOFIN Stokes *I* and *V* spectra of ξ^1 CMa in the spectral region around the Si III (Mult. 2) lines.

Right: FORS2 spectropolarimetric observations from 2010 plotted over the rotation period.