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First HARPSpol discoveries of magnetic fields in massive stars*


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ABSTRACT

In the framework of the Magnetism in Massive Stars (MiMeS) project, a HARPSpol Large Program at the 3.6m-ESO telescope has recently started to collect high-resolution spectropolarimetric data of a large number of Southern massive OB stars in the field of the Galaxy and in many young clusters and associations. We report on the first discoveries of magnetic fields in two massive stars with HARPSpol – HD 130807 and HD 122451, and confirm the presence of a magnetic field at the surface of HD 105382 that was previously observed with a low spectral resolution device. The longitudinal magnetic field measurements strongly vary for HD 130807 from \(-100\) G to \(-700\) G. Those of HD 122451 and HD 105382 are less variable with values ranging from \(-40\) to \(-80\) G, and from \(-300\) to \(-600\) G, respectively. The discovery and confirmation of three new magnetic massive stars, including at least two He-weak stars, is an important contribution to one of MiMeS objectives: the understanding of the origin of magnetic fields in massive stars and their impact on stellar structure and evolution.

Key words. stars: massive – stars: magnetic field – stars: chemically peculiar – stars: individual: HD 122451 – stars: individual: HD 105382 – stars: individual: HD 130807

1. Introduction

MiMeS (Magnetism in Massive Stars) is a broad collaboration that aims to address many questions concerning the magnetism of massive stars. One goal in particular is to determine the global magnetic properties of massive stars with the help of Large Programs (LP) that have been allocated to the high-magnetic properties of massive stars with the help of Large Programs (LP). One goal in particular is to determine the global magnetic fields in detail. This smaller sample of stars is dedicated to the study of the interplay of magnetic fields with the

* Based on observations collected at the European Southern Observatory, Chile (Program ID 187.D-0917).
1 http://www.physics.queensu.ca/~wade/mimes

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1. Introduction

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In 2010, the polarimeter HARPSpol was commissioned at the 3.6 m-ESO telescope (La Silla, Chile). For the first time, we now can access the Southern Hemisphere with a data quality similar to ESPaDOnS and Narval. Therefore, a Large Program was established to complete the ESPaDOnS/Narval field sample, and to take the first steps towards observing massive stars in various open clusters and associations of different ages, to investigate the magnetic field evolution, and the impact of magnetic fields on stellar evolution.

The HARPSpol sample is divided into two components (SC and TC) to follow the same strategy as the Narval and ESPaDOnS LPs. The HARPSpol SC sample contains about 180 stars that include \(\sim 110\) stars in seven clusters, and \(\sim 70\) stars in the field of the Galaxy. The former have been selected from the Catalogue of Open Cluster Data (Kharchenko et al. 2005), while the latter have been chosen from the International Ultraviolet Explorer (IUE) data archive, but also from other catalogues or publications containing highly probable magnetic
stars, in accordance with the ESPaDOnS/Narval target selection (Wade et al. 2009).

This HARPSpol Large Program was allocated four separate runs over two years. During the first run in May 2011, 57 stars were observed including one magnetic calibrator and one TC target, the results which will be presented in a forthcoming paper. We here report on the first discoveries of magnetic fields in massive stars with HARPSpol in HD 130807 and HD 122451, and we confirm the magnetic field in HD 105382 that was previously detected with the low-resolution spectropolarimeter FORS 1 (Kochukhov & Bagnulo 2006; Hubrig et al. 2006). Among the 55 SC stars observed during this run, those three stars are the only ones in which a magnetic field was detected. In Sect. 2 we present the observations and reduction techniques. In Sect. 3 we detail the HARPSpol results on each star, and discuss them in Sect. 4.

2. Observations

We used the HARPSpol polarimeter (Piskunov et al. 2011), installed with the HARPS spectograph (Mayor et al. 2003), at the 3.6 m ESO telescope at La Silla Observatory (Chile), which yields spectra with resolving power \( \lambda / \Delta \lambda \) of about 105 000 and covers the 380–690 nm wavelength region. All spectra were recorded as sequences of four individual sub-exposures taken in different configurations of the polarimeter to yield a full circular polarisation analysis, as described by Donati et al. (1997). The data were reduced using the package “REDUCE” described by Piskunov & Valenti (2002). After reduction, we obtained the intensity Stokes \( I \) and the circular polarisation Stokes \( V \) spectra of the stars, both normalised to the continuum. A null spectrum (\( N \)) was also computed to diagnose spurious polarisation signatures, and to help verify that the signatures in the Stokes \( V \) spectrum are of stellar origin. The log of the observations is presented in Table 1.

To increase the effective signal-to-noise ratio \( S/N \) of our data, we applied the least-squares deconvolution (LSD; Donati et al. 1997) procedure, which uses tailored line-masks of appropriate temperature and gravity for each star. The masks were first computed using the Kurucz ATLAS 9 models of solar abundance (Kurucz 1993), with intrinsic line depths higher than 0.1. We then excluded from these masks hydrogen Balmer lines, and lines whose Landé factor is unknown. Finally we modified the line depths to take into account the relative depth of the lines of the observed spectra. The resulting masks contain 394, 592, and 394 lines for HD 1030807, HD 122451 and HD 105382, respectively. The \( S/N \) of the LSD Stokes \( V \) profiles is about 10 times higher than the \( S/N \) in the original spectra (Table 1).

To perform a reliable magnetic field diagnosis, we computed the detection probability inside the LSD \( V \) profiles (as described in Donati et al. 1997). We consider that an observation displays a “definite detection” (DD) of Stokes \( V \) Zeeman signature if the probability is higher than 0.99999, a “marginal detection” (MD) if it falls between 0.999 and 0.99999, and a “null detection” (ND) otherwise (see Table 1). All observations of HD 130807 and HD 105382 display DD, while two DD and one ND were obtained for HD 122451. The LSD \( I, V, \) and \( N \) profiles are plotted in Fig. 1. In almost all of our observations Zeeman signatures are broad as the \( I \) profiles are clearly detected in the \( V \) profiles, while the \( N \) profiles are consistent with the noise. These results allow us to confidently affirm that magnetic fields are present on the surface of these stars.

We measured for each observation the line-of-sight component of the magnetic field averaged over the visible stellar surface (the so-called longitudinal magnetic field, or \( B_z \)) by integrating the \( I \) and \( V \) profiles over the ranges \([-50,60], [-80,100], \) and \([-70,105] \) km s\(^{-1}\) for HD 130807, HD 122451, and HD 105382, respectively (as described by Alecian et al. 2009). The values are reported in Table 1.

3. Results

3.1. HD 130807

HD 130807 (\( \sigma \) Lup) is a member of the Sco-Cen association (Kharchenko et al. 2005). A companion was detected at an angular distance varying from 0.07 to 0.14 arcsec (Perryman & Egan 1997; McAlister et al. 1990). According to the angular separation, the light of both components entered the HARPSpol fibers during our observations of this target.

From a visual inspection we find that most of the spectrum of HD 130807 is consistent with a synthetic spectrum of a single star of effective temperature \( T_{\text{eff}} = 18 000 \) K, surface gravity log \( g = 4.25 \) (cgs), broadened by \( v \sin i \) \( = 25 \) km s\(^{-1}\), calculated using TLUSTY non-LTE atmosphere models and the SYNSPEC code (Hubeny 1988; Hubeny & Lanz 1992). However, we observe that all \( He \) i lines are substantially weaker than the synthetic ones calculated with solar abundance (Fig. 2), while the \( Si \) ii lines are considerably stronger. The \( Si, N, \) and \( Fe \) lines show variabiliy in depth and shape on a timescale of 1 d. These characteristics suggest that HD 130807 is an \( He \)-weak star with abundance spots on its surface (Jaschek & Jaschek 1974).

Magnetic signatures are detected in almost all lines of the spectrum, similar to the LSD one (Fig. 1, left). Many additional lines are observed in the spectrum that can be caused by \( Fe \) ii, \( Fe \) iii, or \( Ti \) ii enhancements. All these lines show Zeeman signatures similar to the others, with the same variations from one night to the other. They can therefore be attributed to the same star, rather than to a companion, and they are probably the result of the chemical peculiarities at the surface of the star.

A significant shift in radial velocity (\( -6 \) km s\(^{-1}\)) is detected in the strongest spectral lines including the Balmer lines,
between May 22 and May 26–27. The maximum reported angular separation between both visual components implies a distance ≥17 AU, and therefore a period ≥27 years. This radial velocity shift can therefore not be caused by the reported visual companion. A third companion very close to the primary could explain these variations, but more observations are required to fully understand all peculiarities observed in the spectrum.

The variations observed in the V profiles over six days (Fig. 1, left) can be understood in terms of the oblique rotator (OR) model that consists of an inclined dipole placed inside a rotating star (Stibbs 1950). The rotational modulation of the shape of the V profiles and of the $B_t$ values that vary from ~94 to 677 G (Table 1) suggest that the rotation period of the star should be between one and six days. More observations, well-sampled over the rotation period, are required to fully characterise the magnetic field and better constrain the period of HD 130807.

### 3.2. HD 122451

HD 122451 (β Cen) is a double-lined spectroscopic binary with components of similar effective temperatures (25 000 K) and gravities ($\log g = 3.5$, cgs), and a β Cep-type pulsating primary. The system is highly eccentric ($e = 0.835$) and orbits with a period of 357 days (Ausseloos et al. 2002, 2006; Davis et al. 2005).

We obtained three observations of HD 122451 during three different nights. To avoid potential false magnetic detections caused by pulsations, we split each observation into many sequences of four spectra (Table 1), so that the exposure time for one sequence is much shorter than the pulsation period.

The spectra of HD 122451 clearly show two components of similar temperature, but different broadening, confirming the SB2 nature of the system. We adopt the same definition as Ausseloos et al. (2006). The spectral lines appear to be distorted and show rapid variations very likely caused by β Cep-type pulsations. No obvious abundance peculiarity or manifestation of circumstellar matter is observed within the spectra.

In Fig. 1 (middle) we superimposed the LSD $I$, $V$, and $N$ profiles of our observations. According to the ephemeris of Ausseloos et al. (2006), the three observations are roughly at the same orbital phase (~0.5), and both components have similar radial velocities (~14 and ~4 km s$^{-1}$ for the primary and secondary respectively), which explains why it is difficult to distinguish both components in the profiles. The shape of the LSD $I$ profile shows variations during the run, which can be understood in terms of radial pulsations in the primary, which would occasionally broaden the profile. As a result, both components can be clearly distinguished in the profile of May 27 (full black line in Fig. 1, middle), while it is less obvious in the other observations.

Zeeman signatures are detected in many individual spectral lines, which look similar to the LSD V profiles. The signatures are as broad as the secondary profile, meaning that the magnetic field is detected only in the secondary component of the system. However, considering the faint Zeeman signatures in the secondary and the broad line shape of the primary, a magnetic field of the same strength as the secondary’s could exist in the primary without being detected in our observations. To estimate the $B_t$ values of the secondary, we need to extract the $V$ and $I$ profiles with the work of Ausseloos et al. (2006). The spectral lines appear to be distorted and show rapid variations very likely caused by β Cep-type pulsations. No obvious abundance peculiarity or manifestation of circumstellar matter is observed within the spectra.

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of the secondary only from the profiles of the binary. Without any evidence of a magnetic field in the primary, we neglect its contribution to the V profile, which we consider to be entirely from the secondary. But the I profile needs to be corrected. With this aim, we first fitted the I profile of the binary with the method described above for the individual spectral lines. Then we subtracted from the observed I profile the fit of the primary. Finally we have measured $B_I$ using the corrected I and the original V profiles. The values are reported in Table 1.

3.3. HD 105382

HD 105382 (= HR 4618) is member of the Sco-Cen association (Kharchenko et al. 2005). Briquet et al. (2004) classified it as He-weak. The third one (HD 122451) belongs to a binary system (Wade, G. A., Alecian, E., Bohlender, D. A., et al. 2009, in IAU Symp., 259, 333). Among these three stars, two are unambiguously magnetic B stars. These spots are very often correlated with the stellar magnetic fields (e.g. Veto 1990). In the case of HD 105382, Briquet et al. (2004) found a large He spot at a latitude of 60°. If our estimate of its magnetic obliquity is confirmed, this spot would be situated close to the South magnetic pole, demonstrating once more the importance of magnetic fields in the formation of chemical spots.

More observations of these magnetic stars are planned within the HARPSpol large program to perform detailed mapping of their magnetic fields, and better confront the models and theories of magnetic massive stars.

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