Magnetic survey of emission line B-type stars with FORS 1 at the VLT*

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We report the results of our search for magnetic fields in a sample of 16 field Be stars, the binary emission-line B-type star $\upsilon$ Sgr, and in a sample of fourteen members of the open young cluster NGC 3766 in the Carina spiral arm. The sample of cluster members includes Be stars, normal B-type stars and He-strong/He-weak stars. Nine Be stars have been studied with magnetic field time series obtained over $\sim$1 hour to get an insight into the temporal behaviour and the correlation of magnetic field properties with dynamical phenomena taking place in Be star atmospheres. The spectropolarimetric data were obtained at the European Southern Observatory with the multi-mode instrument FORS 1 installed at the 8 m Kueyen telescope. We detect weak photospheric magnetic fields in four field Be stars, HD 62367, $\mu$ Cen, $\alpha$ Aqr, and $\epsilon$ Tuc. The strongest longitudinal magnetic field, $\langle B_z \rangle = 117 \pm 38$ G, was detected in the Be star HD 62367. Among the Be stars studied with time series, one Be star, $\lambda$ Eri, displays cyclic variability of the magnetic field with a period of 21.12 min. The binary star $\upsilon$ Sgr, in the initial rapid phase of mass exchange between the two components with strong emission lines in the visible spectrum, is a magnetic variable star, probably on a timescale of a few months. The maximum longitudinal magnetic field $\langle B_z \rangle = 102 \pm 10$ G at MJD 54333.018 was measured using hydrogen lines. The cluster NGC 3766 seems to be extremely interesting, where we find evidence for the presence of a magnetic field in seven early B-type stars out of the observed fourteen cluster members.

1 Introduction

The majority of emission line B-type stars constitute so-called Be stars, which are defined as rapidly rotating main sequence stars showing normal B-type spectra with superposed Balmer line emission. In addition, these stars are characterized by episodic dissipation and formation of a new circumstellar (CS) disk-like environment, non-radial pulsations, and photometric and spectroscopic variability. A number of physical processes in classical Be stars (e.g., angular momentum transfer to a CS disk, channeling stellar wind matter, accumulation of material in an equatorial disk, etc.) are more easily explainable if magnetic fields are invoked (e.g. Brown et al. 2004). Cassinelli et al. (2002) suggested a Magnetically Torqued Disk model, in which a sufficiently strong magnetic field (of the order of 300 G) channels a flow of wind material towards the equatorial plane to form a disk. Maheswaran (2003, 2005) developed the Magnetic Rotator Wind Disk model, in which Keplerian disks may be formed by magnetic fields of the order of a few tens of Gauss. Very recently, Maheswaran & Cassinelli (2009) obtained solutions for the structure and evolution of a protodisk region, i.e. the disk region that is initially formed when wind material is channeled by dipole-type magnetic fields towards the equatorial plane, showing that magnetorotational instability may assist in the formation of a quasi-steady disk. According to their calculations, magnetic fields of the order of a few tens of Gauss will be able to channel wind flow into a protodisk region.

Due to the high rotation of Be stars and the presence of strong Balmer emission lines, magnetic field measurements are difficult and rare. The only reported magnetic field detection using high-resolution spectropolarimetry of $\omega$ Ori ($80 \pm 40$ G; Neiner et al. 2003) was not confirmed by recent observations with ESPaDOnS (Grunhut et al., in preparation). A longitudinal magnetic field at a level larger than $3\sigma$ has previously been diagnosed in low-resolution spectropolarimetric FORS 1 observations of the three Be stars HD 56014 (=EW CMa; Hubrig et al. 2007), HD 148184 (= $\chi$ Oph; Hubrig et al. 2007), and in HD 208057 (= 16 Peg;
Hubrig et al. 2006a). HD 208057 has $v \sin i = 104 \text{ km s}^{-1}$ and was classified as a Be star by Merrill & Burwell (1943) due to the detection of double emission in H$\alpha$. Recently, Henrichs et al. (2009) confirmed the presence of a magnetic field with new measurements using the spectropolarimeters Narval at the Télescope Bernard Lyot, France, and ESPaDOnS at the Canada France Hawaii Telescope, during 2007. However, the presence of emission in H$\alpha$ was not detected by these observations. Thus, the question whether this star is a classical Be star remains open.

Additional spectropolarimetric measurements are needed to firmly establish the presence of weak magnetic fields in Be stars. Due to the sparseness of the available magnetic field measurements, it is currently not possible to test models, which describe the role of weak magnetic fields in launching and stabilizing circumstellar disks in Be stars. To obtain constraints on the origin of magnetic fields in early B-type stars, it is especially important to study the incidence of magnetic fields in members of clusters of different ages. Here we report the results of our four observing runs with the multi-mode instrument FORS 1 installed at the 8 m Kueyen telescope at the VLT carried out in the last few years with the goal to prove the presence of magnetic fields in a sample of 16 Be stars, the binary emission-line B-type star star $\upsilon$ Sgr, and fourteen members of the young open cluster NGC 3766 in the Carina spiral arm. The investigation of this cluster, which has a high content of Be stars, normal early B-type stars, and He peculiar stars, allows us to draw some first conclusions of incidence of magnetic fields in different groups of early B-type stars.

## 2 Observations and data reduction

The observations reported here have been carried out from 2006 to 2008 in service and visitor mode at the VLT with the FOcal Reducer low dispersion Spectrograph (FORS 1). FORS 1 is a multi-mode instrument equipped with polarisation analyzing optics comprising super-achromatic half-wave and quarter-wave phase retarder plates, and a Wol Baston prism with a beam divergence of 22” in standard resolution mode. The HD numbers, visual magnitudes and spectral types of the studied emission line field B-type stars based on the SIMBAD database are listed in Table 1.

| HD Number | Other Name | V | Spectral Type |
|-----------|------------|---|--------------|
| 33328     | $\lambda$ Eri | 4.2 | B2IVne |
| 41335     | V696 Mon     | 5.3 | B2Vne |
| 56014     | 27 CMA       | 4.7 | B3IIIe |
| 58011     | NN CMA       | 7.2 | B1/B2II/IIIe |
| 58715     | $\beta$ CMi  | 2.9 | B8Ve |
| 58978     | FY CMA       | 5.6 | B1III |
| 60855     | V378 Pup     | 5.7 | B2/B3V |
| 62367     | BD-04 2062   | 7.1 | B9 |
| 88661     | QY Car       | 5.8 | B2IVape |
| 91465     | $p$ Car      | 3.4 | B4Vne |
| 105435    | $\delta$ Cen | 2.6 | B2IVne |
| 120324    | $\mu$ Cen    | 3.5 | B2Vape |
| 127793    | $\eta$ Cen   | 2.3 | B1.5Vne |
| 148184    | $\chi$ Oph  | 4.4 | B2Vne |
| 158427    | $\alpha$ Ara | 2.8 | B2Vne |
| 181615    | $\upsilon$ Sgr | 4.6 | B8II |
| 209409    | $\alpha$ Aur | 4.7 | B7IVe |
| 224686    | $\epsilon$ Tuc | 4.6 | B9IV |

Time-resolved series of ten Be stars have been observed in 2006 in service mode with the GRISM 600B at the resolution $R=2000$ in the wavelength range 3480–5890 Å to cover all hydrogen Balmer lines from H$\beta$ to the Balmer jump. We used the Tektronix chip and a non-standard readout mode, A,1×1,low, allowing us to obtain a signal-to-noise ratio of a few hundred for measurements of the circular polarisation. Further, the readout time was reduced to about 40 s by windowing the CCD.

Since we do not know the magnetic field topology on the surface of Be stars, it is reasonable to study the polarisation induced in the spectral lines by the Zeeman effect across the stellar surface through longer time series of exposures with short integration time and with low detection limit. It is well known that many Be stars exhibit X-ray flares and rapid variability of absorption features (dimples). These features are believed to be produced from an ablation of photospheric material caused by a nearby flare (e.g. Smith et al. 1993). Hence, it is quite possible that measuring the magnetic field on the stellar surface every few minutes, we will be able to study a local transient magnetic field. In this respect we note that the Magnetic Rotator Wind-Disk model (Maheswaran 2003) does not require large-scale organized magnetic fields, axially symmetric fields, or uniformly strong fields across the entire stellar surface. This model also qualitatively applies to stars with magnetic fields consisting of flux loops that emerge from lower latitudes and thread the disk around the Be star.

For each star we performed time-resolved magnetic field measurements over one hour (corresponding to a time series of 20 to 30 measurements per star). In this way we get information on the behaviour of the localized transient magnetic field over at least a part of the stellar surface. A similar study was conducted for the Be star $\lambda$ Eri in the past by Mathys & Smith (2000) with CASPEC at the ESO 3.6 m telescope, where some constraints on a possible presence of a magnetic field were discussed.

The mean longitudinal magnetic field $\langle B_z \rangle$ is the average over the stellar hemisphere visible at the time of observation of the component of the magnetic field parallel to the line of sight, weighted by the local emergent spectral line intensity. The detection of a weak magnetic field $\langle B_z \rangle = 136 \pm 16$ G in one of the stars observed with time-series, $\chi$ Oph, was already reported in our previous work on Be stars (Hubrig et al. 2007). After re-inspection of the previ-
ous measurements of $\chi$ Oph we noted that the detection of this field involved a Zeeman feature in the H$\beta$ line filled with strong emission. Excluding this line from the measurements we obtain a much weaker magnetic field $\langle B_z \rangle = 17 \pm 18$ G. At the low FORS 1 resolution of $R = 2000$ it is difficult to decide whether the observed Zeeman feature is indeed related to the presence of a magnetic field or not and its study at a higher resolution will be worthwhile. This star is not further considered in this work.

Our measurements revealed that one Be star, $\lambda$ Eri (= HD 33328), displays a cyclic variability of the magnetic field. While a few other Be stars in our sample appeared variable too, only for $\lambda$ Eri did the amplitude peak stand out nicely. Understandably, a confirmation of such a behaviour would immediately stimulate a deeper theoretical investigation, and test and further constrain the recently developed magnetic field models for Be stars. For this reason, we carried out follow-up observations of $\lambda$ Eri in 2007 November during two halves of consecutive nights. For these observations we used GRISM 1200B and an $O^0.4$ slit ($R = 4000$) to observe the spectral range 3730–4970 Å, which includes all Balmer lines from H$\beta$ to H$\iota$. This time, however, no cyclic variability of the magnetic field in $\lambda$ Eri was detected. We discuss the possible explanation for the absence of cyclic variability in the Sect. 3.4. Three more Be stars, 27 CMa, $o$ Aqr, and $\epsilon$ Tuc were observed during this run of two half nights.

Hubrig et al. (2007) reported on the presence of a weak magnetic field $\langle B_z \rangle = 38 \pm 10$ G in the binary emission-line B-type star $\upsilon$ Sgr (= HD 181615). Additional three observations of this binary system were obtained in service mode during 2007 August and September with GRISM 1200B and an $O^0.4$ slit.

The most recent observations presented here have been carried out in a visitor run on 2008 March 23 and 24 in the framework of the study of 15 B-type members of the open cluster NGC 3766. The results of this study have in part been reported by McSwain (2008). Unfortunately, the polarimetric spectra of the member star NGC3766-031 were strongly contaminated by a close companion and have not been further considered in our study. During this run, apart from the Be star members of this cluster, we also observed the field Be stars V696 Mon, 27 CMa, NN CMa, $\beta$ CMi, FY CMa, V378 Pup, and HD 62367. These observations have been carried out with the GRISM 600B and a slit width of $0^0.4$.

All observations obtained in 2007 and 2008 have been carried out with a new mosaic detector with blue optimised E2V chips, which was implemented in FORS 1 in 2007. It has a pixel size of 15 $\mu$m (compared to 24 $\mu$m for the previous Tektronix chip) and higher efficiency in the wavelength range below 6000 Å. With the new mosaic detector and the grism 600B we were able to cover a much larger spectral range, from 3250 to 6215 Å, and from 3680 to 5130 Å using grism 1200B. To achieve the highest possible signal-to-noise (S/N) ratio — as is required for accurate measurements of stellar magnetic fields — the non-standard, 200kHz, low, 1 x 1, readout mode was used, which makes it possible to achieve a S/N ratio of more than 1000 with only one single exposure. For each star observed in 2007–2008 we usually took three to five continuous series of two exposures at the position angles of the retarder waveplate $+45^\circ$ and $-45^\circ$. More details on the observing technique with FORS 1 can be found elsewhere (e.g., Hubrig 2004a, 2004b, 2008).

The mean longitudinal magnetic field is diagnosed from the slope of a linear regression,

$$V/I = -\frac{g_{eff} \epsilon}{4 \pi m_e c^2} \lambda^2 \frac{dI}{d\lambda} \langle B_z \rangle + V_0/I_0,$$  \hspace{1cm} (1)

where $V$ is the Stokes parameter which measures the circular polarisation, $I$ is the Stokes parameter observed in unpolarized light, $g_{eff}$ is the effective Landé factor, $\epsilon$ is the electron charge, $\lambda$ is the wavelength, $m_e$ the electron mass, $c$ the speed of light, $dI/d\lambda$ is the derivative of Stokes $I$, and $\langle B_z \rangle$ is the mean longitudinal magnetic field. $V_0/I_0$ is a constant term taking into account the remaining instrumental polarization. Our experience from the study of a large sample of magnetic and non-magnetic Ap and Bp stars (Hubrig et al. 2006b) revealed that this regression technique is very robust and that detections at a significance level larger than $3\sigma$ result only for stars possessing magnetic fields.

Longitudinal magnetic fields were measured in two ways: using only the absorption hydrogen Balmer lines or using the whole spectrum including all available absorption lines. Lines showing evidence for emission were not used in the determination of the magnetic field strength. The feasibility of longitudinal magnetic field measurements in massive stars using FORS 1 in spectropolarimetric mode was demonstrated by recent studies of early B-type stars (e.g., Hubrig et al. 2006a; Hubrig et al. 2008; Hubrig et al. 2009).

3 Results

The results of our magnetic field measurements are summarised in Table 2. In the first three columns we give the name of the targets, indicate whether the star was observed in a longer time series, and the modified Julian date of the middle of the exposures. The mean longitudinal magnetic field $\langle B_z \rangle_{\text{all}}$ measured using all absorption lines is presented in Col. 4. The mean longitudinal magnetic field $\langle B_z \rangle_{\text{hydr}}$ using all hydrogen lines in absorption is listed in Col. 5. All quoted errors are $1\sigma$ uncertainties. In Col. 6 we identify new detections by ND and confirmed detections by CD. We note that all claimed detections have a significance of at least $3\sigma$, determined from the formal uncertainties we derive. These measurements are indicated in bold face. While data for stars with extended time series were also analysed using only the pairwise settings of the retarder waveplate angle of $+45^\circ$ and $-45^\circ$ (see Sect. 3.1), the values of the measured magnetic field presented here were determined using all of the up to 30 exposures.

We detect weak photospheric magnetic fields in four field Be stars, HD 62367, $\mu$ Cen, $o$ Aqr, and $\epsilon$ Tuc. The
The largest longitudinal magnetic field, $\langle B_z \rangle = 117 \pm 38$ G, was detected using hydrogen lines in the Be star HD 62367. Among the Be stars studied with time series, the Be star $\lambda$ Eri displays cyclic variability of the magnetic field with a period of 21.12 min.

The binary star $\upsilon$ Sgr, in the initial rapid phase of mass exchange between the two components with strong emission lines in the visible spectrum (Koubský et al. 2006), is a magnetic variable star, probably on a timescale of a few months. The maximum longitudinal magnetic field $\langle B_z \rangle = -110 \pm 10$ G at MJD 54333.018 was measured using hydrogen lines.

The cluster NGC 3766 seems to be extremely interesting, where we find evidence for the presence of a magnetic field in seven early B-type cluster members out of the fourteen members observed. The strongest magnetic field $\langle B_z \rangle = 1559 \pm 38$ G was measured in the He-weak star NGC3766-170, followed by the second strongest magnetic field $\langle B_z \rangle = 310 \pm 65$ G measured in the He-strong star NGC3766-094. Among the cluster member Be stars, the strongest magnetic field $\langle B_z \rangle = -134 \pm 42$ G was measured in NGC3766-47. Surprisingly, magnetic fields of a similar order were also discovered in the normal early B-type stars NGC3766-111 and NGC3766-176.
In the following subsections we describe the time-resolved observations of nine Be stars (Sect. 3.1), discuss the results of the measurements of other stars with magnetic field detections at 3σ level (Sect. 3.2), and in Sect. 3.3 we present the magnetic field measurements of members of the young open cluster NGC 3766.

3.1 Time-resolved magnetic field measurements: discovery of magnetic field cyclic variability in \( \lambda \) Eri

The nine Be stars with time-resolved magnetic field measurements are very bright objects. The corresponding integration time for a single measurement of the magnetic field with the Kueyen 8-m telescope and FORS 1 accounts for only a few seconds. Taking into account time for overheads (retarder waveplate setting plus readout time), we were able to obtain during one hour 21 consecutive measurements for the faintest Be star in our sample (QY Car) and 30 measurements for the brightest Be star in our sample (\( \eta \) Cen). The periodicity of the time-resolved magnetic field measurements was analysed by application of Breger’s code (1990). In the obtained amplitude spectra a 2.4σ peak corresponding to a period of 21.12 min was detected in the data set of measurements carried out using hydrogen lines in the star \( \lambda \) Eri in 2006 August (see lower panel in Fig. 1). This peak appears with a 2.2σ in the data set of measurements carried out using the whole spectrum (lower panel in Fig. 2). The corresponding data sets for measurements using hydrogen lines and the whole spectrum are presented in Table 3.

To confirm the detected variability, we repeated our measurements of \( \lambda \) Eri about 16 months later on 2007 November 27 and 28 over few hours on each night to sample two different phases of its rotation period. However, this time our observations did not reveal any significant periodicity in any of the data sets. Previous studies of \( \lambda \) Eri indicate that spectral line profiles exhibit short-time periodic variability due to non-radial pulsations with a period of 0.7 days (e.g., Kambe et al. 1993; Rivinius et al. 2003). In addition to these line profile variations, the He I \( \lambda \)6678 line is reported to show dimples with a duration of 2–4 hours (Smith 1994). Smith suggests that such changes in the line profile are consistent with the stellar rotation rate, as if caused by a rooted active spot on the surface. The observed rapid optical line variability develops over tens of minutes or less, implying that violent high-energy events occur close to the surface of this star (Smith et al. 1997). Based on multiwavelength observations in optical, X-rays and FUV, Smith et al. (1997) proposed that the observed violent processes on the surface of this star show great similarity with magnetic flaring. Our observations indicate that a strong field could possibly exist locally, but with a topology such that its net effect can appear only sporadically in disk-integrated variations.

Trying to understand why we failed to detect any periodicity in our measurements in the follow-up observations, we studied the line variations in the polarimetric spectra obtained with FORS 1 on all three observing nights. Interestingly, while spectral lines in Stokes \( I \) spectra obtained in 2006 August appear fairly symmetrical, the spectral lines show rather strong variability in the two time series obtained in 2007 November. In Fig. 1 we present for each time series all spectra in the spectral region 4500 to 4730 Å overlapped.
To show the line profile variations in more detail, we plotted in Fig. 4 five spectra for each time series corresponding to equidistant time intervals over the full time used to obtain each data set. The spectra obtained in 2006 August are presented in the bottom of the plot, and the spectra obtained on 2007 November 27 and 28 are presented in the middle and at the top of the plot, respectively. Asymmetric line profiles are well visible in spectral lines \( \text{Al} \, \text{III} \), \( \text{Si} \, \text{III} \), \( \text{O} \, \text{II} \), \( \text{He} \, \text{I} \), and \( \text{H} \gamma \) in the time series obtained in 2007 November. Since the topology of the magnetic field is not known, it is difficult to estimate the impact of non-radial pulsations causing strong line asymmetries on our measurements. It is quite possible that lines of different elements behave differently with respect to their pulsation amplitudes and shapes of the line profiles. We believe that high resolution spectropolarimeters will be more suitable for field measurements in pulsating stars, since at higher resolution the Zeeman features in individual lines can be studied separately. Our time-resolved magnetic field measurements of the remaining Be stars indicate that four other Be stars may display a magnetic cyclic variability on the time scales of minutes or tens of minutes. The stars \( \text{QY} \, \text{Car} \), \( \delta \, \text{Cen} \), \( \alpha \, \text{Ara} \), and \( \epsilon \, \text{Tuc} \) show weak signals in the Fourier transforms of our data sets, corresponding to periods of 21.86 min, 27.74 min, 9.37 min, and 4.27 min, respectively. These stars are good candidates for future time-resolved magnetic field observations with high-resolution spectropolarimeters.

### Table 3  Magnetic field time series for \( \lambda \, \text{Eri} \) obtained in 2006 August.

| MJD        | \( \langle B_z \rangle_{\text{hydr}} \) | \( \langle B_z \rangle_{\text{all}} \) |
|------------|-----------------------------------|-----------------------------------|
| 53955.37939 | \( -160 \pm 195 \) G               | \( -140 \pm 160 \) G             |
| 53955.38134 | \( -83 \pm 197 \) G               | \( -45 \pm 162 \) G             |
| 53955.38328 | \( 69 \pm 186 \) G               | \( -15 \pm 153 \) G             |
| 53955.38523 | \( -349 \pm 187 \) G             | \( -239 \pm 154 \) G             |
| 53955.38718 | \( 465 \pm 201 \) G             | \( 271 \pm 165 \) G             |
| 53955.39113 | \( 158 \pm 190 \) G             | \( 206 \pm 156 \) G             |
| 53955.39108 | \( 52 \pm 207 \) G               | \( -211 \pm 170 \) G             |
| 53955.39303 | \( -263 \pm 204 \) G             | \( -117 \pm 168 \) G             |
| 53955.39498 | \( -83 \pm 184 \) G             | \( -96 \pm 151 \) G             |
| 53955.39693 | \( -218 \pm 219 \) G             | \( -281 \pm 180 \) G             |
| 53955.39888 | \( -142 \pm 206 \) G             | \( -126 \pm 169 \) G             |
| 53955.40084 | \( 148 \pm 203 \) G             | \( 90 \pm 166 \) G             |
| 53955.40279 | \( 230 \pm 205 \) G             | \( 35 \pm 168 \) G             |
| 53955.40475 | \( 248 \pm 204 \) G             | \( -6 \pm 167 \) G             |
| 53955.40671 | \( 5 \pm 210 \) G               | \( -29 \pm 172 \) G             |
| 53955.40867 | \( -267 \pm 210 \) G             | \( -269 \pm 172 \) G             |
| 53955.41062 | \( -201 \pm 205 \) G             | \( -52 \pm 168 \) G             |
| 53955.41259 | \( -103 \pm 211 \) G             | \( -43 \pm 172 \) G             |
| 53955.41455 | \( -26 \pm 205 \) G             | \( 137 \pm 167 \) G             |
| 53955.41652 | \( 211 \pm 213 \) G             | \( 147 \pm 174 \) G             |
| 53955.41848 | \( -96 \pm 217 \) G             | \( -34 \pm 177 \) G             |
| 53955.42045 | \( 77 \pm 219 \) G             | \( -36 \pm 178 \) G             |

3.2 Other emission line B-type stars showing evidence for the presence of a weak magnetic field

HD 62367: This Be star has only been marginally studied in the past, mainly due to its rather faint magnitude \( V = 7.1 \). It is also one of the faintest Be stars in our sample (see Table 1). According to Yudin (2001) the spectral type of the star is B8e and the \( v \sin i = 114 \, \text{km s}^{-1} \). This star was observed only once and exhibits the strongest...
magnetic field among the Be stars in our sample. Using hydrogen Balmer absorption lines we obtained \( \langle B_z \rangle = 117 \pm 38 \) G.

\( \epsilon \) Tuc = HD 224686: This Be star was classified as B8V with \( T_{\text{eff}} = 13000 \) K and \( \log g = 3.90 \) by Levenhagen & Leister (2006), who also determined \( v \sin i = 300 \) km s\(^{-1}\). A weak magnetic field at a 3\( \sigma \) significance level, \( \langle B_z \rangle = 74 \pm 24 \) G, was detected during our observing run in 2007 November.

\( \upsilon \) Sgr = HD 181615: The emission-line star \( \upsilon \) Sgr is a very unusual object, frequently classified as a Be star due to the presence of strong emission lines in the visible spectrum. It seems to be a magnetic variable star, probably on a few months timescale with a maximum longitudinal magnetic field \( \langle B_z \rangle = -102 \pm 10 \) G measured in hydrogen lines on MJD 54333.018. In Fig. 6 we present the Stokes V spectra in the vicinity of Mg II \( \lambda 4481 \) taken on four different dates over two years. The evolutionary status for this star is not obvious due to the fact that it is a single-line spectroscopic binary system currently observed in the initial rapid phase of mass exchange between the two components (Koubsky et al. 2006). The star dominating the optical and UV line spectra is less massive and has a spectral type B8I, while the second, almost invisible component is more massive by a factor of 1.57 and has a spectral type O9V. The optically visible star is hydrogen poor and the observed spectrum is extremely line rich (see Fig. 7). Hubrig et al. (2007) reported the detection of distinctive Zeeman signatures in the Ca II H&K lines, which are probably formed in the circumstellar disk around this star. Future monitoring of the magnetic field of \( \upsilon \) Sgr over a few months with a high resolution spectropolarimeter would be of extreme interest to understand the role of the magnetic field in the evolutionary process of mass exchange in a binary system.

3.3 Members of the open cluster NGC 3766

The results of the study of fifteen early B-type members of the open cluster NGC 3766 have in part been reported by McSwain (2008), who announced two definite detections in He peculiar stars, NGC3766-094 and NGC3766-170, one
marginal detection in one Be star, NGC3766-047, and one marginal detection in a Be star candidate, NGC3766-045. A careful treatment of the spectropolarimetric data allowed us to detect weak magnetic fields in three additional members of this cluster: in the Be star NGC3766-200 and in the two normal B-type stars NGC3766-111 and NGC3766-176. The cluster members with detected magnetic fields are highlighted in bold face in Table 2. As was already mentioned in Sect. 2, the polarimetric spectra of NGC3766-031 were contaminated by a close companion and have not been considered in our study. As an example, in Fig. 8 we present the observed Stokes $I$ and Stokes $V$ profiles of the He peculiar member of this cluster and of another cluster member, which was classified as a potential Be star by Shobbrook (1985) with longitudinal magnetic fields of $\langle B_z \rangle = +1559 \pm 38$ G and $\langle B_z \rangle = -194 \pm 62$ G, respectively.

The magnetic fields have been detected in stars with $T_{\text{eff}}$ in the range from 15 500 K to 21 435 K and log $g_{\text{polar}}$ from 4.61 to 3.51 (McSwain 2008), indicating that the presence of a magnetic field is not directly related to the stellar evolutionary phase on the main sequence.

4 Discussion

Our search for magnetic fields in Be stars revealed that while their magnetic fields are rather weak, fields of the order of 100 G and less are not rare. Weak magnetic fields are considered to provide a mechanism for launching and stabilizing circumstellar disks in Be stars (e.g. Brown et al. 2008). Since a large fraction of stars in our sample was observed only once, a non-detection of their magnetic field may be explained by temporal variability of their magnetic fields. A cyclical variability with a period of 21.12 min was detected in one data set of time series in $\lambda$ Eri, but could not be confirmed in the two follow-up time series. The cluster NGC 3766 seems to be extremely interesting, where we find clear evidence for the presence of a magnetic field in seven early B-type cluster members out of fourteen members.

Since magnetic fields can potentially have a strong impact on the physics and evolution of B-type stars, it is critical to answer the principal question of the possible origin of such magnetic fields. One important step would be to conduct observations of members of open clusters and associ-
ations at different age. To date, we studied the presence of magnetic fields only in members of a young open cluster in the Carina spiral arm known for its high content of early-B type stars, NGC 3766, with very surprising results. Along with strong magnetic fields detected in He-peculiar stars, weak magnetic fields have been detected in a few normal B type stars and in a few Be stars. We note that the inability to detect magnetic fields in Be stars and normal B-type stars in the past is probably related to the weakness of these fields. Future observations will be worthwhile to determine the structure of these fields using high signal-to-noise spectropolarimetric time series.

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