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# THE EVOLUTION OF MAGNETIC FIELDS IN EARLY B-TYPE STARS

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RESUMEN

Hasta la fecha, solamente un número pequeño de estrellas O y B-tempranas han sido investigadas en la búsqueda de campos magnéticos, y como resultado, solamente se conocen como una docena de B tempranas magnéticas y unas pocas estrellas magnéticas O. La escases de información sobre la existencia, el origen y el papel de los campos magnéticos en estrellas masivas es especialmente preocupante porque los campos magnéticos pueden tener una influencia suprema en la evolución estelar de las estrellas de alta masa. Nuestros estudios se enfocan en los campos magnéticos de las estrellas B tempranas con un fuerte énfasis en la estrellas $\beta$ Cep y SPB. Se han detectado recientemente campos magnéticos longitudinales débiles (hasta $\sim 300$ G) usando FORS 1 en unas pocas estrellas $\beta$ Cep y SPB, demostrando que estos tipos de estrellas tipo B masivas no pueden seguir siendo consideradas como no magnéticas.

ABSTRACT

To date, only a small number of O and early B-type stars have been investigated for magnetic fields, and as a result, only about a dozen magnetic early B-type stars and only few magnetic O stars are known. The lack of information on the existence, origin and role of magnetic fields in massive stars is especially disturbing because magnetic fields may have paramount influence on the stellar evolution of high-mass stars. Our study focuses on the magnetic fields in early B-type stars with a stronger emphasis on $\beta$ Cep and SPB stars. Weak longitudinal magnetic fields (up to $\sim$300 G) have been recently detected using FORS 1 in a few $\beta$ Cep and SPB stars, proving that these types of massive B-type stars can no longer be considered as non-magnetic.

*Key Words:* stars: abundances — stars: atmospheres — stars: early-type, — stars: fundamental parameters — stars: magnetic fields

## 1. INTRODUCTION

Massive stars end their evolution, with a final supernova explosion, as neutron stars or black holes. The initial masses of these stars range from $\sim 8-10\ M_\odot$ to $100\ M_\odot$ or more, which corresponds to spectral types earlier than about B2. While magnetic fields in the sun and solar-like stars have been studied intensively, very little is known yet about their existence, origin and role in massive stars. This is especially disturbing, because magnetic fields may have paramount influence on the stellar evolution of high-mass stars. Maeder & Meynet (2005) examined the effect of magnetic fields on the transport of angular momentum and chemical mixing, and found that the potential influence on the evolution of massive stars is drastic.

Our recent study of the evolution state of hot Bp, pulsating $\beta$ Cephei and slowly pulsating B (SPB) stars indicates that Bp stars are younger and stars with stronger magnetic fields have much lower pulsation amplitudes. Several years ago we started a systematic search for magnetic fields in pulsating B-type stars after the detection of a weak magnetic field in two $\beta$ Cephei stars, in the prototype of the class, $\beta$ Cep itself, by Henrichs et al. (2000) and in V2052 Oph by Neiner et al. (2003a). Neiner et al. (2003b) also detected for the first time a weak magnetic field in the SPB star $\zeta$ Cas. Hubrig et al. (2006) described the detection of weak mean longitudinal magnetic fields of the order of a few hundred Gauss in 13 SPB stars and in the $\beta$ Cephei star $\xi^1$ CMa.

In order to obtain better statistics, it is necessary to increase the sample of targets with studied magnetic fields. Additional magnetic field measurements have been collected with FORS 1 at the VLT in the last two years. With this new dataset, we now have at least one measurement for each of the currently

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TABLE 1

FUNDAMENTAL PARAMETERS OF STARS WITH DETECTED MAGNETIC FIELDS

| HD | $T_{\rm eff}$ [$10^3$ K] | log $g$ [dex] | mass [$M_\odot$] | age [$10^6$ years] | radius [$R_\odot$] | $\log(L/L_\odot)$ | $f$ [%] |
|---|---|---|---|---|---|---|---|
| 11462 | 12.6±0.6 | 4.31±0.20 | 3.17±0.17 | 78±37 | 2.26±0.24 | 2.05±0.11 | 31±17 |
| 25558 | 16.4±0.7 | 4.22±0.20 | 4.88±0.30 | 33±15 | 3.01±0.39 | 2.76±0.13 | 40±21 |
| 40494 | 16.0±0.7 | 3.72±0.20 | 5.69±0.30 | 56± 5 | 4.86±0.39 | 3.14±0.10 | 93± 5 |
| 50707 | 26.2±1.2 | 3.89±0.20 | 12.82±1.17 | 10± 1 | 6.80±1.17 | 4.27±0.16 | 75±13 |
| 52089 | 25.1±1.2 | 3.82±0.20 | 12.50±1.26 | 12± 1 | 7.33±1.30 | 4.27±0.17 | 84±10 |
| 136504 | 19.3±0.9 | 3.89±0.20 | 7.44±0.64 | 28± 3 | 5.21±0.88 | 3.52±0.16 | 83±13 |
| 152511 | 14.8±0.7 | 4.23±0.20 | 4.16±0.26 | 47±22 | 2.75±0.36 | 2.51±0.13 | 39±21 |
| 152635 | 13.8±0.6 | 4.31±0.20 | 3.66±0.20 | 53±26 | 2.44±0.26 | 2.28±0.11 | 31±17 |
| 163254 | 18.2±0.8 | 4.10±0.20 | 5.99±0.43 | 28± 9 | 3.68±0.59 | 3.11±0.15 | 53±22 |
| 169467 | 16.7±0.8 | 4.12±0.20 | 5.21±0.37 | 37±13 | 3.36±0.53 | 2.89±0.15 | 51±22 |
| 179588 | 12.2±0.6 | 4.28±0.20 | 3.05±0.18 | 94±43 | 2.24±0.27 | 1.99±0.12 | 34±19 |
| 183133 | 16.7±0.8 | 3.99±0.20 | 5.55±0.43 | 45± 6 | 4.00±0.67 | 3.04±0.16 | 72±17 |
| 205879 | 12.5±0.6 | 4.23±0.20 | 3.21±0.20 | 94±41 | 2.39±0.33 | 2.09±0.14 | 40±21 |

37 confirmed Southern SPB stars. The SPB-like variability of most of these objects was discovered by the Hipparcos satellite (Waelkens et al. 1998). Their membership to the SPB class has been confirmed by long-term photometric and spectroscopic monitoring projects undertaken by members of the Institute of Astronomy of the University of Leuven.

## 2. SAMPLE DESCRIPTION AND RESULTS

Besides the confirmed SPB stars, we enlarged our magnetic field search to several other Hipparcos SPB stars. In the Hipparcos light curves, these targets show a period of the order of days, which corresponds to the pulsation range of SPB stars. Moreover, all these stars are situated in the SPB instability strip. However, we presently consider them as candidate SPB stars since an additional study of their variability is needed to definitely conclude on their nature. Indeed, chemically peculiar B-type stars and ellipsoidal variables, for which the observed variations of the same order are attributed to rotation and binarity, respectively, instead of pulsations, are also found in the same part of the H-R diagram.

Further, we obtained measurements of several selected $\beta$ Cephei stars. In particular, $\xi^1$ CMa was re-observed with the aim to investigate its magnetic variability, as well as the $\beta$ Cephei star $\delta$ Cet, selected for monitoring because its pulsation behaviour is very similar to that of $\xi^1$ CMa. As an example, we present in Figure 1 the acquired magnetic field measurements of $\xi^1$ CMa over the last 3.7 years.

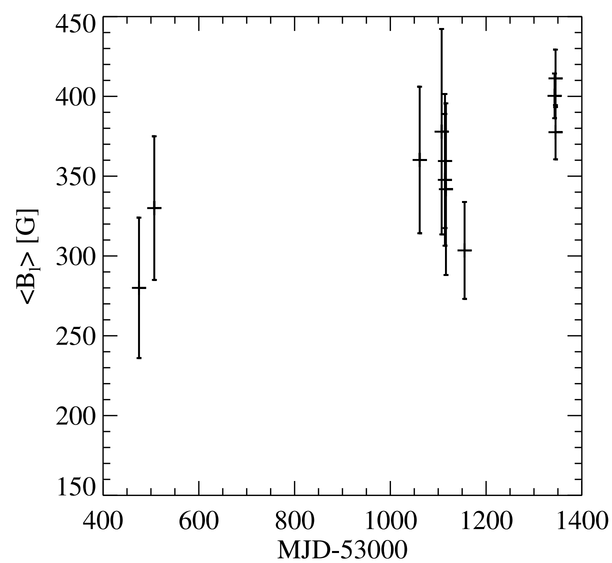


Fig. 1. Longitudinal magnetic field measurements of $\xi^1$ CMa over the last 3.7 years.

No strong variability or polarity change is detected although a slight increasing trend in the strength of the longitudinal field could be present. Two other nitrogen-rich stars were also considered in our sample. The new observations revealed the presence of magnetic fields in ten confirmed SPB and candidate SPB stars and in three $\beta$ Cephei type stars. Finally, we included several B-type standards for comparison purposes. We derived the fundamental parameters for all stars studied. In Table 1 we list

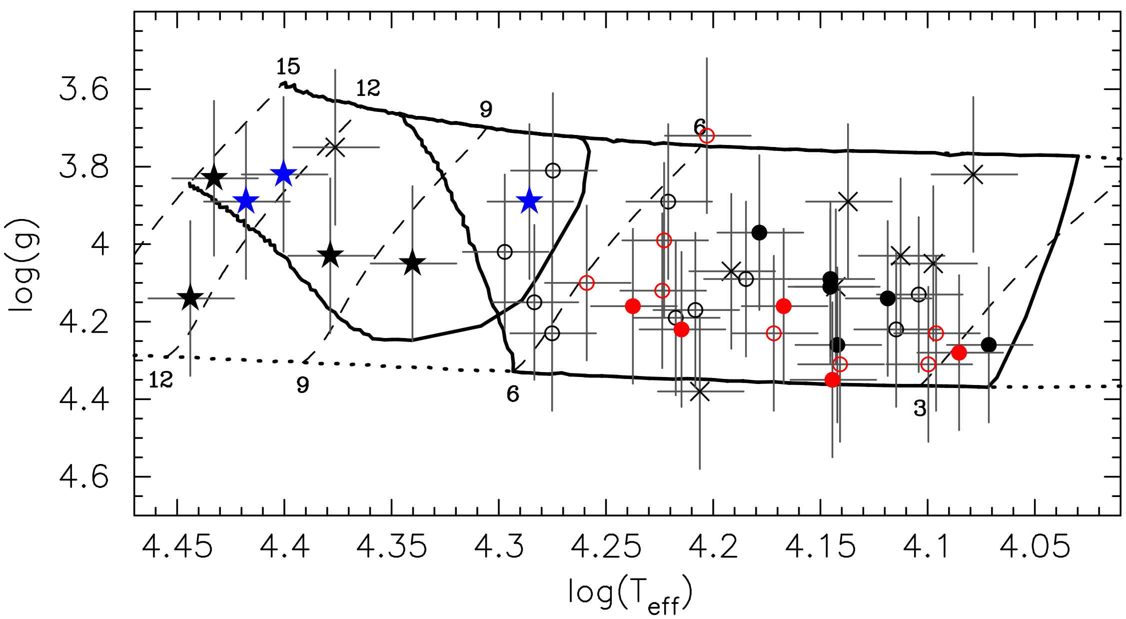


Fig. 2. The position of the studied targets in the H-R diagram. The full lines represent the boundaries of the theoretical instability strips for modes with frequencies between 0.2 and 30 $\mathrm{d}^{-1}$ and $\ell \leq 3$, computed for main-sequence models with 2 $M_\odot \leq M \leq 15$ $M_\odot$ (De Cat et al. 2007). The lower and upper dotted lines show the zero-age main sequence and terminal-age main sequence, respectively. The dashed lines denote evolution tracks for stars with $M = 15$, 12, 9, 6, and 3 $M_\odot$. Coloured symbols correspond to the stars with detected magnetic fields, filled circles to confirmed SPB stars, open circles to candidate SPB stars, filled stars to confirmed $\beta$ Cephei stars and crosses to standard B stars. The parameters of objects with $M > 12$ $M_\odot$ are less reliable because these values were found by extrapolation out of the calibration tables.

them for the stars where we detected magnetic fields in our recent study. Observations in the Geneva photometric system are available for all targets. The mean Geneva magnitudes were used to obtain the effective temperature $T_{\rm eff}$ and the surface gravity $\log g$ with the method described in De Cat et al. (2007). The $T_{\rm eff}$ and $\log g$ values of HD 50707 and HD 52089 are inaccurate because an extrapolation outside the calibration grid was needed. Other stellar parameters were derived from a grid of main-sequence models calculated with the Code Liégeois d' Évolution Stellaire (version 18.2, written by R. Scuflaire) and described as "grid 2" in De Cat (2006). The mass $M$, the radius $R$, the luminosity $\log(L/L_\odot)$ and the age of the star expressed as a fraction of its total main-sequence life $f$ are presented in Columns 4–8 of Table 1.

Their positions in the H-R diagram are displayed in Figure 2.

## 3. DISCUSSION

Our recent study of the evolutionary age of magnetic Bp and SPB stars with accurate parallaxes and available Geneva or Strömgren photometry (Briquet et al. 2007) revealed a significant difference in their

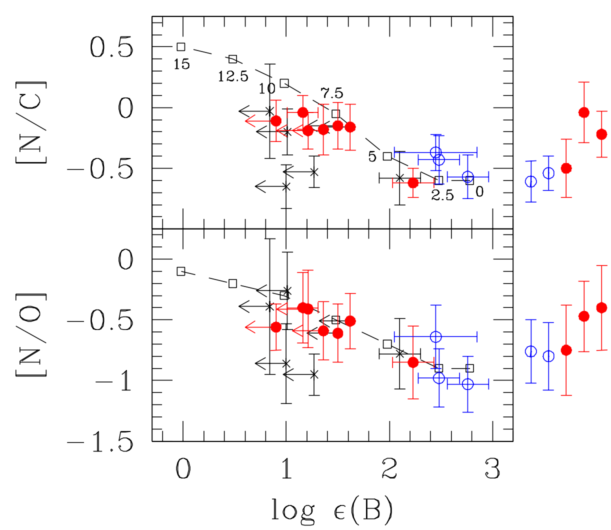


Fig. 3. Red circles: Stars with a detected magnetic field. Blue circles: Stars with null detections. Crosses: Stars without magnetic data. Five stars lacking boron data, but which have been the subject of magnetic searches are shown off scale to the right-hand side of this figure.

ages at a significance level of 98.3%. The Bp stars show much stronger magnetic fields than the SPB stars and are younger as a group. An interesting possibility raised by these results is that at least some Bp stars may transform themselves into SPB stars as they become older. Very recently, Morel et al. (2008) accomplished a study of chemical peculiarities in a sample of slowly rotating early-type B dwarfs with detected weak magnetic fields. This sample includes among other stars also a number of SPB and $\beta$ Cephei stars for which we carried out a magnetic field survey in recent years. Noteworthy, an NLTE abundance analysis strongly supports the existence of a population of nitrogen-rich and boron-depleted slowly rotating B stars (Figure 3). The presently available observational data suggest a higher incidence of chemical peculiarities in stars with detected magnetic fields. These results open a new perspective for the selection of the most promising targets for magnetic field surveys of massive stars using chemical anomalies as selection criteria.

Currently available observational results are still marginal and further studies of the magnetic fields in hot B stars, both pulsating and non-pulsating, are necessary to provide important information on the magnetic field geometry and its evolution.

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