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MAGNETIC FIELDS IN MASSIVE STARS

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RESUMEN

Aunque se acumula evidencia indirecta a favor de la presencia de campos magnéticos en estrellas de gran masa, la detección de dichos campos sigue siendo un desafío observacional. Revisamos aquí los descubrimientos recientes en estrellas masivas de distintos tipos y discutimos brevemente estrategias para futuras observaciones espectropolarimétricas.

ABSTRACT

Although indirect evidence for the presence of magnetic fields in high-mass stars is regularly reported in the literature, the detection of these fields remains an extremely challenging observational problem. We review the recent discoveries of magnetic fields in different types of massive stars and briefly discuss strategies for spectropolarimetric observations to be carried out in the future.

Key Words: polarization — stars: circumstellar matter — stars: magnetic fields — stars: oscillations

1. INTRODUCTION

An increasing number of observations of hot stars provide indirect evidence that magnetic fields must be present in those stars: Cyclic behaviour on a rotational timescale observed in the UV wind lines (e.g., Henrichs et al. 2005), the presence of narrow X-ray emission lines (Cohen et al. 2003), non-thermal radio emission (Bieging et al. 1989), etc. In spite of numerous indirect evidence only very few direct magnetic field detections have been reported so far. Magnetic fields are accessible through the Zeeman effect: the Zeeman components of spectral lines are polarised and thus permit magnetic fields to be measured even in rapidly rotating massive stars where rotation broadening, etc., prevents the resolution of Zeeman components.

2. RECENT SEARCHES

Currently, direct measurements are achieved only in two O stars, θ^1 Ori C and HD 191612 with $B_{\rm eff}$ values of a few hundred Gauss (Donati et al. 2002, 2006). To study the incidence of magnetic fields in O stars, we recently obtained high S/N spectropolarimetric observations of eleven O stars with FORS 1 at the VLT with a typical accuracy of the field determination of about 30–70 G. However, no evidence of a magnetic field was found, leading to the conclusion that large scale, dipole like magnetic fields are not widespread among O-type stars.

Among early B-type stars, a magnetic field has been discovered in the B0.2V star τ Sco and in one of the hottest β Cephei stars, the B0.7IV star ξ^1 CMa. Two more β Cephei stars, β Cep (Henrichs et al. 2000) and V2053 Oph (Neiner et al. 2003a), with spectral types B2III and B2IV, exhibit a weak magnetic field. The star ξ^1 CMa has the largest magnetic field of up to 300 G (Hubrig et al. 2006), whereas the magnetic field for the other three stars is much weaker with corresponding $B_{\rm eff}$ values less than 100 G. A magnetic field of the order of a few hundred Gauss has recently been discovered for slowly pulsating B-type stars (Neiner et al. 2003b; Hubrig et al. 2006). The effect of the magnetic field on the oscillation properties of β Cephei stars and slowly pulsating B-type stars has not been studied in detail yet. In Figures 1 and 2 we present the most recent magnetic field observations of the hottest β Cephei star ξ^1 CMa.

Another type of massive stars, rapidly rotating Be stars, lose mass and initially accumulate it in a rotating circumstellar disk. Much of the mass loss is in the form of outbursts and so additional mechanisms such as the beating of nonradial pulsation modes or magnetic flares must be at work. Previously, only two Be stars have been found as weekly magnetic with $B_{\rm eff}$ values less than 100 G (Neiner et al. 2003c; Hubrig et al. 2006). Our recent search for magnetic fields in 15 Be stars with FORS 1 at the VLT revealed that out of our sample five Be stars present circular polarisation signatures in lines formed in the circumstellar environment (Hubrig et al., in preparation). Furthermore, for a few stars we measured a field of the order of 100 G, changing its field polarity every 8–9 minutes. Clearly, time series are needed

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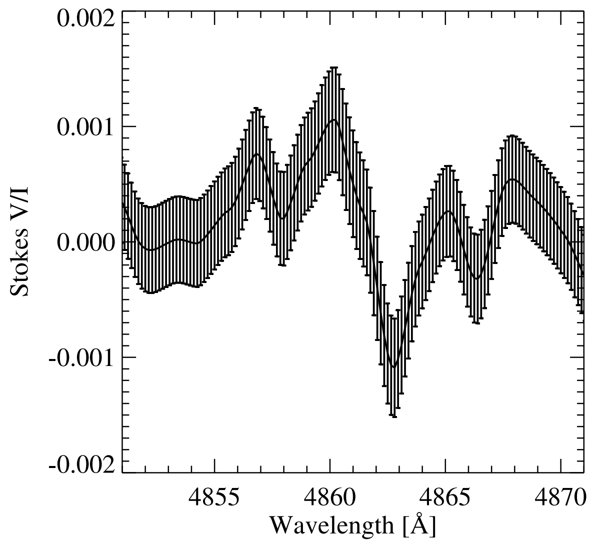

Fig. 1. Stokes V/I spectra of the β Cephei star ξ^1 CMa around the Hβ line. The thickness of the plotted line corresponds to the uncertainty of the polarisation measurements determined from photon noise.

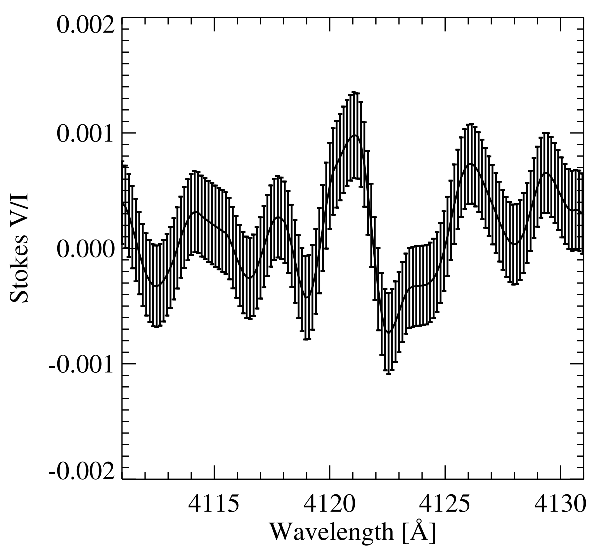

Fig. 2. Stokes V/I spectra of the β Cephei star ξ^1 CMa around the He II line at 4121 Å.

to study these local transient magnetic fields. As it has already been discussed by Maheswaran (2003) in the framework of his Magnetic Rotator Wind-Disk Model, magnetic fields can consist of flux loops that emerge from lower latitudes and thread the disk around the Be star.

3. DISCUSSION

Magnetic fields are indeed present in hot massive stars. Potential progress in their study may come from achieving better accuracy of the measurements of magnetic fields or from the detailed studies of polarised line profiles, in the case that the magnetic fields of massive stars have structures significantly more complex than those of classical Ap and Bp stars.

The Hanle effect is a relatively new magnetic diagnostic in stellar astrophysics, but can probably be used to study circumstellar magnetic fields. This effect produces a depolarisation of the scattered radiation and a rotation of the plane of polarisation (e.g., Ignace et al. 2004). A program for such observations is currently allocated at the VLT with FORS 1 and we are expecting to receive the data in the middle of 2007.

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DISCUSSION

I. Howarth - You grouped HD 148259 and HD 153262 separately from other Be stars, so I was unsure if these were stars showing stellar fields? Or are all the Be Stars showing only "disk" fields?

S. Hubrig - HD 148259 and HD 153262 show a field of the order of 100 G, changing its field polarity every 8-9 minutes. We believe that these fields can be attributed to the circumstellar material, but more detailed studies are needed.

H. Zinnecker - Let me react to your last comment on the prospect of magnetic field measurements of massive stars with extremely large telescopes (ELT). AT the recent ELT conference in Marseille I insisted several times that we must not design a big telescope that cannot observe magnetic fields. I believe this concern was noted and its importance finally realised. It would be a shame if the future 42 m ESO-ELT would not be able to make spectropolarimetric Zeeman measurements at very high spectral resolution!

S. Hubrig - I completely agree. As a matter of fact, we have strongly emphasized the need for spectropolarimetric capability of ELT on ELT science nearly one year ago (2006, IAU Symp. 232, 248)

G. Rauw - You mentioned that 11 O stars had been observed with FORS1 but no magnetic field was detected. Where the O stars selected on showing indirect evidence for a magnetic field? And what is the upper limit on the fields in this sample?

S. Hubrig - The accuracy of longitudinal magnetic field measurements was mostly about 50–60 G if we use only hydrogen lines for our measurements. We can reach about 30 G if we also include metal lines. The sample of 11 O stars has been carefully selected from a IUE archival search of O star spectra based on specific UV-line variability, similar to confirmed magnetic stars.

N. Smith - Ap stars tend to be older with more ordered field geometry, while more massive stars with magnetic fields are young with less ordered field geometry. Is this a continuous trend or are they two distinct groups?

S. Hubrig - There is an obvious difference between the evolutionary state of both groups, as Ap stars exhibit magnetic fields only when they are evolved from the ZAMS. Contrary, Bp stars show the strongest magnetic fields when they are close to the ZAMS. Still the geometry of their magnetic fields is dominated by a dipole, although it seems that more massive stars have to be more frequently modelled with a more complex geometry, including higher order multipole moments.

Virpi reviewed her career and had some time to remind us of important issues that still need to be looked at.