Clumping in Hot Star Winds
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Magnetic fields and wind variability in massive stars

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This paper describes the thesis work of Schnerr (2007) entitled "Magnetic fields and mass loss in massive stars", which aimed at a better understanding of the impact of magnetic fields on the winds of massive stars.

1 Introduction

The goal of this PhD project was to increase our understanding the role of magnetic fields in massive stars (M≥10 $M_\odot$), as magnetic fields strongly impact both their formation and evolution, and many unexplained phenomena observed in massive stars are likely related to magnetic fields. In this paper we list the known magnetic massive stars, summarise the indirect evidence for the presence of magnetic fields in these stars, such as various types of variability observed in UV wind lines, report new direct measurements of their magnetic field strengths, and discuss results of models of the impact of magnetic fields on the structure of the stellar wind.

2 Indirect evidence for magnetic fields in massive stars

The most important indirect evidence of magnetic fields in massive stars is the observed, rotationally modulated, variability in their UV wind lines (see e.g. Henrich et al. 2005). Examples of such variability are shown in Fig. 1. Magnetic fields have been suggested as a possible cause for this variability (see also Sect. 2.1).

Ud-Doula & Owocki (2002) showed that the type of variability caused by a magnetic field can be characterised by the magnetic confinement parameter η_*:

$$\eta_* = \frac{B_{*,\mathrm{eq}}^2 R_*^2}{\dot{M} v_\infty}, \qquad (1)$$

where $B_{*,\mathrm{eq}}$ is the magnetic field strength at the stellar equator, R_* the stellar radius, $\dot{M}$ the mass-loss rate and v_∞ the terminal wind velocity. All currently known magnetic massive stars (listed in Table 1) have $\eta_* \gg 1$, which means that the behaviour of their winds is dominated by the magnetic field. Such stars are called oblique rotators. For stars with $\eta_* < 1$, the wind dominates over the magnetic field, but even such a weak field could still result in observable variability in the wind. The fact that only relatively strong magnetic fields have been detected is likely due to the sensitivity of the current instrumentation. The known population of magnetic massive stars might only be the tip of the iceberg.

Other indicators for the presence of a magnetic field are non-thermal radio emission likely due to synchrotron radiation (White 1985, see also Schnerr et al. 2007c), anomalous X-ray emission (e.g. Oksala et al. 2005 and Waldron & Cassinelli 2001), chemical peculiarities related to reduced mixing due to magnetic fields, and variable (double peaked) emission lines such as Hα and He II (e.g. Moffat & Michaud 1981, Rauw et al. 2001 and Stahl et al. 1996).

2.1 Types of UV wind-line variability

A thorough investigation of OB stars observed with IUE by ten Kulve (2004, see also Howarth & Prinja 1989, Kaper et al. 1996, Fullerton 2003 and Henrichs 2005) revealed three different types of UV wind-line variability (Fig. 1). Next to the known DAC-type variability observed at high velocities (near v_∞) and the magnetic-type variability close to line centre, a third type is found with variability at intermediate velocities.

All known magnetic massive stars observed by IUE show magnetic-type variability, except ω Ori and θ^1 Ori C which show DAC-type variability. In all these stars the UV wind-line variability is stricly periodic (see Fig. 2), except perhaps ω Ori where the periodicity was only observed for a period of three days (Peters 1996). Most O stars show DAC-type variability, usually with a cyclic behaviour but not strictly periodic. Cranmer & Owocki (1996) presented a model to explain this type of variability by a disturbance at the base of the wind. As a cause for this disturbance both magnetic fields and non-radial pulsations have been suggested. However, the observed periods of the variability are of the order of the stellar rotation period, and no pulsations modes

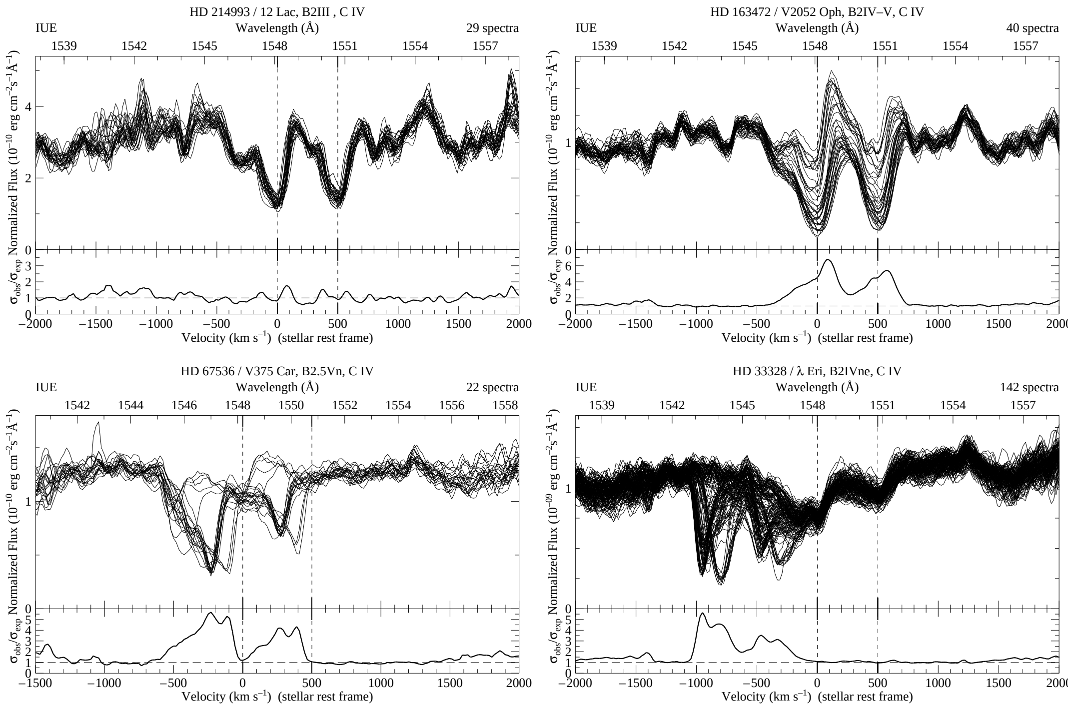

Figure 1: Examples of the different types of variability found in the UV wind lines of massive stars. Shown are: a non-variable star (12 Lac - top left), magnetic type variability (V2052 Oph - top right), intermediate type variability (V375 Car - bottom left) and DAC-type variability (λ Eri - bottom right). Figures after ten Kulve (2004).

(or beating of different modes) with the right periods have been observed (see e.g. Henrichs 1999).

3 Line profile modeling

To investigate the impact of a magnetic field on the stellar wind of a massive star, we have modeled the case of the B1IV star β Cephei using a MHD code to determine the wind geometry in the presence of a magnetic field (see ud-Doula et al. 2002) and a SEI based code to calculate corresponding line profiles. We find that for simple phenomenological models with enhanced density in the magnetic equator (presumably due to magnetic channeling of the wind) the observed variability of the wind lines is qualitatively reproduced. However, when full 2D-MHD models are used to determine the geometry of the stellar wind, significant differences are encountered that are likely due to X-ray ionisation which has not been included in the models (see Schnerr et al. 2007b).

4 New B-field measurements

Currently only a rather small sample of magnetic massive stars is known (see Table 1). To increase this number we have started a large observational program to search for new magnetic massive stars. For this program we have observed 11 O-type stars at three different epochs with FORS1 at the VLT and obtained a total of 136 magnetic field measurements of 25 OB stars with Musicos at the TBL (Schnerr et al. 2007a). Typical 1σ errors of the order of 40-100 gauss were achieved, but no new magnetic fields have been detected. From this we conclude that if magnetic fields are responsible for the observed UV wind-line variability in massive stars, they must either be weak ($\eta_* = 0.1 - 1$) or relatively small scale (perhaps similar to sunspots), or both.

5 Conclusions

The winds of many massive stars are highly variable. For the stars that are known to have strong magnetic fields (which are listed in Table 1) the (periodic) variability observed in their UV-wind lines is clearly related to the magnetic field. However, other types of variability are also observed of which the cause has not yet been established. Our working hypothesis is that magnetic fields are related to all types of UV wind-line variability, and that the type of variability is determined by the magnetic wind confinement

Table 1: The known magnetic massive stars and their properties.

Object	Spectral Type	Mass ($M_\odot$)	$B_{\rm polar}$ (G)	$P_{\rm rot}$ (days)	Reference
θ^1 Ori C	O4-6V	45	1100±100	15.4	Donati et al. (2002)
HD 191612	O6-8	∼30	∼1500±	538?	Donati et al. (2006a)
τ Sco	B0.2V	∼15	∼500±	41	Donati et al. (2006b)
β Cep	B1IV	12	360±40	12.00089	Henrichs et al. (2000)
V2052 Oph	B1V	10	250±190	3.63883	Neiner et al. (2003)
ζ Cas	B2IV	9	340±90	5.37045	Neiner et al. (2003)
ω Ori	B2IVe	8	530±200	1.29	Neiner et al. (2003)
14 pulsating stars	B1–B8	2-14	few 10^2	>1	Hubrig et al. 2006
He-peculiar (∼25)	B1–B8	$\lesssim$10	10^3–10^4	0.9–22	

parameter η_* and the magnetic field configuration.

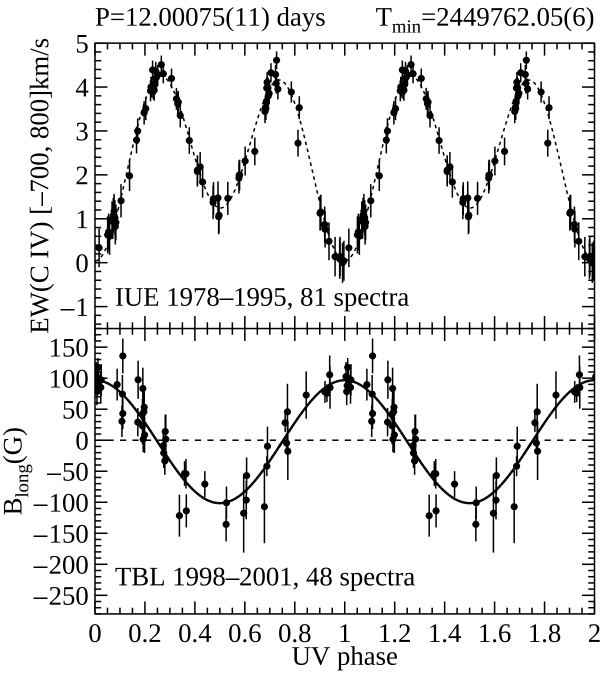

Figure 2: The variability of the equivalent width of the CIV line (top) in β Cephei shows the same period as the magnetic field (bottom), which is the rotational period of the star. Figure after Henrichs et al. (2005).

References

Cranmer, S.R., Owocki, S.P. 1996, ApJ, 462, 469

Donati, J.-F., Babel, J., Harries, T.J., et al. 2002, MNRAS, 333, 55

Donati, J.-F., Howarth, I.D., Bouret, J.-C., et al. 2006a, MNRAS, 365L, 6

Donati, J.-F., Howarth, I.D., Jardine, M.M., et al. 2006b, MNRAS, 370, 629

Fullerton, A.W. 2003, ASPC, 305, 333

Henrichs, H.F. 1999, Proc. IAU Coll. 169, Eds. Wolf et al., Lect. Notes in Phys., Vol. 523, 305

Henrichs, H.F., de Jong, J.A., Donati, J.-F., et al. 2000, Proc. IAU Colloquium 175, ASP, Vol. 214, p.324

Henrichs, H.F., Schnerr, R.S., & ten Kulve, E. 2005, ASPC, 337, 114

Howarth, I.D. & Prinja, R.K. 1989, ApJS, 69, 527

Hubrig, S., Briquet, M., Schöller, M., et al. 2006, MNRAS, 369L, 61

Kaper, L., Henrichs, H.F., Nichols, J.S., et al. 1996, A&AS, 116, 257

Kulve, E. ten, 2004, Master Thesis, Univ. of Amsterdam

Moffat, A.F.J., Michaud, G. 1981, ApJ, 251, 133

Neiner C., Geers V.C., Henrichs H.F., et al. 2003a, A&A, 406, 1019

Neiner C., Hubert A.-M., Fremat, Y., et al. 2003b, A&A, 409, 275

Neiner C, Henrichs H.F., Floquet, M., et al. 2003c, A&A, 411, 565

Oksala, M.E., Gagné, M., Cohen, D.H., et al. 2005, ASPC, 337, 289

Peters, G. 1996, Be Star Newsletter, 31, 16

Rauw, G., Morrison, N.D., Vreux, J.-M., et al. 2001, A&A, 366, 585

Schnerr, R.S. 2007, PhD thesis, University of Amsterdam

Schnerr, R.S., Henrichs, H.F., Neiner, C. et al. 2007a, A&A, submitted

Schnerr, R.S., Henrichs, H.F., Owocki, S.P., et al. 2007b, ASPC, 361, 488

Schnerr, R.S., Rygl, K.L.J., van der Horst, A.J., et al. 2007c, A&A, 470, 1105

Stahl, O., Kaufer, A., Rivinius, T., et al. 1996 A&A, 312, 539

ud-Doula, A., & Owocki, S.P. 2002, ApJ, 576, 413

Waldron, W.L., Cassinelli, J.P. 2001, ApJ, 548L, 45

White, R.L. 1995, ApJ, 289, 689

Kubat: If β Cep is not a Be star, what is the source of the Hα emission?

Schnerr: Using spectro-astrometic observations we have shown in Schnerr et al. (2006, A&A) that the Hα emission actually originates from the binary companion of β Cep, which is likely a normal Be star.

Cassinelli: Steve Shore found that for stars with strong fields the outflow was out of the magnetic polar region. But you said that for β Cep the flow cut the B field equator.

Cohen: In θ' Ori C it also was assumed that the wind is strongest over the magnetic poles, but once the field was measured it turned out that the strongest wind is in fact in the magnetic equatorial plane.

Sonneborn: Shore's work on mass loss/wind in oblique rotators is for stars with strong magnetic fields, so mass loss along the magnetic poles is not surprising.

Schnerr: I agree that the very high field strength may explain the different behavior.