Investigating the spectroscopic, magnetic and circumstellar variability of HD 57682

Benjamin Mauclaire[1], Jason H. Grunhut[2 †]

[1] Observatoire du Val de l'Arc, 13530 Trets, France
[2] Department of Physics, Engineering Physics & Astronomy, Queen's University, Kingston, Ontario, Canada, K7L 3N6

Introduction

In 2010, the O9IV star HD 57682 was one of only eight convincingly detected magnetic O-type stars. These small numbers are both a reflection of the rarity of O-type stars with detectable magnetic fields, and the challenge of detecting such fields when present. The present study seeks to refine and elaborate the preliminary results reported by [2].

Physical parameters:

Spectral type	O9IV (Walborn 1972)
T_{eff} (K)	$34\,500 \pm 1000$
$log\ g$ (cgs)	4.0 ± 0.2
$R_\star$ $(R_\odot)$	$7.0^{+2.4}_{-1.8}$
$log\ (L_\star/L_\odot)$	4.79 ± 0.25
$M_\star$ $(M_\odot)$	17^{+19}_{-9}
$log\ \dot{M}$ $(M_\odot\ yr^{-1})$	-8.85 ± 0.50
v_∞ $(km\ s^{-1})$	1200^{+500}_{-200}
$log\ (L_X/L_{Bol})$	-6.34

Since 2007, a long-term French compain for Be stars (including O-type candidates) has been initiated with the launch of the BeSS database [1]. In this context, in February 2010, Coralie Neiner (GEPI, Paris-Meudon obsevatory) sent a request to amateurs for spectroscopic monitoring of HD 57682 on the Hα line during MOST satellite run. However, abrupt changes in the line studied prompted us to contact J. Grunhut, lead author of HD 57682 magnetism discovery paper [2]. It was then the beginning of a survey of nearly a year that resulted in an article that appeared in 2012 in MNRAS [3].

Data and observations

Spectropolarimetric observations were mainly collected with the high-resolution ($R \sim 68\,000$) ESPaDOnS spectropolarimeter from which mean average profiles were extracted. Additional spectroscopic data come from the ESO CES and mostly from amateur LHIRES3 ($R \sim 15\,000$) spectra stored in BeSS database. Dynamics spectra (Figs 1, 2) show signs of periodicity:

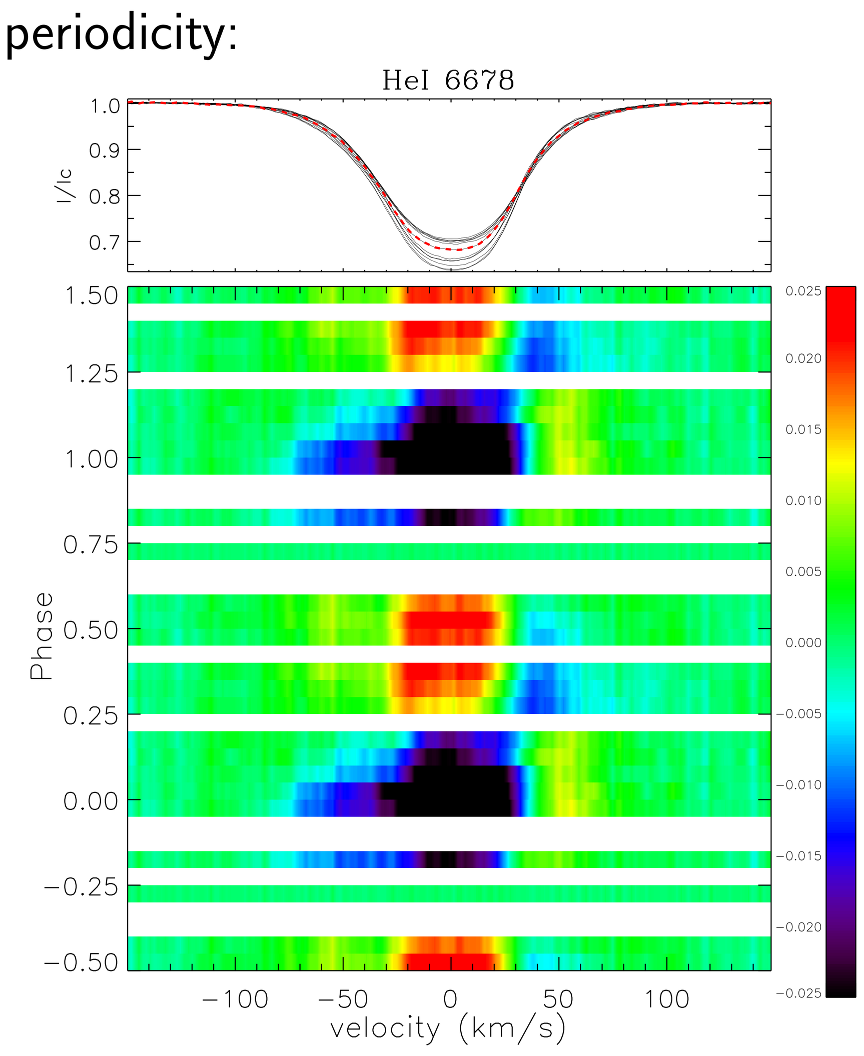

Figure 1: Phased variations in selected spectral lines with sinusoidal equivalent width variations. Plotted is the difference between the observed profiles and the profile obtained on 24 December 2010 (dashed-red, top panel).

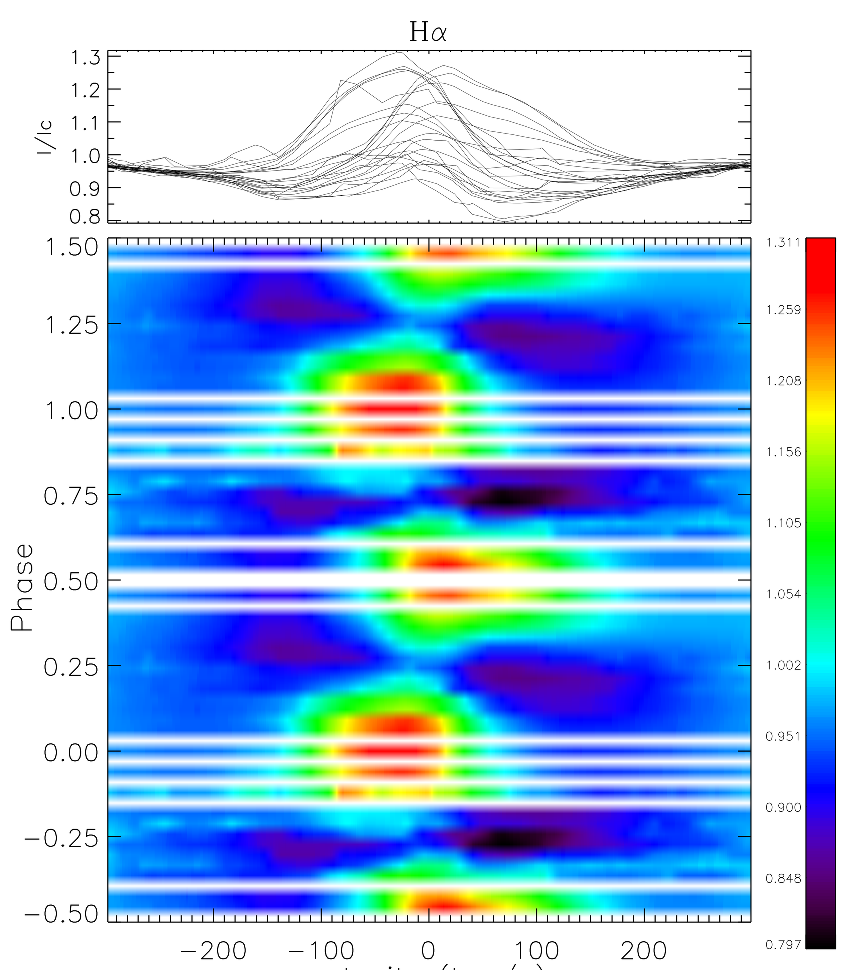

Figure 2: Same as Fig. 1 but for spectral lines (Hα line) here that show evidence of two emission features per rotation cycle. Red spots highlight the circumstellar emission.

- Surface line-of-sight component B_ℓ of the magnetic field values were obtained by measuring the first-order moment of the Stokes V profile from spectropolarimetric observations, normalized by the intensity profile.
- The dipole magnetic field strength B_d is determined from comparing B_ℓ curve to a grid of models (Fig. 4) as described in Results section.
- Hα EW and V_{radial} measurements are primarily coming from BeSS observations of HD 57682 fed by amateurs (51 out of 67 spectra). Period analysis of Hα EW and B_ℓ enable an accurate rotation period measurement.
- Ephemeris were based on rotation period computed from periodogram (Fig. 5) and $HJD0$ corresponds to B_ℓ maximum: $\mathrm{HJD}^{max}_{B_\ell} = 2453347.71(35) + 63.5708(57) \cdot E$. (1)

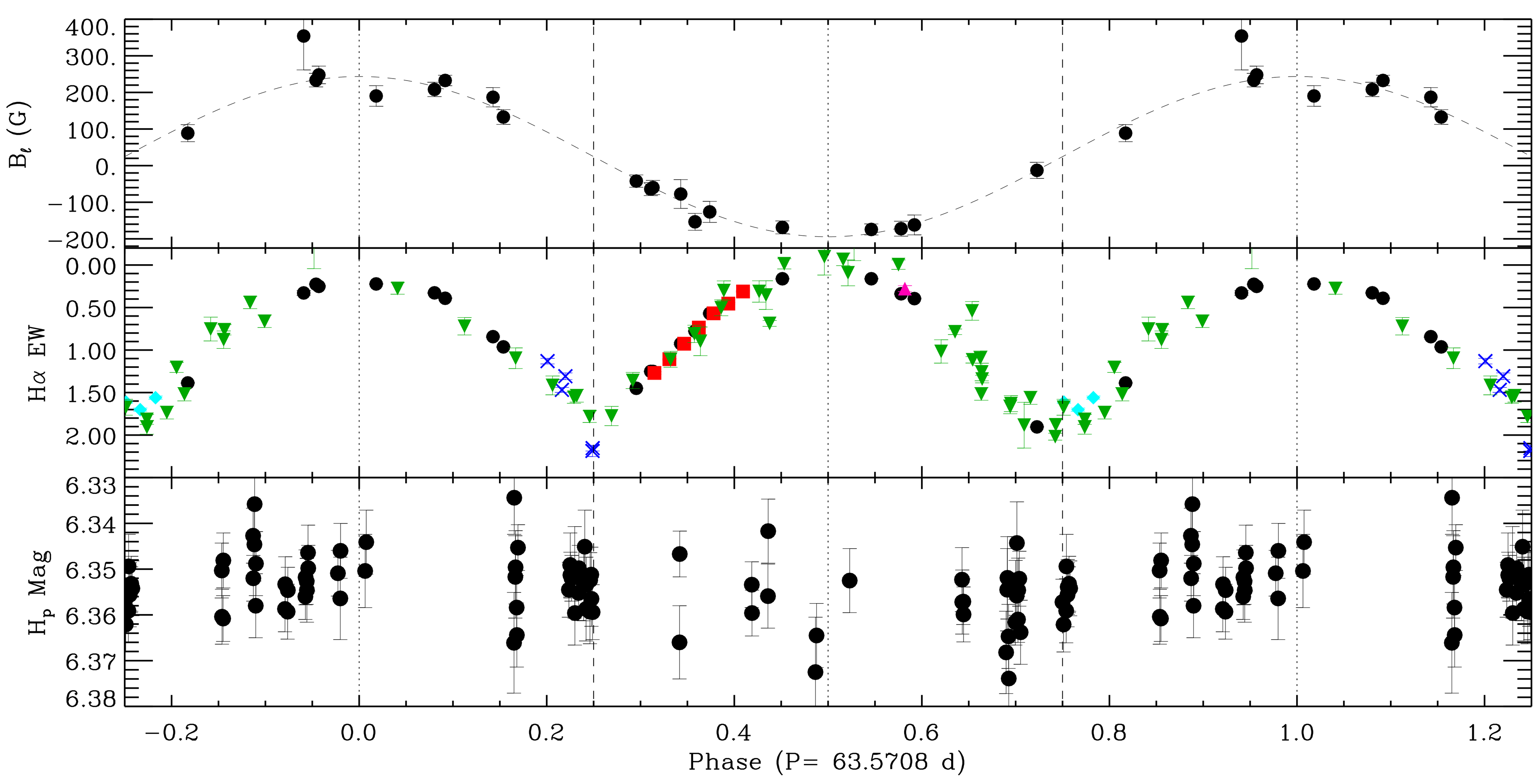

Figure 3: Phased observational data using the ephemeris of Eq. 1. **Upper:** Longitudinal magnetic field variations measured from mean average profiles of the ESPaDOnS spectra. **Middle:** Hα equivalent width variations measured from ESPaDOnS (black circles), CES (red squares), FEROS (blue Xs), Las Campanas Observatory (turquoise diamonds), UVES (pink up-facing triangles), and **BeSS (green down-facing triangles)** datasets. **Lower:** Hipparcos photometry. The dashed curve in the upper frame represents a least-squares sinusoidal fit to the data.

† Affiliation at the time of paper publication.

Methods and results

The magnetic field geometry was investigated assuming the field is well described by the Oblique Rotator Model (ORM). Method described below allowed to fix the dipole magnetic field strength B_d and its obliquity β relative to the rotation axis.

A χ^2 minimisation was carried out, comparing the observed B_ℓ curve to a grid of computed longitudinal field curves to determine B_d and β for a fixed linear limb darkening coefficient of 0.35. B_ℓ-fit (Fig. 4) and profile-fit allow geometric caracterisation of the magnetic field: $B_b \sim 915$ G, $\beta \sim 60°$.

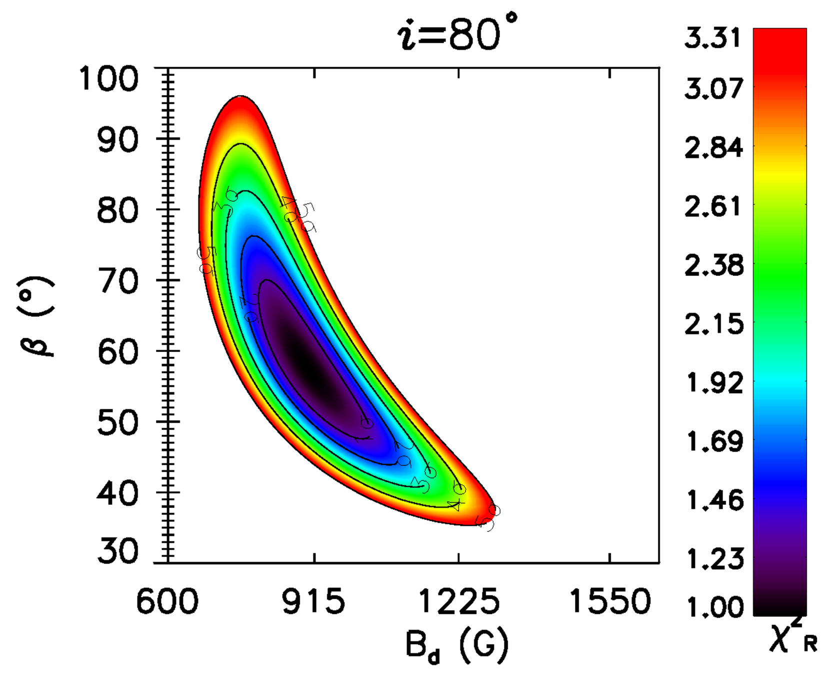

Figure 4: χ^2 landscape as a function of dipole field strength (B_d) and obliquity angle of the magnetic axis relative to the axis of rotation (β). Shown are the intervals corresponding to 1, 2, 3, 4, and 5σ confidence, assuming $i = 80°$.

From this new data set, it was possible to constrain the rotation period to 63.5708 ± 0.0057 d (Fig. 5), to examine the variations of several lines and to refine the geometry of the longitudinal magnetic field coming from a dipole almost perpendicular ($79 \pm 4°$) to the axis of rotation and intensity 900 ± 60 G (Fig. 4). Moreover, the modeling of the variations of the Hα line shows that its emissions are generated by an equatorial ring of optically thick plasma and confined by the stellar magnetic field.

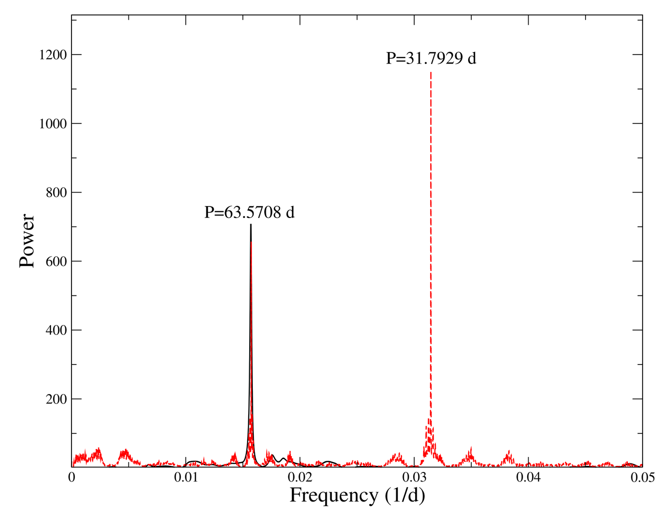

Figure 5: Periodograms obtained from the B_ℓ measurements (solid black) and from the Hα EW variations including contributions from the first harmonic (dashed red). Note the strong power present in the Hα periodogram at $P = 31.7927$ d but the lack of power from the B_ℓ measurements at this period. However, a consistent period is found at $P = 63.5708$ d from both datasets.

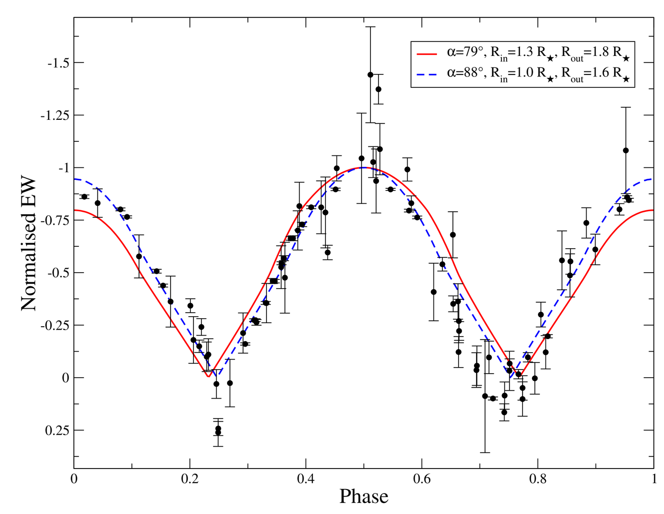

Figure 6: "Toy" model compared to phased Hα equivalent width measurements (black circles). The solid red curve represents a model with an $\alpha = 79°$ between the rotation axis and the disc axis, as inferred from the fits to the B_ℓ variations, while the dashed blue curve represents the best-fit model with an $\alpha = 88°$. Both models assume $i = 60°$.

Hα emission variation is often attributed to the variable projection of a flattened distribution of magnetospheric plasma. To this end, we explored the potential of using a "Toy" model to fit the observed Hα EW variations. A comparison between the predicted and observed EW values is shown in Fig. 6. This model lead us to explain Hα EW behaviour by an equatorial disc (Fig. 7).

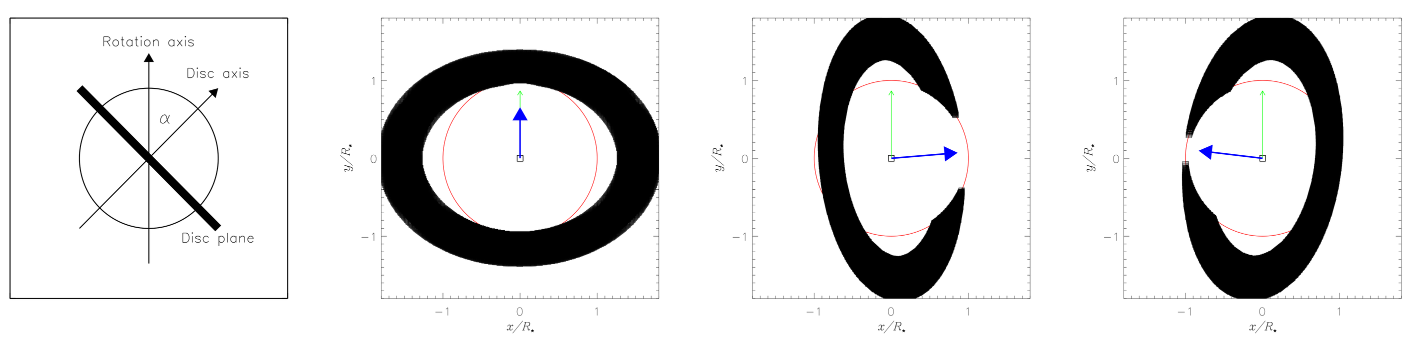

Figure 7: Illustration of our "Toy" model for the Hα emission disc. The left panel provides an example schematic diagram showing the orientation of the plane of the disc for a given disc inclination α relative to the rotation axis. The other panels represent projections of the disc (solid black) and central star (solid red) onto our line-of-sight during phases 0.0, 0.33, and 0.66.

Conclusion

Our investigation have allowed us to study HD 57682's magnetic and magnetospheric properties at a level of detail not currently achievable for any other magnetic O-type star. Our analysis indicate a highly complex behaviour that can be used as a testbed for future 3D MHD simulations to better understand non-rotationally supported magnetospheres.

References

[1] J. Bouvier, A. Chalabaev, and C. Charbonnel, editors. *SF2A-2007: Semaine de l'Astrophysique Francaise*, July 2007.

[2] J. H. Grunhut, G. A. Wade, W. L. F. Marcolino, and al. *MNRAS*, 400:L94–L98, Nov. 2009.

[3] J. H. Grunhut, G. A. Wade, J. O. Sundqvist, B. Mauclaire, and al. *MNRAS*, 426:2208–2227, Nov. 2012.