X-ray emission and the incidence of magnetic fields in the massive stars of the Orion Nebula Cluster

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Introduction

- Stellar magnetic fields are well known to produce X-rays in late-type, convective stars like the Sun.
- However, X-ray emission coming from OB stars is often explained by radiative instabilities resulting in a multitude of shocks in their winds (Lucy & White 1980, Owocki & Cohen 1999).
- The Chandra Orion Ultradepth Project (COUP) was dedicated to observing the Orion Nebula Cluster (ONC) in X-rays. The OBA sample (20 stars) was studied with the goal of disentangling the respective roles of winds and magnetic fields in producing X-rays (Stelzer et al. 2005).
- The production of X-rays by radiative shocks should be the dominant mechanism for the subsample of O to early-B stars which have «strong winds». However, aside from 2 of those stars, all targets showed X-ray intensity and/or variability which were inconsistent with the small shock model predictions.
- We have undertaken a study with ESPaDOnS to explore the role of magnetic fields in producing this diversity of X-ray behaviours.

Figure 1: Periodic X-ray modulation of the ONC star JW660. From Stelzer et al. (2005).

Observations

- 8 stars of the COUP «strong wind» OB subsample were observed with the echelle spectropolarimeter ESPaDOnS at CFHT. High resolution (R=65,000) measurements of Stokes I and V were obtained under good conditions, with an appreciable signal to noise ratio.
- The mean Stokes I and V profiles were extracted with the Least Square Deconvolution technique (LSD) of Donati et al. (1997), which allows the use of many lines to increase the level of detection of a magnetic field Stokes V signature.
- 2 stars show field signatures: \textit{β}\textsuperscript{2} Ori C (for which a field has already been detected by Donati et al. 2002) and Par 1772 (shown in Figure 2, along with the non-detection case \textit{β}\textsuperscript{1} Ori D).

Figure 2: Least Square Deconvolved profiles for \textit{β}\textsuperscript{1} Ori D and Par 1772. In black are the mean Stokes I profiles (bottom), the mean Stokes V profiles (top) and the N diagnostic null profile (middle). In red are the best fit models from our magnetic analysis. A clear Stokes V signature is detected for Par 1772.

Magnetic analysis

- The modeling of the LSD Stokes V profile can constrain the surface field strength in a detection case, and provide upper limits for a non-detection.
- We sampled the 4-dimensional parameter space (\iota, \beta, \phi, B) which describes a centred dipolar magnetic configuration. \iota is the projected angle of the rotation axis, \beta is the angle between the magnetic axis and the rotational axis, \phi is the rotational phase, B is the polar field strength.
- For each configuration, we calculated the reduced \chi\textsuperscript{2} of the model fit to the observed LSD Stokes V profile. Interested by the range of possible field strengths admitted by the data, we extracted the best fit for all configurations for a given (B,\beta). Figure 3 shows the field strengths and obliquities that are consistent with the observations within the 3\textalpha limit.
- As we only obtained a single phase observation of each star, there is a broad range of possible field strengths in the case of a non-detection, because when \beta = 90°-\iota, geometries exist for which there is no Stokes V signature, notwithstanding the field

Figure 3: Maps of admissible dipole field strengths and obliquities for \textit{β}\textsuperscript{1} Ori D and Par 1772. The colorbar represents the minimum \chi\textsuperscript{2} value for a given (B,\beta) (varying \iota and \phi through all values). Contours show associated probabilities.

Table 1

<table>
<thead>
<tr>
<th>ID</th>
<th>Spec Type</th>
<th>v\textsubscript{sin} (km/s)</th>
<th>B\textsubscript{\phi} (G)</th>
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<tr>
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<td>1100±100 (3\alpha)</td>
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<td>131</td>
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<td>55</td>
<td>&lt;300</td>
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<tr>
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<td>49</td>
<td>&lt;150</td>
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<td>180</td>
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<td>&lt;150</td>
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<tr>
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<td>98</td>
<td>800–2500</td>
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<td>210</td>
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Discussion

- This study of the Orion stellar cluster represents a complete magnetic survey of a co-evolved and co-environmental population of massive stars.
- A continuous distribution of magnetic fields in neutron star progenitor main sequence stars (above 8 solar masses) has been predicted by Ferrario and Wickramasinghe (2006). Interestingly, we find 2 stars (25%) with fields above 1 kG, whereas W & F predict only 6%.

Figure 4: Predicted magnetic field distribution of massive stars (8-45M\textsubscript{\odot}) on the main sequence. From Ferrario and Wickramasinghe (2006)