First study of large-scale magnetic fields and magnetospheric accretion processes in Class I protostars, observed with SPIRou

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Context

- ❑ Magnetism regulates star–disk interactions and angular momentum transfer in protostars.
- ❑ Protostellar magnetic fields remain poorly constrained.
- ❑ Magnetospheric accretion diagnostics are still challenging in Class I protostars.
- ❑ First study of a sample of Class I and Flat-Spectrum (FS) protostars and magnetic maps of protostellar surfaces.
- ❑ Observations obtained with SPIRou, a high-resolution near-infrared spectropolarimeter at the Canada France Hawaii Telescope (CFHT).
- ❑ Part of the PROMETHEE project (PI: E.Alecian) on protostellar magnetism.

Techniques

Magnetic field → Zeeman polarisation and broadening of atomic lines. Measured on photospheric lines.

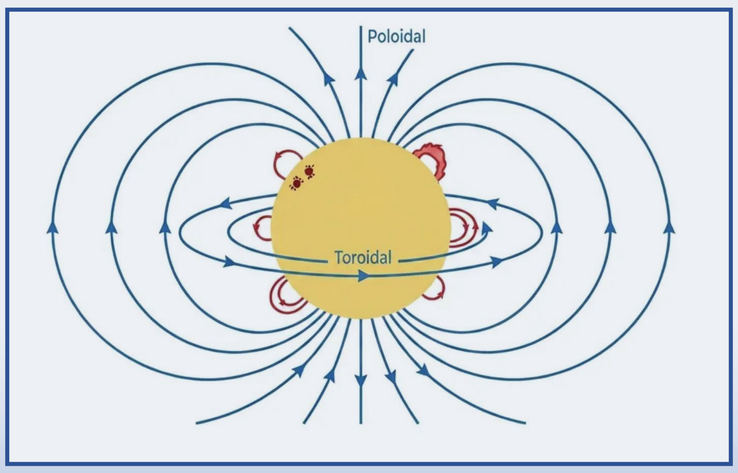


Fig.1: Sketch illustrating the magnetic field at different scales. The large-scale field is shown in blue, with the poloidal and toroidal fields clearly distinguishable. The small-scale field is shown in red. The former can be measured through polarization, the later through line broadening.

❖ Large-scale magnetic field:

1 Least-Squares Deconvolution (LSD) (Donati+1997), *SpecpolFlow*[1] pipeline (Folsom+2025)

2 Longitudinal magnetic field (B_l) measurement:

$$B_l = -2.14 \times 10^{11} \frac{\int v\, V(v) dv}{\lambda z c \int [I_c - I(v)] dv}$$

(E1): Wade et al. 2000

3 Zeeman Doppler Imaging (ZDI), *ZDIpy* code[2] (Folsom+2018)

❖ Total-scale magnetic field:

4 Zeeman broadening, <B>, *SYNMAST* code (Kochukhov+2007)

[1]https://folsomcp.github.io/specpolFlow/

[2]https://github.com/folsomcp/ZDIpy

B detection in Class I

SCAN ME

Drouglazet et al. (2026)

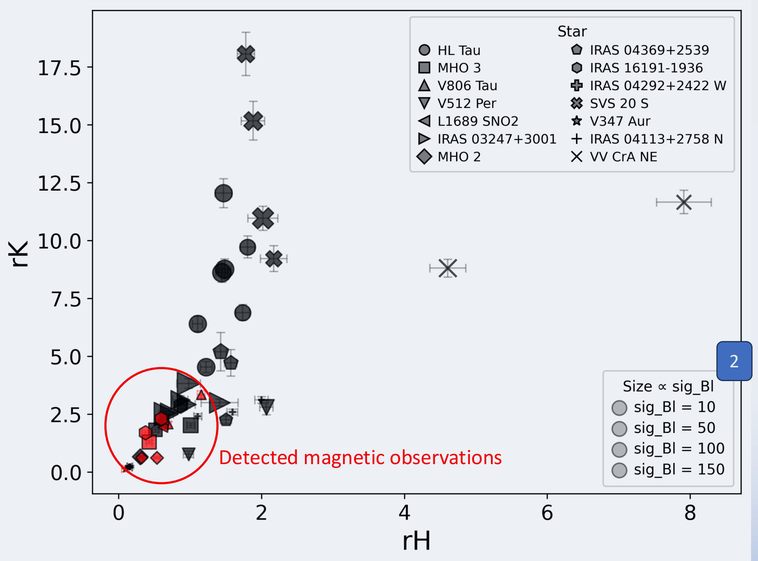


Fig.2: K-band vs H-band veiling for all observations. Symbol size reflects the longitudinal field uncertainty. Magnetic observations are shown in red, non-detections in black.

Analysis of the **large-scale** magnetic fields of 15 Class I and FS protostars with 2 to 7 observations per objects, using SPIRou.

Determination of the Teff, vsini, B_l, veiling.

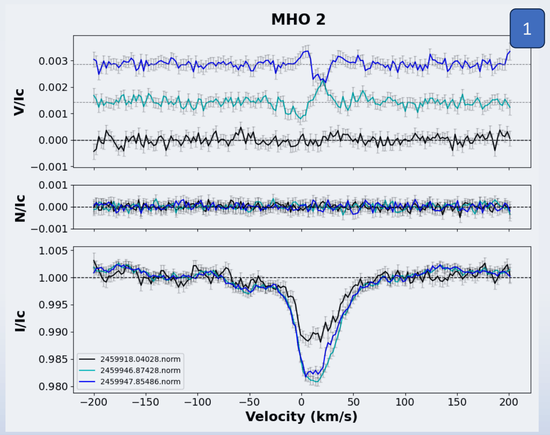


Fig.3: LSD profiles, Stokes V, N and I of MHO 2.

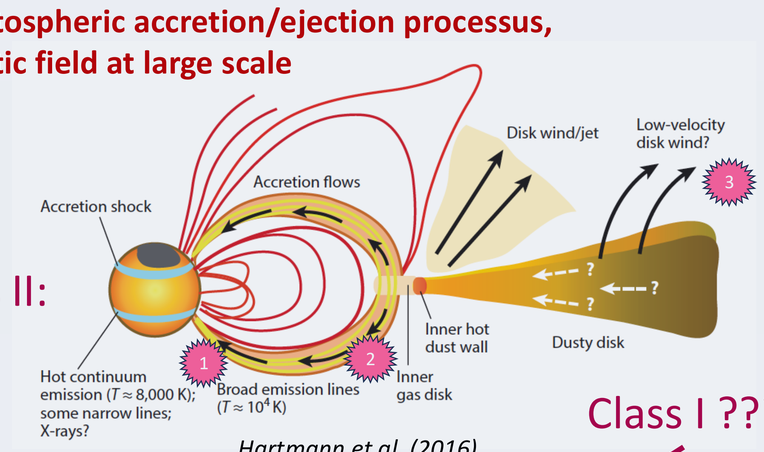
Magnetic detection on 6 protostars **(40%)**

Less magnetic detection at higher veiling (see Fig.2) !

Accretion/ejection lines

Magnetospheric accretion/ejection processus, Magnetic field at large scale

Class II:



Hartmann et al. (2016)

Class I ???

PROMETHEE

SPIRou observations, 18 Class I and FS protostars, 2-26 number of night and 8-104 observations per objects, total: 162 nights dataset.

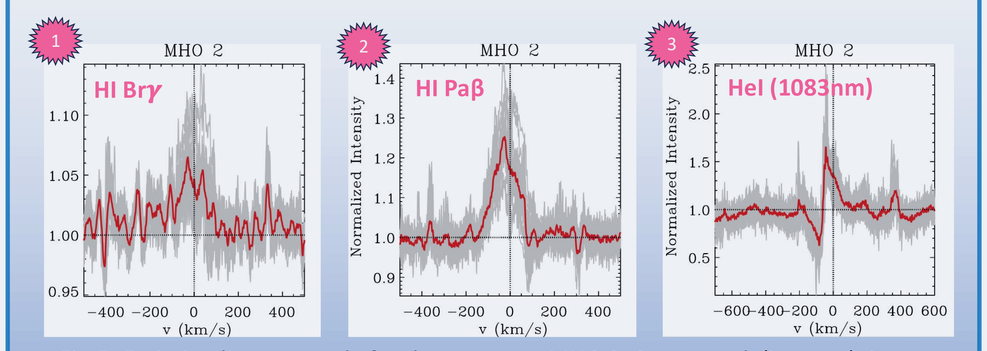


Fig.5: Emission lines example for the protostar MHO 2, Sousa et al. (in prep.), in grey individuals profiles (in total 26 profiles) and in red the mean profile.

Magnetic field map & measurements

3 MHO 2, ZDI magnetic map:

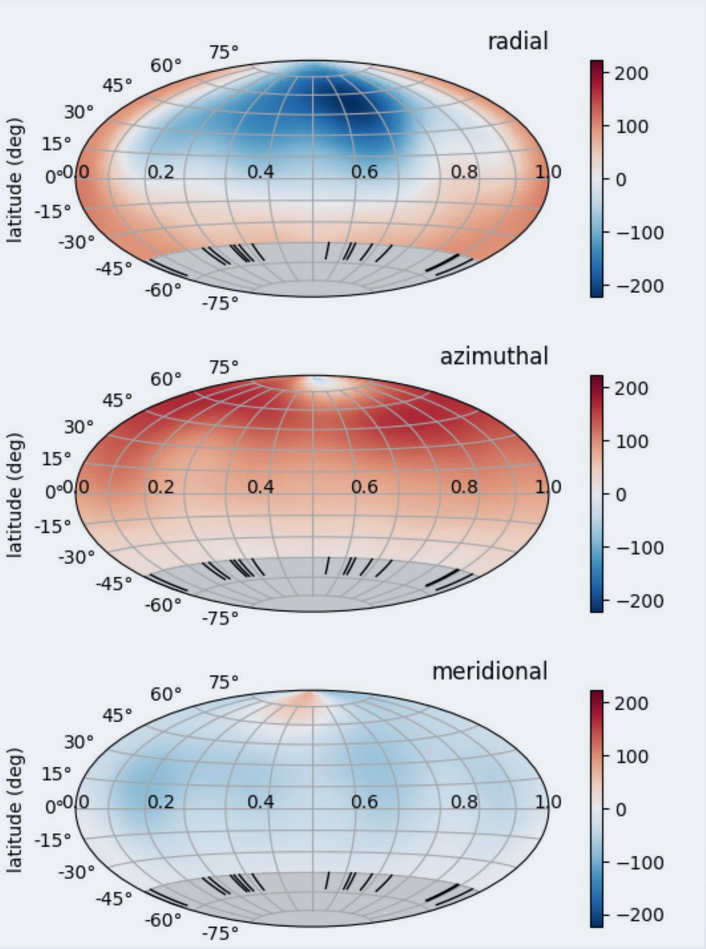


Fig.3: ZDI magnetic map showing the radial, azimuthal and meridional component of MHO 2 using *ZDIpy* (Drouglazet et al., in prep.). Grey regions indicate areas impossible to constrain. Colour scale corresponds to the signed magnetic field strength in Gauss (G).

Temporal monitoring (~15 obs.) of three sources. We estimated the **topology** and the **geometry of large-scale magnetic field** in Class I and FS protostars.

→ Map the magnetic field at the surface of the protostar using ZDI method fitting Stokes V profiles (Fig.3). Determination of the period, using Lombe-Scargle periodogram on B_l.

Zeeman broadening: we **estimated the total-scale magnetic field** on individual line (Fig.4). Use of Na, Ti (magnetic sensitive) and OH, CO lines (insensitive to magnetic field) to determine <B>.

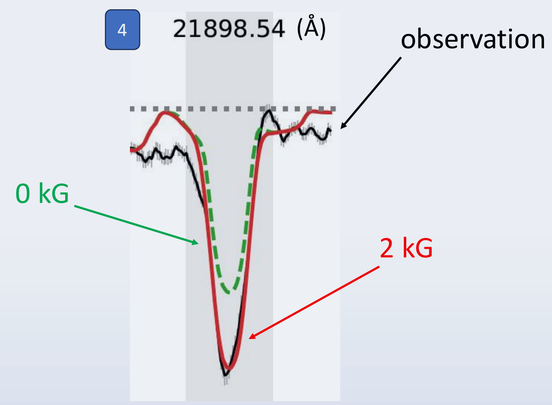


Fig.4: Zeeman broadening and intensification example on Ti line for one observation of MHO 2.

LSD periodogram			ZDI			Zeeman broadening		
Source ID	Period (d)	Inclination (°)	Poloidal (%)	Toroidal (%)	Dipole max (G)	⟨B⟩ filling factor 0 kG	2 kG	4 kG
MHO 2	3.1 ±0.1	40 ±4	47	53	155	0.03	0.96	0.01
V806 Tau	3.3 ±0.1	48 ±3	91	9	264	0.86	0.10	0.04
L1689 SNO2	3.7 ±0.1	41 ±4	90	10	470	0.26	0.50	0.24

Tab.1: Table showing the values for different Class I protostars. Period, inclination, percentages of poloidal and toroidal fields, dipole strength maximum, and filling factors for 0, 2 and 4 kG are listed same as the method used (Drouglazet et al., in prep.).

Conclusion

Magnetic analysis of 15 Class I and FS protostars using SPIRou data (median Teff ~ 4000 K):

- Large-scale magnetic field detected in 6/15 sources, with $\boldsymbol{B_l}$ ~ **80–200 G**. Magnetic detections are anti-correlated with veiling likely due to observational biases.
- Dipole max ~ 0.15 - 0.47 kG, significantly smaller than what is usually observed in Class II targets.
- Total magnetic field strength **<B> around 2 kG** (consistent with Flores et al. 2024).

Accretion/ejection lines analysis on 18 Class I and FS objects:

- Accretion lines (HI, HeI) have lower equivalent widths in Class I versus Class II.
- HeI emission line detection rate is twice lower in Class I than Class II. The detection rate of redshifted absorption in HeI is very low in Class I: 6% vs 57% in Class II.

→ Preliminary indication of more complex B-field and weaker Bdip in Class I vs Class II + weaker indication of magnetospheric accretion in accretion diagnostics.

Contact me!

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