Magnetism, evolution and rotation of Intermediate-Mass T Tauri Stars (IMTTS)

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Introduction

- Alecian 2014: « Magnetic fields along the PMS phase »

IMTTS

= Convective envelope dynamo magnetic field

Herbig Ae

= Radiative envelope dynamo magnetic field
Introduction

IMTTS (object of this study) we expect common dynamo magnetic fields

Herbig Ae and later... 5-10% of stars: very intense B (300 - 30 kG), stable, and mainly dipolar fields

These are « fossil magnetic fields »

- Alecian 2014: « Magnetic fields along the PMS phase »
Aim / methodology

- We want to bring **observational constraints** on a large sample of Herbig Ae precursors:
  - 38 intermediate-mass T Tauri stars (IMTTS)
    - Mass: 1.2 - 3.5 solar masses
    - Teff: 4800 - 7500K
    - SpT: early K - early F
    - vsin(i): 5 - 200 km/s
    - accreting or not
  - Spectropolarimetry
    - (ESPaDOnS / HARPSpol)
  - Stellar fundamental parameters
  - Magnetic field properties and topologies
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Stellar fundamental parameters
Magnetic field properties and topologies

- Villebrun et al. 2017 (in prep): « Magnetic fields and fundamental stellar parameters in 38 intermediate-mass T Tauri stars »
Determination of stellar parameters

- **Teff** and **vsin(i)** from ZEEMAN spectrum synthesis code:
  - MARCS atmosphere, solar abundances, log(g)=4
  - COUP 1350 ESPaDOnS spectrum (black) and its fit (red)
    - Teff = 5590 K  (σ = 130 K)
    - vsini = 61.8 km/s  (σ = 1.0 km/s)

- about the ZEEMAN code: *Landstreet 1988* ; *Folsom et al. 2012*
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- **Bolometric luminosity** from GAIA parallaxes (when available) or associated cluster/SFR distances
  + magnitudes from the literature using (V-J) color calculations.

  - magJ from 2MASS catalog (Cutri et al. 2003)
  - magV mainly from Kharchenko (2001), or NOMAD catalog
  - Theoretical (V-J) for IMTTS from Pecault & Mamajek (2013)
  - Theoretical (BC)j from Pecault & Mamajek (2013)
  - Total to selective extinction Rj from Casagrande et al. (2010)
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**Typical uncertainties:** 100-150K, 1-2km/s, 0.05-0.1 log(L)
Magnetic fields: detection

- **Longitudinal mean magnetic field** using the « Least Square Deconvolution » (LSD) technique

- creation of a **weighted mean absorption line** using a mask that takes into account the depth and Landé factor of each line
  (mask synthesized from our Teff and VALD lines)

1. the stokes V profile must be located inside the I profile
2. the stokes N profile must be flat (spurious signature)
3. false alarm probability must be high

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- Only 17 stars (out of 38) are magnetic!

- About the LSD technique: Donati et al. 1997
Magnetic fields: limit of detection

- In case of non-detection: we compute the **upper-limit value** of the magnetic field

**Oblique rotator model** (parameters: $i$, beta, phase, $B_d$)
we need to try many configurations with different values of $B_d$

**Monte-Carlo simulations**

- *[Alecian et al. 2016]*: «Magnetic field of the system HD 5550»

For this star, the combination of 4 observations
(4 colored lines) results in 95% detection of a
field $B_d = 2100$G (plain black line)
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→ **Monte-Carlo simulations**

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1 dot = 1 non-magnetic star → when $v \sin(i)$ is high,
the stokes V signature is diluted into noise
Positioning of our sample in the HRD

- Top left small symbols = HAeBes (from previous studies)

- Blue line ↔ Conv. / Rad. limit ↔ Mconv / Mtot = 1%

- Green line ↔ Mconv / Mtot = 99%

- Only 2 of these stars have magnetic map (CR & CV Cha)
  - Hussain et al. 2009

- PMS evolutionary model: CESAM code
Positioning of our sample in the HRD

- half of them are actually NOT convective!

- almost all the convective stars host a magnetic field (red)

- almost all the radiative stars lost their magnetic field (black)

- BUT the HRD is model dependent!! ....

- PMS evolutionary model: CESAM code
**Problematic**: could the stellar model assumptions infer our future estimates of R, M, age, internal structure? Are the discrepancies between different PMS models smaller than our observational uncertainties?

**In all 3 cases**: sun calibrated / no rotation / no mass loss / no diffusion / no overshooting

**CESAM**

(Yveline LEBRETON)

- $Z_{ini} = 0.0131$
- $Y_{ini} = 0.2539$
- $\alpha = 1.6223$
- EoS: *OPAL (2005)*
- Opacities: *OPAL (1996)*
- Abundances: *Asplund (2005)*
- Atmosphere: *Eddington gray atmosphere*

**Geneva CODE**

(Lionel HAEMMERLE)

- $Z_{ini} = 0.0122$
- $Y_{ini} = 0.2485$
- $\alpha = 1.6$
- EoS: *OPAL (1996)*
- Opacities: *OPAL (1996)*
- Abundances: *Asplund (2005)*
- Atmosphere: *Meynet & Maeder (1996)*

**Geneva STAREVOL**

(Florian GALLET, Corinne CHARBONNEL, Louis AMARD)

- $Z_{ini} = 0.0134$
- $Y_{ini} = 0.2676$
- $\alpha = 1.973$
- EoS: *Siess (2000)*
- Opacities: *Livermore*
- Abundances: *Asplund (2005)*
- Atmosphere: *PHOENIX (Allard 2011)*
PMS model influence on the HR diagram

Blue = CESAM  Red = Starevol Geneva  Green = Geneva Code
PMS model influence on the HR diagram

Blue = CESAM
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Observational prospectives

- we selected 7 IMTTS with different internal structures

CR Cha /// IRAS 22144 /// V1000 Sco /// V1156 Sco
HBC 741 /// HD 133938 /// V1149 Sco

Monitoring of Stokes I and V signatures (obtained with HARPSpol or ESPaDOnS) + Zeeman Doppler Imaging

= already observed or accepted

= still in our « shopping-list »
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Monitoring of Stokes I and V signatures
( obtained with HARPSpol or ESPaDOnS)
+
Zeeman Doppler Imaging

Surface magnetic field topology
and brightness maps
+
Confusograms

= already observed or accepted

= still in our « shopping-list »
Conclusion & more to do...

- Fundamental parameters are now well constrained for these stars:
  \[ \text{Teff @ 100-150K} \quad \text{vsini(i) @ 1-2km/s} \quad \text{log(L/Lsol) @ 0.05-0.1} \]

- Threshold of magnetic detection is typically < 1000G (except for fast-rotators)

- The transition between magnetic and non-magnetic stars match with the convective/radiative limit of PMS models

- Magnetic field loss is fast, as it occurs over a timescale of 1 Myr at most

- In the radiative region, we have less than 10% of magnetic stars (2 out of 21)

- A spectropolarimetric monitoring of 7 IMTTS (HARPSpol + ESPaDOnS) is ongoing