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

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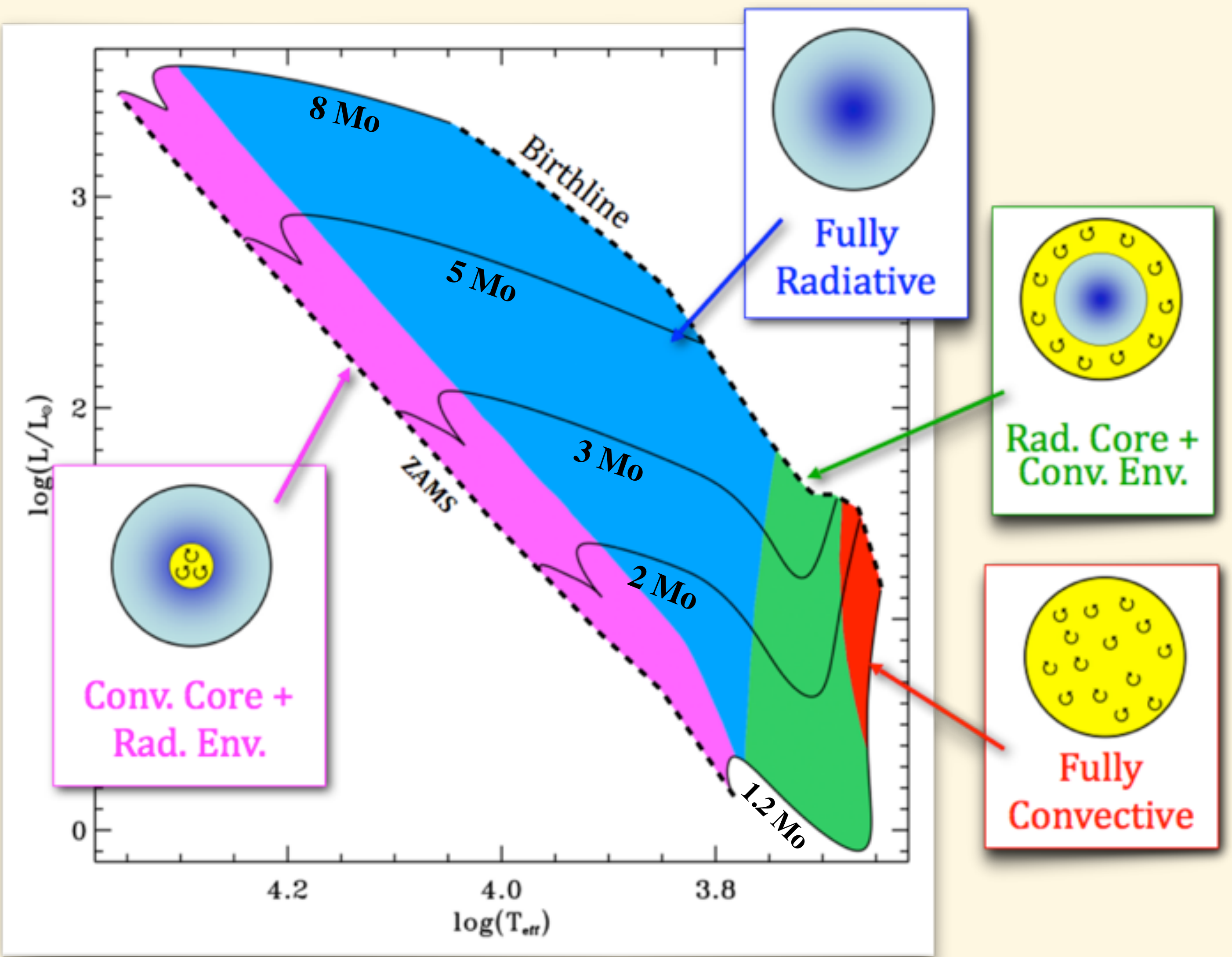
Introduction



IMTTS

=

Convective enveloppe

dynamo magnetic field

Herbig Ae

=

Radiative enveloppe

~~dynamo magnetic field~~

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

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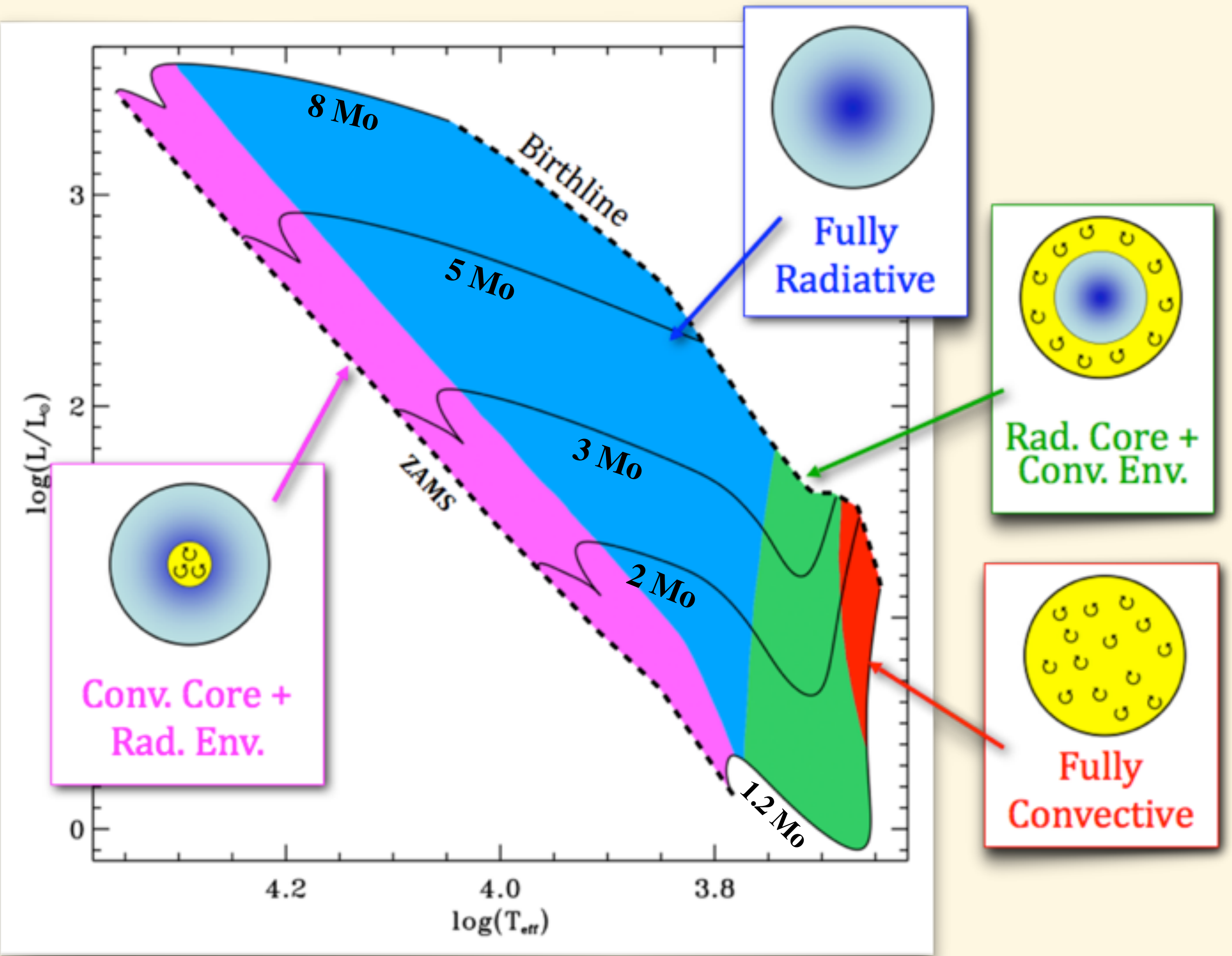

- Alecian 2014 : « Magnetic fields along the PMS phase »

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 »

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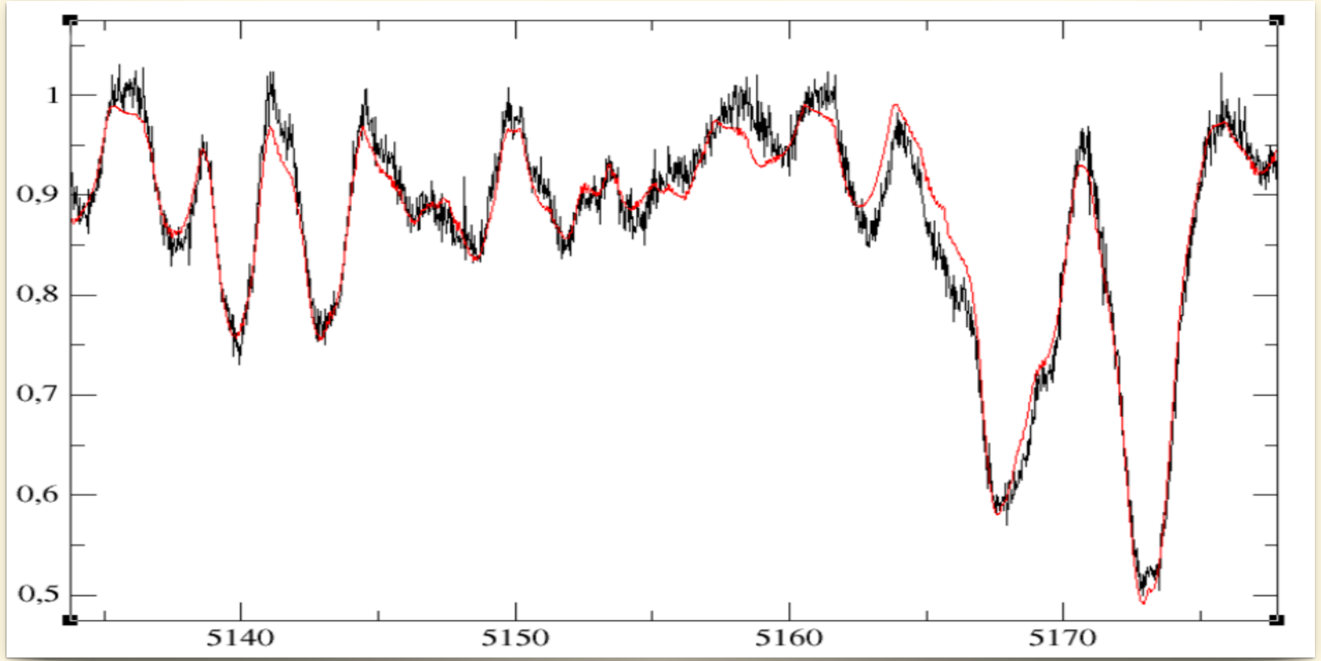
- Villebrun et al. 2017 (in prep) : « Magnetic fields and fundamental stellar parameters in 38 intermediate-mass T Tauri stars »

Determination of stellar parameters

- **Teff** and **vsin(i)** from ZEEMAN spectrum synthesis code :

  MARCS atmosphere, solar abundances, log(g)=4

  - about the ZEEMAN code : **Landstreet 1988 ; Folsom et al. 2012**



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)

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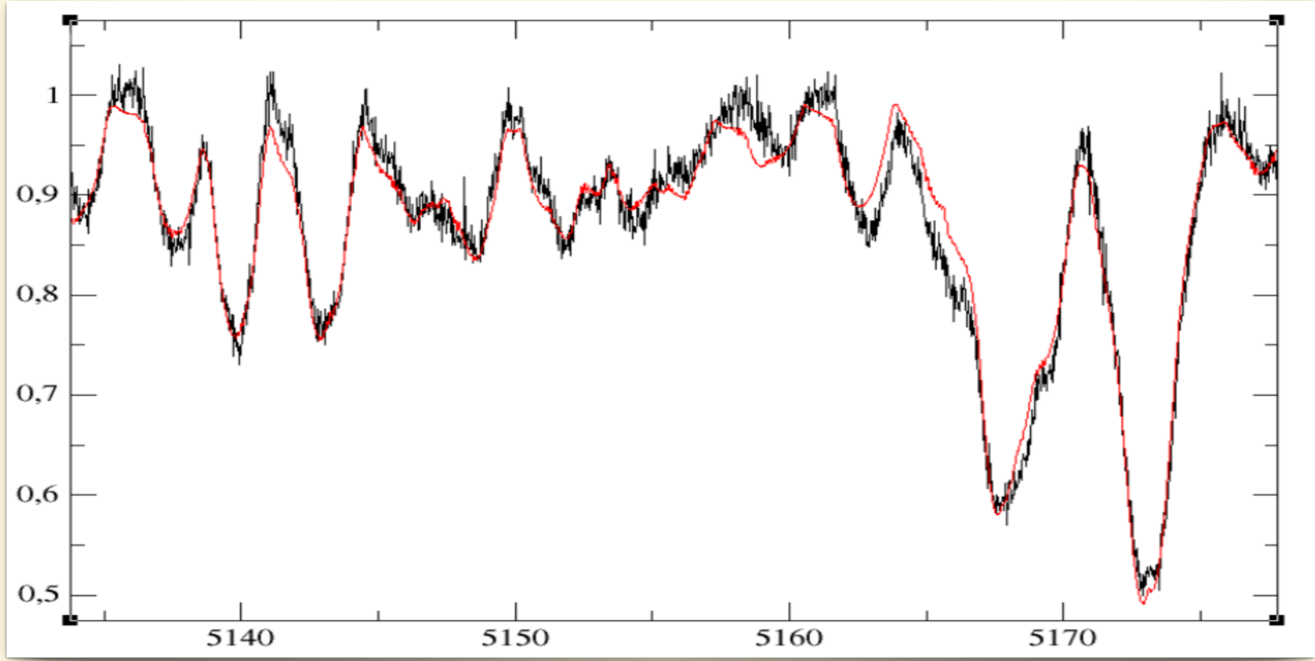

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- **Bolometric luminosity** from GAIA parallaxes (when available) or associated cluster/SFR distances

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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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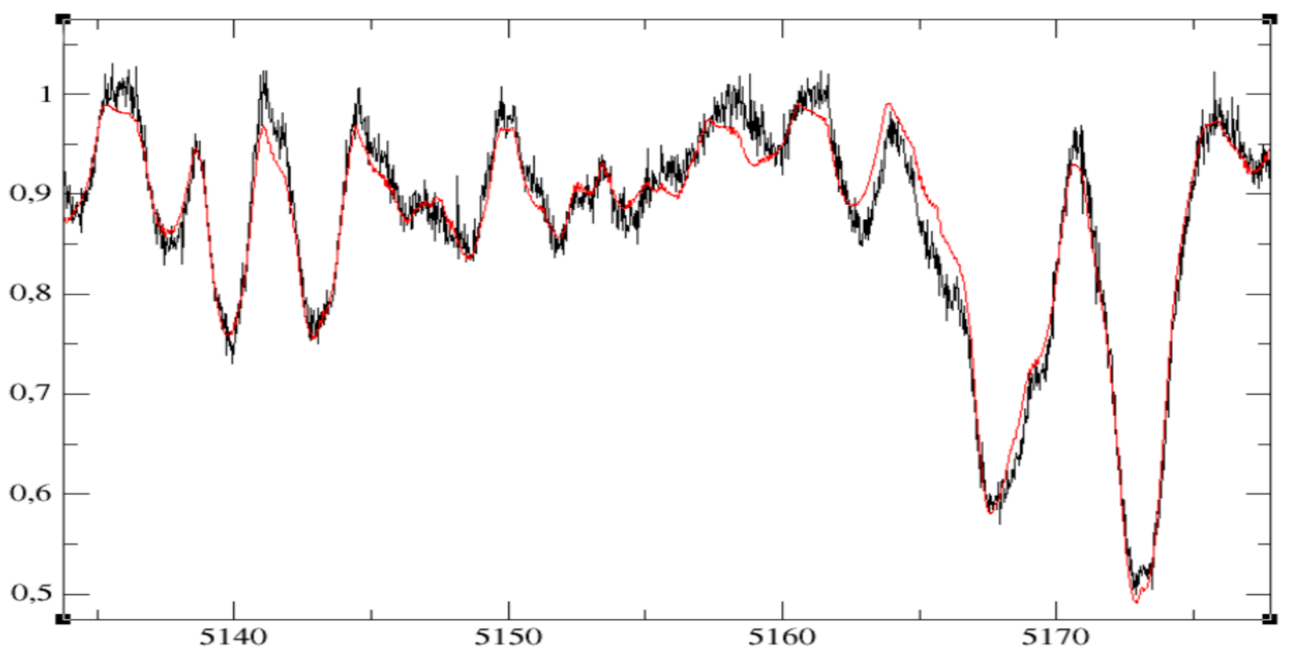

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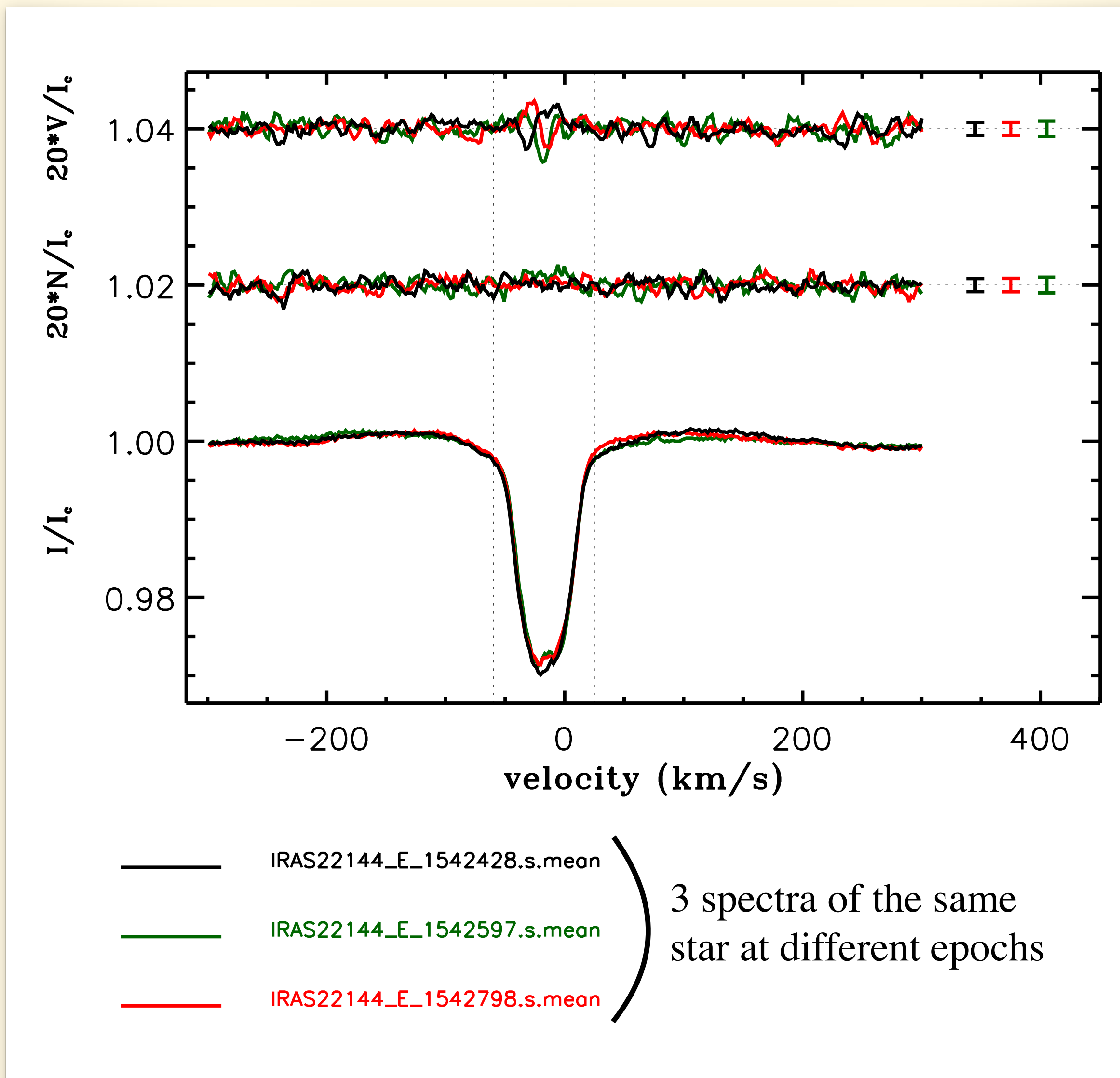
Typical uncertainties : 100-150K 1-2km/s 0.05-0.1 log(L)

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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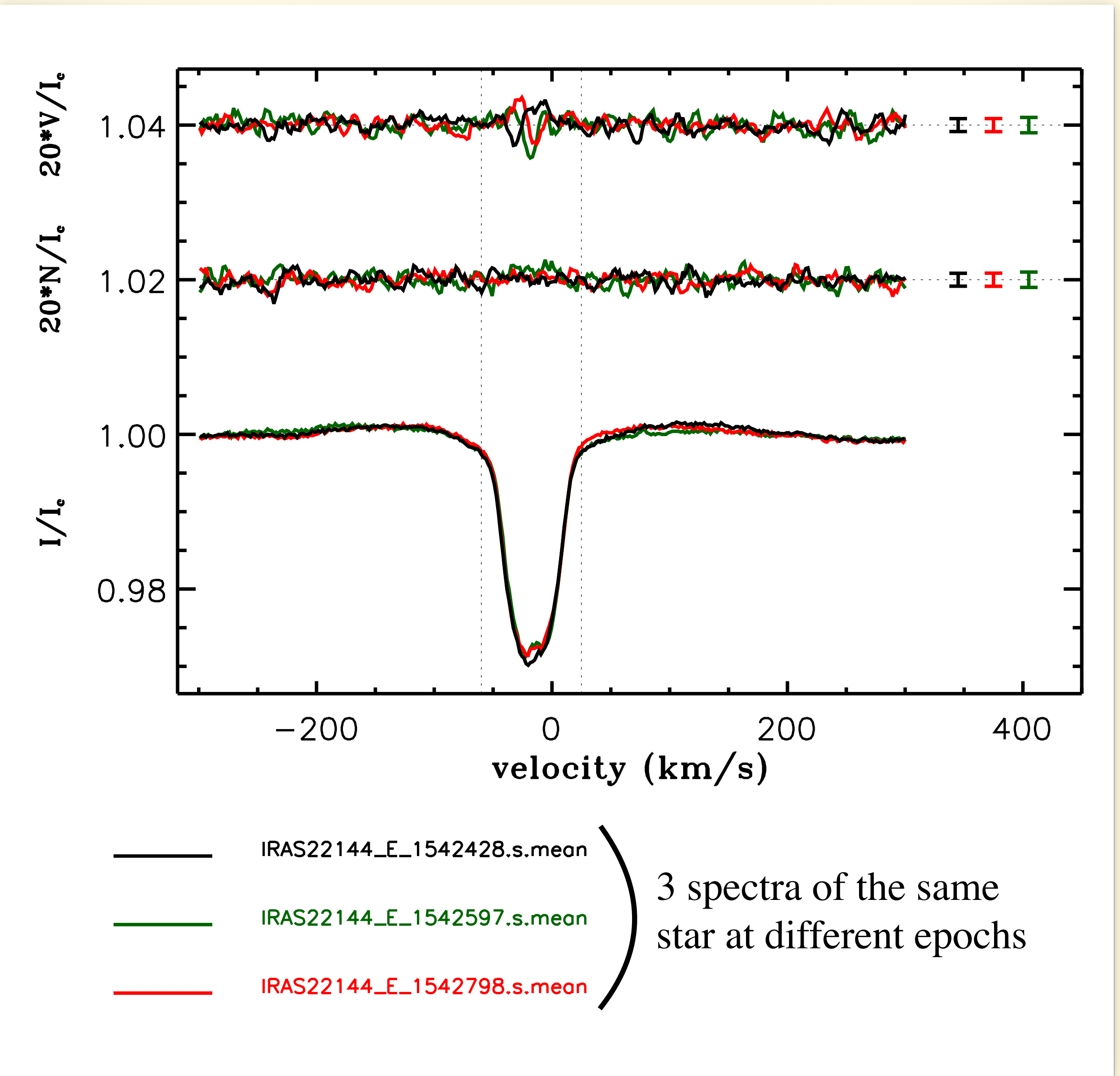

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Only 17 stars (out of 38) are magnetic !

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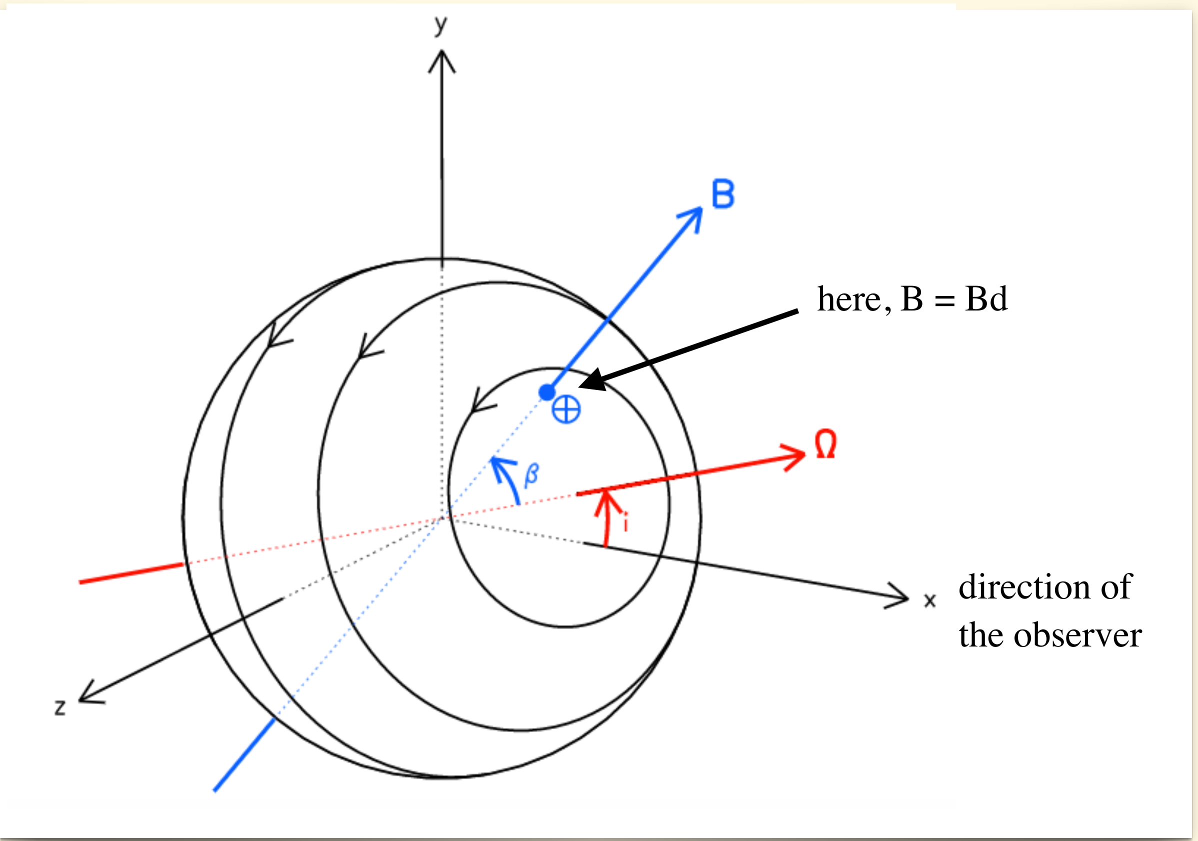
Magnetic fields : limit of detection

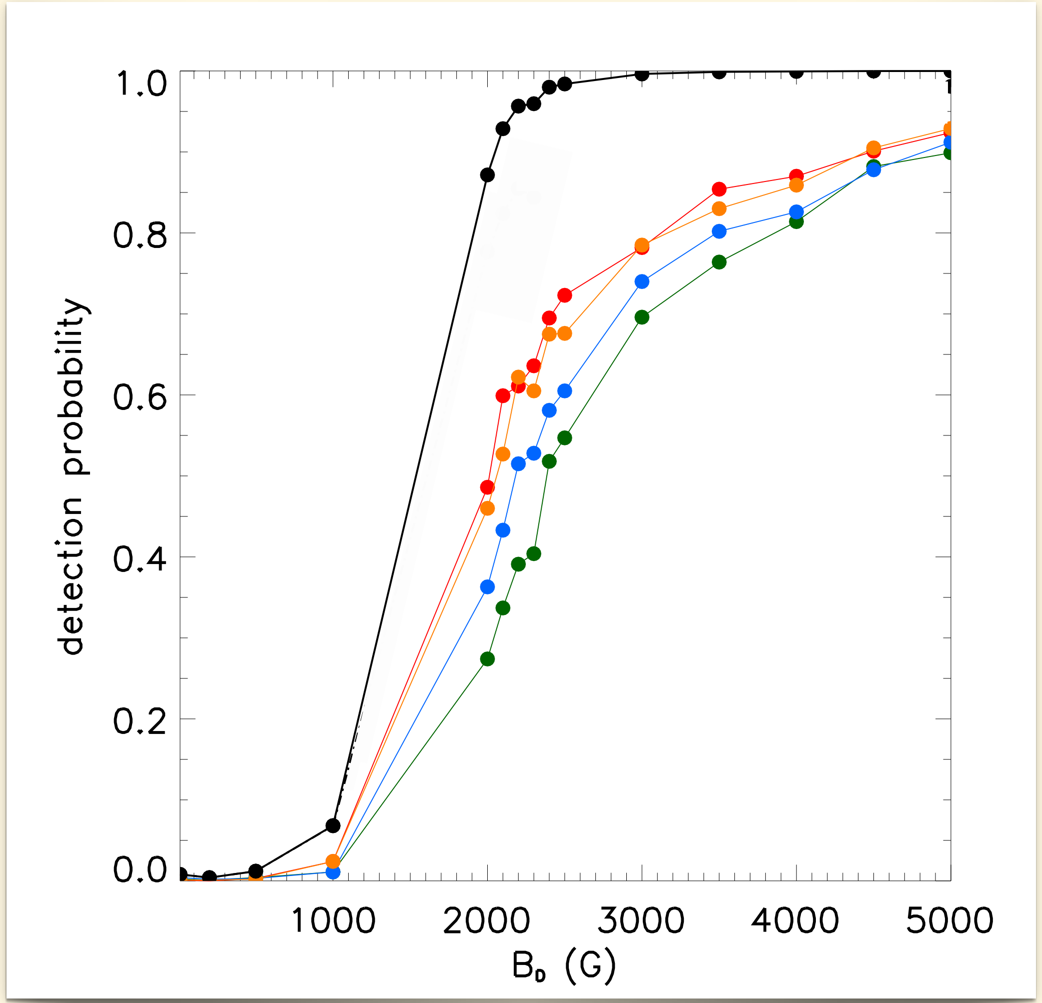
- In case of non-detection : we compute **the upper-limit value of the magnetic field**



Oblique rotator model (parameters : i, beta, phase, Bd)

we need to try many configurations with different values of Bd

➞ **Monte-Carlo simulations**



For this star, the combination of 4 observations (4 colored lines) results in 95% detection of a field Bd = 2100G (plain black line)

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

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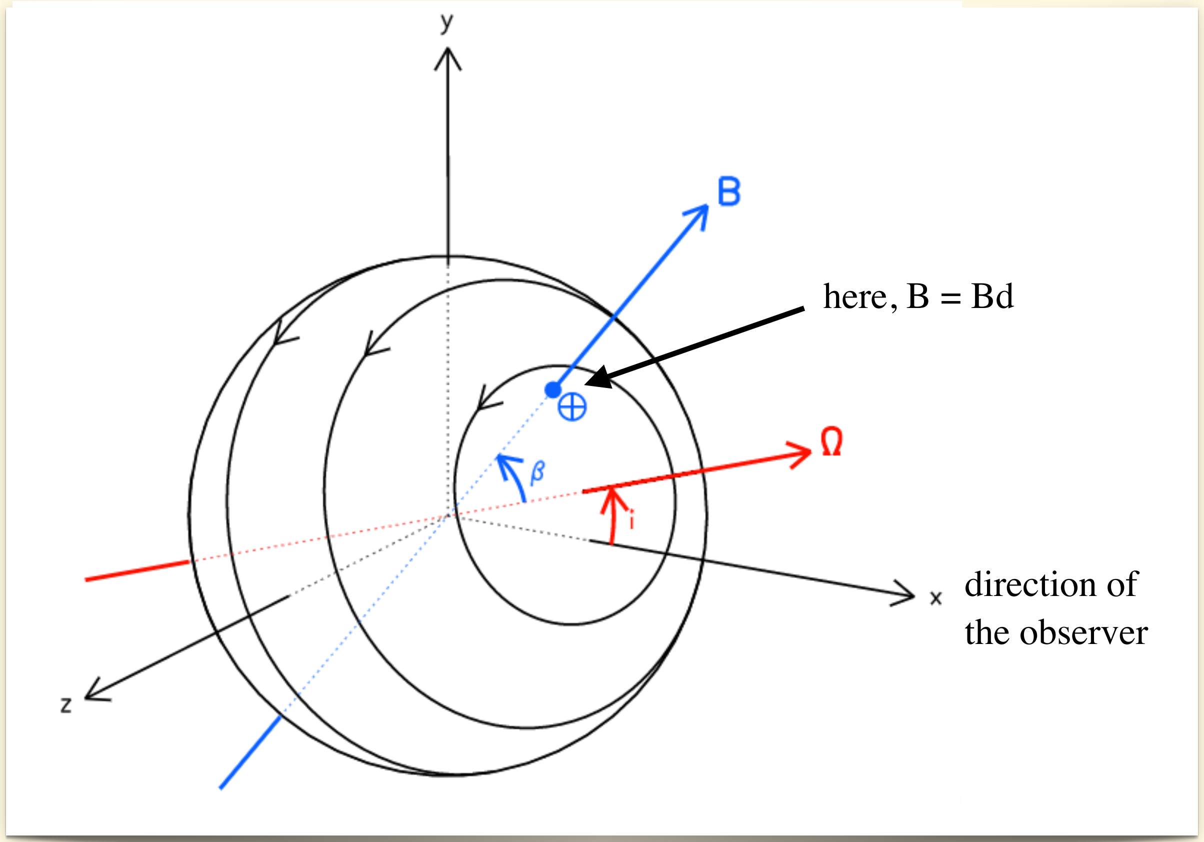

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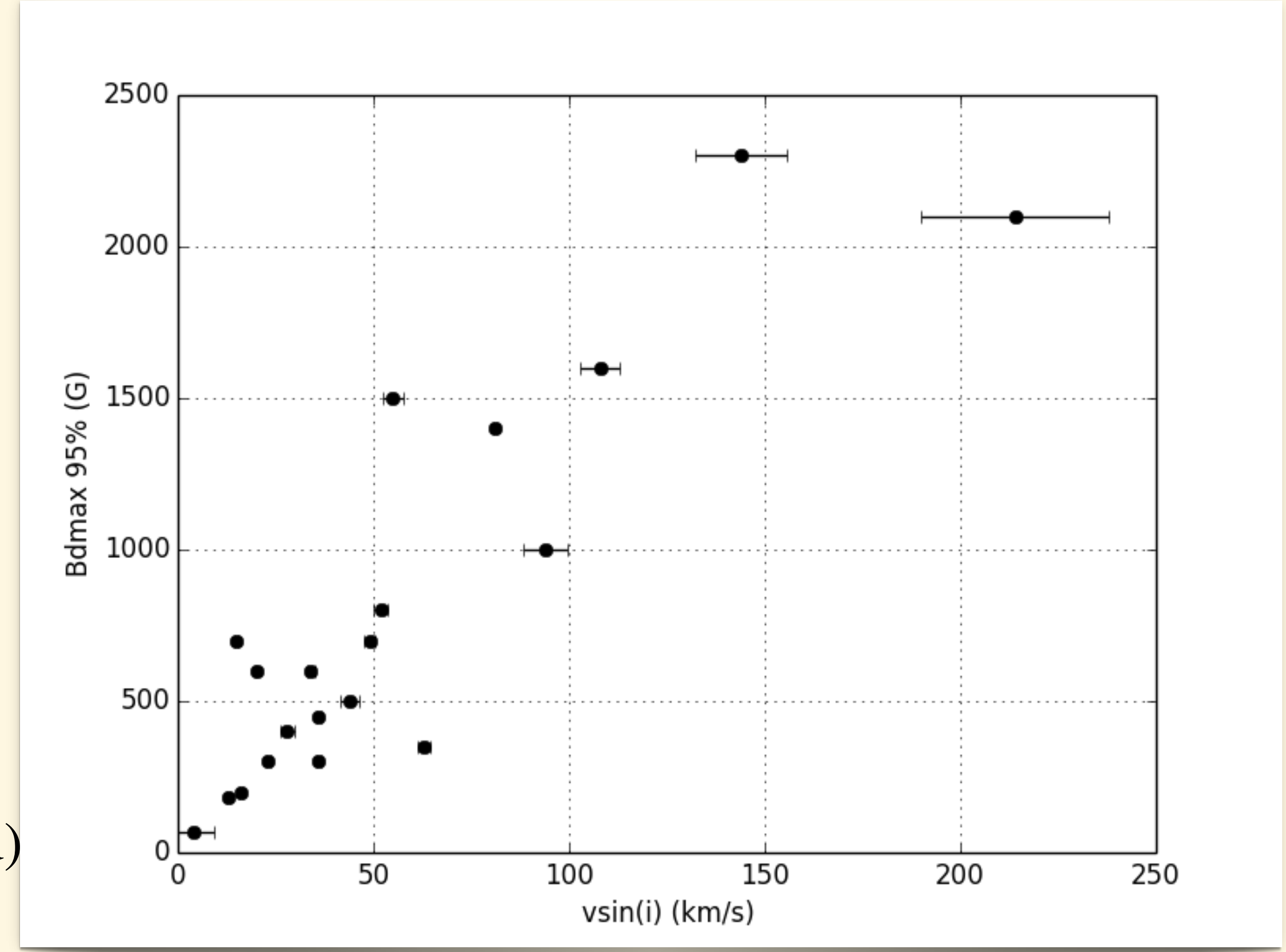

1 dot = 1 non-magnetic star ➡ when vsin(i) is high, the stokes V signature is diluted into noise

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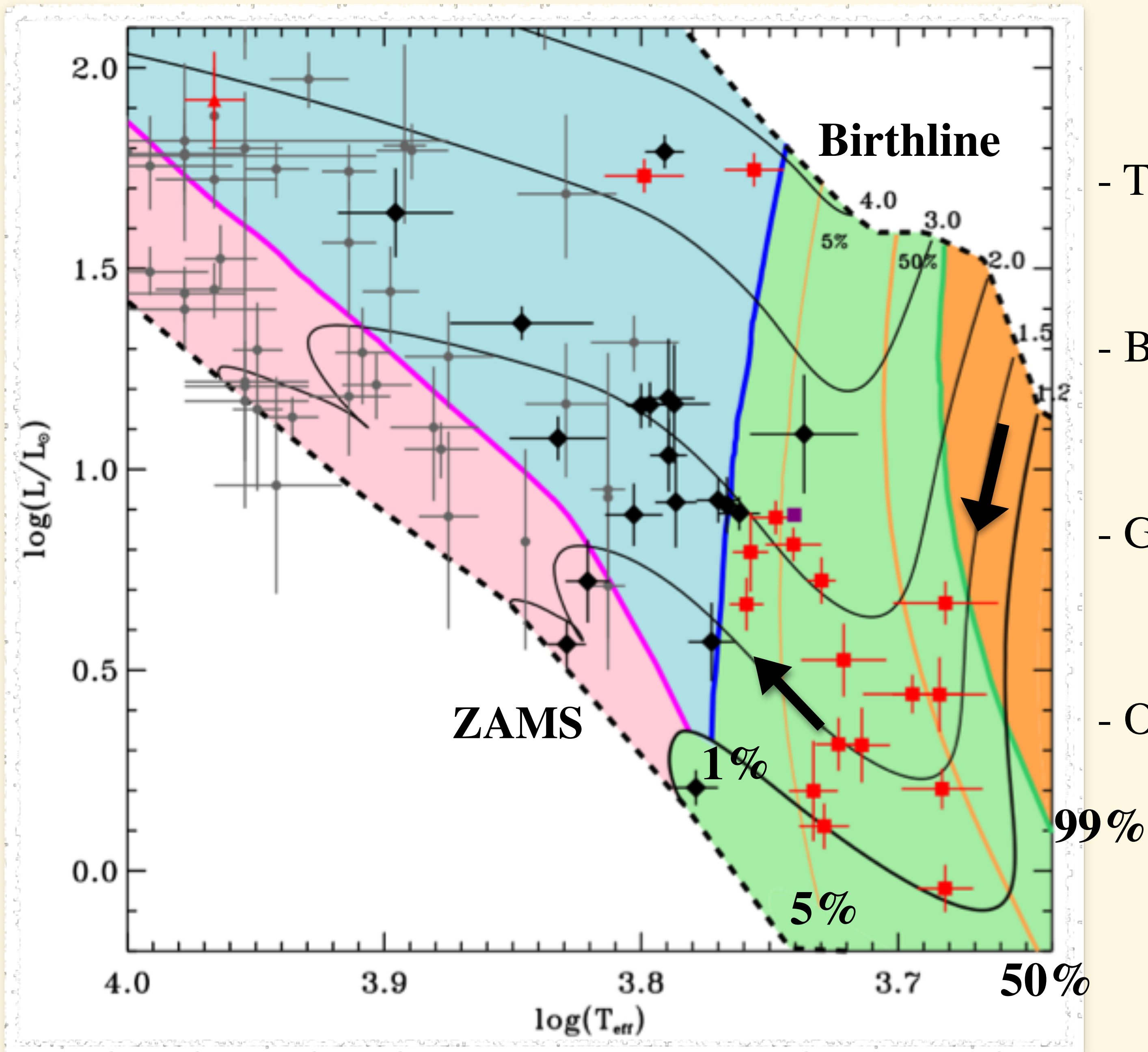
Positioning of our sample in the HRD



- 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**

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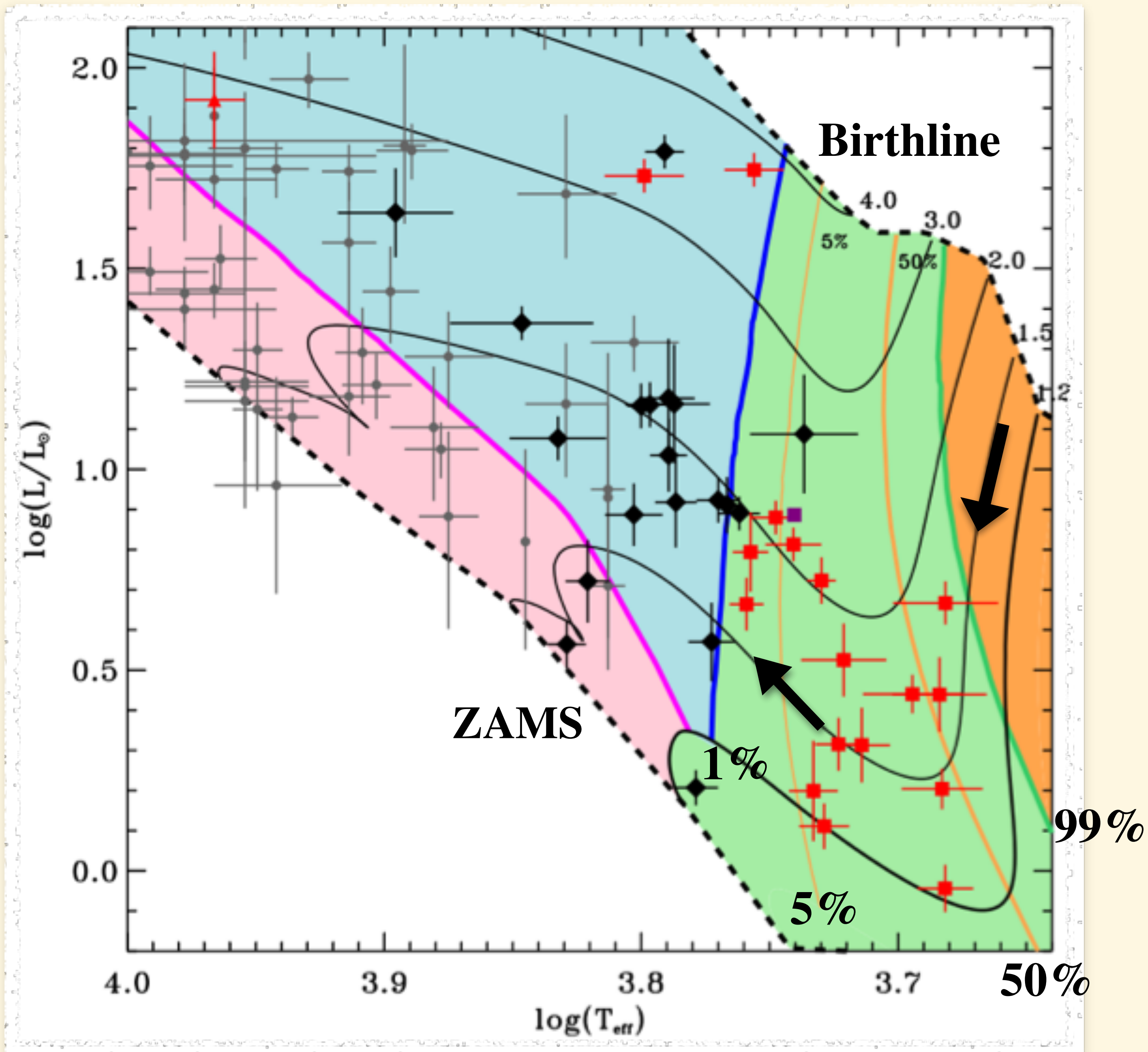


- PMS evolutionary model : **CESAM code**

- **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 model influence on the HR diagram

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)

Zini = 0.0131
Yini = 0.2539
α = 1.6223
EoS : *OPAL (2005)*
Opacities : *OPAL (1996)*
Abundances : *Asplund (2005)*
Atmosphere : *Eddington gray atmosphere*

Geneva CODE

(Lionel HAEMMERLE)

Zini = 0.0122
Yini = 0.2485
α = 1.6
EoS : *OPAL (1996)*
Opacities : *OPAL (1996)*
Abundances : *Asplund (2005)*
Atmosphere : *Meynet & Maeder (1996)*

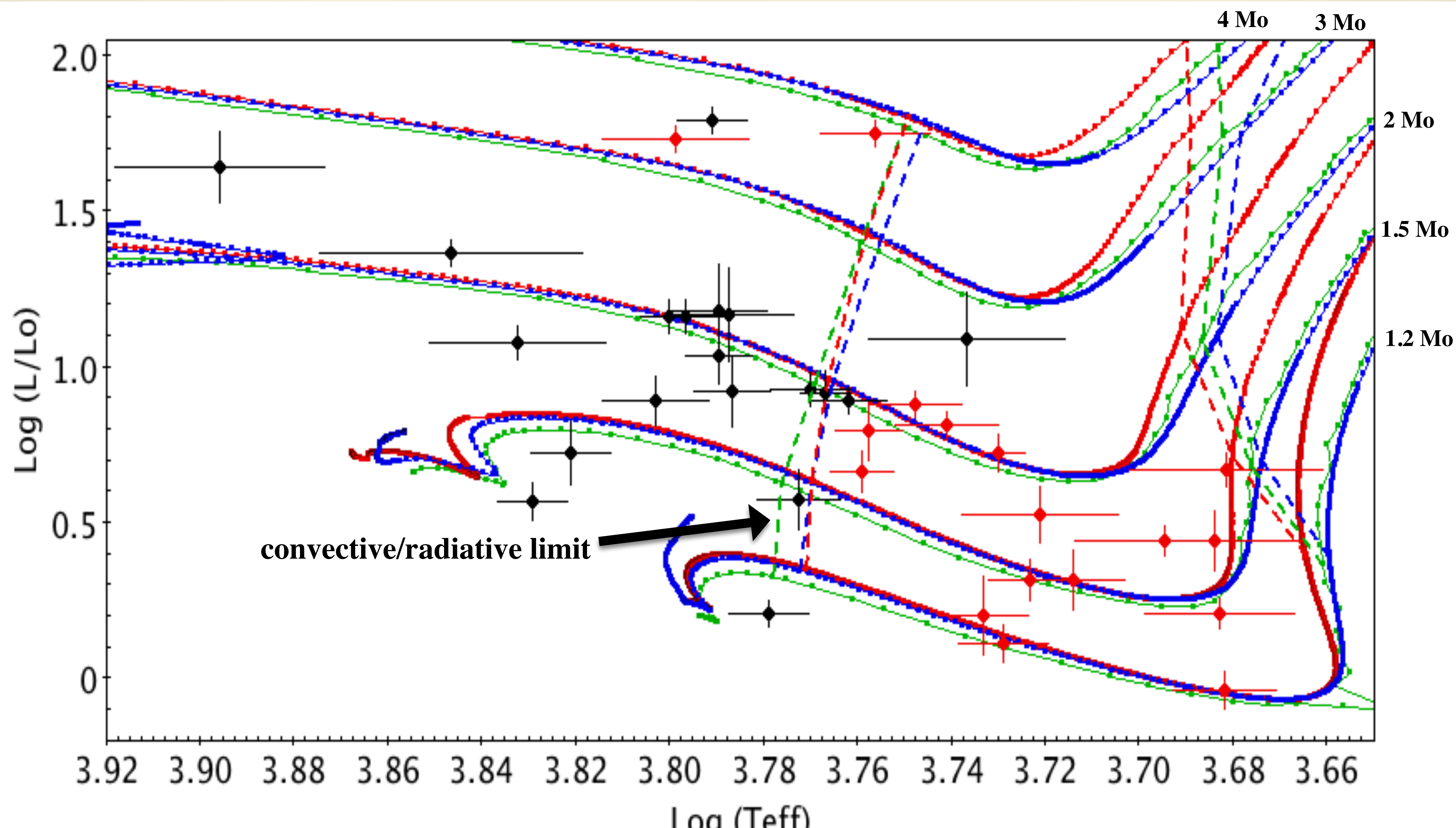
Geneva STAREVOL

(Florian GALLET, Corinne CHARBONNEL, Louis AMARD)

Zini = 0.0134
Yini = 0.2676
α = 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



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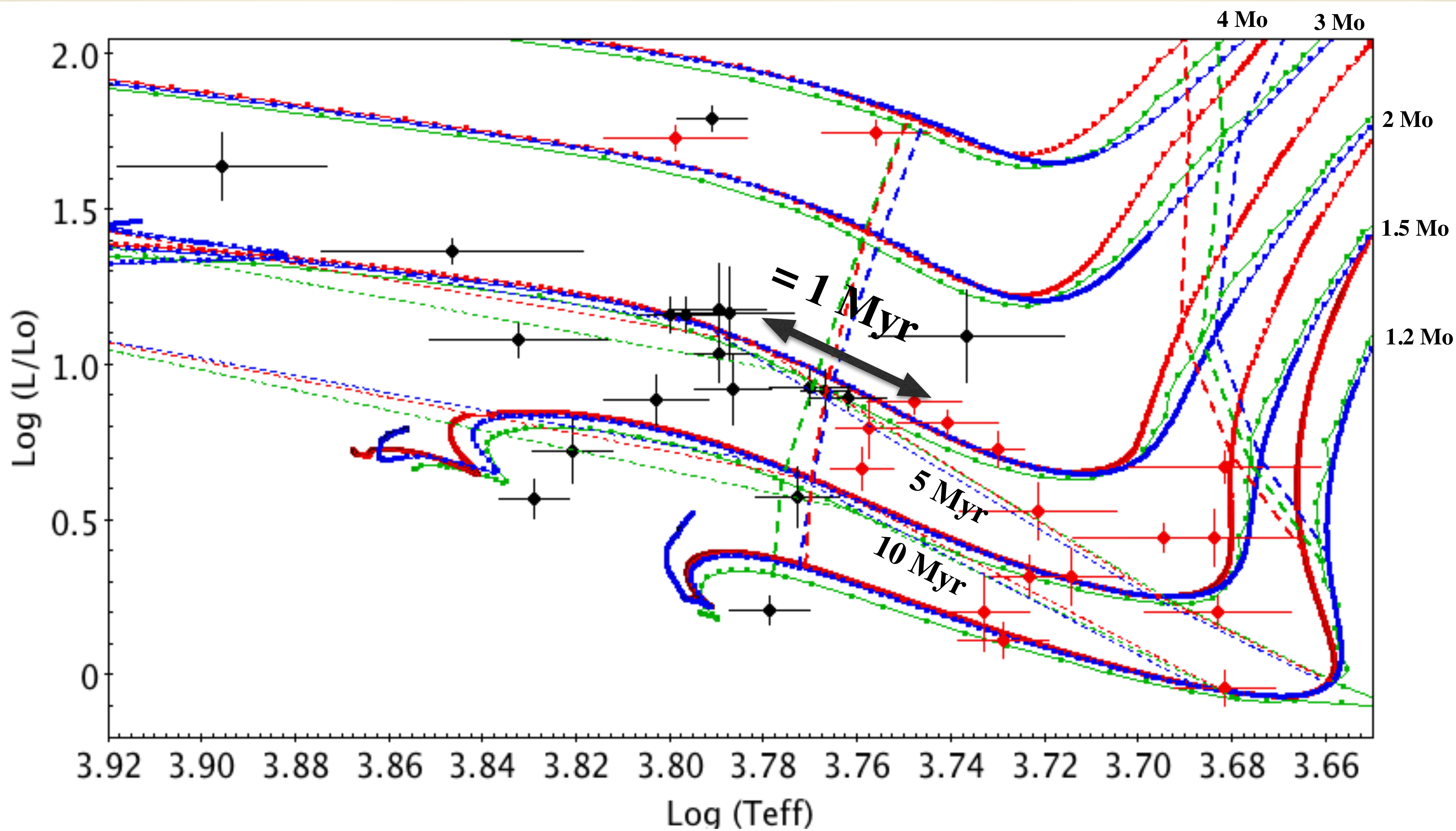
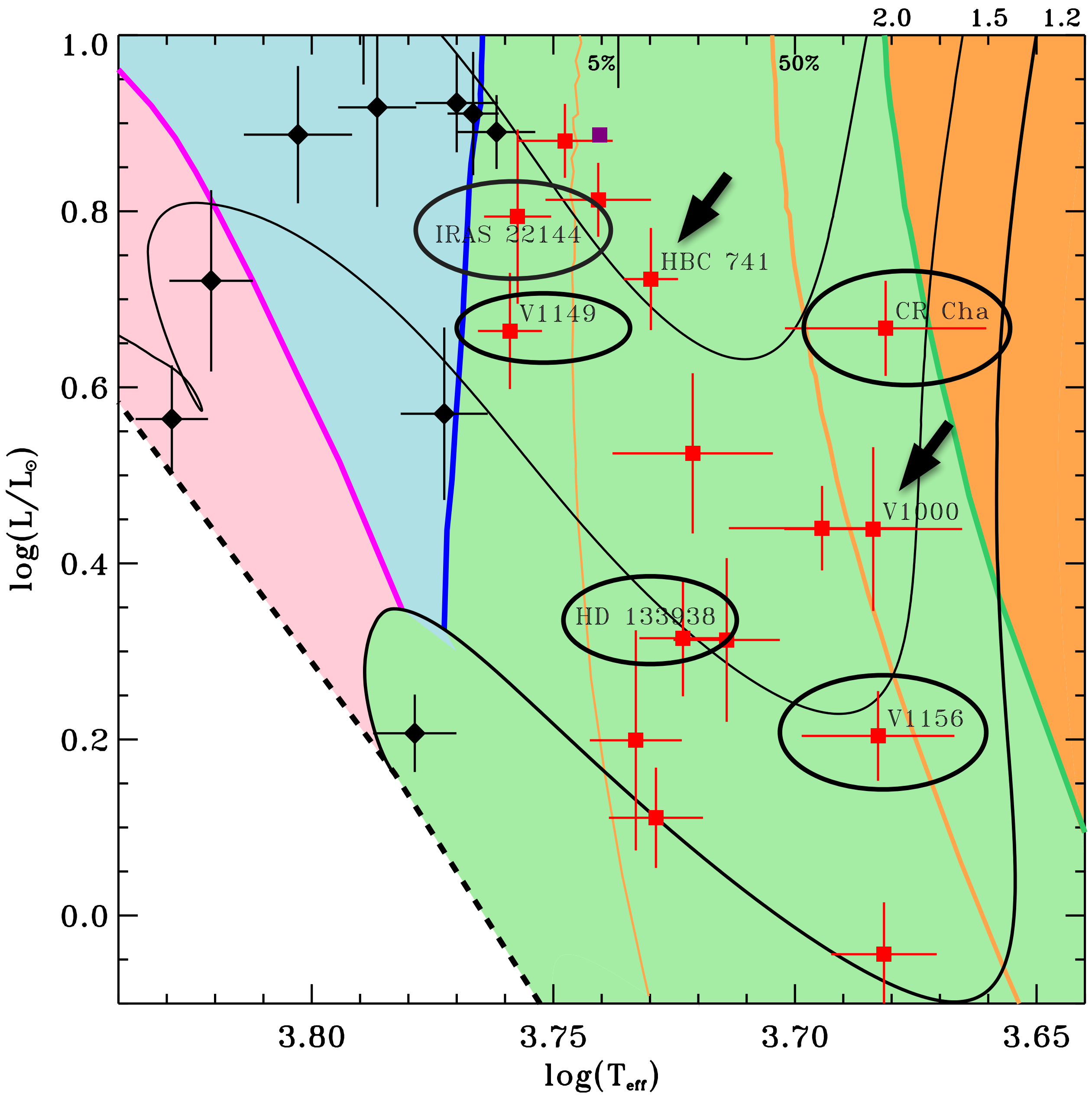


Observational prospectives



= already observed or accepted

= still in our « shopping-list »

- we selected **7 IMTTS with different internal structures**

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

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

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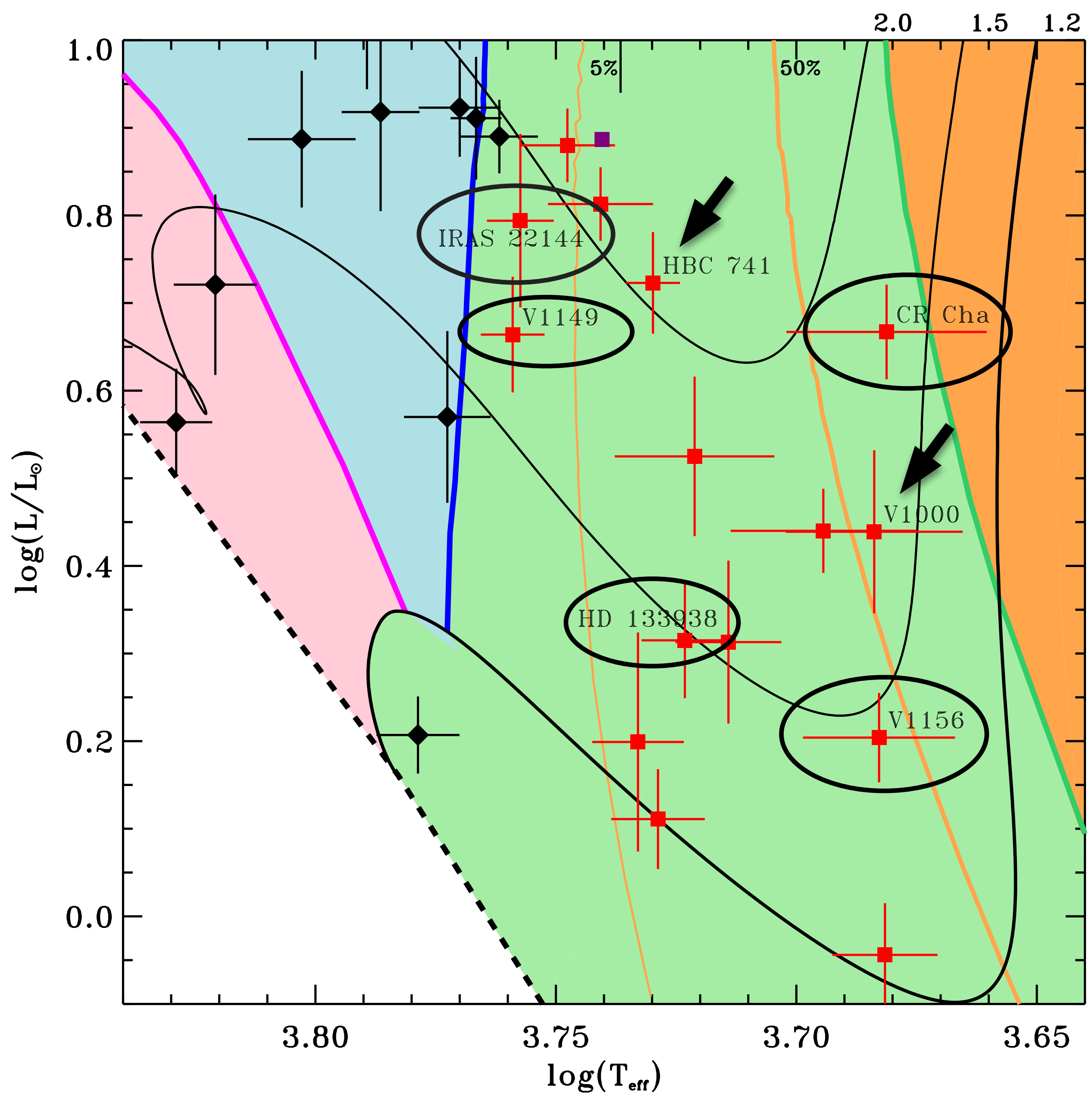

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Monitoring of Stokes I and V signatures
(obtained with HARPSpol or ESPaDOnS)
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Zeeman Doppler Imaging

Surface magnetic field topology and brightness maps
+
Confusograms

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

Conclusion & more to do…

- **Fundamental parameters are now well constrained for these stars :**
  Teff @ 100-150K vsini(i) @ 1-2km/s 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