Magnetic fields of pre-main sequence low- and intermediate-mass stars

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STARRY Final conference, June 2019

MAGNETIC FIELD MEASUREMENTS

Zeeman effect

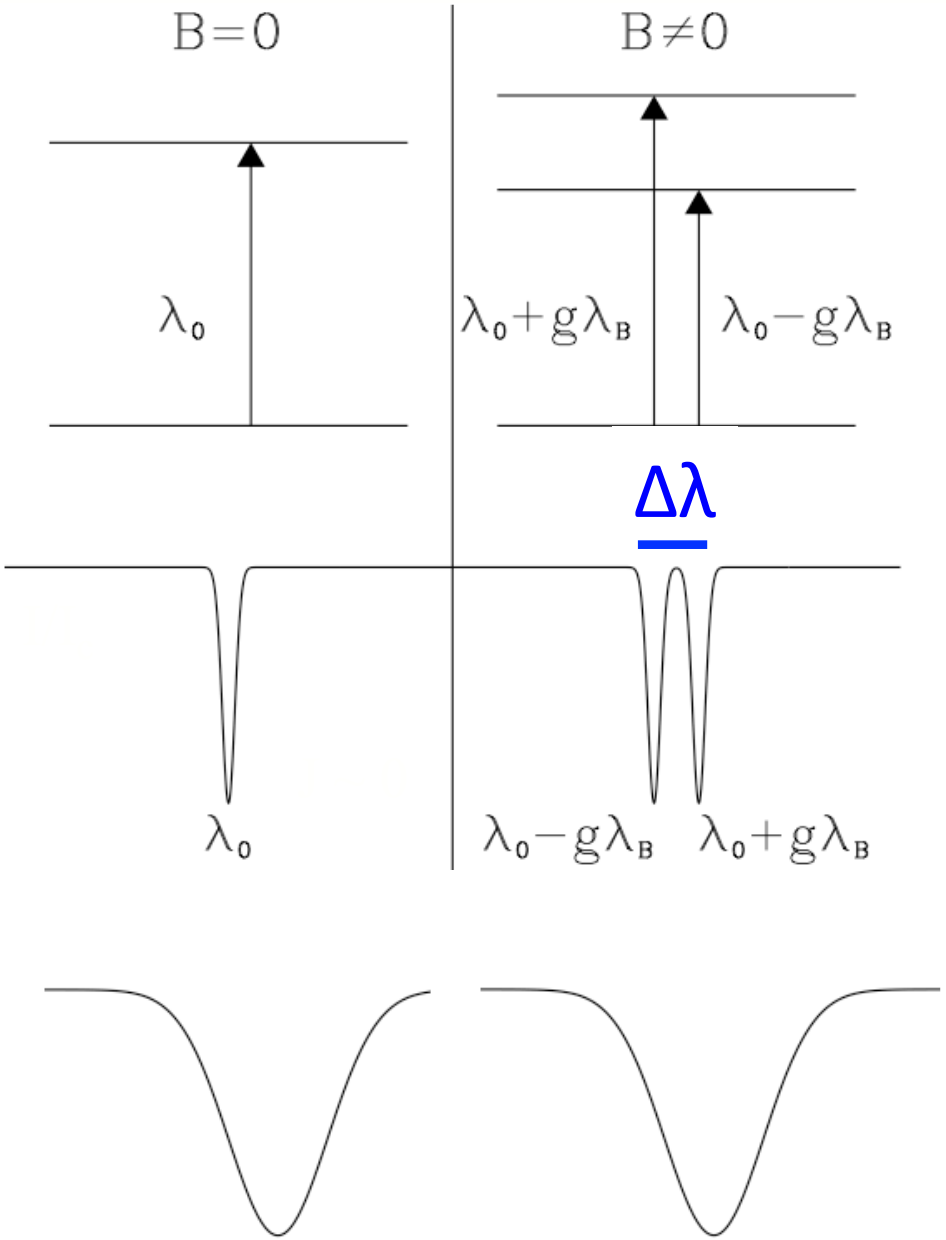
- if $B_l \neq 0$

  →line splitting

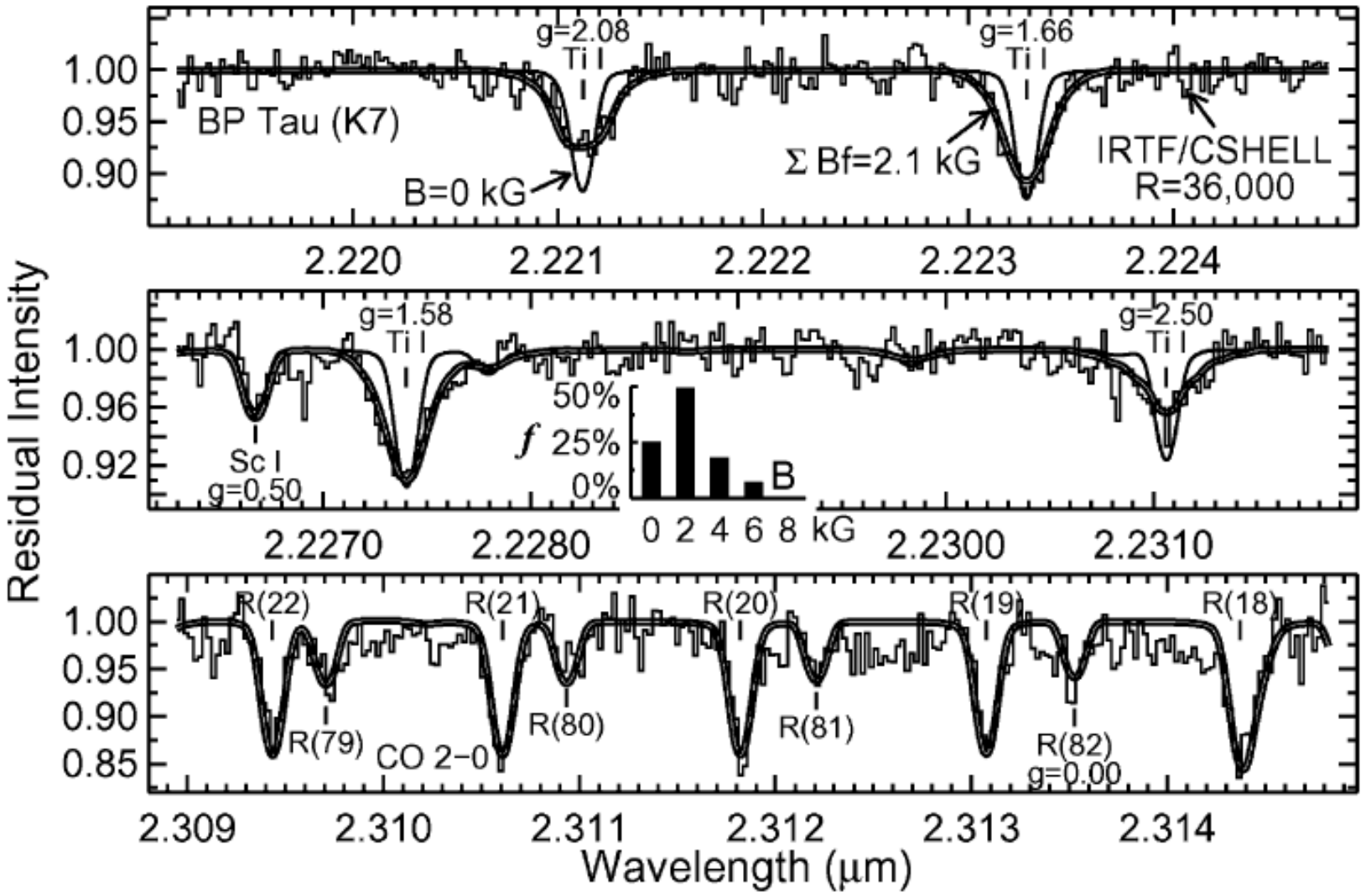
- In the weak field approx.:

$$\Delta\lambda = Cg\lambda^2|\mathbf{B}|$$

Modulus of magnetic field



Zeeman broadening



Ti I lines

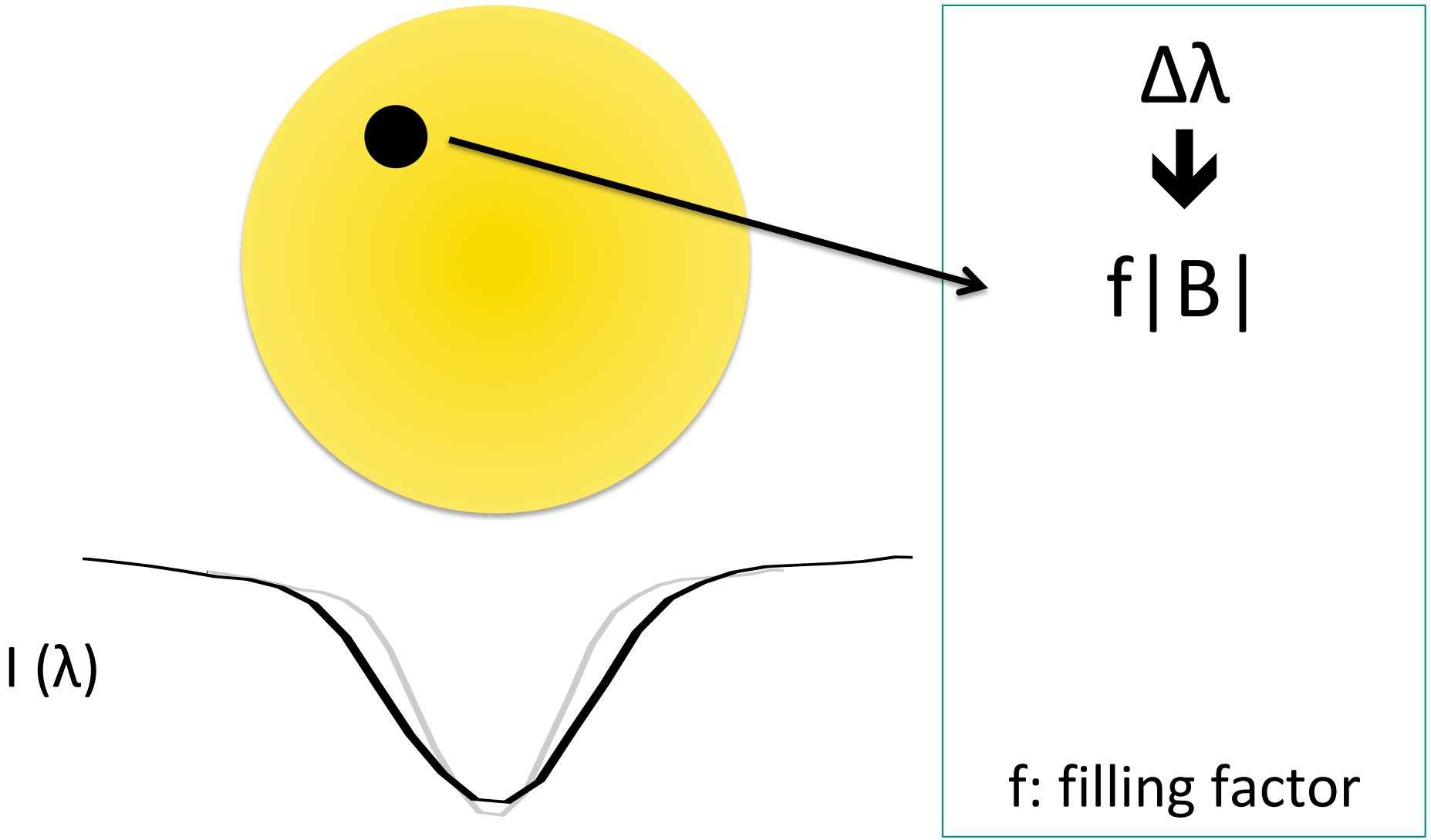
B sensitive

CO lines

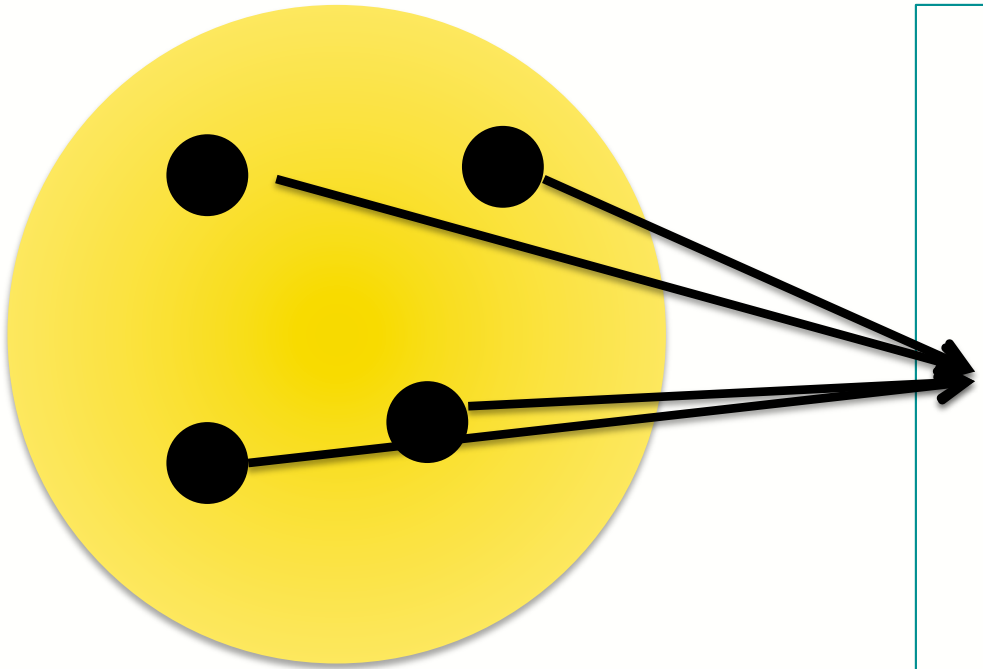
~~B sensitive~~

Johns-Krull 2009

Zeeman broadening
What do we measure ?



Zeeman broadening
What do we measure ?

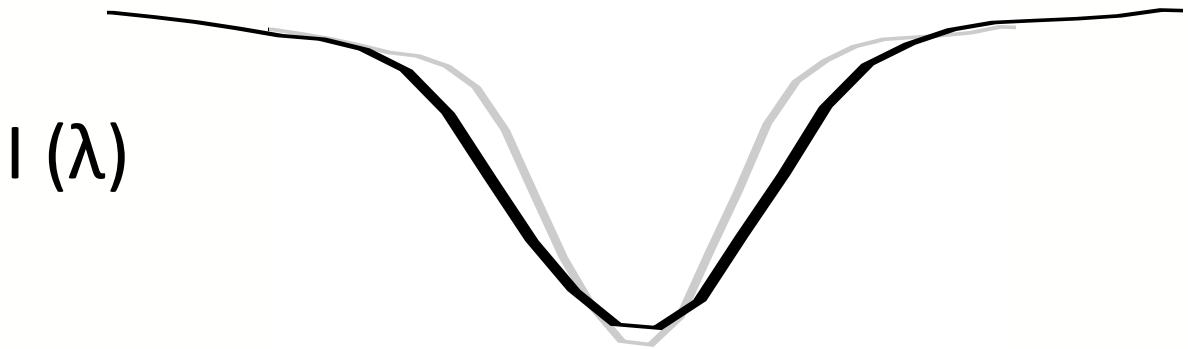


$\Delta\lambda$

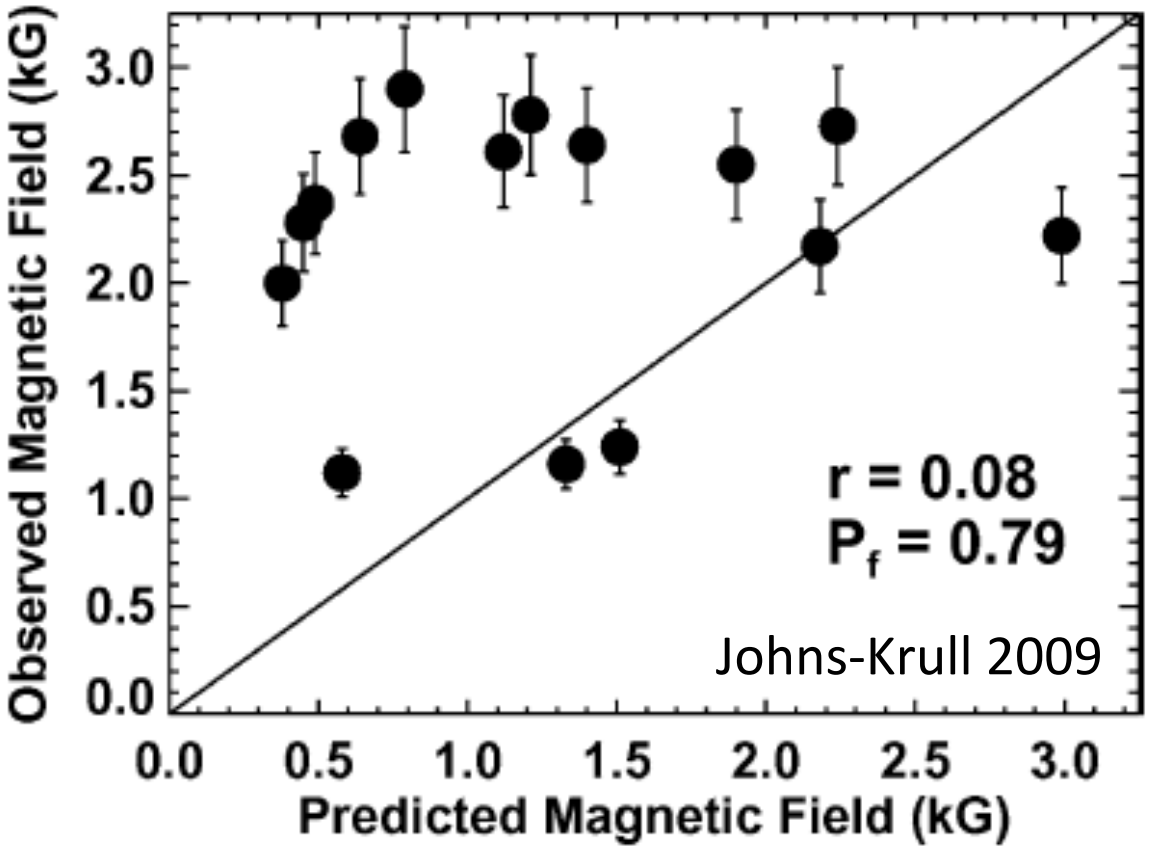
$\Sigma f_i |B_i|$

$\langle |B| \rangle$

f: filling factor



Disk-locking prediction



|B| Important for understanding dynamos processes

NOT for magnetospheric accretion processes

Zeeman effect

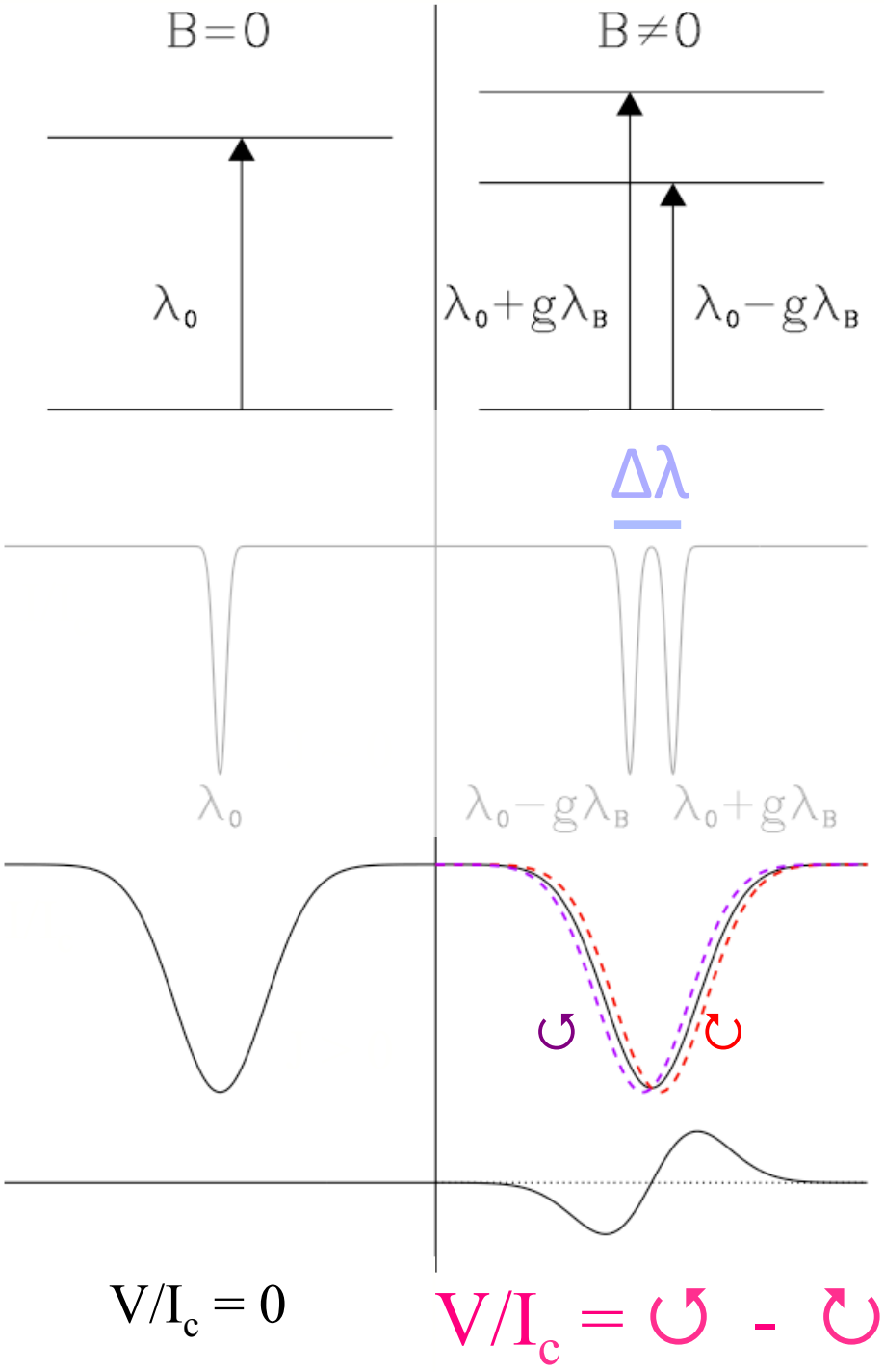
- if $B_l \neq 0$
  - →line splitting
  - →line circular polarisation
- In the weak field approx.:

$$\Delta\lambda = Cg\lambda^2 |B|$$

Modulus of magnetic field

$$V = -Cg\lambda^2 (dI/d\lambda) B_l$$

Longitudinal magnetic field



Stokes V Observations

*High-resolution spectropolarimeter:

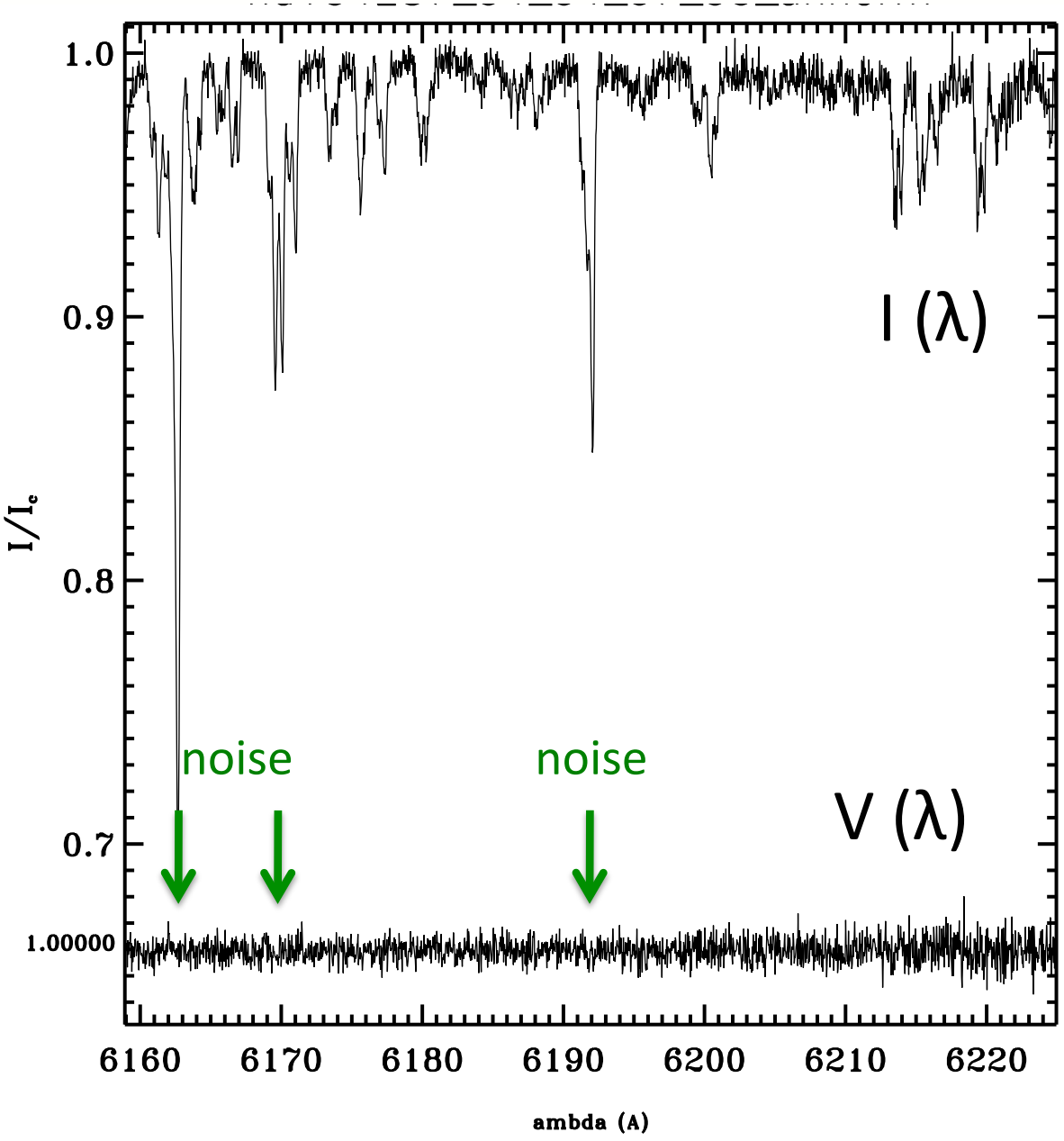
ESPaDOnS @ CFHT

NARVAL @ TBL

HARPSpol @ ESO3.6m

SPIRou @ CFHT

=> Require multi-line analysis

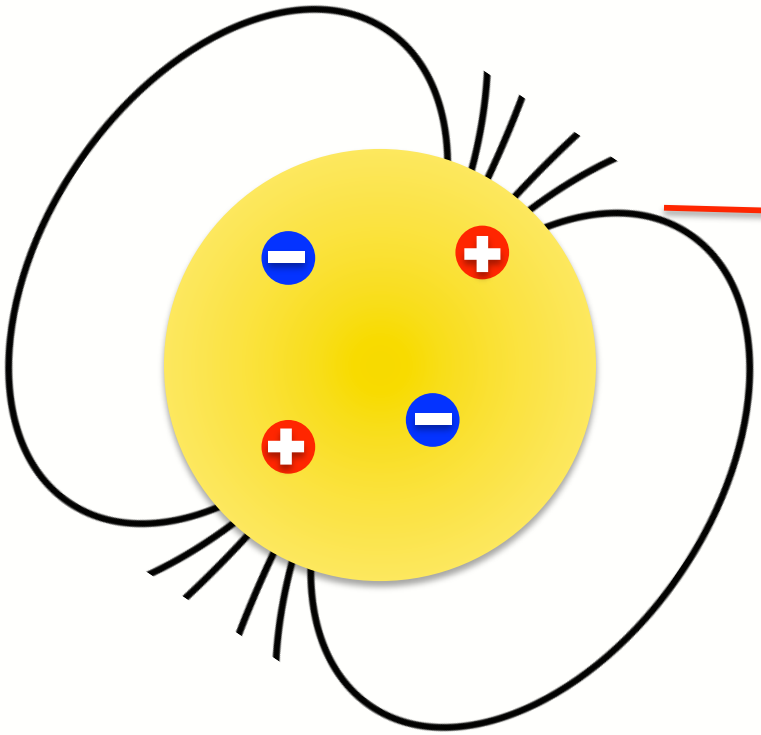


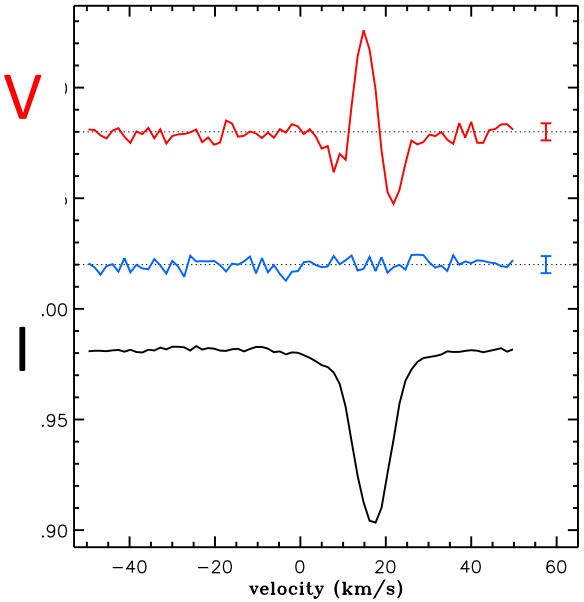
Multi-line analysis methods:

- PCA (Semel et al. 2006)
- SVD (Carroll et al. 2012)
- LSD (Donati et al. 1997)

Zeeman V signature

LSD mean profiles

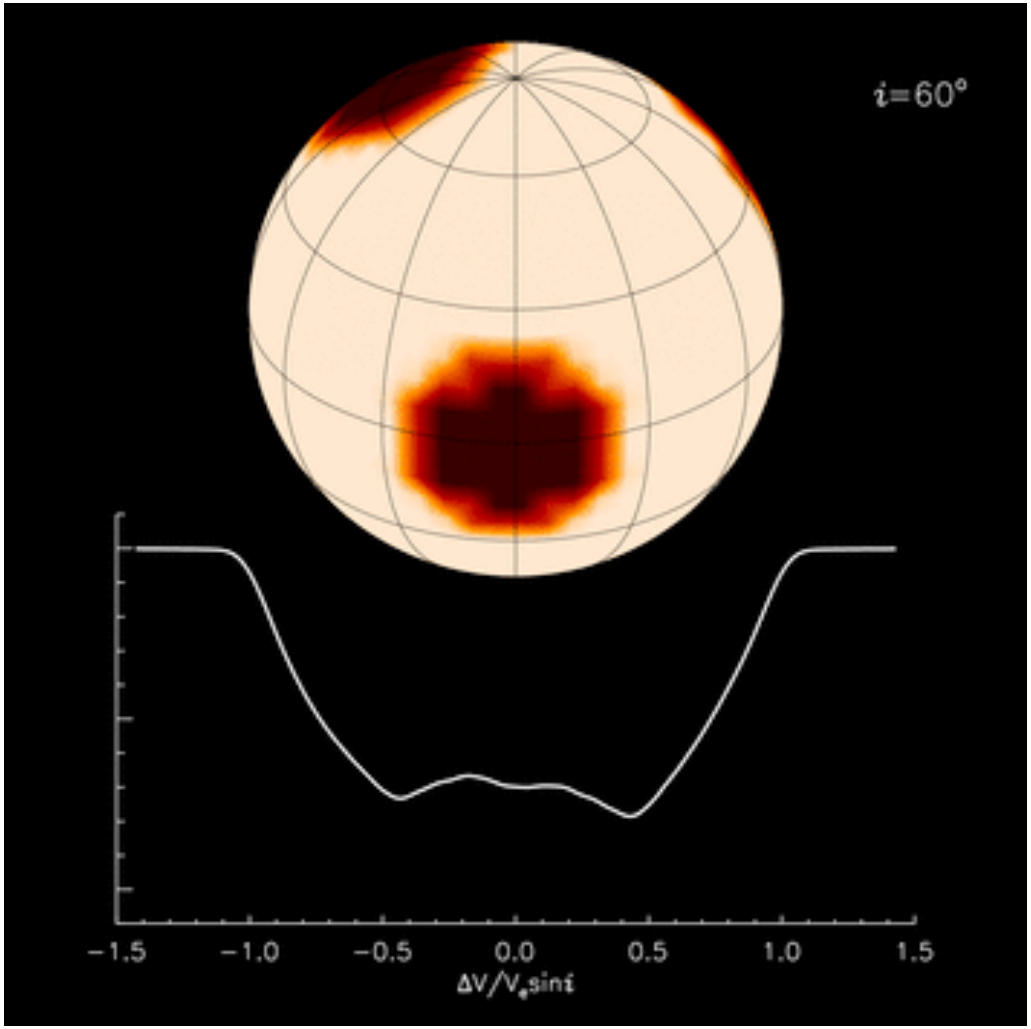


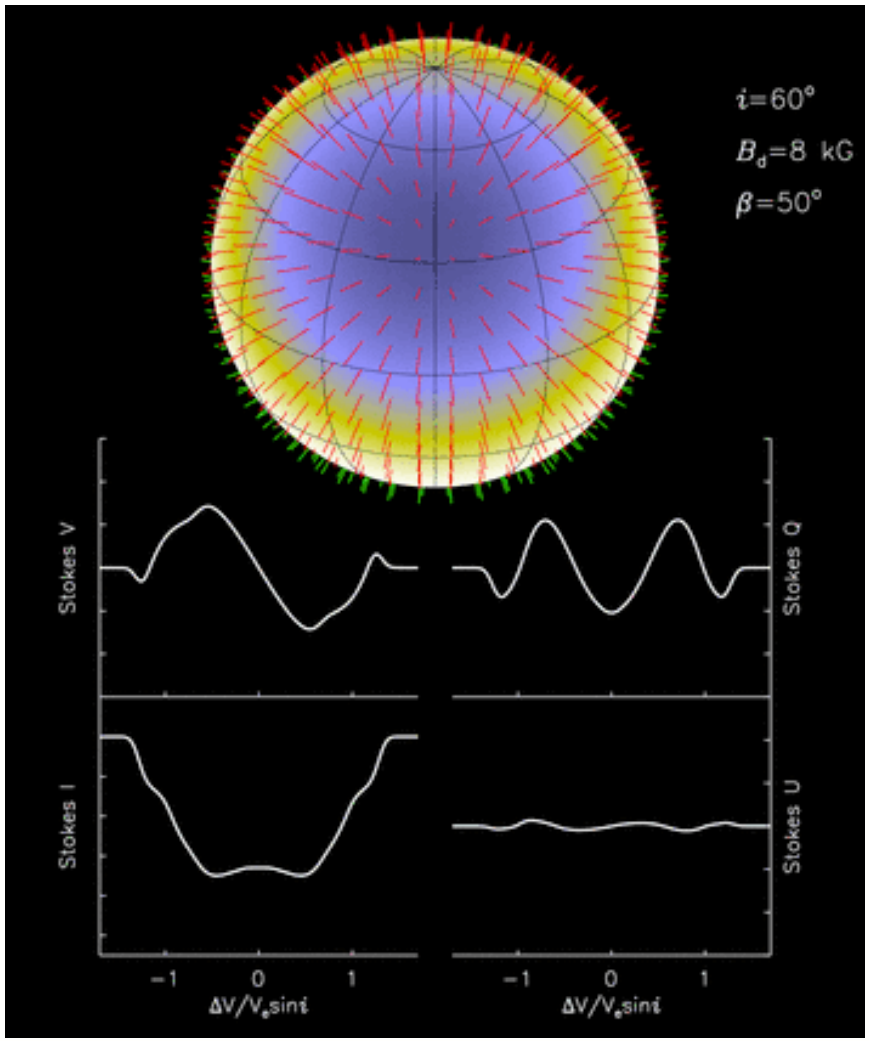


V ➔ B_l

➔ Large scale field

Zeeman Doppler Imaging

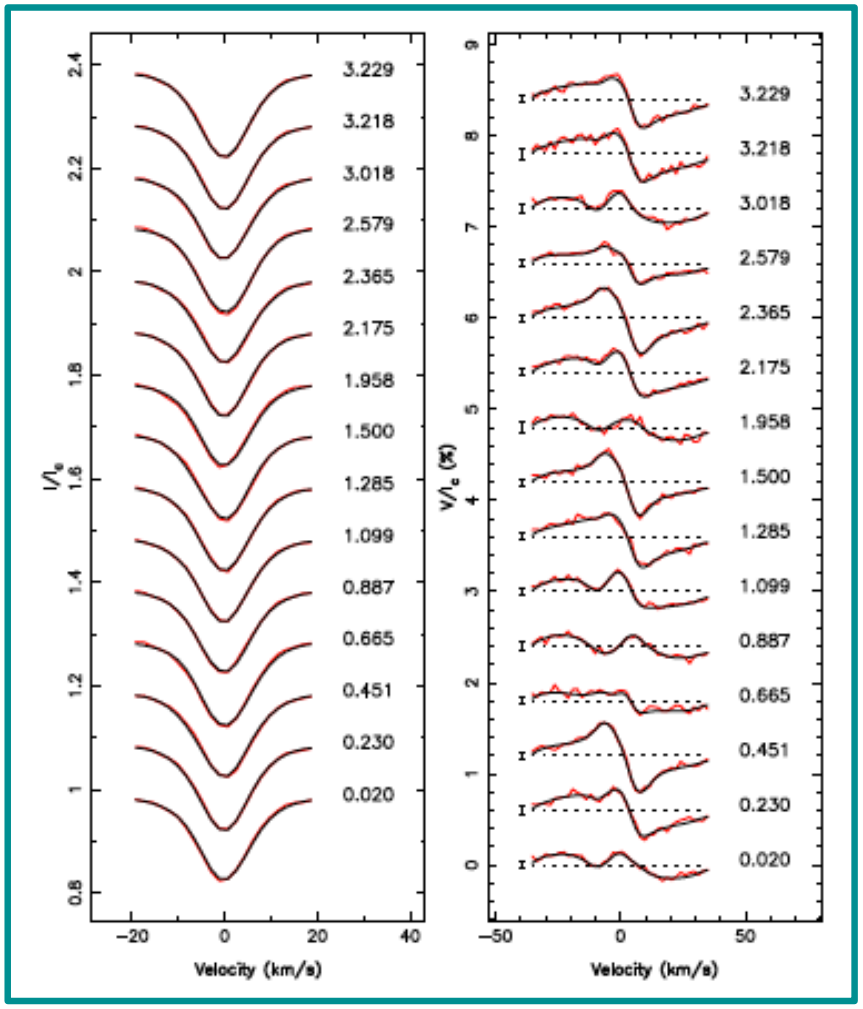


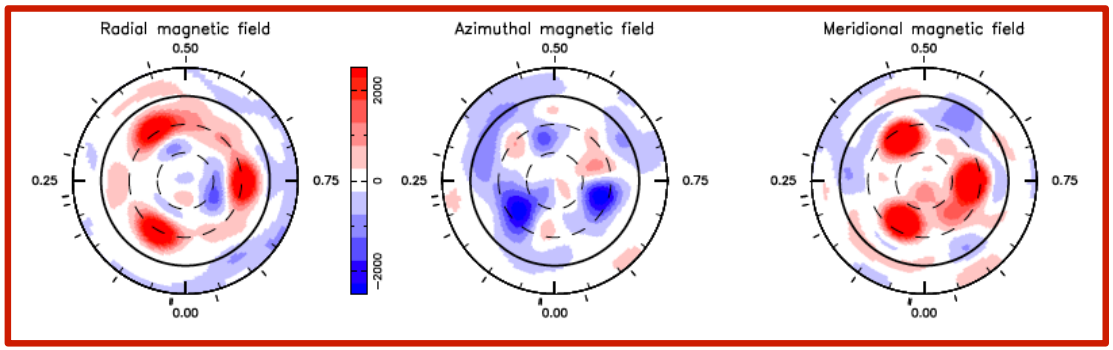


ZDI of TWA 8A

Hill+2019

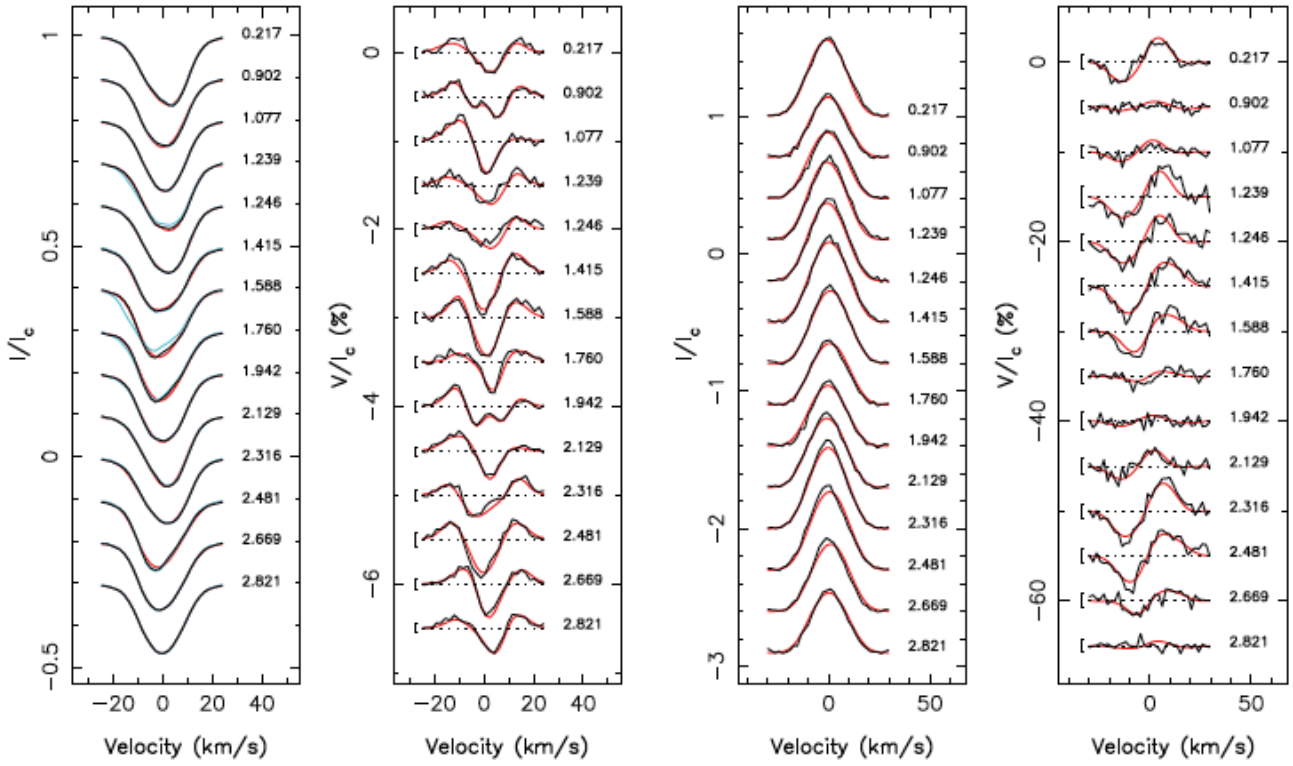
1. Monitoring over few Prot
2. Spherical harmonic decomposition
3. Potential field extrapolation

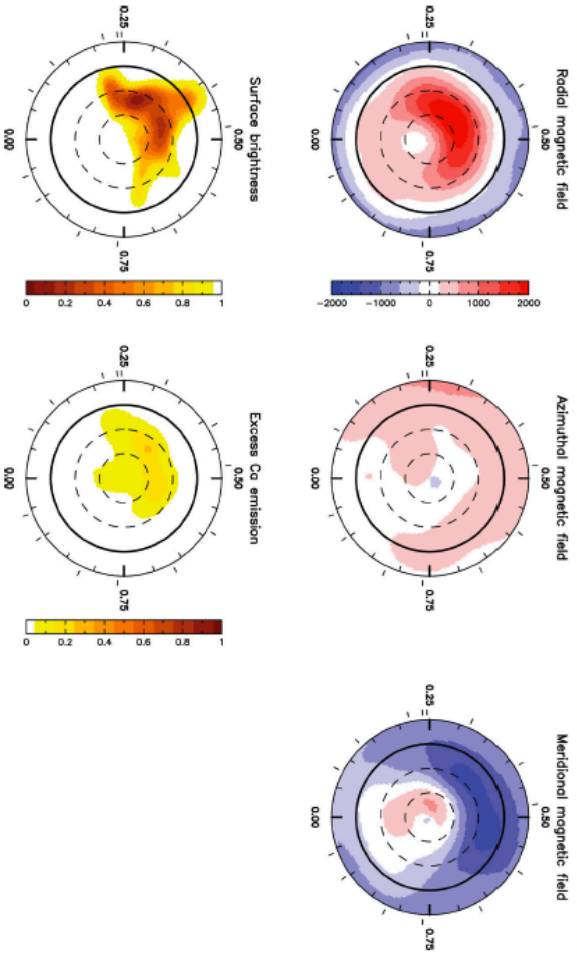




Photospheric + Ca IRT lines

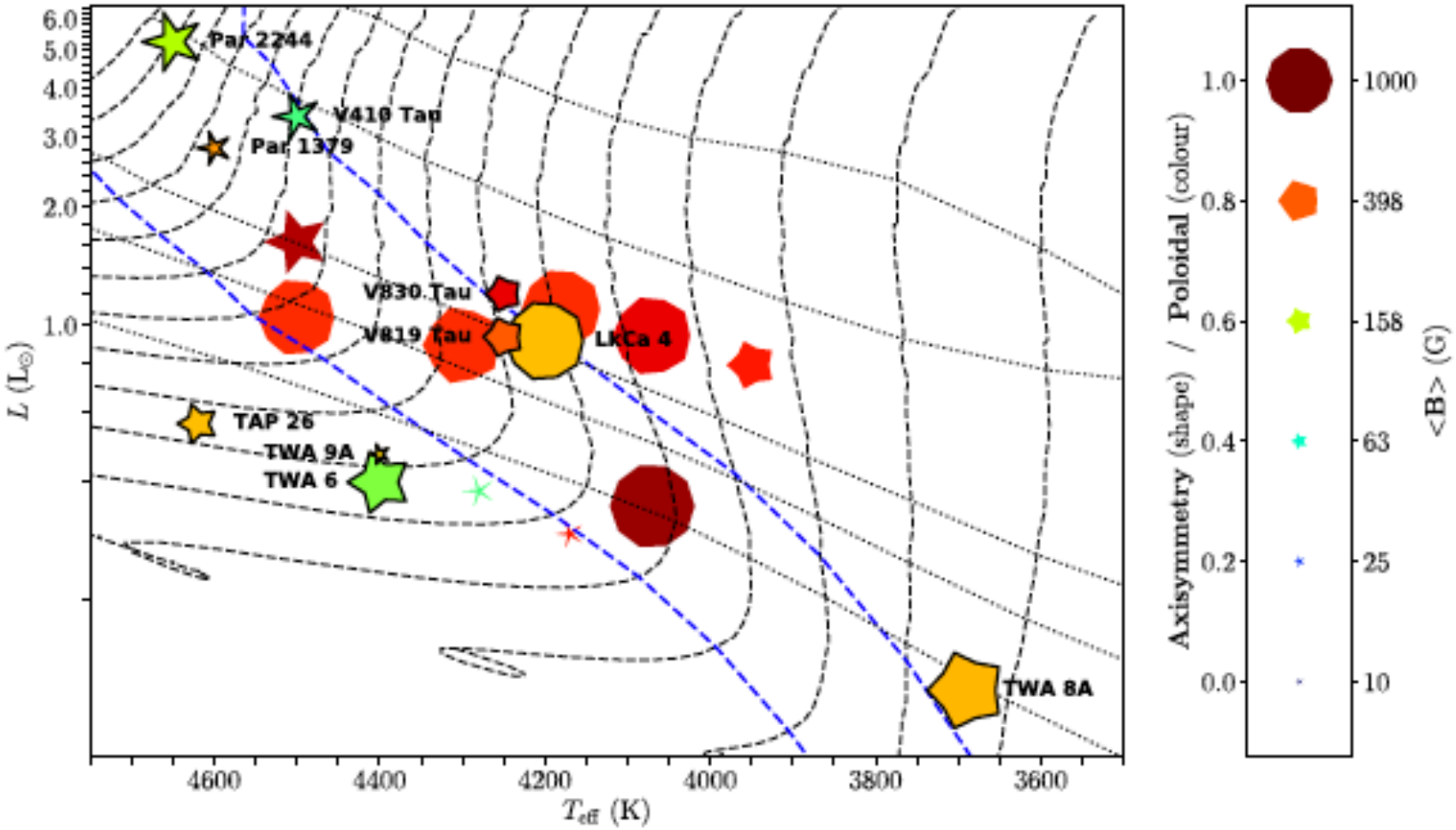
LkCa 15, Donati+2019





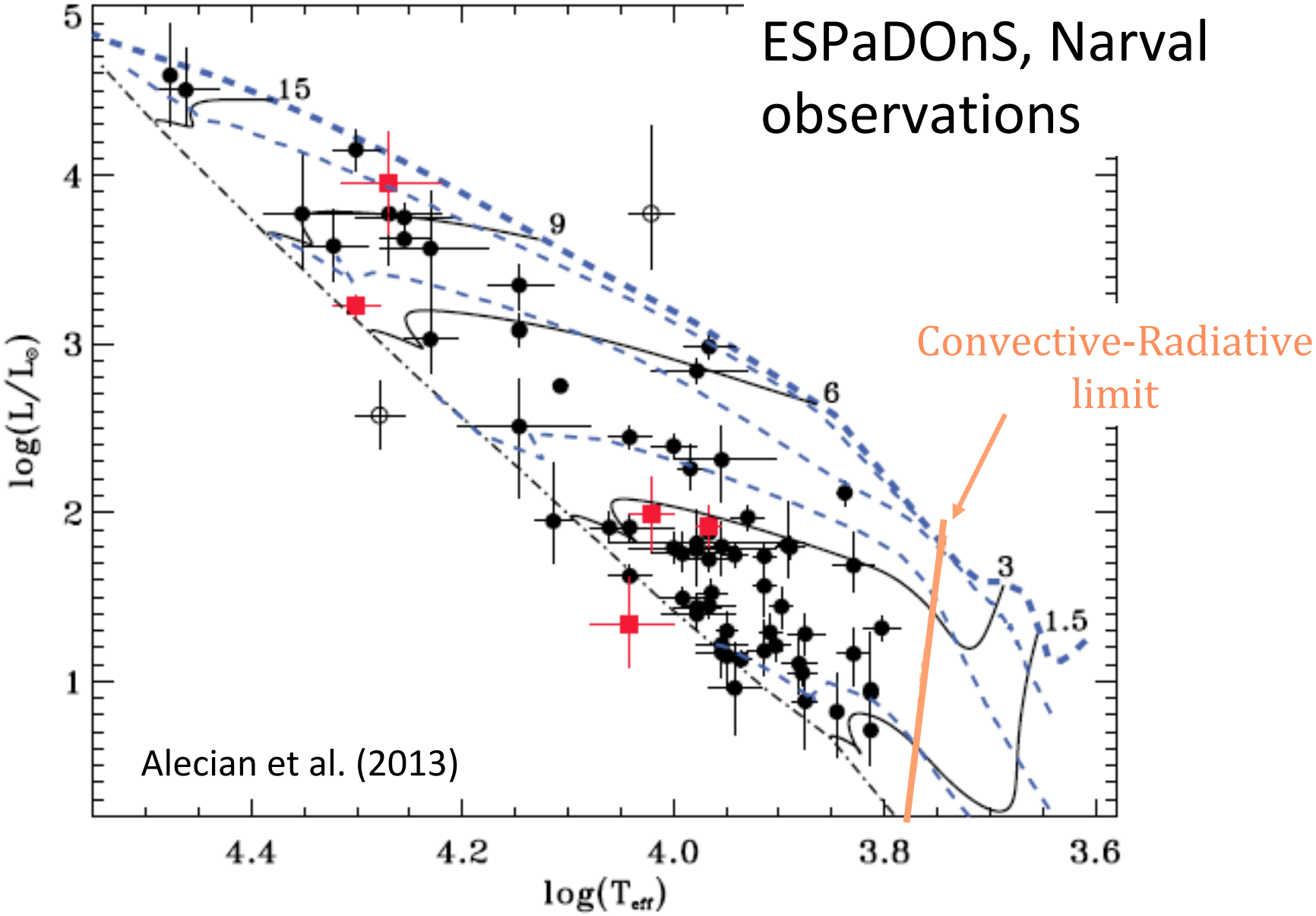
Magnetic properties in T Tauri stars

MAPP and MaTYSSE projects (PI: J.-F Donati)
ESPaDOnS, HARPSpol, Narval



Hill et al. (2019, 2017), Donati et al. (2019 … 2011)

The Herbig Ae/Be survey



Basic Magnetic properties

Herbig Ae/Be stars

- 300 G – 3 kG
- Dipolar
- Stable

- Fossil field
  (non continuously sustained by dynamo)

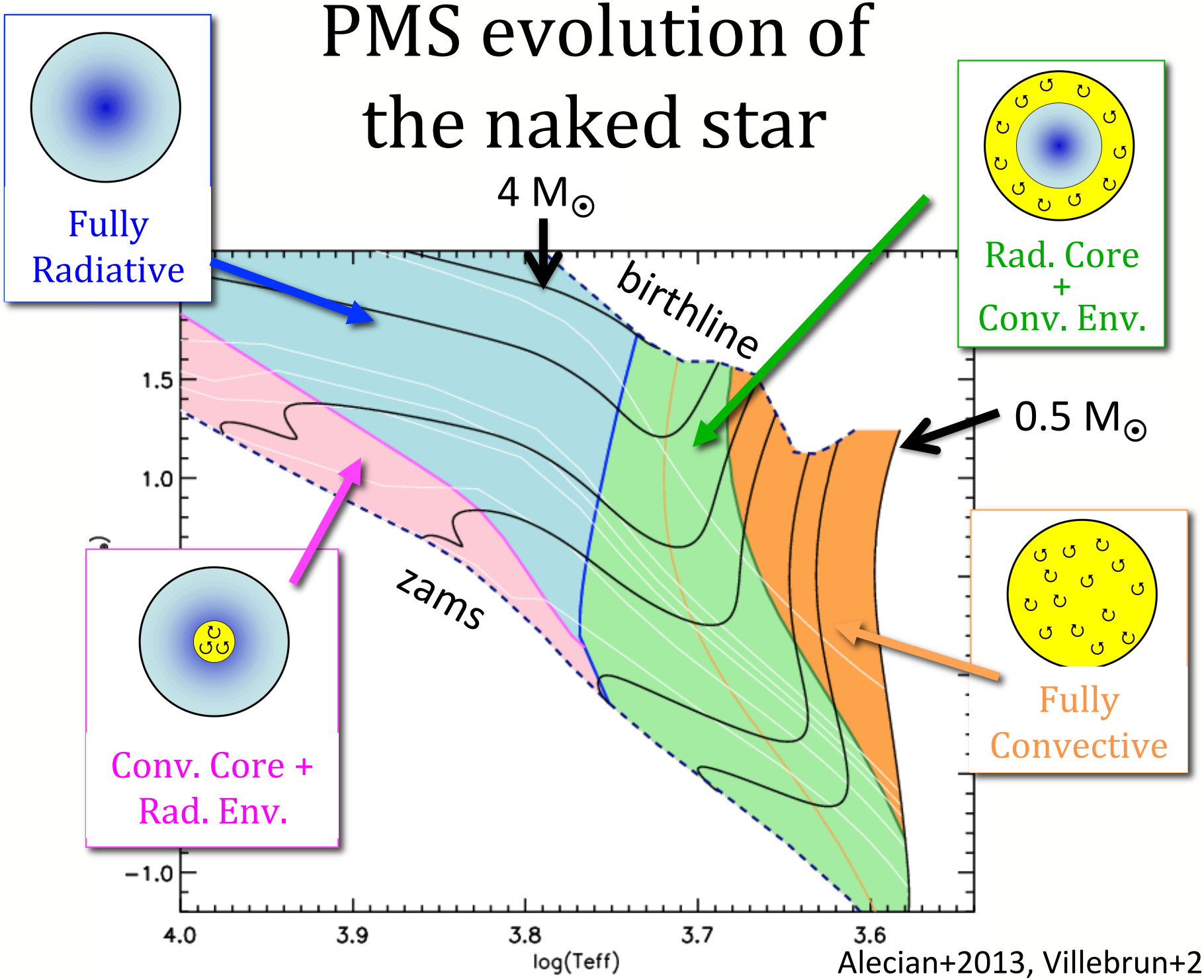
T Tauri stars

- 1 to 5 kG
- Topology strongly dependent on the internal structure
- Highly variable

- Dynamo fields

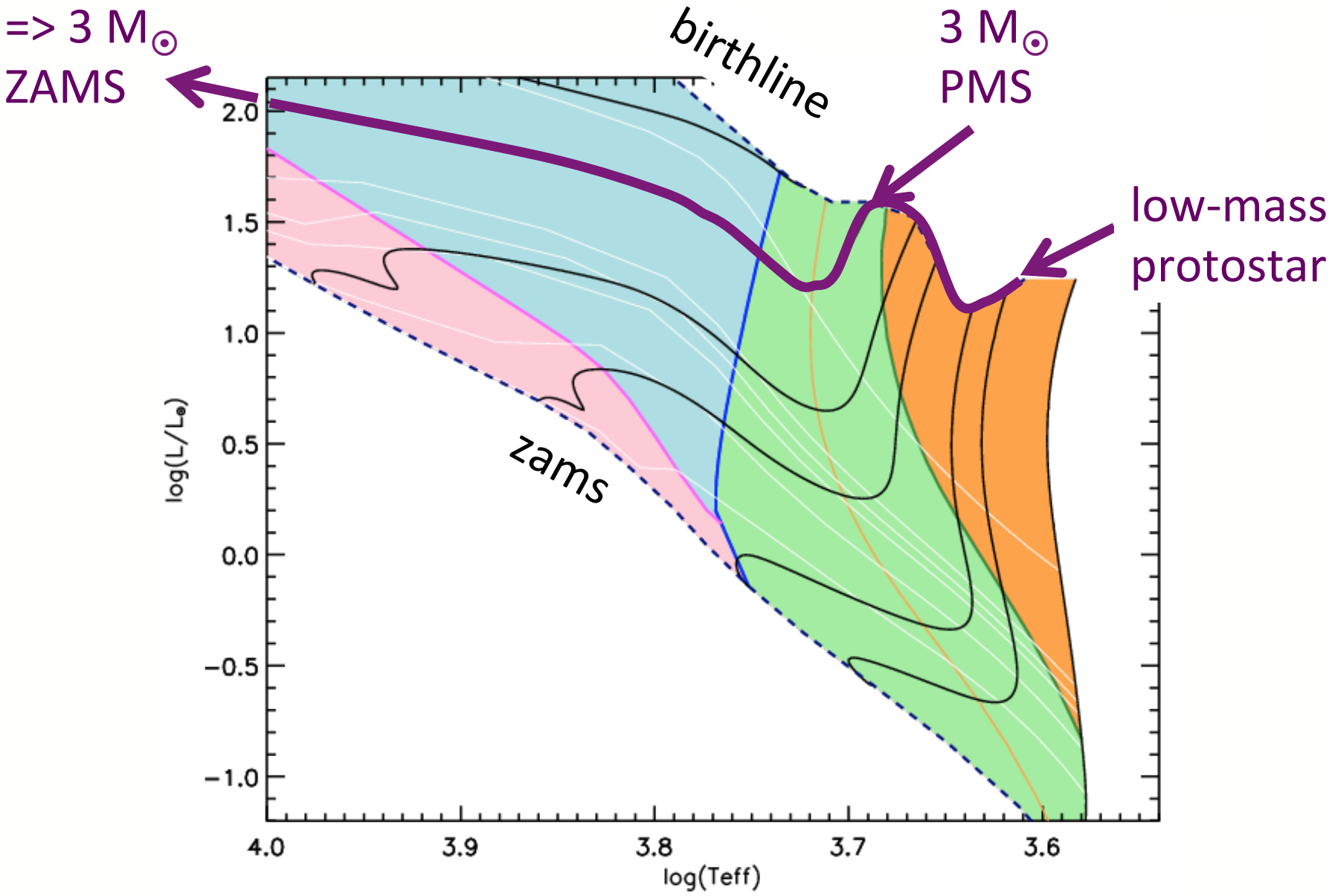
THE ORIGIN OF MAGNETIC FIELDS IN RADIATIVE STARS

PMS evolution of the naked star

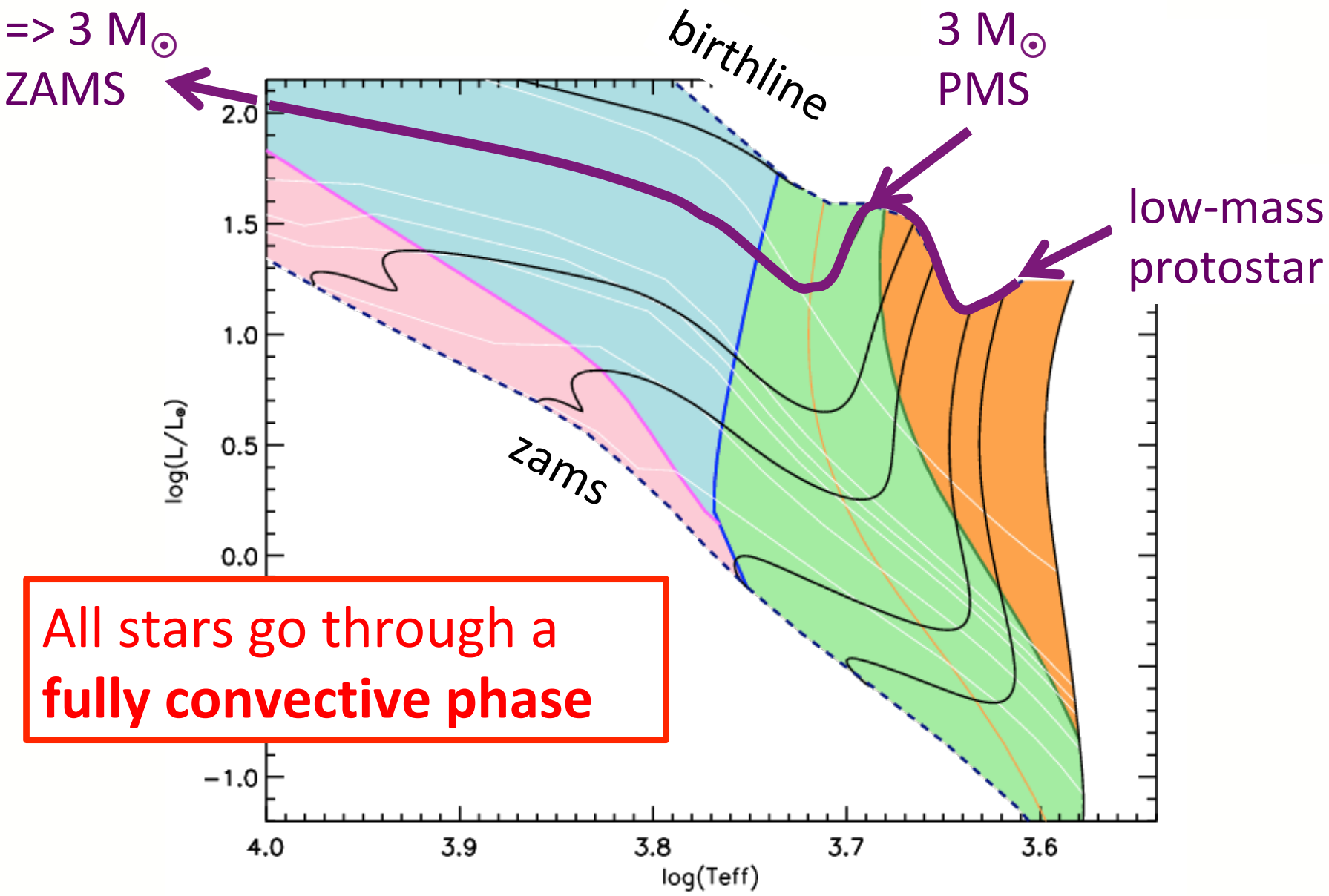


Alecian+2013, Villebrun+2019

PMS evolution of the naked star



PMS evolution of the naked star



All stars go through a **fully convective phase**

Field relaxation during the **PMS** phase

No rotation

- Numerical and analytical work:

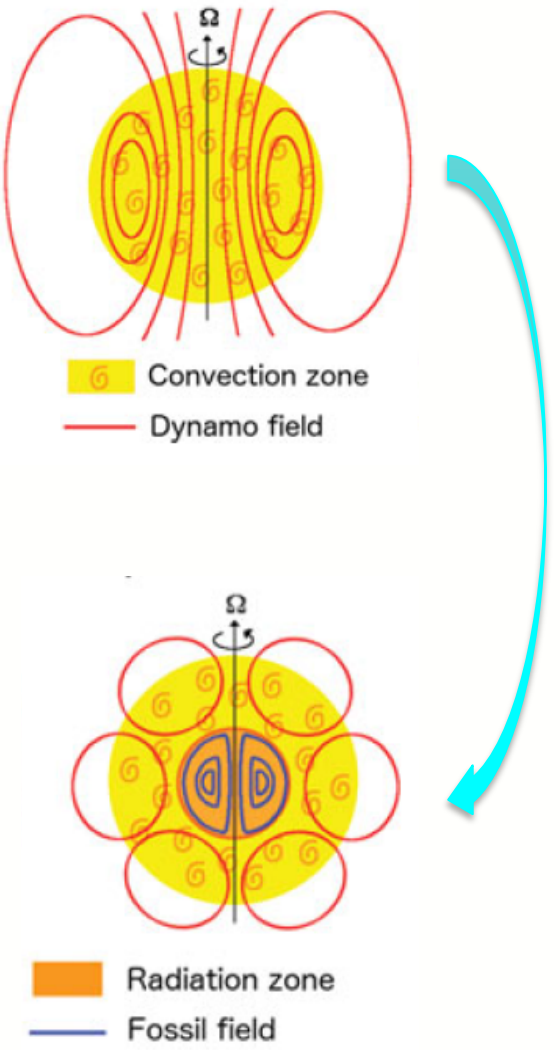
  $\Rightarrow$ Mixed stable configurations

  (Braithwaite & Nordlund 2006 ; Duez et al. 2010 ; Duez & Mathis 2010)

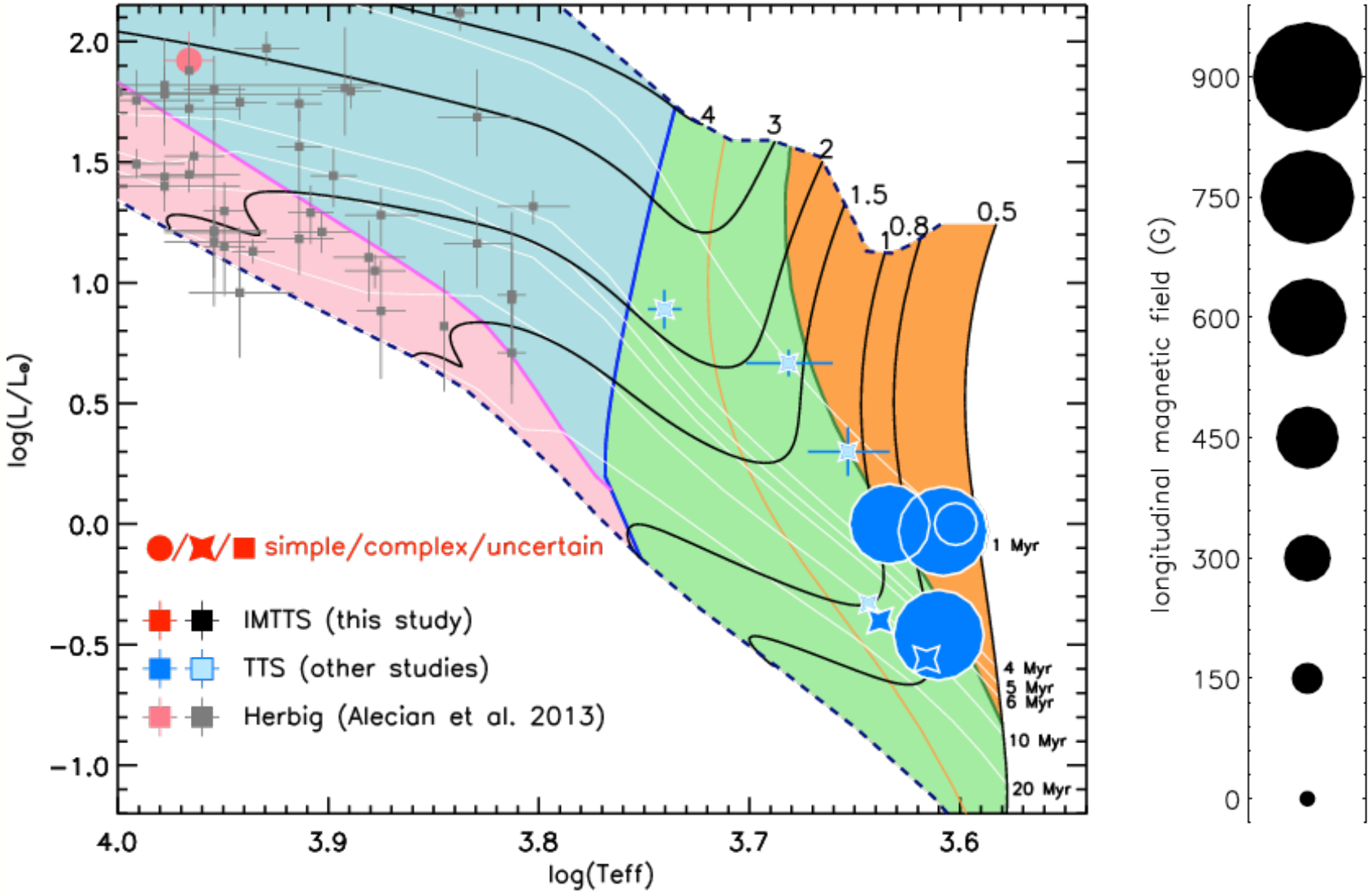
With rotation

- Lowest energy state: dipolar fields
- Initial helicity and angular momentum impact the final state

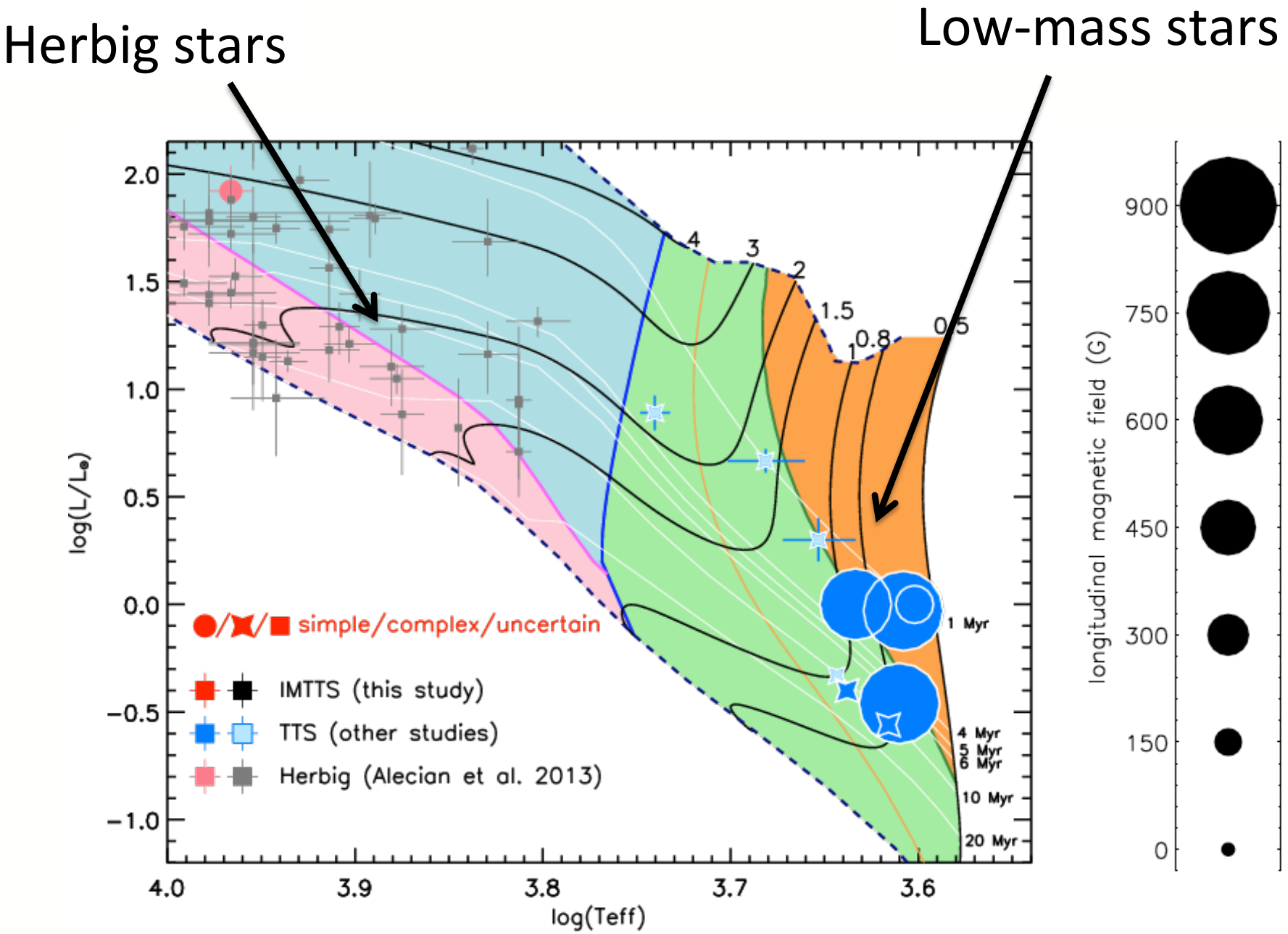
  (Emeriau & Mathis 2015)



Back in 2014


2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
log(L/L⊙)
4.0
3.9
3.8
3.7
3.6
log(Teff)
4
3
2
1.5
1
0.8
0.5
simple/complex/uncertain
IMTTS (this study)
TTS (other studies)
Herbig (Alecian et al. 2013)
1 Myr
4 Myr
5 Myr
6 Myr
10 Myr
20 Myr
900
750
600
450
300
150
0
longitudinal magnetic field (G)

Back in 2014


Herbig stars
Low-mass stars
log(L/L⊙)
log(Teff)
4.0
3.9
3.8
3.7
3.6
2.0
1.5
1.0
0.5
0.0
−0.5
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longitudinal magnetic field (G)
900
750
600
450
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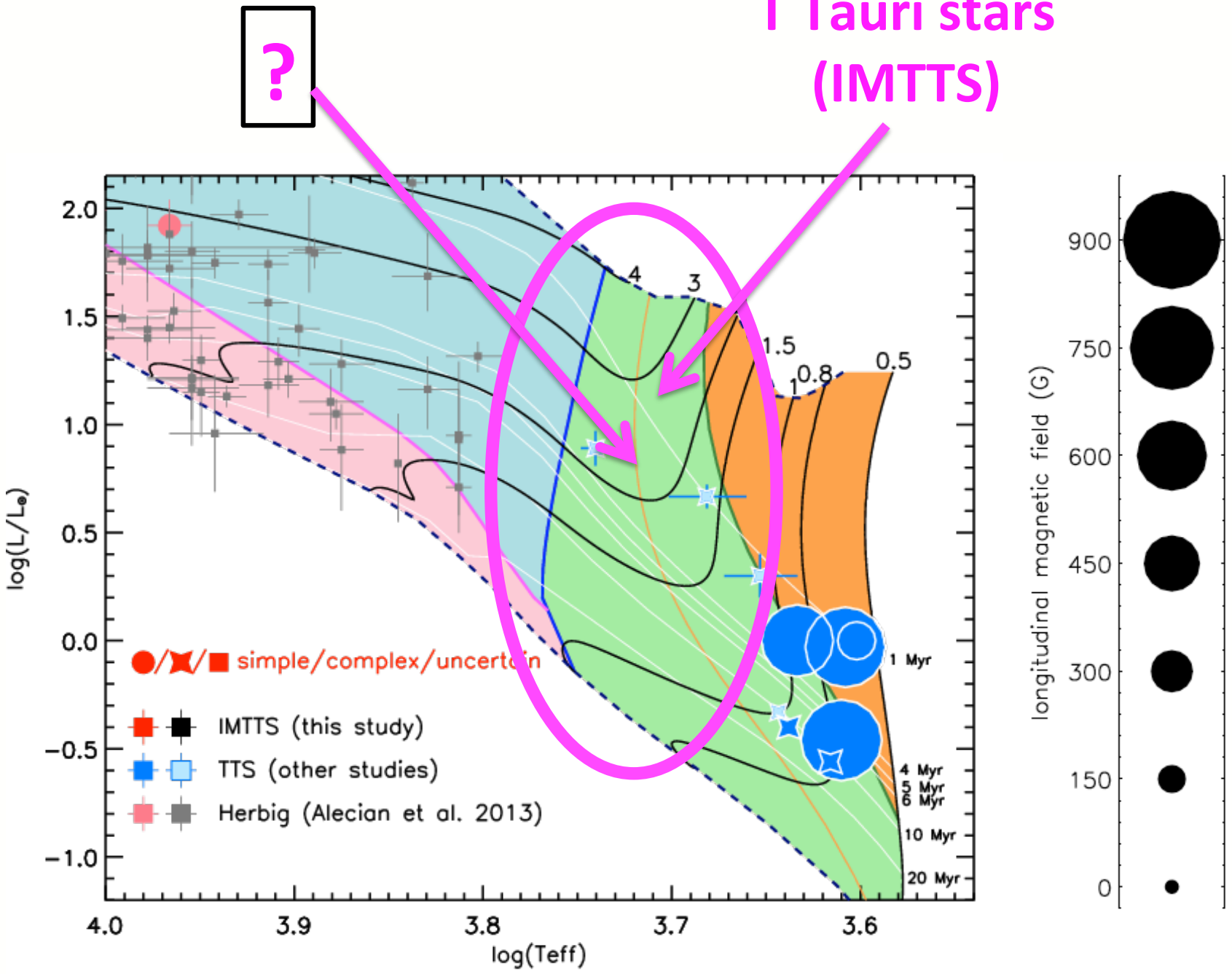
0

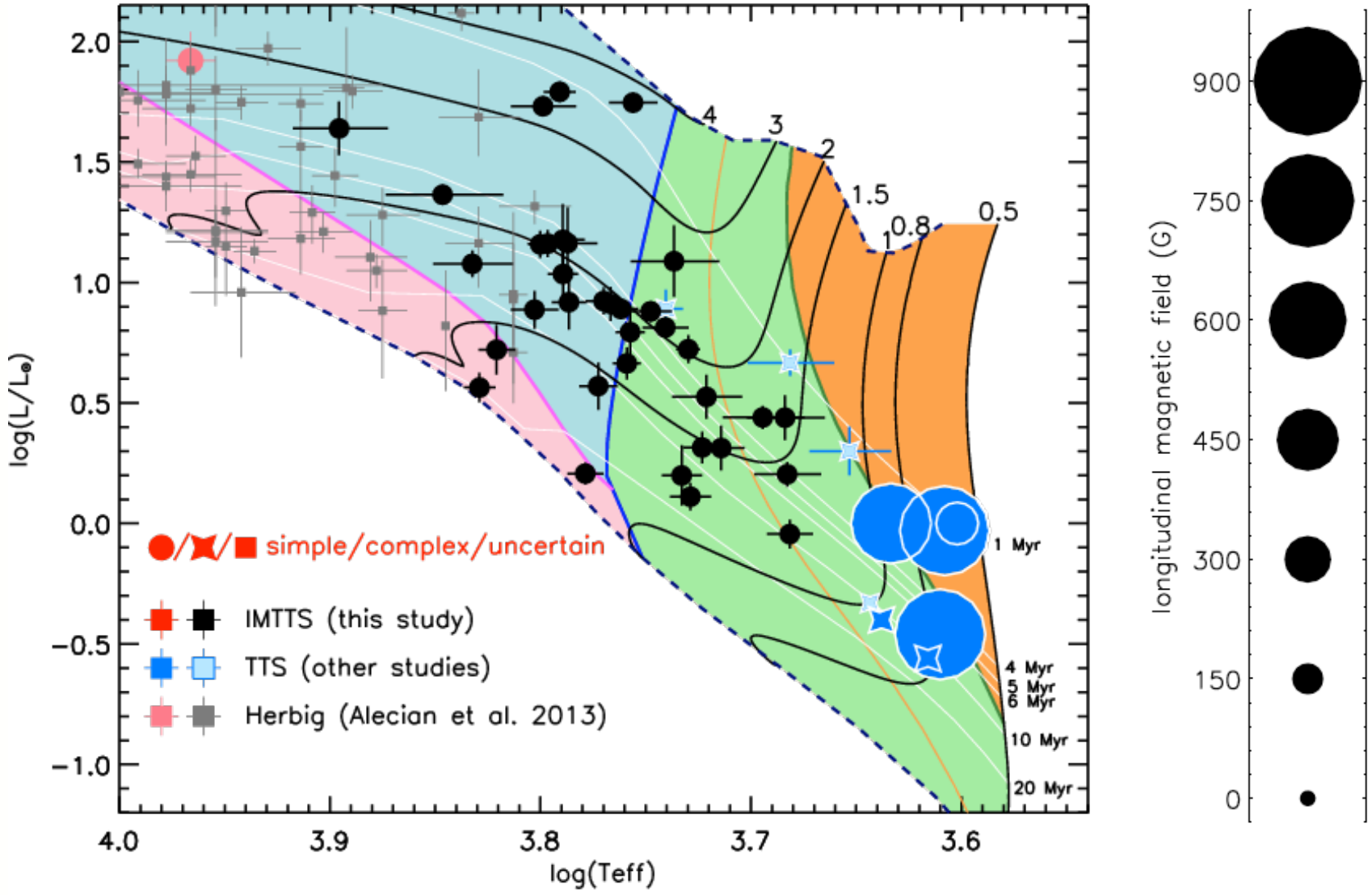
Back in 2013

Intermediate-mass T Tauri stars (IMTTS)



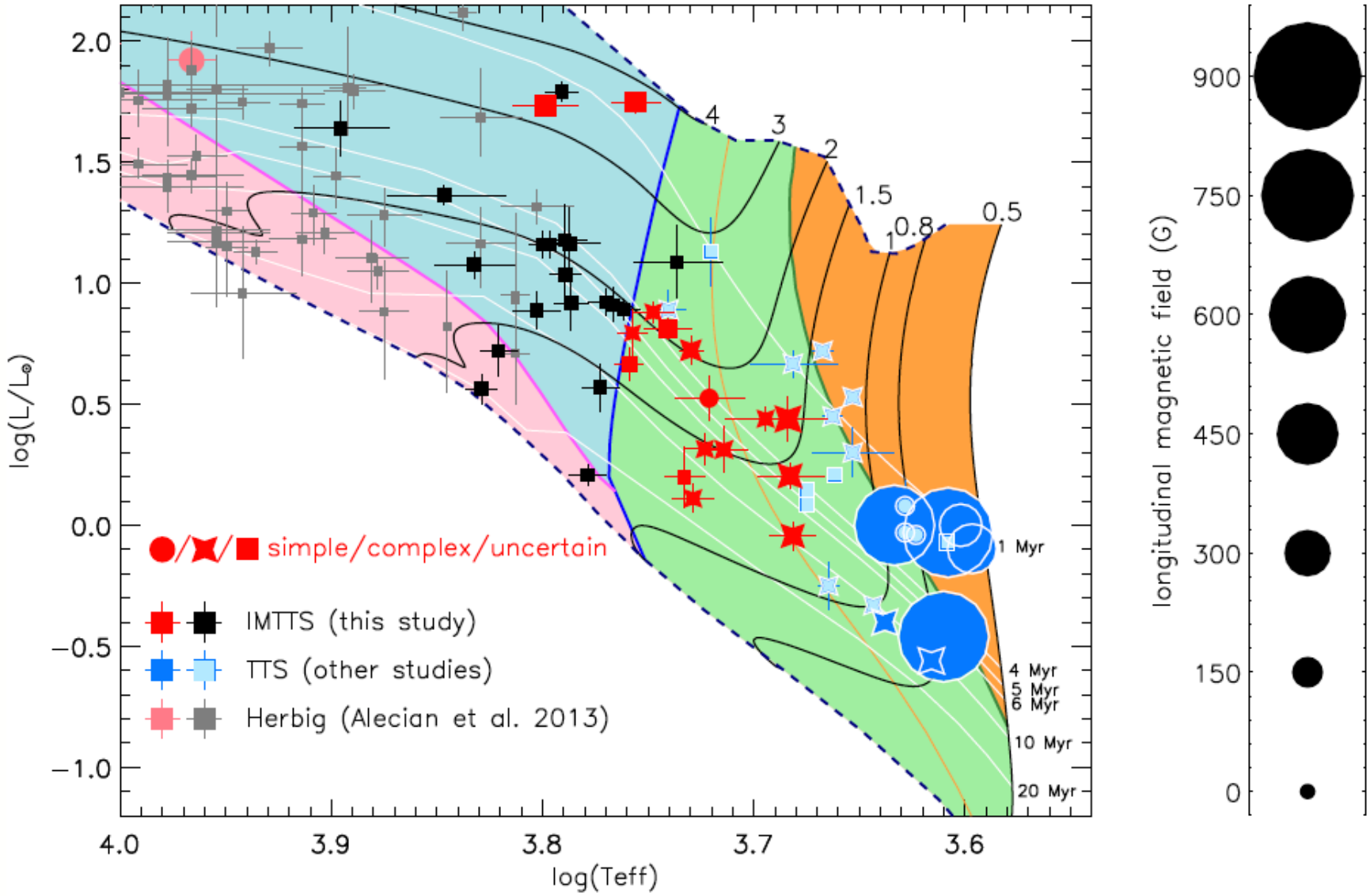
IMTTS Survey

ESPaDOnS + HARPSpol snapshot observations
38 targets (PIs: Alecian, Hussain)



IMTTS Survey Results

Villebrun et al. (2019)



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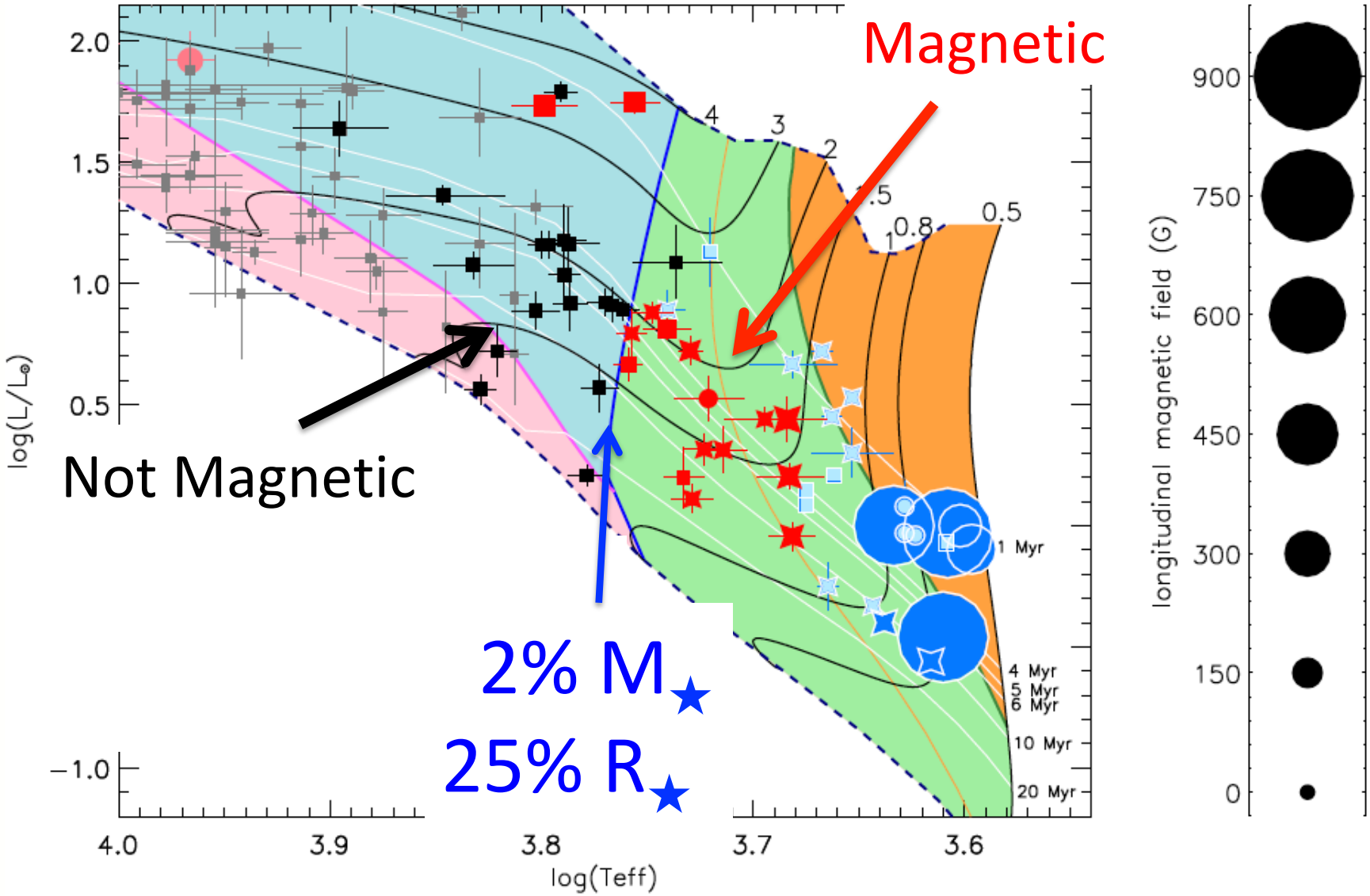

IMTTS Survey Results

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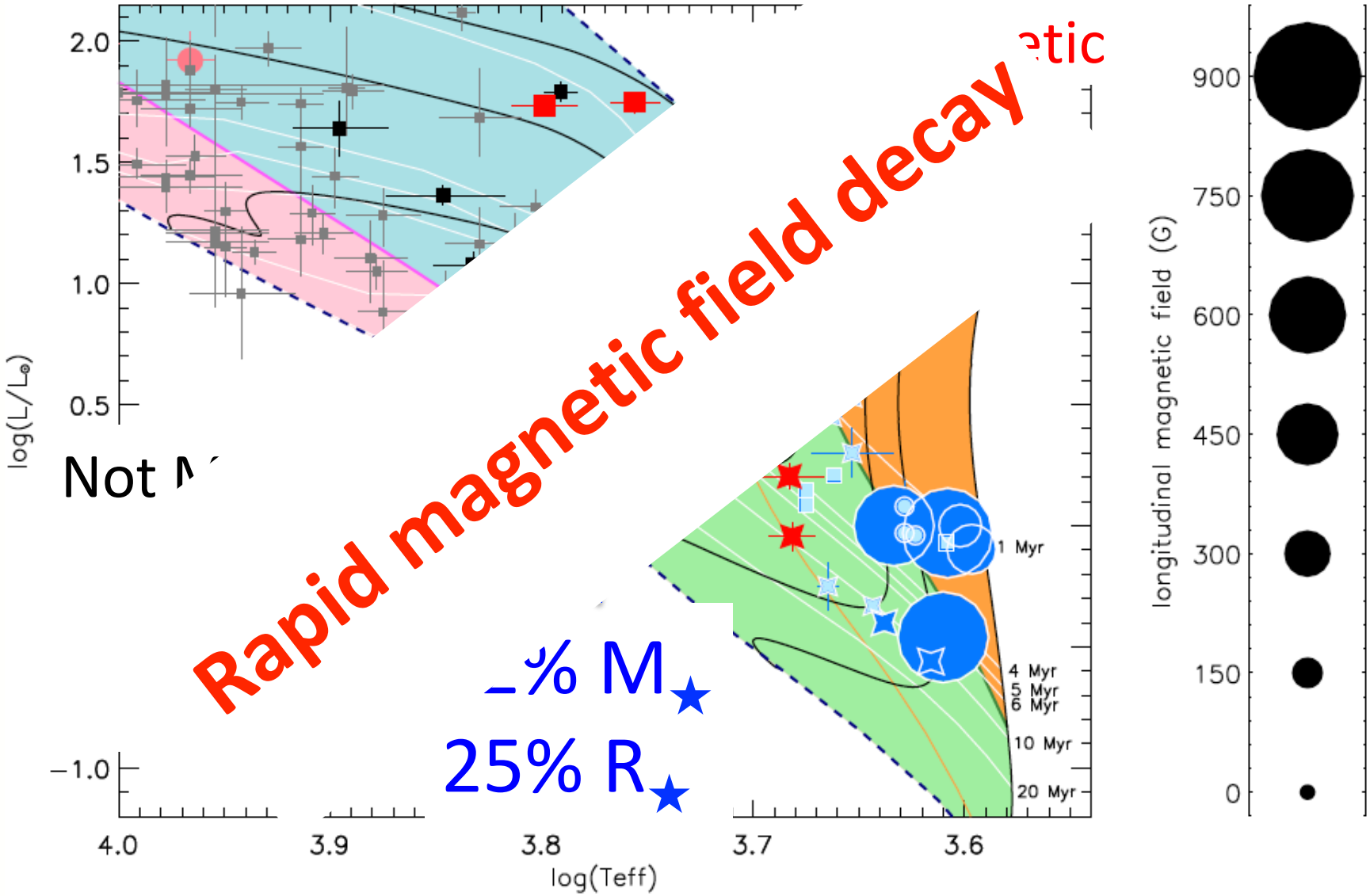
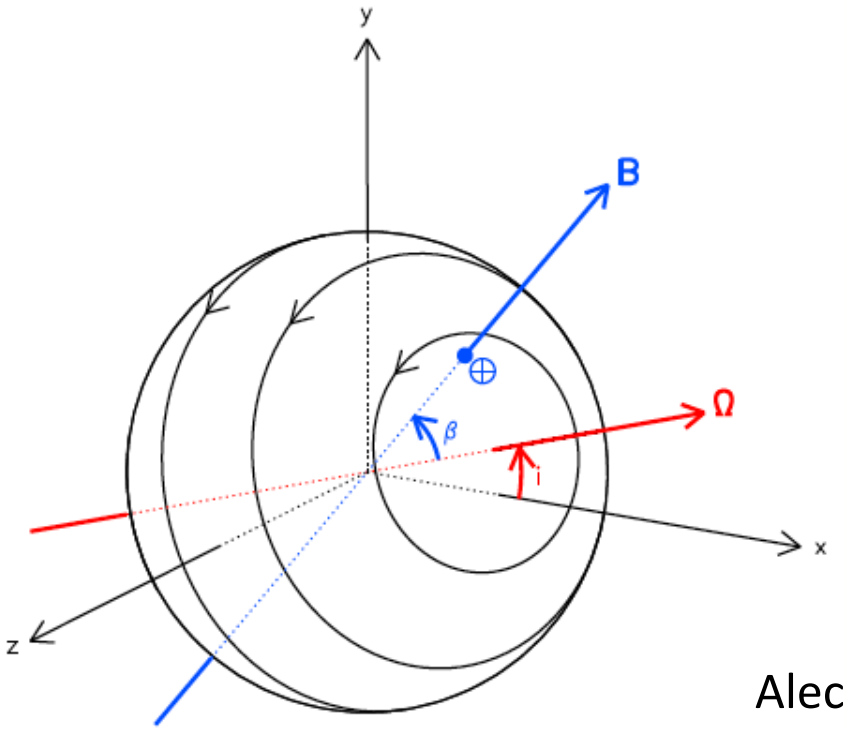


HOW NON-MAGNETIC ARE NON-MAGNETIC STARS ?

B limit determination

- Hypothesis: a dipolar field may be hidden in the V signal
- MC simulations
  - i, β, ϕ_{rot} random trials
  - B_d fixed
  - Compute noisy synthetic V profiles
  - Compute the # of detection



Alecian et al. (2016), Alecian et al. in prep.

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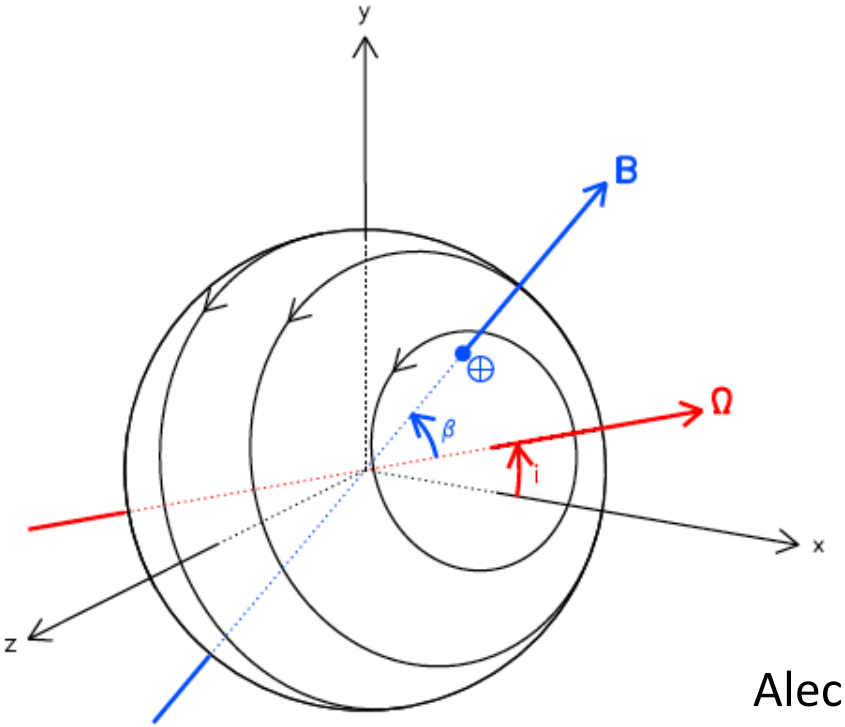
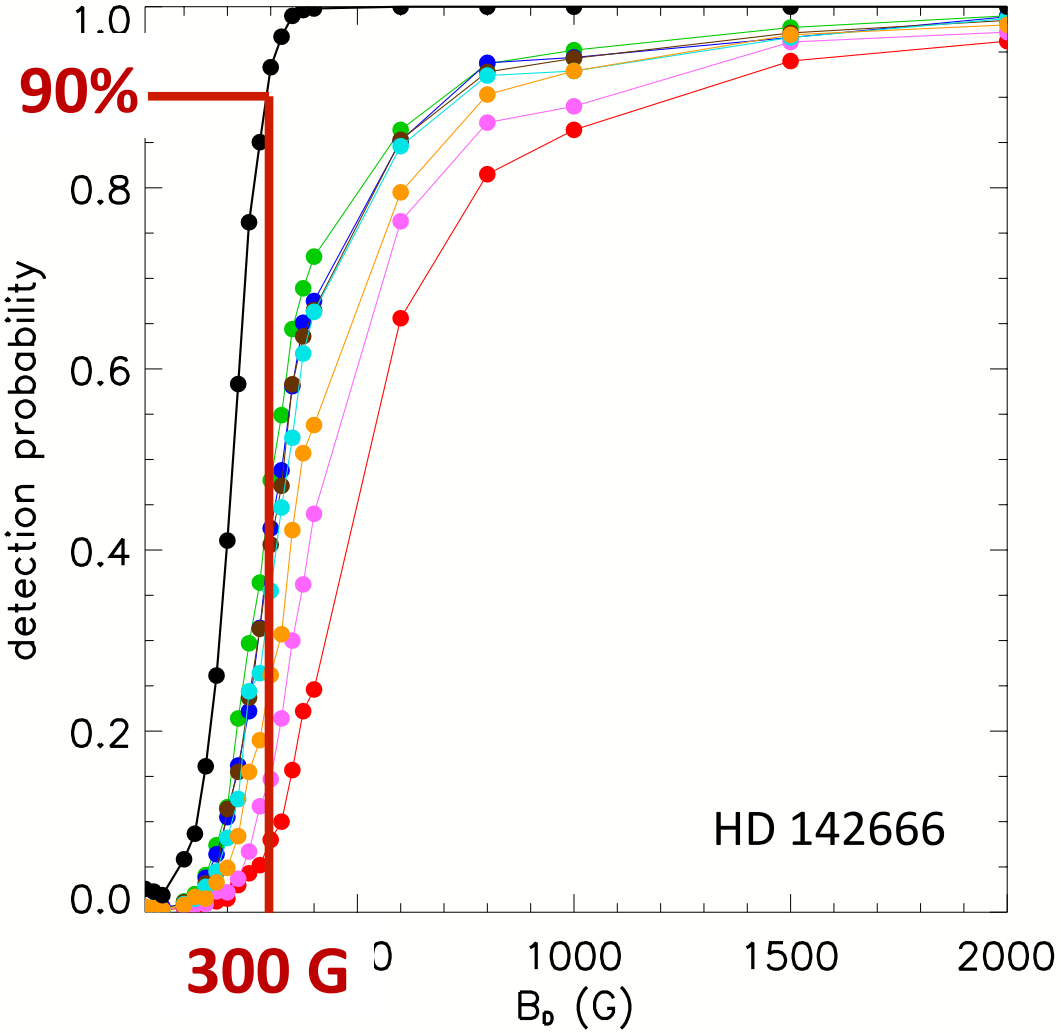
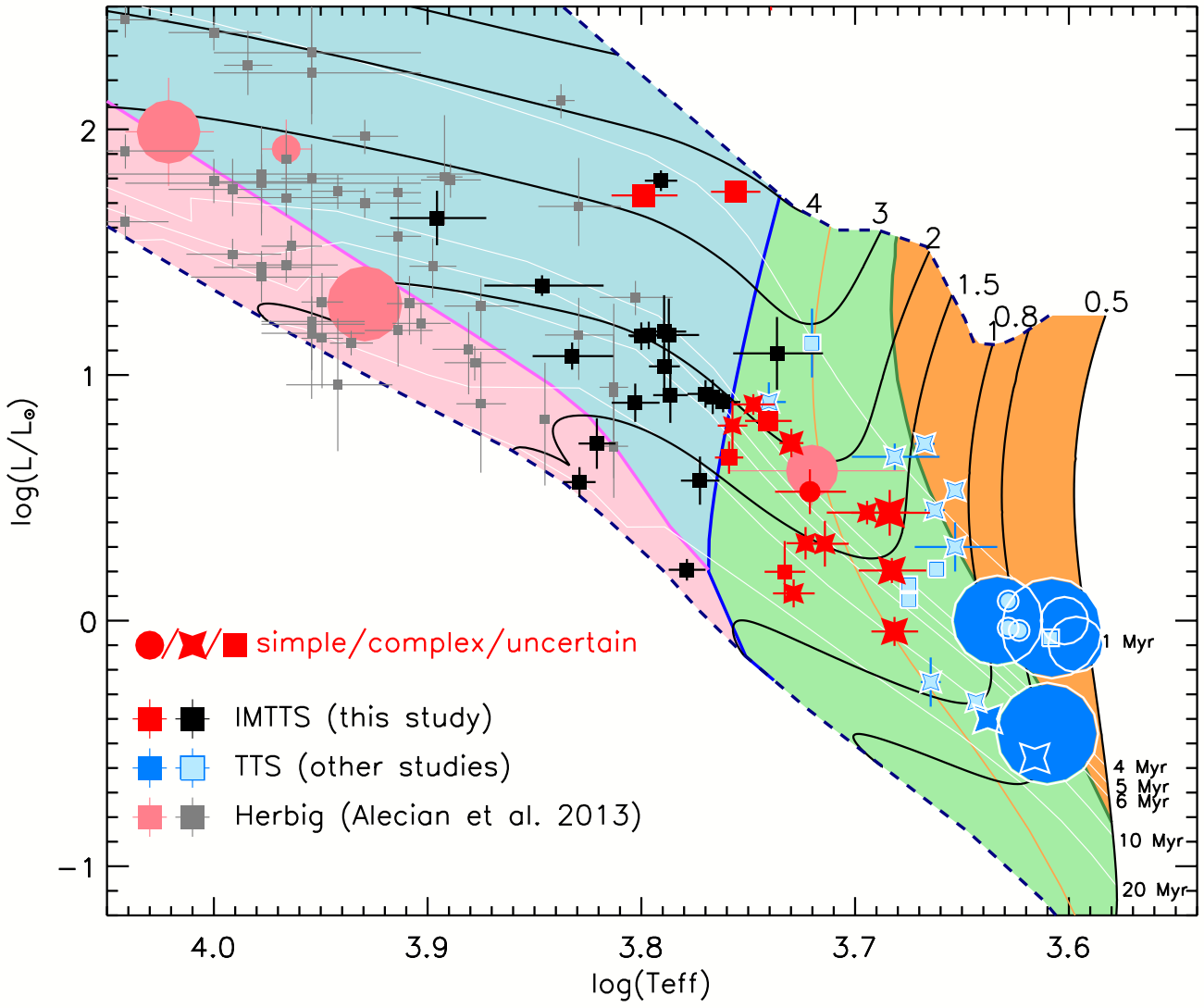




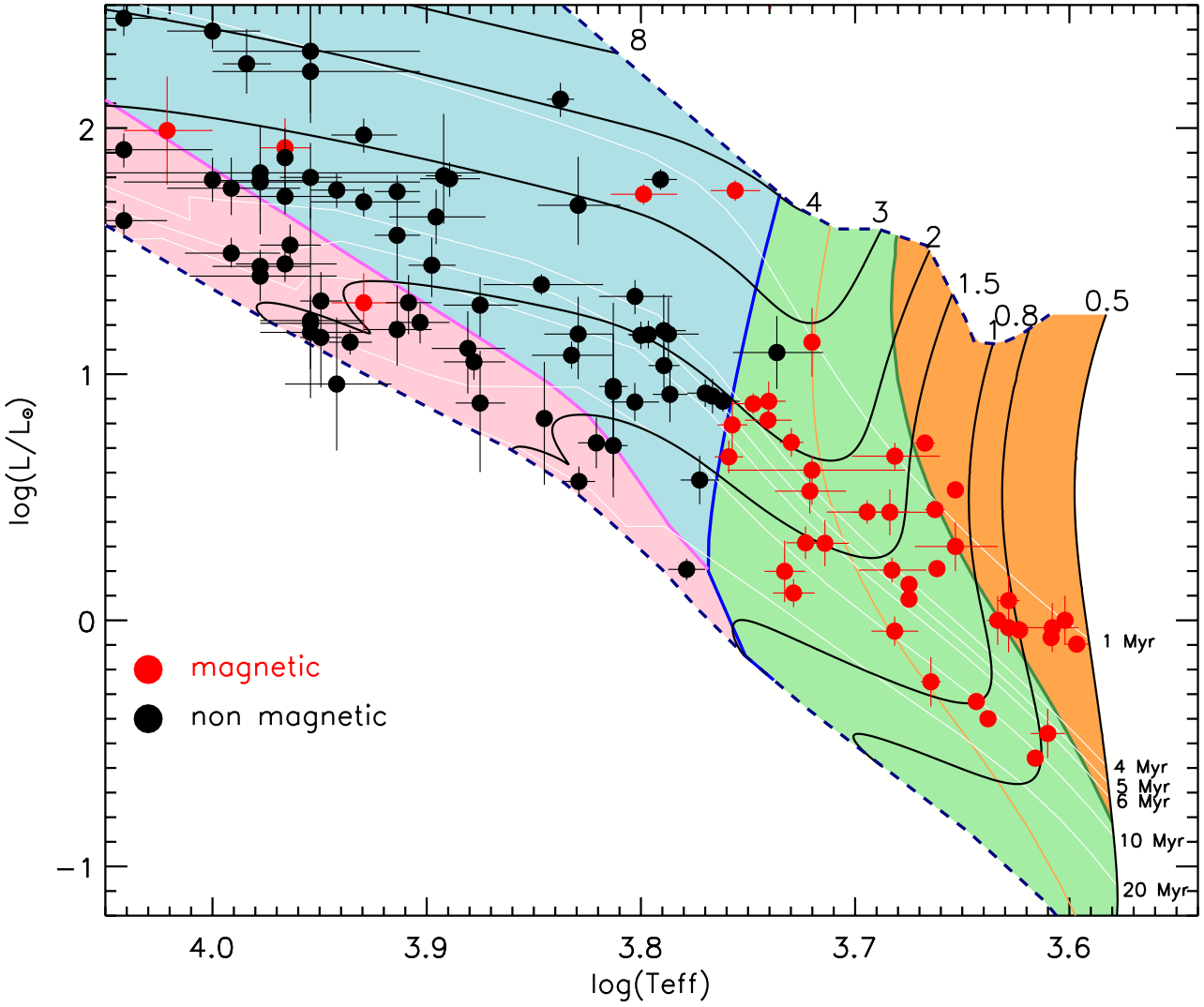
Alecian et al. (2016), Alecian et al. in prep.

Magnetism at intermediate-masses



Adapted from Villebrun et al. 2019

Magnetism at intermediate-masses



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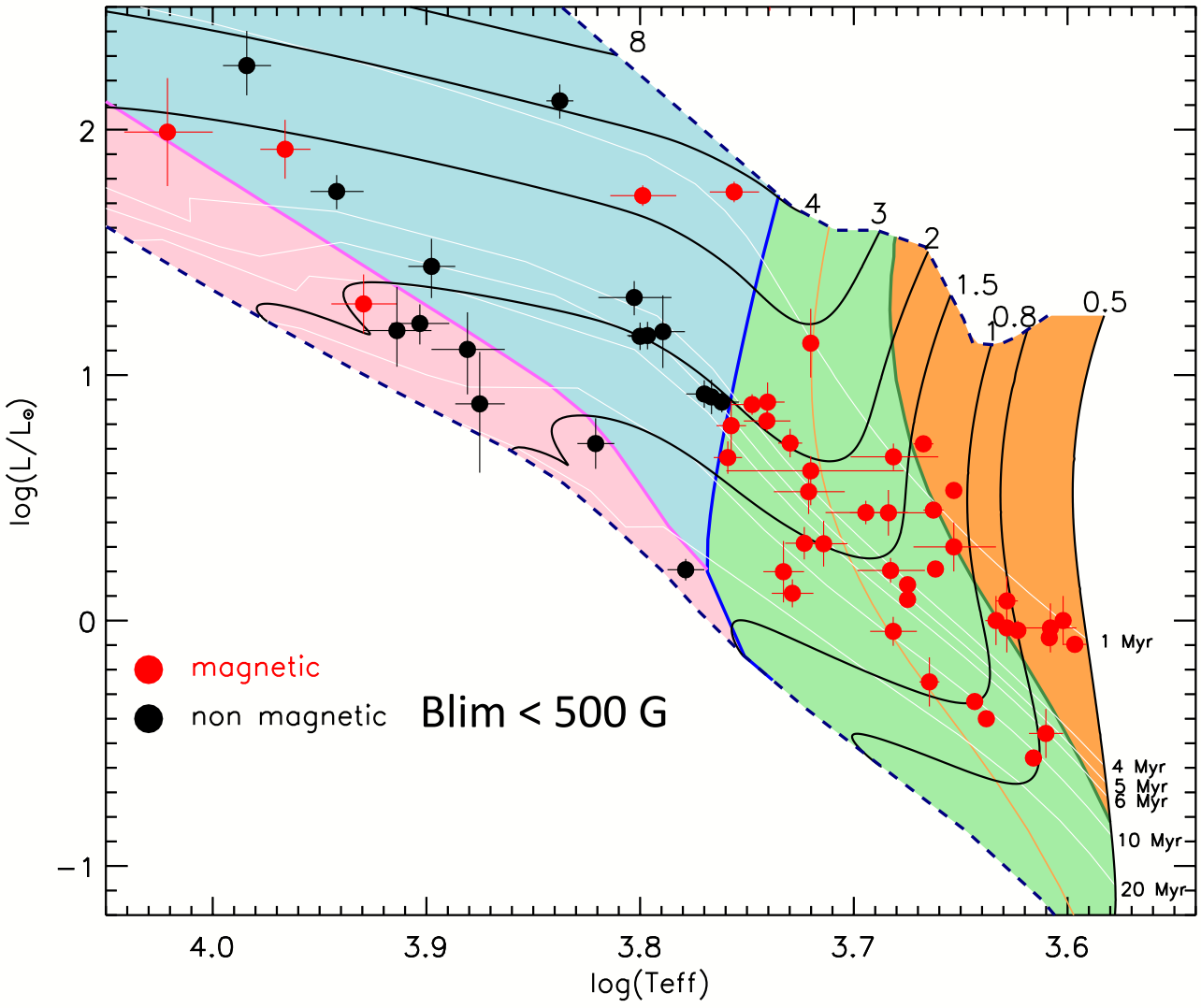
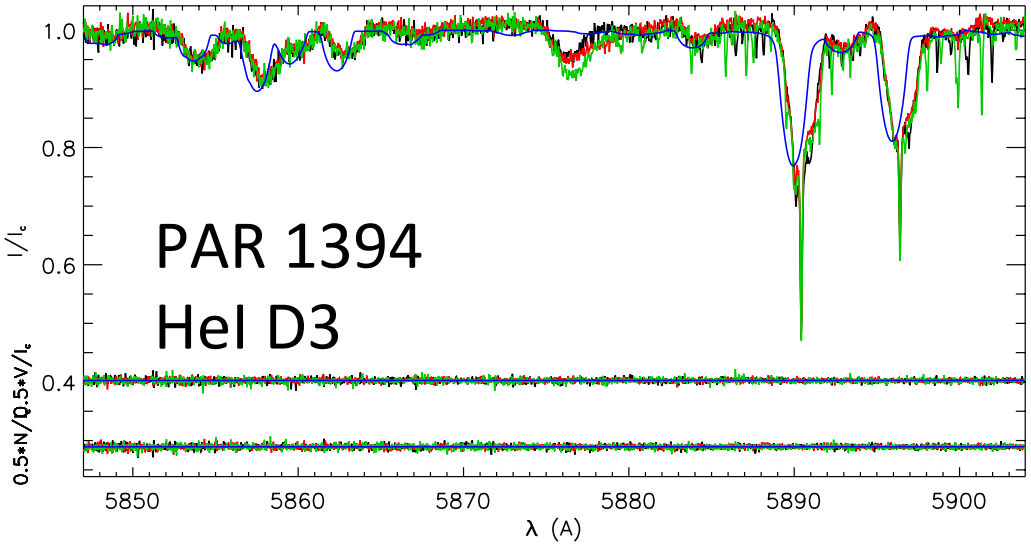
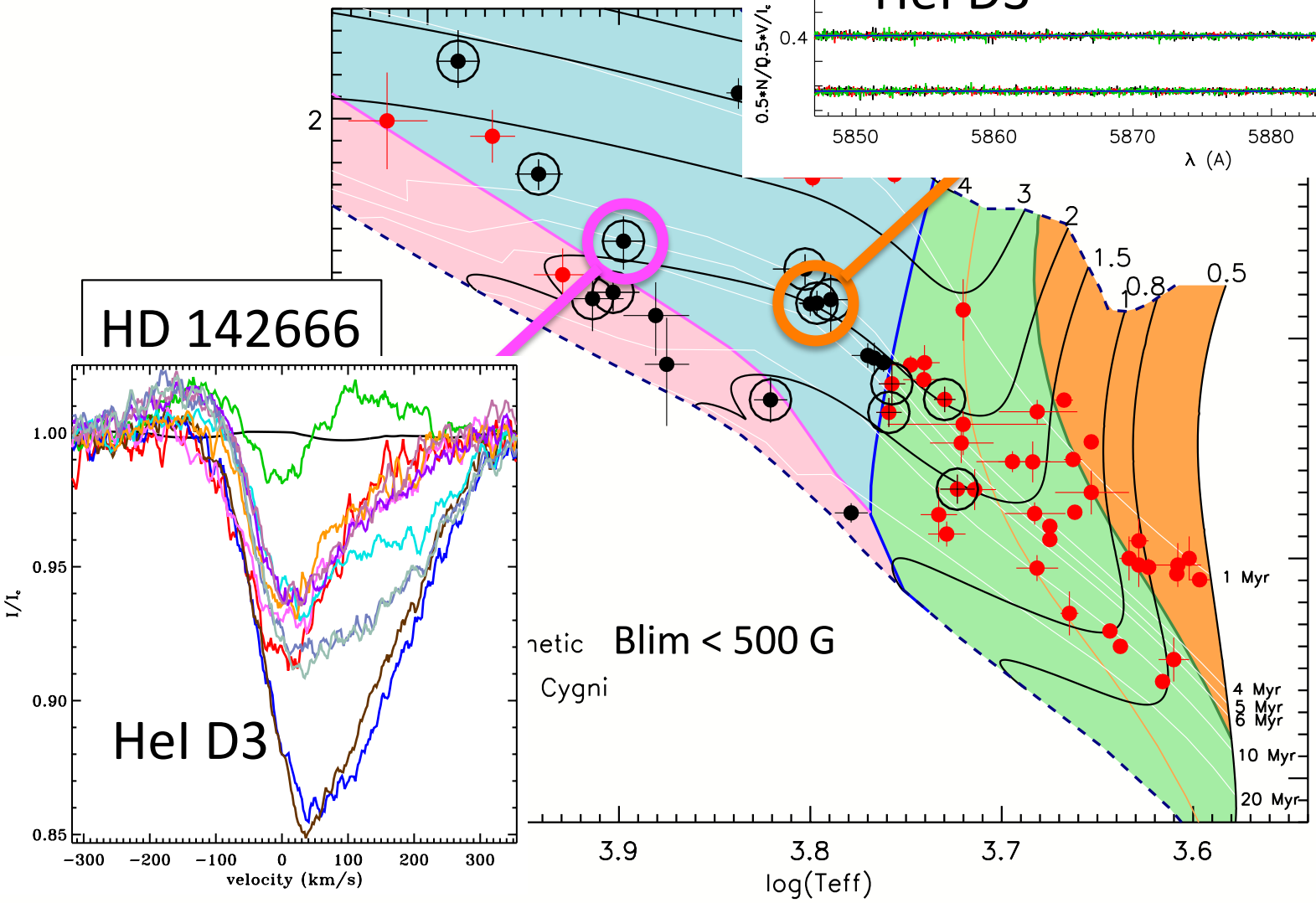
Magnetism at intermediate-masses



Alecian, Lebreton et al. in prep.

Accretion signa
magne





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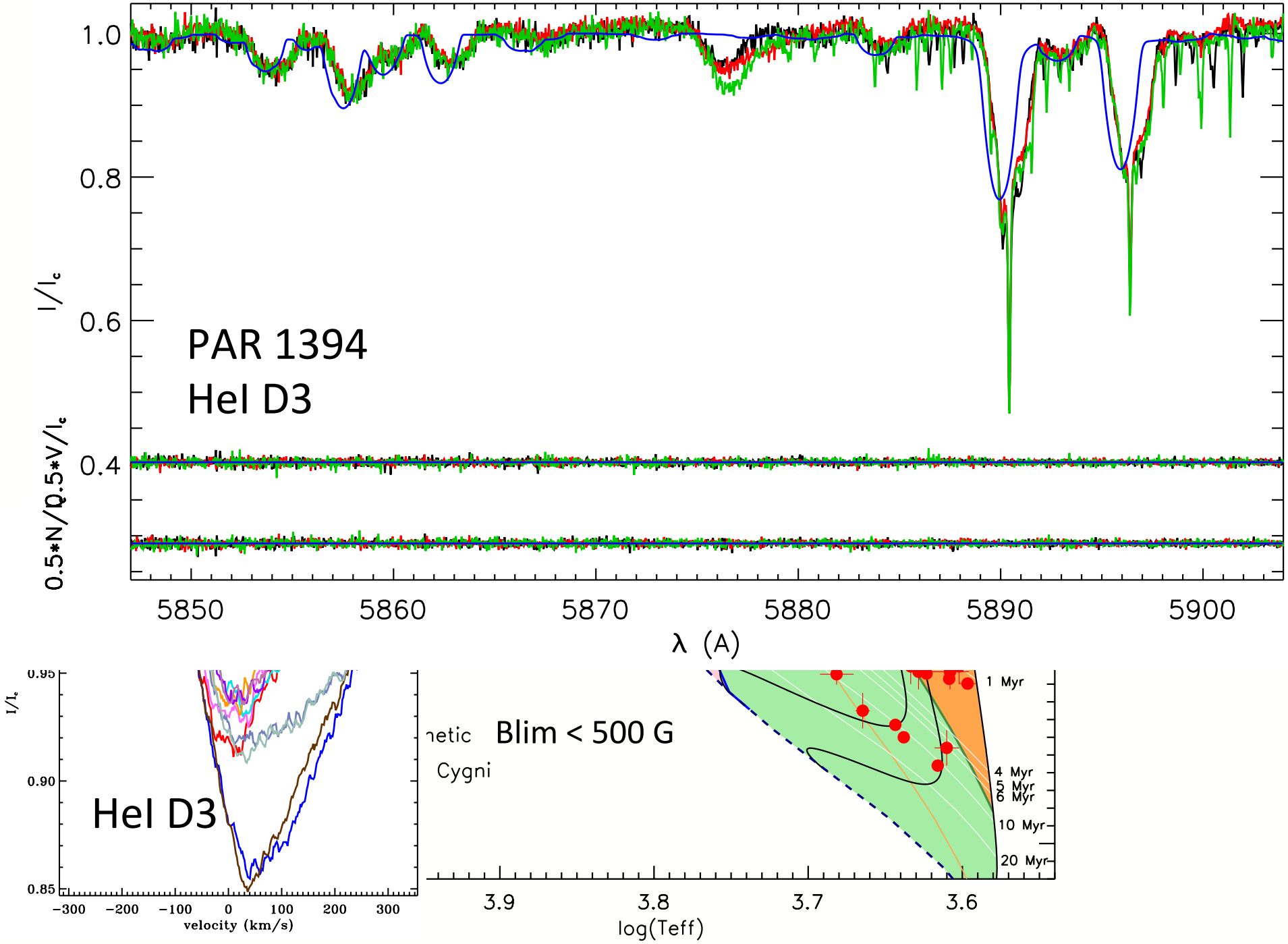

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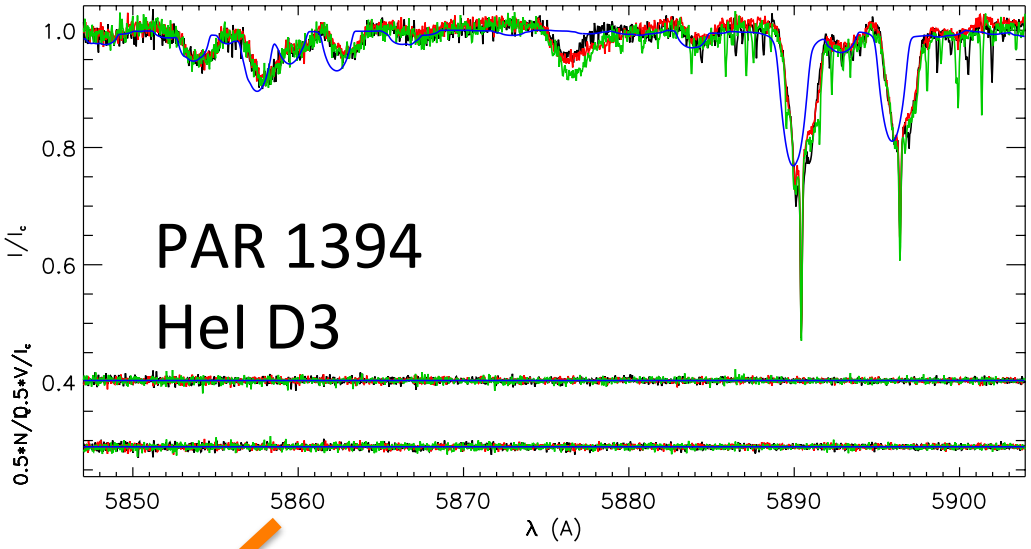
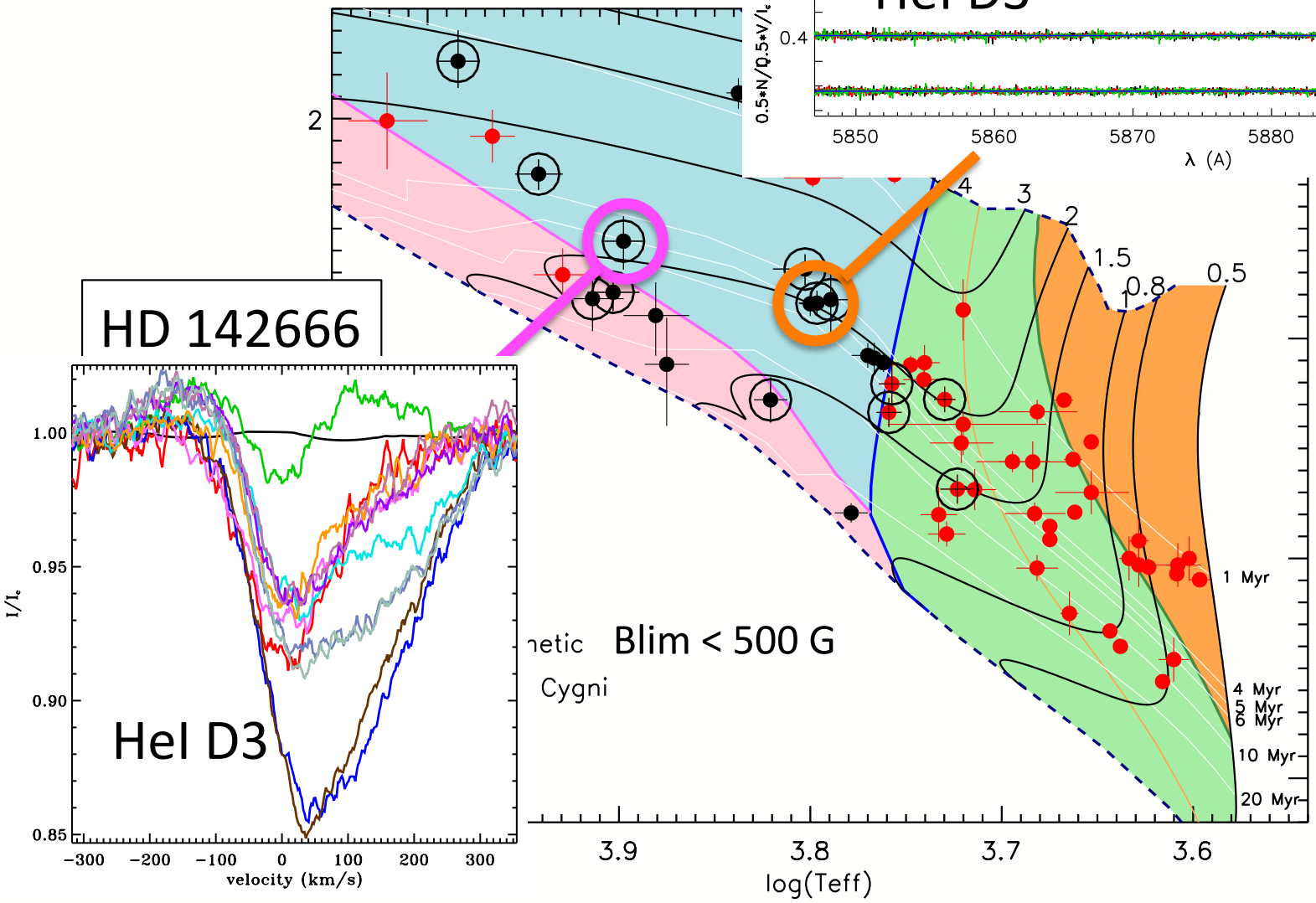




Alecian, Lebreton et al. in prep.

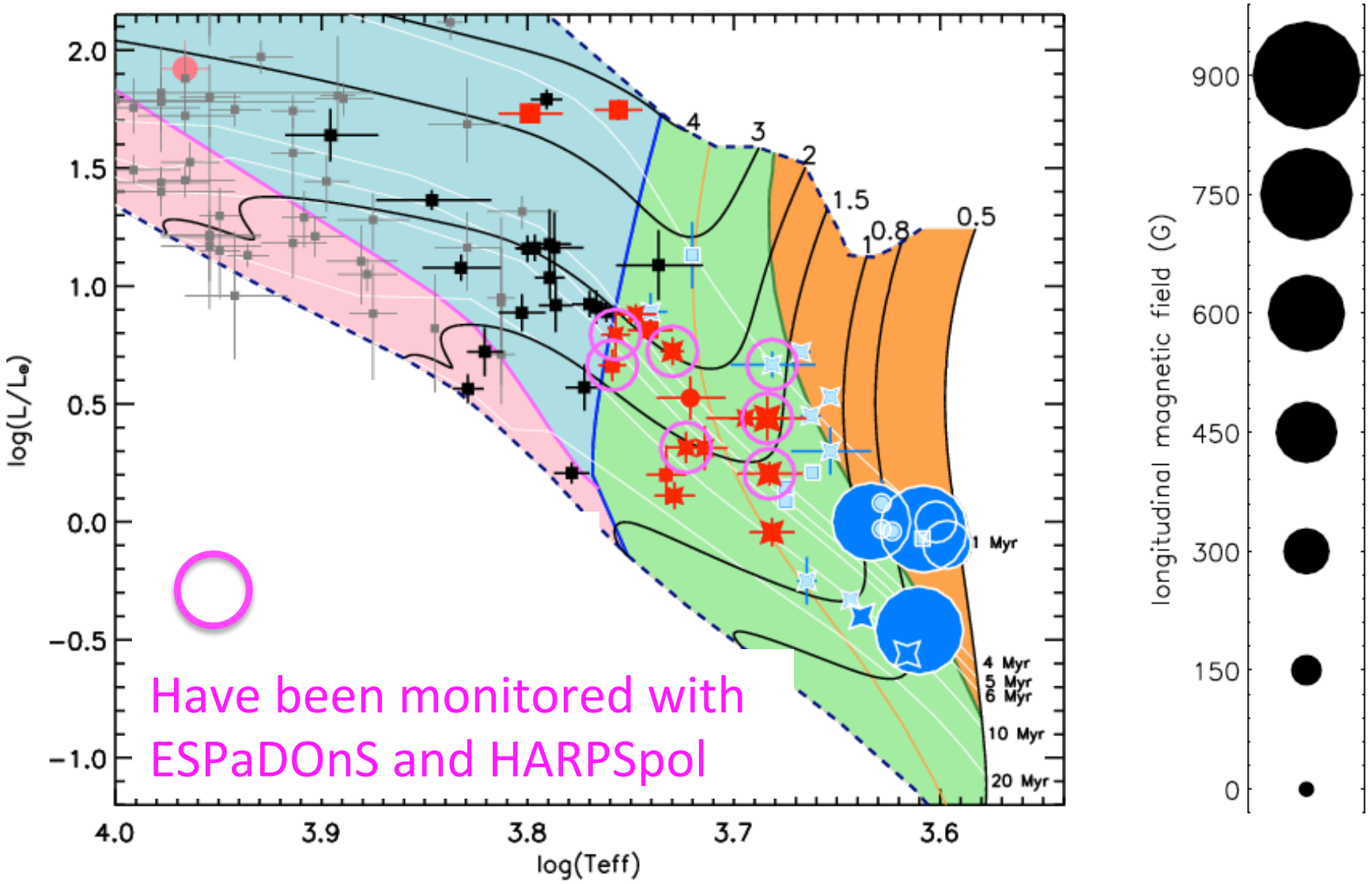
Take Home Messages

- B-field of TTS become more complex as the convective envelope become thiner
- WTTS and CTTS show similar field properties
- Once $M_{CE} < 2\ M_{\star}$ magnetic field disappears, within few 0.1 Myr (for $M_{\star} < 3M_{\odot}$)
- Some HAes have low B-field but show strong accretion signatures

What’s next ?

What's next ?

Monitoring IMTTS



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What's next ?

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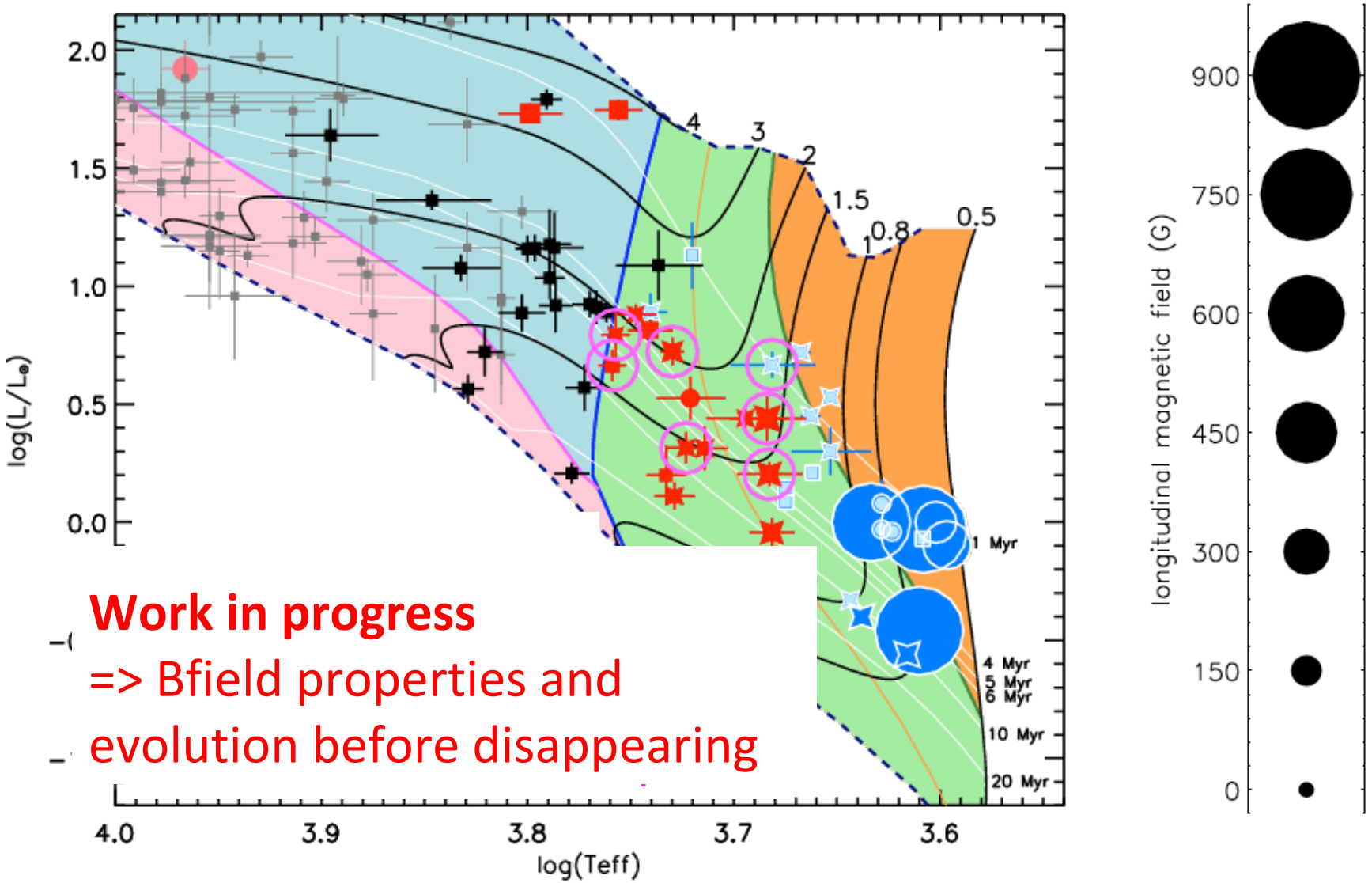

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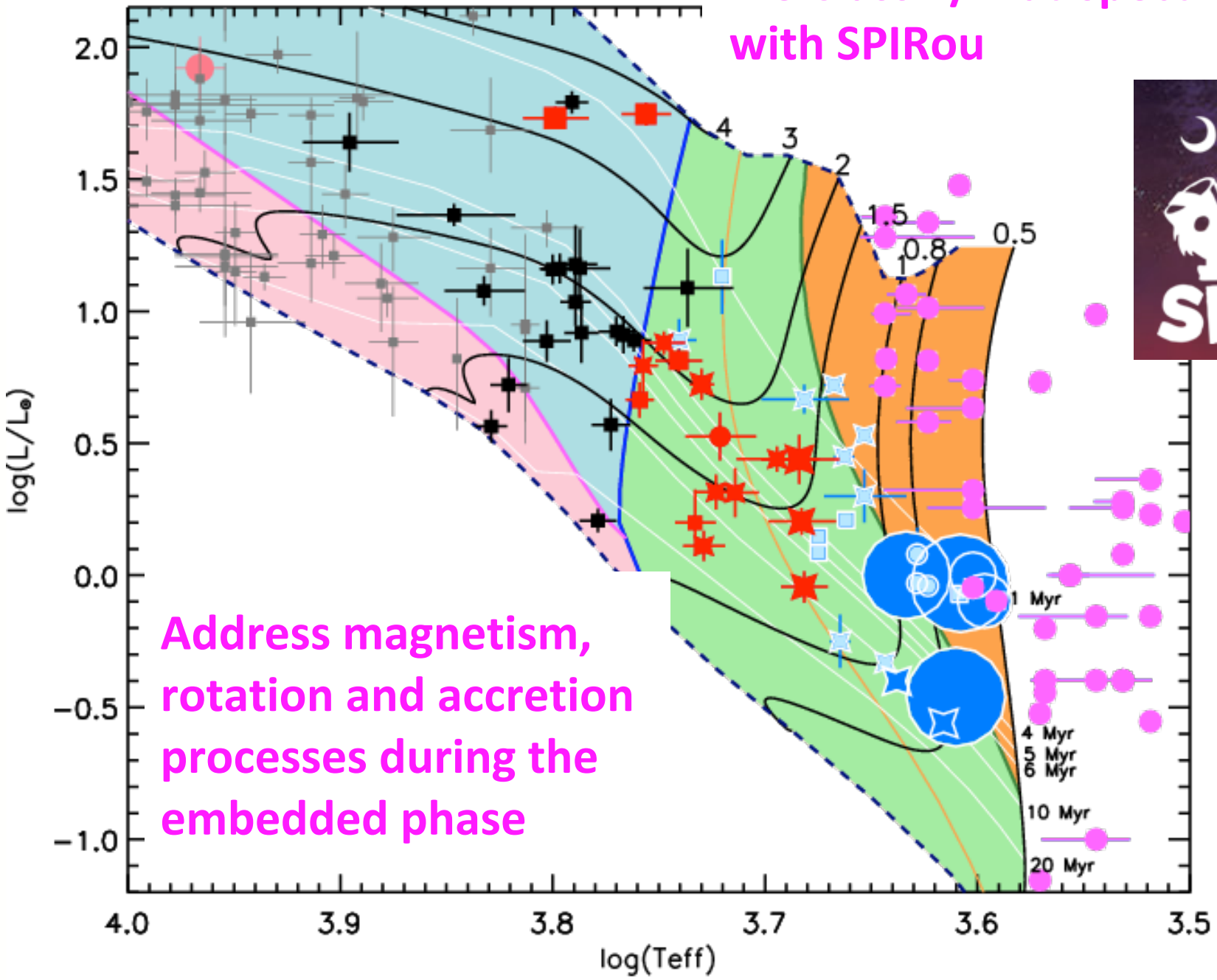
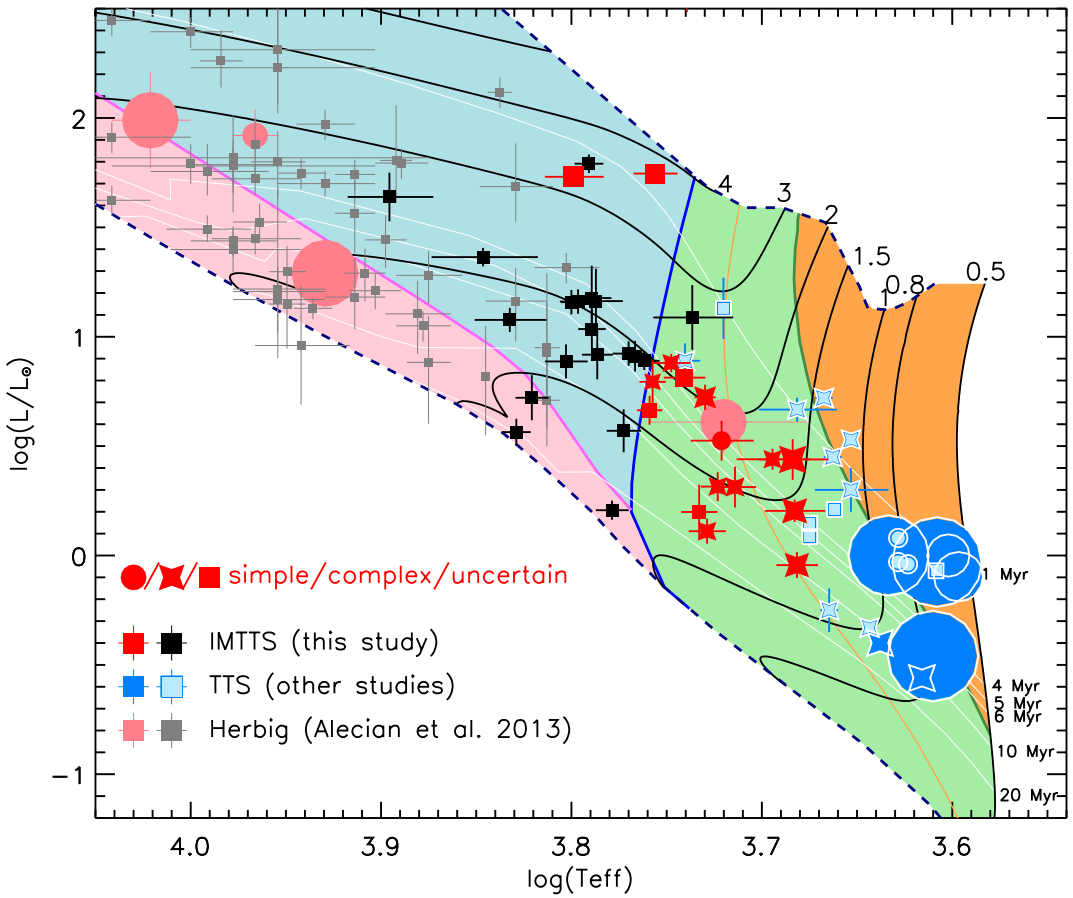
What's next ?

The Class I / Flat-spectrum objects with SPIRou



Address magnetism, rotation and accretion processes during the embedded phase


log(L/L⊙)
log(Teff)
4.0
3.9
3.8
3.7
3.6
2
1
0
−1
4
3
2
1.5
1
0.8
0.5
simple/complex/uncertain
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1 Myr
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THANK YOU !