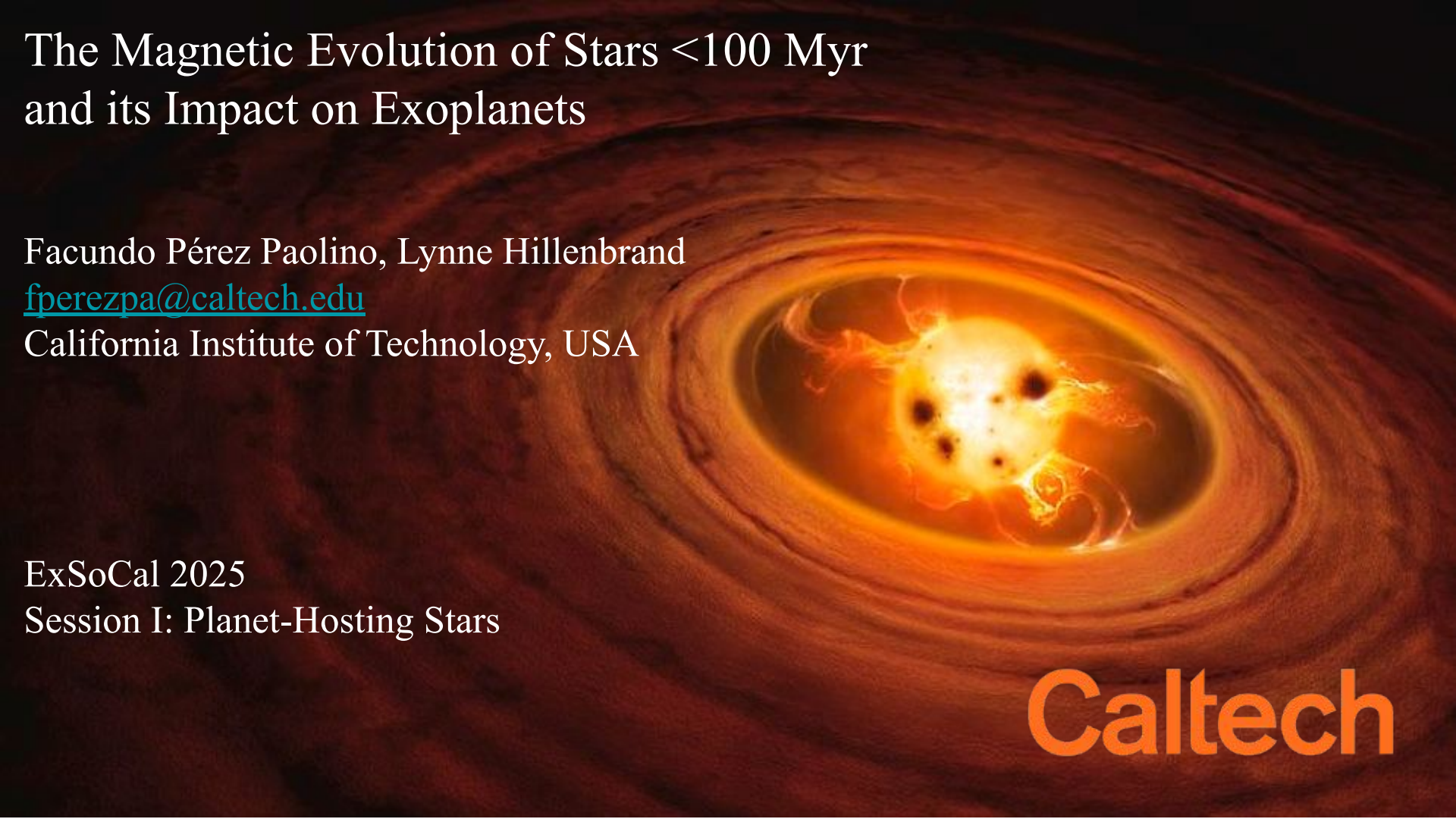
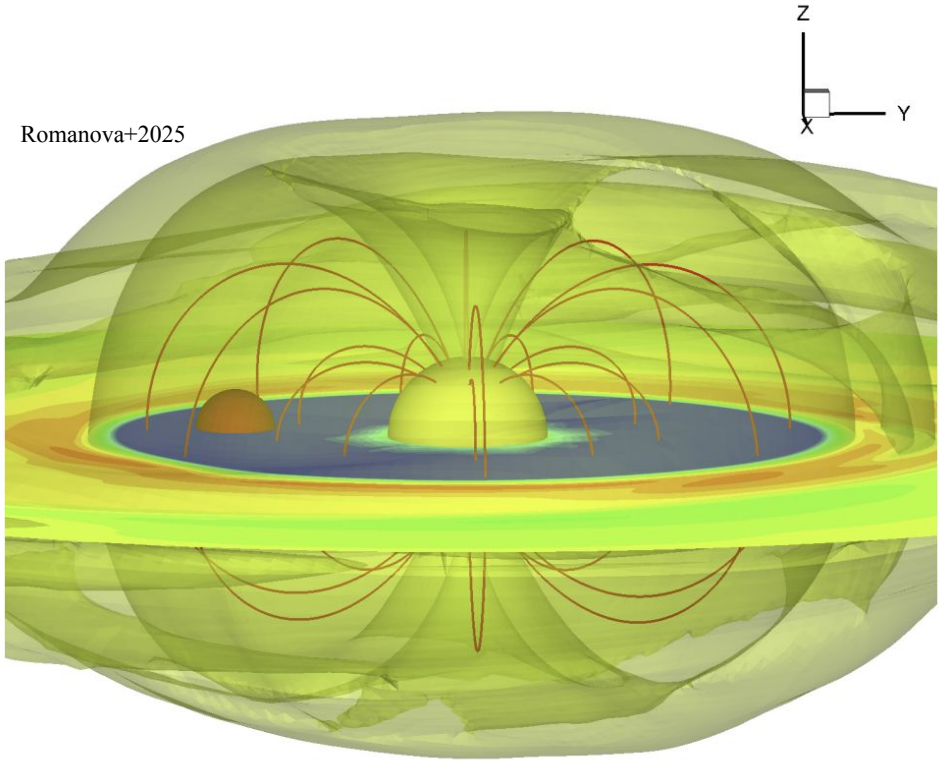
The Magnetic Evolution of Stars <100 Myr and its Impact on Exoplanets



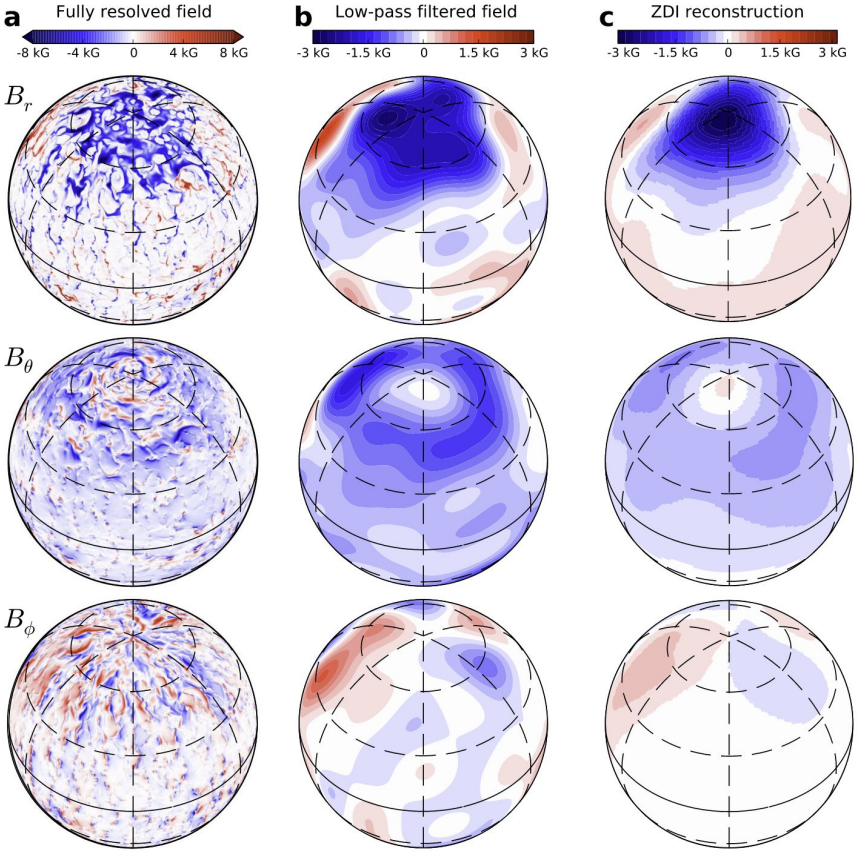
Facundo Pérez Paolino, Lynne Hillenbrand
fperezpa@caltech.edu
California Institute of Technology, USA

ExSoCal 2025
Session I: Planet-Hosting Stars

Caltech



Romanova+2025



Yadav+2015

- Stellar dynamos generate magnetic fields 0-10 kG (surface) with diverse topologies

Why care about young star magnetism?

- PMS stars change structure, rotation, and spot properties simultaneously
- Most prior work focuses on small samples, with activity proxies, at narrow ages
- **There doesn’t exist a map of stellar magnetism vs. age vs. mass vs. structure…**
  - **Yet it affects nearly every facet of stellar life and activity**

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Early on structure matters more than rotation

- PMS stars start fully convective
- Radiative cores appear at mass dependent ages
- Rotation-activity relations are not expected to hold at all (oh no!)

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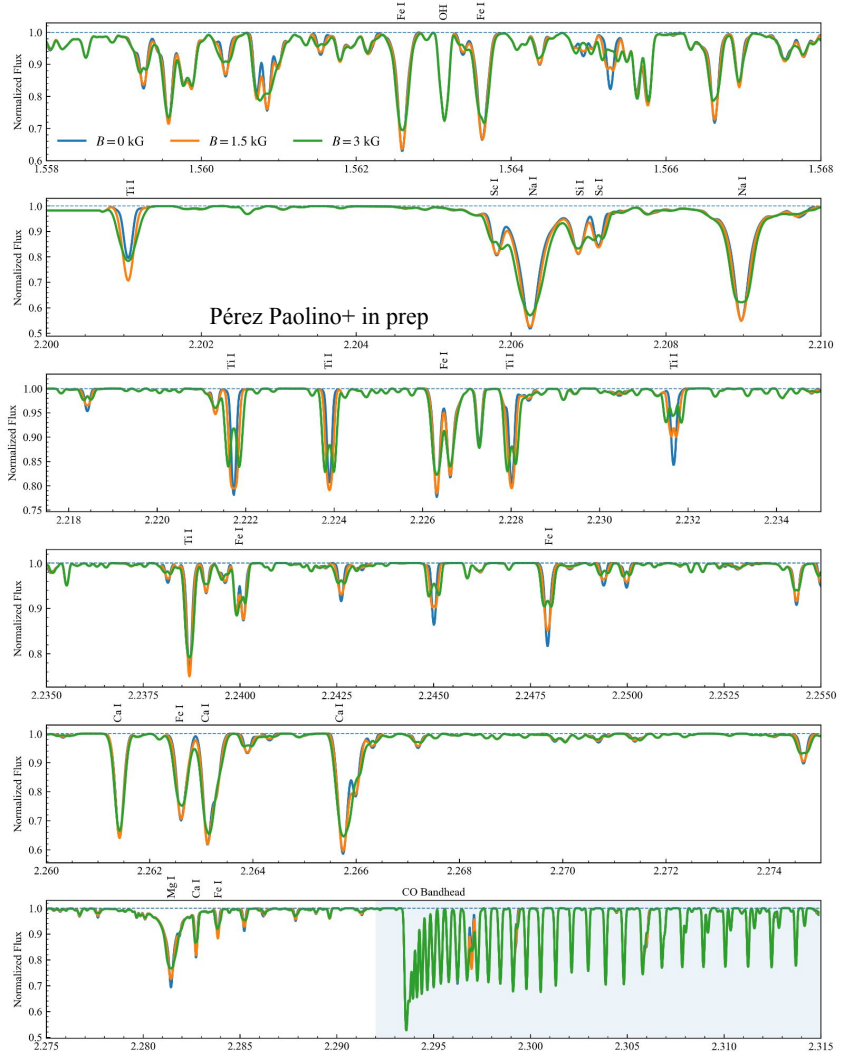
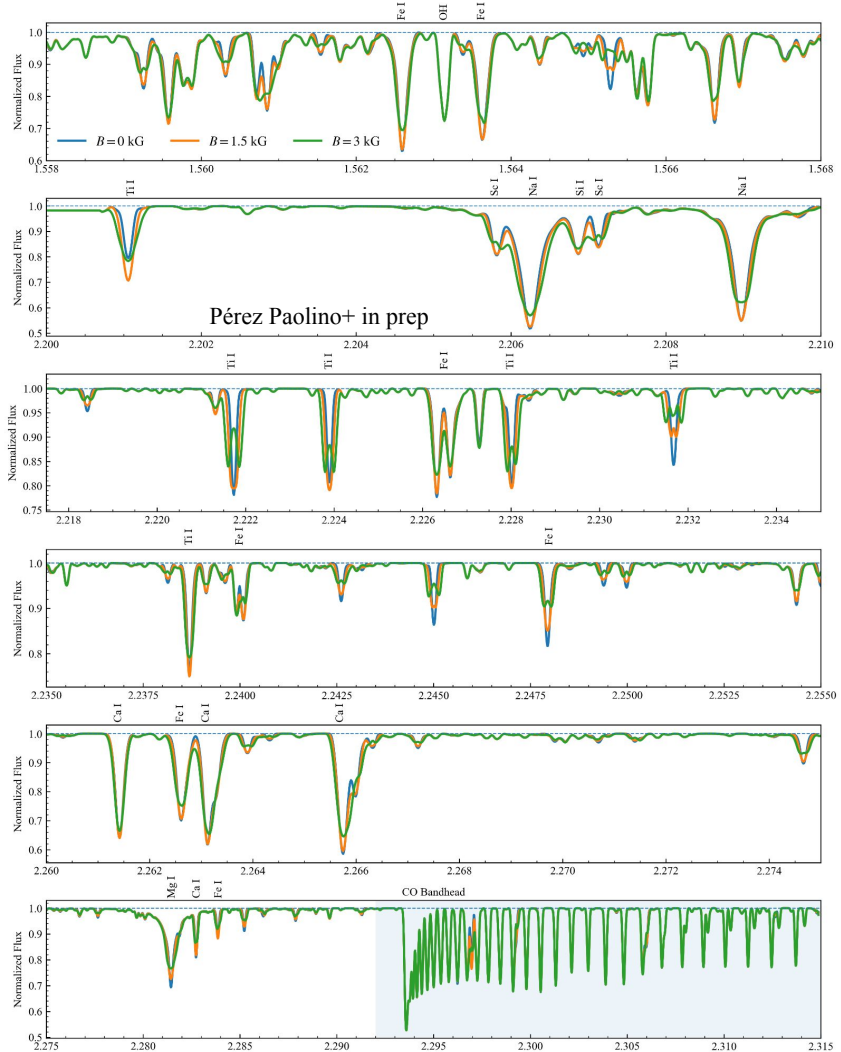
So what did we do?

- **Constructed the largest survey of magnetism across age and mass to date**



Magnetic fields at the stellar surface affect spectral lines:

- Zeeman Broadening
  - Zeeman Intensification
  - Zeeman Splitting



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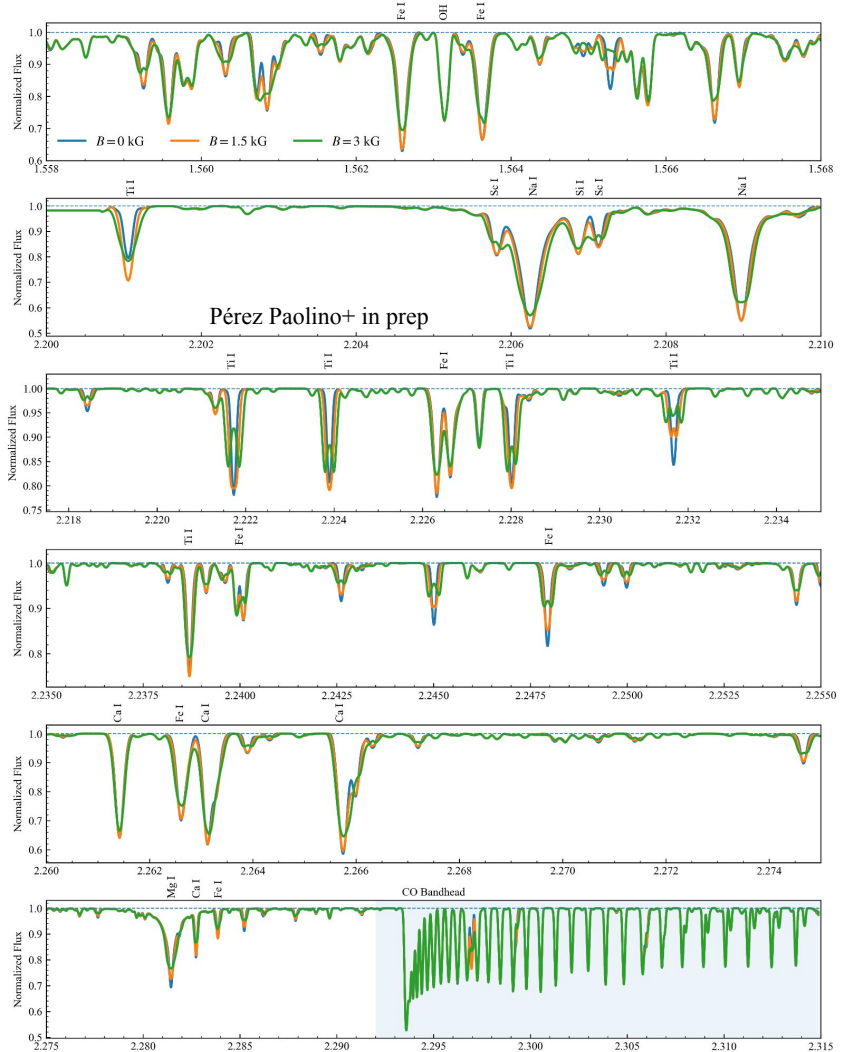
Use MOOGSTOKES magnetized radiative transfer to measure B from magnetically sensitive lines at high-resolution



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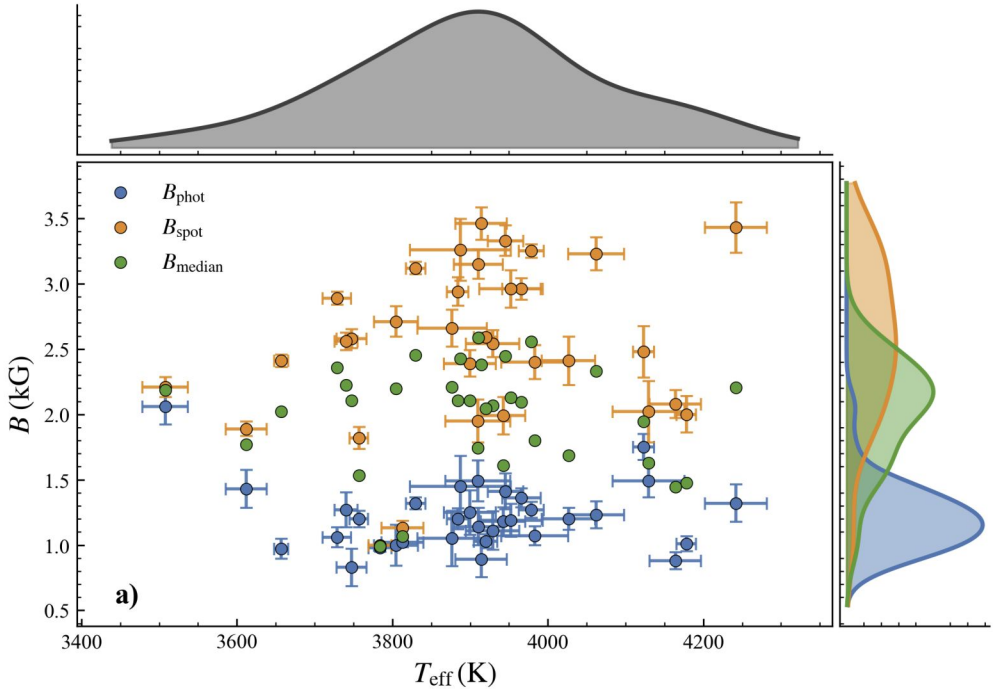
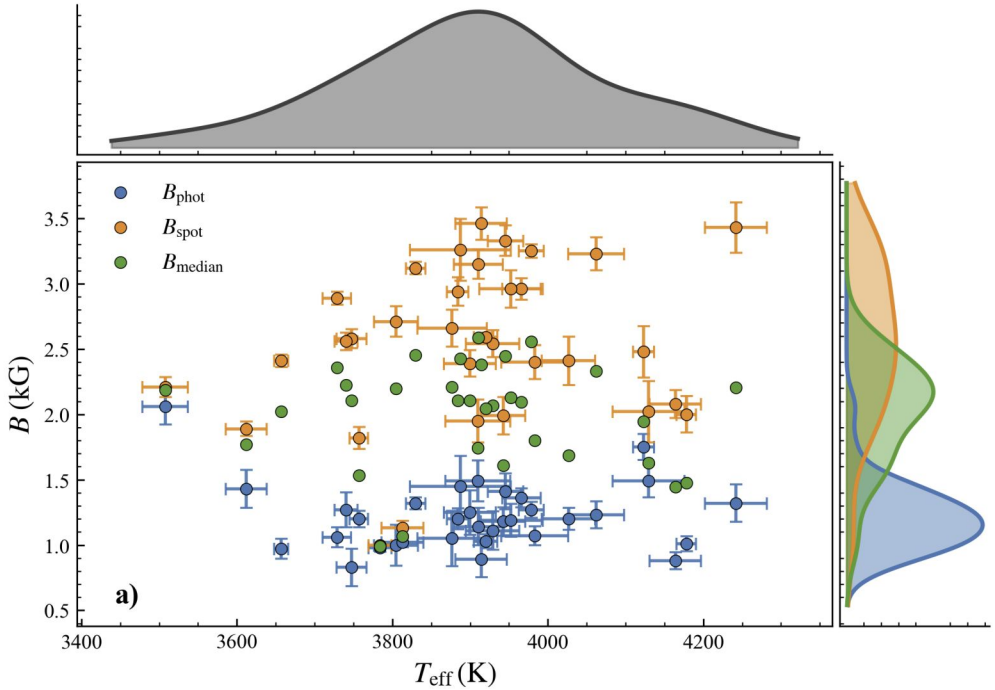
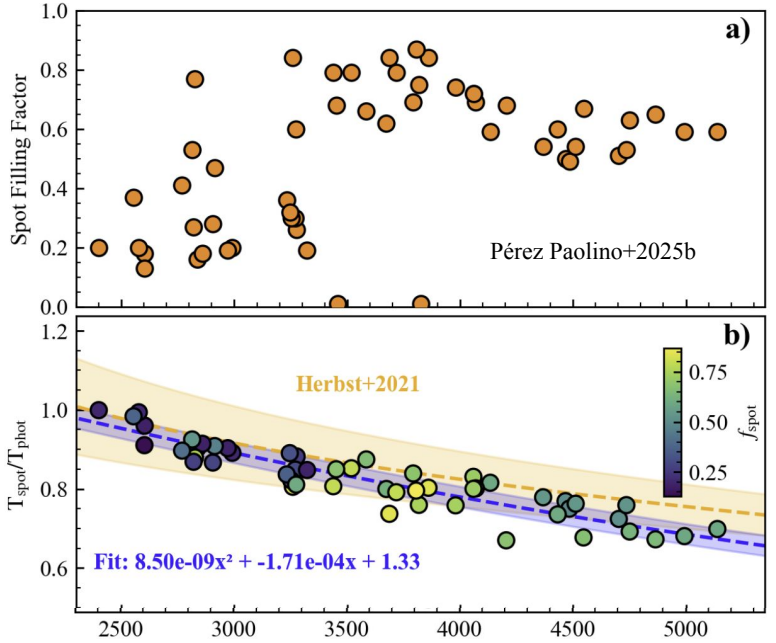
Surface averaged **unresolved** field strength **<Bf>** or magnetic flux



Pérez Paolino+2025c



Pérez Paolino+2025c



Dataset - Raw and Reduced IGRINS Archive (RRISA)

- Uniform reduction, telluric corrected
- Over 18,000 spectra of 3,000 stars
- R~45000

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Methods

- MOOGSTOKES + MCMC for T, B, logg, etc.
- Feiden+2016 magnetic isochrones for mass, age, structure
- Tess+K2 for rotation periods

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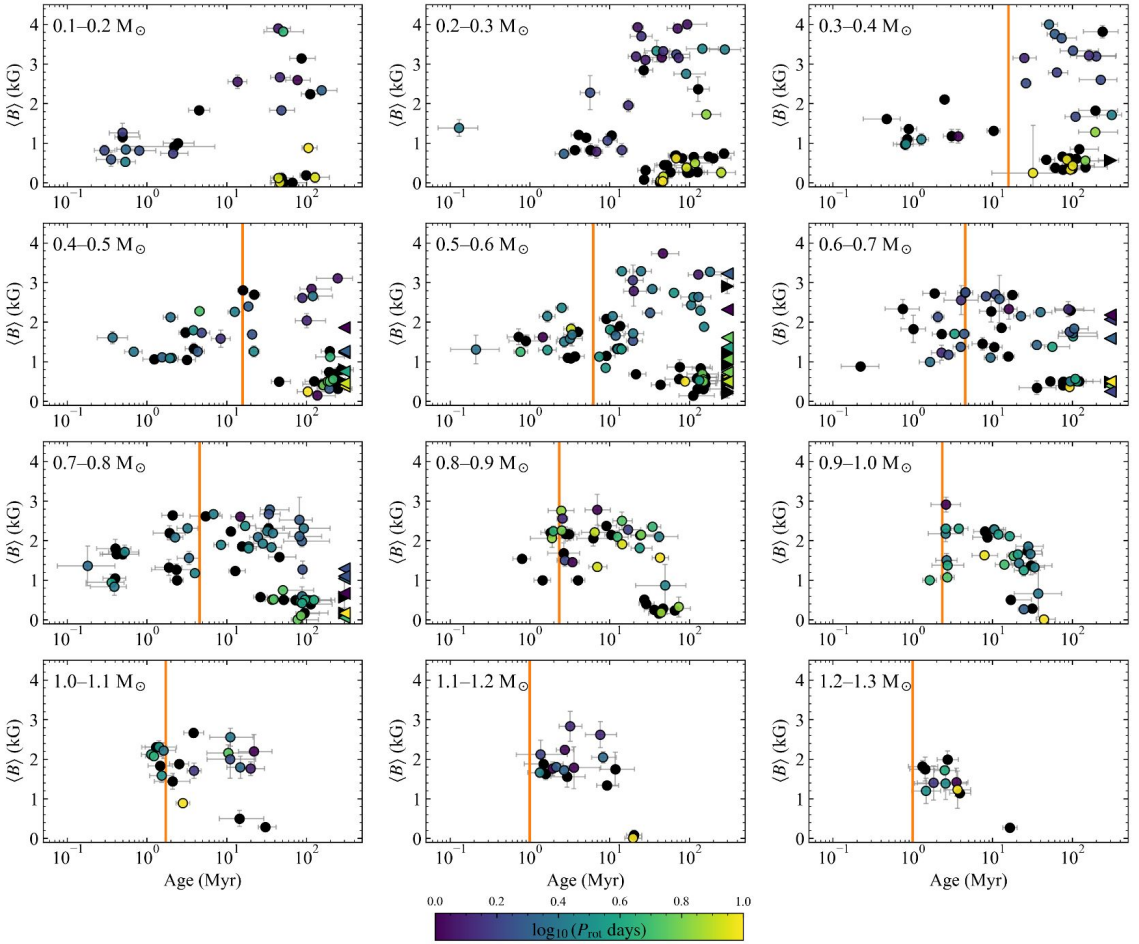
Final sample

- 506 stars spanning
  - 0-300 Myr
  - 0.1-1.5 Msun
  - 314 w/ rotation periods

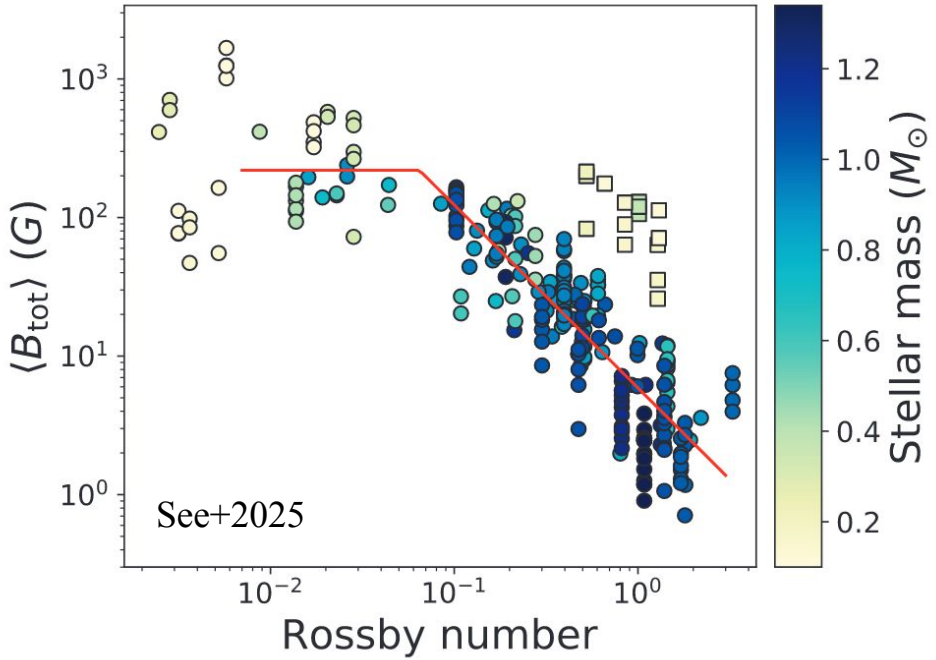
Empirical Results - Magnetic field evolution by mass bin

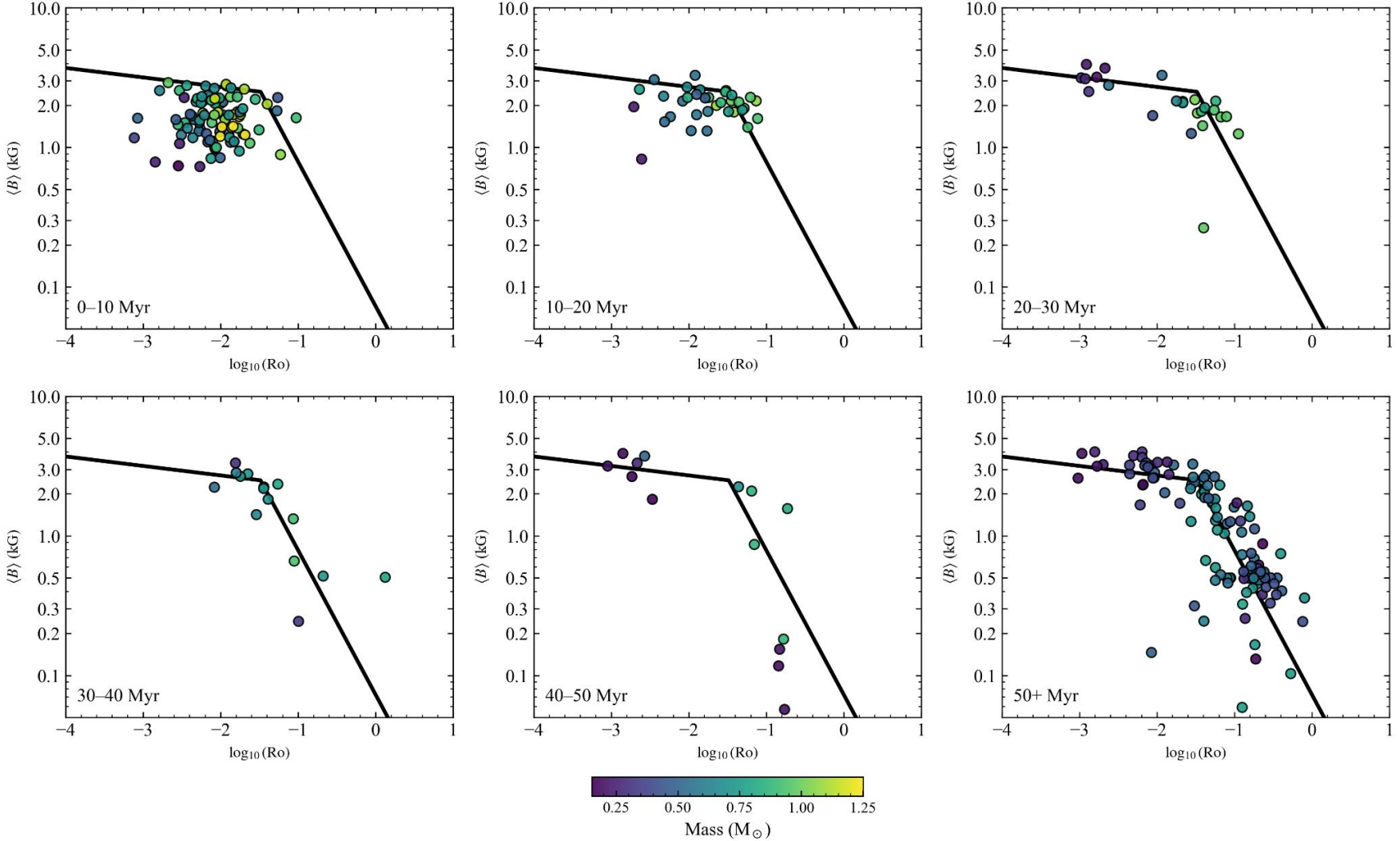


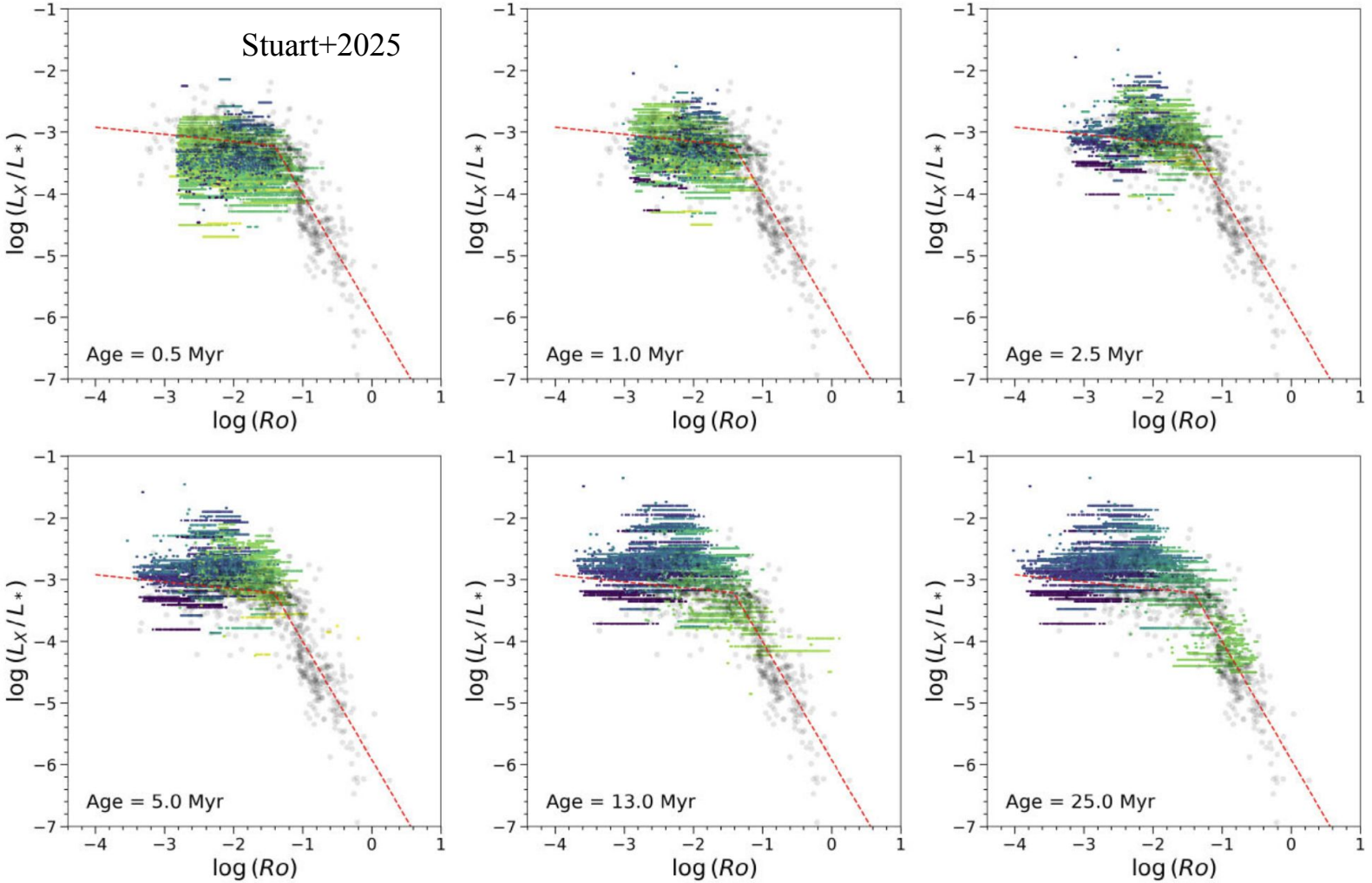
- Period separation at older ages
- Mass dependent evolution at younger ages

$$Ro = \frac{P_\star}{\tau_c},$$

$$\frac{\text{Stellar rotation period}}{\text{Convective turnover time}}$$

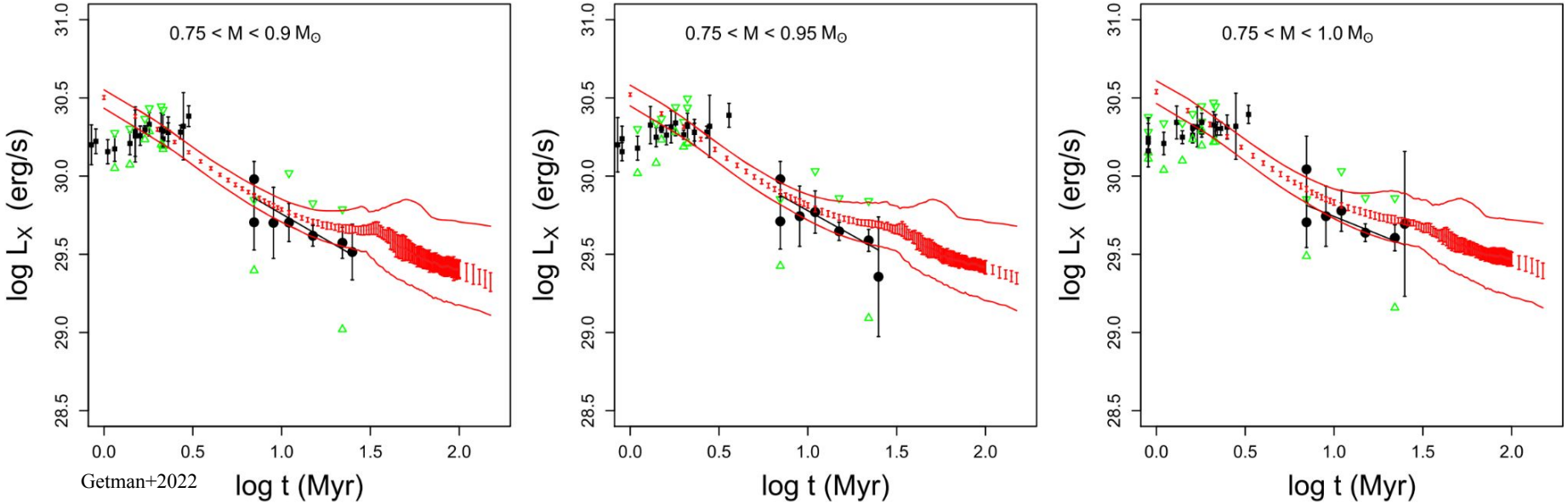



0–10 Myr
10–20 Myr
20–30 Myr
30–40 Myr
40–50 Myr
50+ Myr
⟨B⟩ (kG)
log10(Ro)
Mass (M⊙)
0.25
0.50
0.75
1.00
1.25


Stuart+2025
log (L_X/L_*)
log (Ro)
Age = 0.5 Myr
Age = 1.0 Myr
Age = 2.5 Myr
Age = 5.0 Myr
Age = 13.0 Myr
Age = 25.0 Myr

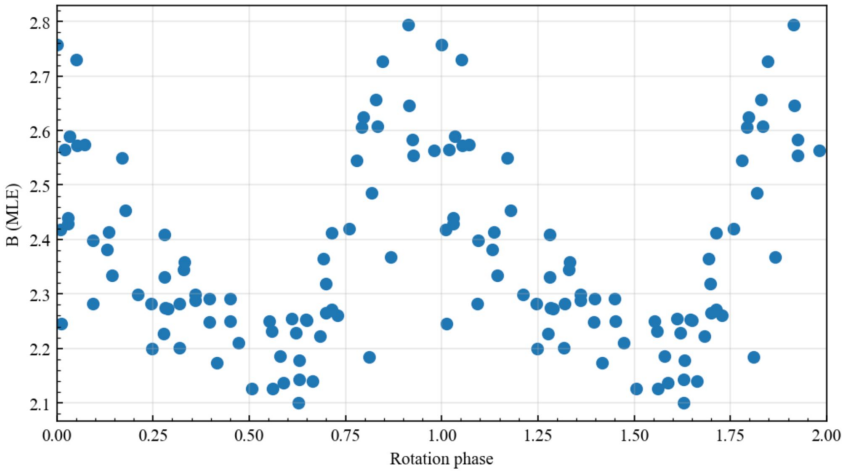
Why does this matter for exoplanets?

- The most important time for an exoplanets atmosphere is early on (<30 Myr) when X-rays are strongest
- However, most assumed X-ray evolution models assume a simple saturated -> unsaturated evolution after ~100 Myr which we empirically know is **Not True**



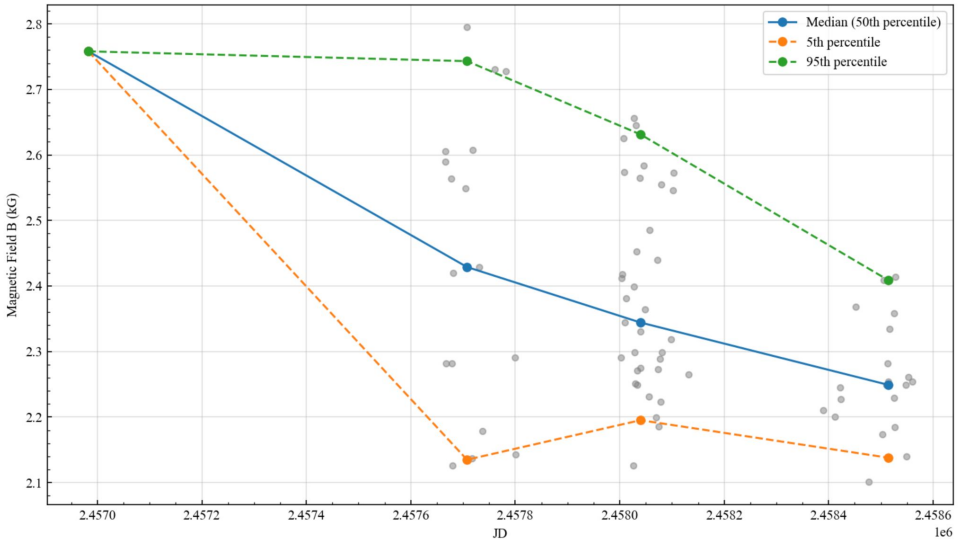
- If B changes by factors as high as ten during the first 20 Myr then mass loss rates could be off by as much as 10^2-10^3

As if that wasn't enough… Magnetic fields are highly variable



Short term - Rotation

Long term - cycles?



Conclusion

- PMS magnetism is poorly understood
- We built the largest survey of magnetism across mass and age (<300 Myr)
- Structure drives evolution during the first 100 Myr of stellar (and exoplanet) life
- Rotation activity relations emerge after 20 Myr for the most massive stars
- This can severely affect early exoplanet evolution
- This picture is also variable in short and long timescales…

Questions?

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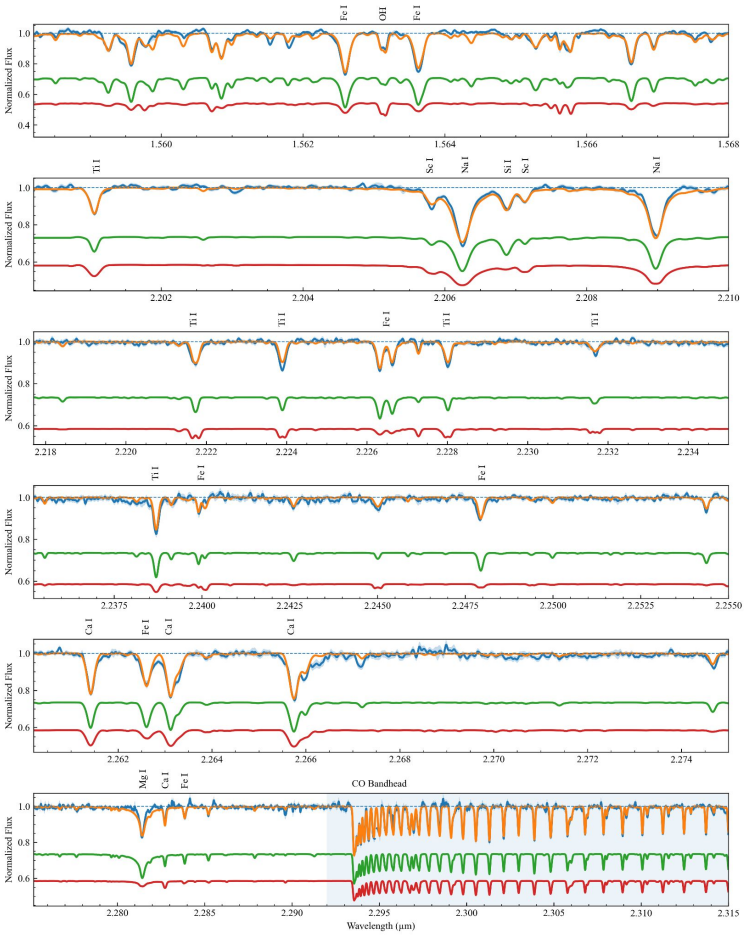
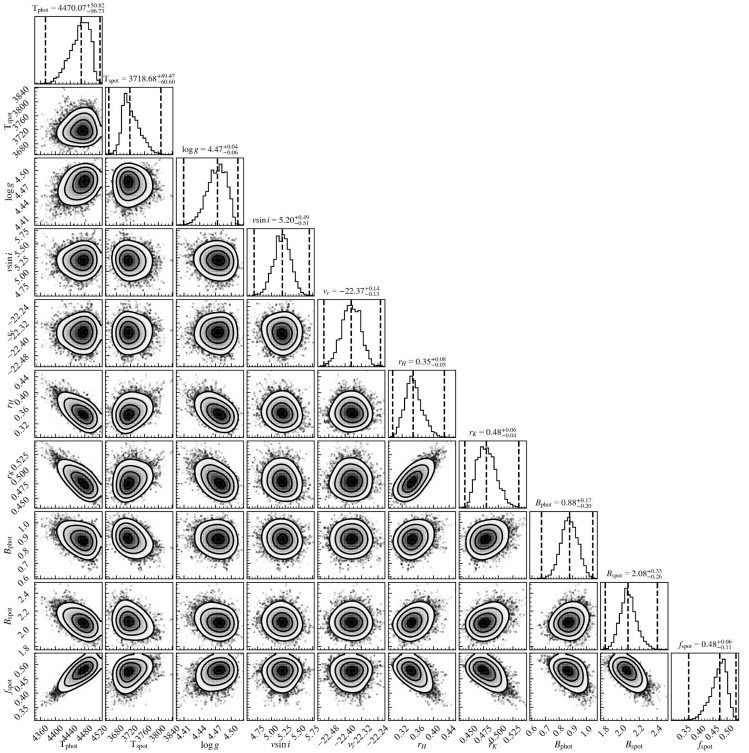
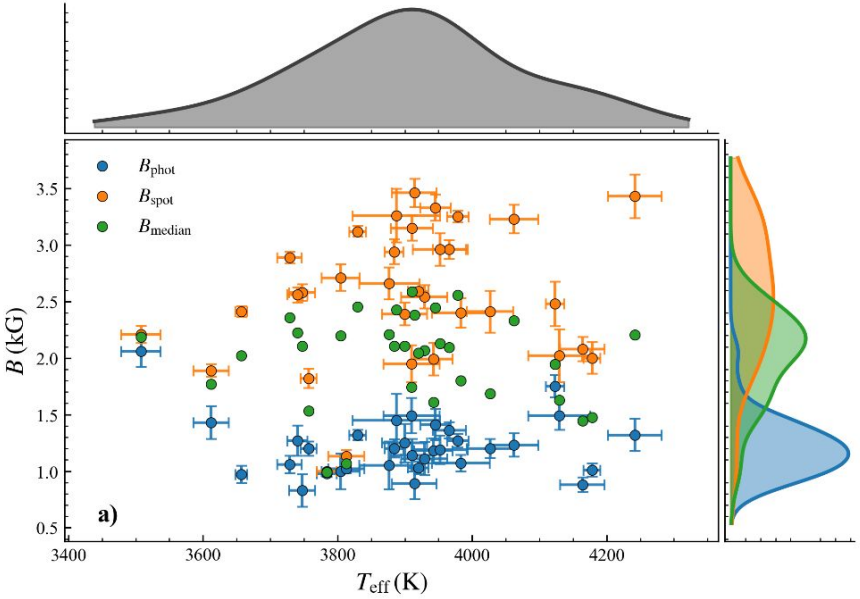
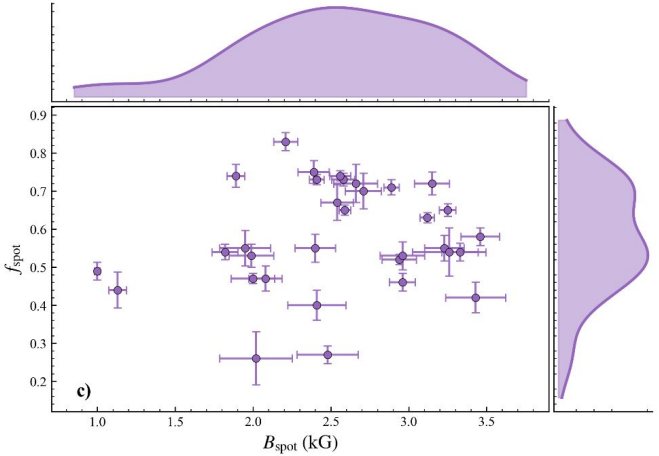
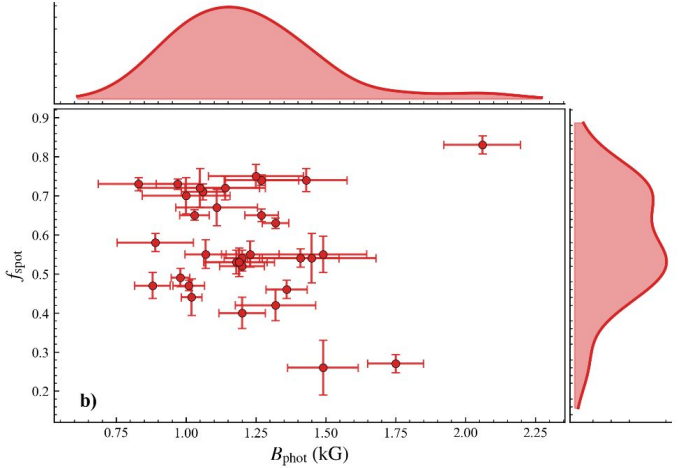
Extras


Fe I
OH
Fe I
Ti I
Sc I
Na I
Si I
Sc I
Na I
Ti I
Ti I
Fe I
Ti I
Ti I
Ti I
Fe I
Fe I
Ca I
Fe I
Ca I
Ca I
Mg I
Ca I
Fe I
CO Bandhead
Normalized Flux
Wavelength (μm)


$T_{phot} = 4470.07^{+30.82}_{-26.73}$
$T_{spot} = 3718.68^{+60.47}_{-60.60}$
$\log g = 4.47^{+0.04}_{-0.06}$
$v\sin i = 5.20^{+0.09}_{-0.21}$
$v_r = -22.37^{+0.14}_{-0.13}$
$r_H = 0.35^{+0.08}_{-0.05}$
$r_K = 0.48^{+0.06}_{-0.03}$
$B_{phot} = 0.88^{+0.17}_{-0.20}$
$B_{spot} = 2.08^{+0.33}_{-0.26}$
$f_{spot} = 0.48^{+0.06}_{-0.11}$
T_{phot}
T_{spot}
$\log g$
$v\sin i$
v_r
r_H
r_K
B_{phot}
B_{spot}
f_{spot}

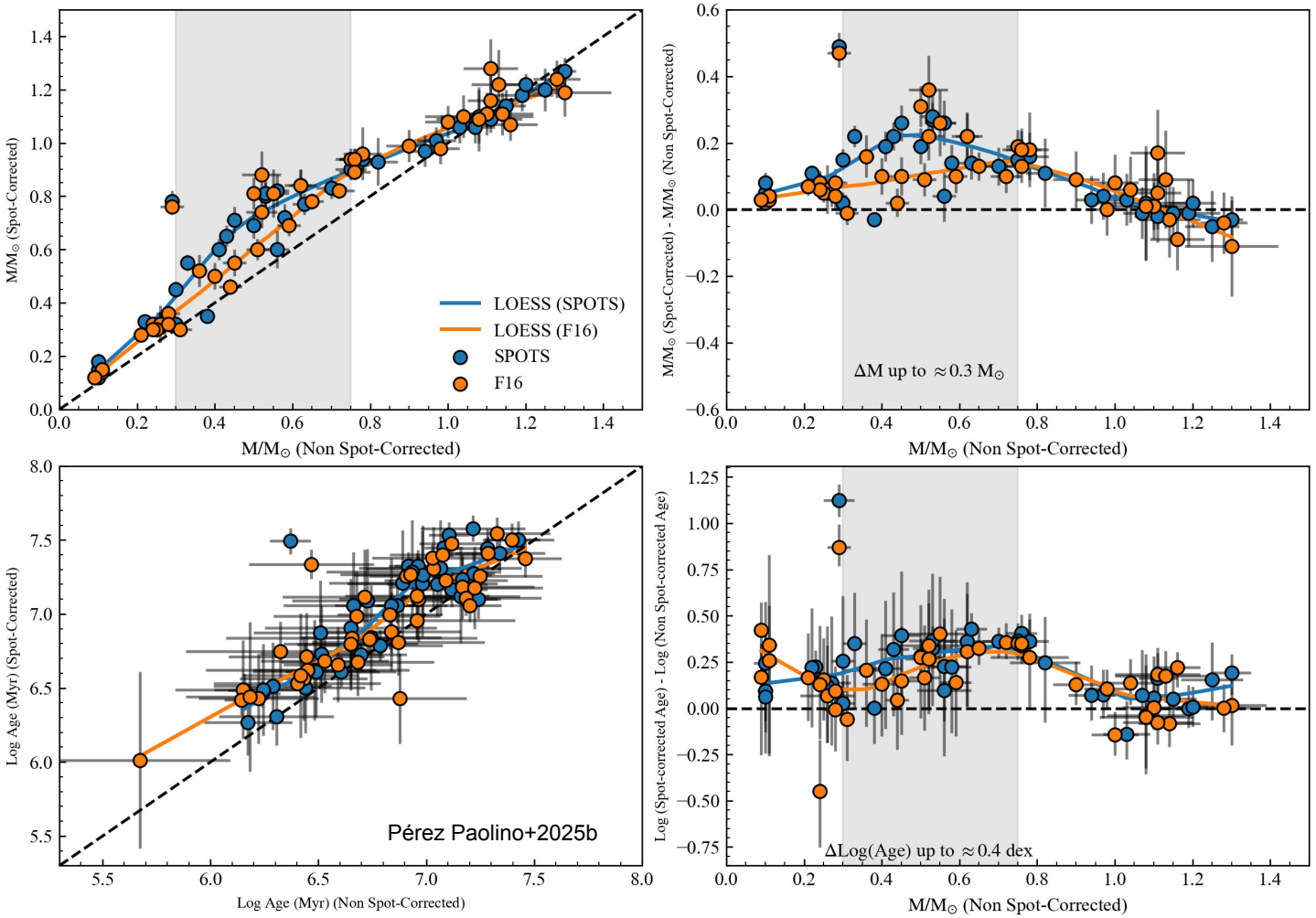


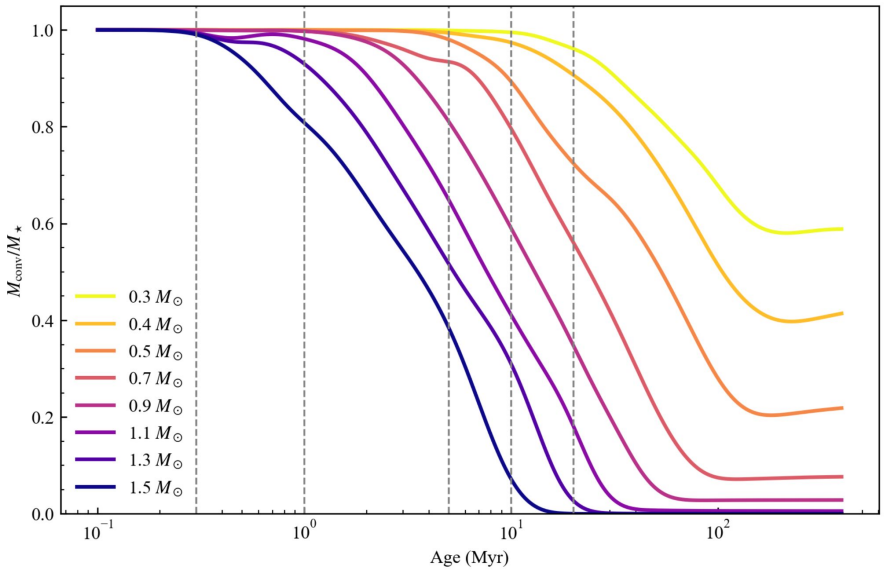




We recover the canonical ≈2 kG surface integrated field in YSOs!

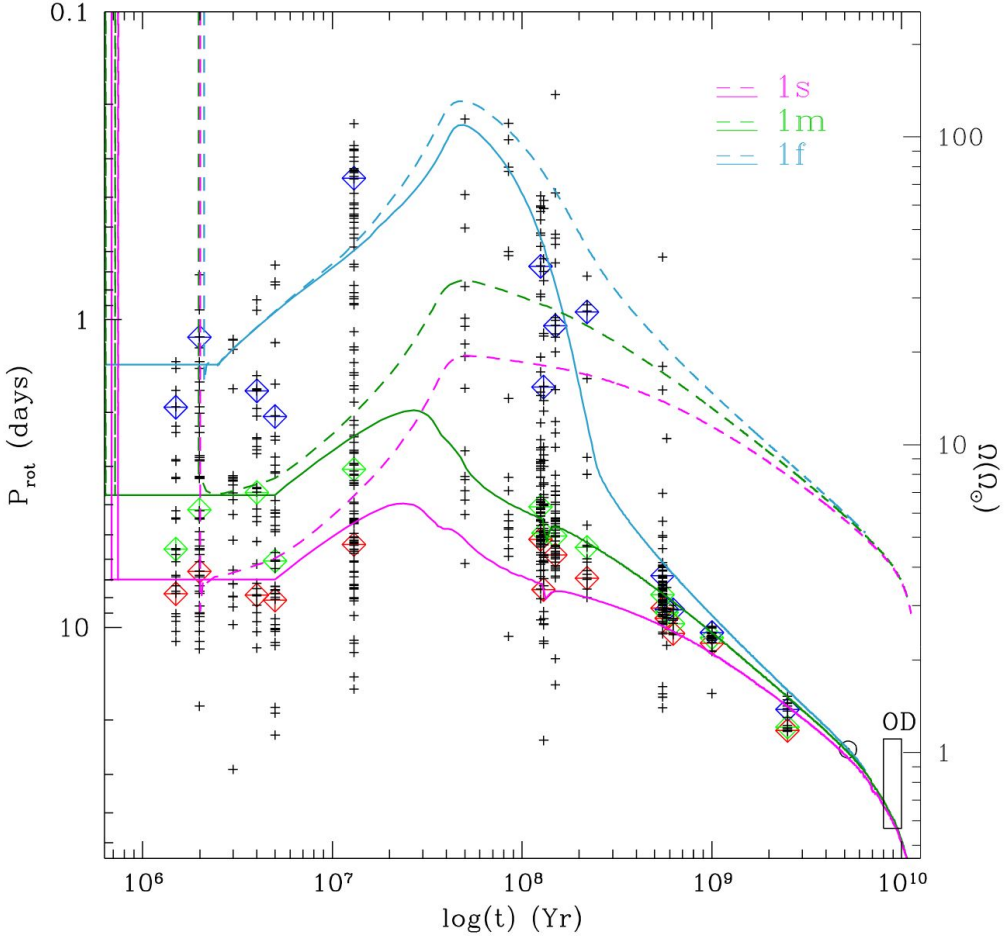
No correlation between magnetic field strengths and spot filling factors. Topology? Future work!

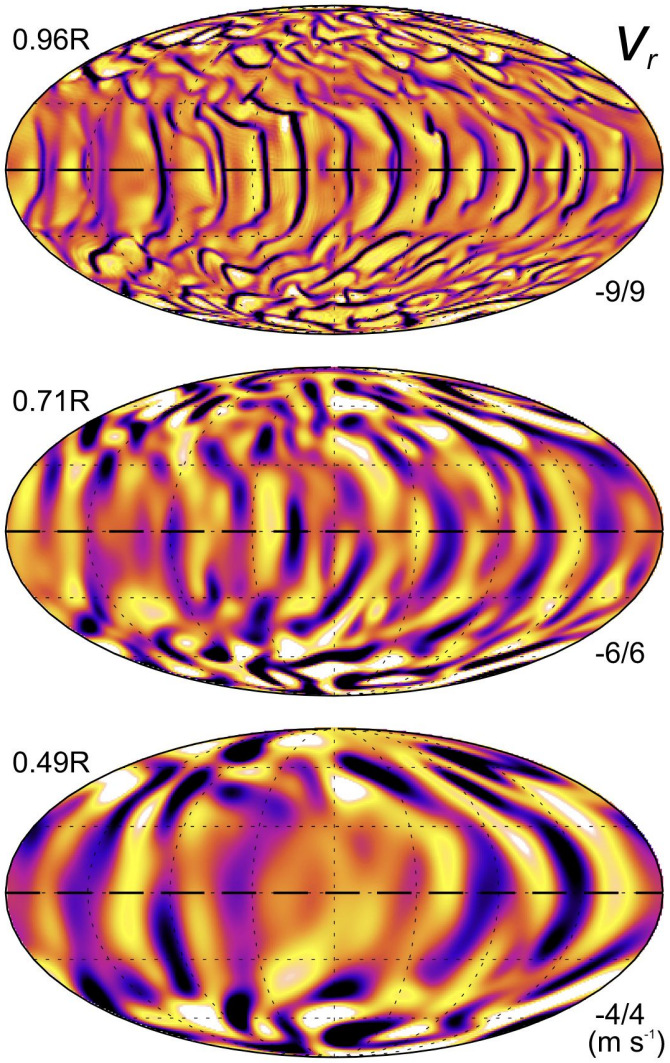

M/M⊙ (Spot-Corrected)
M/M⊙ (Non Spot-Corrected)
LOESS (SPOTS)
LOESS (F16)
SPOTS
F16
M/M⊙ (Spot-Corrected) - M/M⊙ (Non Spot-Corrected)
ΔM up to ≈0.3 M⊙
Log Age (Myr) (Spot-Corrected)
Log Age (Myr) (Non Spot-Corrected)
Pérez Paolino+2025b
Log (Spot-corrected Age) - Log (Non Spot-corrected Age)
ΔLog(Age) up to ≈0.4 dex

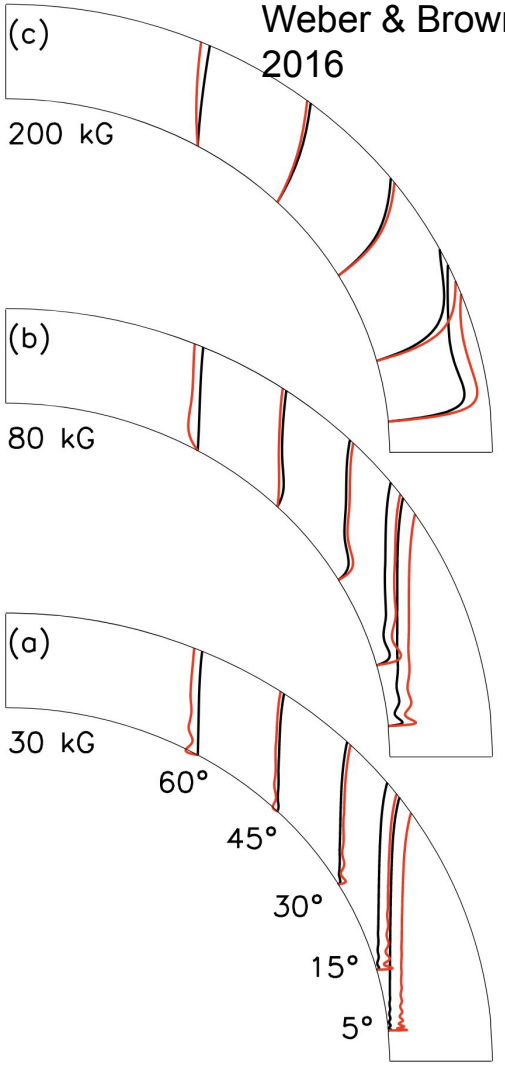


Mass-dependent formation of radiate core

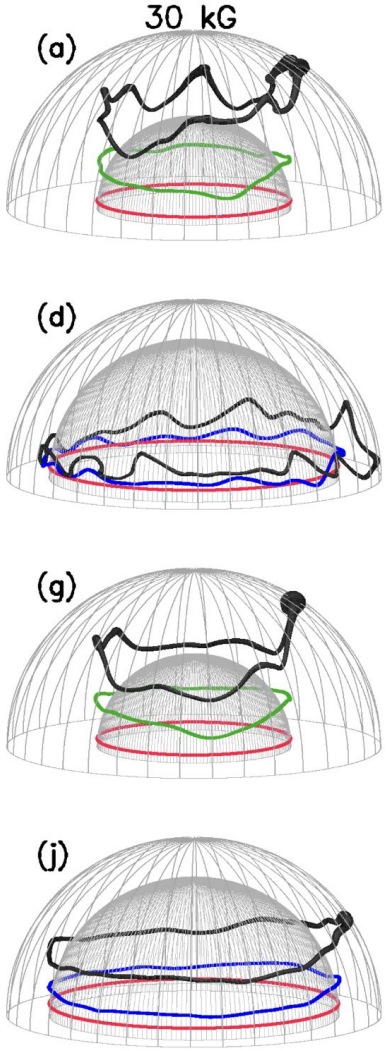
Disk locking -> Core-envelope decoupling

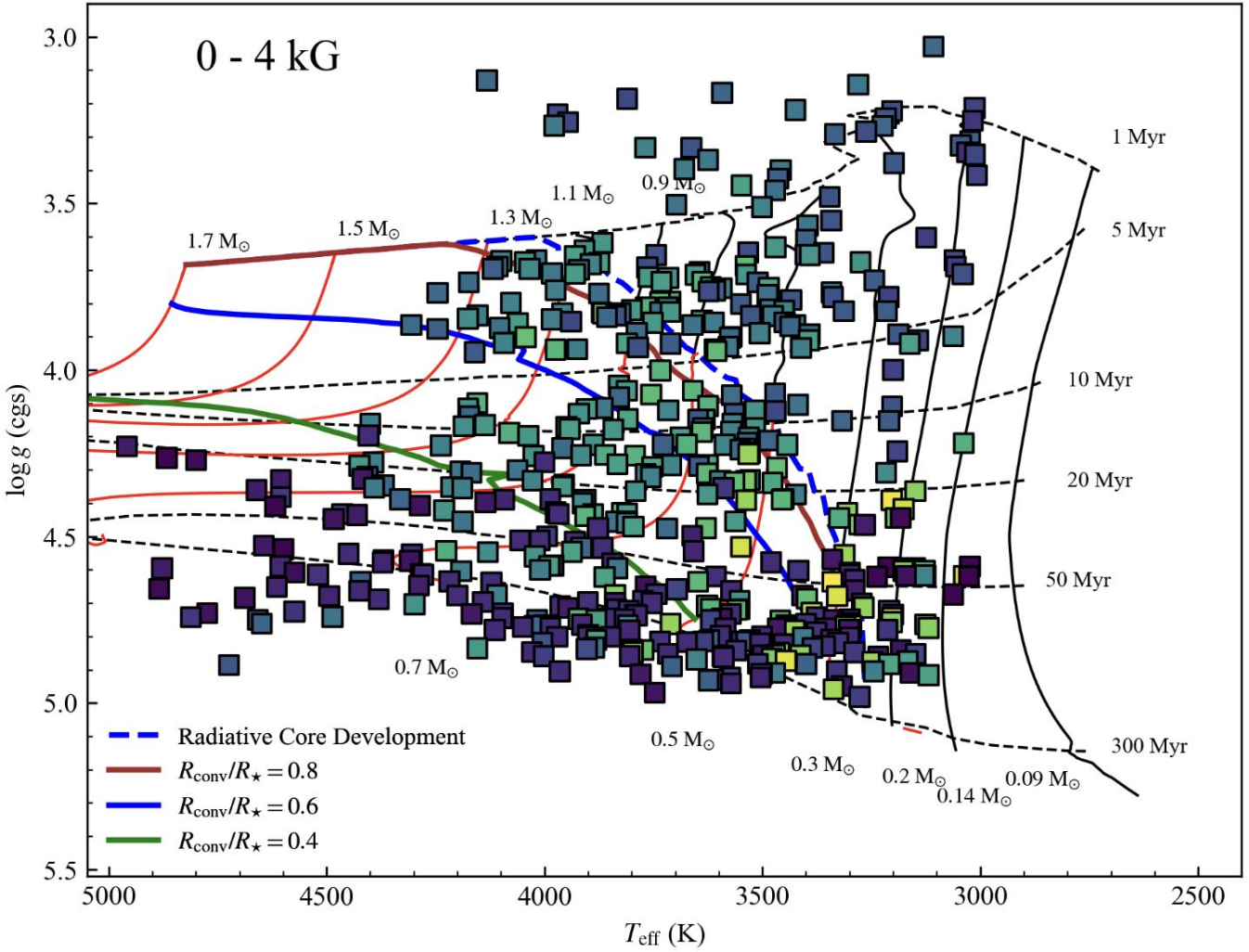






Weber & Browning 2016




0 - 4 kG
log g (cgs)
$T_{\rm eff}$ (K)
3.0
3.5
4.0
4.5
5.0
5.5
5000
4500
4000
3500
3000
2500
1.7 M⊙
1.5 M⊙
1.3 M⊙
1.1 M⊙
0.9 M⊙
0.7 M⊙
0.5 M⊙
0.3 M⊙
0.2 M⊙
0.14 M⊙
0.09 M⊙
1 Myr
5 Myr
10 Myr
20 Myr
50 Myr
300 Myr
Radiative Core Development
$R_{\rm conv}/R_\star = 0.8$
$R_{\rm conv}/R_\star = 0.6$
$R_{\rm conv}/R_\star = 0.4$