Ages For Exoplanet Host Stars

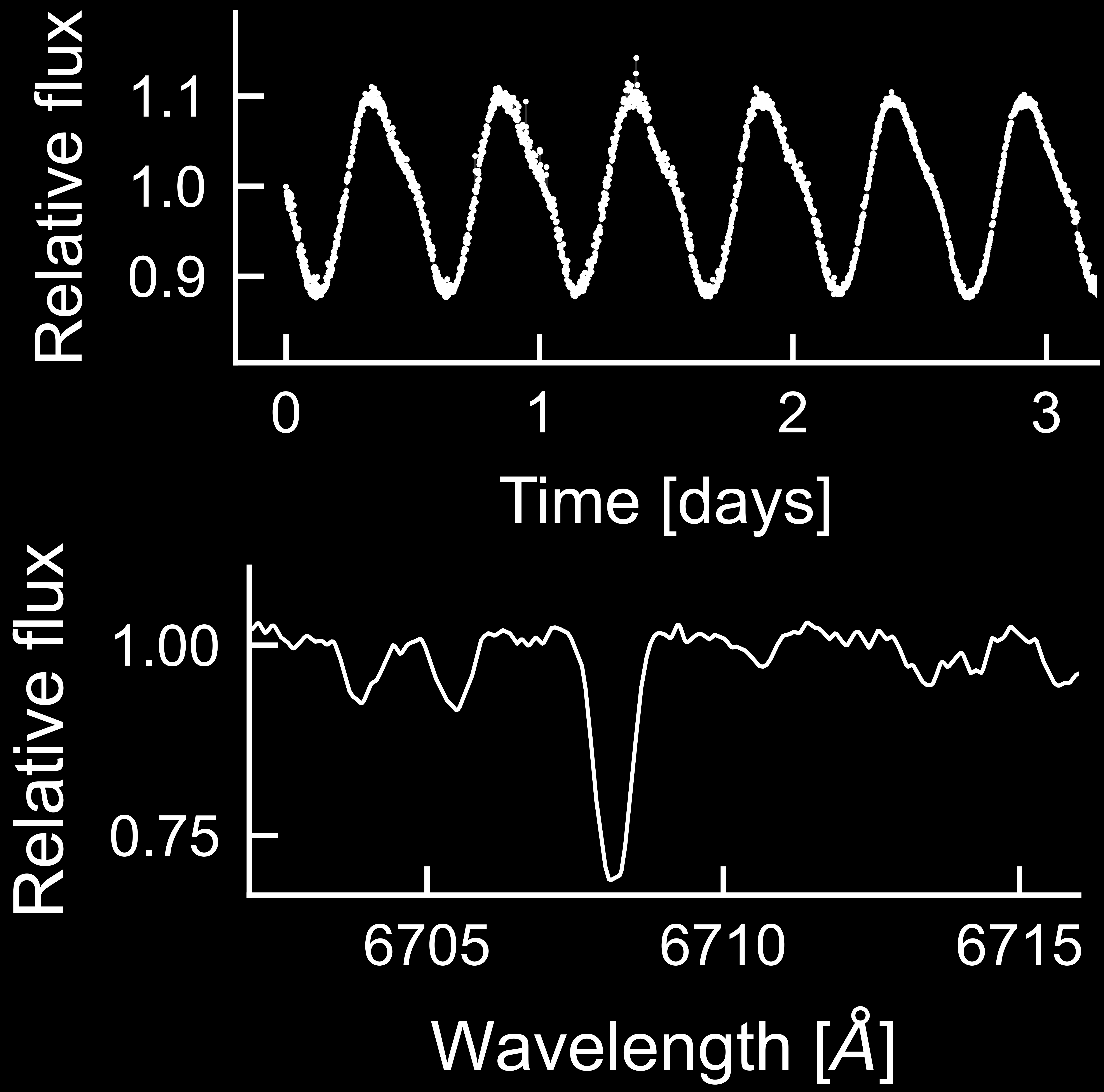
Rotation & Lithium in the Kepler Field

Luke Bouma

Carnegie Fellow @ Observatories

February 3, 2025

Image: Yuri Beletsky



Relative flux
1.1
1.0
0.9
0
1
2
3
Time [days]
Relative flux
1.00
0.75
6705
6710
6715
Wavelength [Å]

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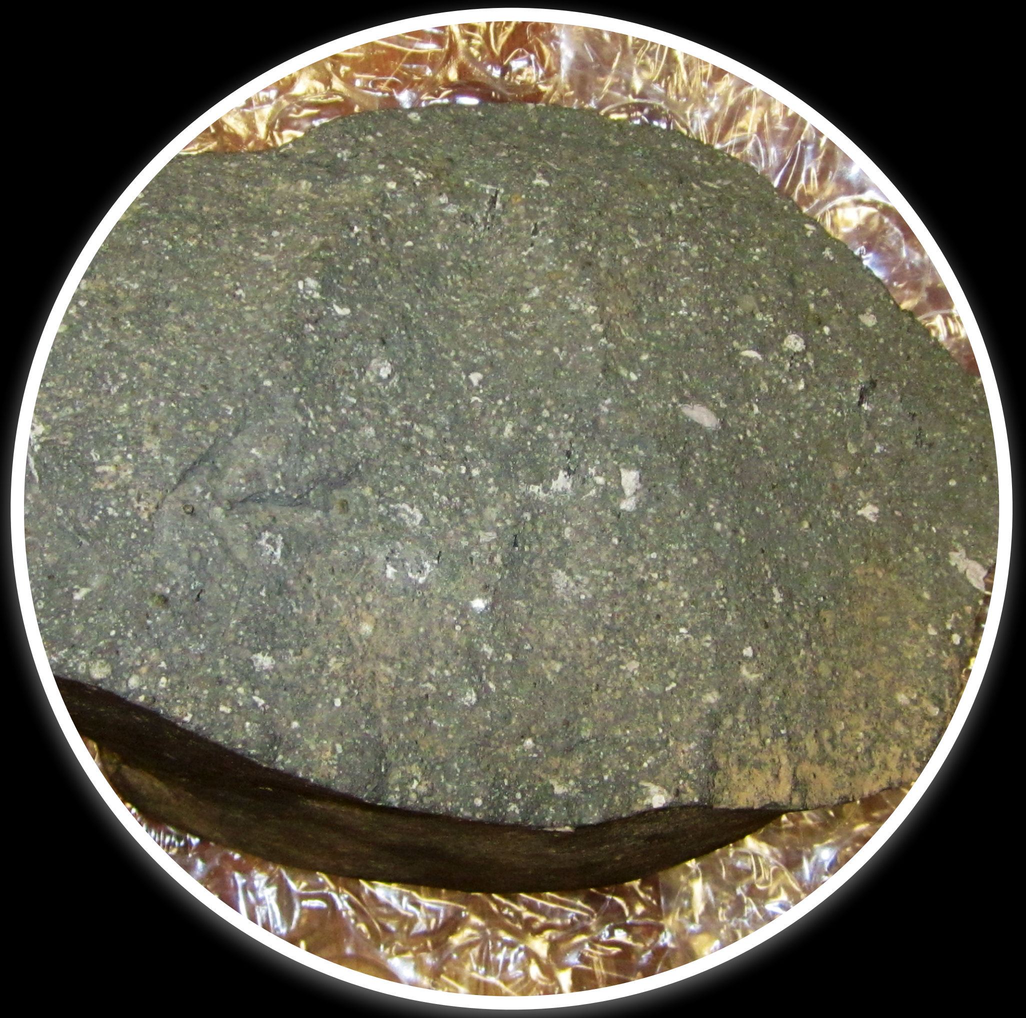
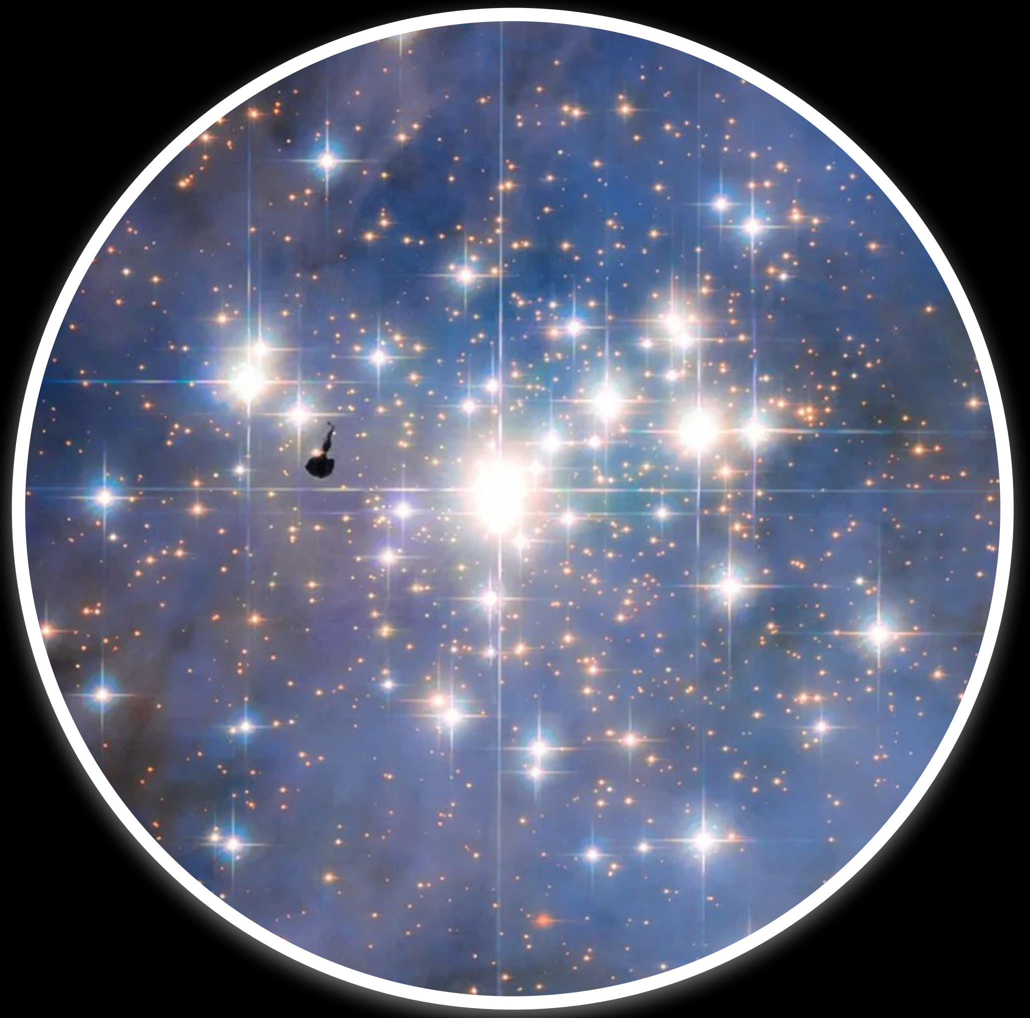
Evolutionary stories require good ages



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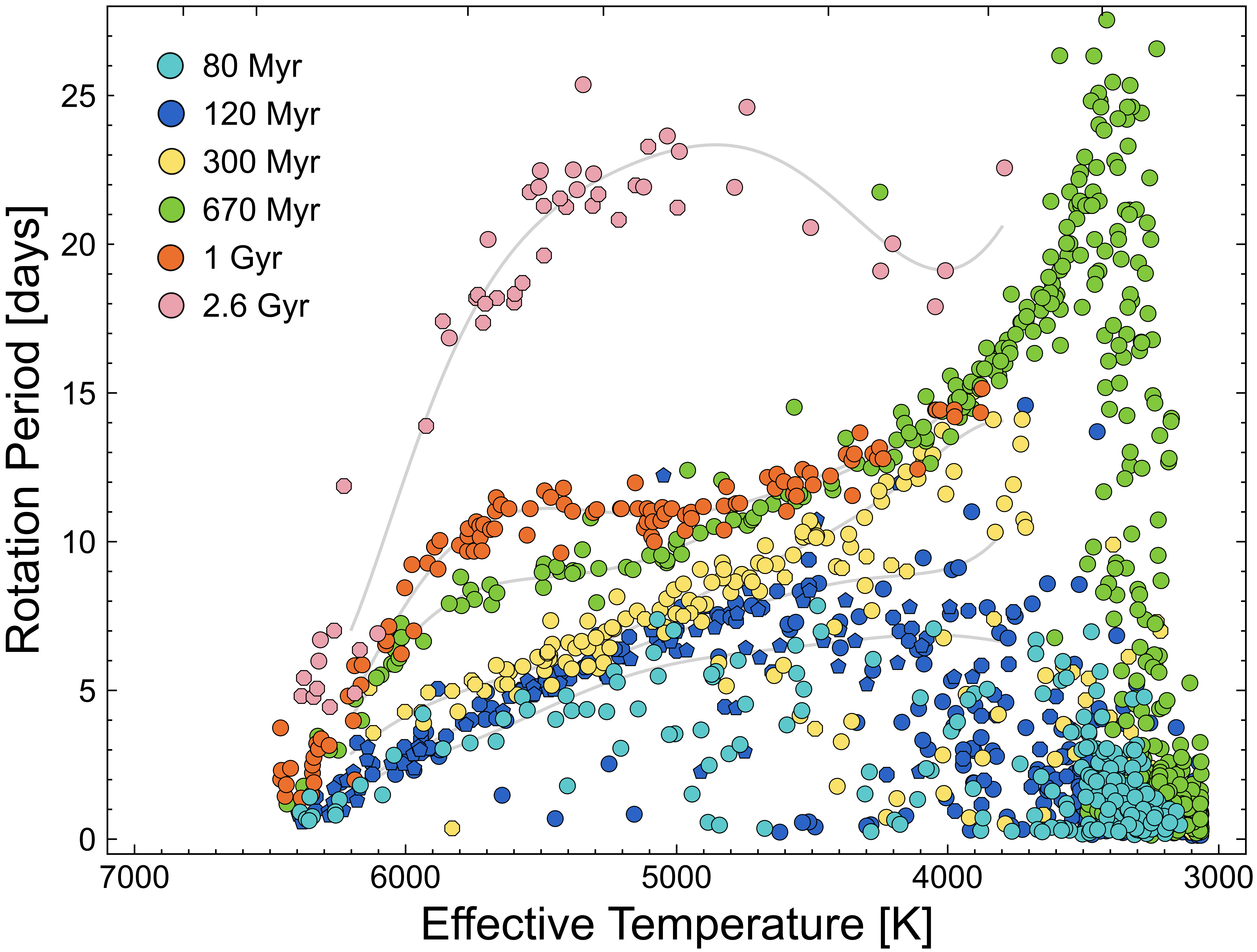
Open cluster rotation sequences show how stars spin down



Binaries are removed;
Fit from 3800 to 6200 K

Bouma+2023

α Per: Boyle & Bouma 23, Pleiades: Rebull+16, Blanco-1: Gillen+20, Psc-Eri: Curtis+19b, NGC-3532: Fritzewski+19
Group-X: Messina+22, Praesepe: Rampalli+21, NGC-6811: Curtis+19a, NGC-6819: Meibom+15, Ruprecht-147: Curtis+20

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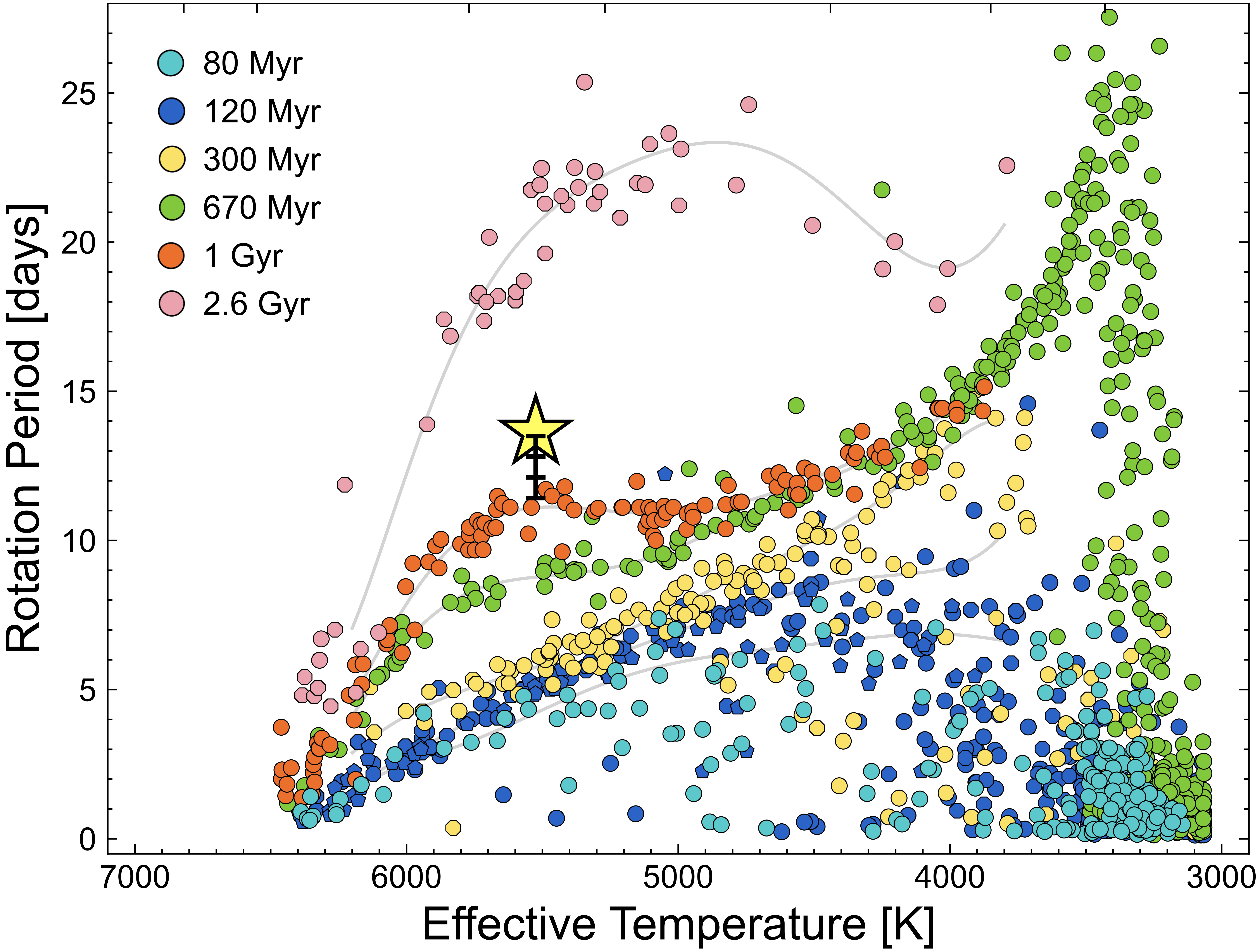

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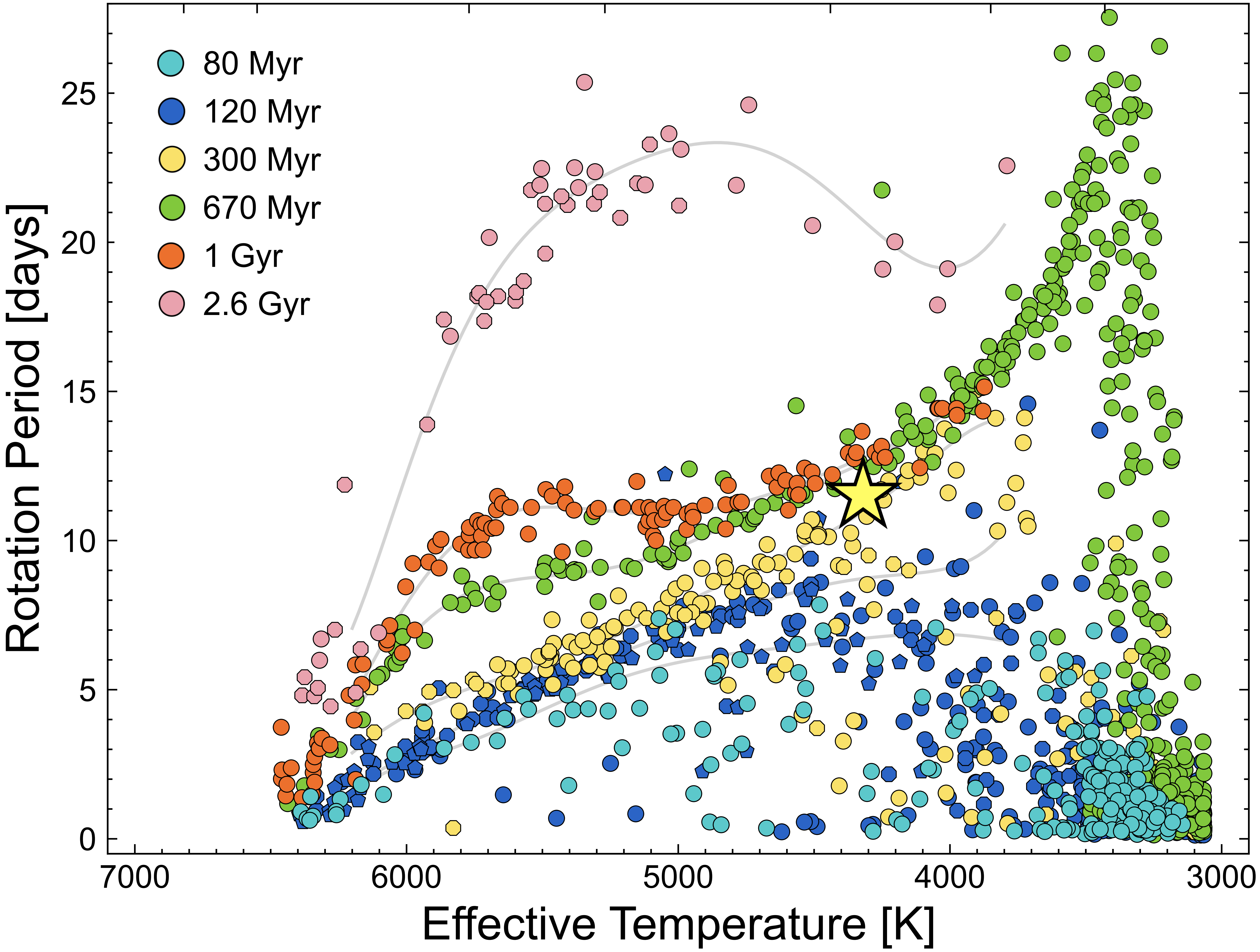
Bouma+2023

Different ages can produce the same rotation period



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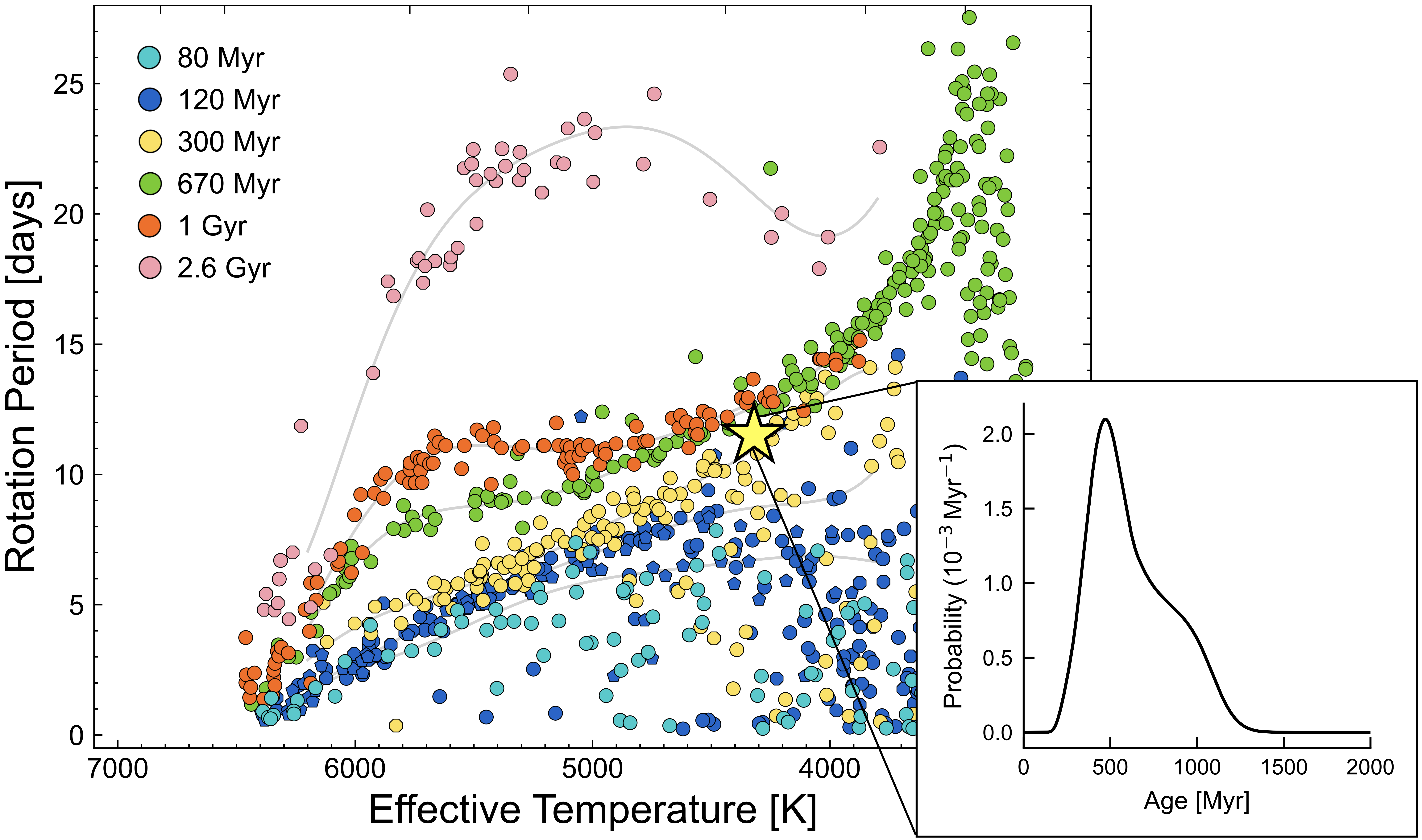

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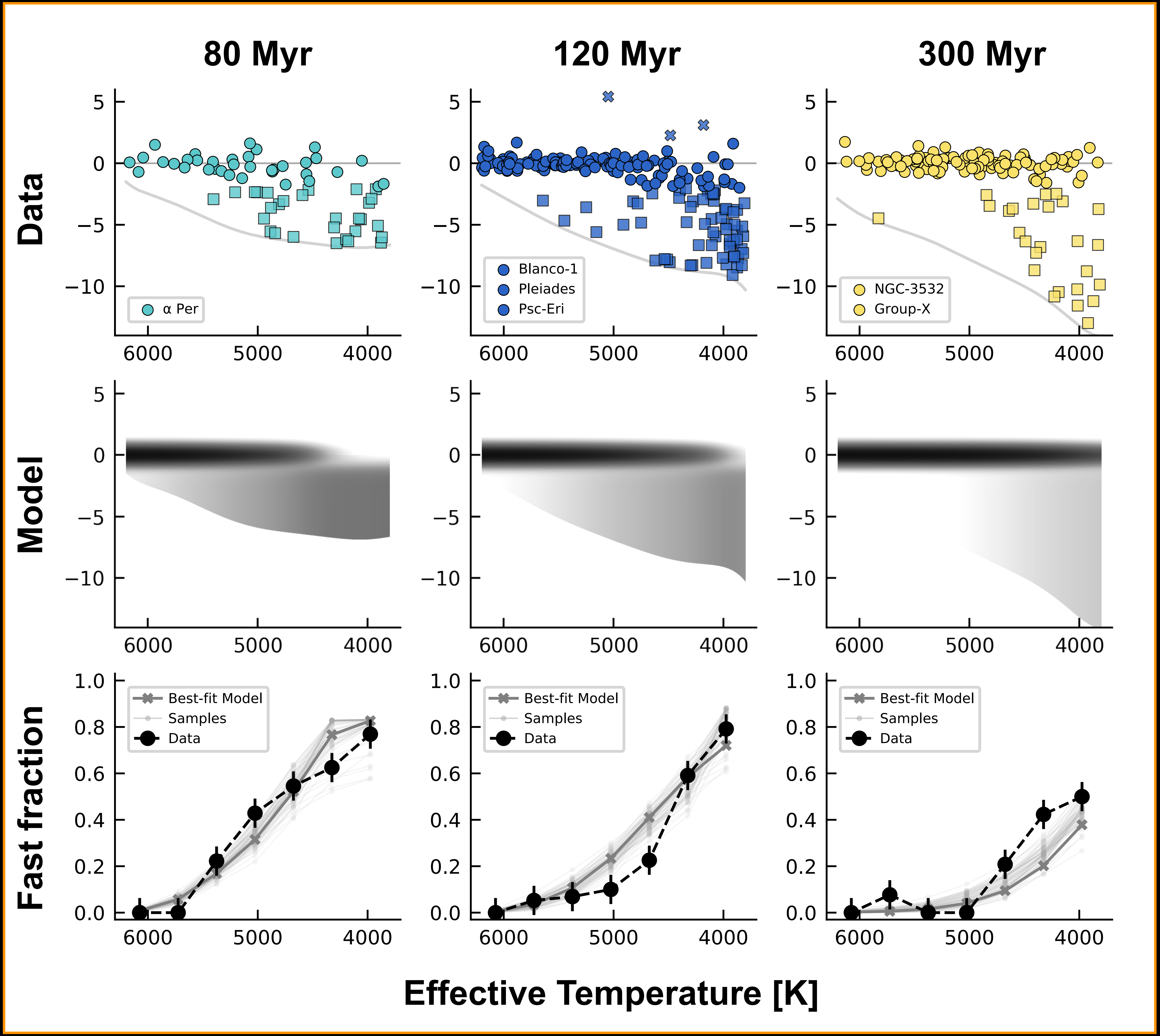
1) Interpolates between clusters
0.08 - 4 Gyr, FGK (3800-6200 K)

2) Fits the scatter
Normal + trailing uniform distribution
Let uniform distribution converge with ZAMS

3) Calculates $p(t \mid P_{\mathrm{rot}}, T_{\mathrm{eff}})$ by marginalizing over scatter

- Reproduces <4 Gyr spin-down
  With the evolving fast fraction!
  With stalled spin-down!
- $P_{\mathrm{rot}}, T_{\mathrm{eff}} \not\Rightarrow$ unique age
  Range of ages dictated by scatter in data

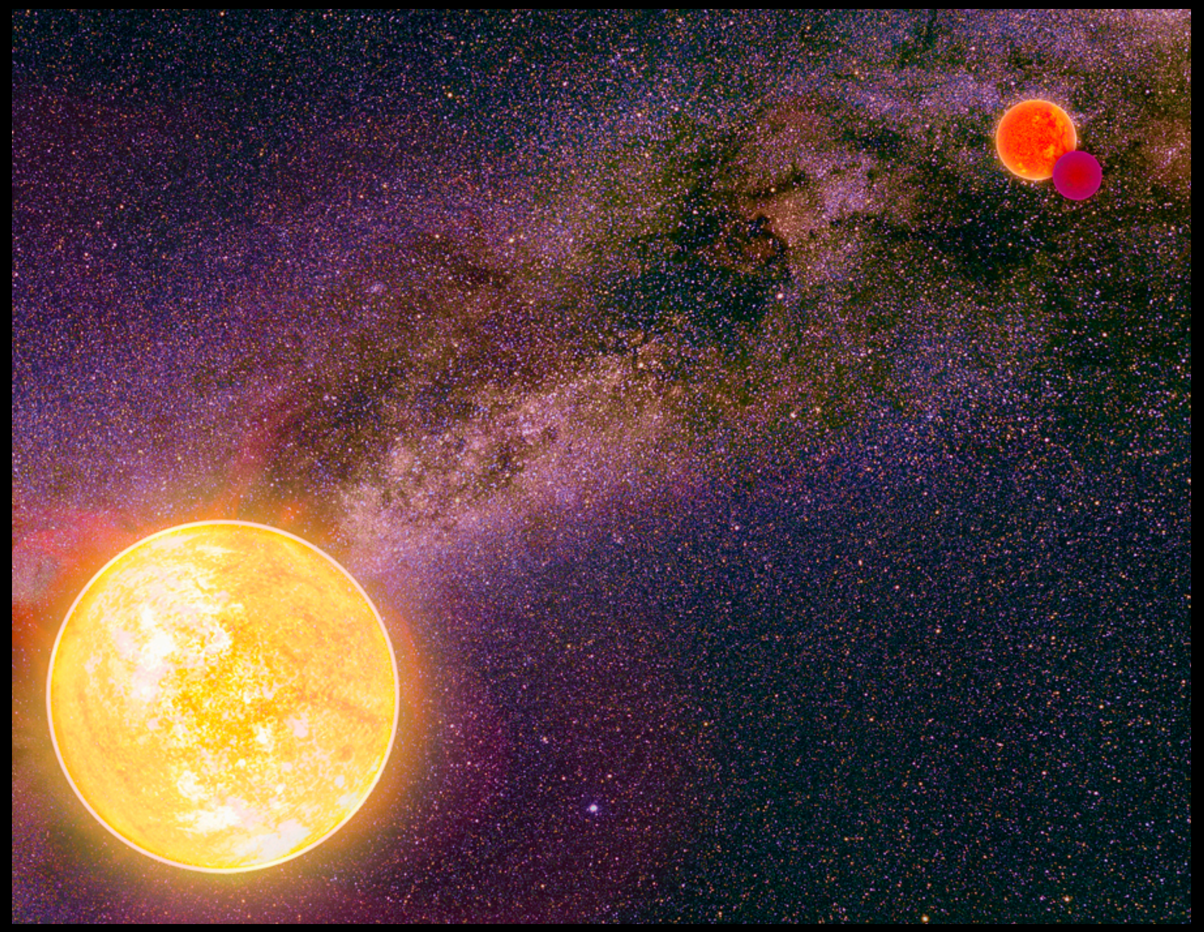
`pip install gyro-interp`



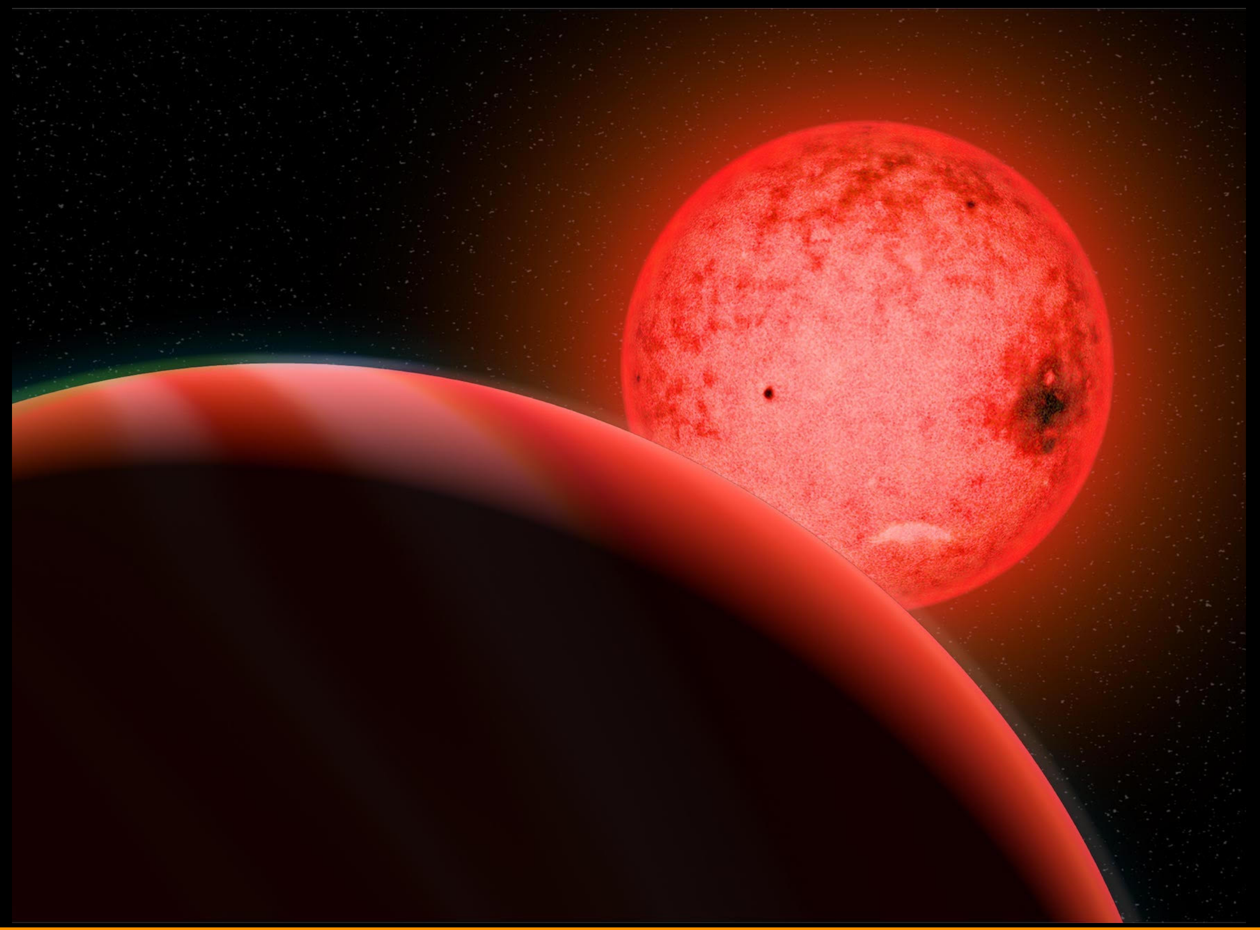
Bouma+2023

Current limitations

Assumes single,
main-sequence stars



Calibration beyond 4Gyr,
and for M-dwarfs

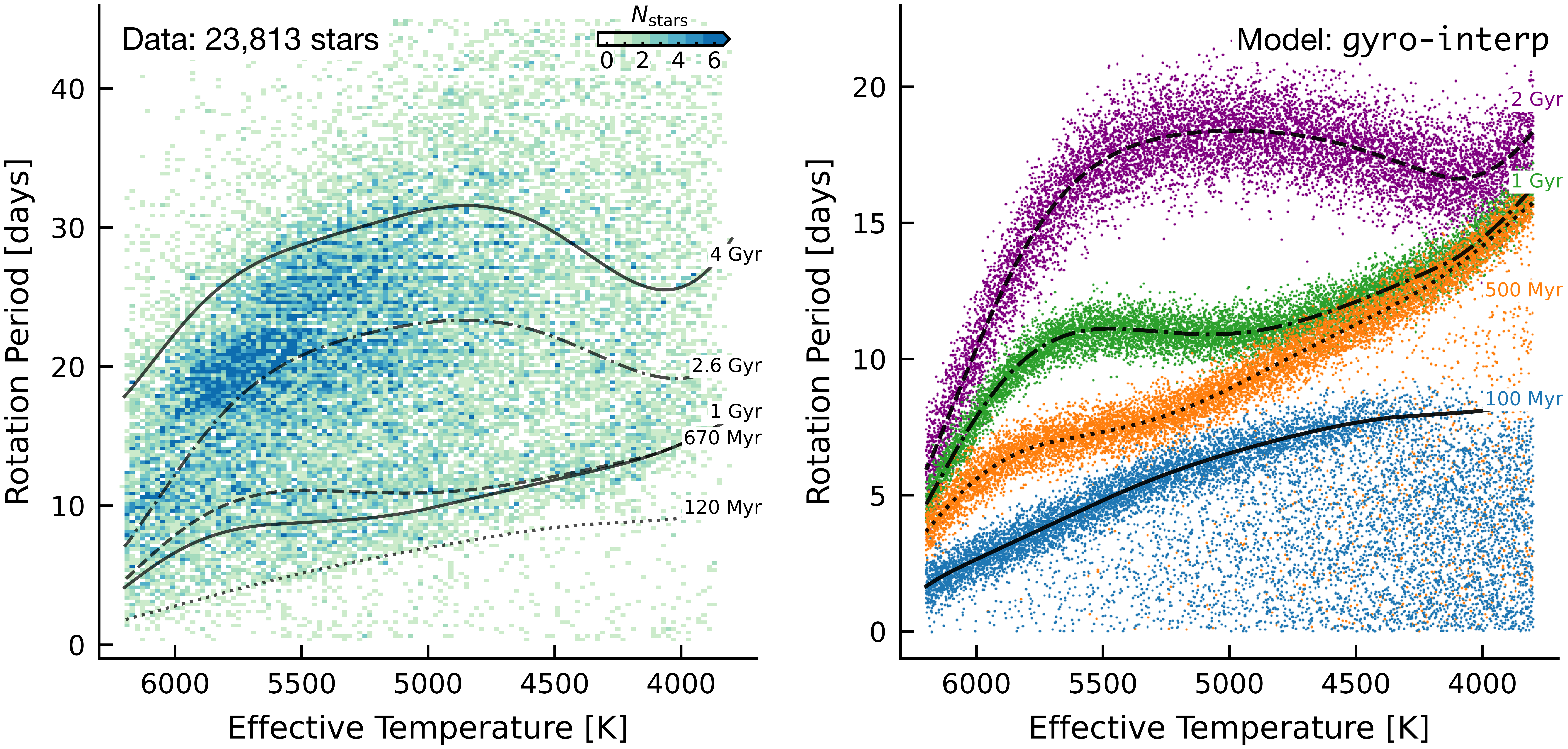


Engle & Guinan 2023
Lu+2024
Saunders+2024

Assumes near-solar
metallicities

Amard & Matt 2020
Claytor+2020
See+2024

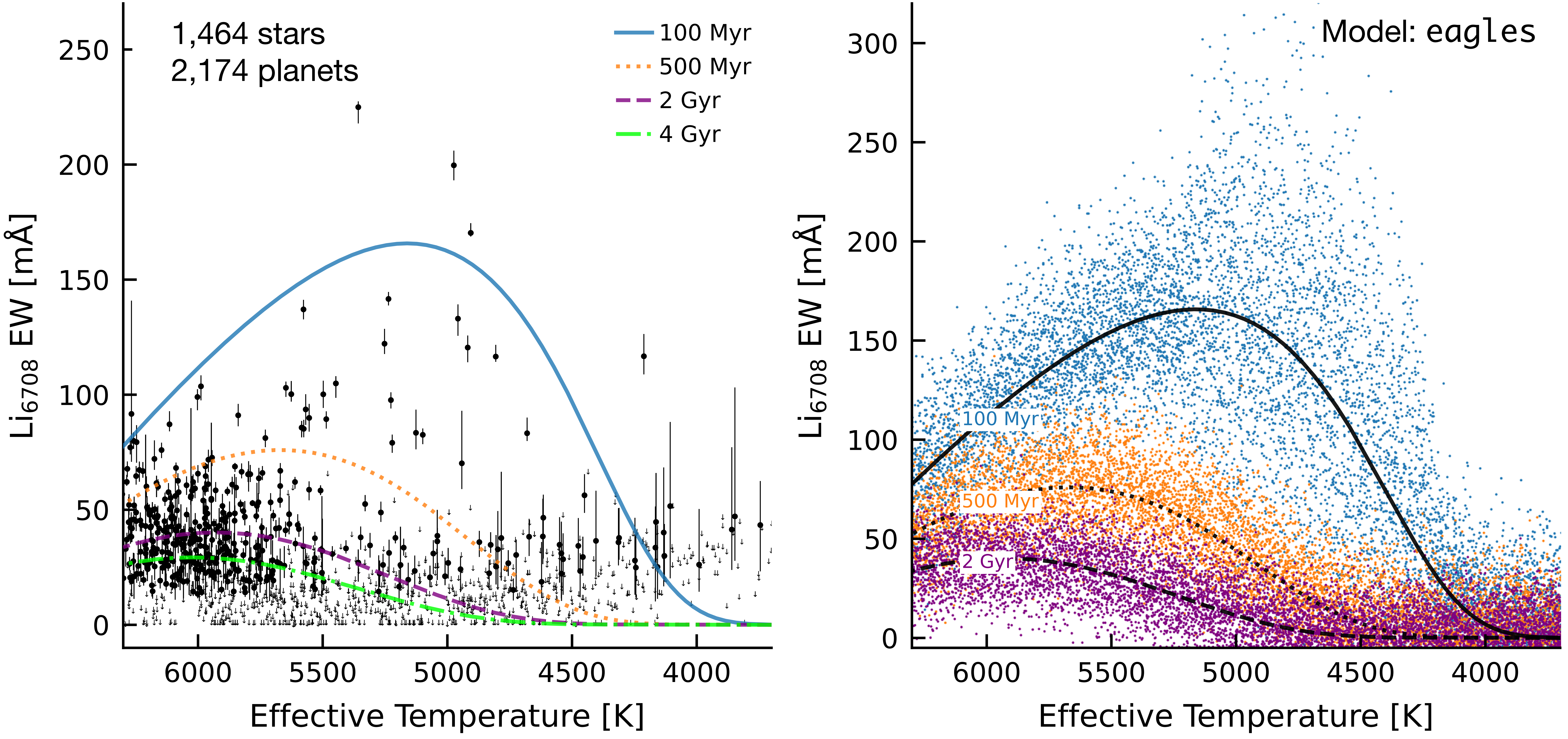
Kepler detected rotation for ≈one in three of its targets



Binaries are removed!

P_{rot}: McQuillan+14, Mazeh+15, Santos+19, Santos+21. T_{eff}: Berger+20

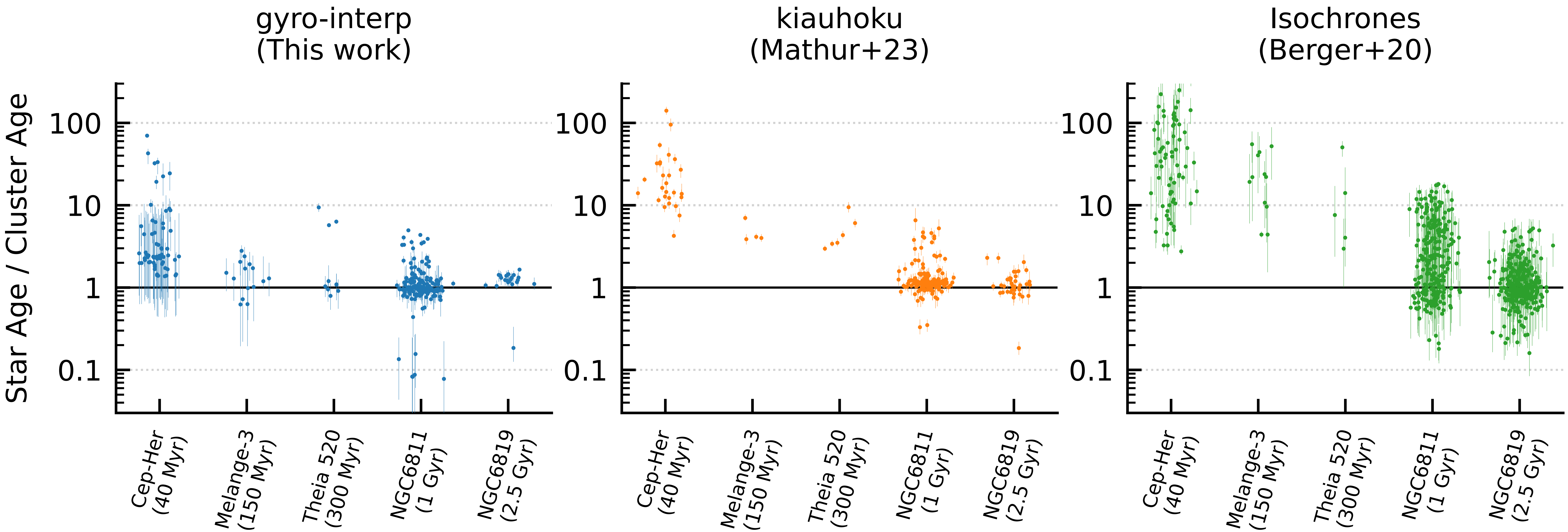
Most Kepler Objects of Interest have Keck/HIRES spectra



Model: Jeffries+23, Weaver+24

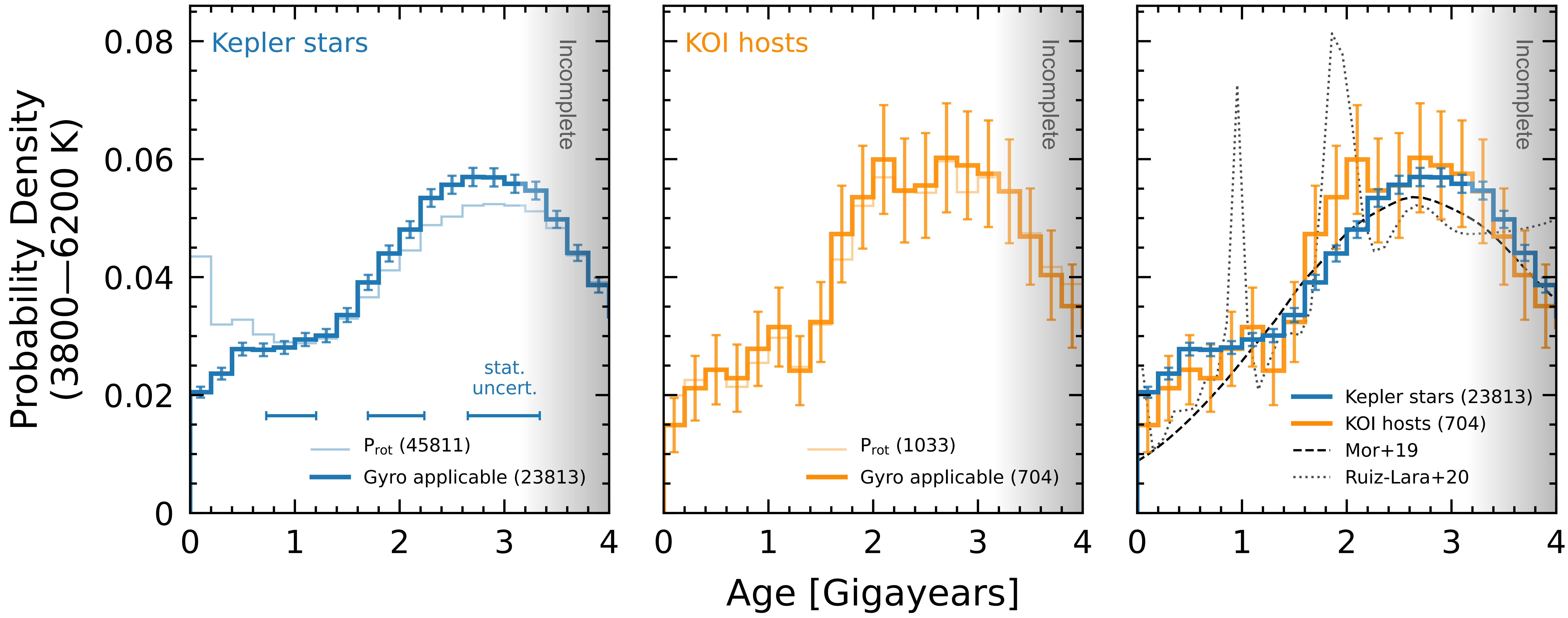
Li: Fulton+17, Johnson+17, Petigura+17, Berger+18, Bouma+24

We blindly recover ages of known stars in Kepler’s open clusters

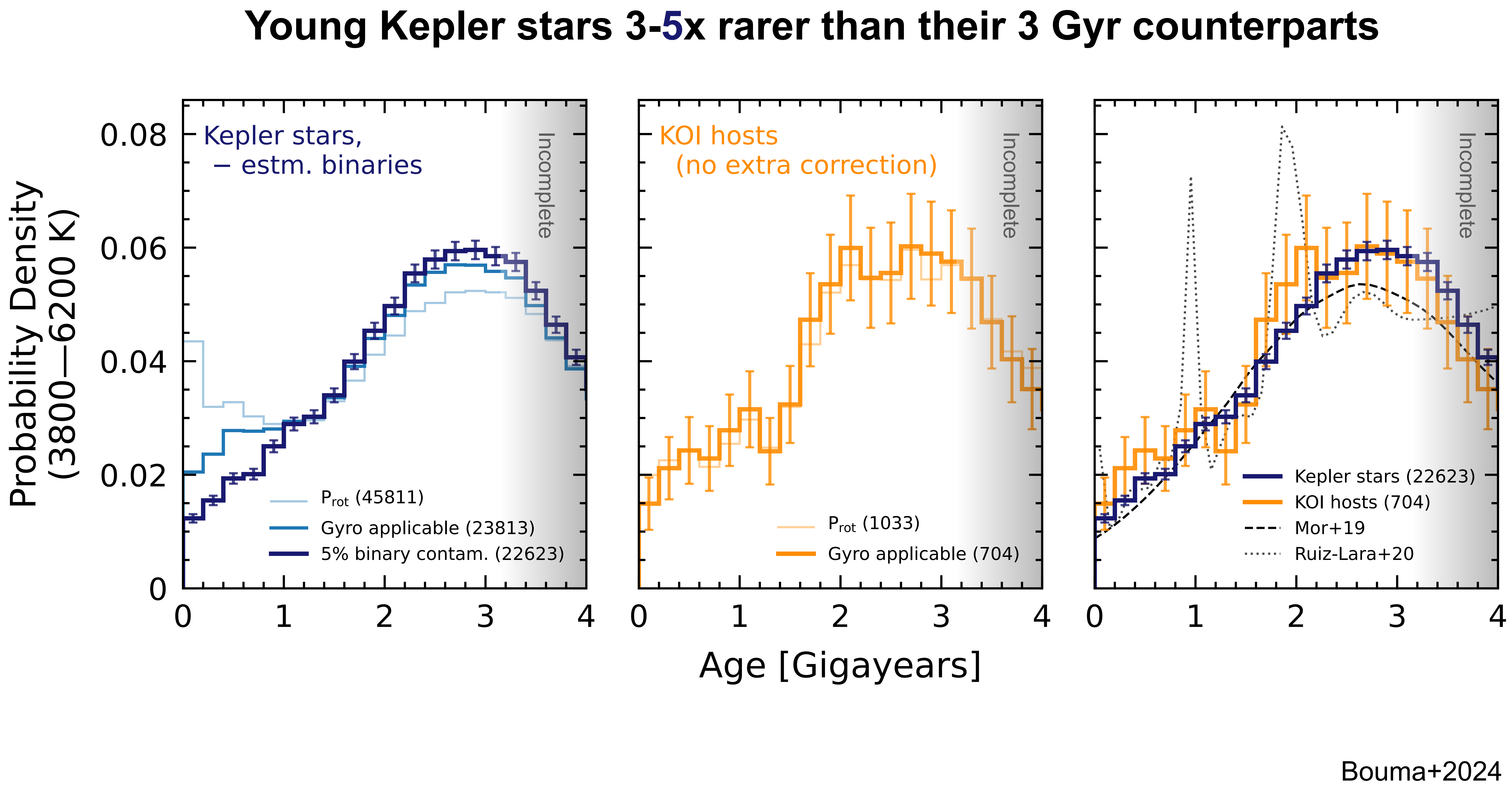


Bouma+2024

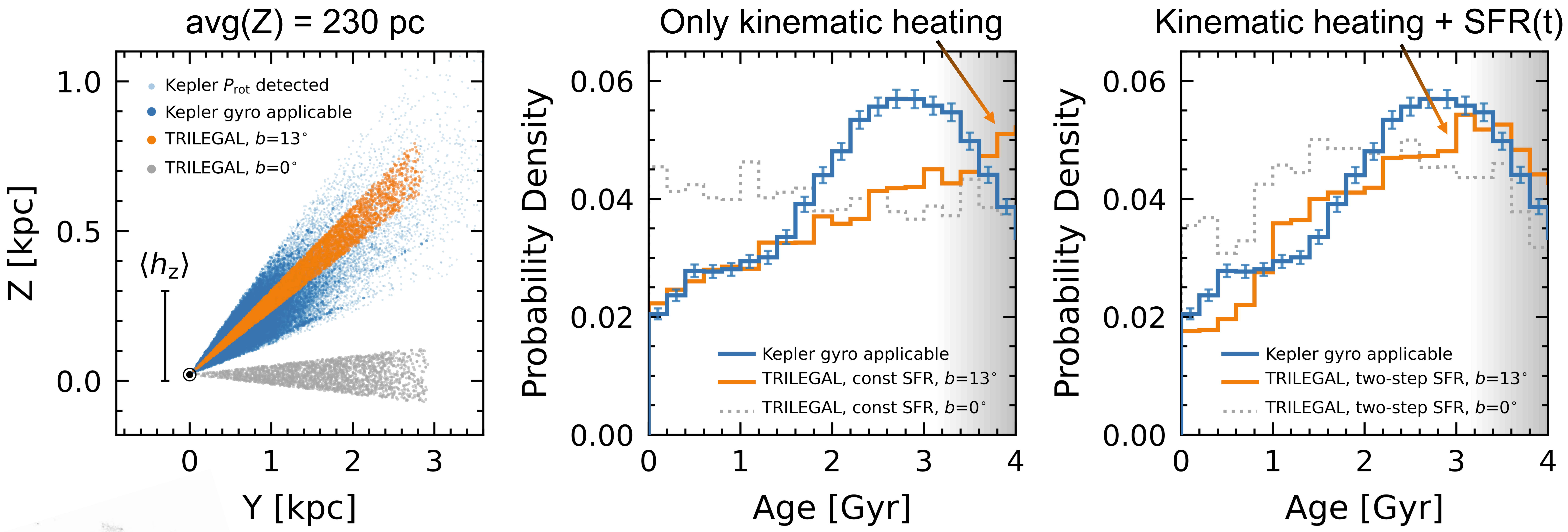
Young Kepler stars 3-5x rarer than their 3 Gyr counterparts

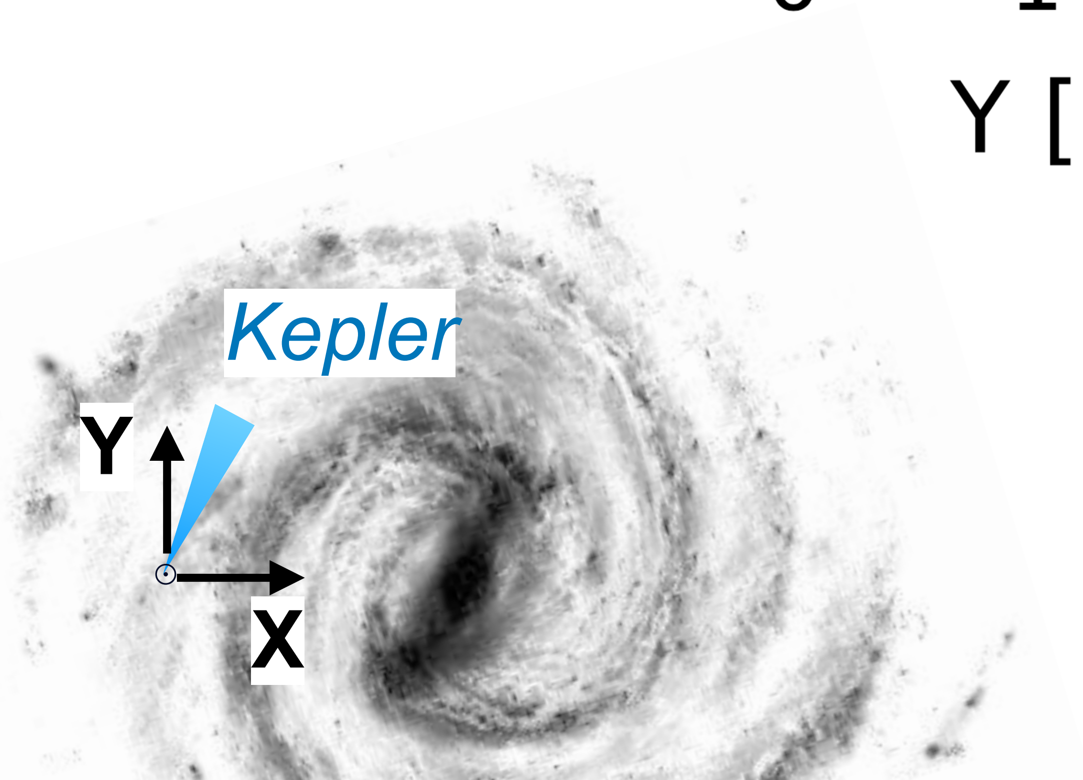


Bouma+2024


Young Kepler stars 3-5x rarer than their 3 Gyr counterparts
Probability Density (3800—6200 K)
Kepler stars, − estm. binaries
KOI hosts (no extra correction)
Incomplete
Incomplete
Incomplete
P_{rot} (45811)
Gyro applicable (23813)
5% binary contam. (22623)
P_{rot} (1033)
Gyro applicable (704)
Kepler stars (22623)
KOI hosts (704)
Mor+19
Ruiz-Lara+20
Age [Gigayears]
Bouma+2024

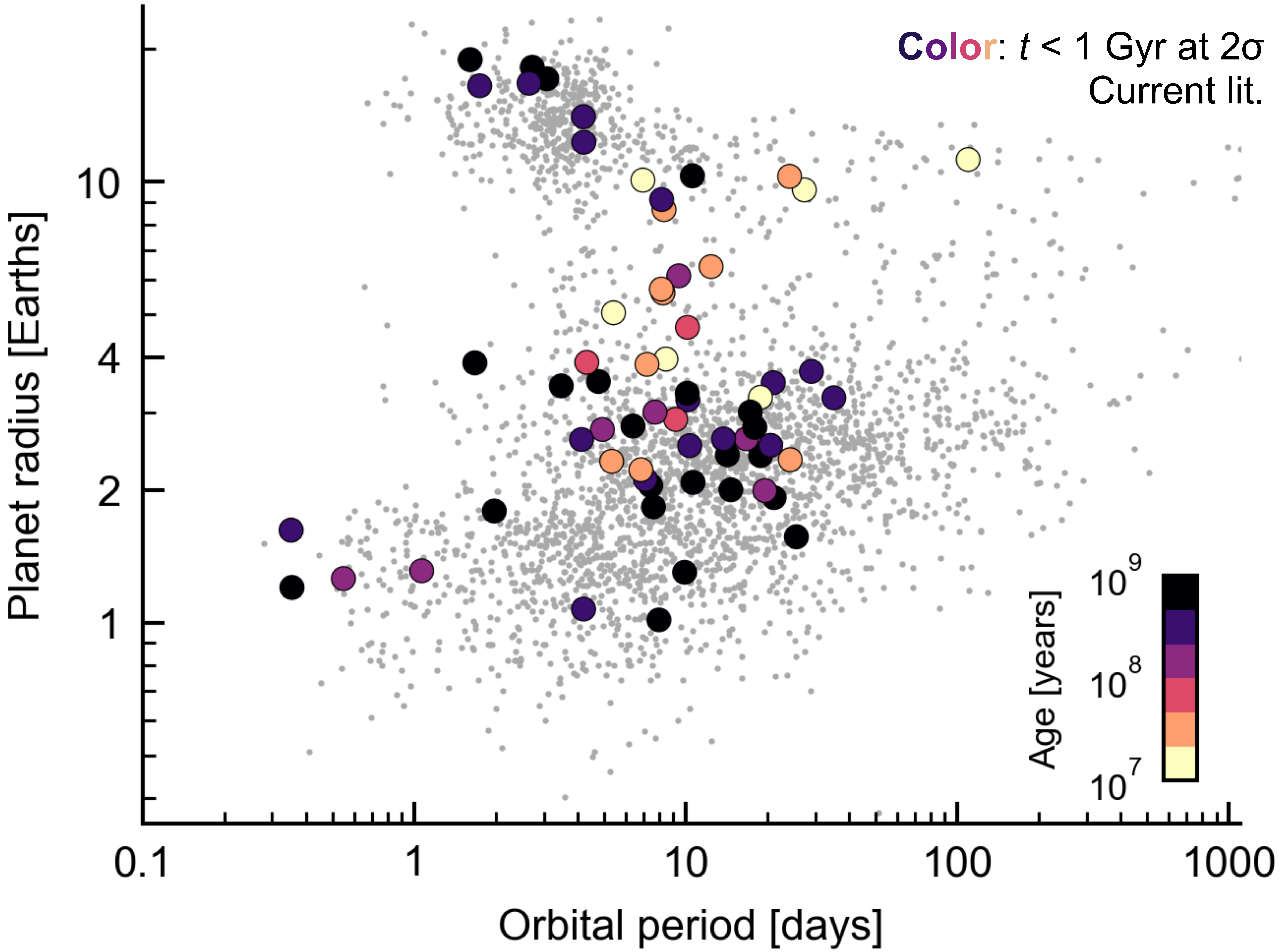
Kepler's age distribution is a product of both kinematic heating & star formation history





Bouma+2024

Field ages offer 2-3x expansion for demographics at 0.1-1 Gyr



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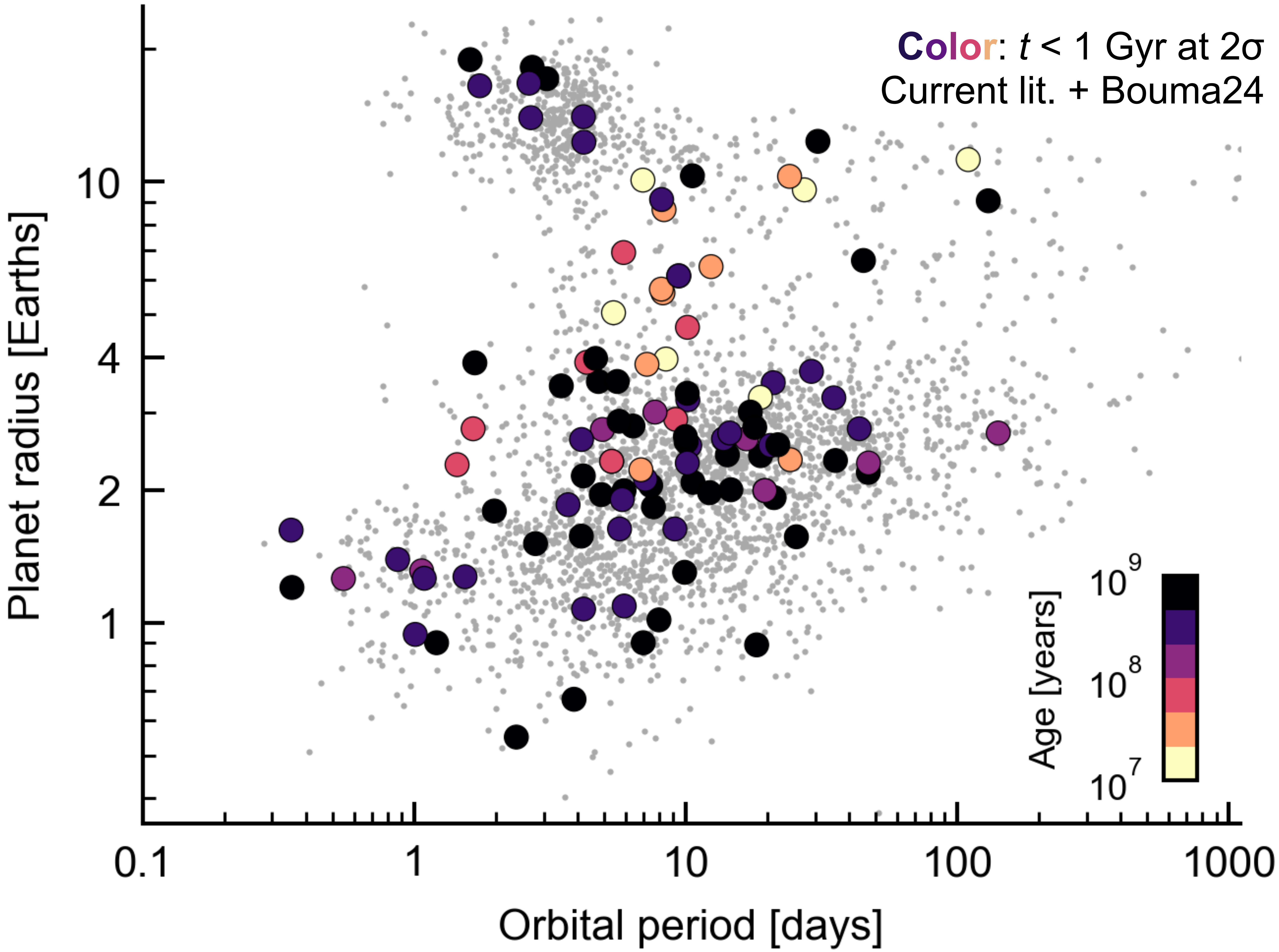

Bouma+2024

Image: Yuri Beletsky

The precision limit for rotational and lithium ages is set by intrinsic scatter in open cluster distributions.

- Rotation: *gyro-interp* (**Bouma+23**)
- Lithium: *eagles* (Jeffries+23, Weaver+24)
- Calibrated for: single FGK stars at < 4 Gyr near solar metallicity

Youngest Kepler stars 3-5x rarer than stars 3 Gyr old.

- Age distribution product of both kinematic heating and declining SFR
- Unresolved photometric binaries main source of uncertainty

Know thy Galaxy, know thy planet age distribution.

- Rotational ages for ~100 Kepler planets with t < 1 Gyr (**Bouma+24**)
- Expands 0.1-1 Gyr sample 2-3x for demographic studies
- TESS, PLATO, Roman, & Rubin offer sensitivity to broader populations, young & old.

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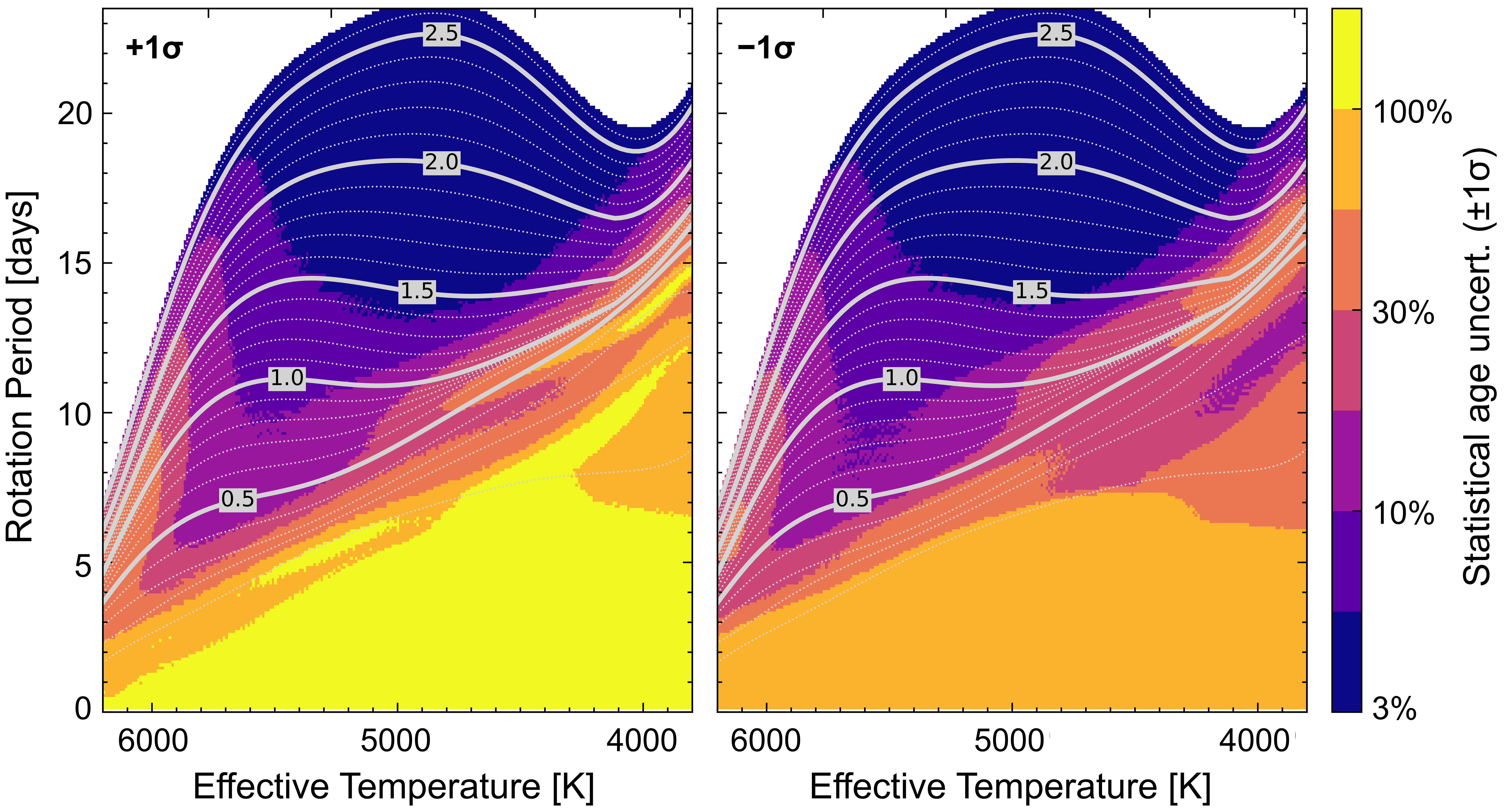
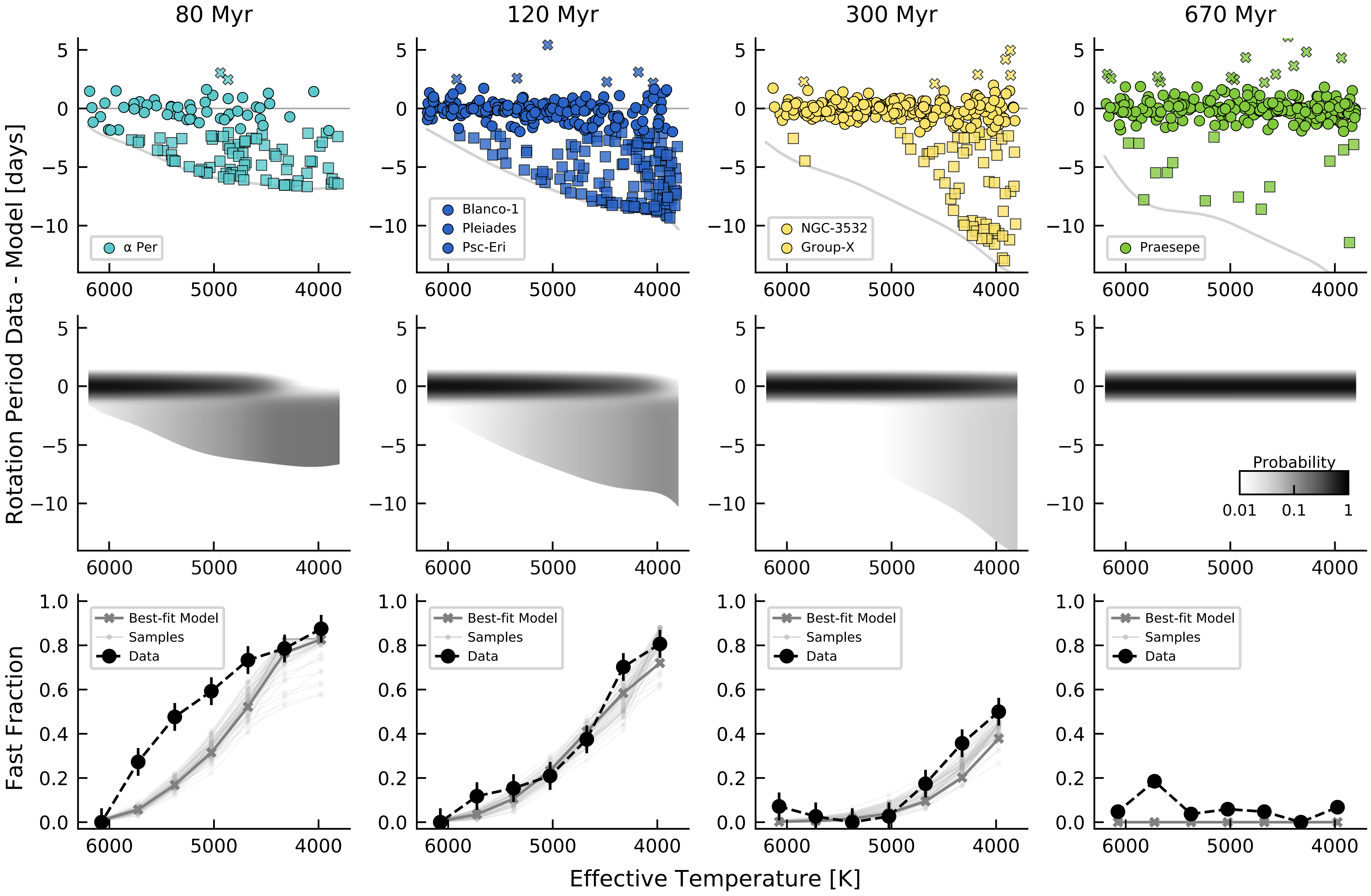
lgbouma.com

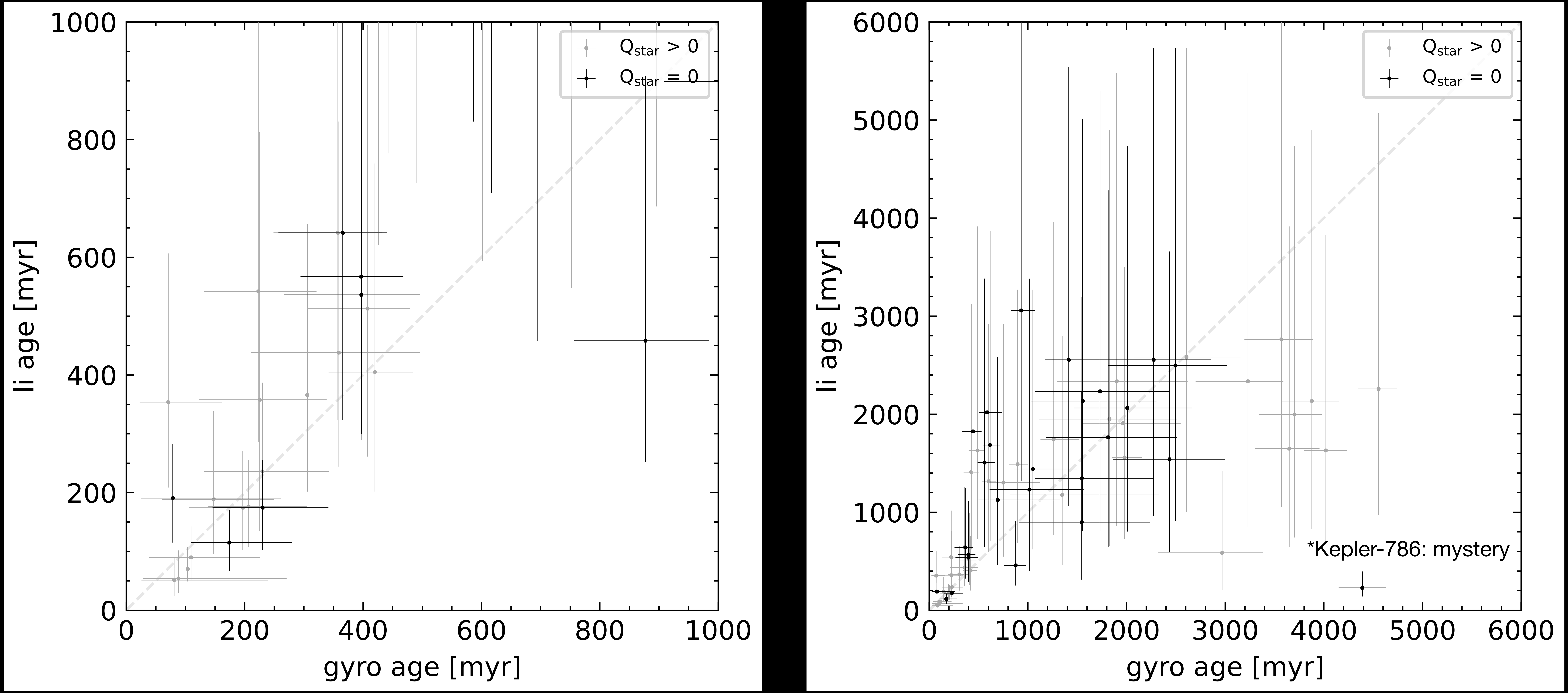
bonus

How precise are gyro-interp ages?



How do unresolved binaries affect gyro ages?

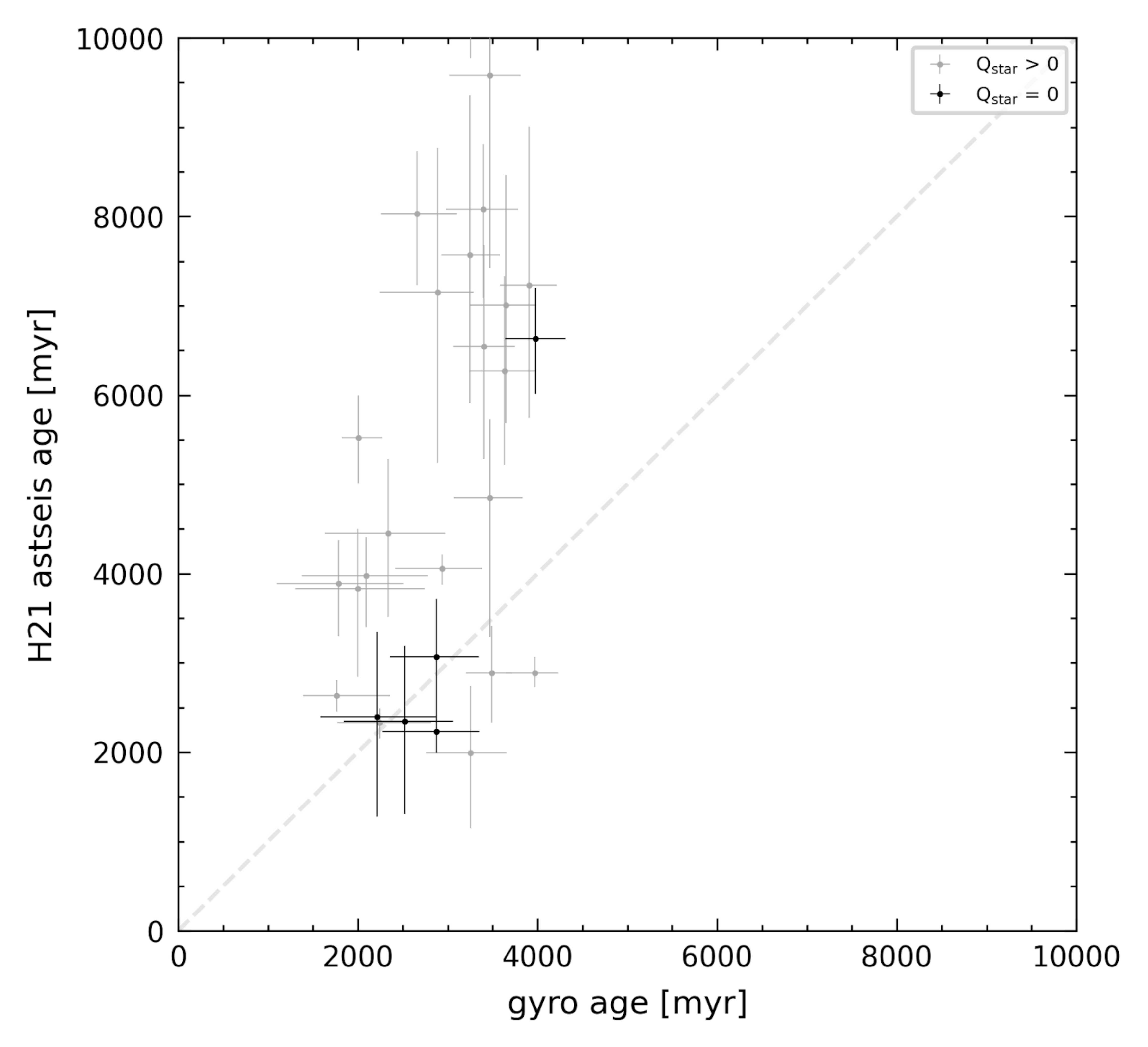




gyro-interp (Prot) vs. eagles (Li) age scale comparison

They mostly* agree, but not many stars overlap!

Bouma+24 suppl.



Regarding the asteroseismic sample: We crossmatched our Table 2 against Hall+2021 (hereafter H21). H21 included 94 stars. The match yielded 27 stars with Teff<6200K and finite gyro-interp ages. Most (20/27) of these stars raise our "far from main sequence" quality flag, based on their location in the logg vs Teff plane – such stars would not be in our default sample in e.g. Figure 6. One star (KIC 10454113) tripped other flags (too luminous; high RUWE), another was flagged a metallicity outlier (KIC 10963065). This left five stars to compare:

KIC	adopted_Teff	gyro_median	gyro_-1sigma	gyro_+1sigma	Prot	Age	e_age_lc	e_Age	P	__Fe_H_
10644253	6039	2211.0	631.0	655.0	10.88	2.3936	1.1179	0.9582	38.005288	0.06
3735871	6117	2525.0	681.0	536.0	10.76	2.3457	1.0380	0.8464	15.810470	-0.04
3427720	6038	2872.0	601.0	480.0	13.85	2.2339	0.2396	0.2396	31.590512	-0.06
10079226	5955	2872.0	516.0	475.0	15.51	3.0643	0.7027	0.6548	16.789238	0.11
3544595	5589	3975.0	336.0	340.0	27.95	6.6300	0.6200	0.5700	26.062736	-0.18

Table: Right five columns are from Hall+21 (which sourced ages from Silva-Aguirre+2015's BASTA routine); remaining columns are from this work.

The youngest four stars agree. The older one does not; KIC 3544595 has a 3.8σ older t_ast than t_gyro (6.6 +/- 0.6 Gyr vs 4.0 +/- 0.3 Gyr).

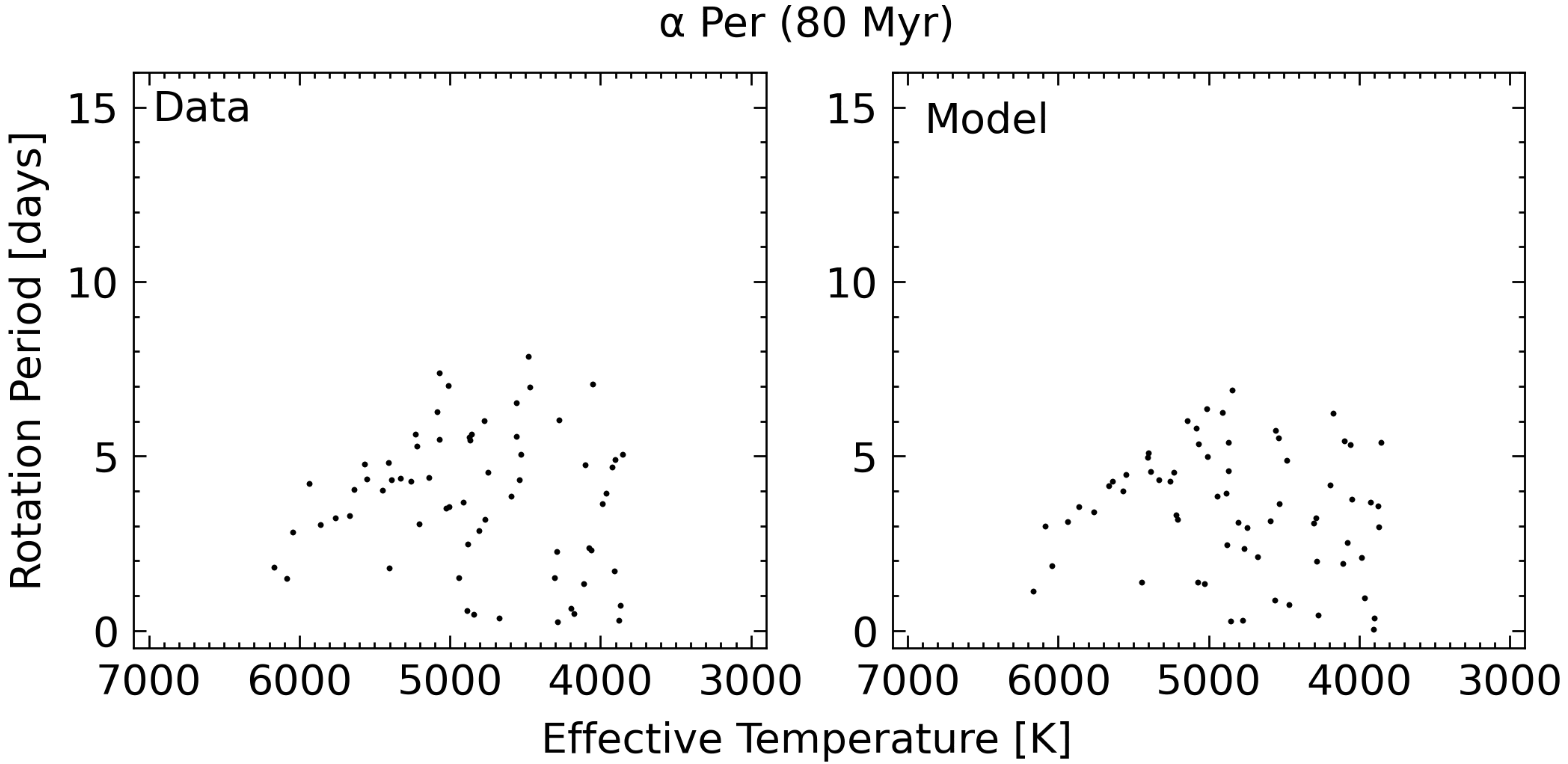
It is worth checking whether the rotation period and temperature of this latter star is consistent with the interpolation-based gyro age that we quote. The other figure below, which shows the Ruprecht-147 and M67 sequences, suggests that it is.

The implication of this crossmatch, if taken at face value, is that some fraction of our "t_gyro > 3 Gyr" stars could be seismically older, in line with the WMB hypothesis. Section 8.2 includes paragraphs discussing this possibility in greater detail.

gyro-interp (Prot) vs. Hall+21 (astseis) age scale comparison

4/5 agree, heavily influenced by "far from MS" quality flag

Bouma+24 suppl.



α Per (80 Myr)
Data
Model
Rotation Period [days]
Effective Temperature [K]
0
5
10
15
7000
6000
5000
4000
3000

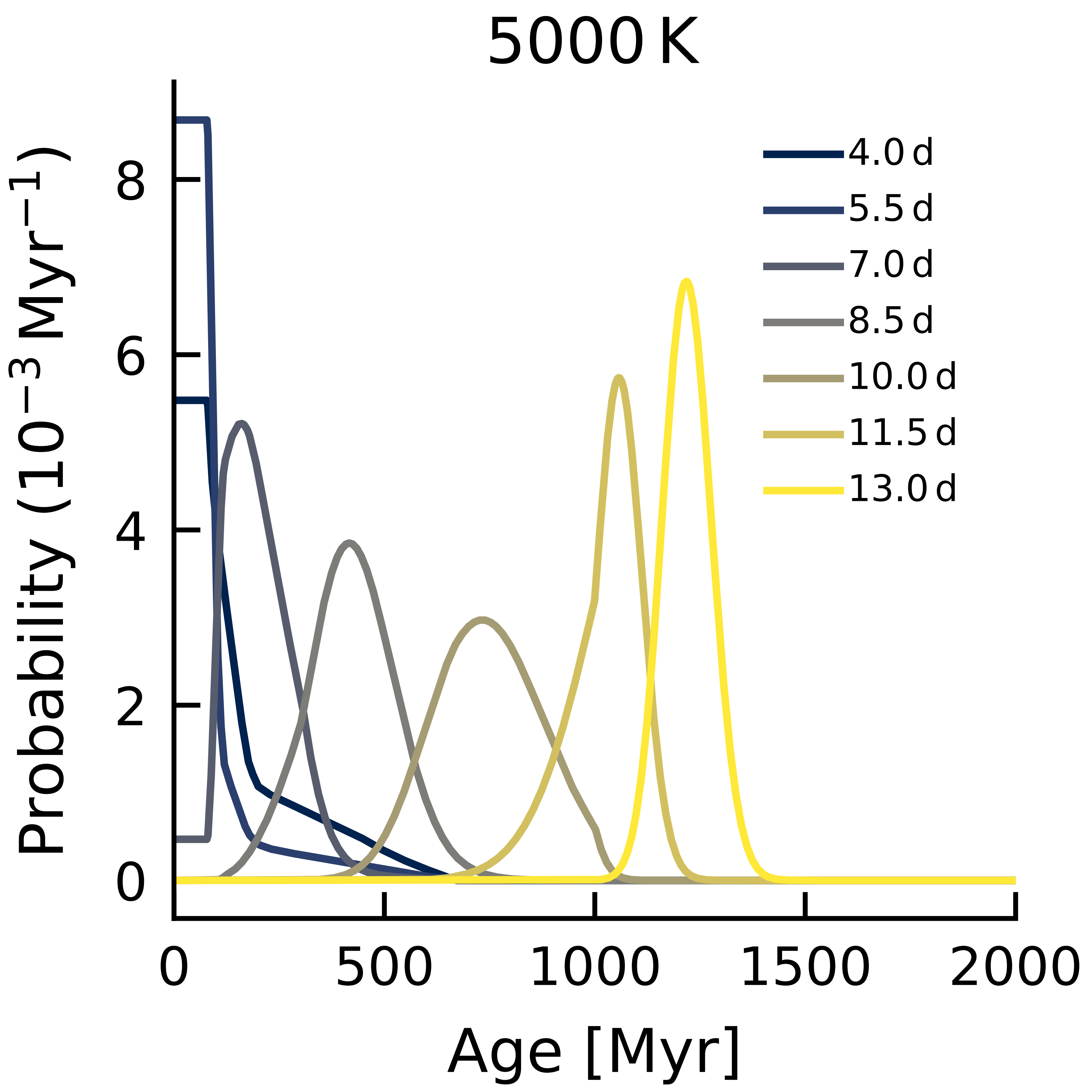
github.com/**lgbouma/gyro-interp**

```python
from gyrointerp import gyro_age_posterior

# units: days
Prot, Prot_err = 11, 0.2

# units: kelvin
Teff, Teff_err = 4500, 100

# evaluate the age posterior
age_posterior = gyro_age_posterior(
    Prot, Teff,
    Prot_err=Prot_err, Teff_err=Teff_err
)
```



How good is $P_{rot} \sim t^{1/2}$?