Stellar rotation

the missing piece in Stellar physics

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07/14/2021

Why stellar rotation is important?

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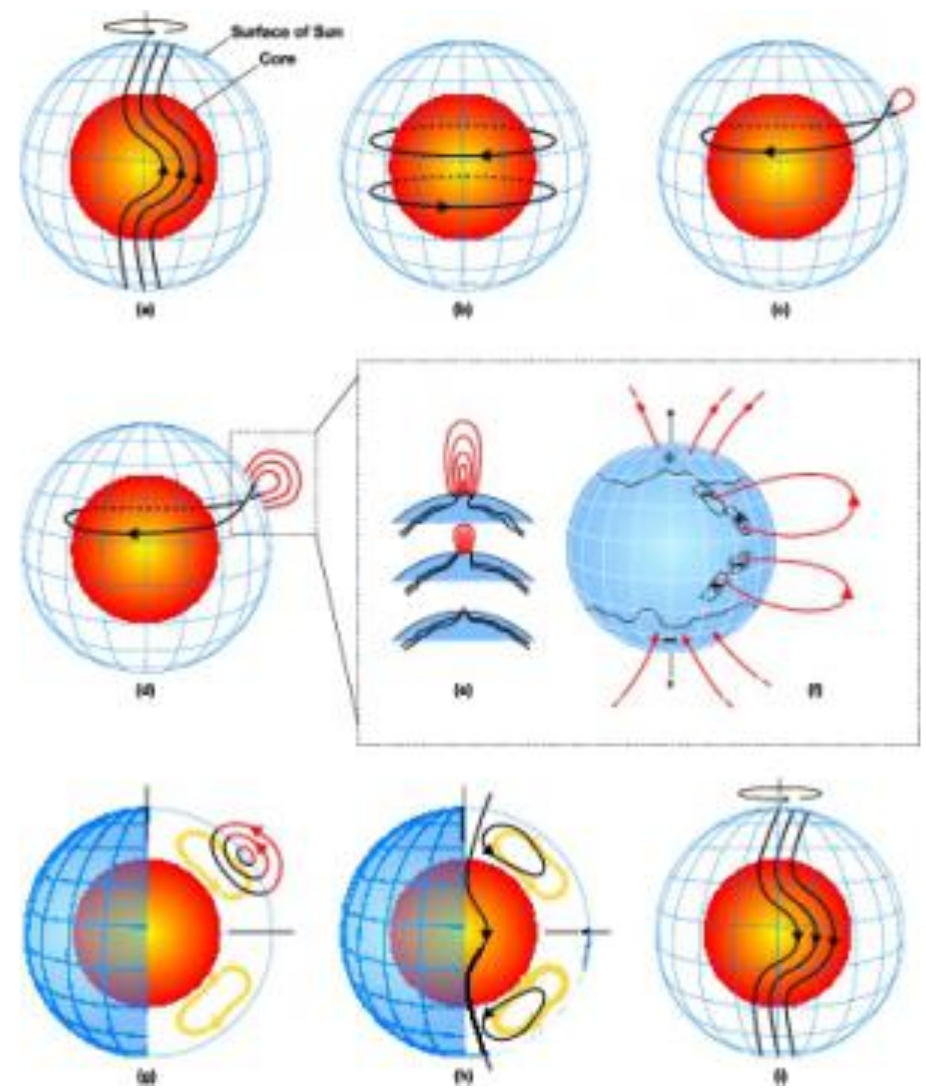
- Dynamo-driven magnetic activity
- Stellar winds
- Surface abundances
- Chemical yields
- Internal structure
- External structure



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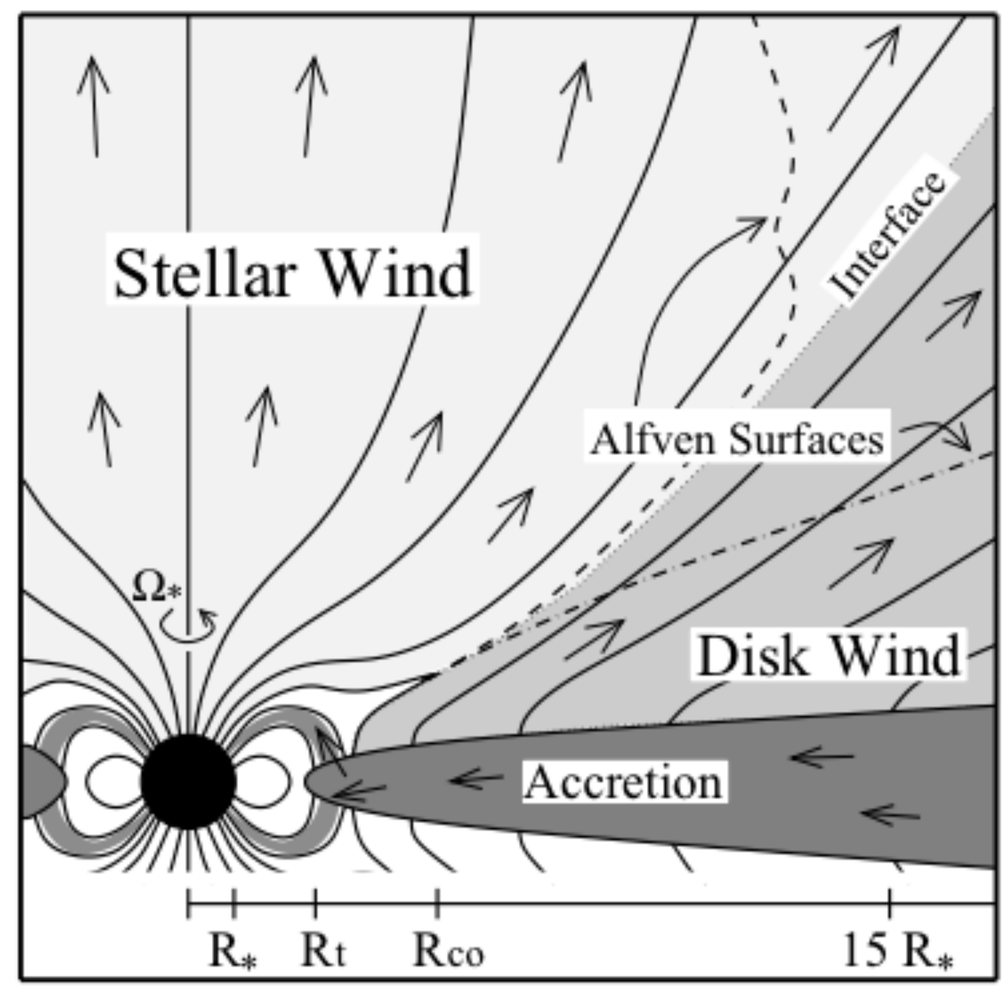

Matt & Pudritz 2005

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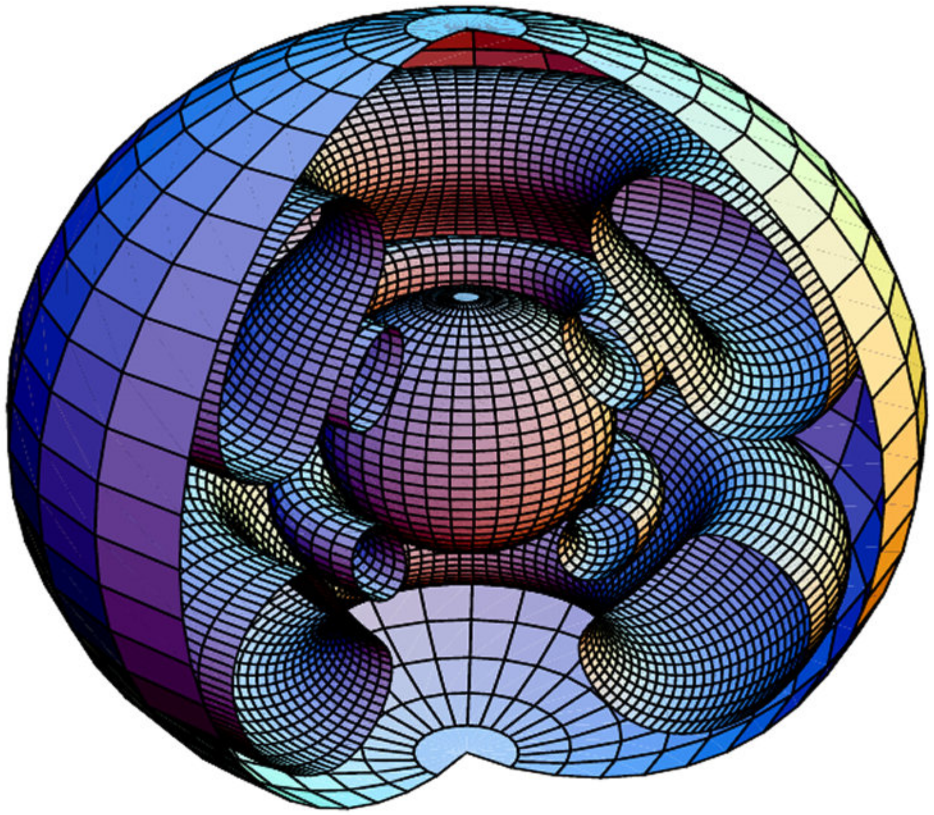

Maeder & Meynet 2011

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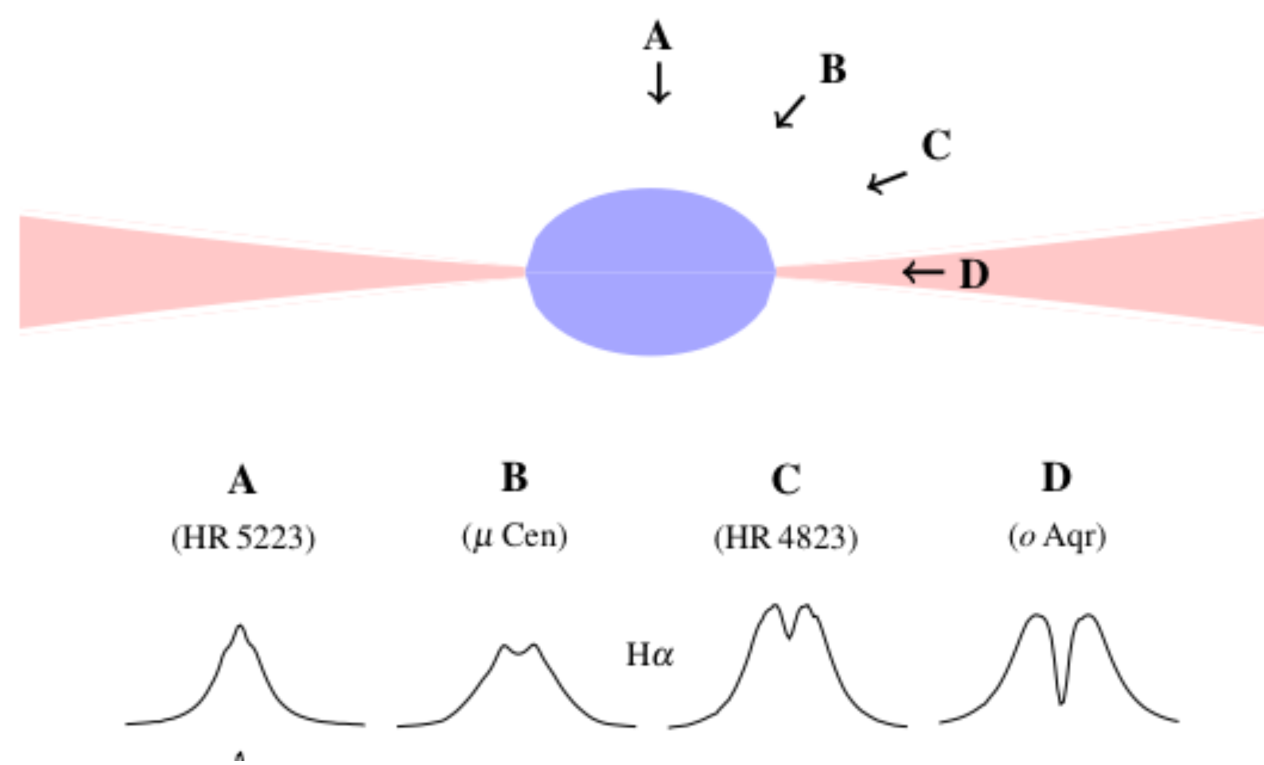
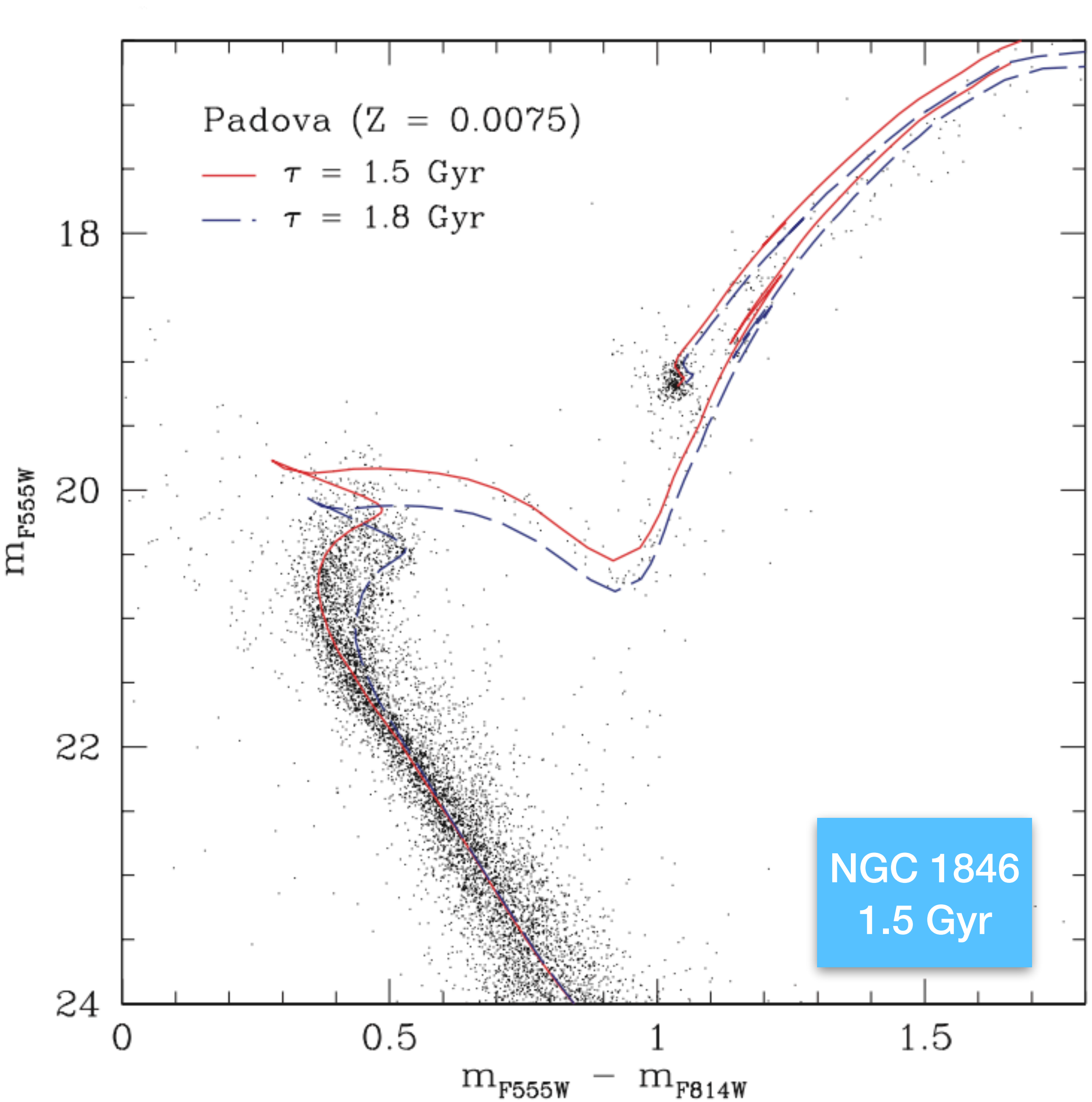


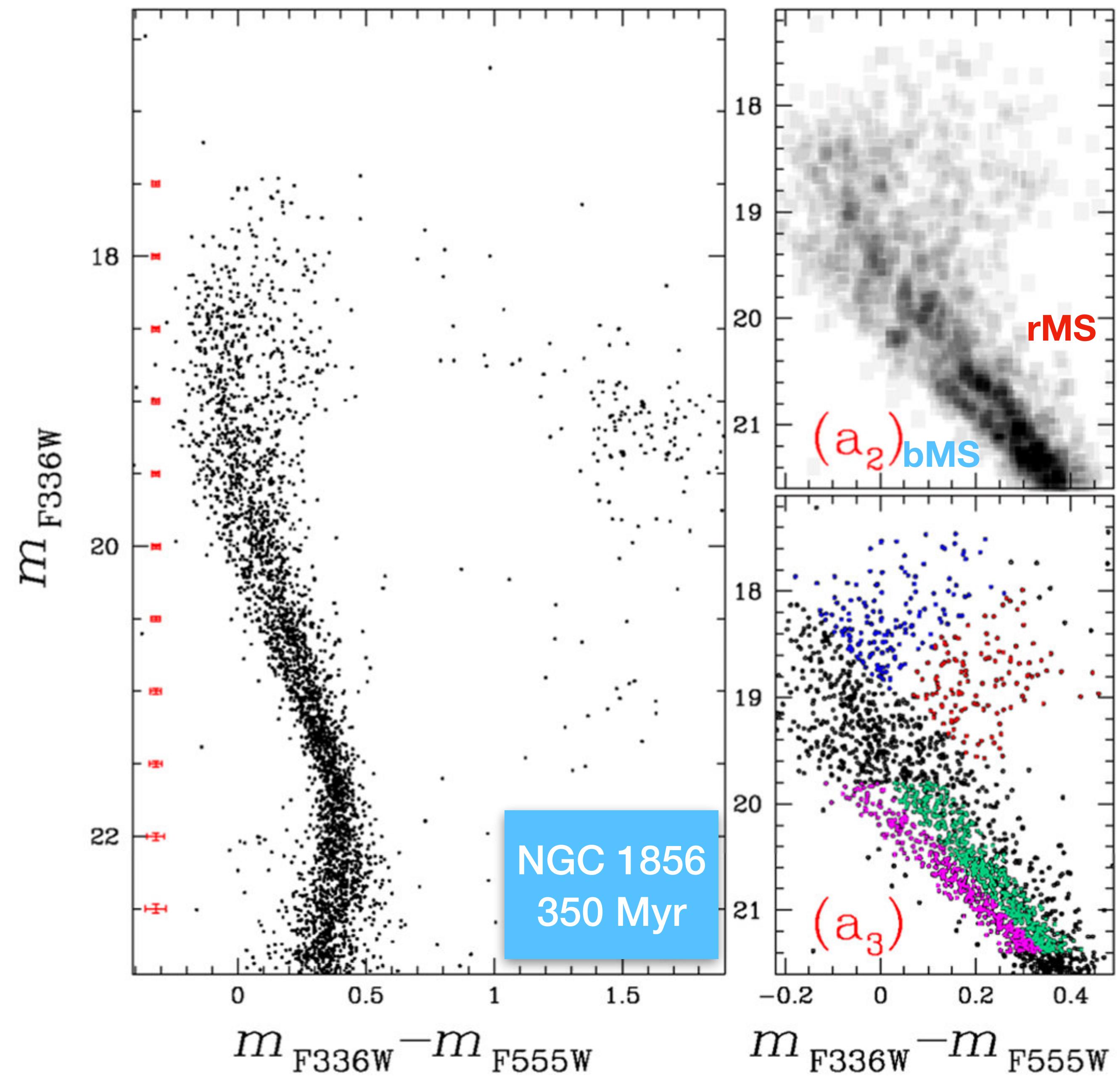
Rivinius+2013

extended MSTO and split MS

Found in Magellanic Clouds clusters



Mackey et al. 2008

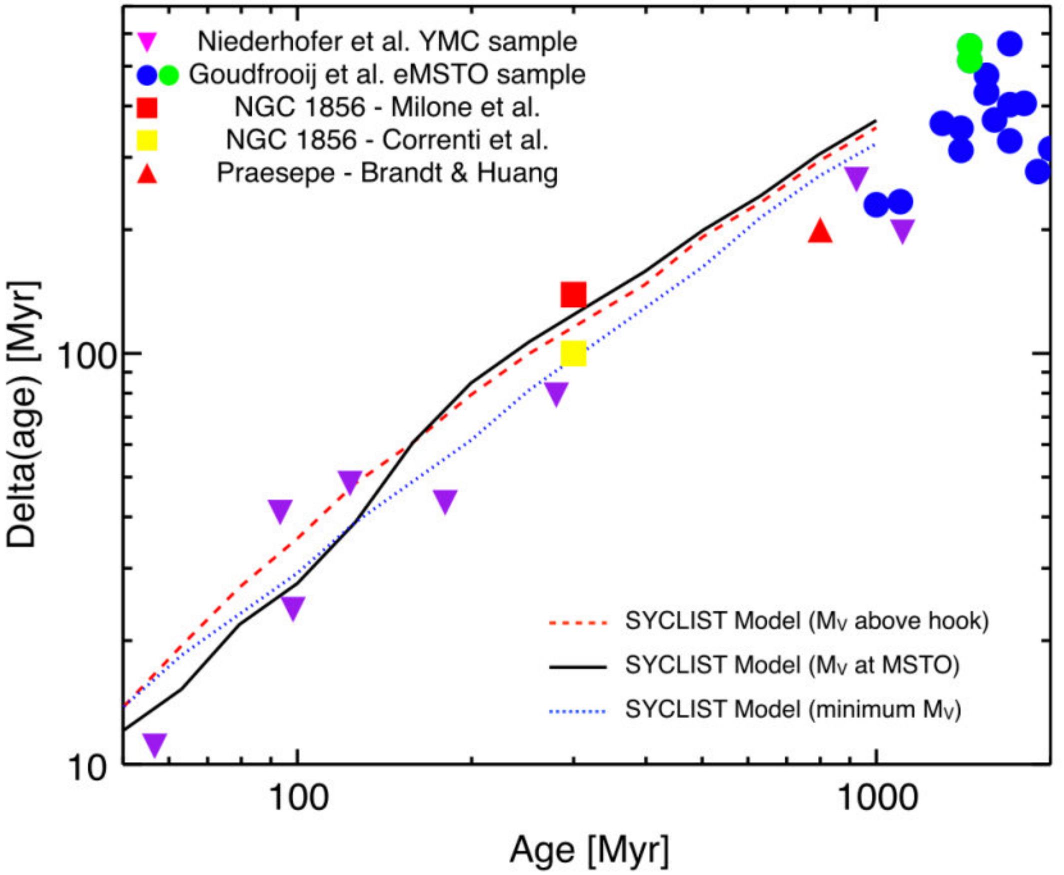


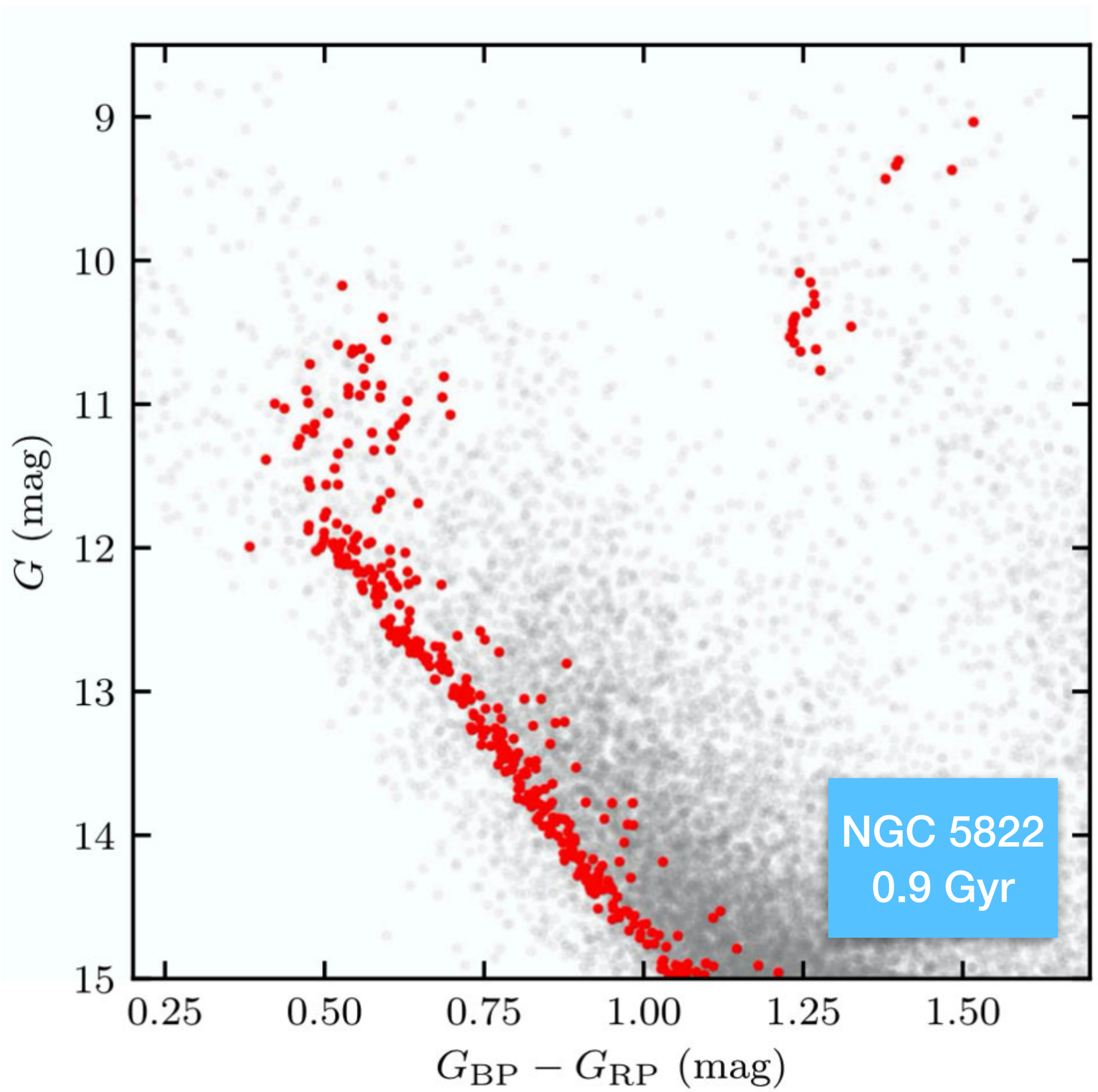
Milone et al. 2015

Not only in MC clusters

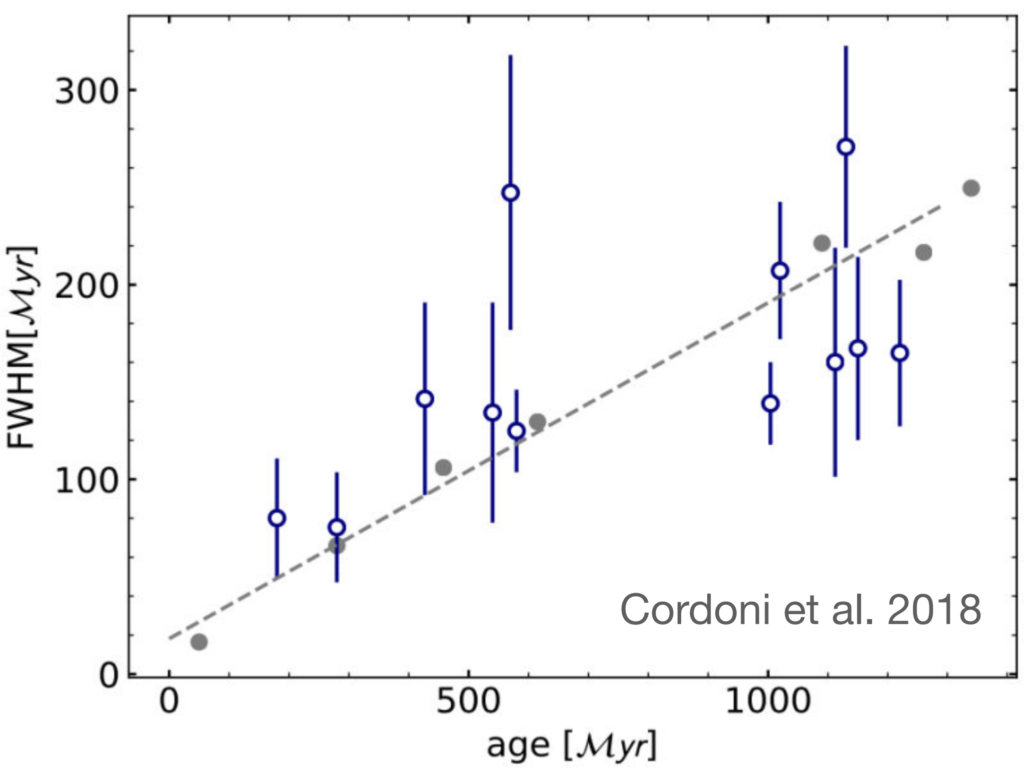
But also in Galactic OCs

Niederhofer et al. 2015





Sun et al. 2019a



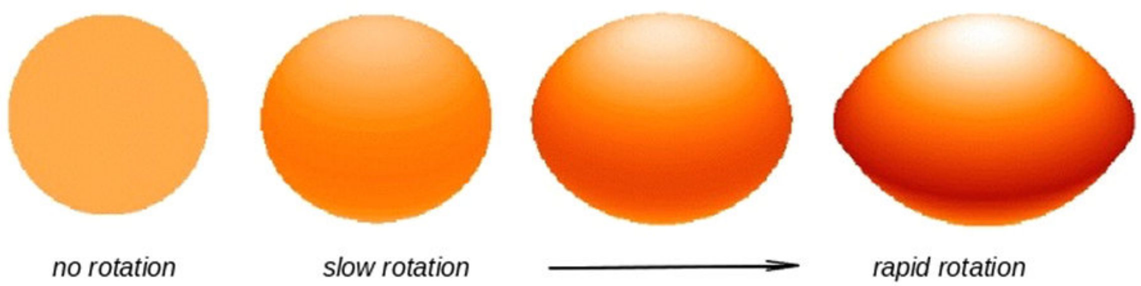
What causes eMSTO and split MS?

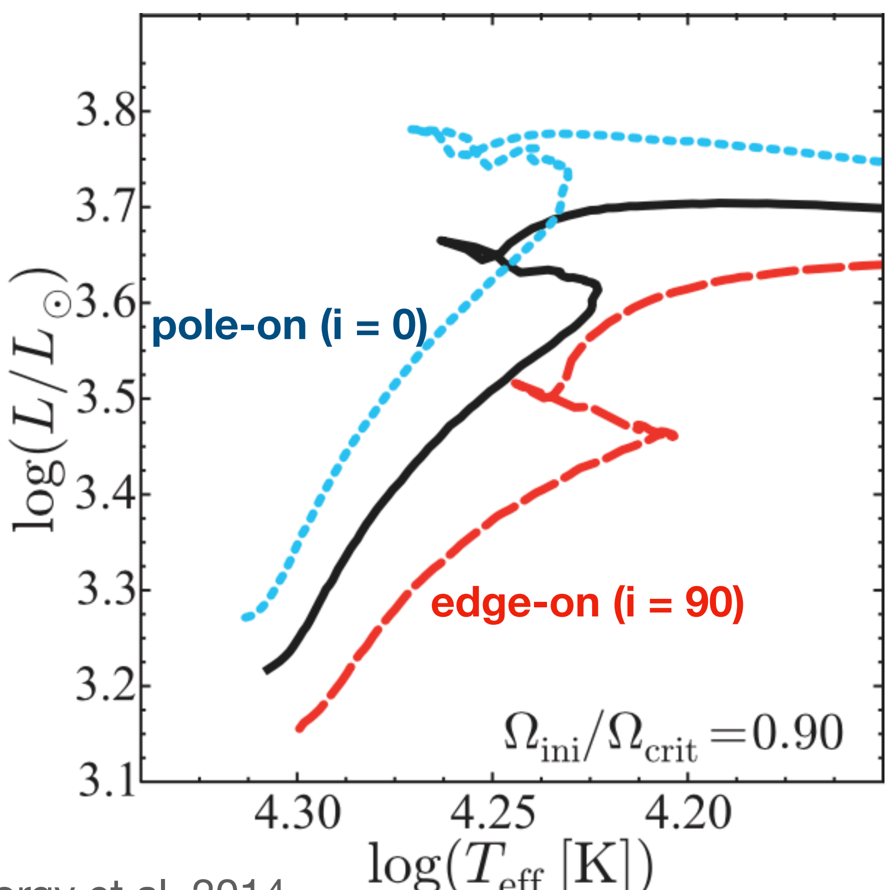
- Extended star formation history (eSFH)
- Variability
- A wide range of **stellar rotations**

What causes eMSTO and split MS?

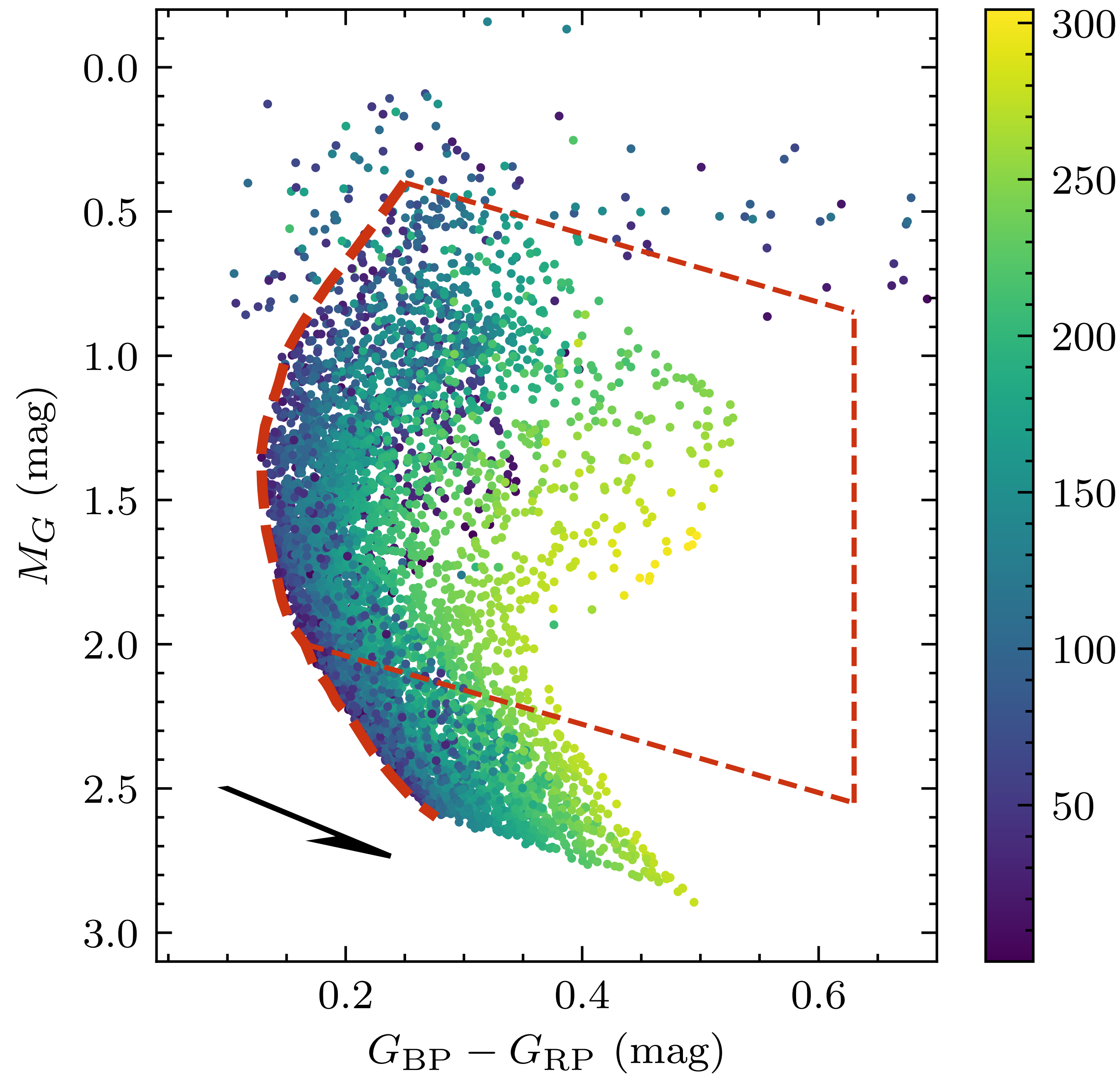
Stellar rotation

Gravity darkening





Georgy et al. 2014

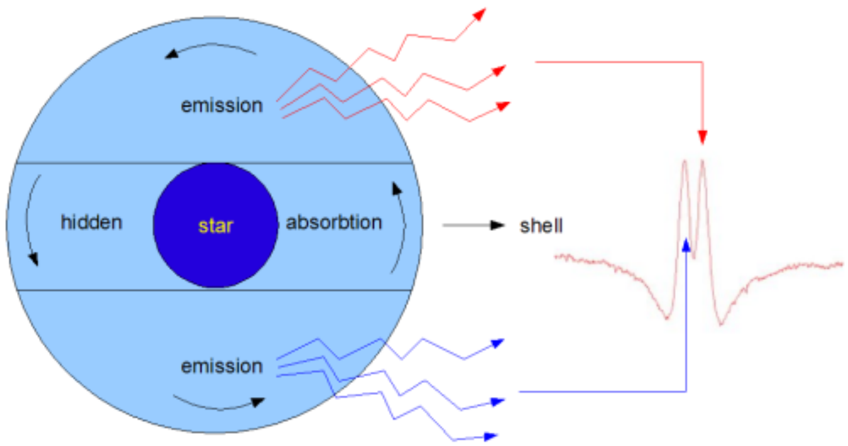


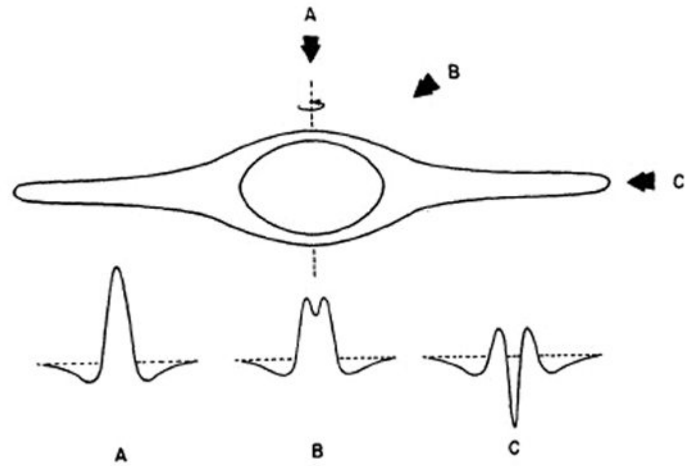
It's mainly $v \sin i$ that affects the locus of a star in the CMD

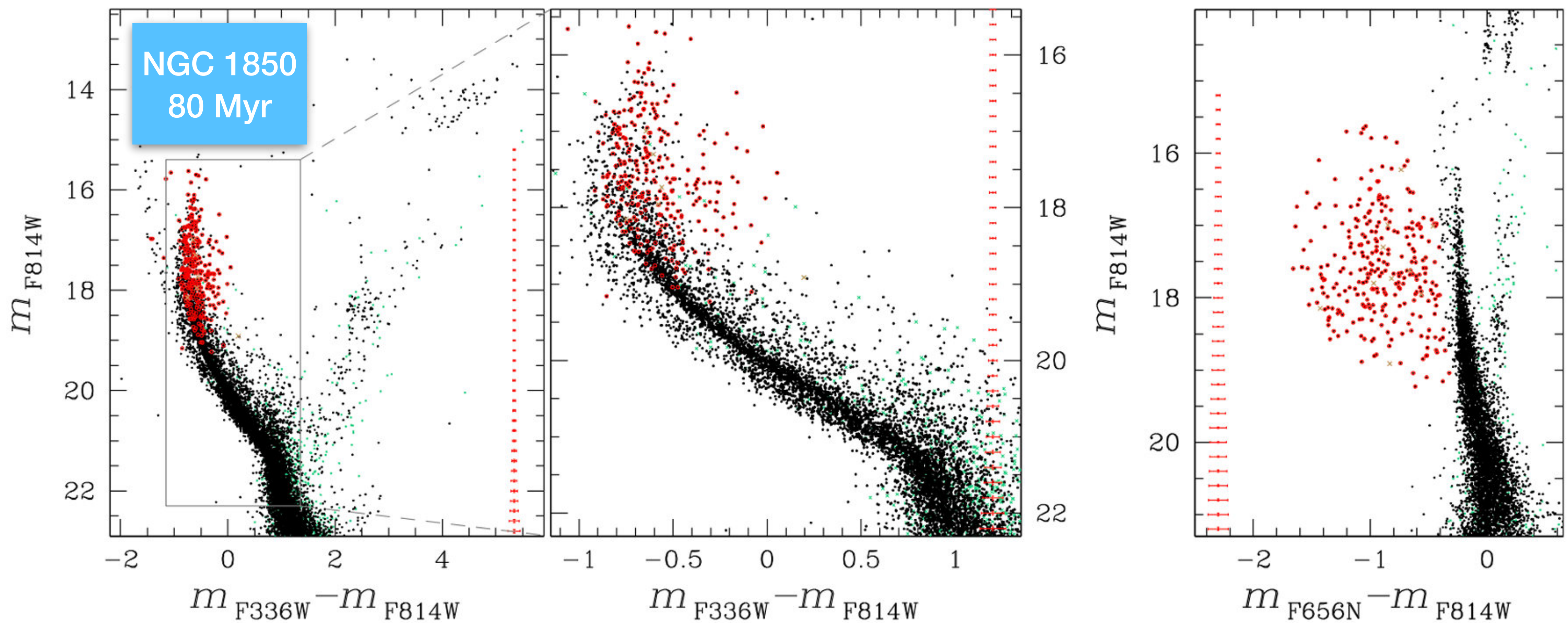
How well is stellar rotation model?

1. Rotation detection through photometry

Be stars



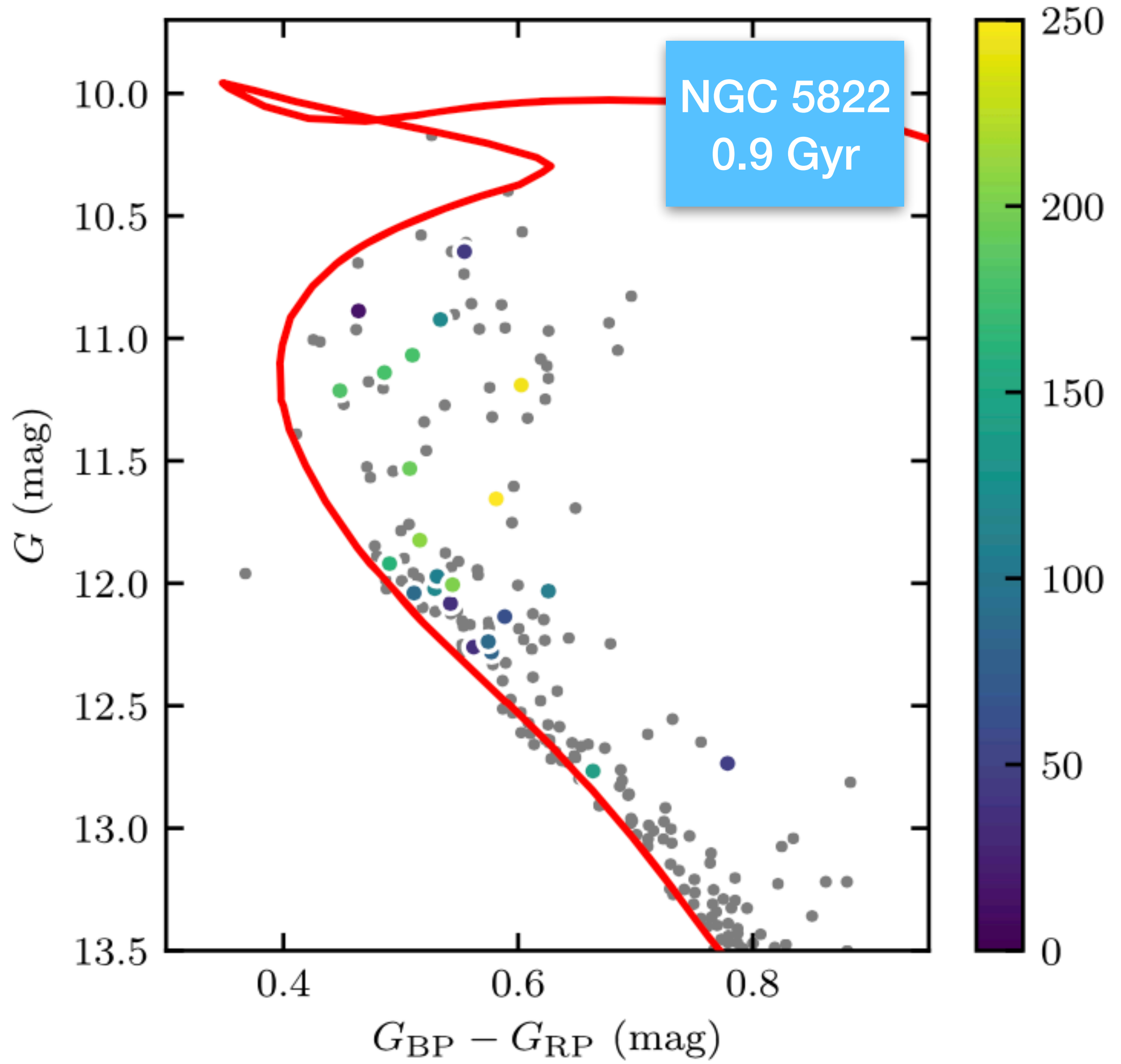


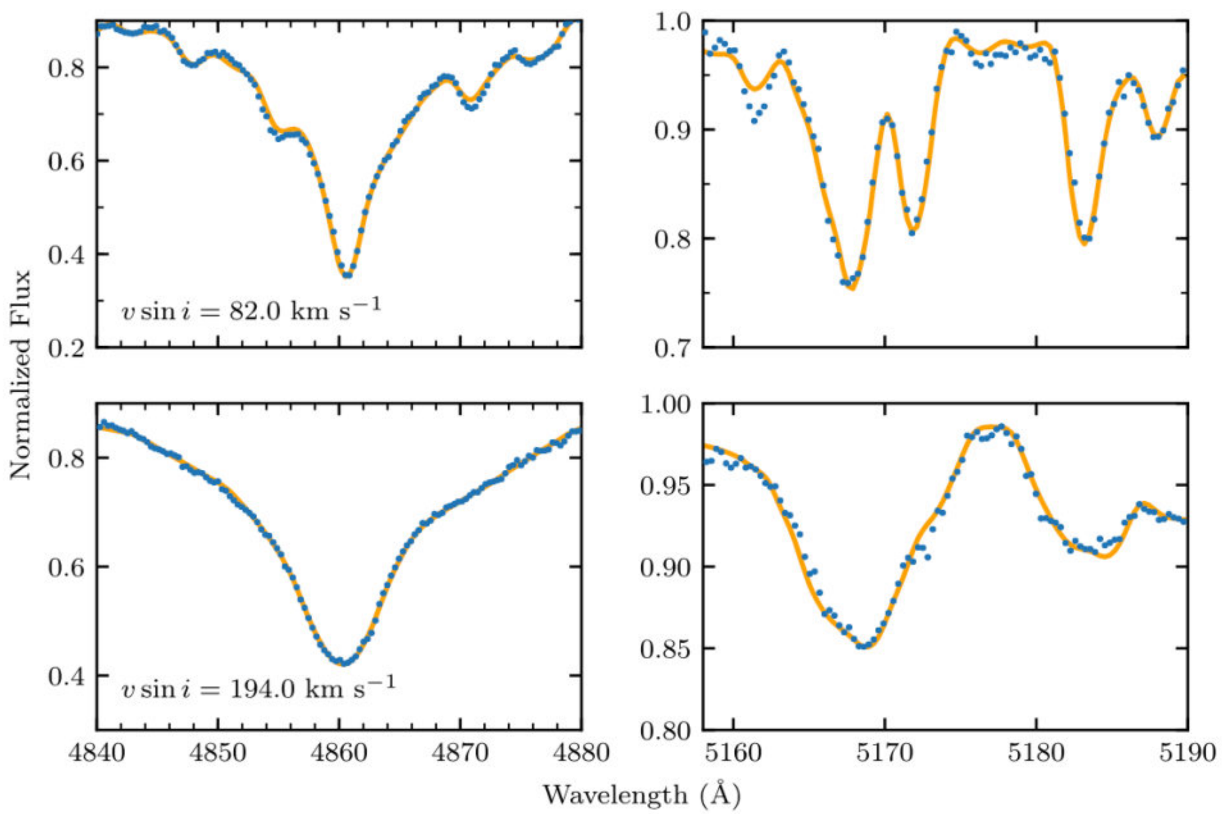


Milone et al. 2018

How well is stellar rotation model?

2. Rotation detection through spectroscopy





South Africa Large Telescope (*SALT*)
Multi-object Spectroscopy (MOS)
R ~ 4000

Sun et al. 2019a

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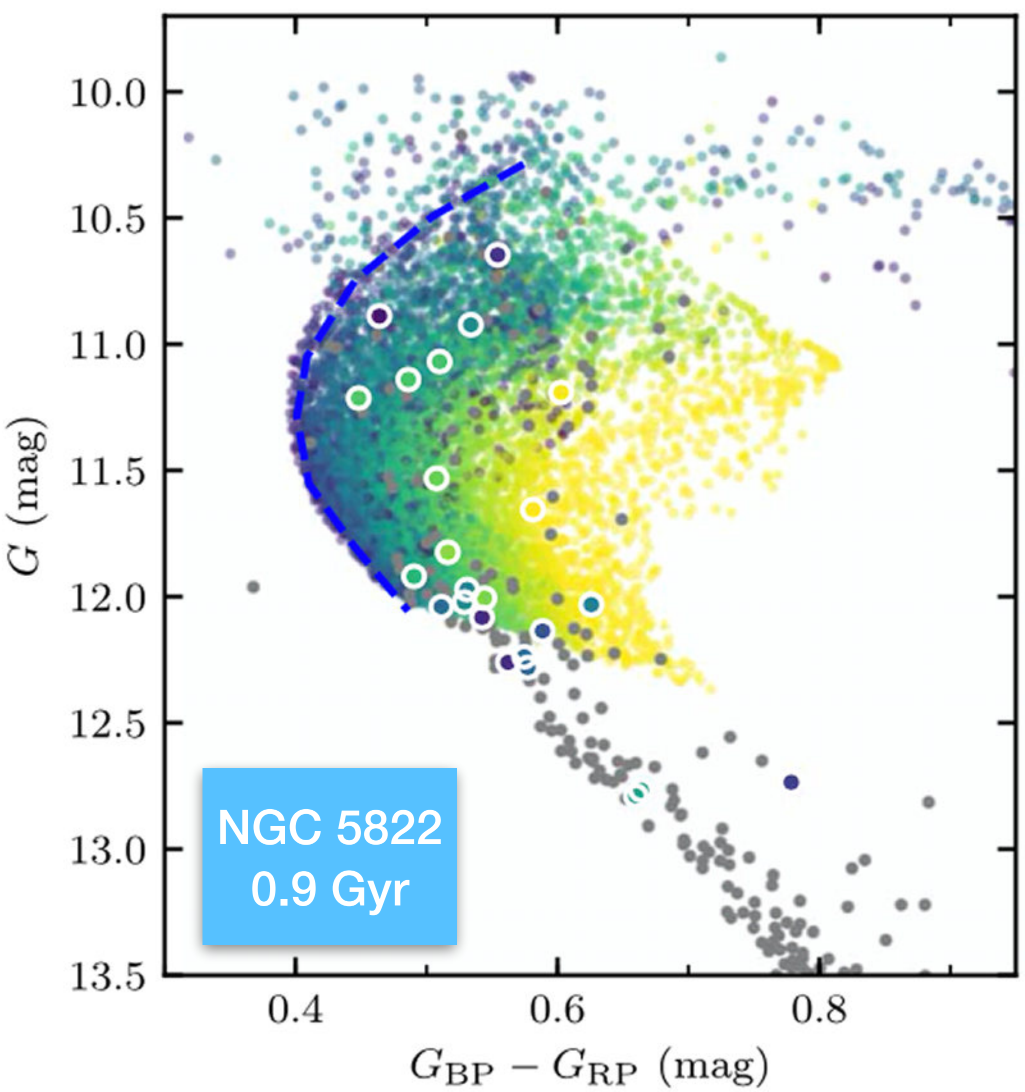
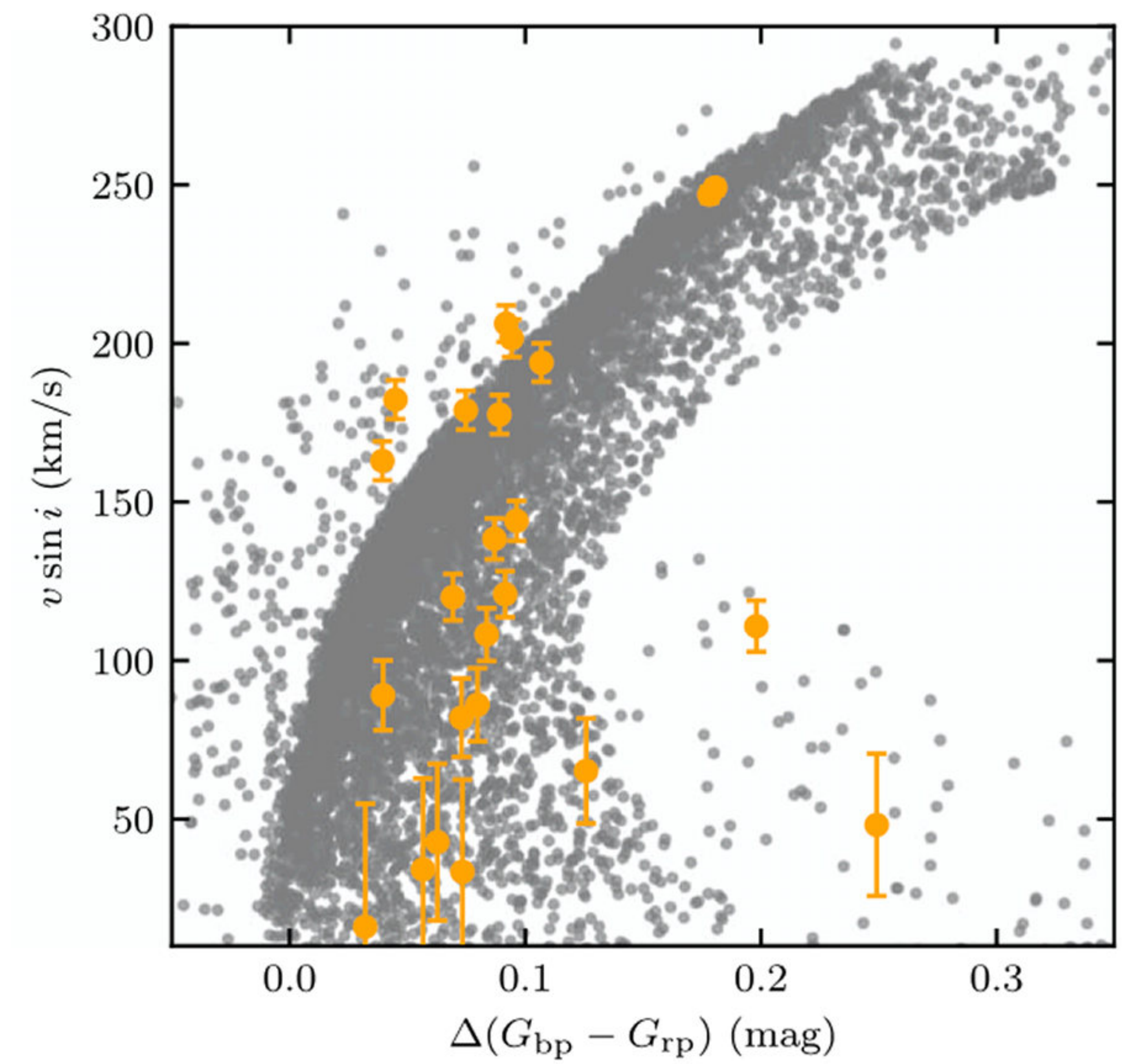


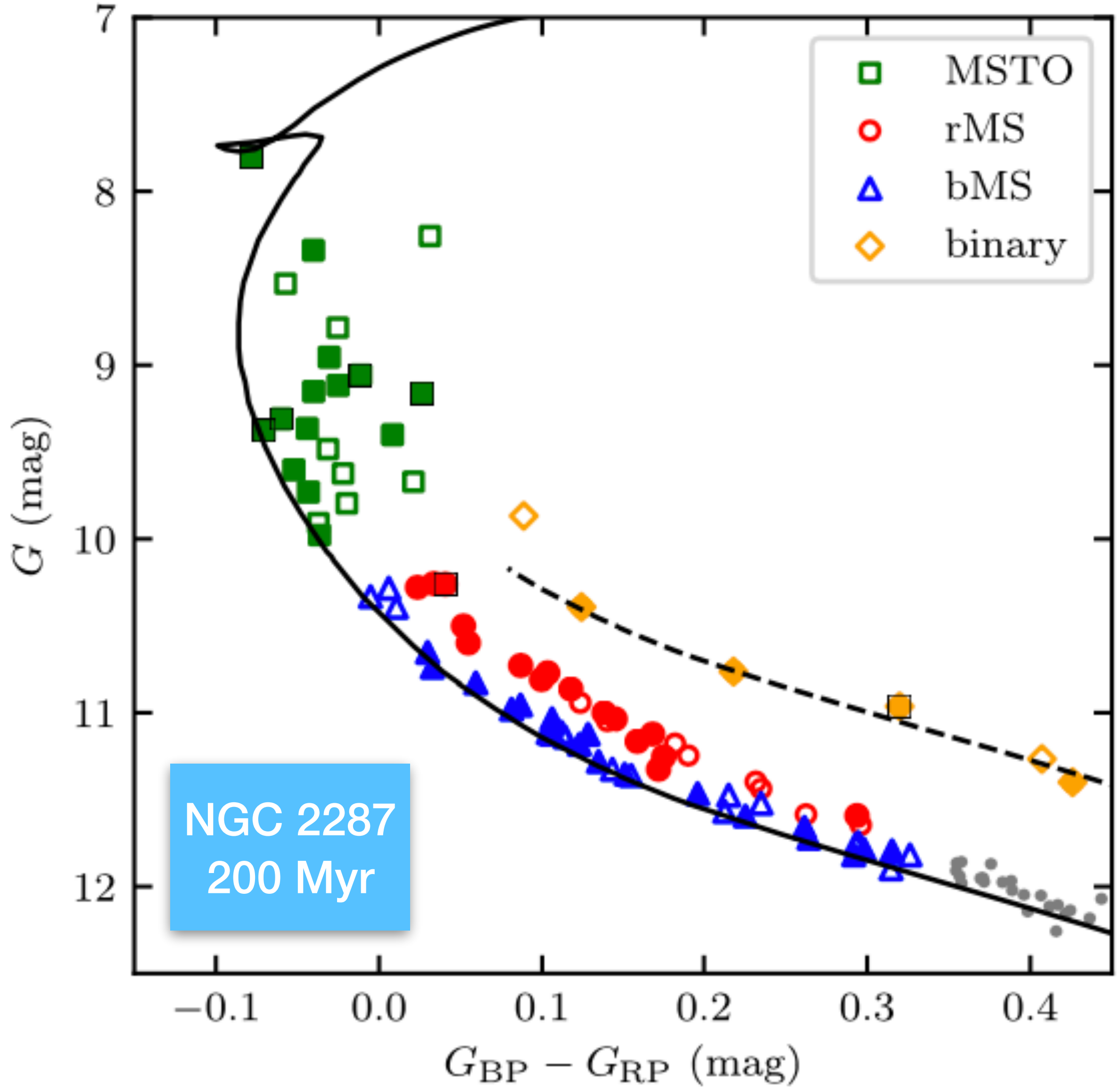


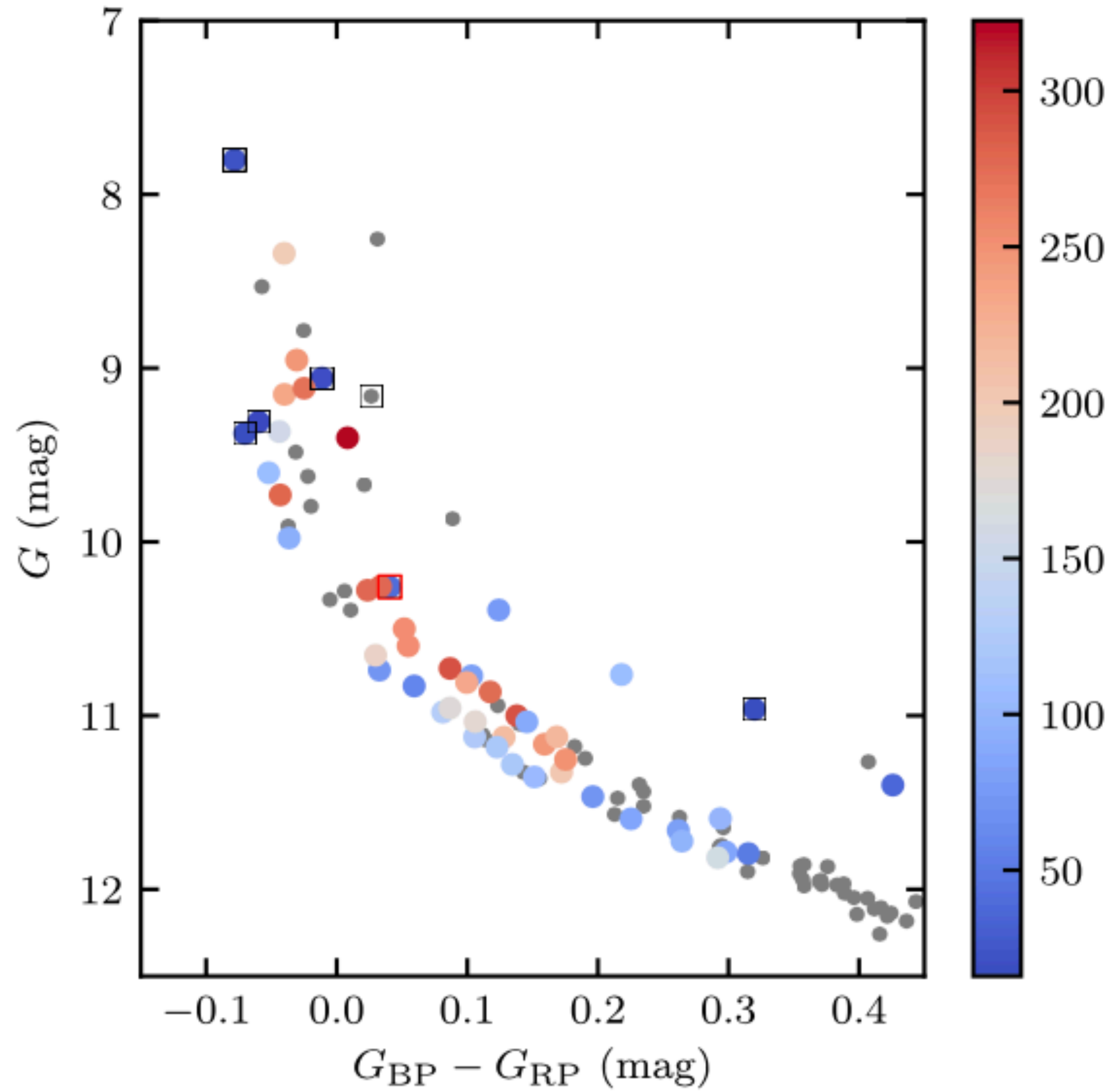
- The loci of the main-sequence stars in the eMSTO region show a clear correlation with the projected rotational velocities
- Fast rotators are located on the red side of the eMSTO and slow rotators are found on the blue side

How well is stellar rotation model?

2. Rotation detection through spectroscopy

A **well-separated** double MS



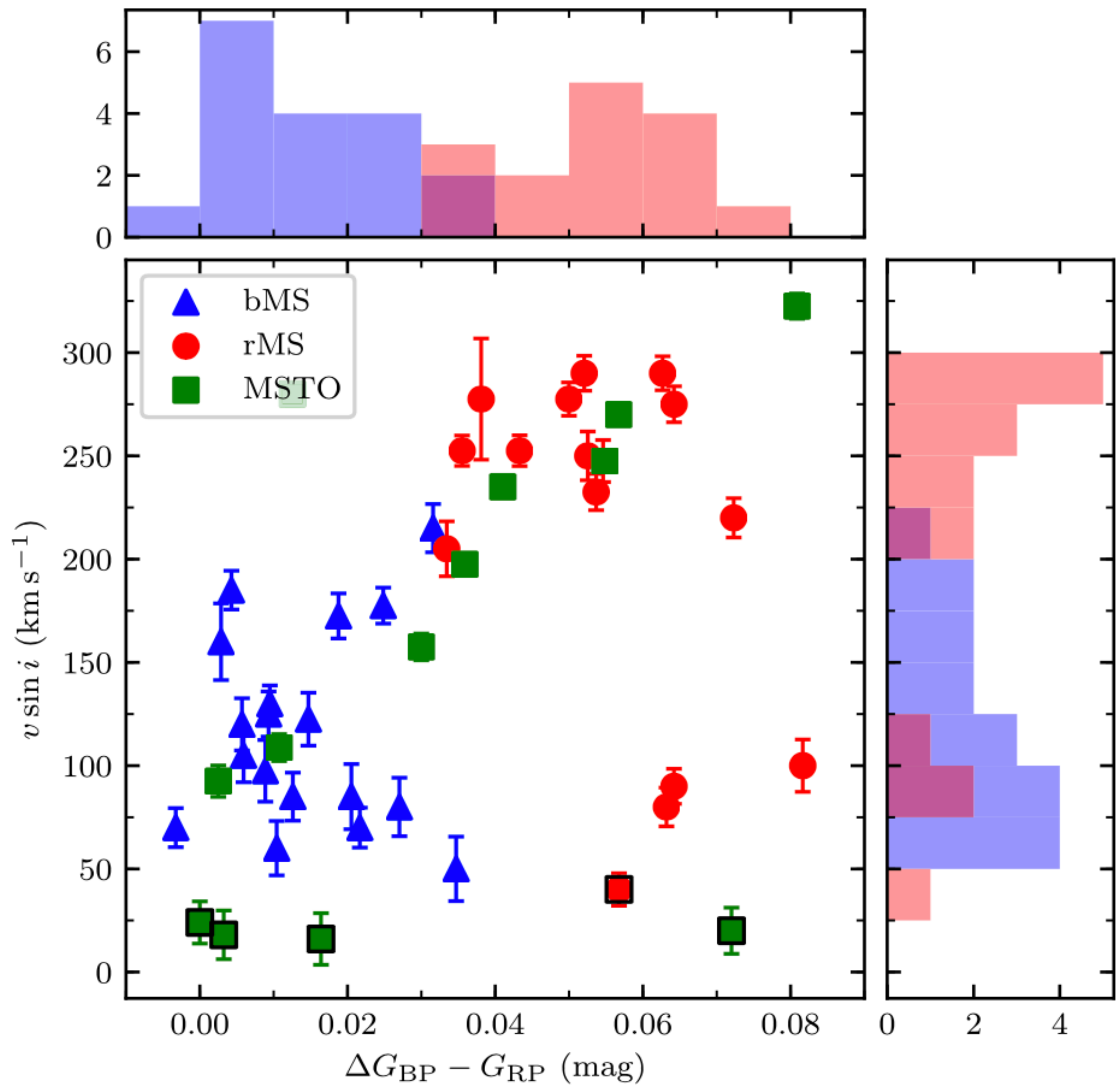


Sun et al. 2019b

How well is stellar rotation model?

2. Rotation detection through spectroscopy

- The mean projected rotational velocity for bMS and rMS stars are $111\,\mathrm{km\,s^{-1}}$ and $255\,\mathrm{km\,s^{-1}}$, respectively.
- Rapidly rotating stars are generally redder than slowly or non-rotating stars



Sun et al. 2019b

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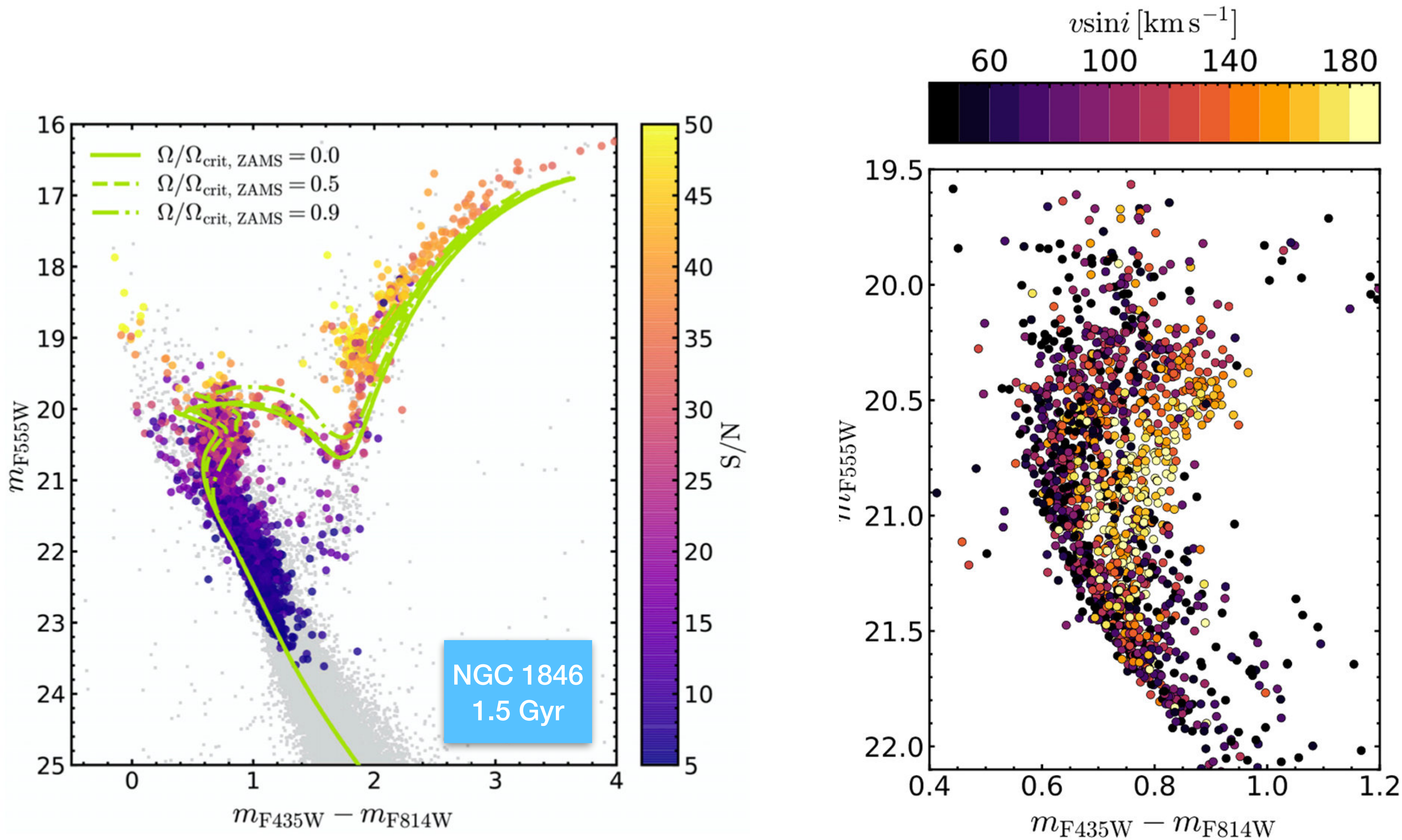
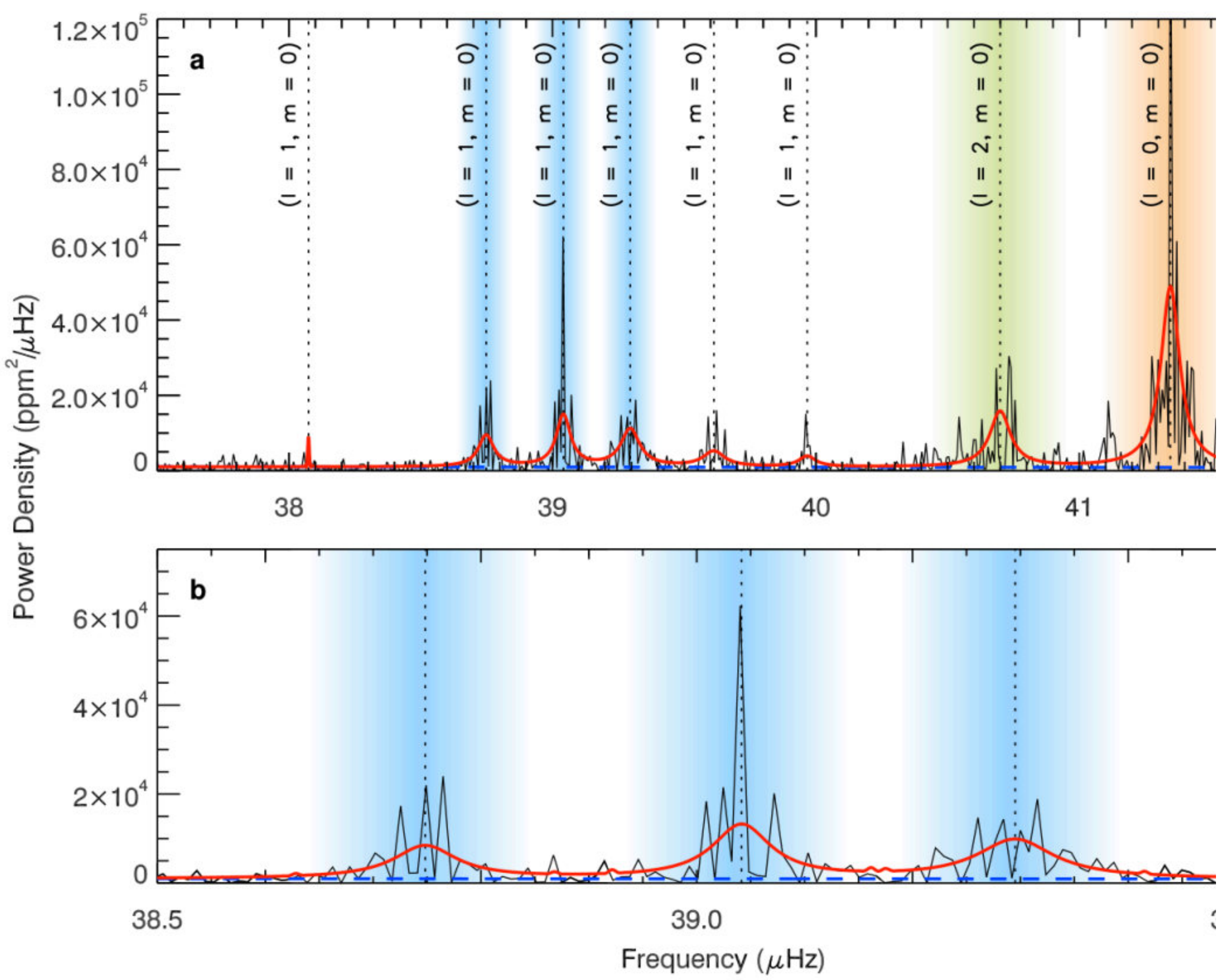
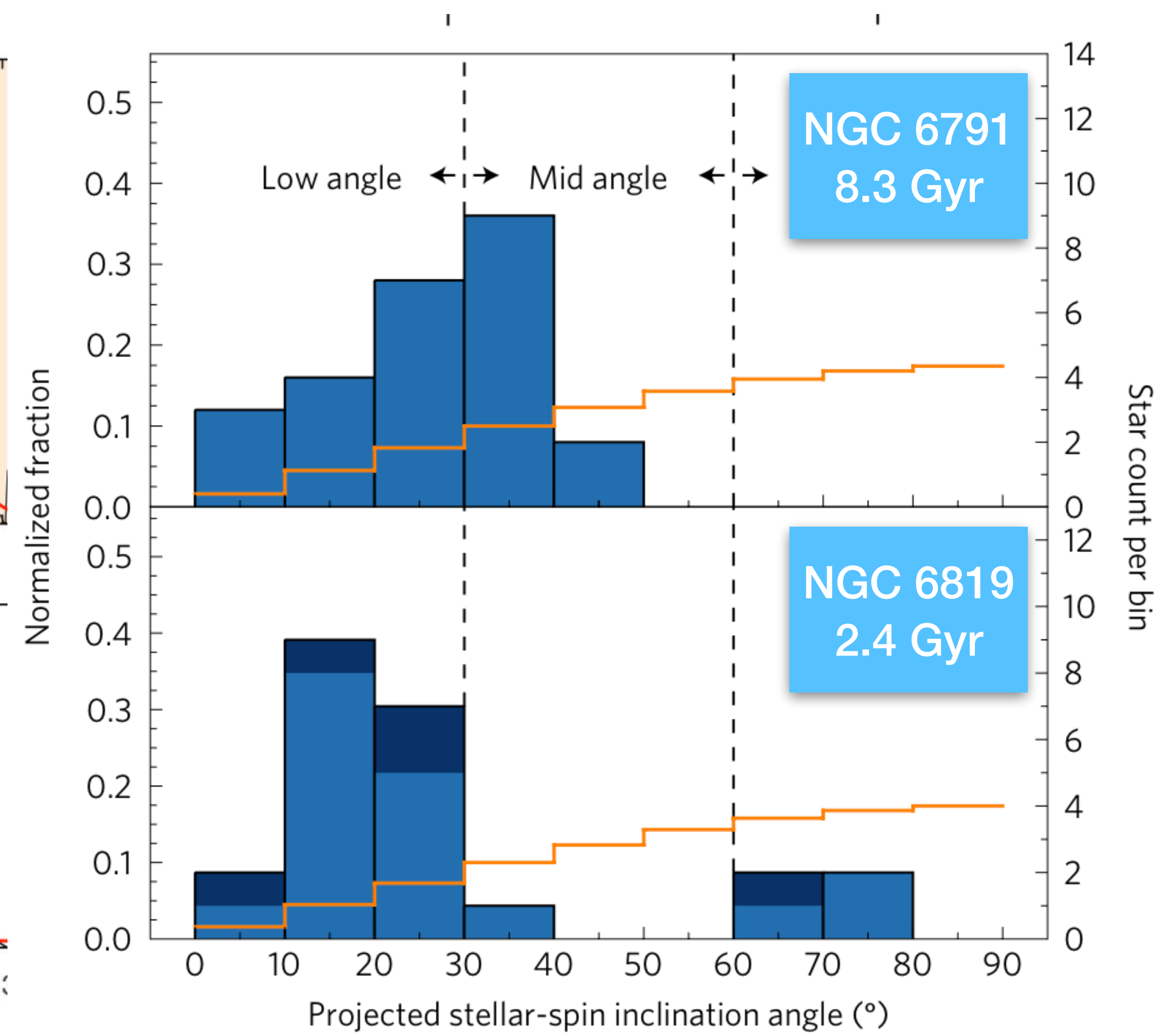


Kamann et al. 2020

From $v \sin i$ to v_{eq}

Knowledge from Asteroseismology

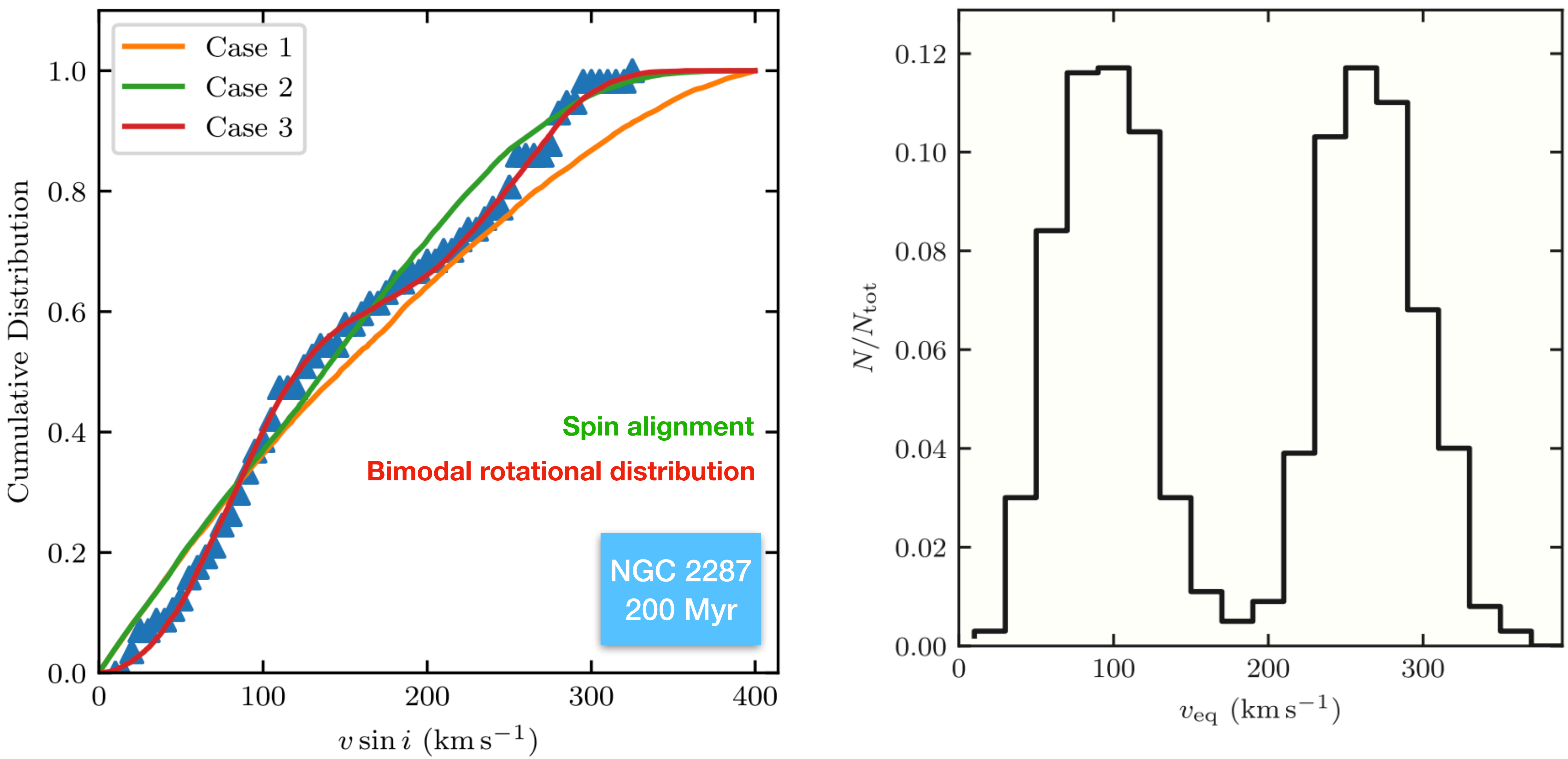




Corsaro et al. 2017

From $v \sin i$ to v_{eq}

Evidence against Spin alignment

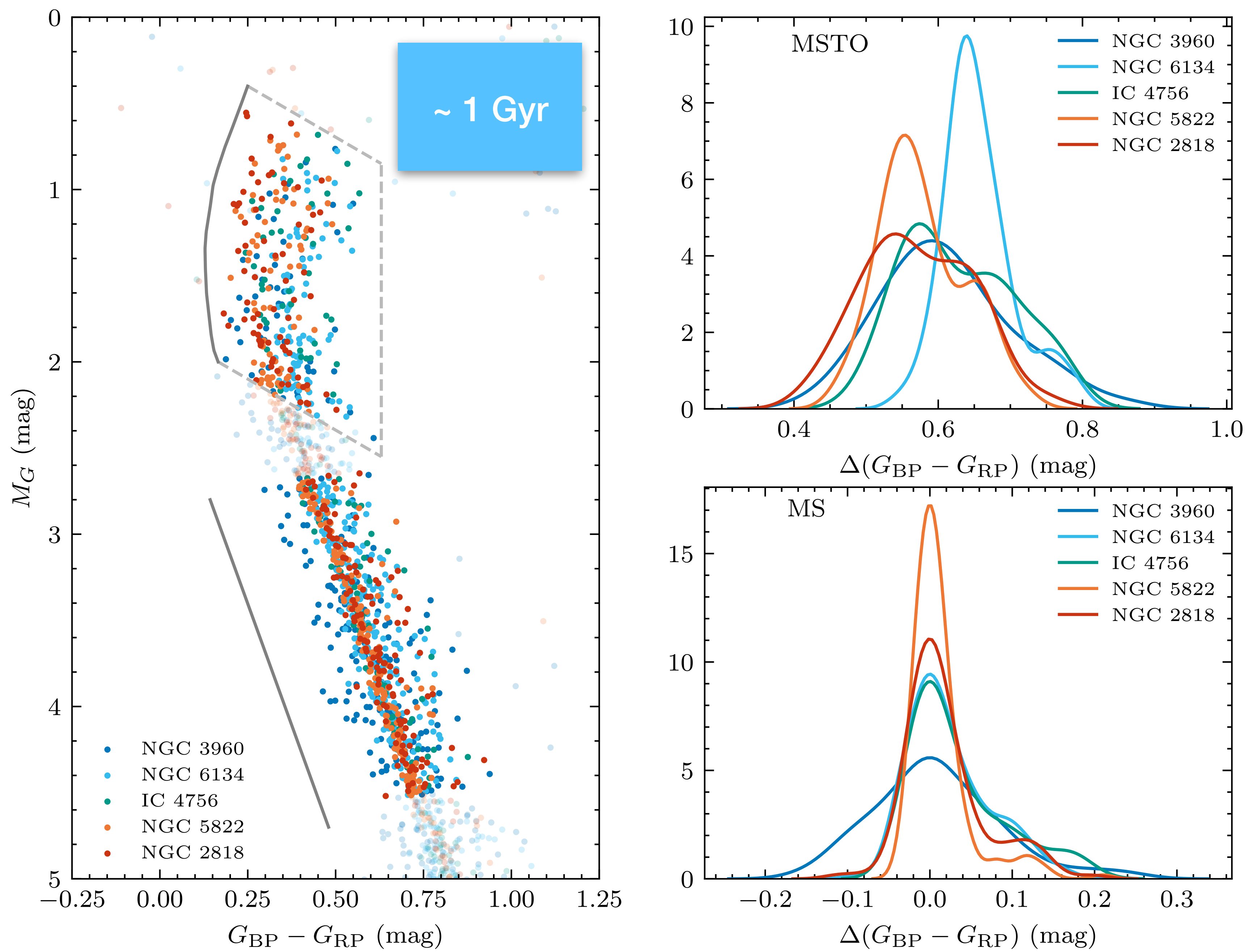


Sun et al. 2019b

Stellar rotation in star clusters

How to unravel the stellar rotation distribution

- Five Galactic OCs that have similar chronological (~ 1 Gyr) and dynamical ages
- Four clusters were observed with SALT

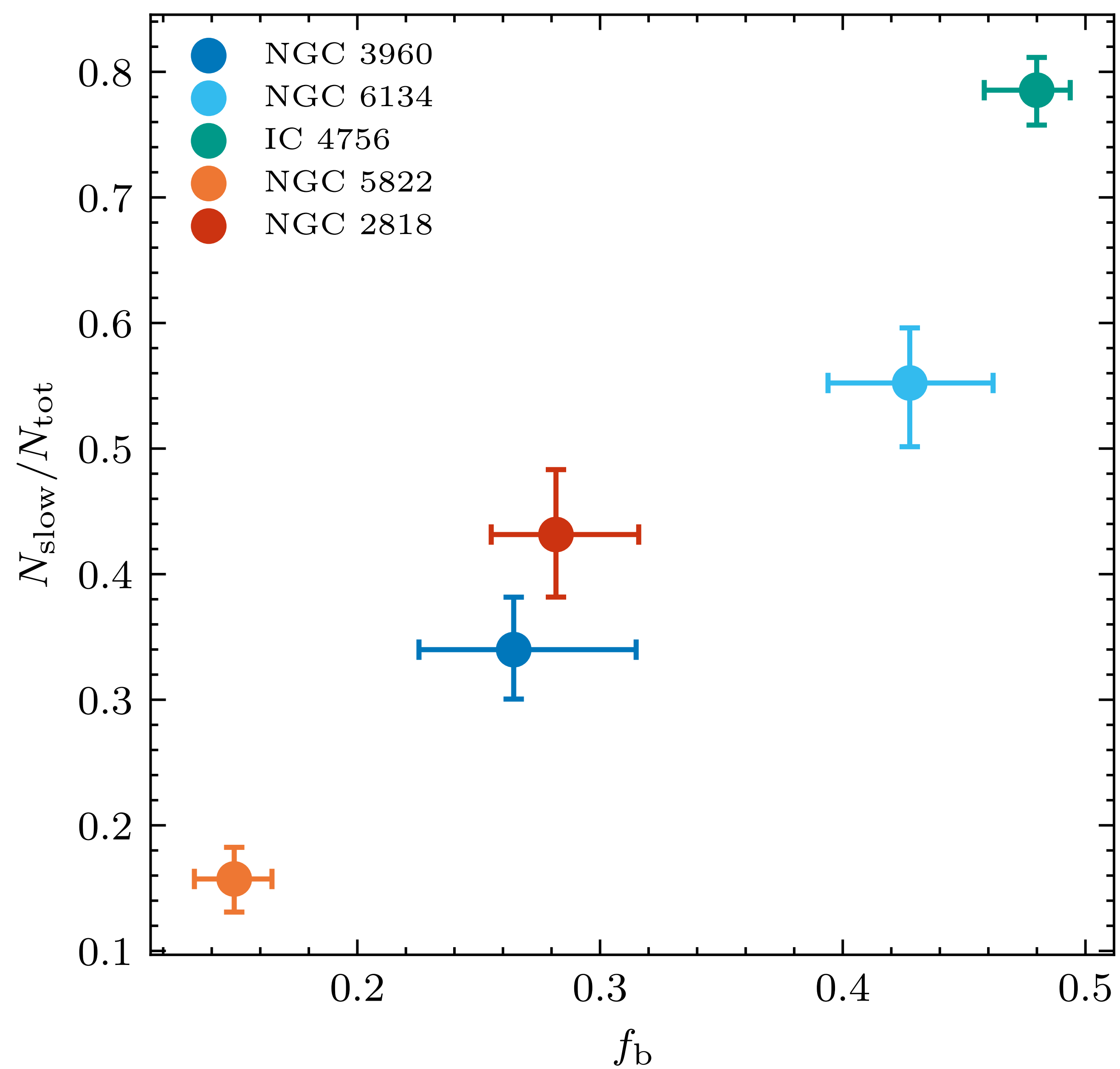


Sun et al. 2020

Stellar rotation in star clusters

Binary-driven stellar rotation evolution

- $N_{\text{slow}}/N_{\text{tot}}$
- A tight correlation between the number ratio of slow rotators and the clusters' binary fractions



Stellar rotation in star clusters

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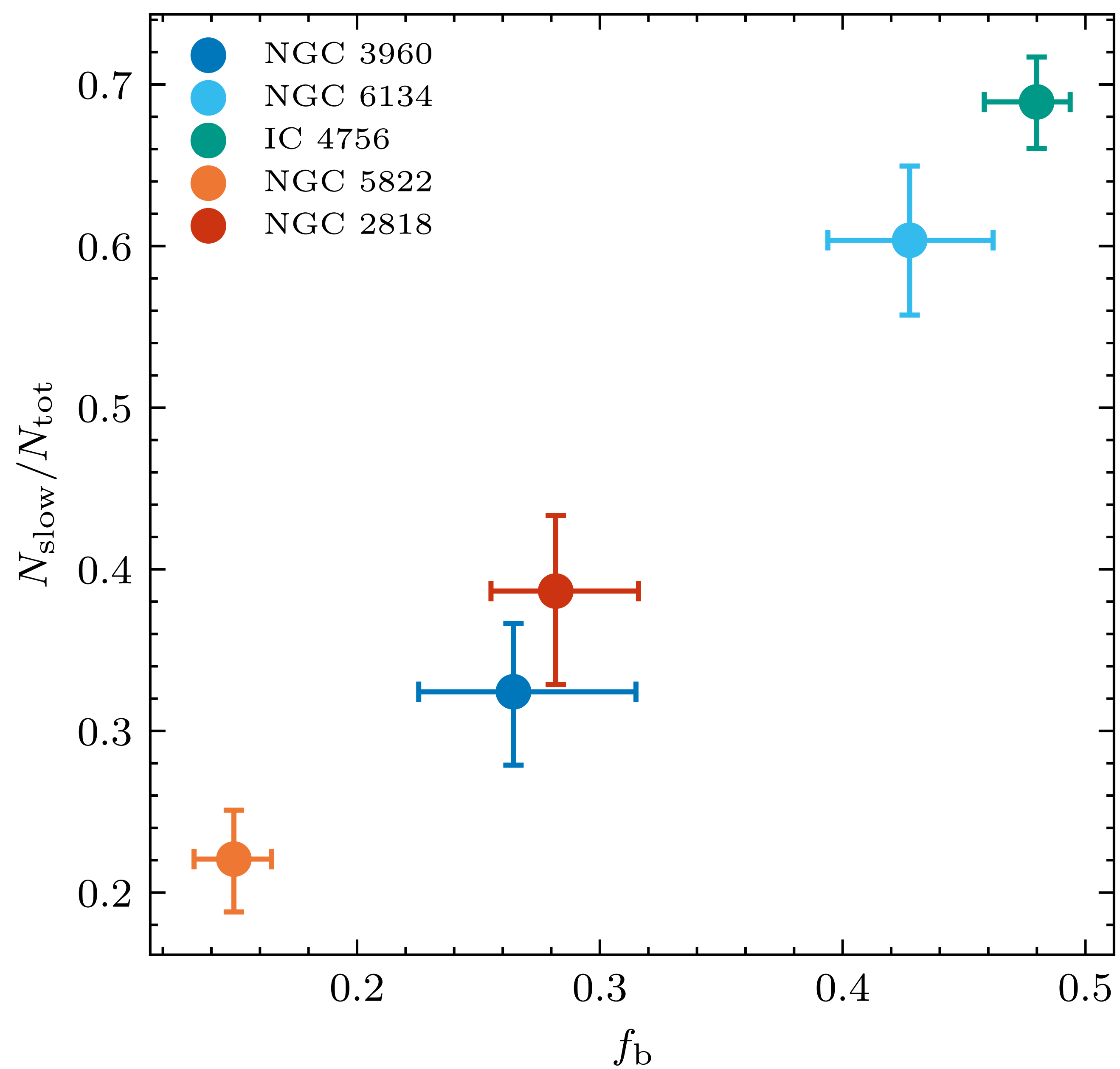

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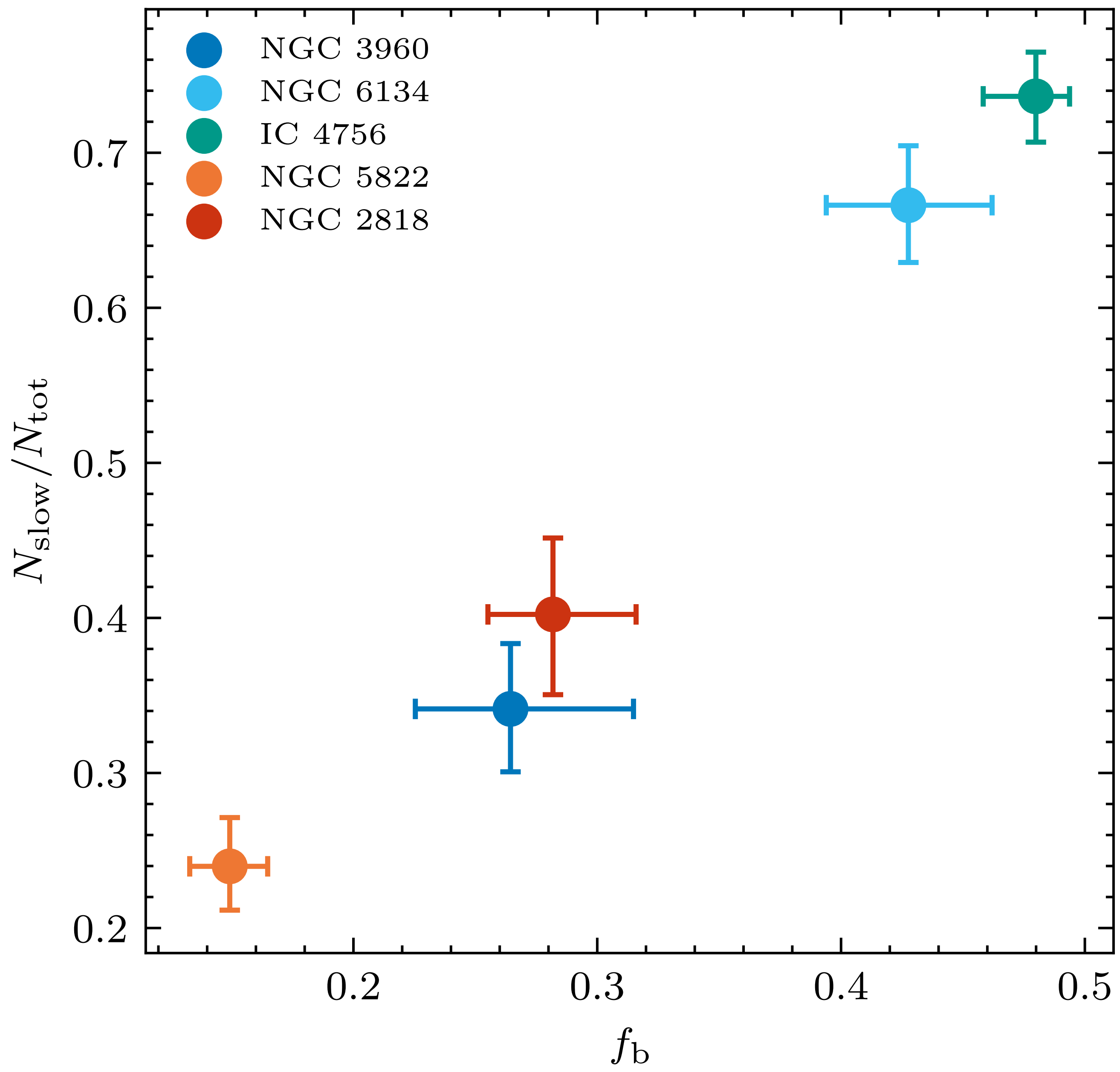
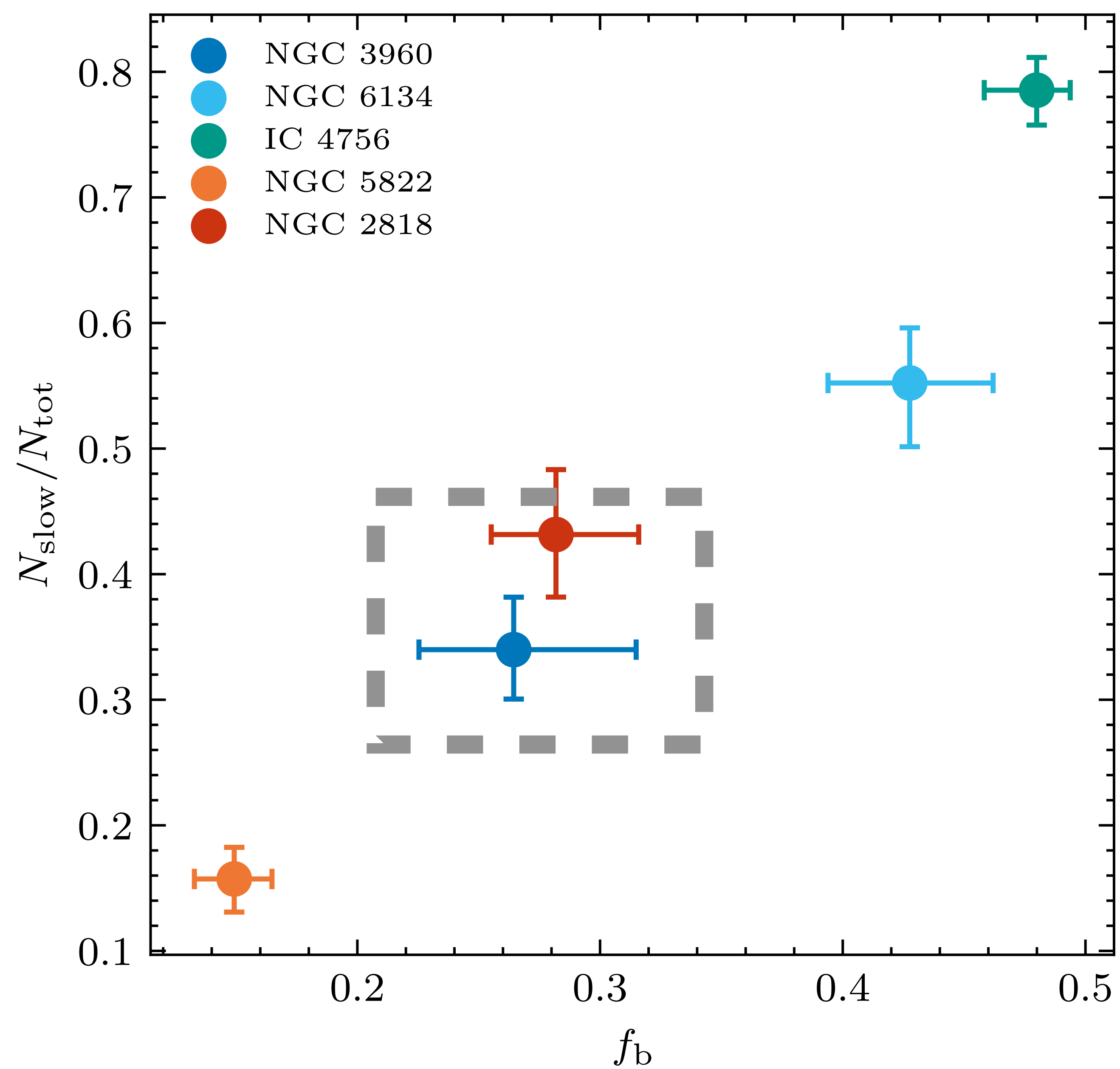


Binary-driven stellar rotation evolution

Does it exist in Magellanic Clouds?

- Magellanic Clouds clusters have approximately constant number ratios (25% — 45%)
- Their binary fractions are around 0.3



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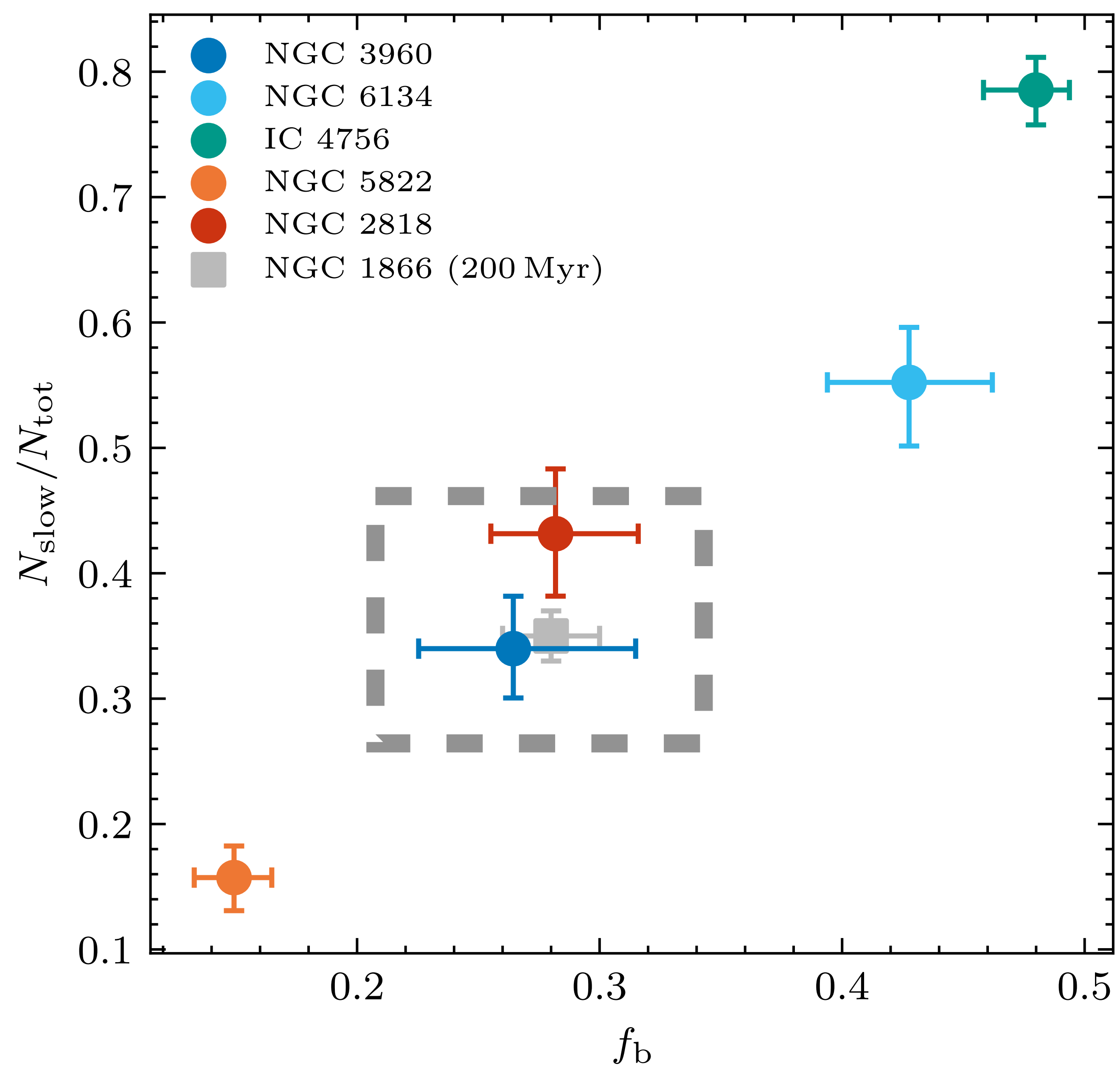

Binary-driven stellar rotation evolution

Does it exist in Magellanic Clouds?

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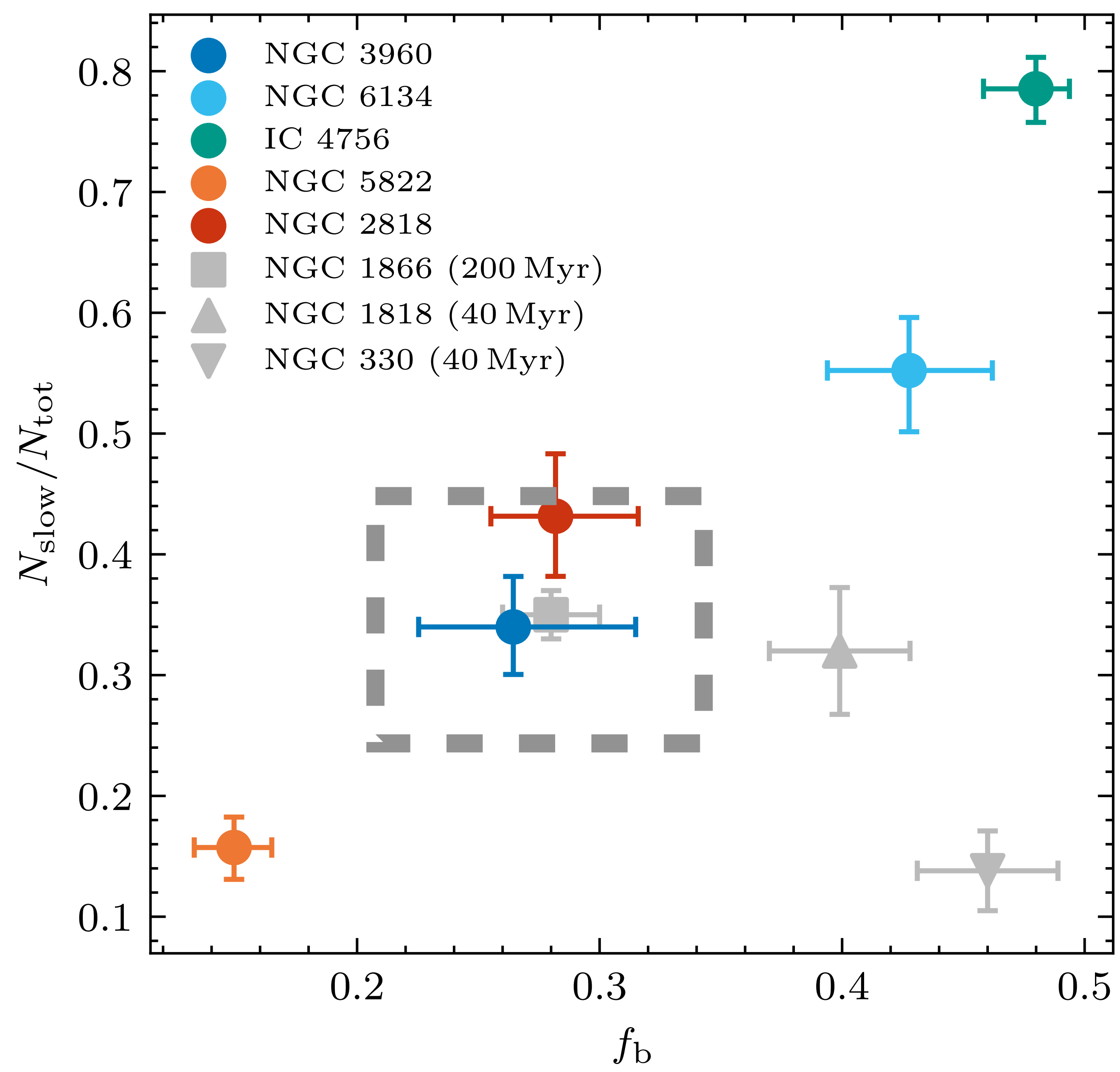
- Young clusters evolve toward this correlation through dynamical evolution



What causes the correlation?

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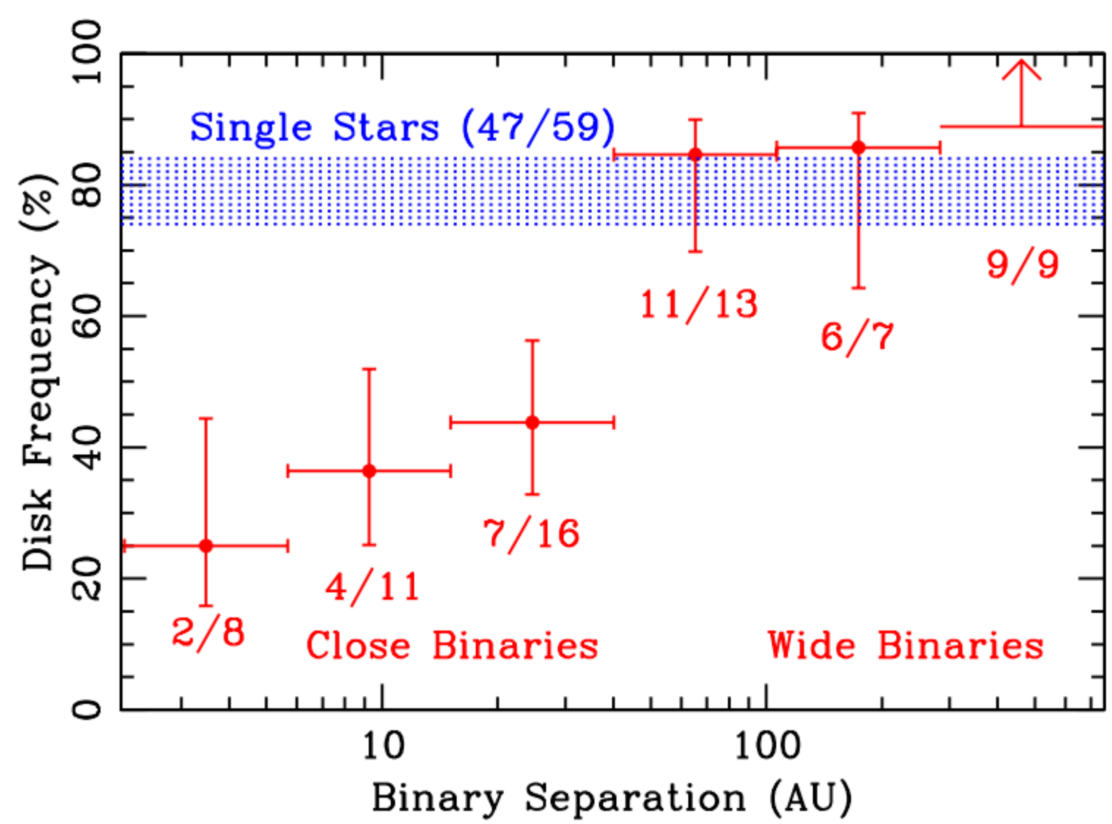
Scenario A

- Within the first few Myr:
  Slow rotators have been able to retain their circumstellar discs throughout their PMS lifetimes while rapid rotators may have lost the discs destroyed by binaries (Bastian et al. 2020)
  Disk-locking

- Binaries may be expected to destroy discs around the individual stars

- Higher f_b ->
  Shorter disk lifetime ->
  Less slow rotators

- In **conflict** with our results



Kraus et al. 2012

What causes the correlation?

Scenario B

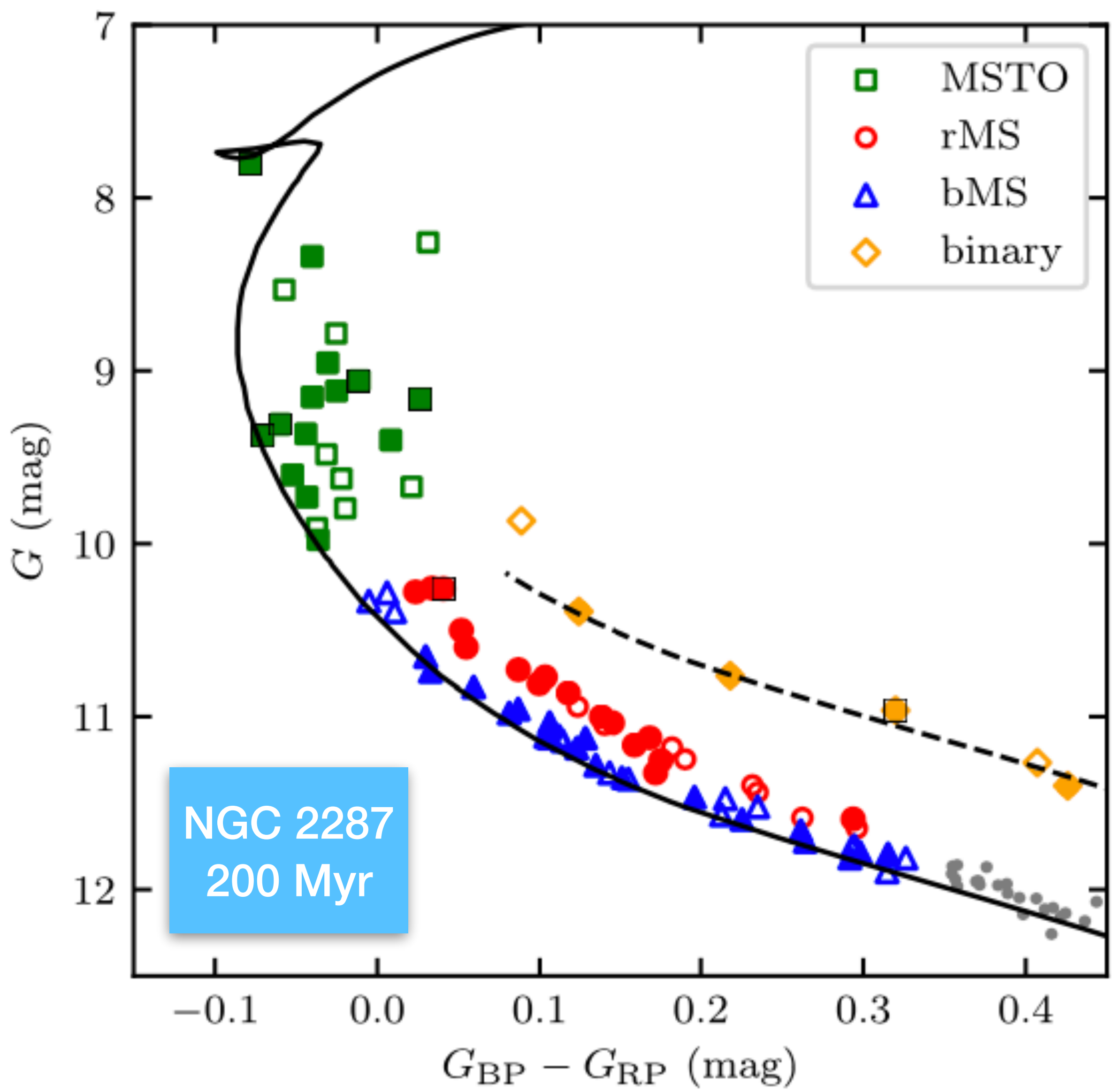
- a few tens of millions of years:
  bMS in young clusters might be the outcome of braking of the rapidly rotating population. The deceleration might be due to interaction between close binaries through magnetic-wind braking or tidal torques (D'Antona et al. 2015 & 2017)
  Tidal-locking

- Higher binary fraction ->
  More slow rotators

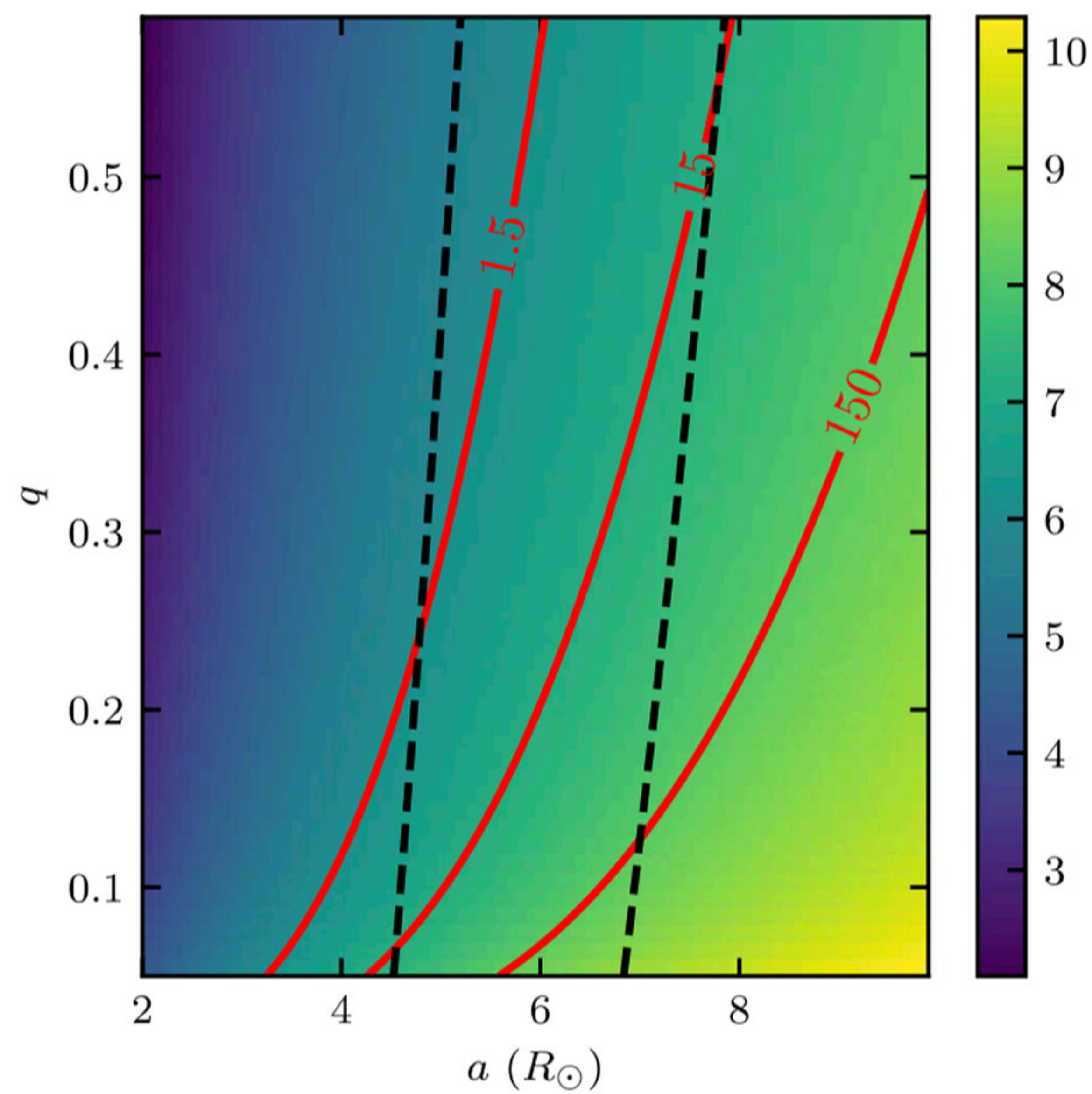
- Only close binaries may
  become tidally locked

What causes the correlation?

Scenario B



Synchronization timescale



Sun et al. 2019b

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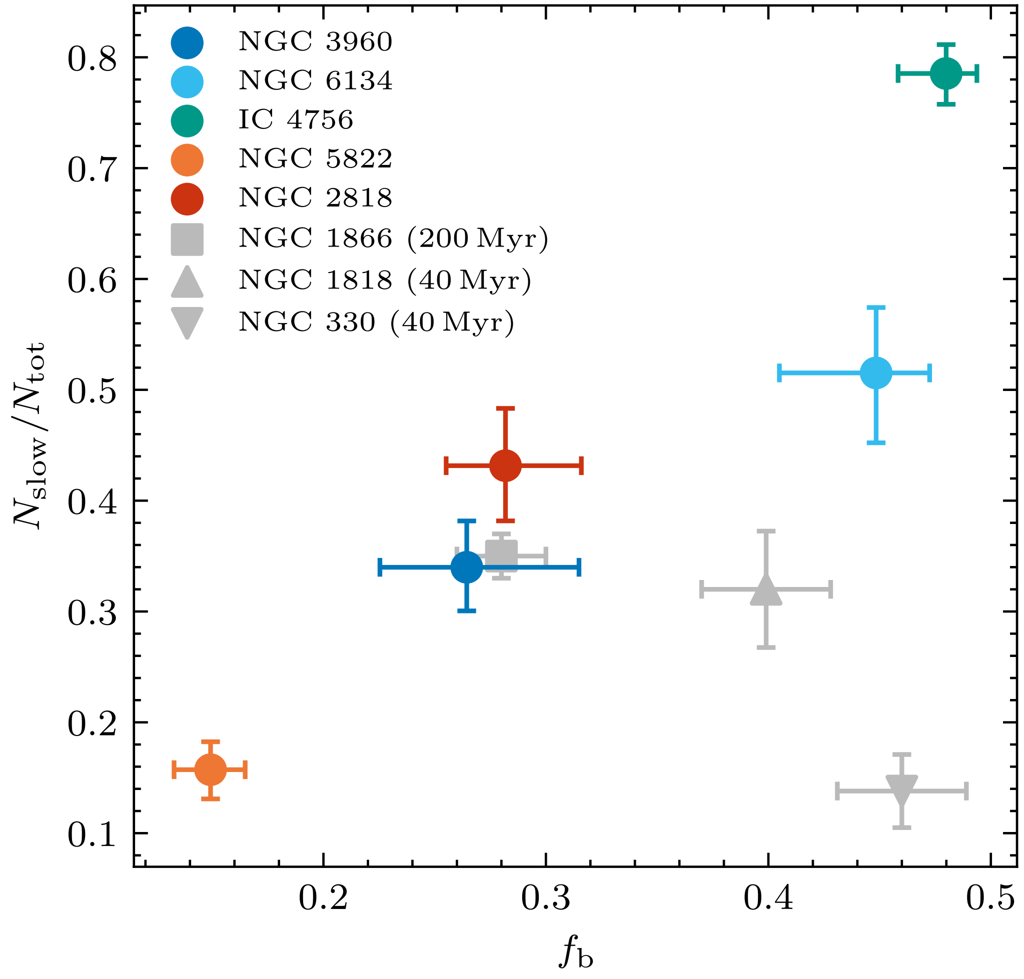
  Tidal-locking

- Higher binary fraction ->
  More slow rotators

- Only close binaries may become tidally locked

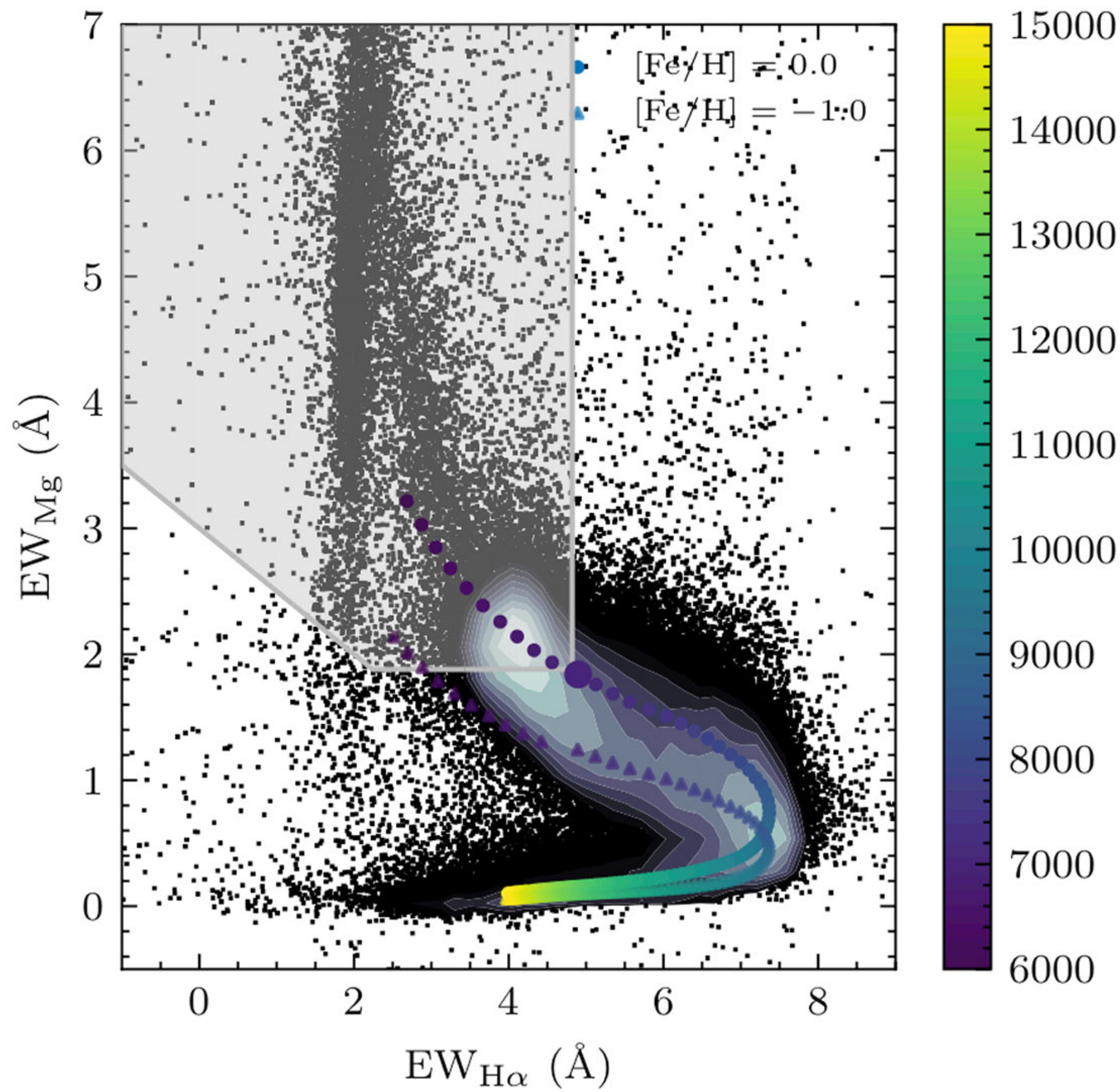
- N_{slow}/N_{tot} is **comparable** to f_b in our result

- The slope is **greater** than unity



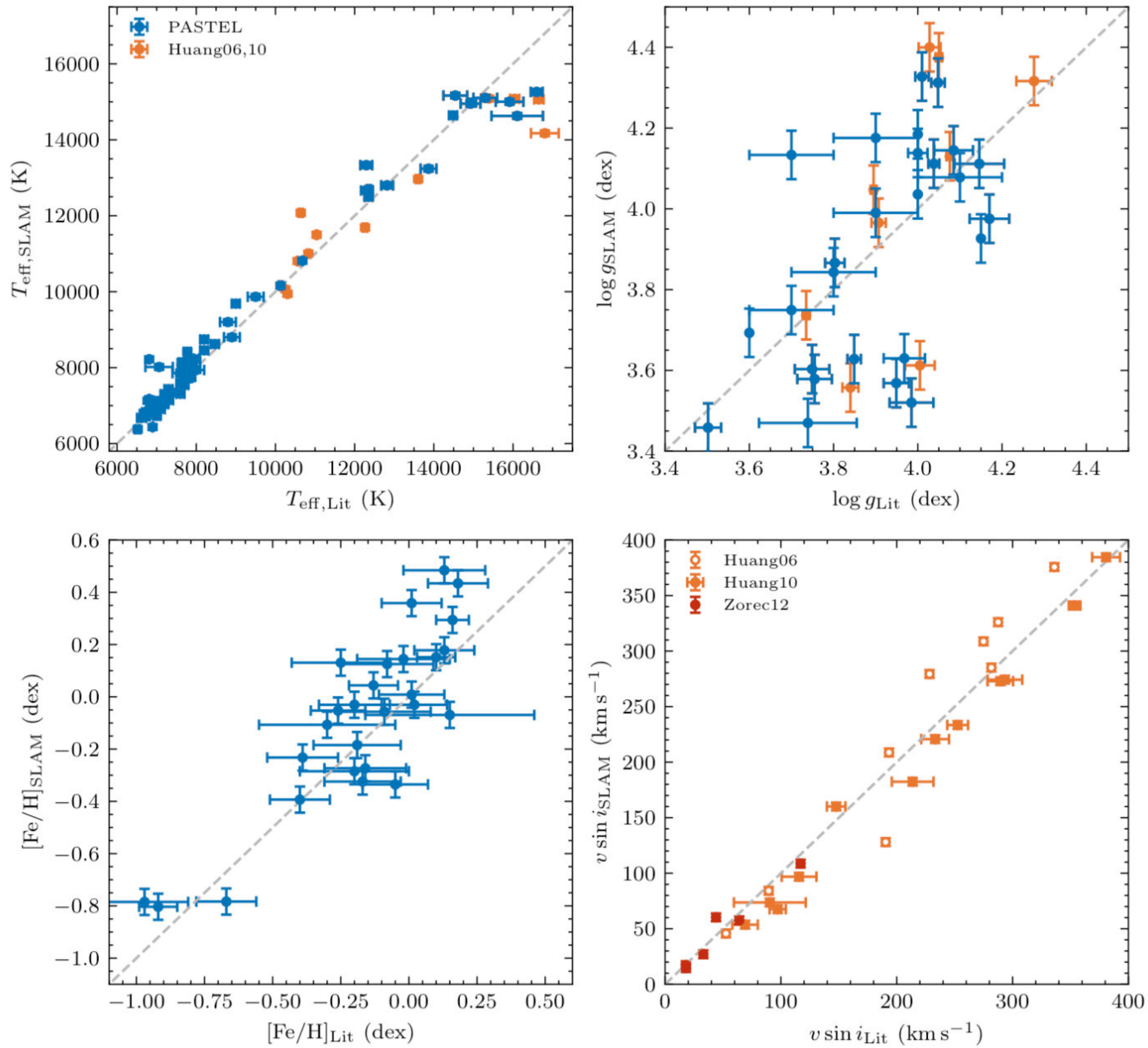
Do we know rotation in the field?

- LAMOST MRS DR7, with $v \sin i$ down to a few km/s
- Line indices of Mg Ib and Hα
- Stellar LAbel Machine (SLAM)
- Scatters for $T_{\rm eff}$, $\log g$, [M/H], and $v \sin i$ are $\sim$ 75 K, 0.06 dex, 0.05 dex, and 3.5 $\rm km\,s^{-1}$



Sun+2021a, submitted to ApJS

Do we know rotation in the field?



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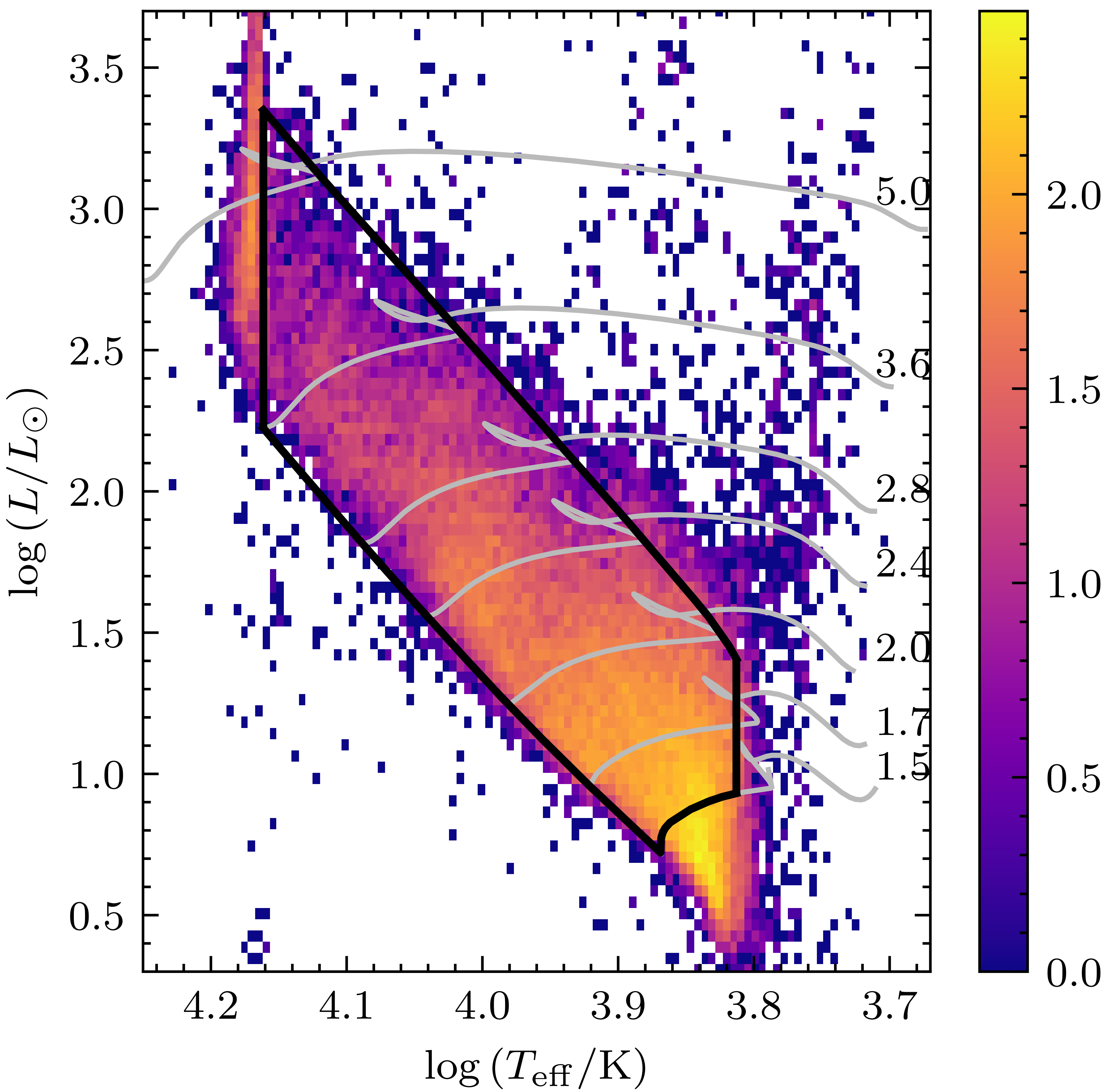
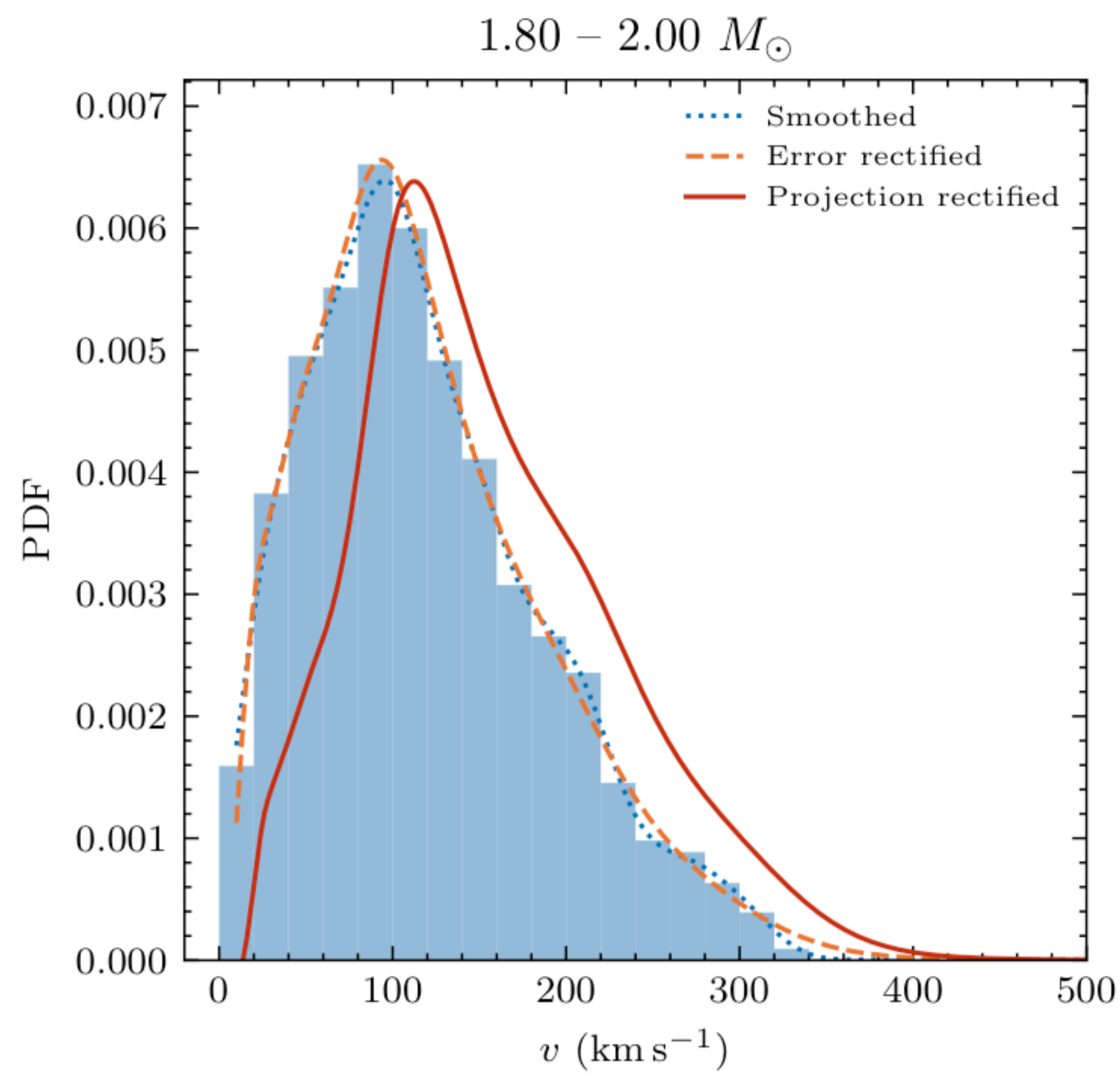


Do we know rotation in the field?

- The largest catalog (40034) of late-B and A-type main sequence stars from LAMOST MRS DR7
- We can statistically rectify the projection effect and the error distribution
- Contamination is important (binary, chemical peculiar stars, periodic variables, cluster members)

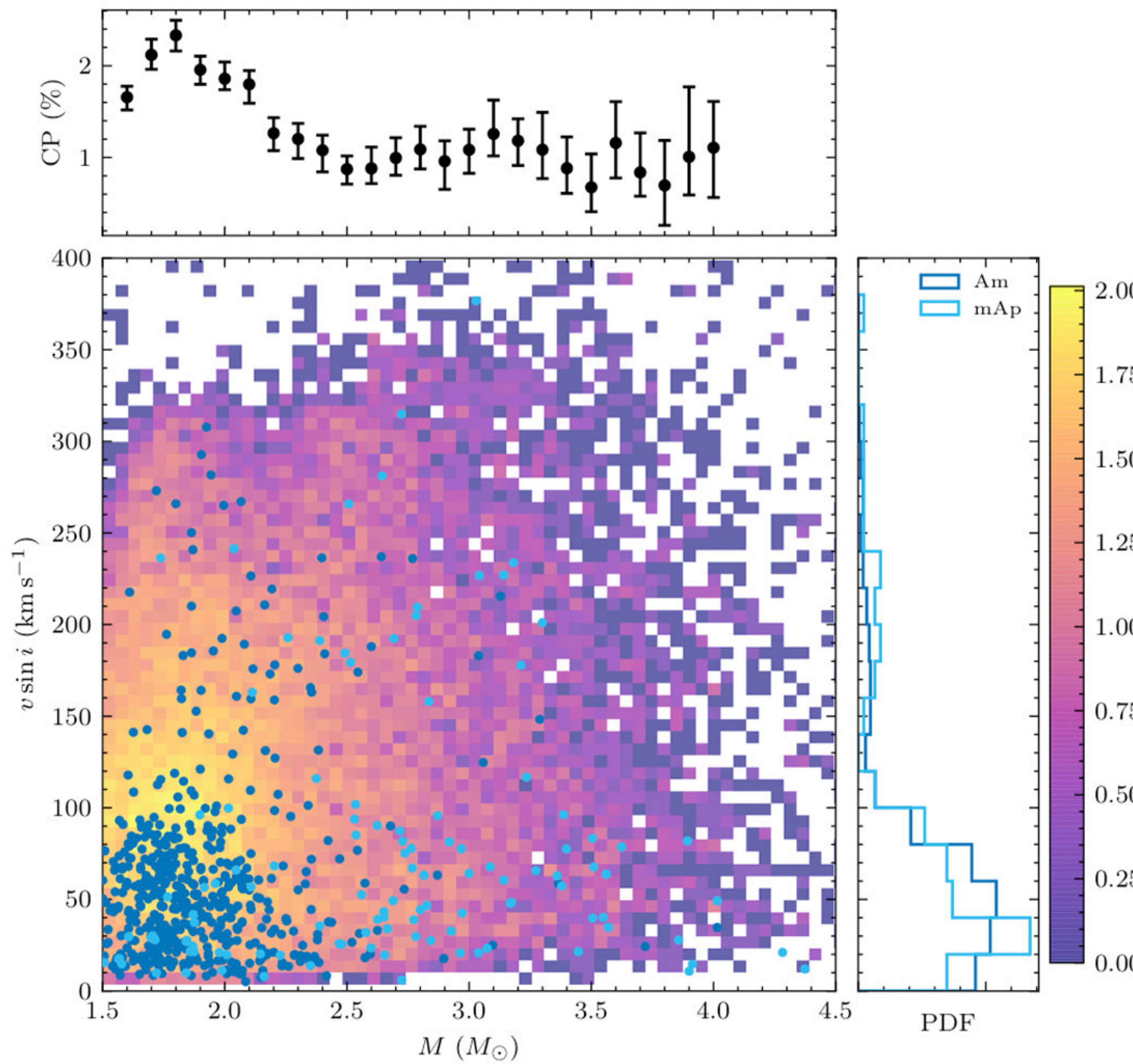


Sun+2021b, accepted by ApJ

Do we know rotation in the field?

Chemical peculiar stars

- early-type MS stars exhibiting anomalous chemical abundances
- metallic line (Am), magnetically peculiar (mAp), stars with enhanced Hg ii and Mn ii (HgMn), and He-weak stars
- CP stars tend to be slow rotators



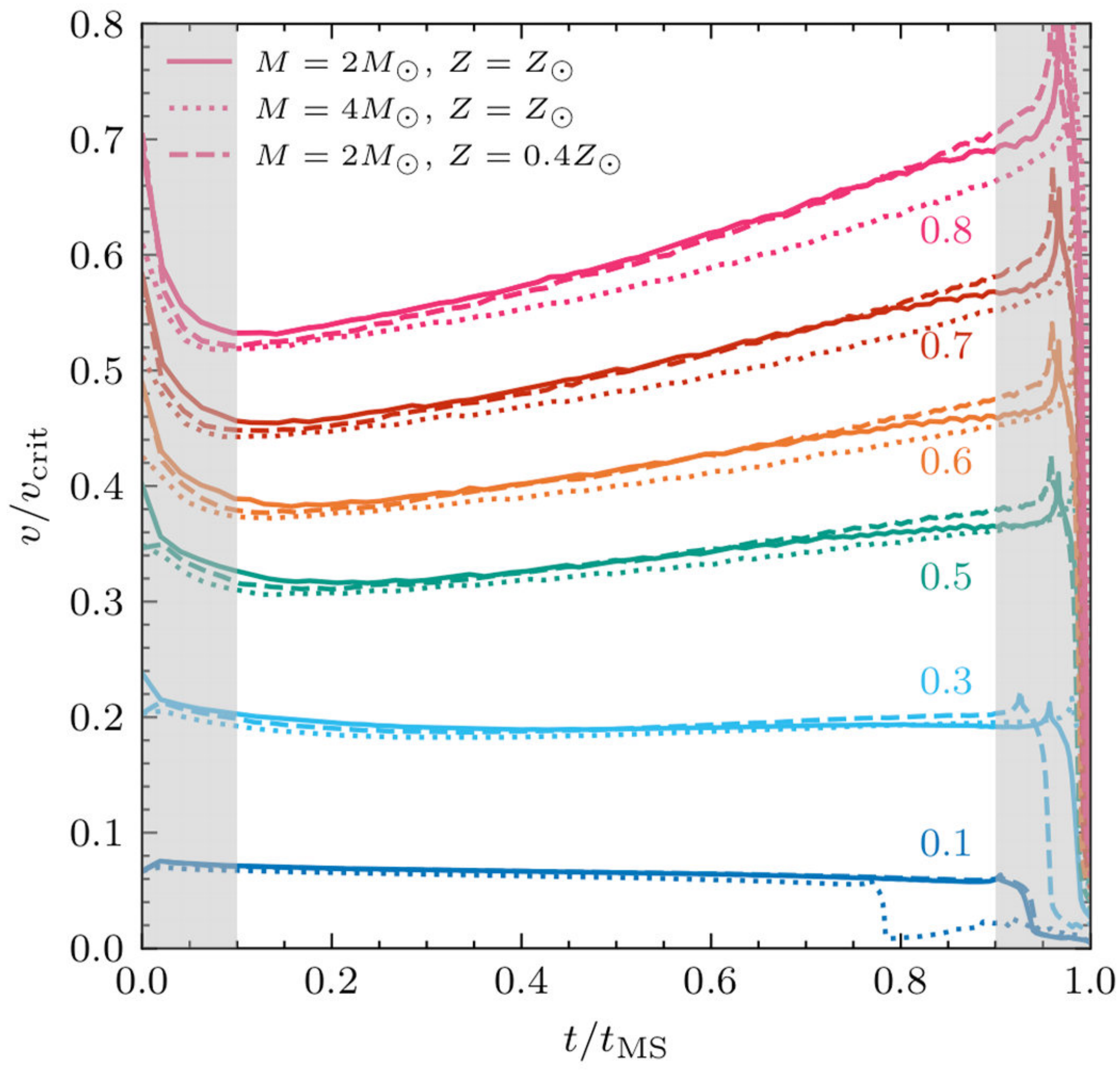
Do we know rotation in the field?

How to quantify rotation?

- $v\left(M, \omega_{\text{init}}, t/t_{\text{MS}}\right)$

- v changes as a function of time, and also depends on the stellar mass

- v/v_{crit} is almost constant over its MS lifetime



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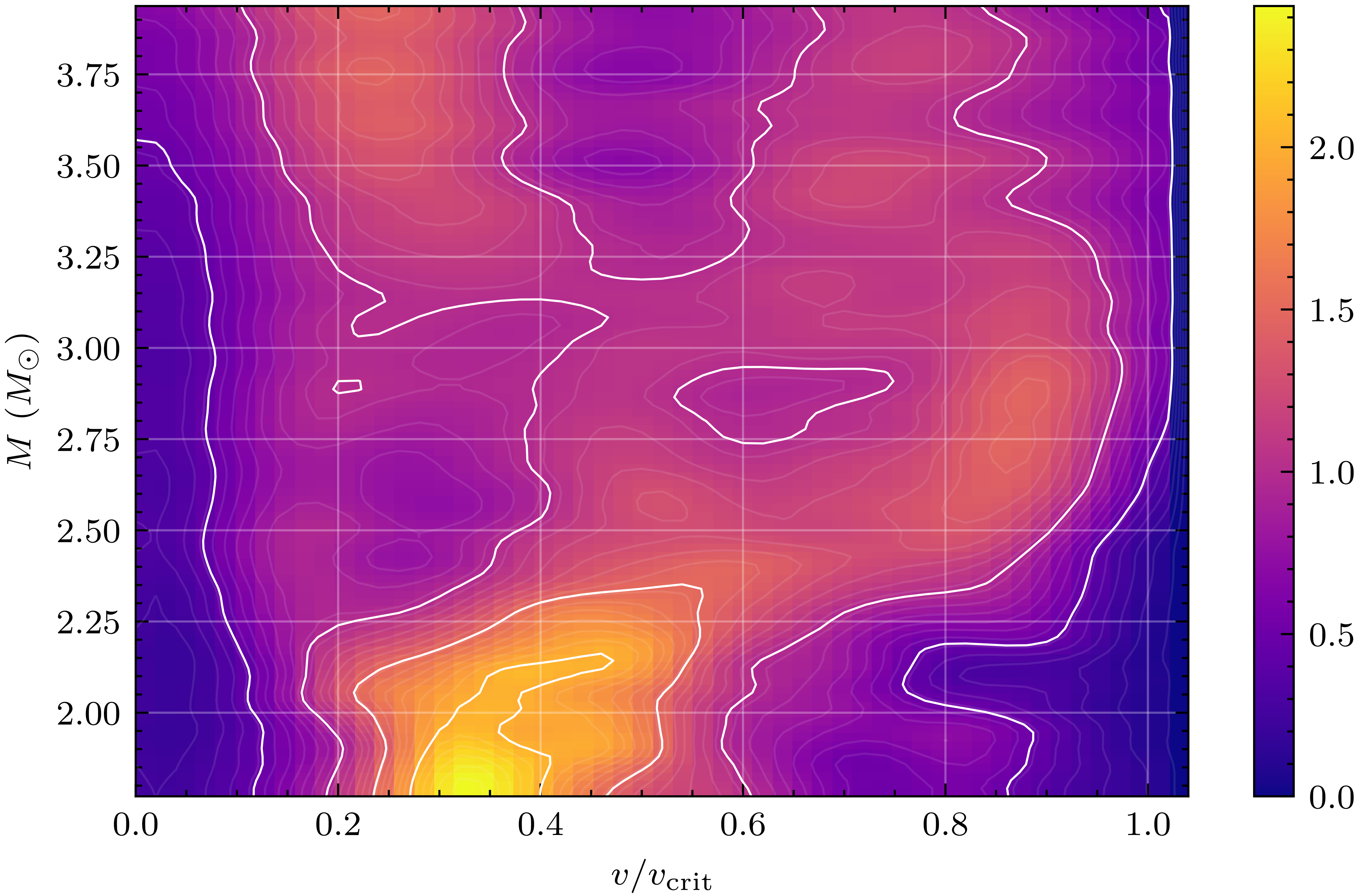

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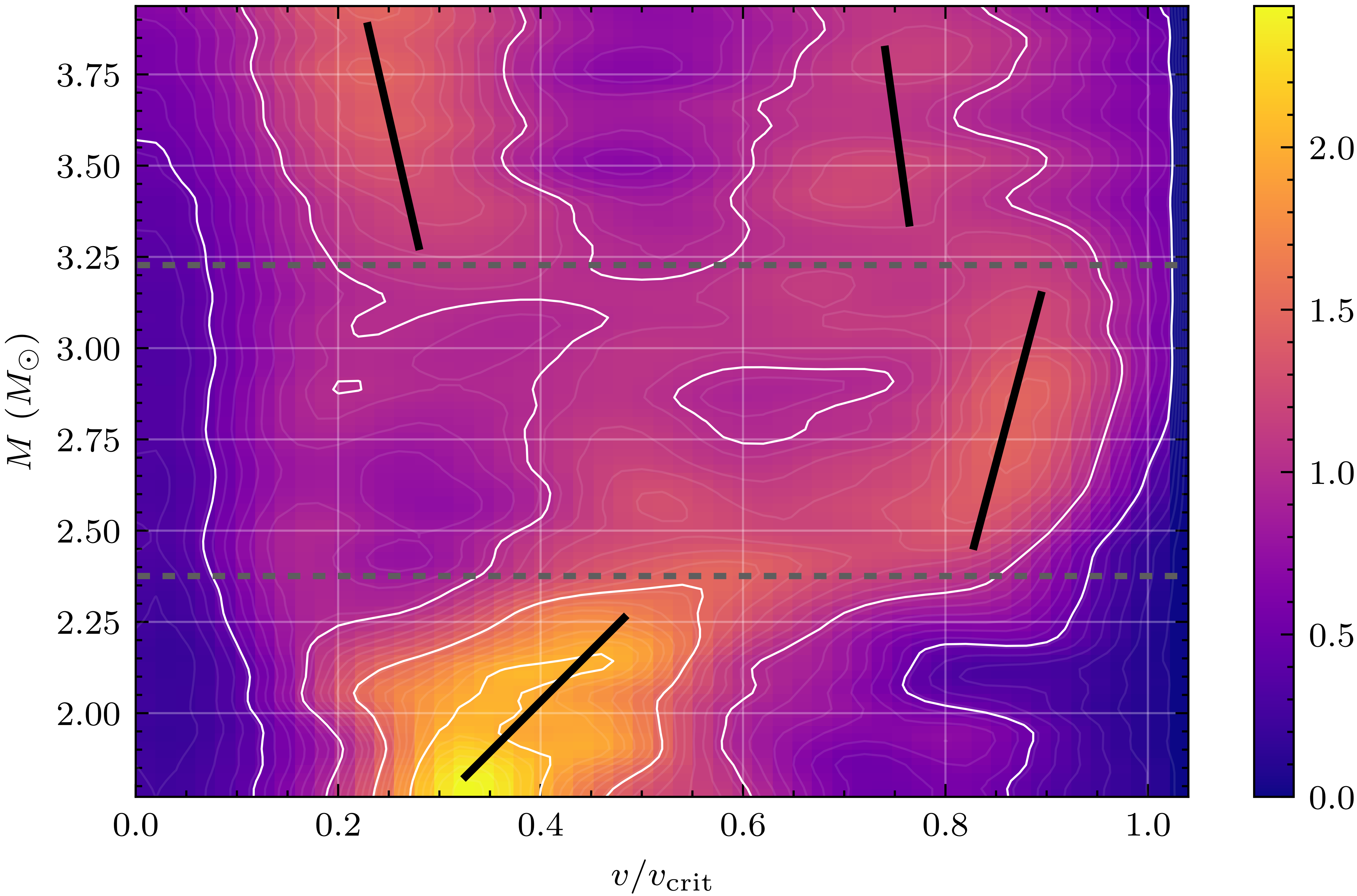

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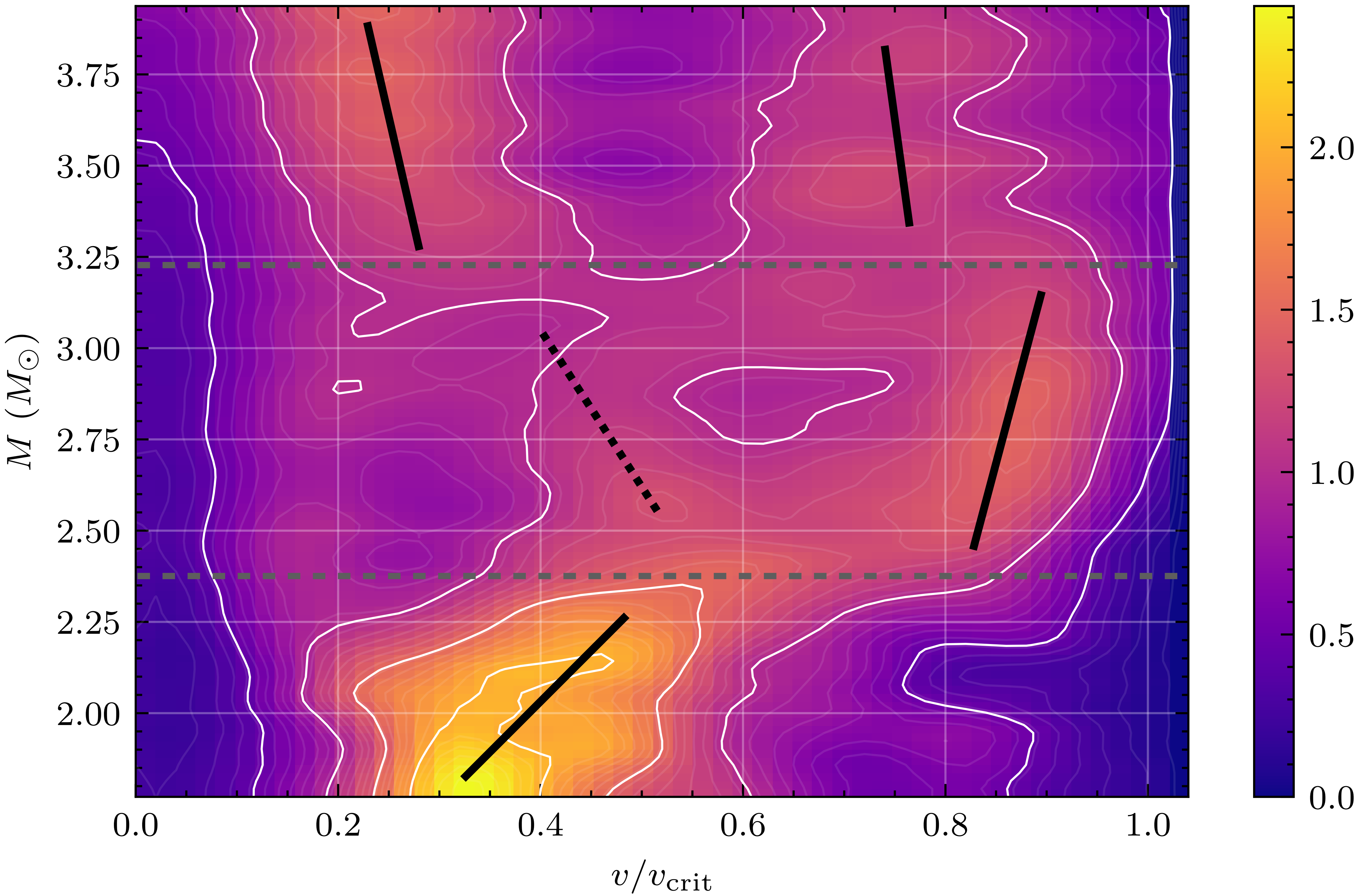
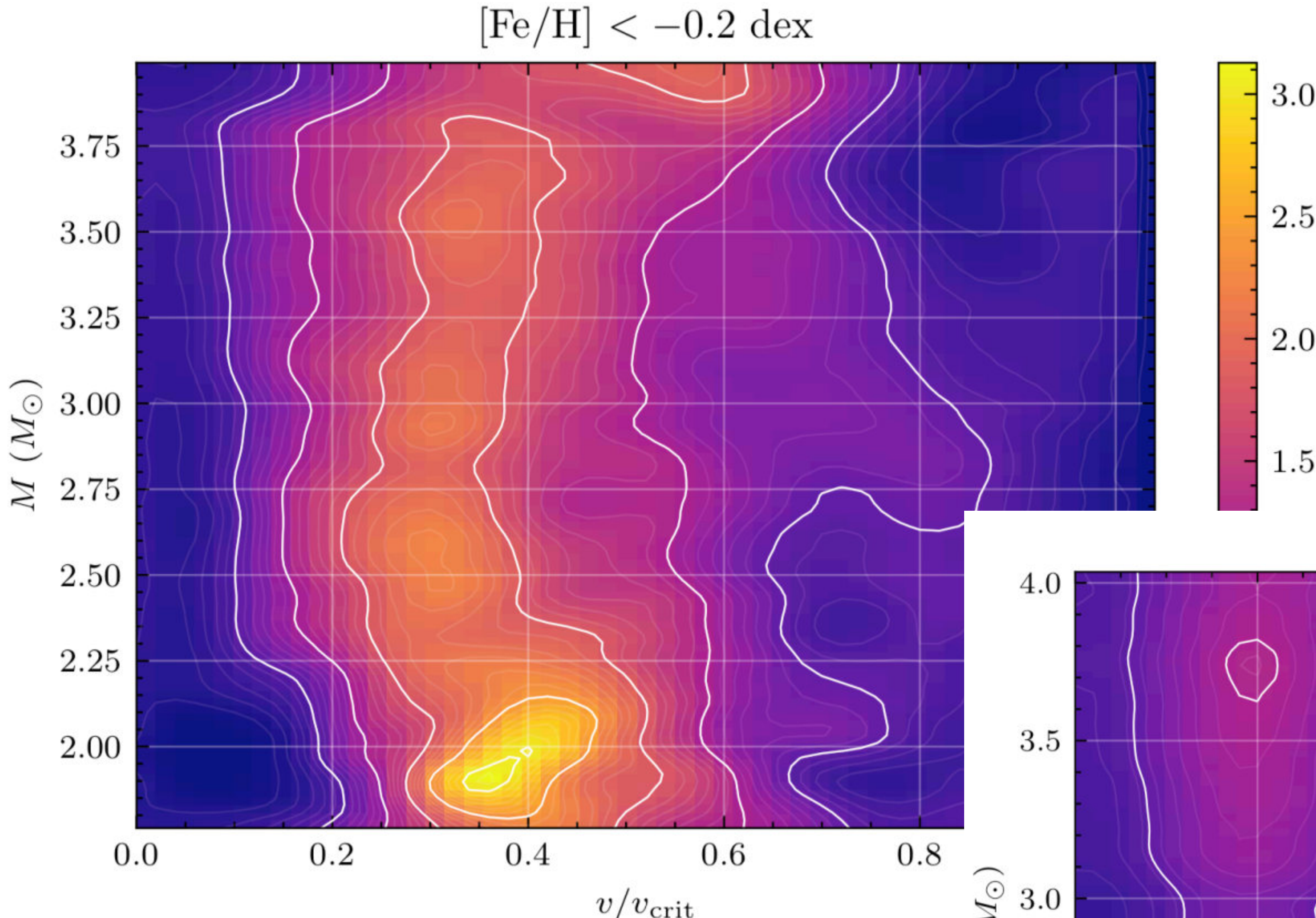
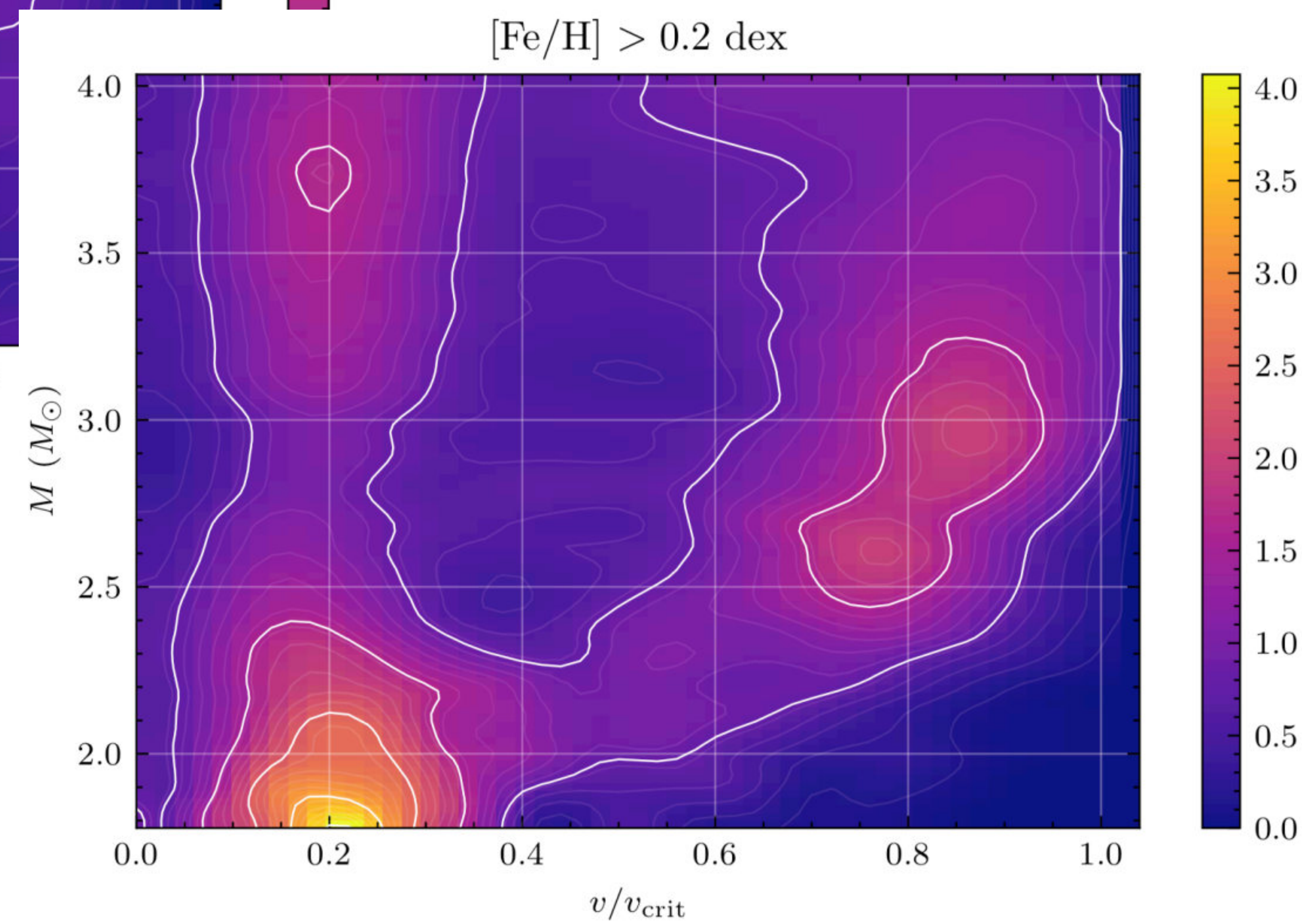


Do we know rotation in the field?

Dependence on metallicity

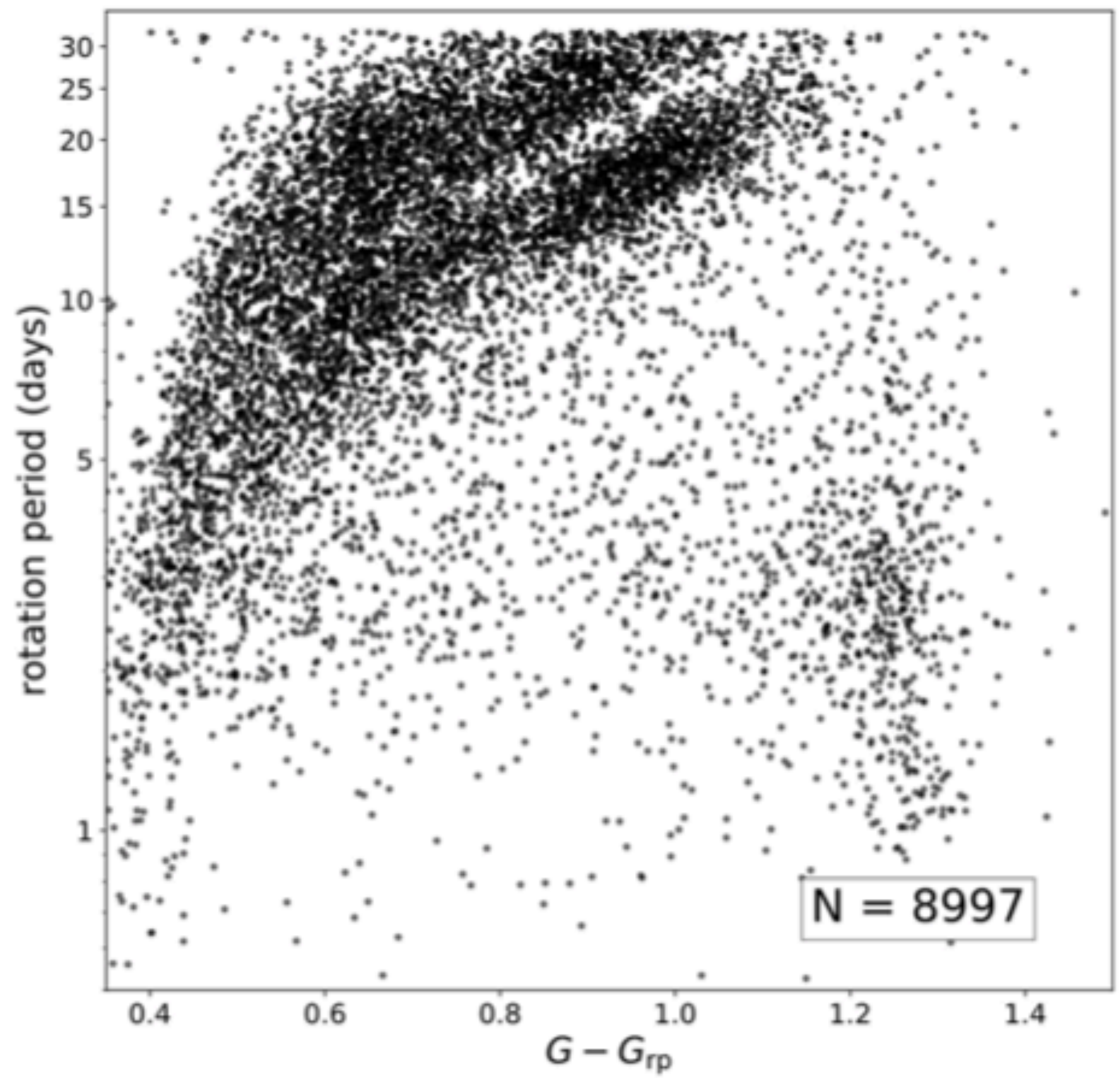




Do we know rotation in the field?

Bimodality in late-type MS stars

- K2 targets with Gaia DR 2
- A gap in the rotation period-color diagram $0.57M_\odot < M < 0.76M_\odot$
- Departure from Skumanich spin down law rather than a bimodal star formation history



Gordon+2021

Take-home message

- Differences in stellar rotation rates are a key driver of extended MSTOs and split MSs in star clusters.
- Fast rotators appear redder than their slowly rotating counterparts.
- Bimodal rotation distribution is prevalent in star clusters and field (but at different mass regime)
- We still don’t know the origin of such bimodality, future long-term photometric observation could be beneficial