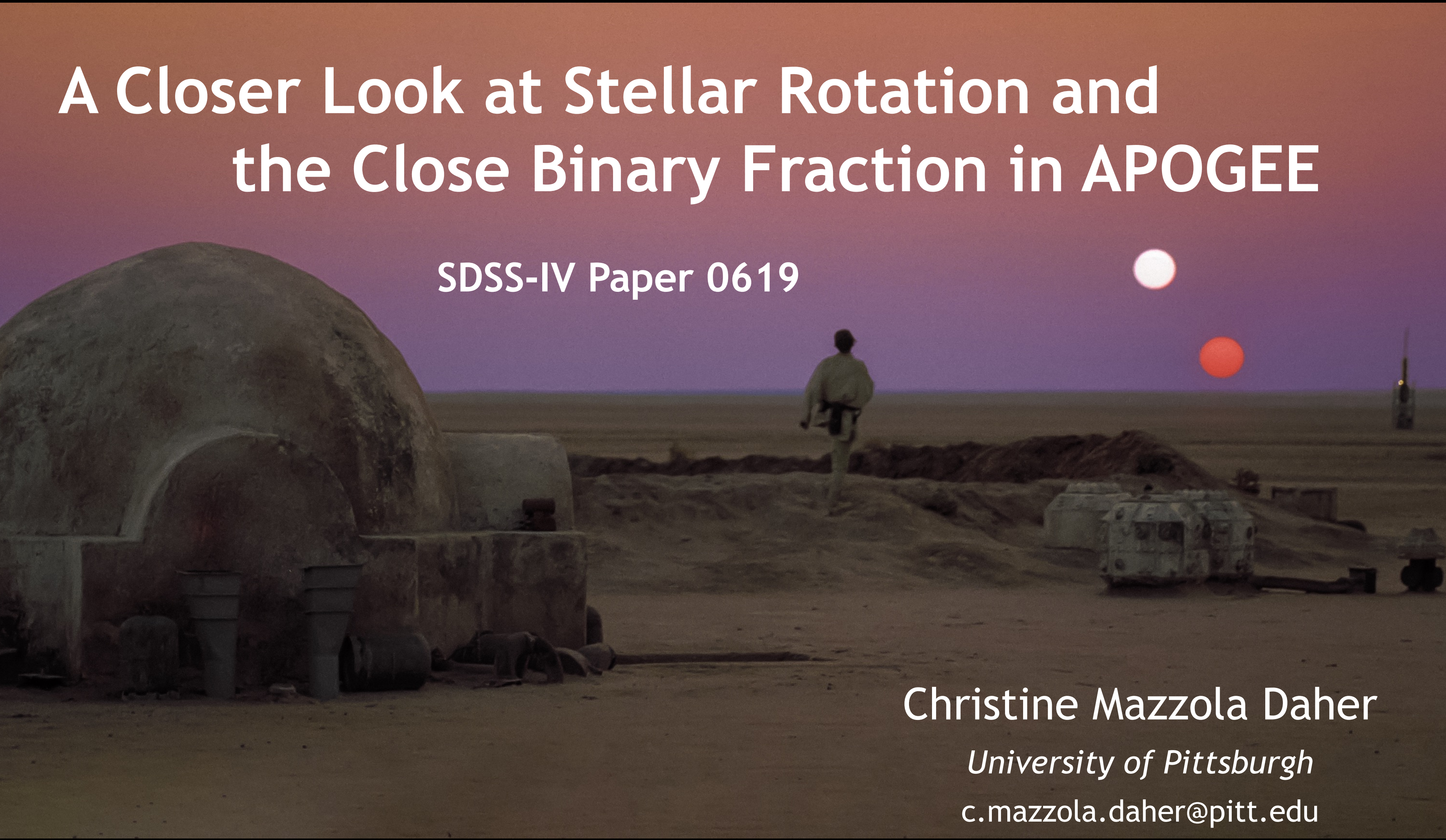
A Closer Look at Stellar Rotation and the Close Binary Fraction in APOGEE

SDSS-IV Paper 0619



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So why study binaries anyway?

Because stellar multiplicity affects or is tied to practically every area of astronomy!

Astro2020 Science White Paper

Stellar multiplicity: an interdisciplinary nexus

Thematic Areas: ☑ Planetary Systems ☑ Star and Planet Formation
☑ Formation and Evolution of Compact Objects ☑ Cosmology and Fundamental Physics
☑ Stars and Stellar Evolution ☑ Resolved Stellar Populations and their Environments
☑ Galaxy Evolution ☑ Multi-Messenger Astronomy and Astrophysics

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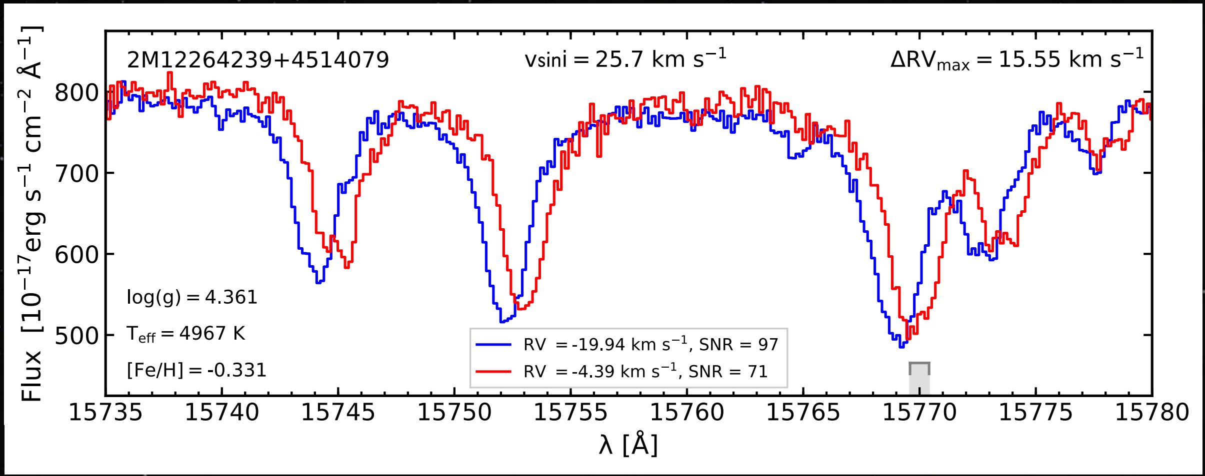
Close Binaries in APOGEE DR14

APOGEE RVs, T_{eff}, log(g)



Daher+21 (in-prep)

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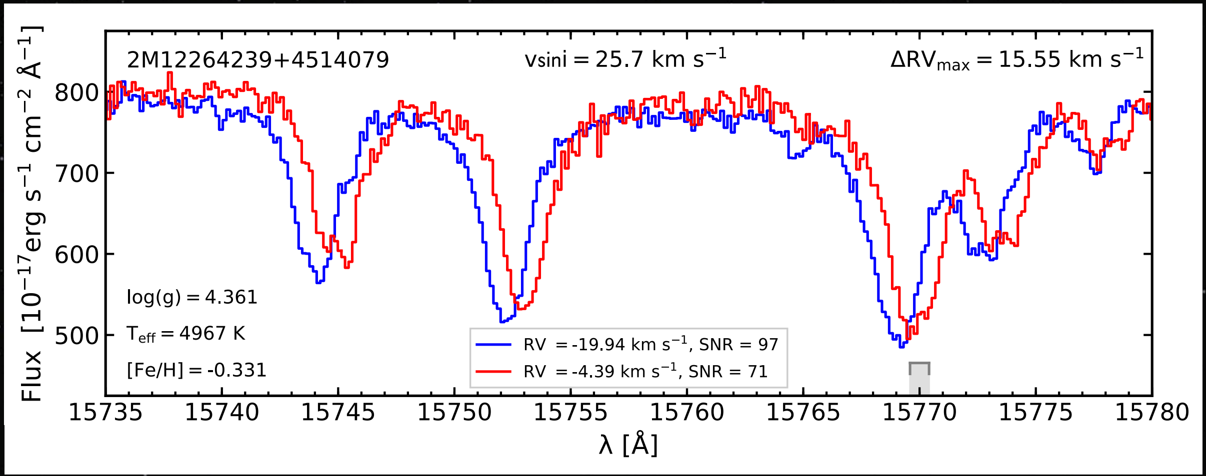
APOGEE RVs, T_{eff}, log(g)

v sin(i) : ASPCAP value + extra rotation fit by Jamie's pipeline

[Tayar+2015, Dixon+2020]



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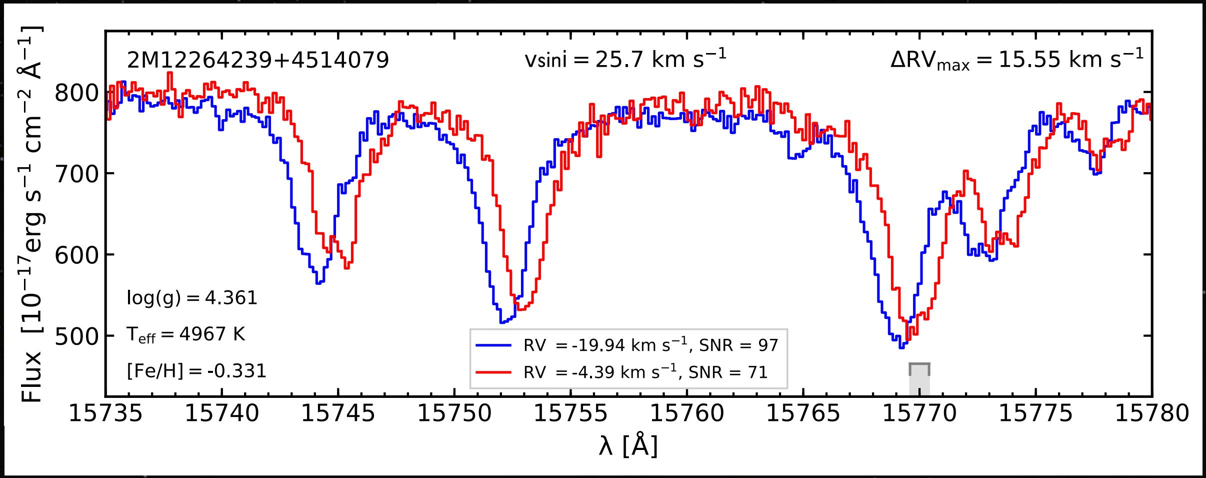
[Tayar+2015, Dixon+2020]

Masses, distances, and ages from isochrone fits

[Sanders & Das 2018]



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SB2s identified in Marina's CCF analysis removed

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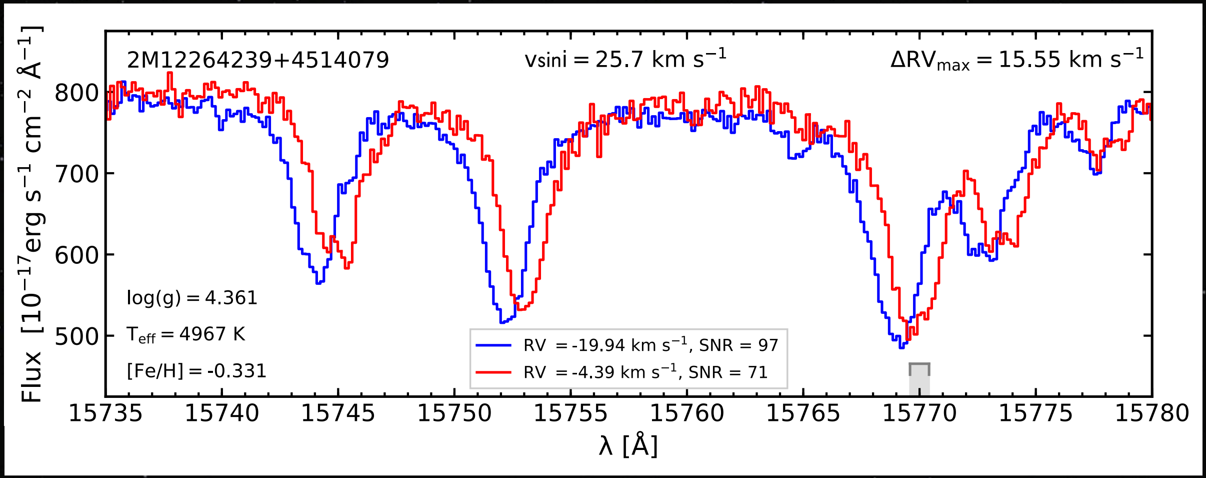

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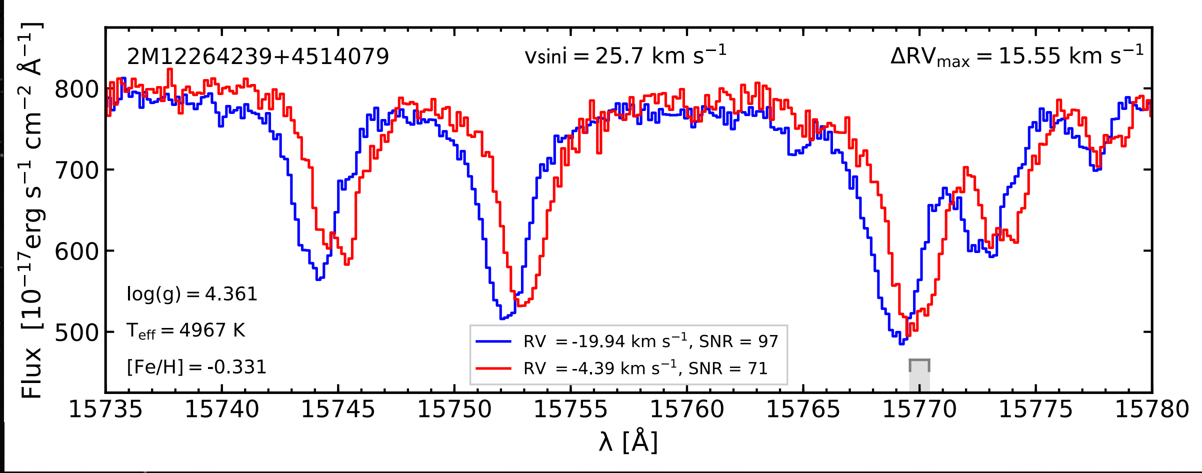

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$$\Delta RV_{max} = |RV_{max} - RV_{min}|$$

Need 2+ RVs to identify likely close binaries!

Close Binaries in APOGEE DR14

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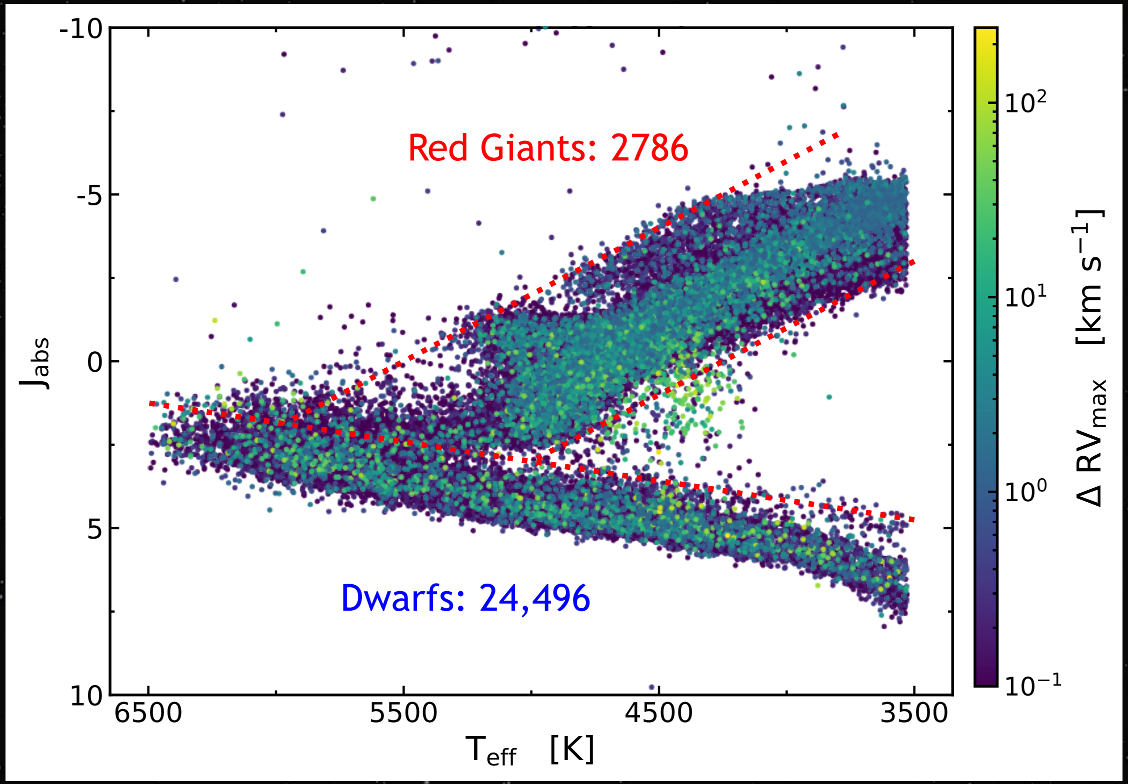
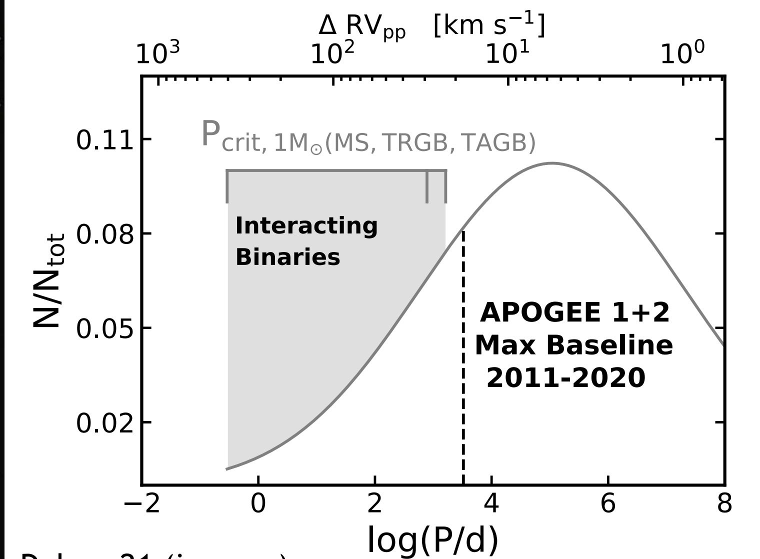


Daher+21 (in-prep)

Close Binaries and Evolution

Raghavan+10: lognormal period distribution for Sun-like stars in the Solar neighborhood



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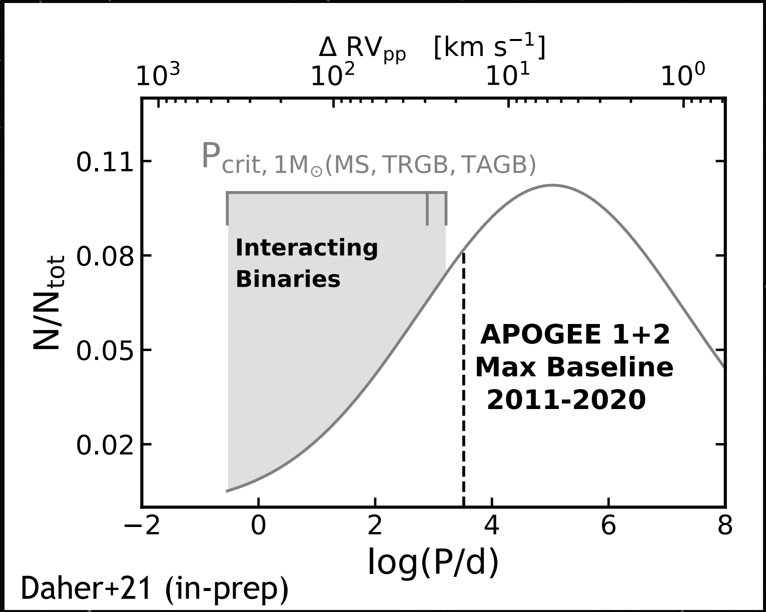
Close Binaries and Evolution

Raghavan+10: lognormal period distribution for Sun-like stars in the Solar neighborhood

Critical period for RLOF to occur at $q = M_2/M = 1$:

$$P_{crit} \propto \sqrt{\frac{R^3}{GM}}$$



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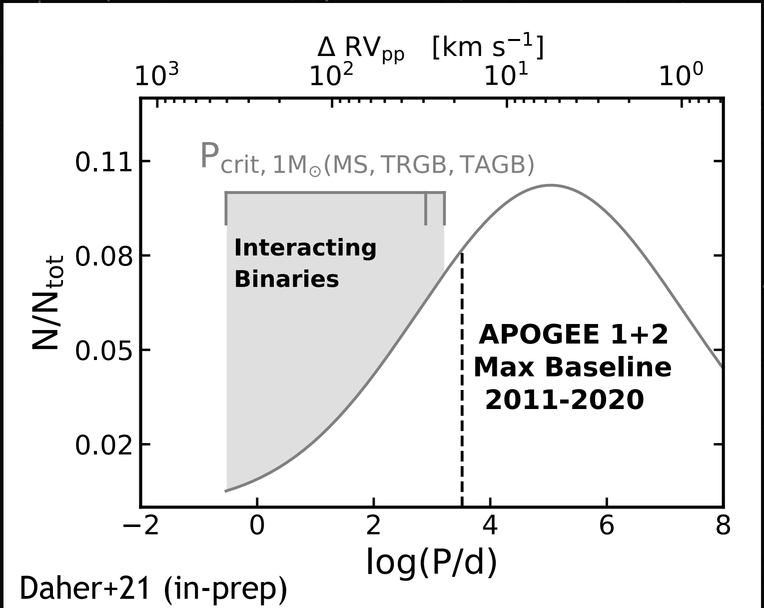

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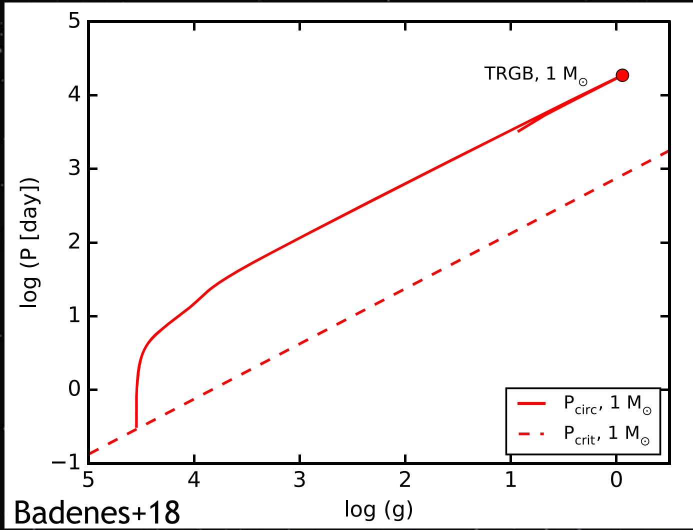


Badenes+18

$P_{\rm crit}$ changes as the primary evolves

Increases as the star expands (ascends RGB)

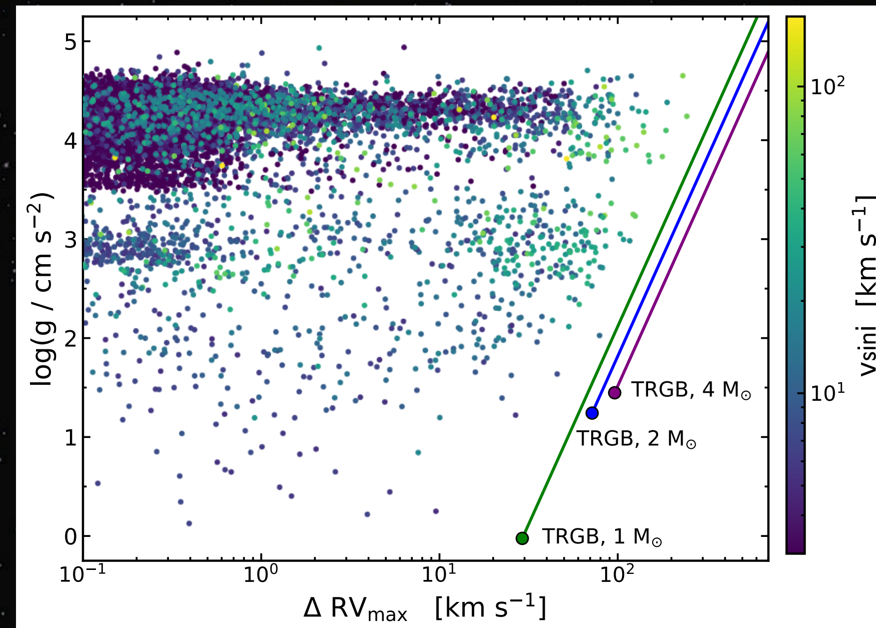
Close Binaries and Evolution

Compare observed ΔRV_{max} to the max peak-to-peak shift of the RV curve,

$$\Delta \mathrm{RV}_{\mathrm{pp}} \propto \left(\frac{M}{\mathrm{P}_{\mathrm{crit}}}\right)^{1/3}$$

$$\mathrm{P}_{\mathrm{crit}} \propto \left(\frac{GM}{g^3}\right)^{1/4}$$

Dwarfs and subgiants: smaller P_{crit} → larger max ΔRV_{max} values [Badenes+2018]



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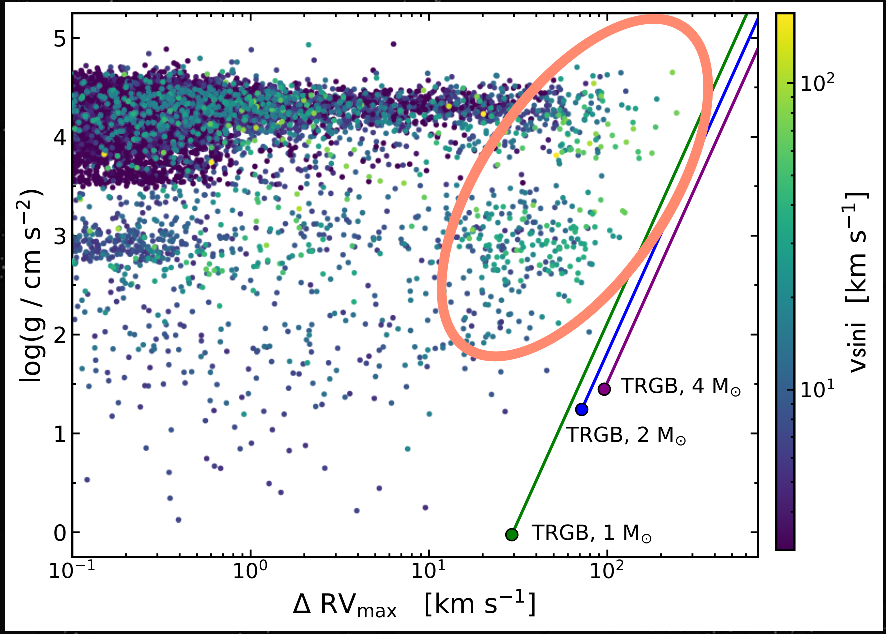
Stars with large ΔRV_{max} → larger rotation speeds, $v\sin(i)$



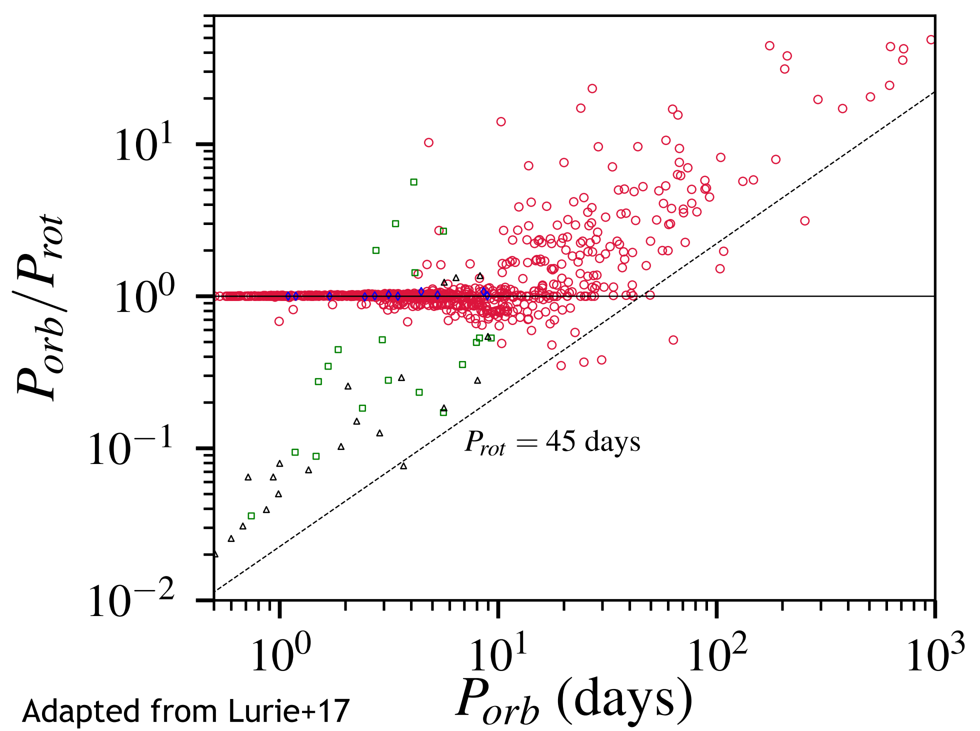
Daher+21 (in-prep)

Hints of tidal interactions in close binaries?

Close Binaries and v sin(i)

Rotational Synchronization

A short-period binary's P_{orb} and its stars' P_{rot} tend to become synchronized due to tidal interactions: $P_{rot} \approx P_{orb}$

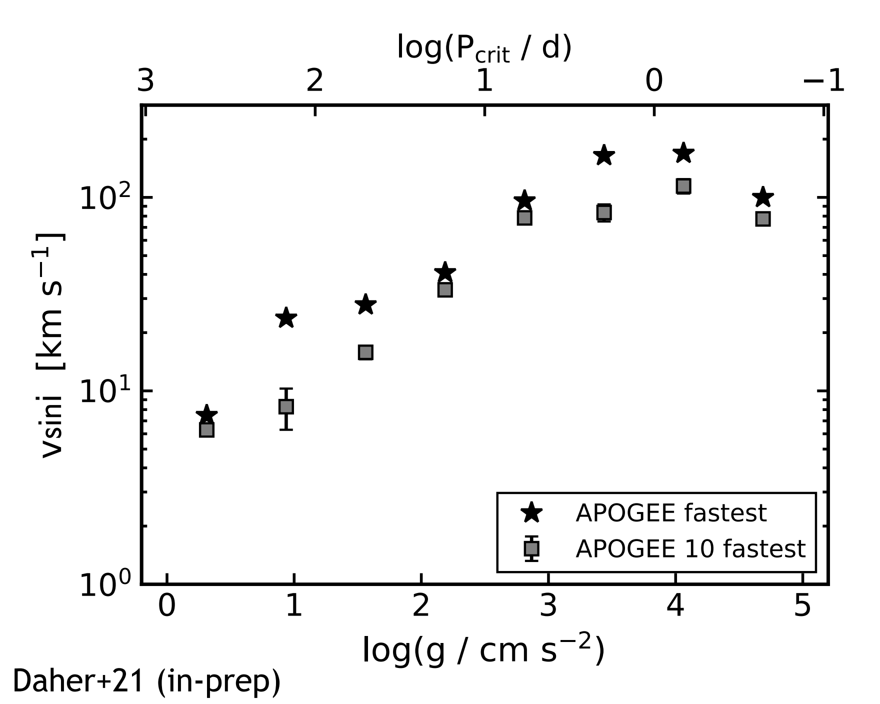


Adapted from Lurie+17

Close Binaries and *v* sin(i)

Compare the fastest rotators as a function of log(g):

- Gray squares: median *v* sin(i) of the 10 fastest rotators
- Black stars: *v* sin(i) of fastest rotator



Close Binaries and *v* sin(i)

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- Gray squares: median *v* sin(i) of the 10 fastest rotators
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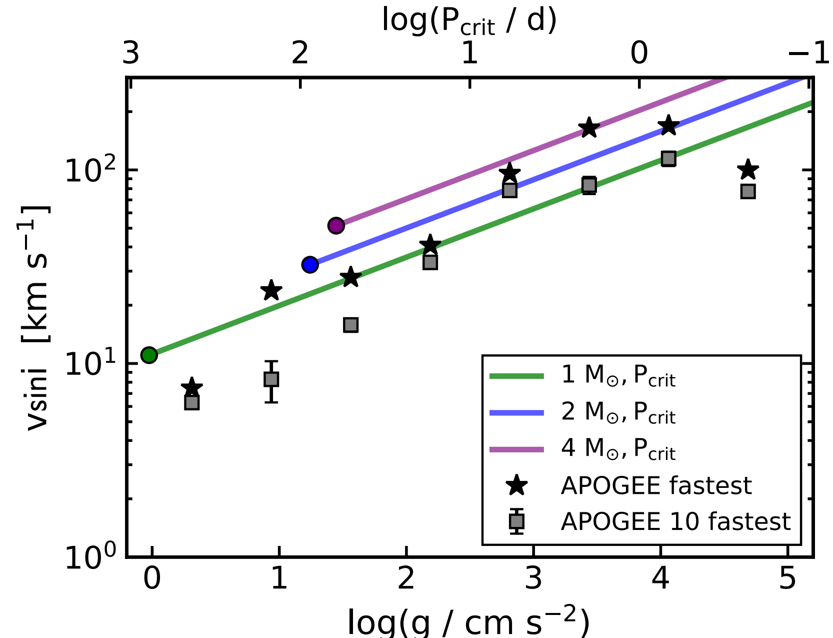
Compare them against the max *v* sin(i) we expect from rotational synchronization, $P_{rot} \approx P_{crit}$:

$$v \sin(i) \propto \frac{1}{P_{rot}} \sqrt{\frac{GM}{g}}$$

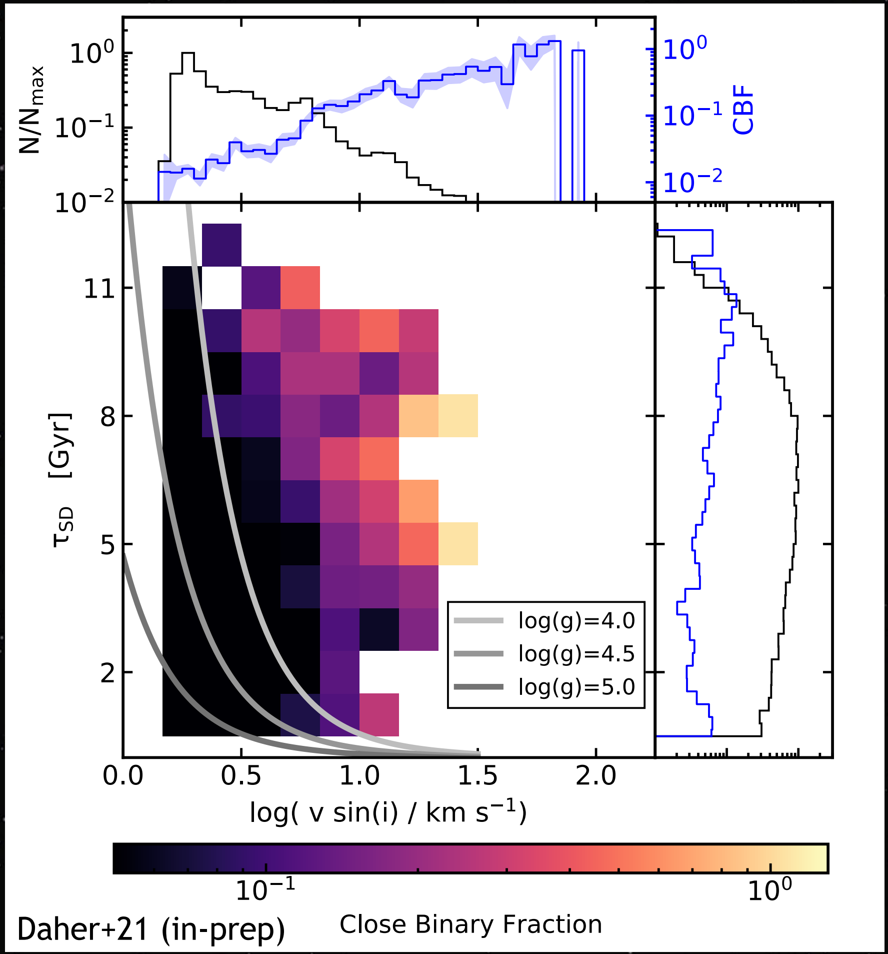
$$P_{crit} \propto \left(\frac{GM}{g^3}\right)^{1/4}$$



Daher+21 (in-prep)

Close Binaries and Gyrochronology

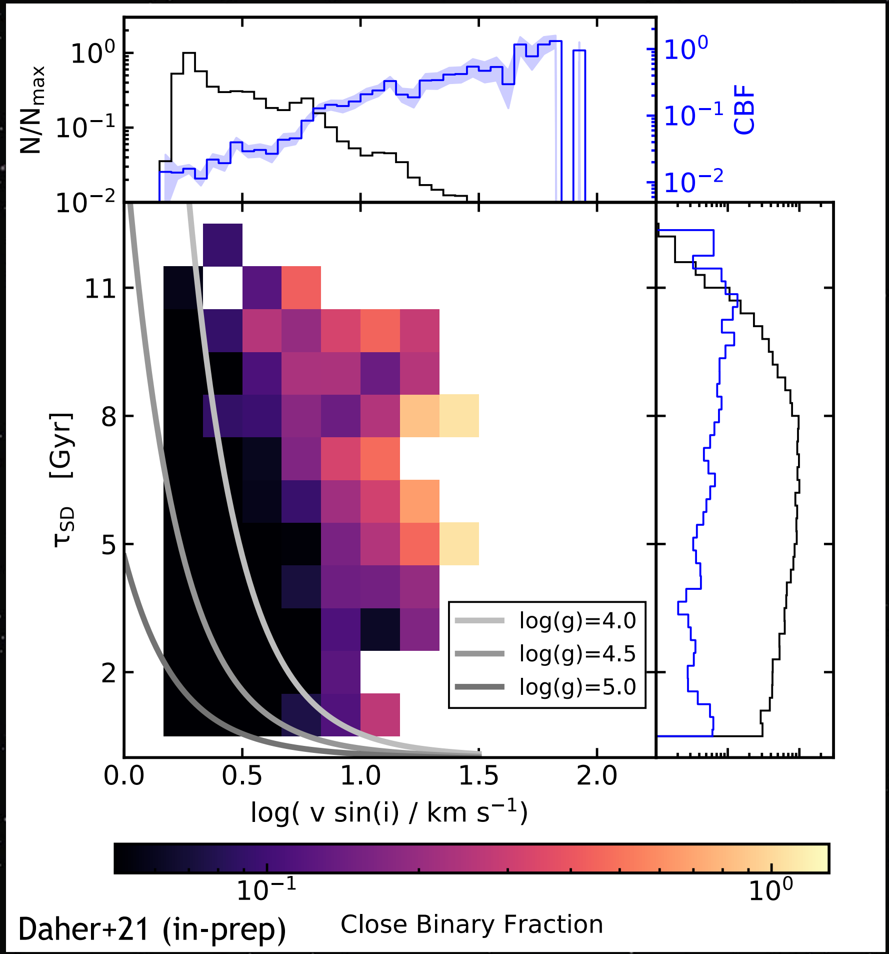
Let's consider dwarfs below the Kraft break (T_{eff} < 6200 K).



Close Binaries and Gyrochronology

Predictions from Gyrochronology

1. Young stars can rotate at a range of speeds due to leftover angular momentum from birth



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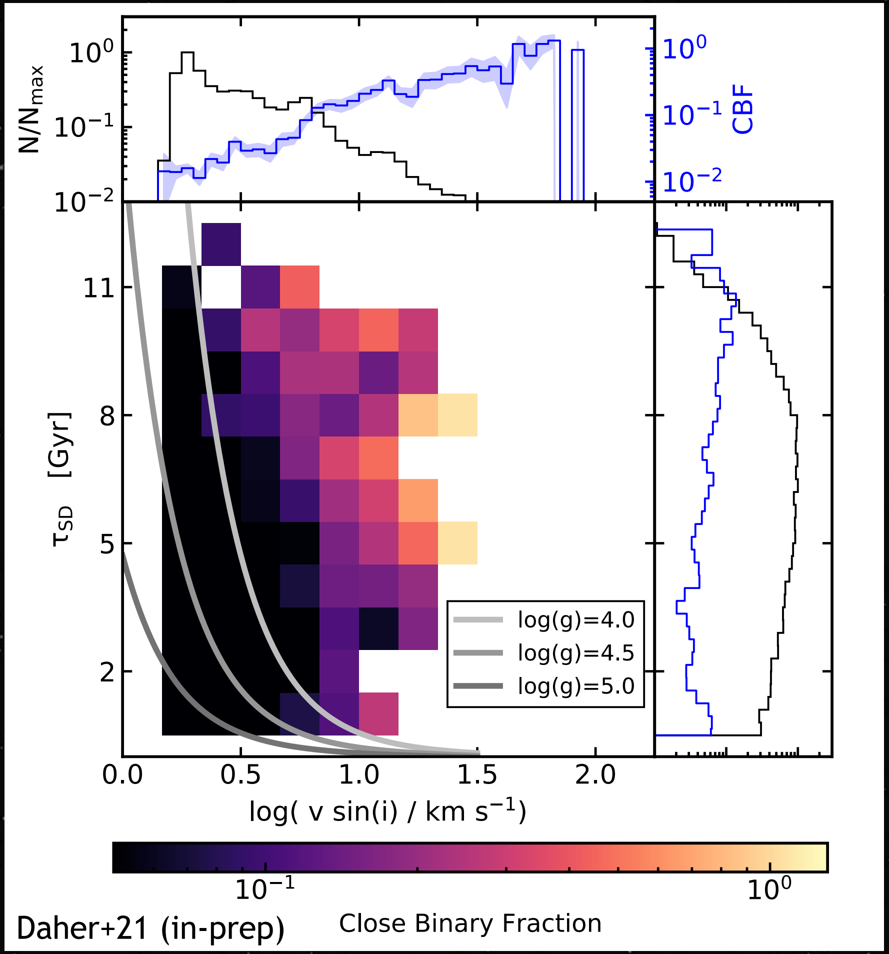
1. Young stars can rotate at a range of speeds due to leftover angular momentum from birth

2. In isolation, older stars will naturally spin down over time, so we expect few to no rapid rotators



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Predictions from Gyrochronology

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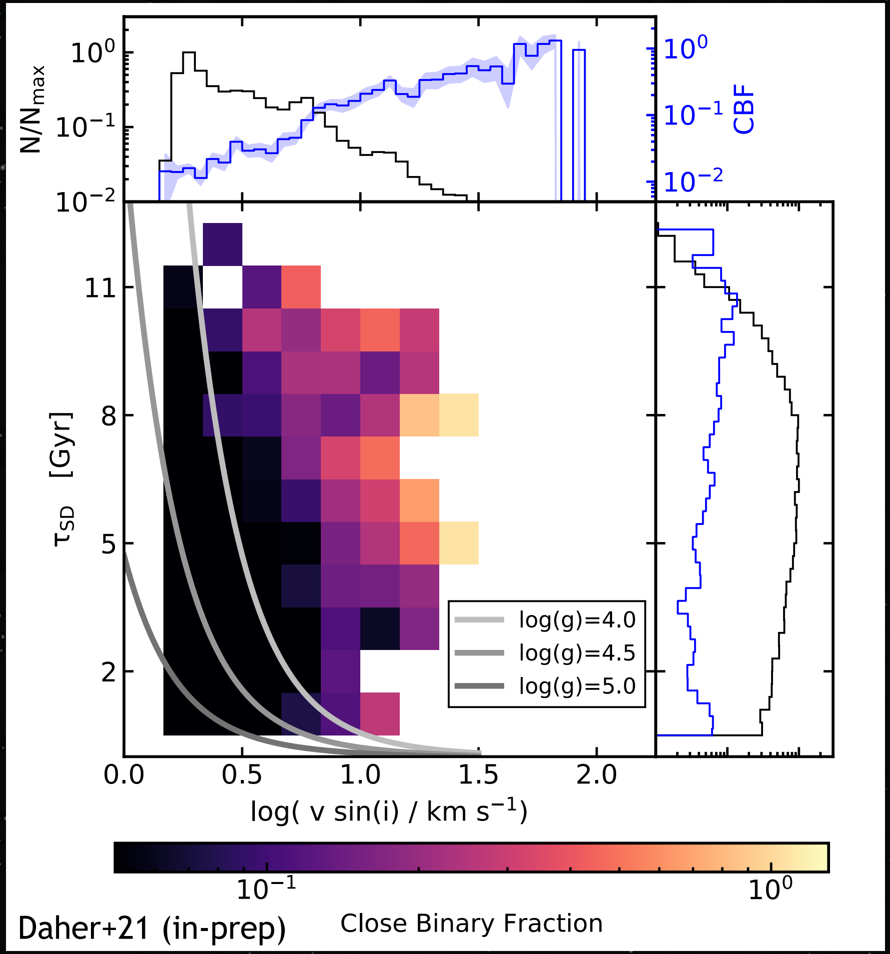
3. Rotationally synchronized binaries rapidly rotate regardless of age once synchronization has occurred



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Conclusions

- APOGEE's formula for success:
  (high-res spectra + multi-epoch RV curves) x ~10^5 Milky Way field stars
  = large, statistical sample to study stellar multiplicity

- Sparse RV curves? No problem! Just use ΔRV_{max} to infer the presence of close companions up to $\log(P/\mathrm{d}) \leq 4$.

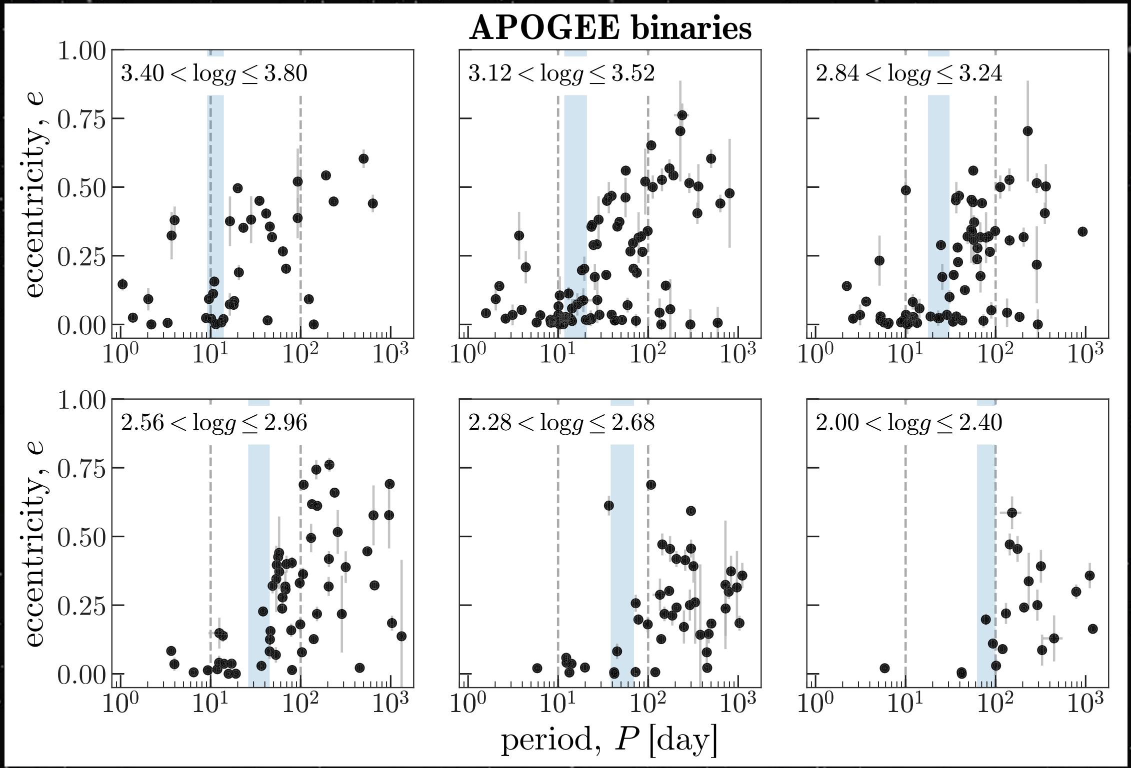
- With this, we've found:
  - Hints of tidal interactions via rotation: trends in data agree with simple rotational synchronization limits + attrition of short period systems as stars evolve
  - Link between age, rotation, and binarity: age-dependent correlation between rotation and CBF agree with expectations from gyrochronology

Background image credit: *Star Wars*, 1977

EX: Binaries and $v \sin(i)$

Tidal interactions in close binary systems can lead to several effects.

- Tidal circularization: short-period orbits tend to become circularized — $e \approx 0$

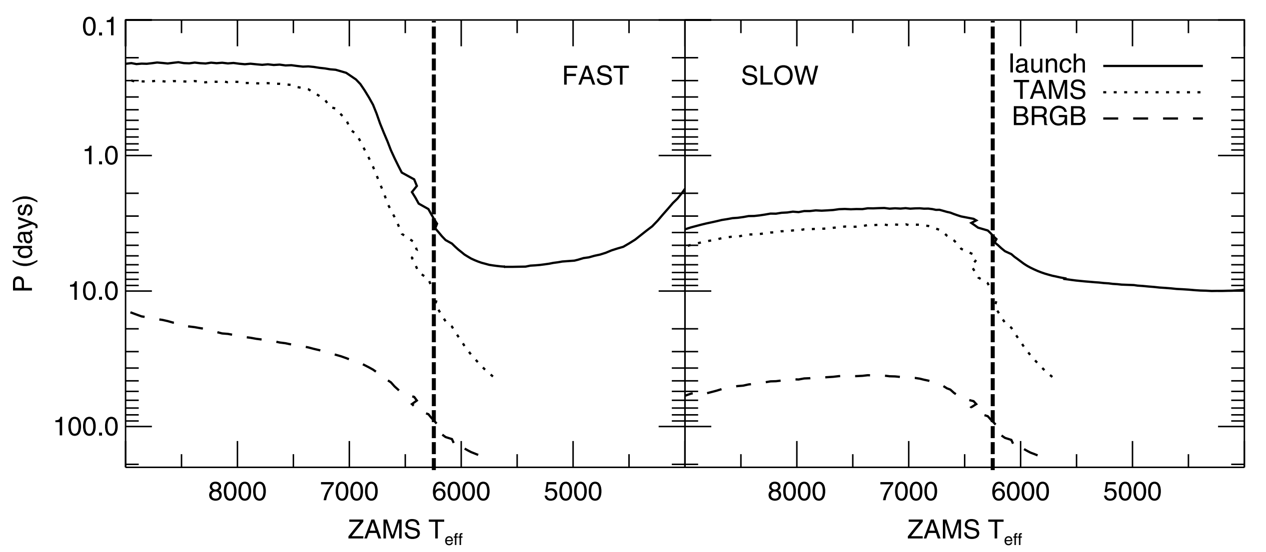


Price-Whelan & Goodman 2018

EX: Binaries and Gyrochronology

Rotation is tied to stellar age via the Kraft break (T_{eff}≈6200 K, M≈1.3 $M_\odot$)

Below the Kraft break: the star's convective envelope produces a magnetized wind that loses angular momentum and thus slows its rotation over its MS lifetime



van Saders & Pinsonneault 2013

EX: Multiplicity and Gyrochronology

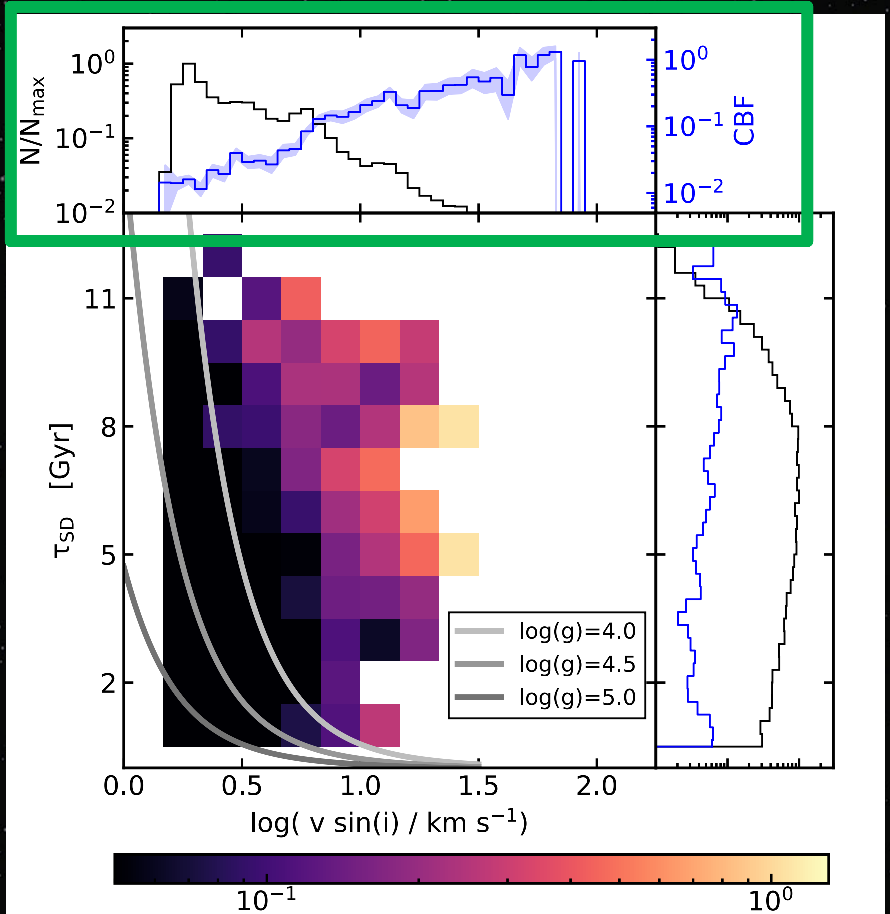
Let's consider dwarfs that are below the Kraft break (T_{eff} < 6200 K).

In the top panel, we observe a strong correlation between *v* sin(i) and the close binary fraction!

RV variability fractions + completeness corrections

= completeness-corrected CBFs

[Moe+2019, Mazzola+2020]



Daher+21 (in-prep)

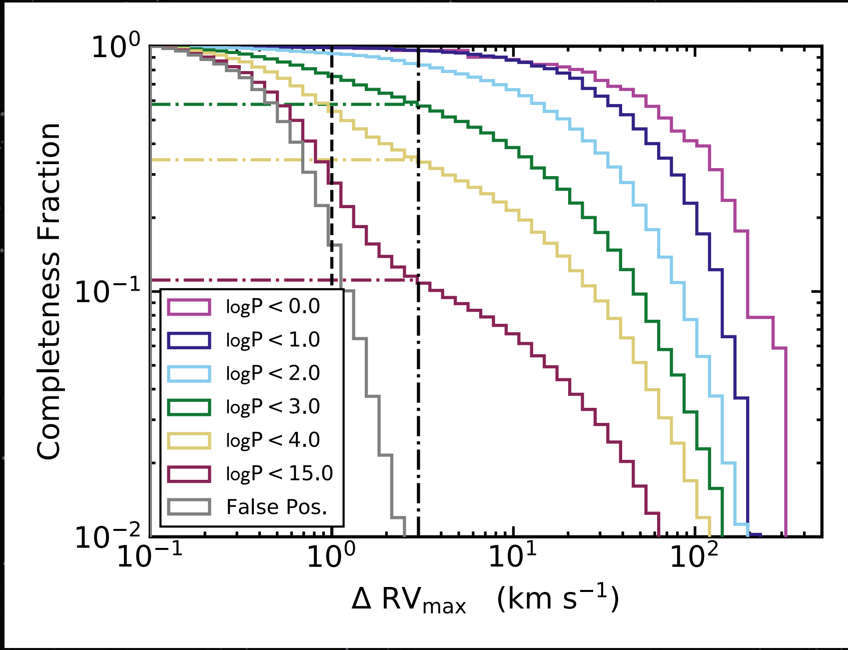
EX: Completeness Corrections

Choosing a threshold is important… but how important? We can check!

Monte Carlo sampler to simulate ΔRV_{max} distributions

- Observationally motivated parameter distributions when possible
- Theoretical expectations when not
- Randomly assign APOGEE visit histories: N_{visits} and time lags between visits

[See Badenes & Maoz 2012, Maoz+12, Badenes, CMD+18, Moe+19, Mazzola+20]



Adapted from Mazzola+20

Can use this to estimate a completeness-corrected close binary fraction!