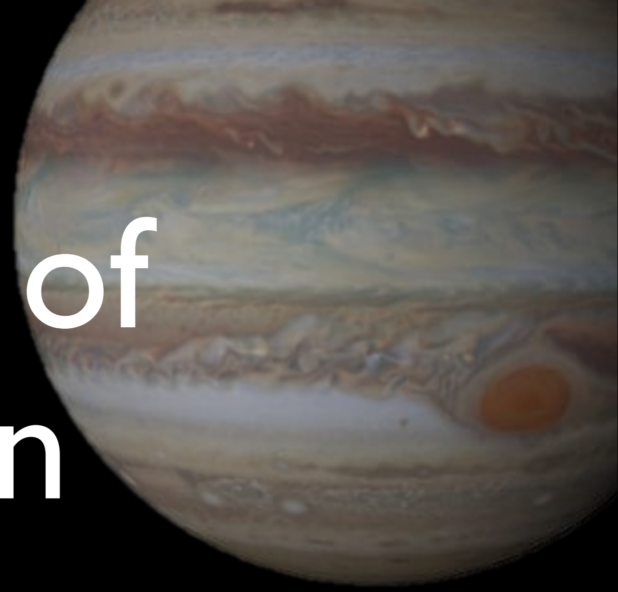

Establishing the Epoch of Giant Planet Migration

A Near-Infrared Precision Radial Velocity Survey with the Habitable-Zone Planet Finder (HPF)

Quang Tran

FINESST Fellow, The University of Texas at Austin

Collaborators: Brendan Bowler, Bill Cochran, Mike Endl, Gummi Stefánsson, Suvrath Mahadevan, Joe Ninan, Chad Bender, Samuel Halverson, Arpita Roy, Ryan Terrien

Overview

Setting up the problem

- Why are we interested in giant planet migration?
- What are the difficulties involved in studying this phenomenon?

Solving the problem

- How are we investigating giant planet migration in a unique way?
- Where are we with understanding the issue?
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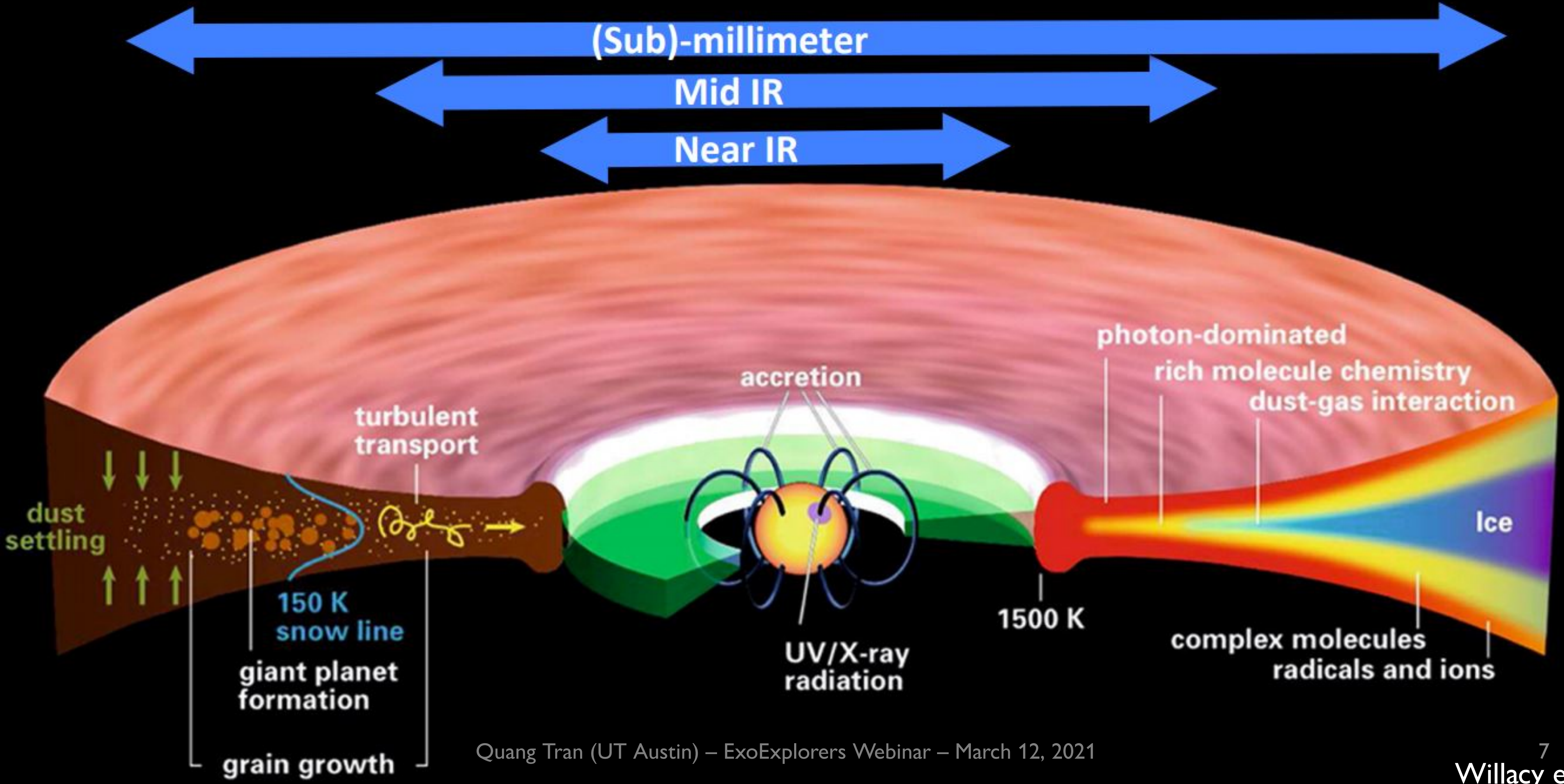

Willacy et al. 2015

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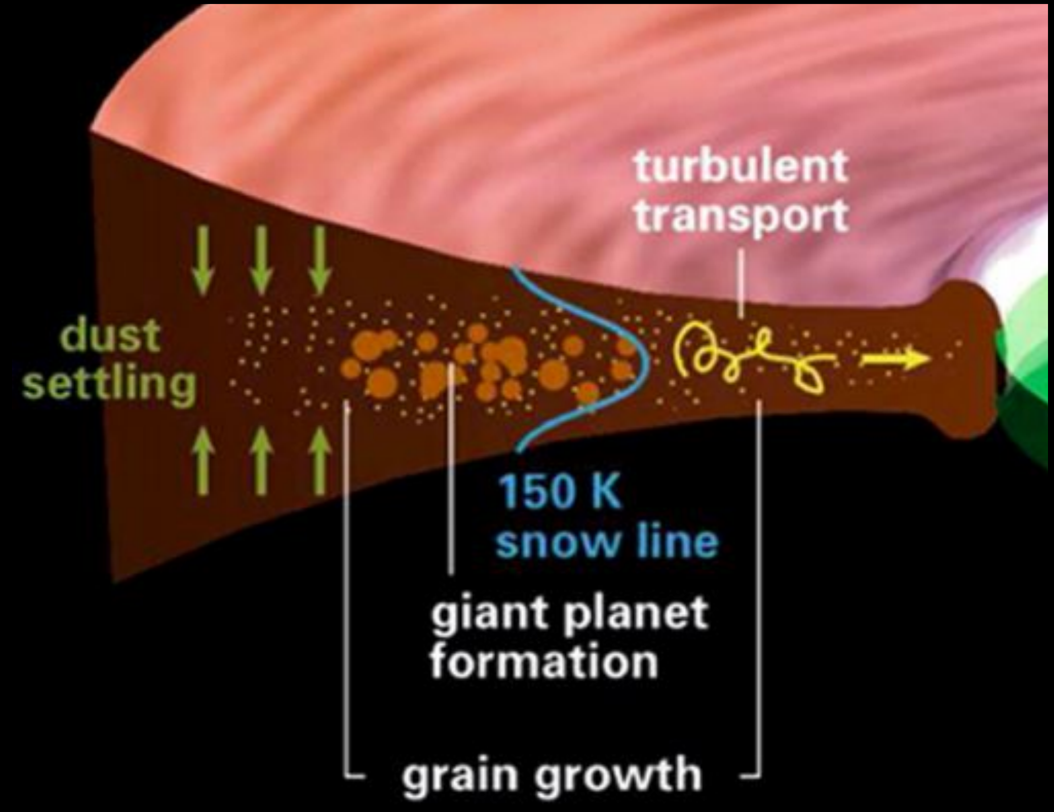
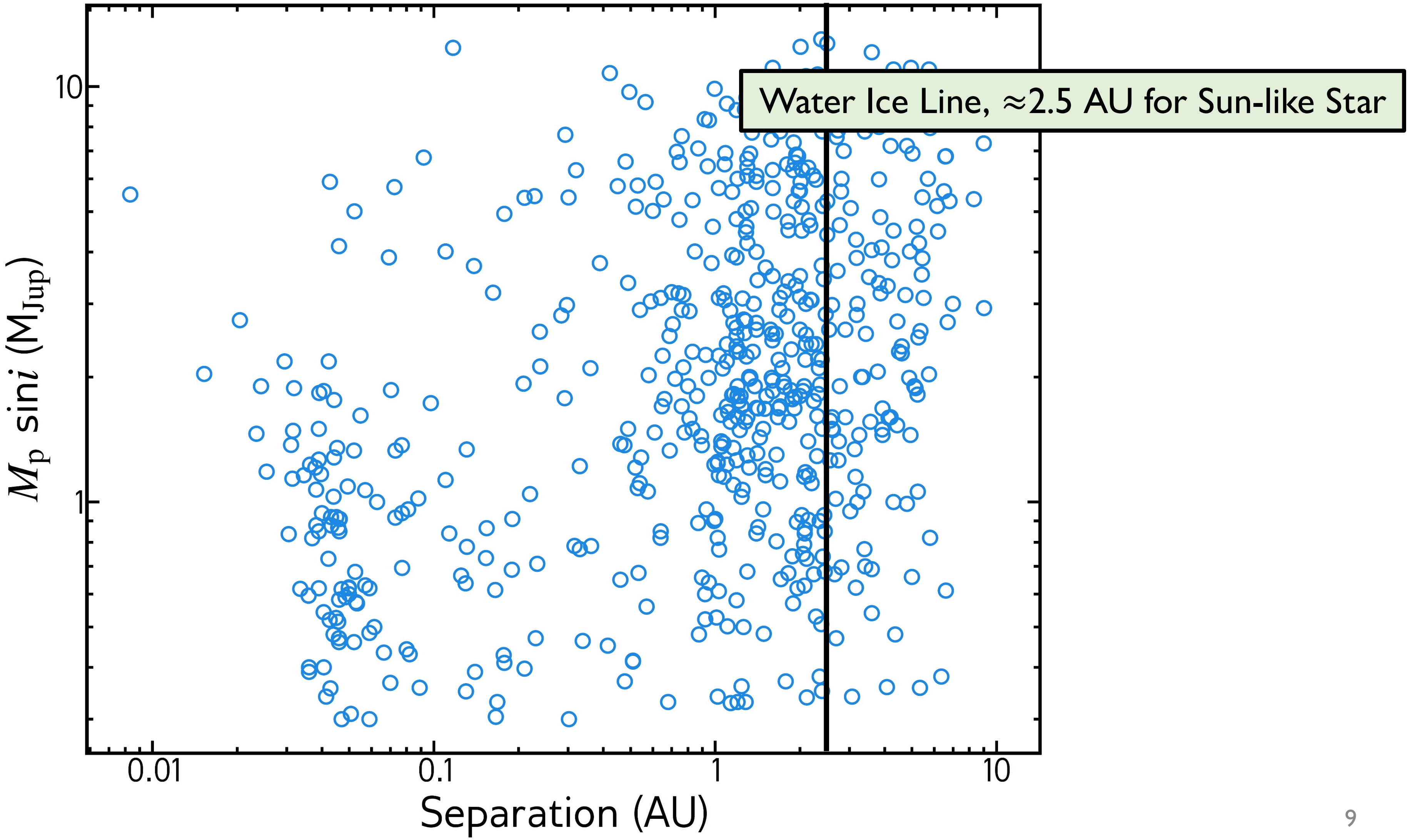


Willacy et al. 2015

There exists an appreciable population of gas giants interior to the water ice line



exoplanet.au, Schneider (2011)

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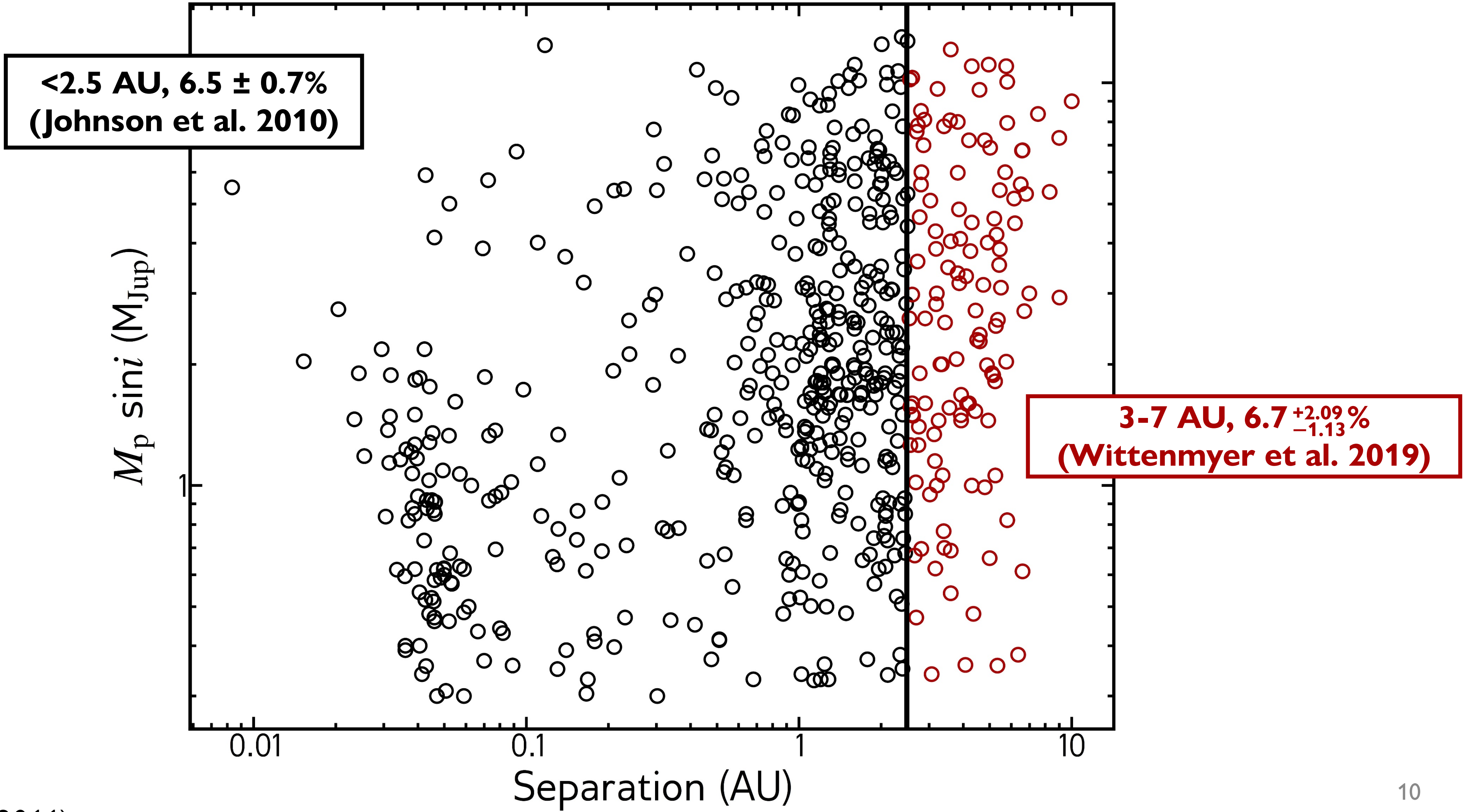

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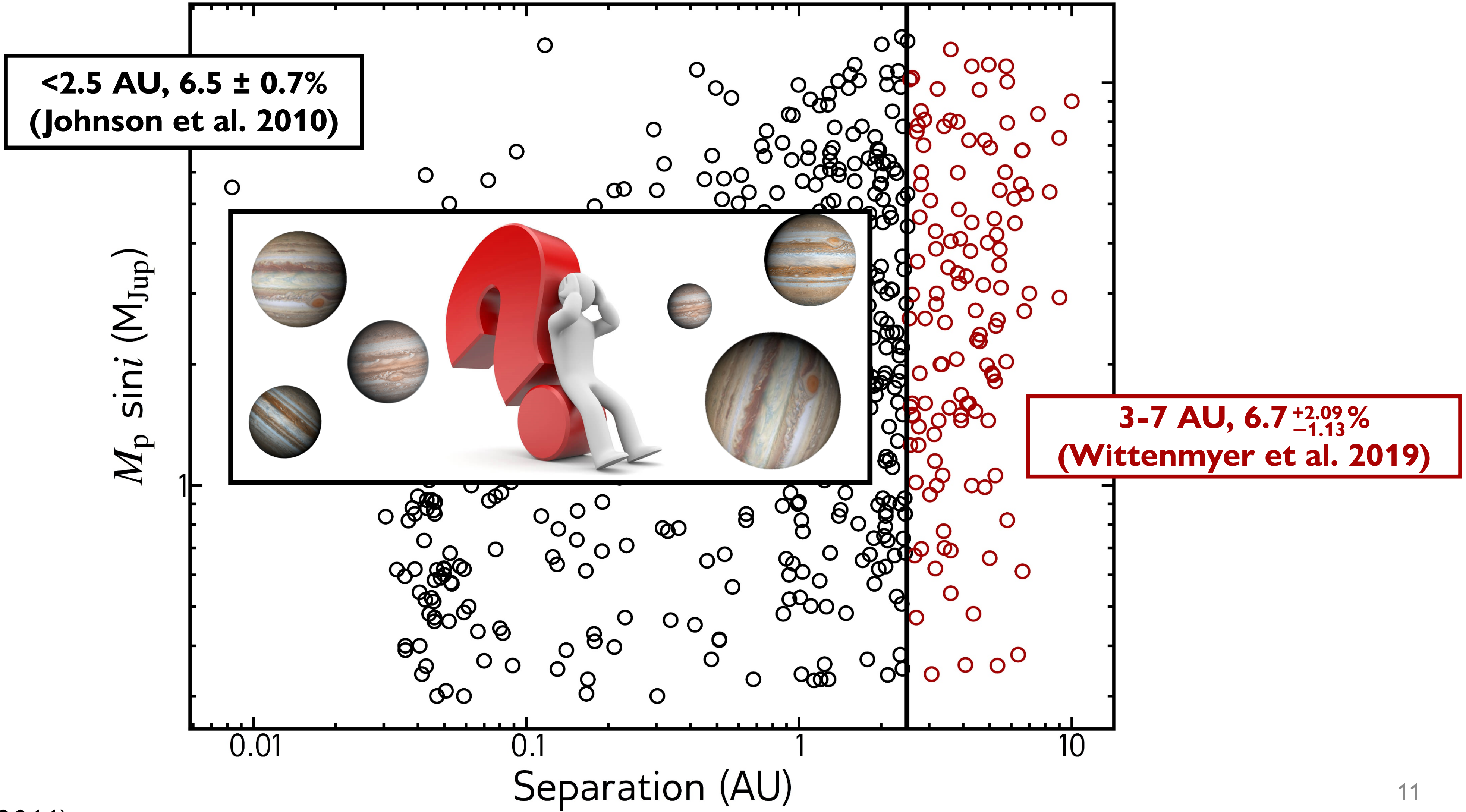
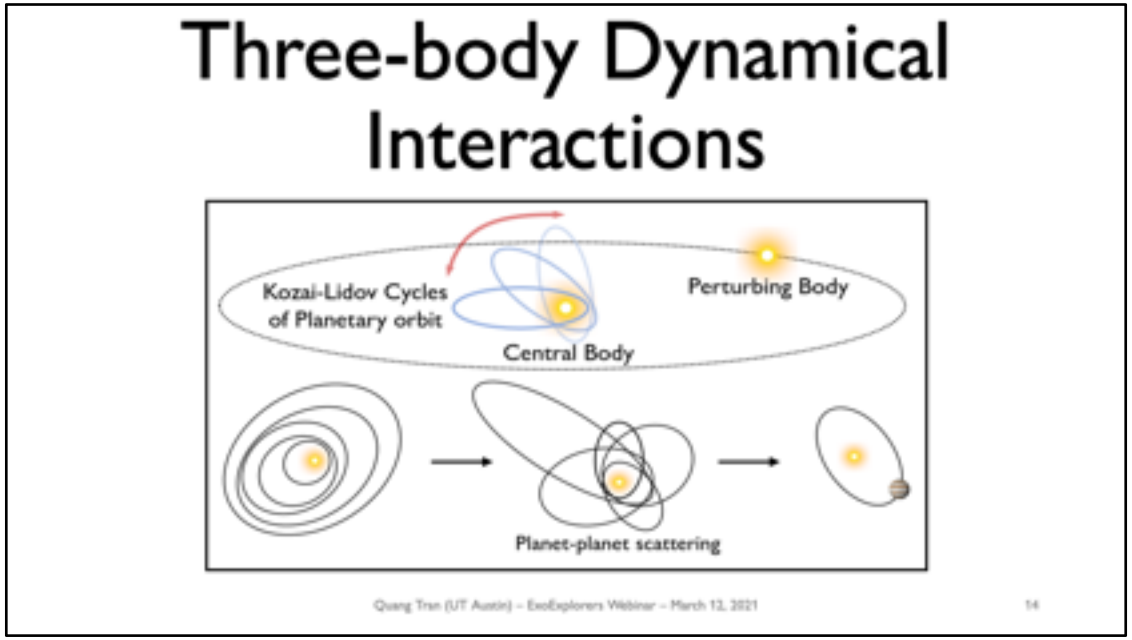


exoplanet.au, Schneider (2011)

Two broad migration mechanisms can explain this population of giant planets

(e.g., Ward 1997; Papaloizou 2007; Levrard et al. 2009; Kley & Nelson 2012; Albrecht et al. 2012; Batygin 2012)



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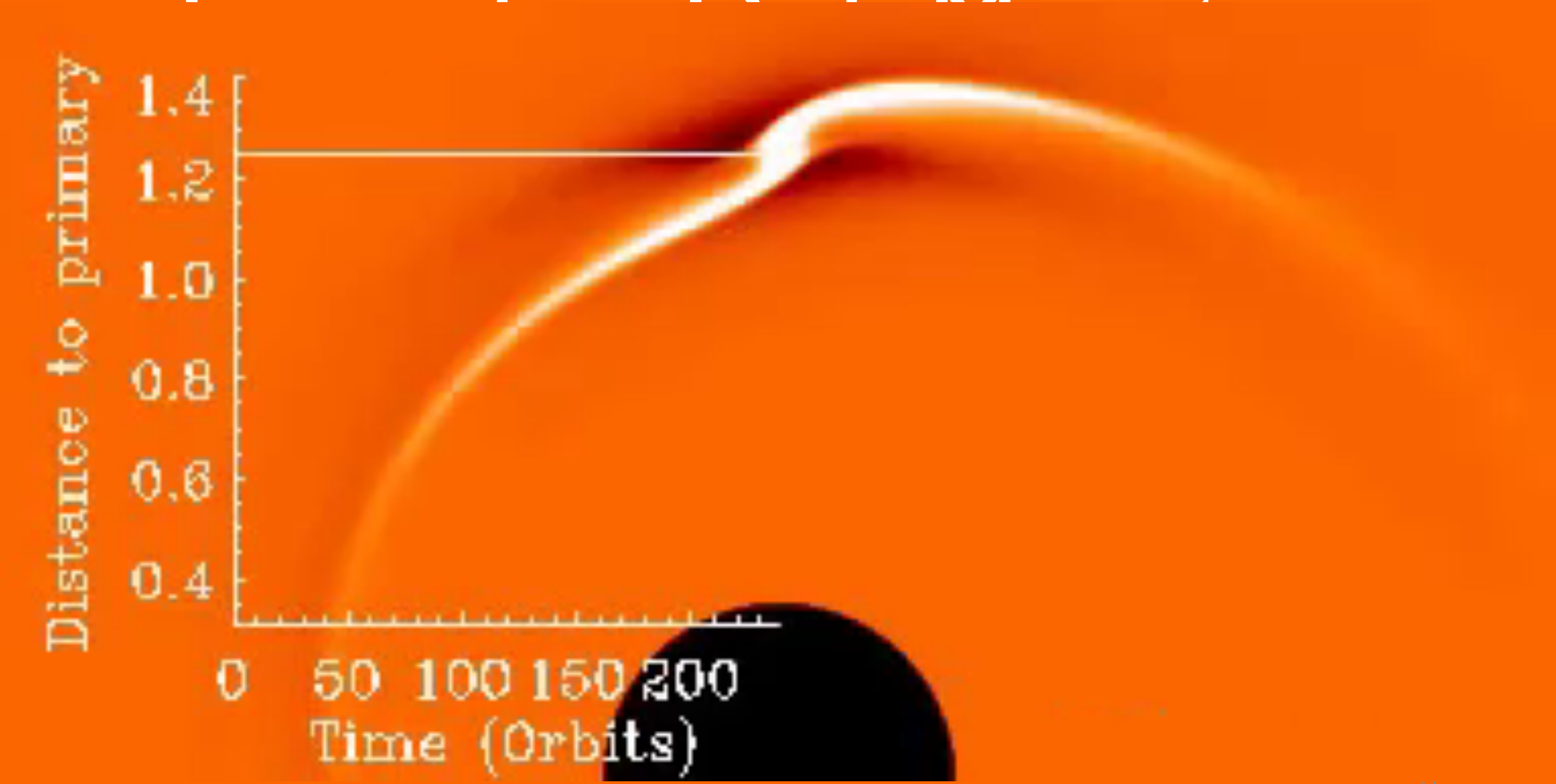
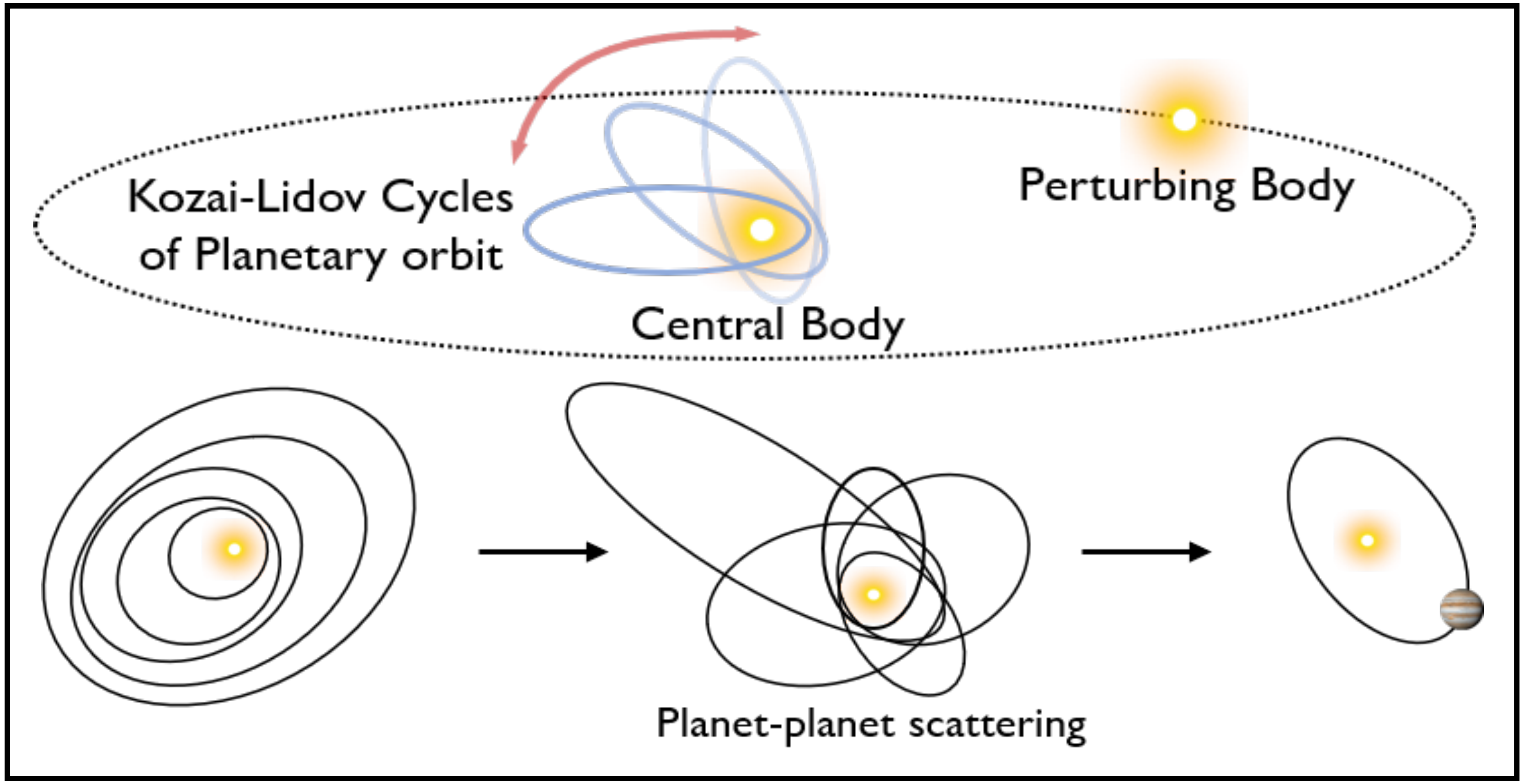


Credit: F. Masset 2002

Three-body Dynamical Interactions



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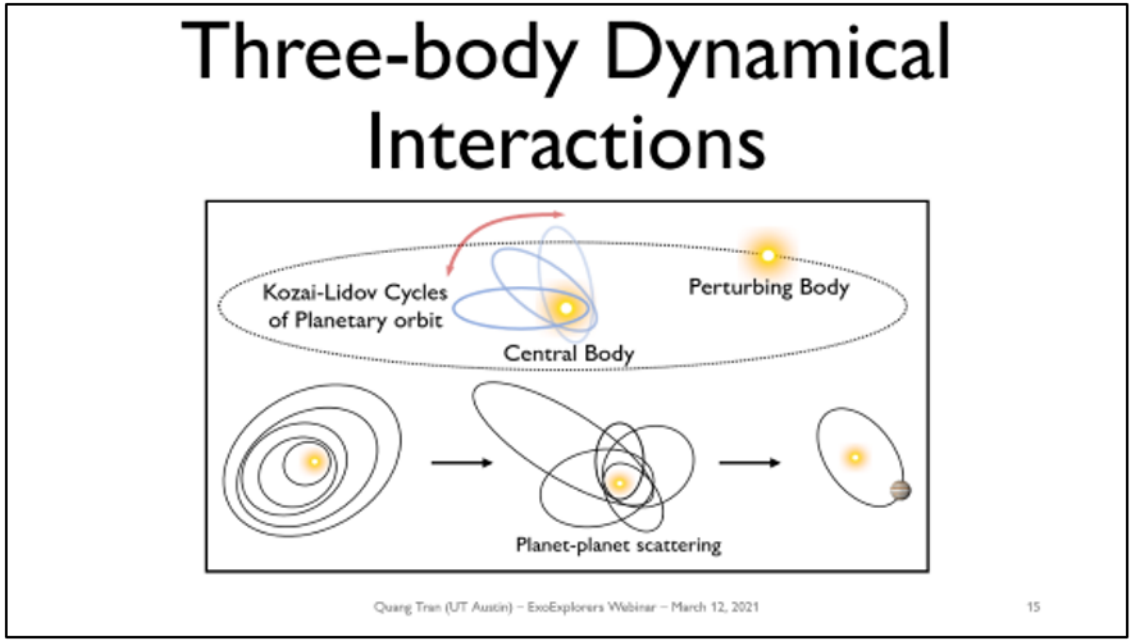

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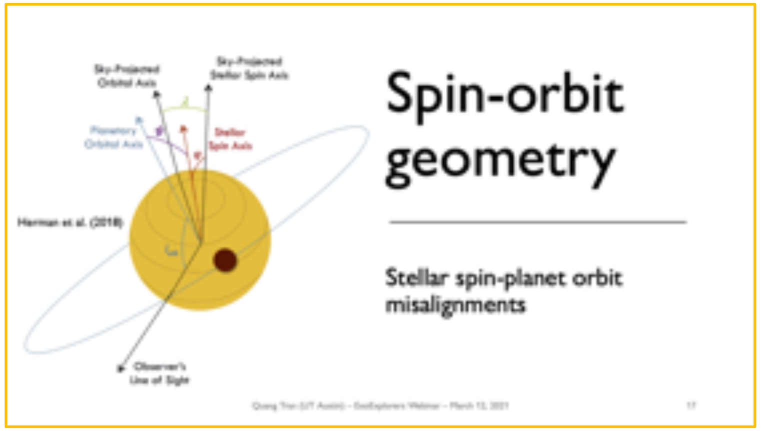
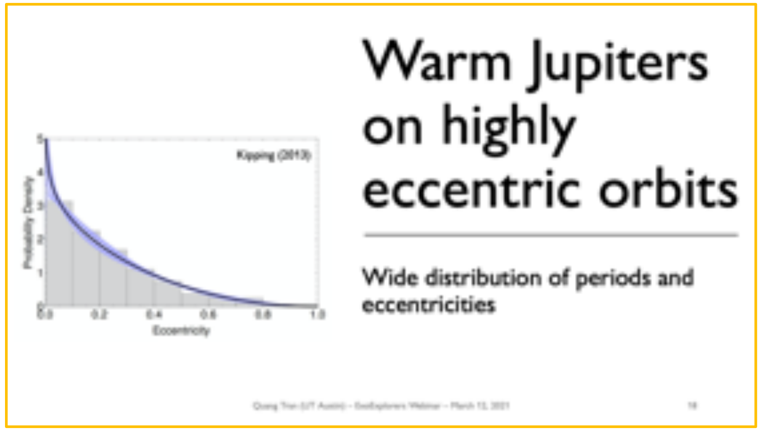
None alone can explain the observed properties of the giant planet population



(e.g., Huber et al. 2013)



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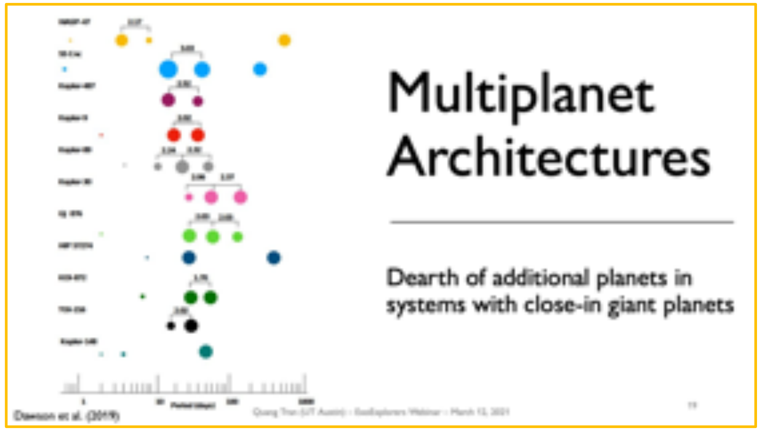

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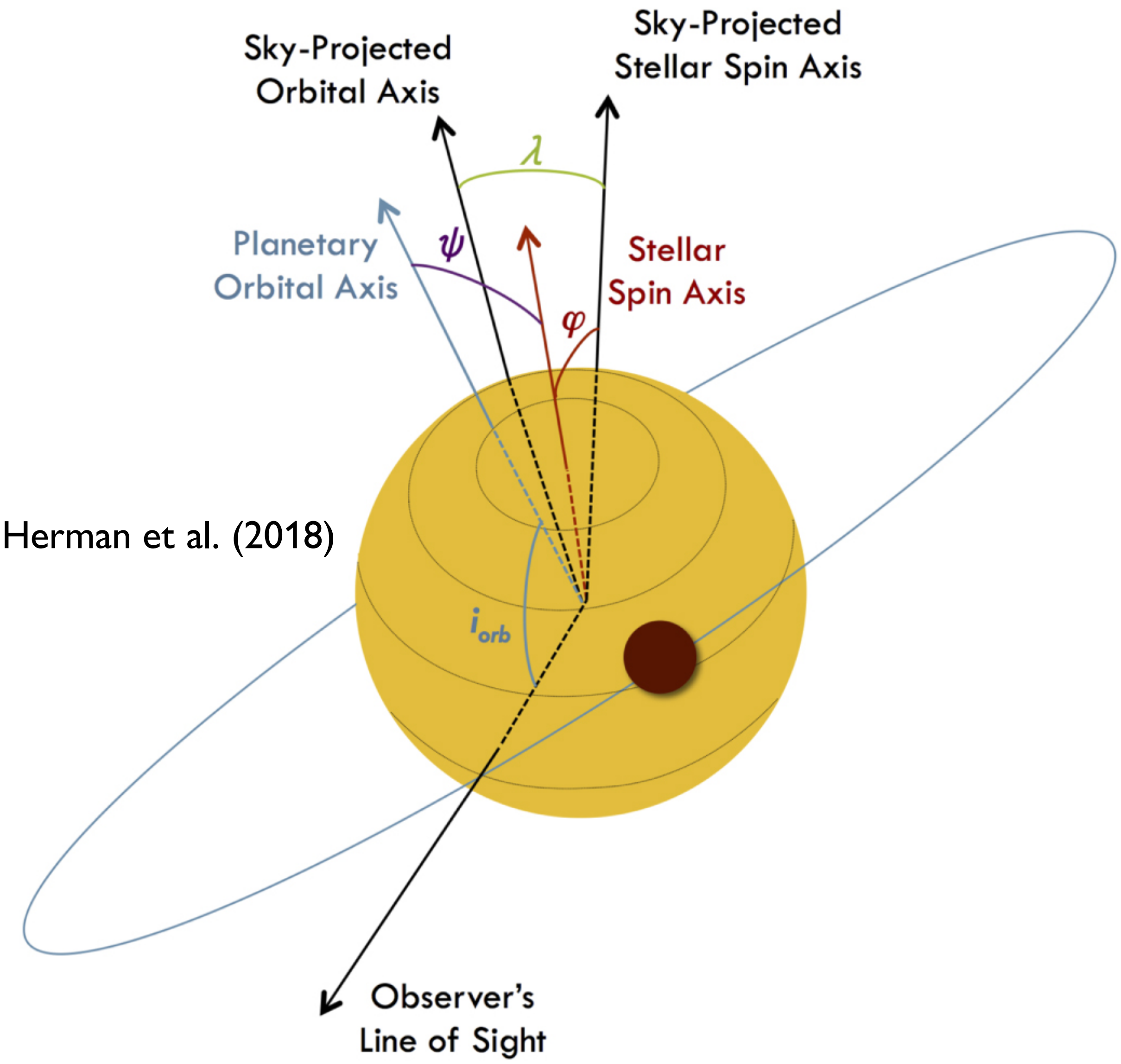
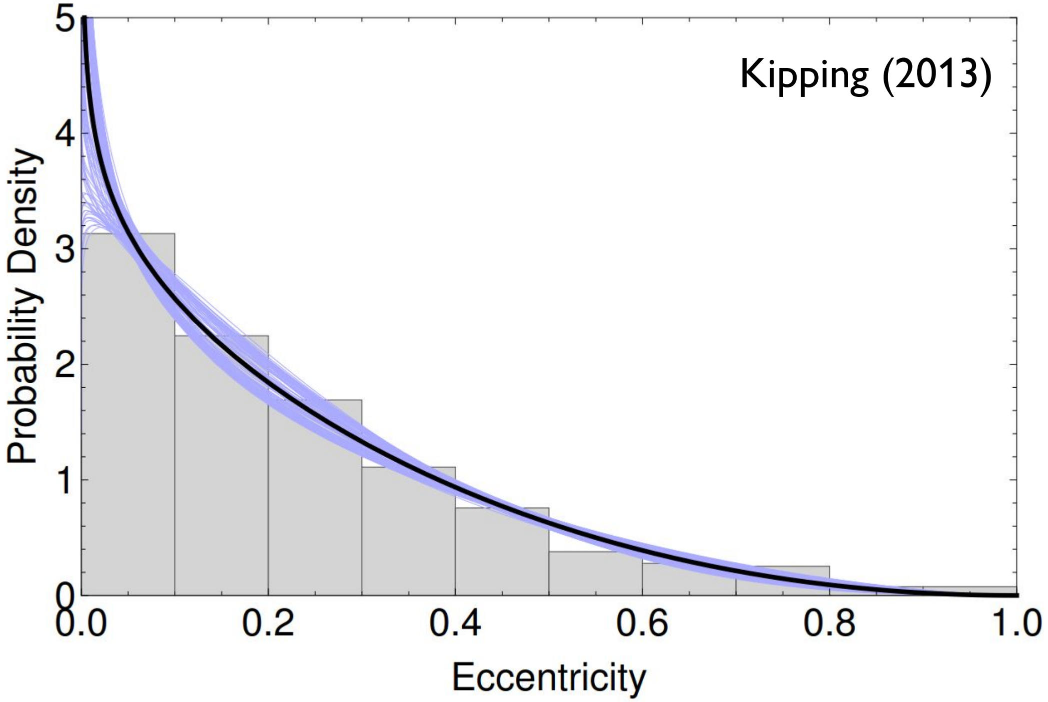


Herman et al. (2018)

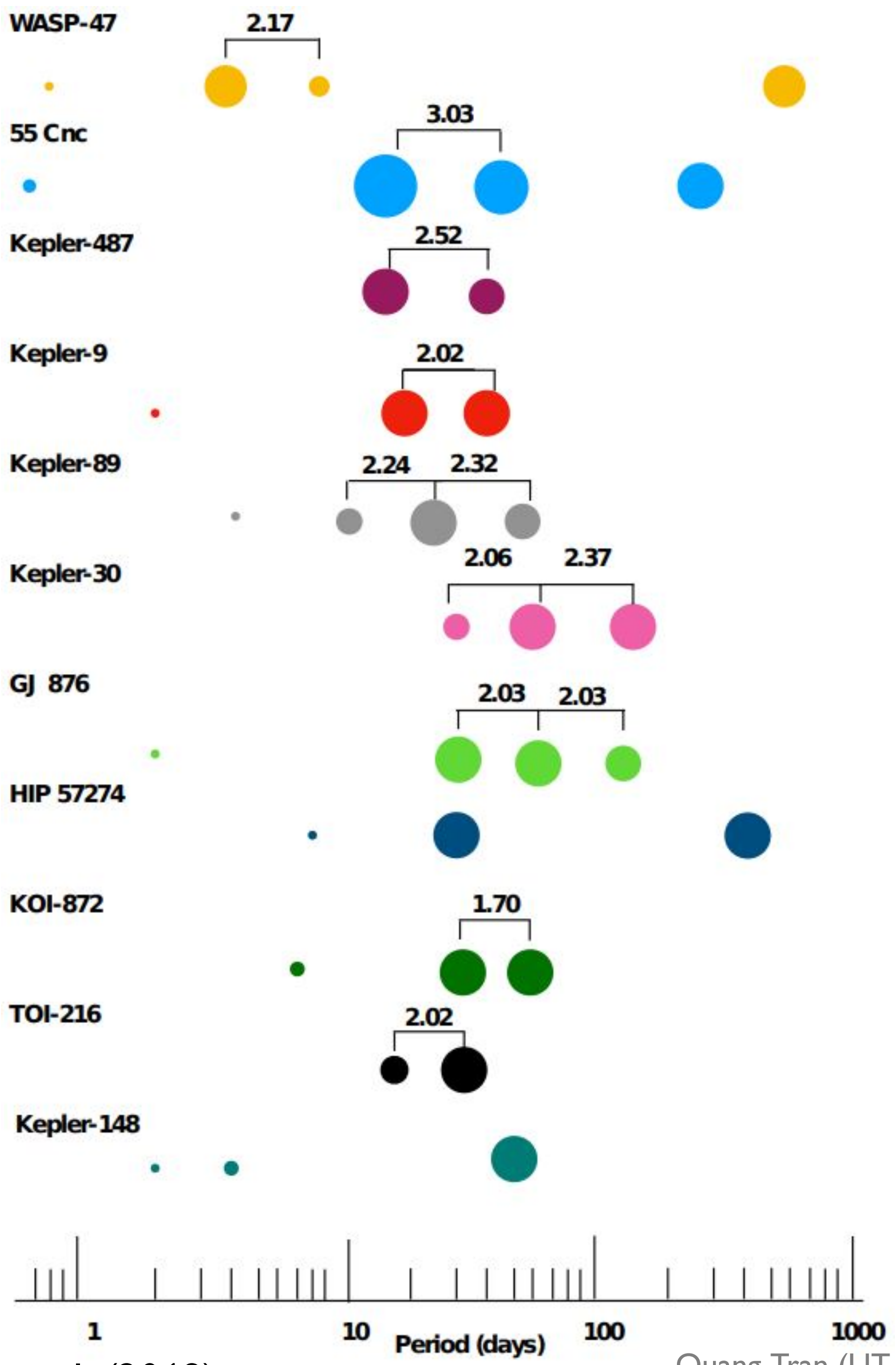
Spin-orbit geometry

Stellar spin-planet orbit misalignments

Warm Jupiters on highly eccentric orbits



Wide distribution of periods and eccentricities



Dawson et al. (2019)

Multiplanet Architectures

Dearth of additional planets in systems with close-in giant planets

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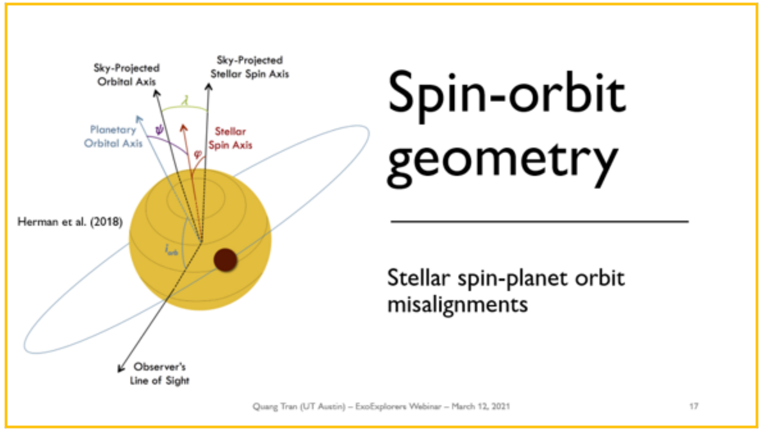

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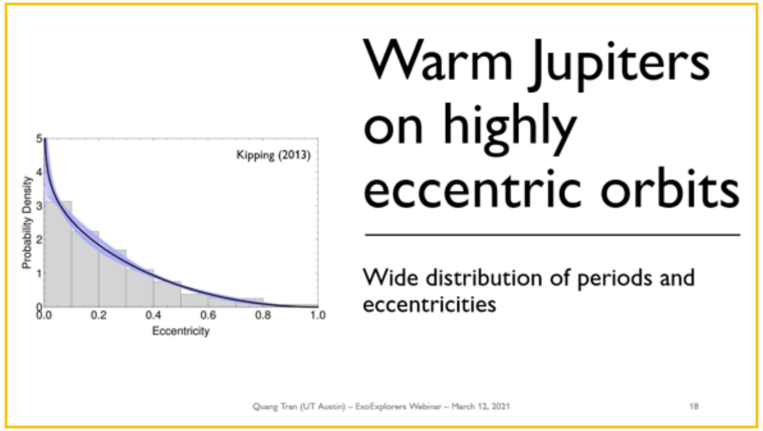

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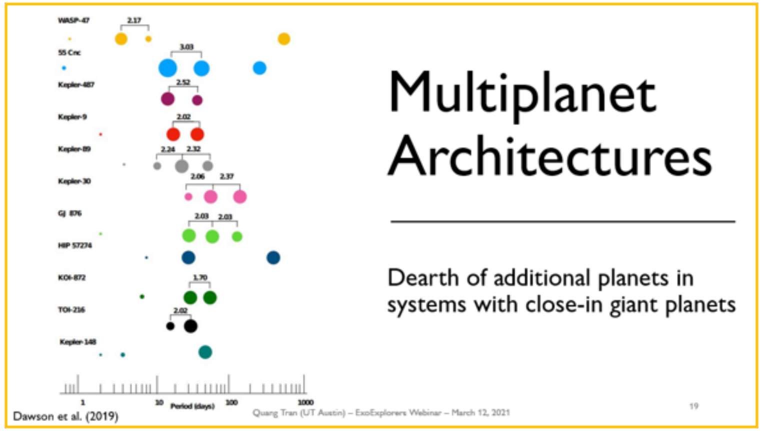

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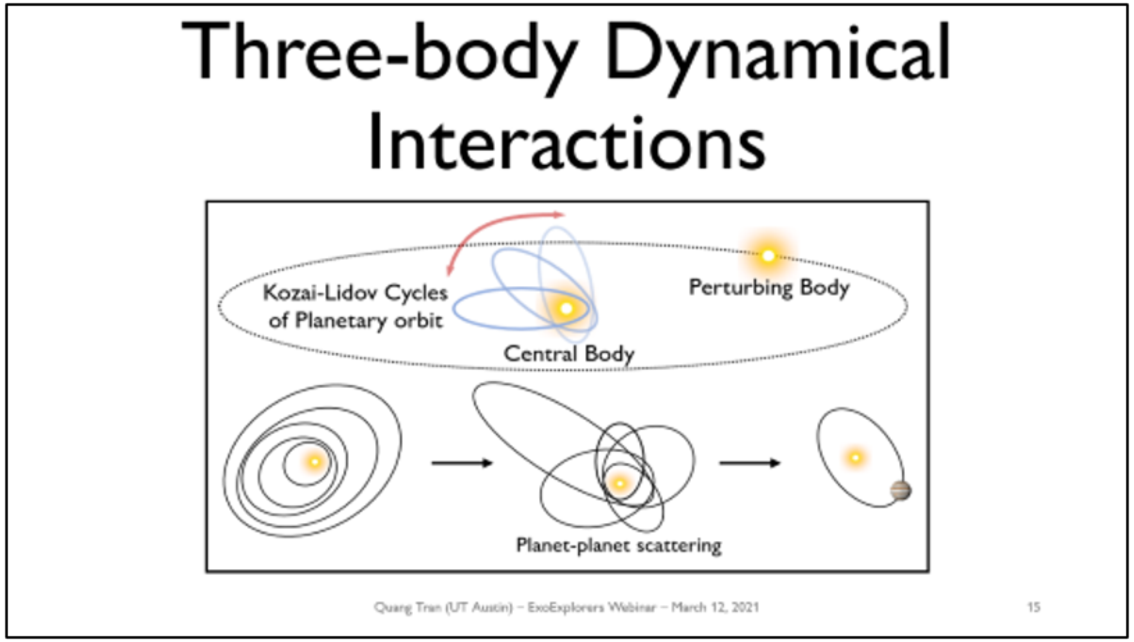
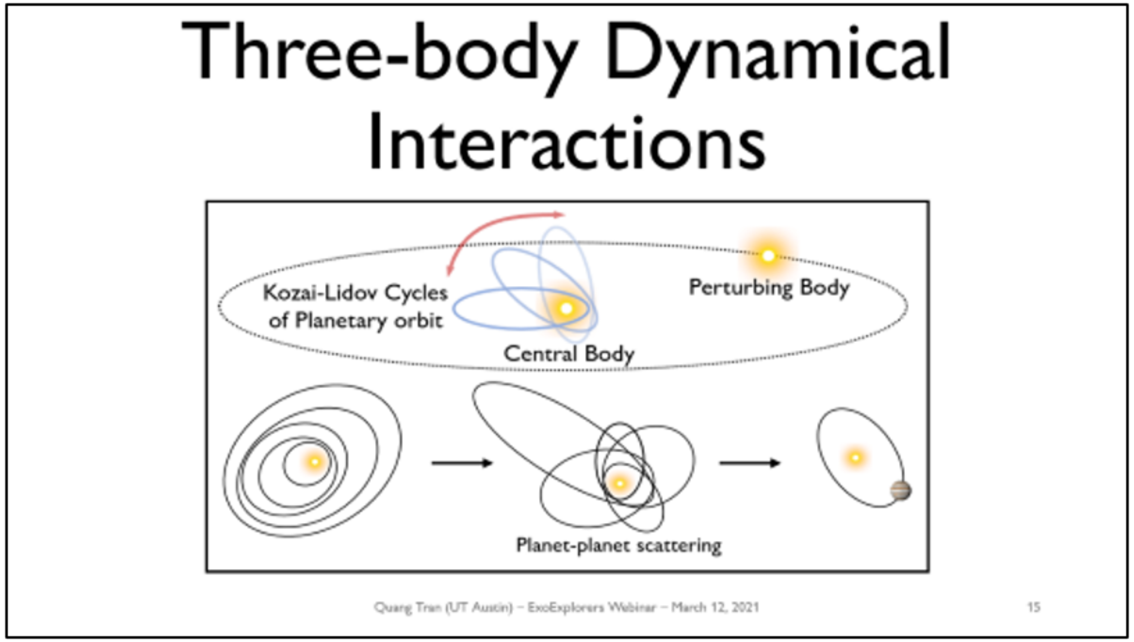


(e.g., Wu & Murray 2003; Fabrycky & Tremaine 2007; Jurić & Tremaine; Chatterjee et al. 2008; Triaud et al. 2010; Naoz et al. 2011)

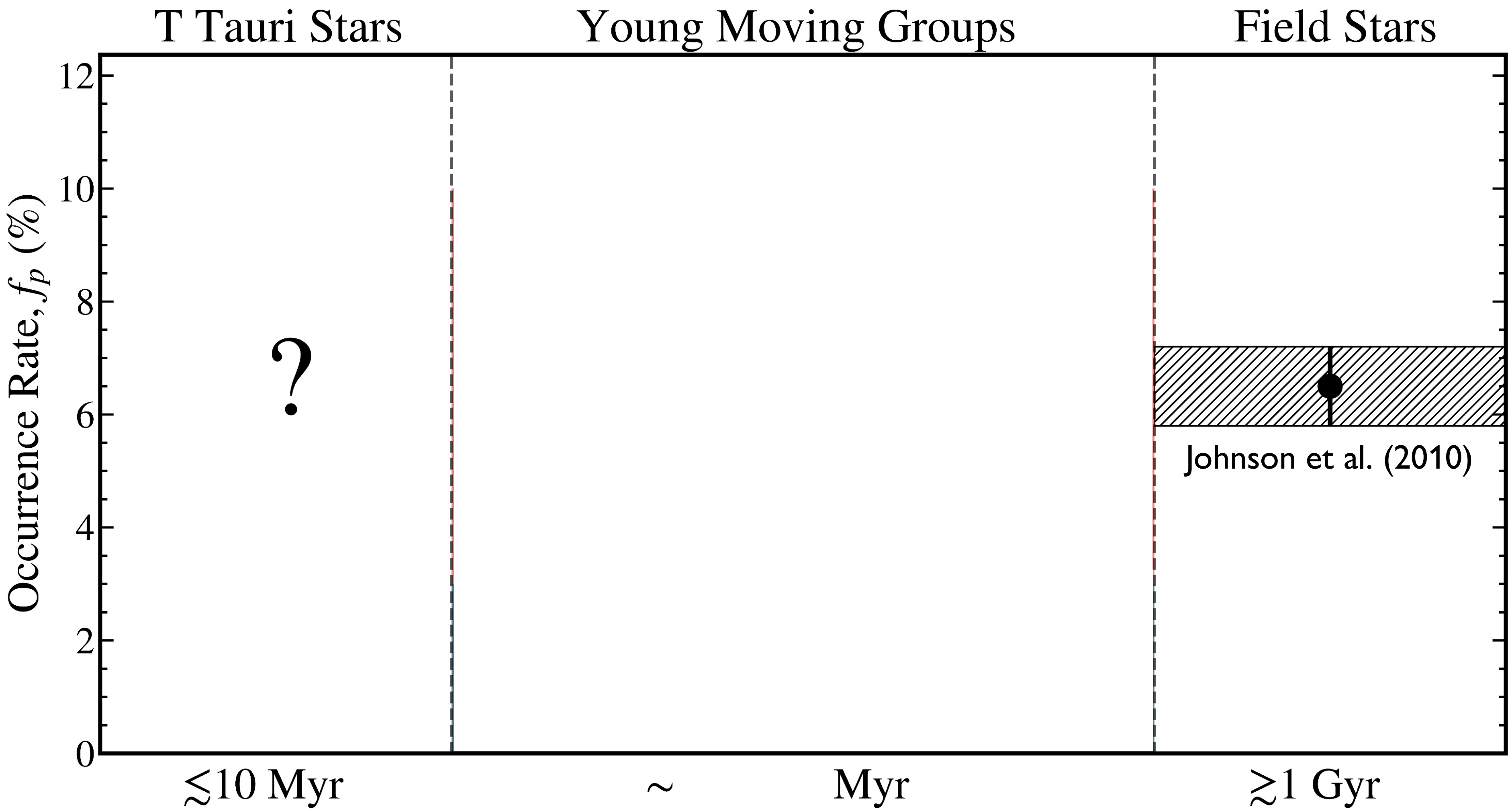
We can observationally distinguish these migration pathways because they operate on distinct timescales:

Disk migration must have taken place prior to ~10 Myr



Dynamical mechanisms occur on the order of $10^7 – 10^{10}$ yr

We can observationally distinguish these migration pathways by examining the <2.5 AU population



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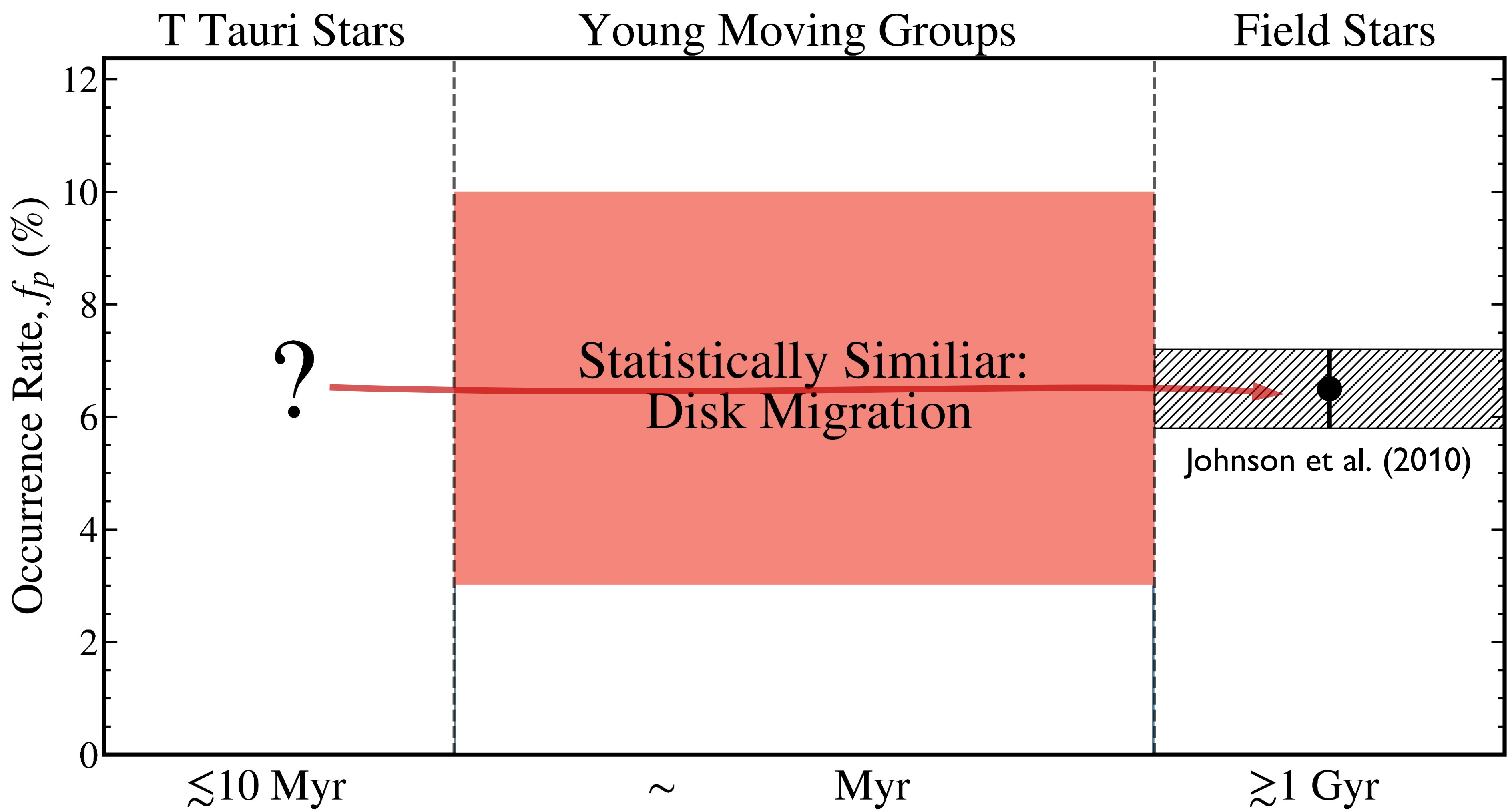

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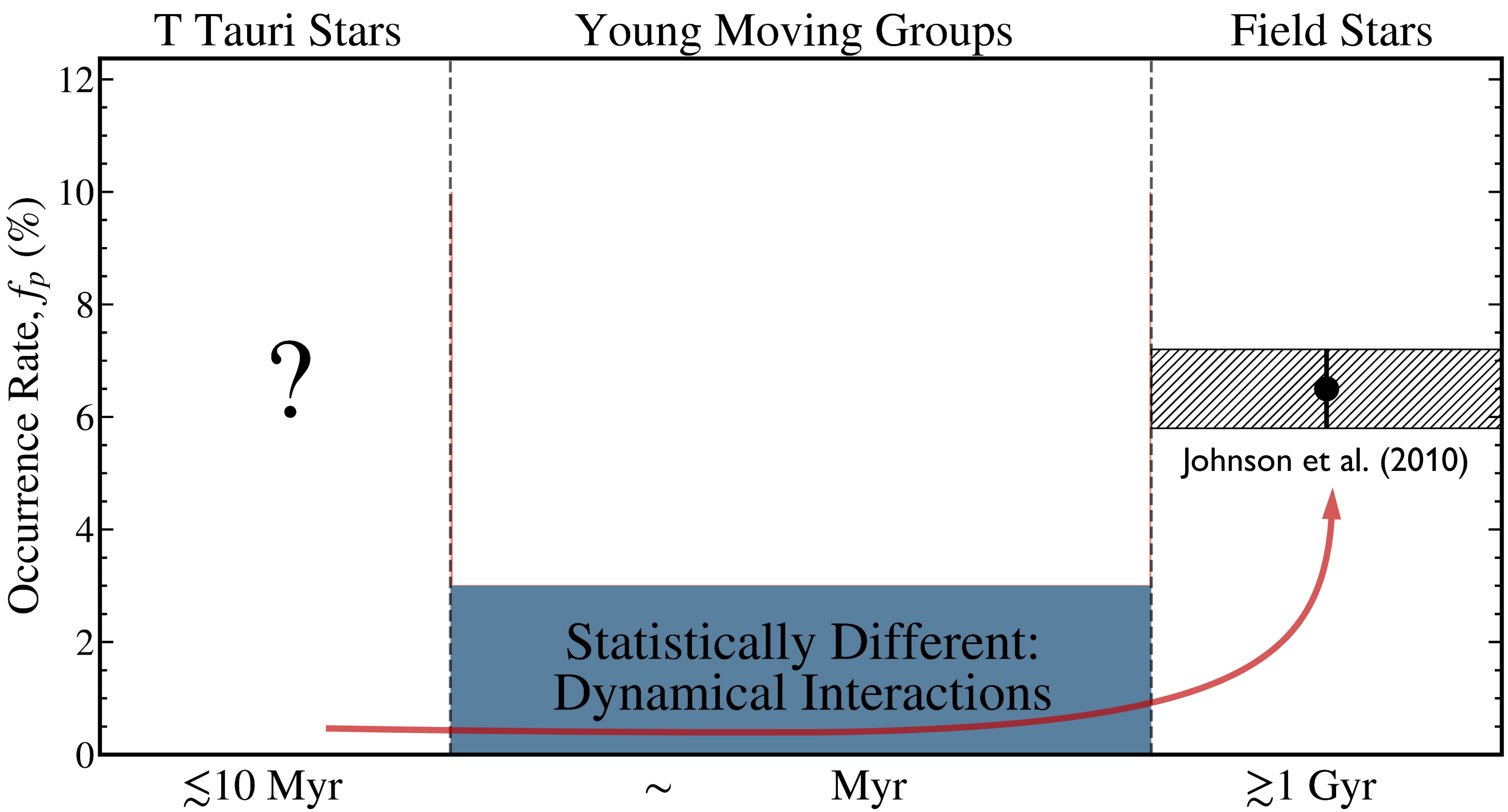

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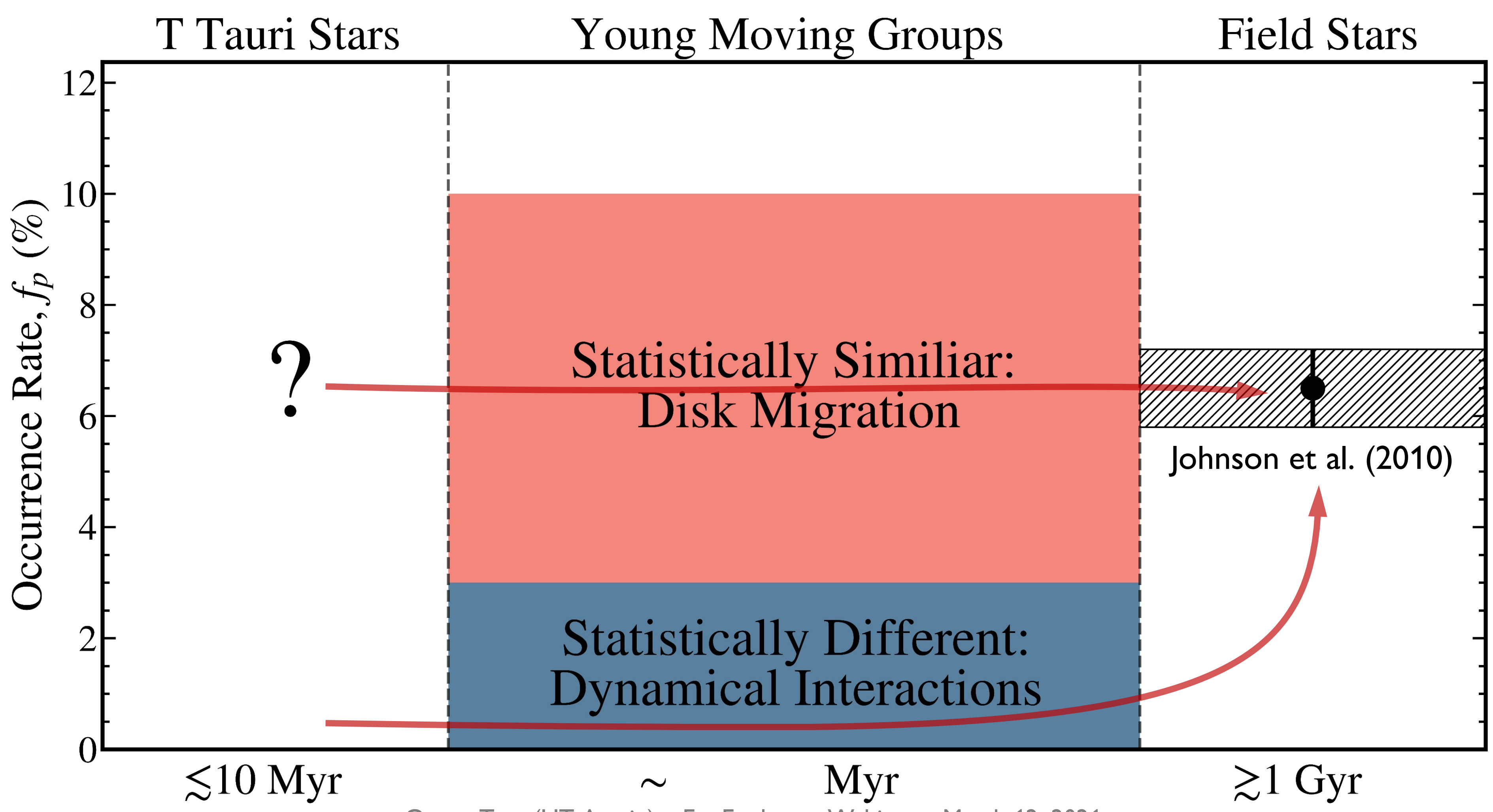
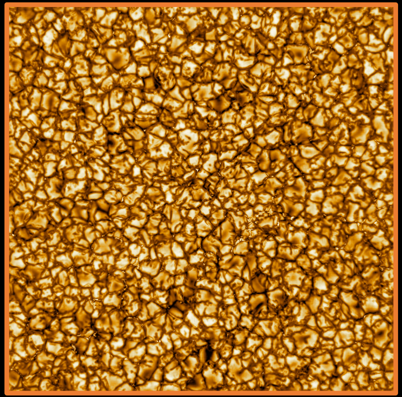


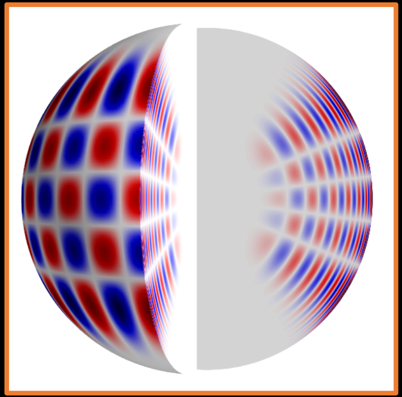
Why have we not already done this? Young stars have strong non-dynamical astrophysical variations

Image Credit: DKIST



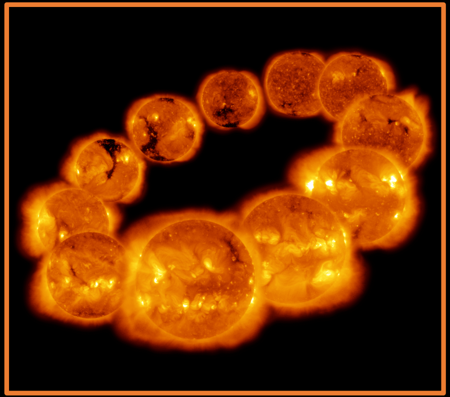
Granulation

Image Credit: Warrick Ball



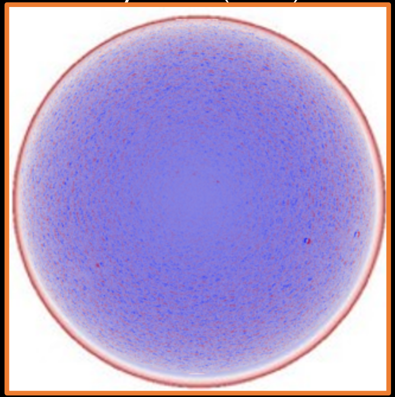
P-mode Acoustic Oscillations

Image Credit: NOAA/NASA



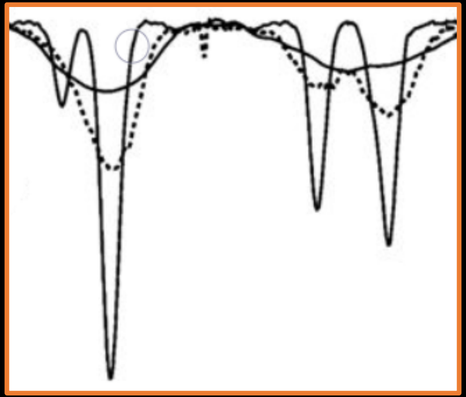
Long-term Magnetic Activity Cycles

Hathaway & Upton(2014), Hathaway et al. (2015)



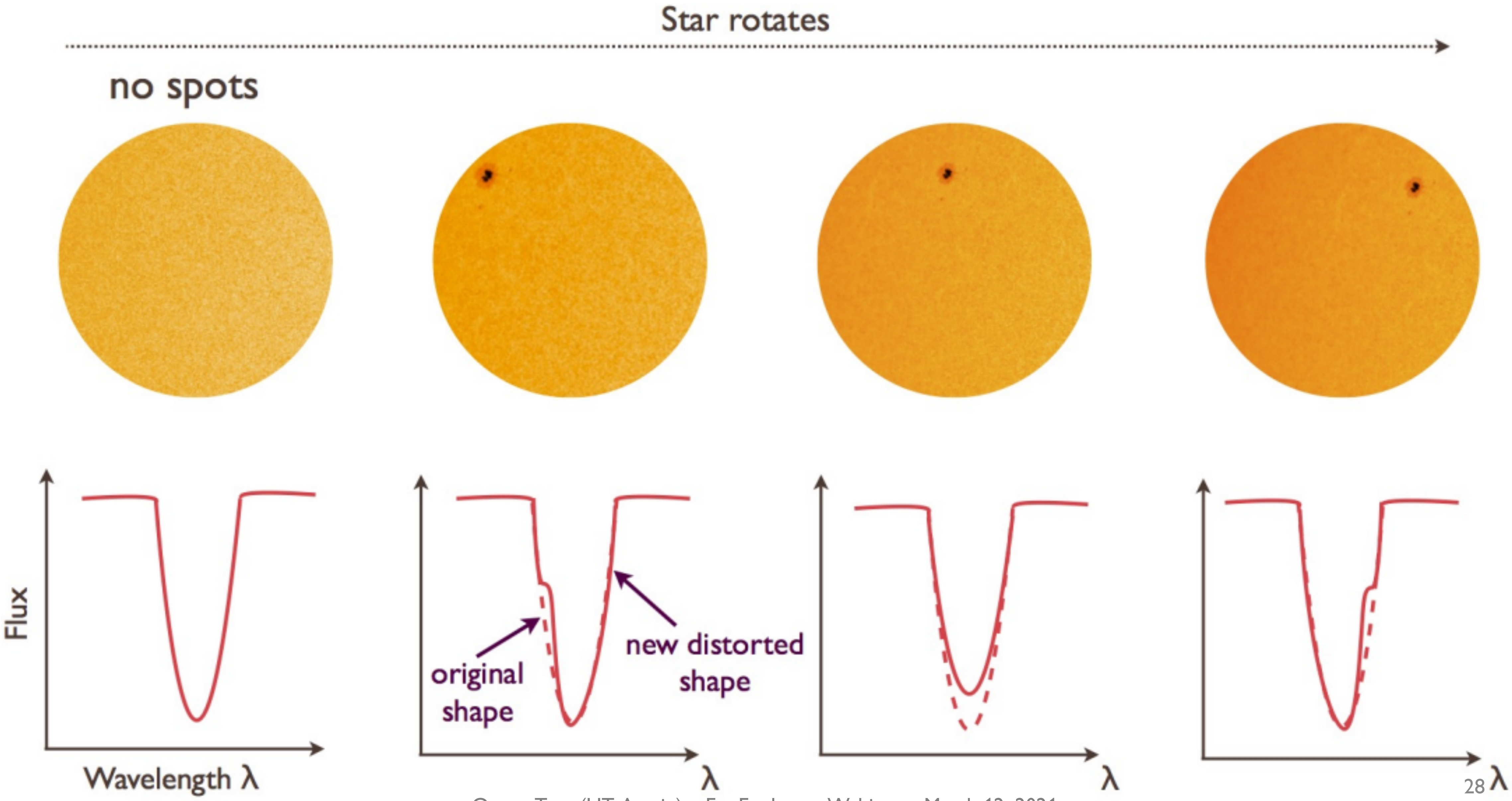
Convective Blueshift Suppression

Gray (2005)



Stellar Rotational Broadening

Starspot-induced variability is especially pernicious



Haywood (2015)

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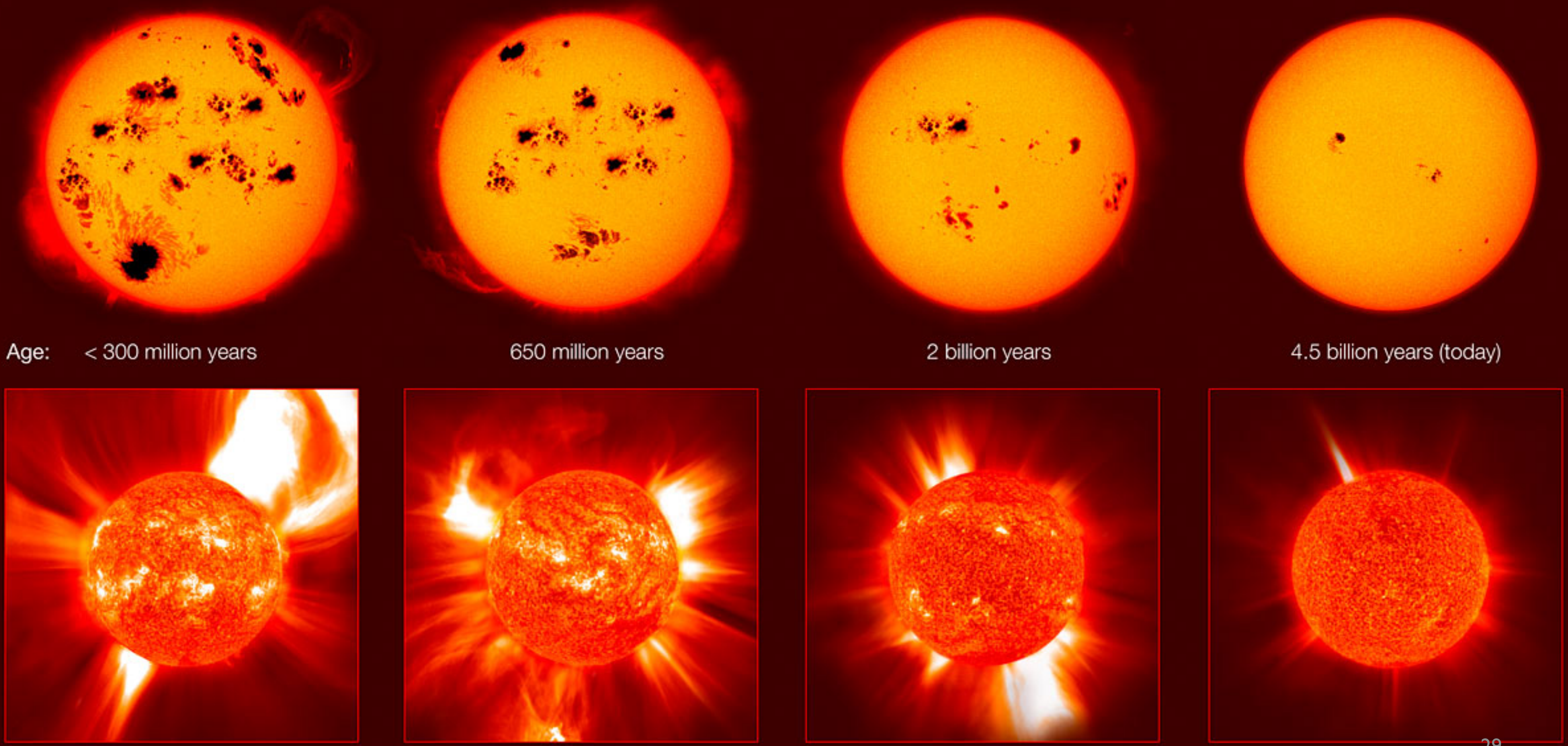

Image Credit: IAU

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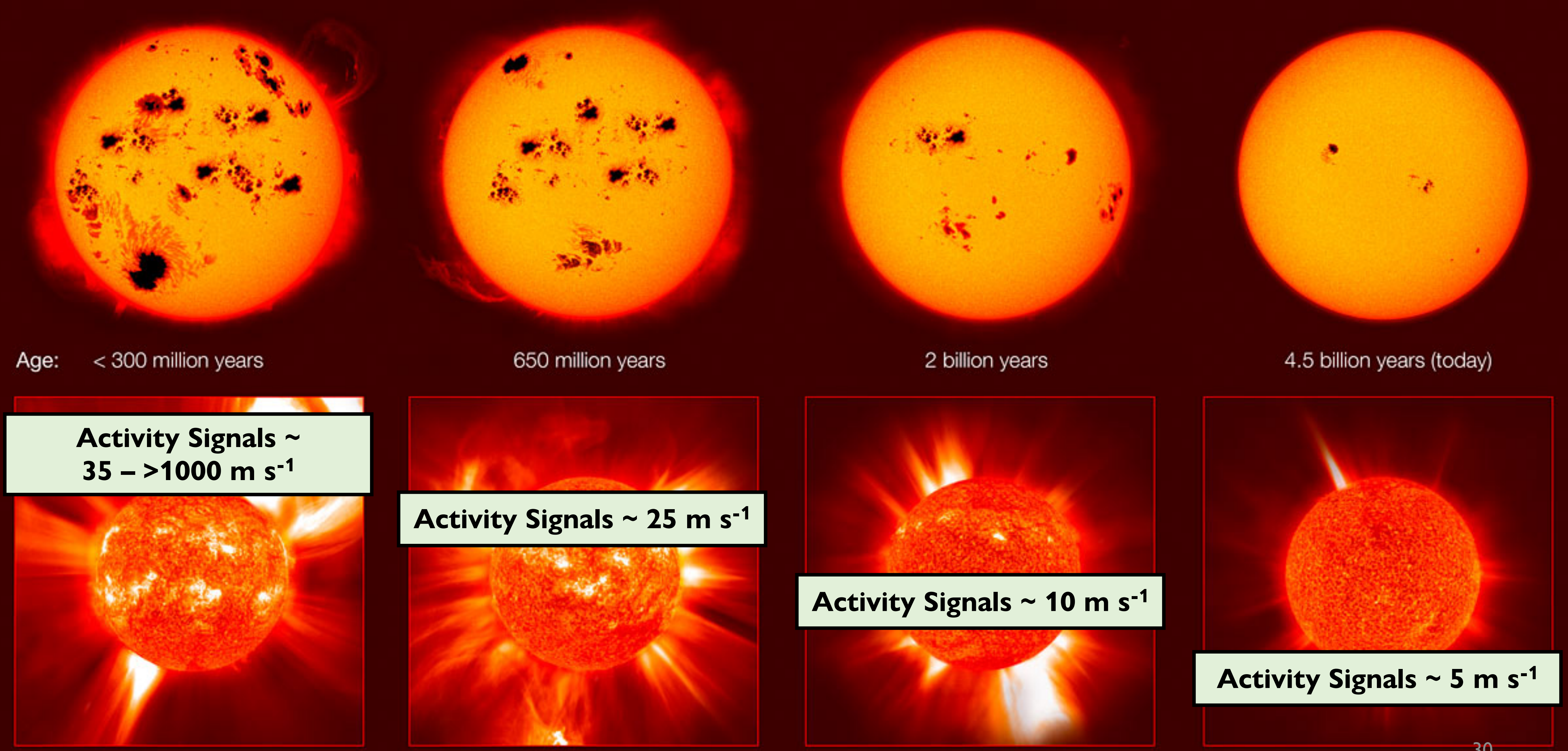

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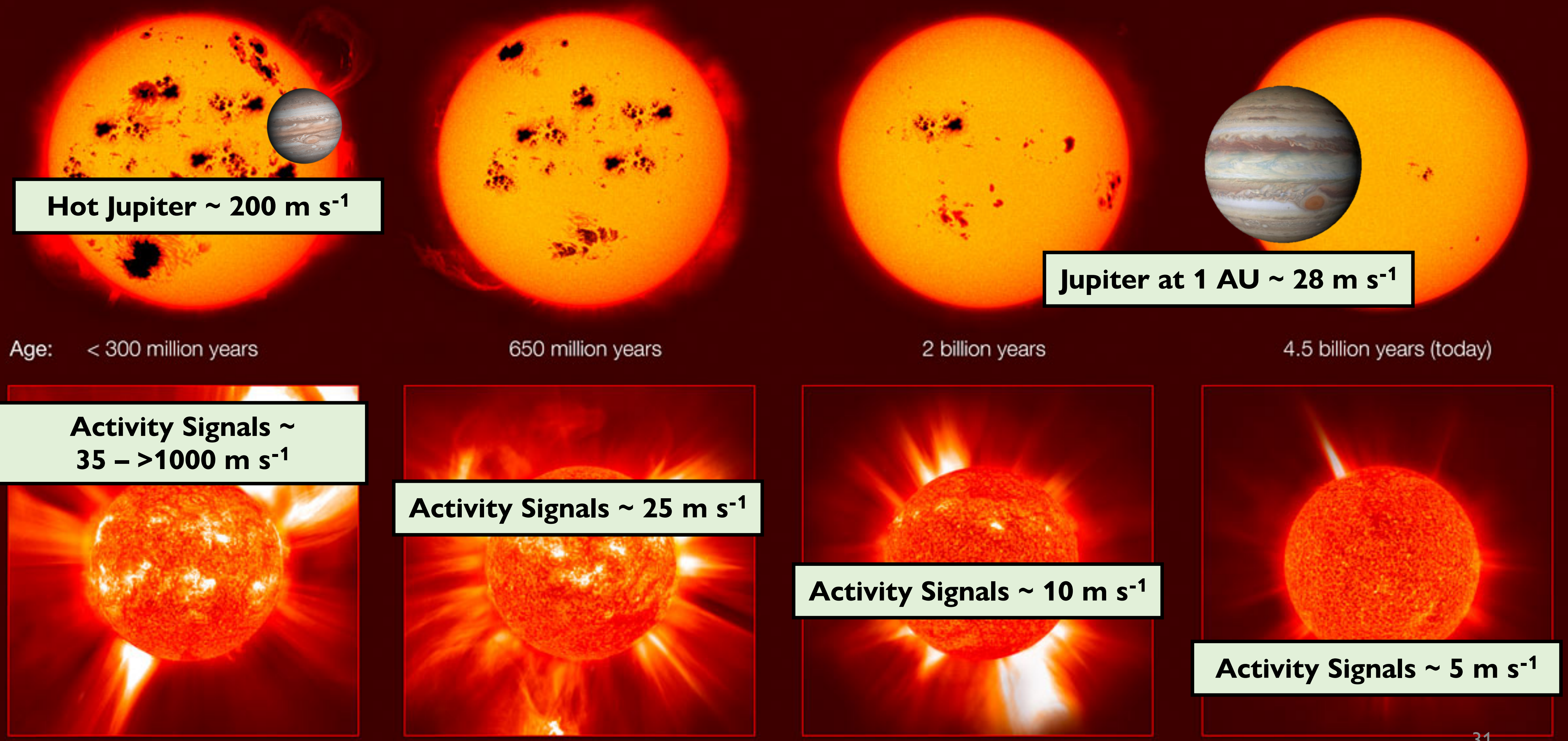

Image Credit: IAU

Recap

Setting up the problem

Why are we interested in giant planet migration?

The origin of gas giants interior to the water ice line remains undetermined.

What are the difficulties involved in studying this phenomenon?

Studying young stars is difficult due to their increased magnetically-induced activity.

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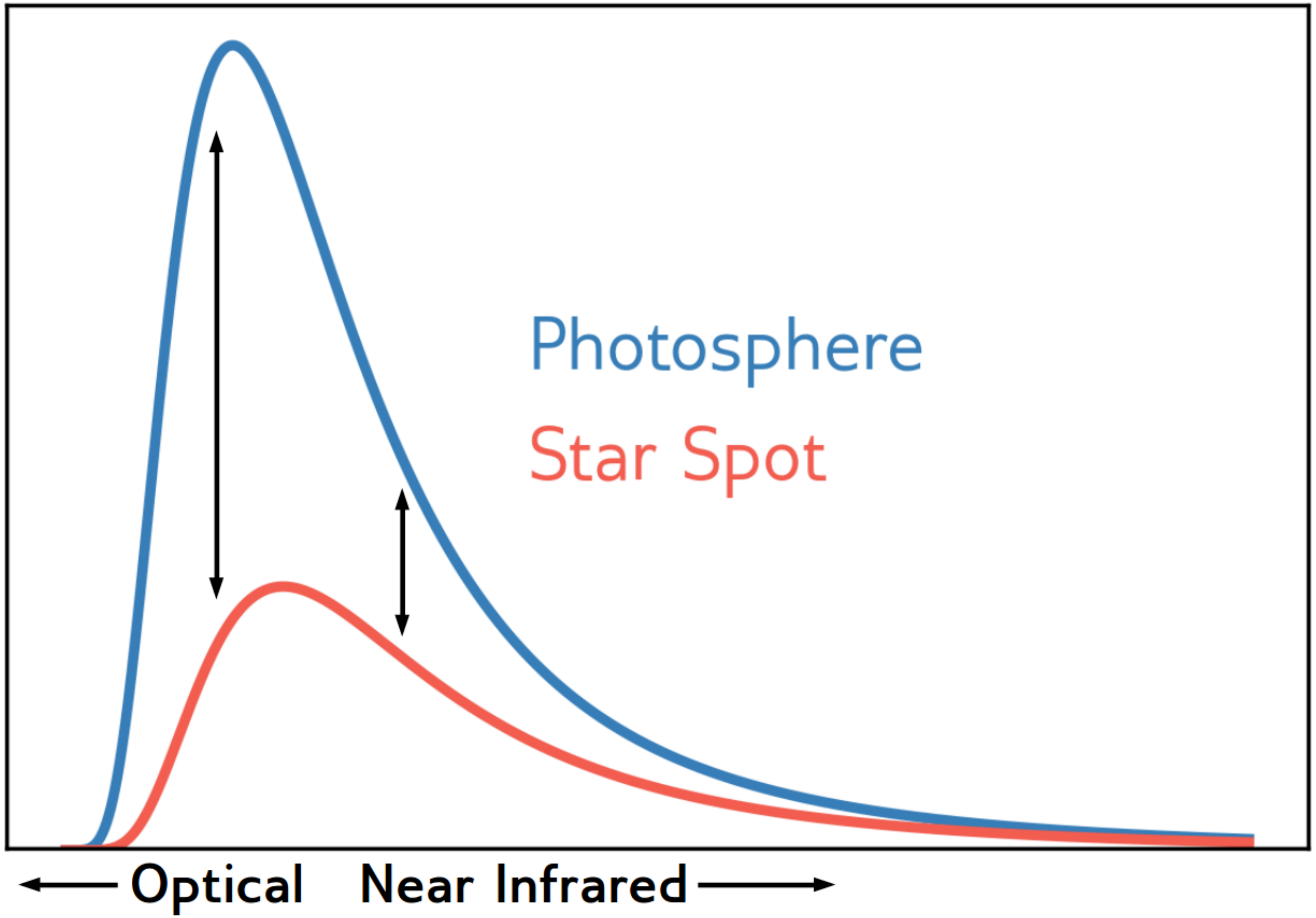
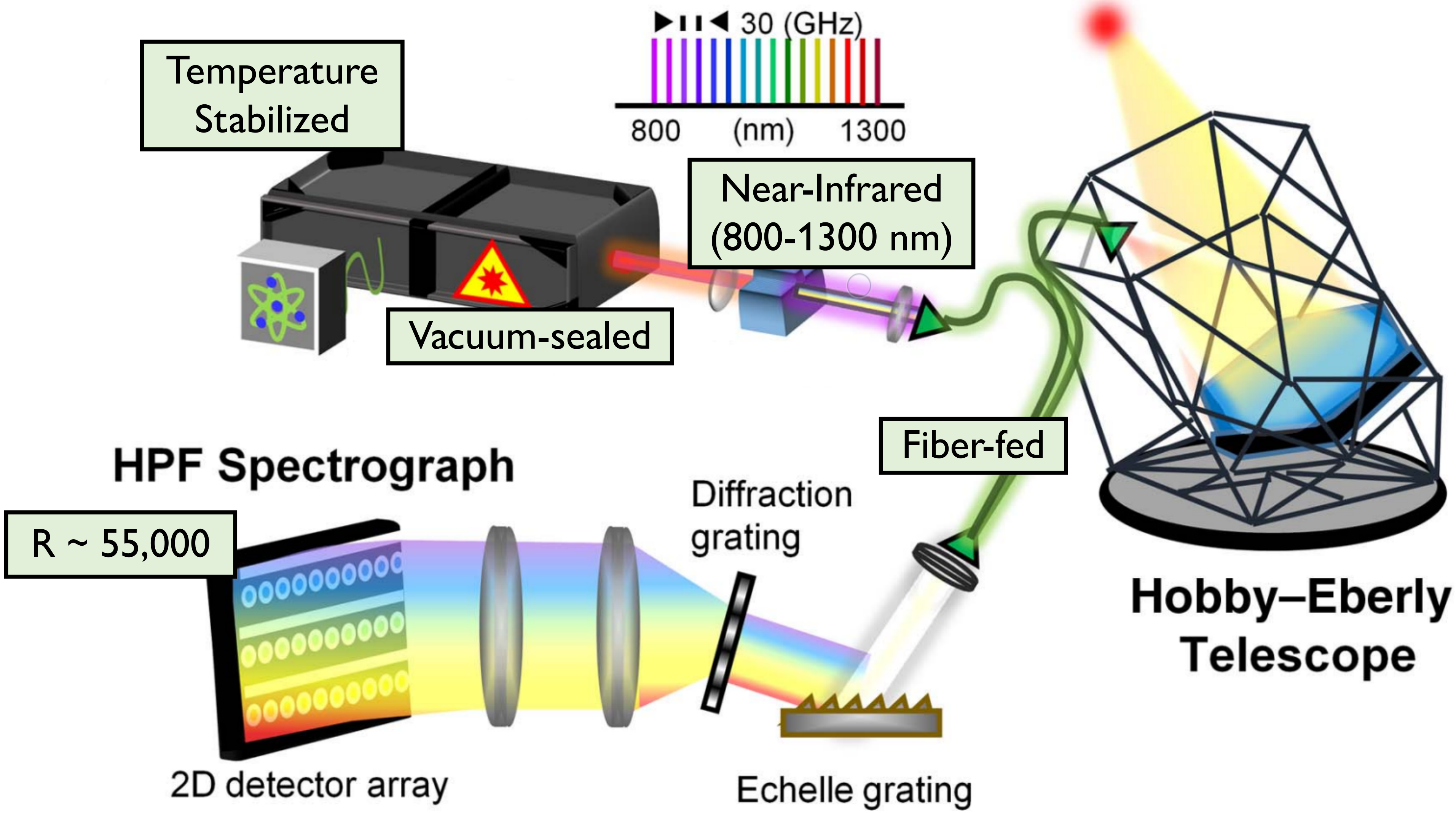
Observing at near-infrared wavelengths is expected to reduce the radial velocity contributions of starspots



HPF is the ideal instrument to leverage this wavelength dependence to detect giant planets around young stars



Metcalf et al. (2019)

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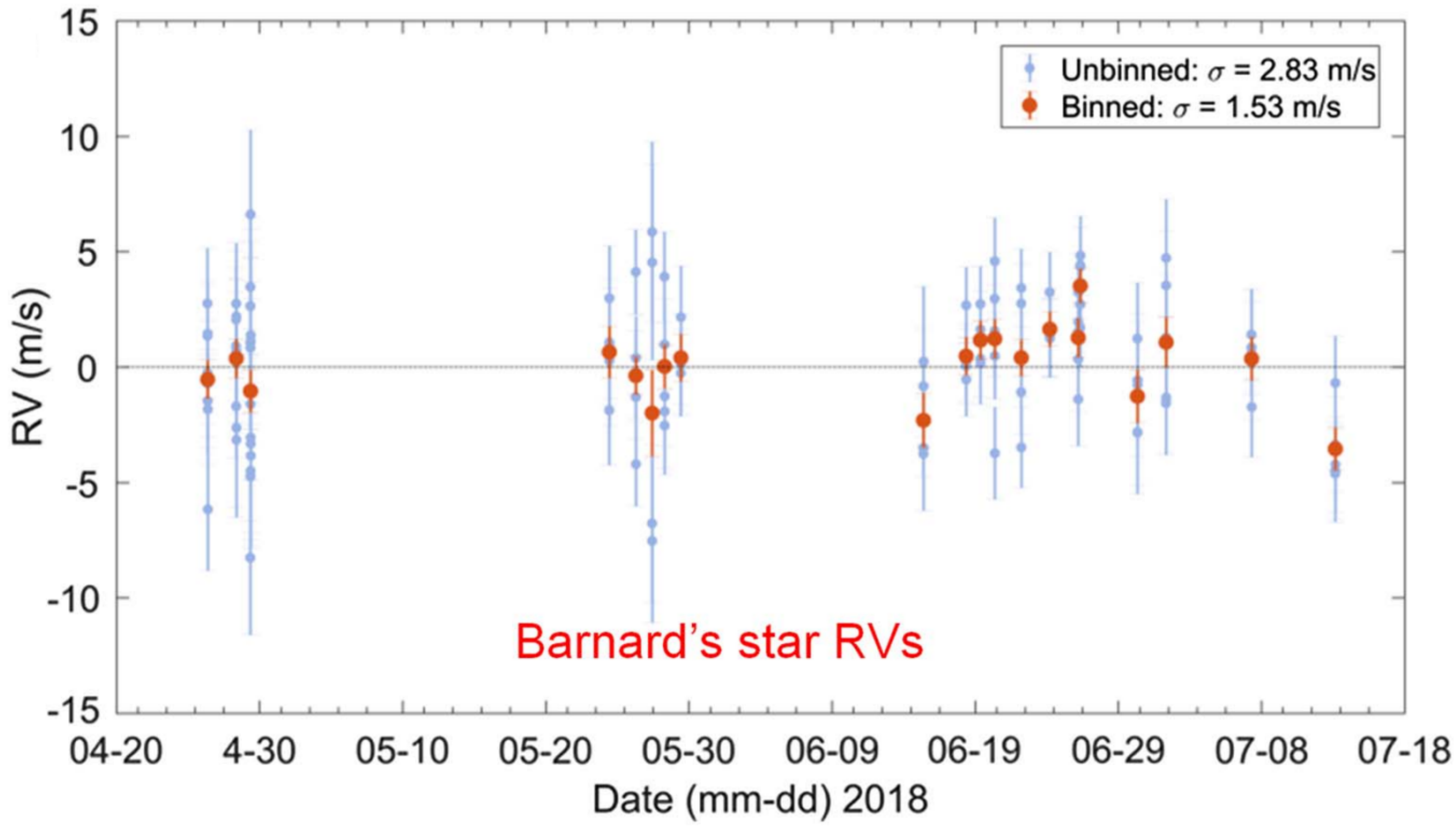
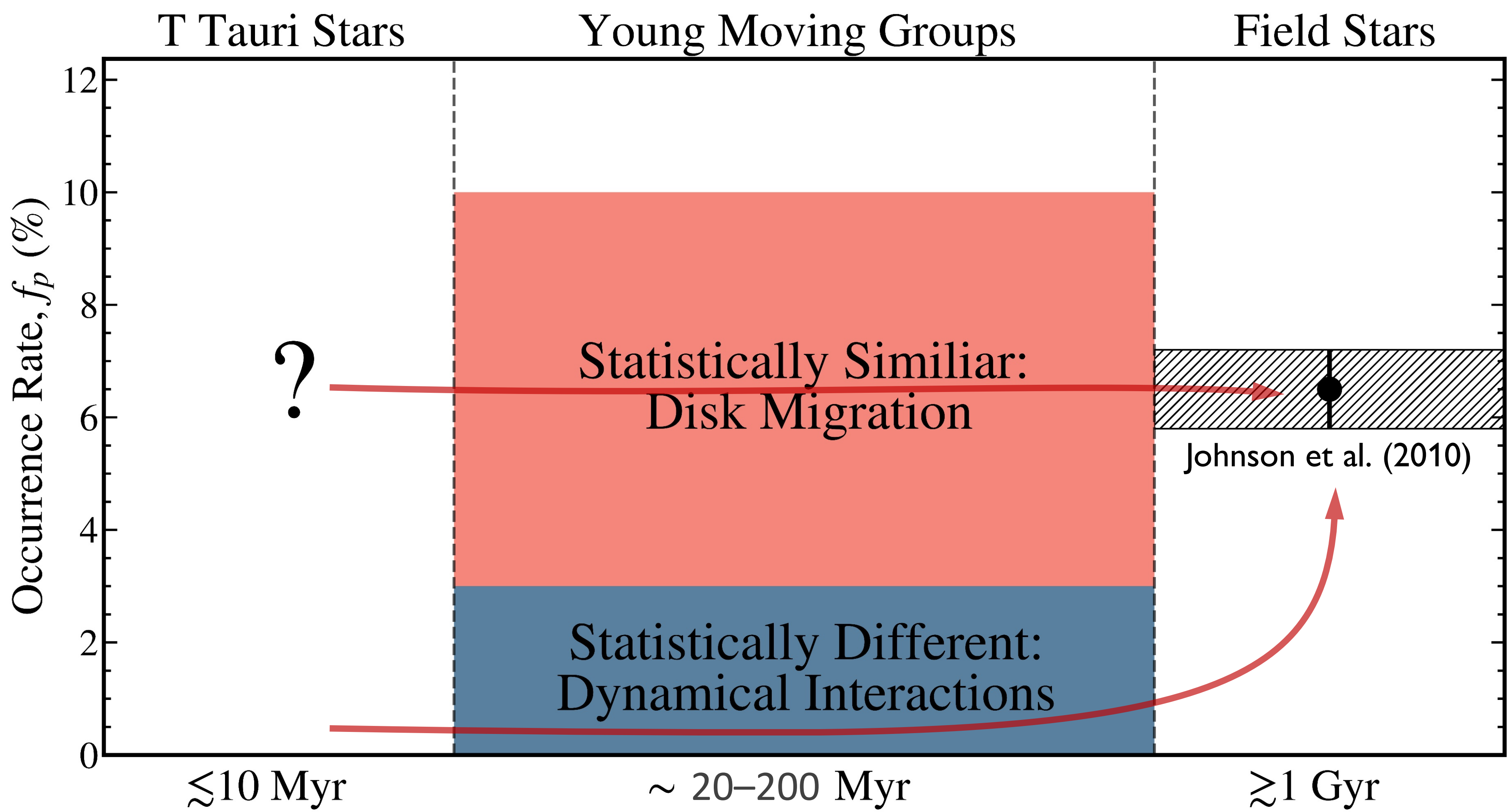
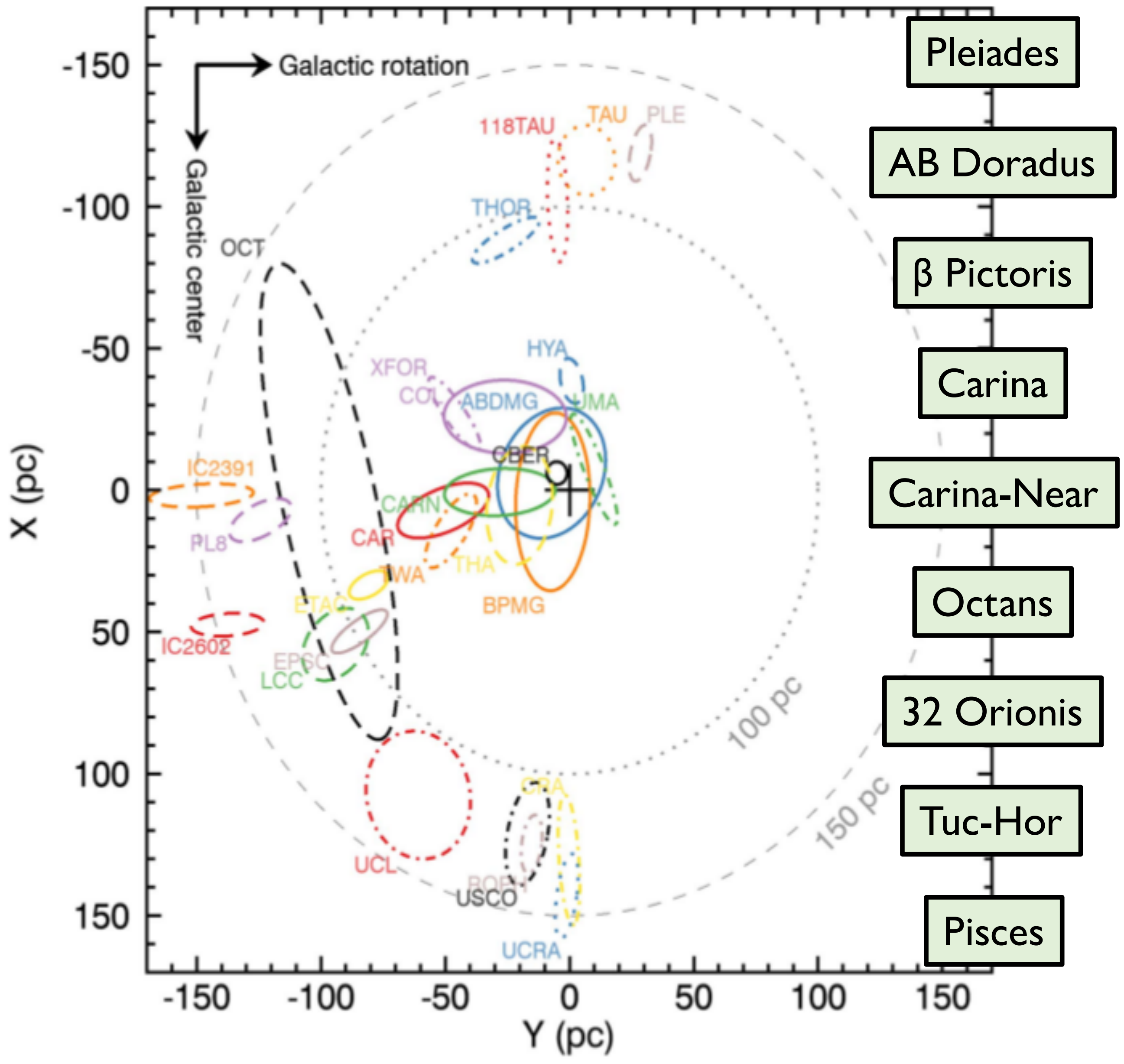


Metcalf et al. (2019)

A Near-Infrared Precision Radial Velocity Survey of Young Solar Analogs with HPF

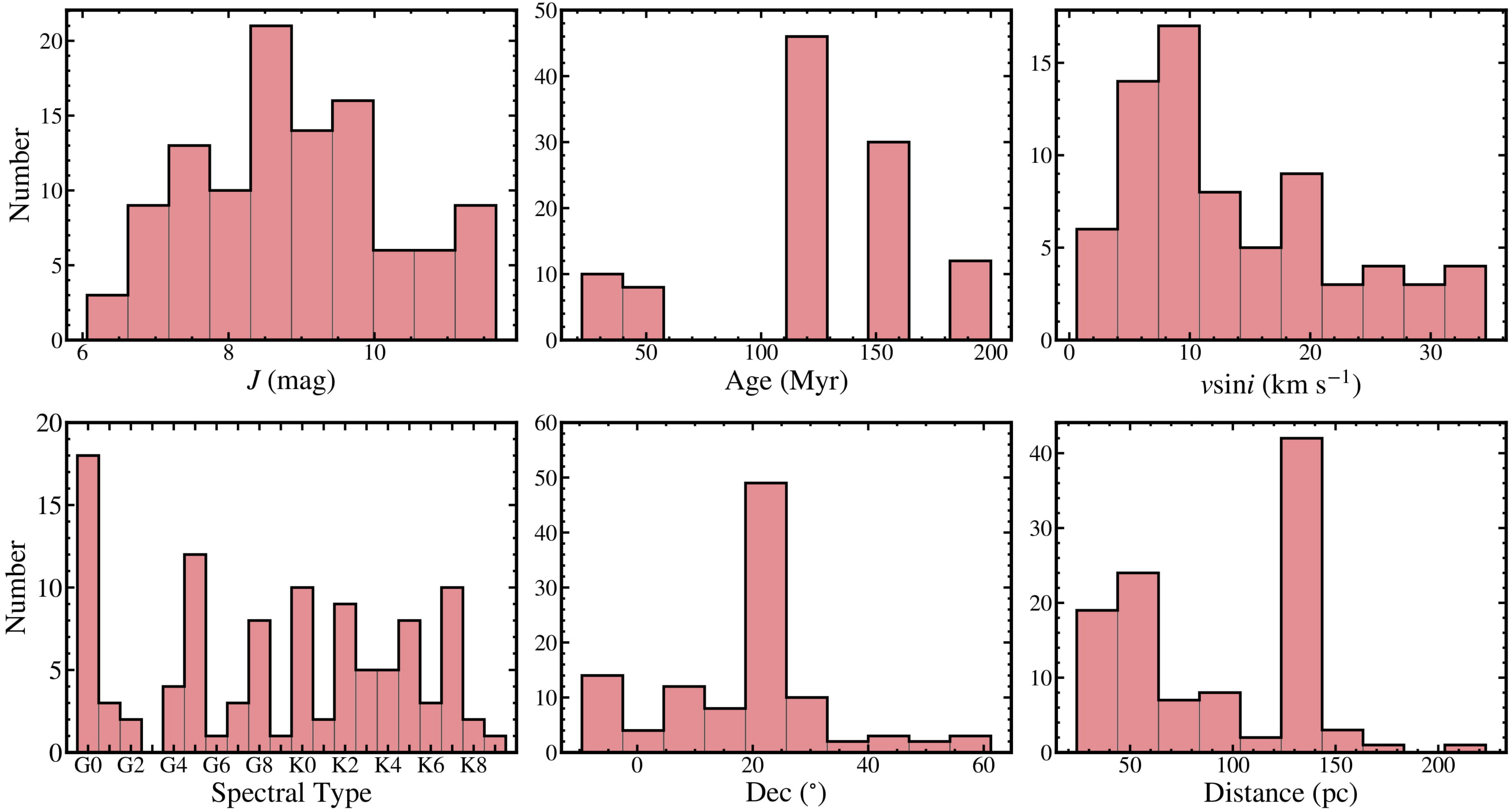




Young Moving Groups provide bright, nearby, and well-characterized targets in this age range

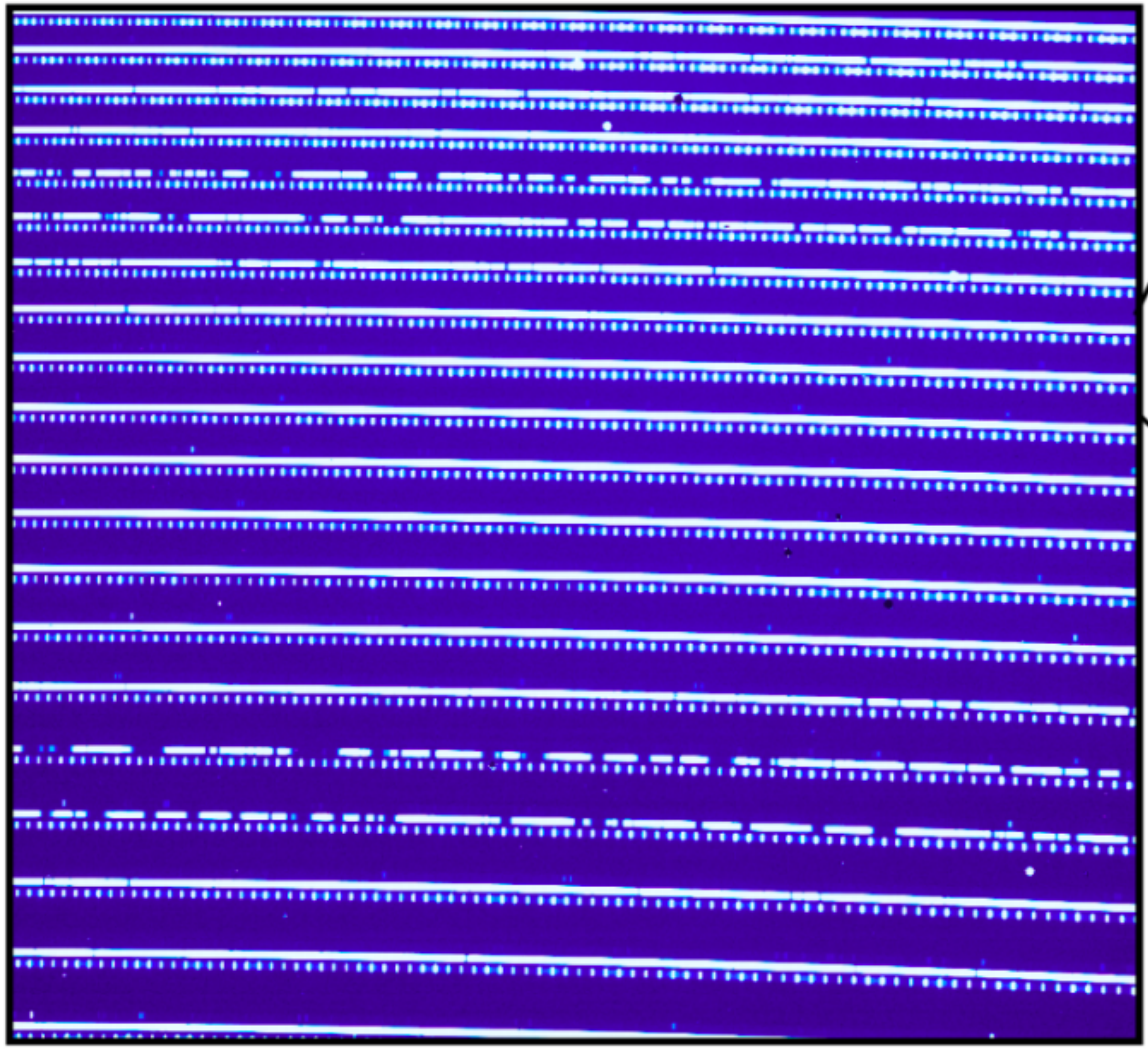
Gagne et al. (2018)

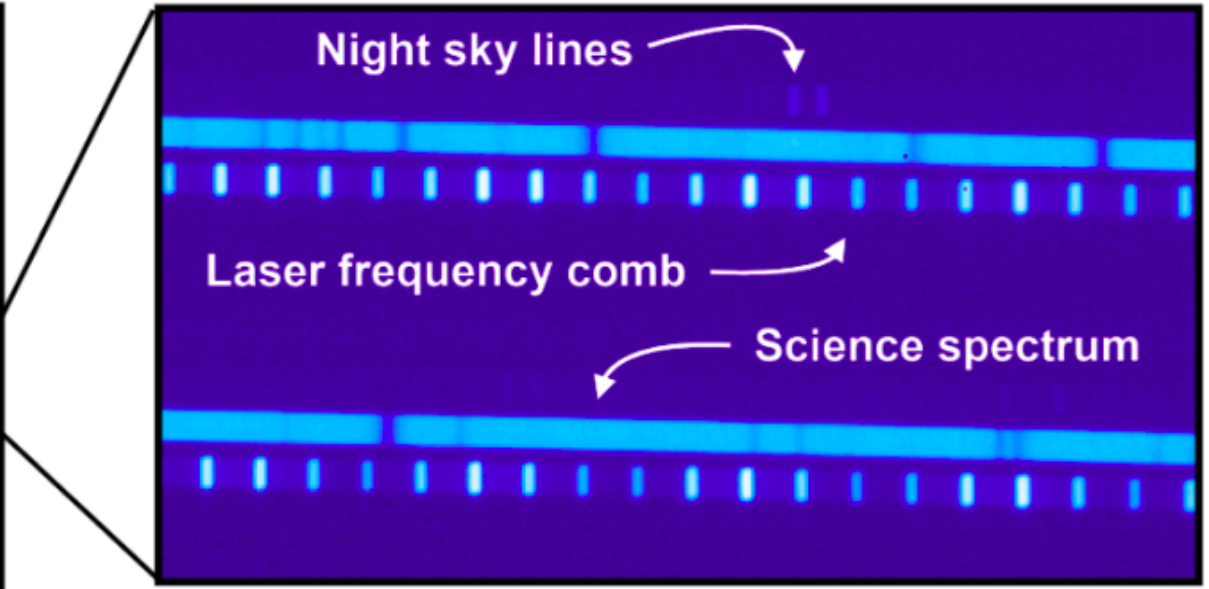
Summary of Survey Target List

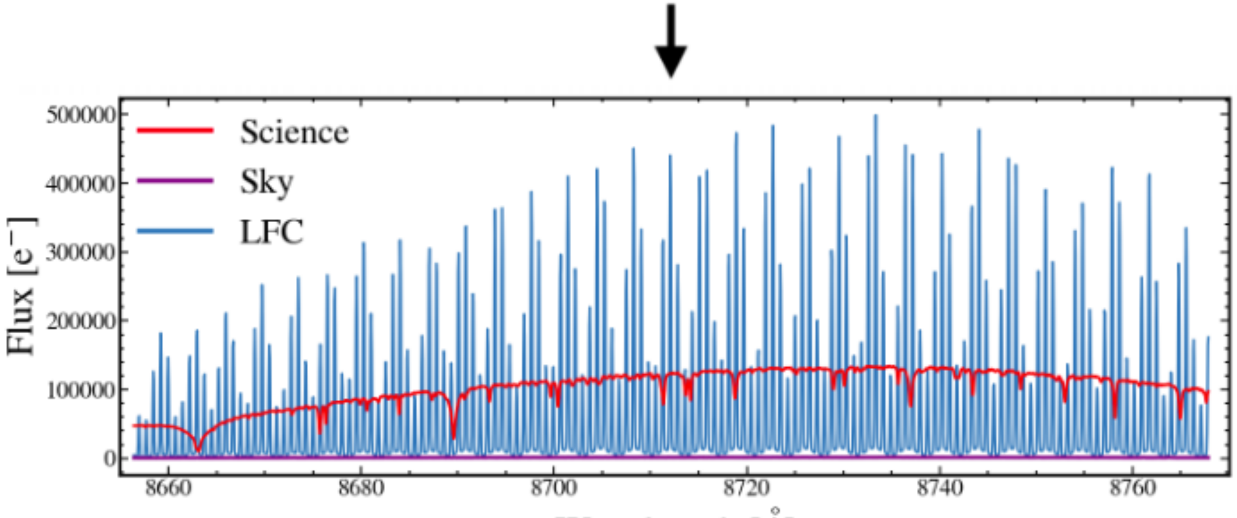


Tran et al. 2021 (accepted; arXiv:2101.11005)

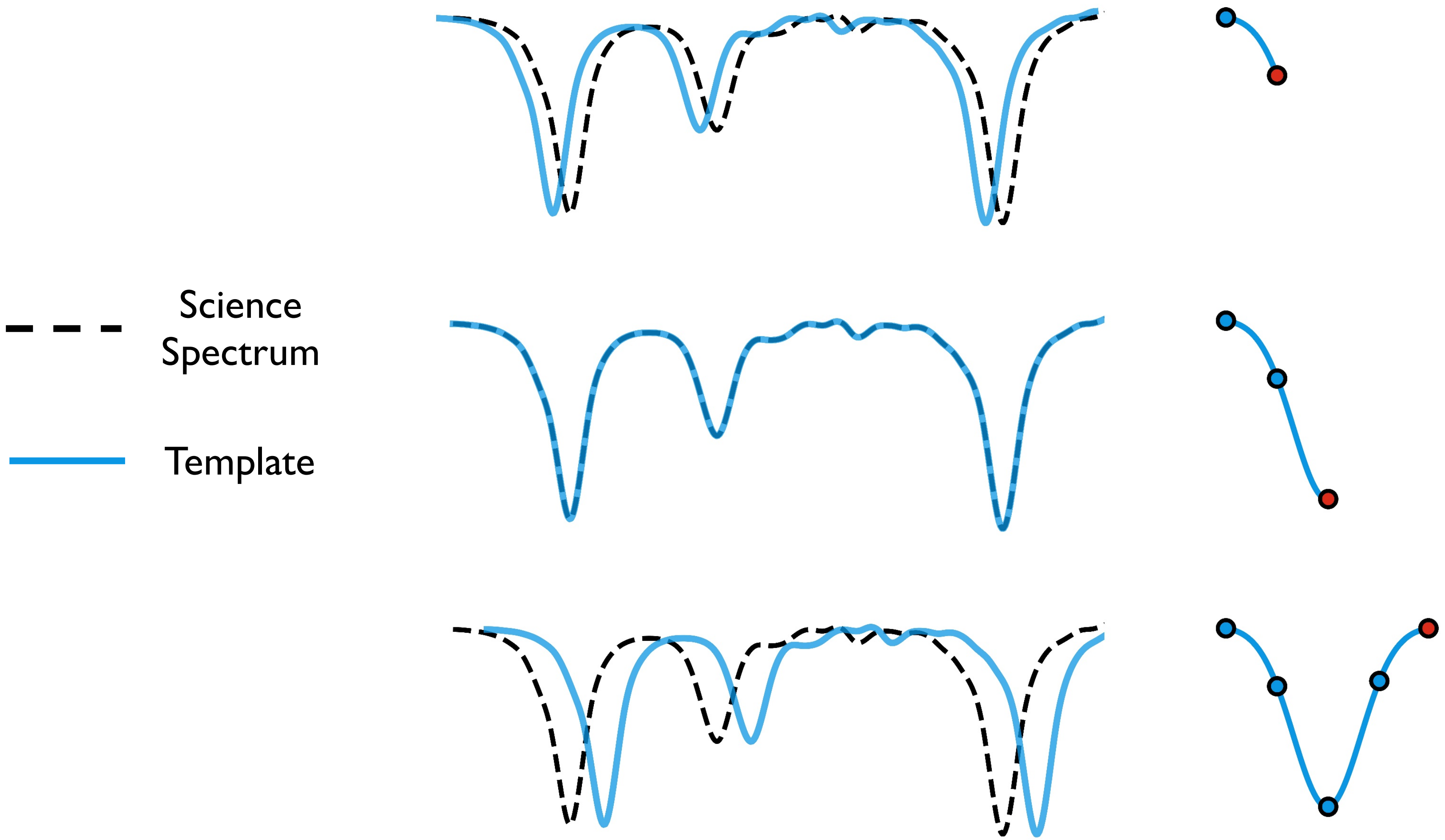
HPF Data




Night sky lines
Laser frequency comb
Science spectrum


500000
400000
300000
200000
100000
0
Flux [e⁻]
Science
Sky
LFC
8660
8680
8700
8720
8740
8760
Wavelength [Å]

Precision Radial Velocity Pipeline: Least-Squares Matching

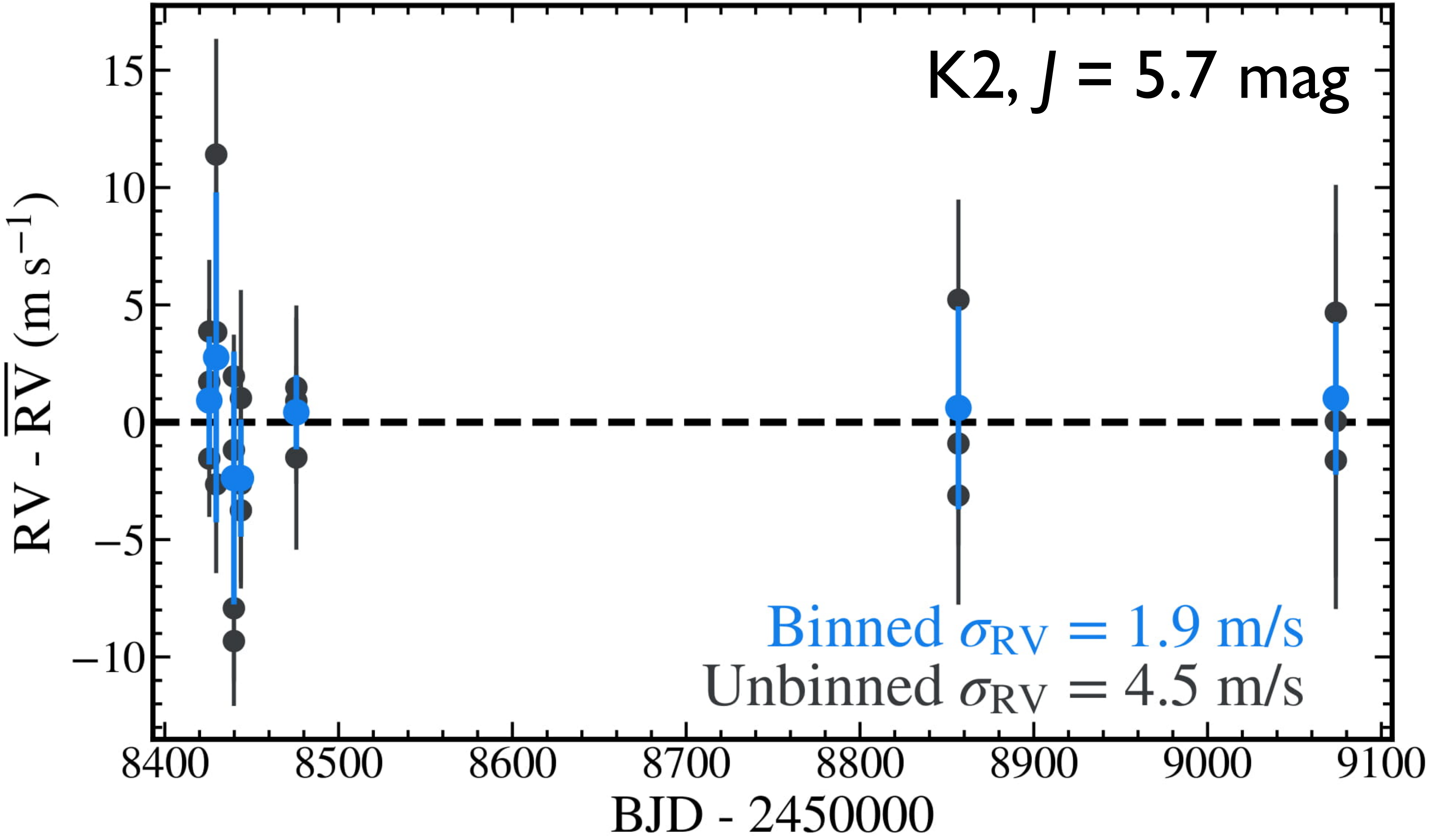


1) $V_{Template} < V_{Target}$

2) $V_{Template} = V_{Target}$

3) $V_{Template} > V_{Target}$

Precision Radial Velocity Pipeline: On-sky Stability at the sub-2 m/s Level on RV Standard



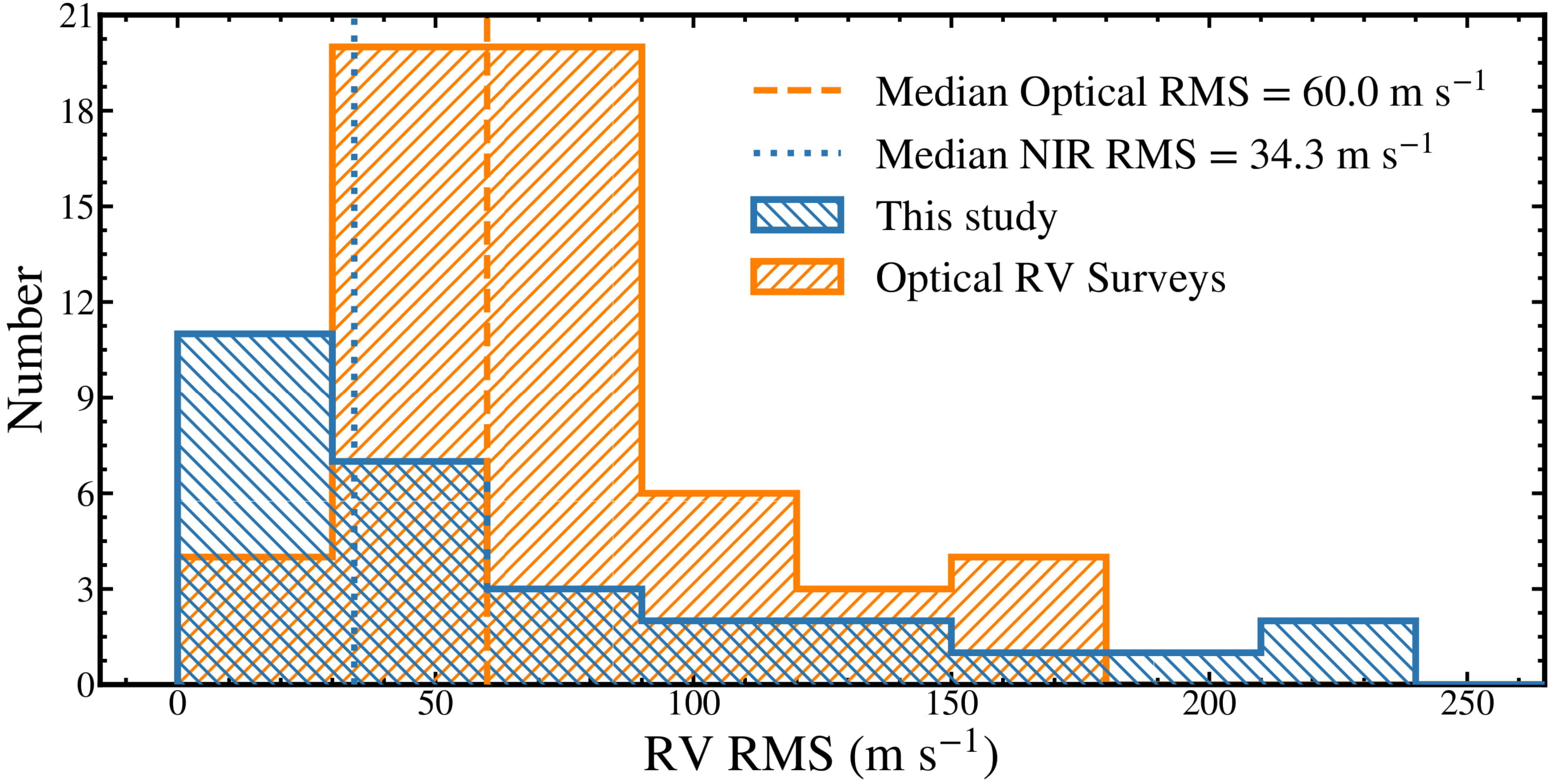
Tran et al. 2021 (accepted; arXiv:2101.11005)

For more information, check out my paper!

SCAN ME

https://arxiv.org/abs/2101.11005

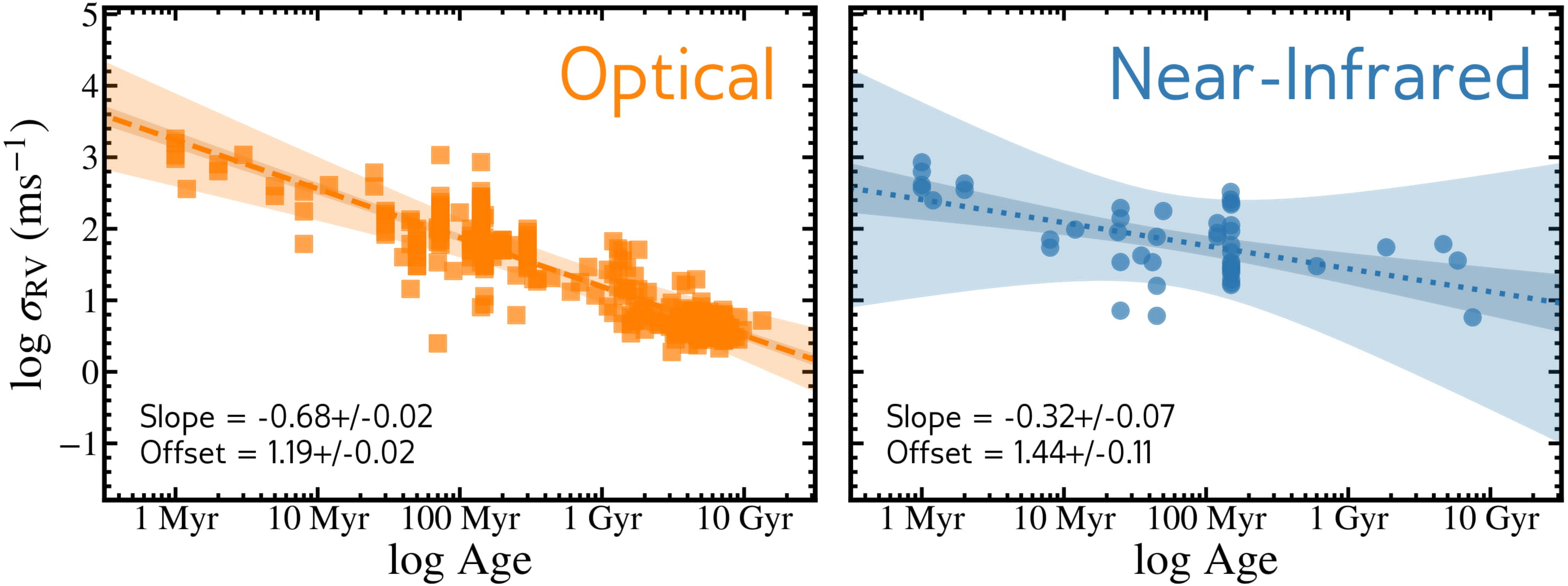
Results from the first 14 Months: Observed NIR RV RMS Distribution of Science Targets



The median NIR RMS is reduced by a factor of nearly 2 from the optical RV RMS based on a sample of stars with similar ages (20-200 Myr), rotational velocities (<30 km/s), and spectral types (GK).

Tran et al. 2021 (accepted; arXiv:2101.11005)

Results from the first 14 Months: Stellar Jitter Decays Logarithmically with Age



RV scatter obeys a logarithmic relationship with stellar age in both NIR and optical. This trend is shallower in the NIR s.t. RV scatter is lower in NIR at younger ages and higher at older.

Tran et al. 2021 (accepted; arXiv:2101.11005)

Future Work

1. Continue survey out to 4 years to reach giant planets at snowline, measure their occurrence rate, and compare with field sample
2. Implement multiwavelength follow-up for high RMS objects of interest (simultaneous optical and NIR plus photometric observations)
3. Develop tools to mitigate stellar activity in this age range

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Solving the problem

- How are we investigating giant planet migration in a unique way?
  - Search for giant planets around young Solar analogs in NIR with HPF
- Where are we with understanding the issue?
  - Demonstrated <2 m s^{-1} precision on RV standard with RV pipeline
  - Measured a median NIR RV RMS of 34.3 m s^{-1}, reduced by factor of two from the optical RV jitter values for similar stars
  - Found several high RV RMS values potentially caused by close-in planets
- What are the next steps we are taking?
  - Follow up on these objects of interest
  - Continue the survey out to 4 years to reach water ice line

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- Search for giant planets around young Solar analogs in NIR with HPF

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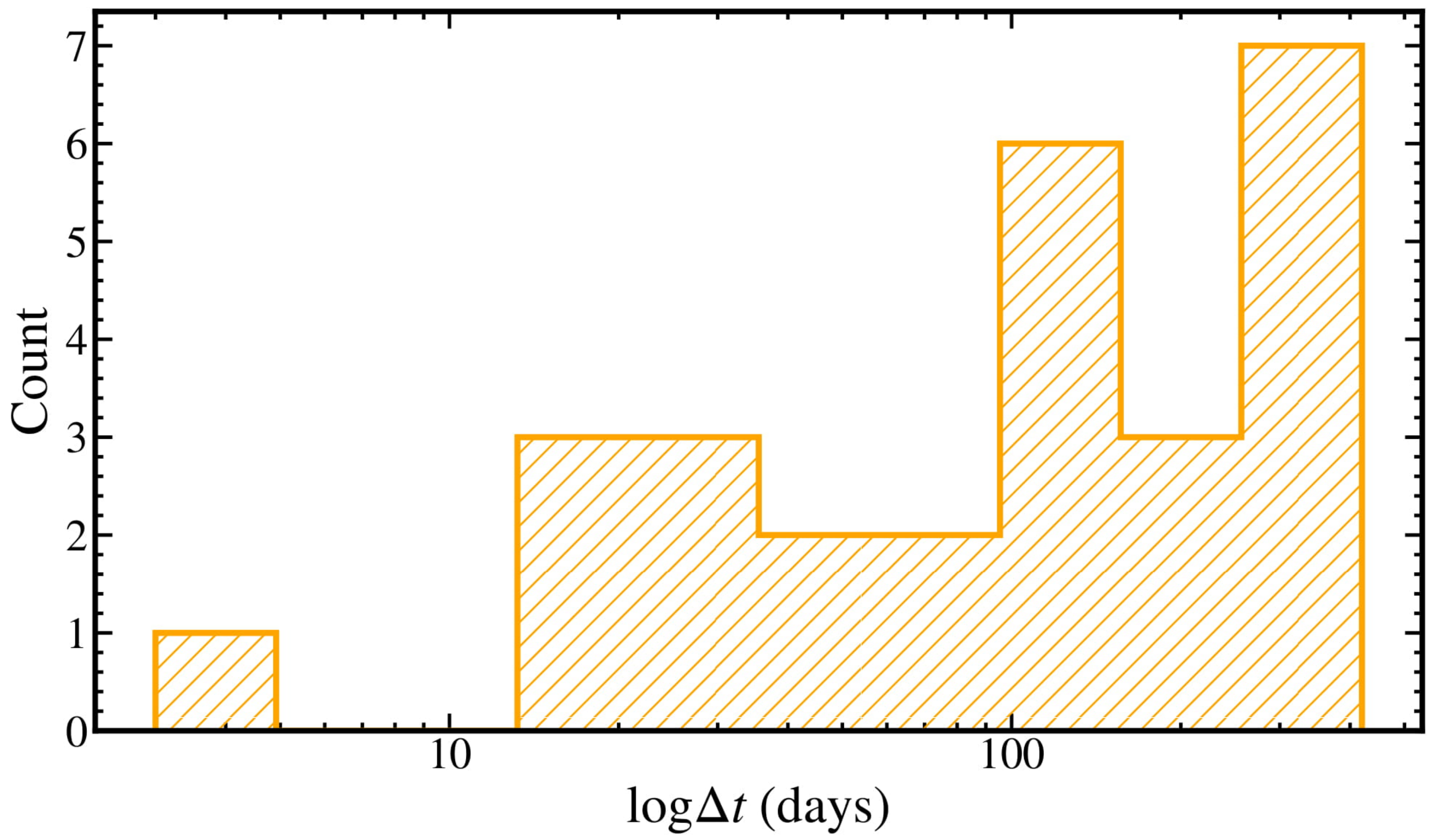
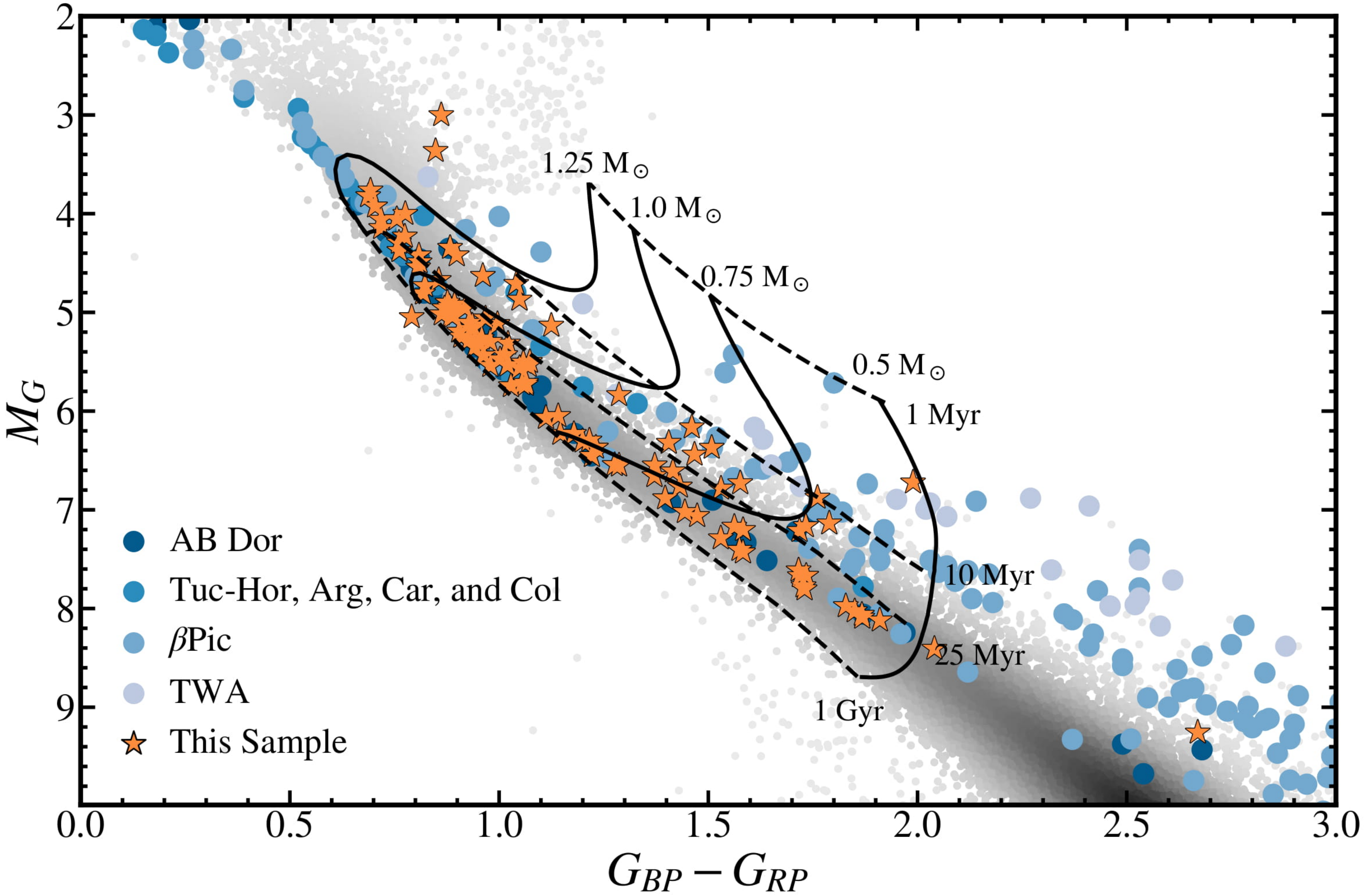
Supplementary Slides



Tran et al. 2021 (accepted; arXiv:2101.11005)



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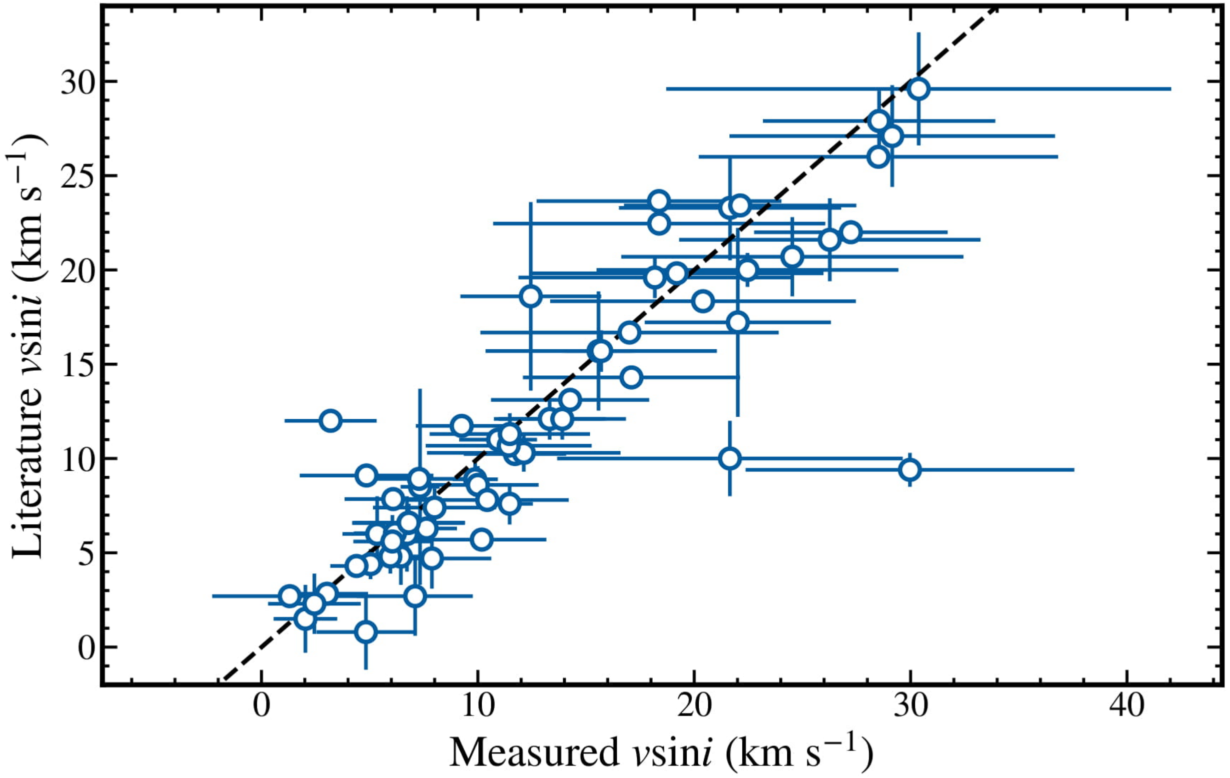

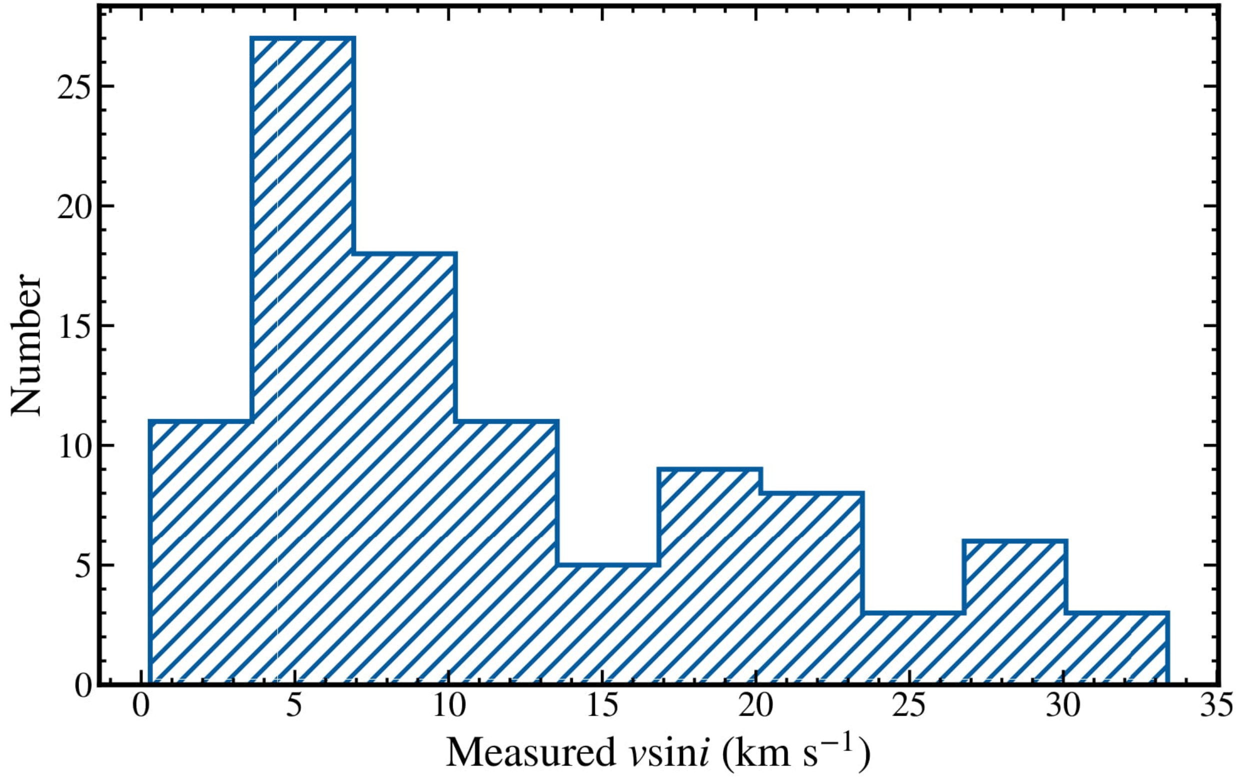

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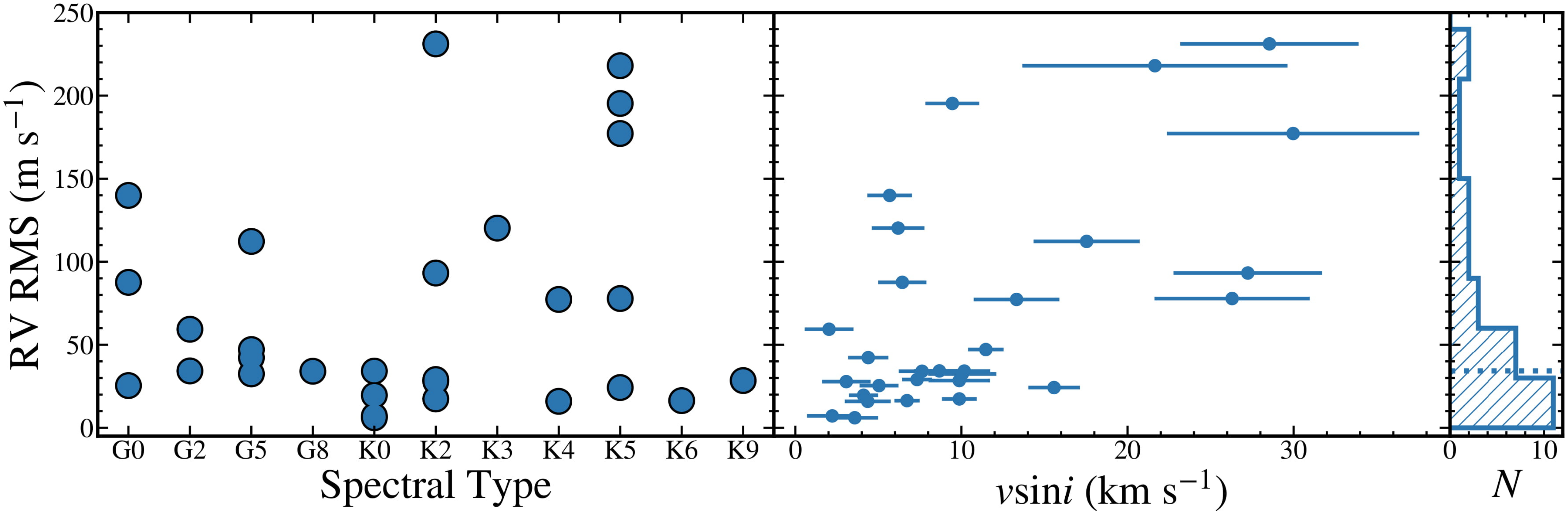

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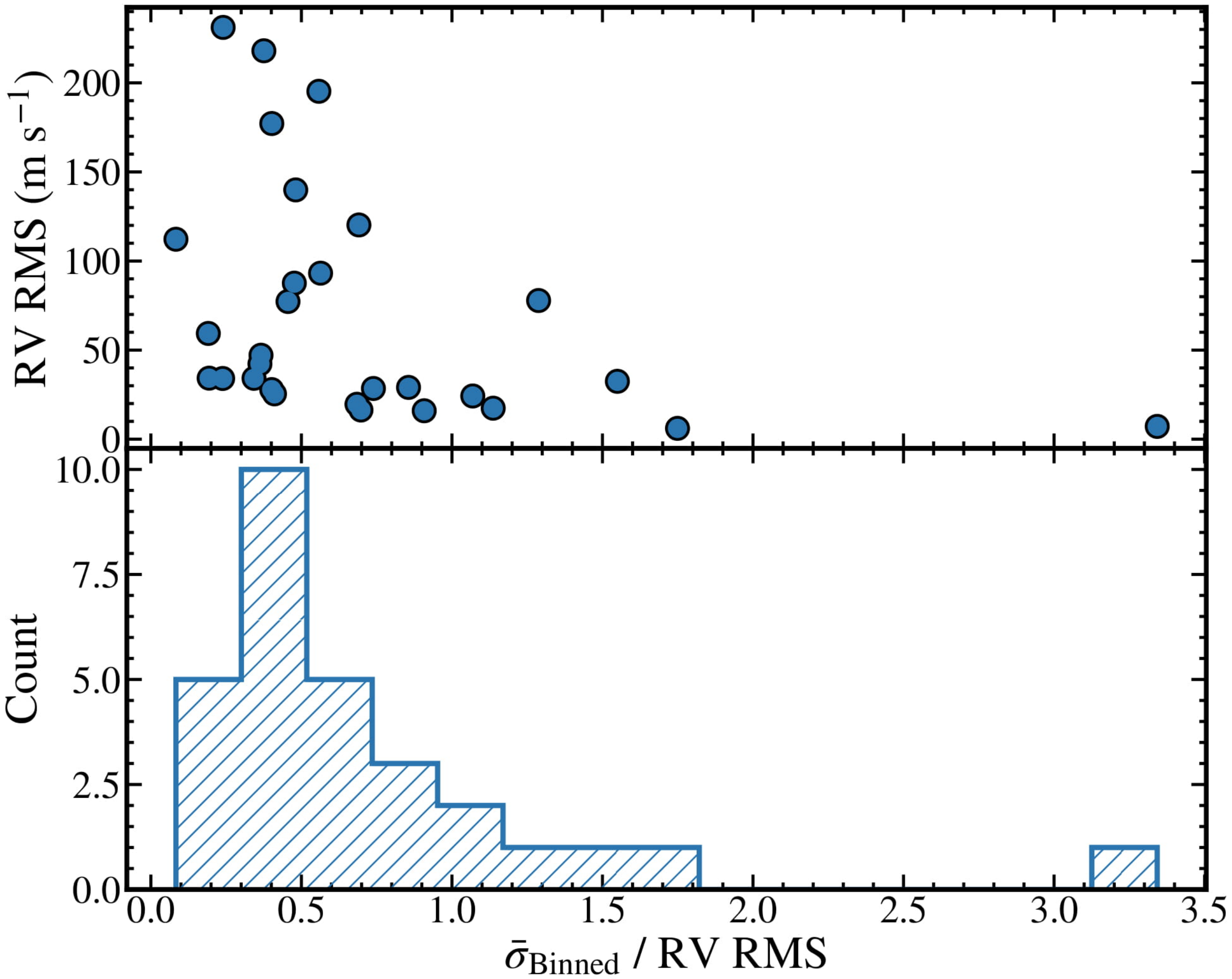

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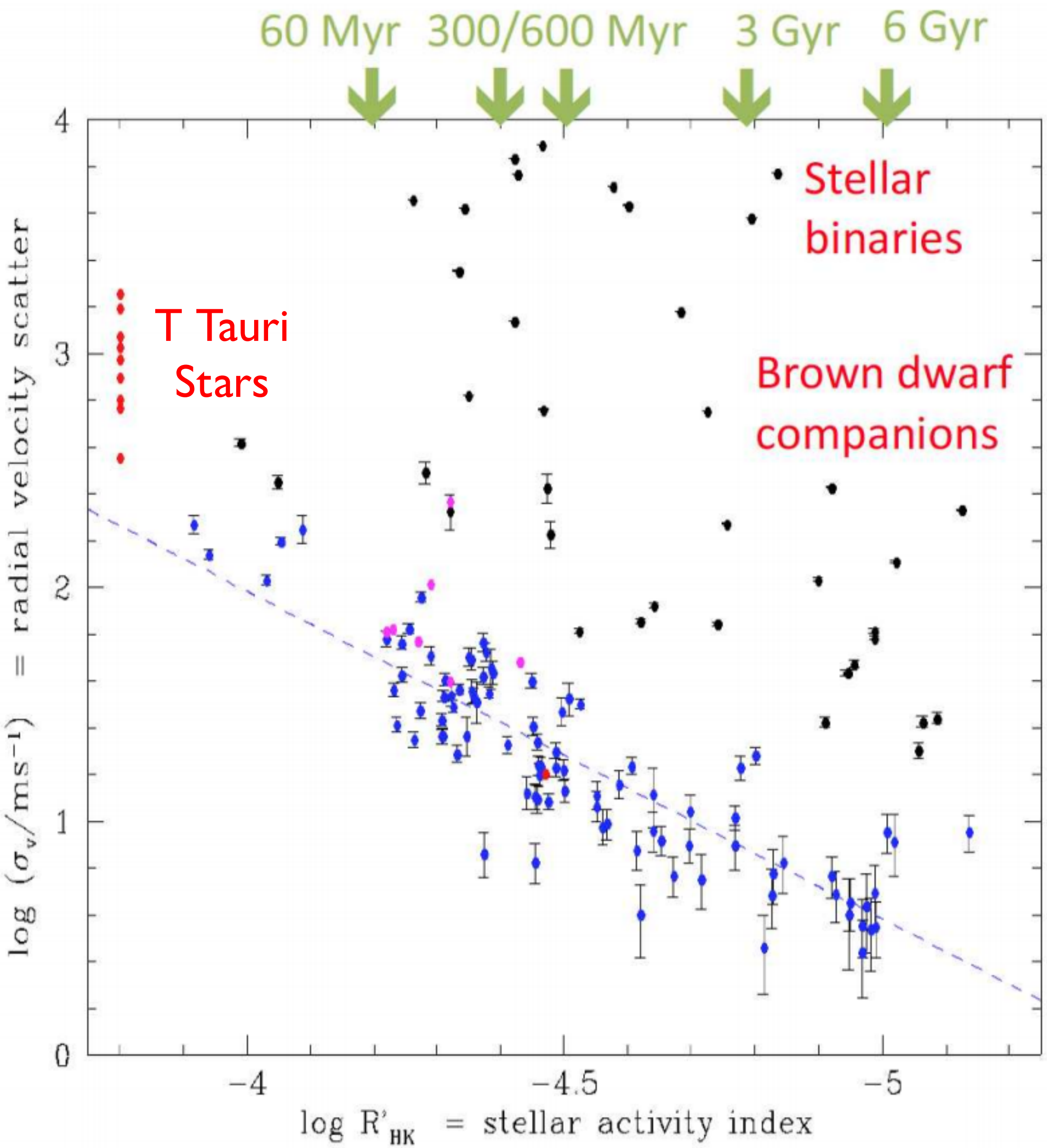
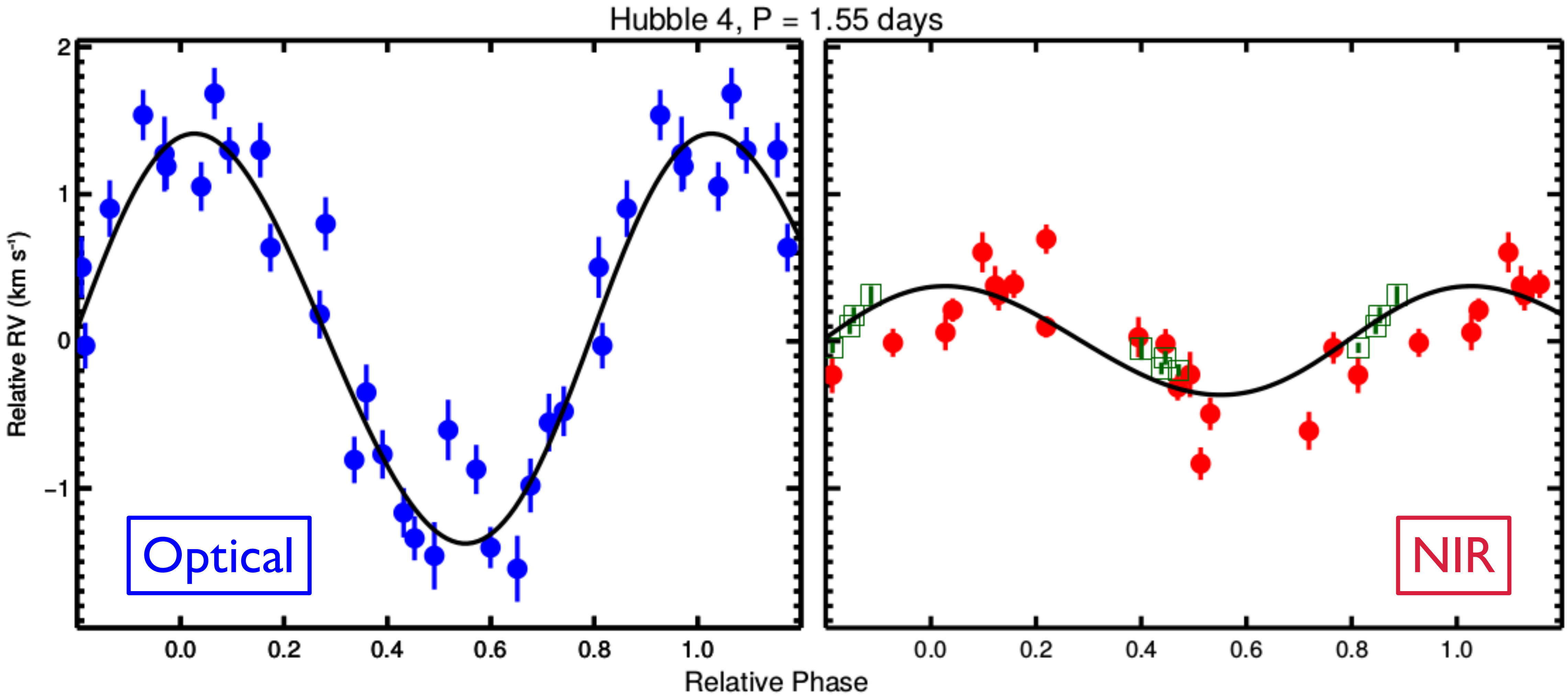
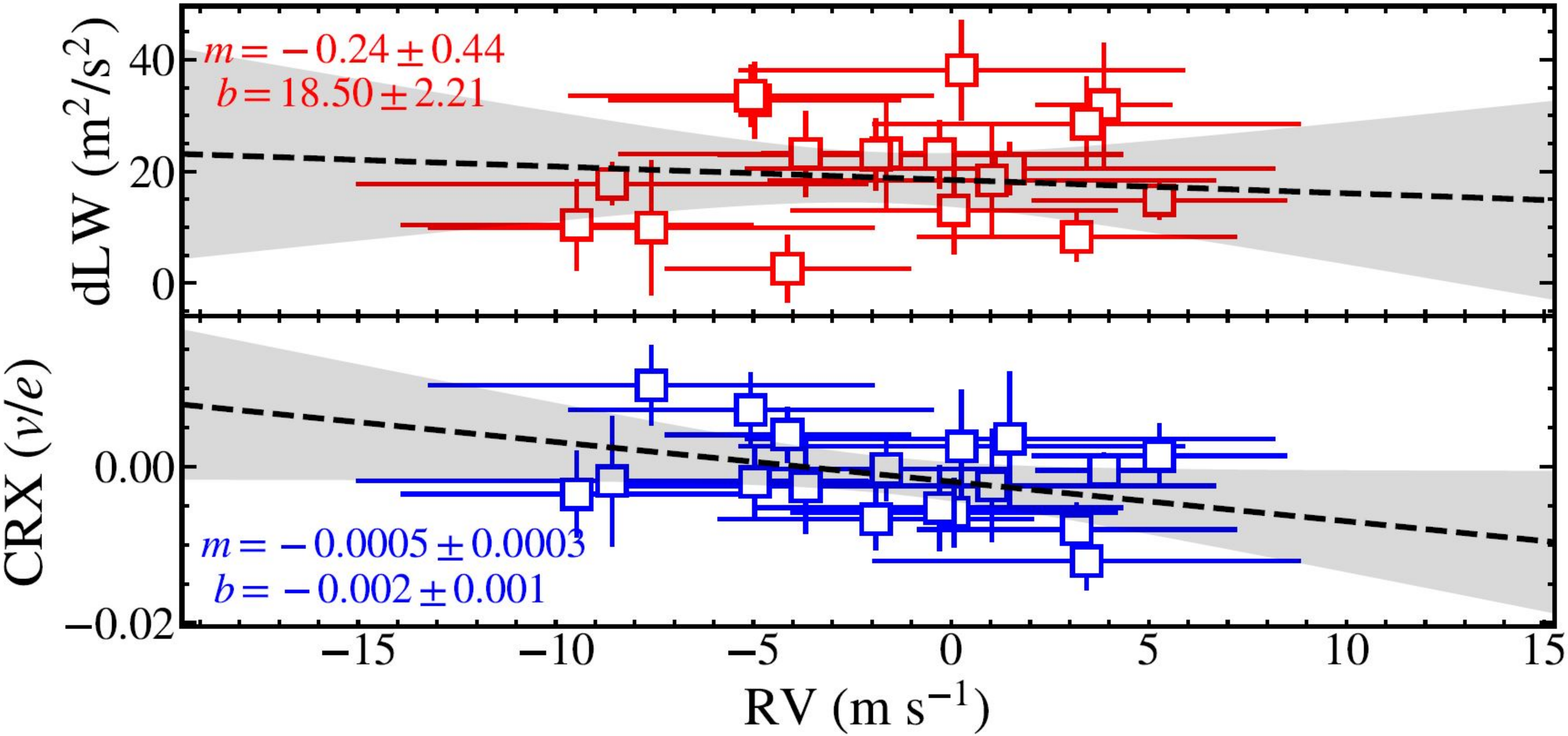


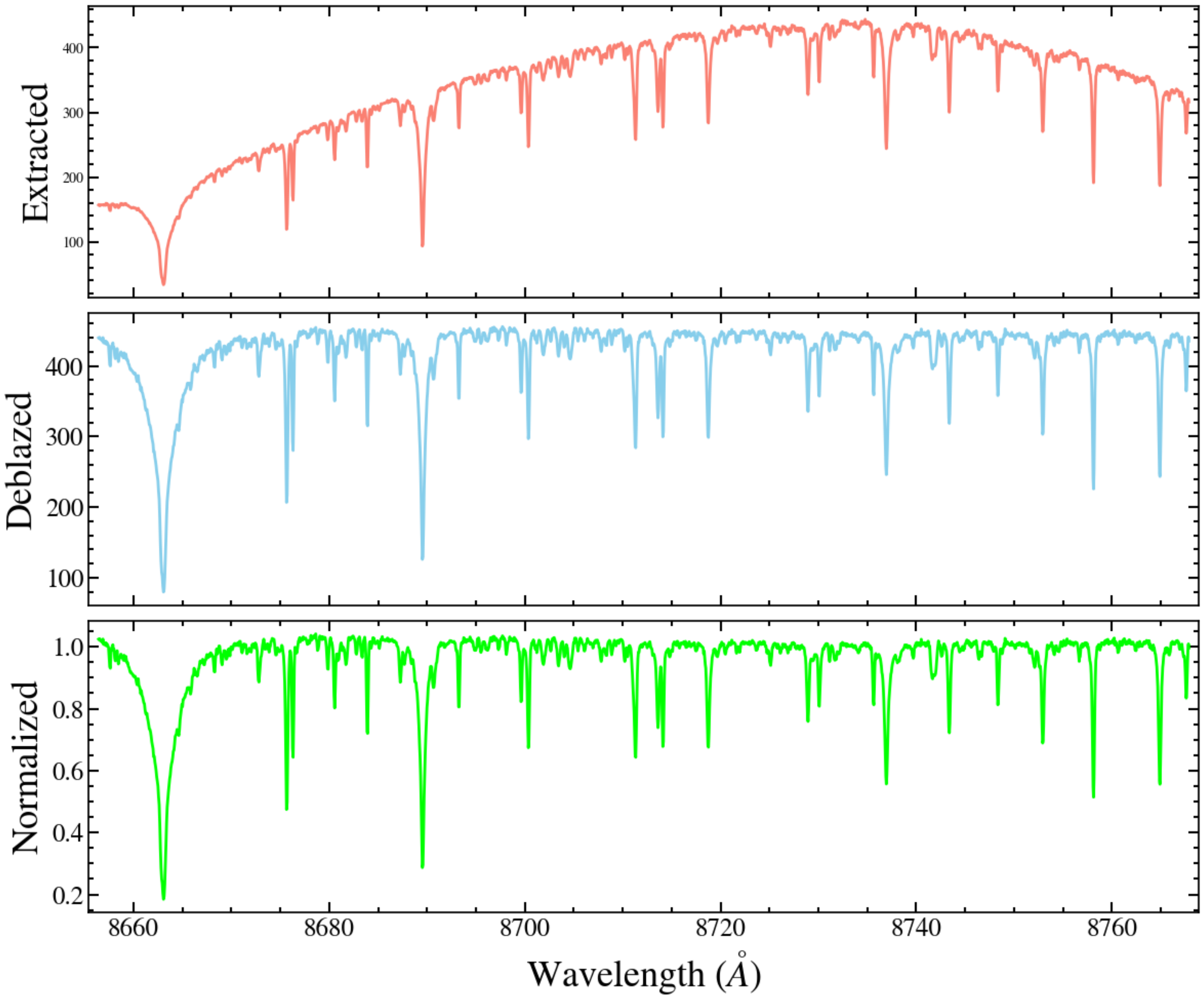
Hillenbrand et al. 2015



Crockett et al. 2012

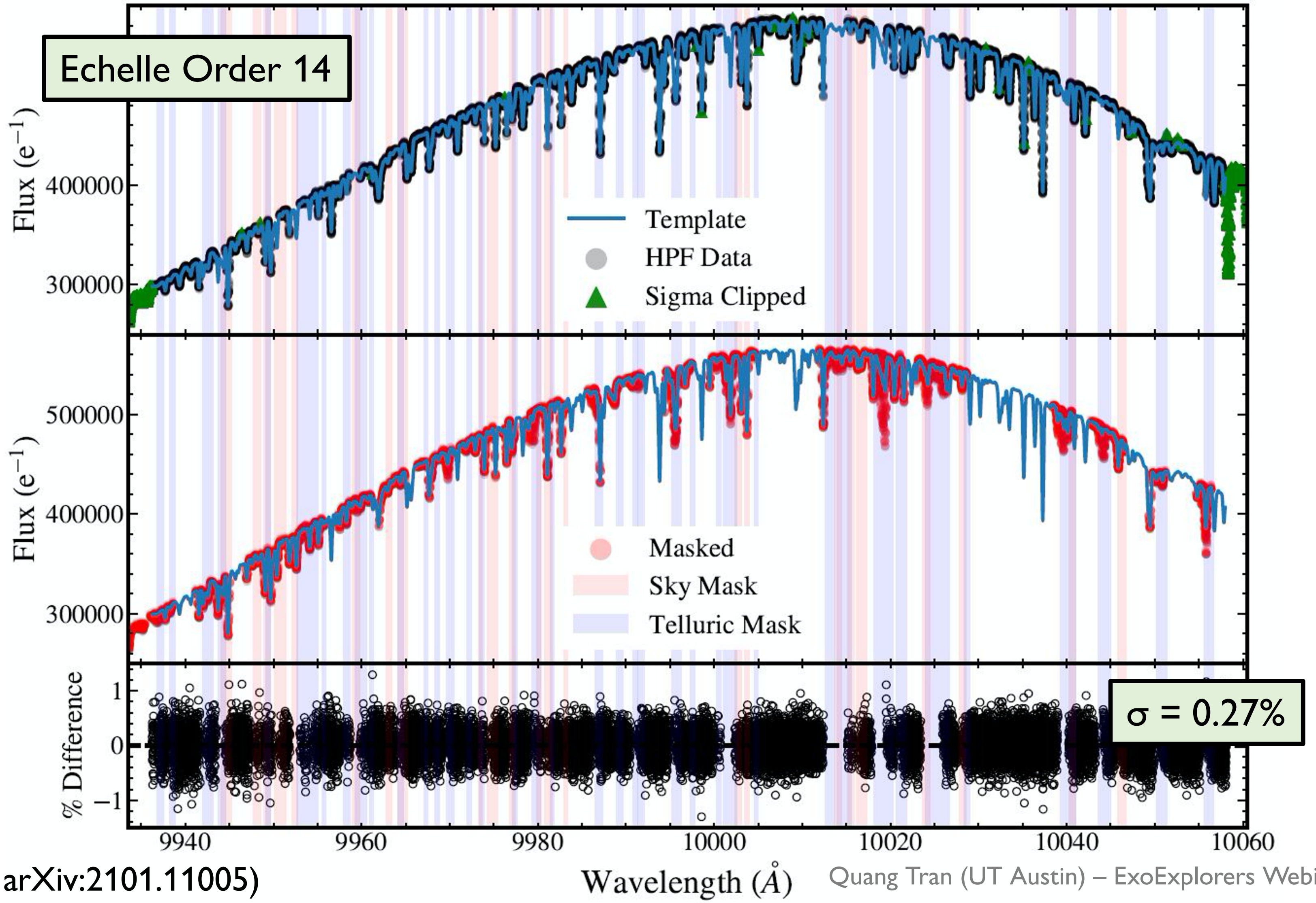


$m = -0.24 \pm 0.44$
$b = 18.50 \pm 2.21$
dLW (m^2/s^2)
40
20
0
CRX (v/e)
0.00
−0.02
$m = -0.0005 \pm 0.0003$
$b = -0.002 \pm 0.001$
−15
−10
−5
0
5
10
15
RV ($m\ s^{-1}$)



Extracted
400
300
200
100
Deblazed
400
300
200
100
Normalized
1.0
0.8
0.6
0.4
0.2
8660
8680
8700
8720
8740
8760
Wavelength (Å)

Precision Radial Velocity Pipeline: Template Creation



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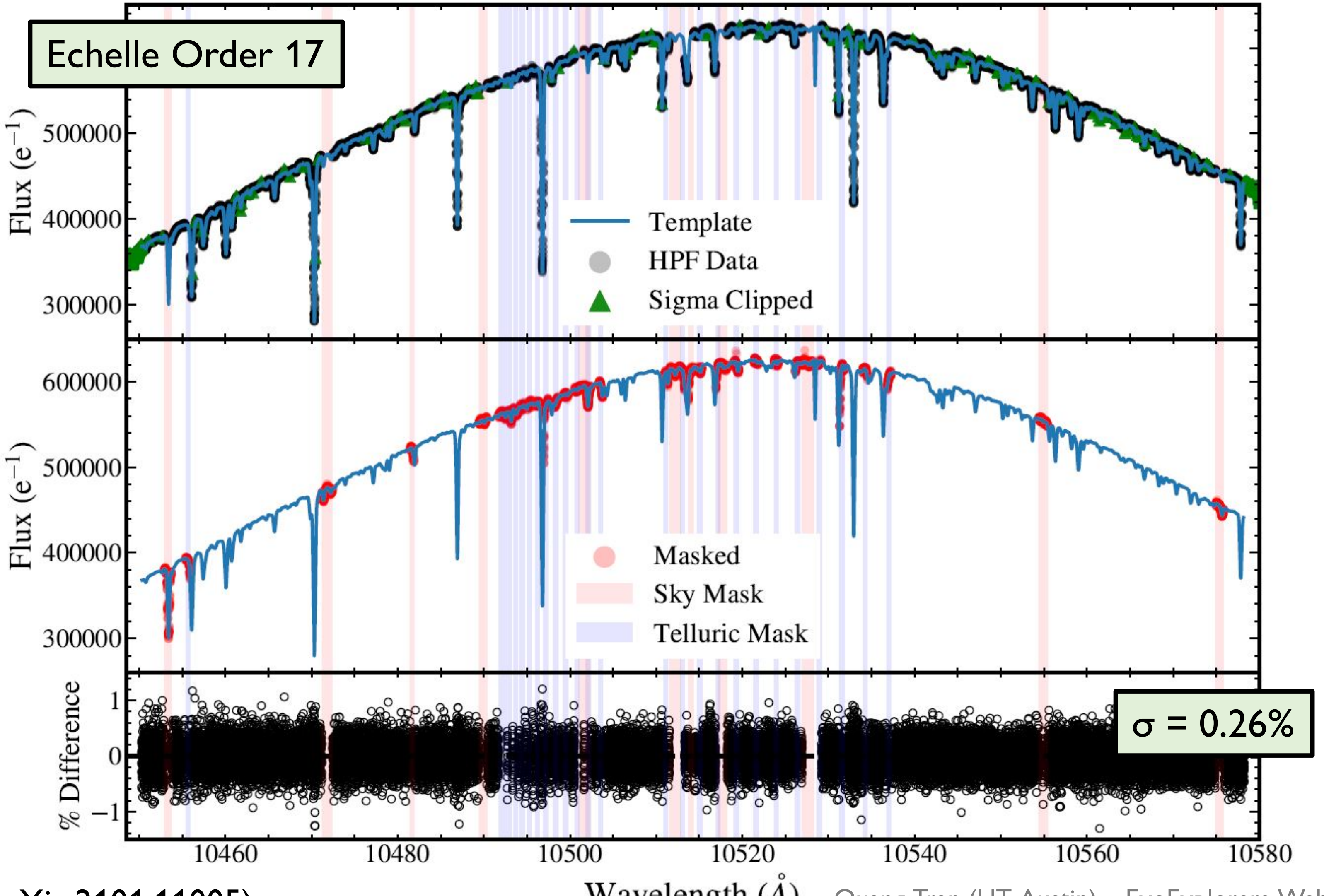
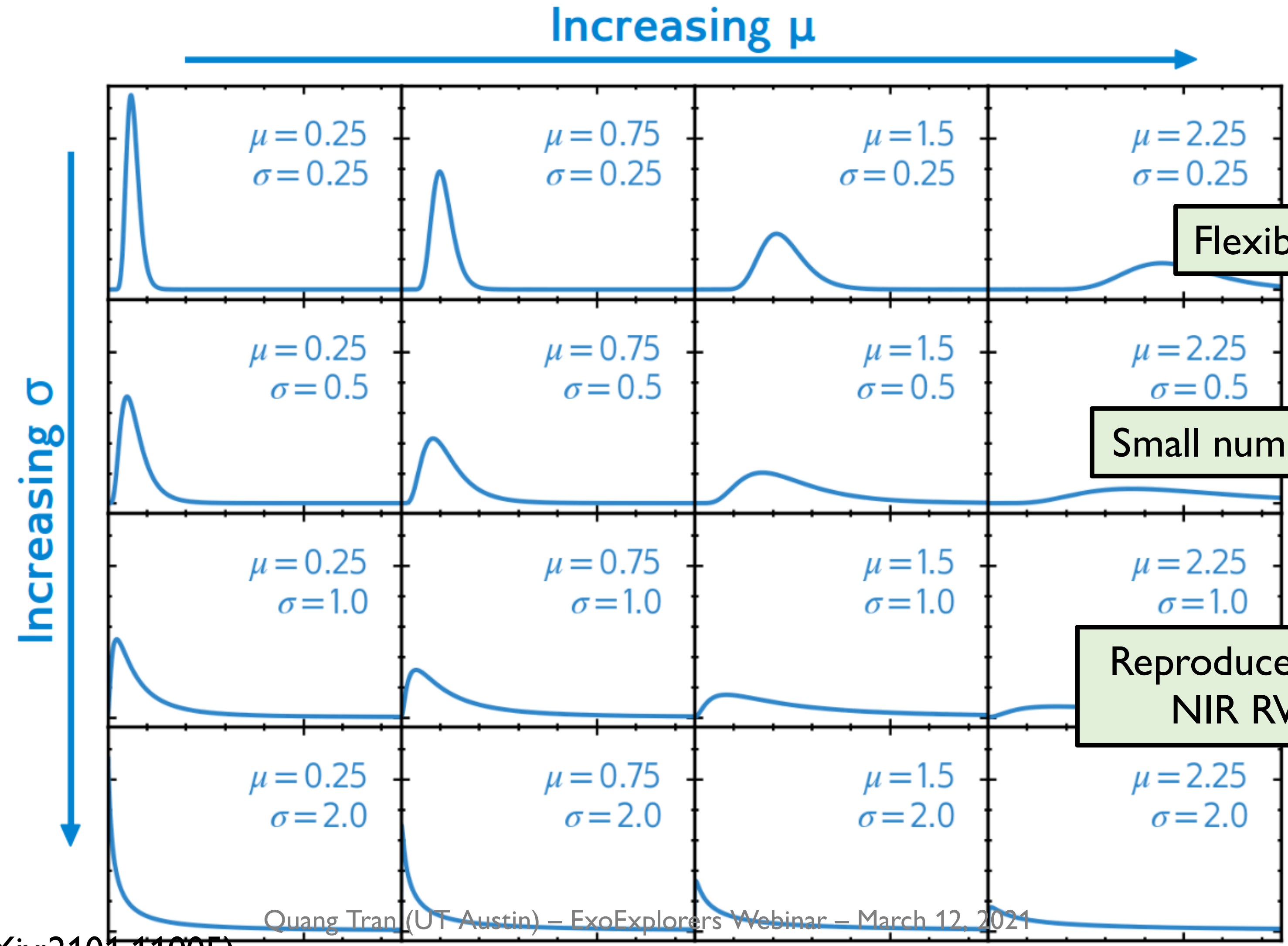


Tran et al. 2021 (accepted; arXiv:2101.11005)

The log-normal distribution as a population-level parametric model of stellar jitter



Flexible

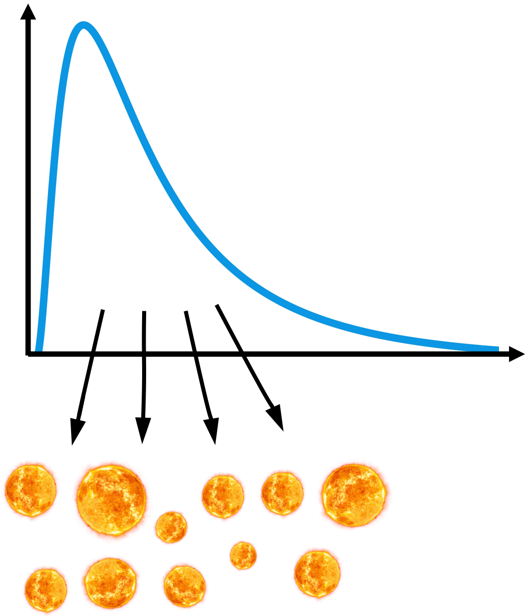
Small number of shape parameters

Reproduces observed optical and NIR RV RMS distributions

Tran et al. 2021 (accepted; arXiv:2101.11005)

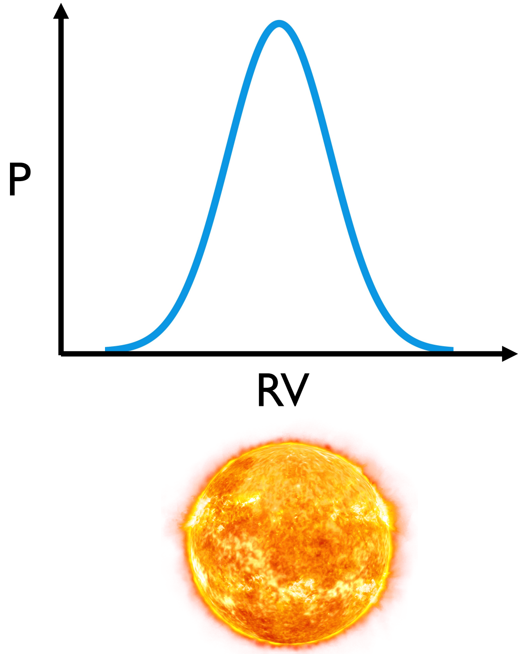
Modelling Stellar Noise

Characteristic Stellar Noise



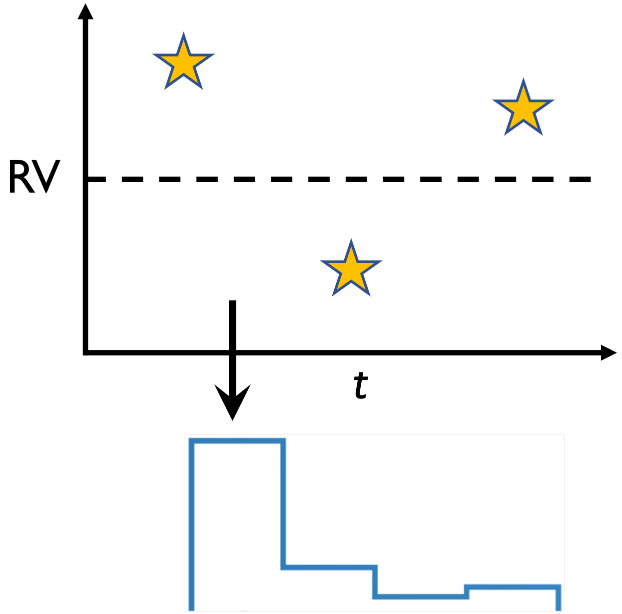
$$P(\mathcal{X}) \sim e^{\mathcal{N}(\mu_{\mathrm{jit}},\sigma^2_{\mathrm{jit}})}$$

Synthetic Star



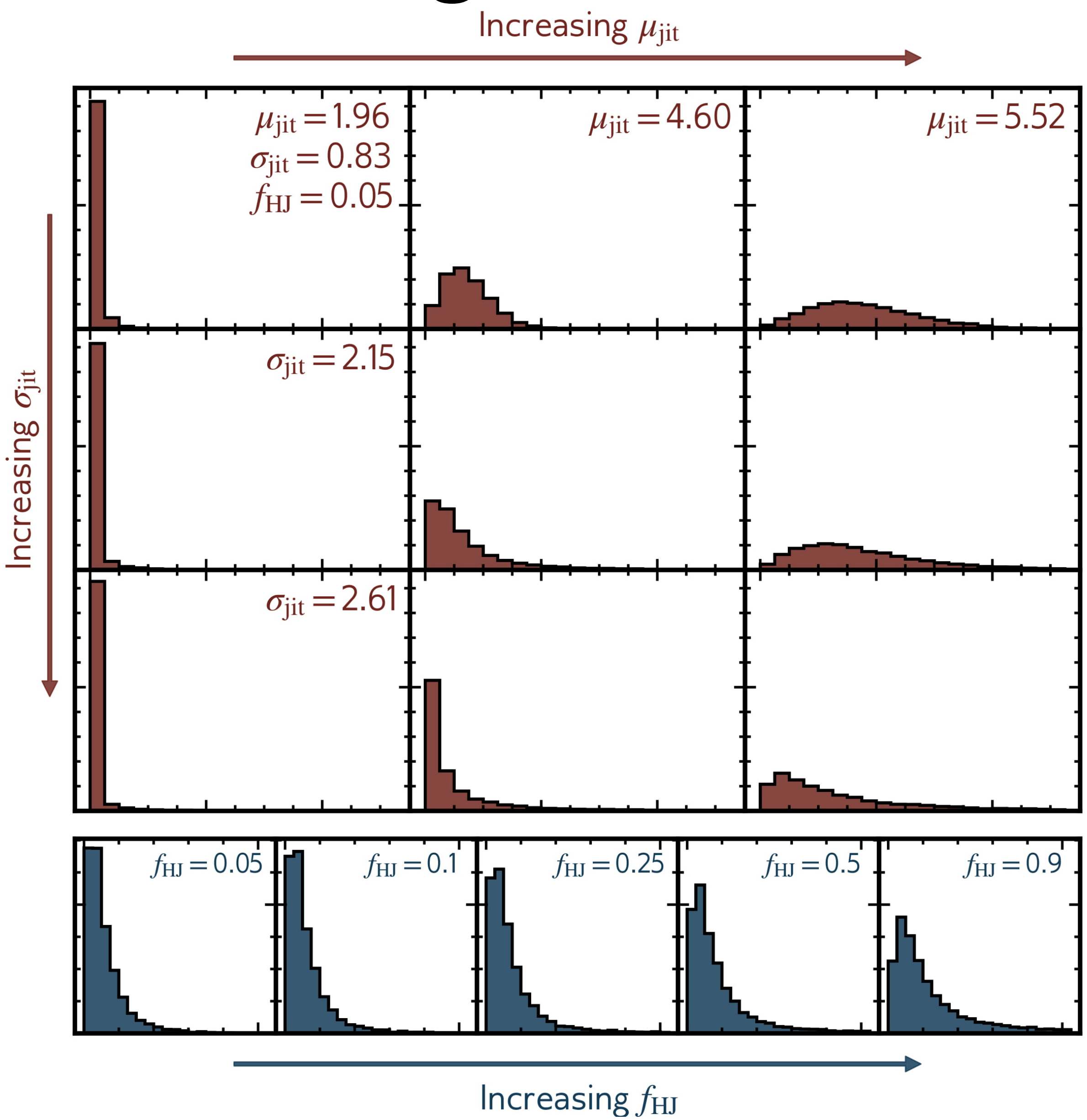
$$P(\mathrm{RV}) \sim \mathcal{N}(0, \mathcal{X})$$

RV RMS Value



$$\mathrm{RMS} = \sigma(\mathrm{RV}_1, \mathrm{RV}_2, \mathrm{RV}_3)$$

Modelling Stellar Noise



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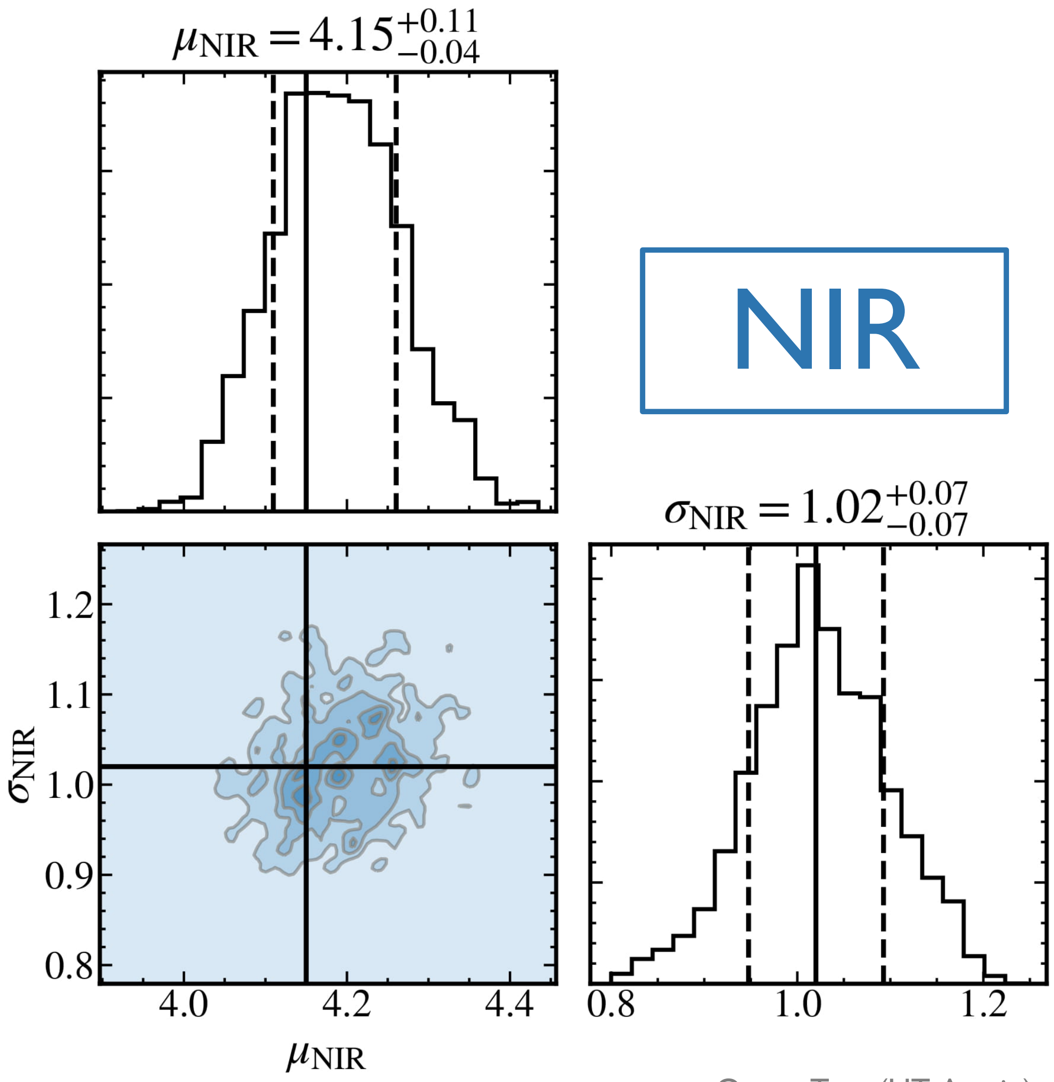

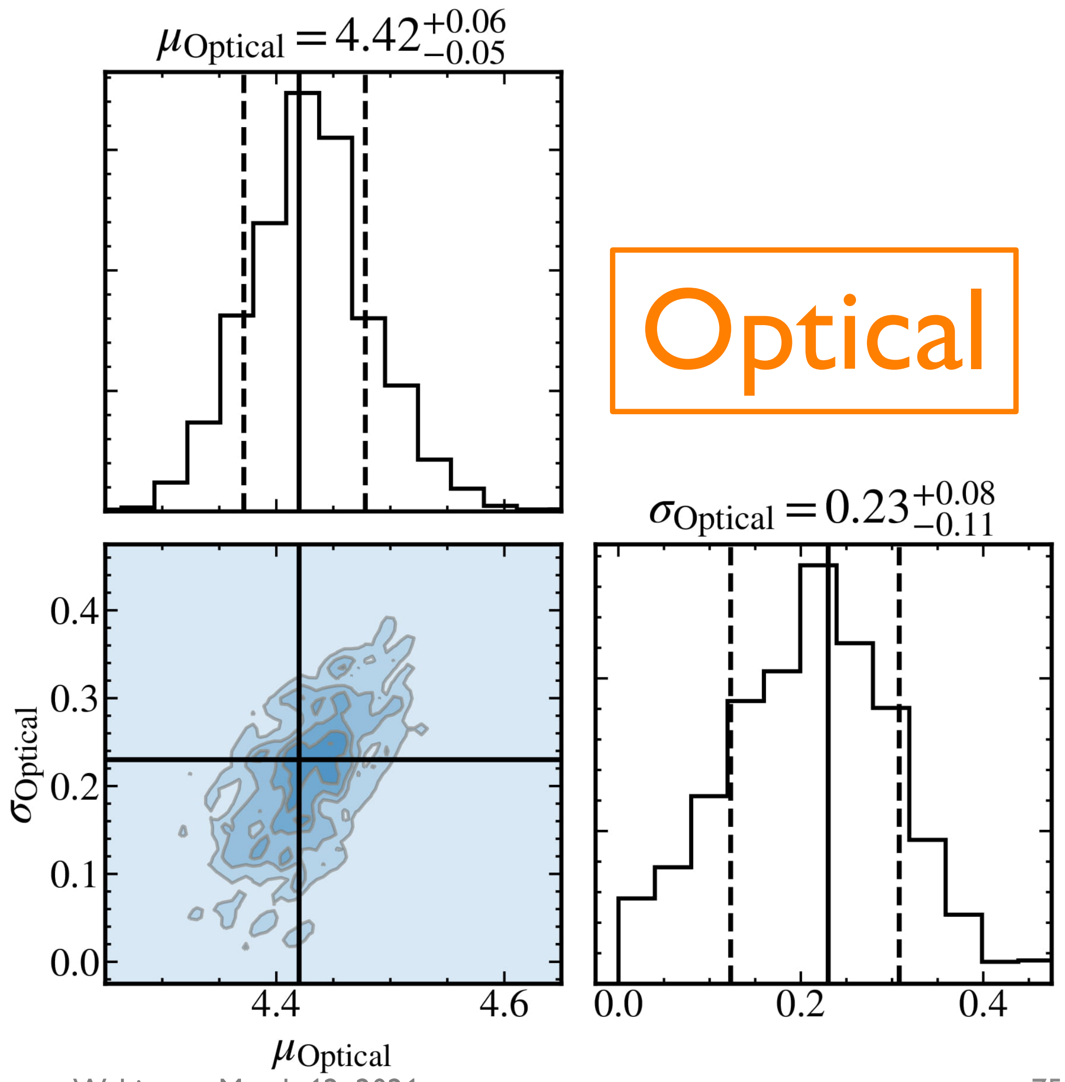

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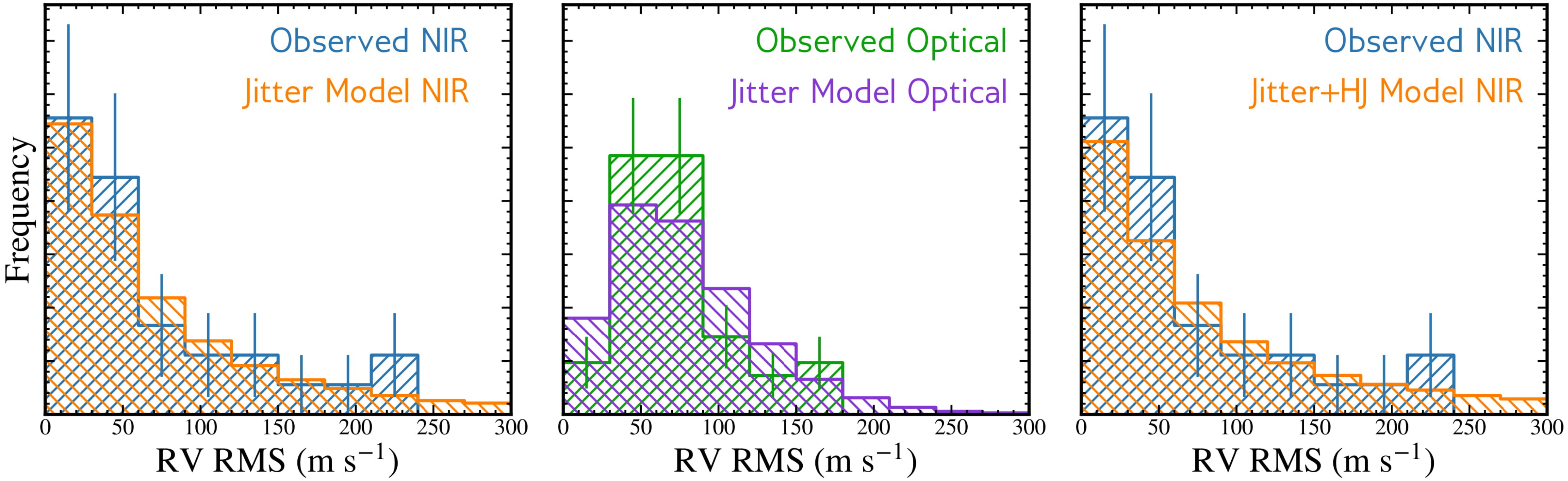
Modelling Stellar Noise and Simulating Hot Jupiters



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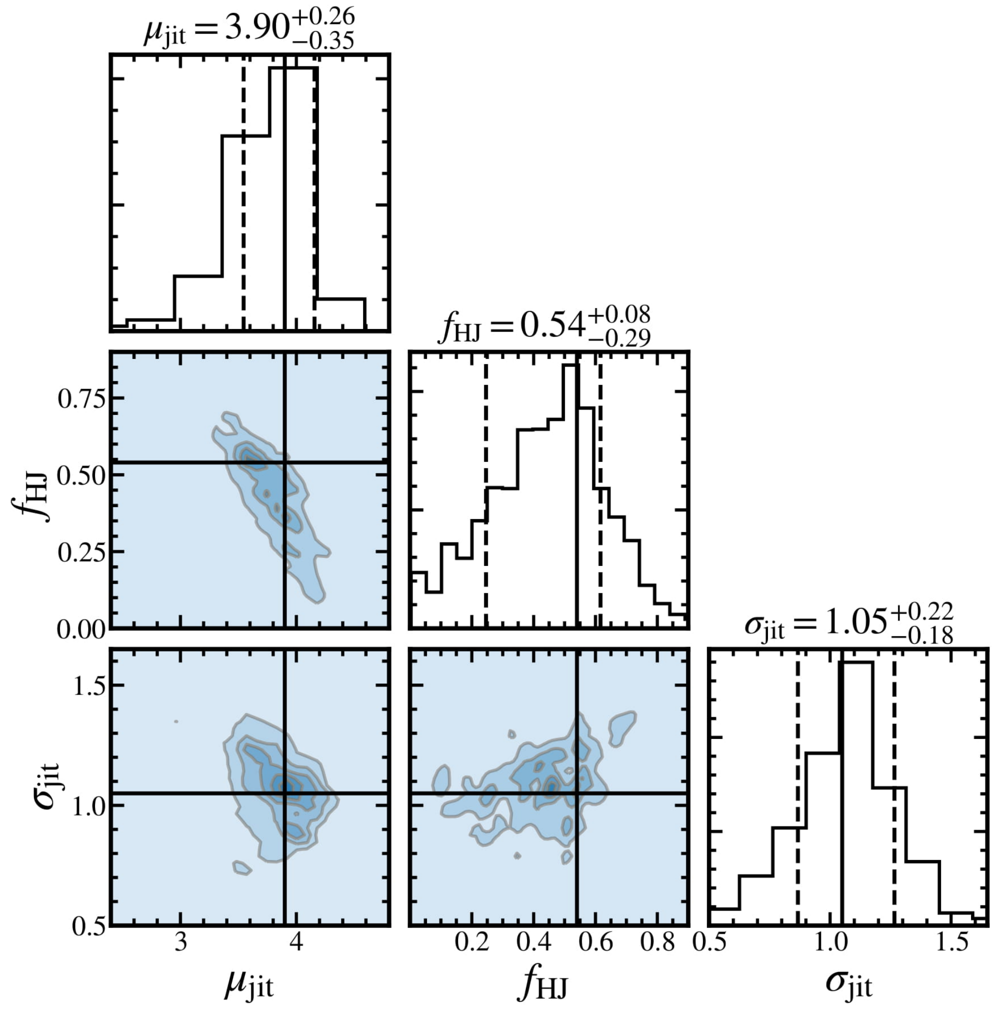

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