INDIANA UNIVERSITY
BLOOMINGTON

Single-Star Warm-Jupiter Systems Tend to Be Aligned, **Even Around Hot Stars**

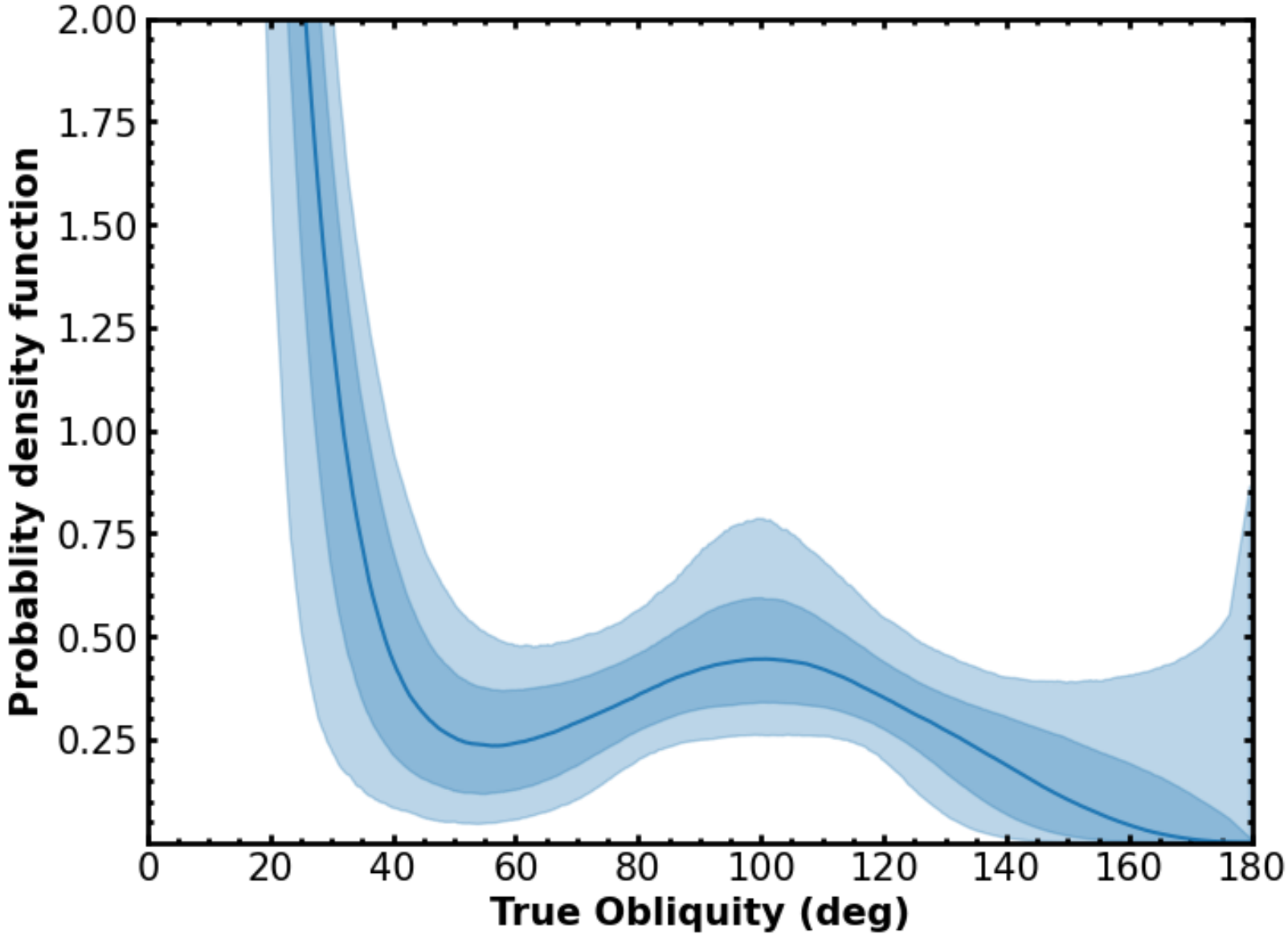
Xian-Yu Wang

Malena Rice, Songhu Wang,

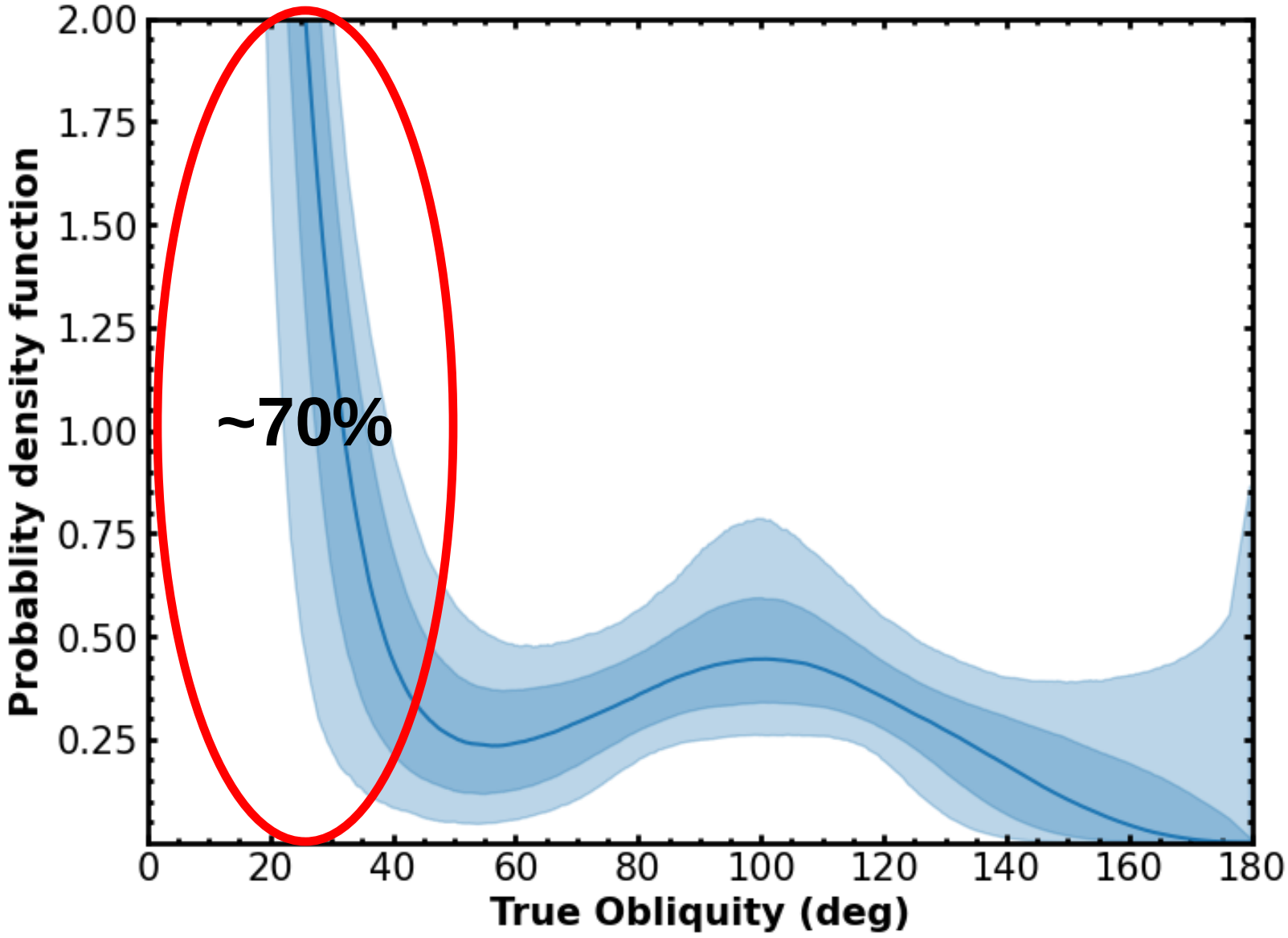
TESS team, NEID team, KPF team, PFS team

Know Thy Star, Know Thy Planet 2 | Feb 6, 2025, Caltech

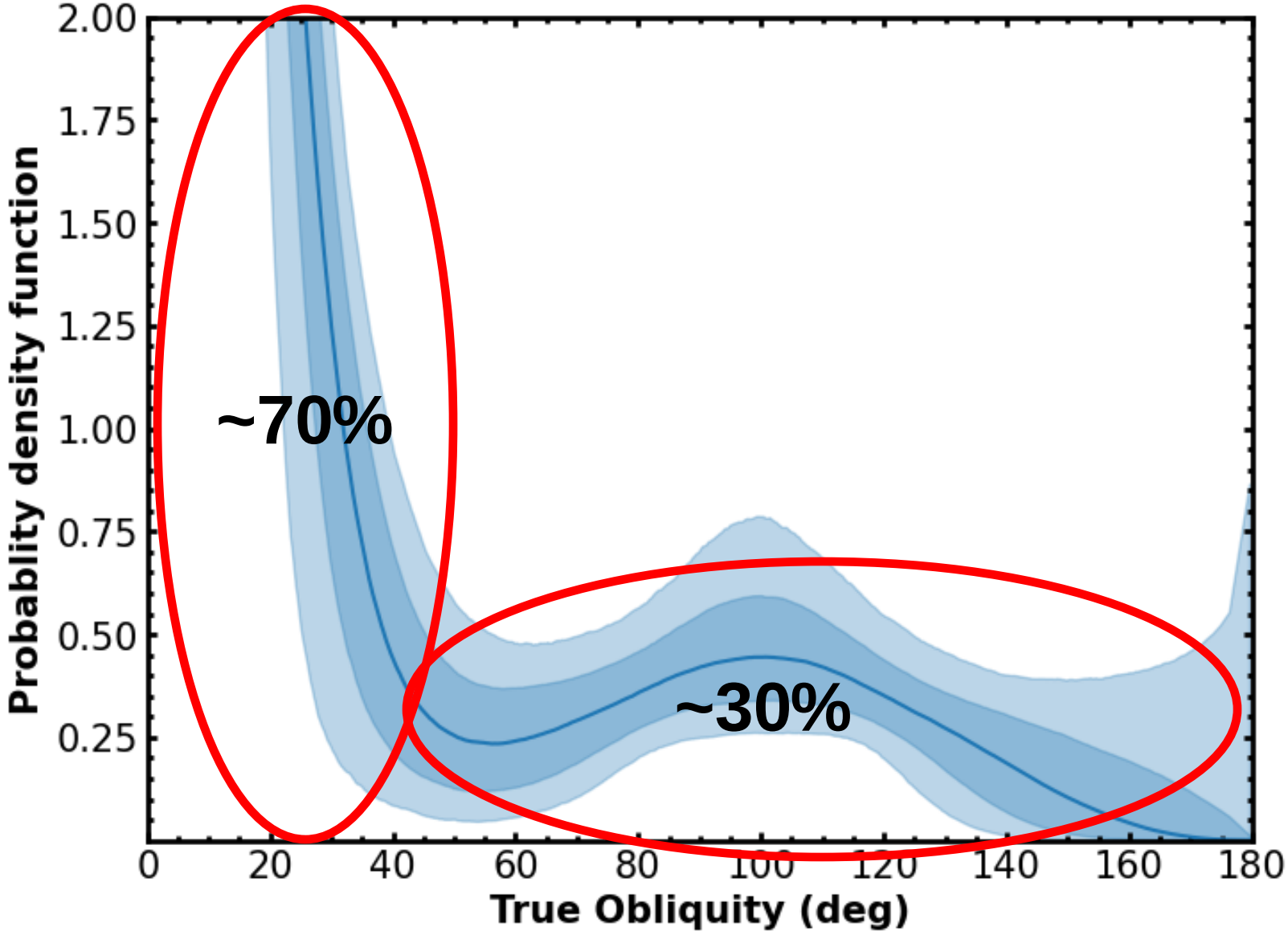
Hot-Jupiter Systems' Stellar Obliquities



Most of hot-Jupiter Systems are Aligned



Some hot-Jupiter Systems are Misaligned

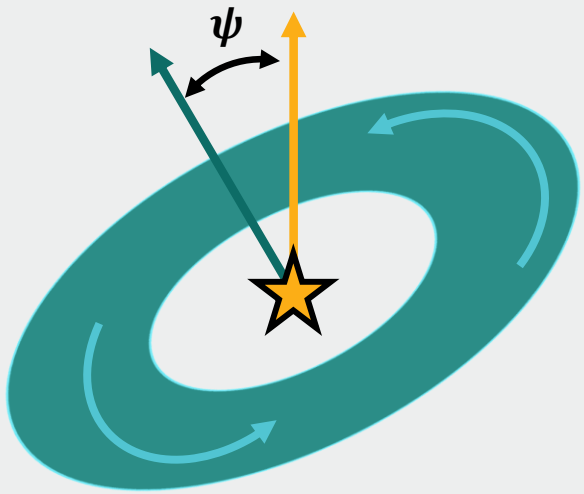


Origin of Misalignment: Primordial or Post-Formation?

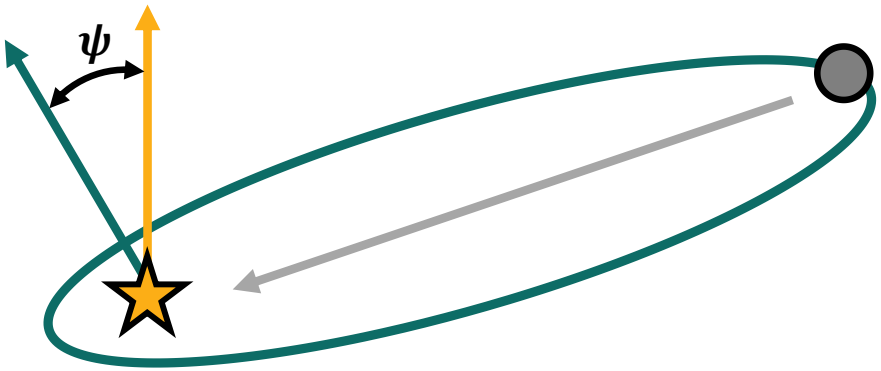
Affects all types of planets

Confined to Hot planets

Primordial

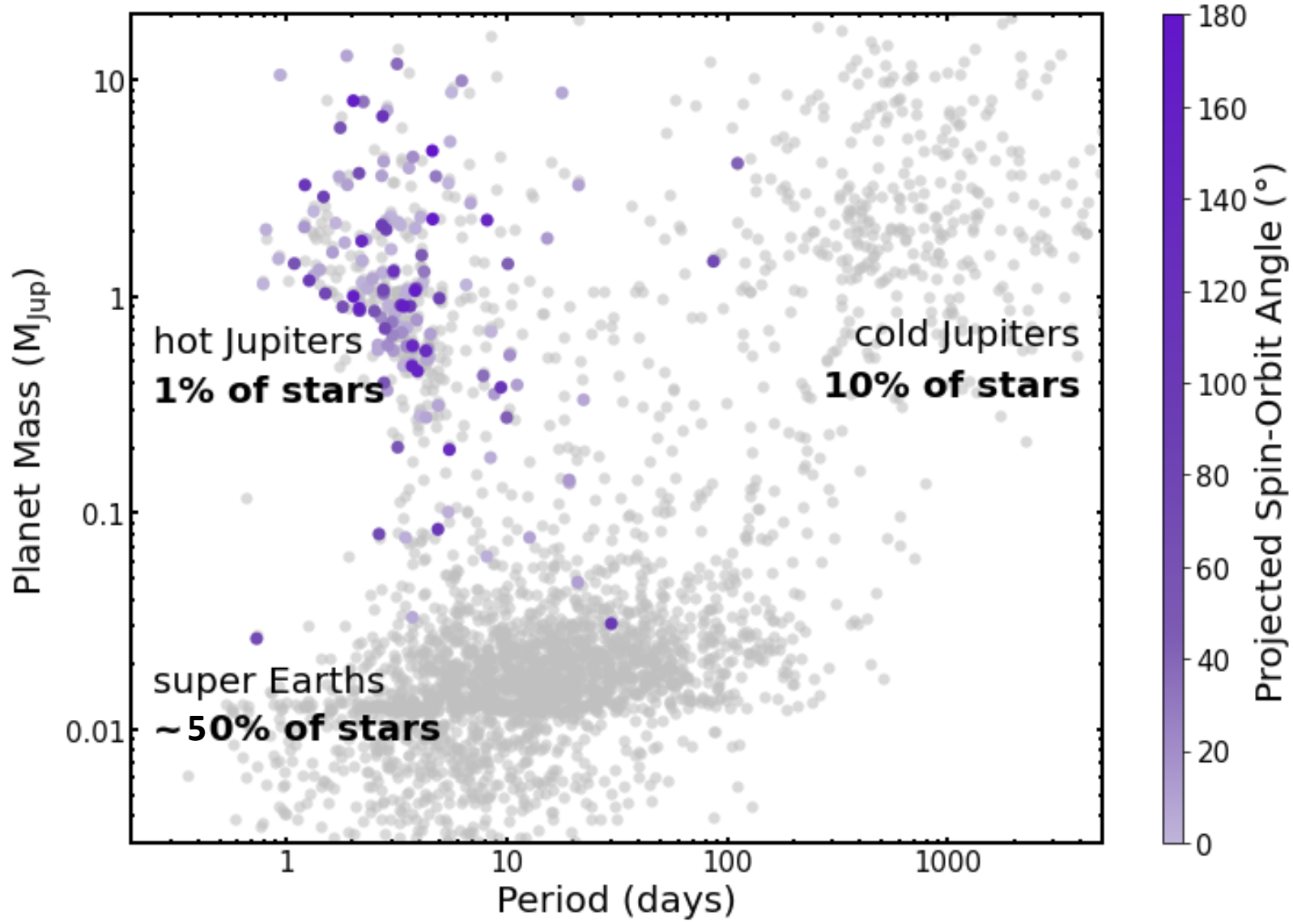


Post formation

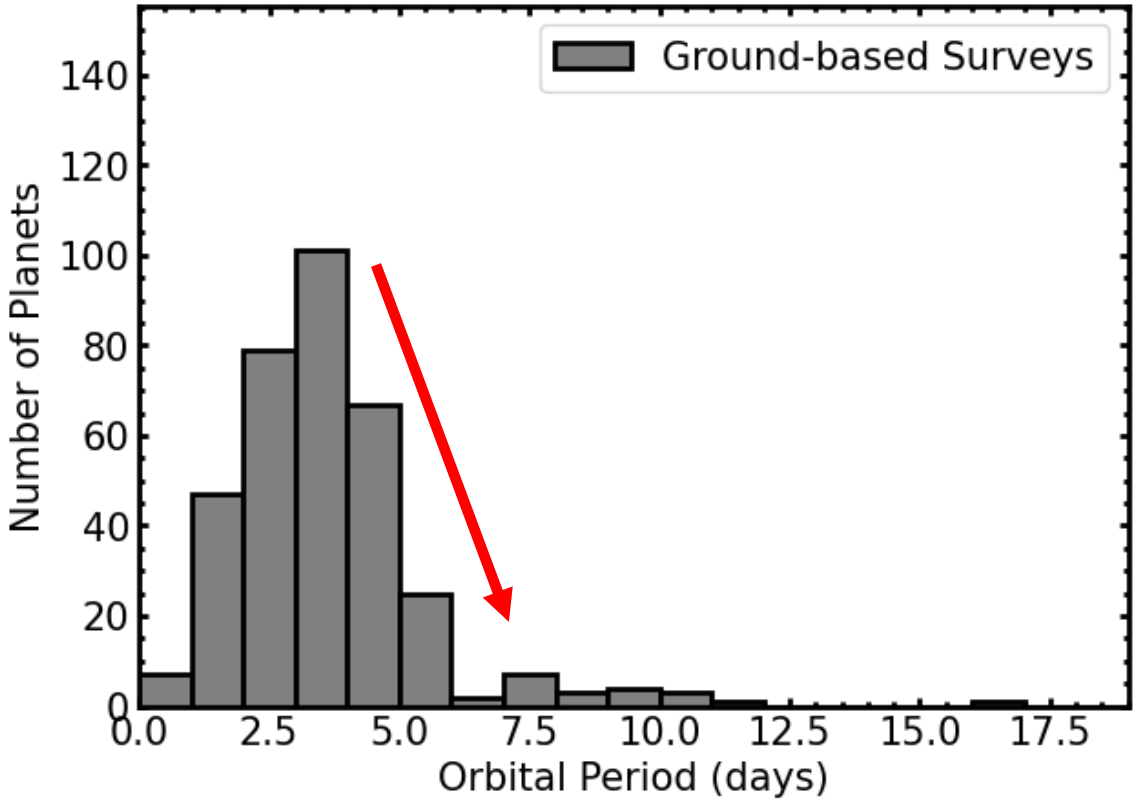


Modified from Albrecht, Dawson, & Winn (2022)

Only a Few Measurements for Warm Jupiters

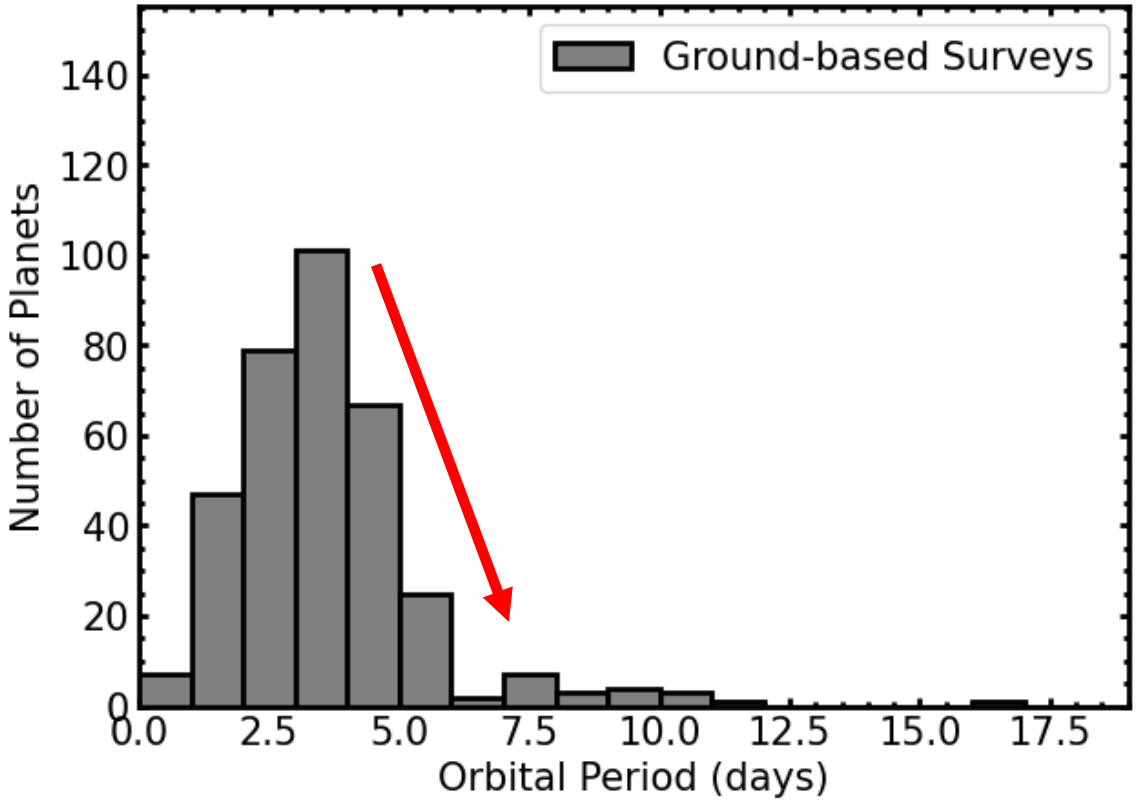


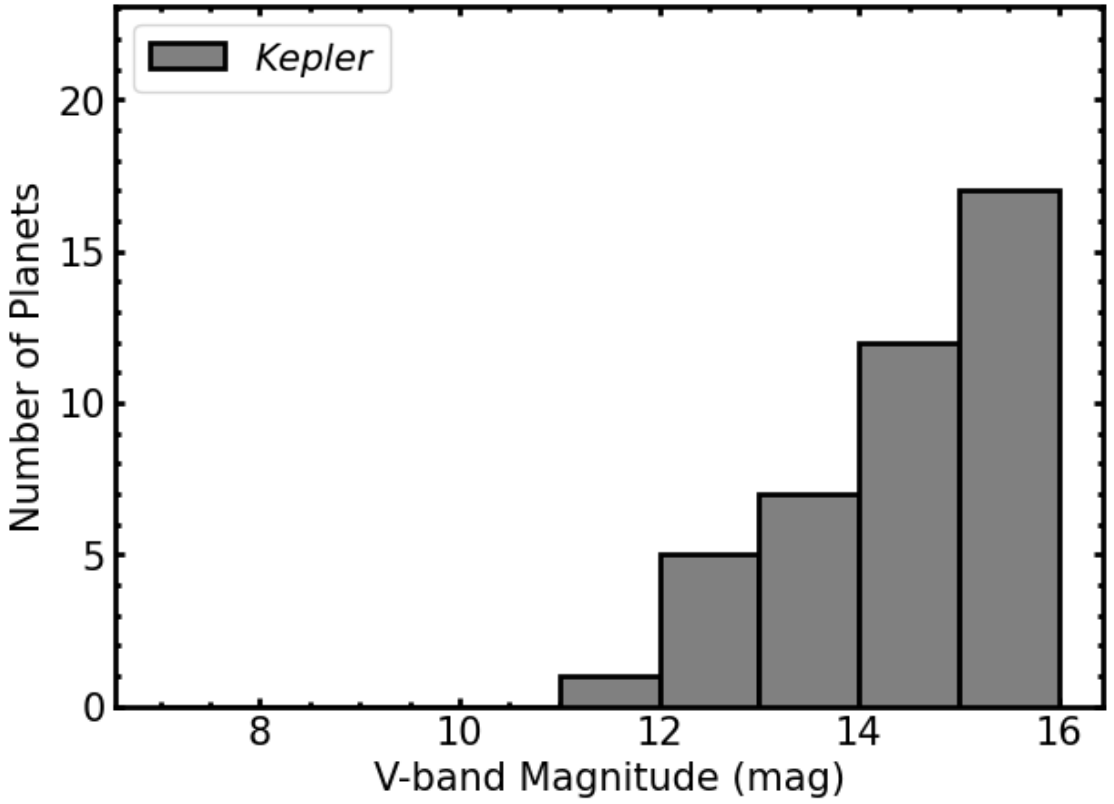
Ground-based Surveys are insensitive to Warm Jupiters



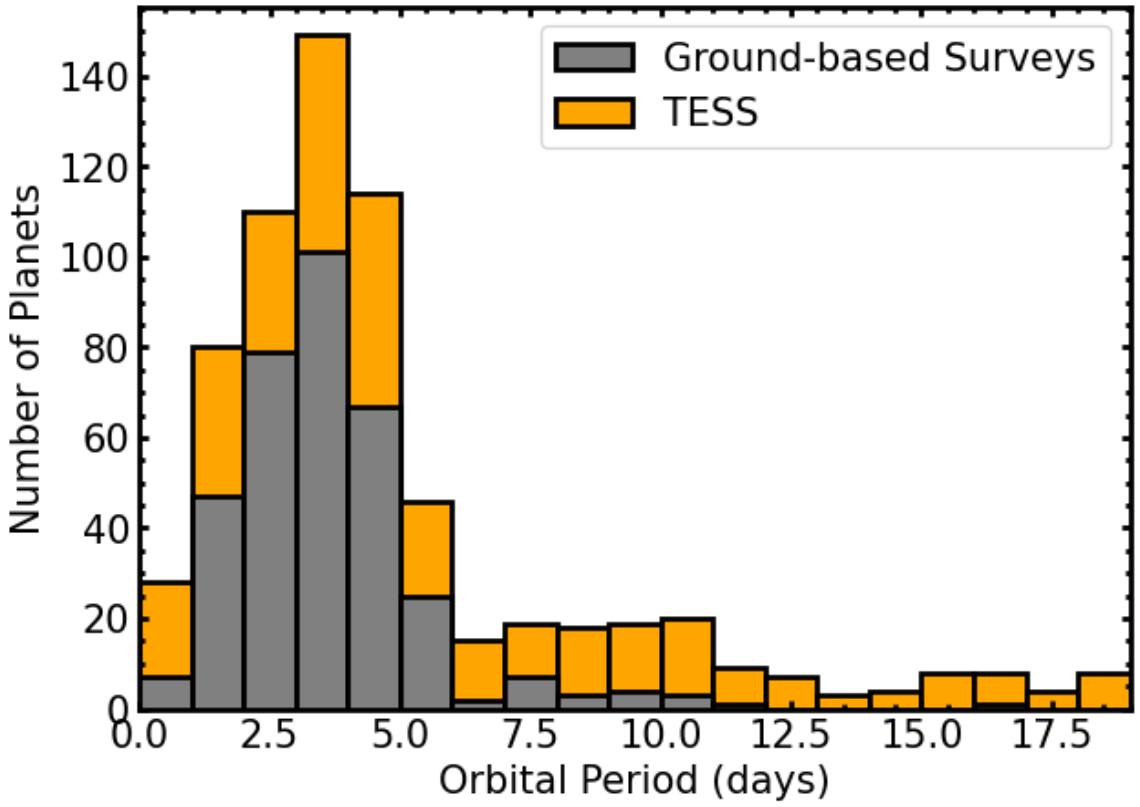
Super-WASP, Pollacco et al. 2006; HATNet, Bakos et al. 2004; HATSouth, Bakos et al. 2013; TrES, Alonso et al. 2004; KELT, Pepper et al. 2007; XO, McCullough et al. 2005

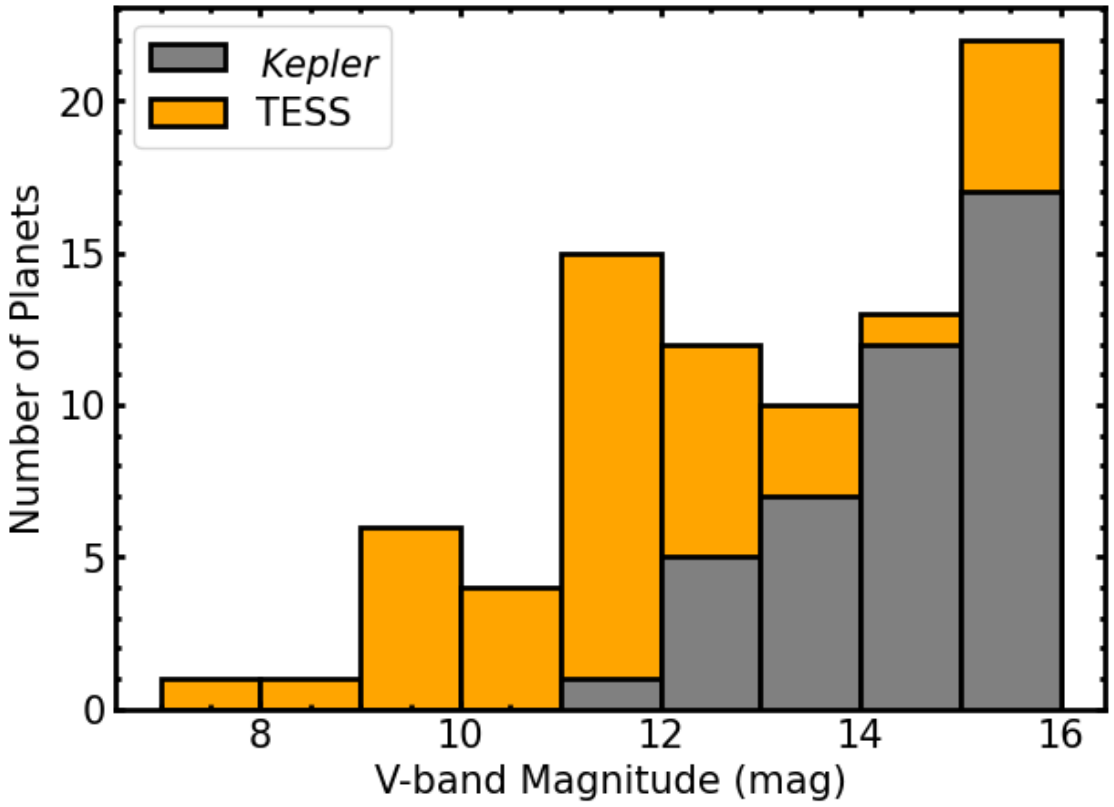
Kepler targets are too faint



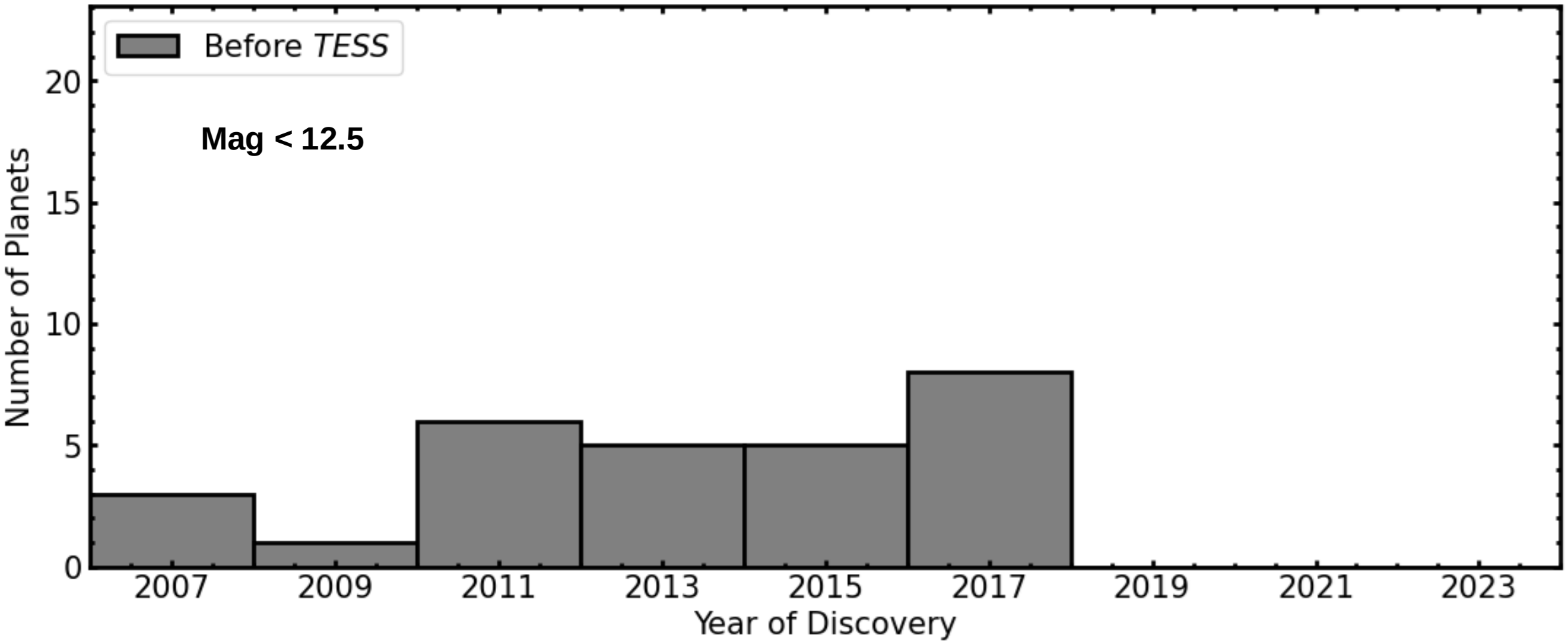


More bright Warm Jupiters from *TESS*

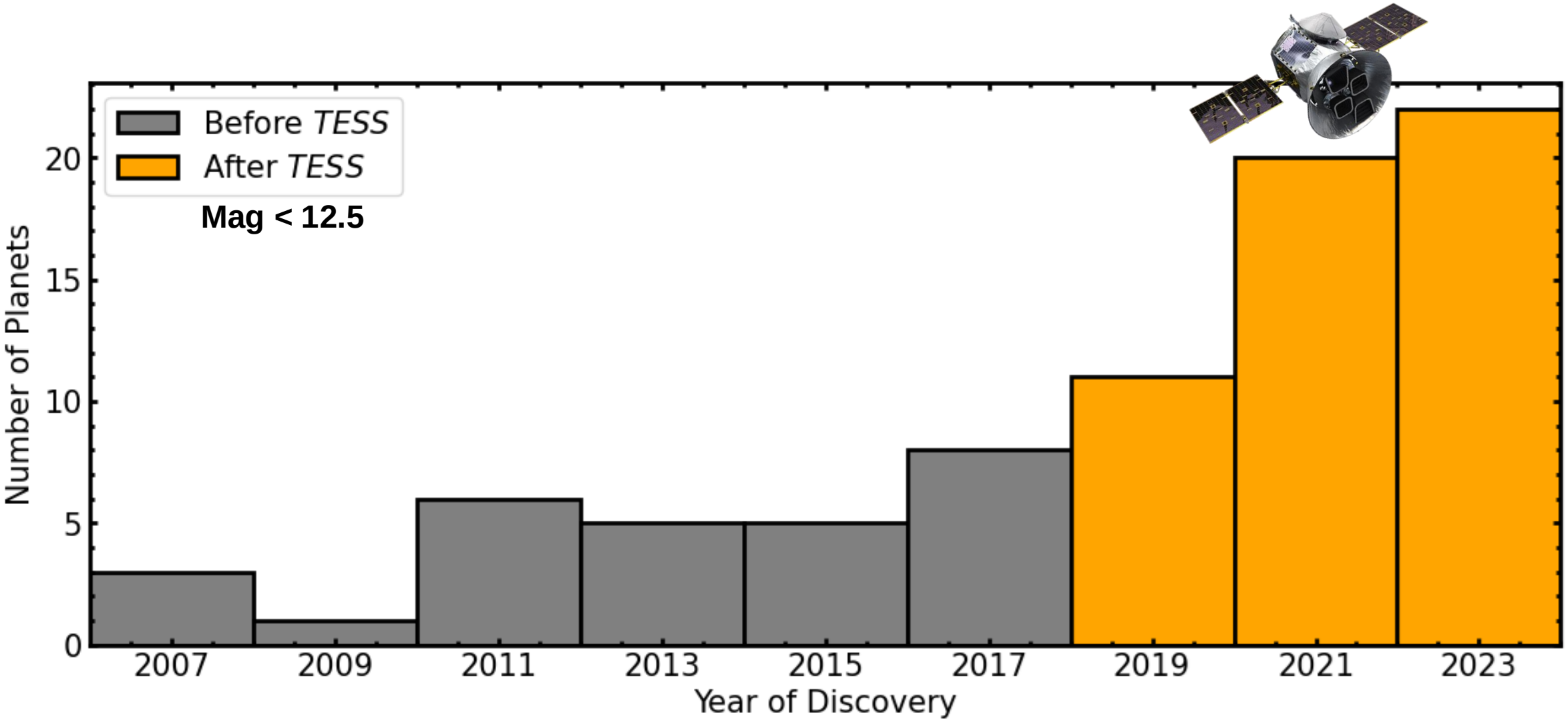




Detection of Warm Jupiters Before TESS Was Relatively Challenging



TESS is boosting the Warm-Jupiter Sample



The Stellar Obliquities in Long-period Exoplanet systems (SOLES) survey


Malena Rice


Songhu Wang


Xian-Yu Wang


Jiayin Dong


Jack Lubin


Brandon Radzom

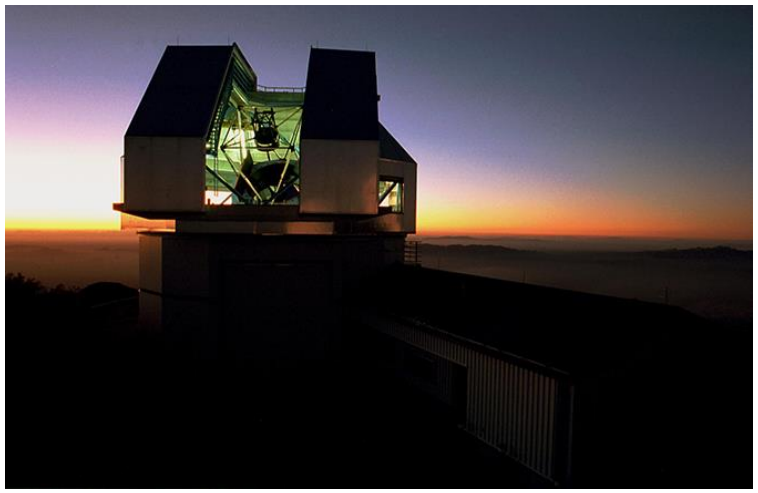

Kyle Hixenbaugh


Emma Dugan


Josette Wright


Qingru Hu

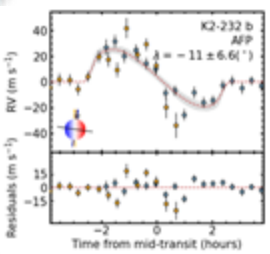

HIRES/Keck


NEID/WIYN

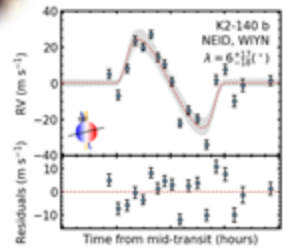

PFS/Magellan

SOLES: R-M Measurements for 12 Warm Jupiters

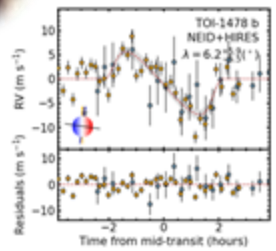
Wang S et al. 2021



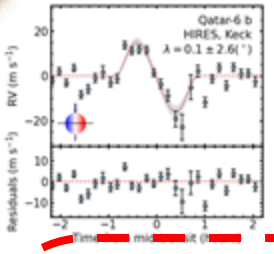
Rice et al. 2021



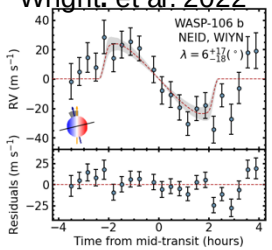
Rice, et al. 2022



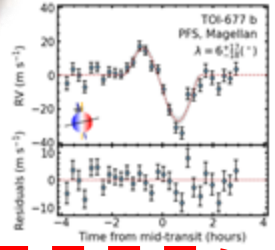
Rice, et al. 2023

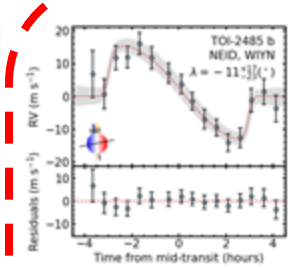


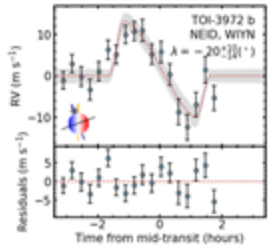
Wright, et al. 2022

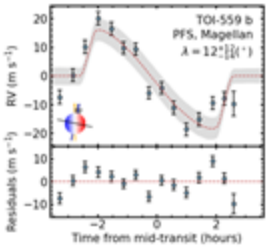


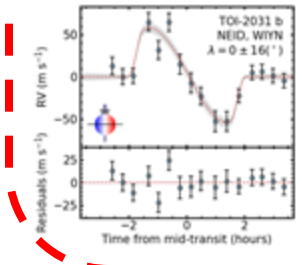
Hu. et al. 2024

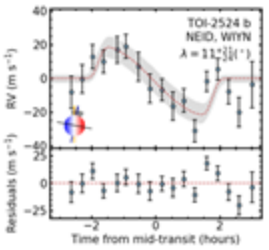


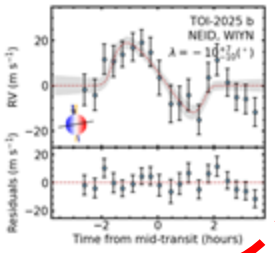








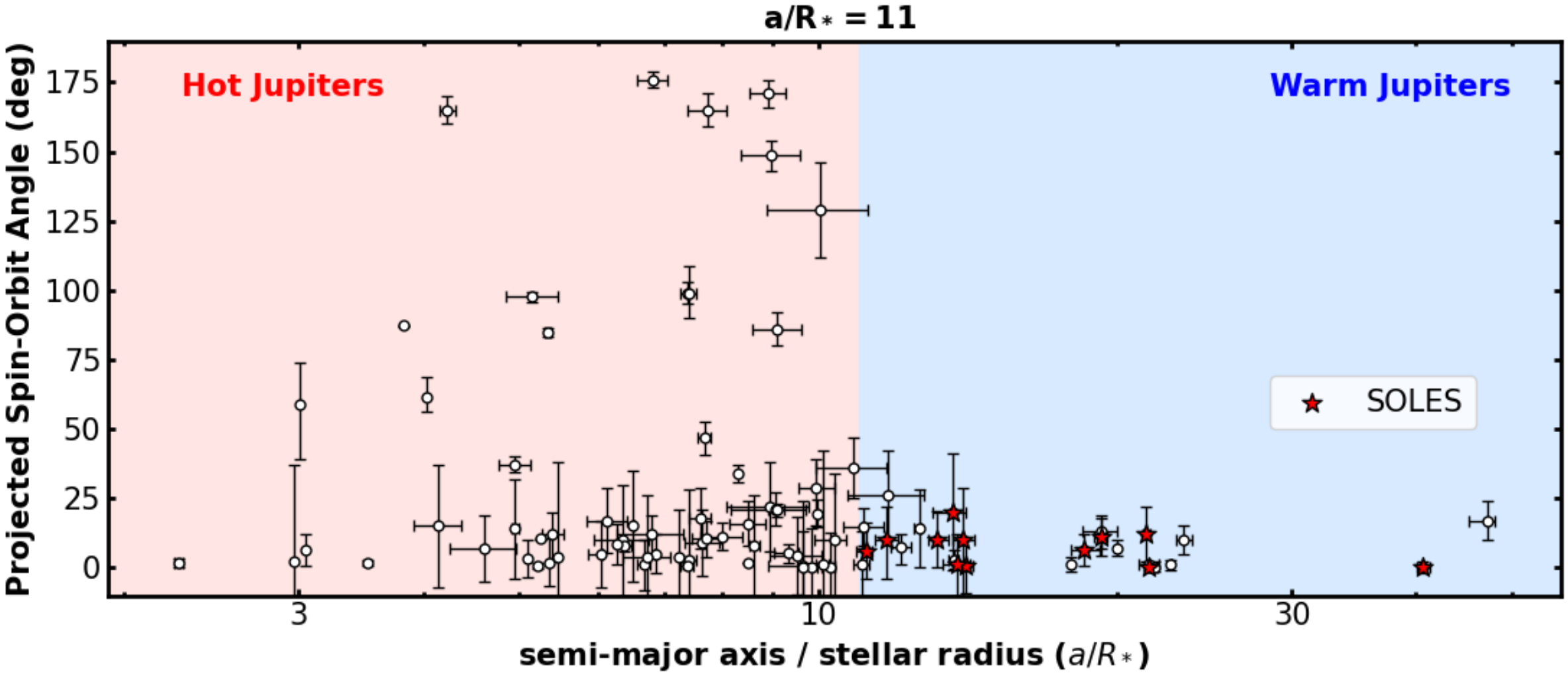




Wang et al. (2024), in revision

#1 Single-Star Warm-Jupiter systems tend to be aligned

SOLES: Half of the Warm Jupiters with Stellar Obliquities



See also Rice et al. (2022)

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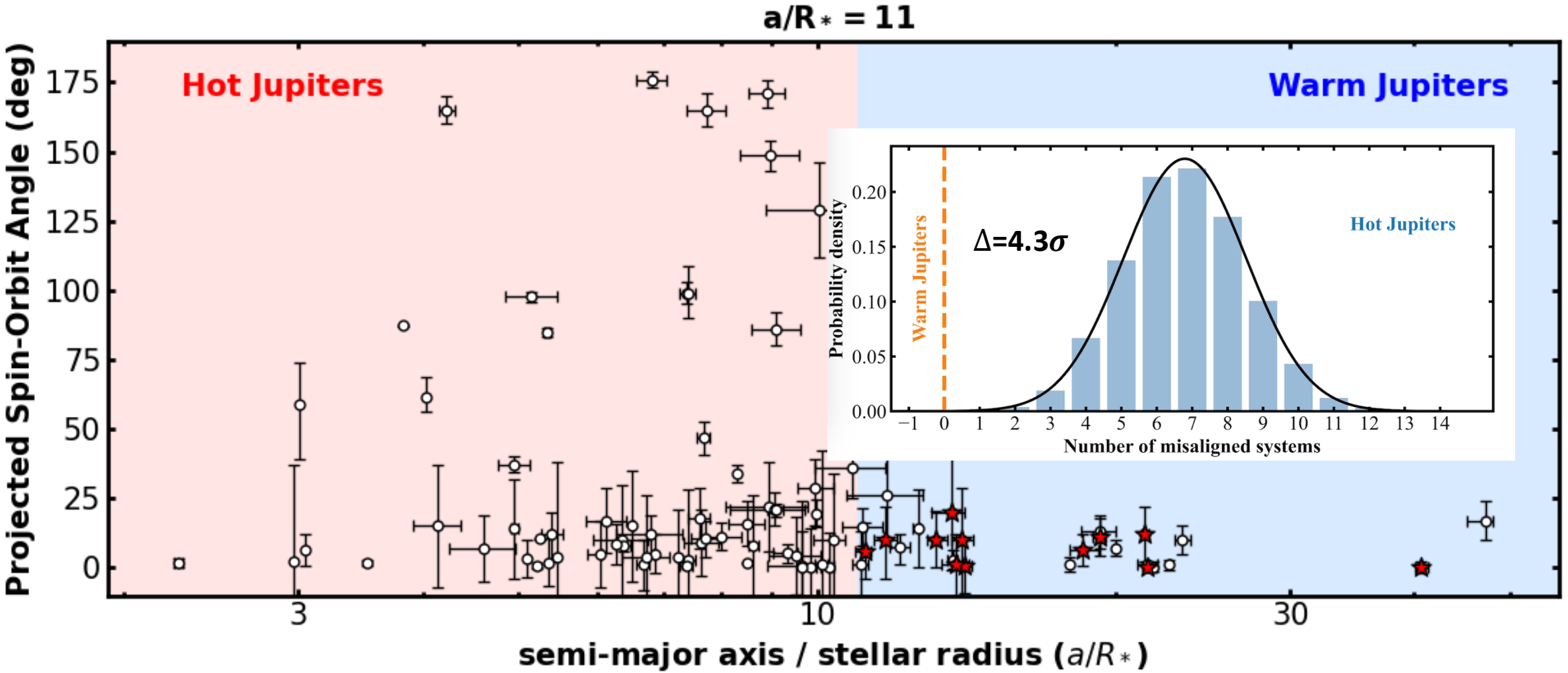
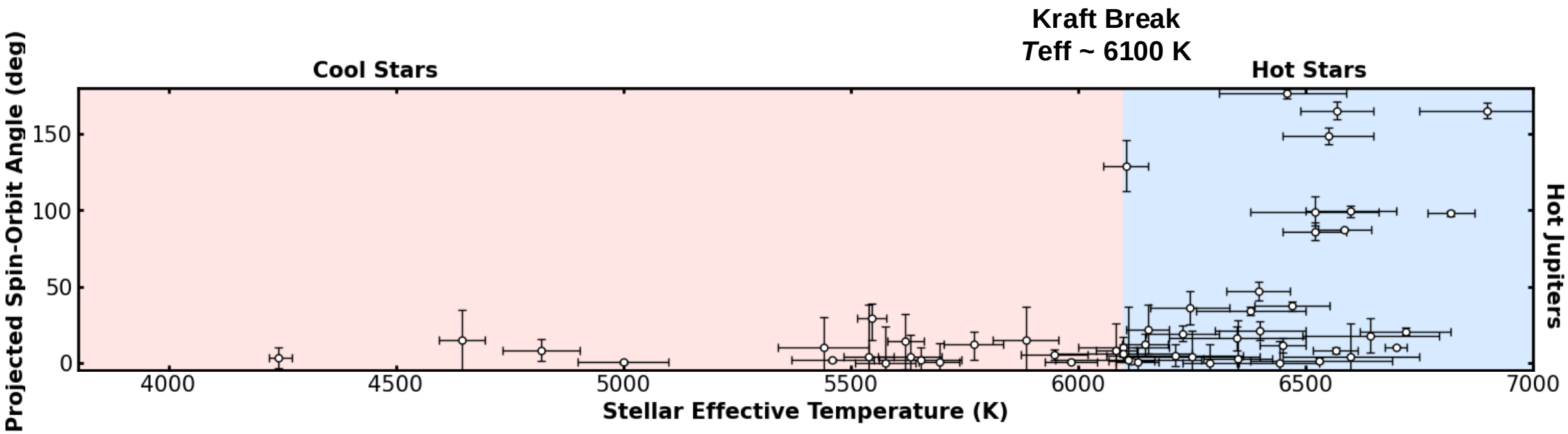


See also Rice et al. (2022)

#2 No T_{eff} - λ relation for Warm-Jupiter Systems:

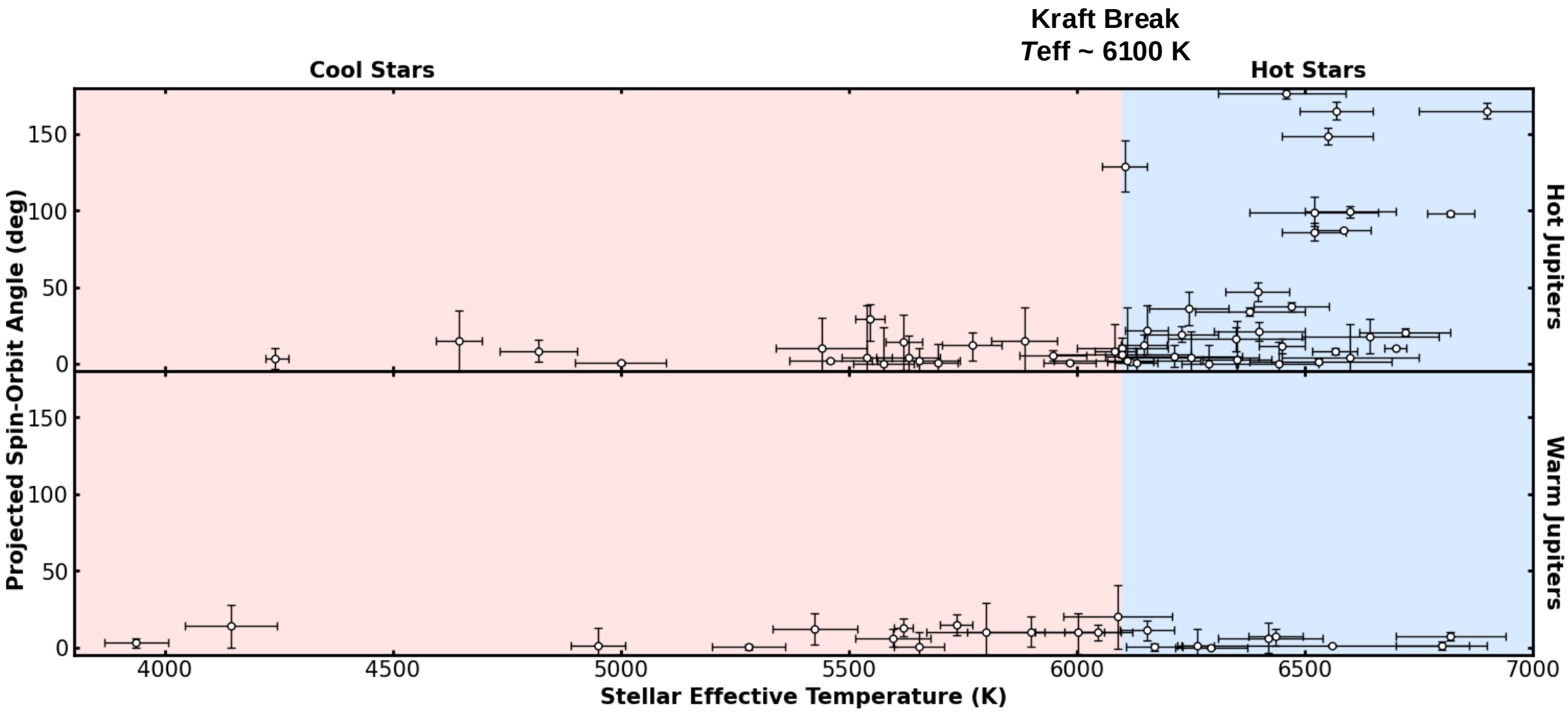
All aligned, Even around hot Stars

Hot Stars with Hot Jupiters Have High Obliquities

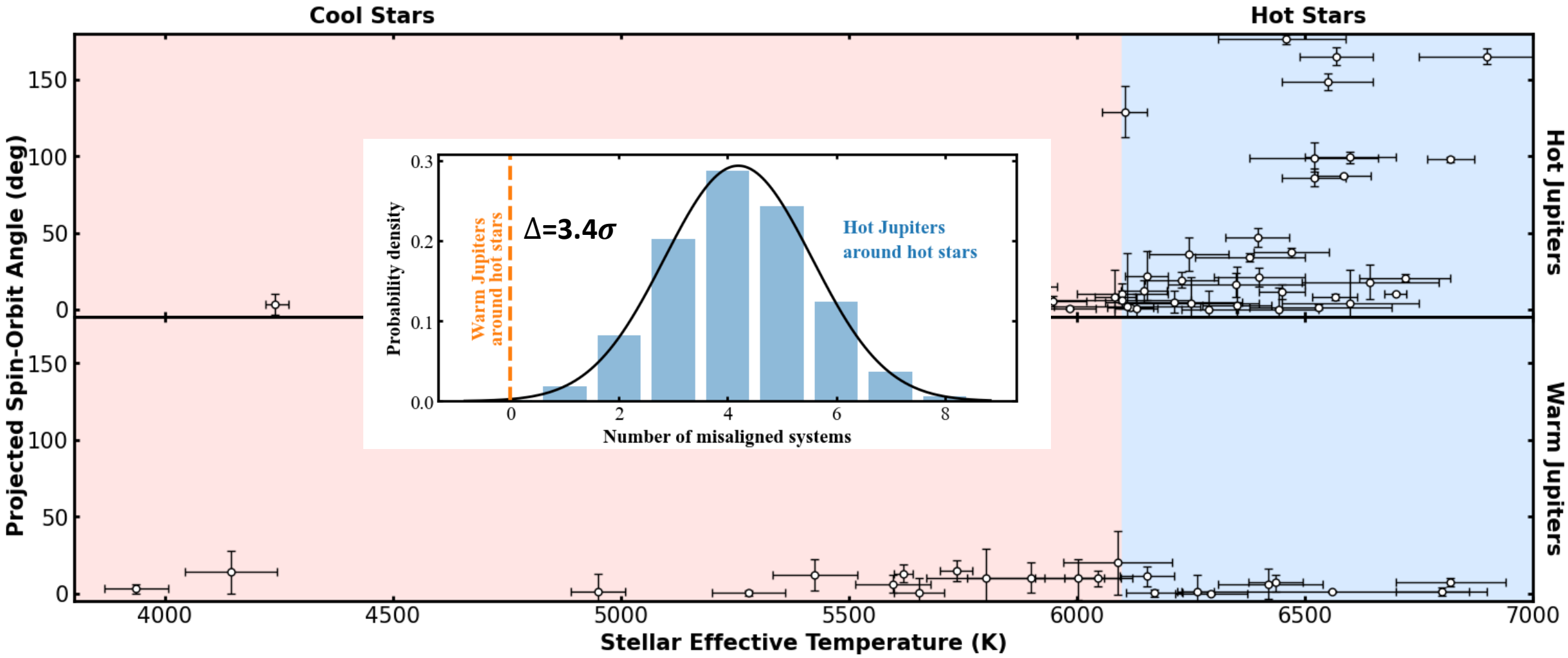


Winn et al. (2010), Schlaufman 2010

Single-Hot-Star Warm-Jupiter Systems tend to be aligned



Warm Jupiter around Hot Stars tend to be aligned



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Stellar obliquities of eight close-in gas giant exoplanets

J. Zak[1,2,3], H. M. J. Boffin[3], E. Sedaghati[4], A. Bocchieri[5], Z. Balkoova[1], M. Skarka[1,6], and P. Kabath[1]

[1] Astronomical Institute of the Czech Academy of Sciences, Fričova 298, 25165 Ondřejov, Czech Republic; e-mail: zak@asu.cas.cz
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[3] European Southern Observatory, Karl-Schwarzschild-str. 2, 85748 Garching, Germany
[4] European Southern Observatory, Casilla 13, Vitacura, Santiago, Chile
[5] Dipartimento di Fisica, La Sapienza Università di Roma, Piazzale Aldo Moro 5, Roma, 00185, Italy
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+8

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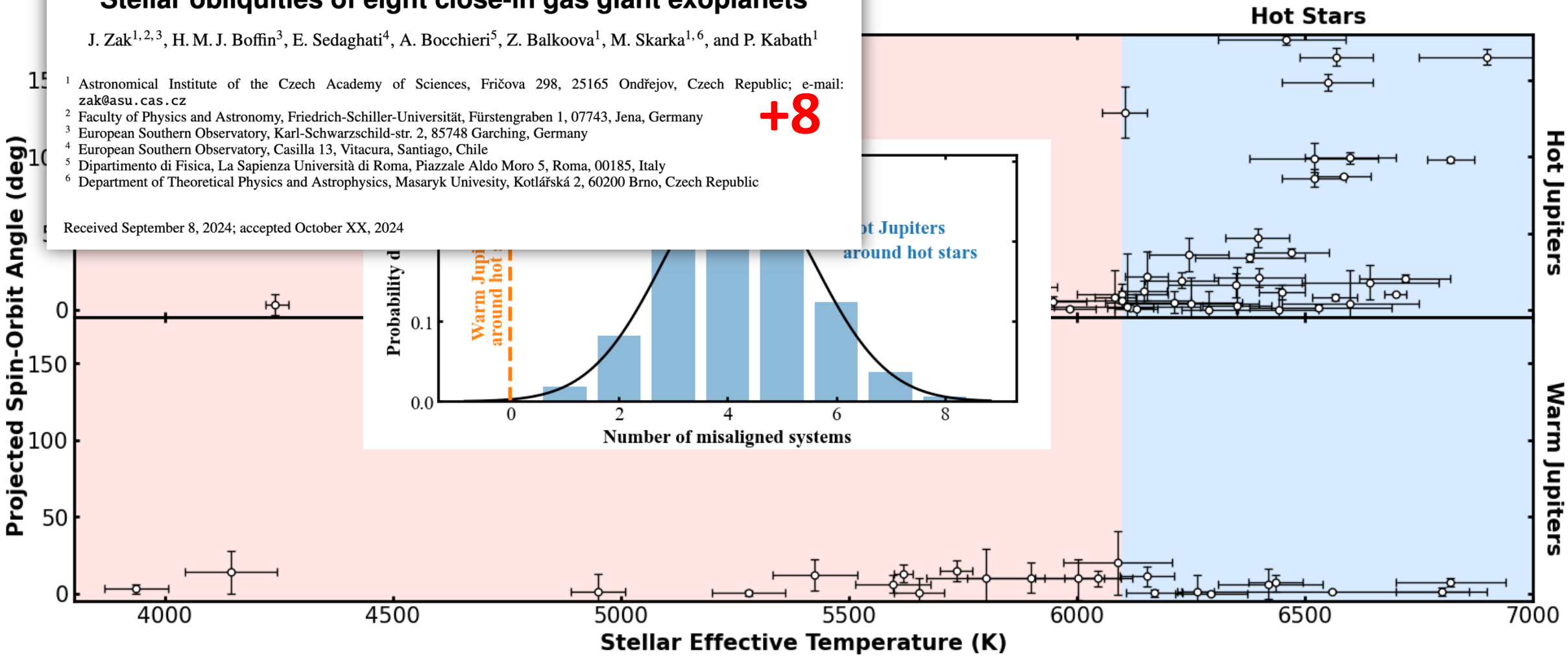

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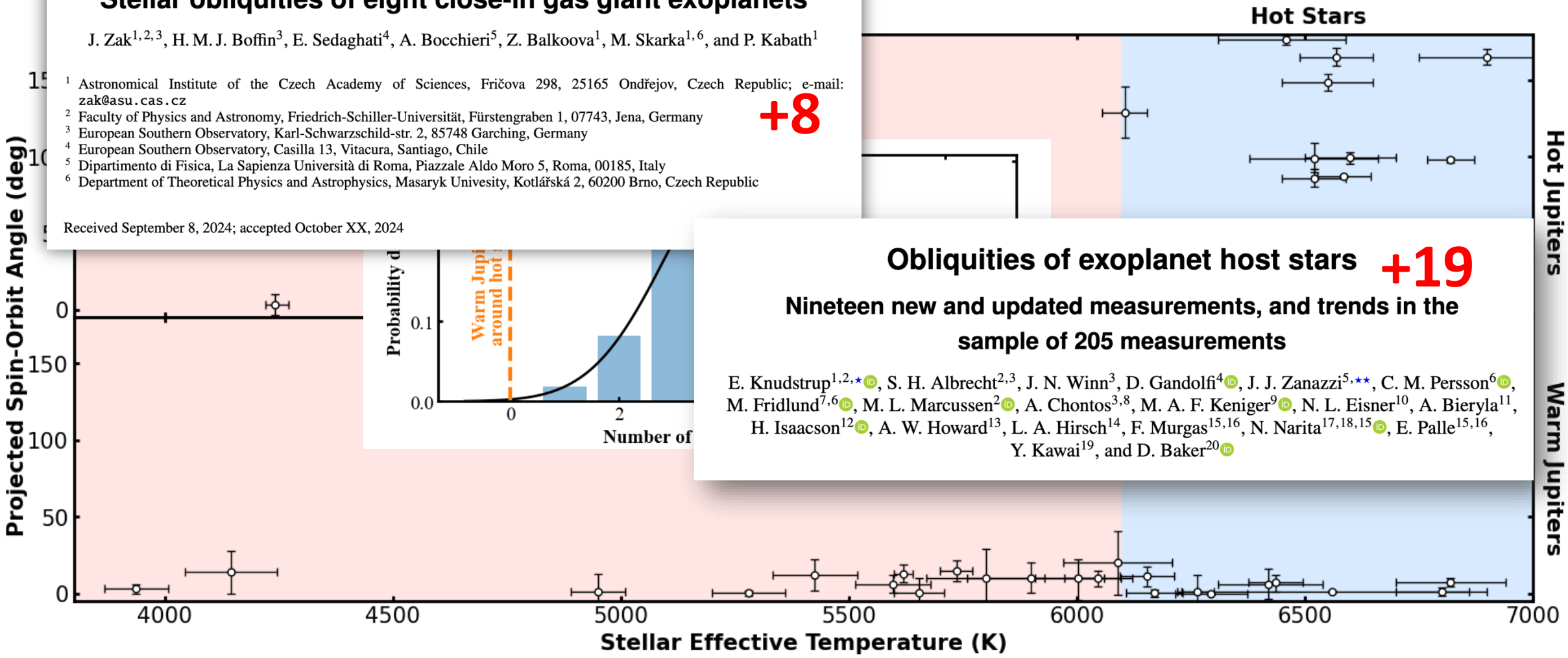
Obliquities of exoplanet host stars +19

Nineteen new and updated measurements, and trends in the sample of 205 measurements

E. Knudstrup[1,2,⋆], S. H. Albrecht[2,3], J. N. Winn[3], D. Gandolfi[4], J. J. Zanazzi[5,⋆⋆], C. M. Persson[6], M. Fridlund[7,6], M. L. Marcussen[2], A. Chontos[3,8], M. A. F. Keniger[9], N. L. Eisner[10], A. Bieryla[11], H. Isaacson[12], A. W. Howard[13], L. A. Hirsch[14], F. Murgas[15,16], N. Narita[17,18,15], E. Palle[15,16], Y. Kawai[19], and D. Baker[20]



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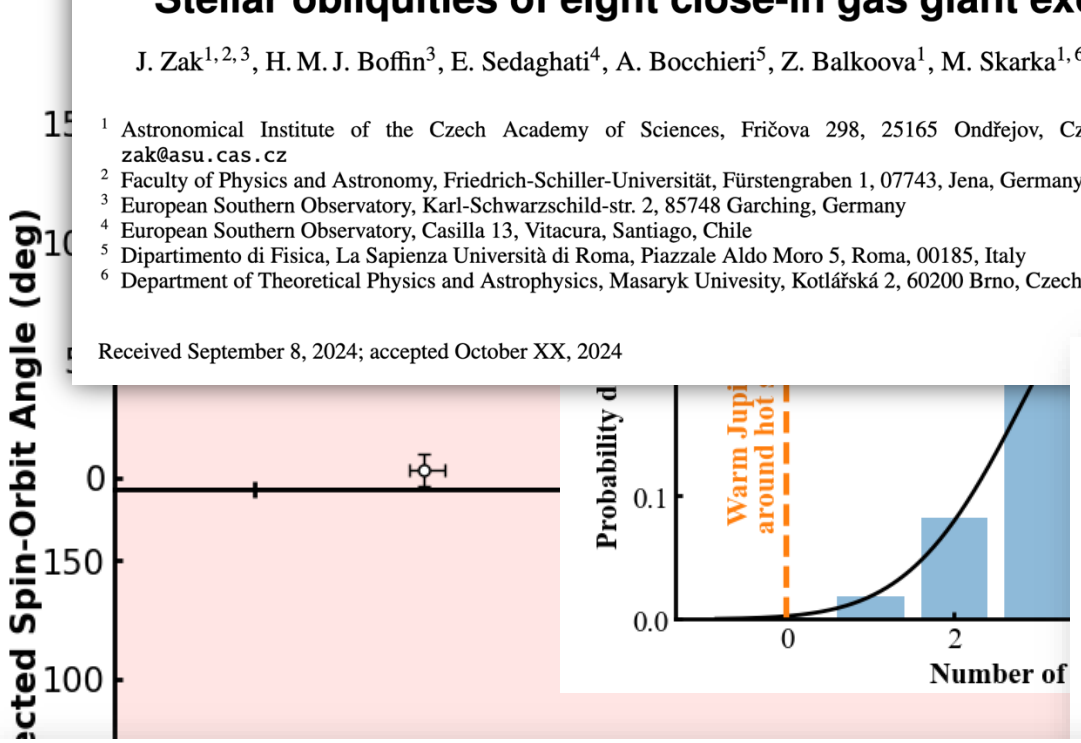

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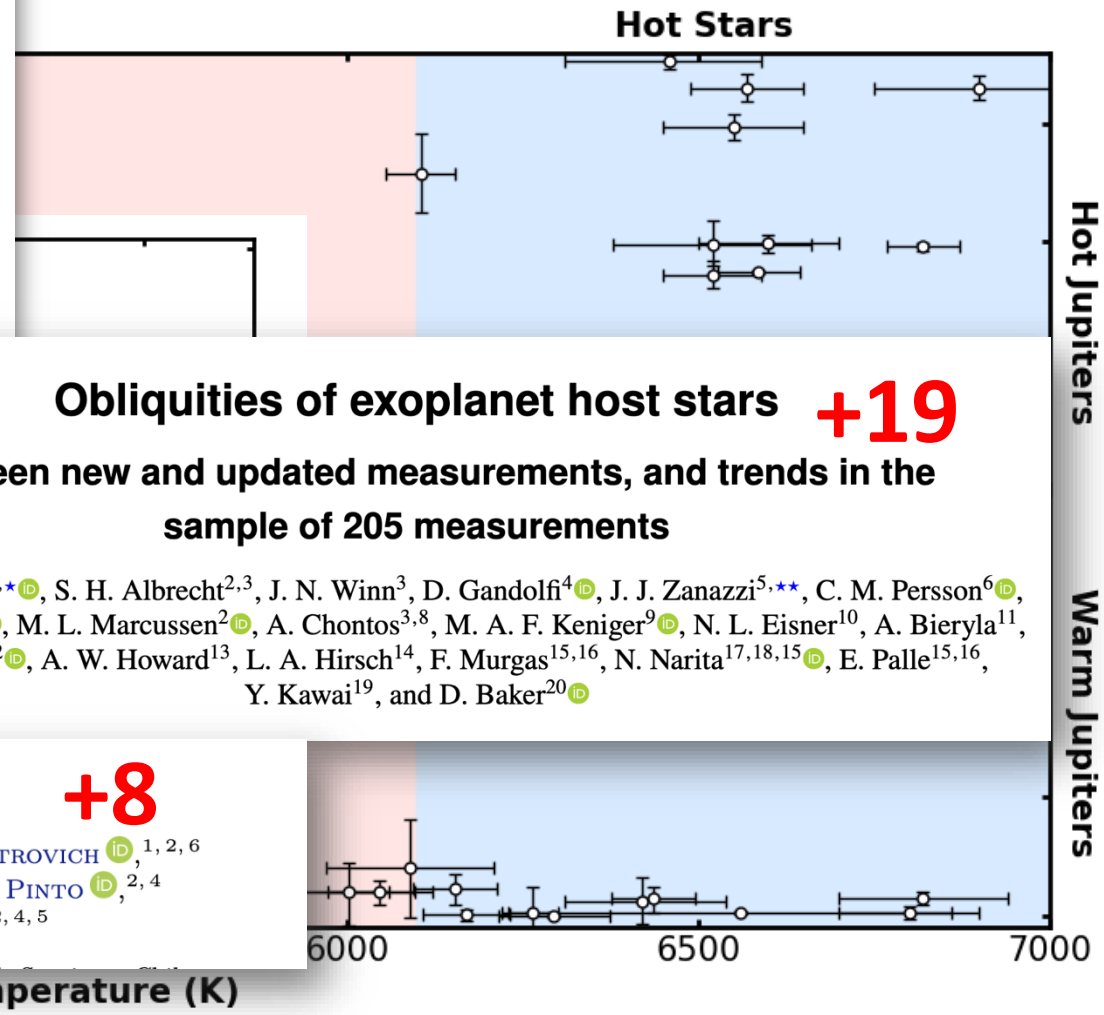

The Spin-Orbit Alignment of 8 Warm Gas Giant Systems*

+8

Juan I. Espinoza-Retamal[1,2,3], Andrés Jordán[4,2,5], Rafael Brahm[2,4], Cristobal Petrovich[1,2,6], Elyar Sedaghati[7], Guðmundur Stefánsson[3], Melissa J. Hobson[2,8], Marcelo Tala Pinto[2,4], Diego J. Muñoz[9], Gavin Boyle[5,10], Rodrigo Leiva[2,11] and Vincent Suc[2,4,5]

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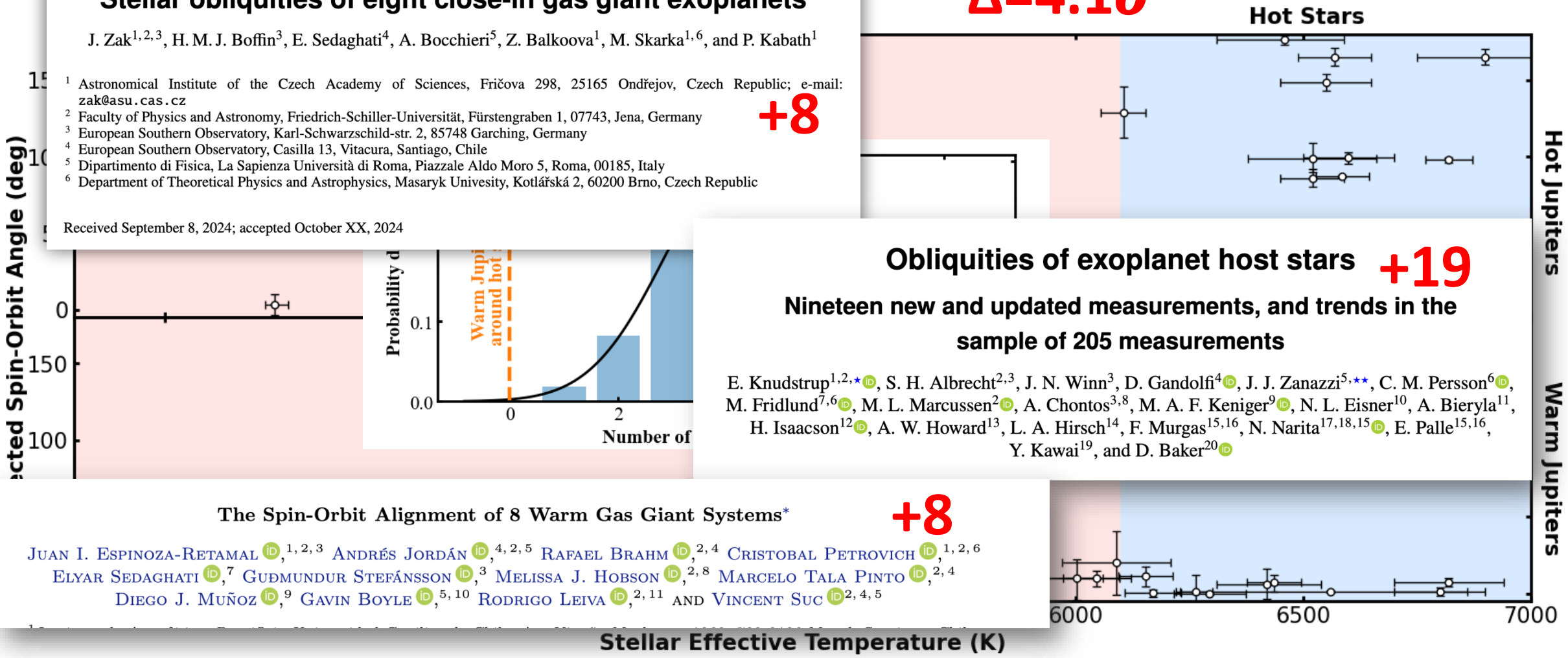
Δ=4.1σ



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Affects all types of planets

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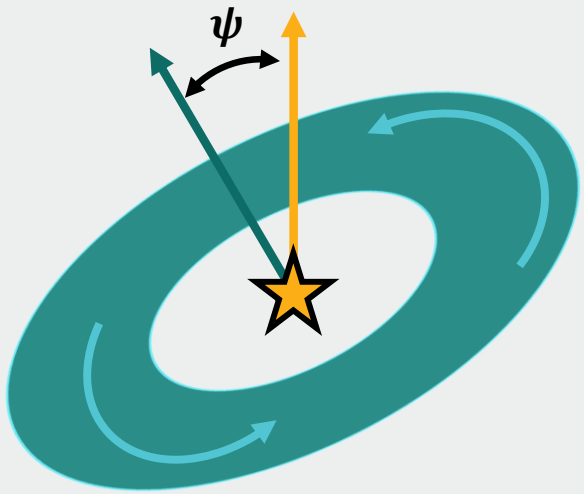
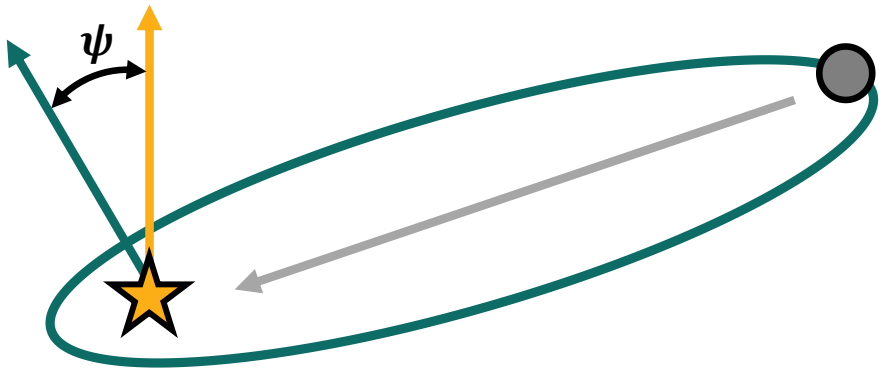
Primordial



Post formation

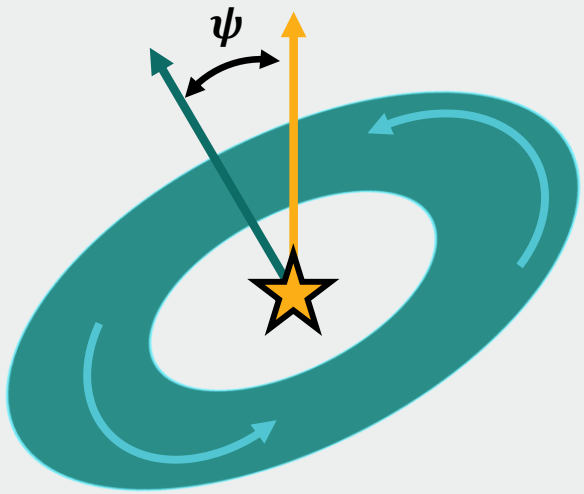


Albrecht, Dawson, & Winn (2022)

Spin-Orbit Misalignment is Not Primordial

Affects all types of planets

Primordial



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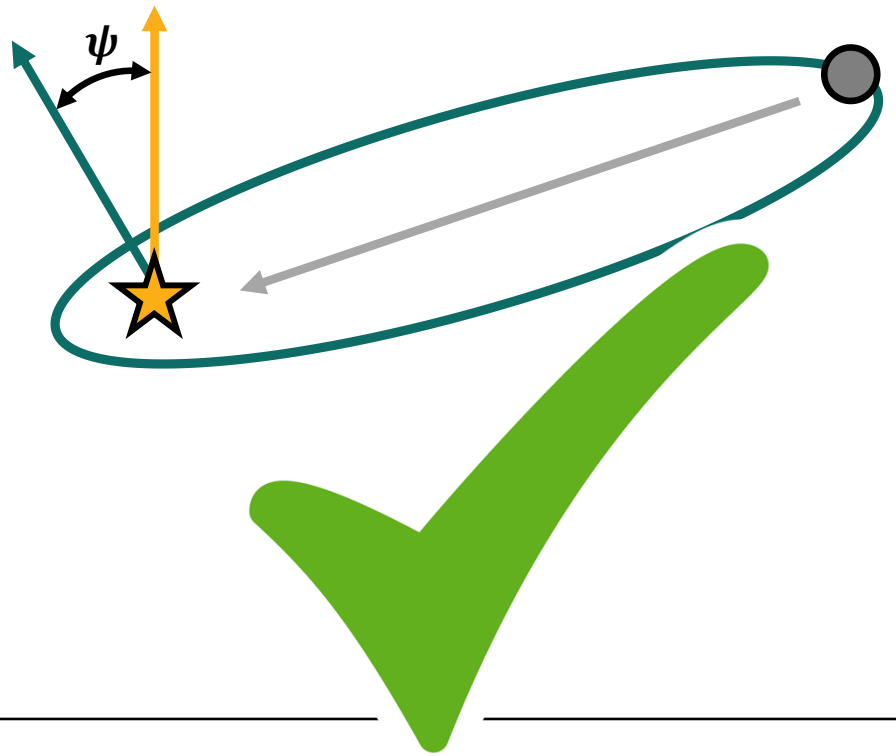
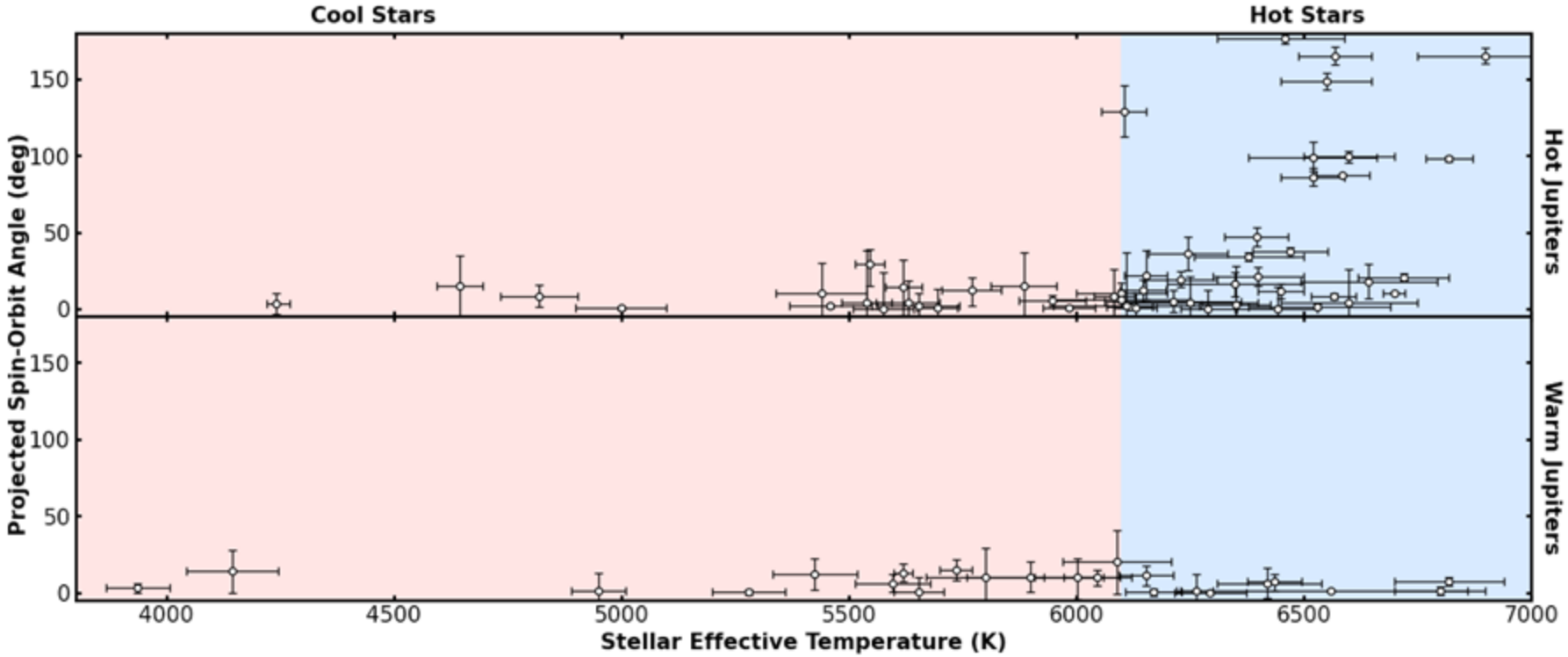
Post formation



Albrecht, Dawson, & Winn (2022)

Single-Star Warm Jupiters tend to be aligned, Even around Hot Stars

Spin-Orbit Misalignment is Not Primordial



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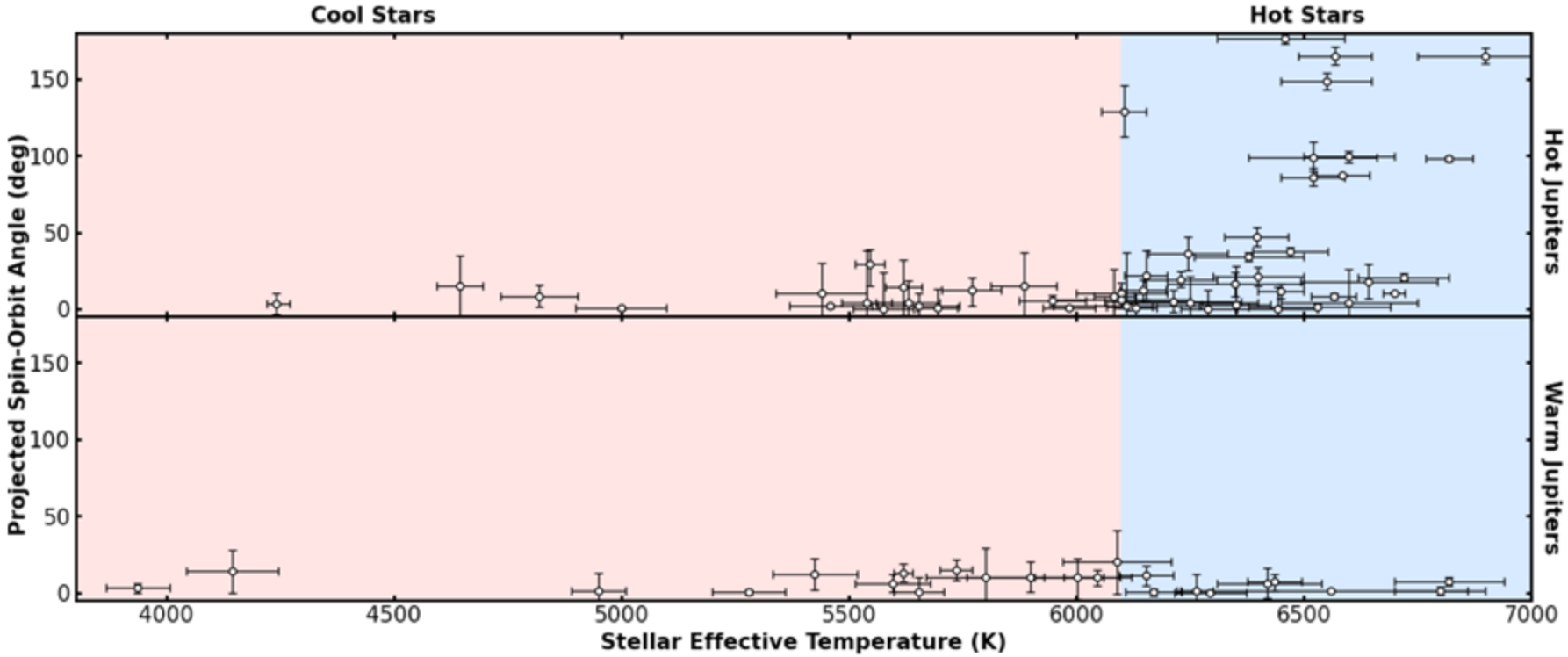

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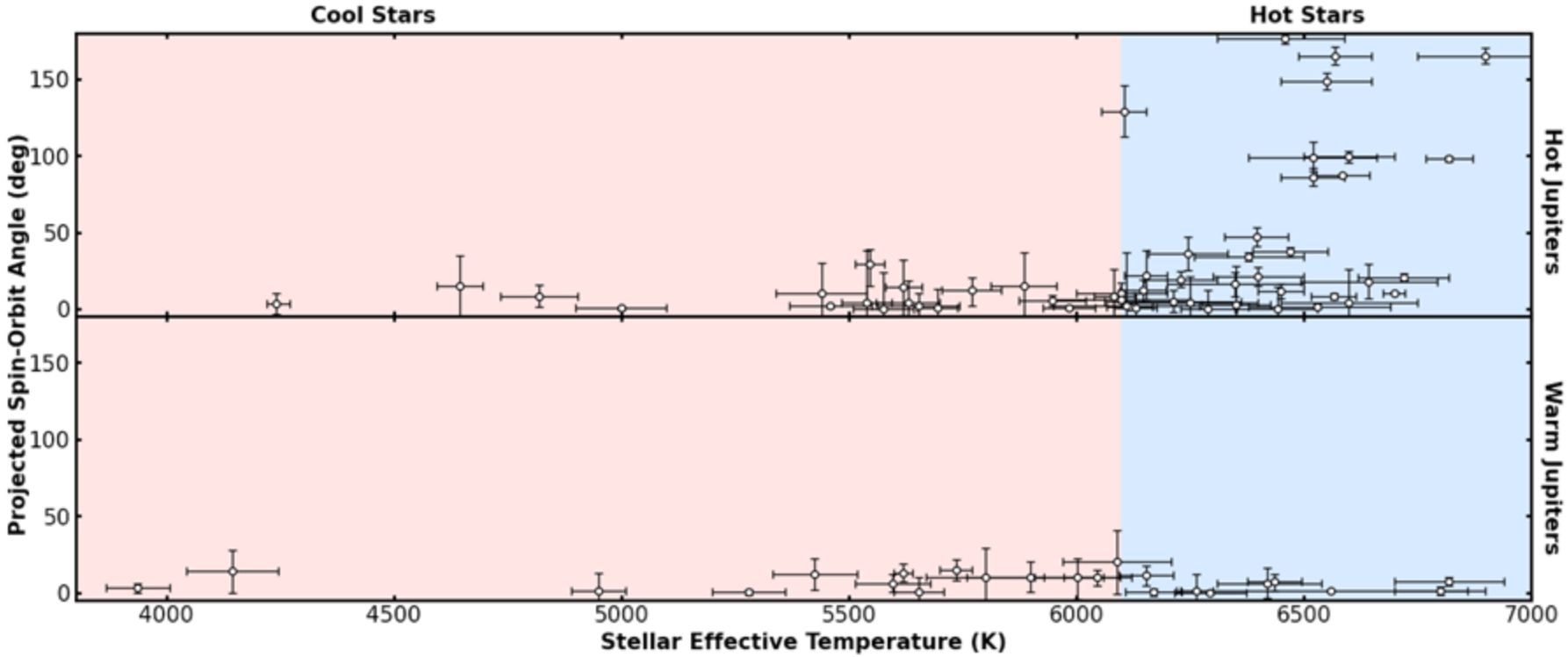

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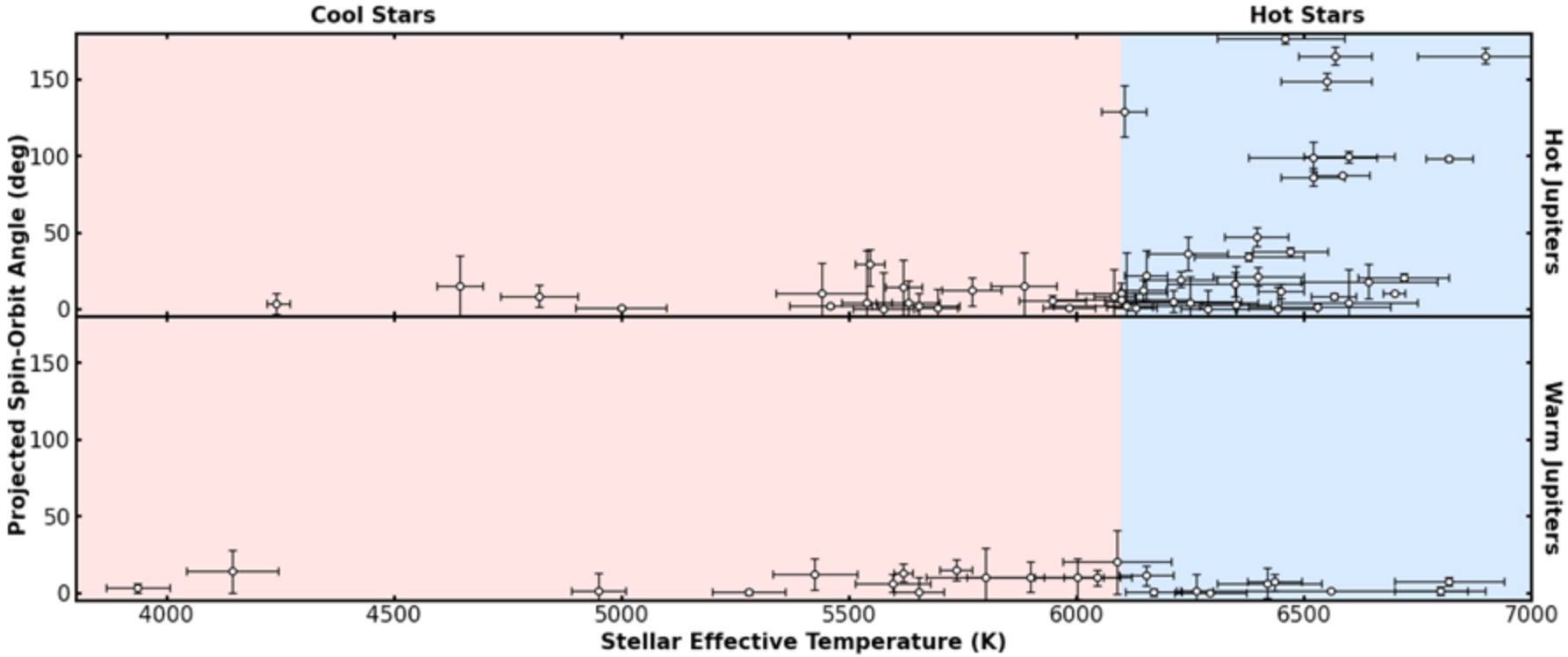

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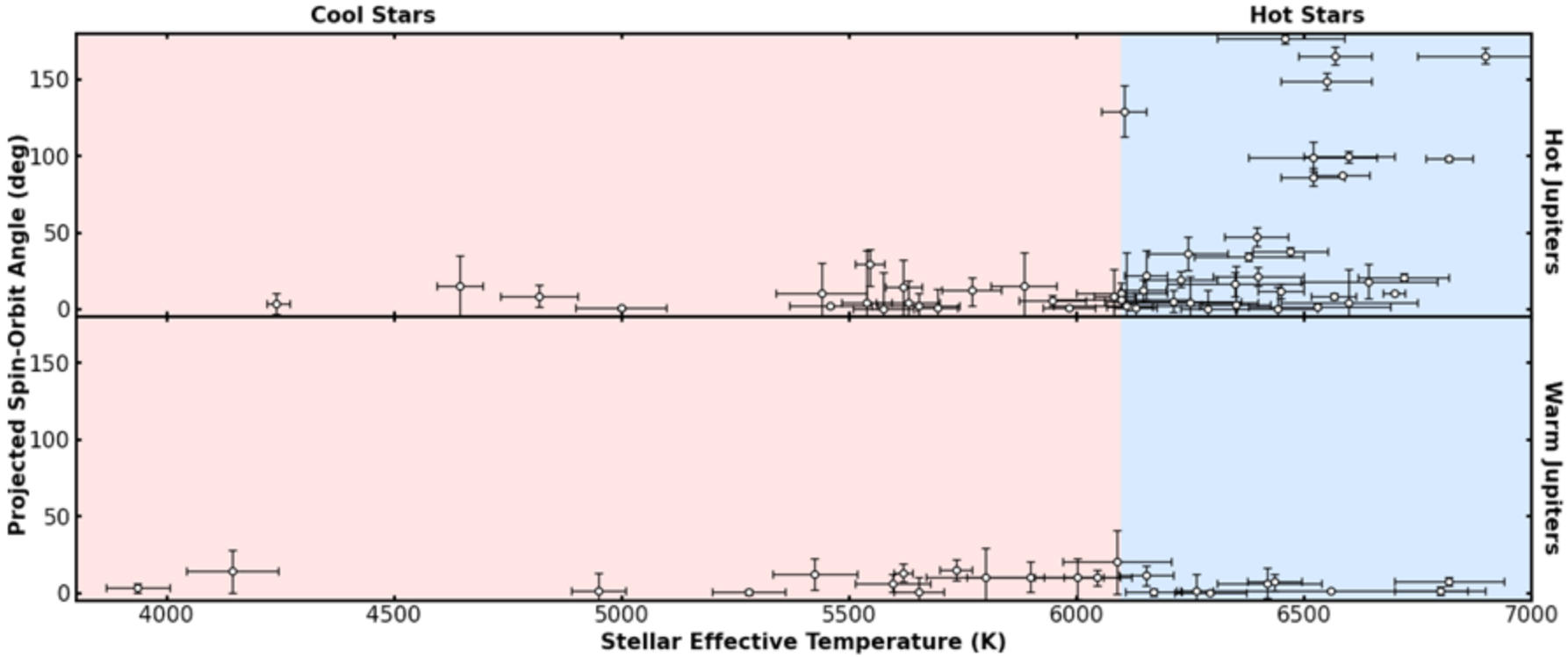

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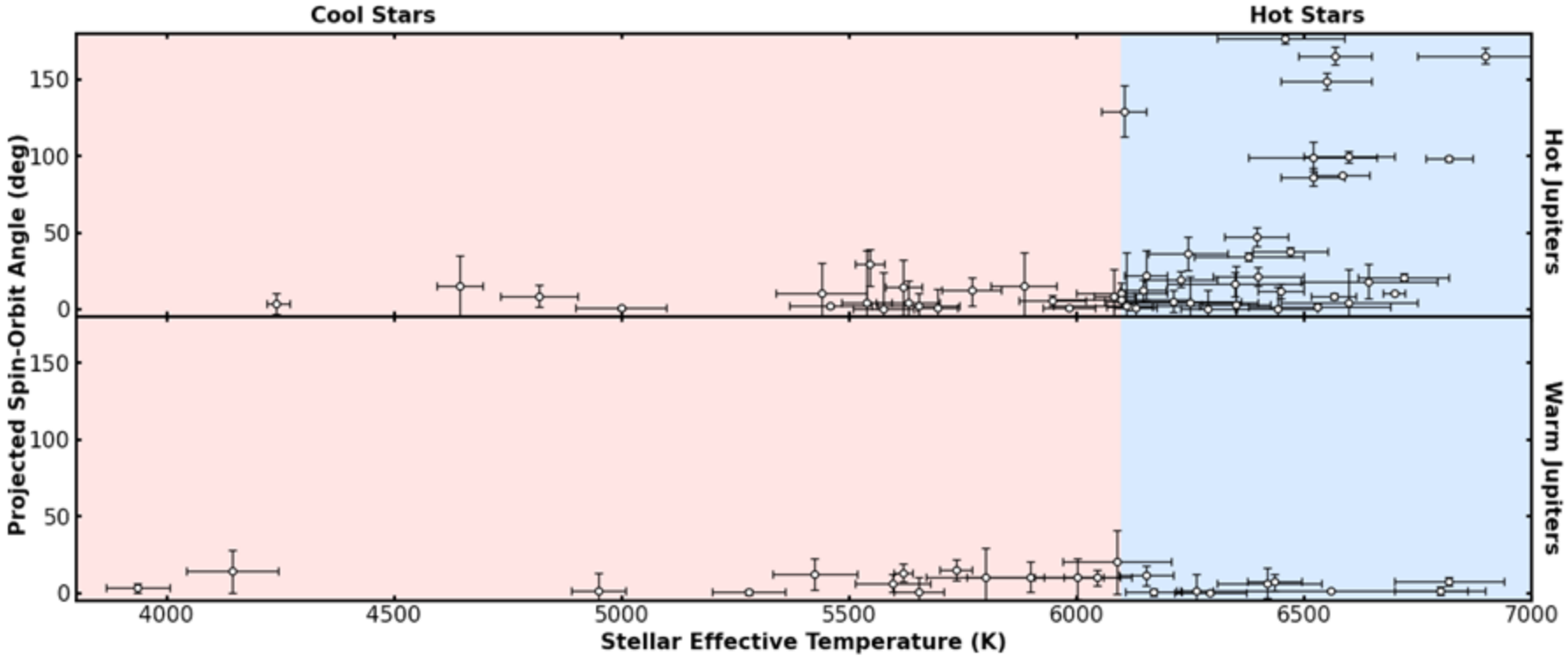

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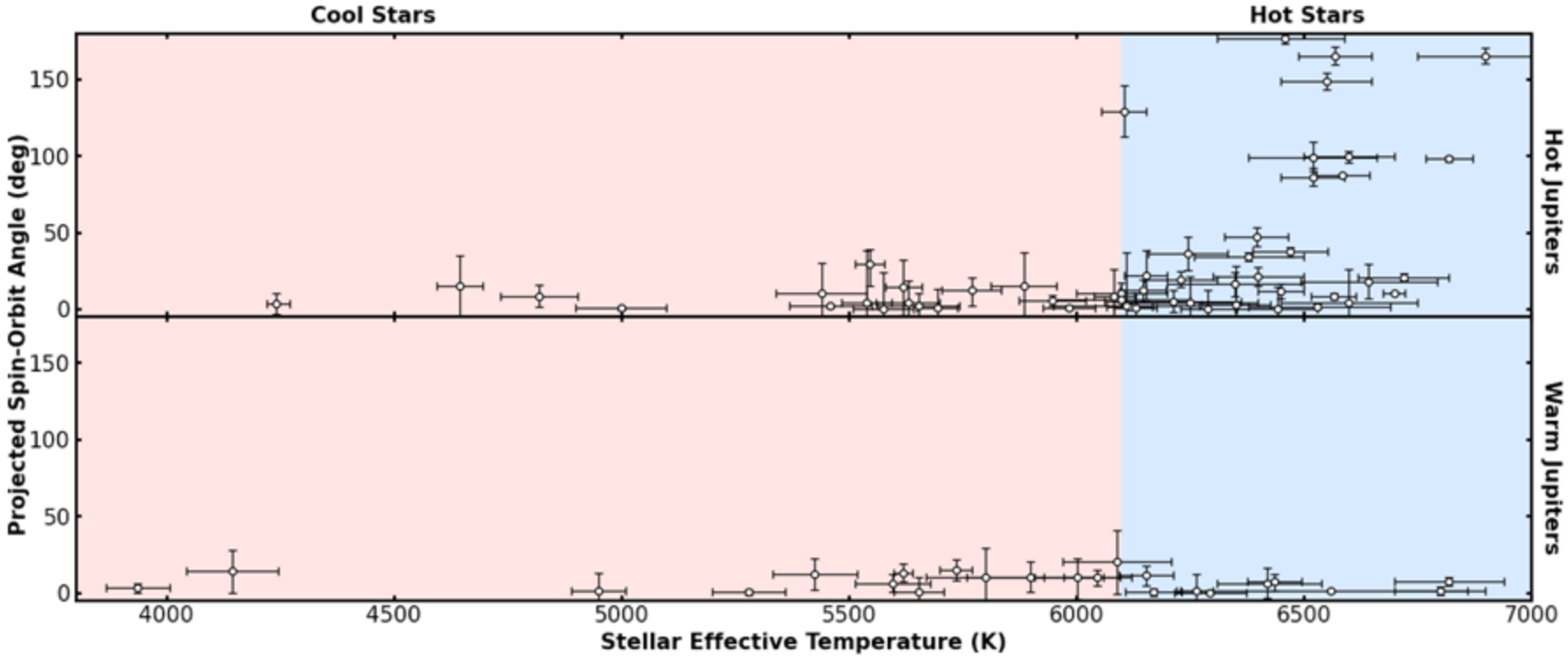
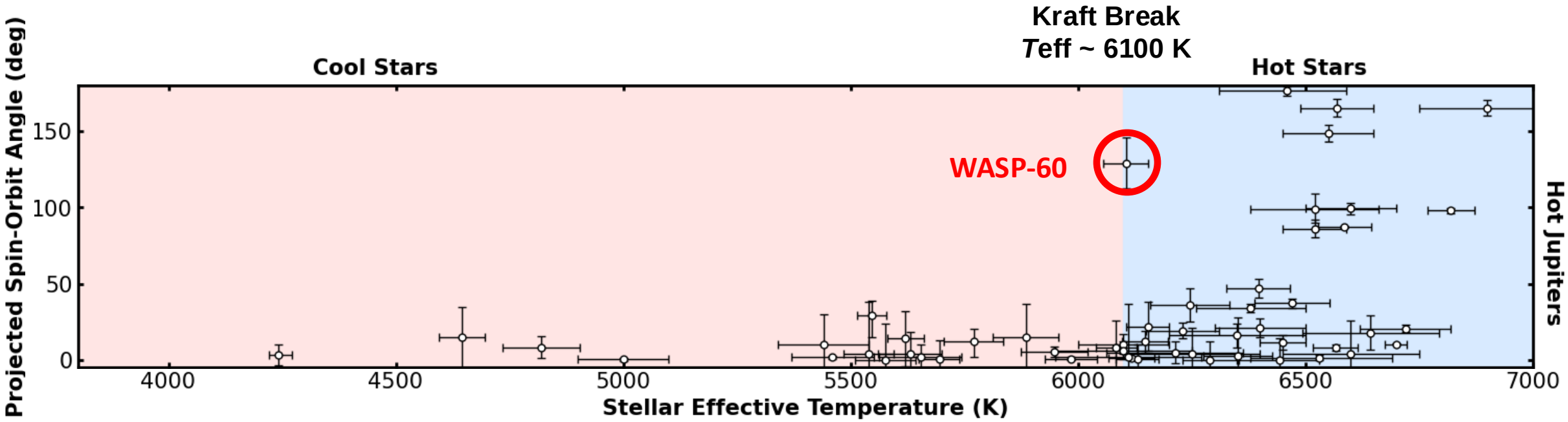
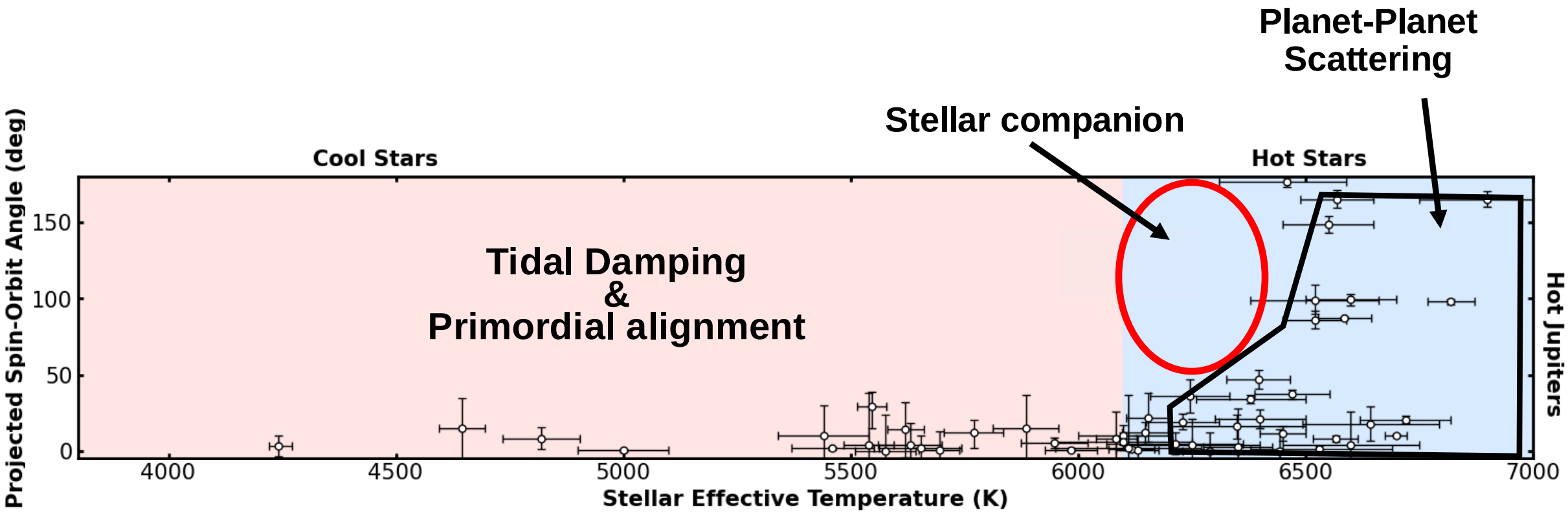


Hot Stars with Hot Jupiters Have High Obliquities

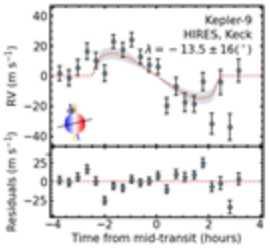


Binaries and multi-star systems contribute to misalignment around the Kraft break

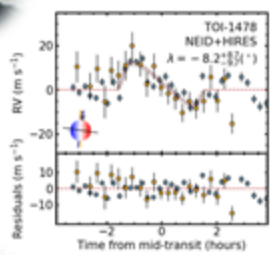


Compact-multi-planet Systems also Tend to be aligned

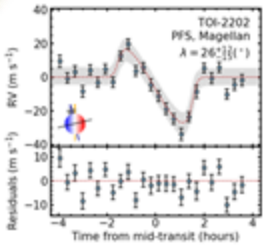
Wang S et al. 2018

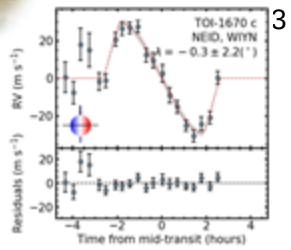


Wang X. et al. 2022



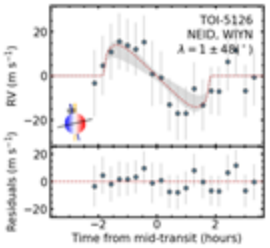
Rice, et al. 2023

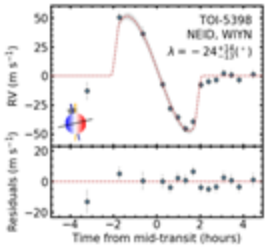




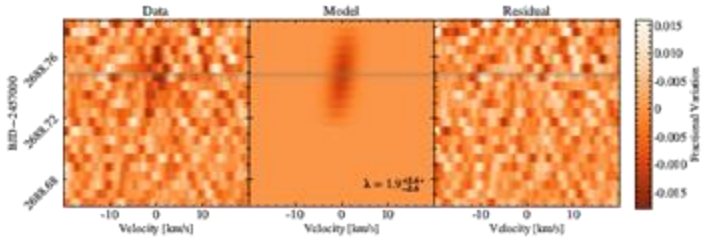
3

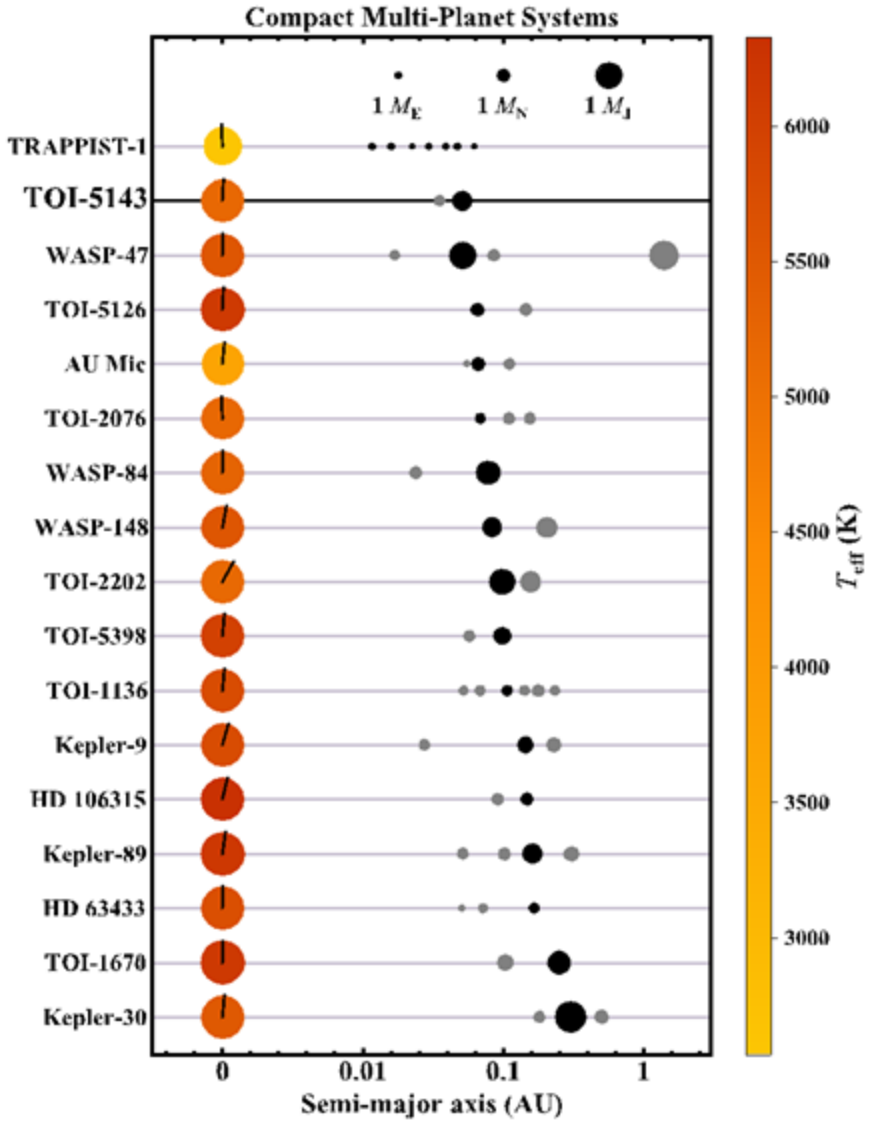
Radzom et al. 2024





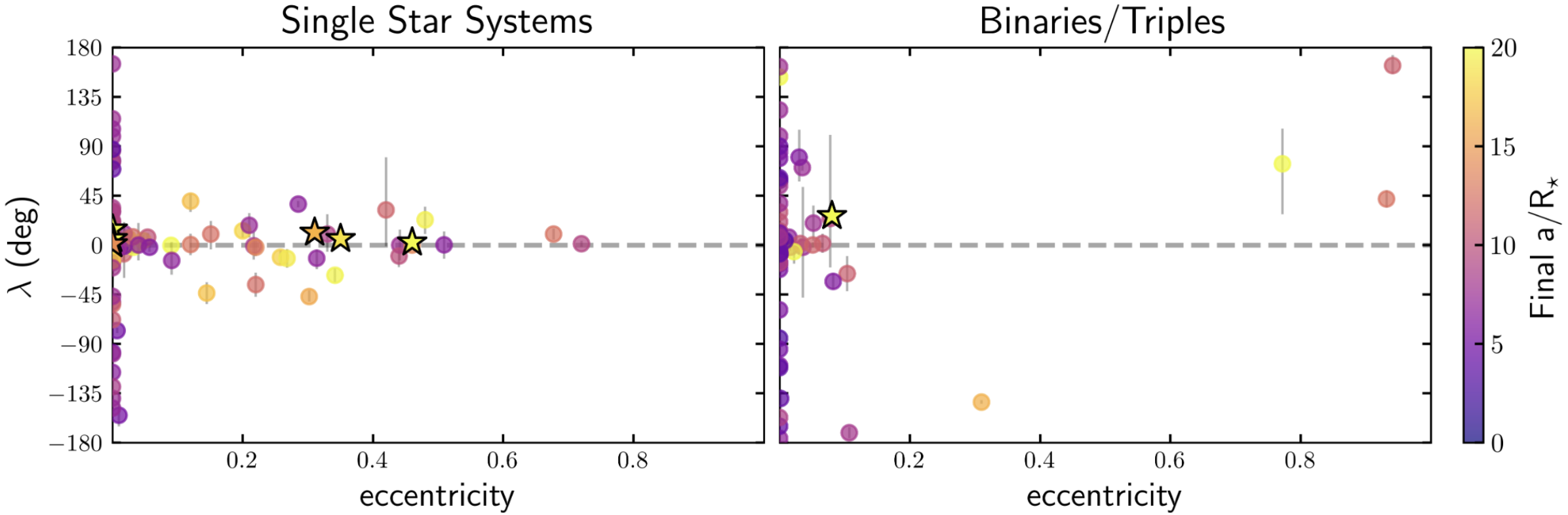
Radzom et al. 2025





Albrecht et al. (2013), Wang et al. (2022)
Radzom et al. (2024), Radzom et al. (2025)

Exciting eccentricity is easier than exciting obliquity



Espinoza-Retamal et al. (2025)

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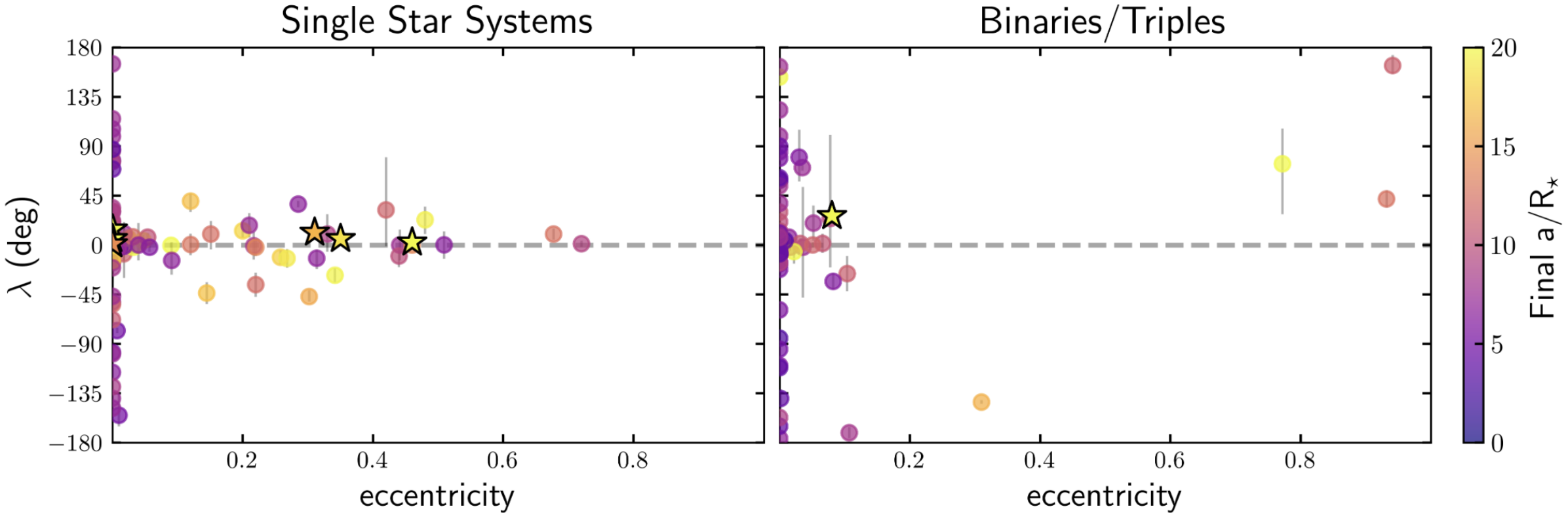
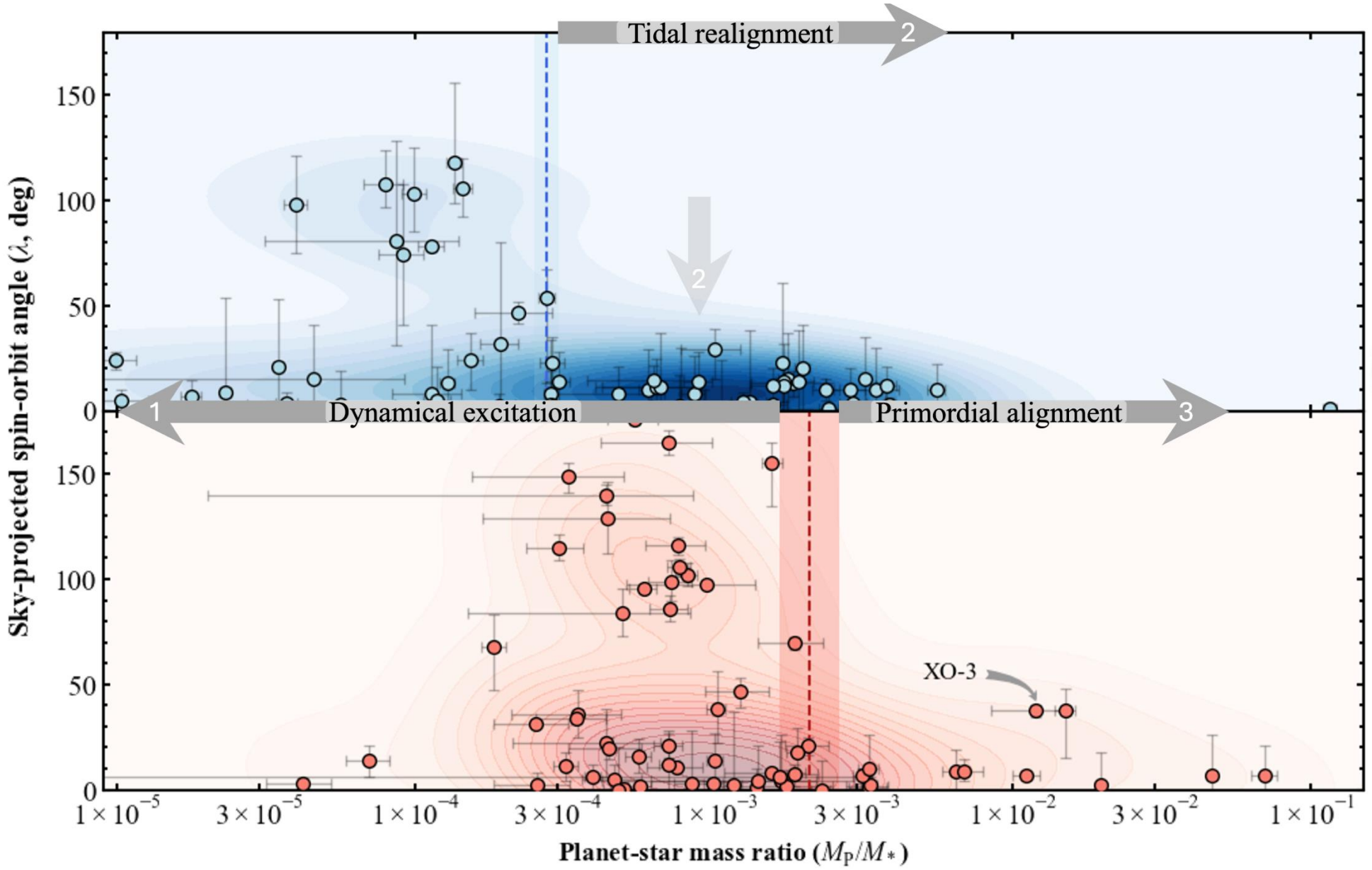


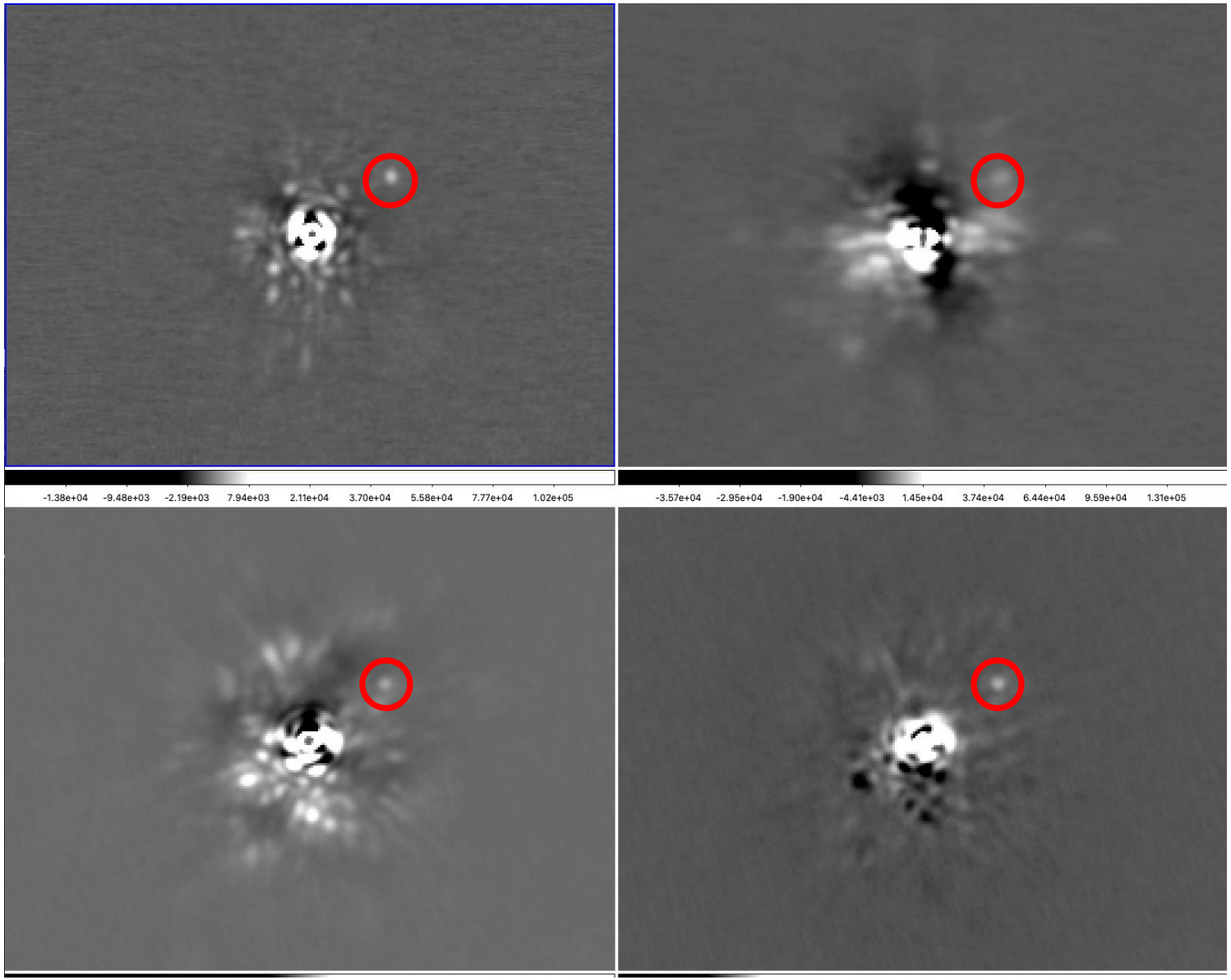
Espinoza-Retamal et al. (2025)

The Highest Mp/M∗ Systems Exhibit Low Obliquities, Even around Hot Stars



Jace Rusznak (applying grad school)

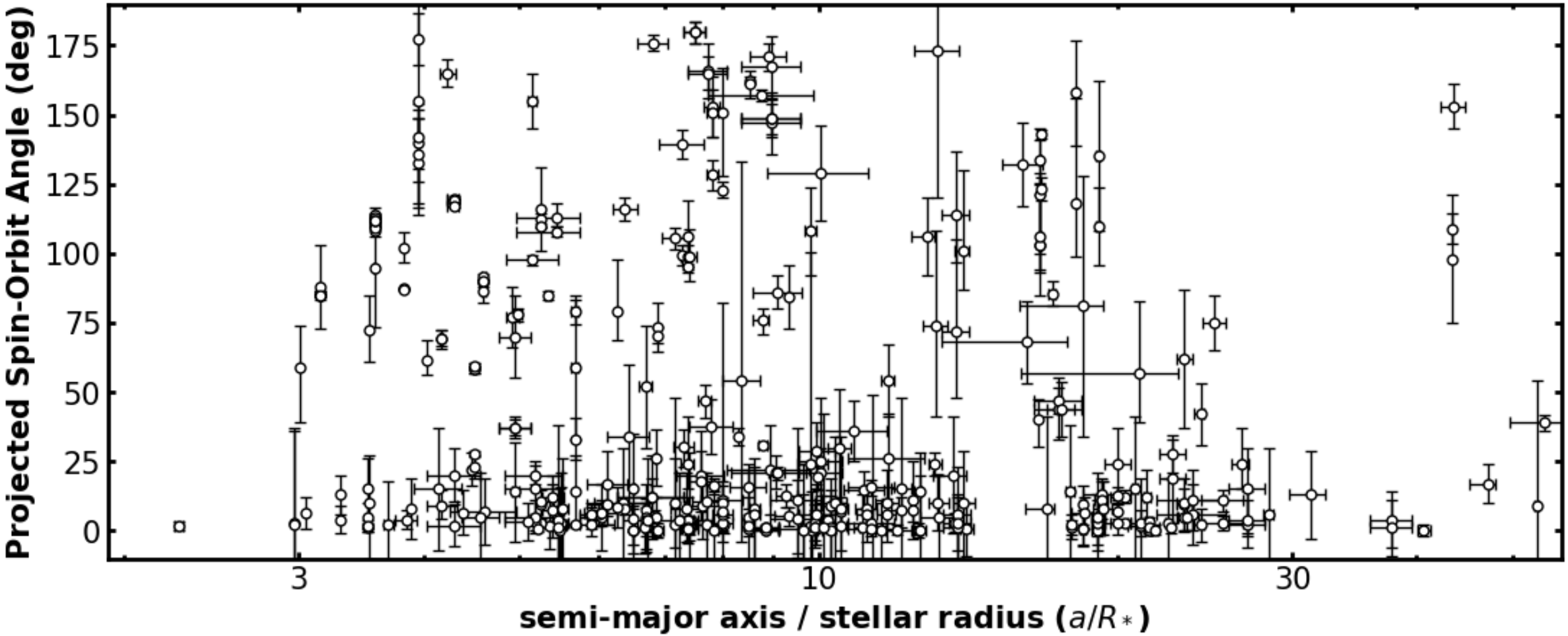
~~XO-3 b~~ XO-3 A b



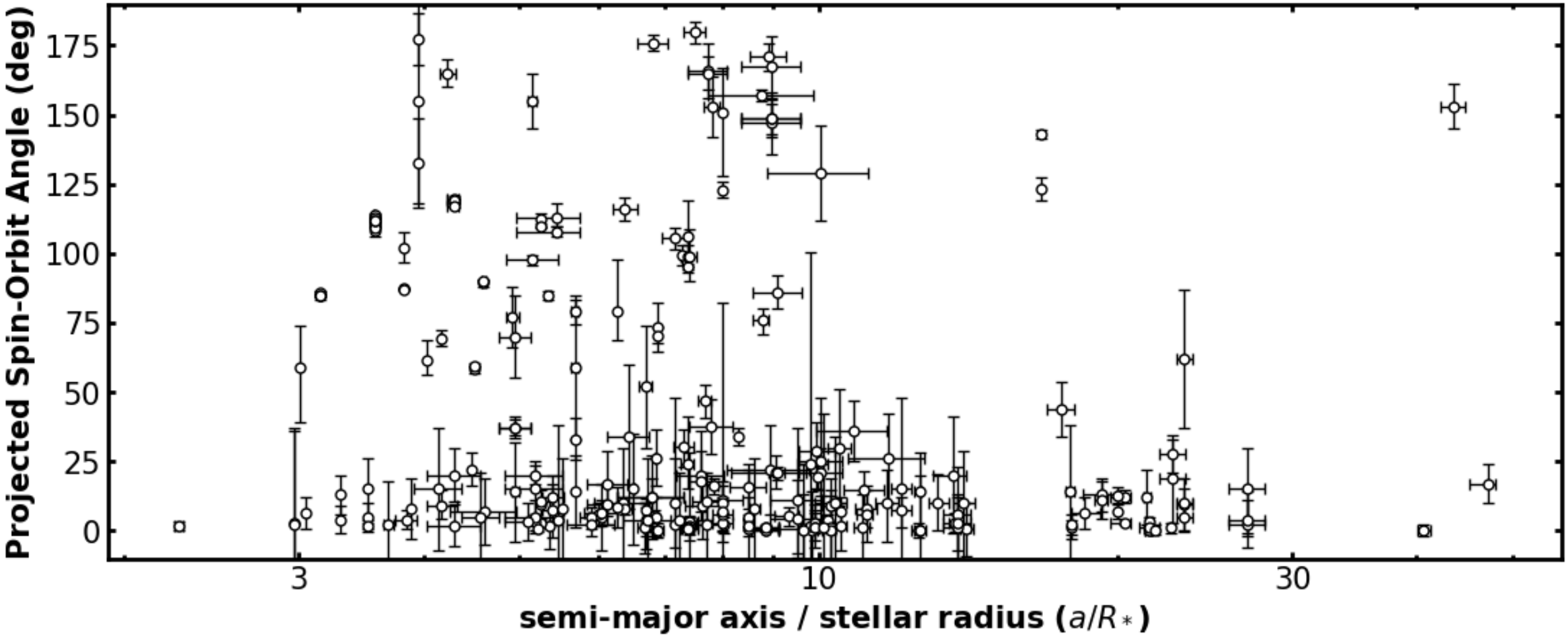
M4-M5 star at ~90 AU

Adam L. Kraus, personal communication, Dec 09, 2024

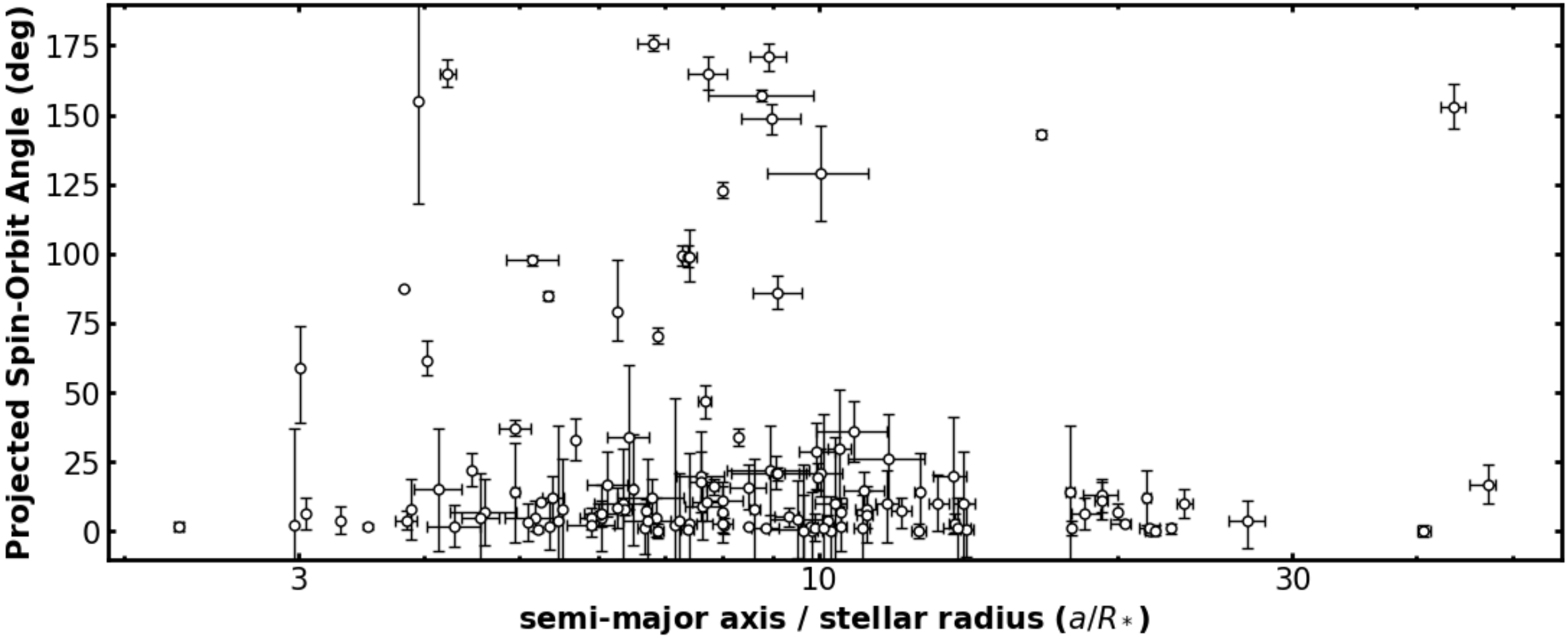
Sample Construction



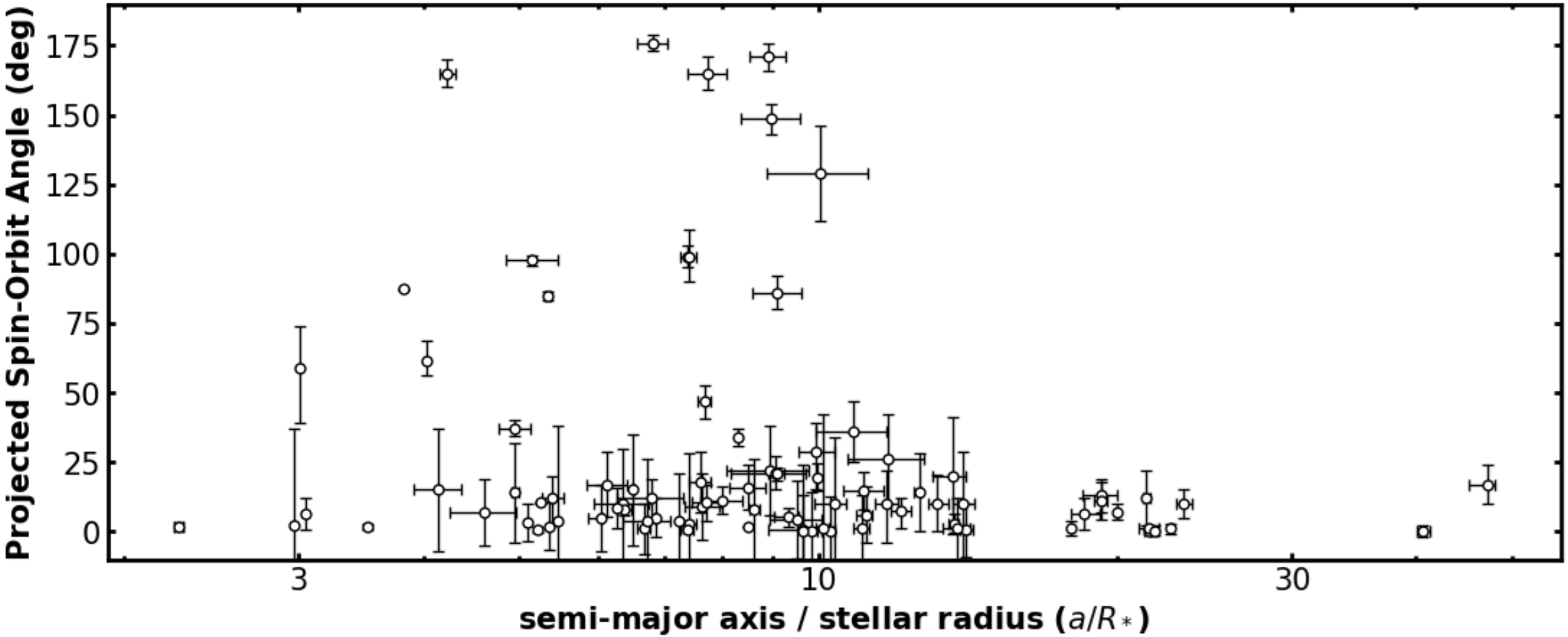
Removed low-mass planets (< 0.3 M_{Jup})



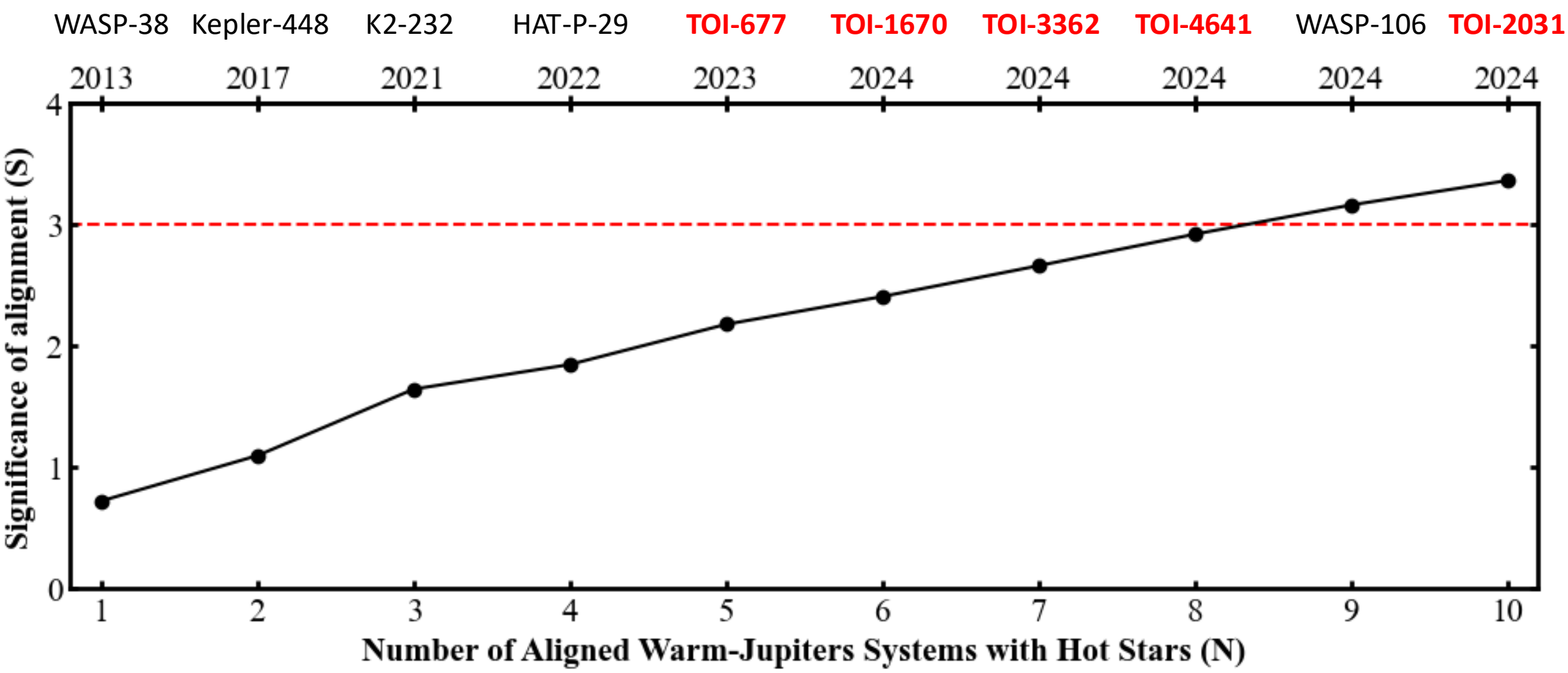
Retained Only RM and DT Measurements



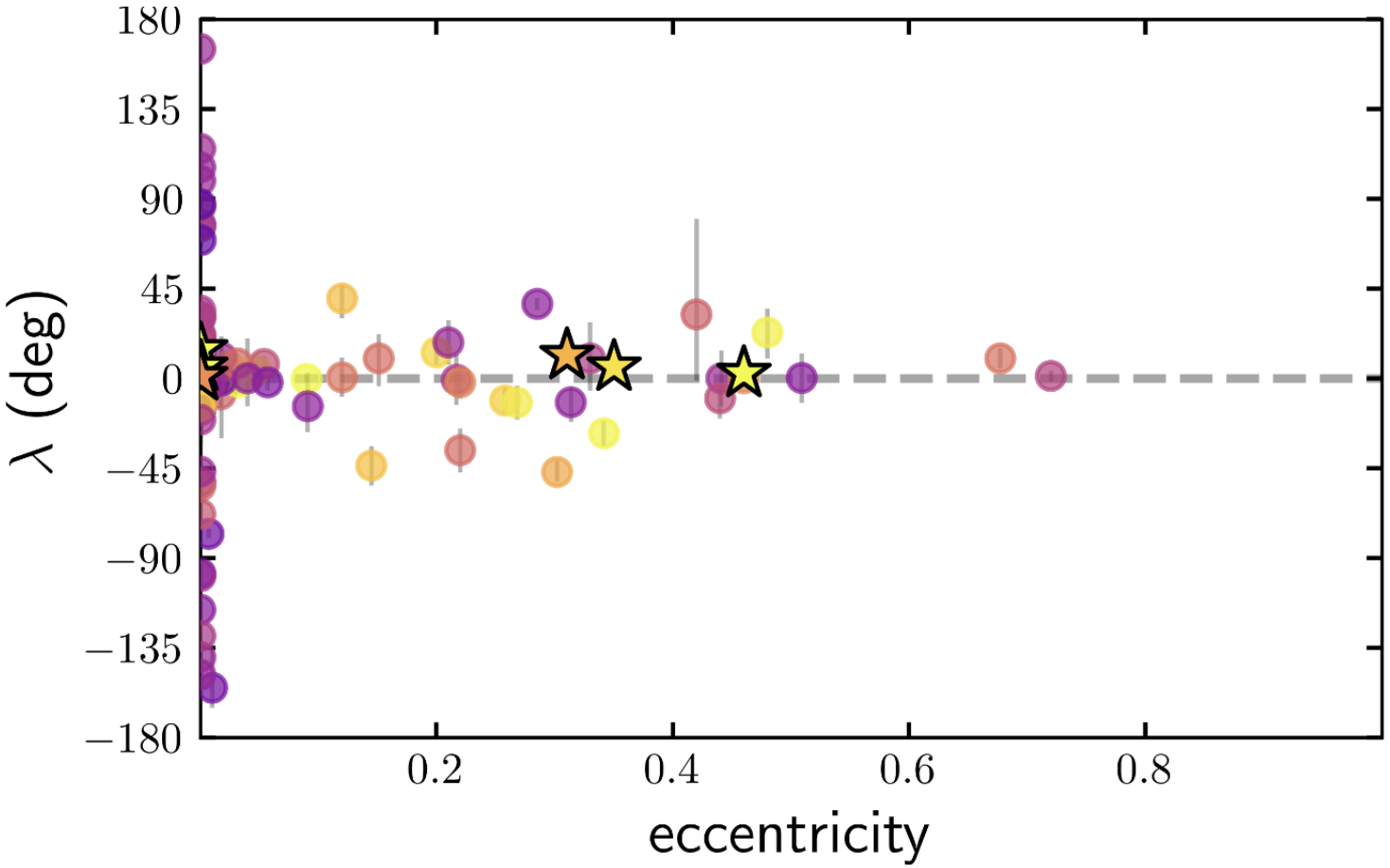
Removed binary and multi-star systems



Five TOI warm-Jupiter systems with hot stars got measured

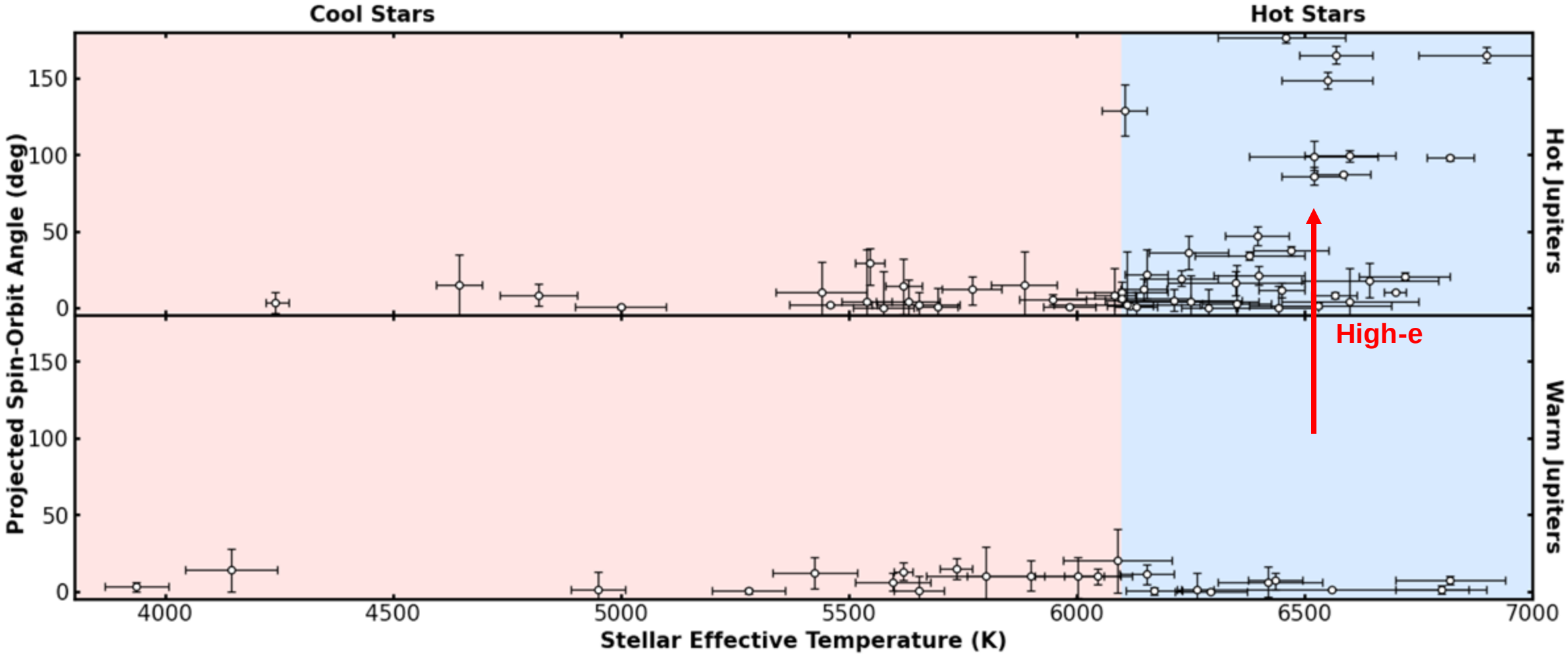


Hot Jupiter: Low eccentricity, High Obliquity

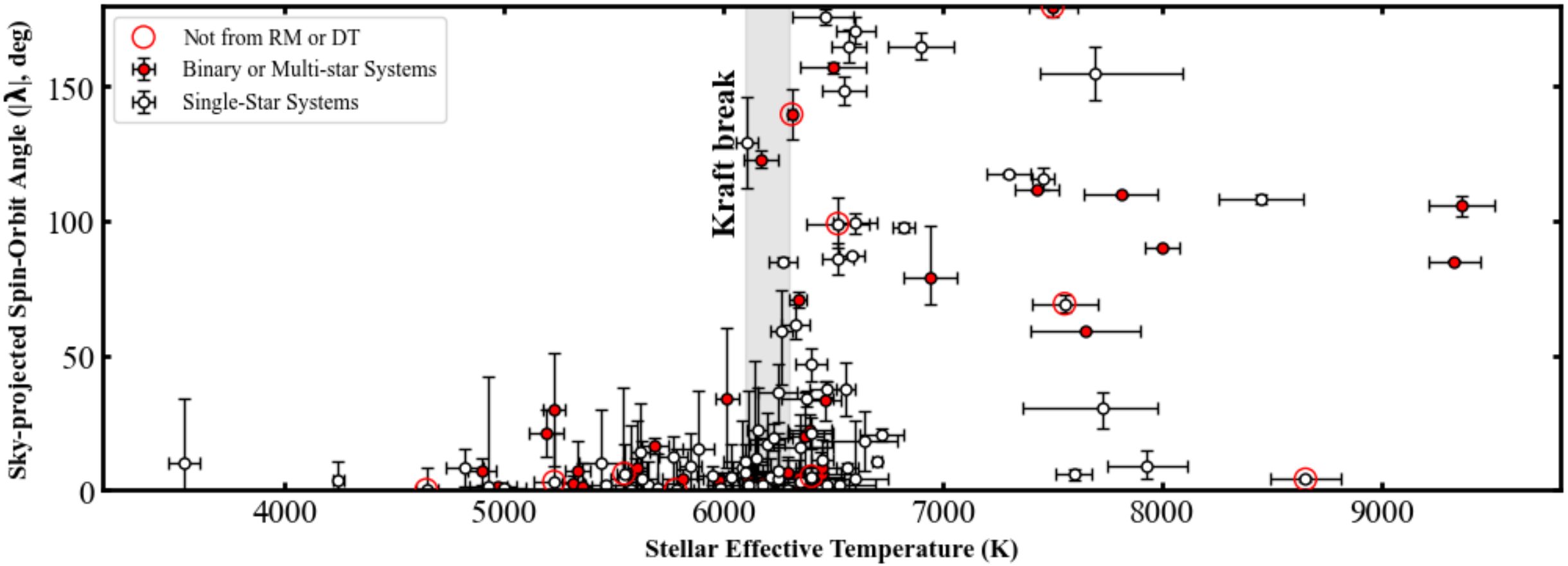


Espinoza-Retamal et al. (2025)

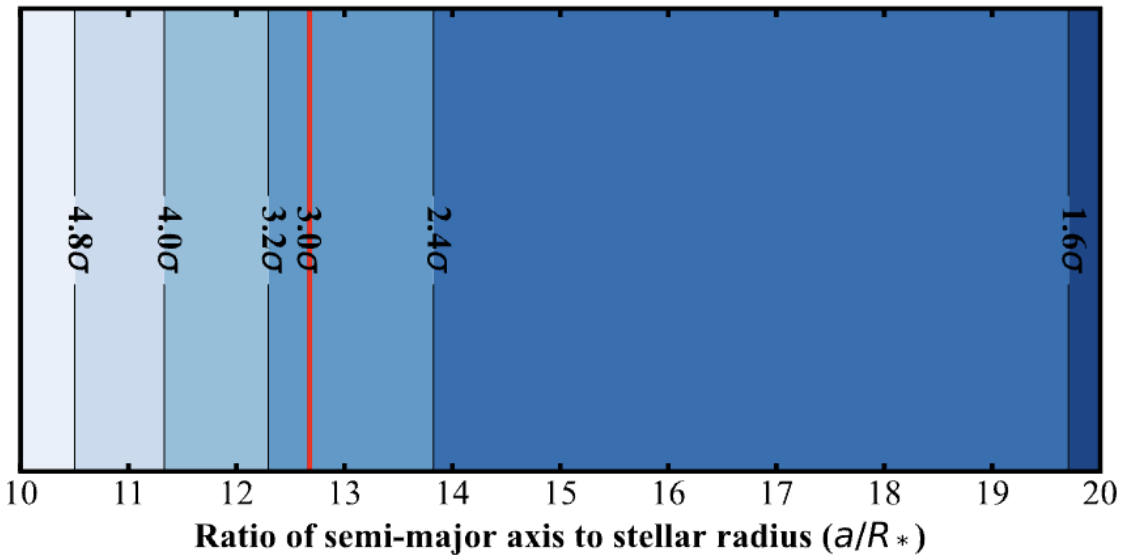
Warm Jupiters: Becoming Hot Jupiters before getting misaligned

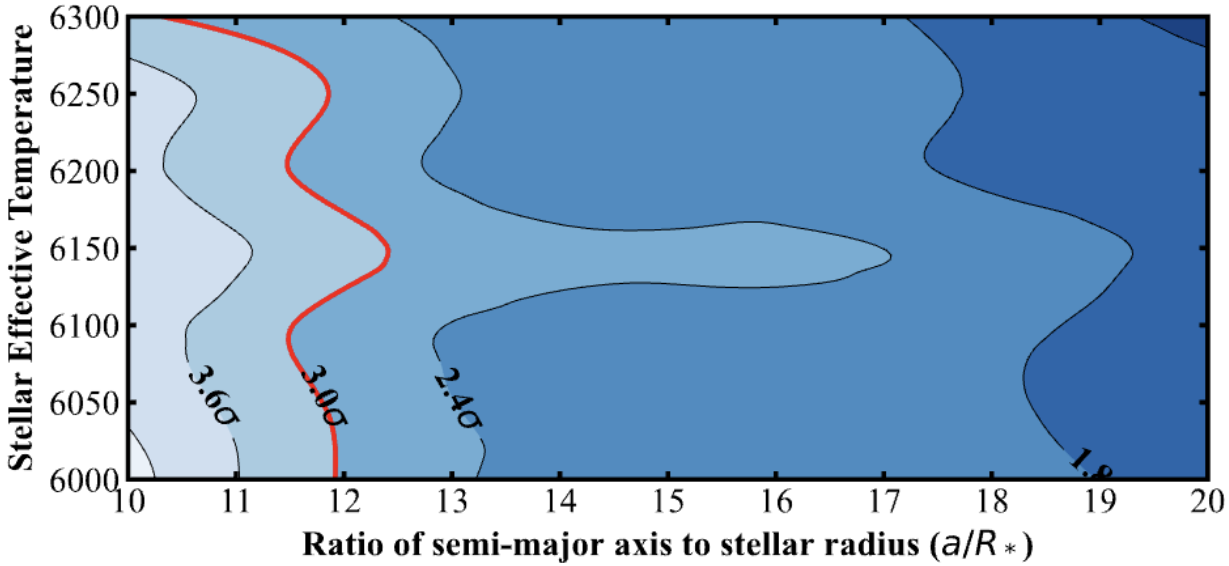


Binary and Multi-Star Systems make contribution to misalignment

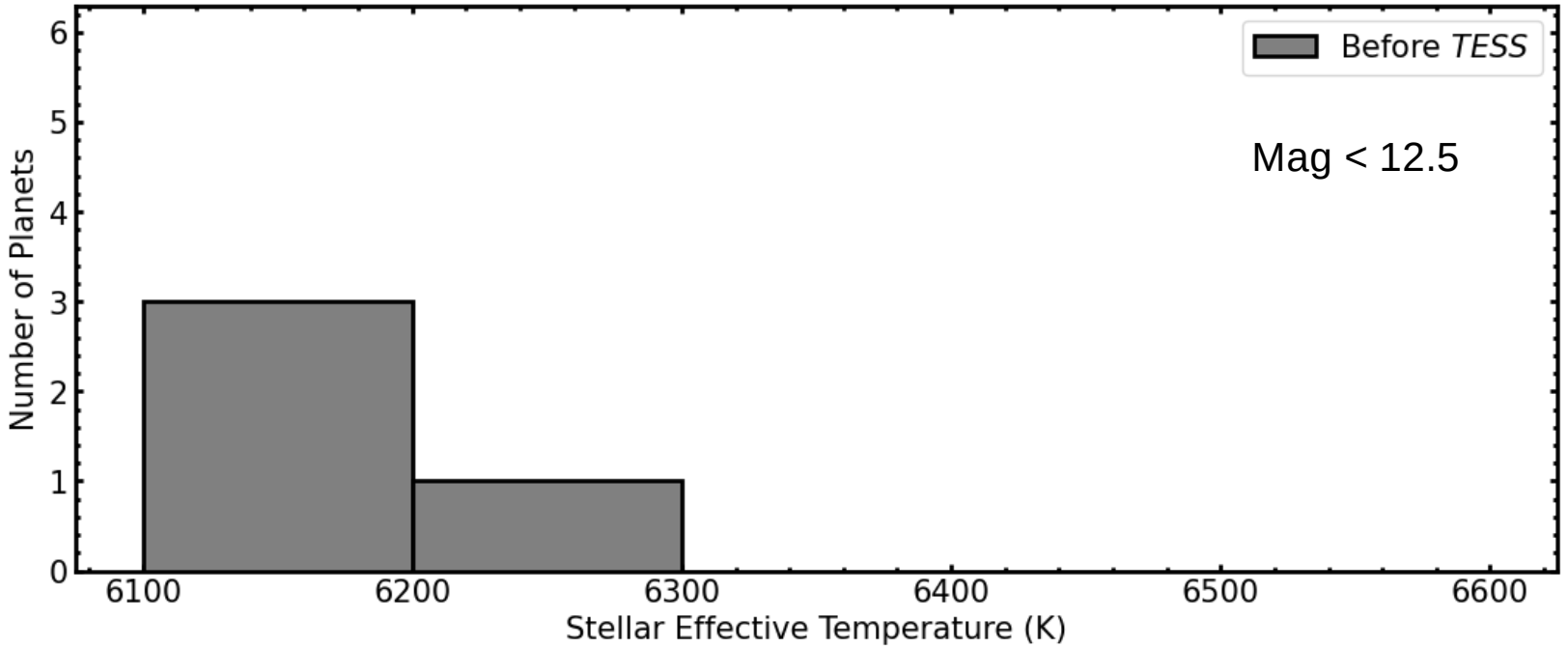


Significance level dependency on a/R$_*$ and T_{eff}

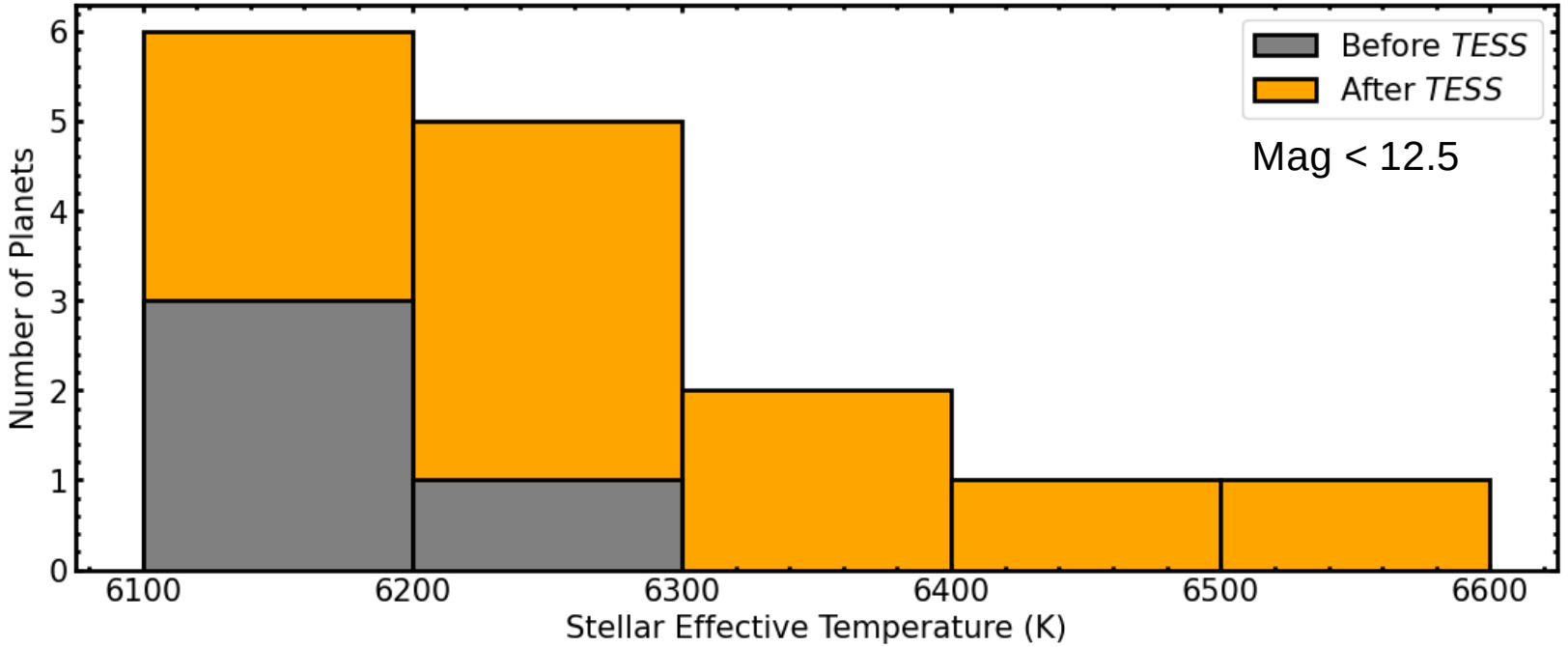




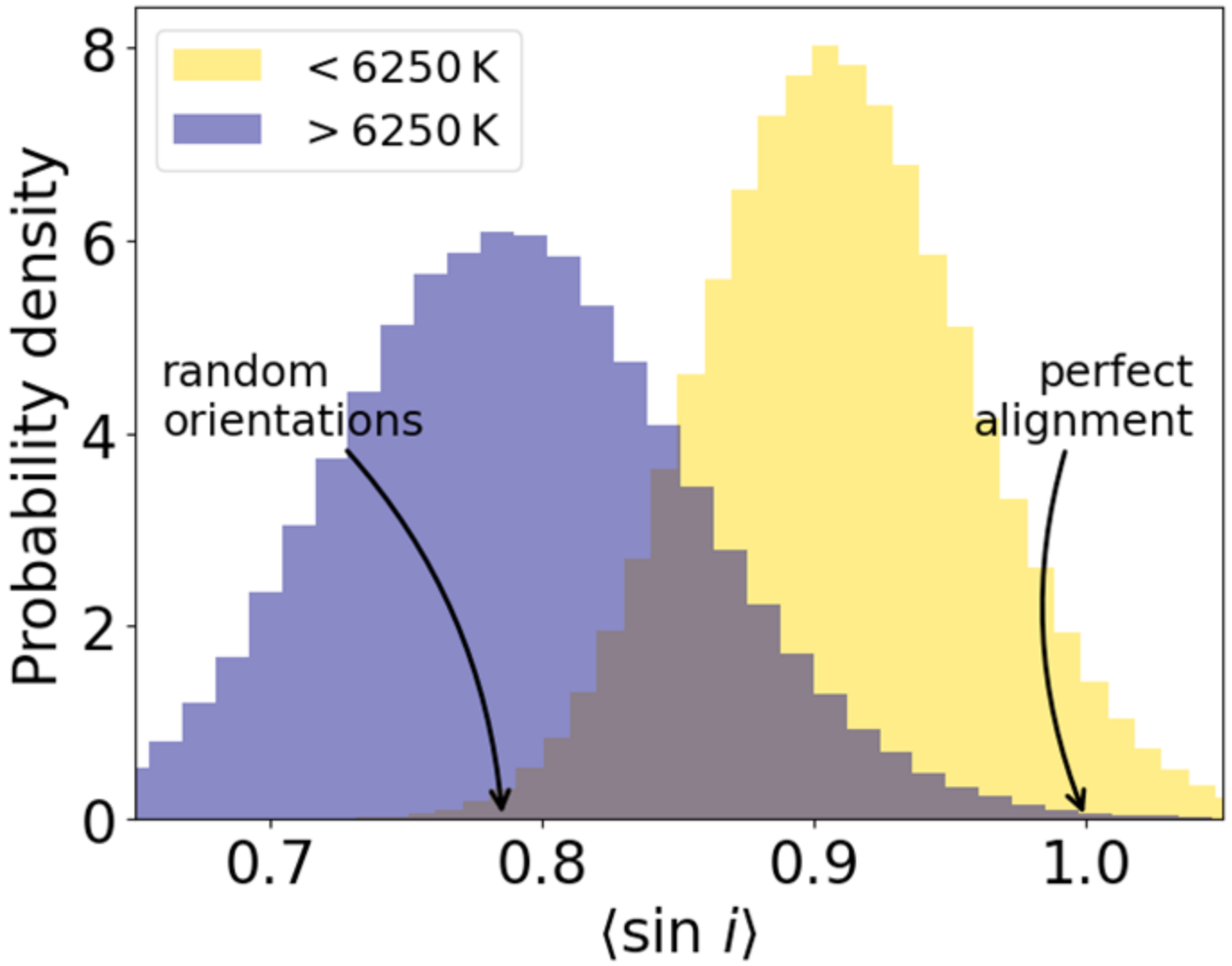
Only 5 Warm Jupiters around Hot Stars Systems before *TESS*



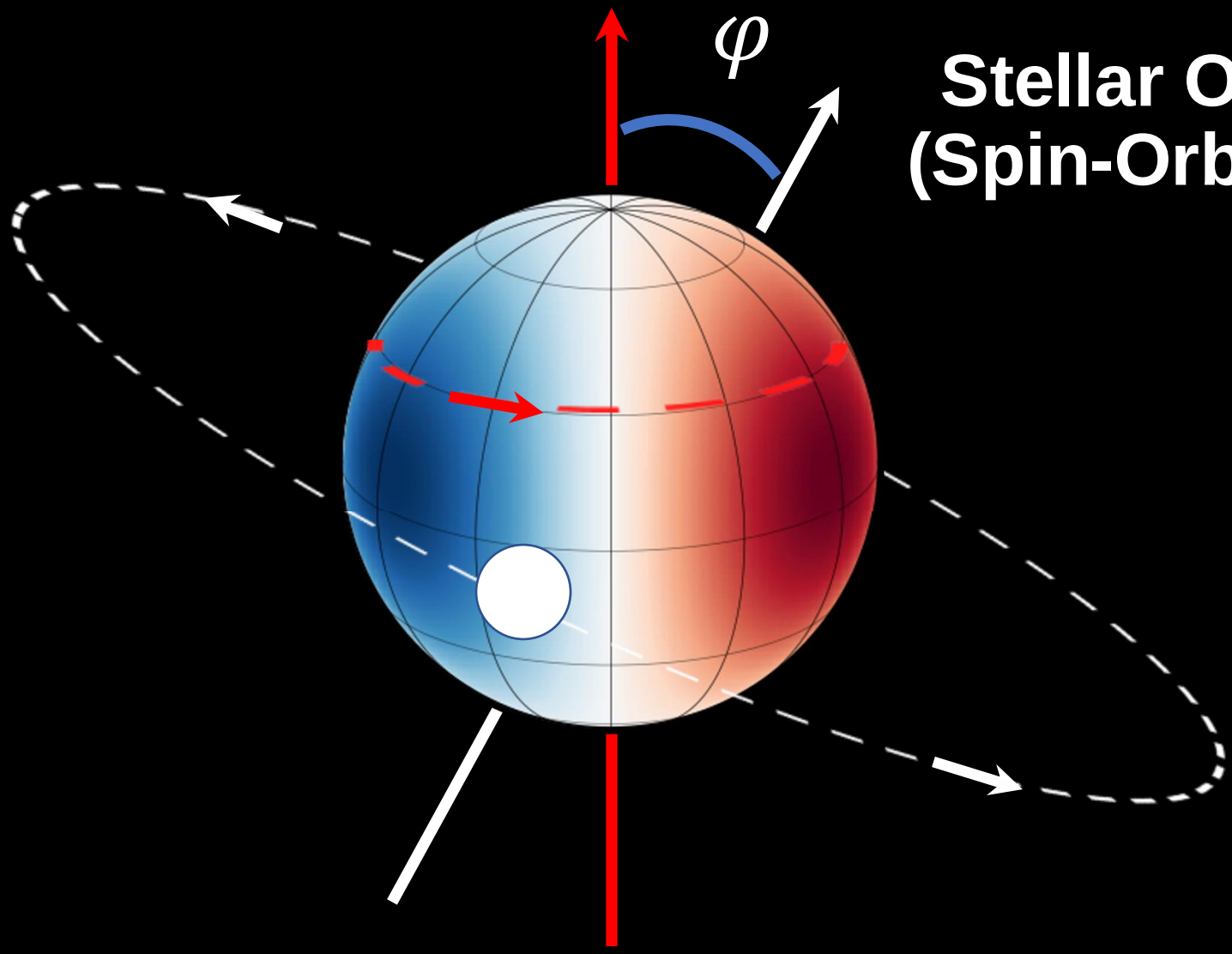
TESS Boosts the Warm Jupiters around Hot Stars Sample



One possible change of the picture in the future



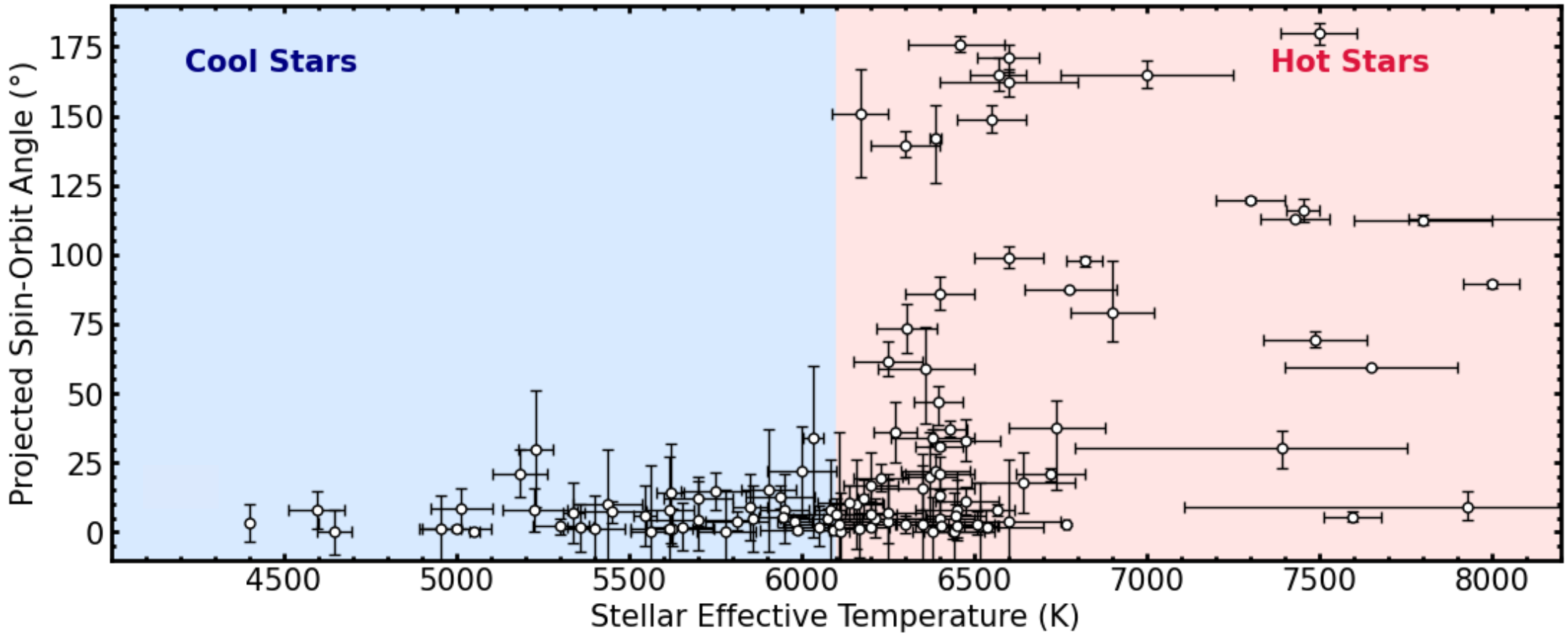
Louden et al. (2024)



Stellar Obliquity (Spin-Orbit Angle)

Tidal Realignment? OR Dynamical excitation?

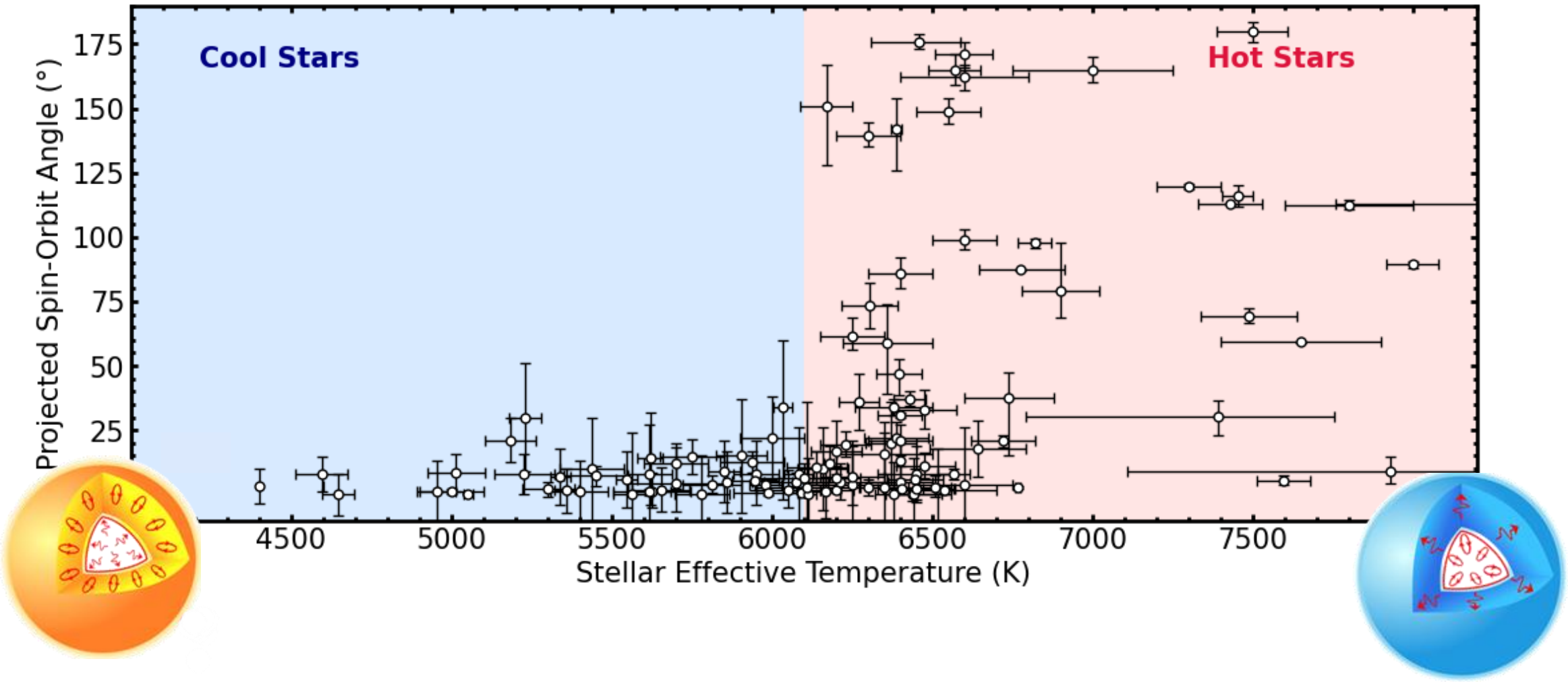
Kraft Break
*T*eff ~ 6100 K



Winn et al. (2010), Schlaughman 2010

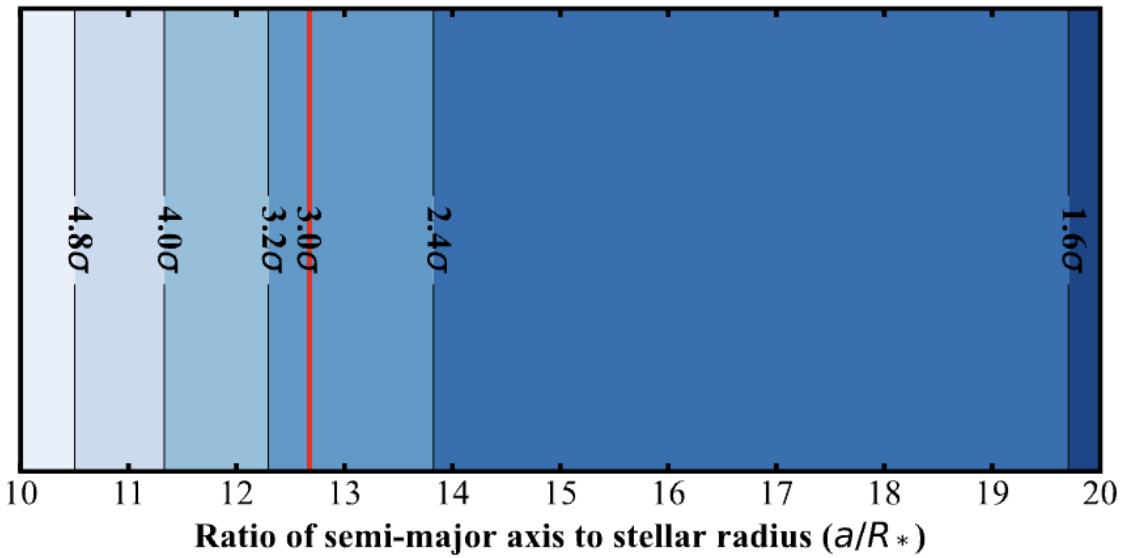
Hot Stars with Hot Jupiters Have High Obliquities

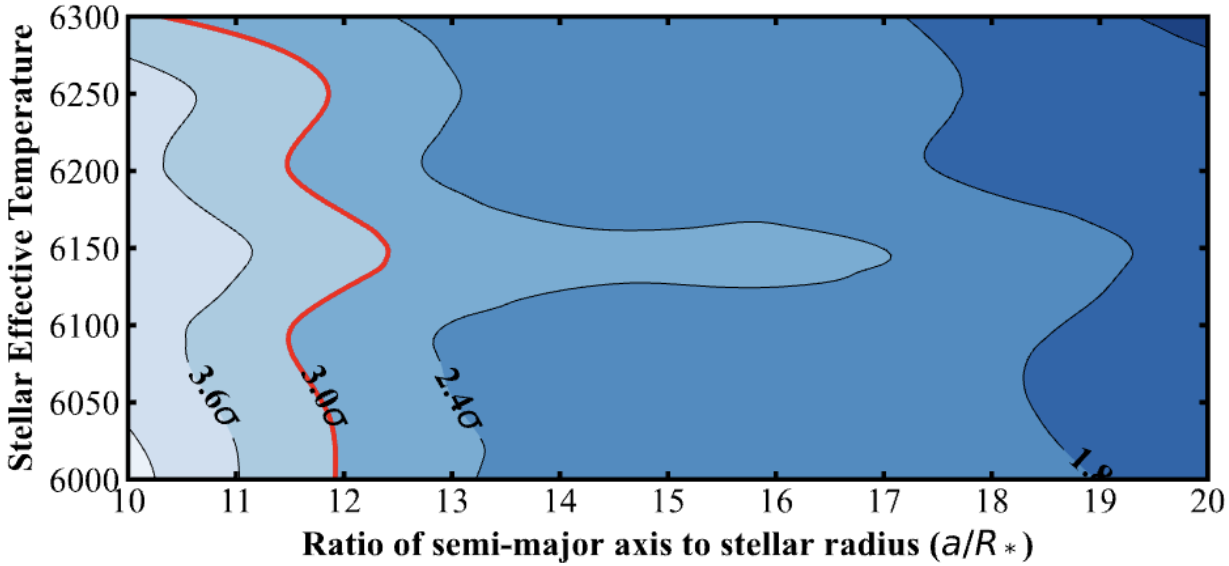
Kraft Break
*T*eff ~ 6100 K



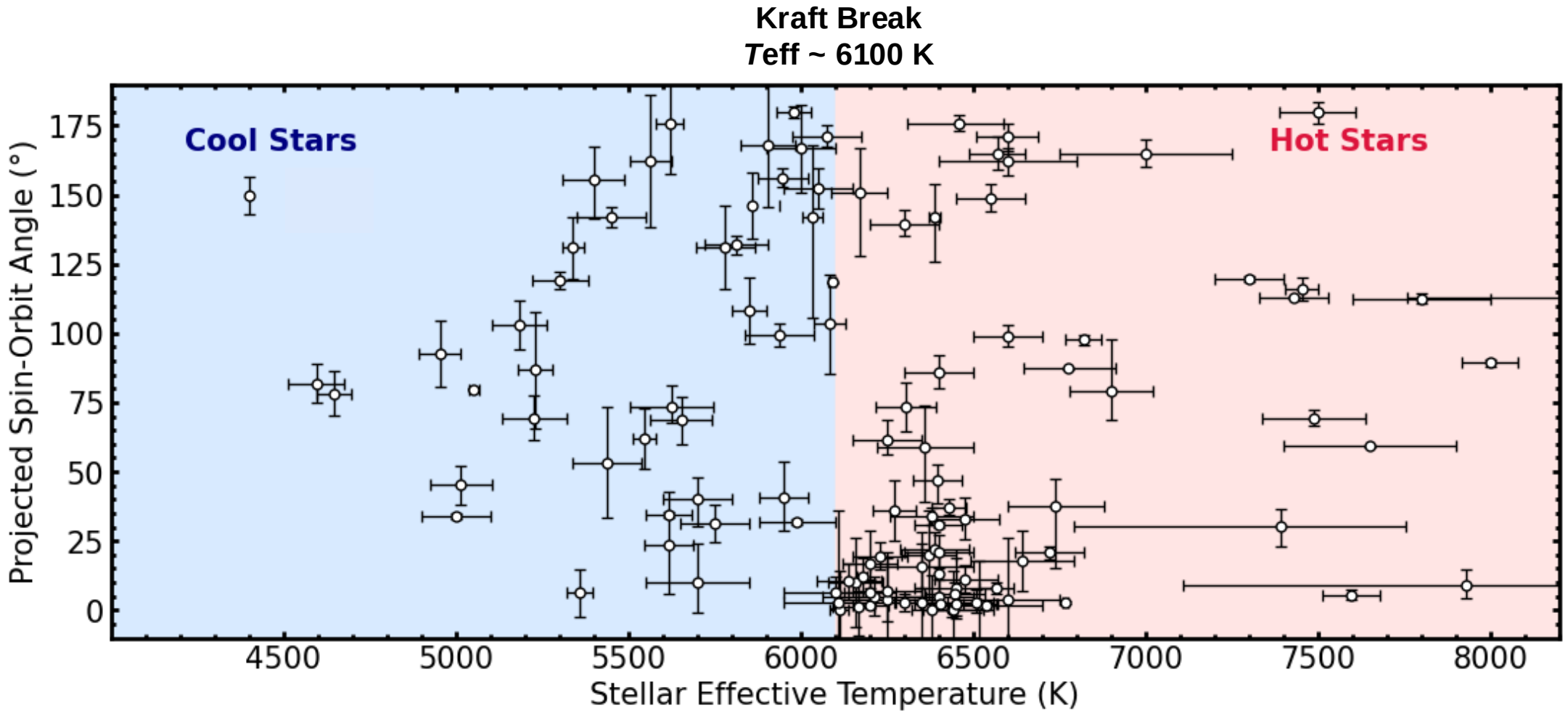
Winn et al. (2010), Schlaughman 2010

Significance level dependency on a/R$_*$ and T_{eff}





Universal Misalignment for Cool and Hot Stars



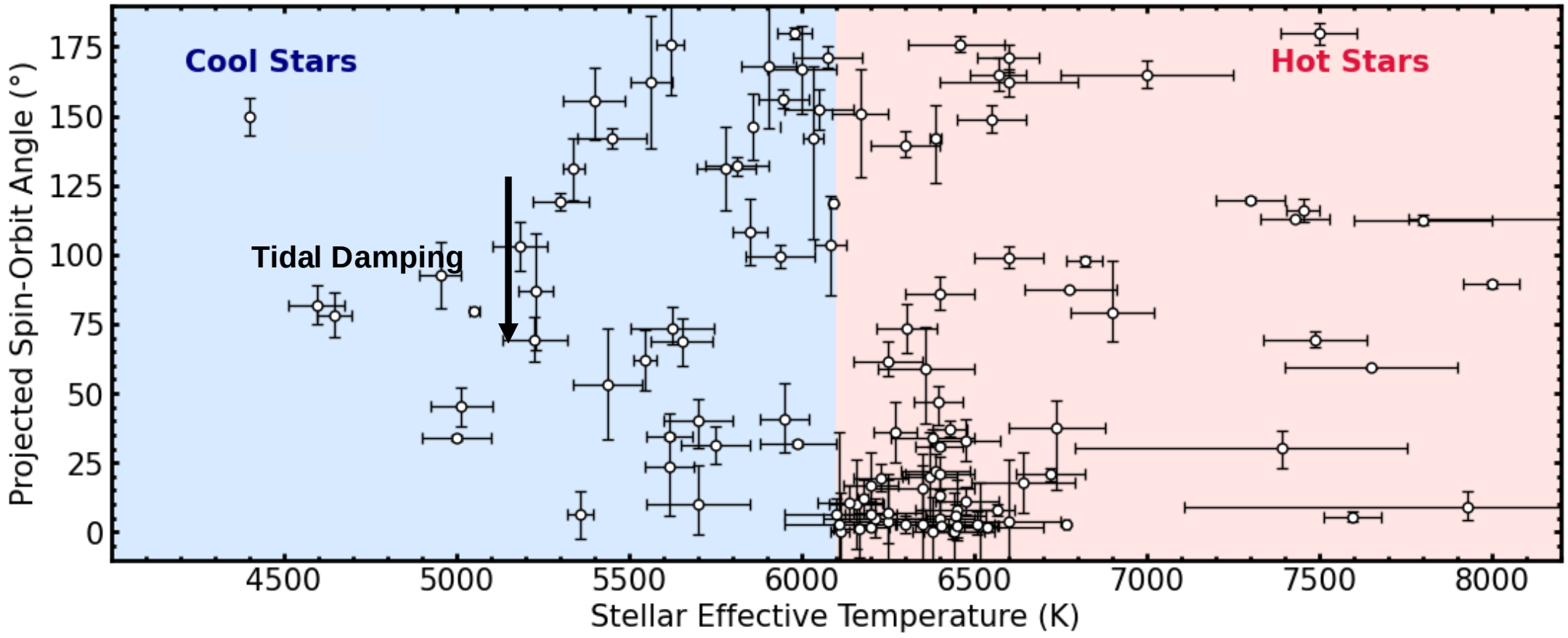
Winn et al. (2010), Schlaufman 2010

Tidal Damping Realigned Hot Jupiters with Cool Stars Systems

Thick Convective Zone

Kraft Break
***T*eff ~ 6100 K**

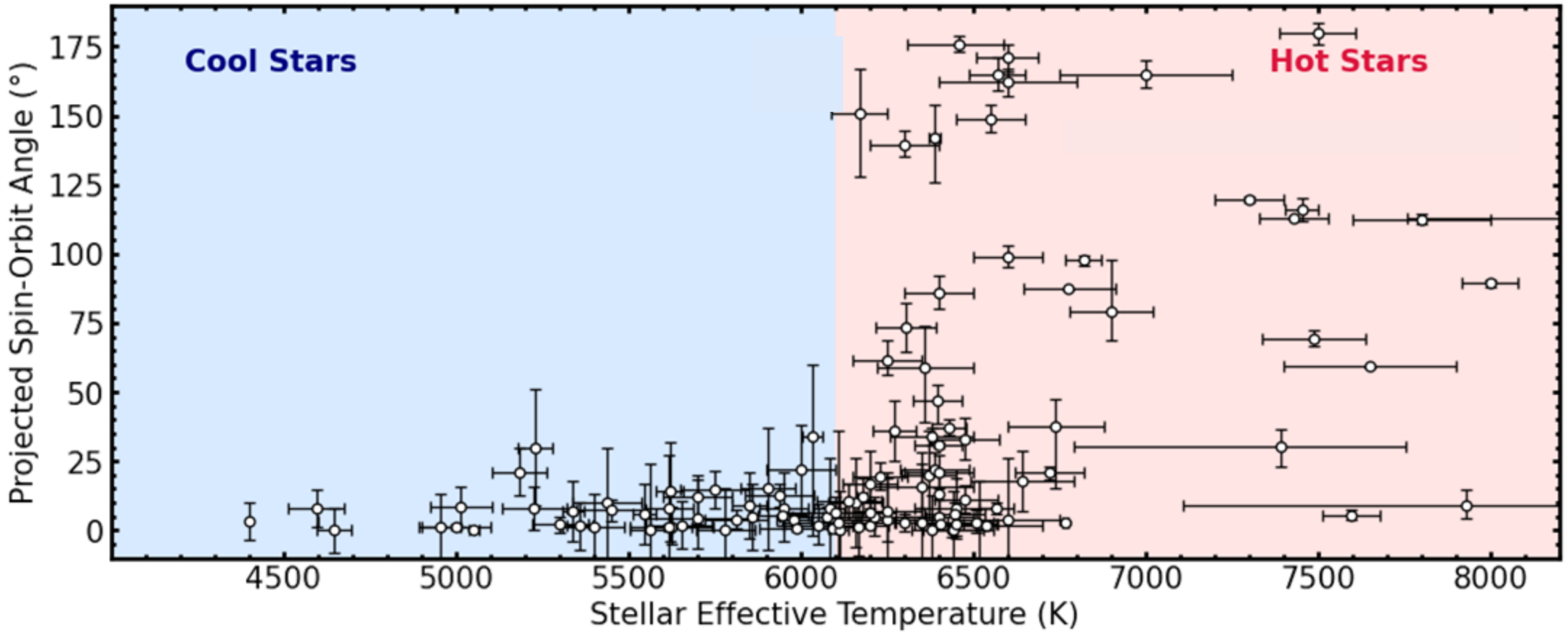
Fully Radiative



Winn et al. (2010), Schlaufman 2010

Tidal Damping Realigned Hot Jupiters with Cool Stars Systems

Kraft Break
***T*eff ~ 6100 K**



Winn et al. (2010), Schlaufman 2010

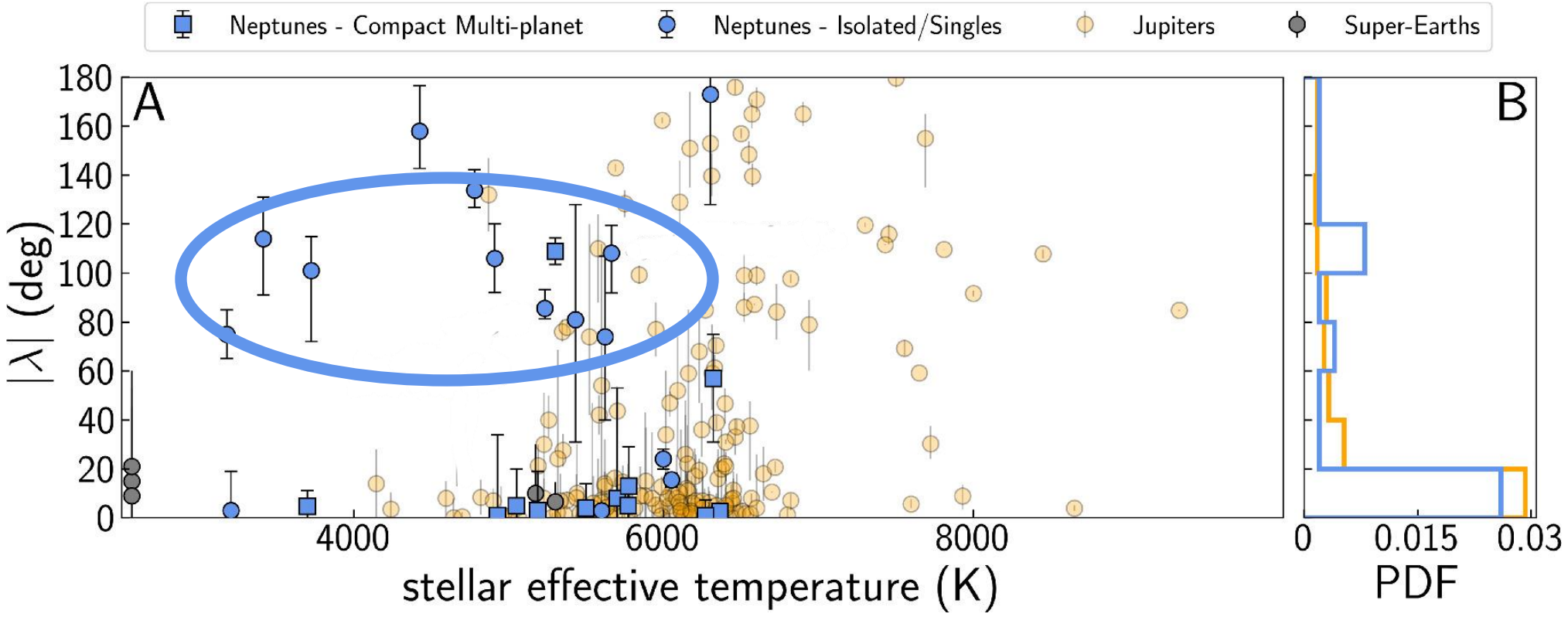
$$\cos\psi = \cos i_* \cos i + \sin i_* \sin i \cos\lambda$$

i : Orbital Inclination ← Transit and Astrometry

i_* : Stellar Inclination ← Vsini + Stellar potation period

λ : Projected spin-orbit angle ← RM, AS, SC, GD, and etc.

SubSaturn: Misaligned, Polar, and Eccentric



Disk-driven Resonance

1.Inclination Excitation Phase: A nodal secular resonance increases the inclination until it reaches a critical threshold.

2.Eccentric Instability & Resonance Detuning: At the critical inclination, a linear eccentric instability disrupts the resonance, stopping further inclination growth. General relativistic precession raises this critical inclination, making polar orbits a post-Newtonian effect.

Petrovich et al. (2020)

Tidal Heating & Kozai

1: Rapid orbit changes due to Kozai oscillations.

2: As tidal heating **triples** the planet's radius, resulting in even stronger tides and suppresses the Kozai effect.

3: Once suppressed, the planet's orbit precesses more slowly due to **tides and GR**, and there is also **slower circularization**.

Gao & Li (2025), in prep

More puffy, more misaligned