Results from the TESS-Keck Distant Giants Survey

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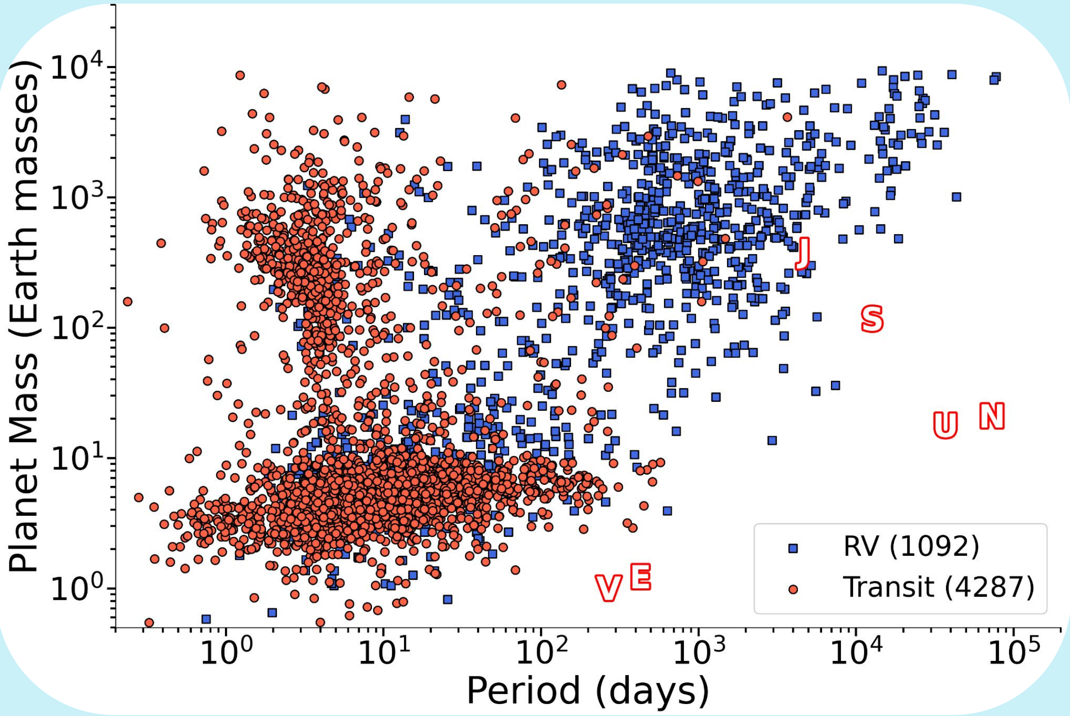
March 26, 2026

We have discovered ~6,000 planets, mostly with transits and RVs



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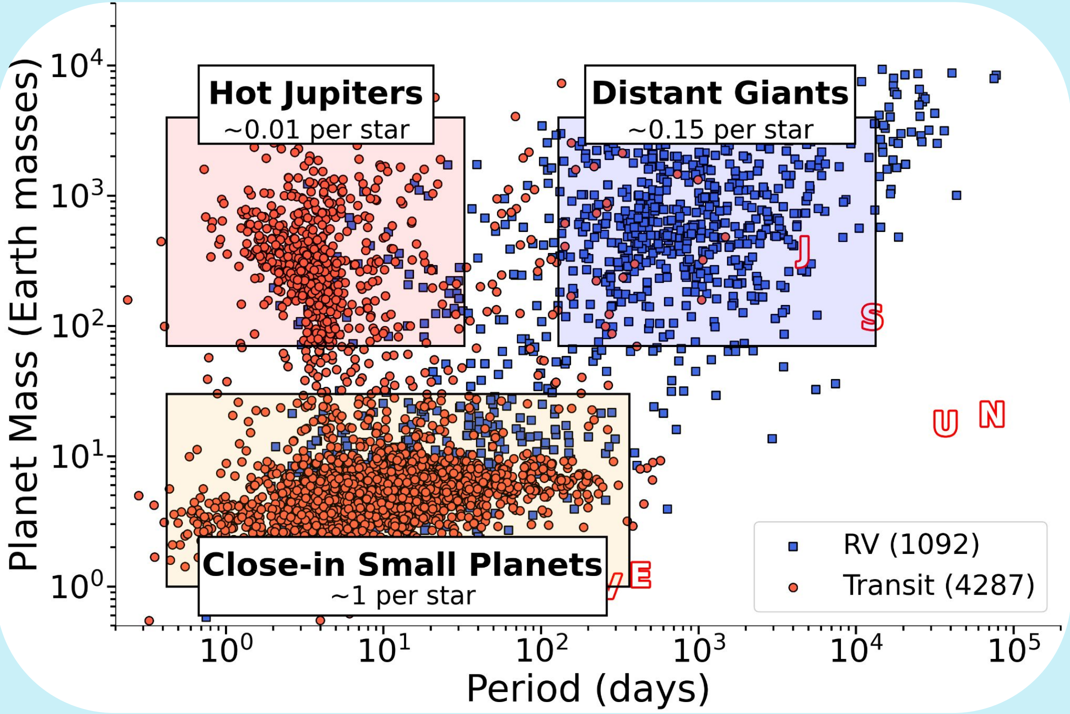

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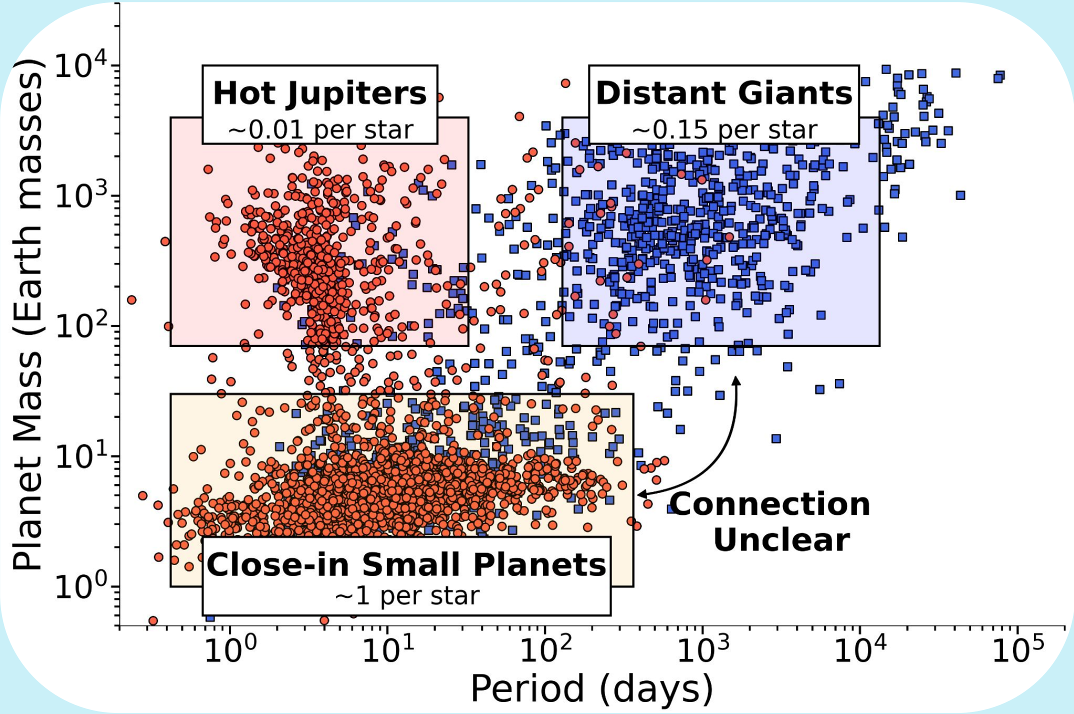


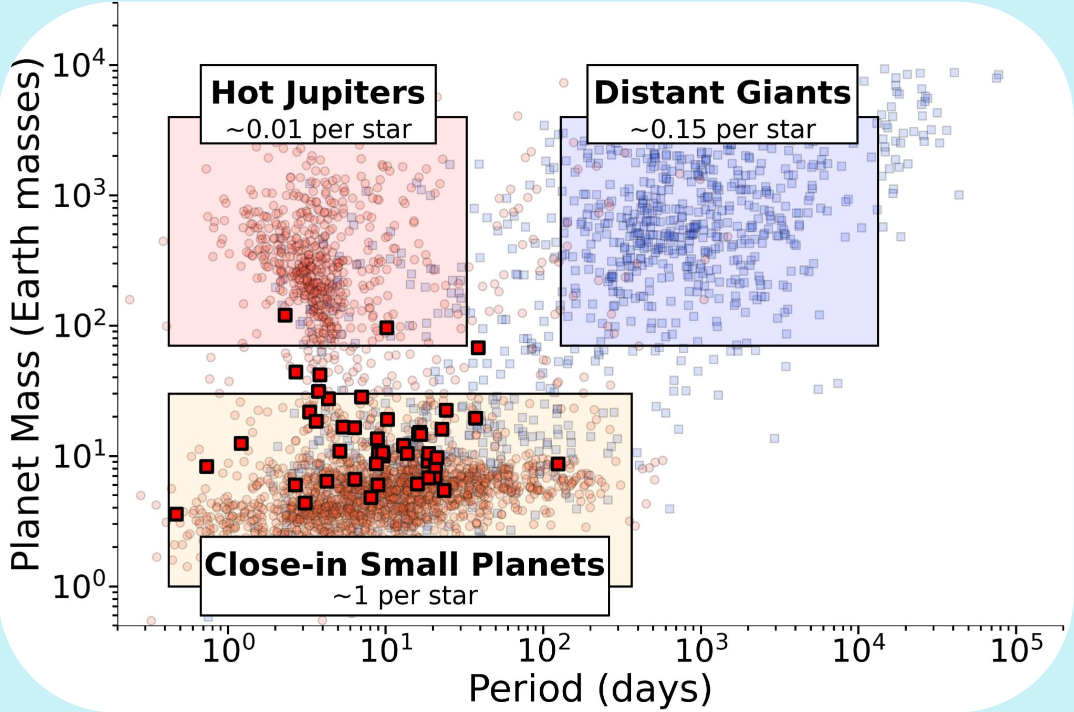
Key features of the TESS-Keck Distant Giants Survey

- High observational and sample purity
  - Three-year RV survey with Keck/HIRES and Lick/APF
  - Starting sample: 47 Sun-like TESS targets with a TOI
- Count both full ("resolved") orbits and trends to calculate statistics
- Include sensitivity maps to account for missed planets
- Goal: calculate P(DG|CS), the probability of DGs in systems with a CS
  - CS: transiting, $P<100$ d, $R_p<4\ R_E$
  - DG: a=1-10 AU, M=70-4000 M_E (<1 M_{Sat} - 13 M_{Jup})

1) The Distant Giants Survey: design, detections, and results
    - <u>Target selection function and observing strategy</u>
    - Full orbits and trends
    - Conditional occurrence: P(DG|CS)
2) Results and Comparison to Other Work
3) Future Directions

The Distant Giants Survey was designed to find giant companions

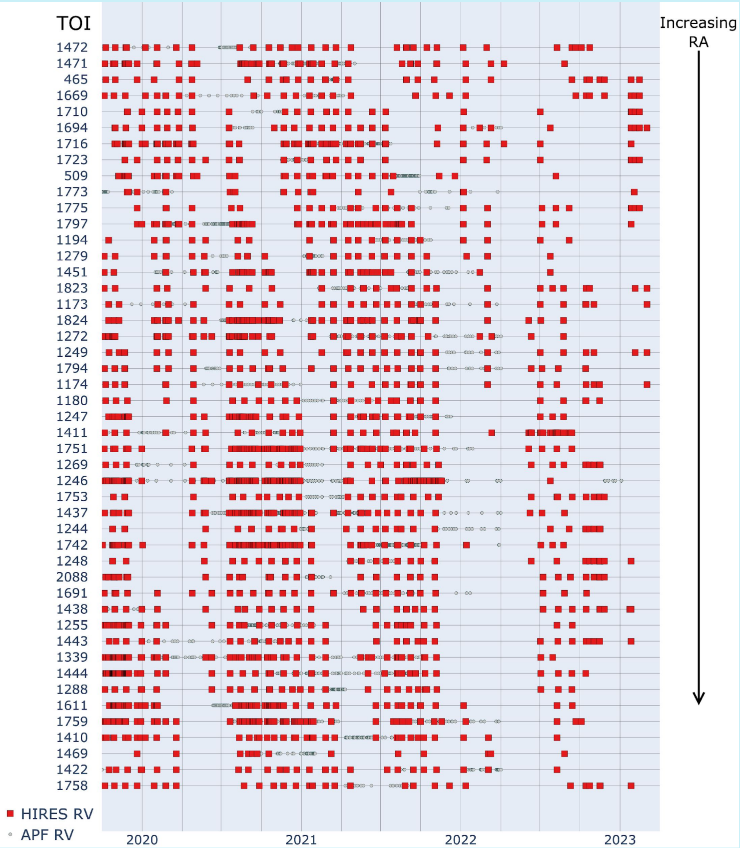
- 47 Sun-like *TESS* targets hosting at least one transiting planet
- Monthly RV observations over 3 years to look for giants



The Distant Giants Survey was designed to find giant companions

Results

- 3.5 year survey duration
- 4000+ RV observations(!)
- 2 m/s RV precision



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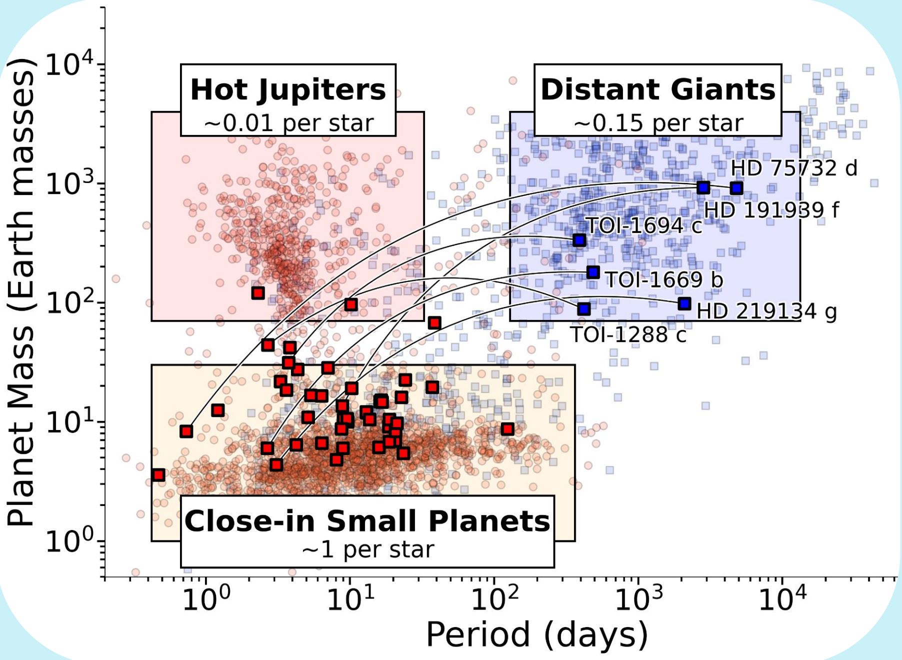
The Distant Giants Survey was designed to find giant companions

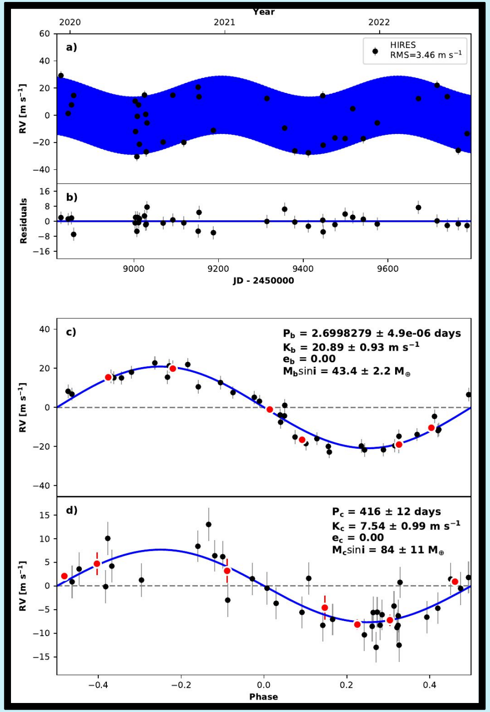
Results
- 3.5 year survey duration
- 4000+ RV observations(!)
- 2 m/s RV precision
- 4 new distant giants with full orbits
- 6 RV trends which could be planetary



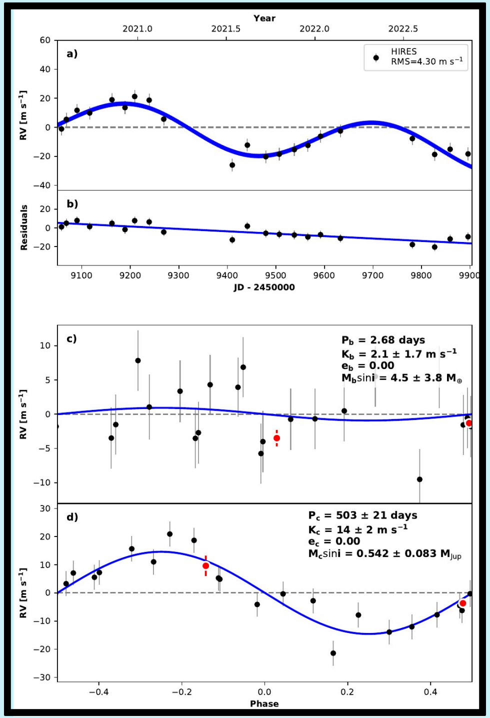
Van Zandt et al. (2023)

Three of the resolved giants have periods shorter than the survey baseline

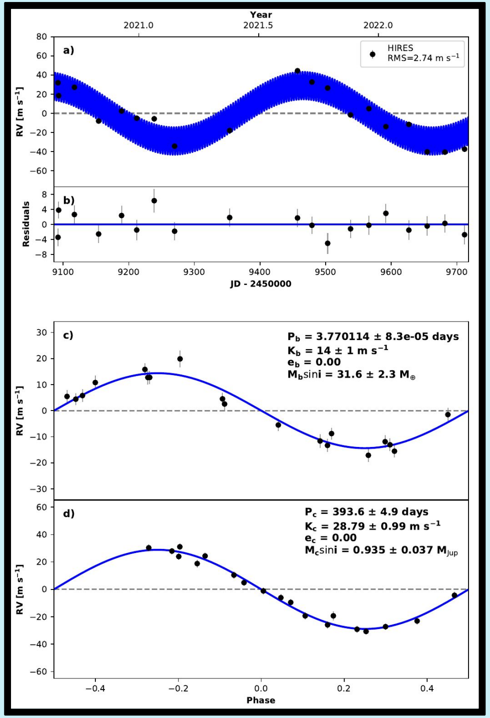
TOI-1288 (416 d)



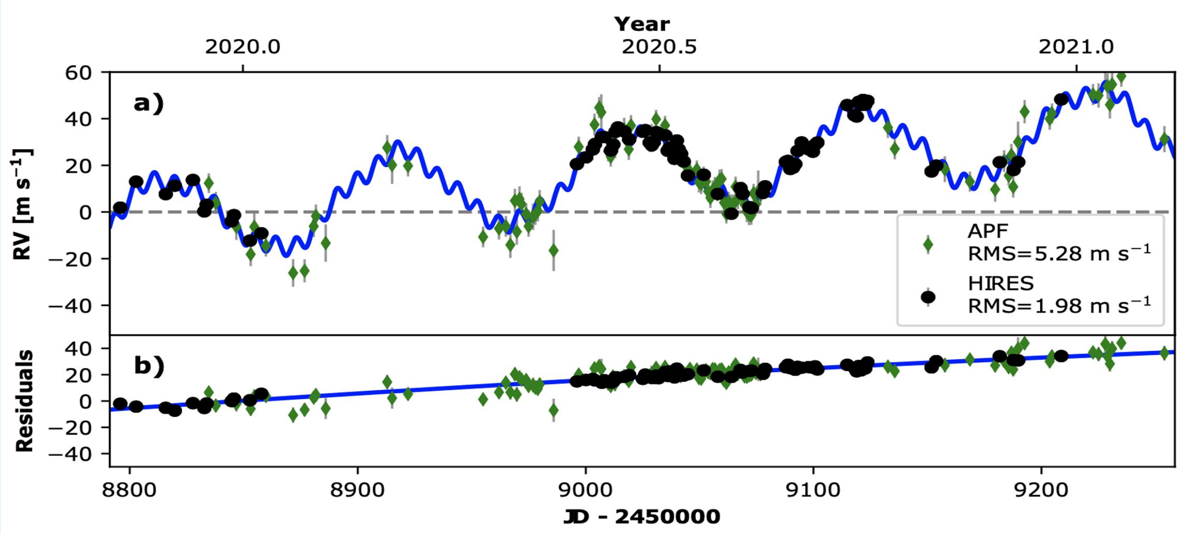
TOI-1669 (503 d)



TOI-1694 (394 d)

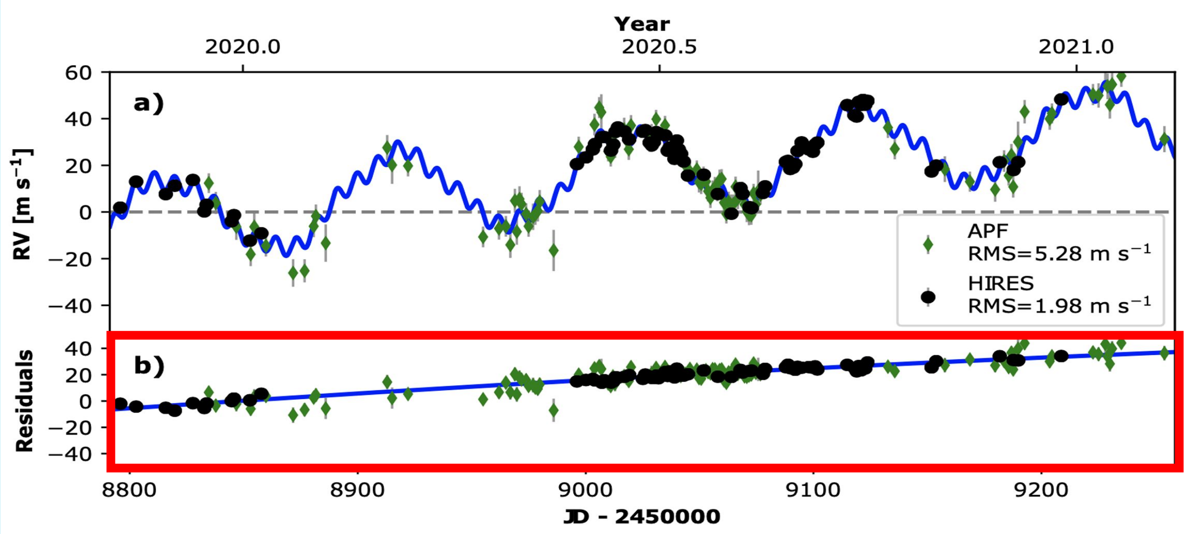


HD 191939 f was a trend in 2022



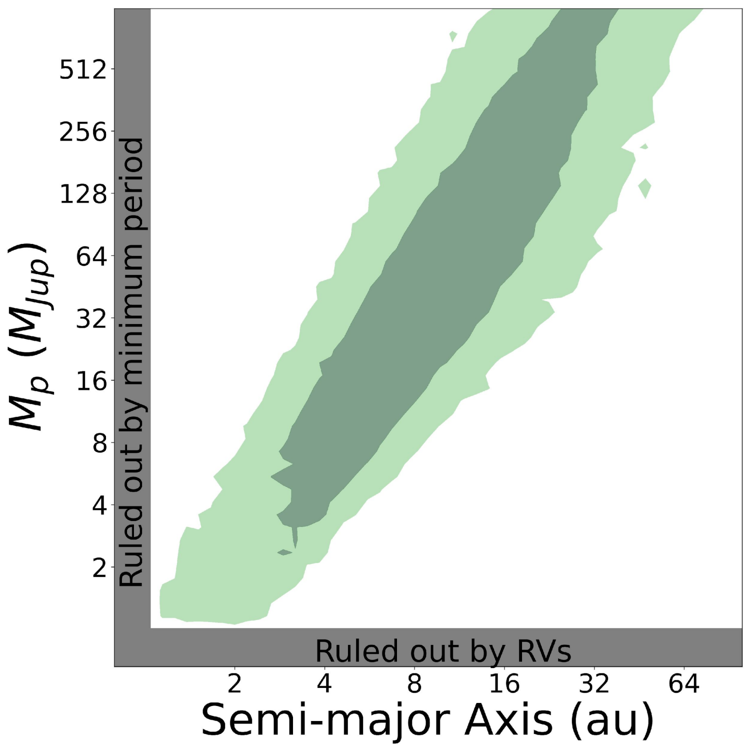
HD 191939 f was a trend in 2022

RV trends indicate a long-period companion, but can't constrain orbital elements.



RVs alone can narrow down companion properties

HD 191939

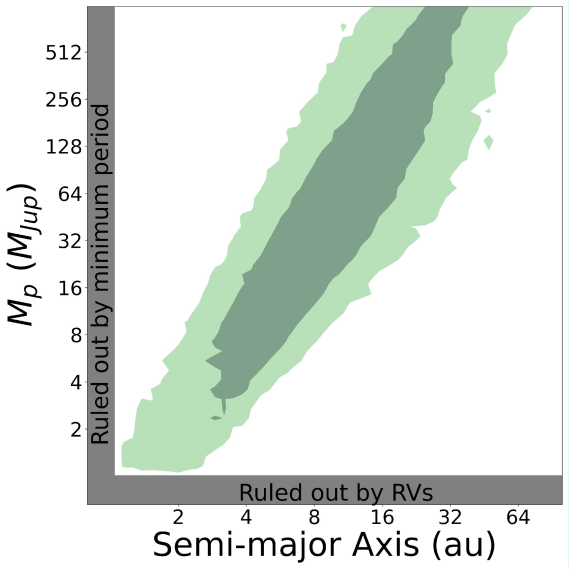


- Choose a set of model companion parameters
- Calculate the corresponding trend (and curvature)
- Compare to the measured trend/curvature values
- Repeat ~10^8 times

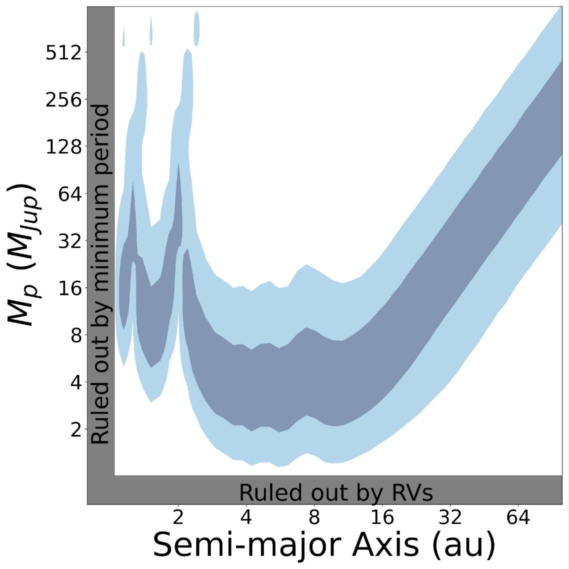
RVs and astrometry can give tight constraints

HD 191939

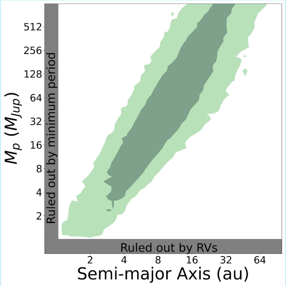
RV



Astrometry



RVs and astrometry can give tight constraints



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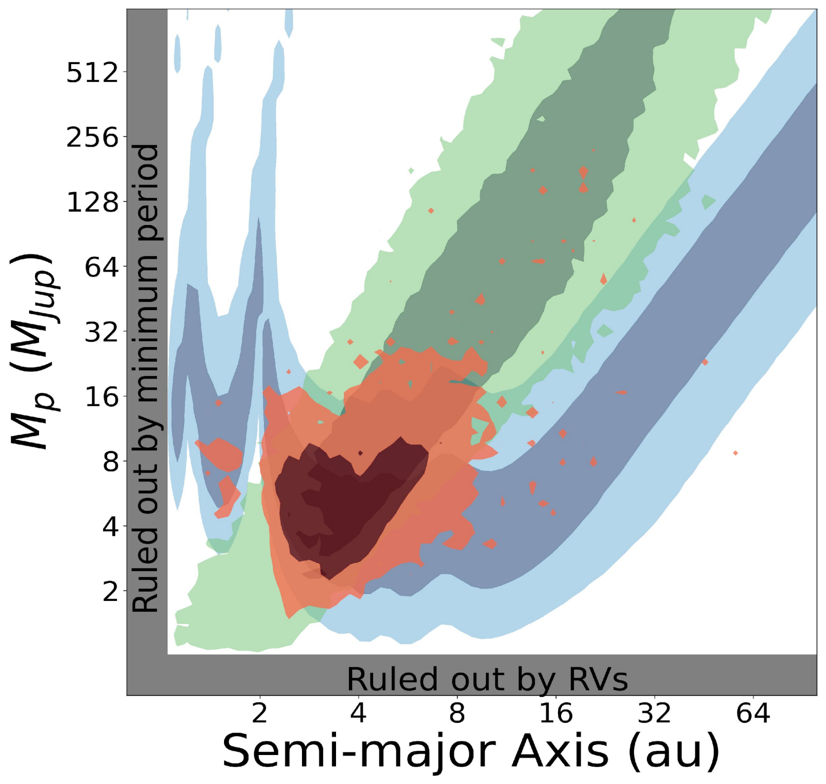
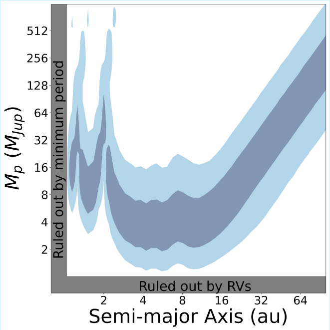
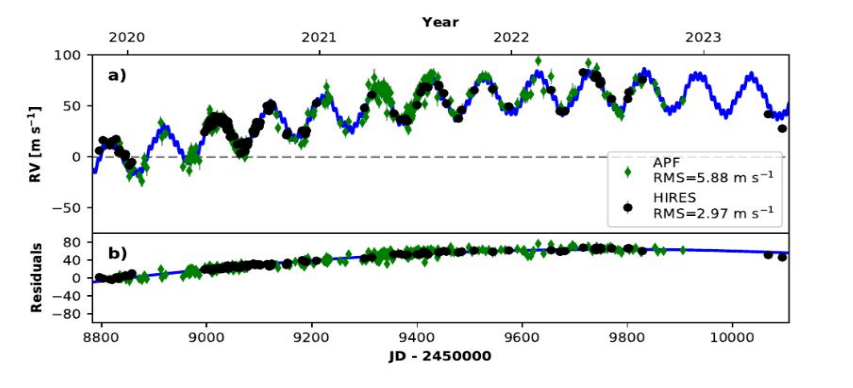


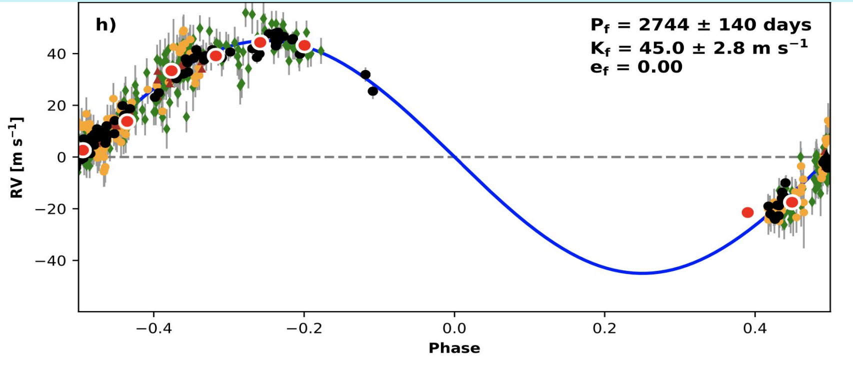


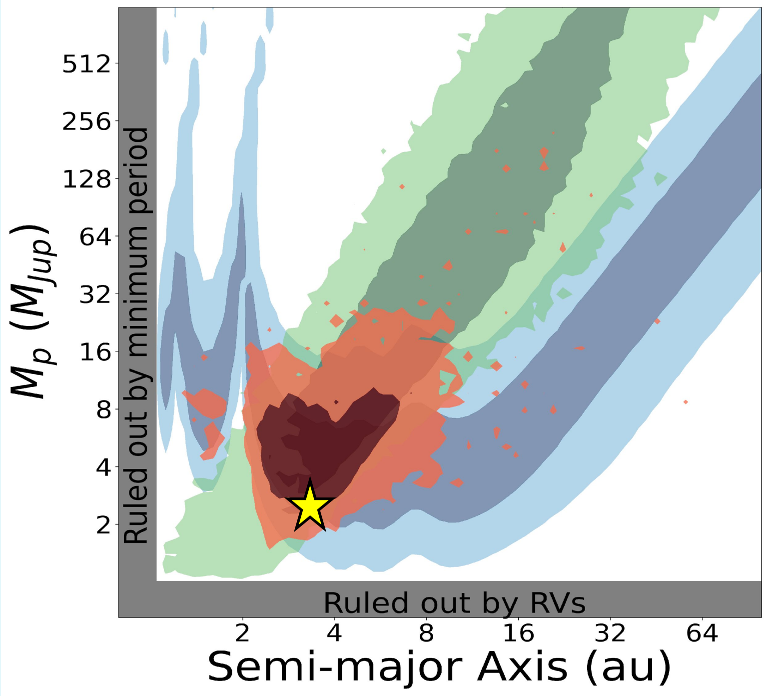
Super-Jupiter or low-mass brown dwarf at a few AU

Van Zandt et al. (2024a)

New RVs later confirmed our initial prediction





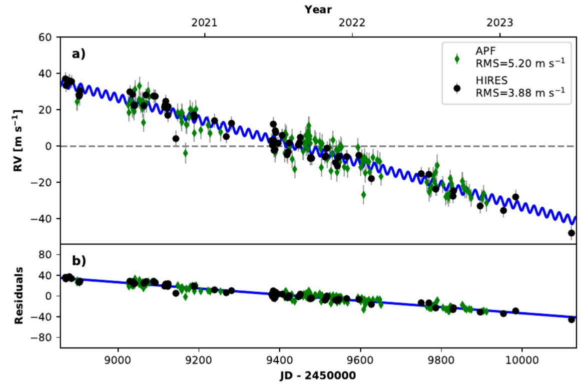


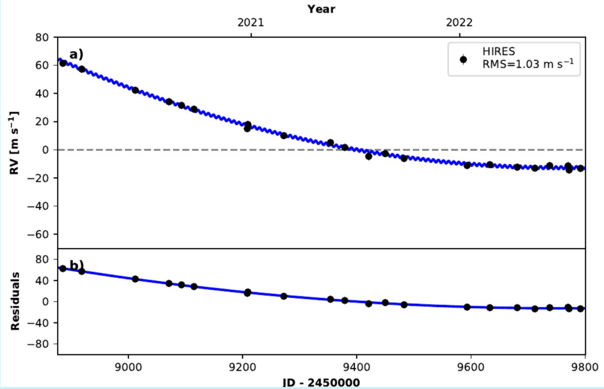
Lubin, Van Zandt, et al. (2022)

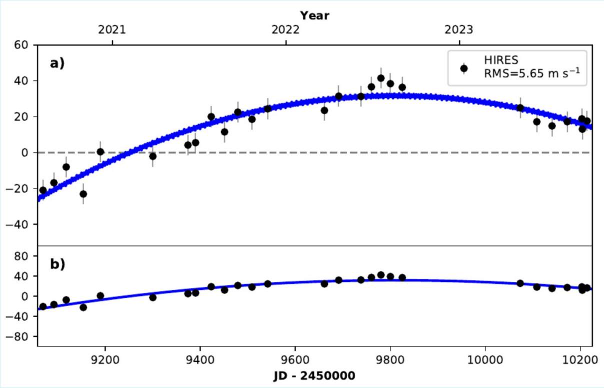
Lubin, Petigura, Van Zandt, et al. (2024)

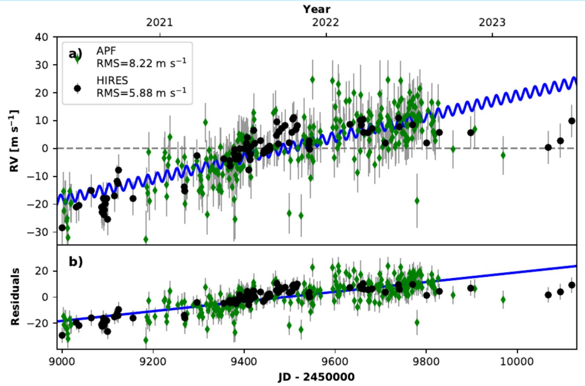
Using a 3-year survey to search for giant planets with P $\gtrsim$ 1 year, we expected to find a high fraction of trends

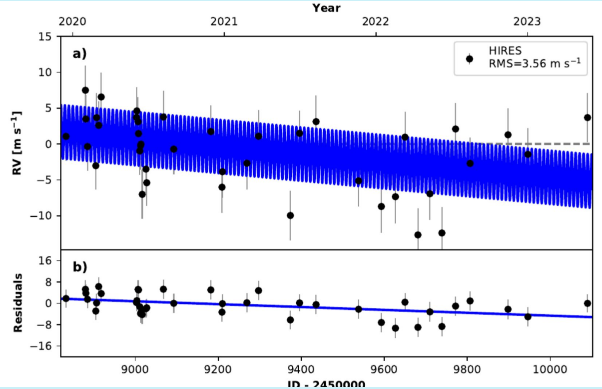
Using a 3-year survey to search for giant planets with P ≳ 1 year, we expected to find a high fraction of trends – and we did!

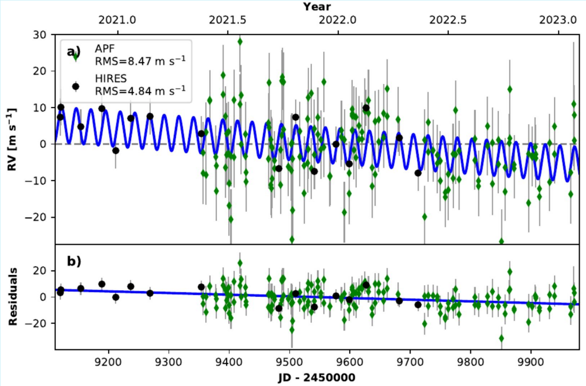






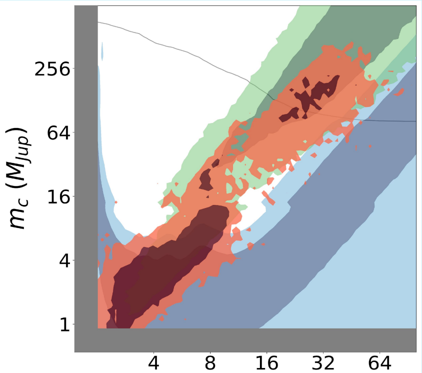




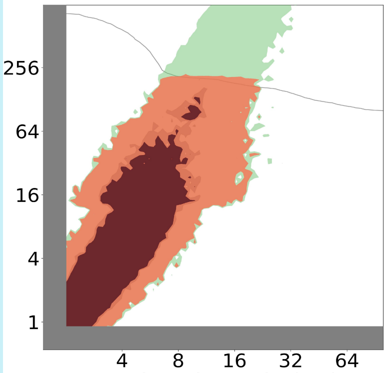


We found trends in 6 other systems

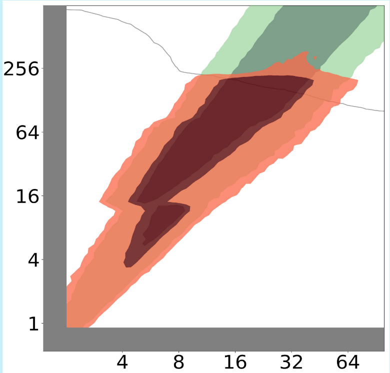
HD 12572



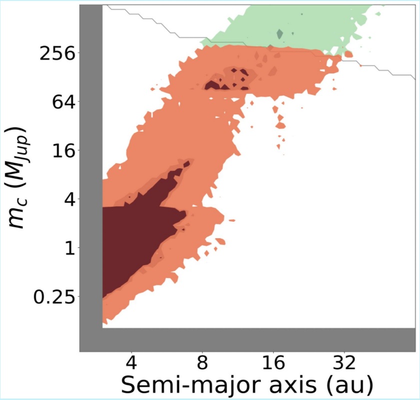
TOI-1174



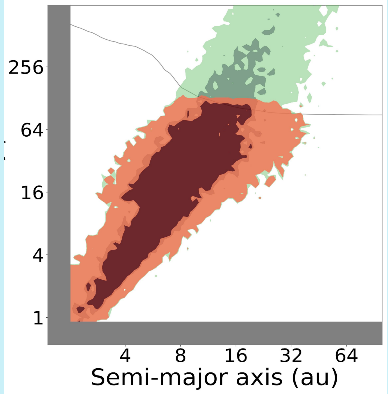
TOI-1438



HD 93963



HD 156141



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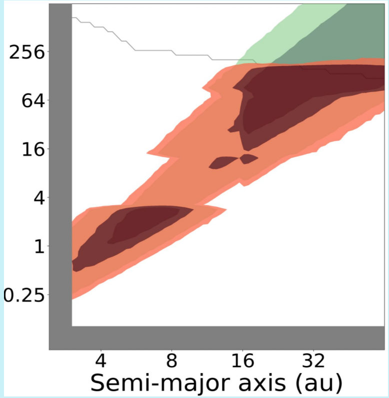

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    - Target selection function and observing strategy
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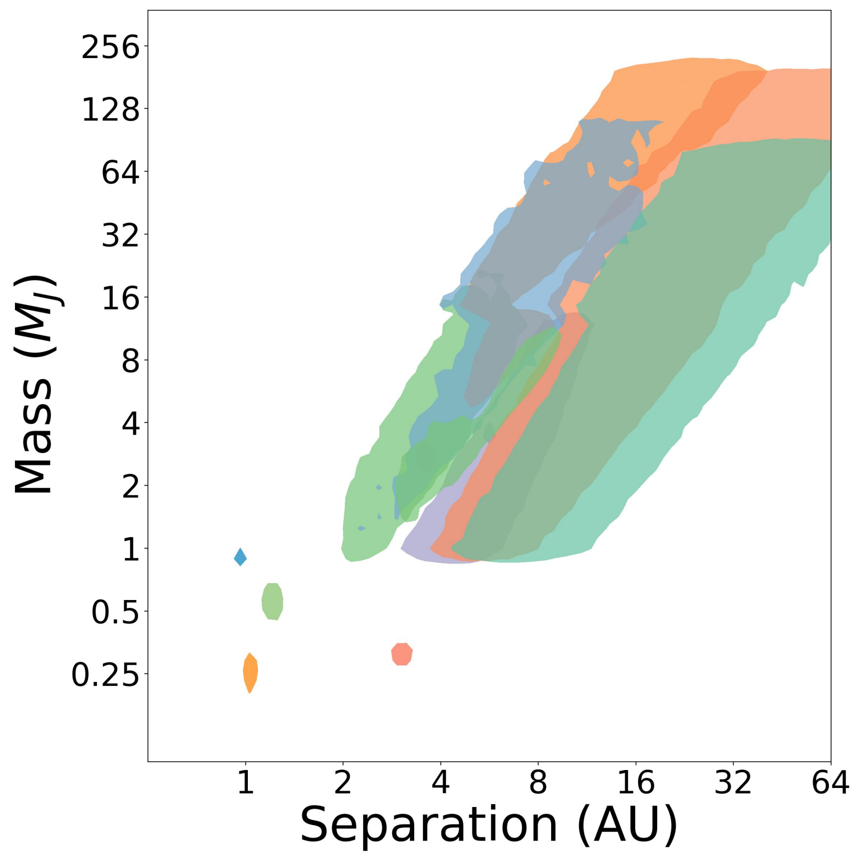
    - <u>Conditional occurrence: P(DG|CS)</u>
2) Results and Comparison to Other Work
3) Future Directions

Both trends and full orbits contribute to the P(DG|CS) measurement

- All posteriors can now be treated under the same framework



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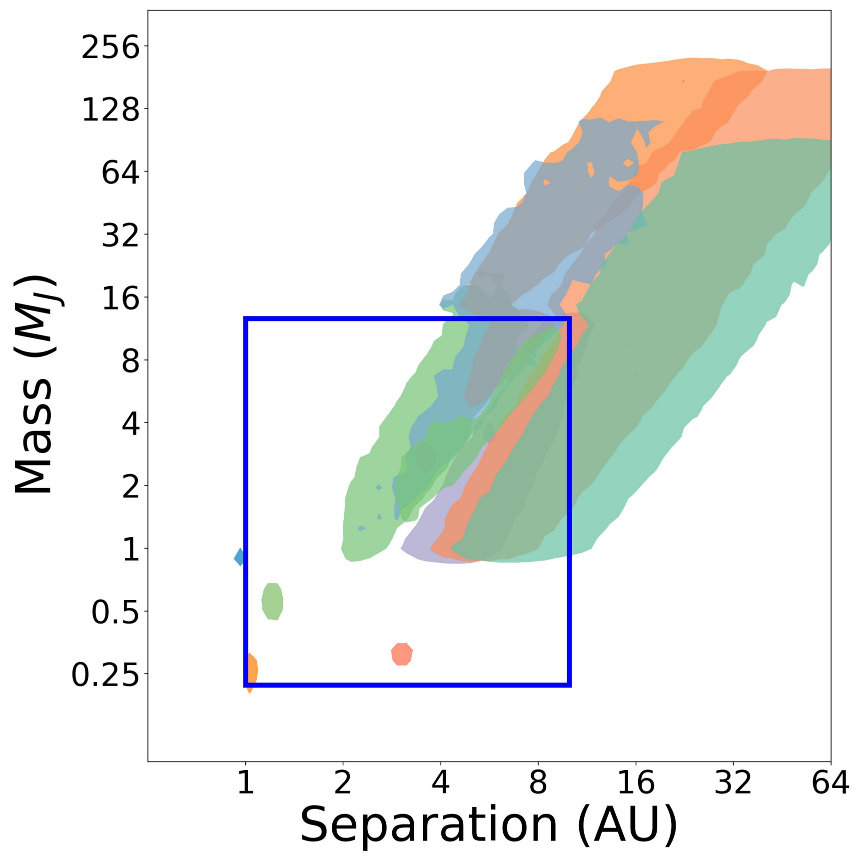
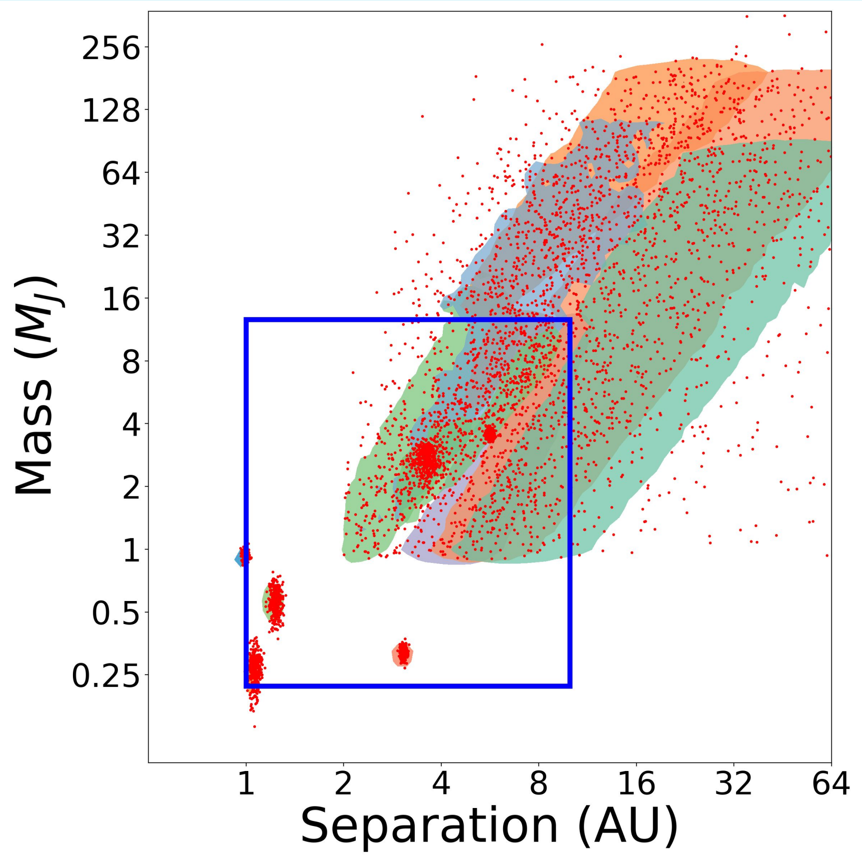
- Define the region over which we want to measure giant planet occurrence



Both trends and full orbits contribute to the P(DG|CS) measurement

- All posteriors can now be treated under the same framework
- Define the region over which we want to measure giant planet occurrence
- Count partial posteriors in proportion to their overlap with the region of interest



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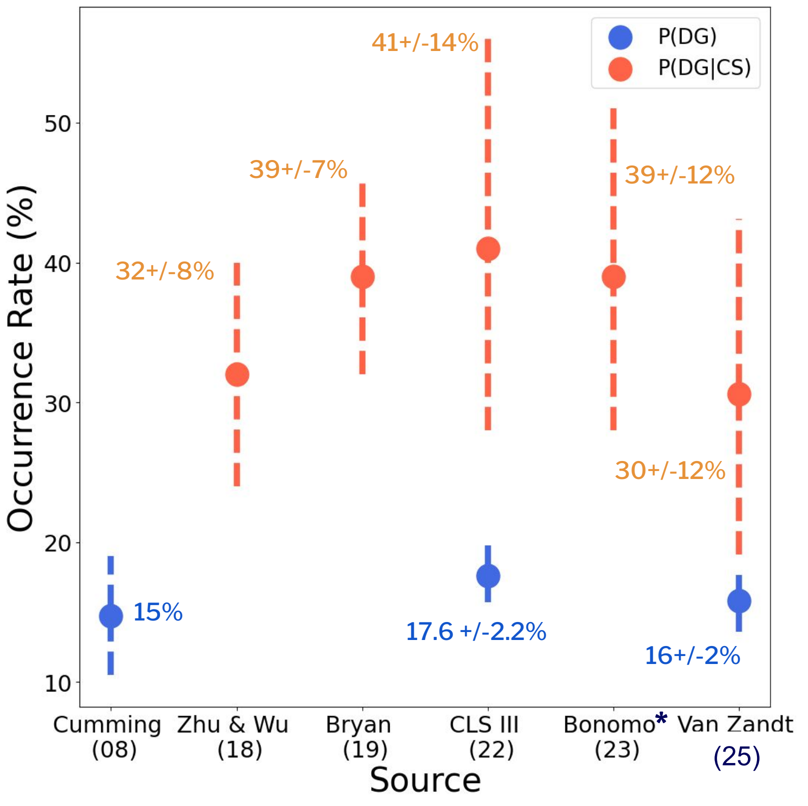
Distant giant occurrence rates by study

- Previous studies share similarities:
  - P(DG|CS) is larger than P(DG)
  - Sample sizes too small to measure P(DG|CS) precisely

- My results fit the same picture, but with a high-purity sample



Van Zandt et al. (2025)

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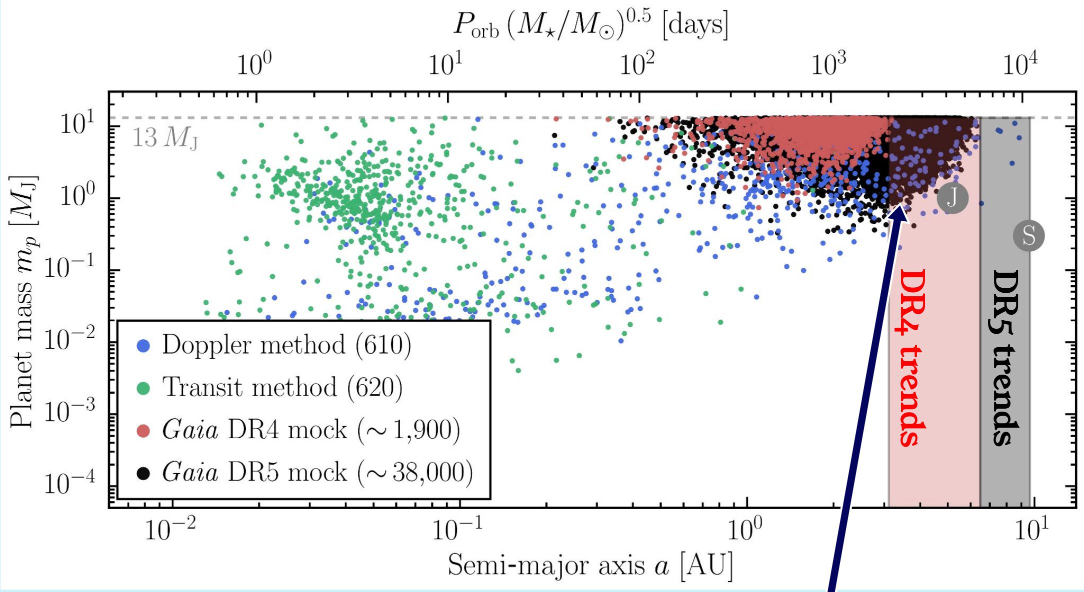
Gaia DR4 will give access to thousands of astrometric planets

- Lammers & Winn (2026) predictions:
  - 1900 DR4 planets (P<5.5 yr)
  - 38000 DR5 planets (P<15 yr)
- Including trend detections gives sensitivity to ~3x longer periods
  - With DR4, we can include trends from DR5
  - With DR5, we can go out to 30-year orbits
- Expanded sample will allow larger samples with cuts on stellar mass, metallicity, etc.
  - Bryan+24,25; Bonomo+25



Many DR5 planets will be trends in DR4

Adapted from Lammers & Winn (2026)

Key Takeaways

- Close-in small planets are known to be common, while outer giants are rarer
  - P(DG)~16%

- I conducted the Distant Giants Survey to measure the prevalence of distant giants in systems with a close-in small planet: P(DG|CS)
  - Key features: transit-only sample, trend analysis code, Poisson occurrence framework

- I measured P(DG|CS) to be ~30%, indicative of an enhancement over P(DG)

- Gaia DR4 will enable much more precise statistics, with ~1,900 planets and tens of thousands of trends in Dec. 2026

Supplemental

1) The Distant Giants Survey: design, detections, and results
    - Target selection function and observing strategy
    - Full orbits and trends
        - Informative mass prior for trend analysis
    - Conditional occurrence: P(DG|CS)
2) Results and Comparison to Other Work
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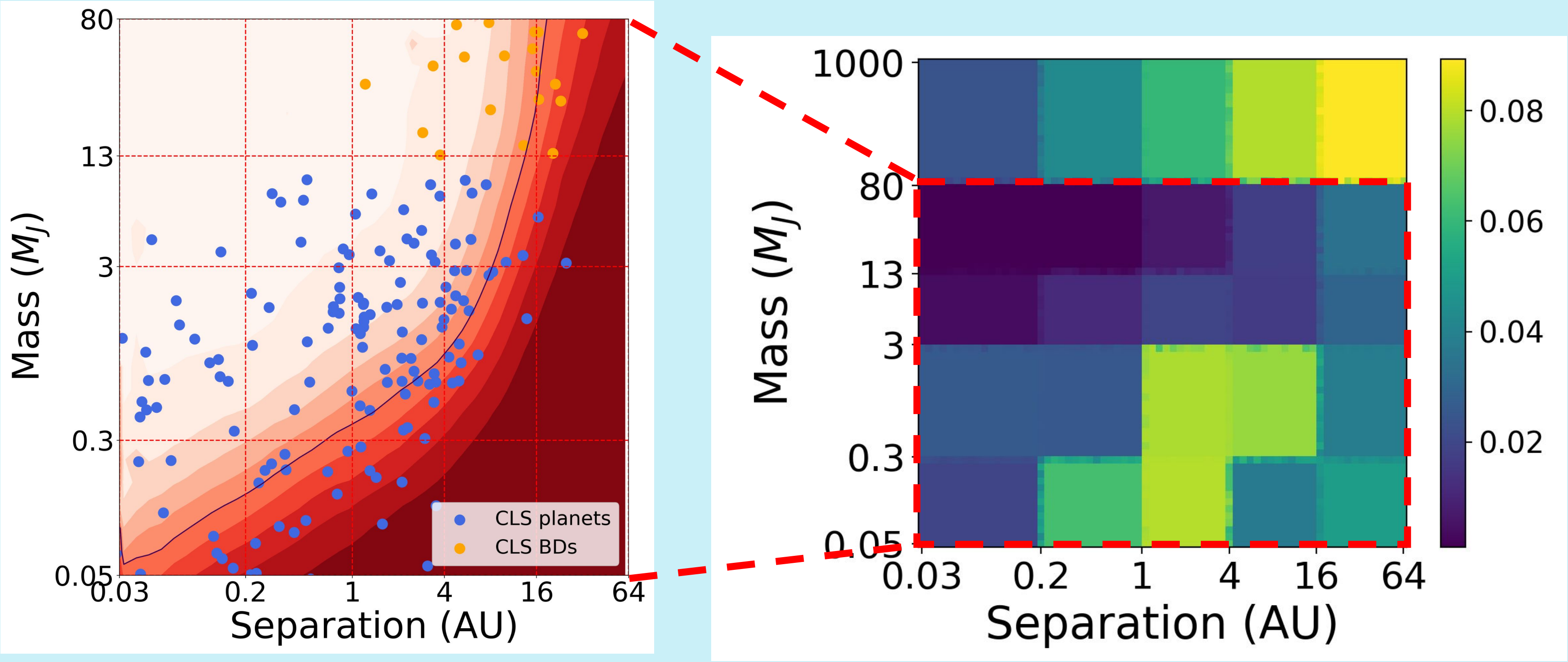
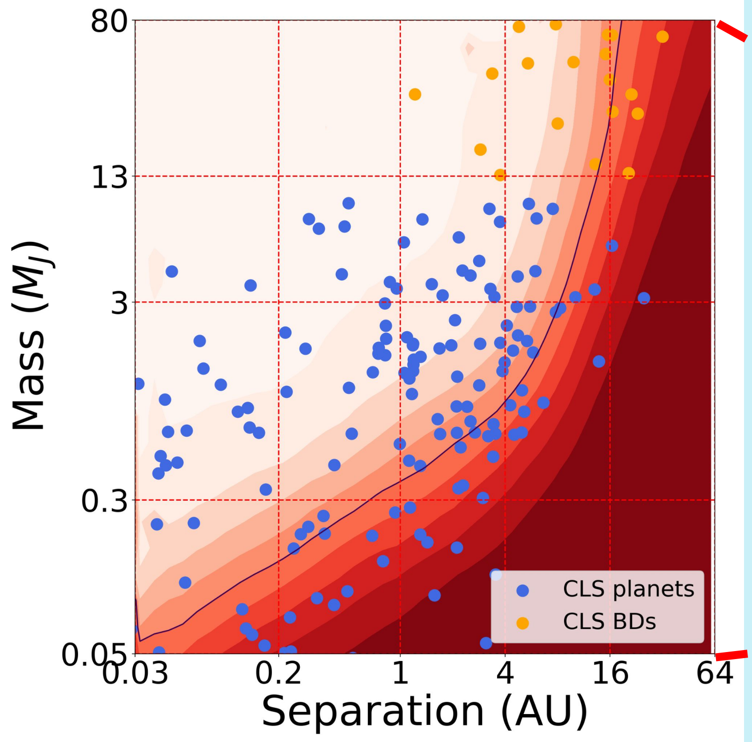
Motivation:
How do we incorporate our prior knowledge that some objects are intrinsically more/less common than others?

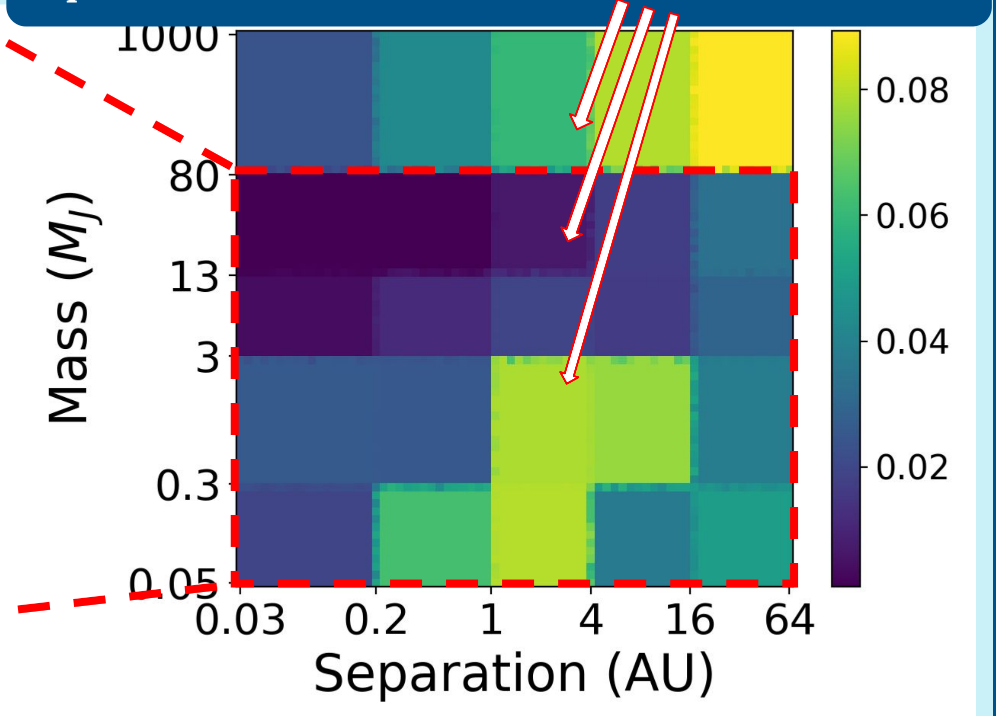
Informative mass/separation prior for trend analysis



Informative mass/separation prior for trend analysis

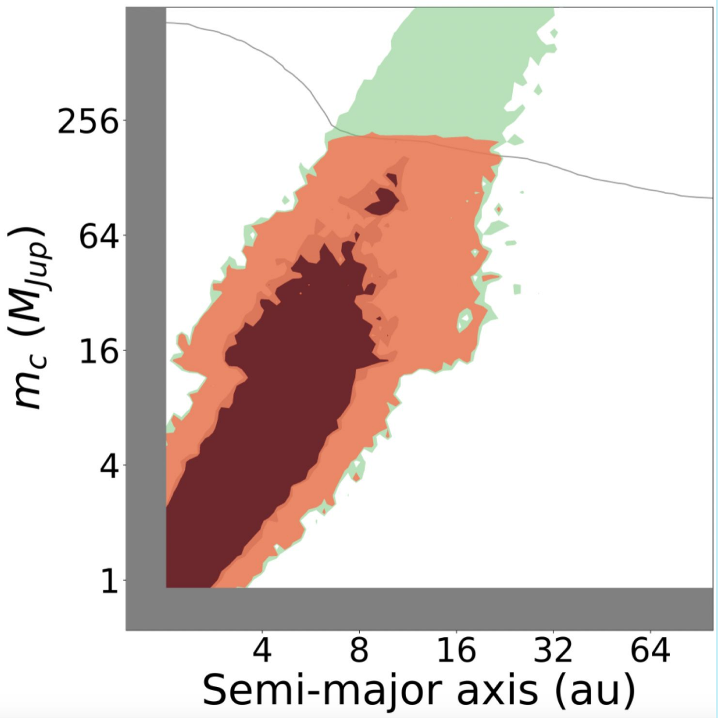


Planets and stars are much more common than BDs, as expected



Informative mass/separation prior

TOI-1174
(log-uniform mass/SMA prior)



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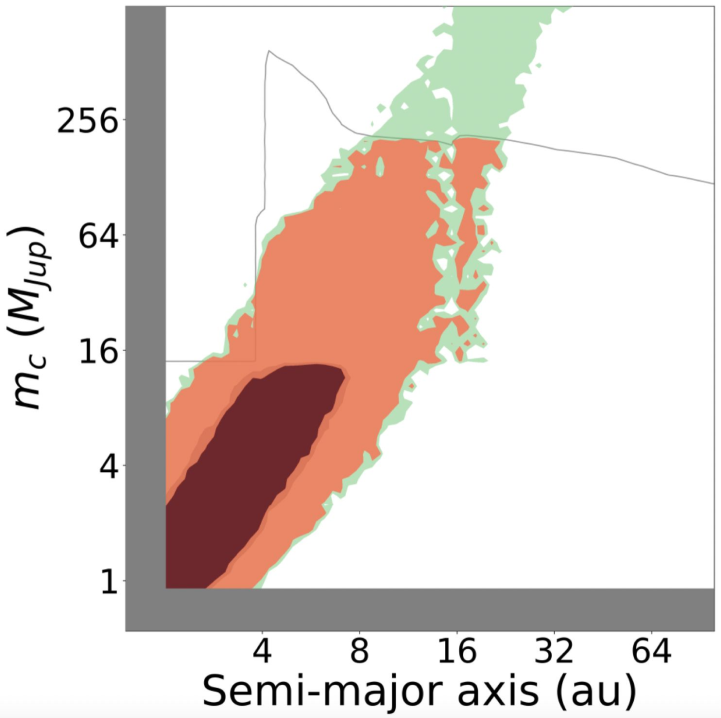
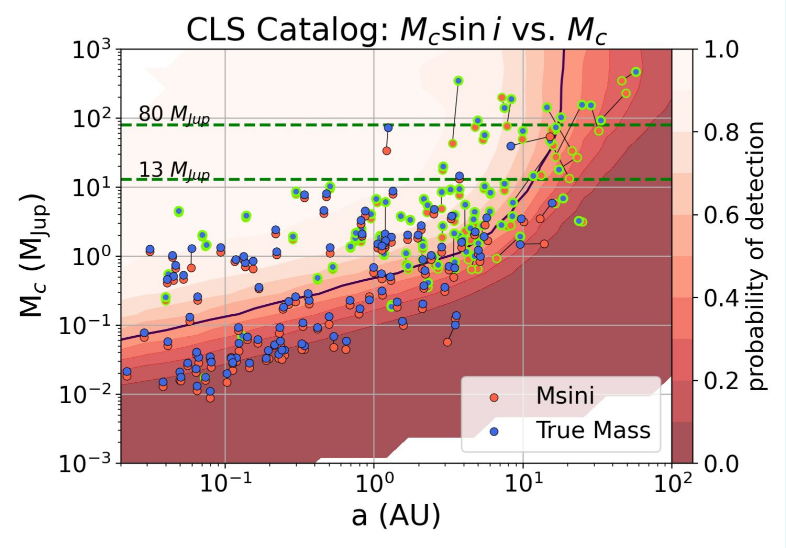
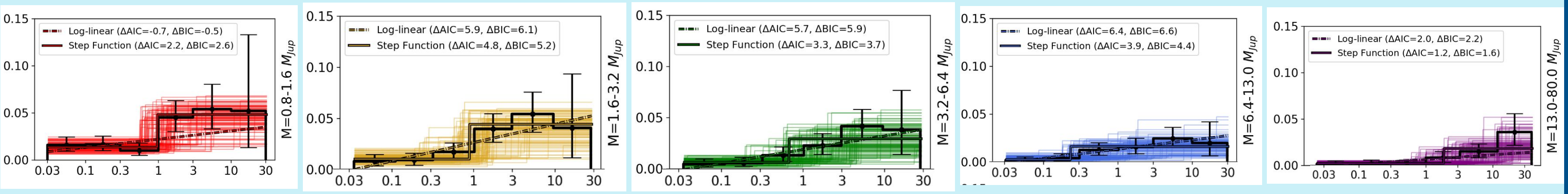


3D mass measurements will clarify the planet/BD divide

- Hipparcos-Gaia astrometry enabled 3D orbit fits → true mass instead of Msini
- Revised occurrence rates at all masses/separations
- 7/18 “BDs” in the CLS were actually stars





Van Zandt et al. (2026, Accepted)

1) The Distant Giants Survey: design, detections, and results
    - Target selection function and observing strategy
    - Full orbits and trends
        - Informative mass prior for trend analysis
    - <u>Sensitivity correction</u>
    - Conditional occurrence: P(DG|CS)
2) Results and Comparison to Other Work
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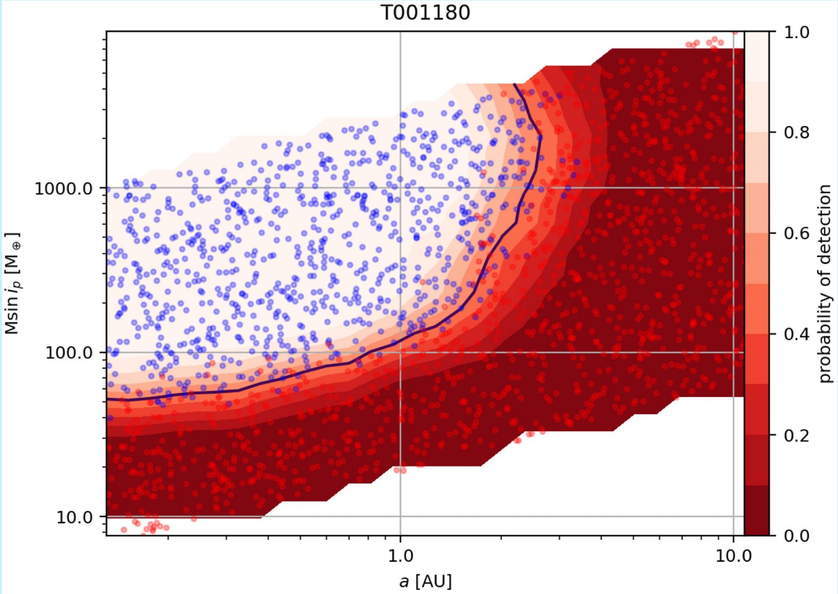
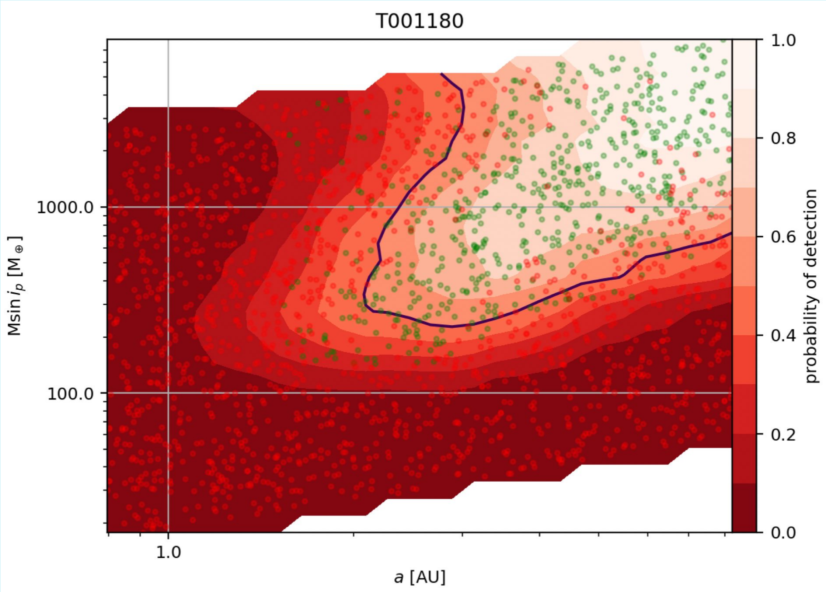
Completeness tells you how much to boost your results to make up for what you missed

Sensitivity to complete orbits

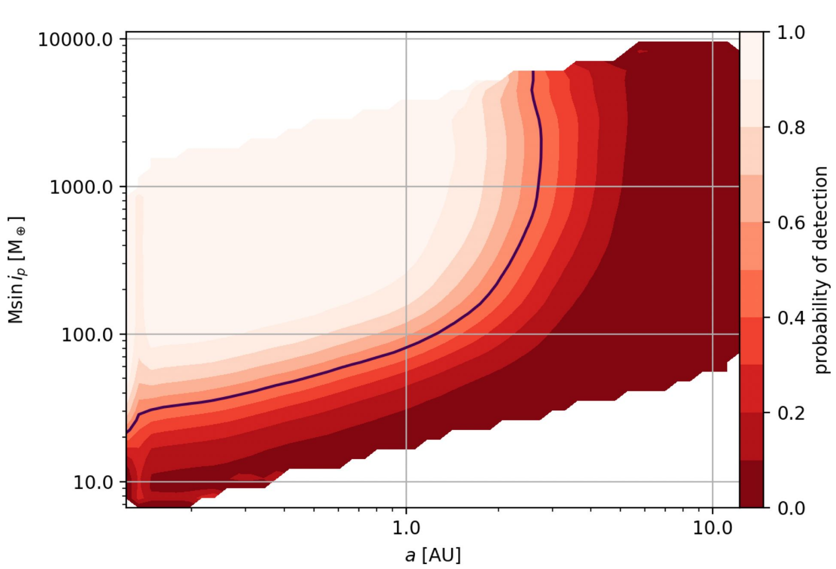


Sensitivity to trends



Survey-averaged completeness maps capture the completeness of all targets

Sensitivity to complete orbits



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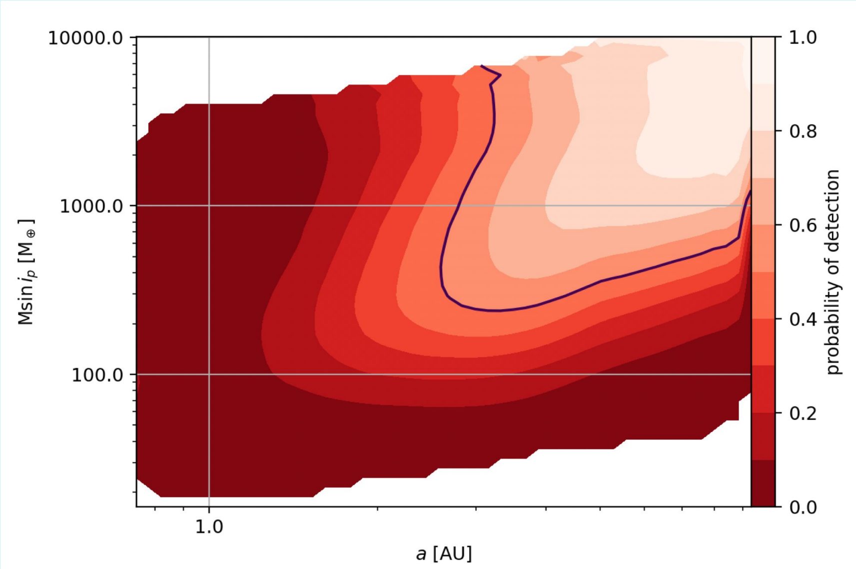
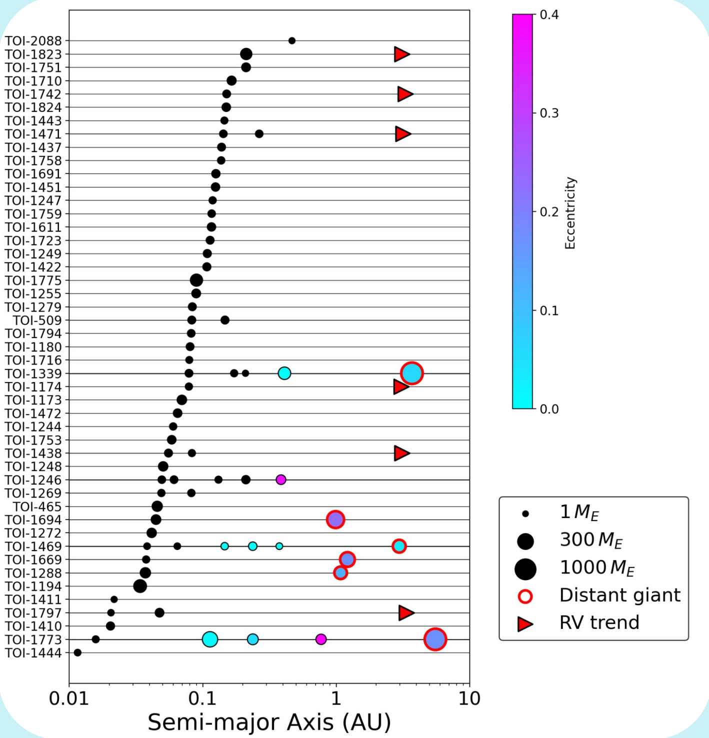


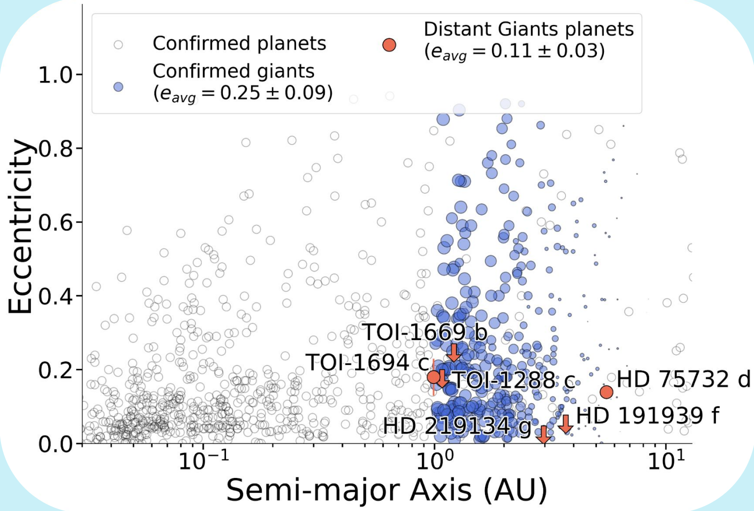
Dynamical correlations point to possible DG-CS interaction

1) Outer giants have shorter-period companions (3σ)



2) Outer giants have more inner companions (1σ)

3) Outer giants are less eccentric (1.5σ)



Van Zandt et al. (2025)

Occurrence Figures

Table 3. DG Occurrence Rates

DG mass limits ($M_\oplus$)	$N_\star$ (CLS)	N_{DG} (CLS)	P(DG)	CS radius limits ($R_\oplus$)	$N_{transiting}$	$N_{resolved}$	N_{trend}	P(DG|CS)
70-4000	598	55	$16^{+2}_{-2}\%$	1-4	35	1.0	5.2	$30^{+14}_{-12}\%$
				1-6	42	2.2	5.9	$33^{+12}_{-11}\%$
30-6000	598	74	$20^{+2}_{-2}\%$	1-4	32	1.0	4.8	$33^{+13}_{-12}\%$
				1-6	39	3.0	5.5	$38^{+14}_{-13}\%$
158-6356	598	54	$16^{+2}_{-2}\%$	1-4	32	0.8	4.3	$24^{+11}_{-10}\%$
				1-6	39	1.2	5.0	$23^{+11}_{-9}\%$

NOTE—Field and conditional distant giant occurrence rates under different planet definitions. The first DG mass limit is our nominal definition. The second and third match Rosenthal et al. (2022) and Bryan et al. (2019), respectively. We require that CS and DG planets have $a < 1$ AU and $a = 1 - 10$ AU, respectively. For the other two cases, we adopt the CS and/or DG separation limits given in Rosenthal et al. (2022) ($a = 0.023 - 1$ AU for CS and $0.23 - 10$ AU for DG) and Bryan et al. (2019) ($a = 1 - 20$ AU for DG). We calculated field occurrence rates using the CLS sample (Rosenthal et al. 2021), to which we applied a mass cut ($M_\star \geq 0.6\,M_\odot$) to exclude M dwarfs.

Poisson Occurrence Model

Assumptions:
- Planet occurrence at any given point in (a,m) space
  - is an independent event
  - with a fixed probability

Probability of observing N_p planets with any mass/separation

Occurrence rate density, the value of interest

$$\mathcal{L}_j \propto e^{-\Lambda_j} \prod_{k=1}^{K} \left[\frac{1}{N_k} \sum_{n=1}^{N_k} \frac{\lambda(\boldsymbol{\omega}_k^{(n)}|\boldsymbol{\theta}) Q(\boldsymbol{\omega}_k^{(n)})}{p(\boldsymbol{\omega}_k^{(n)}|\boldsymbol{\alpha})} \cdot \mathbb{1}_{n,k,j} \right]^{w_{k,j}} . \quad (1)$$

Probability of N_p planets possessing the observed masses/separations

Companion weight, corresponding to overlap fraction

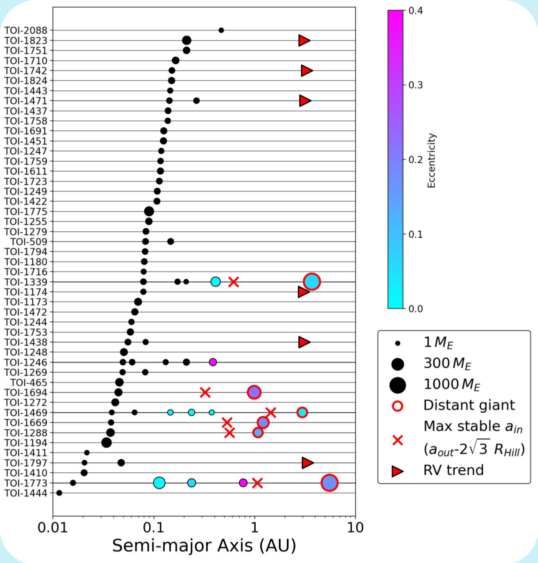
Possible causes of dynamical correlations

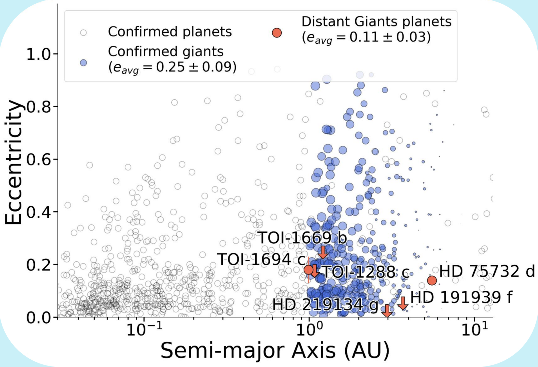
Observed correlations

1) Outer giants have shorter-period companions (3σ)
2) Outer giants have more inner companions (1σ)
3) Outer giants are less eccentric (1.5σ)

Possible contributors

1) Resonant transport – outer giants entrain planetesimals into MMRs and drive short-period planets to short separations (Batygin & Laughlin 2015)
2) Necessity of stability – inner companions must be at least 2√3 mutual Hill radii from their giants, setting an upper limit on their semi-major axes (Gladman 1993, Fabrycky+2014)
3) Depletion of solids – while metal-rich disks may promote the formation of CS and DG planets, *local* depletion of solids may prevent them from forming nearby (e.g. Chiang & Laughlin 2013, Hansen & Murray 2013)
4) Selection effect - We find giants in systems with more sensitivity. These systems also have more CS, and more CS means higher probability of a very close-in CS





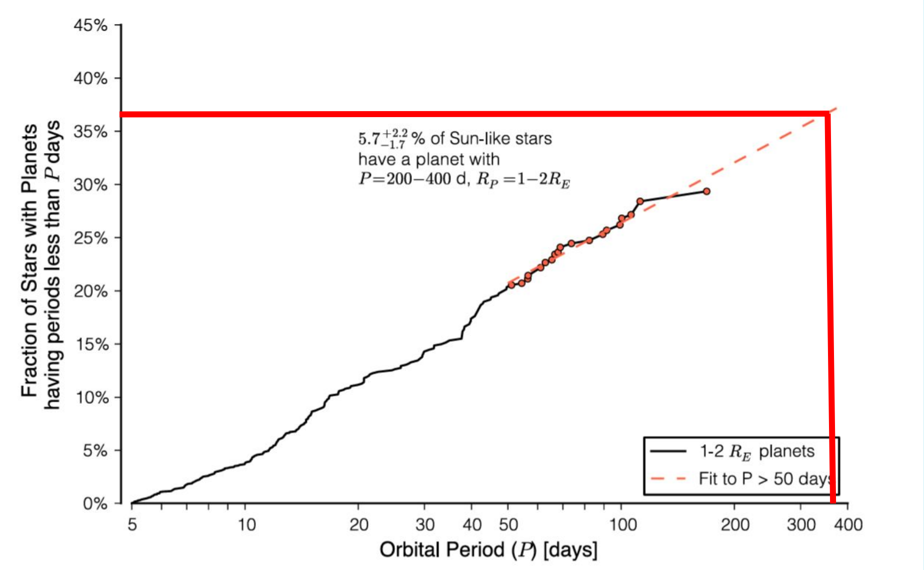
Distant Giants selection criteria

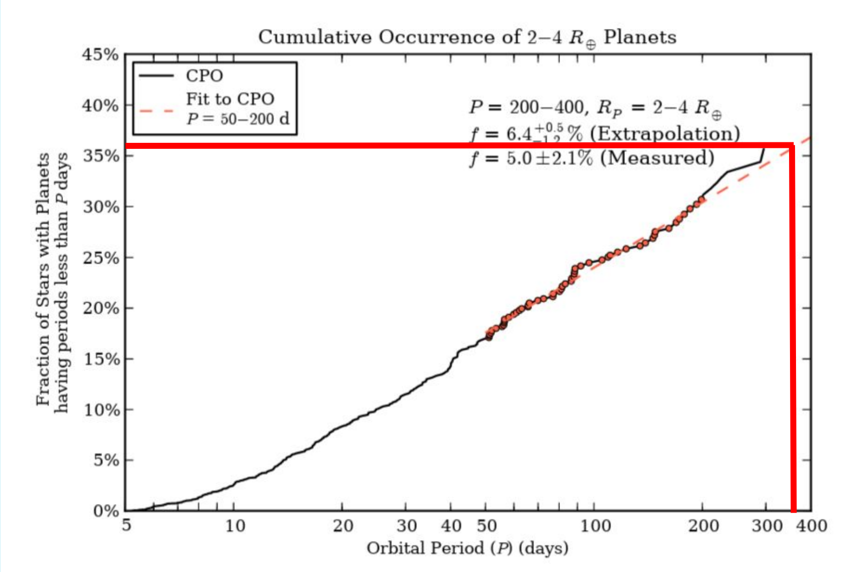
Table 1. Survey Criteria

Parameter	TKS	Distant Giants Survey		
		Photometric	Manual	Spectroscopic
Declination	$> -30°$	$> 0°$	—	—
V	< 13.0	< 12.5	—	—
Evolutionary State	MS or SG	MS	—	—
RUWE	< 2	< 1.3	—	—
R_P	$< 22\ R_\oplus$	$< 10\ R_\oplus$	—	—
Transit Pipeline	—	—	SPOC	—
Detection Significance	SNR > 10	—	MES > 12	—
Close Companion	$\Delta V > 5$ or sep $> 2''$	—	$\Delta V > 5$ or sep $> 4''$	—
$M_\star$	—	—	—	$0.5\ M_\odot < M_\star < 1.5\ M_\odot$
$T_{\rm eff}$	< 6500 K	—	—	< 6250 K
$v \sin i$	—	—	—	< 5.0 km/s
$\log R'_{\rm HK}$	—	—	—	< -4.7

Note—Filters applied to 2045 TESS systems to produce the Distant Giants sample. TKS filters are taken from Chontos et al. (2021). Although other filters were applied to produce the TKS sample, we show only those used in our survey's target selection process. MS and SG refer to main sequence and subgiant stars, respectively.

The total occurrence of planets <4 RE is near 100%

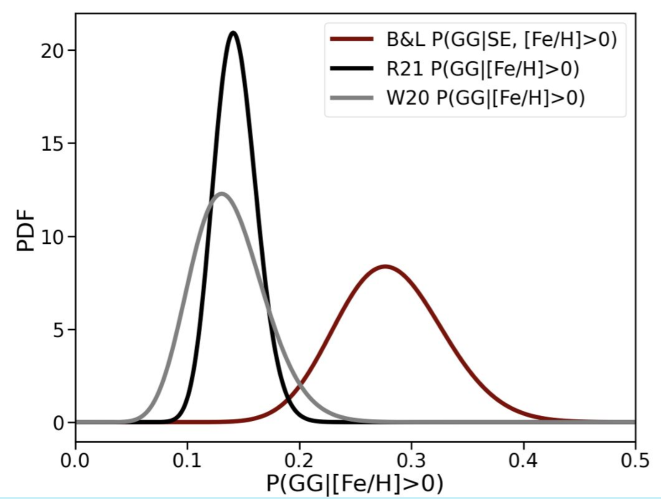


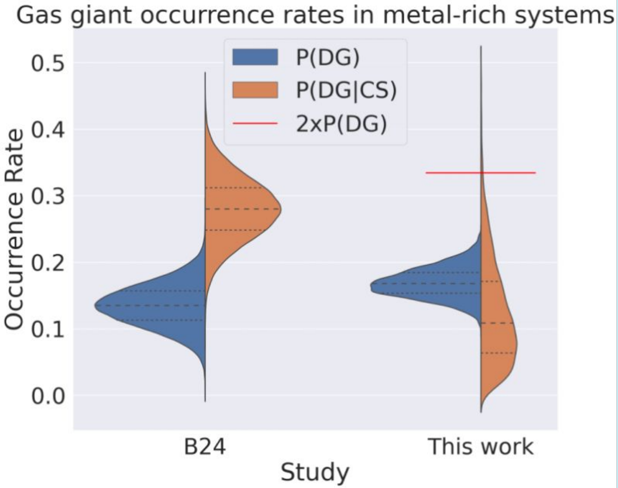


Petigura et al. (2013)

A possible metallicity correlation

- Bryan & Lee (2024) found a high-significance enhancement of giant companions specifically in a large, heterogeneous sample of metal-rich systems.
- Using the California Legacy Survey sample, which is homogeneous but relatively small, I followed their analysis and found that, for their definition of a giant, P(DG|CS) was actually *diminished* in metal-rich systems.

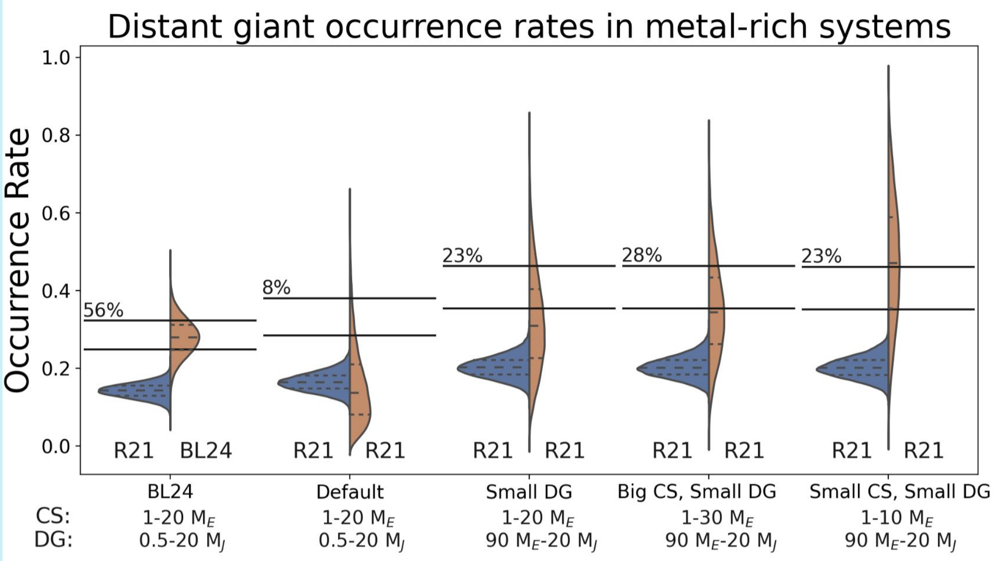




Van Zandt et al. (2024b)

A possible metallicity correlation

- Recalculating P(DG | CS) under different giant planets definitions, we saw some enhancements
- However, these enhancements were mirrored in the *non*-metal-rich systems, suggesting that metallicity was not responsible



Van Zandt et al. (2024b)

Informative mass/separation prior

Stellar occurrence increases out to ~45 AU

Small planets drop off beyond ~10 AU

Brown dwarfs and giant planets have similar distributions