The Occurrence of Brown Dwarfs and Planets from RVs and Astrometry

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Collaborators
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- $M<13\ M_J$: planet, $13\ M_J<M$: brown dwarf

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More detail in Greg's talk!

Goal

determine whether companion dynamics/host star properties point to a specific planet/BD mass divide

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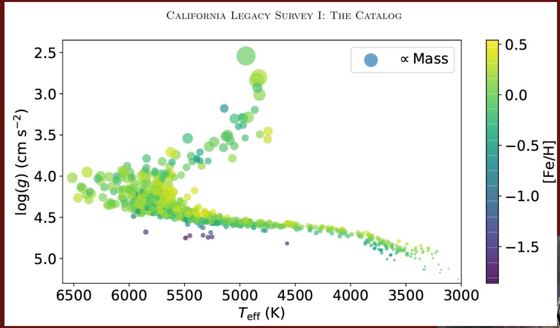
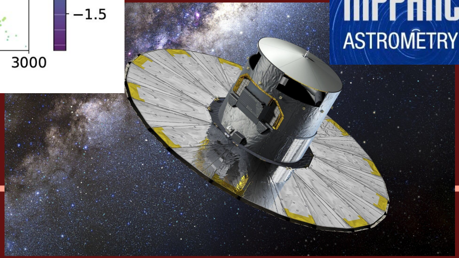
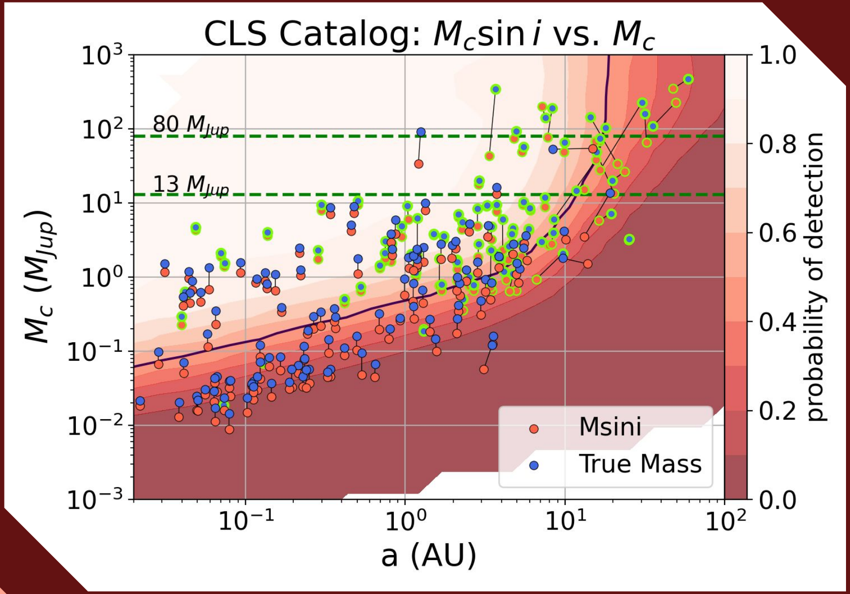
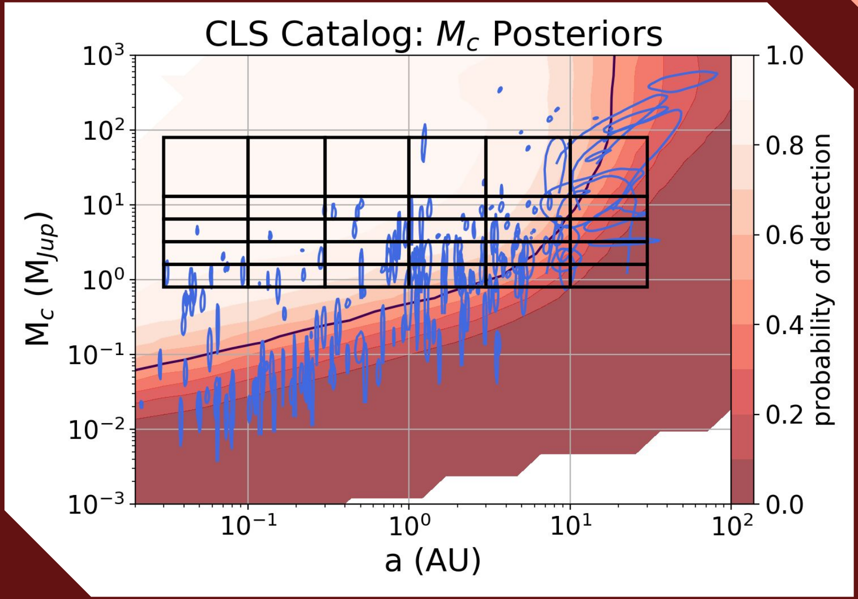




CLS + Hipparcos-Gaia = precise orbits for hundreds of companions around 719 stars out to 10 AU!

I refit the 128 planet/BD hosting CLS systems with Orvara, using HGCA astrometry when available





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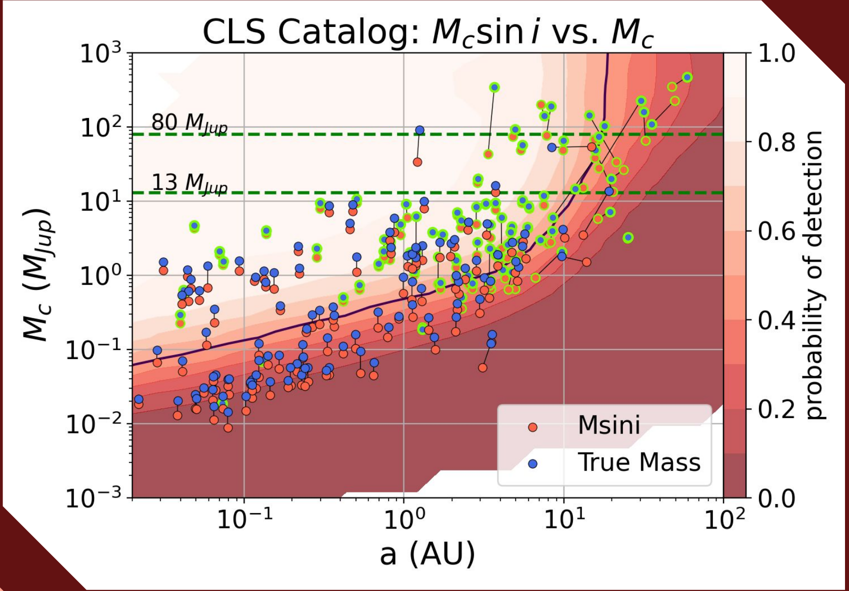
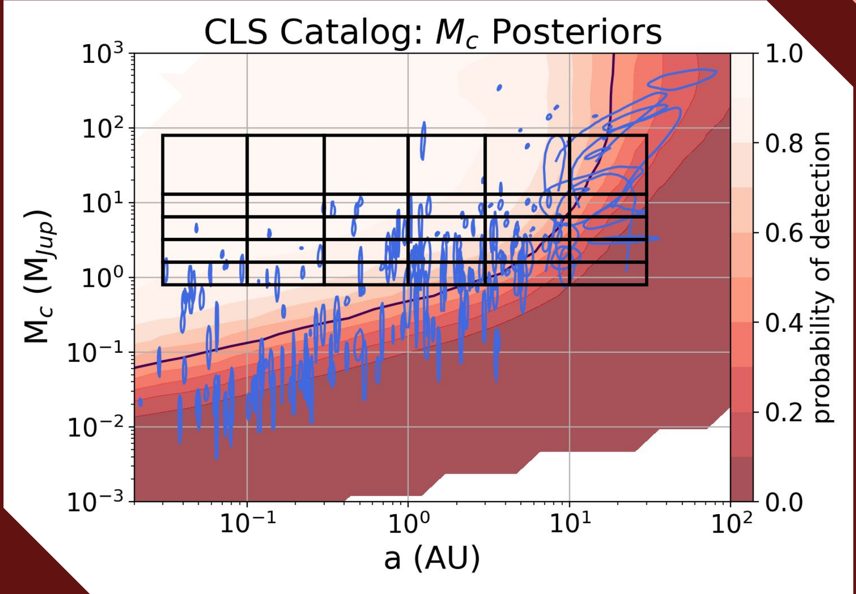




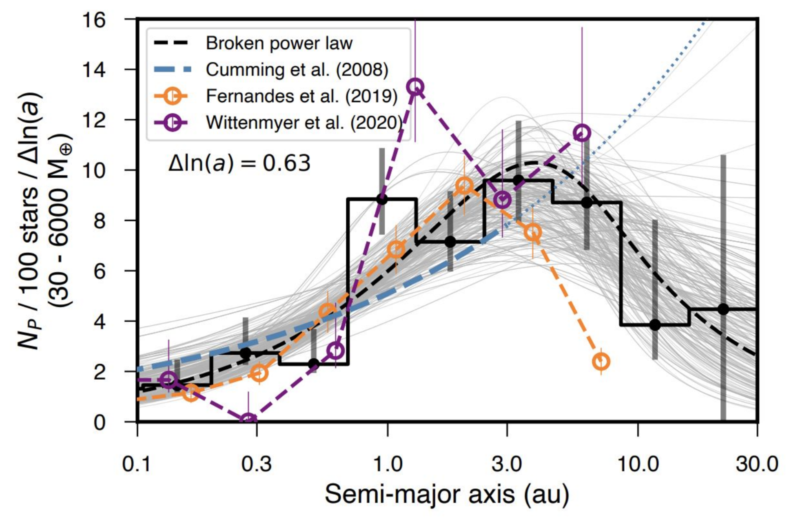
7/18 (40%) of Doppler BDs are stars

With a refit sample, we can examine population-level parameter distributions

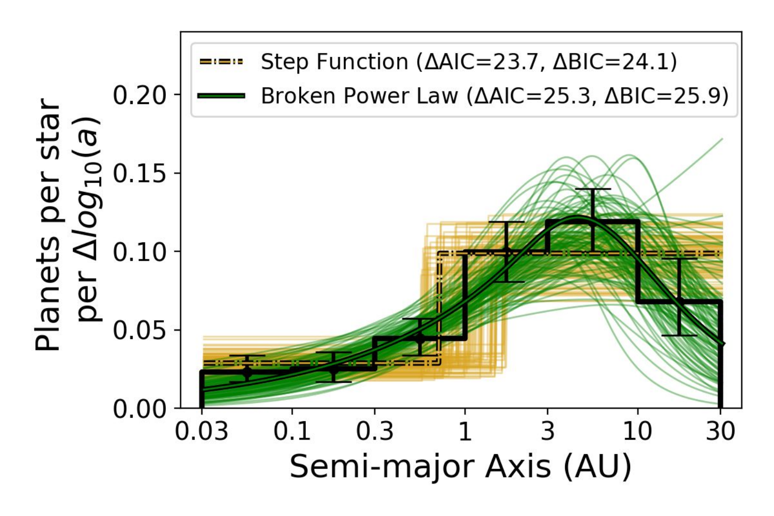
- Do higher-mass companions orbit lower-metallicity stars? Giacalone et al. (2025)
- Do higher-mass companions tend to have higher eccentricities? Gilbert, Van Zandt, et al. (2025)
- How common are high-mass companions compared to lower-mass ones? Van Zandt et al. (2025)

The semi-major axis distribution is consistent with Fulton et al. (2022)

Msini = 0.1-18.9 M_J (Fulton+2022)



M = 0.8-80 M_J (Van Zandt et al. 2025)



Both distributions show a peak between 1-10 AU followed by a marginally significant fall-off at *a*>10 AU

The occurrence plateau between 1–10 AU is relevant to planet formation

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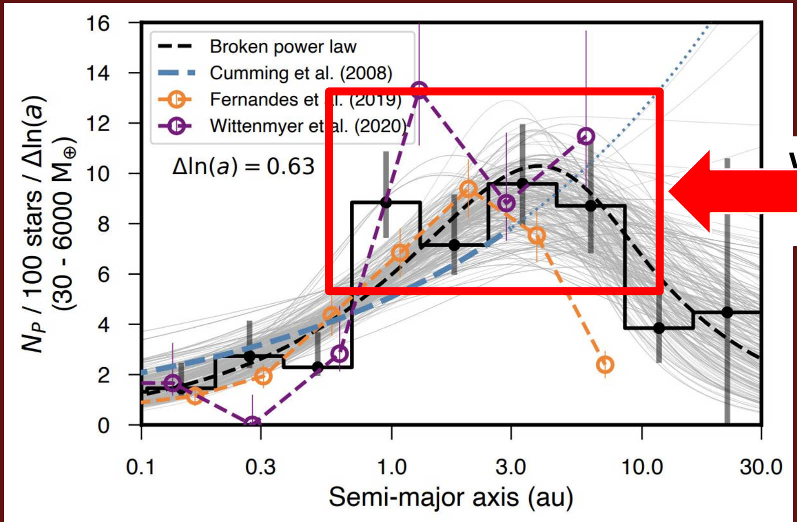

What's going on here?

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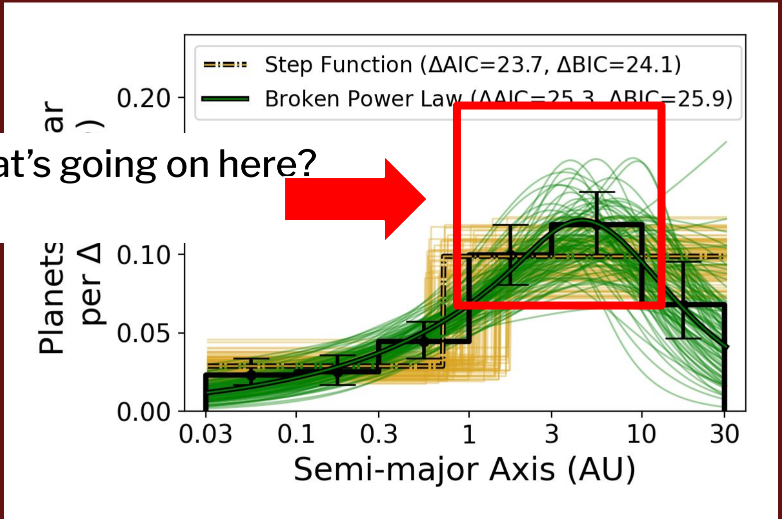
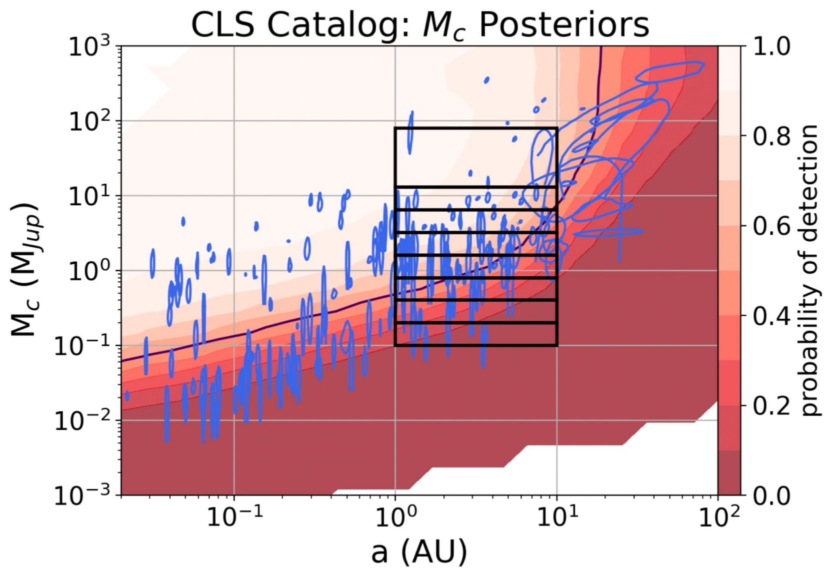
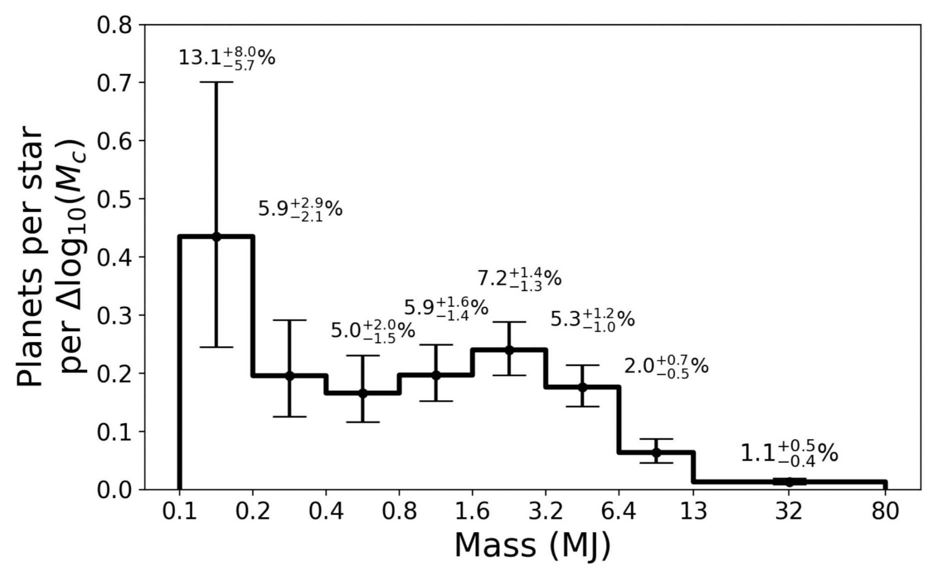


Both distributions show a peak between 1-10 AU followed by a marginally significant fall-off at *a*>10 AU

The mass distribution between 1-10 AU shows that BDs and super-Jupiters are rare near the snow line





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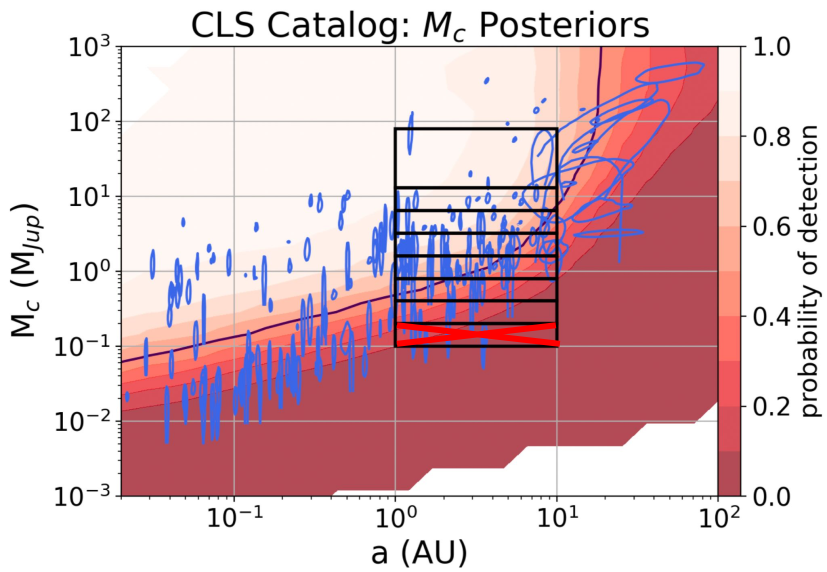
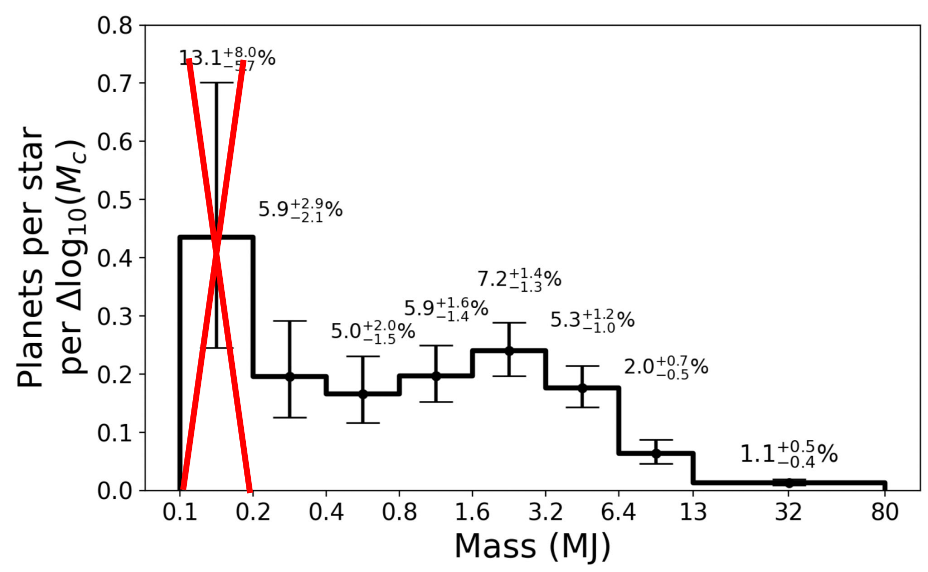
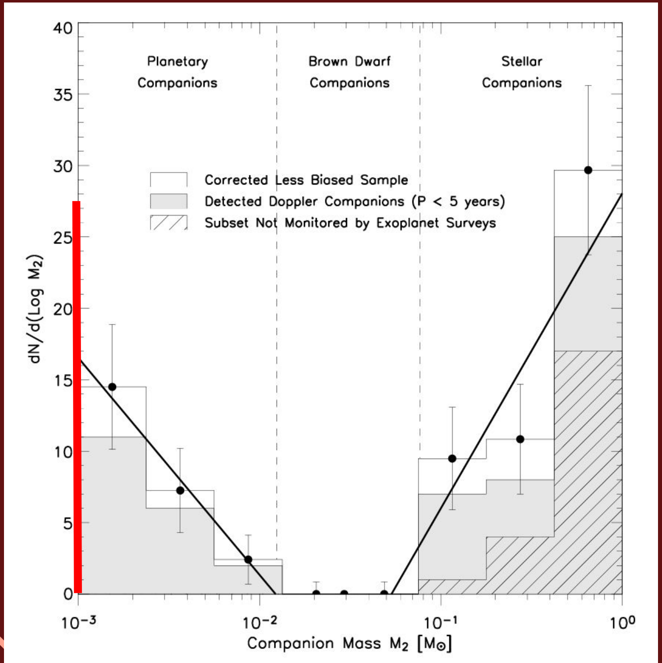




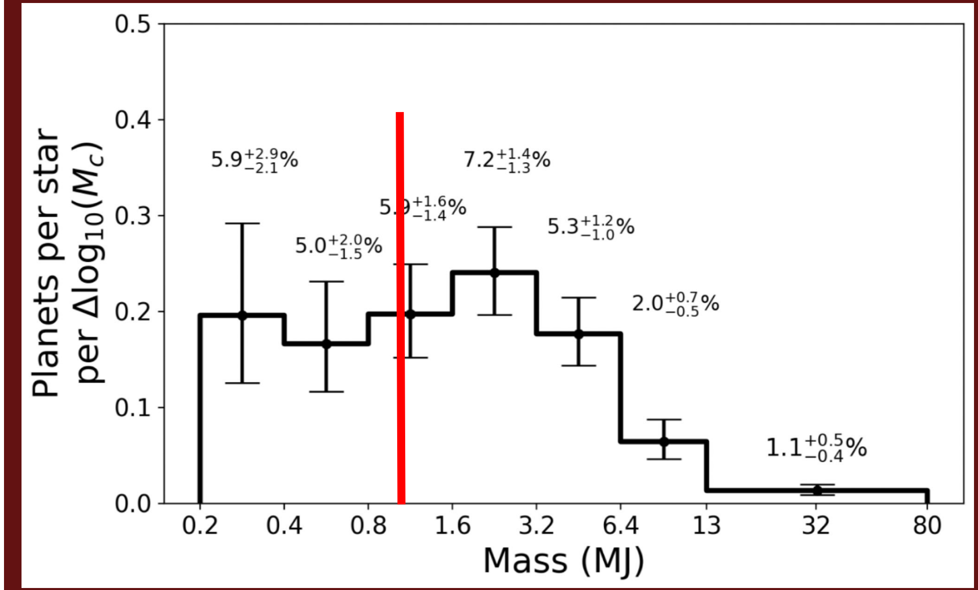
The BD desert extends to 10 AU

Occurrence rates for P<5 yr



Grether & Lineweaver (2006)

Occurrence rates between 1-10 AU



Van Zandt et al. (2025)

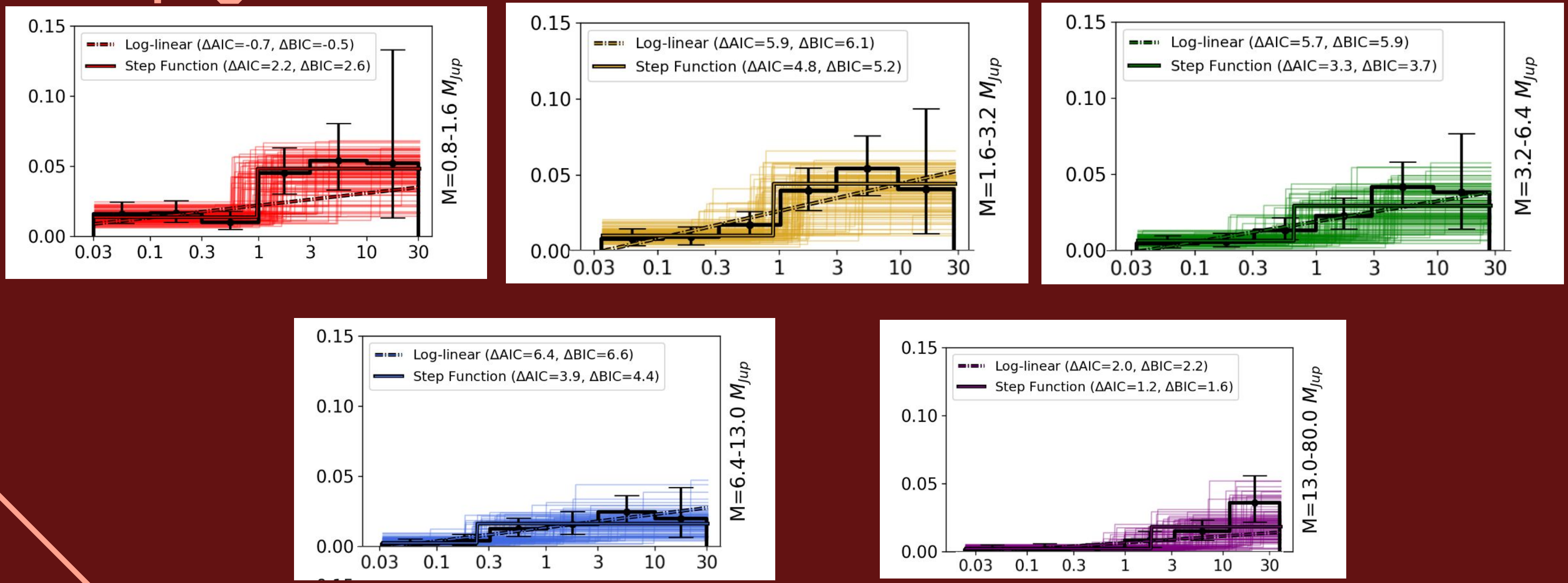
KEY TAKEAWAYS

sin(i) contamination can be highly relevant for rare objects — half of RV "brown dwarfs" may be stars

The BD desert **extends to at least 10 AU**

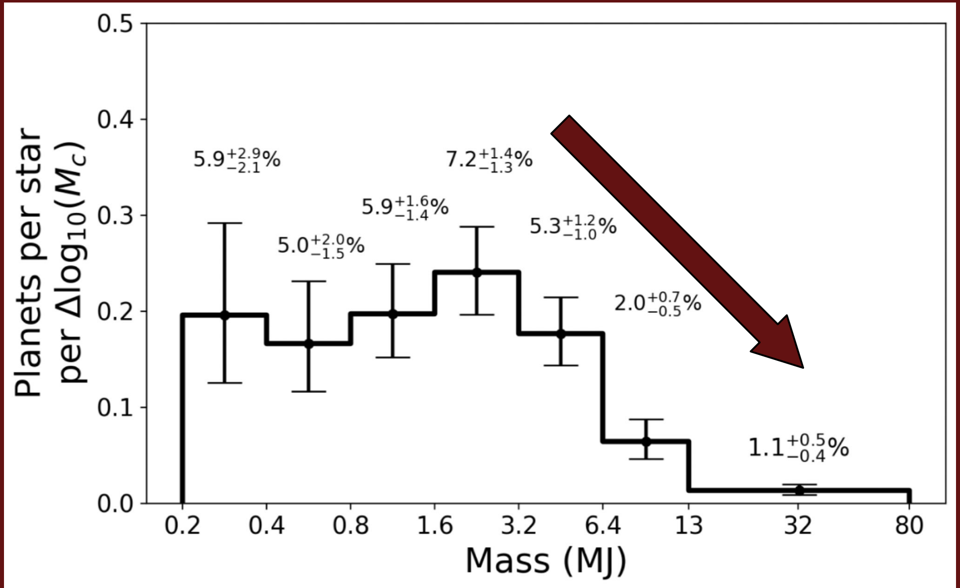
The mass and semi-major axis distributions of planets/BDs **do not indicate a sharp divide**; the mechanisms that form them likely act in overlapping mass regimes

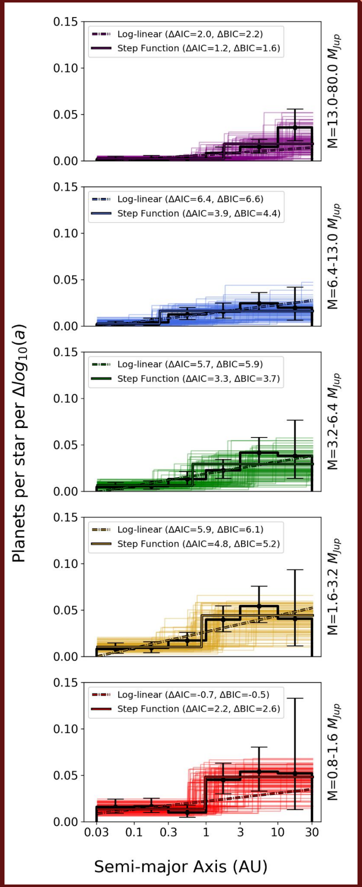
The SMA distribution does not vary sharply with mass



Semi-major Axis (AU)

SUPPLEMENTAL – no sharp planet/BD transition evident from mass and SMA distributions





No clear evidence of a sharp distribution change

SUPPLEMENTAL: “brown dwarf” companions from the CLS

- 7/18 BDs → stars
- 7/15 BDs with HGCA

Table 1. Companions with $M_c \sin i = 13\text{–}80\, M_{\rm Jup}$

System Name	Companion Index	a_i (AU)	$M_c \sin i$ ($M_{\rm Jup}$)	a_f (AU)	M_c ($M_{\rm Jup}$)	HGCA?
HD126614	1	$16.613^{+1.544}_{-1.549}$	$27.407^{+5.833}_{-5.551}$	$24.746^{+17.652}_{-7.764}$	$157.449^{+215.837}_{-60.066}$	True
HD168443	1	$2.879^{+0.032}_{-0.028}$	$17.769^{+0.352}_{-0.361}$	$2.912^{+0.026}_{-0.023}$	$19.908^{+1.226}_{-1.195}$	True
HD26161	0	$20.430^{+6.516}_{-6.518}$	$13.430^{+5.737}_{-6.220}$	$15.133^{+2.380}_{-1.332}$	$47.251^{+6.571}_{-4.817}$	True
HD28185	1	$15.766^{+6.286}_{-5.869}$	$42.183^{+36.696}_{-38.151}$	$8.503^{+0.273}_{-0.276}$	$6.004^{+0.596}_{-0.602}$	True
HD38529	1	$3.736^{+0.010}_{-0.009}$	$13.212^{+0.096}_{-0.101}$	$3.742^{+0.010}_{-0.010}$	$14.728^{+4.399}_{-1.176}$	False
HD66428	1	$22.434^{+13.061}_{-12.980}$	$27.272^{+20.275}_{-19.524}$	$17.424^{+10.660}_{-5.803}$	$18.168^{+10.779}_{-6.258}$	True
HD68988	1	$13.086^{+3.732}_{-3.646}$	$15.056^{+1.942}_{-2.194}$	$11.668^{+0.876}_{-0.694}$	$14.588^{+0.805}_{-0.612}$	True
HD111031	0	$32.061^{+13.771}_{-12.357}$	$65.343^{+40.779}_{-38.709}$	$28.477^{+10.535}_{-5.780}$	$155.224^{+41.017}_{-31.547}$	True
HD16160	0	$16.348^{+0.289}_{-0.275}$	$67.383^{+1.505}_{-1.506}$	$17.905^{+0.229}_{-0.230}$	$102.414^{+2.661}_{-2.632}$	True
HD18445	0	$1.208^{+0.017}_{-0.016}$	$34.177^{+5.277}_{-5.630}$	$1.244^{+0.024}_{-0.019}$	$72.901^{+46.741}_{-11.441}$	False
HD190406	0	$15.536^{+0.318}_{-0.305}$	$67.231^{+2.021}_{-1.933}$	$16.546^{+0.254}_{-0.256}$	$73.366^{+1.989}_{-2.001}$	True
HD211681	0	$7.790^{+0.189}_{-0.182}$	$76.437^{+3.365}_{-3.090}$	$8.311^{+0.151}_{-0.157}$	$188.877^{+7.688}_{-7.775}$	True
HD239960	0	$15.261^{+5.520}_{-6.023}$	$53.934^{+11.627}_{-11.766}$	$8.225^{+0.989}_{-0.647}$	$39.639^{+23.184}_{-6.086}$	False
HD4747	0	$9.841^{+0.165}_{-0.161}$	$49.197^{+1.681}_{-1.539}$	$9.933^{+0.136}_{-0.138}$	$66.040^{+1.755}_{-1.818}$	True
HD68017	0	$21.389^{+4.438}_{-4.530}$	$33.801^{+5.684}_{-5.446}$	$14.414^{+0.276}_{-0.259}$	$143.328^{+2.143}_{-2.062}$	True
HD8765	0	$3.358^{+0.052}_{-0.054}$	$42.985^{+1.500}_{-1.555}$	$3.679^{+0.051}_{-0.053}$	$346.259^{+17.806}_{-17.099}$	True
HIP63510	0	$4.774^{+0.050}_{-0.054}$	$74.231^{+3.108}_{-3.094}$	$4.954^{+0.036}_{-0.036}$	$92.976^{+2.250}_{-2.239}$	True
HD167665	0	$5.390^{+0.072}_{-0.076}$	$48.401^{+1.474}_{-1.364}$	$5.480^{+0.078}_{-0.079}$	$56.990^{+2.791}_{-2.456}$	True

Note. a_i and $M_c \sin i$ values are from Rosenthal et al. (2021), while a_f and M_c values are from this work.

30 years of RVs with the California Legacy Survey

- RV-only fits for 200+ companion-hosting stars
- Median t_{base}=21 years and N_{obs}=74
- 128 systems hosting a planet/BD (<80 M_J)
- 195 total companions

Rosenthal et al. (2021)