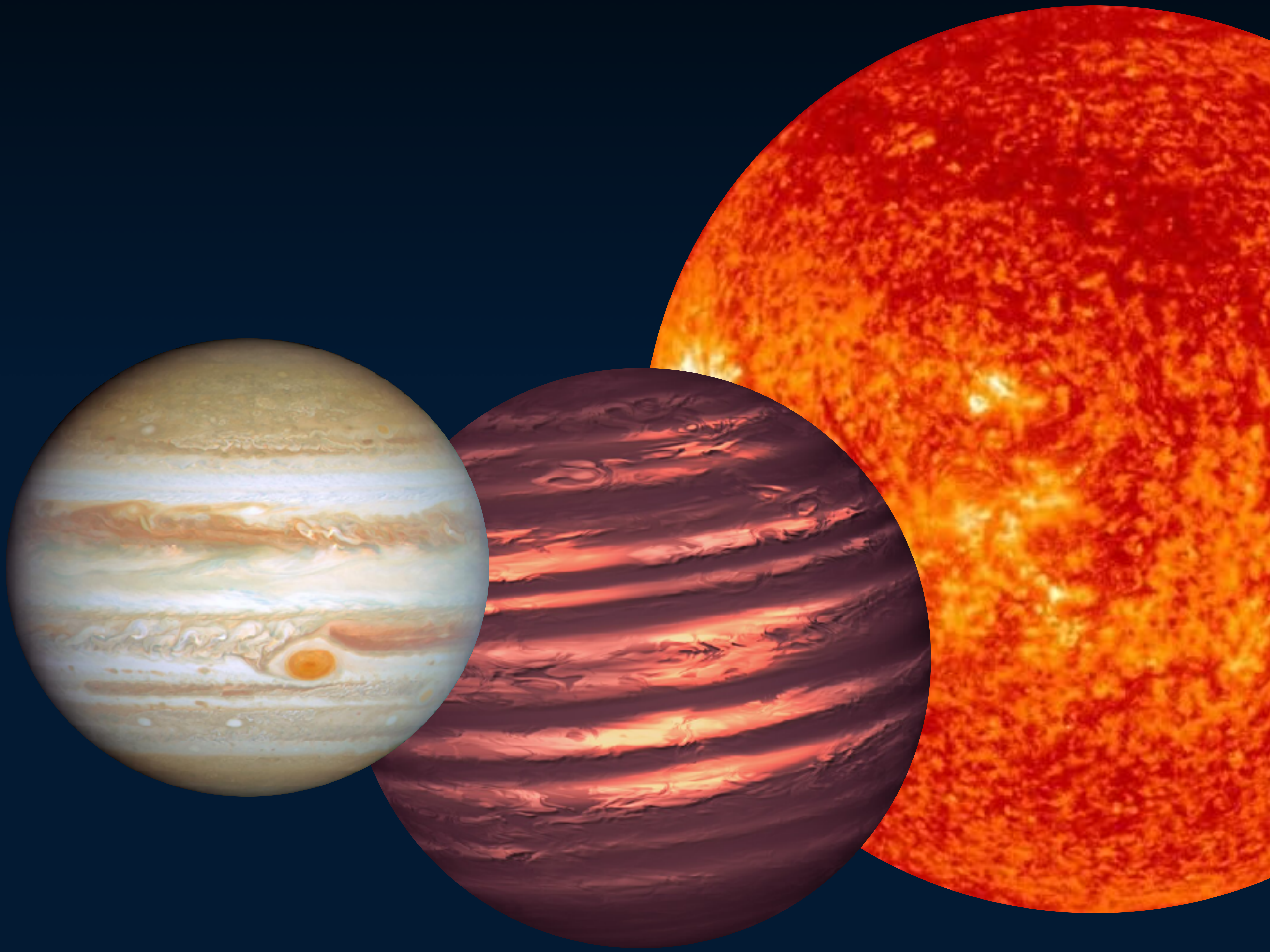
What's the difference between a giant planet and a brown dwarf?

Greg Gilbert (Caltech)

Collaborators: Judah Van Zandt, Steven Giacalone, Andrew Howard, Erik Petigura, Luke Handley

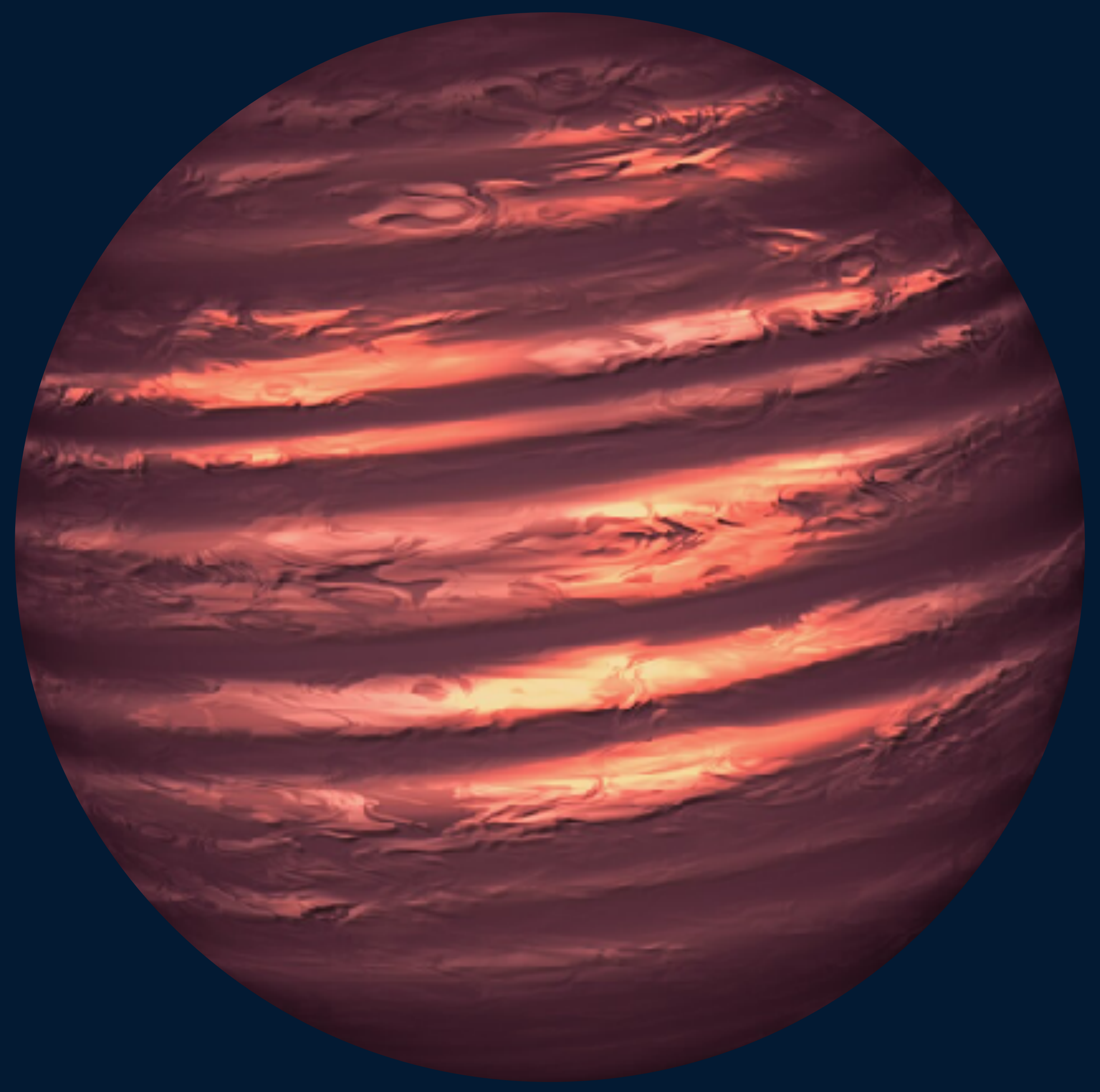


ExoSoCal | 17 Dec 2025 | Los Angeles, CA

Giant Planets

up to ~13 M_{Jup}

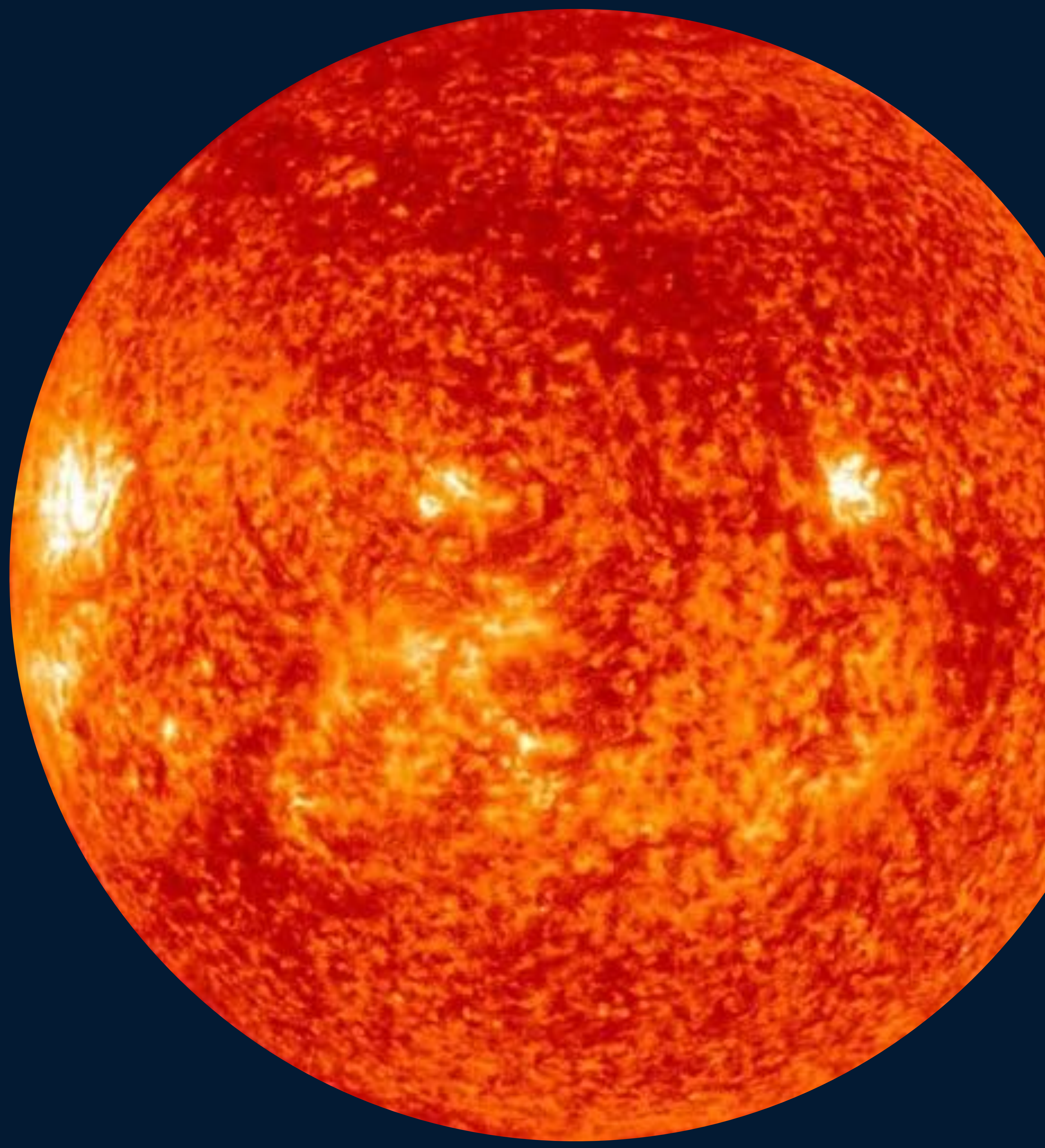
Brown Dwarfs



~13-80 M_{Jup}

Deuterium fusion

Stars



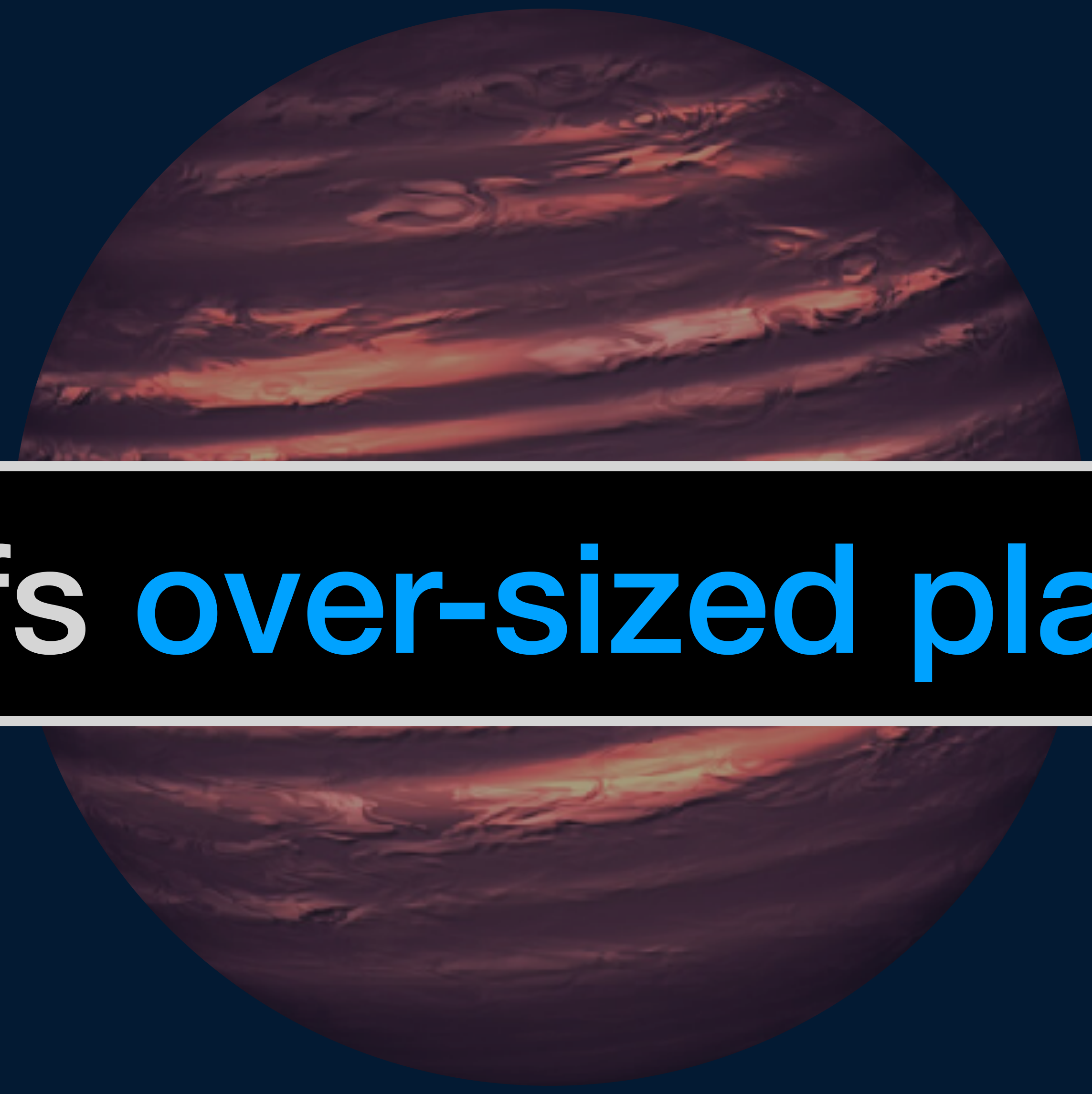
over 80 M_{Jup}

Hydrogen fusion

Giant Planets

up to ~13 M_{Jup}

Brown Dwarfs



~13-80 M_{Jup}

Deuterium fusion

Stars

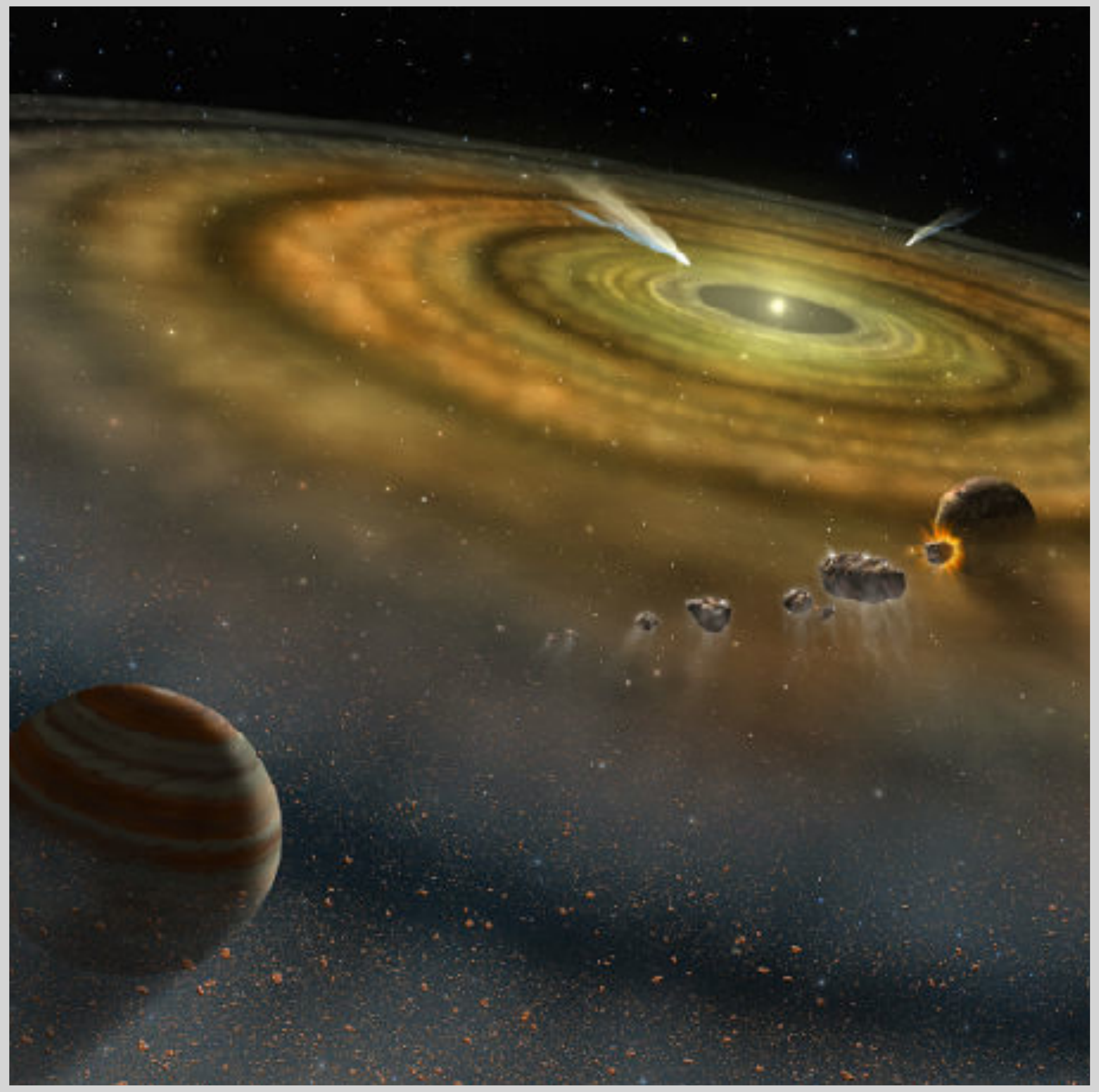
over 80 M_{Jup}

Hydrogen fusion

Are brown dwarfs over-sized planets or failed stars?

Definitions based on formation mechanism

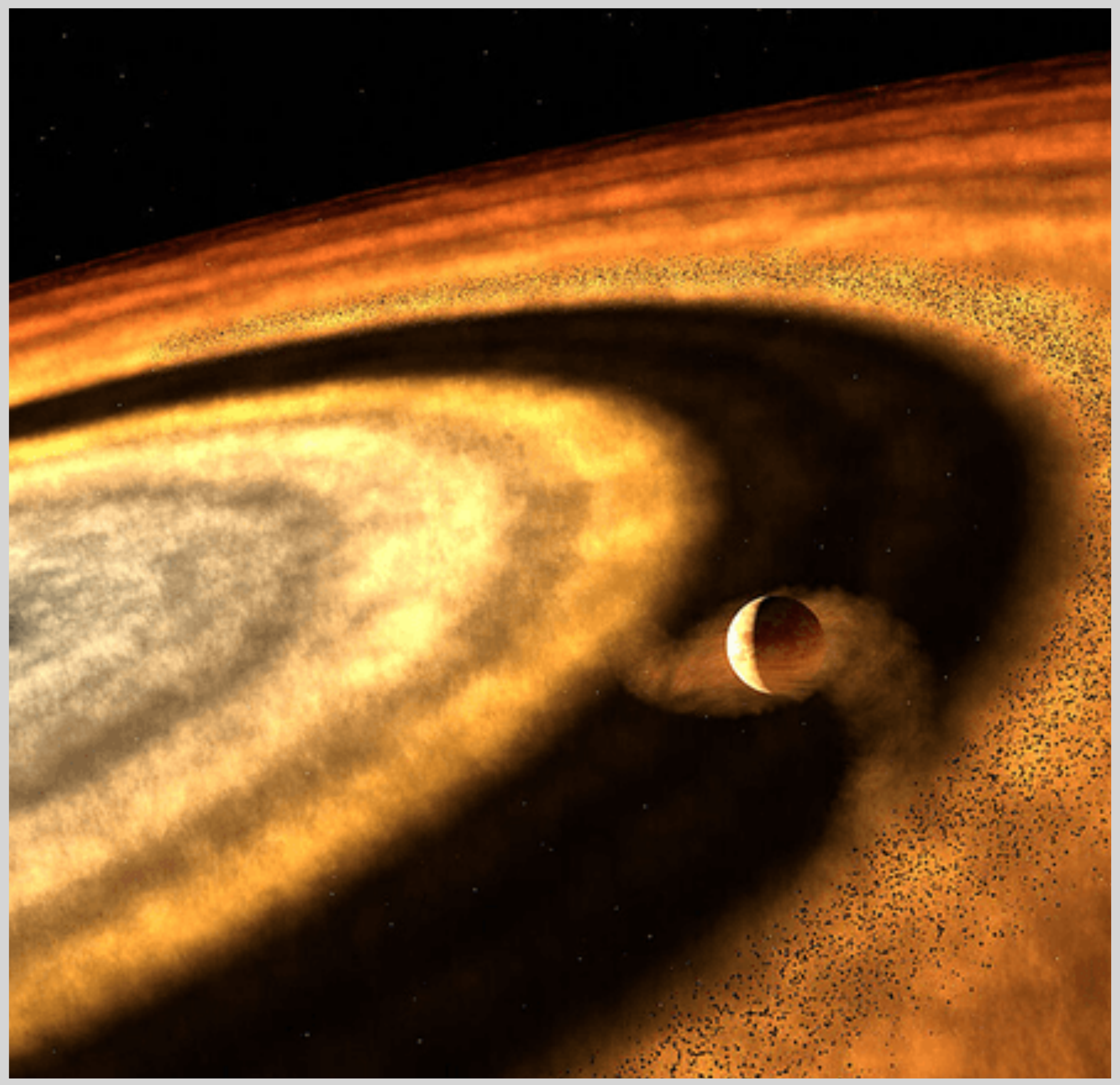
Core Accretion



Bottom-up

Planet-like

Disk Instability



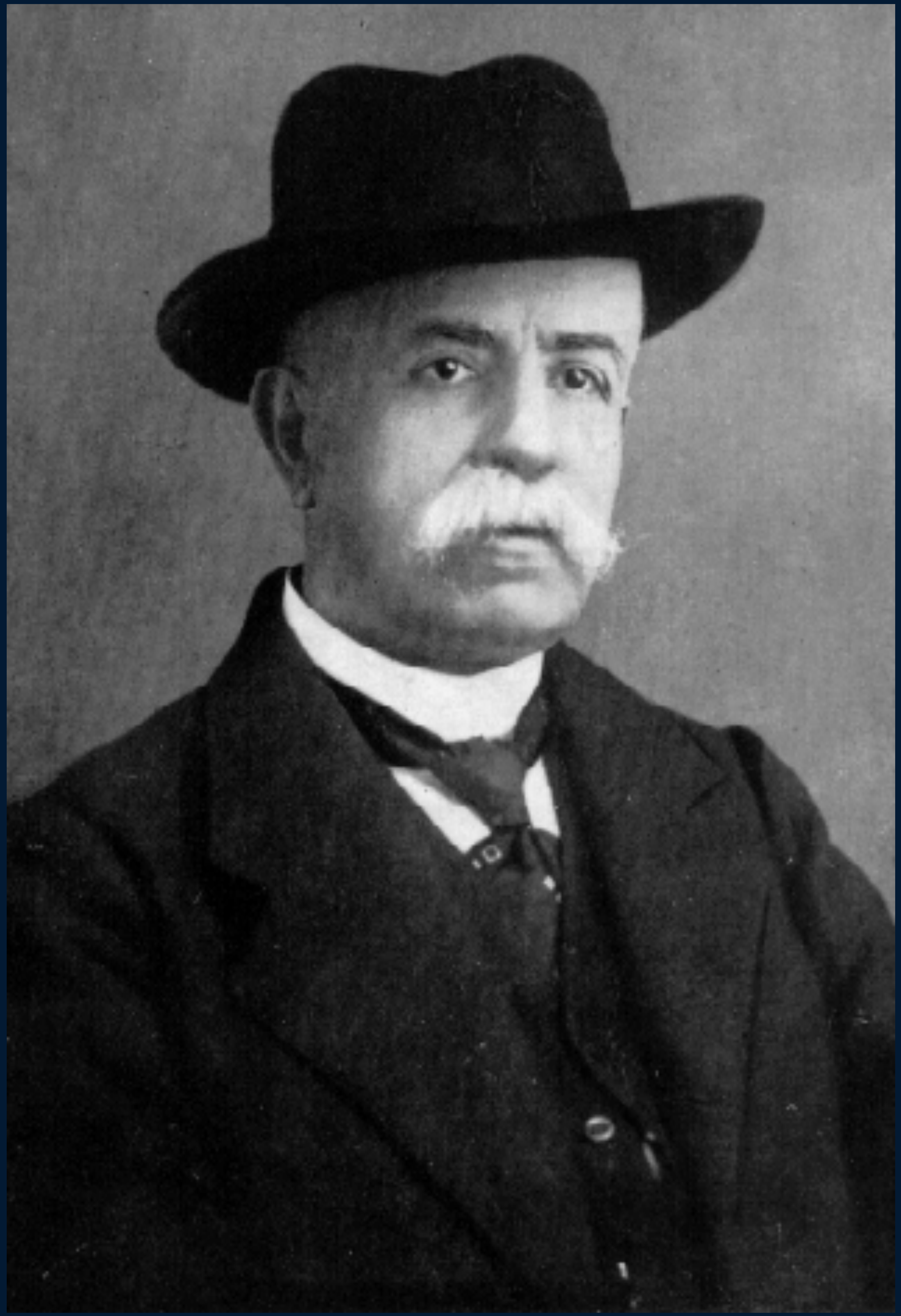
Top-down

???

Cloud Fragmentation

Top-down

Star-like



"A ~~tensor~~ planet is an object that ~~trans~~forms like a ~~tensor~~ planet"

— Grigori Ricci Curbastro

Definitions based on formation mechanism

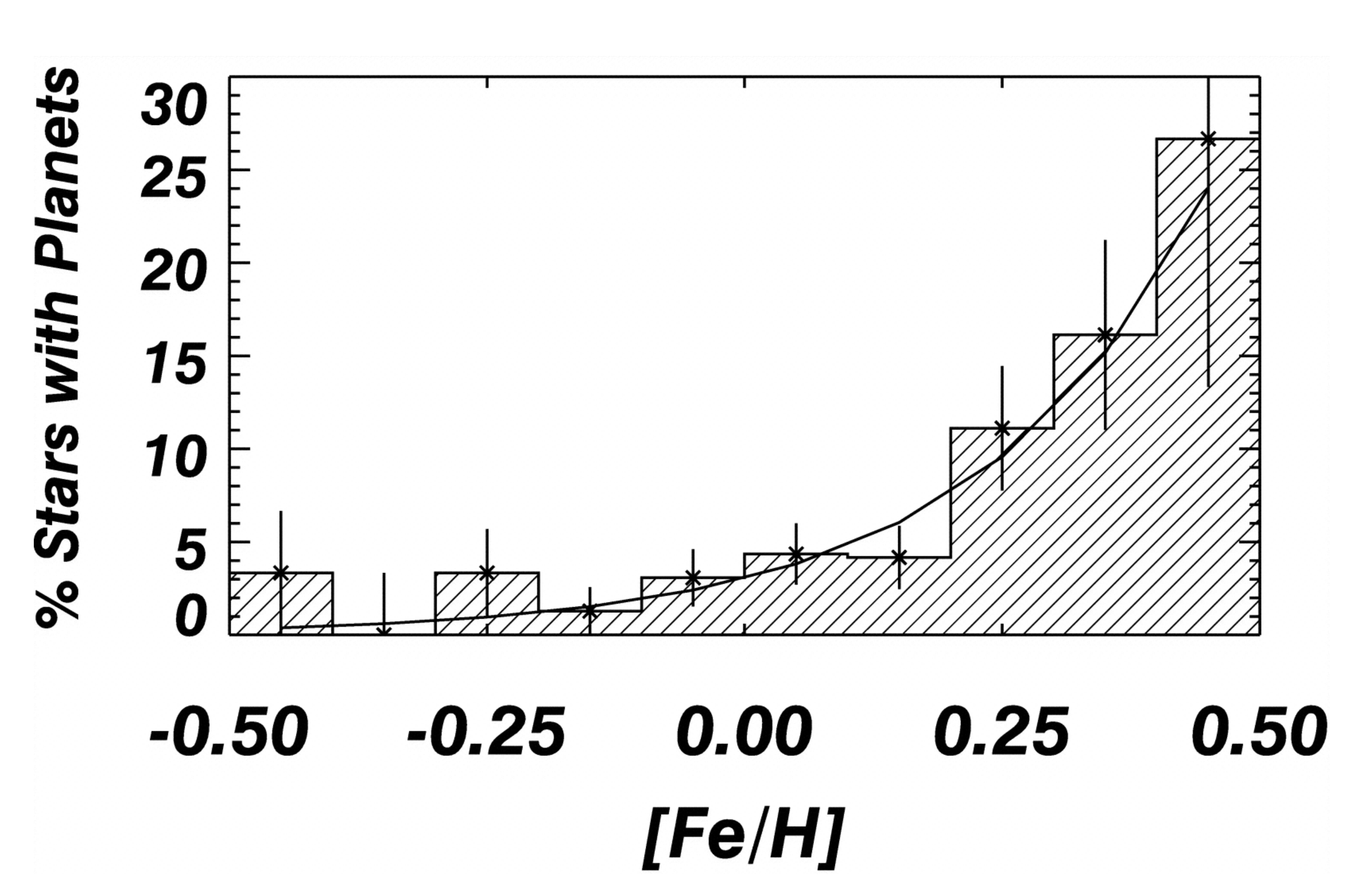
Core Accretion

Disk Instability

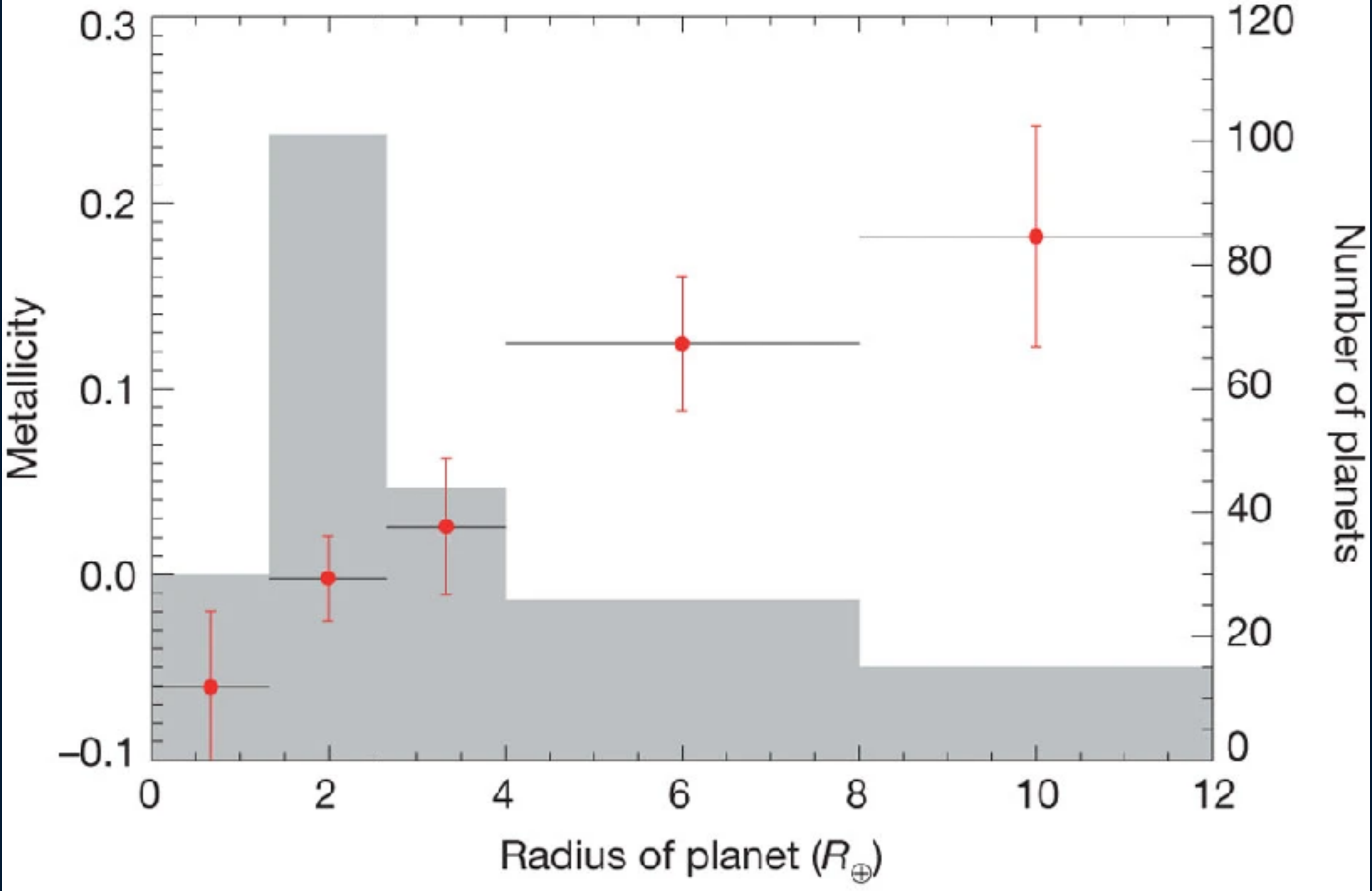
Cloud Fragmentation


Core Accretion
Disk Instability
Cloud Fragmentation
"It forms like a planet, I say"
?

[Fe/H] previous results



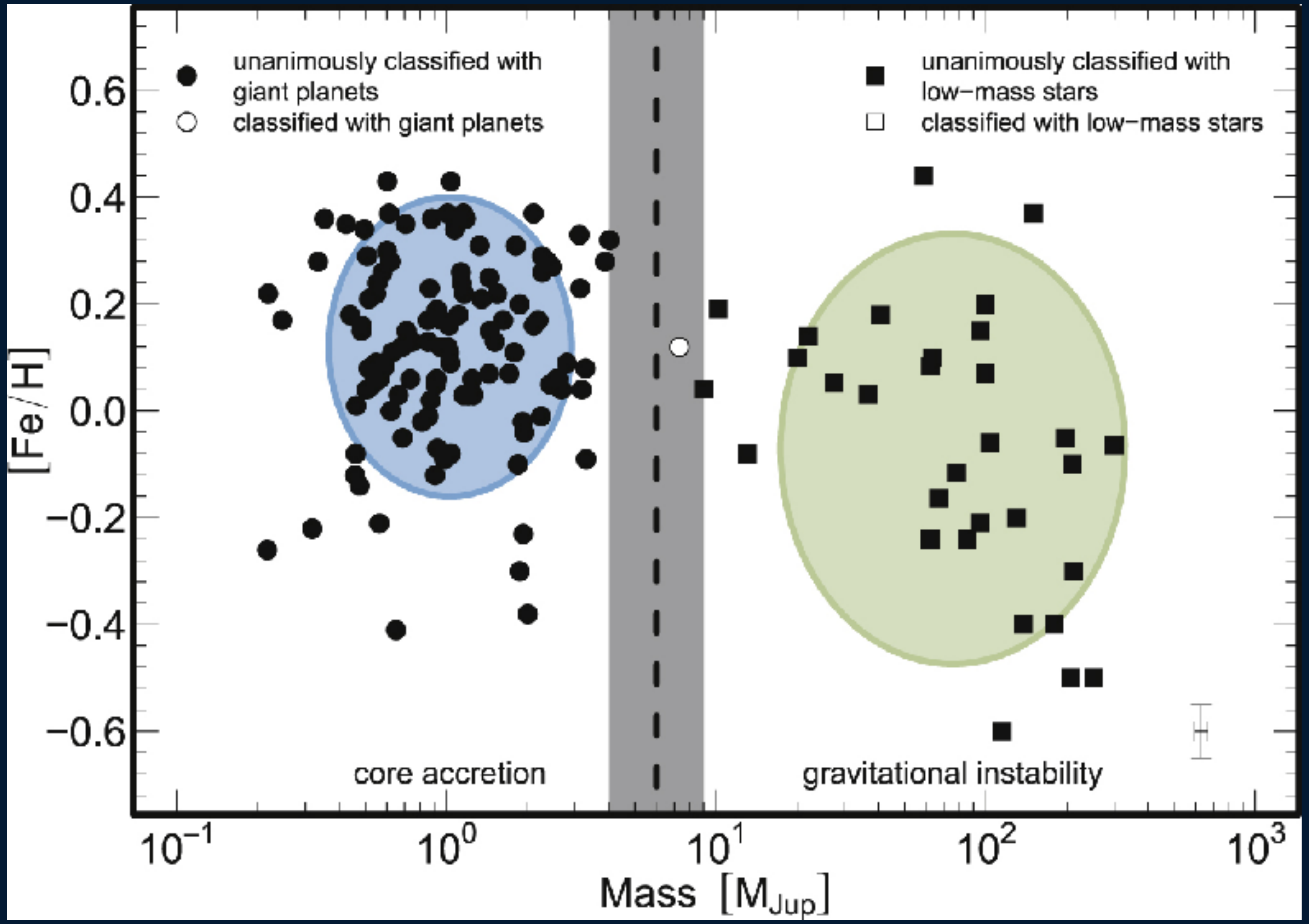
Fischer & Valenti (2005)



Buchhave et al. (2012)

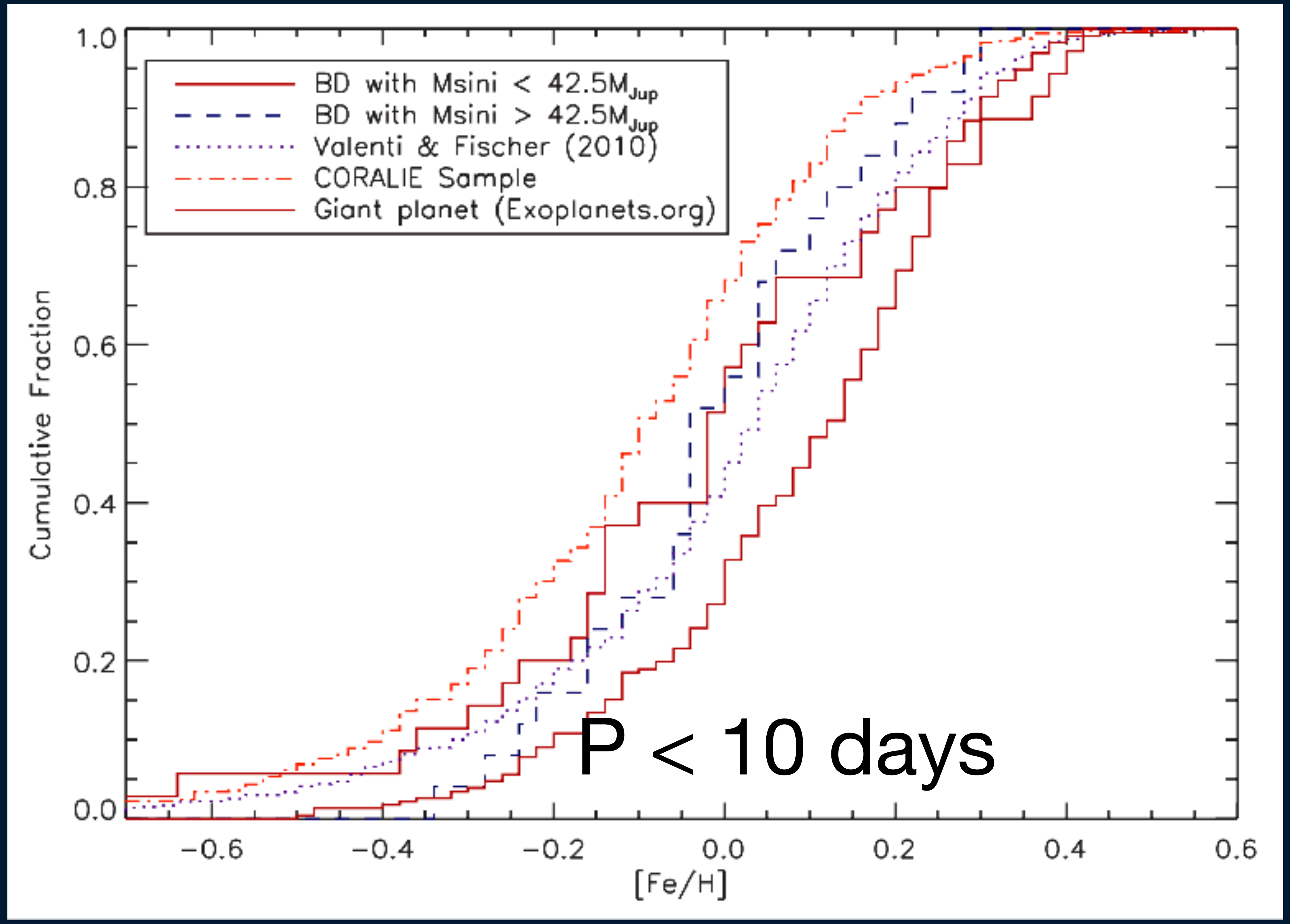
[Fe/H] previous results

$P < 10$ days $\rightarrow \sim 6 M_{\mathrm{Jup}}$



Schlaufman 2018

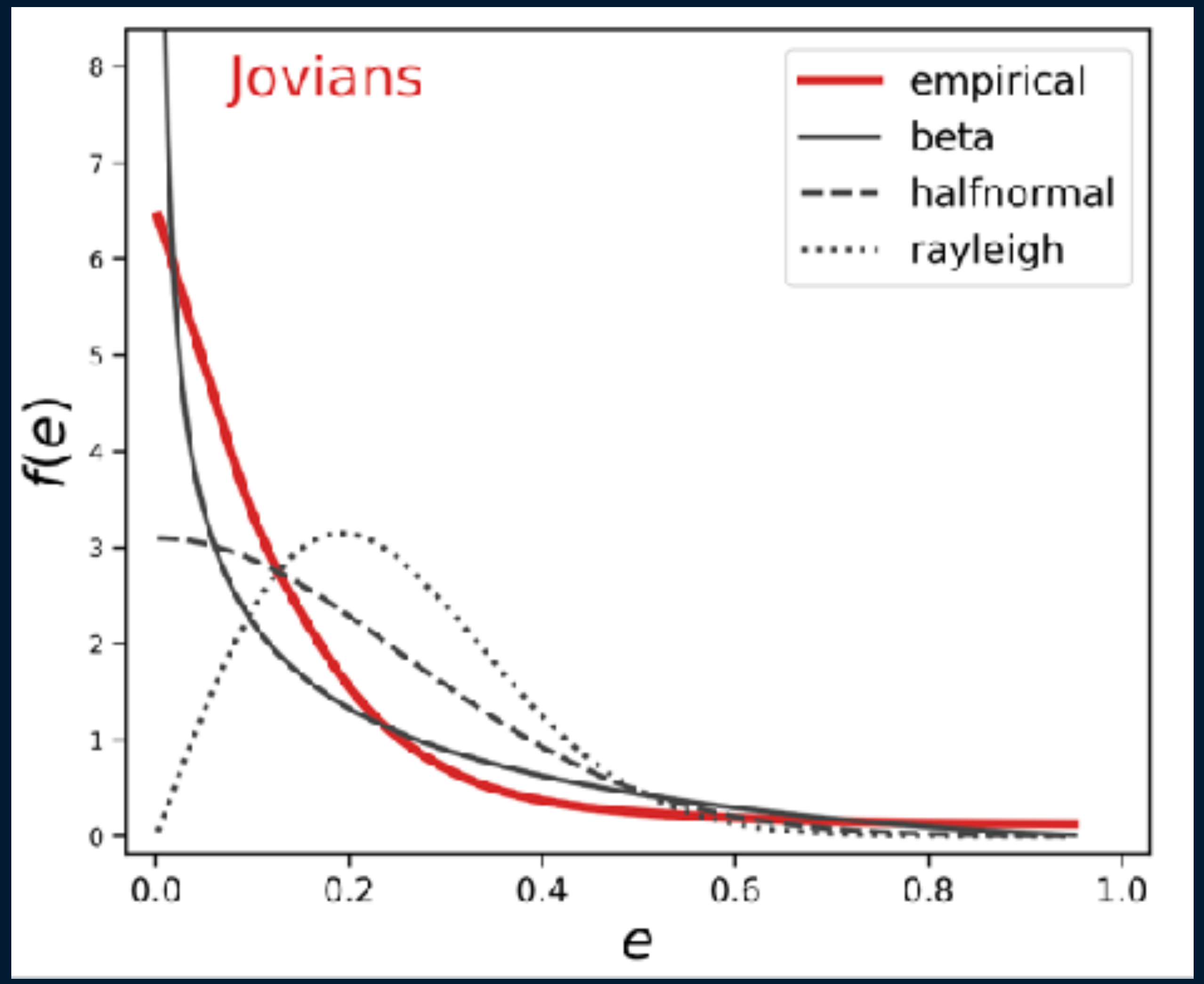
$P < 100$ days $\rightarrow \sim 42 M_{\mathrm{Jup}}$



Ma & Ge 2014

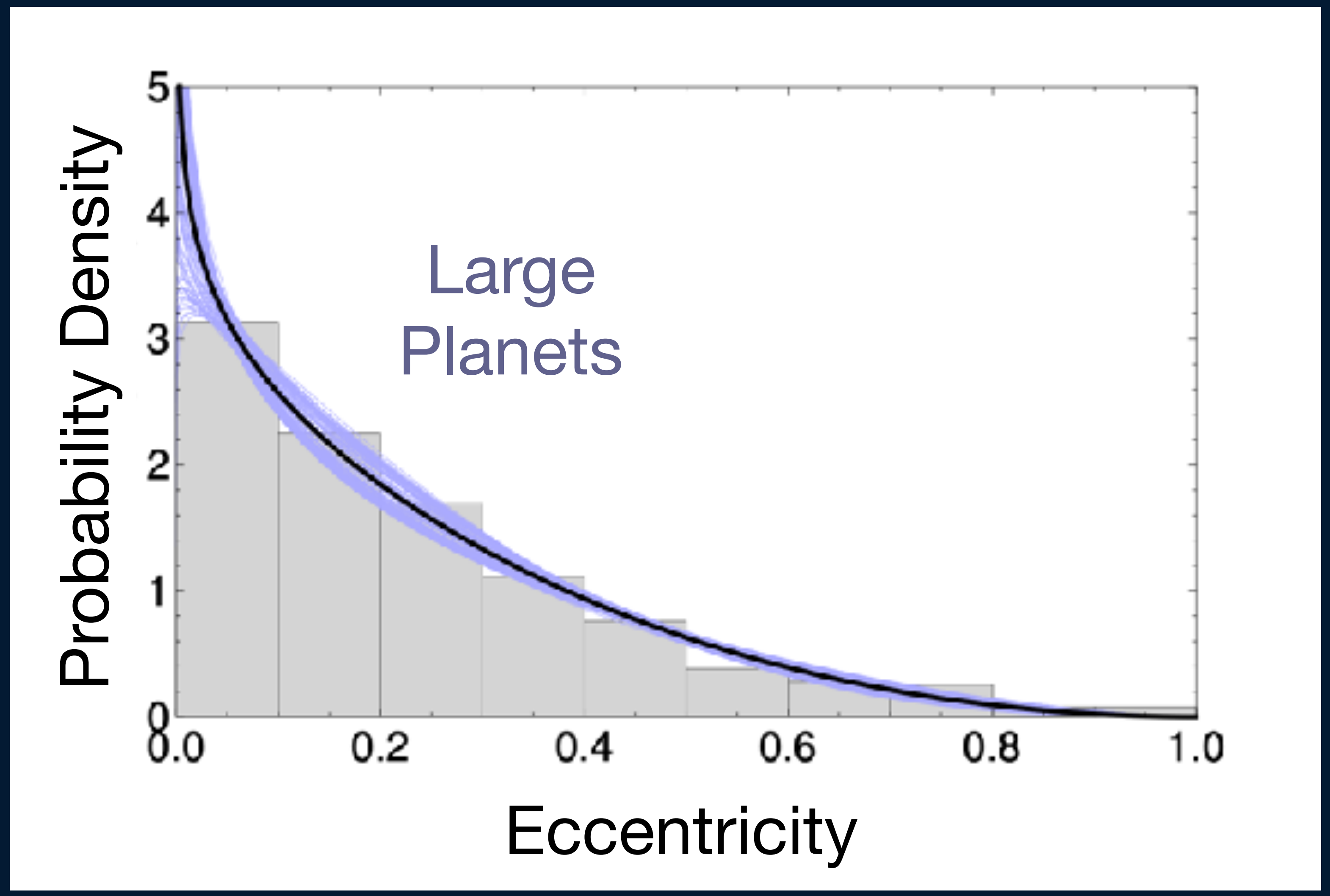
Eccentricity previous results

Transits, $P < 100$ days



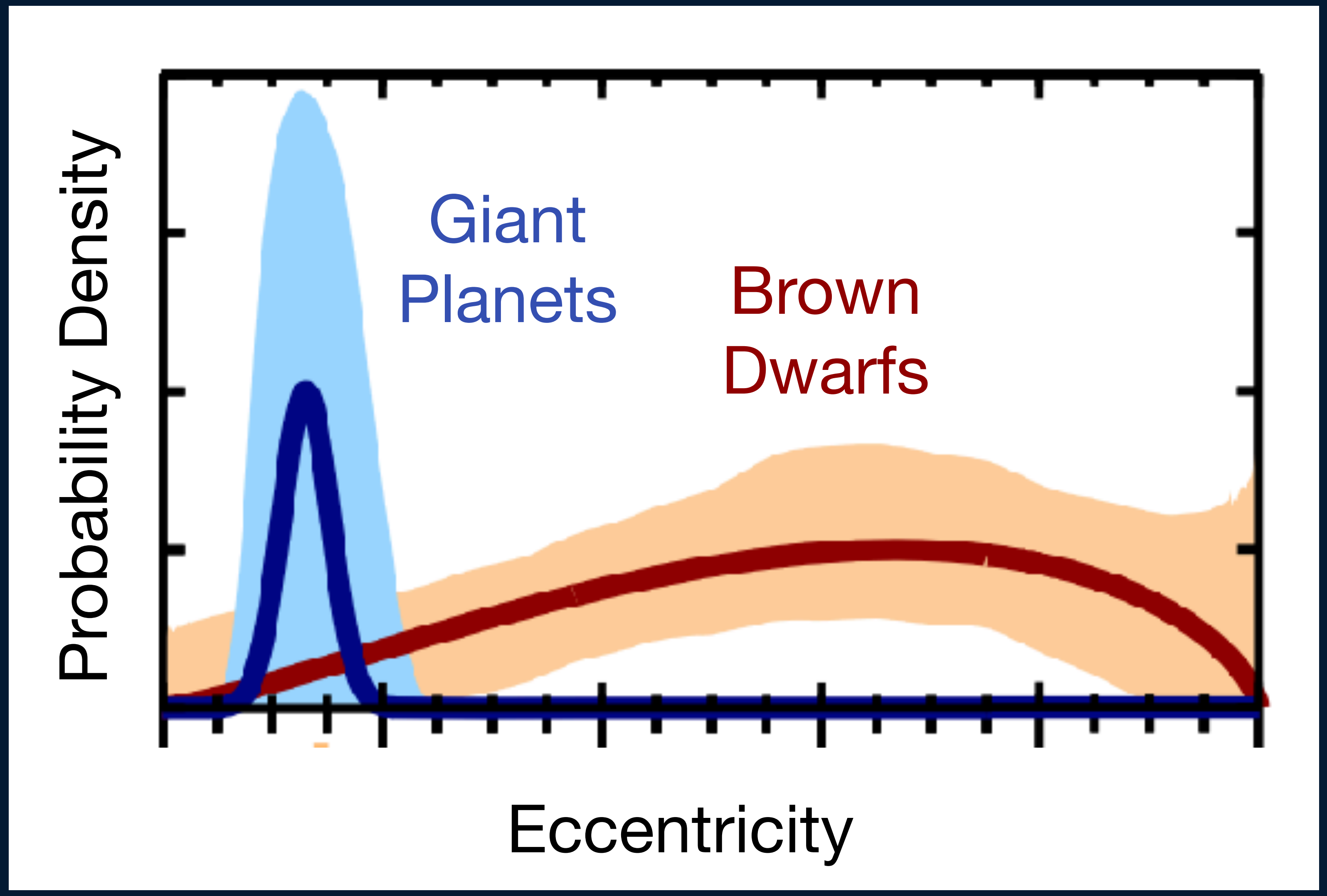
Gilbert, Petigura, & Entrican (2025)

Doppler $\langle P \rangle \approx 400$ days



Kipping (2013)

Direct Imaging, 5-10 AU

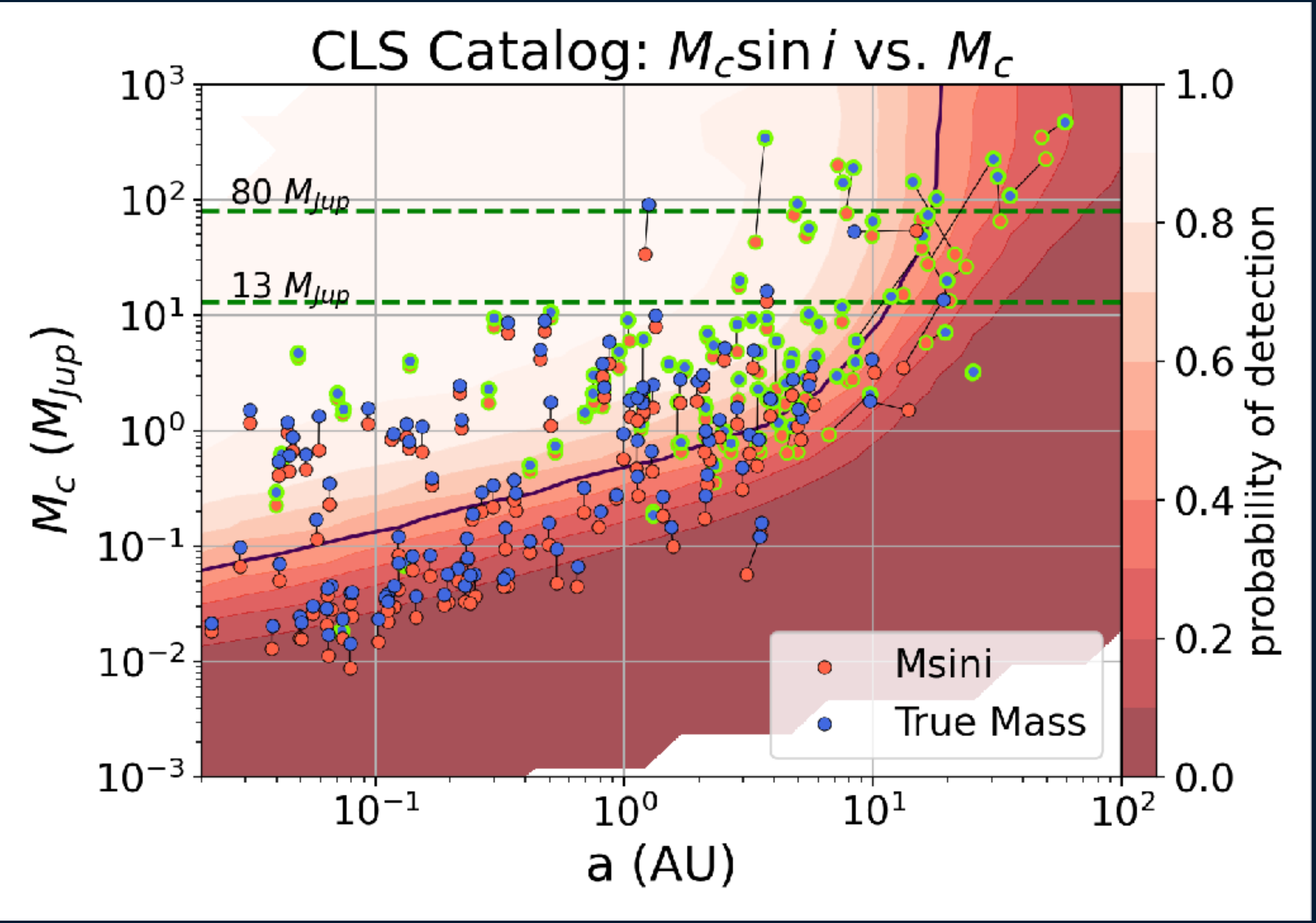


Bowler, Blunt, & Nielsen (2020)

Giant planets across a range of star-planet separations have $\langle e \rangle \approx 0.2$

Giant planets and brown dwarfs near the ice line

California Legacy Survey RVs + Gaia Astrometry



Van Zandt, Gilbert, et al. (in review)

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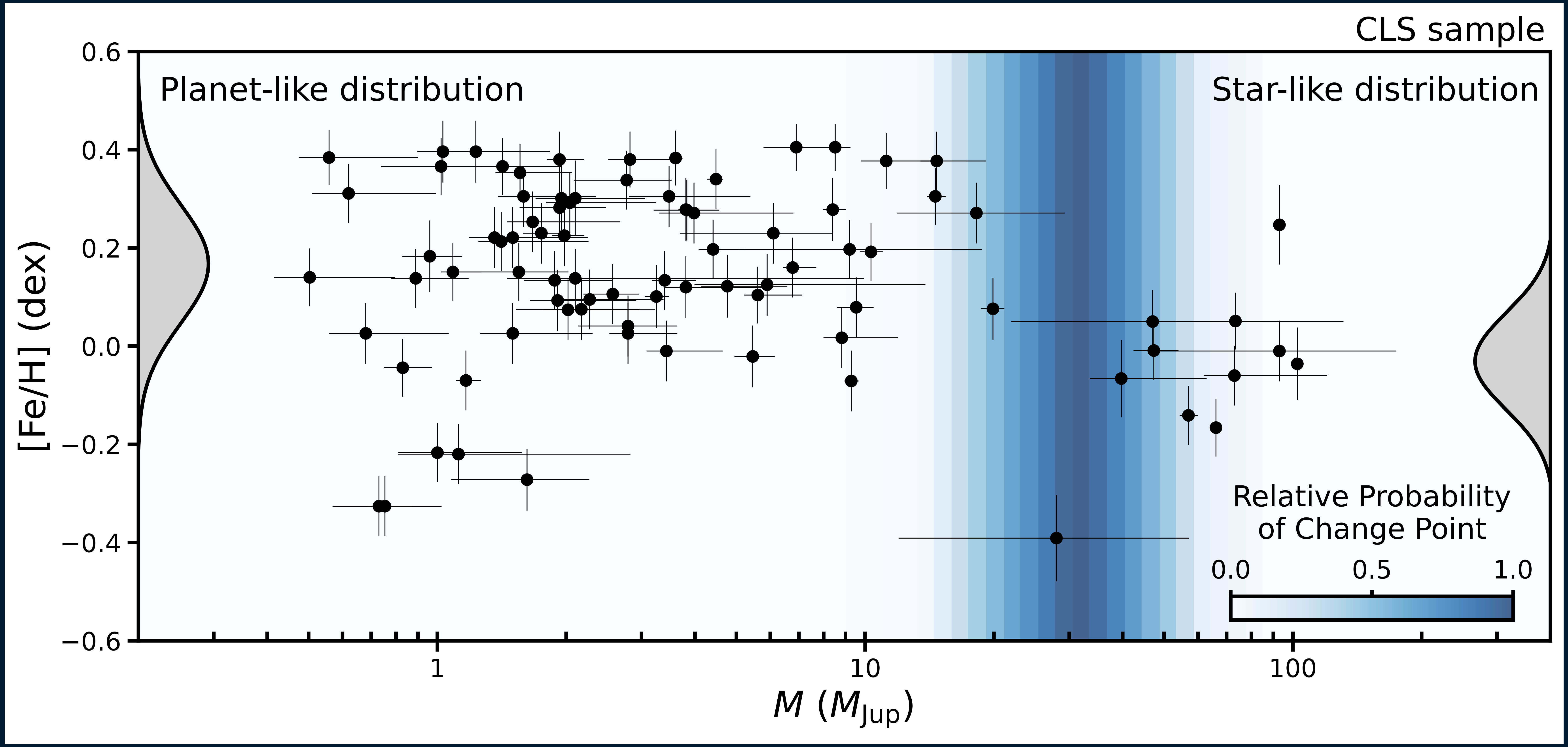

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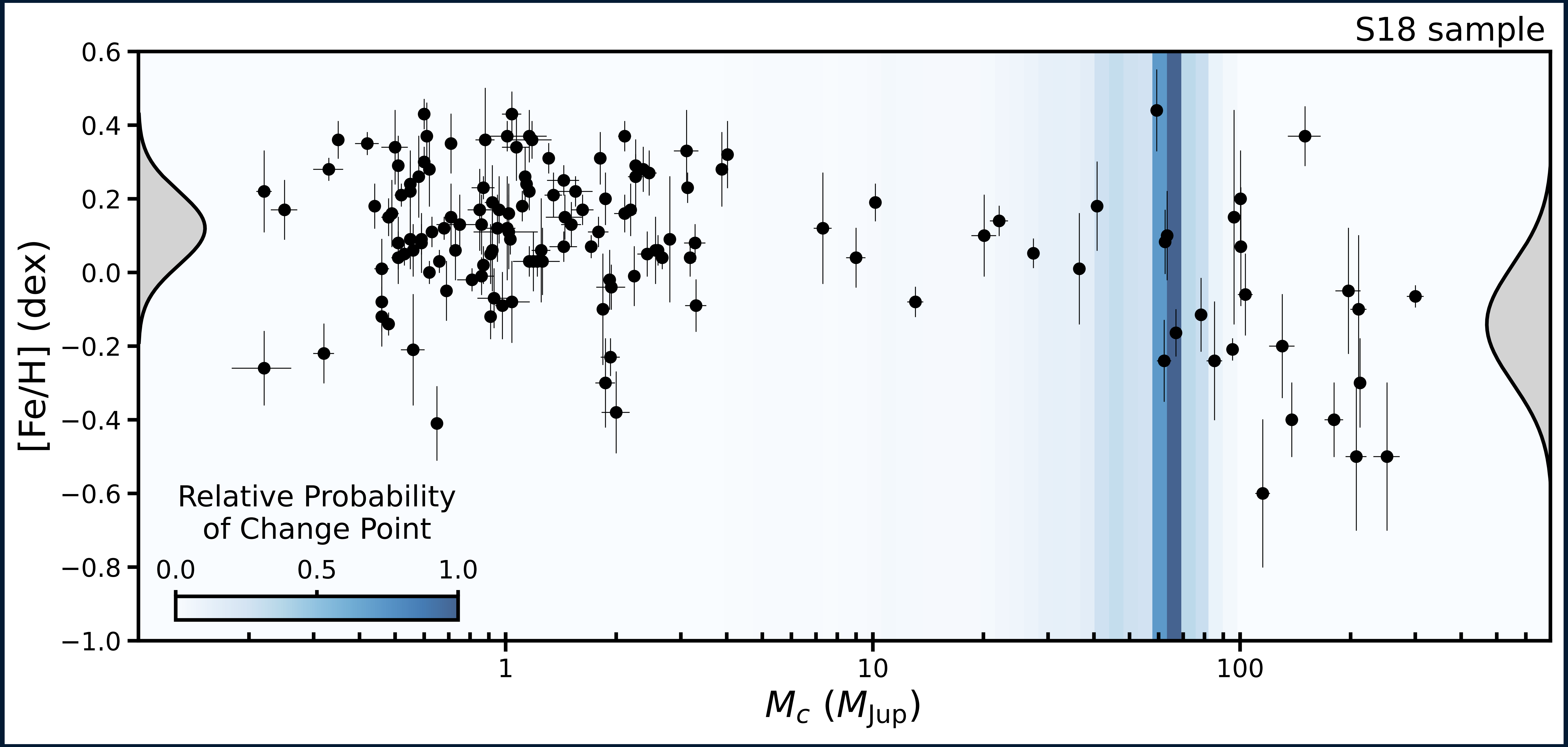
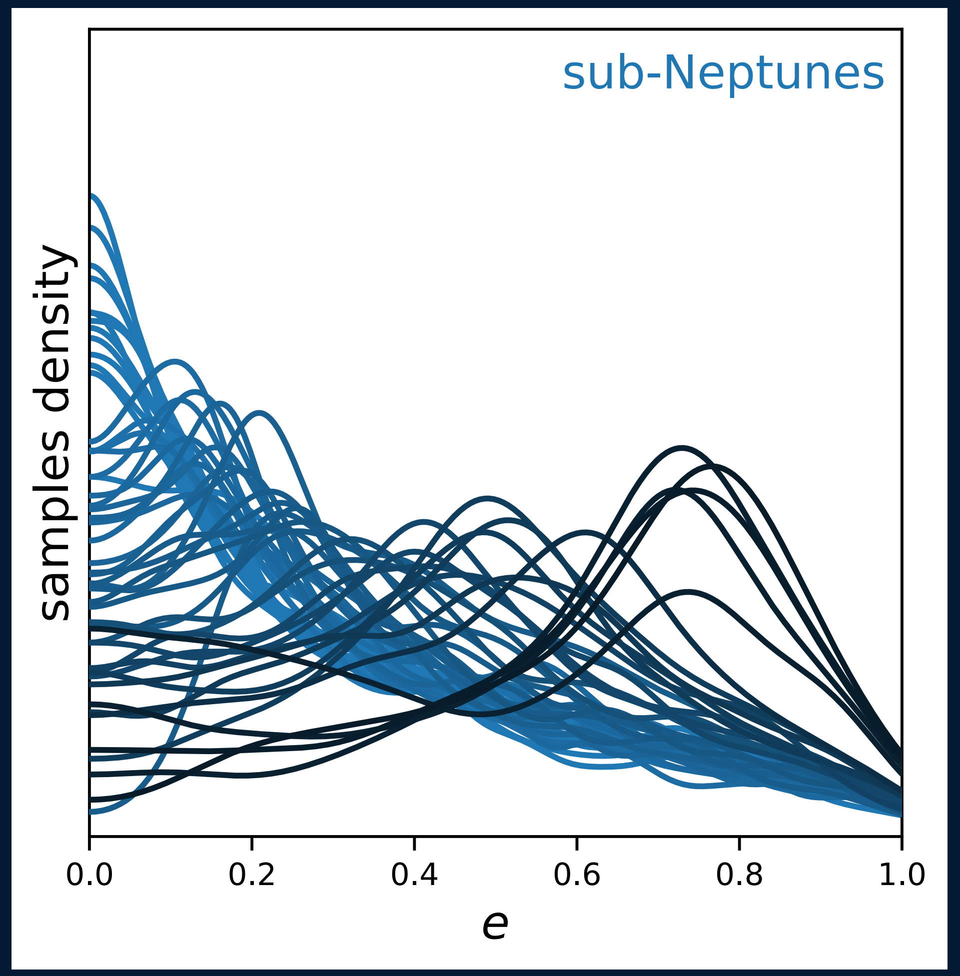
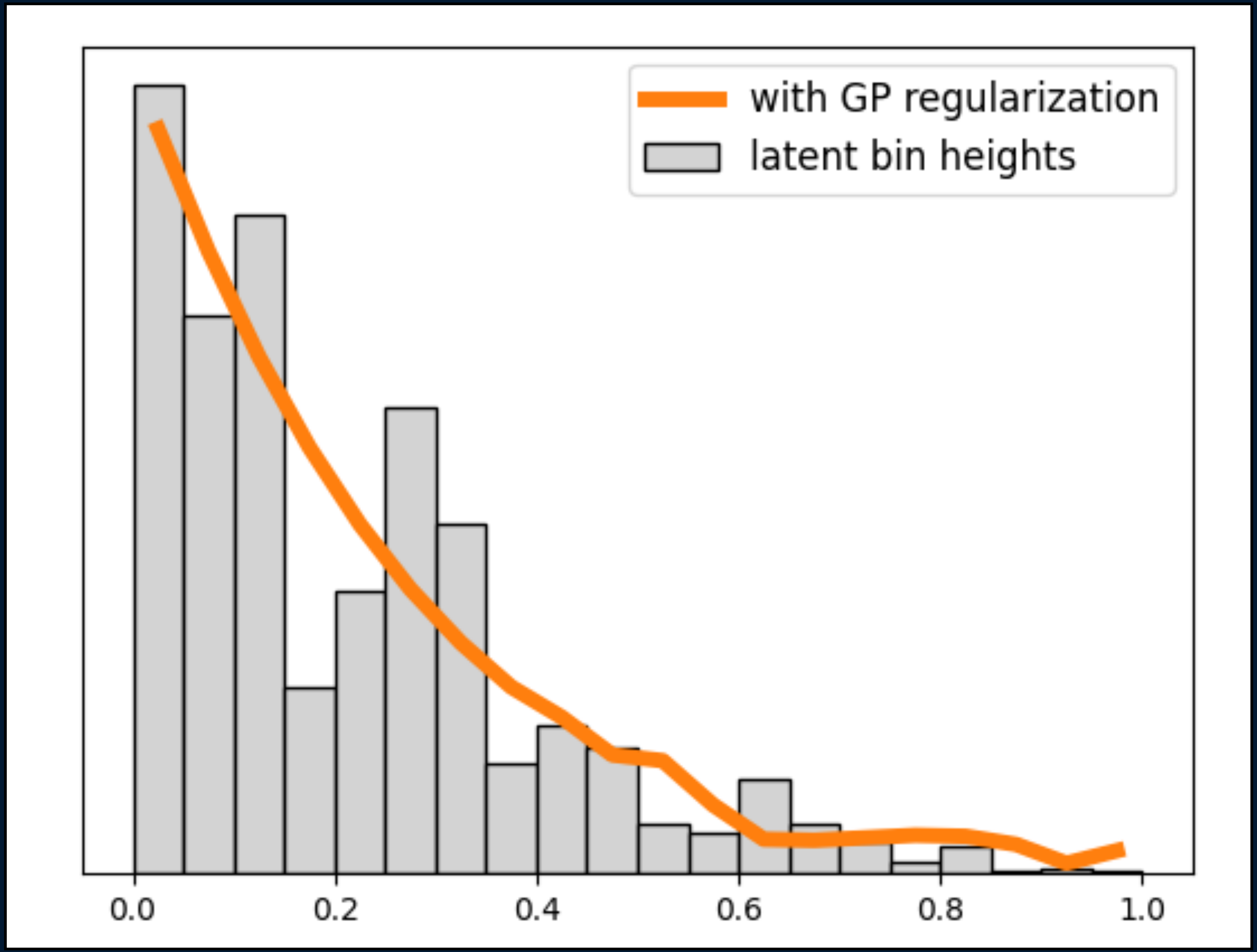


Giacalone, Howard, Gilbert et al. (2025)

We infer population $f(e)$ from individual $\{e\}_i$ with a Hierarchical Bayesian Model





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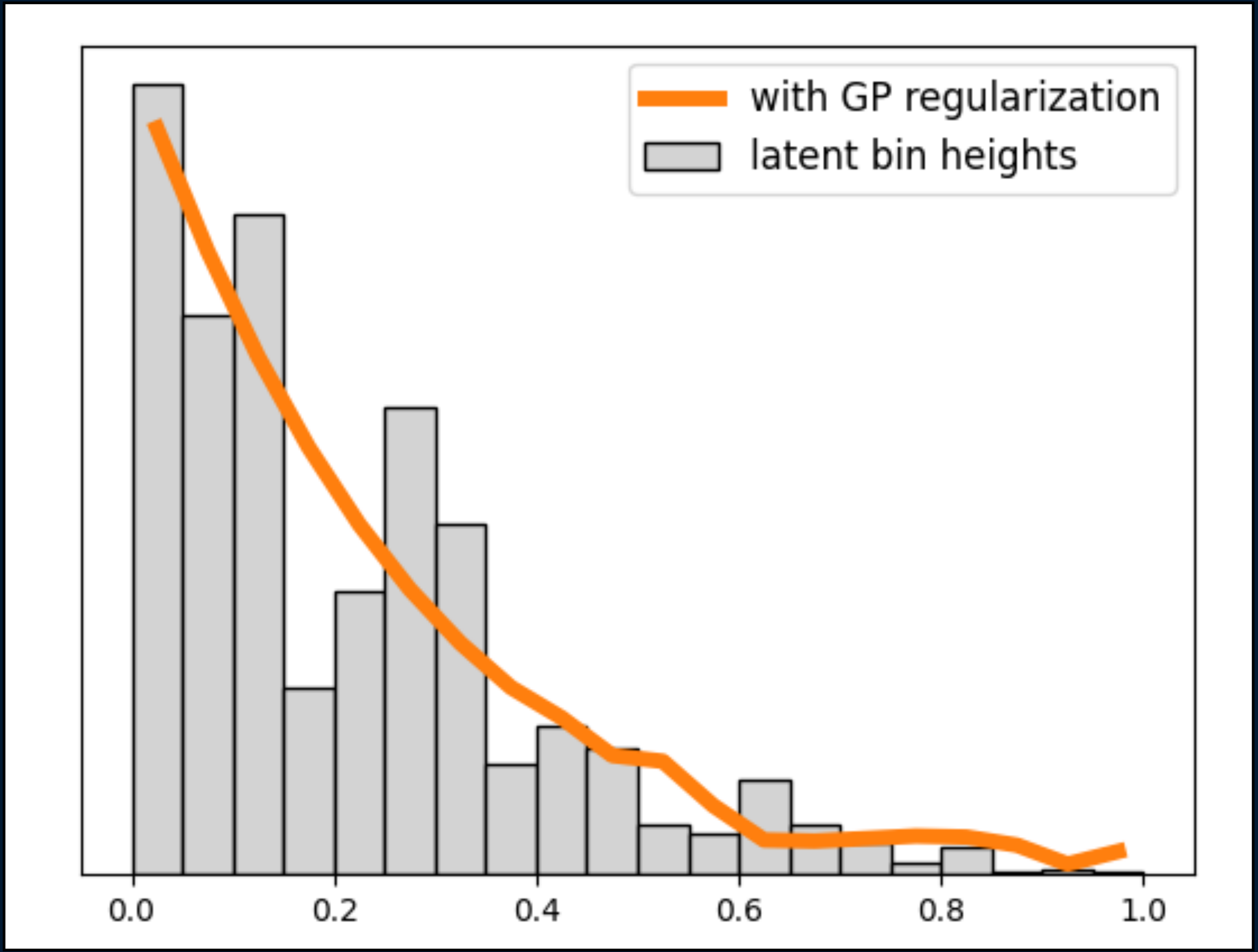

Empirical Histogram

- 25 bins $\rightarrow \Delta e \sim 0.04$
- GP regularization enforces smoothness
- Agnostic to underlying distribution shape

Hogg+ (2010) | Foreman-Mackey+ (2014)
Van Eylen+ (2019) | Bowler+ (2020)
Masuda+ (2022) | Sagear & Ballard (2023)

Gilbert, Petigura, & Entrican (2025)

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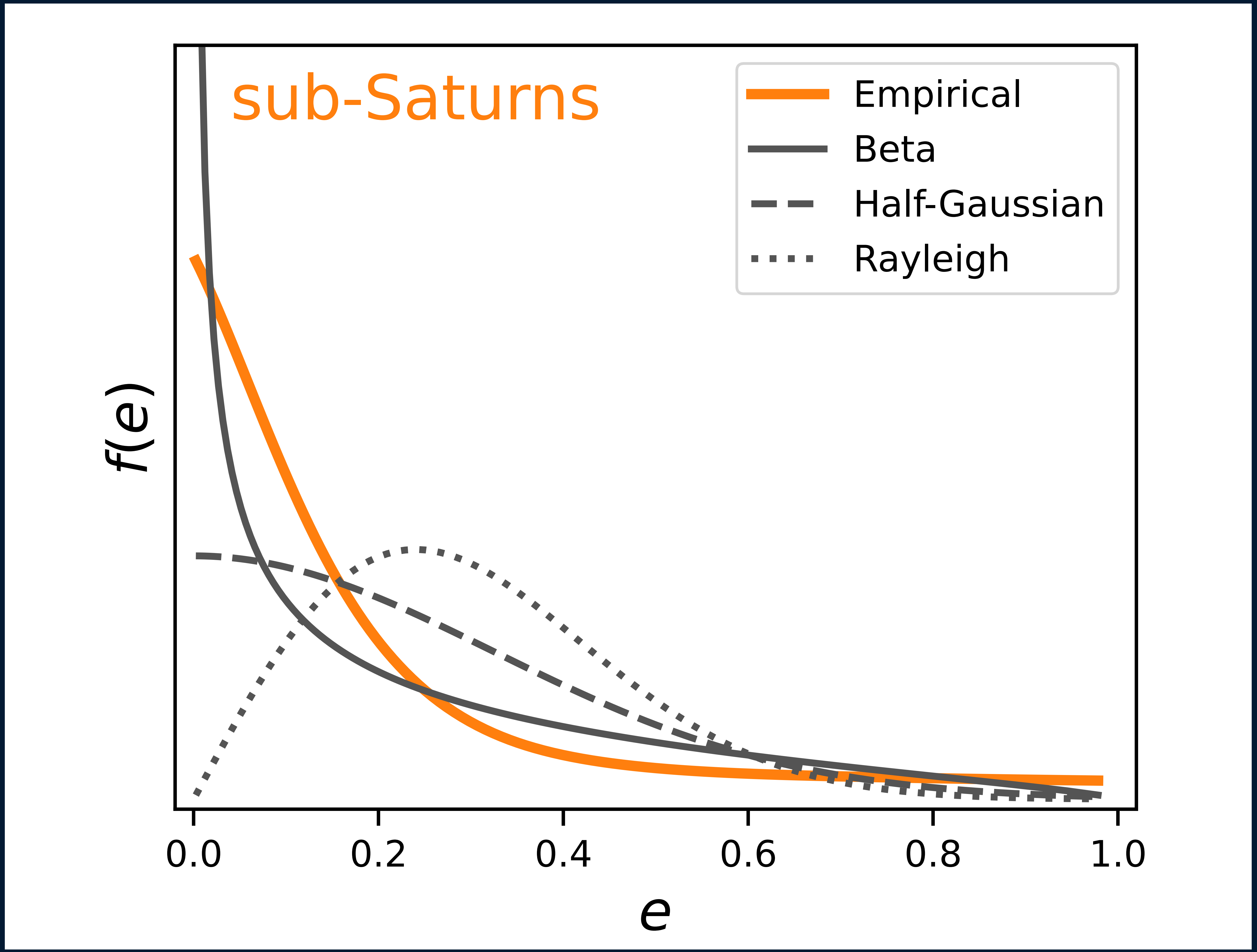

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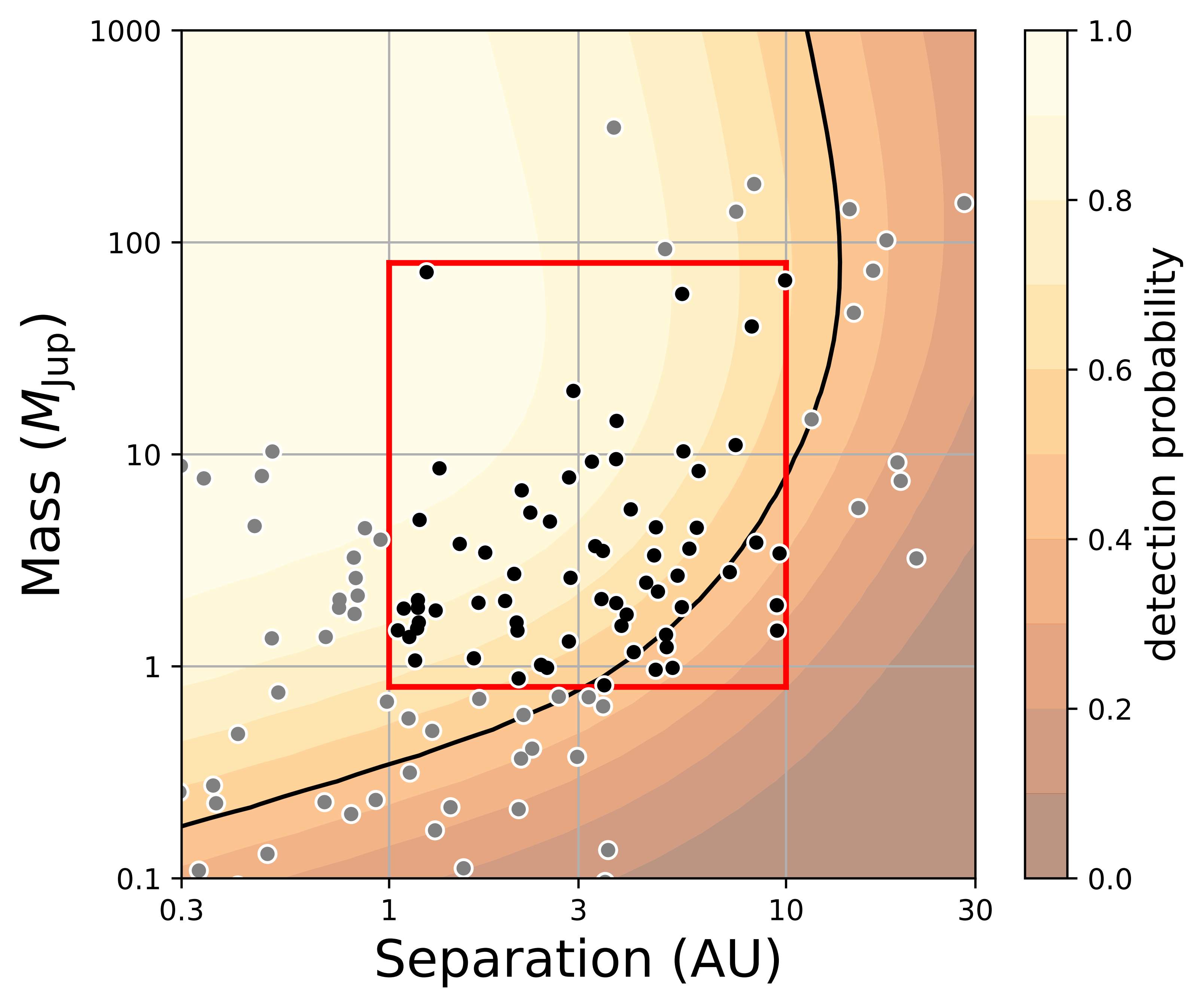
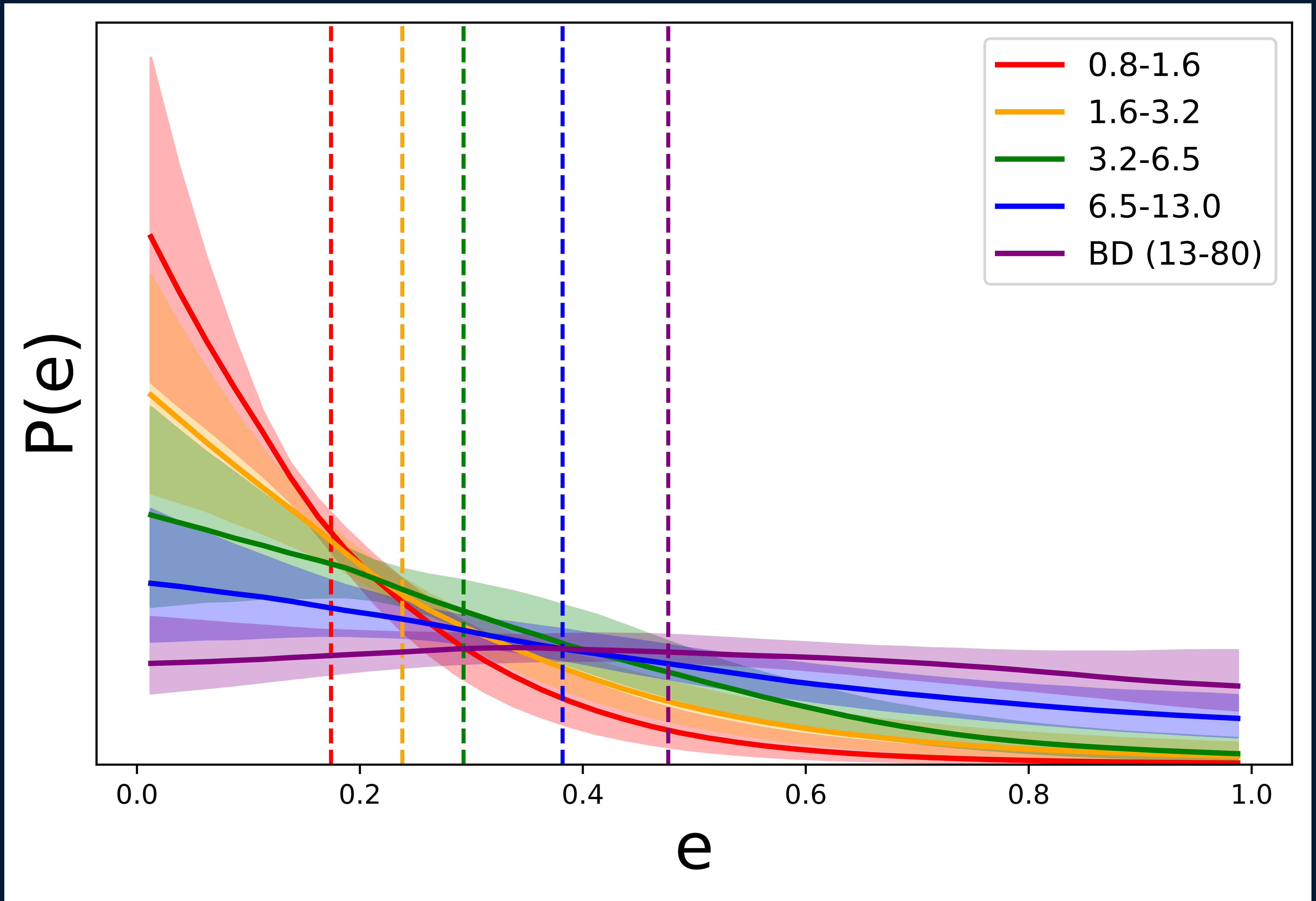




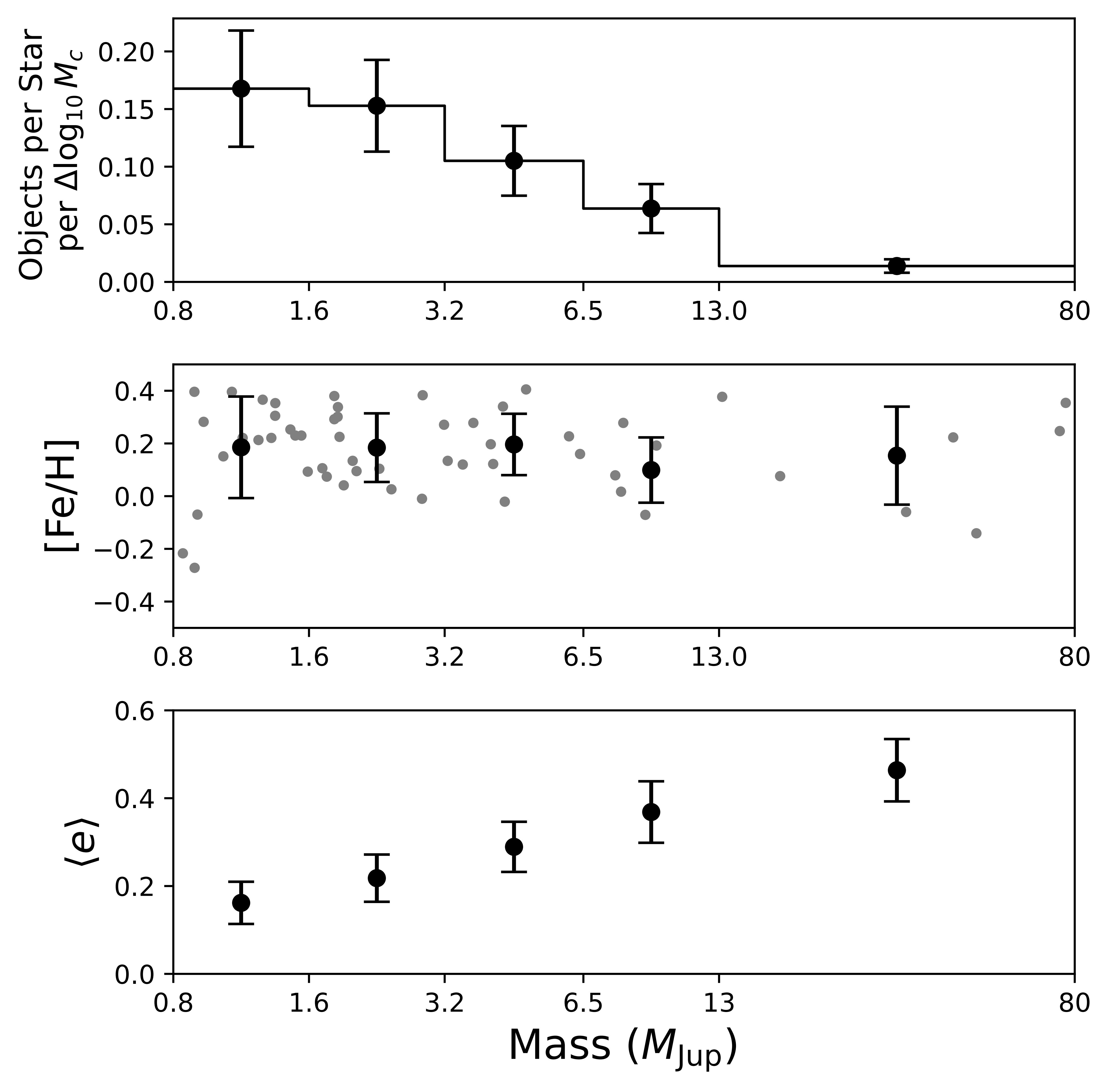
Gilbert, Van Zandt, et al. (2025)

CLS | $a = 1 - 10$ AU | $M_p = 0.8 - 80\ M_J$

Monotonic decrease in occurrence

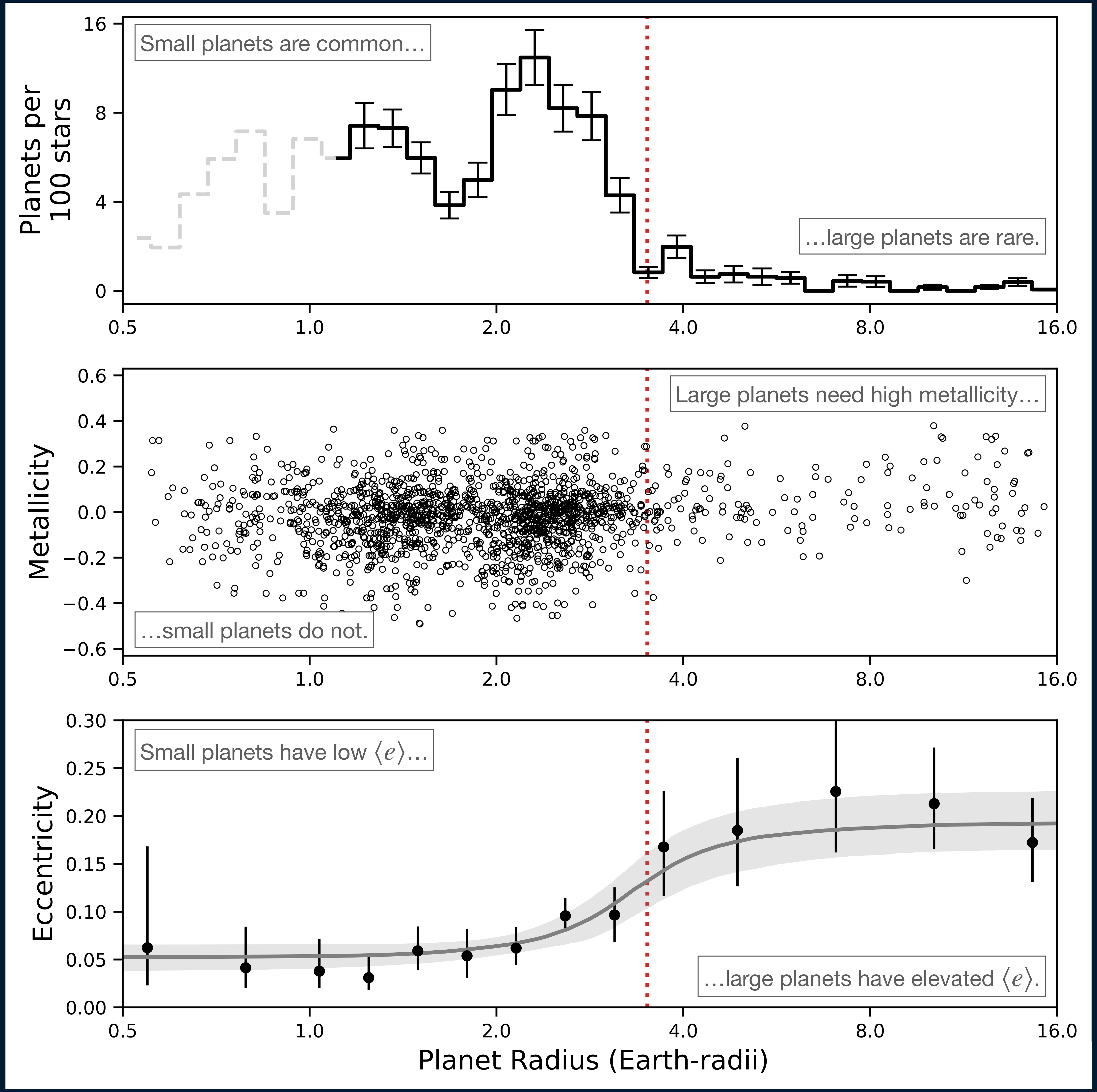
No / weak trend in host star [Fe/H]

Monotonic increase in eccentricity



Gilbert, Van Zandt, et al. (2025)

Kepler | $P < 100$ days | $R_p = 0.5 - 16\ R_\oplus$



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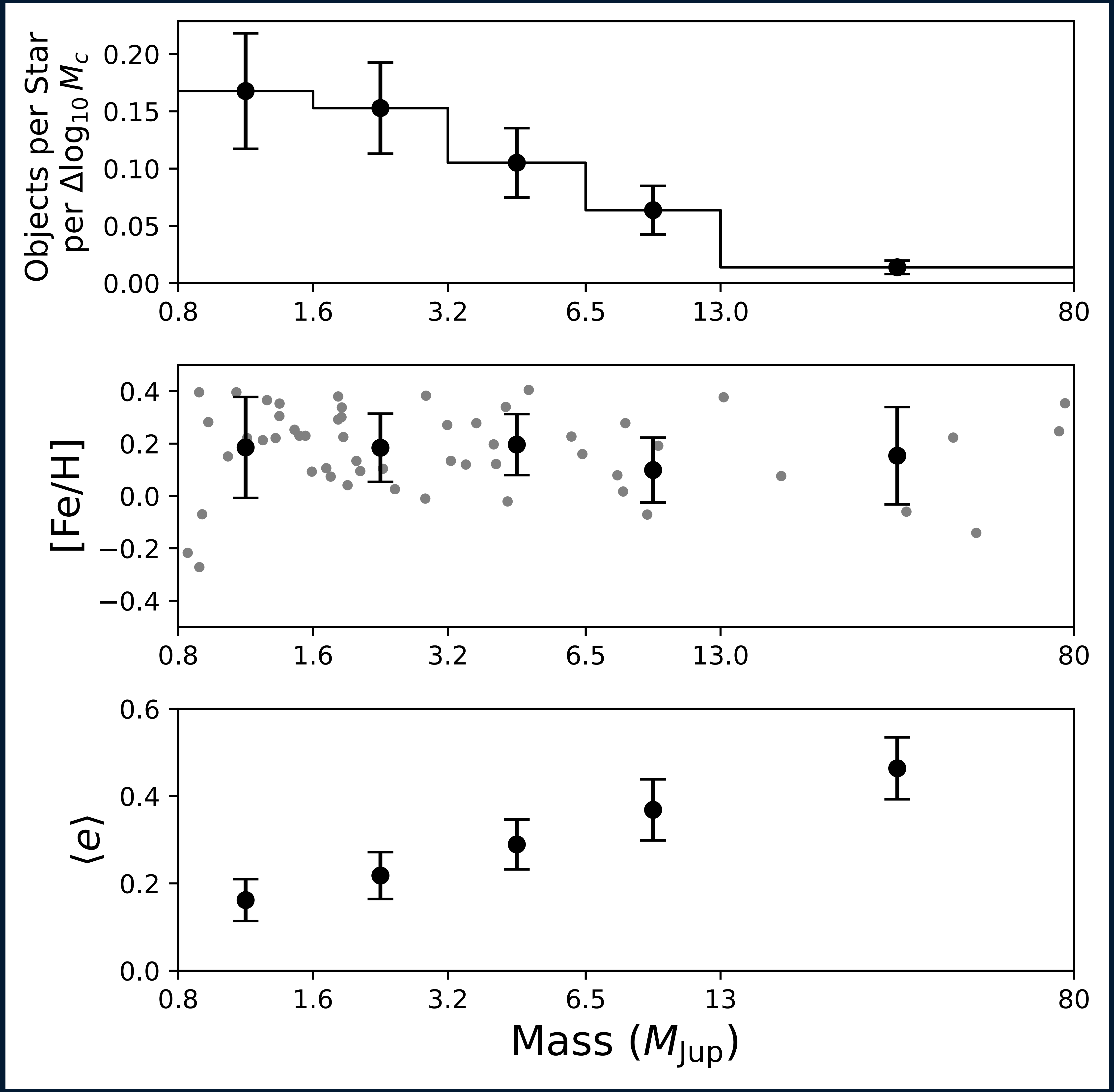


Gilbert, Van Zandt, et al. (2025)

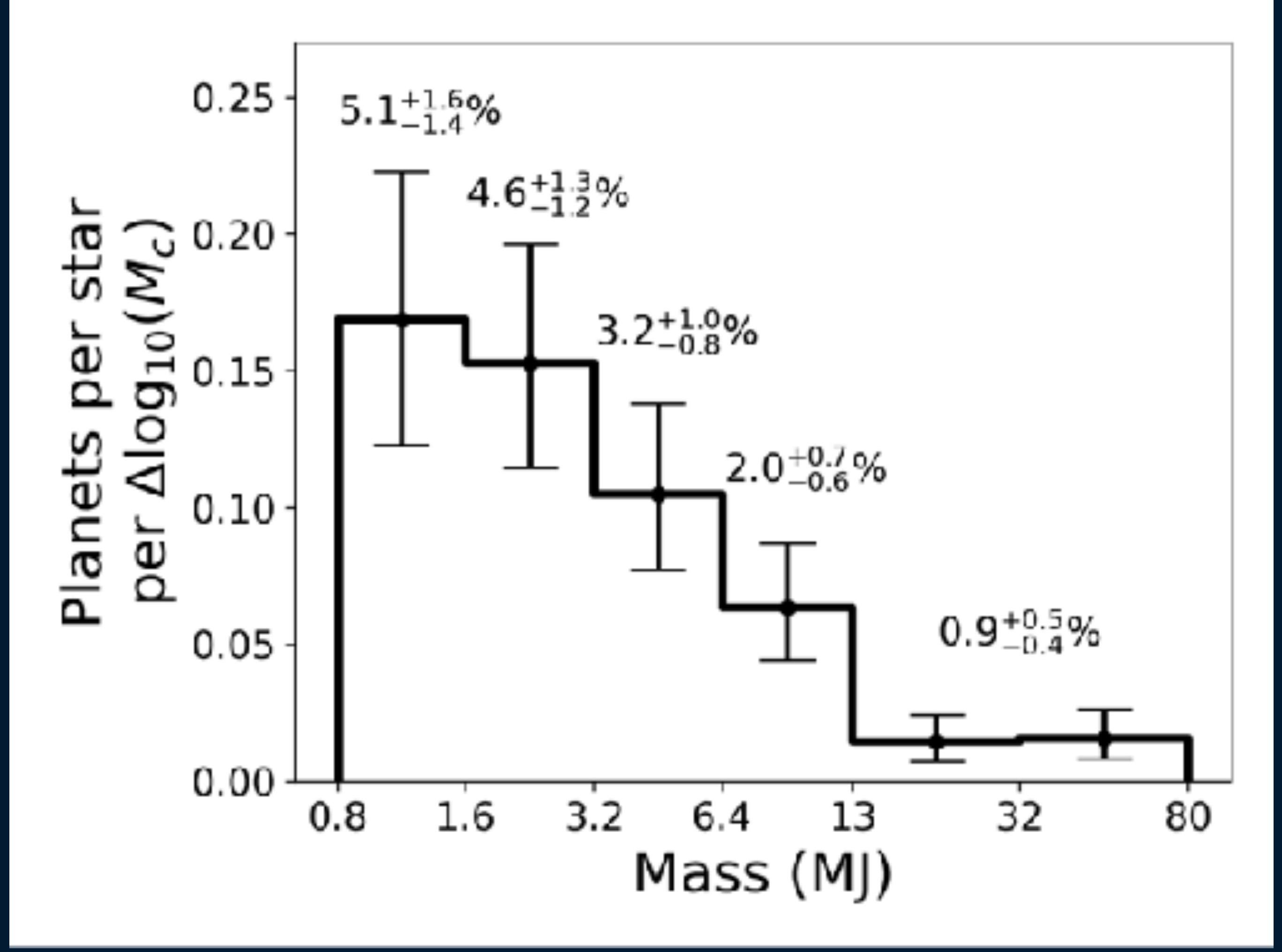
The emerging picture of planet formation

- Planets form via core accretion on nearly circular orbits
- Systems with larger planets experience greater dynamical excitation
- High metallicity raises likelihood of forming giant planets
- Giant planets transition into brown dwarfs gradually, with core accretion and gravitational instability regimes overlapping between 1-10 MJ

A smooth transition from giant planets to brown dwarfs near the ice line from…

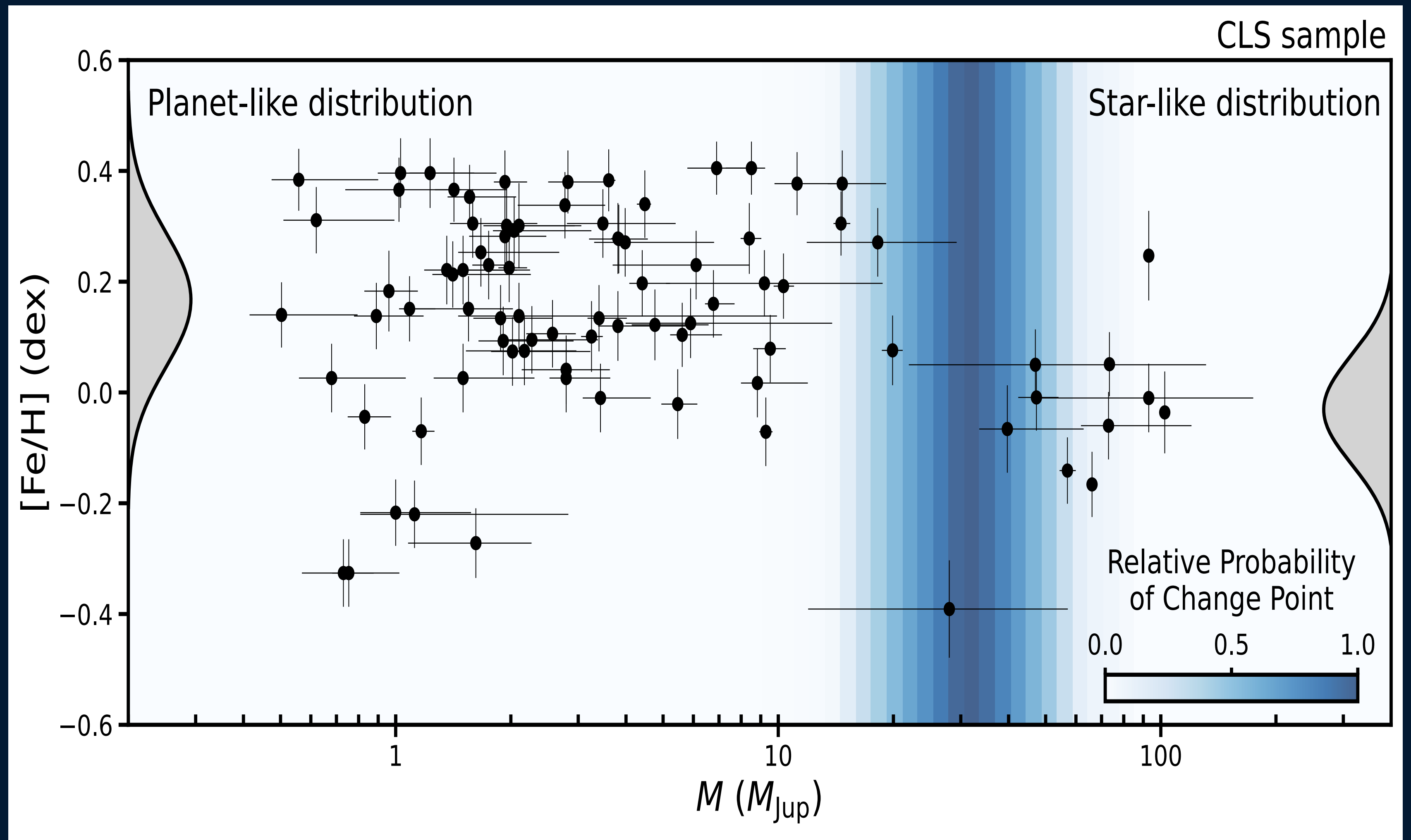
Occurrence rates

Van Zandt, Gilbert, et al. (in review)



Metallicity

Giacalone, Howard, Gilbert, et al. (2025)



Eccentricity

Gilbert, Van Zandt, et al. (2025)