Combining microlensing and transit demographics

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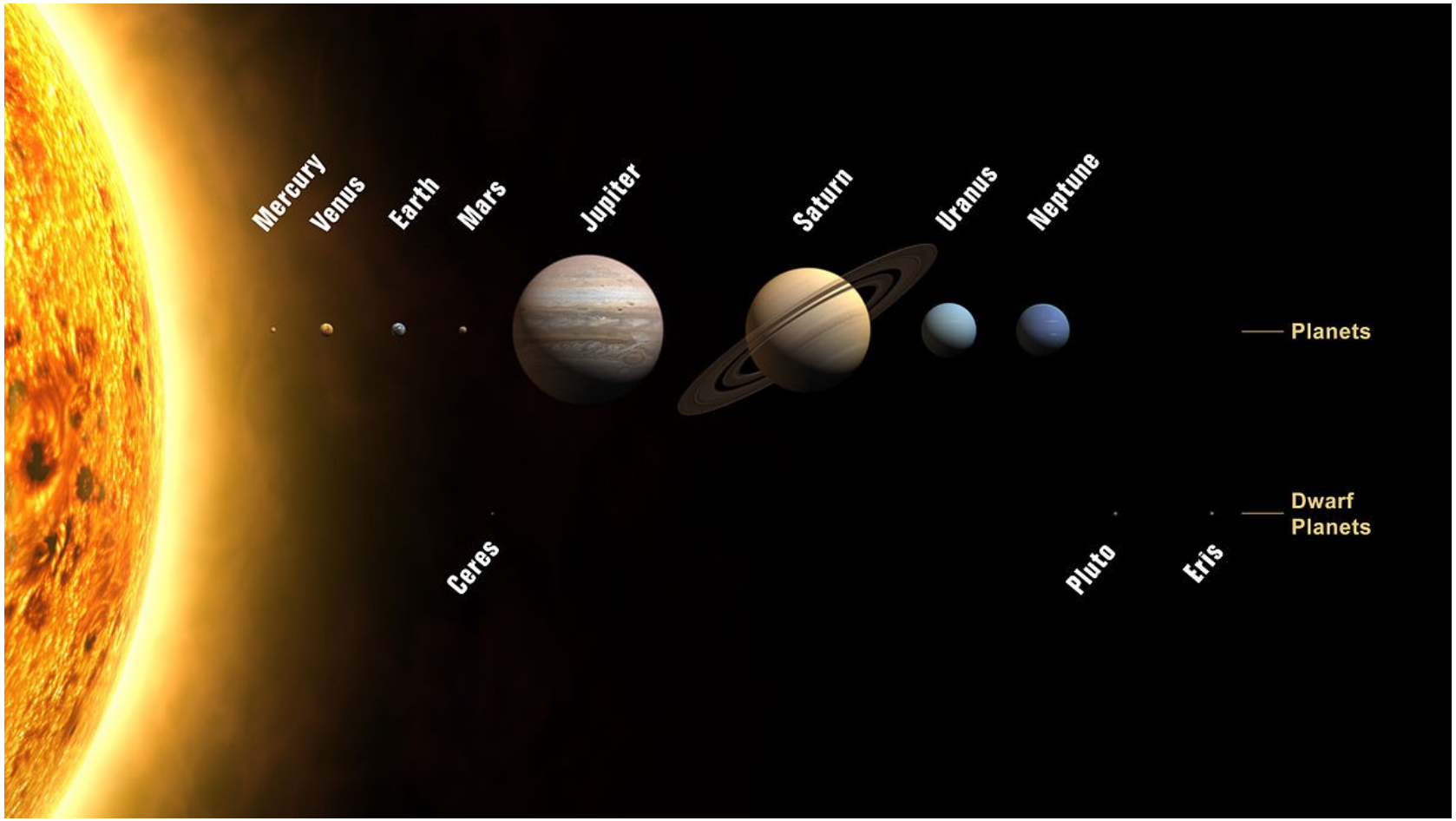
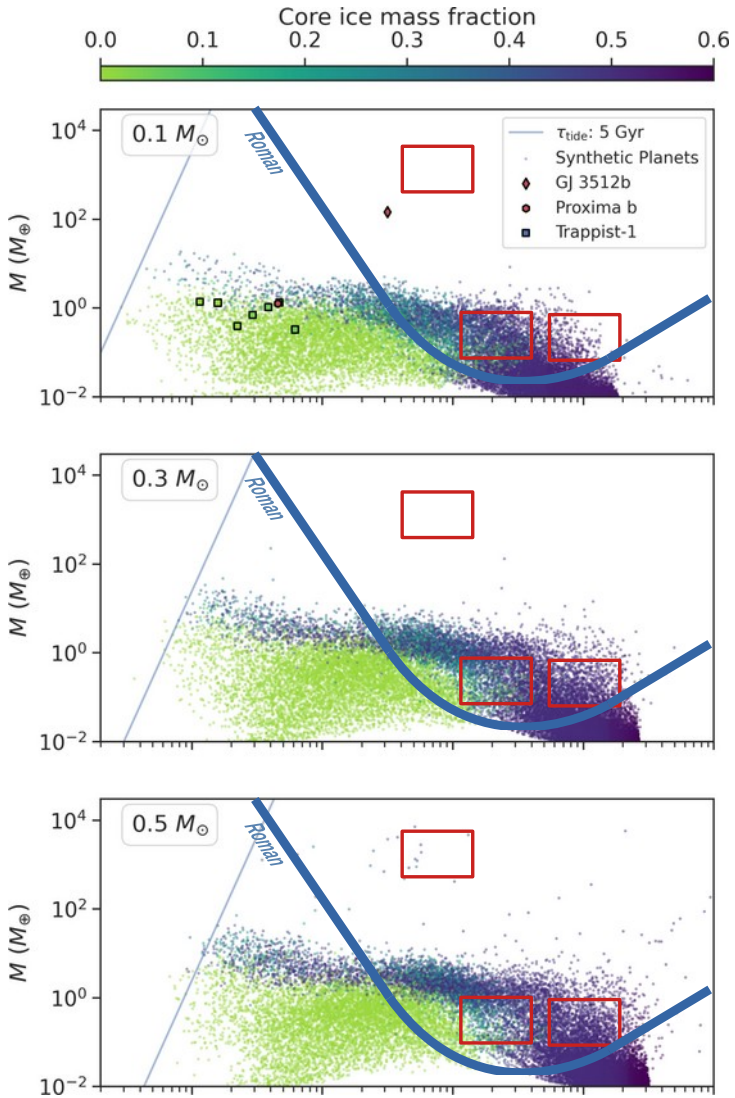
Why should we care about exoplanet demographics?

Is the architecture of our solar system typical?



Roman and planet formation

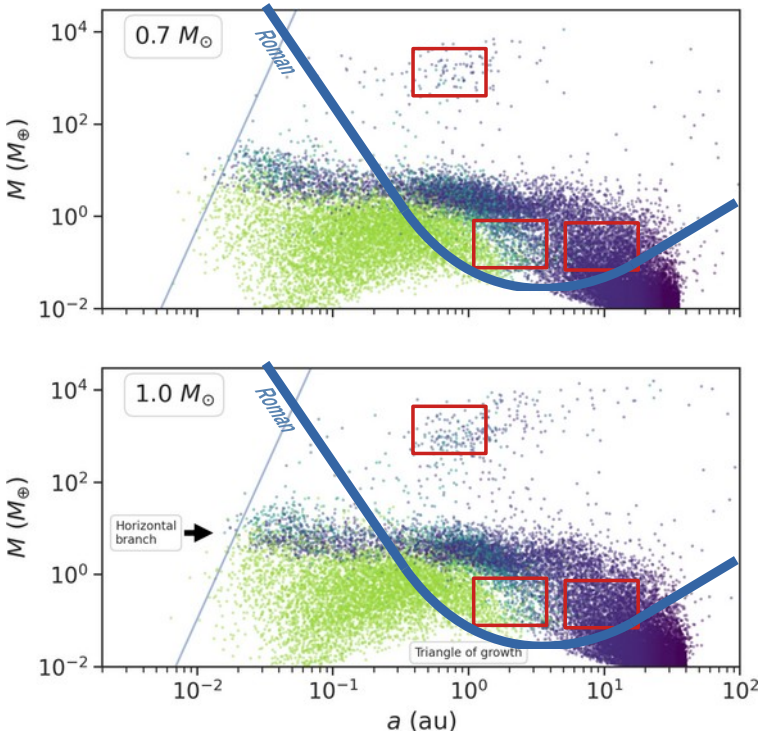
Each panel based on 1000 simulated systems, each seeded with 50 planet embryos



Burn et al (2021)

NGPPS simulations from the Mordasini-led Bern Planet Formation Group

Roman sensitivity curve from Penny et al (2019)



The Drake Equation

$$N = R_* \cdot f_\mathrm{p} \cdot n_\mathrm{e} \cdot f_\mathrm{l} \cdot f_\mathrm{i} \cdot f_\mathrm{c} \cdot L$$

f_p : fraction of stars hosting planets
Roman will make the
best determination
yet of this parameter

n_e : average number of habitable planets
per star that hosts planets
Roman will make the
first ever determination
of this parameter

What is the demographic distribution of exoplanets?

An ill-posed question with no answer!

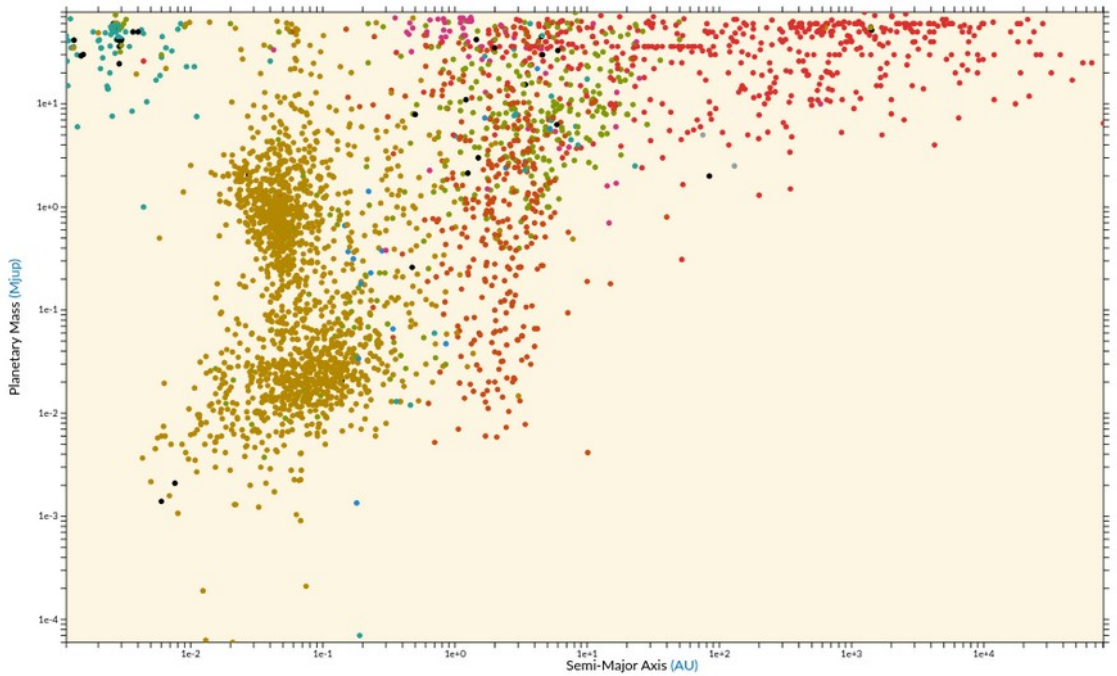
Examples of better posed demographic questions:

- What is the average number of planets per star as a function of Galactic location?
- What is the frequency of habitable zone planets around FGK stars within 1 kpc of the Sun?
- What does the underlying planet period vs radius frequency distribution look like?
- What does the underlying planet mass vs projected host separation look like?
- What is the occurrence of Jupiters around M dwarf stars as a function of host metallicity?

Generally we are interested in knowing the underlying abundance of exoplanets that fit specified criteria. The criteria may cover combinations of properties about the planets, their hosts and/or their environment.

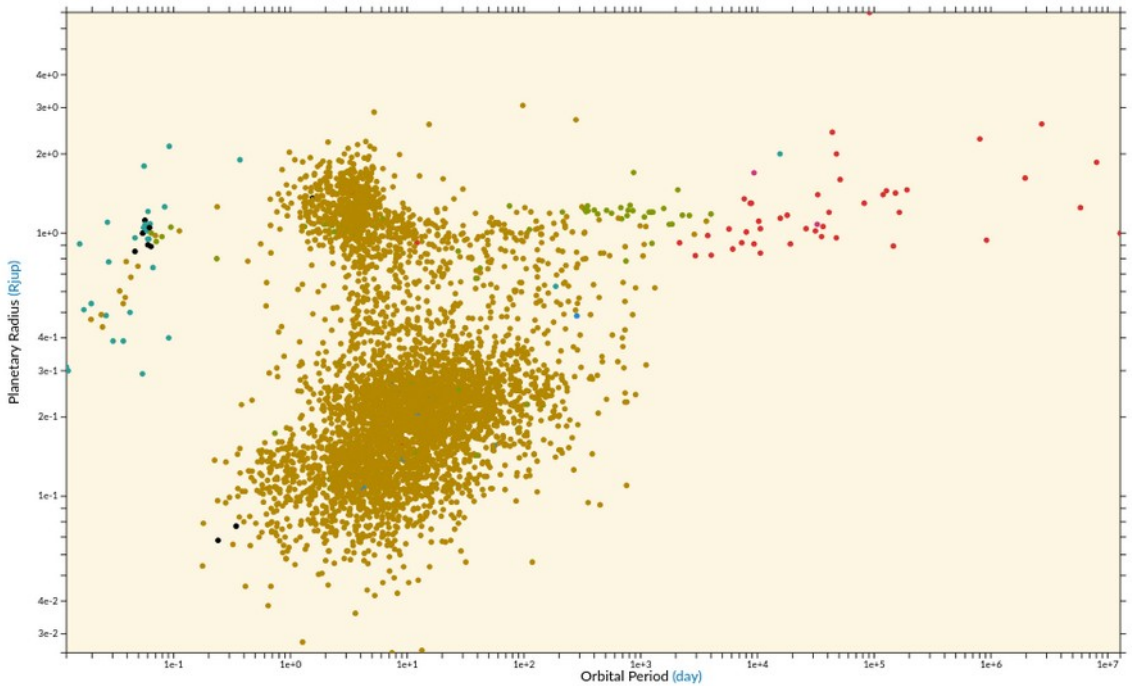
The choice of demographic question is constrained by the detection method. Transit and microlensing communities have historically pursued answers to different demographic questions

Demographic parameters



Microlensing discovery space (almost)

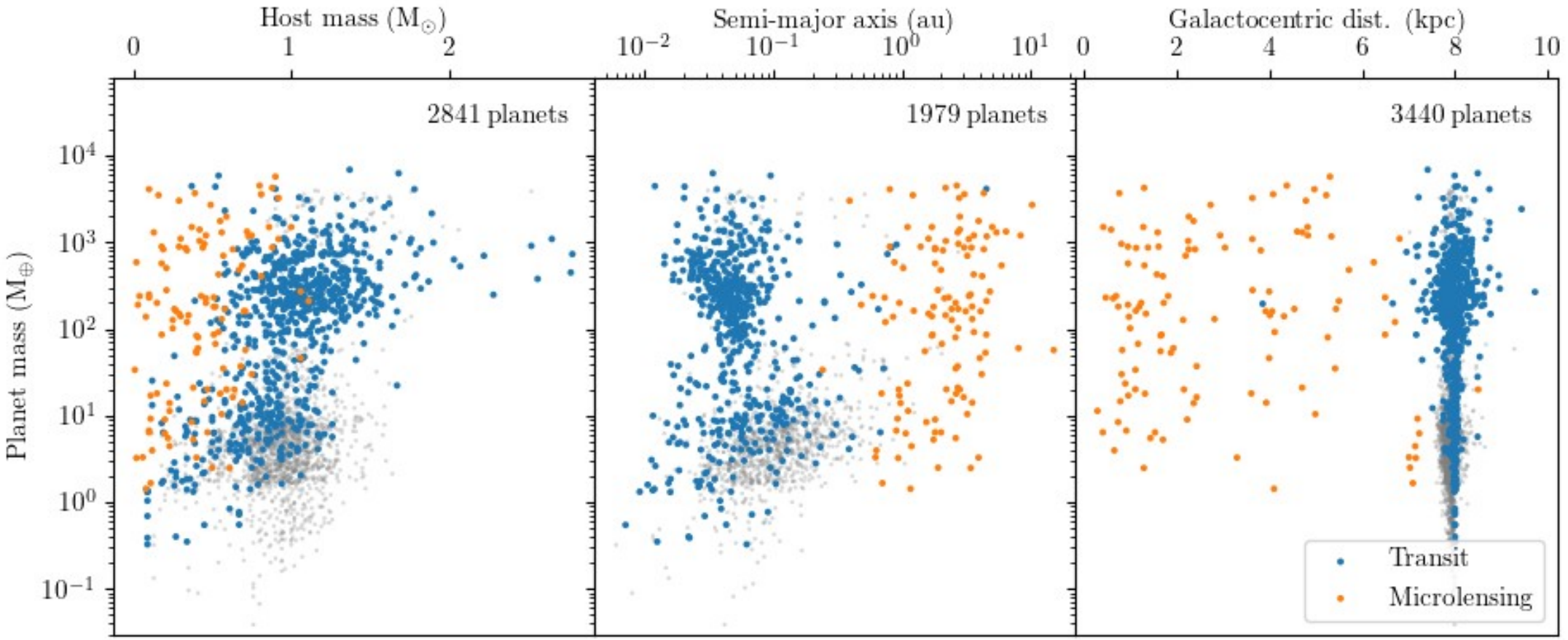
Transit discovery space



Joint transit-microlensing demographic analyses need to be able to project into the natural exoplanet discovery space of each method

Microlensing vs transit samples

But current transit and microlensing samples are strongly separated in Galactic and stellar discovery space too!



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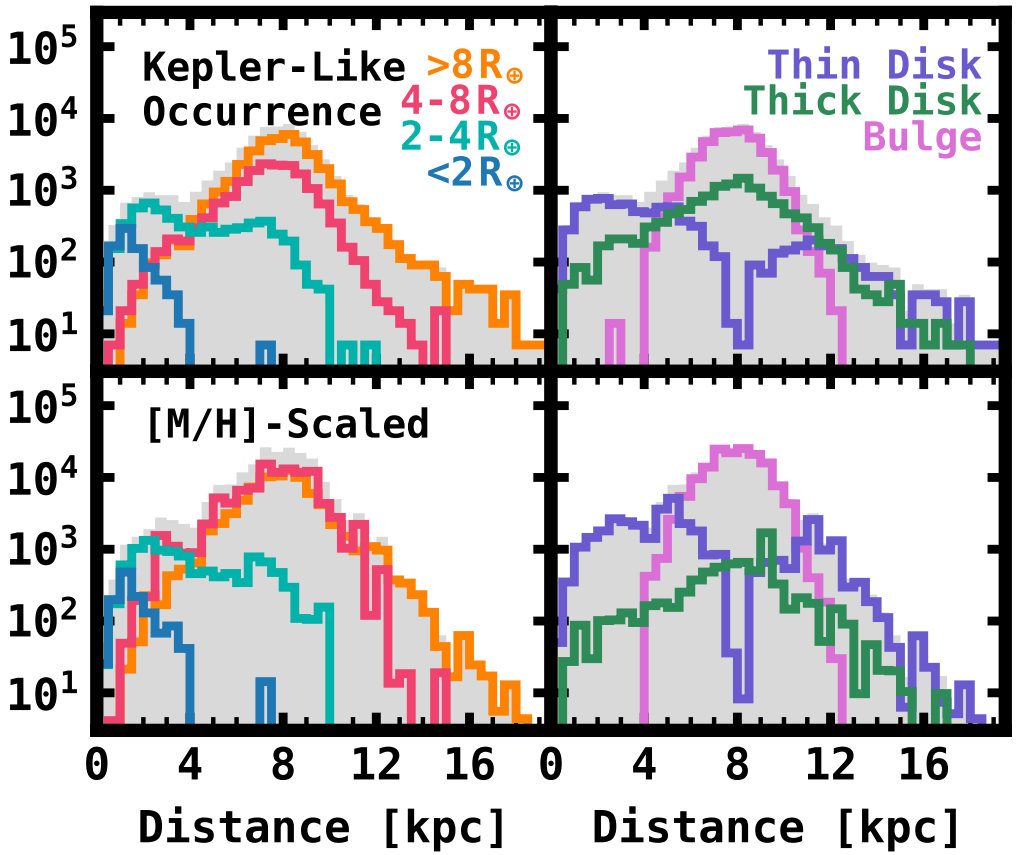


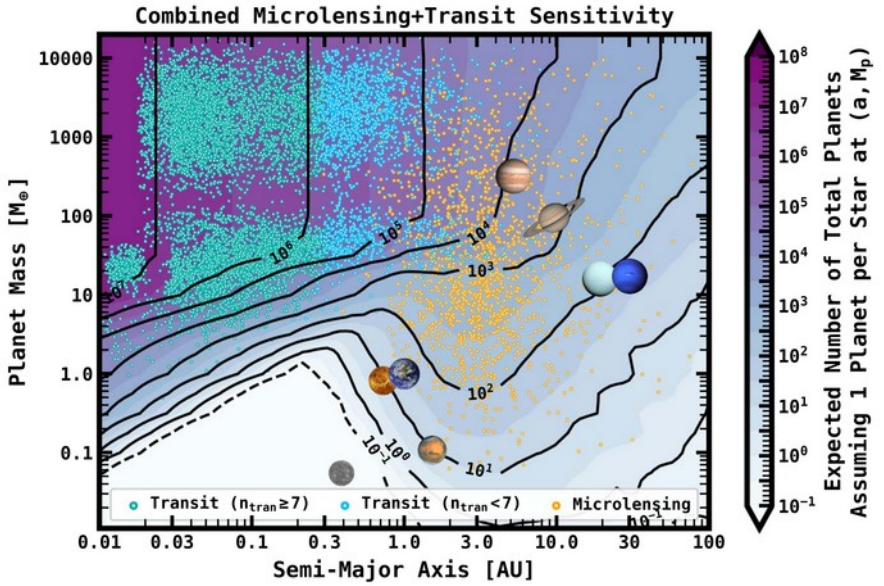
The situation will be substantially improved thanks to Roman

Wilson et al (2023)

What will Roman do for us?

- **Space based - more sensitive and less photometry systematics**
- **Large samples - great demographic resolution!**
- **Hot and cool exoplanets from the same dataset**
- **Hot and cool planets sampled from similar Galactic phase space volumes for the first time - wider mix of hosts and better overlap of transit and microlens host properties**
- **Survey design well optimized to minimize contamination**
  - many direct mass measurements from microlensing
  - transit selection will have good contaminant rejection through astrometry and colour info.

Wilson et al (2023)



Demographic parameters

	Observable parameters		Discovery space parameters		Discovery space parameters w. host info
Microlensing:	$t_E, \mu_{\rm rel}, \pi_E$	$\rightarrow$	$M_{\rm p}/M_*, s$	$\rightarrow$	$M_p, a_\perp$ $(a_\perp \neq a!)$
Transits:	$\delta, t_{0,i}$	$\rightarrow$	$R_{\rm p}/R_*, P$	$\rightarrow$	R_p, P

Transit and microlensing discovery space parameters are correlated

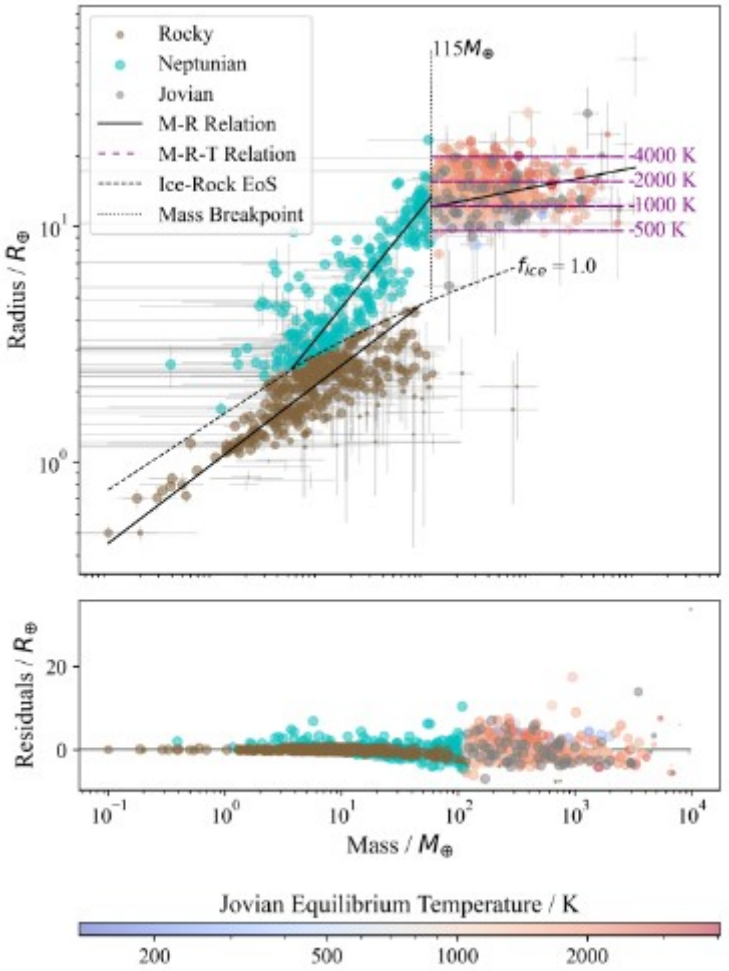
$\rightarrow$ demographic modelling of both samples should use consistent priors

$\rightarrow$ motivates joint modeling approach

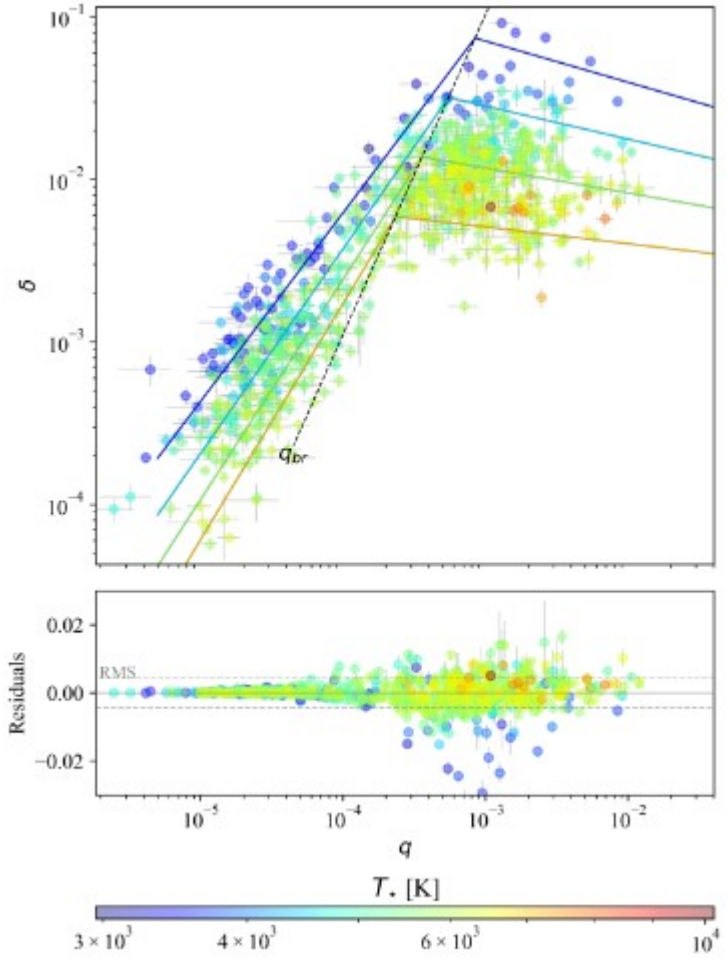
Linking transit and microlensing discovery spaces

Planet mass-radius relation

- Not continuous!



M_p vs R_p relation
Edmondson, Norris & Kerins (2023)



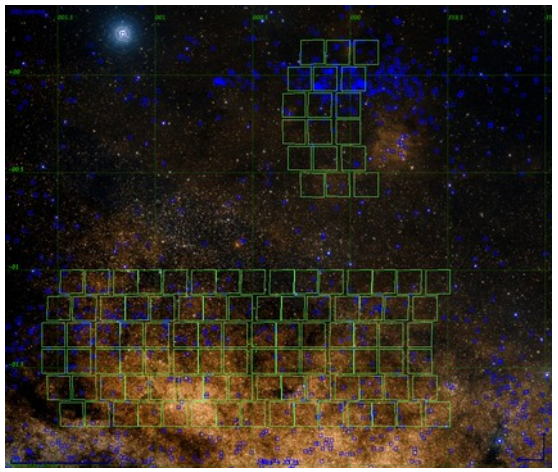
δ vs q relation
Edmondson & Kerins (2026)

Planet-host mass ratio vs transit depth relation

- Continuous!

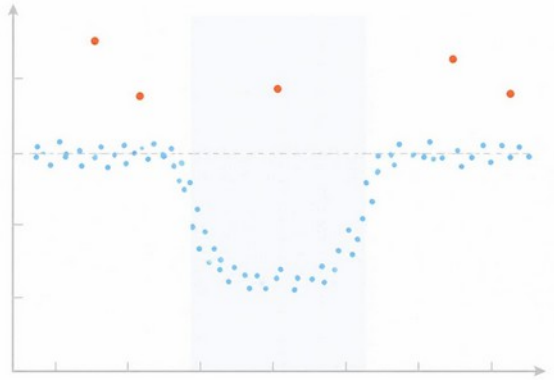
From survey to demographics

Survey design

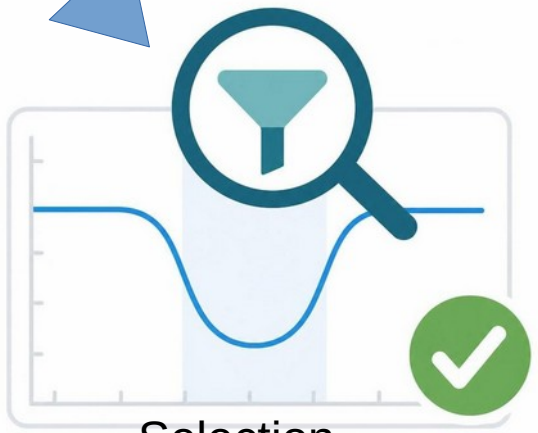


Raw data cleaning

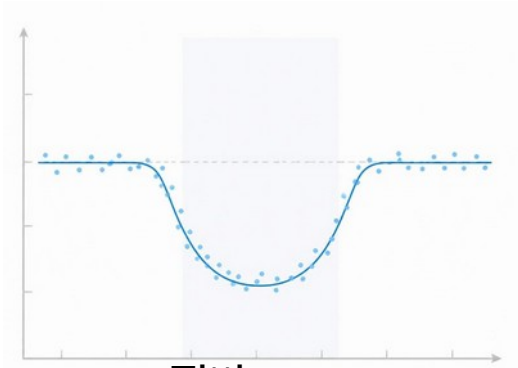
Lightcurve cleaning



Selection biases are present at every stage



Selection



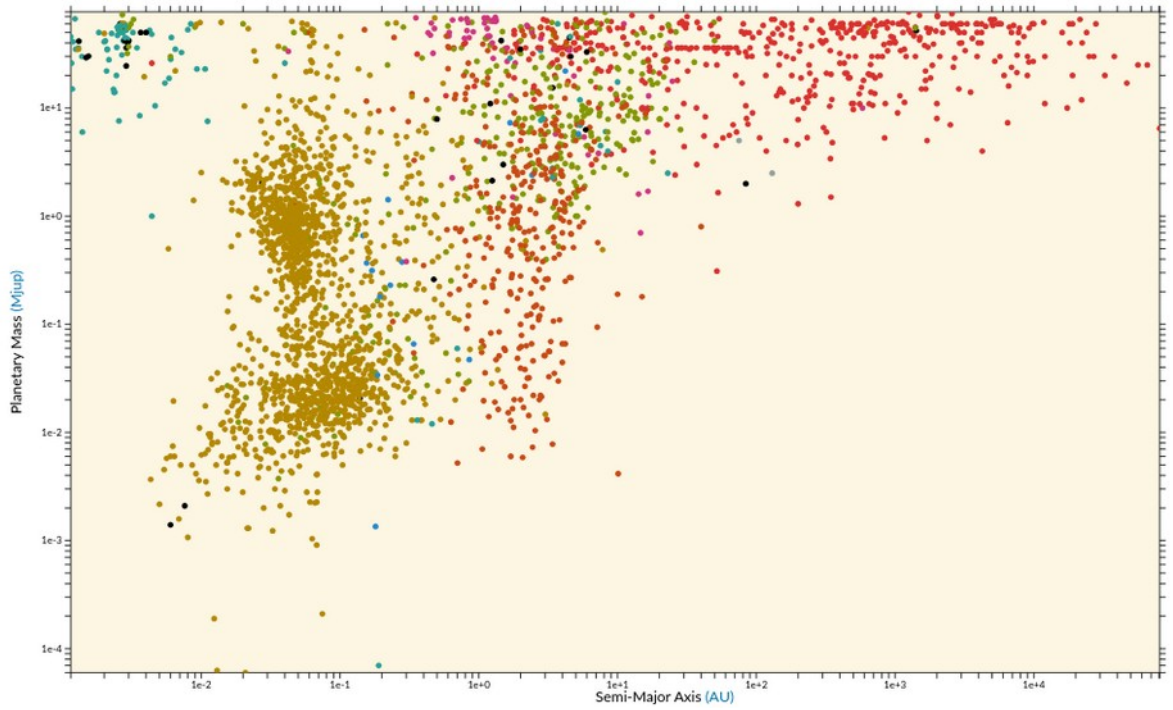
Fitting

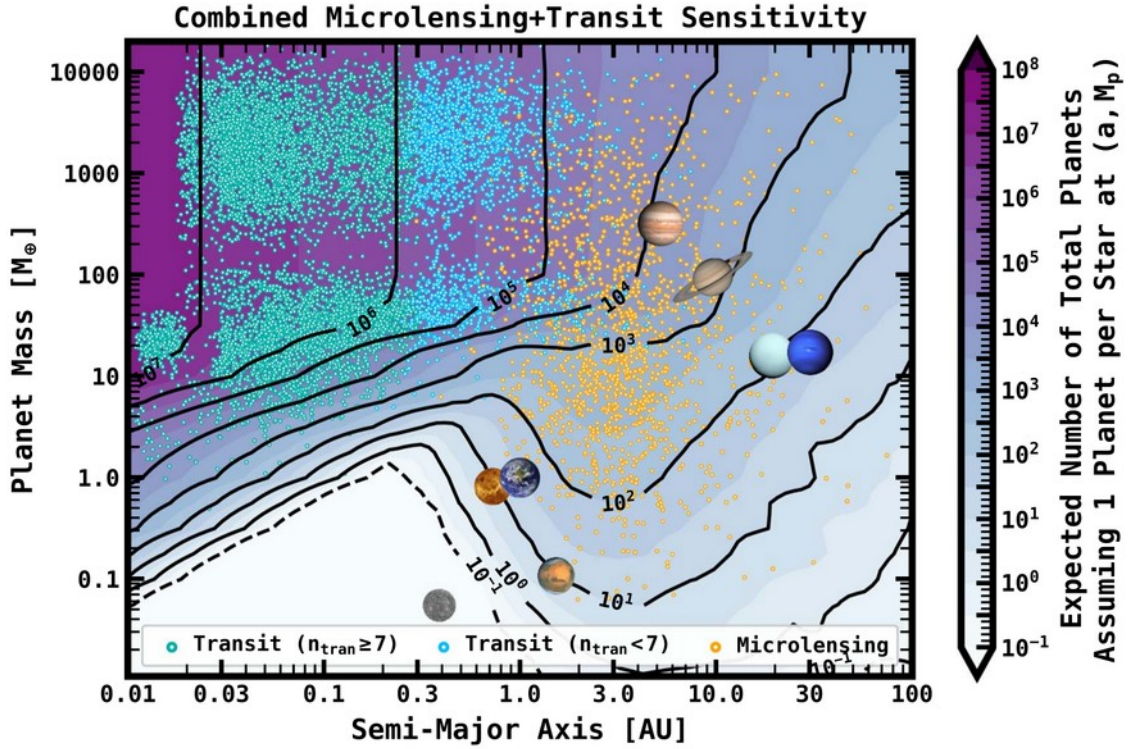
$R_p, P, \ldots$

Discovery space parameters

From survey to demographics

Survey and selection must also be simulated through forward modelling. Allows computation of selection pipeline detection efficiency. This in turn allows recovery of underlying population from the observed population.

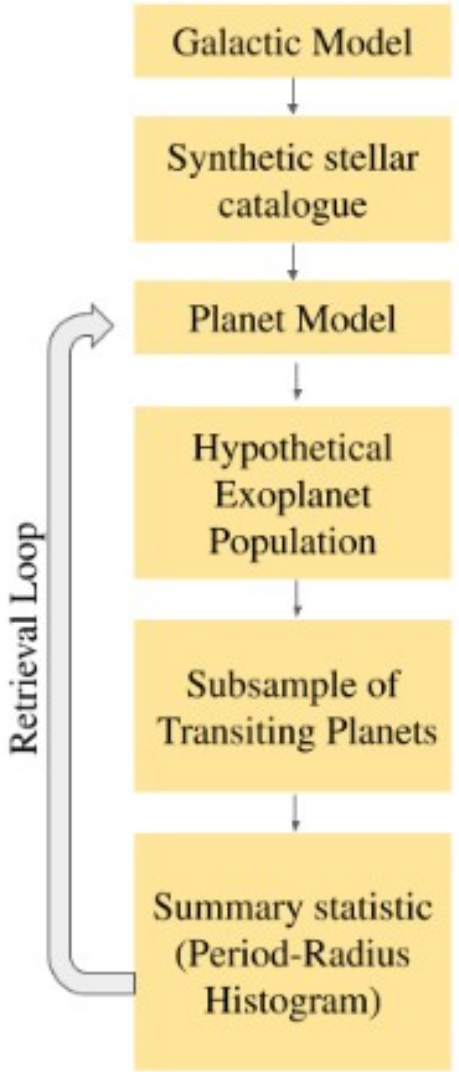




When more can be less and less may be more

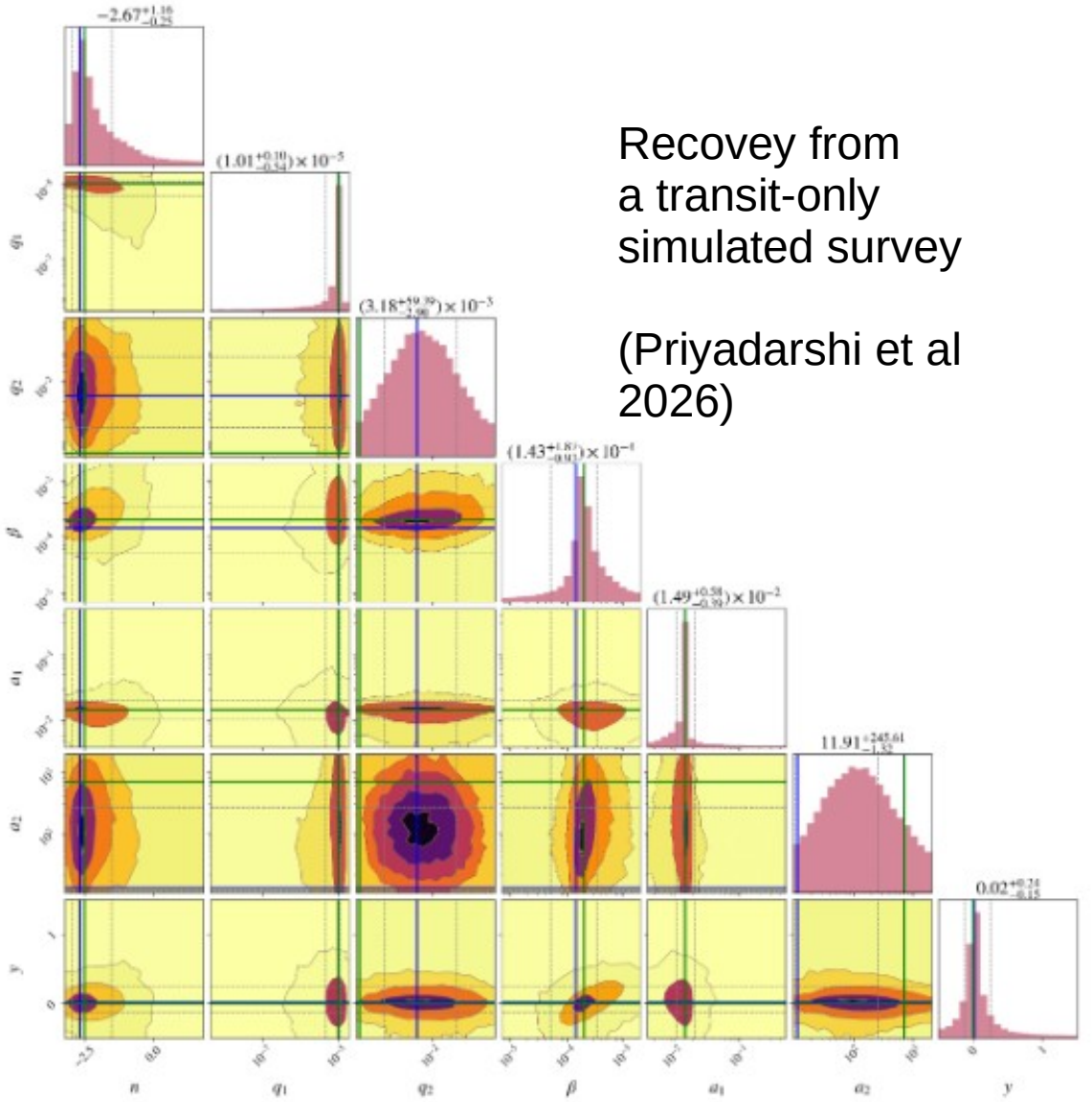
- Larger datasets allow for better demographic resolution. So instead of the demographic frequency $f(P,R_{\rm p})$, the large Roman dataset might allow us to explore $f(M_*,P,R_{\rm p})$ or even $f(\mathbf{r},M_*,P,R_{\rm p})$
- Selection algorithms control the size of the dataset.
  - Too strict: sample is too small for extensive demographic analysis
  - Too relaxed: increased sample contamination
- Contamination can come in 2 forms:
  - **false positives** - e.g background eclipsing binaries spoofing exoplanet transit signals.
  - **biased parameter recovery** - e.g. blended fit favouring an Earth when the signal is really from a Jupiter.
- Balance of sample quantity and quality must be optimised. Can be done through survey design and selection pipeline design.
- In the end, demographic analysis must be robust to residual contamination $\rightarrow$ contaminants and effects unaccounted for in fitting should also be forward modeled.

Roman-era demography: TAED



TAED flow diagram for a simulated transit survey Priyadarshi et al (2026)

Technique-agnostic exoplanet demography (TAED). Framework suitable for demographic retrieval from combinations of spatio-kinematic based exoplanet detection methods such as transit, microlensing, RV or astrometry.



Recovey from a transit-only simulated survey

(Priyadarshi et al 2026)

What should be the chosen discovery space?

For joint transit-microlensing demographic retrieval, a minimum of four planet parameters seem necessary:

- Planet-host mass ratio q - project to δ for transits
- Planet host separation a - project to s (microlensing) and P (transits)
- Planet orbit eccentricity e - also needed to project a to s and will affect transit yield and duration disribution.
- Planet mutual inclination Δi - affects relative yield of single and multi-transit systems. Microlensing essentially unaffected.

Summary

- Roman will be a revolution for exoplanet demography
- Hot and cool exoplanets detected over Galactic scales
- Demographics will be great for testing planet formation models and also for providing first credible estimate of the Galactic abundance of habitable zone Earth-sized planets.
- For best demographic results we need to do joint transit-microlensing demographic analyses: TAED approach
- Forward modeling needs to incorporate effects of contamination and parameter bias
- By knitting together Galactic, stellar and planetary models into a single framework, demographics will benefit from future observational constraints in any of these domains
- Roman will not just be great at hunting for planets. It can also be used to hunt for populations of common contaminants and also to constrain the structural properties of the Galaxy. These studies will also have a direct impact on exoplanet demography