Hands-On Session 1: Exoplanet Occurrence Rates

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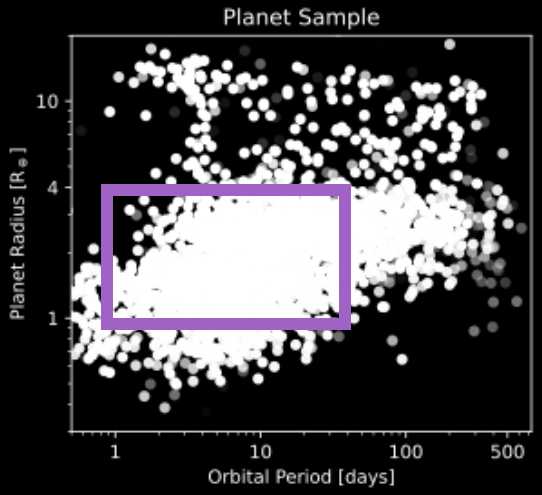
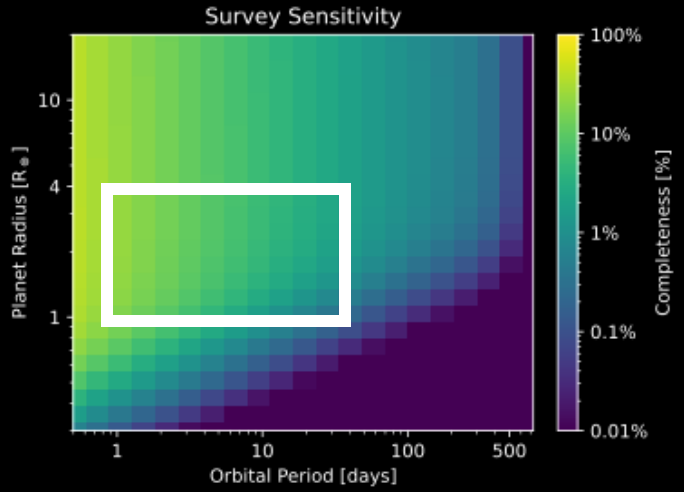
with help from Melanie Swain, Elise Furlan, Tracy Chen & Chas Beichman!
and all the Hands-On helpers!!

Exoplanet Occurrence Rates: the intrinsic (de-biased) frequencies of planets

You'll learn how to:

- calculate occurrence rates
  - as functions of planet & star properties.
- model occurrence rate distributions
  - using data from one or more surveys.



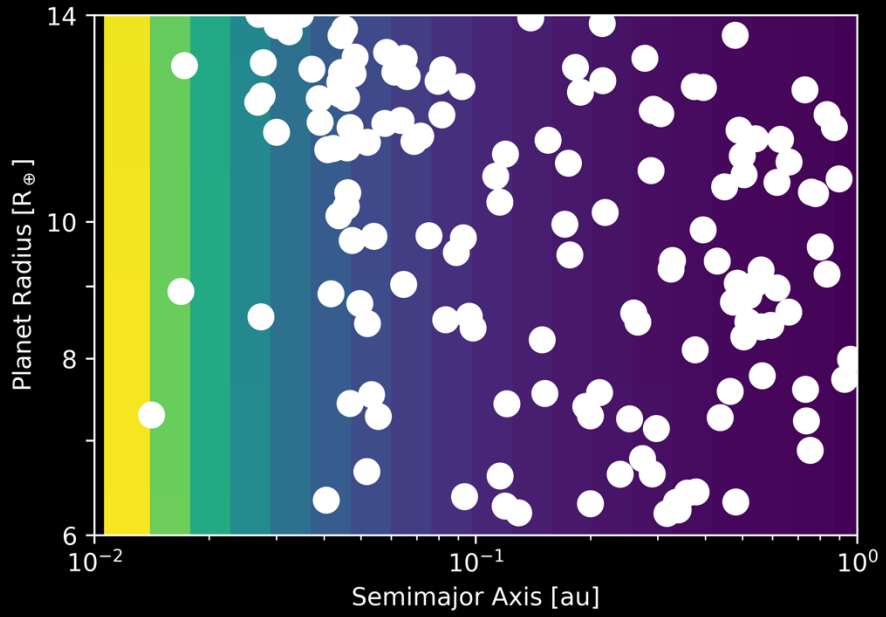


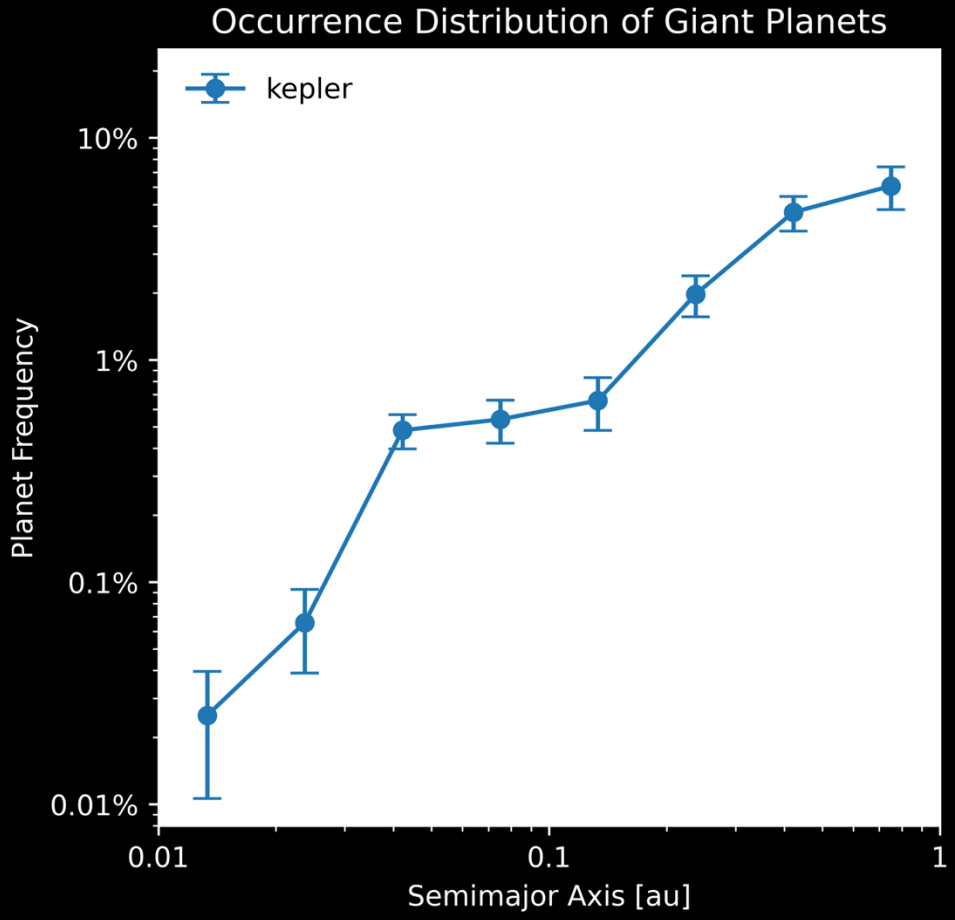
IDEM: Inverse Detection Efficiency Method

1. Define a type of planet to focus on (usually a range in size & separation).
2. Count contributions from each planet.
3. Divide by how sensitive you are to that planet.
4. Divide by the number of stars.

$$\text{Occ.} = \frac{1}{\#\text{ of Stars}} \sum_{i=0}^{\#\text{ of Planets}} \frac{1}{\text{Completeness}(i)}$$

Range of Bins

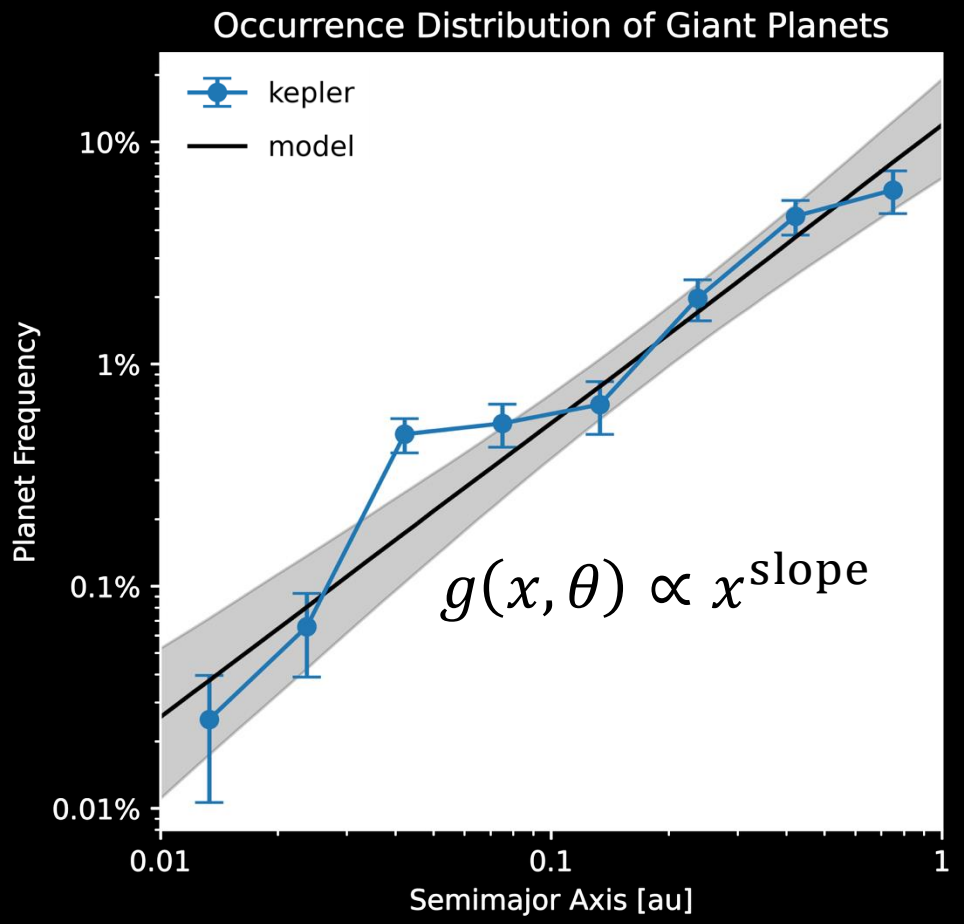




Occurrence models describe how occurrence rates change with planet separation (x) and size (y).

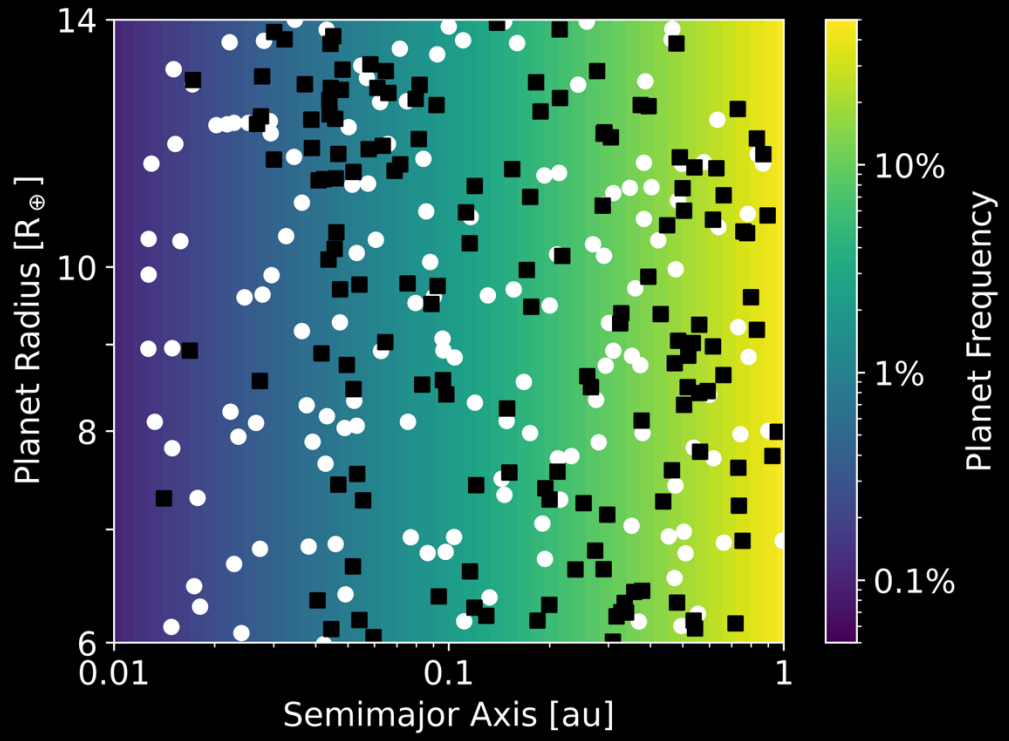
$$\frac{d\ \mathrm{Occ.}}{dx\ dy} \approx F_0 \cdot g(x, y, \theta)$$

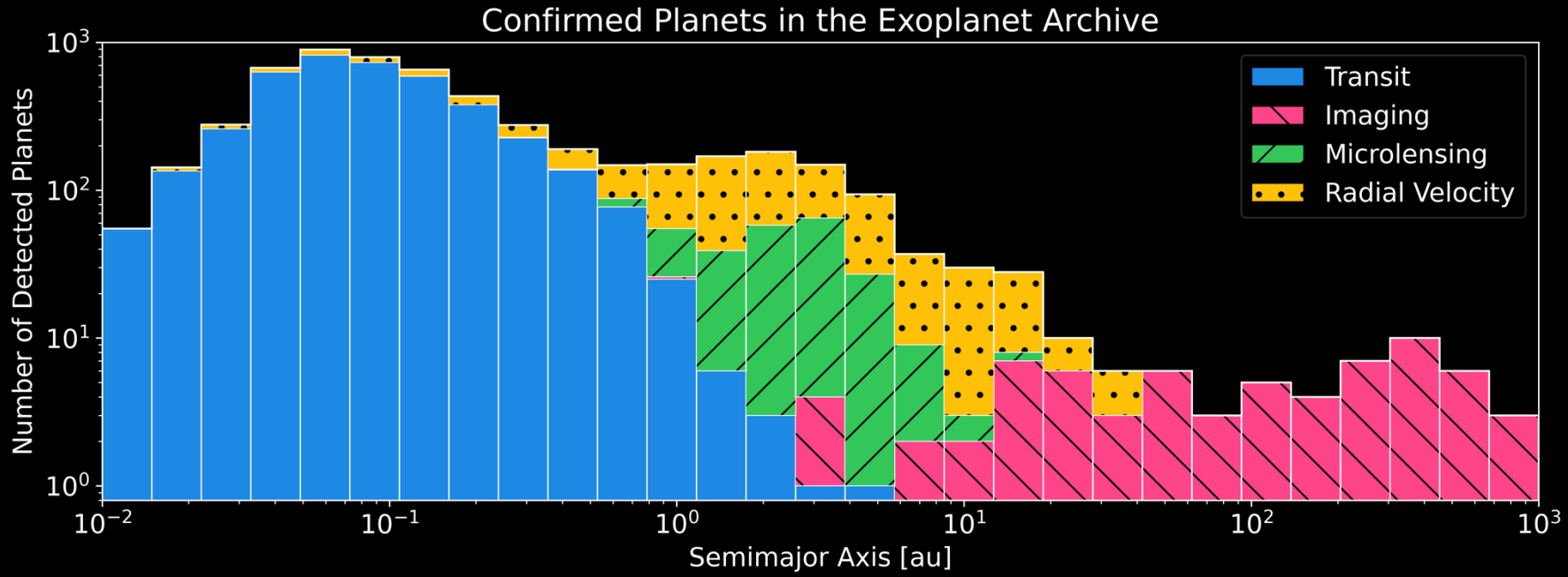
1. Overall occurrence rate (F_0)
2. Shape function (g) that uses free parameters (θ) to describe how occurrence changes with planet properties (x, y).



Occurrence models are fit through an iterative Markov chain Monte Carlo (MCMC) process.

1. Use population model to simulate synthetic planets.
2. Combine with survey completeness metrics to determine observability of each planet.
3. Compare ”simulated observed” population with real survey data.

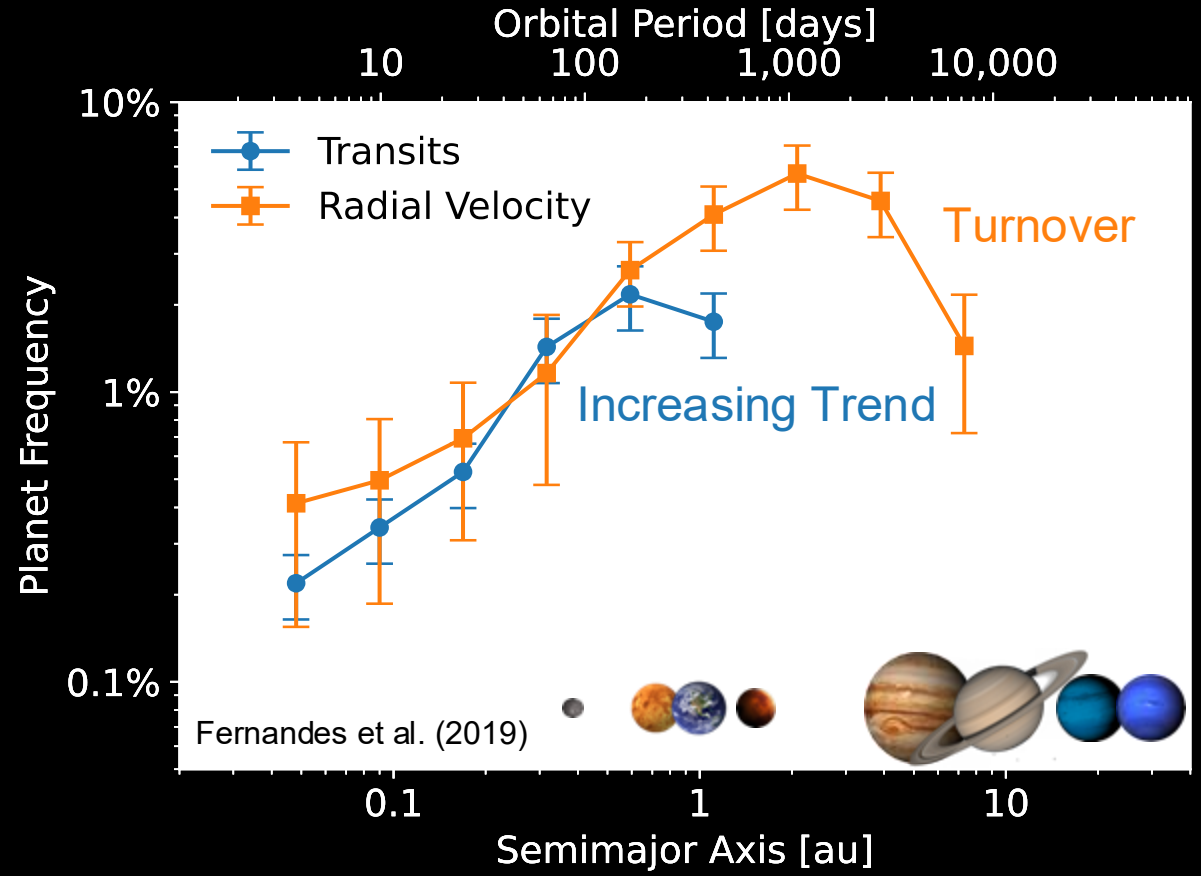




Combined Demographics:

using data from multiple surveys/methods to better study planet populations

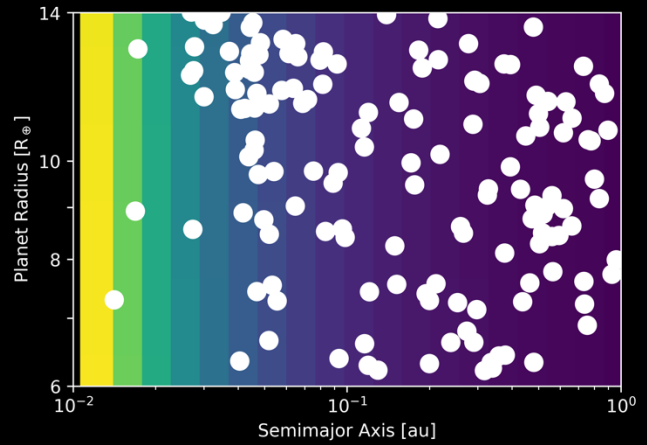
Clanton & Gaudi (2014, 2016); Kunimoto & Bryson (2021)

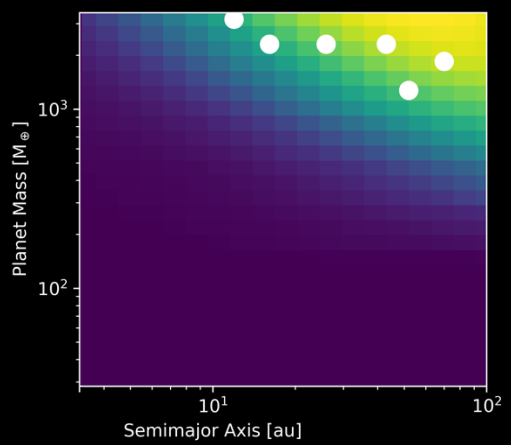


The shape of this distribution tells us about giant planet formation & migration.

see e.g., Fernandes et al. (2019), Vigan et al. (2019), Fulton et al. (2021), Lagrange et al. (2023)

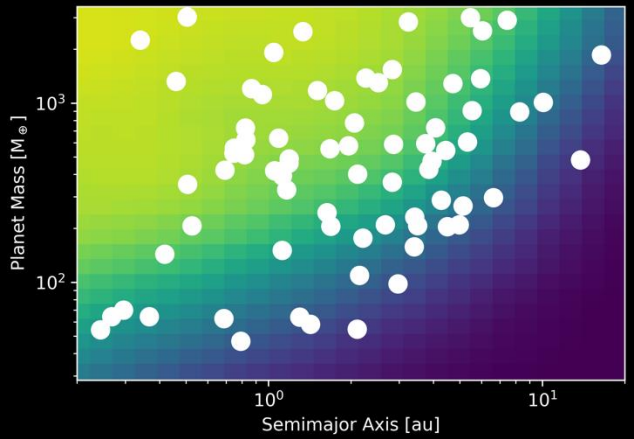
Transits
(Kepler)

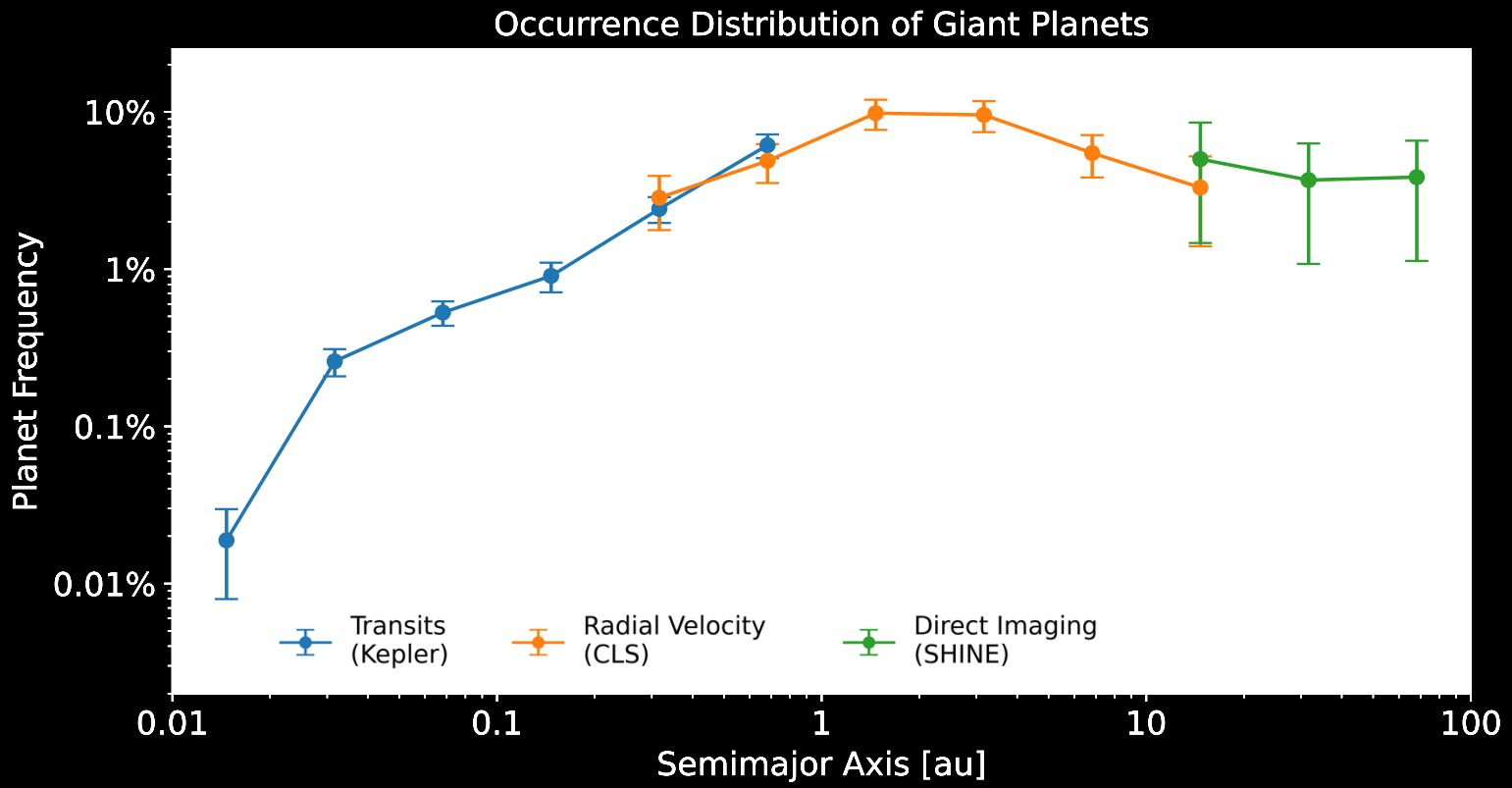




Imaging
(SHINE)

Radial Velocity
(California Legacy Survey)



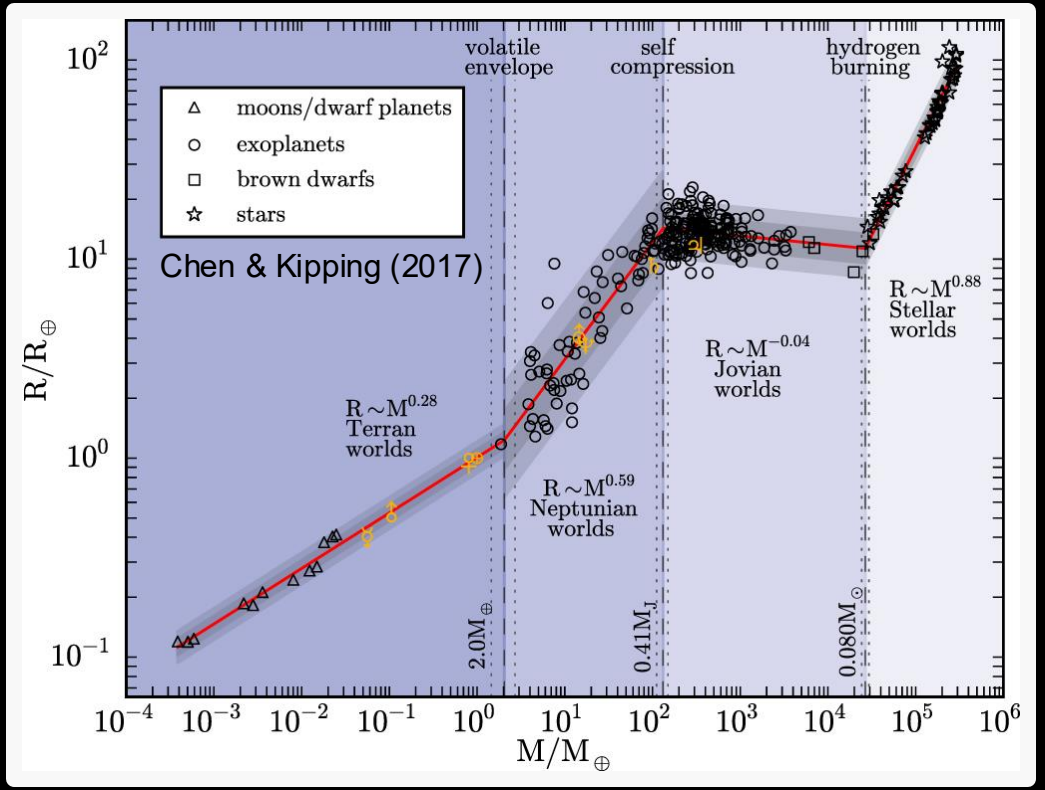

Occurrence Distribution of Giant Planets
Planet Frequency
10%
1%
0.1%
0.01%
0.01
0.1
1
10
100
Semimajor Axis [au]
Transits
(Kepler)
Radial Velocity
(CLS)
Direct Imaging
(SHINE)

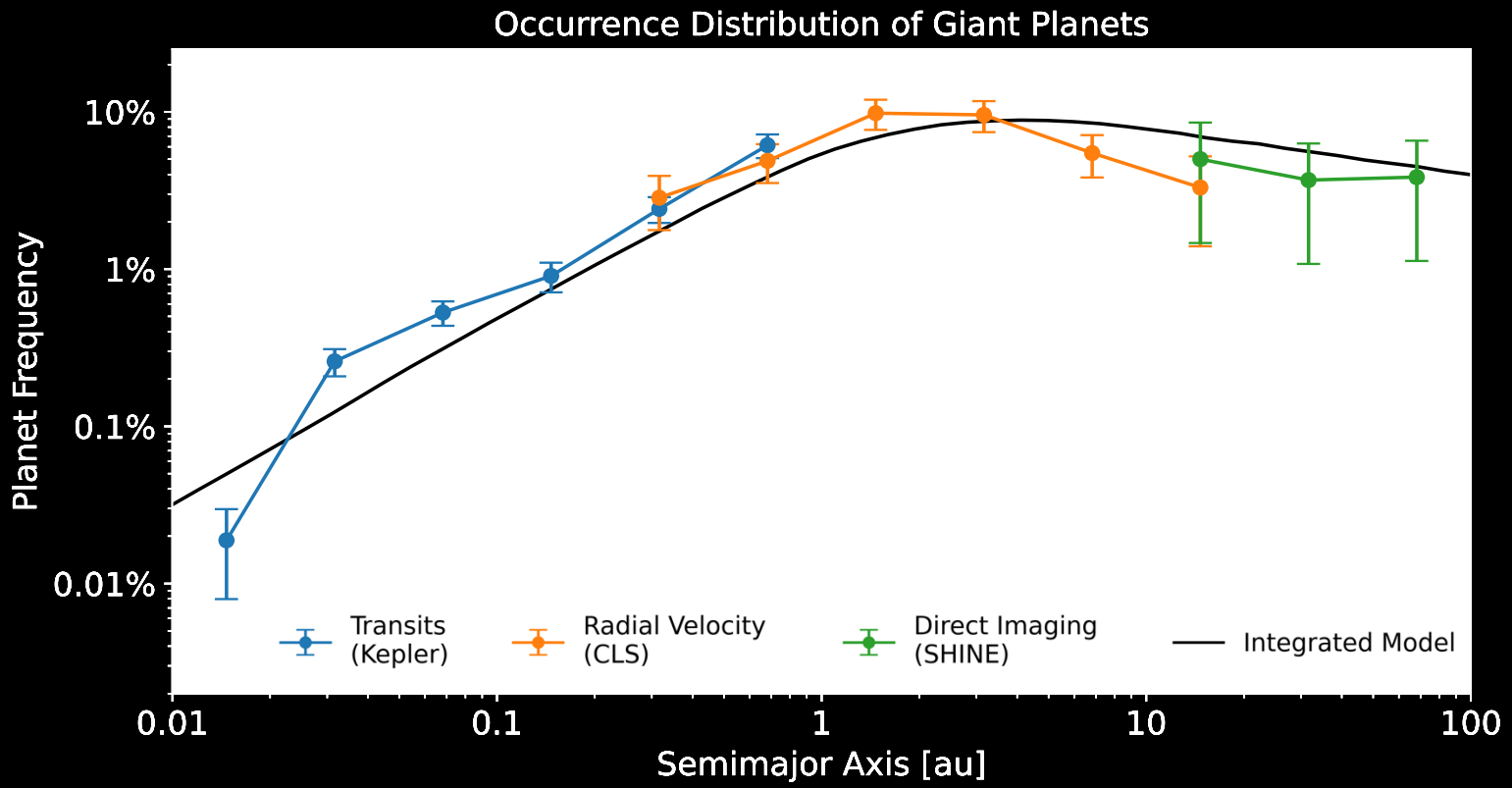
odds of landing heads on two coin flips = odds of one flip × odds of a different flip

odds of one model fitting two surveys = odds of the model fitting *each survey independently*, multiplied together

Problem:
transits measure planet radii, but other methods measure planet mass.

Solution:
1. Model occurrence as a function of planet mass.
2. Pass your model through a mass-radius relation.
3. Compare to transit surveys.

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Transits (Kepler)
Radial Velocity (CLS)
Direct Imaging (SHINE)
Integrated Model

How do occurrence measurements change:

1. with different combinations of survey data?
2. depending on what type of model you fit?
3. as a function of stellar mass?