Impacts on Planet Formation: Planet Occurrence around Metal-Poor Stars

Kiersten Boley
NSF Graduate Research Fellow
Advisors: Dr. Jessie Christiansen & Prof. Ji Wang
The Ohio State University

ExoExplorers
20 May 2022

*When did the **first** planets form?*

Image Credit: NASA

Image Credit: NASA

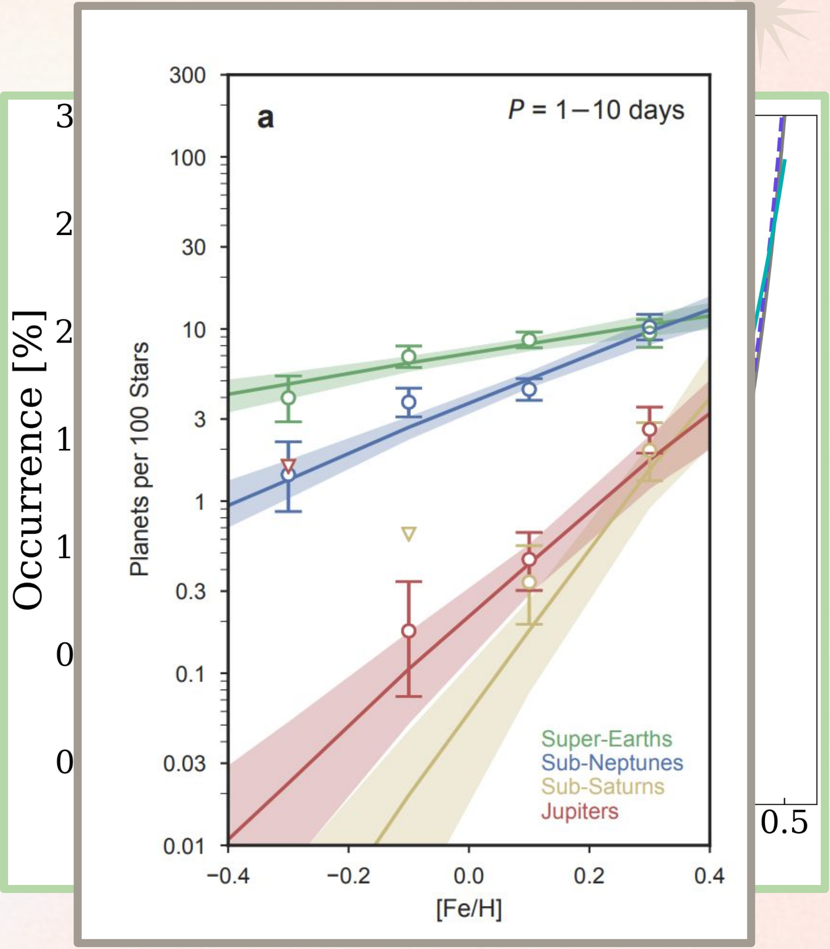
Motivation

How much material is required to form a planet?

Petigura et al. 2018

Motivation

- Host Star metallicity is thought to be a tracer for the protoplanetary disk
- Giant planets have been shown to be strongly correlated with metallicity for dwarf stars



Petigura et al. 2018

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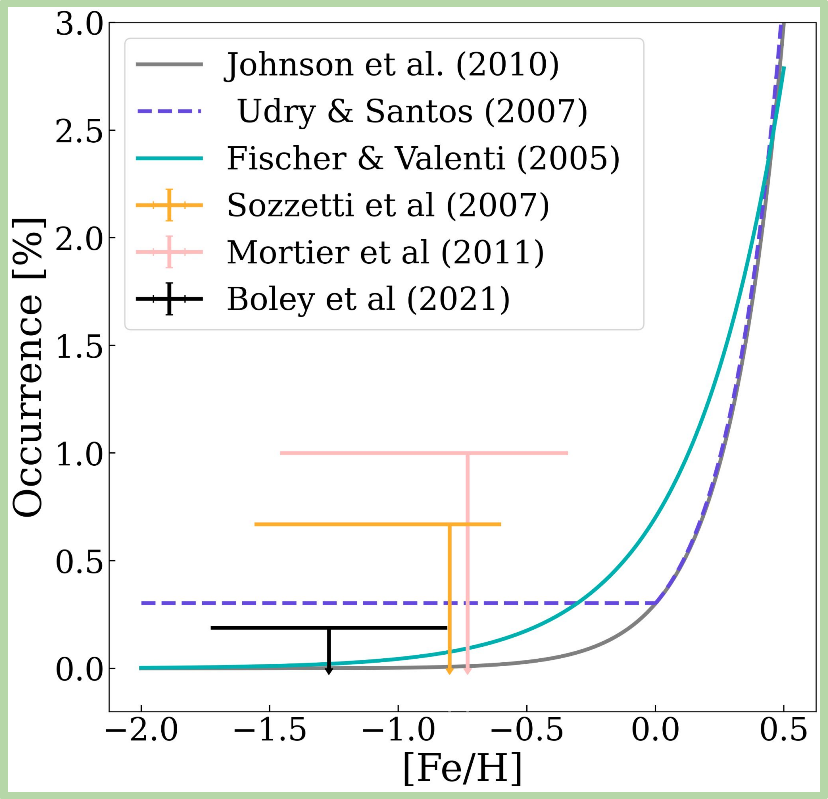

Motivation

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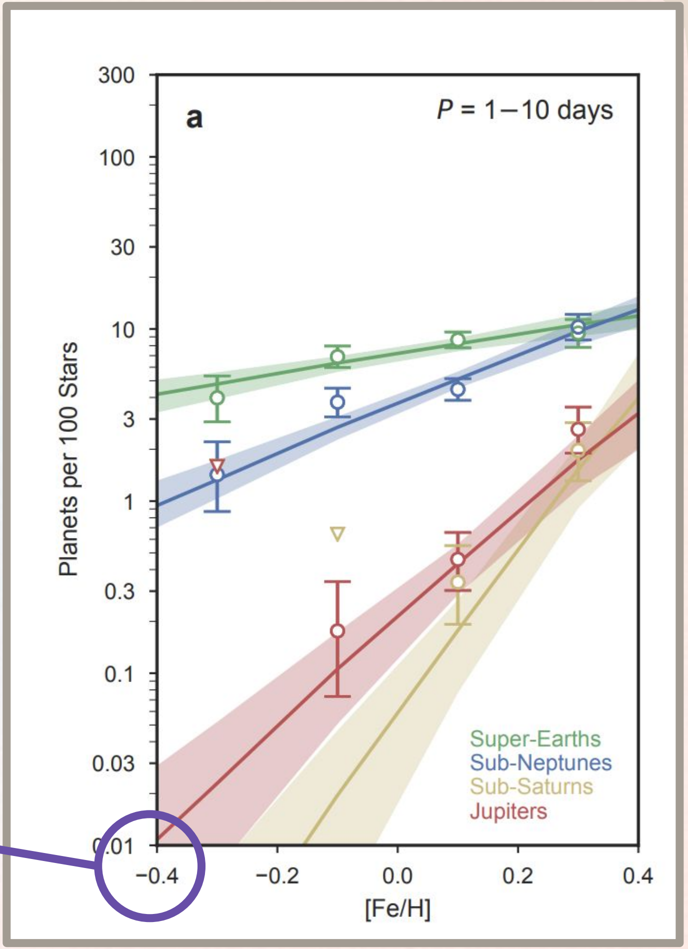
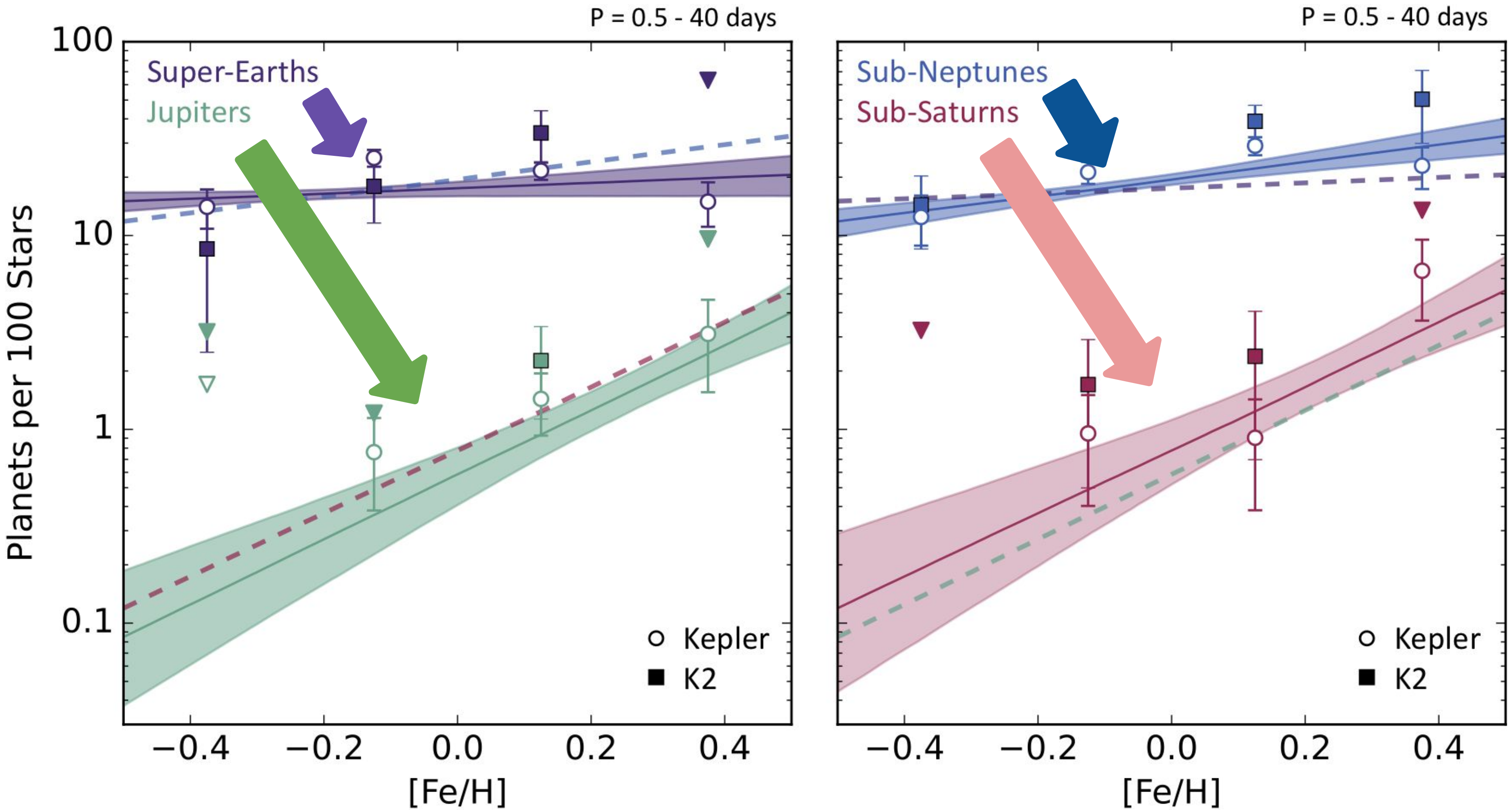
- Giant planets have been shown to be strongly correlated with metallicity for dwarf stars

Still above the metallicity limit at which no planets can form
Johnson et al 2012



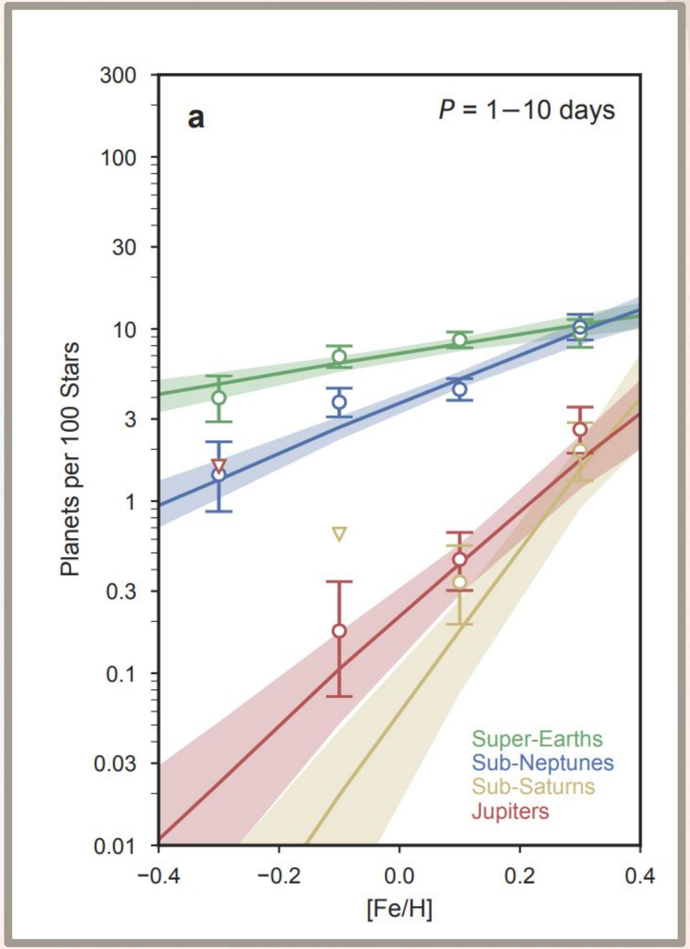
Petigura et al. 2018



Zink et al. (in prep)

Motivation

- Host Star metallicity is thought to be a tracer for the protoplanetary disk
- Giant planets have been shown to be strongly correlated with metallicity for dwarf stars
- Transit method along with TESS enable larger data sets than previous works

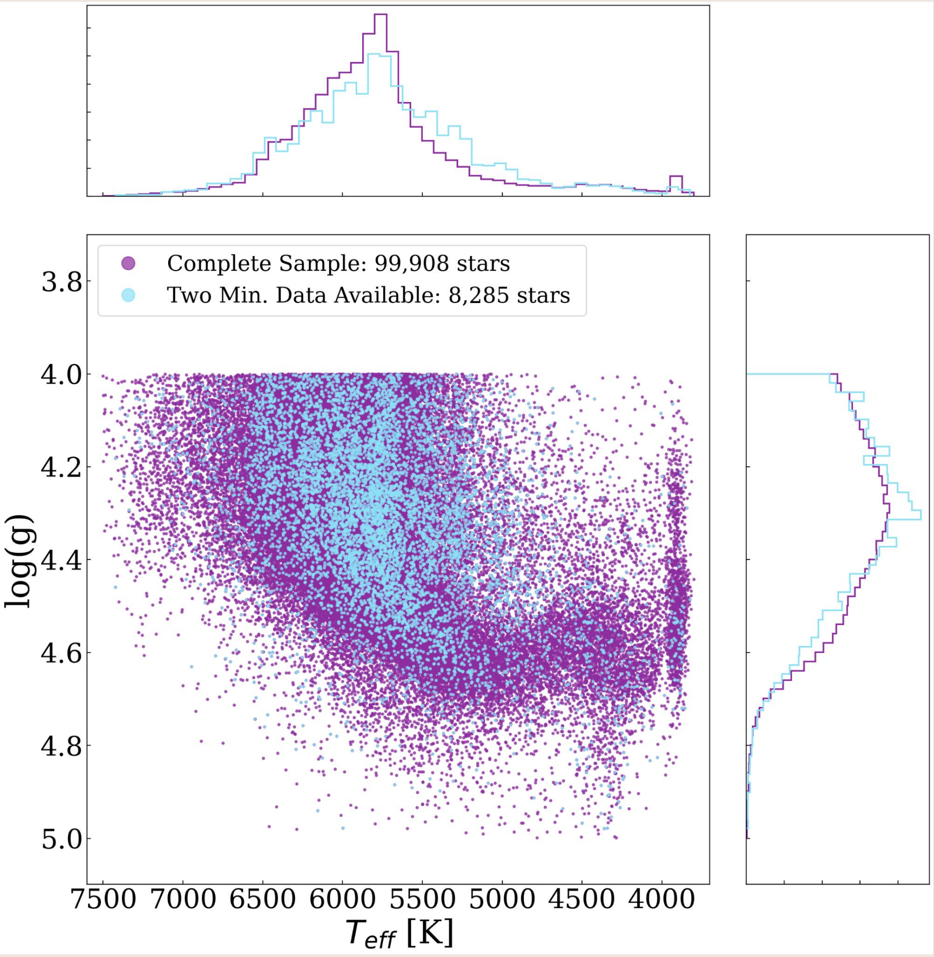


Petigura et al. 2018

Sample Selection

The sample was constructed using the following criteria:

- ❖ Spectroscopically derived [Fe/H]
  - ➢ [Fe/H]< -0.4
- ❖ Tess Magnitude < 14 mags
- ❖ Log (g) > 4
- ❖ Effective Temperature < 7500 K



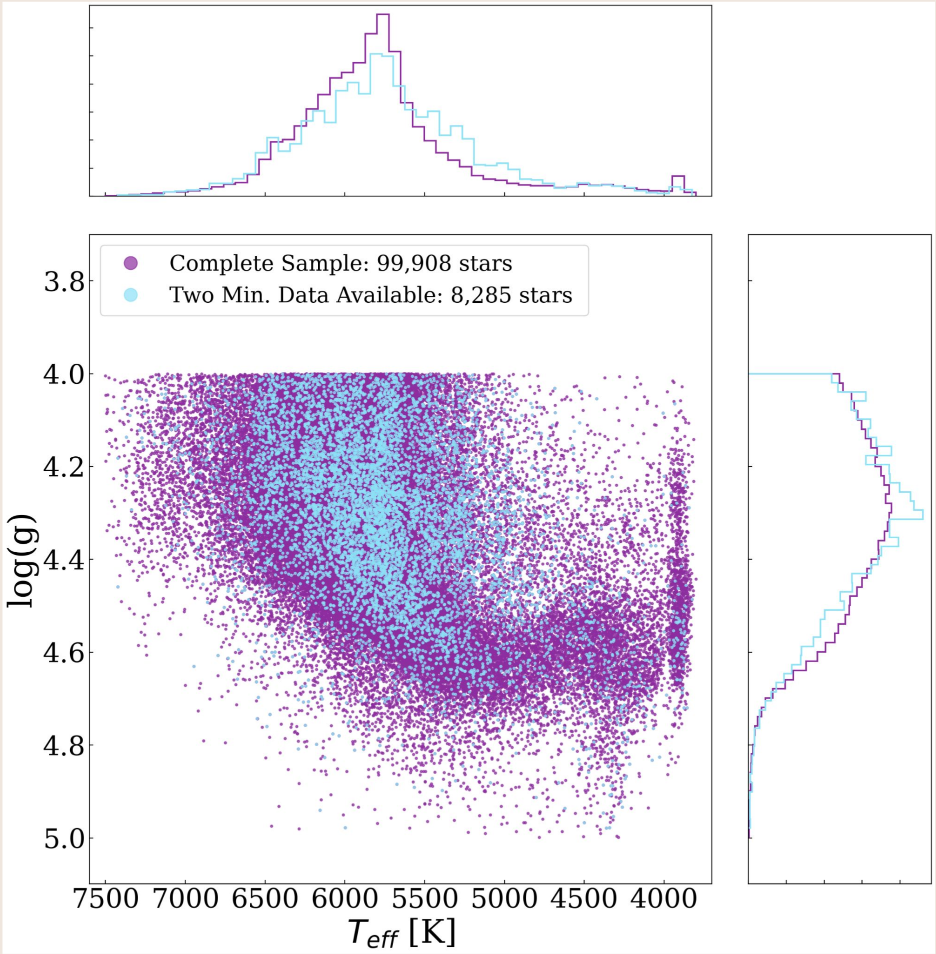
Sample Selection

Metallicity range based on spectra:

(-1.0 ≤ [Fe/H] ≤ -0.4)

Spectral Types:

F-M dwarfs

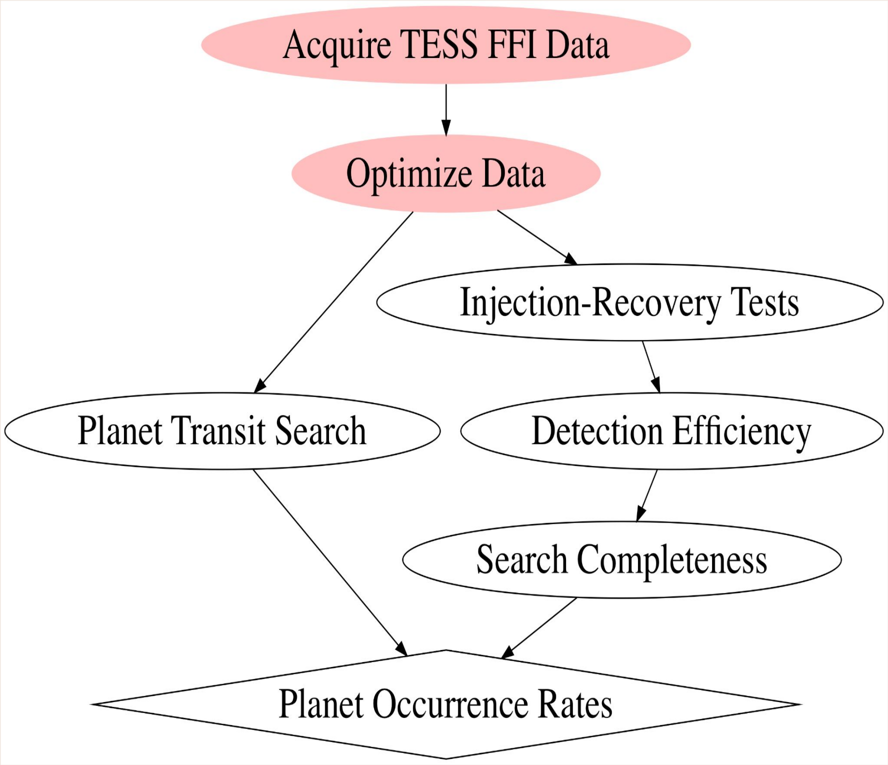


METHOD

- TESS FFI data from ~100,000 metal-poor stars acquired from MAST

- The data is optimized for planet transit searches

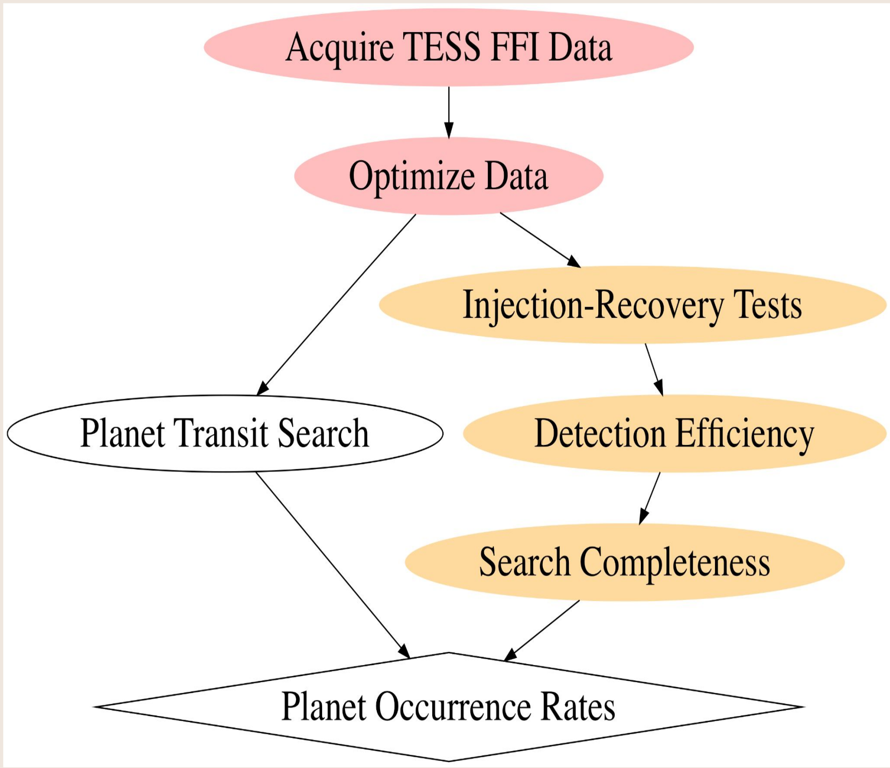
For more details check out:
Boley et al (2021)



METHOD

Two pipelines that run in parallel:

- Planet Detection Pipeline
  - Detects any planets with the sample
- Planet Injection Pipeline
  - Determines the search completeness of our pipeline

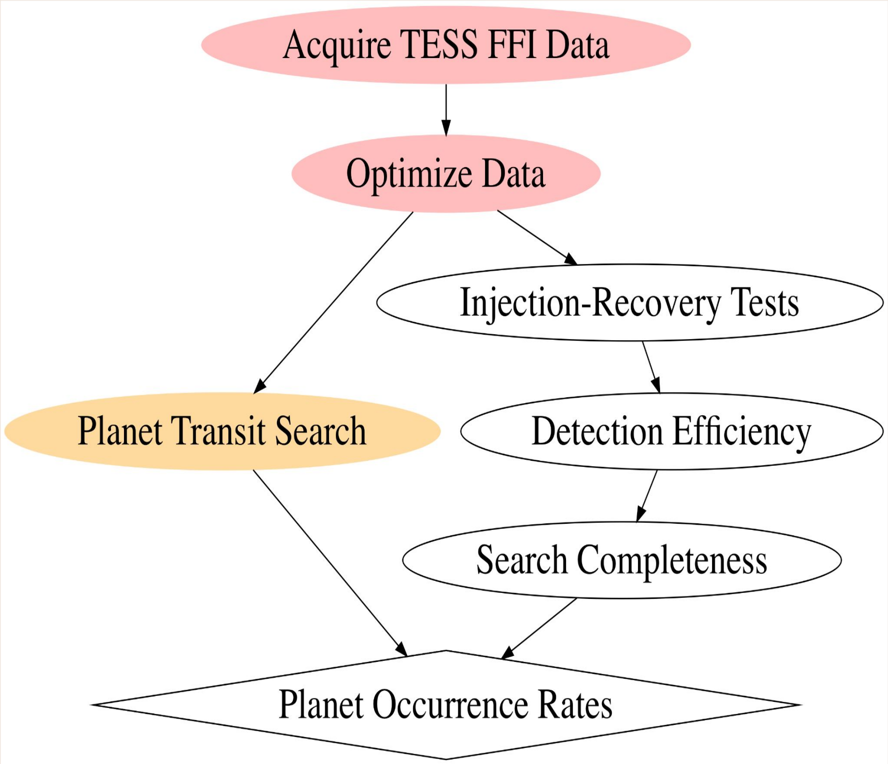


Method

Planet Detection Pipeline

Transit Search Algorithm:

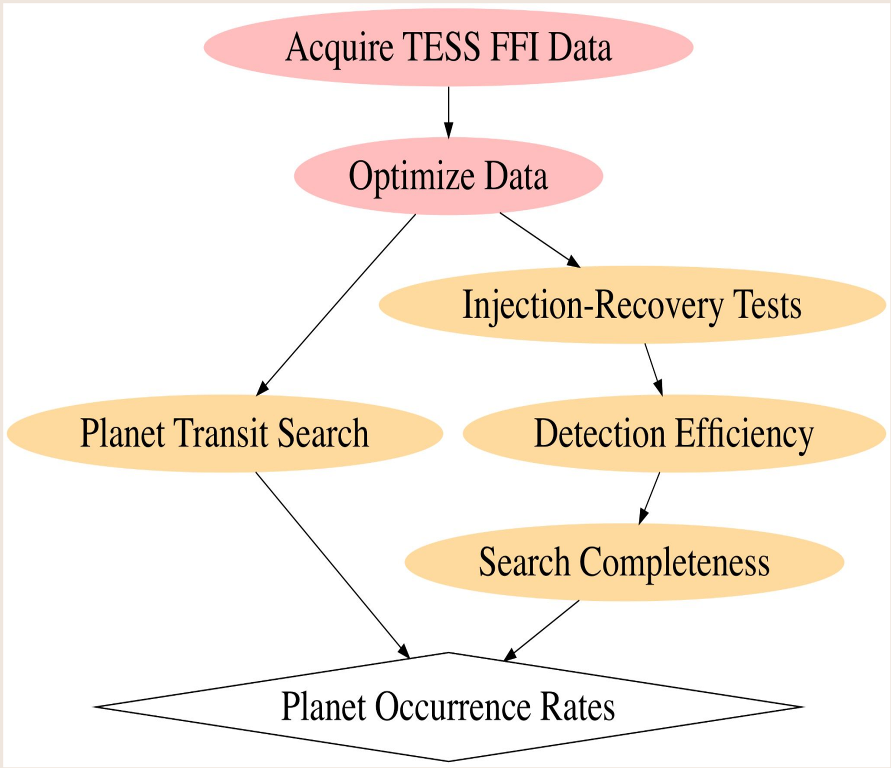
- Transit Least Squares (TLS)
  - Based on Kepler light curves
- Edi-Vetter
  - Planet Candidate Vetting Software



Method

Planet Injection Pipeline

- Injection-Recovery Test
    - 100 synthetic planet signals injected into each light curve
- Detection Efficiency
- Search Completeness combines
    - Geometric Transit Probability
    - Detection Efficiency



CALCULATING PLANET OCCURRENCE

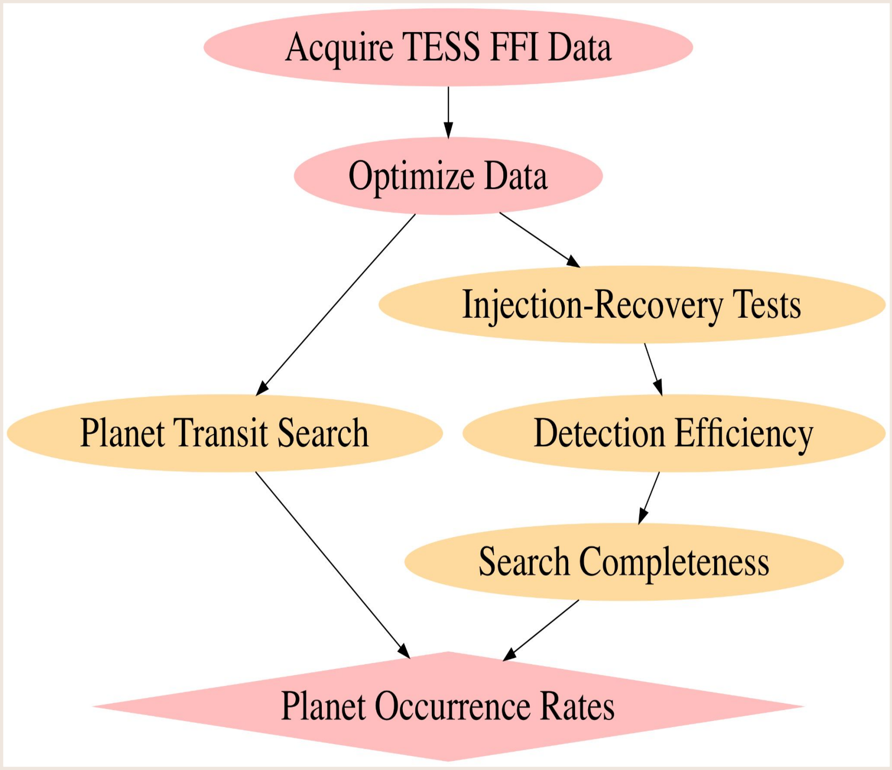
For bins without planet detections, we place upper limits using:

$$P(d, N, f_p) = f_p^d \, (1 - f_p)^{N-d} \, \frac{N!}{(N-d)!}$$

f_p = Planet Frequency

d= Number of Planet Detections

N= Total Sample Size



Calculating Planet Occurrence

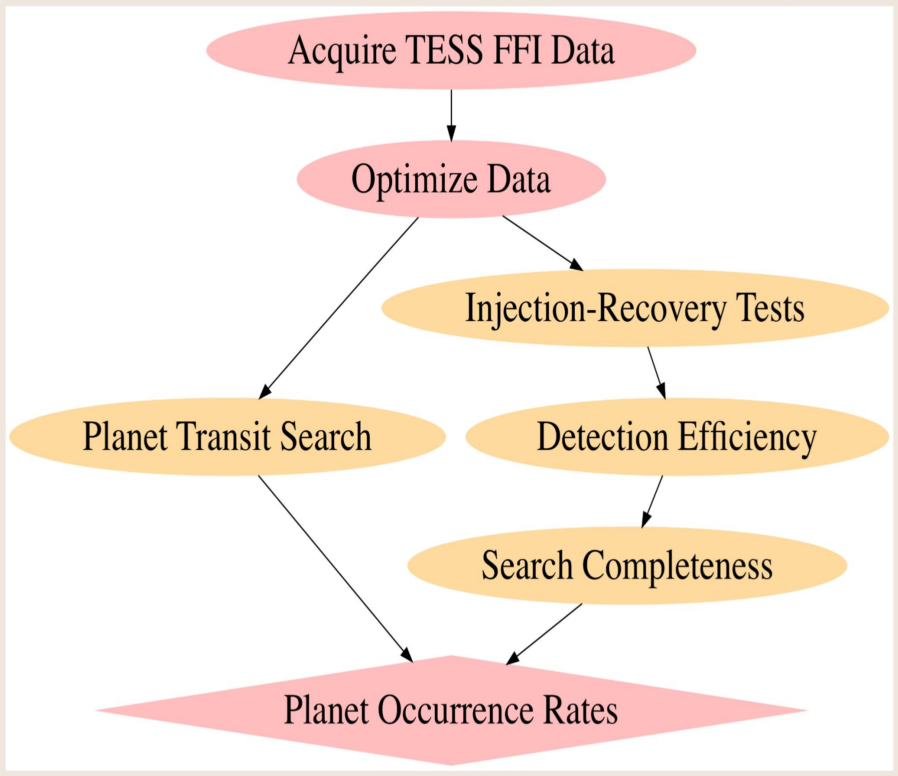
For bins without planet detections, we place upper limits using:

$$f_{p,max} = 1 - (1 - C)^{\frac{1}{N+1}}$$

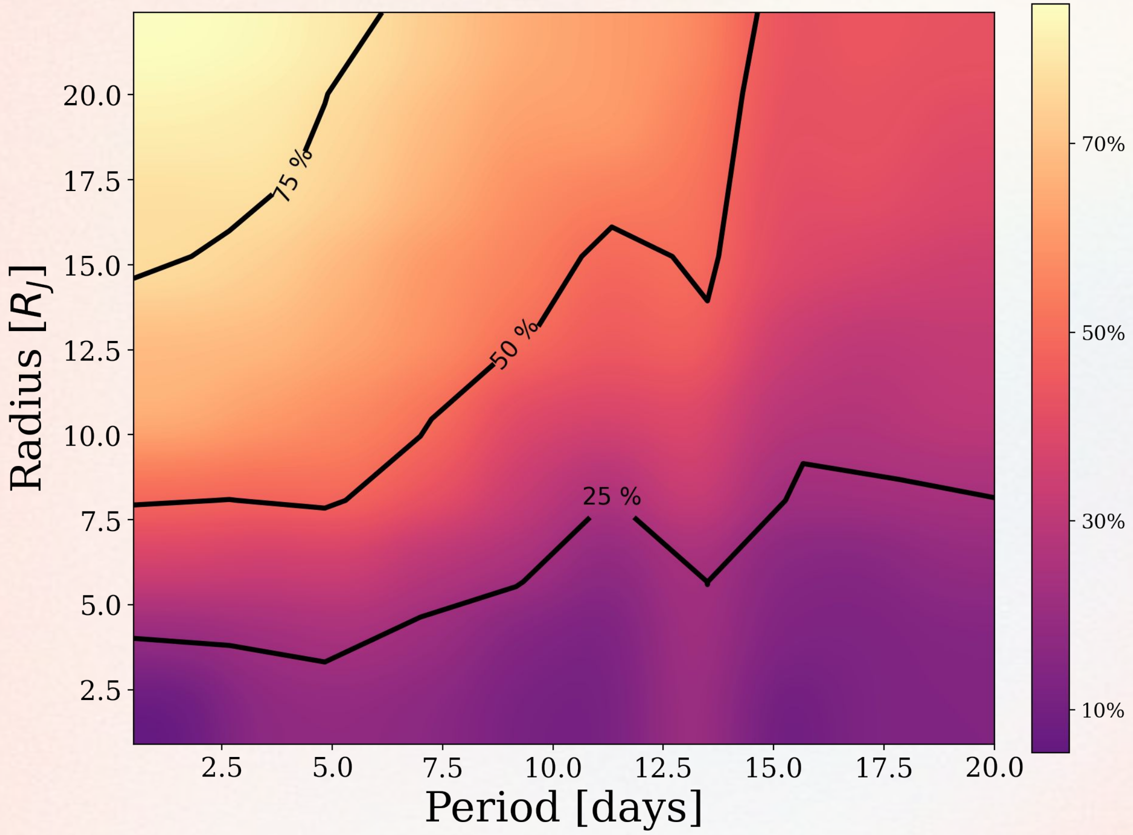
Upper limit of Planet Occurrence

Confidence Interval

Total Effective Sample Size



Preliminary Detection Efficiency

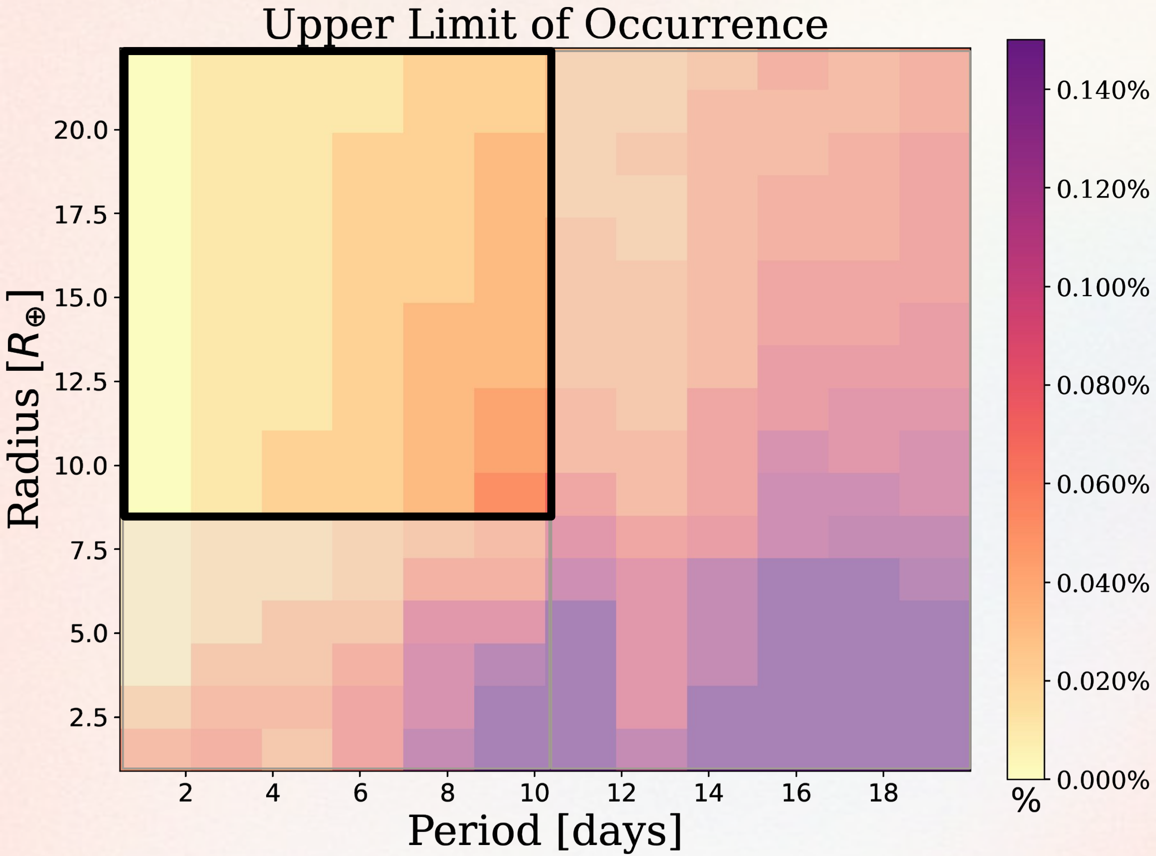


<u>FFI Data</u>

Detection Efficiency by planet type between for periods 0.5-10 days :

- Jupiters: 66%
- Sub-Saturns: 33%
- Sub-Neptunes: 16%
- Super-Earths: 14%

Preliminary Upper Limits

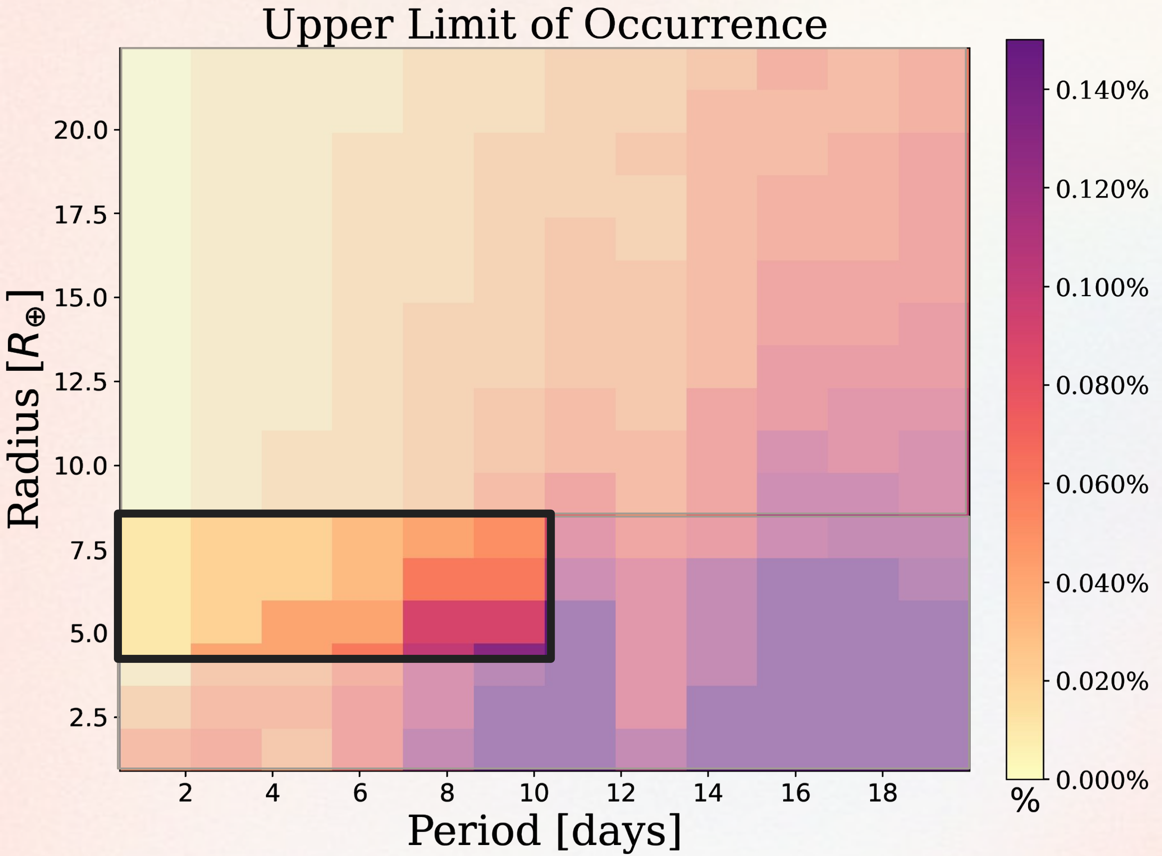


FFI Data

Average upper limits of planet occurrence for periods 0.5-10 days:

- Jupiters : 0.016%

Preliminary Upper Limits

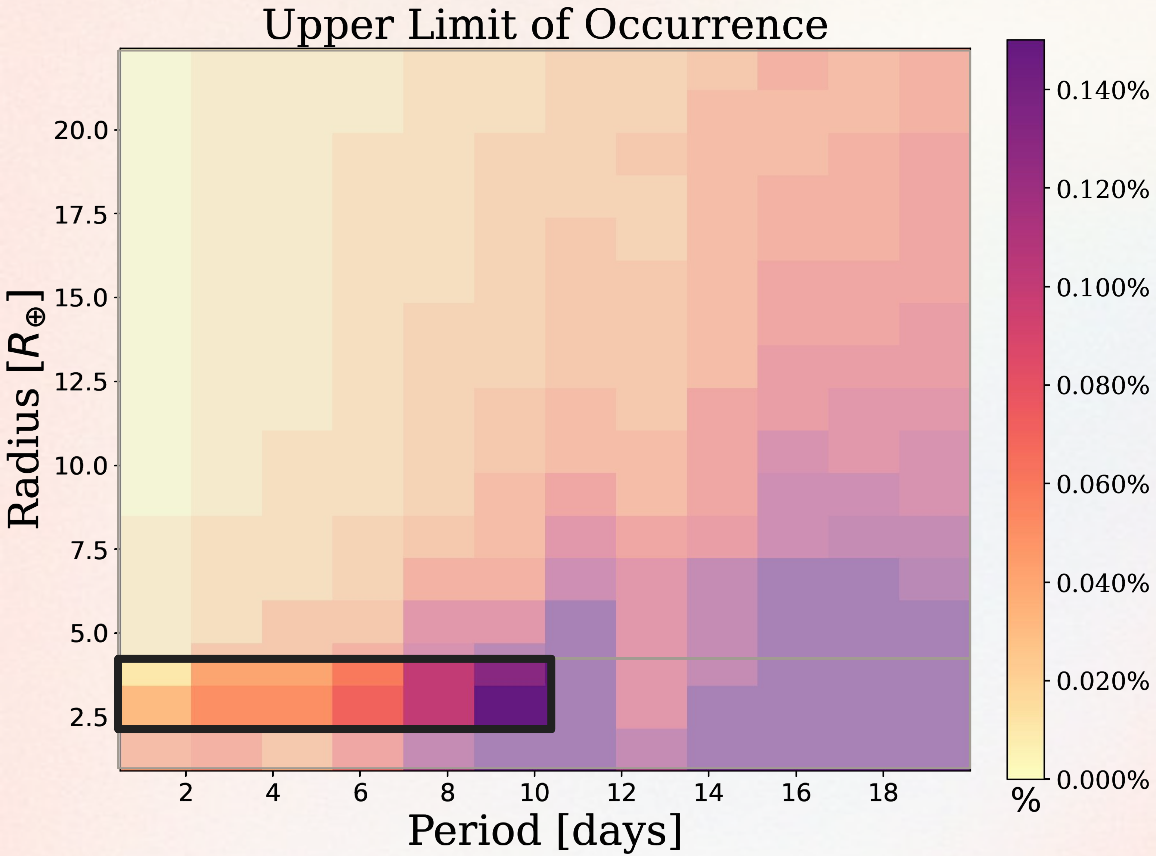


FFI Data

Average upper limits of planet occurrence for periods 0.5-10 days:

- Jupiters : 0.016%
- Sub-Saturns: 0.037 %

Preliminary Upper Limits

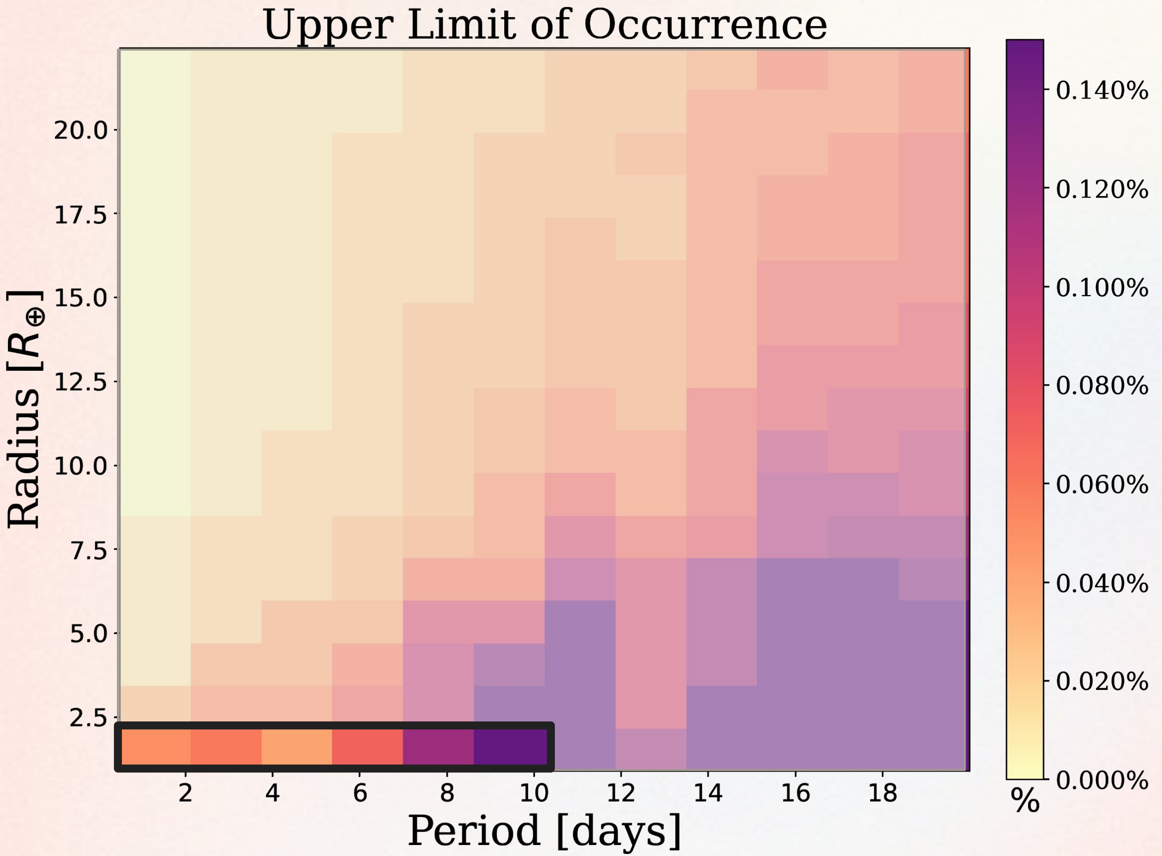


<u>FFI Data</u>

Average upper limits of planet occurrence for periods 0.5-10 days:

- ❖ Jupiters : 0.016%
- ❖ Sub-Saturns: 0.037 %
- ❖ Sub-Neptunes: 0.071%

Preliminary Upper Limits

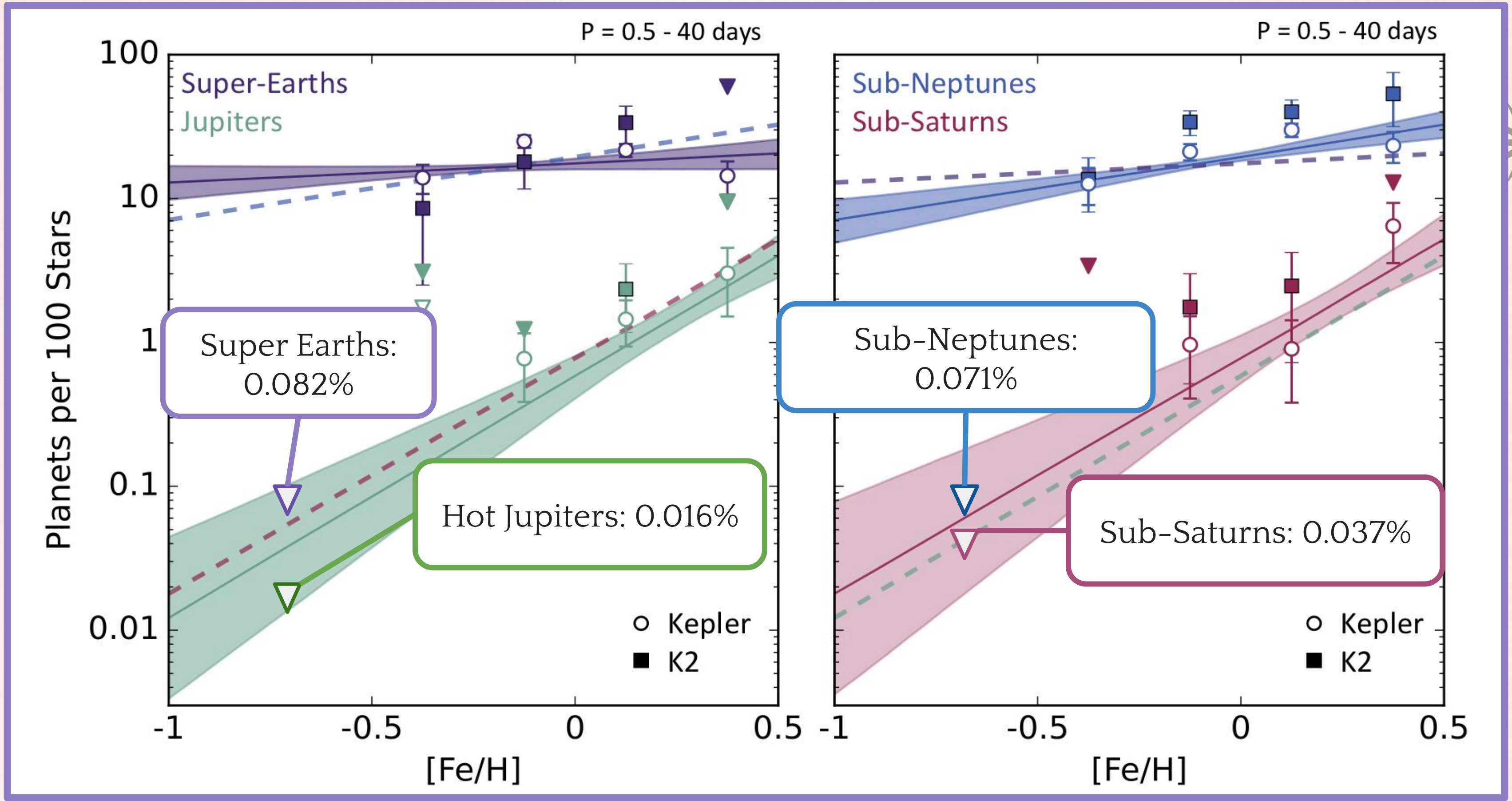


<u>FFI Data</u>

Average upper limits of planet occurrence for periods 0.5-10 days:

- Jupiters : 0.016%
- Sub-Saturns: 0.037 %
- Sub-Neptunes: 0.071%
- Super-Earths: 0.082%

Comparison



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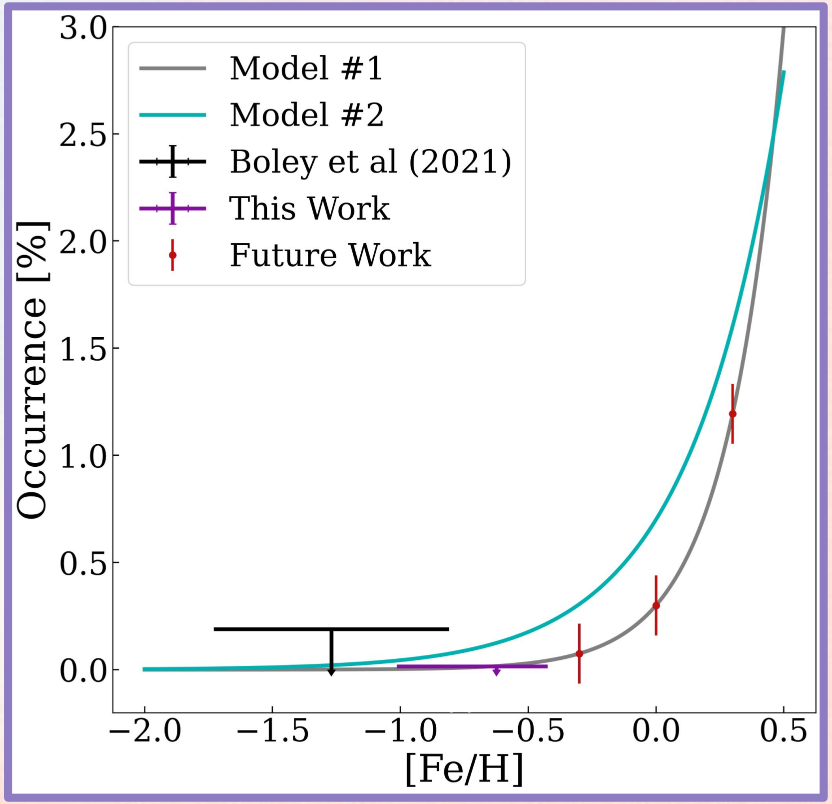
Future work

Metallicity

Constraining planet occurrence as a function of metallicity

Connecting planet formation to the evolution of our galaxy



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Metallicity

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Alpha Elements

Investigating planet occurrence in terms of alpha element abundance

Such as C, O, Ca, Mg, Si

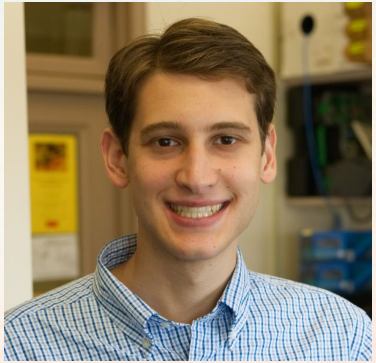
Host stars with low [Fe/H] have been shown to have high alpha elemental abundance (Adibekyan 2012a)

Outreach

astro [sound] bites

Alex Gagliano

Sabrina Berger



Will Saunders

Kiersten Boley

Astro [Sound] Bites

astro
[sound]
bites

- Astronomy / Science Podcast that aims to make astronomy more accessible
- Target audience: undergrads, grads, amateurs, and the public
- High-level summaries of research papers aimed at **undergrad science** level

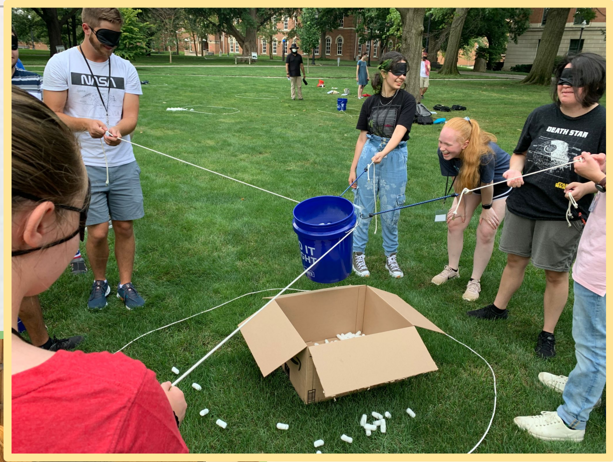
Check out our website!

URSA Program

Undergraduate Residential Summer Access (URSA) Program

- 2 week summer pre-arrival program for incoming students from **under-represented** backgrounds
- We aim to provide academic resources and introduce them to research
- We also aim to **build a strong cohort** between the students that will help them in future classes

URSA Program



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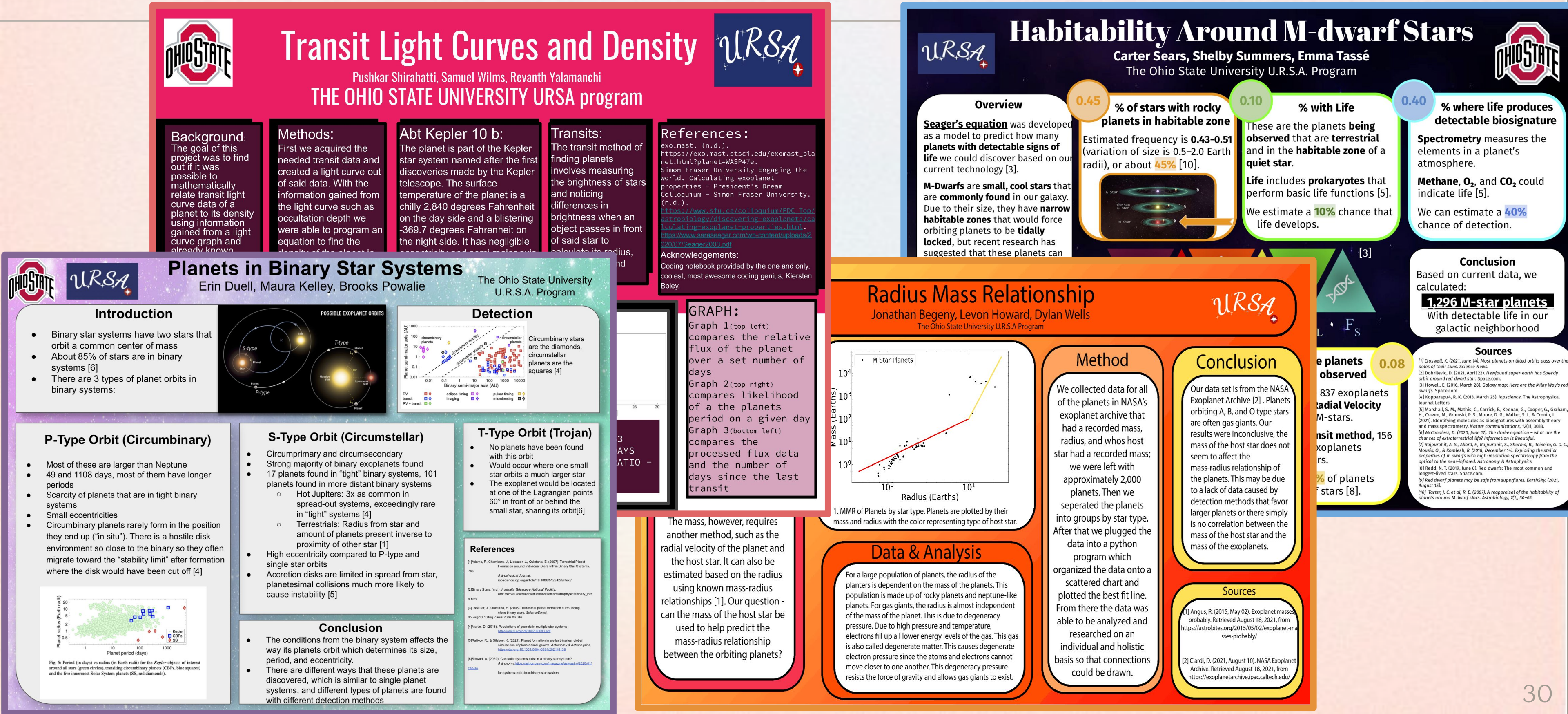

Summary

- Planet formation requires a sufficient amount of metals to build a planet
- With this sample, we will place the most stringent constraints on planet occurrence rates around metal-poor stars ($-1 < [Fe/H] < -0.4$)

THANK YOU!

Boley et al. 2021
Check it out!

@KierstenBoley

kboley3.github.io

boley.62@osu.edu