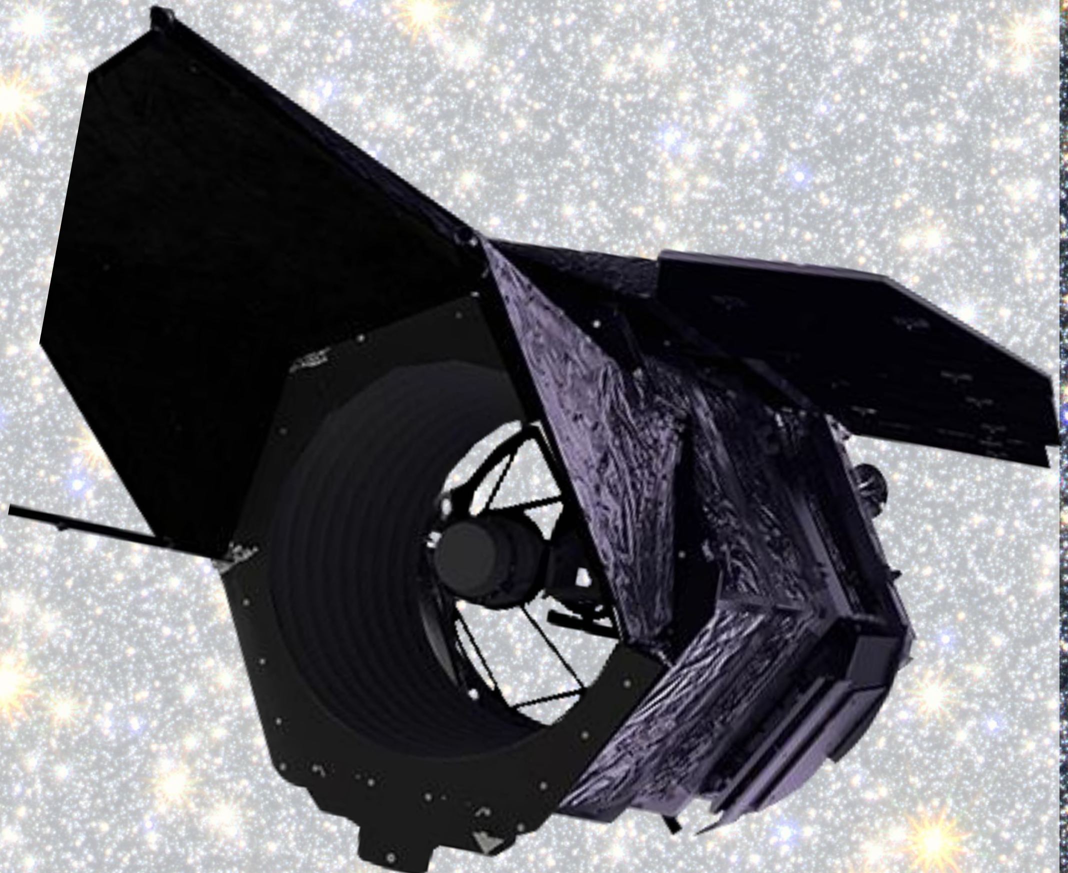
Roman’s Transiting Planet Yield



Robby Wilson
University of Maryland/NASA GSFC
Sagan Summer Workshop
July 22, 2026

Motivation

- Plan for needed Infrastructure

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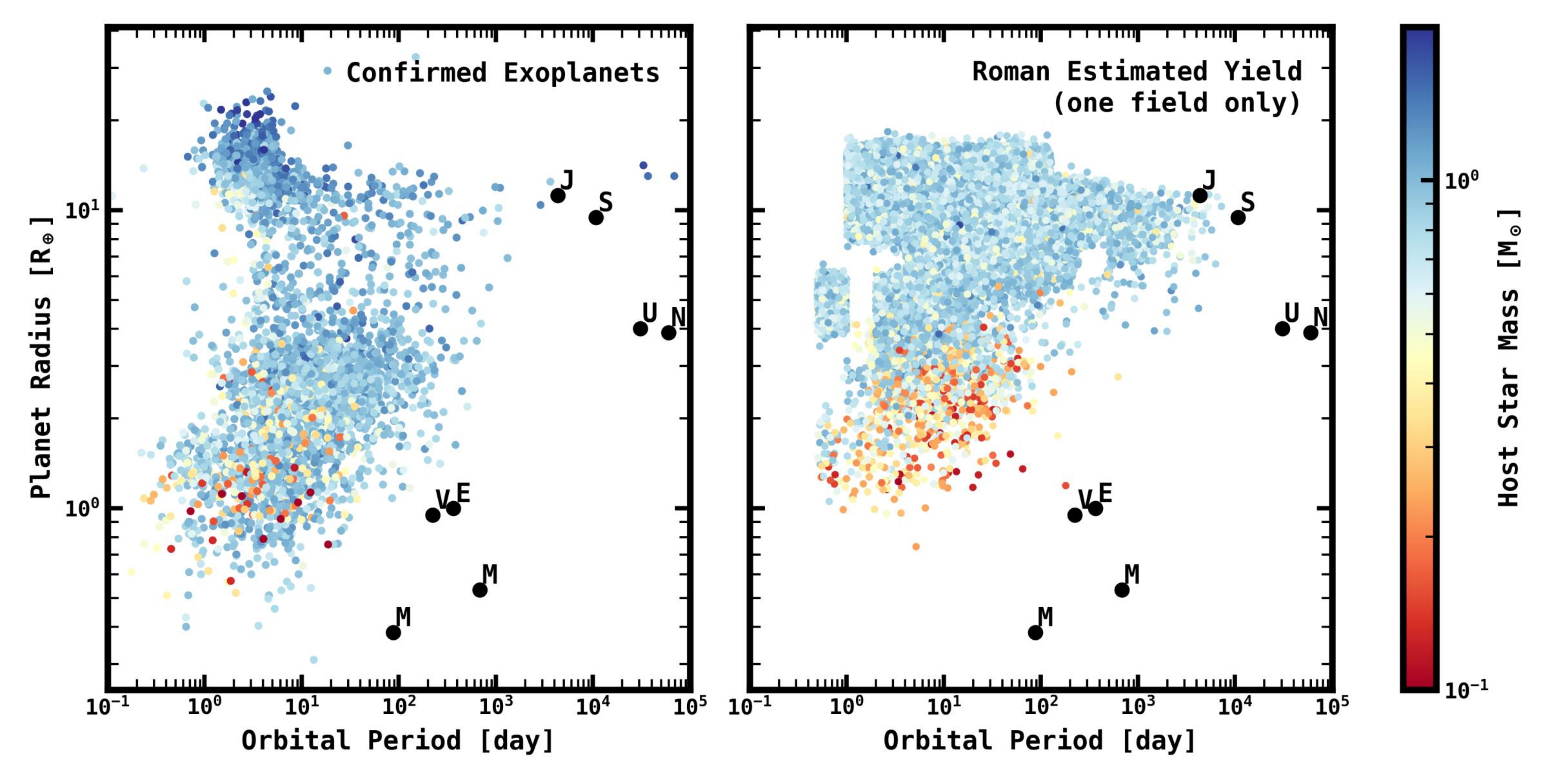
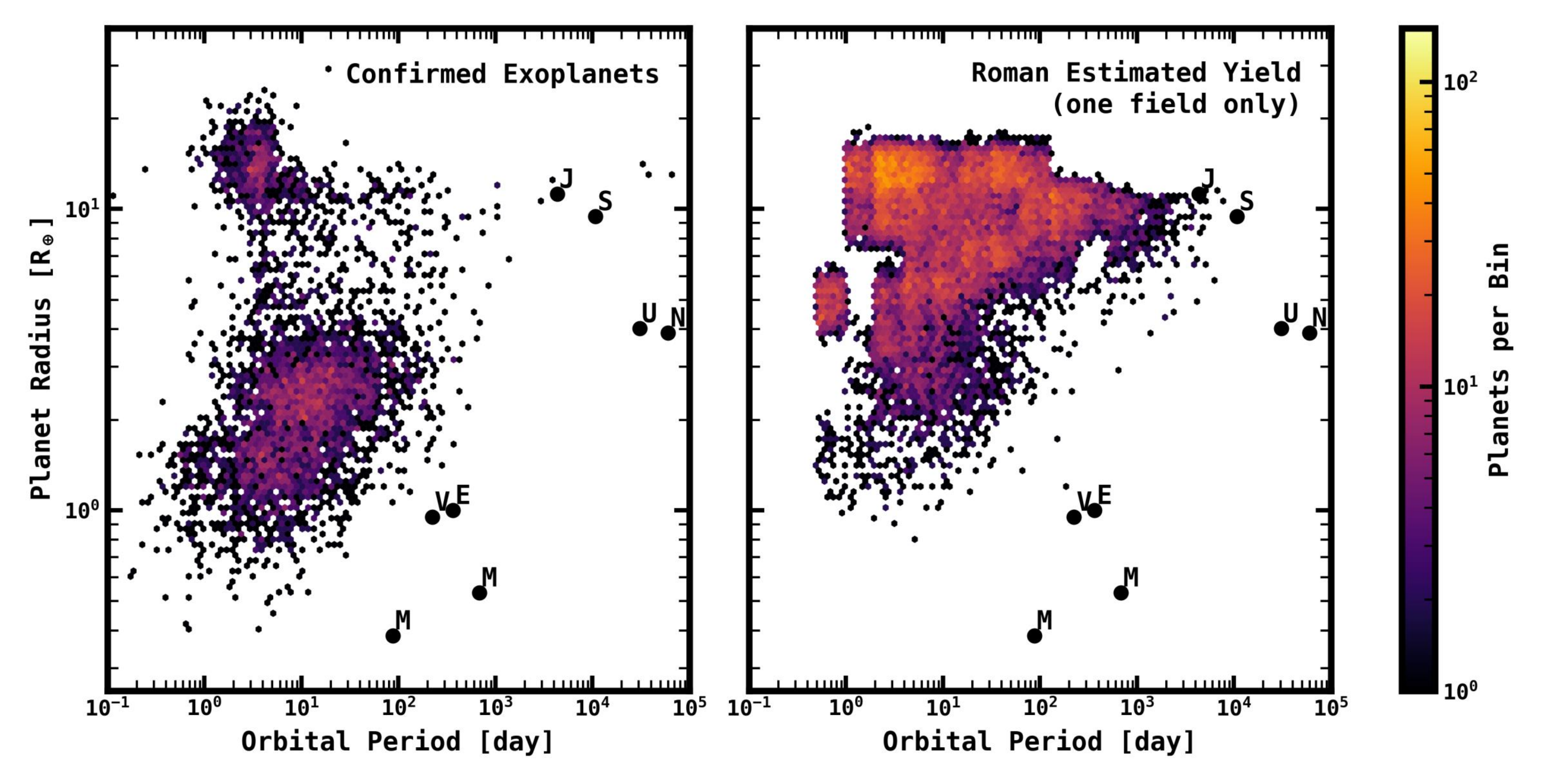
- Identify Opportunities for New Science



Confirmed Exoplanets
Roman Estimated Yield
(one field only)
Planet Radius [R⊕]
Orbital Period [day]
Orbital Period [day]
Host Star Mass [M☉]
J
S
U
N
V
E
M
M



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Planet Radius [R⊕]
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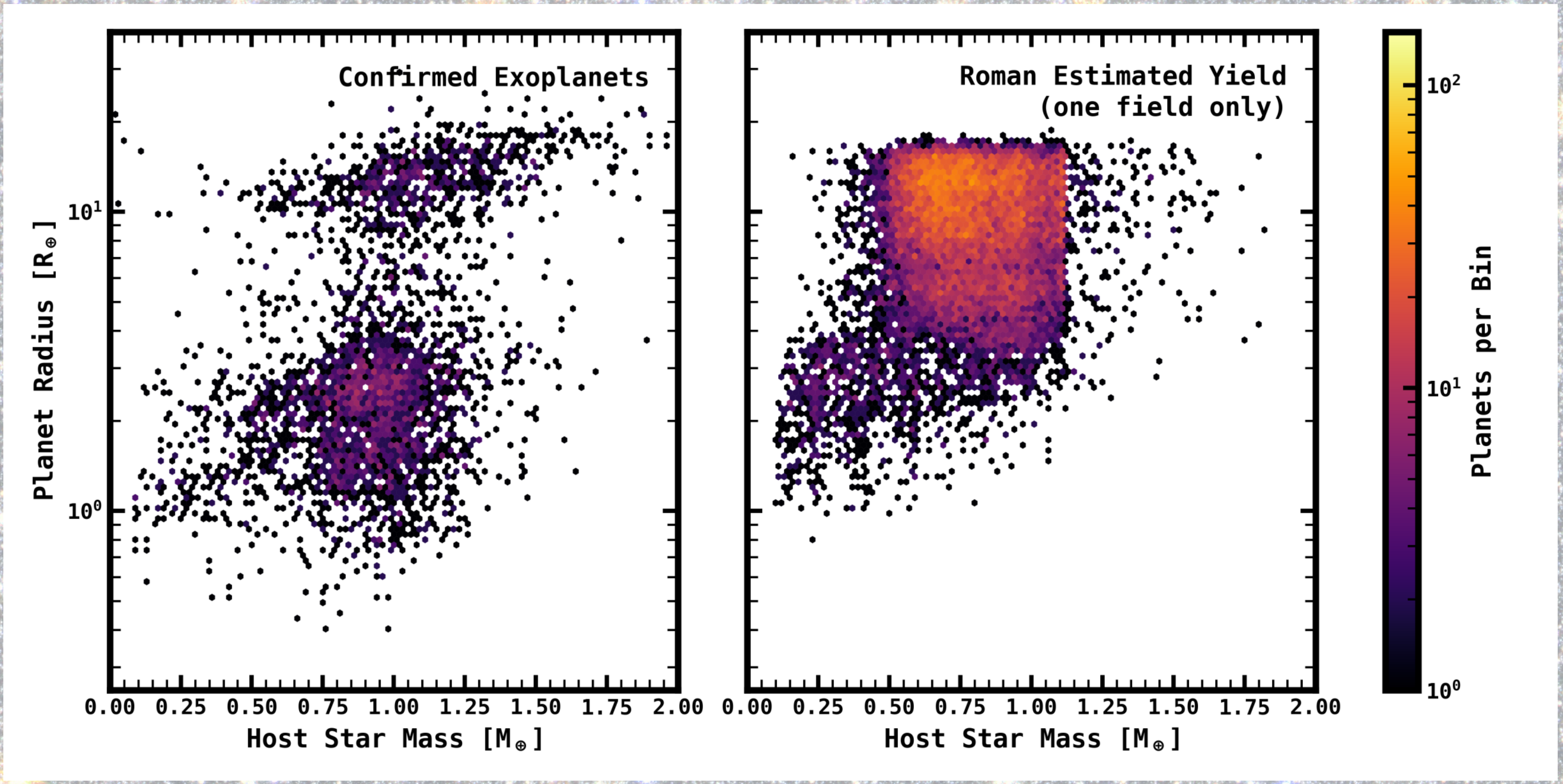
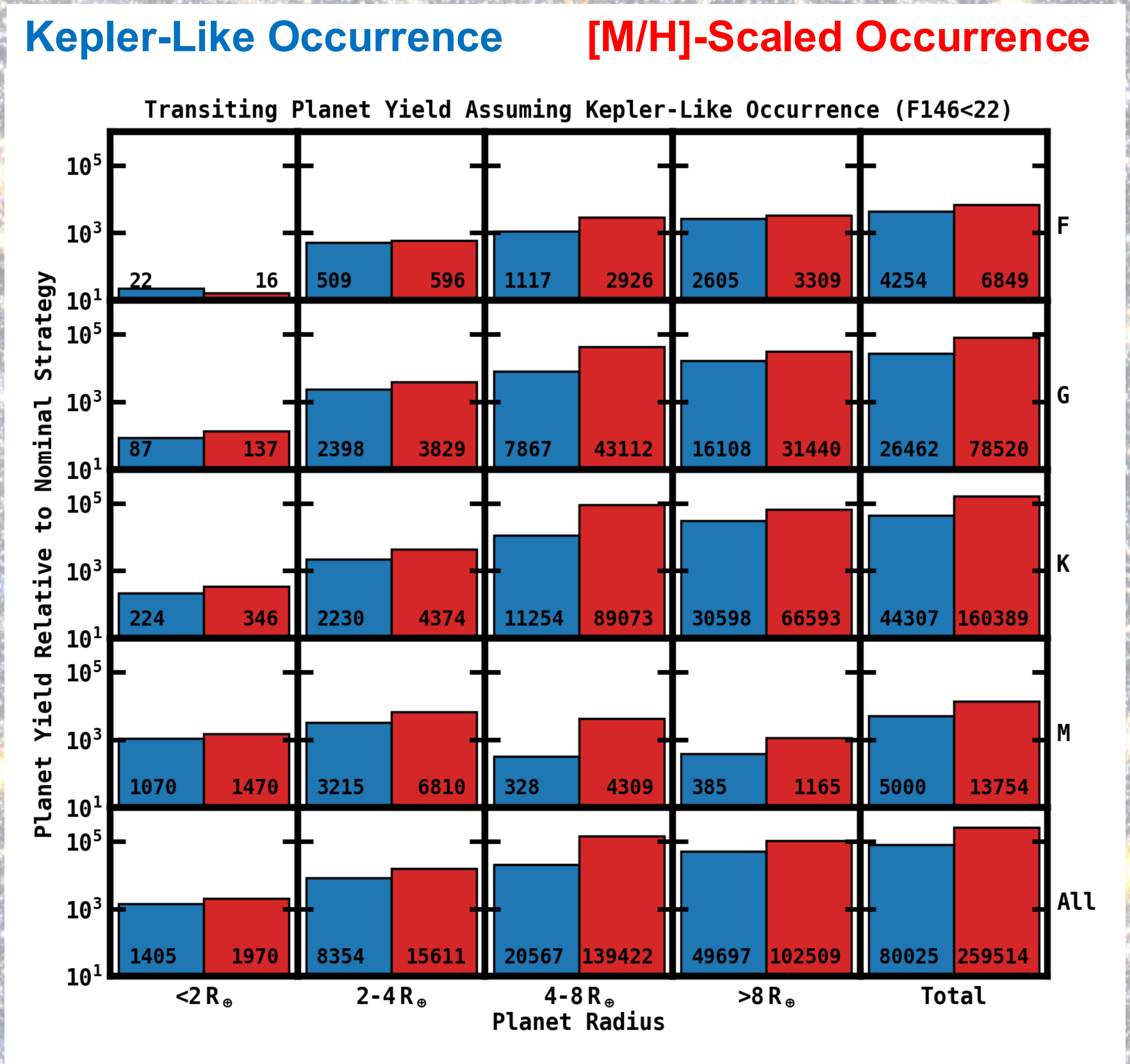
Planets per Bin
J
S
U
N
V
E
M
M
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}



Confirmed Exoplanets
Roman Estimated Yield
(one field only)
Planet Radius [R⊕]
10^{1}
10^{0}
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Host Star Mass [M⊕]
Host Star Mass [M⊕]
Planets per Bin
10^{2}
10^{1}
10^{0}

GBTDS Transit Opportunities

1. Demographics of (Ultra-) Hot Jupiter Atmospheres
2. Demographics for *Rare** Planetary Systems
3. Demographics across all major Galactic populations



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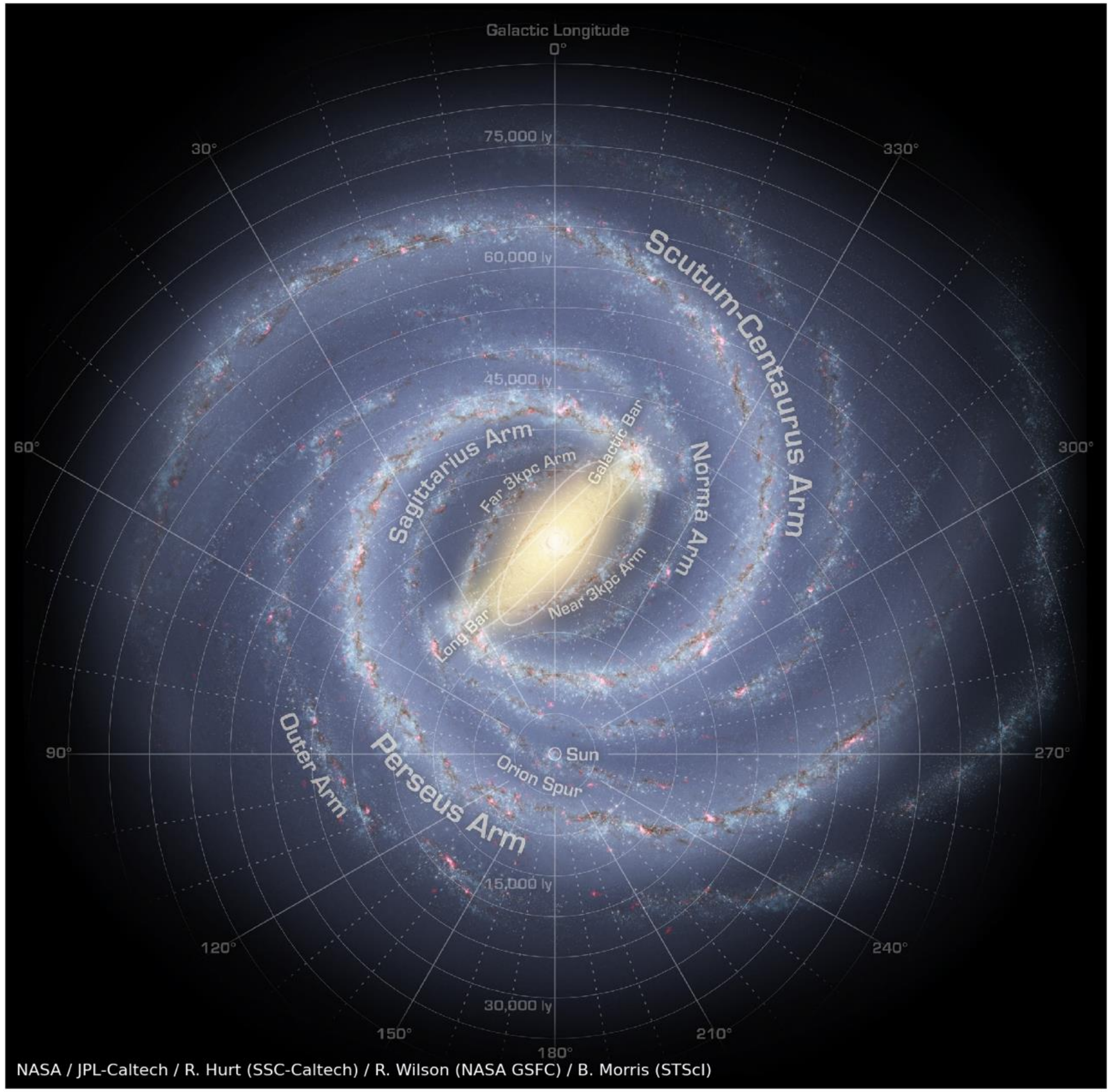

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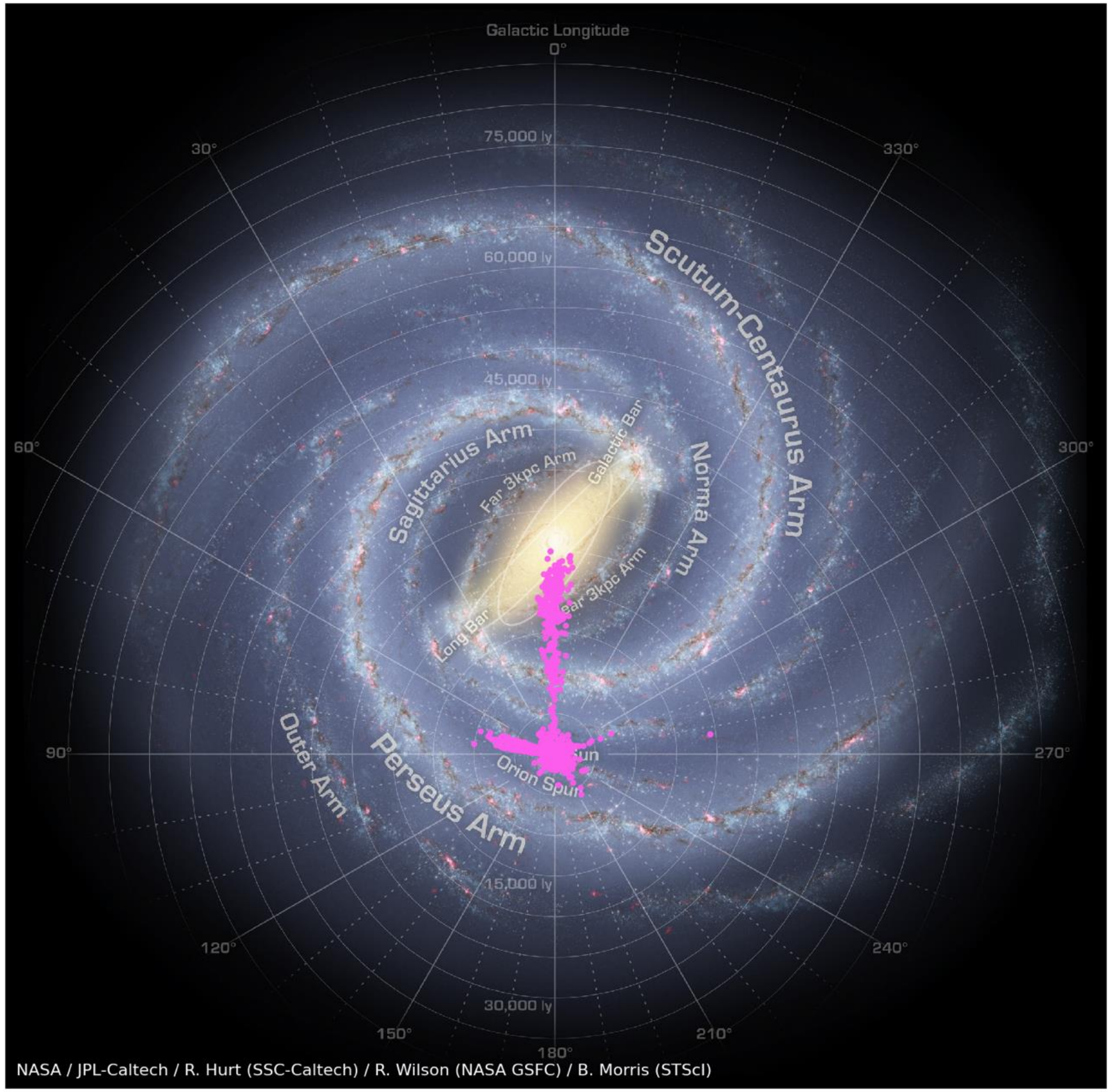

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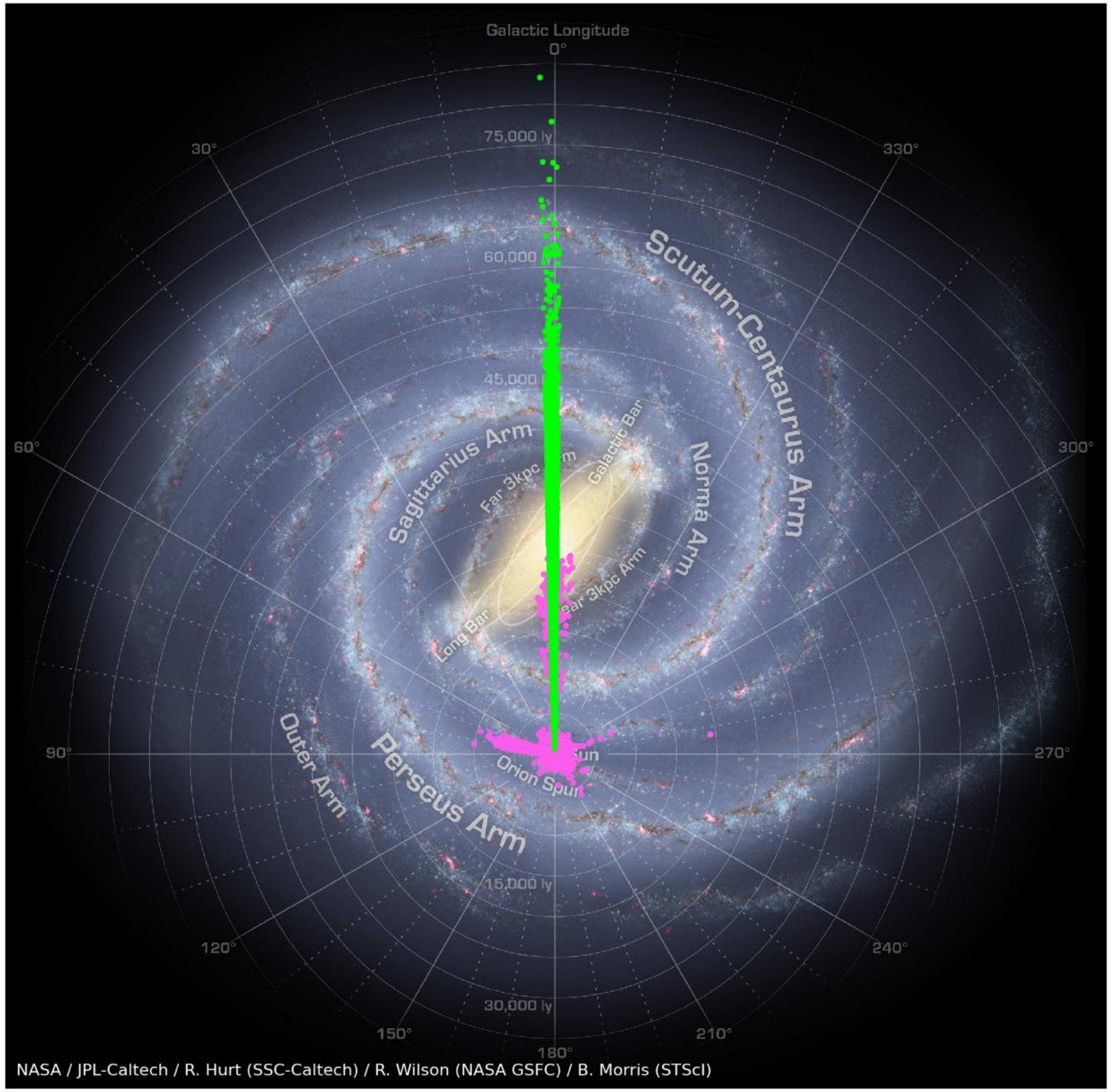


Motivation

- Plan for needed Infrastructure
- Identify Opportunities for New Science
- Forward Modeling to Measure Occurrence Rates

Demographics across all major Galactic populations

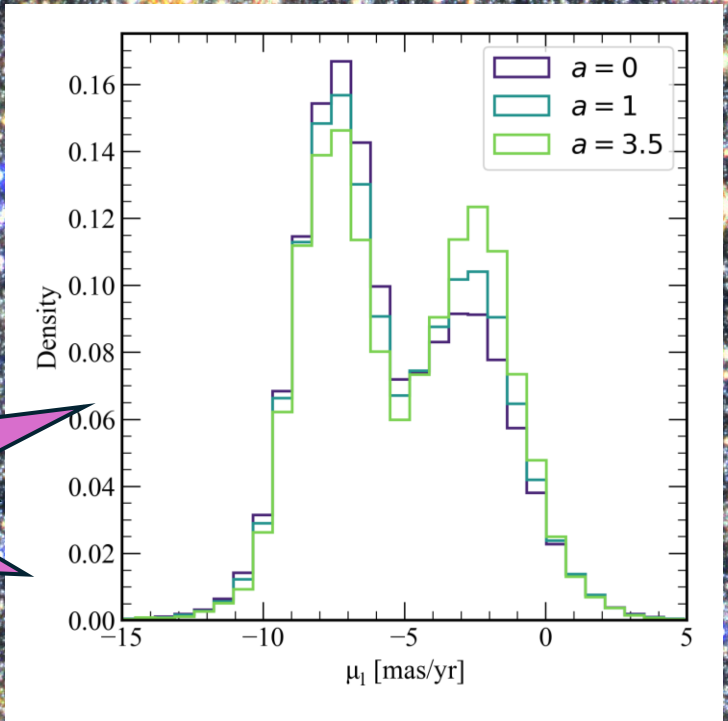
Planets found in every Major Galactic Population:

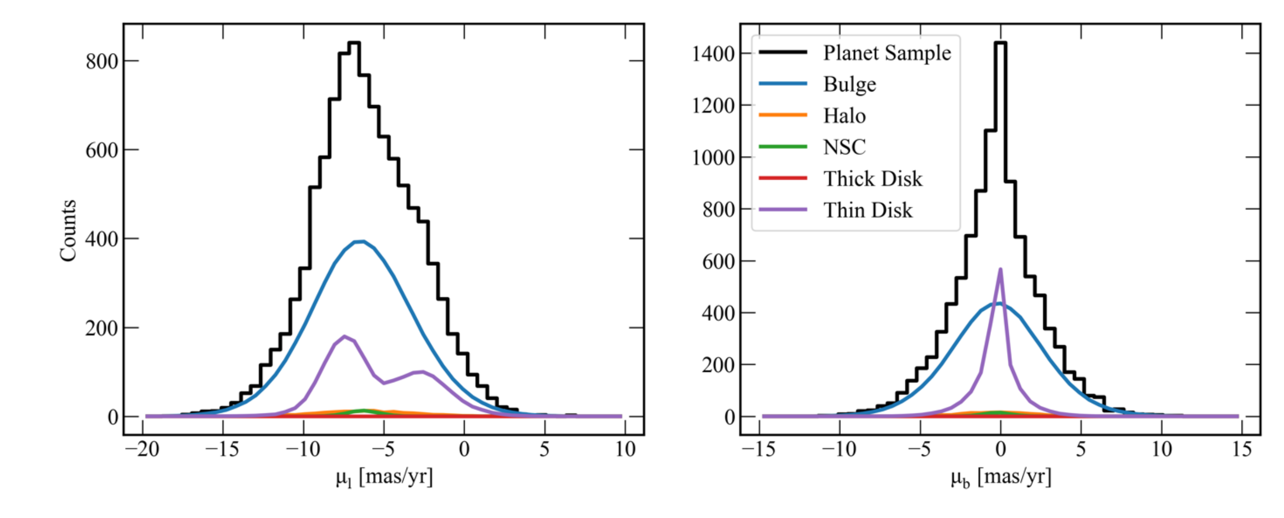
- **Bulge/Bar: ~69%**
- **Thin: ~13%**
- **Thick Disk/Thick Bulge: ~18%**

With Metallicity Effects:

- **Bulge/Bar: ~80%**
- **Thin: ~17%**
- **Thick Disk/Thick Bulge: ~3%**

See Matt's Poster!





$$N_p = N_\star \times F_p \times \eta$$

Number of Planets

Number of Stars Searched for Planets

Number of Planets per Star

Fraction of Planets that are detected

$$N_p = N_\star \times F_p \times \eta$$

$$F_p = \frac{N_p}{N_\star \times \eta}$$

Yield calculations are complementary to occurrence rate calculations (See Michelle's talk)

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Number of Planets

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Number of Planets per Star

Fraction of Planets that are detected

Yield = (~10^8 *stars*) x (~1 *planet/star*) x (~10^{-3} *detected*) = ~10^5 planets detected

Number of Stars Searched for Planets

Number of Planets around Star *i*

$$N_p = \sum_{i}^{N_\star} \sum_{j}^{n_{pl,i}} \eta_j$$

Total Number of Planets (i.e., Yield)

Probability that planet *j* is detected orbiting star *i*

Procedure

$$N_p = \sum_{i}^{N_\star} \sum_{j}^{n_{pl,i}} \eta_j$$

1. Gather a Sample of Planet-Search Stars

2. Assign an appropriate number of planets to each star based upon planet occurrence rates

3. Determine which planets will be detected.

4. Sum up all detected planets to calculate the Yield

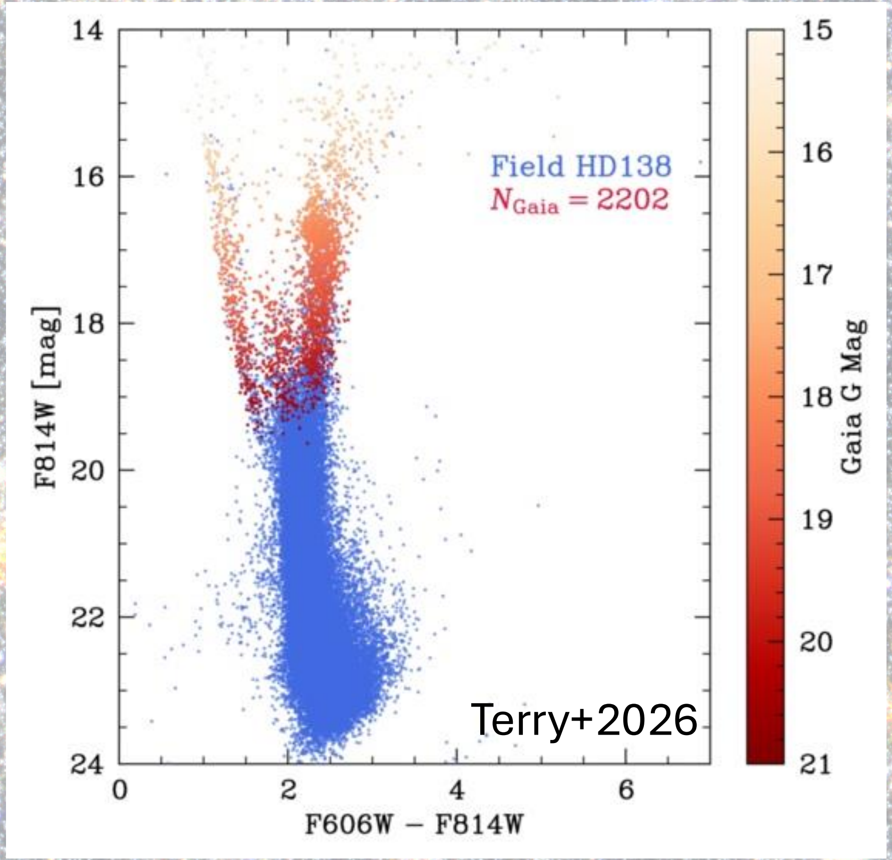
$N_\star$: *Number of Stars Searched for Planets*

Complications

- We do not yet know what stars *Roman* will search

Solution:

- Estimate the sample of planet search stars using Galactic models



The Milky Way Model

Image credit: NASA/ESA/S. Farrell (University of Sydney)

The Milky Way Model

Thick Disk
- Extends to R~5 kpc, Z~3 kpc
- Old Population (~8-10 Gyr)
- Similar Chemically to Bar/Bulge

Bulge/Bar:
- Extends to R~3 kpc
- Consistent with Mono-Age Population (~10 Gyr)
- Elevated in Alpha Abundances

Thin Disk
- Extends to R>20 kpc, Z~0.5 kpc
- Age Gradient: dAge/dR<0
- Metallicity Gradient: dMet/dR<0

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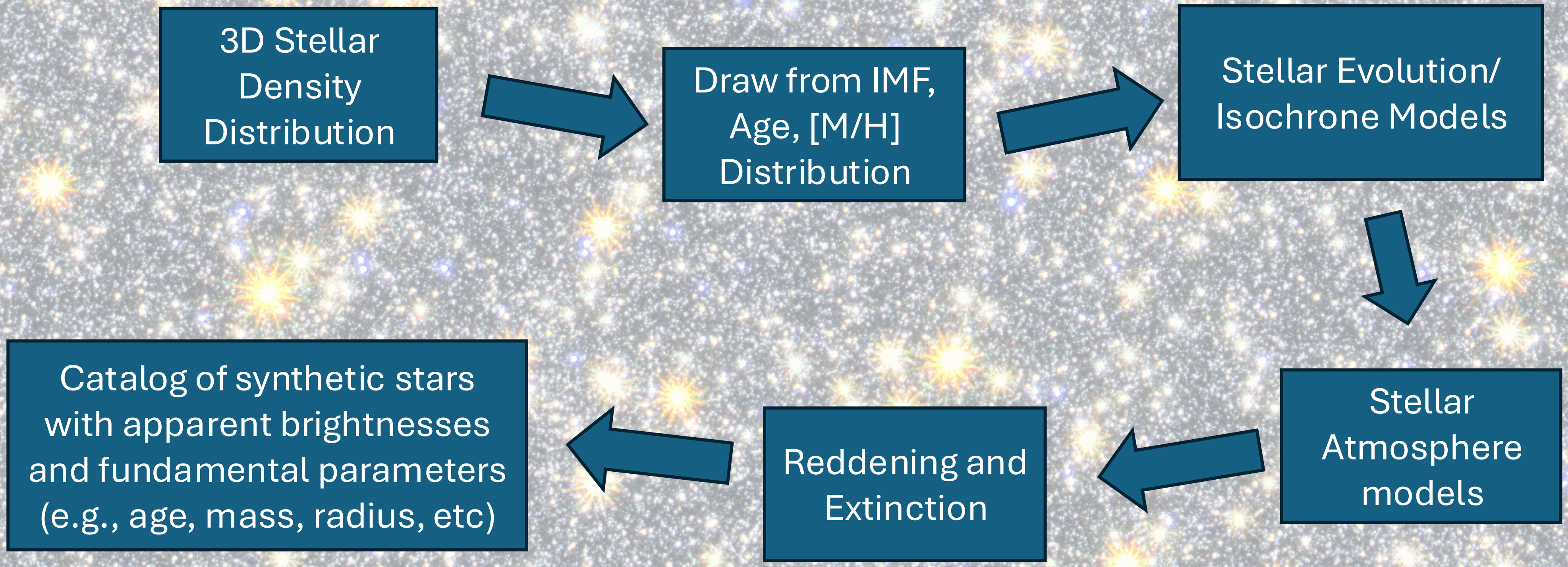
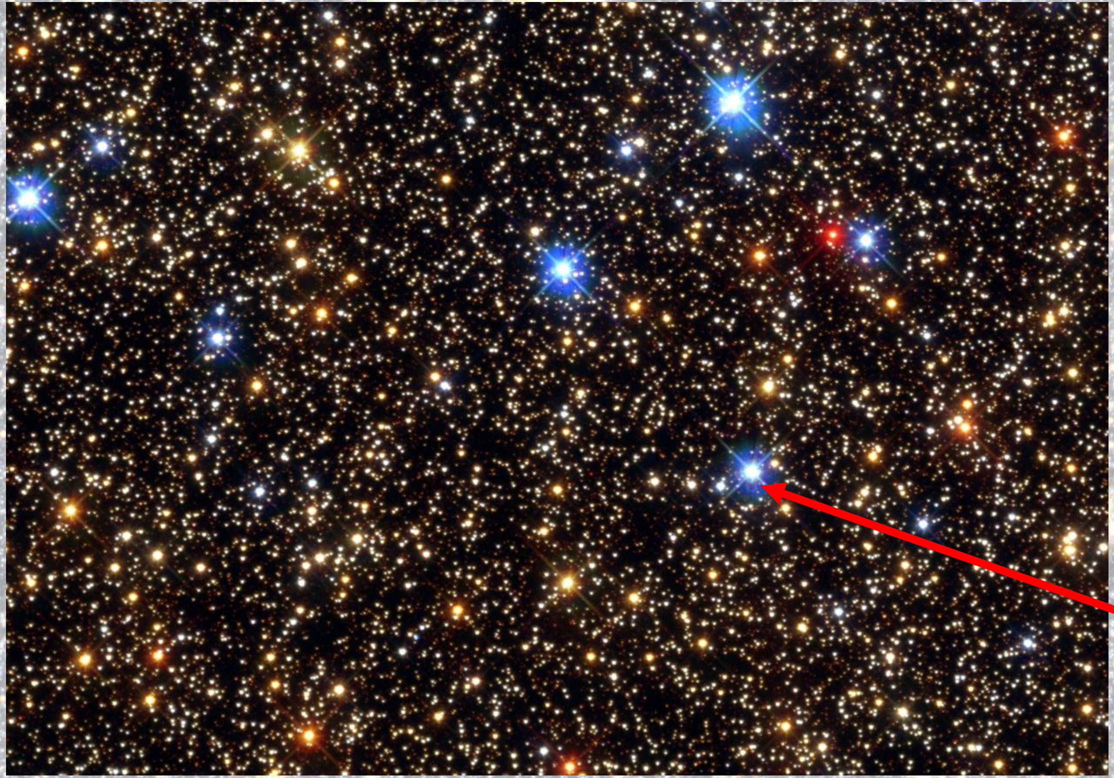


$N_\star$: Number of Stars Searched for Planets

- Empirical constraints?



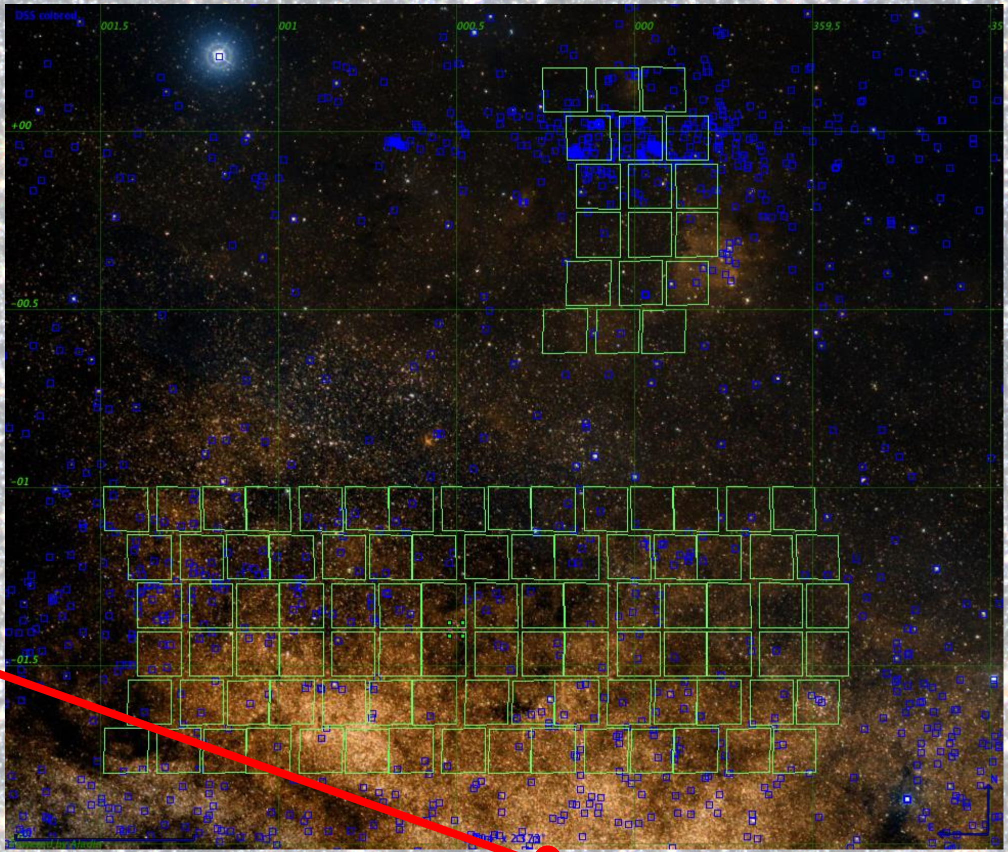
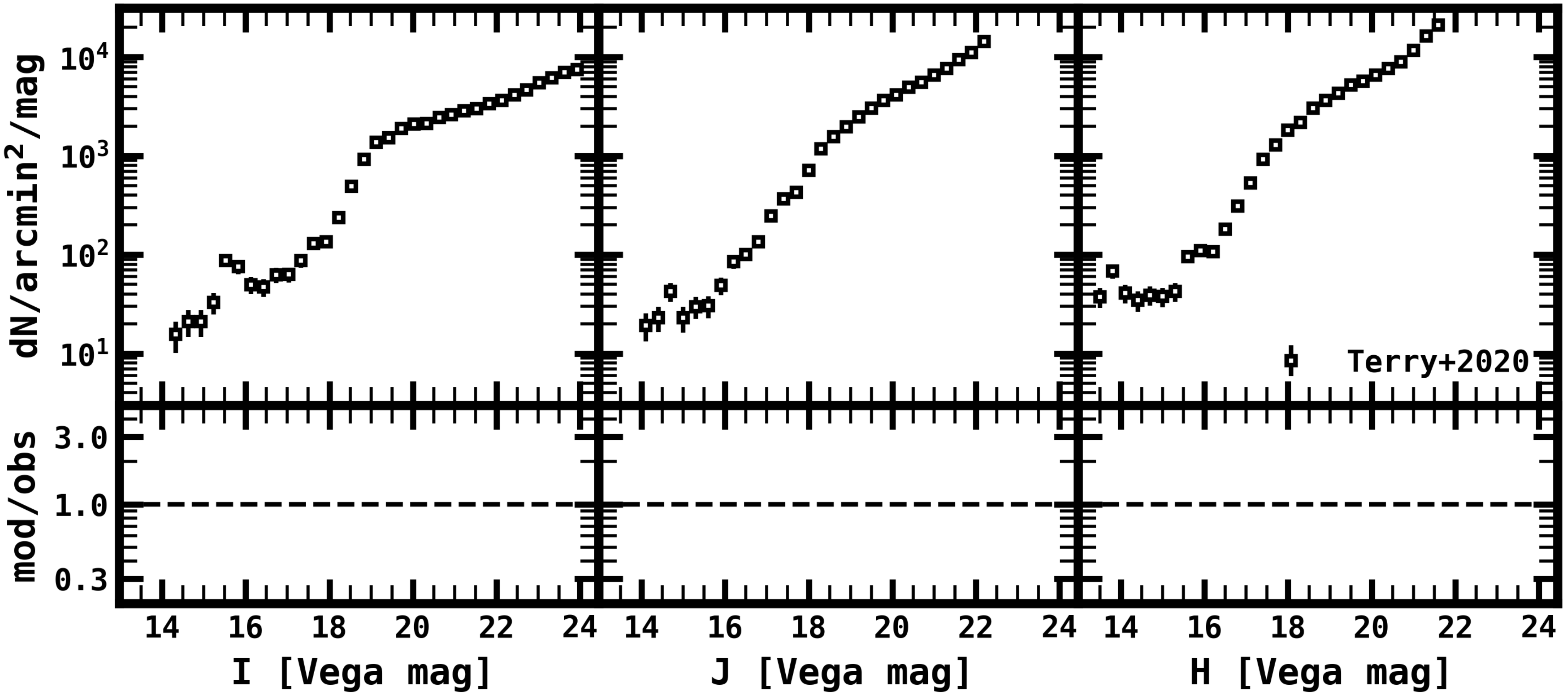
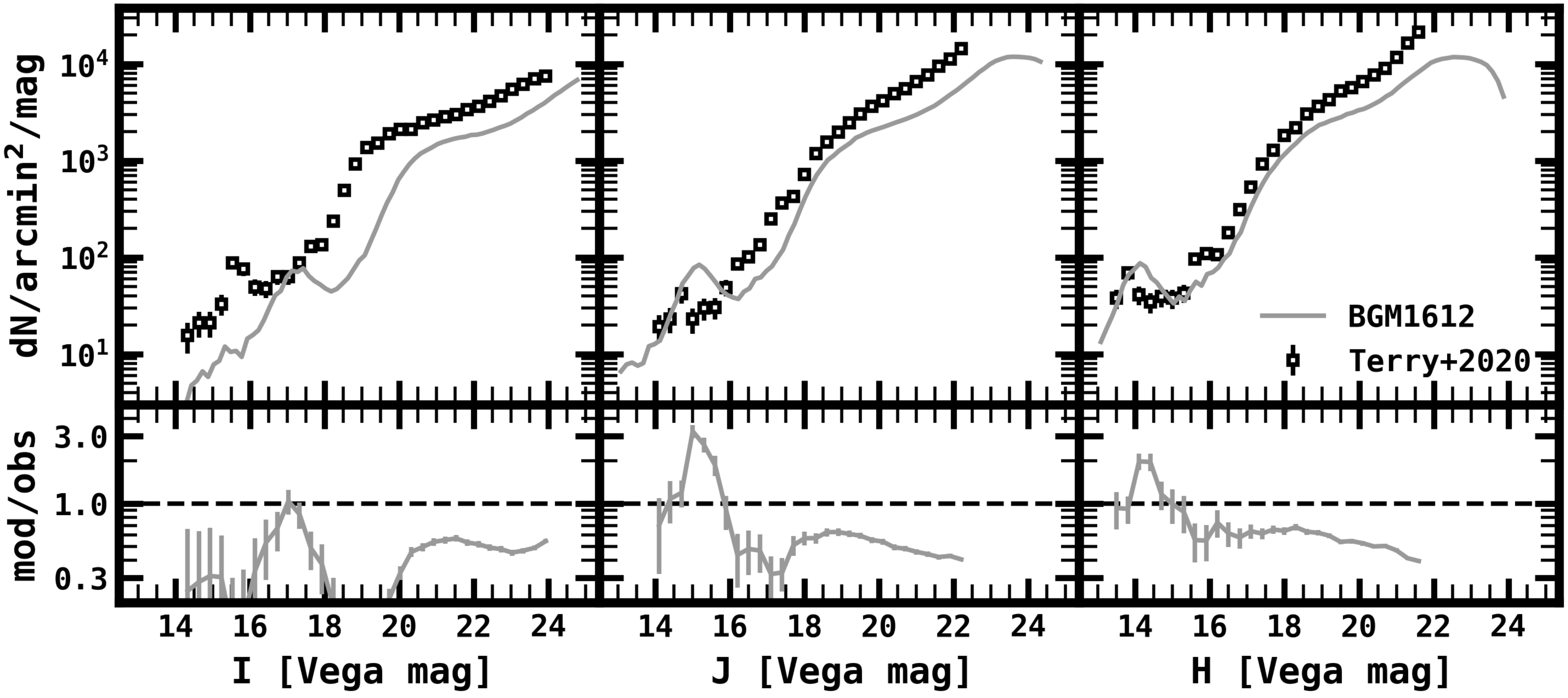
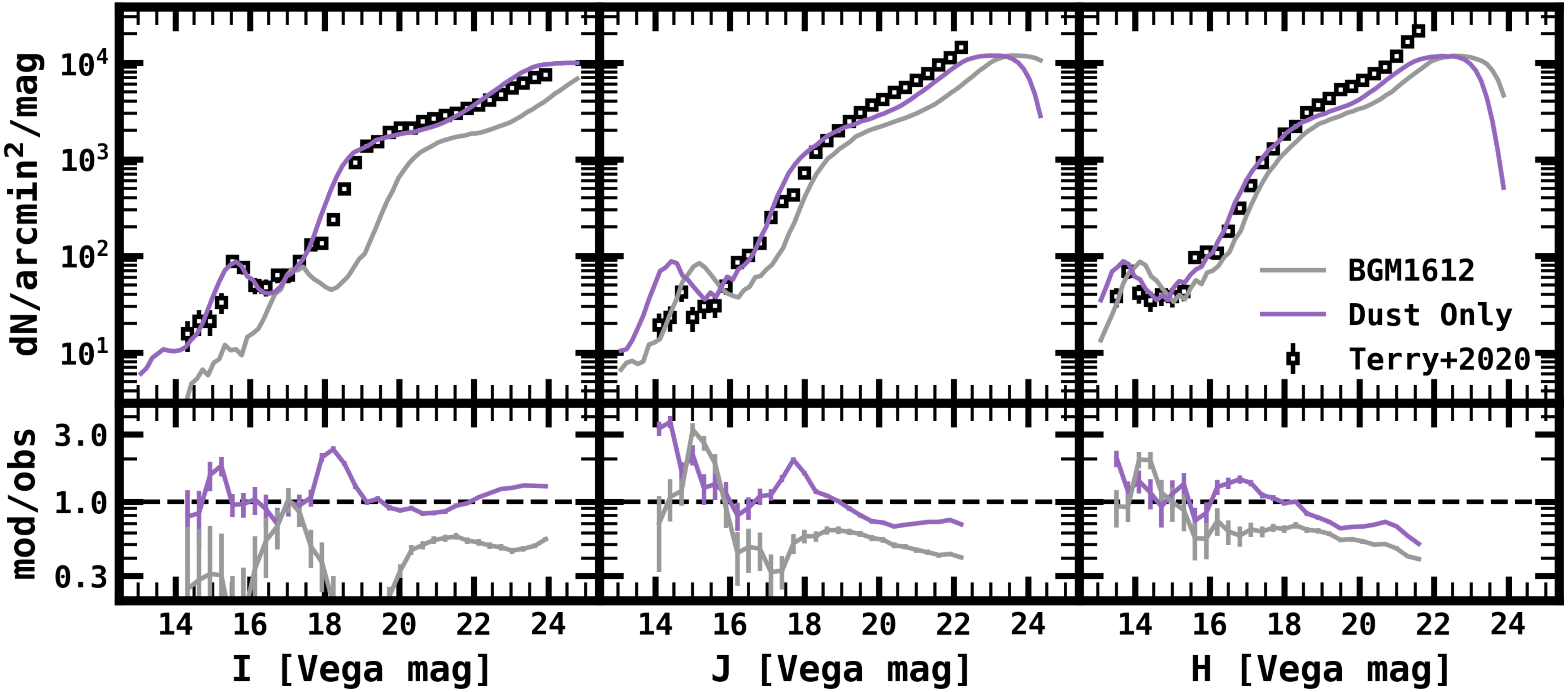


Image Credit: Brown+2009, 2010



dN/arcmin2/mag
mod/obs
Terry+2020
I [Vega mag]
J [Vega mag]
H [Vega mag]


dN/arcmin^2/mag
10^1
10^2
10^3
10^4
mod/obs
0.3
1.0
3.0
14 16 18 20 22 24
I [Vega mag]
J [Vega mag]
H [Vega mag]
BGM1612
Terry+2020



dN/arcmin²/mag
mod/obs
I [Vega mag]
J [Vega mag]
H [Vega mag]
BGM1612
Dust Only
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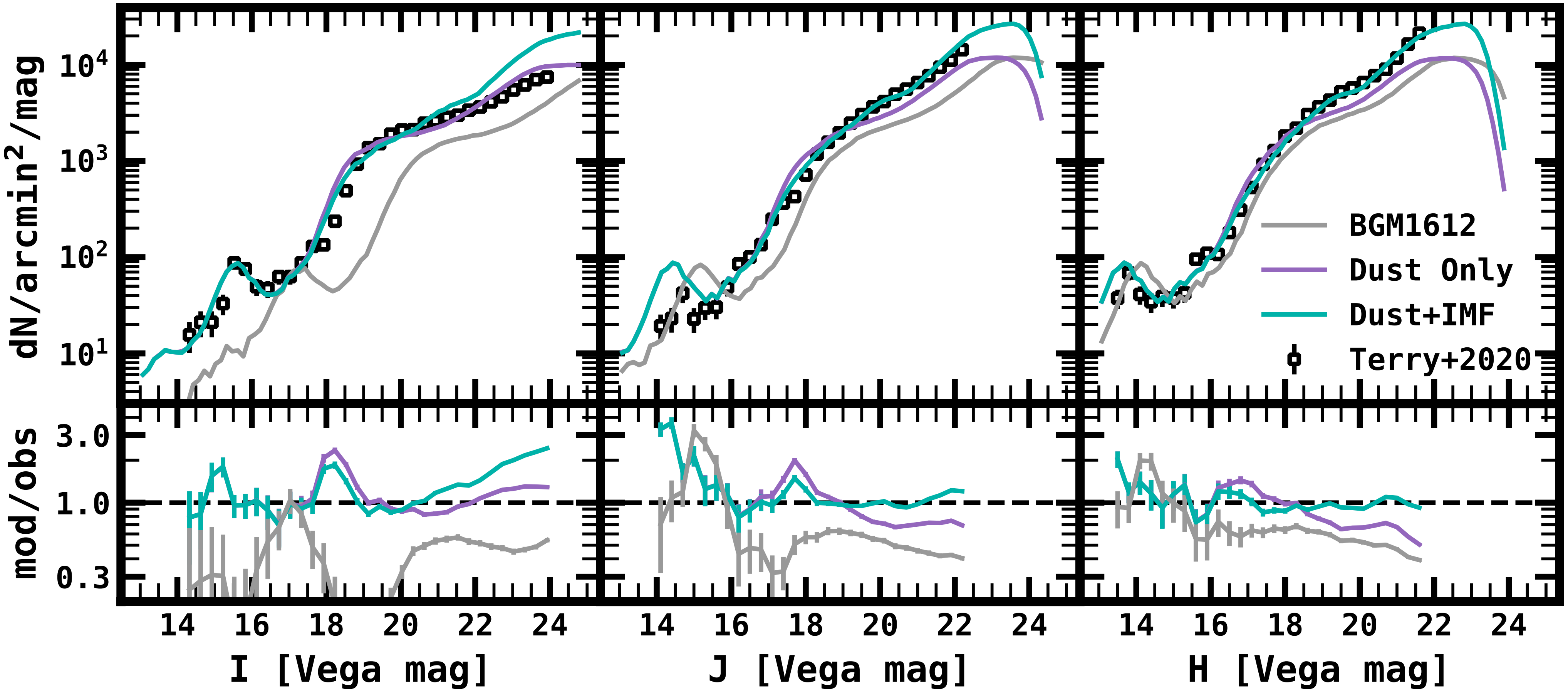

dN/arcmin^2/mag
10^4
10^3
10^2
10^1
mod/obs
3.0
1.0
0.3
14 16 18 20 22 24
I [Vega mag]
J [Vega mag]
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BGM1612
Dust Only
Dust+IMF
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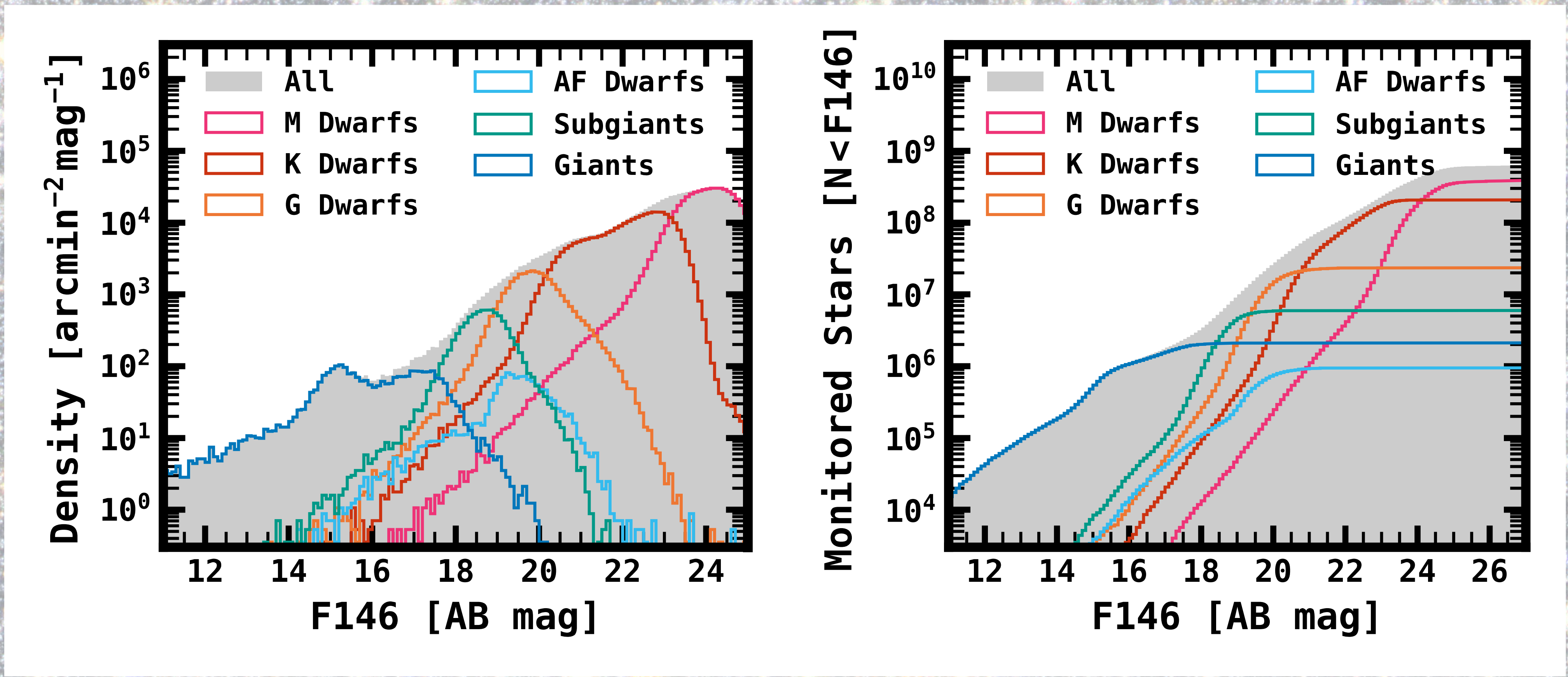

Below 22nd mag:

- **~10^4 Stars per arcmin^2**
- **~81 Million Total**
- **~1.5 Million Giants**
- **~1 Million AF Type**
- **~20 Million G-Type**
- **~54 Million K-Type**
- **~4.9 Million M-Type**
- **~450,000 M5-9V Type**

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F_p: Planet Occurrence Rate (Number of Planets per Star, n_{pl})

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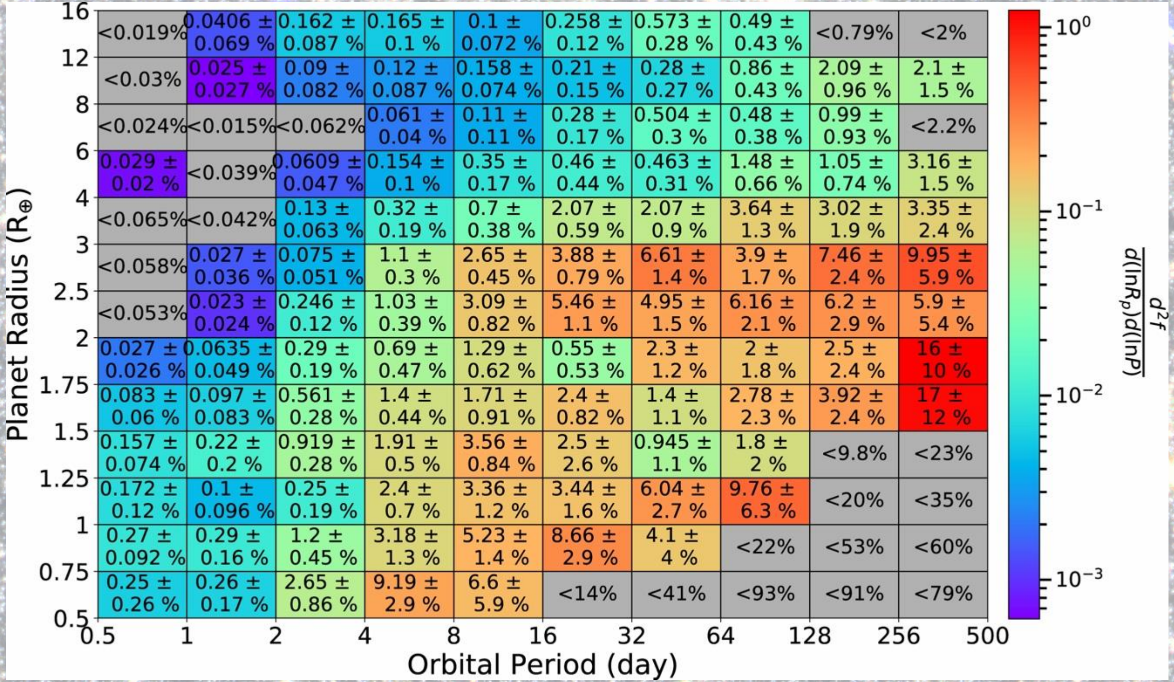
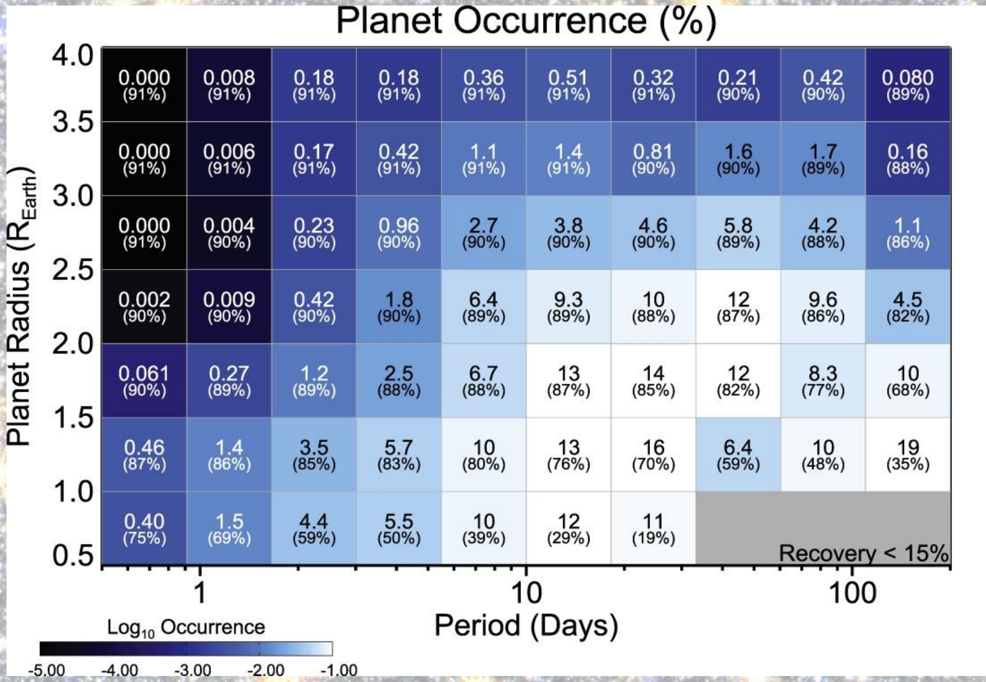
Sun-Like Stars



Hsu+2019

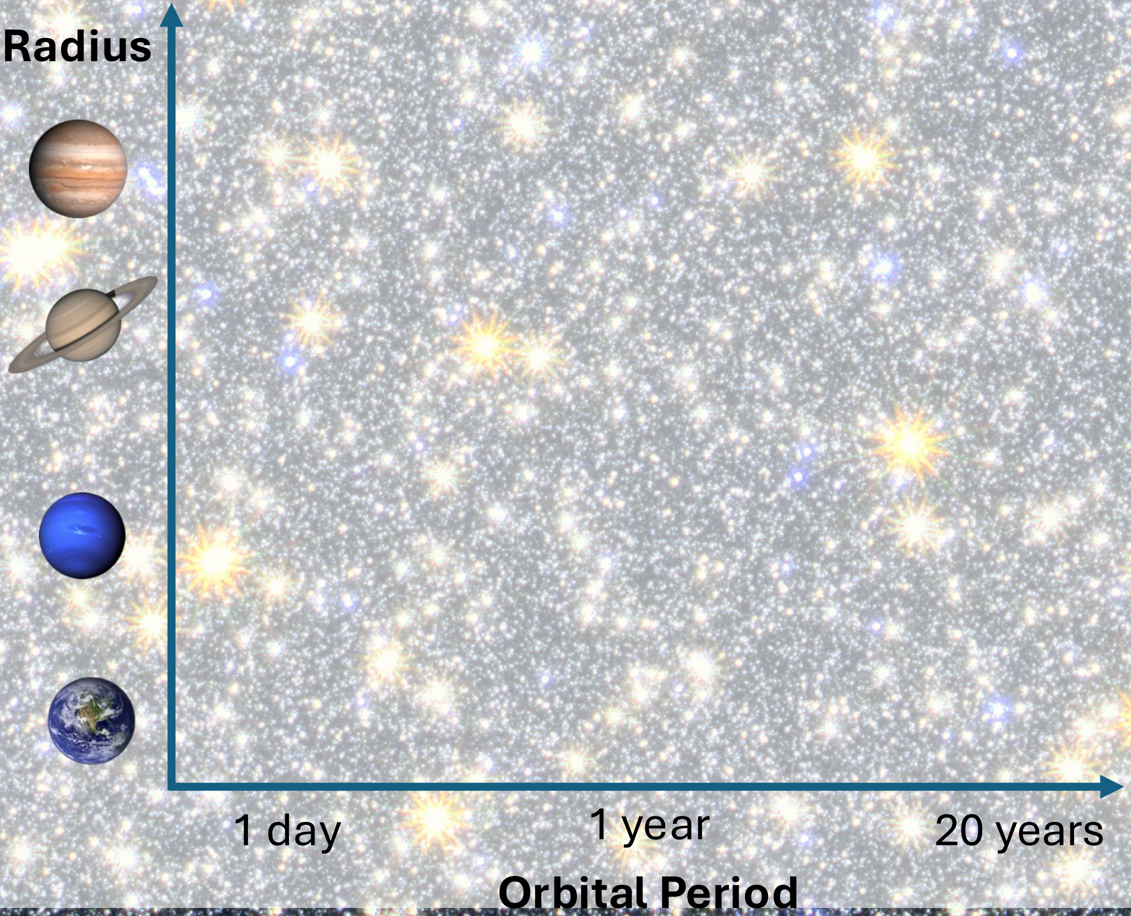
M Stars



Dressing+2015

F_p: Planet Occurrence Rate (Number of Planets per Star, n_{pl})

How do we extrapolate to unknown populations?



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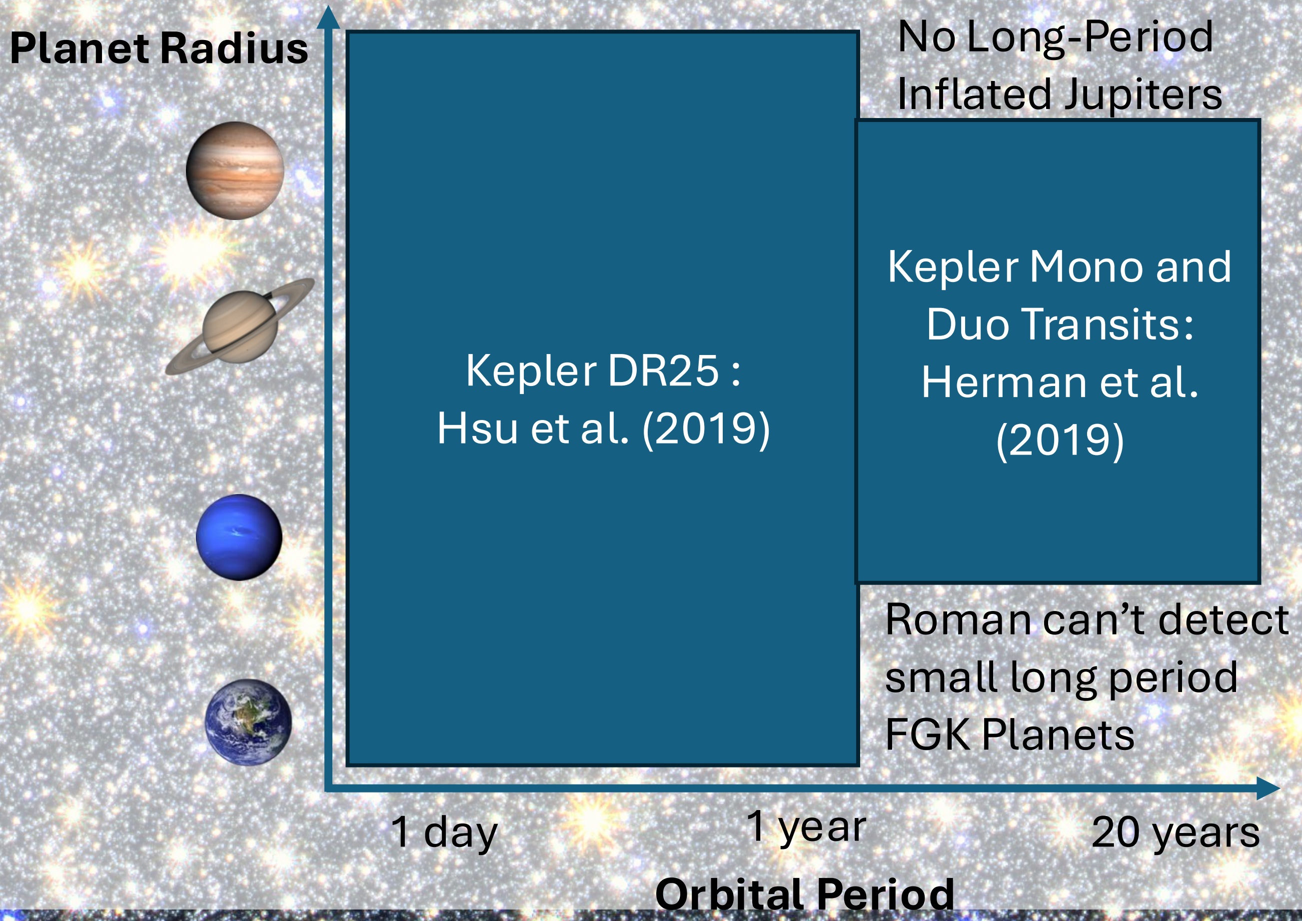
- **FGK Stars**
  - **Plug in results from Kepler**



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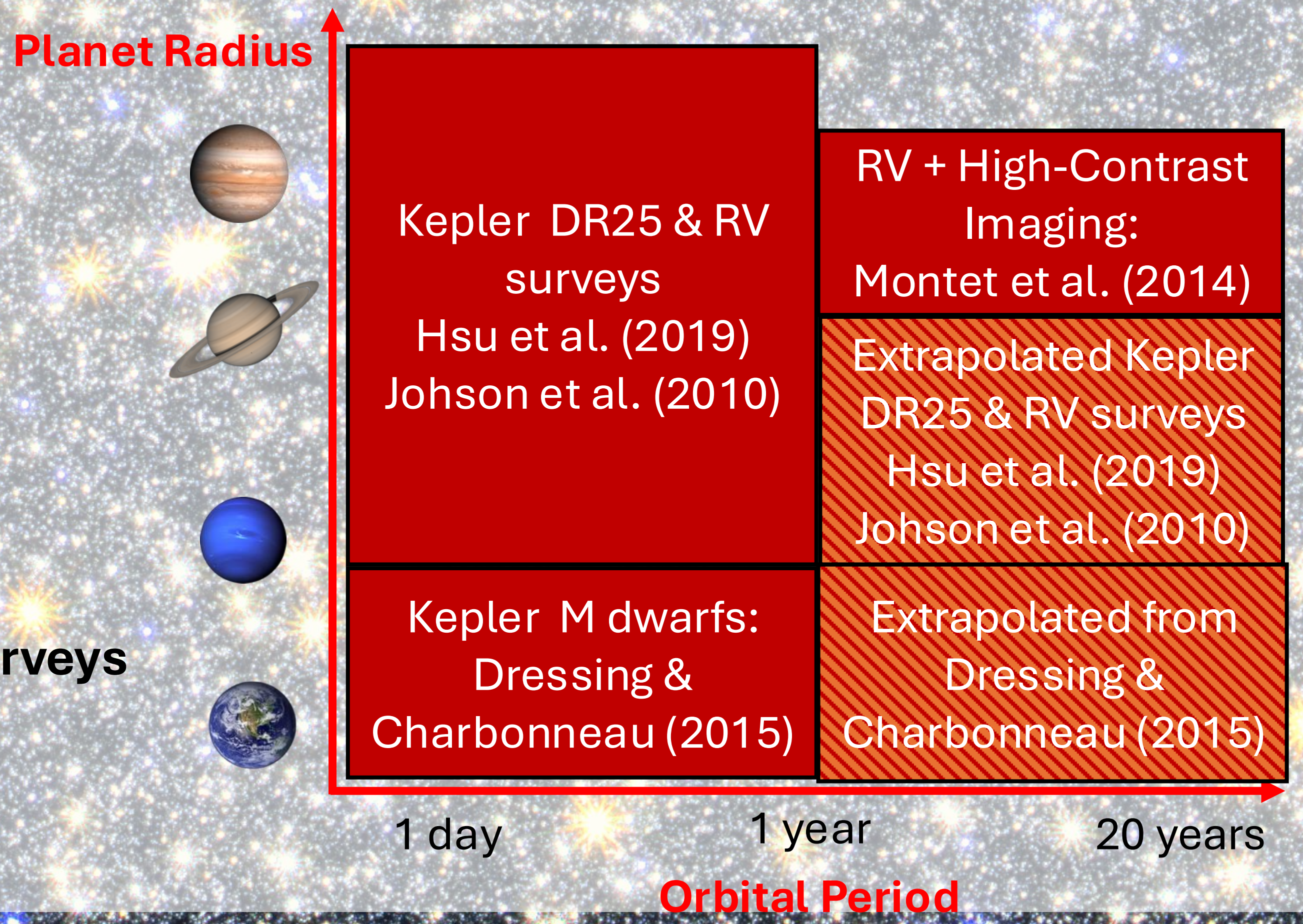
  - **RVs, Direct imaging**



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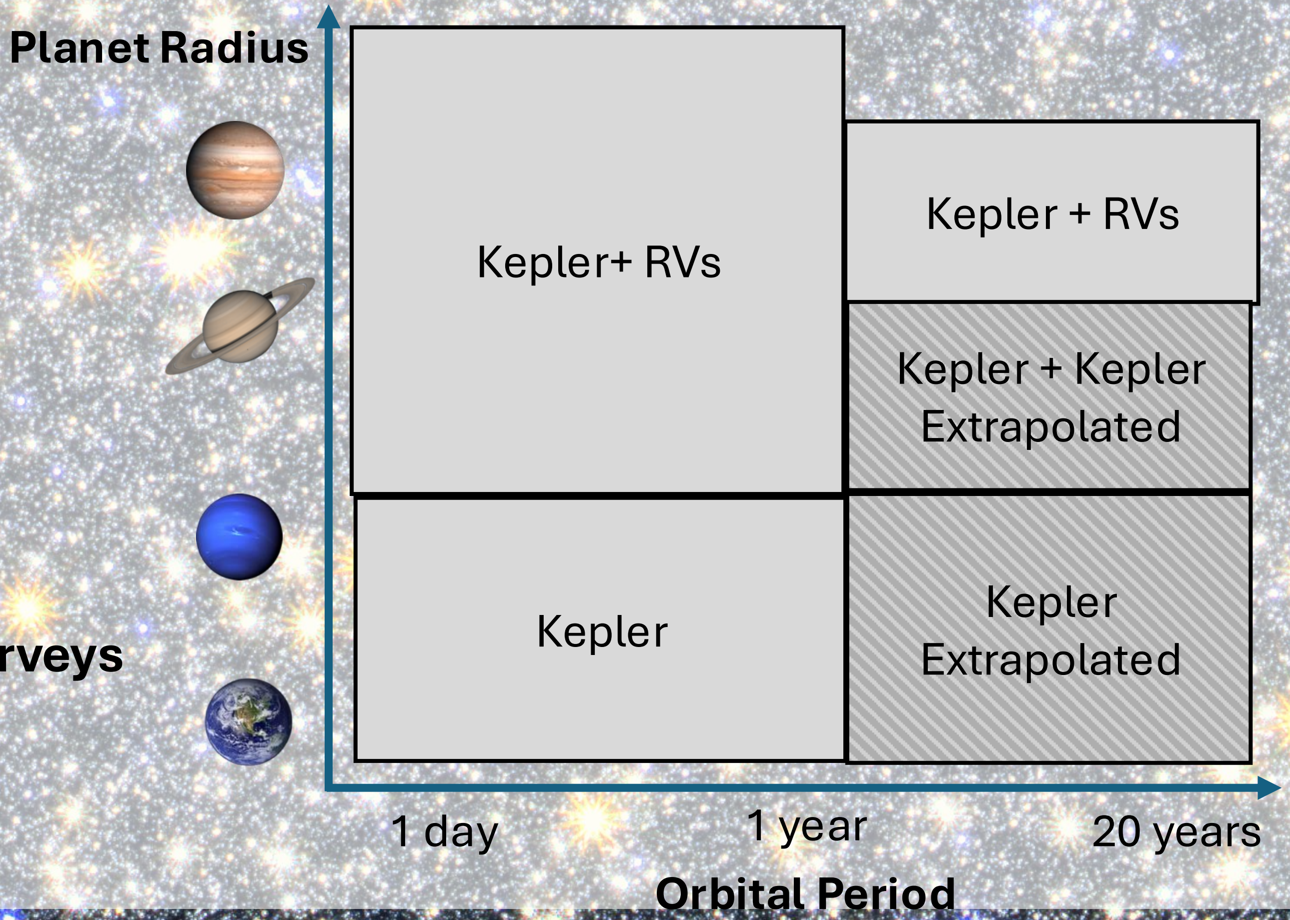

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** Probability that a transit occurs

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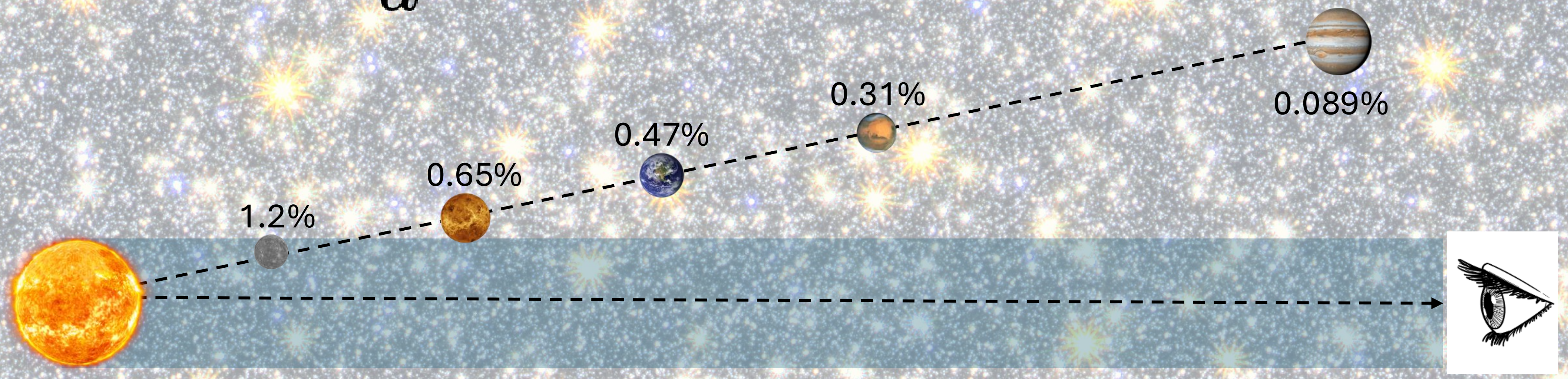
**** Probability that a transit occurs**

$$p_{\mathrm{transit}} \approx \frac{R_\star}{a}$$

Highly biased toward close-in planets



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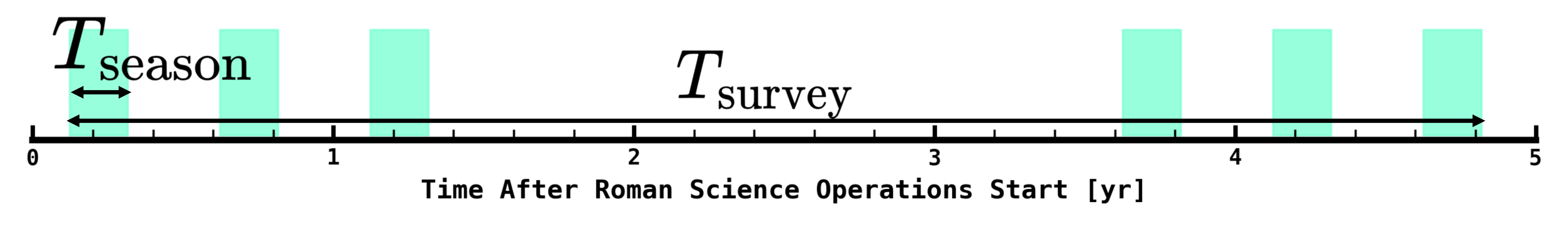

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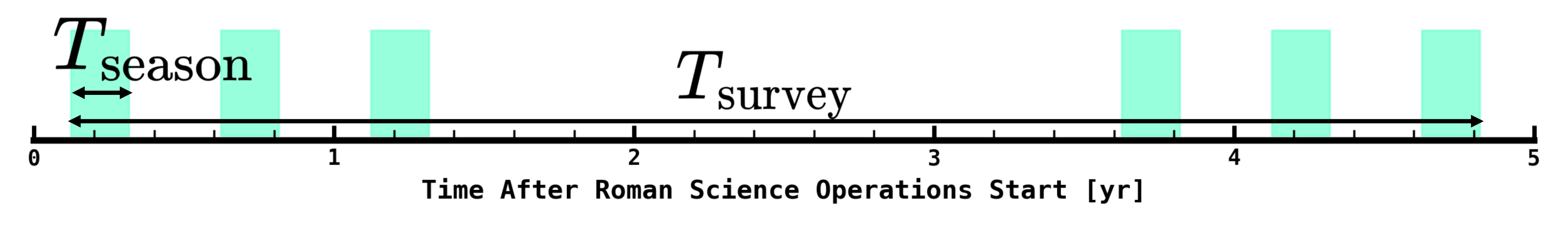

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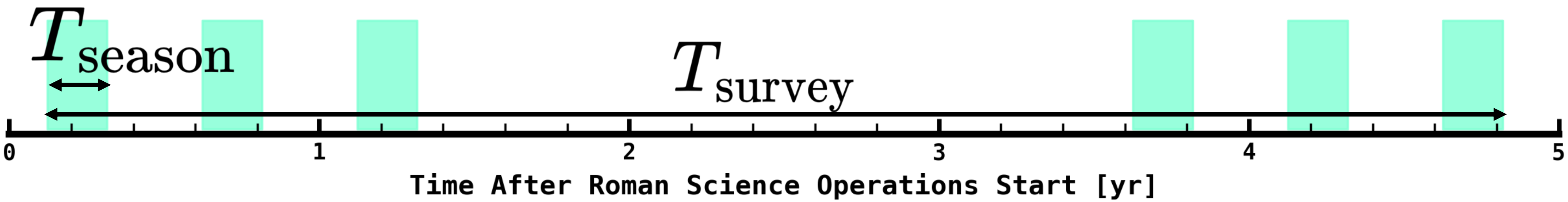

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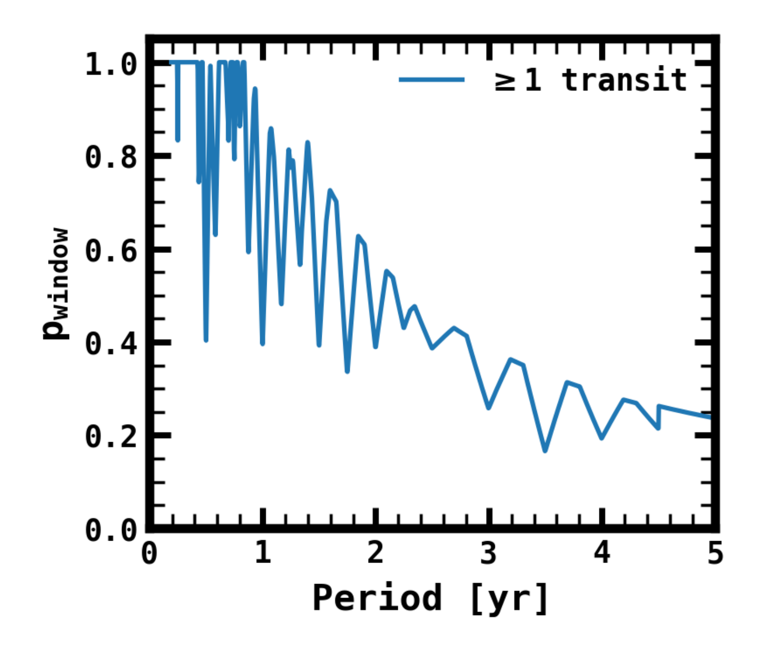

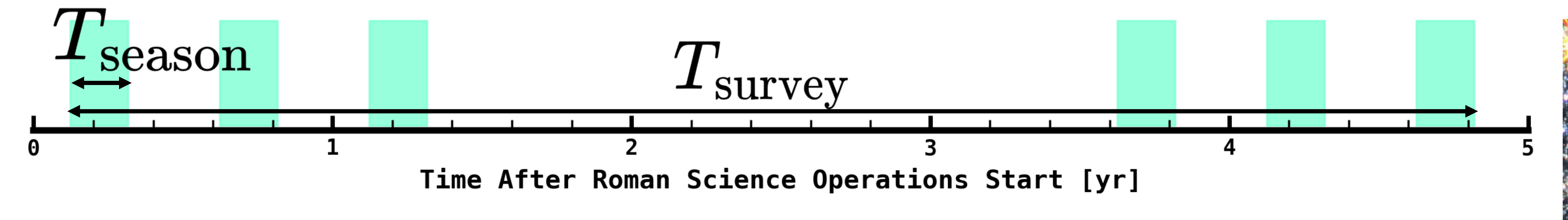

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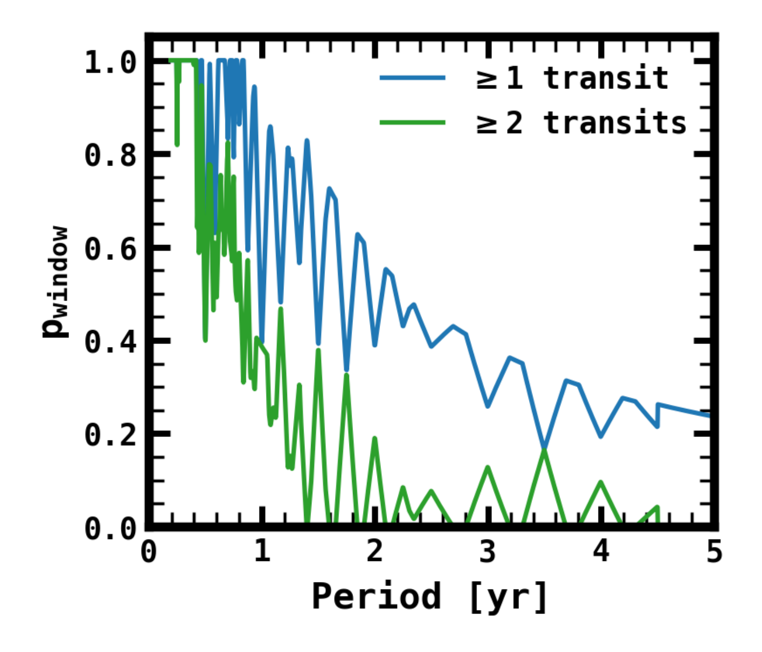

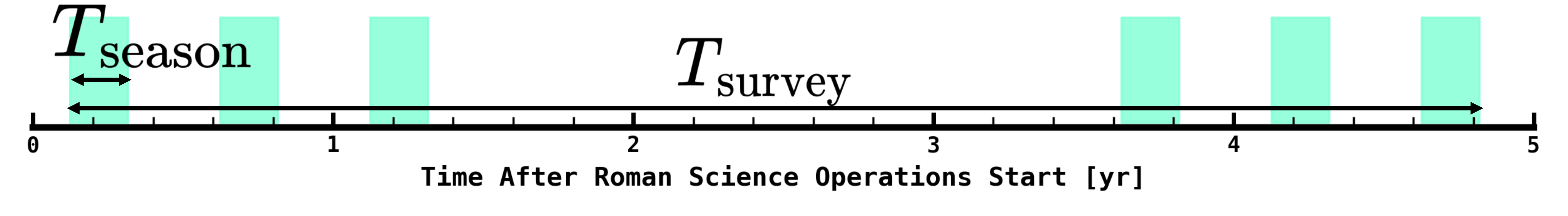

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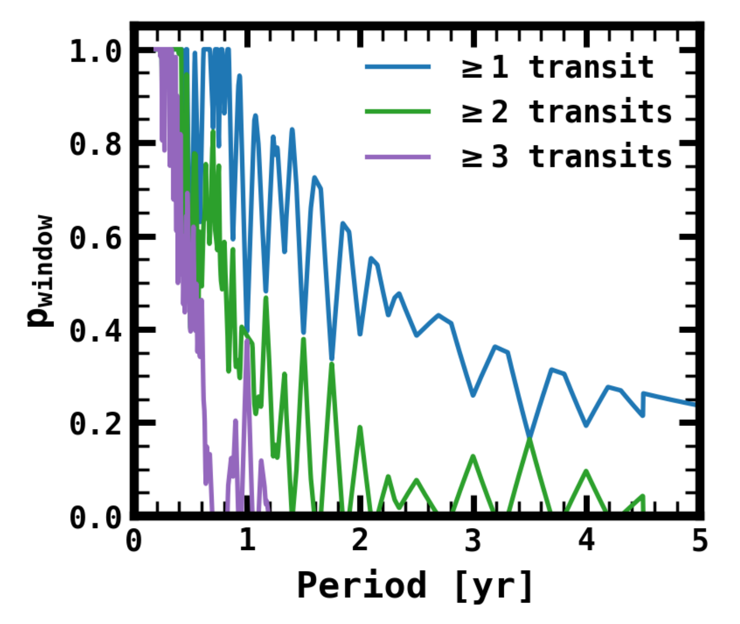

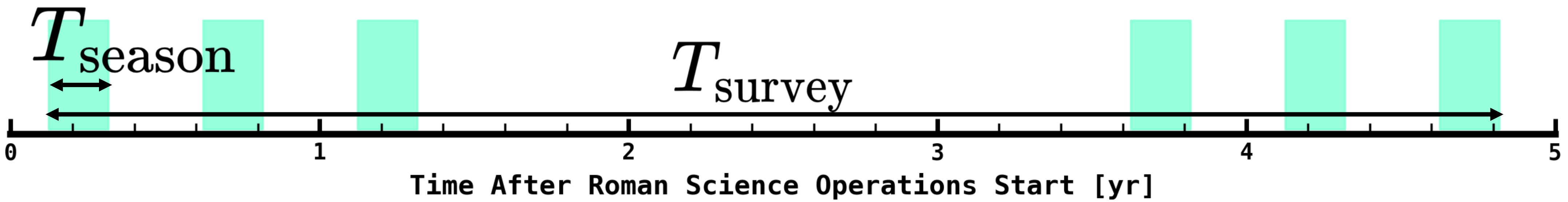

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**** Probability that an observed transit is detected**

What is a detection?

Calculate Multiple Event Statistic (MES)

- H_0 (No Transit): MES=0 with variance 1
- H (Transit): MES > 0 with variance 1

$$\boxed{Z_i = \frac{x_i^{\,T} R s_i}{\sqrt{s_i^{\,T} R s_i}}}$$

η: *Survey Efficiency*

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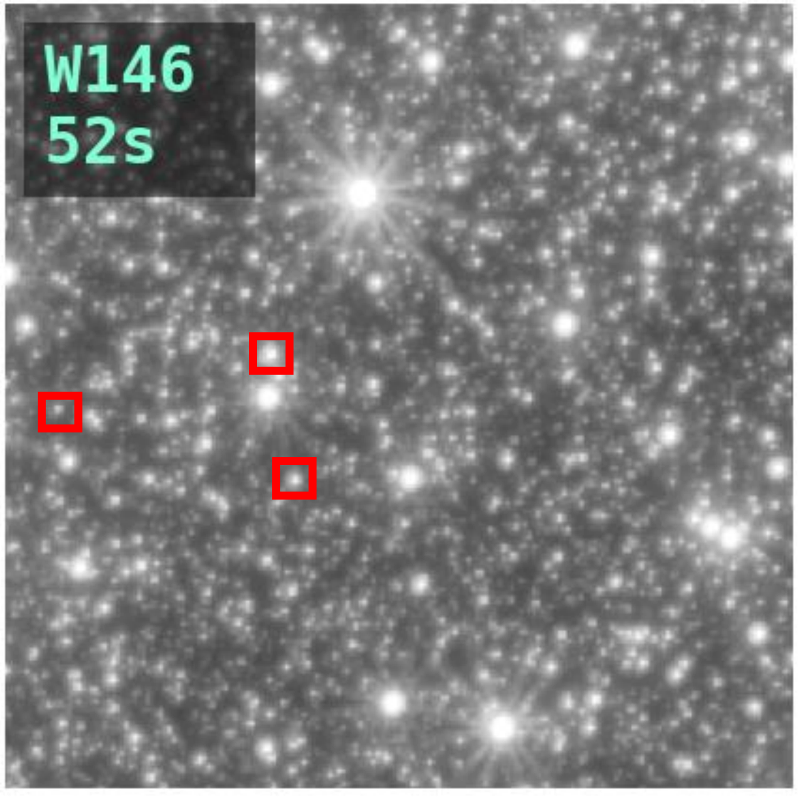
Model this process using injection/recovery experiments

- Must be done at pixel level to model crowding

η: Survey Efficiency

$$\eta = p_{\text{transit}} \times p_{\text{window}} \times p_{\text{detect}}$$

**** Probability that an observed transit is detected**



η: Survey Efficiency

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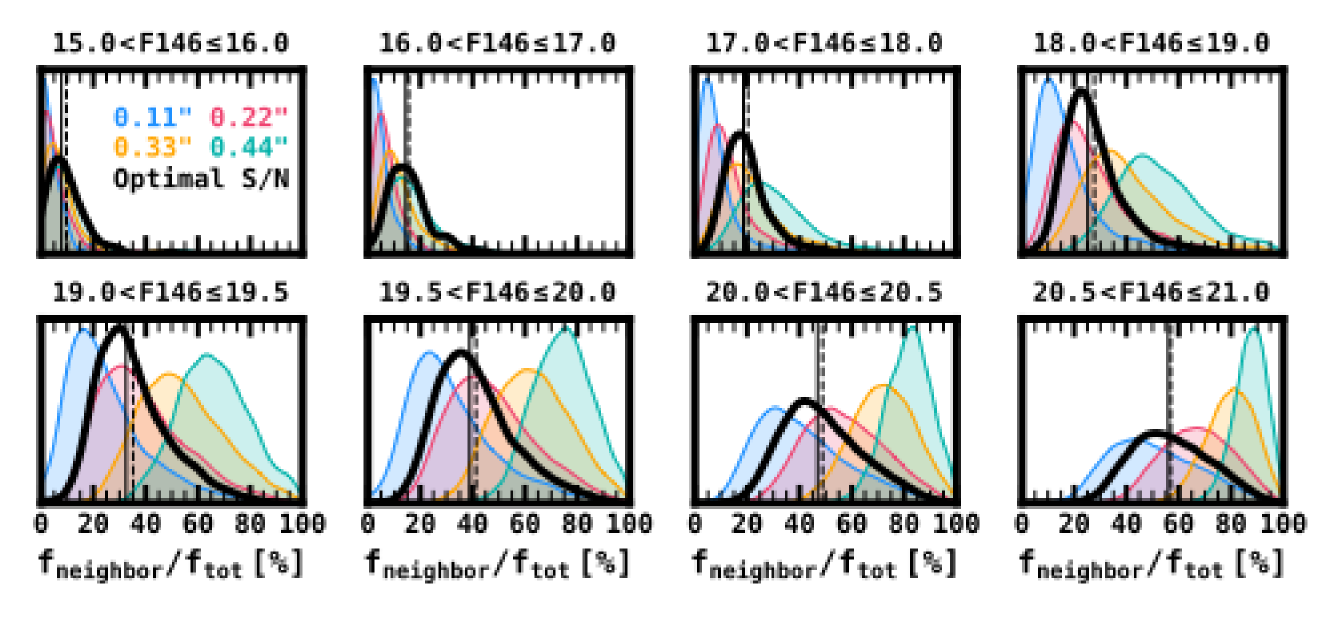
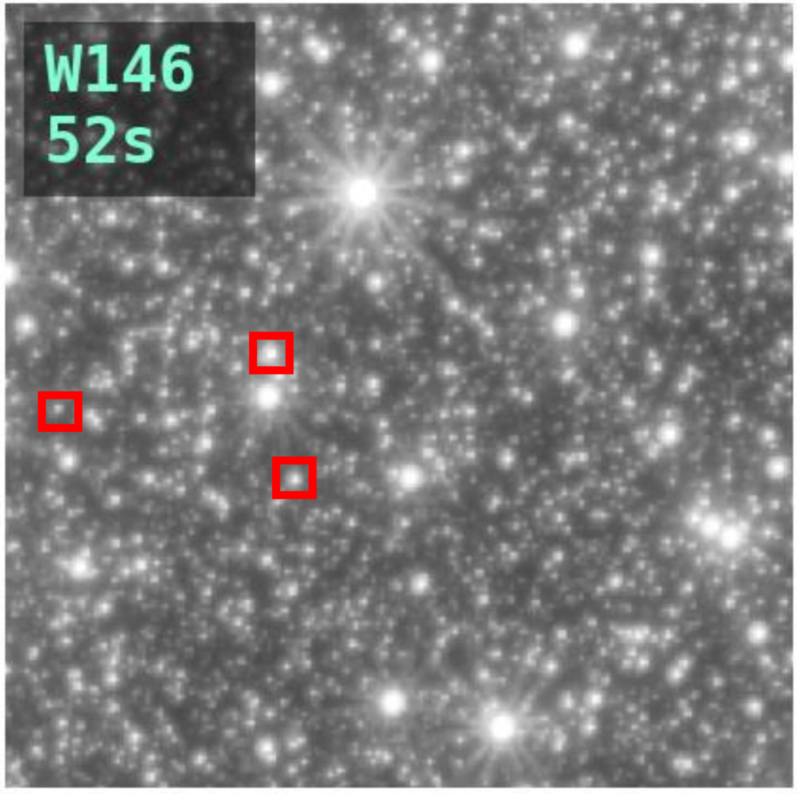
** Probability that an observed transit is detected





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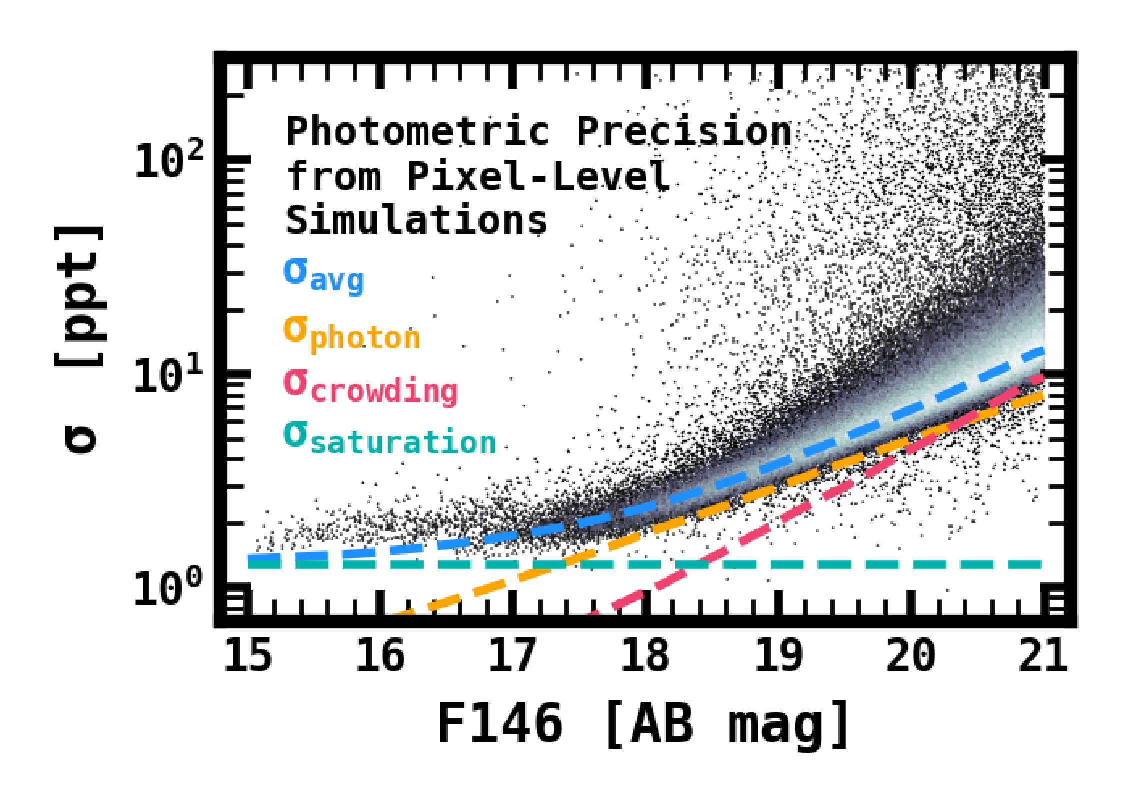

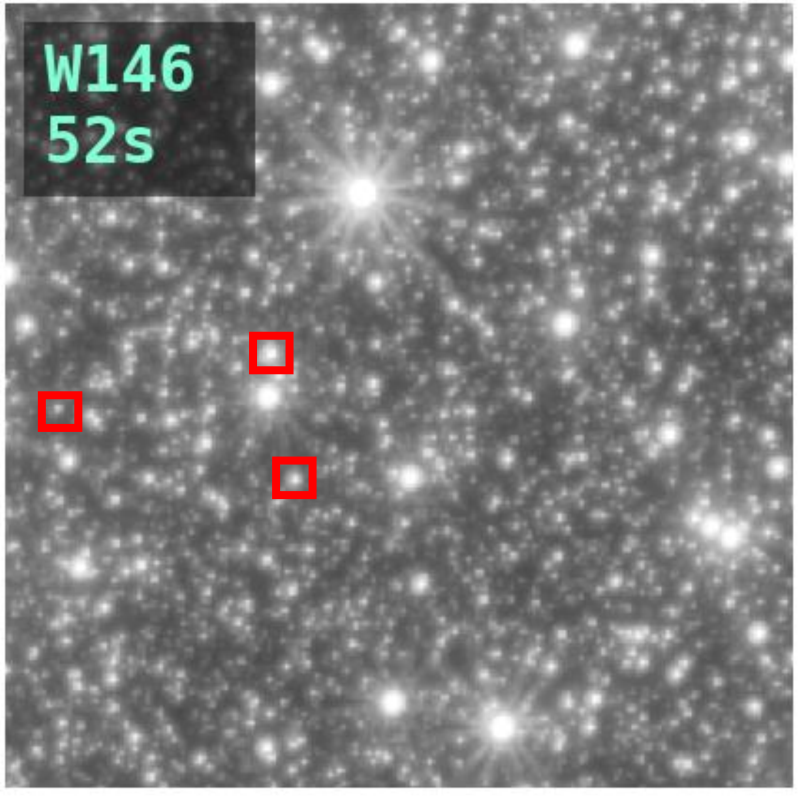

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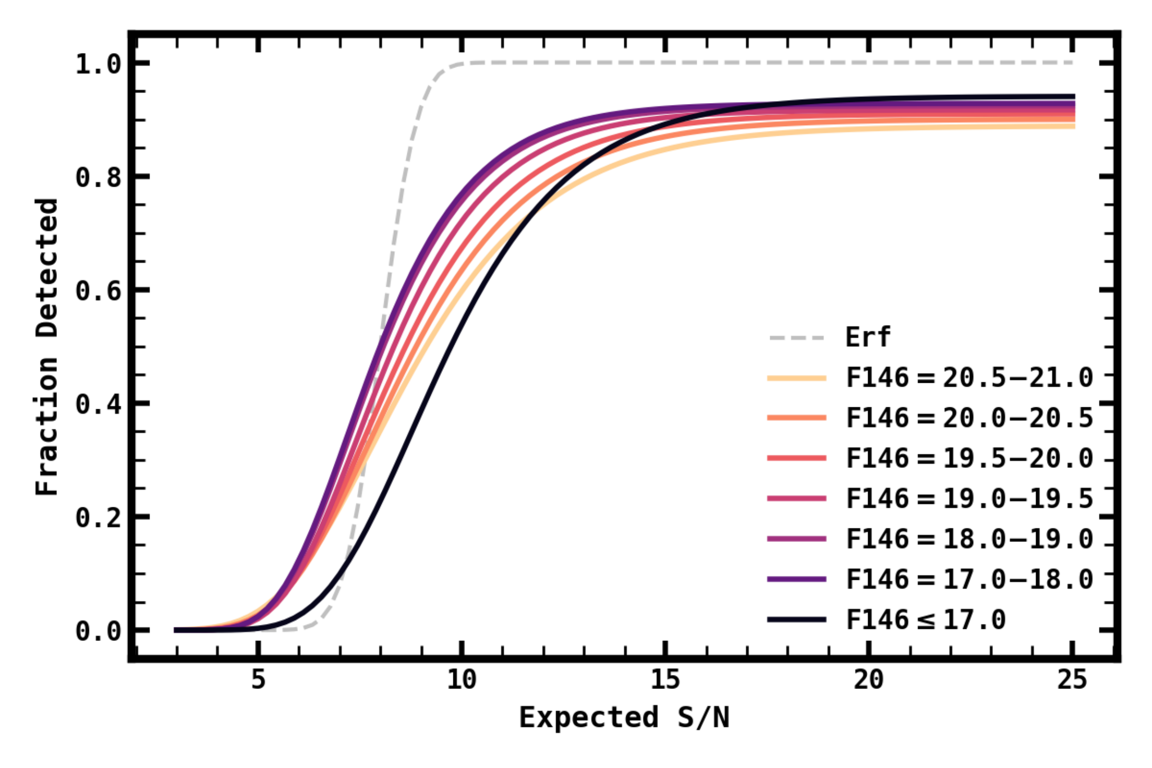

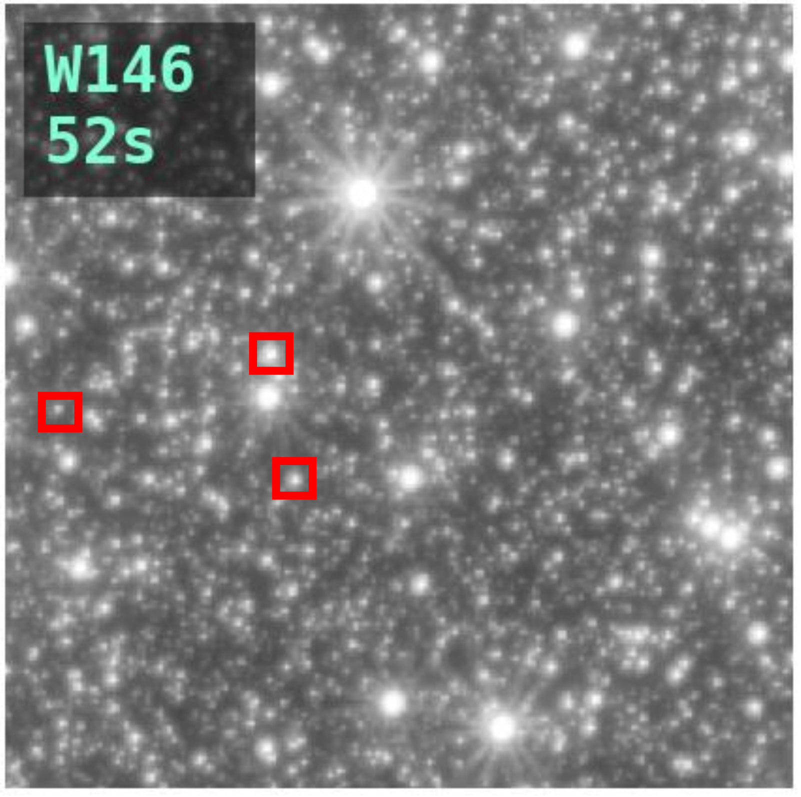

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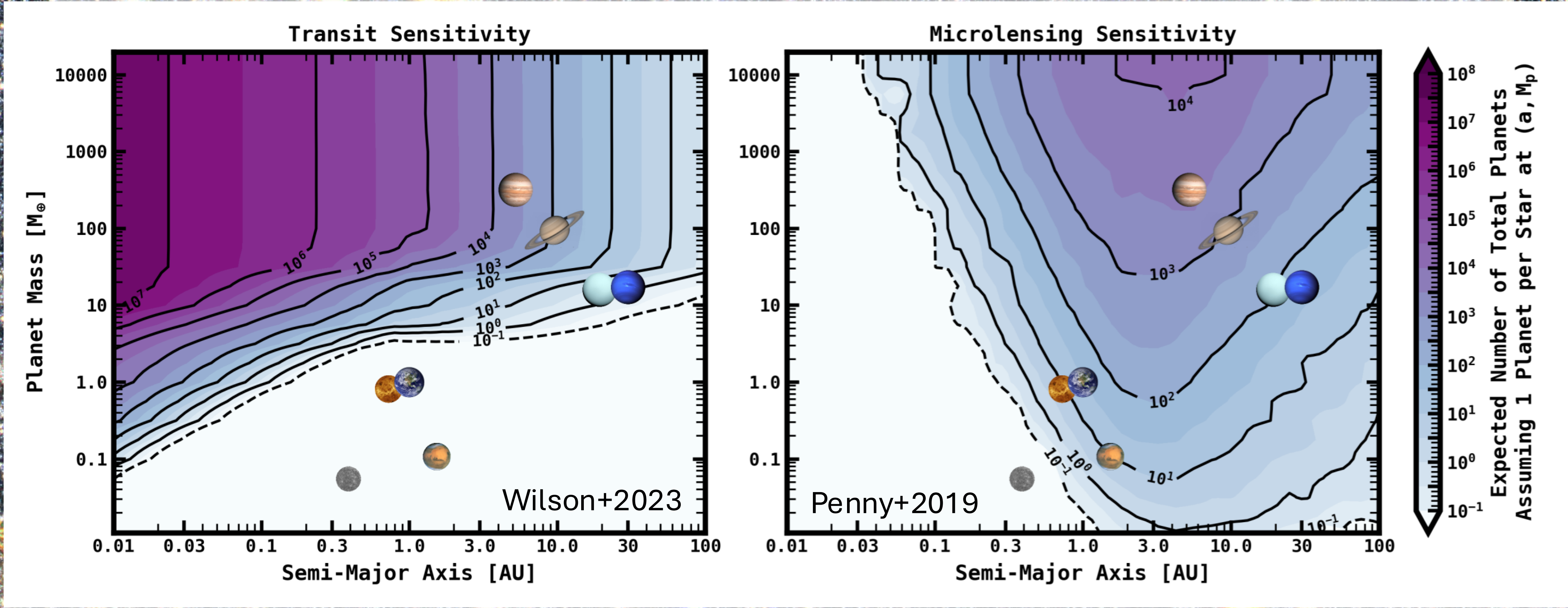


$$N_p = N_\star \times F_p \times \eta$$

Number of Planets

Number of Stars Searched for Planets

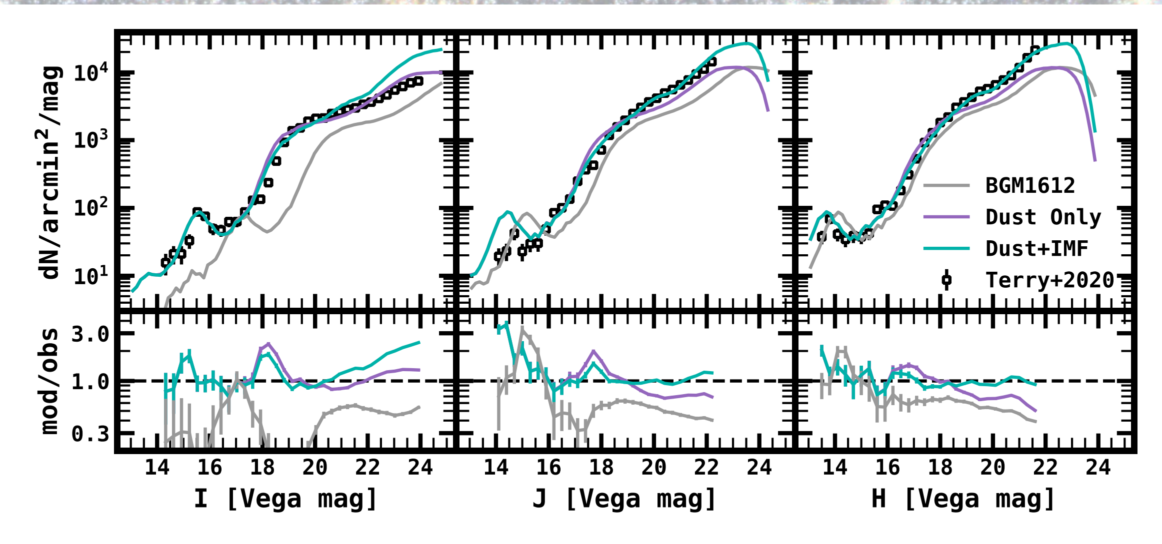
Number of Planets per Star

Fraction of Planets that are detected

Yield = (~10^8 *stars*) x (~1 *planet/star*) x (~10^{-3} *detected*) = ~10^5 planets detected

$$N_p = N_\star \times F_p \times \eta$$

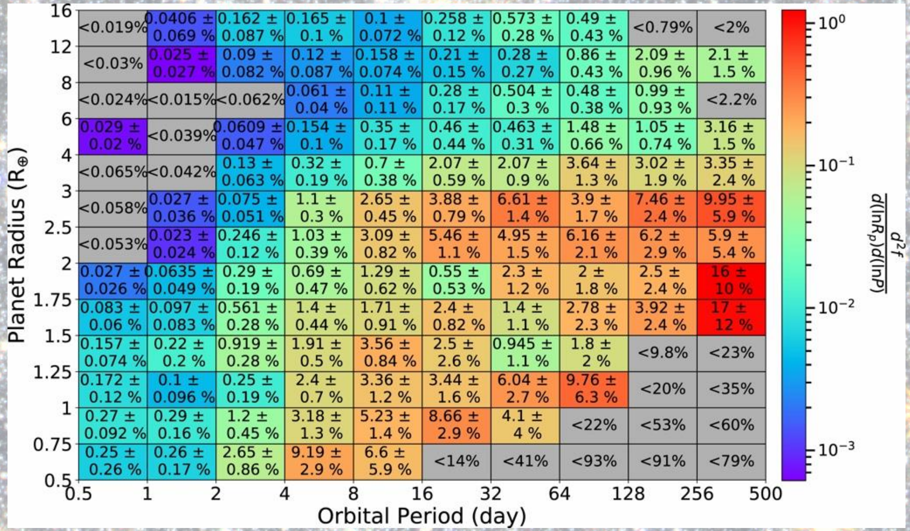
Number of Stars Searched for Planets

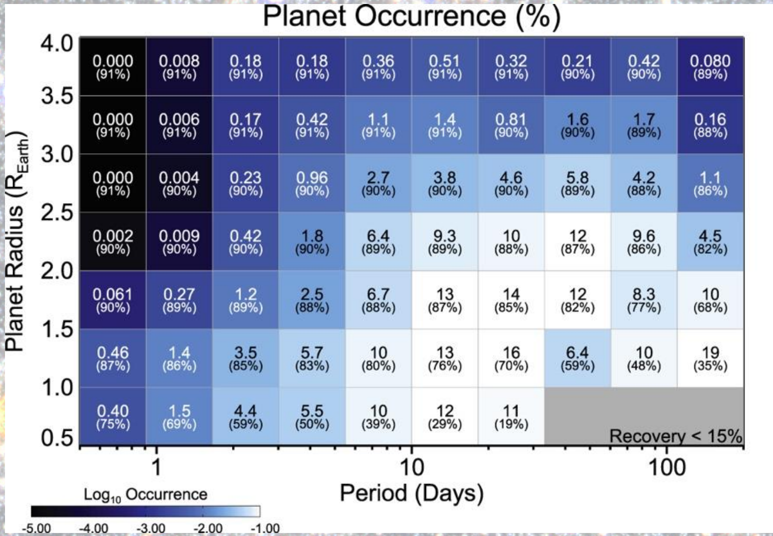


Yield = (~10^8 *stars*) x (~0.1-10 *planet/star*) x (~10^{-1}-10^{-6} *detected*) = ~10^5 planets detected

$$N_p = N_\star \times F_p \times \eta$$

Number of Planets per Star





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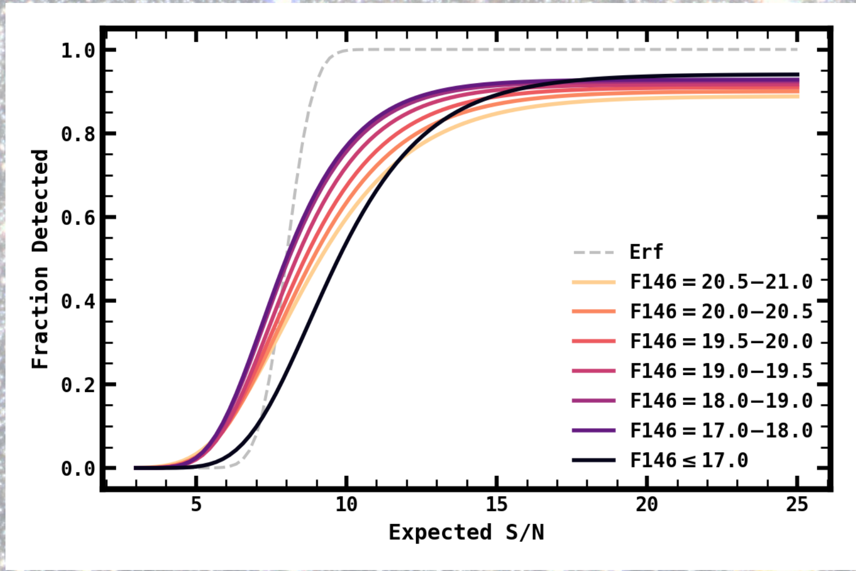

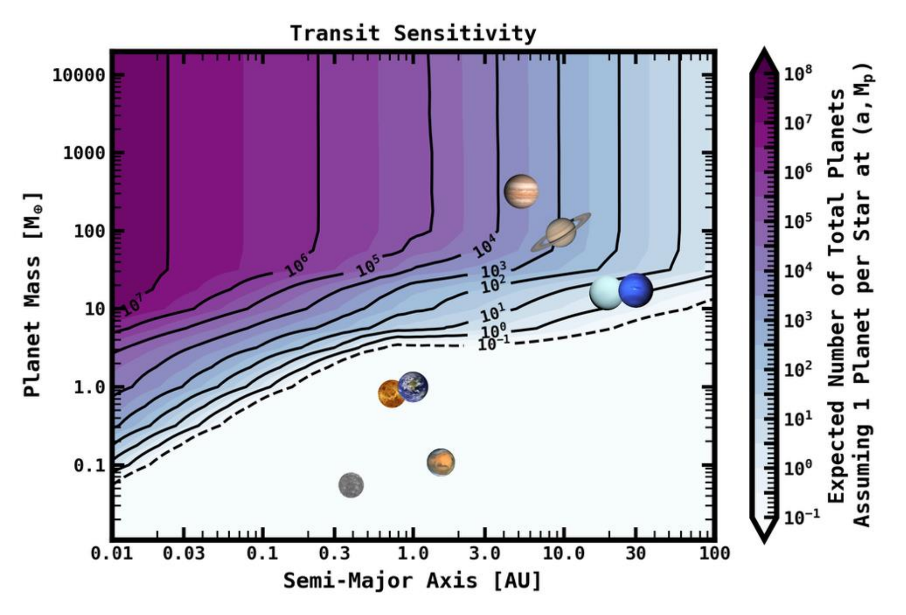

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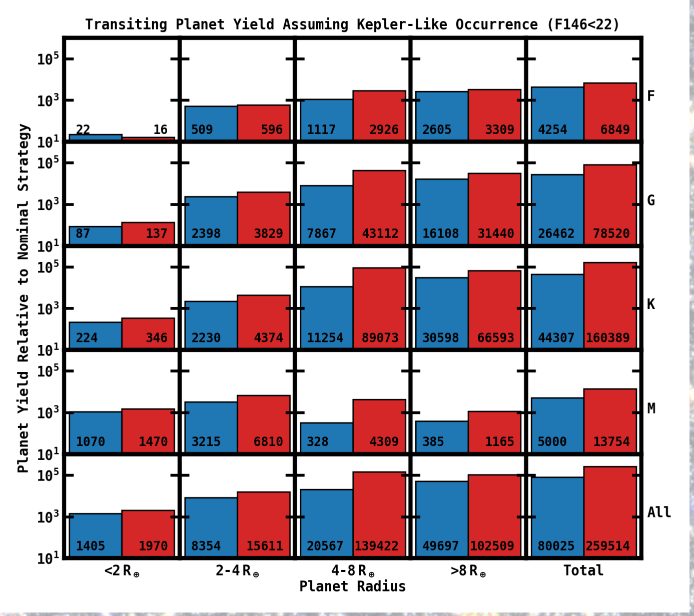

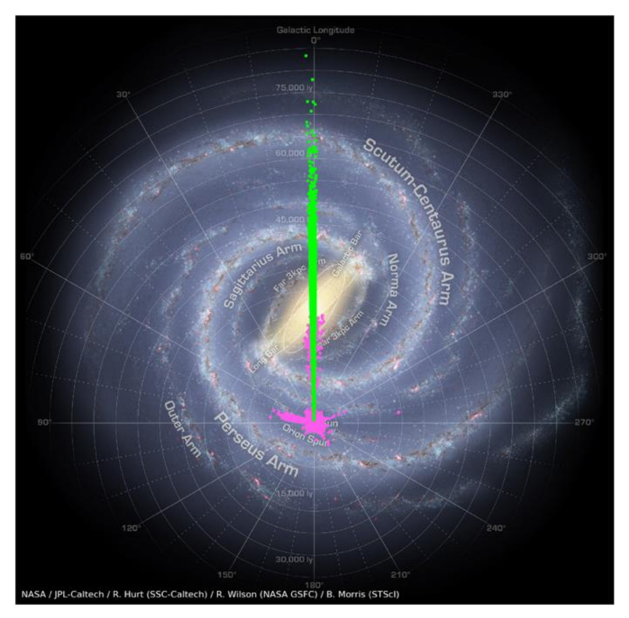

Yield = (~10^8 *stars*) x (~0.1-10 *planet/star*) x (~10^{-1}-10^{-6} *detected*) =

~10^5 planets detected

Takeaways

- **Yield Calculations can be used to determine science goals**
  - ***Planets in Varying Galactic Populations:***
    - Are planet occurrence trends driven by stellar correlations?
  - ***Long-Period Planets***
    - Roman sensitive to Jupiter/Saturn analogs in both transit and microlensing
  - ***The planets that previously considered rare, will not feel so rare anymore***
- ***For now, the presented yield calculations are a forecast***
  - *But soon, the framework can be used to extract occurrence rates*