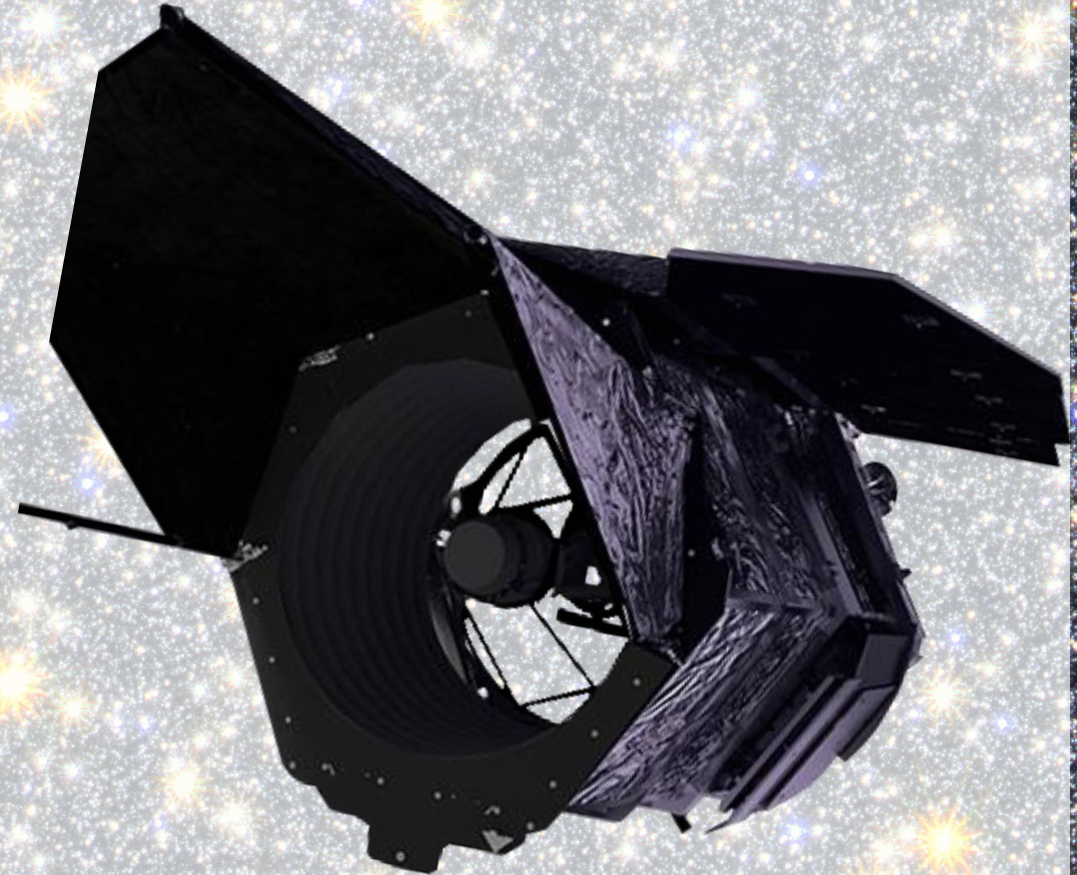


Roman's Transiting Planet Yield

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

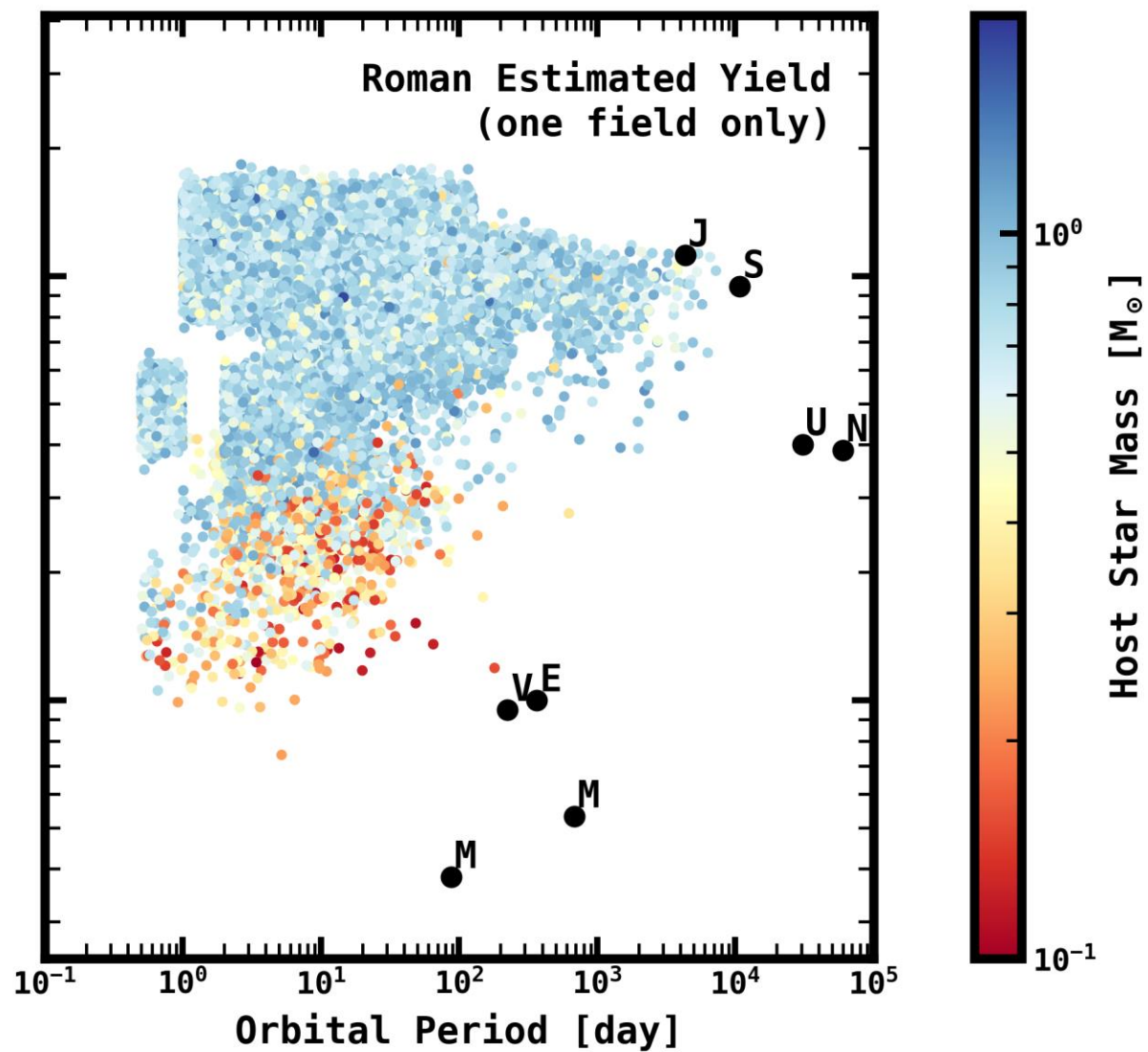
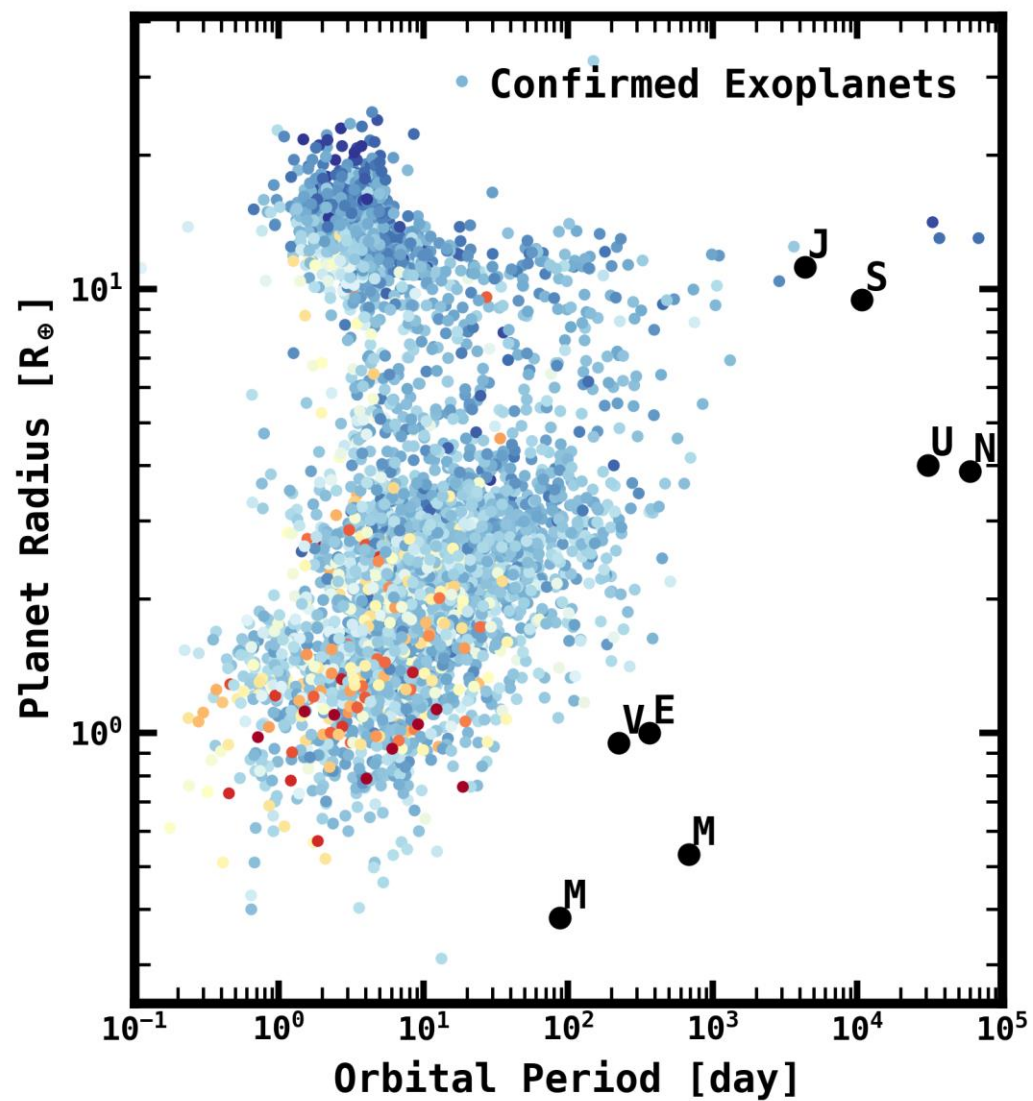


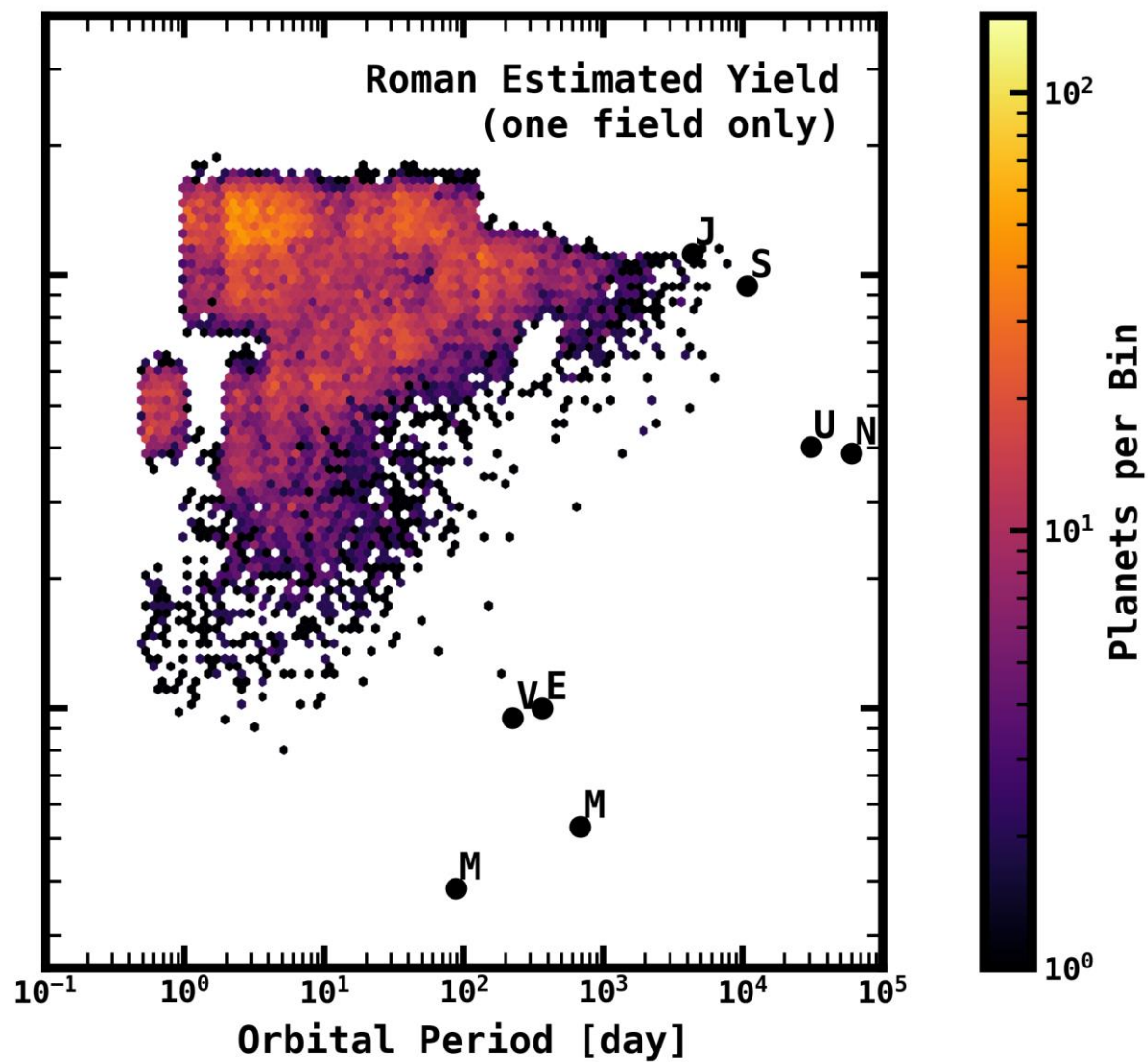
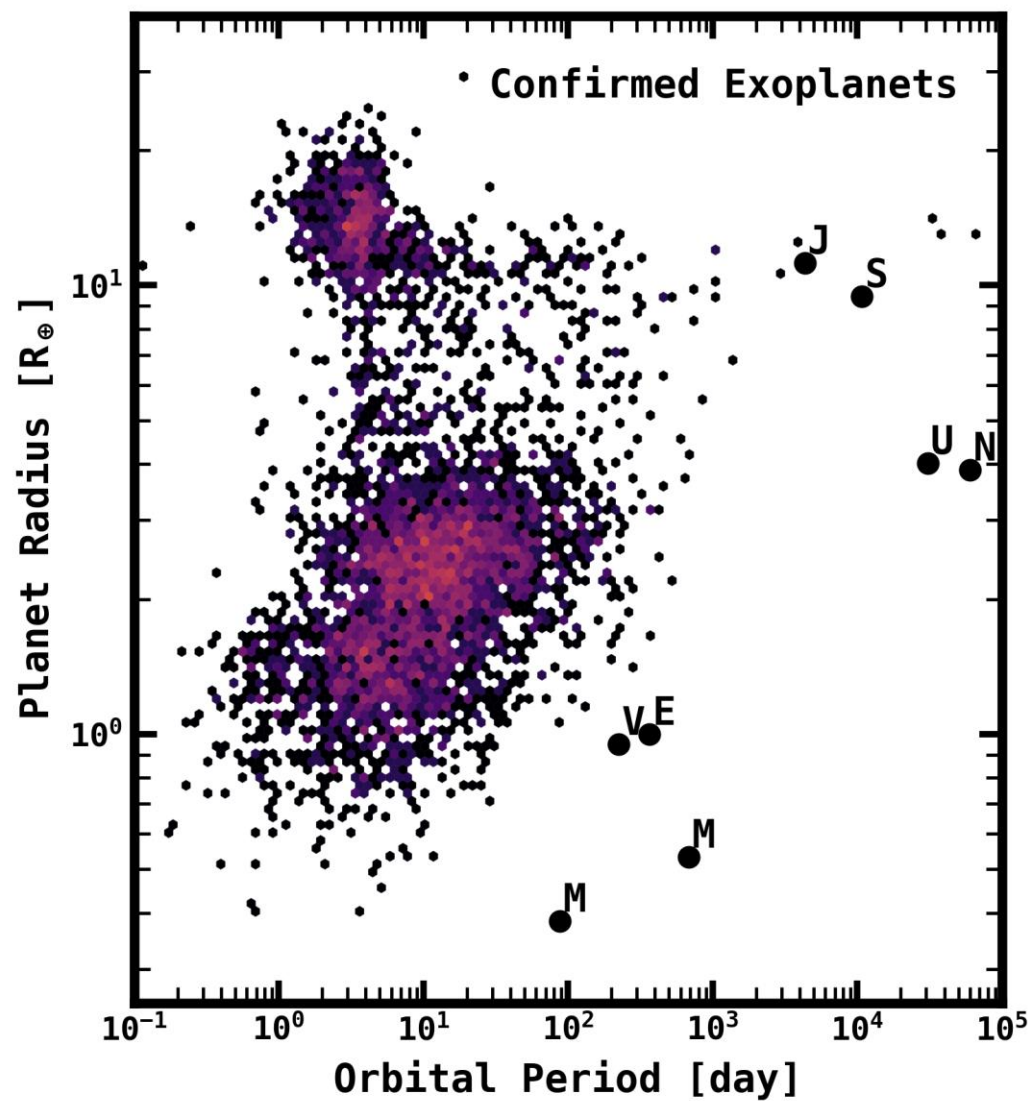
Motivation

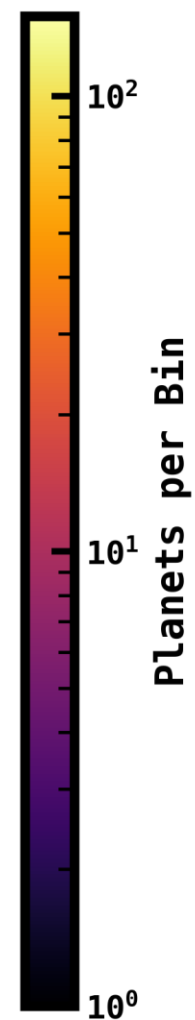
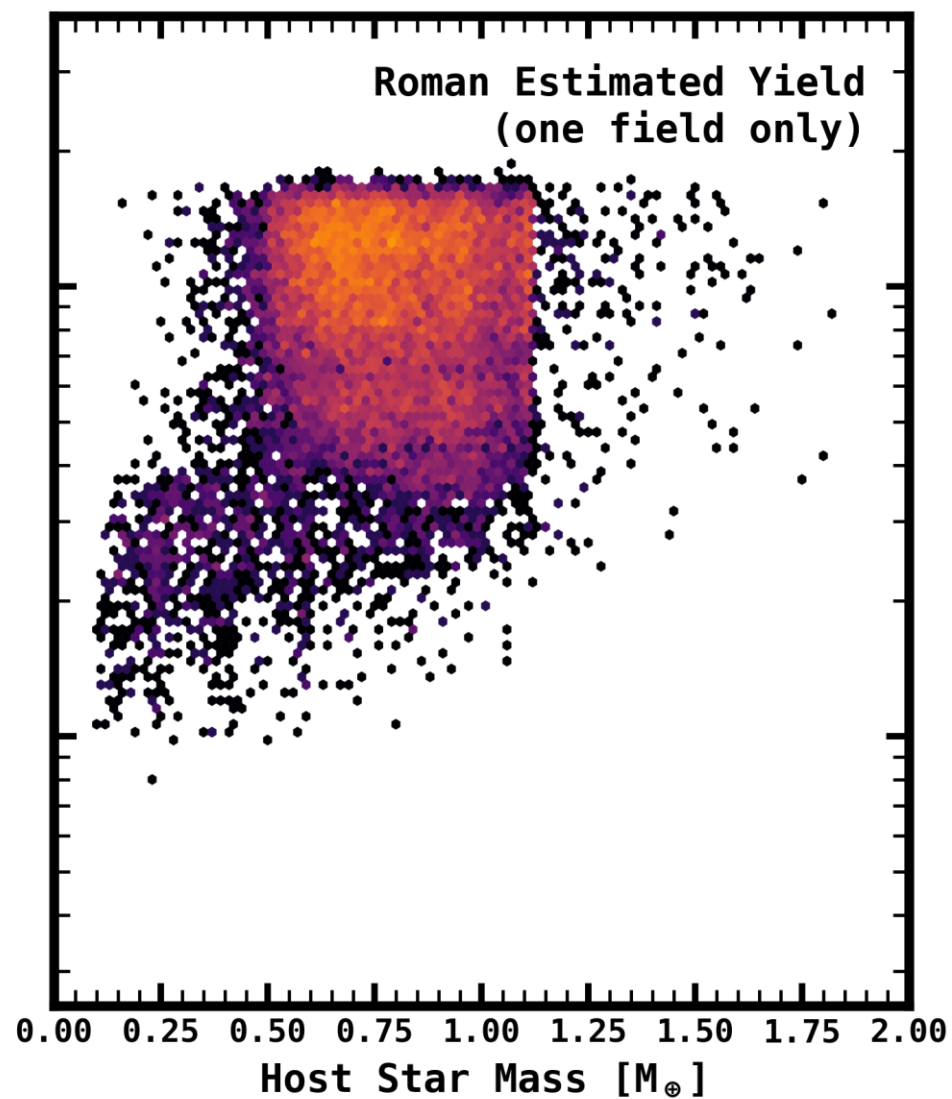
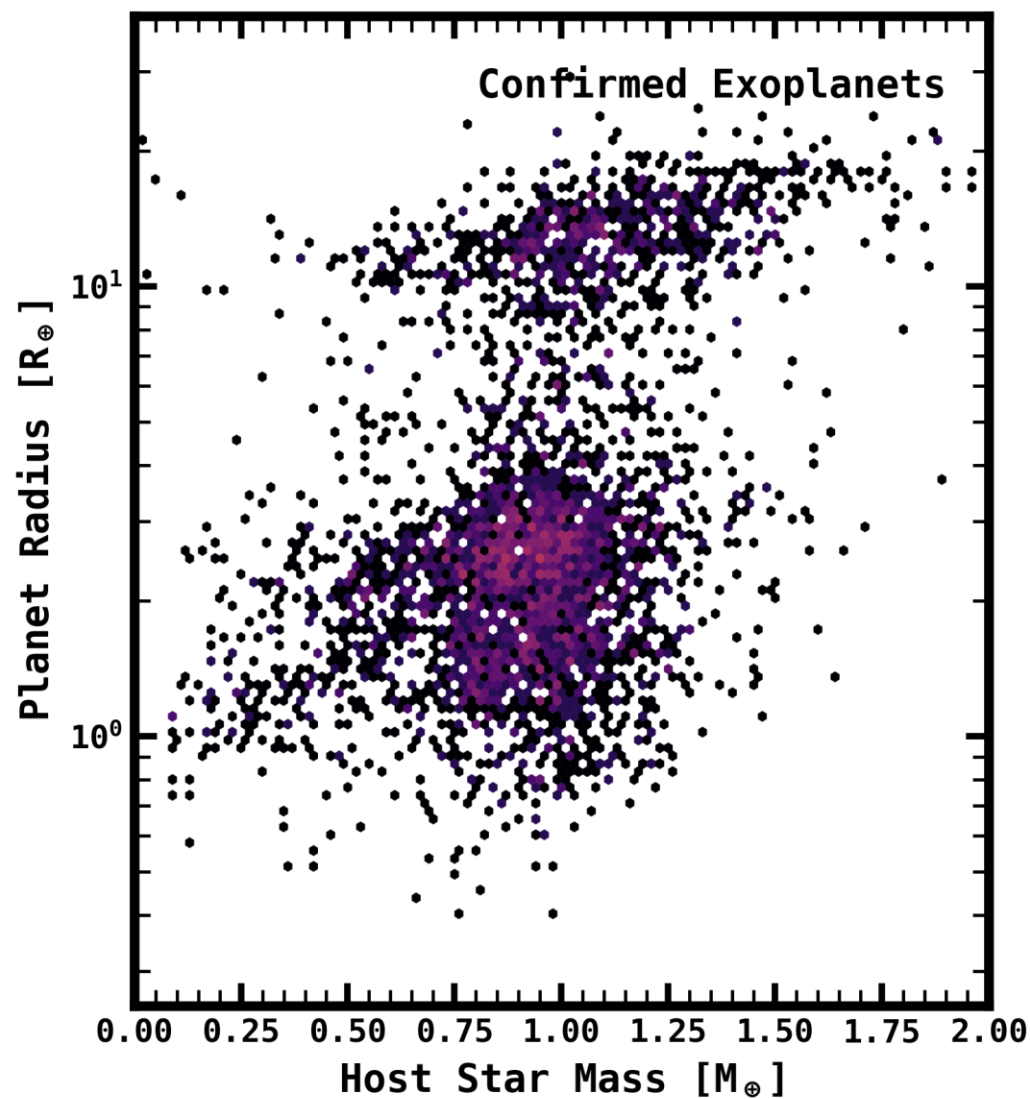
- **Plan for needed Infrastructure**

Motivation

- **Plan for needed Infrastructure**
- **Identify Opportunities for New Science**





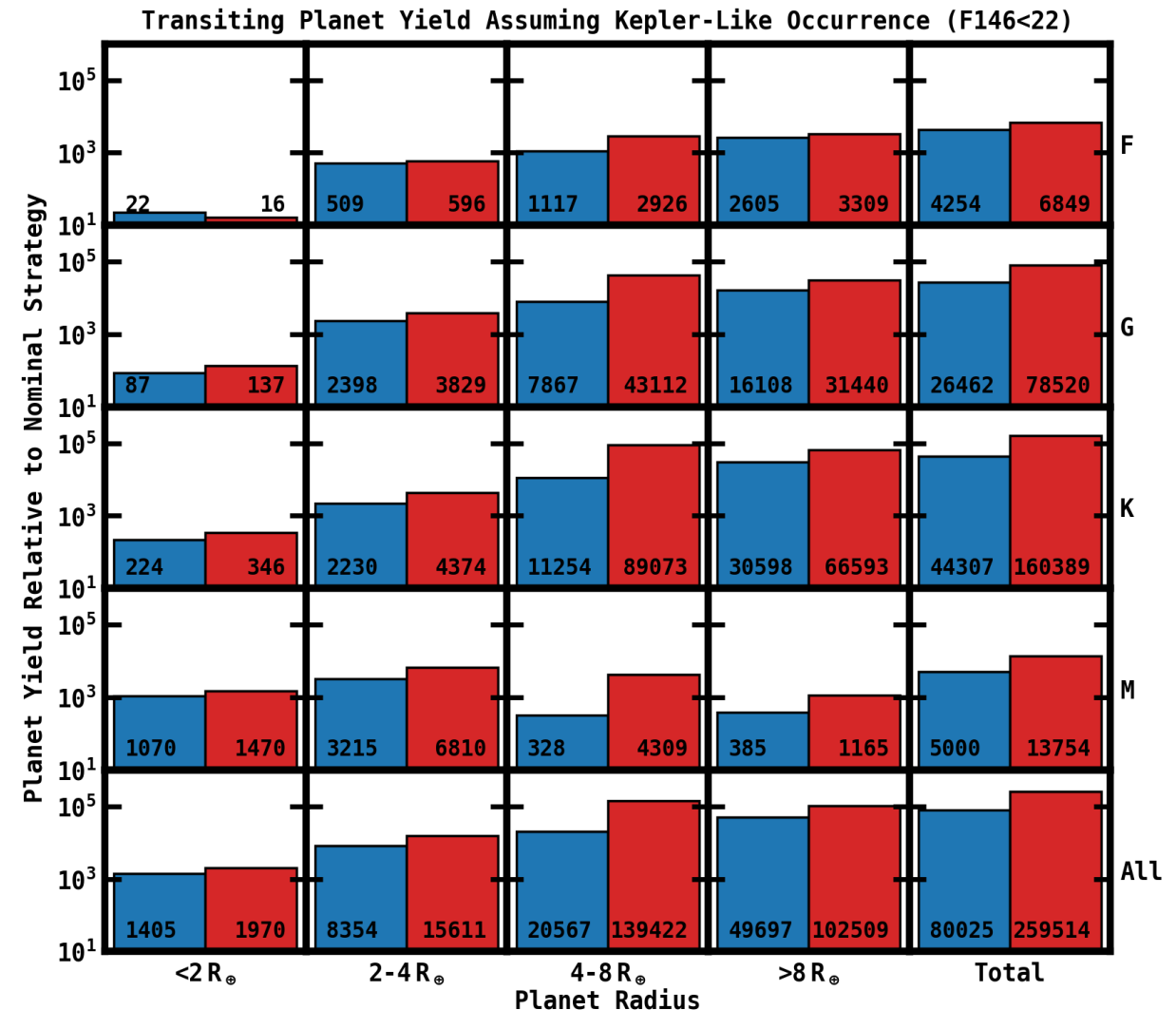


GBTDS Transit Opportunities

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

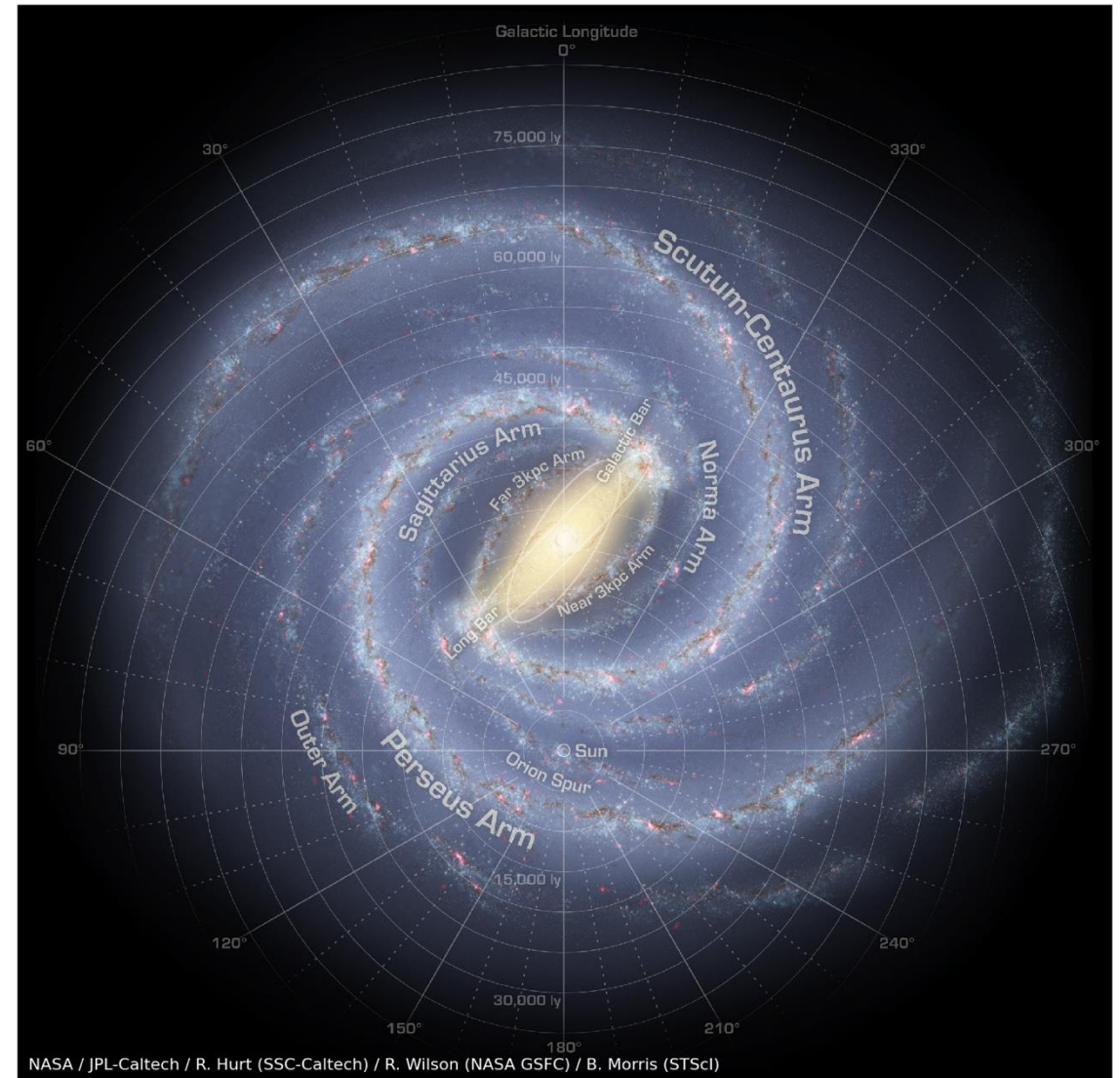
Kepler-Like Occurrence

[M/H]-Scaled Occurrence



GBTDS Transit Opportunities

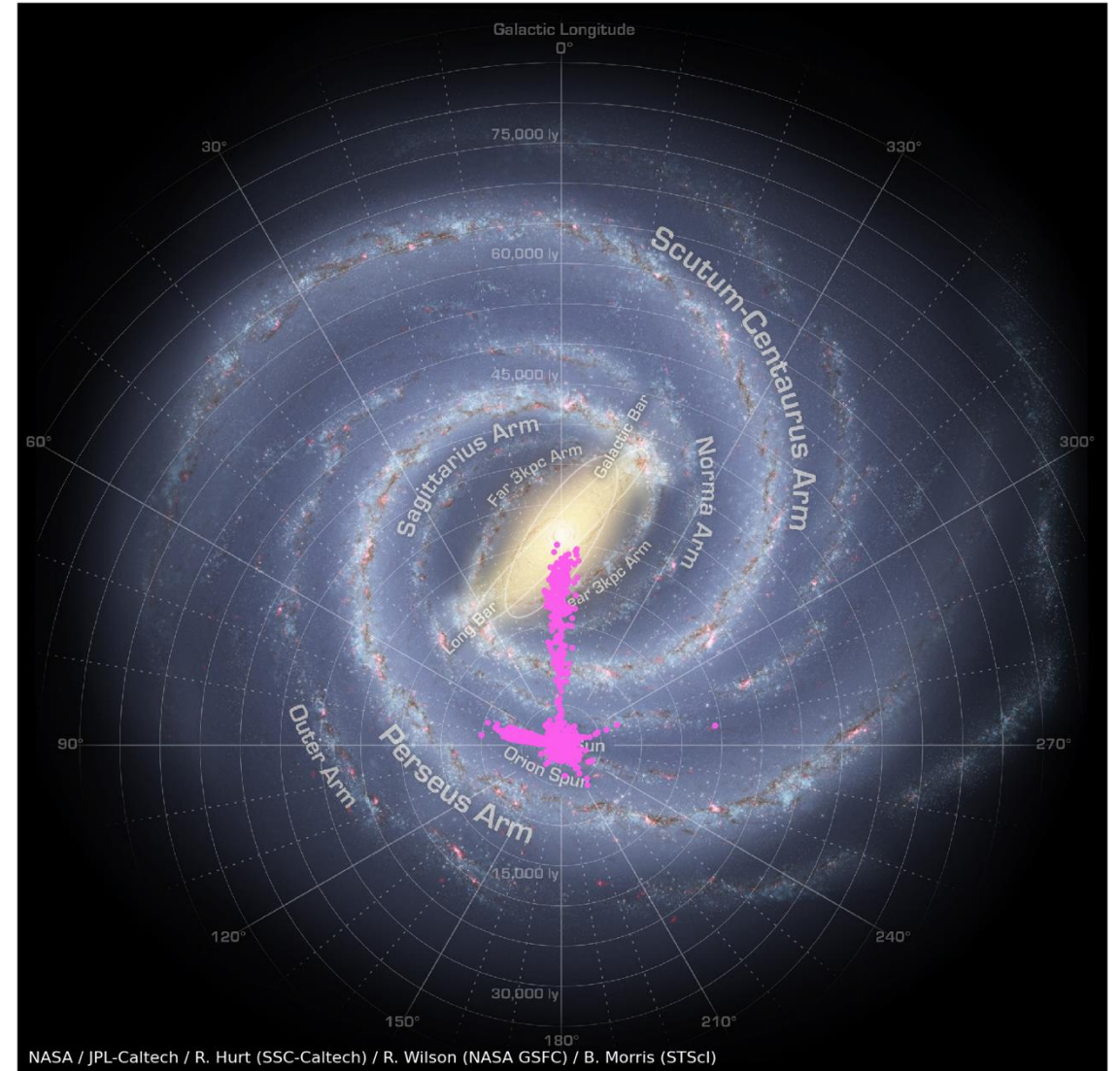
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2. Demographics for *Rare** Planetary Systems
3. Demographics across all major Galactic populations



NASA / JPL-Caltech / R. Hurt (SSC-Caltech) / R. Wilson (NASA GSFC) / B. Morris (STScI)

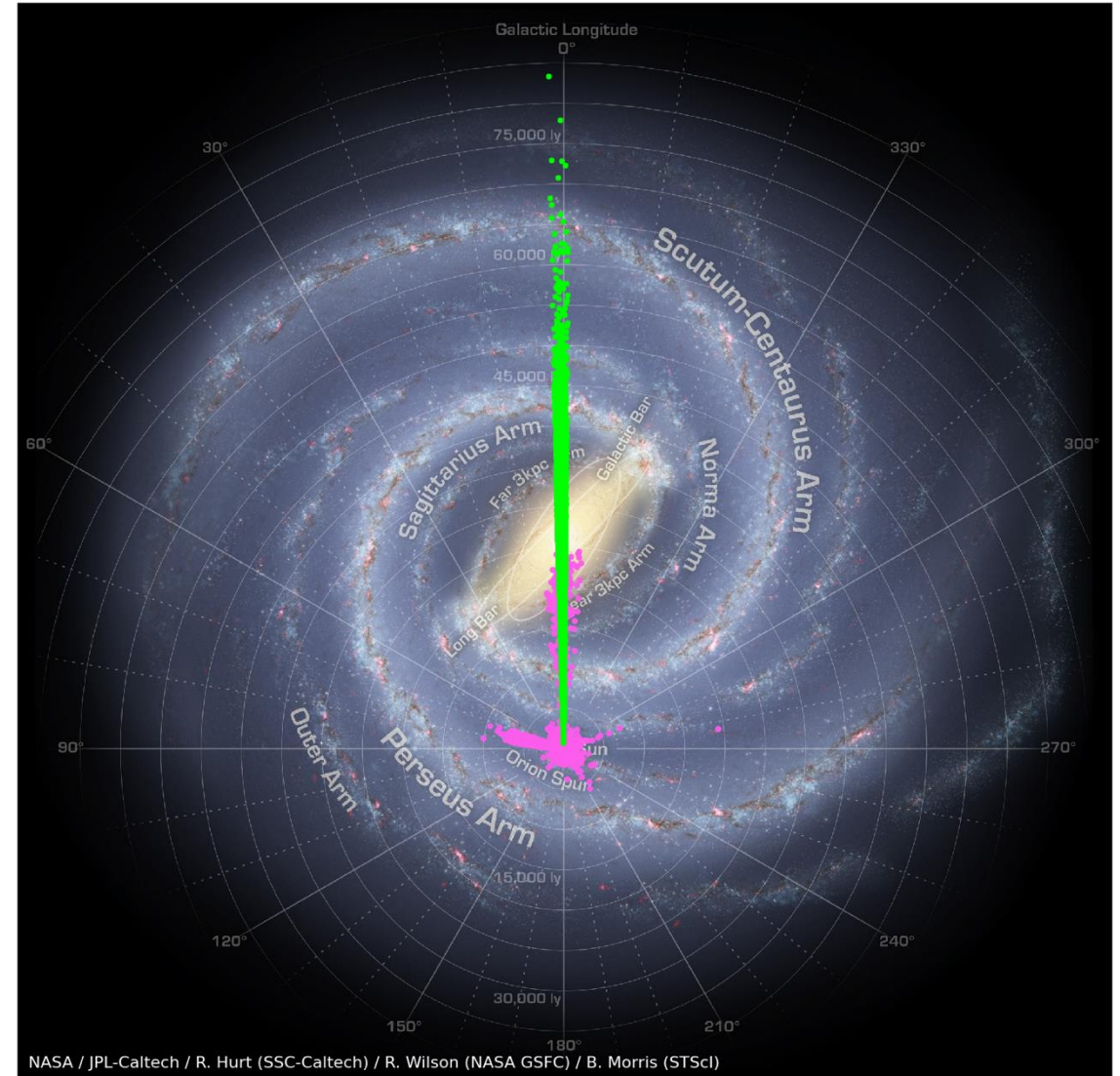
GBTDS Transit Opportunities

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GBTDS Transit Opportunities

1. Demographics of (Ultra-) Hot Jupiter Atmospheres
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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:

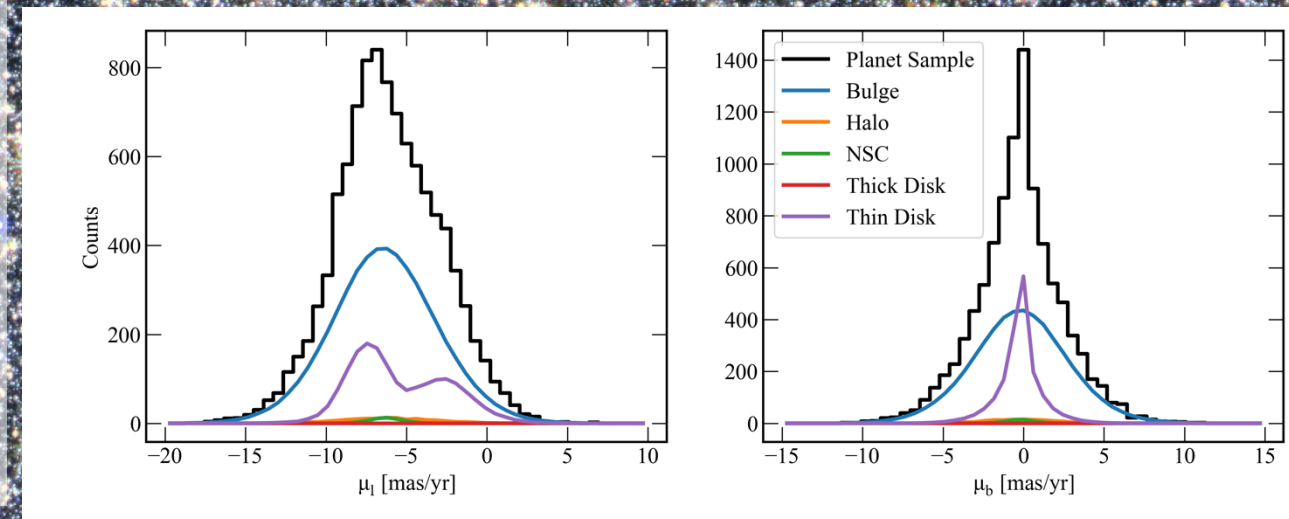
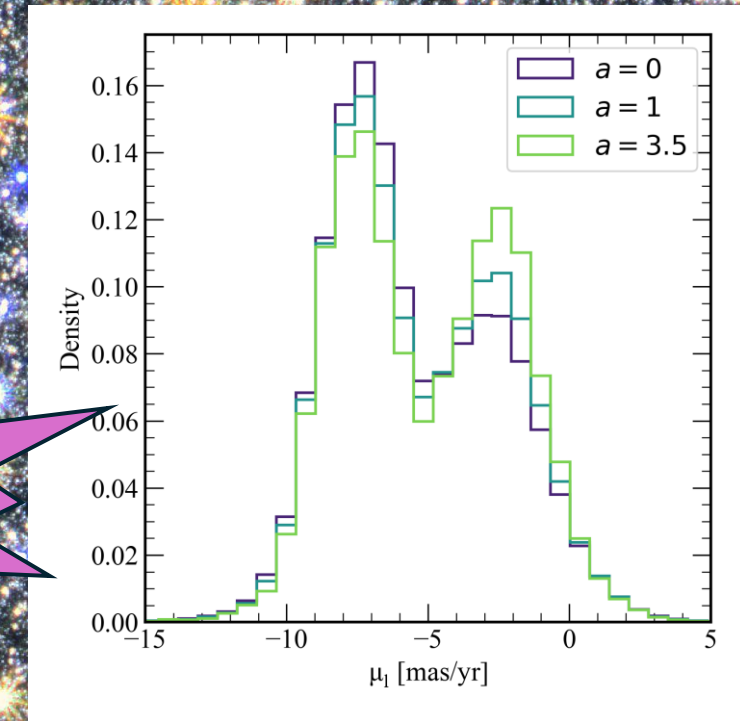
- Bulge/Bar: ~69%
- Thin: ~13%
- Thick Disk/Thick Bulge: ~18%

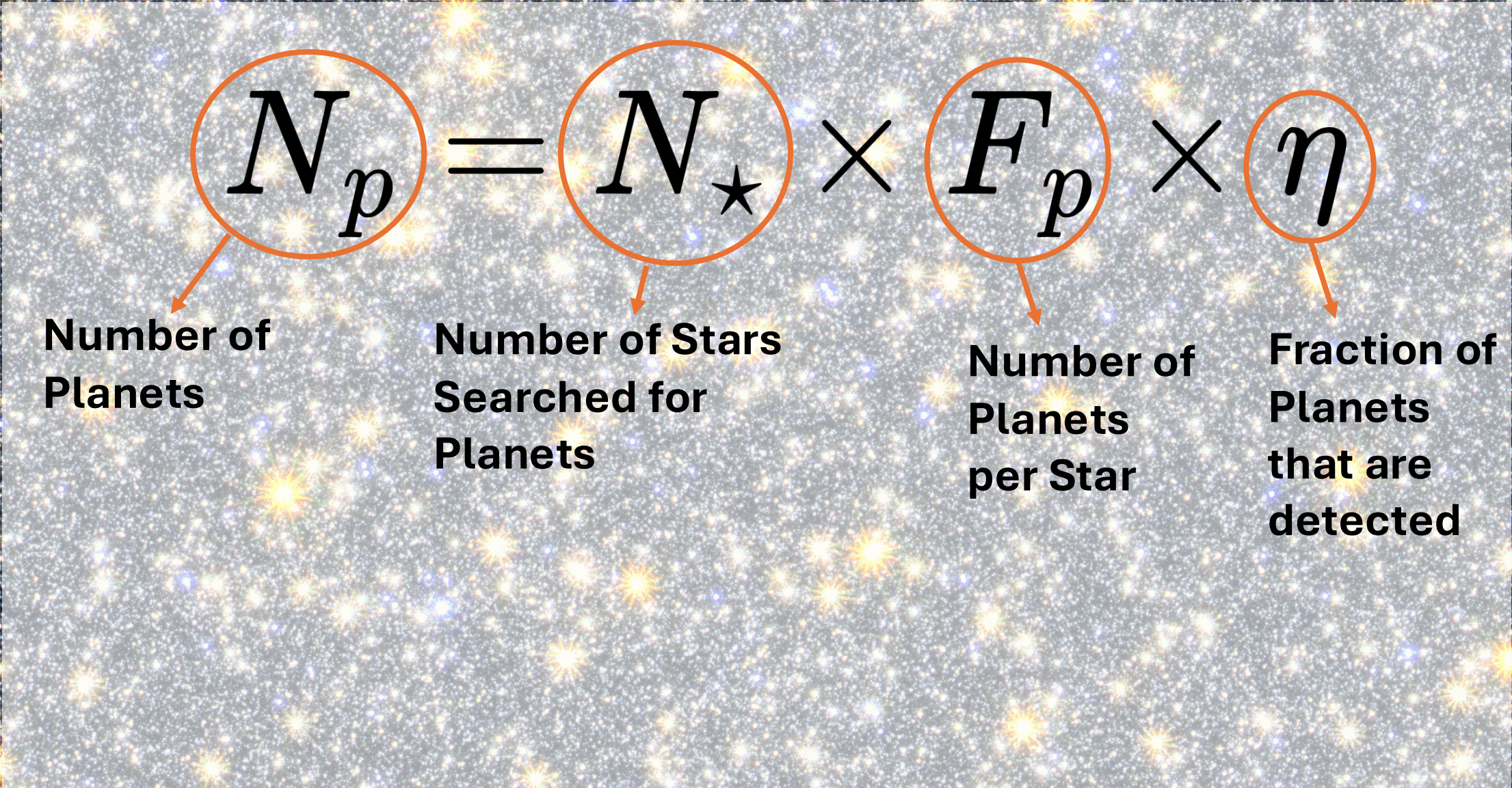
With Metallicity Effects:

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



See Matt's
Poster!




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

The diagram shows the equation $N_p = N_{\star} \times F_p \times \eta$ with each variable circled in orange. Arrows point from each circle to its corresponding label below: N_p to 'Number of Planets', $N_{\star}$ to 'Number of Stars Searched for Planets', F_p to 'Number of Planets per Star', and η to 'Fraction of Planets that are detected'.

**Number of
Planets**

**Number of Stars
Searched for
Planets**

**Number of
Planets
per Star**

**Fraction of
Planets
that are
detected**

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

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

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

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

Number of
Planets

Number of Stars
Searched for
Planets

Number of
Planets
per Star

Fraction of
Planets
that are
detected

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

The diagram illustrates the equation for the total number of planets discovered, N_p , which is equal to the sum over all stars i of the product of the number of planets around star i ($n_{pl,i}$) and the probability that a planet j is detected (η_j). The equation is
$$N_p = \sum_i \sum_j n_{pl,i} \eta_j$$
 The variables are defined as follows:

- N_p : Total Number of Planets (i.e., Yield)
- $N_\star$: Number of Stars Searched for Planets
- $n_{pl,i}$: Number of Planets around Star i
- η_j : Probability that planet j is detected orbiting star i

Arrows indicate the mapping from the labels to the corresponding symbols in the equation: N_p points to the leftmost N_p ; $N_\star$ points to the $N_\star$ in the denominator of the first sum; $n_{pl,i}$ points to the $n_{pl,i}$ in the numerator of the first sum; and η_j points to the η_j in the second sum.

Procedure

1. Gather a Sample of Planet-Search Stars

$$N_p = \sum_i^{N_\star} \sum_j^{n_{pl,i}} \eta_j$$

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

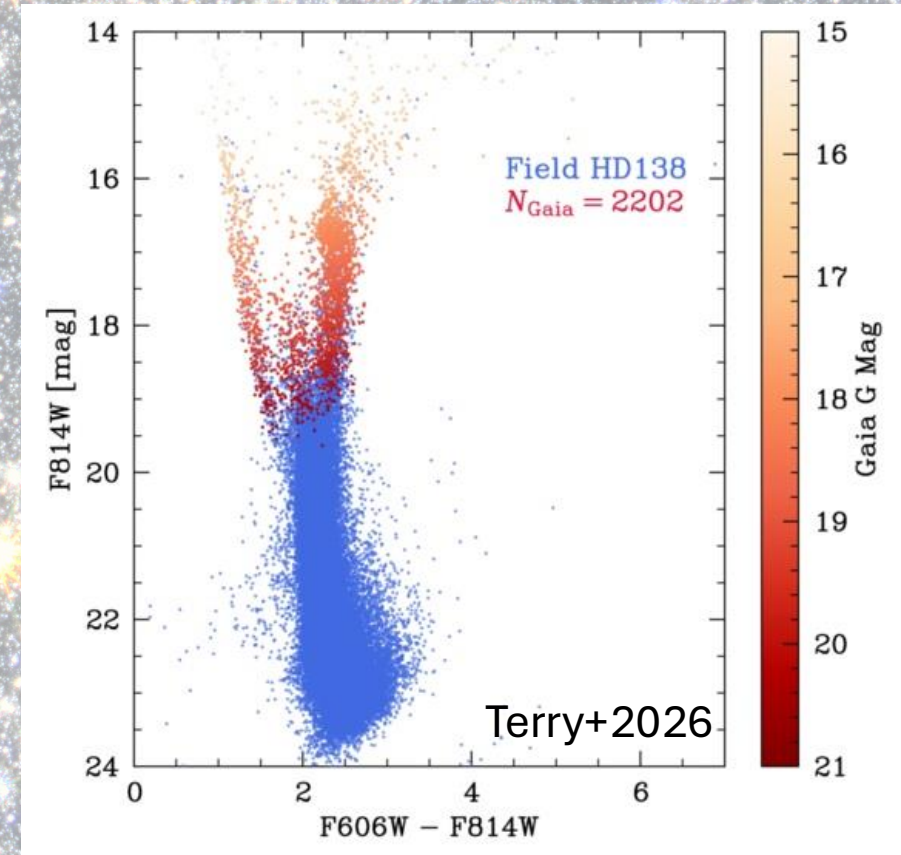
$N_{\star}$: Number of Stars Searched for Planets

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 $R \sim 5$ kpc, $Z \sim 3$ kpc
- Old Population ($\sim 8-10$ Gyr)
- Similar Chemically to Bar/Bulge

Bulge/Bar:

- Extends to $R \sim 3$ kpc
- Consistent with Mono-Age Population (~ 10 Gyr)
- Elevated in Alpha Abundances

Thin Disk

- Extends to $R > 20$ kpc, $Z \sim 0.5$ kpc
- Age Gradient: $d\text{Age}/dR < 0$
- Metallicity Gradient: $d\text{Met}/dR < 0$

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

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Bulge/Bar:

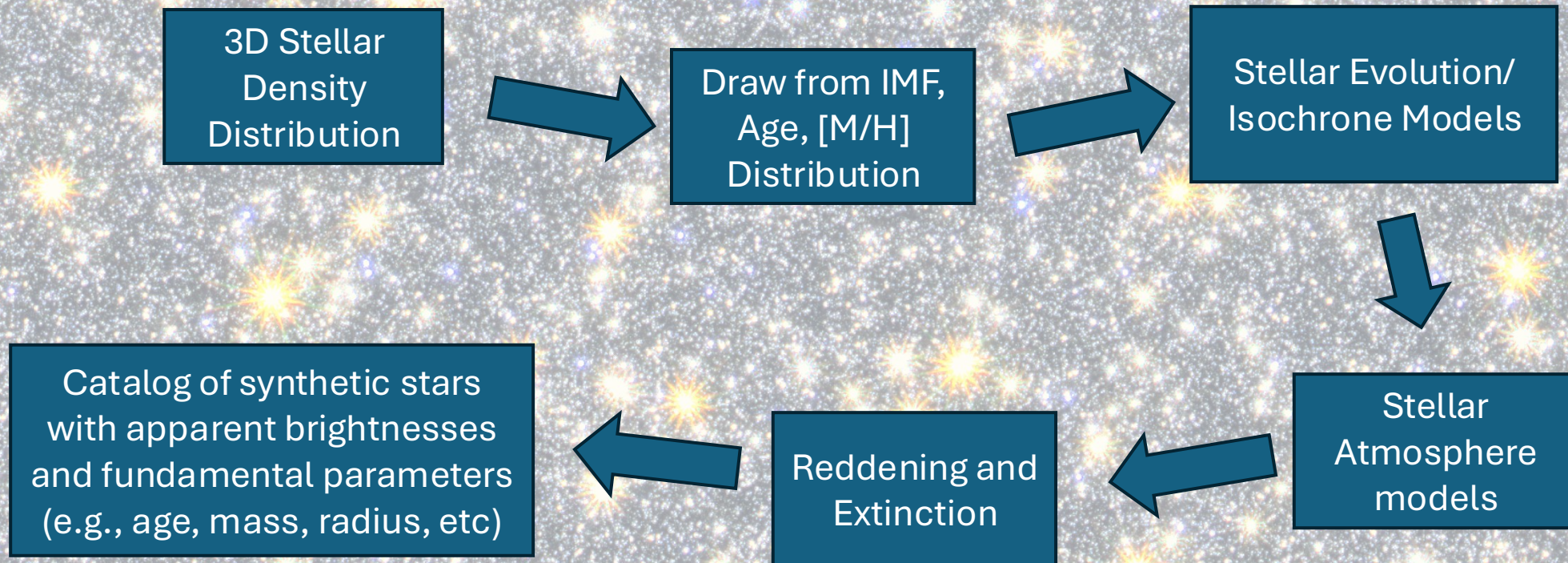
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Image credit: NASA/ESA/S. Farrell (University of Sydney)

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



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

- Empirical constraints?

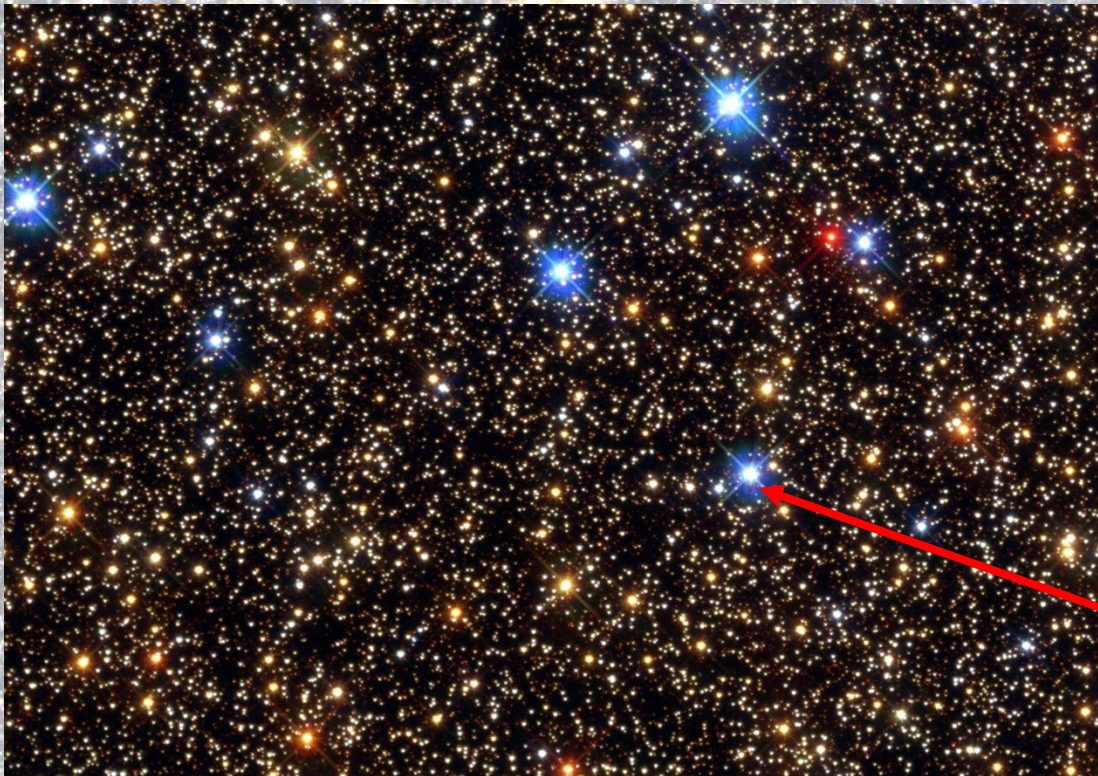
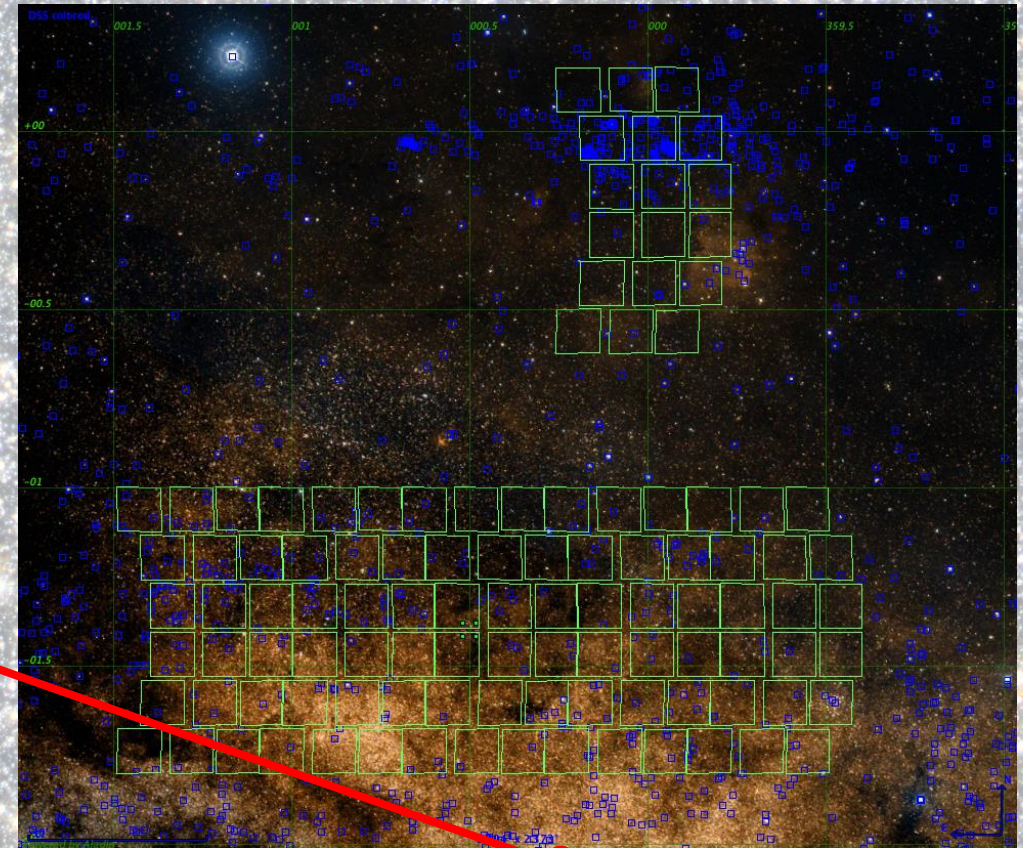
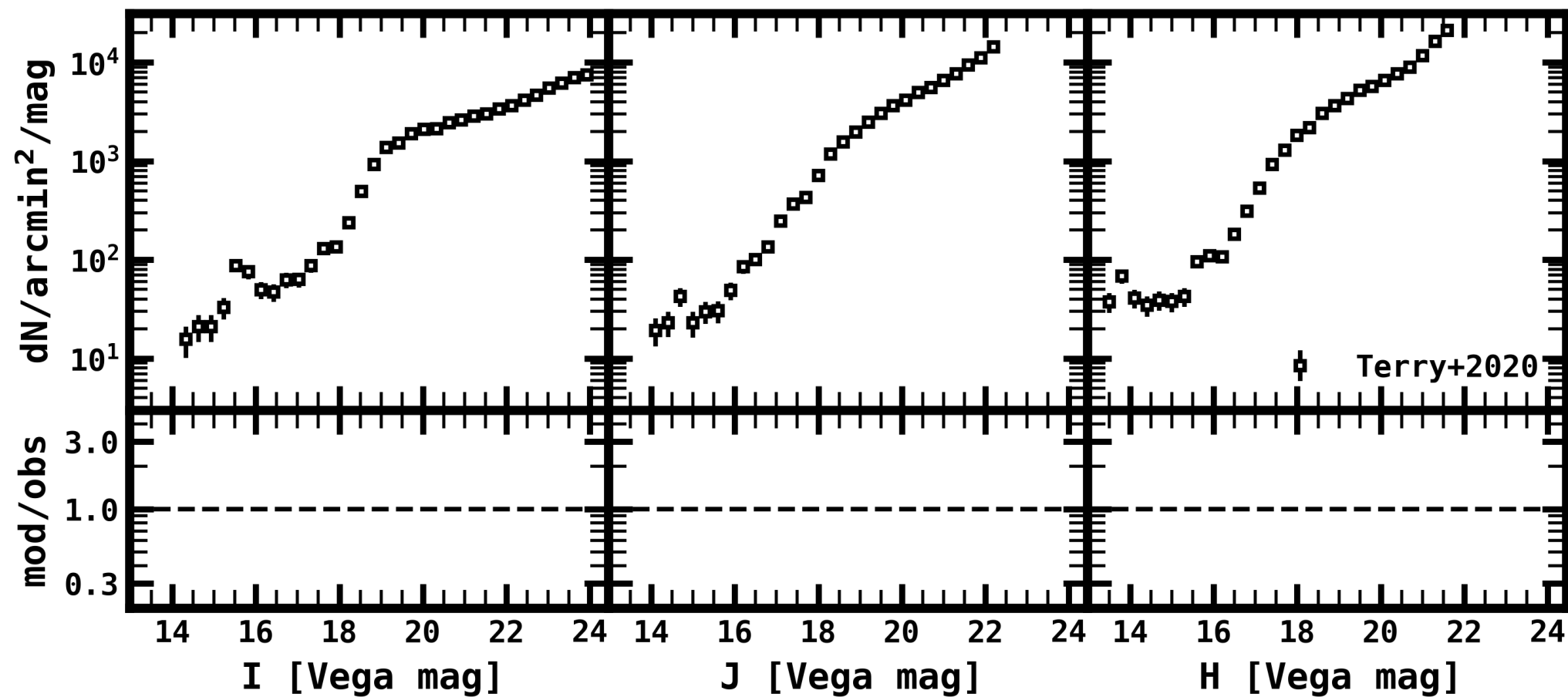
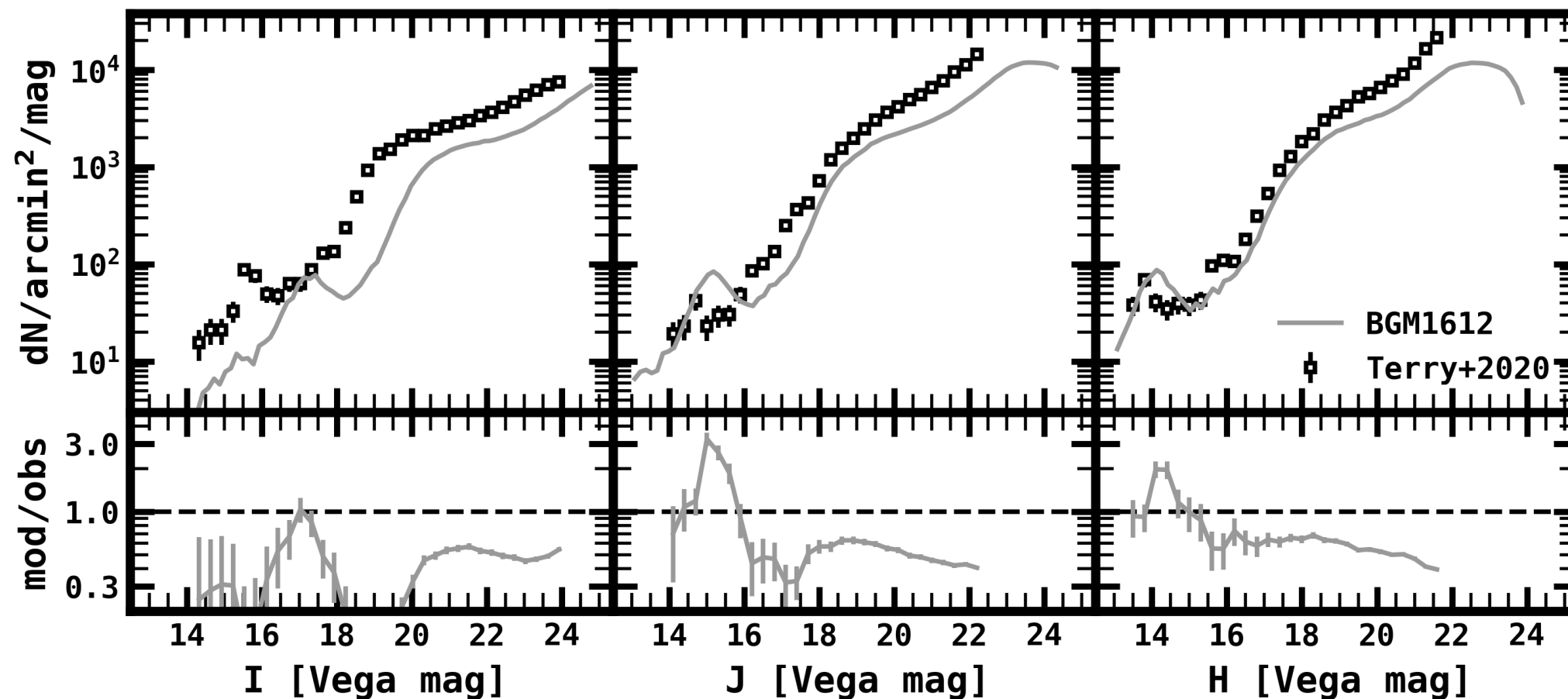
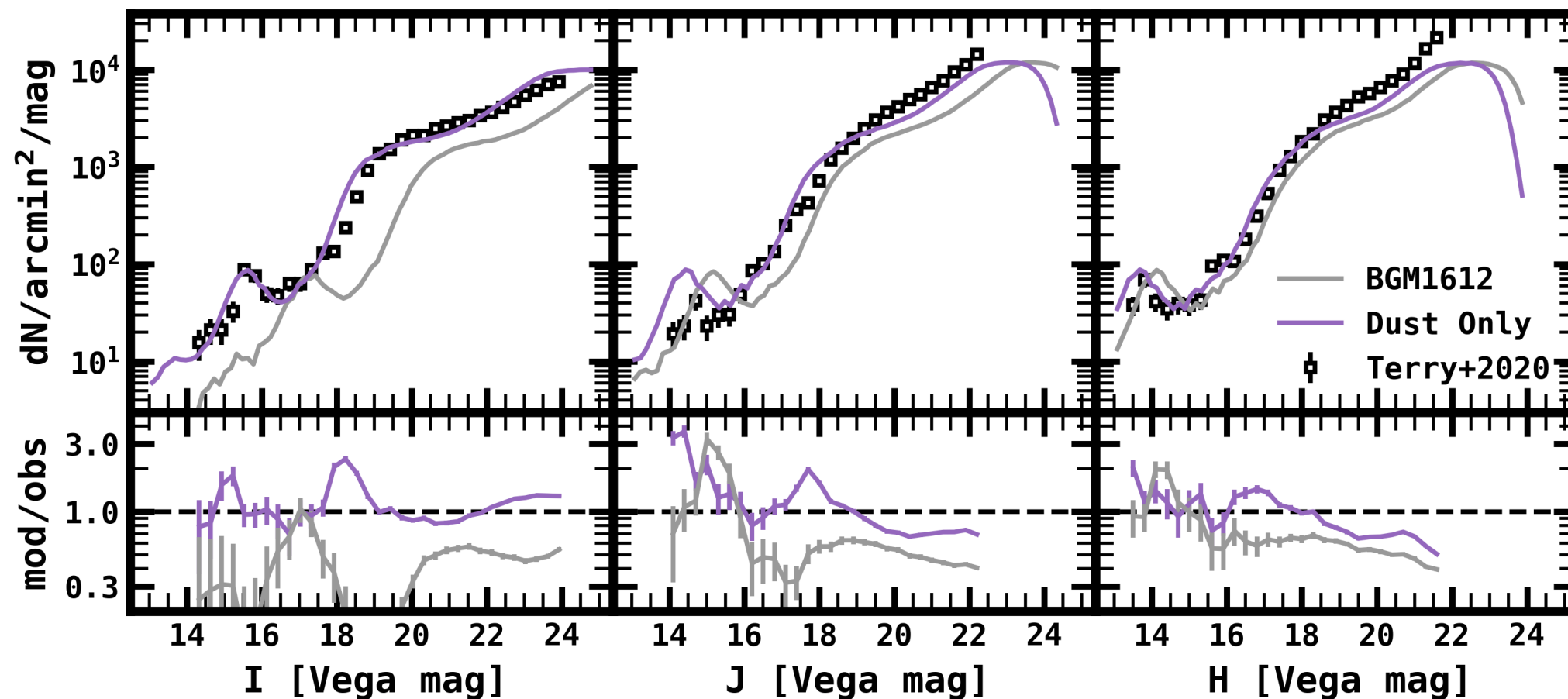


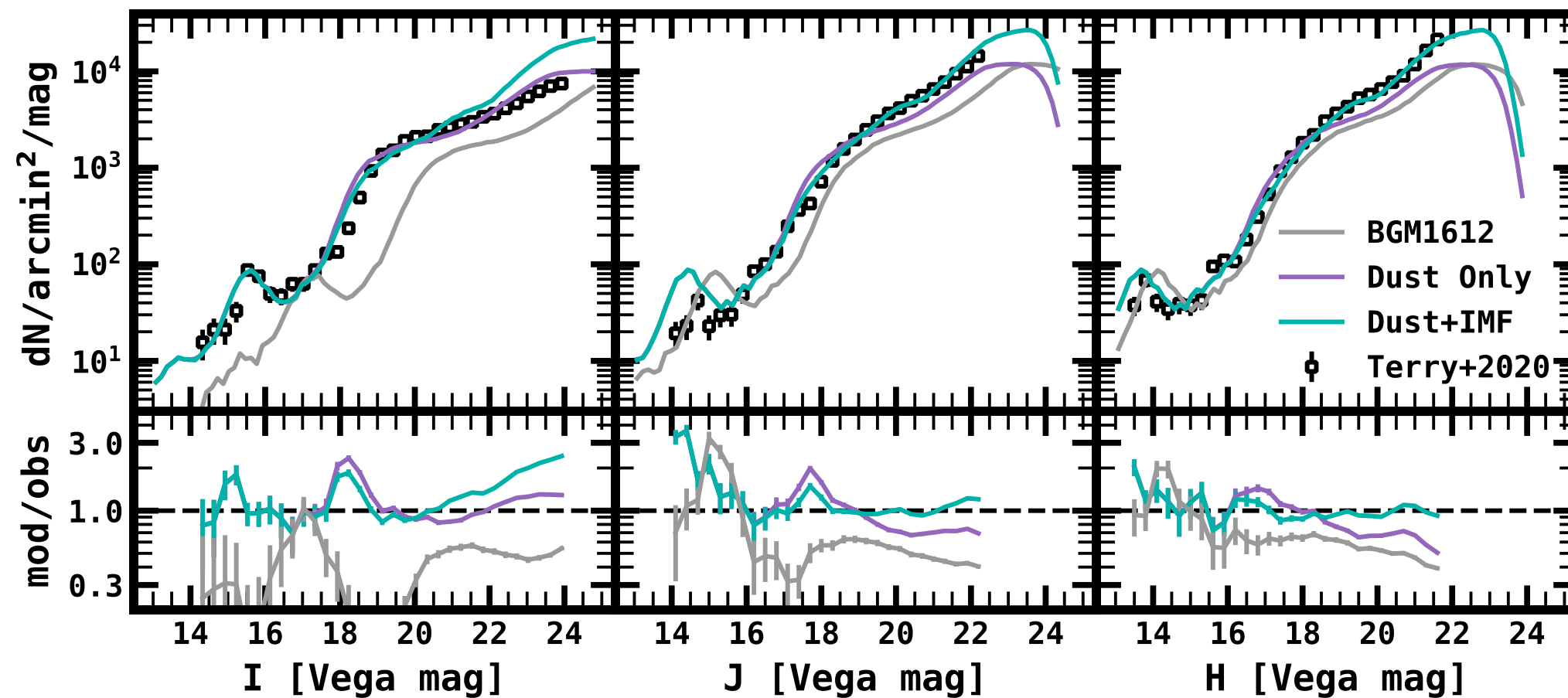
Image Credit: Brown+2009, 2010

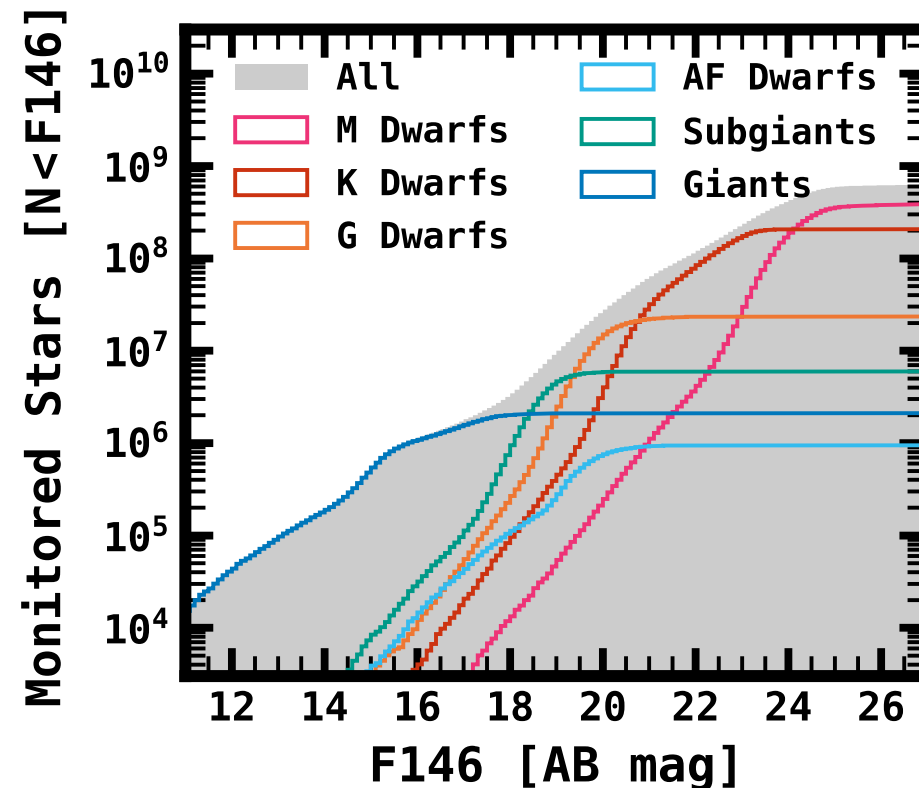
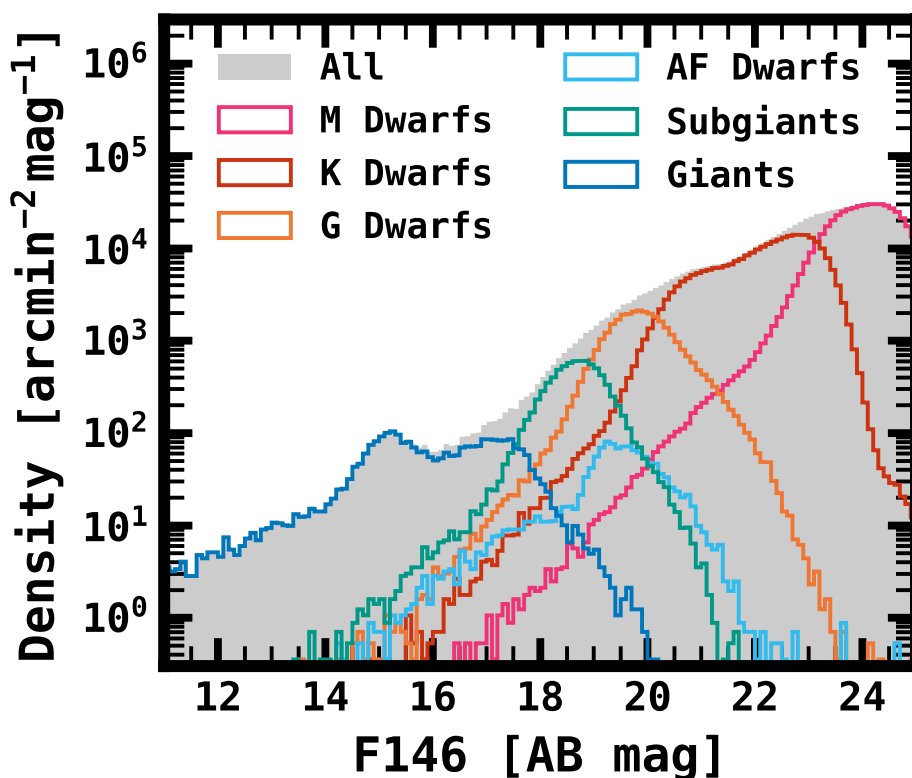












Below 22nd mag:

- ~10⁴ Stars per arcmin²
- ~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

The diagram illustrates the equation for the total number of planets, N_p , which is equal to the sum over all stars i of the product of the number of planets around star i , $n_{pl,i}$, and the probability that a planet j is detected orbiting star i , η_j . The equation is
$$N_p = \sum_i N_{\star} \sum_j n_{pl,i} \eta_j$$
 (Note: The original image contains a typo in the equation, it should be $n_{pl,i}$ instead of η_j in the second sum). Annotations include: a green checkmark pointing to $N_{\star}$ with the label "Number of Stars Searched for Planets"; an arrow pointing from $n_{pl,i}$ to the label "Number of Planets around Star i "; an arrow pointing from η_j to the label "Probability that planet j is detected orbiting star i "; and an arrow pointing from N_p to the label "Total Number of Planets (i.e., Yield)".

Number of Stars Searched for Planets

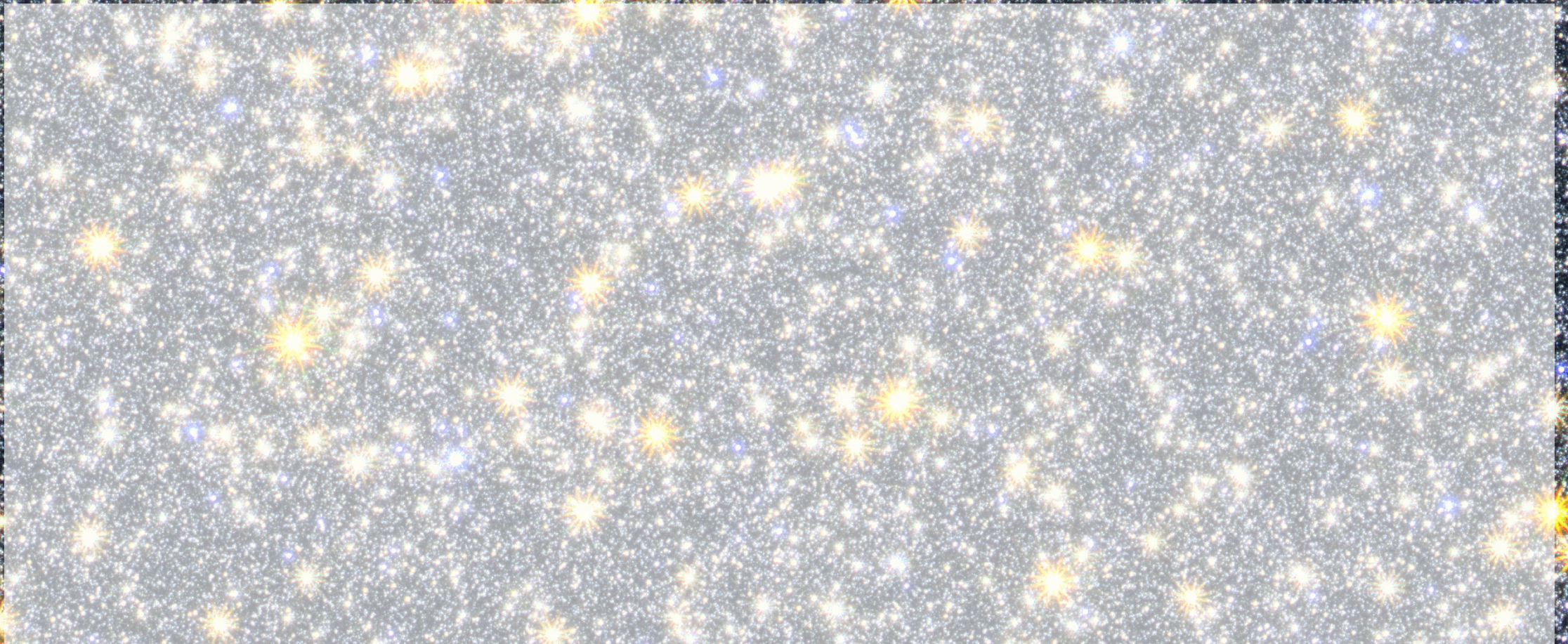
Number of Planets around Star i

Probability that planet j is detected orbiting star i

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

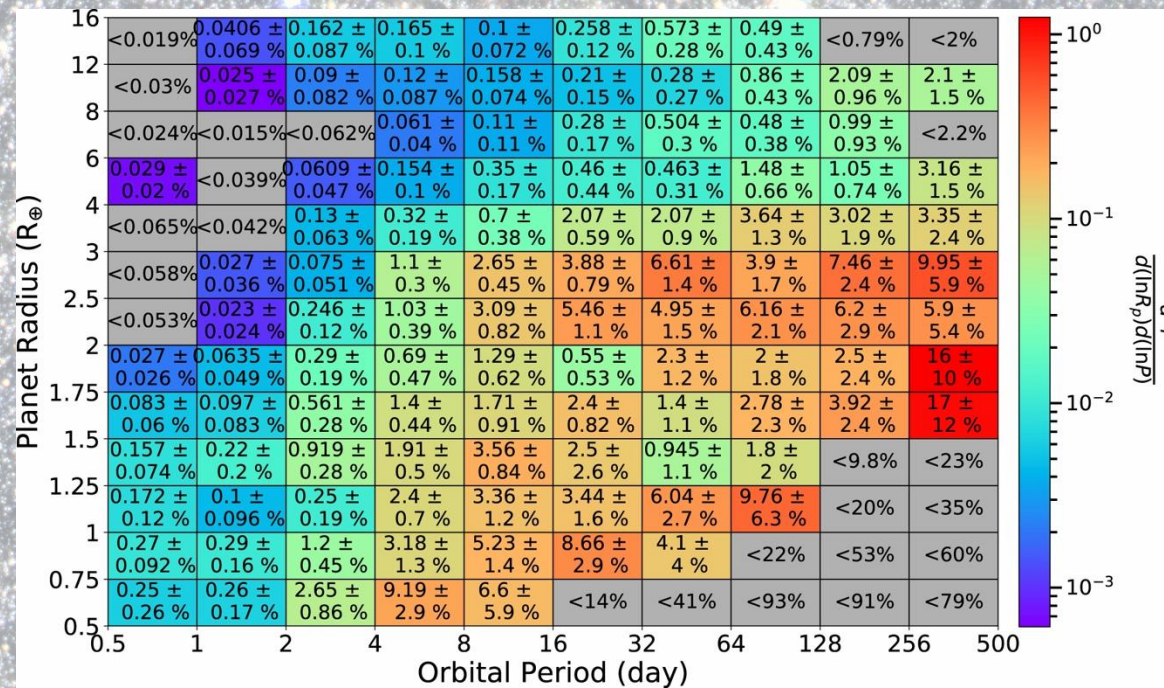
$$N_p = \sum_i N_{\star} \sum_j n_{pl,i} \eta_j$$

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



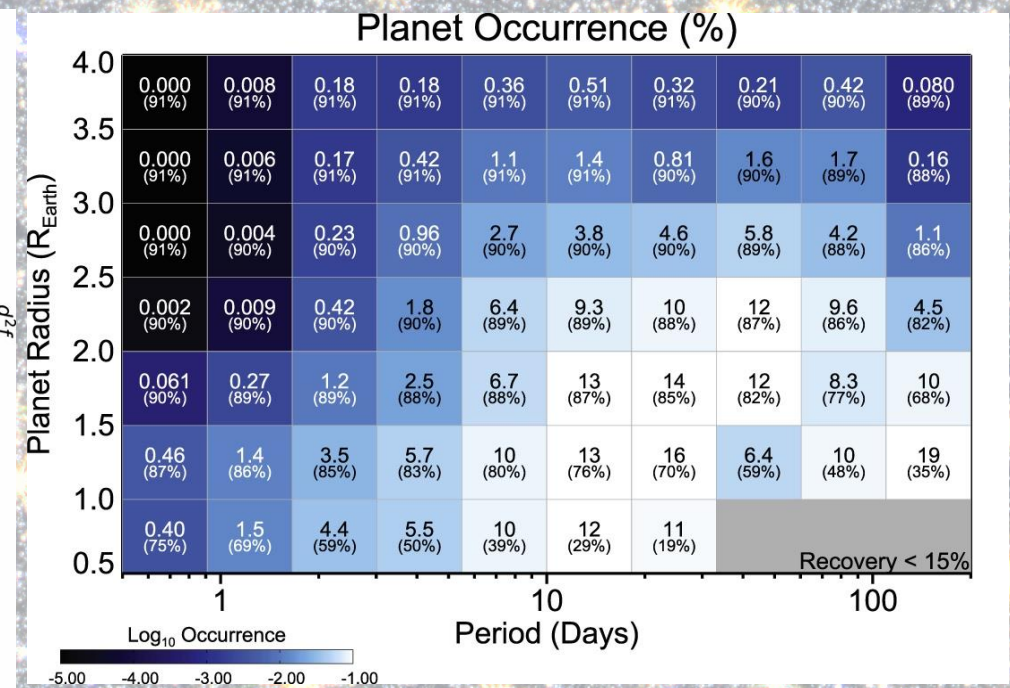
F_p : Planet Occurrence Rate (Number of Planets per Star, n_{pl})

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?**

Planet Radius



1 day

1 year

20 years

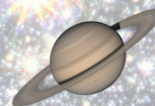
Orbital Period

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

How do we extrapolate to unknown populations?

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

Planet Radius



Kepler DR25 :
Hsu et al. (2019)

No Long-Period
Inflated Jupiters

Kepler Mono and
Duo Transits:
Herman et al.
(2019)

Roman can't detect
small long period
FGK Planets

1 day

1 year

20 years

Orbital Period

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

How do we extrapolate to unknown populations?

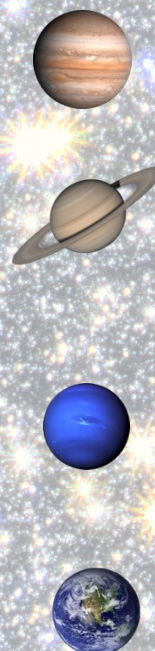
- **FGK Stars**

- Plug in results form Kepler

- **M Stars**

- Need to supplement transit surveys
- RVs, Direct imaging

Planet Radius



Kepler DR25 & RV surveys
Hsu et al. (2019)
Johson et al. (2010)

RV + High-Contrast Imaging:
Montet et al. (2014)

Extrapolated Kepler DR25 & RV surveys
Hsu et al. (2019)
Johson et al. (2010)

Kepler M dwarfs:
Dressing &
Charbonneau (2015)

Extrapolated from
Dressing &
Charbonneau (2015)

1 day

1 year

20 years

Orbital Period

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

How do we extrapolate to unknown populations?

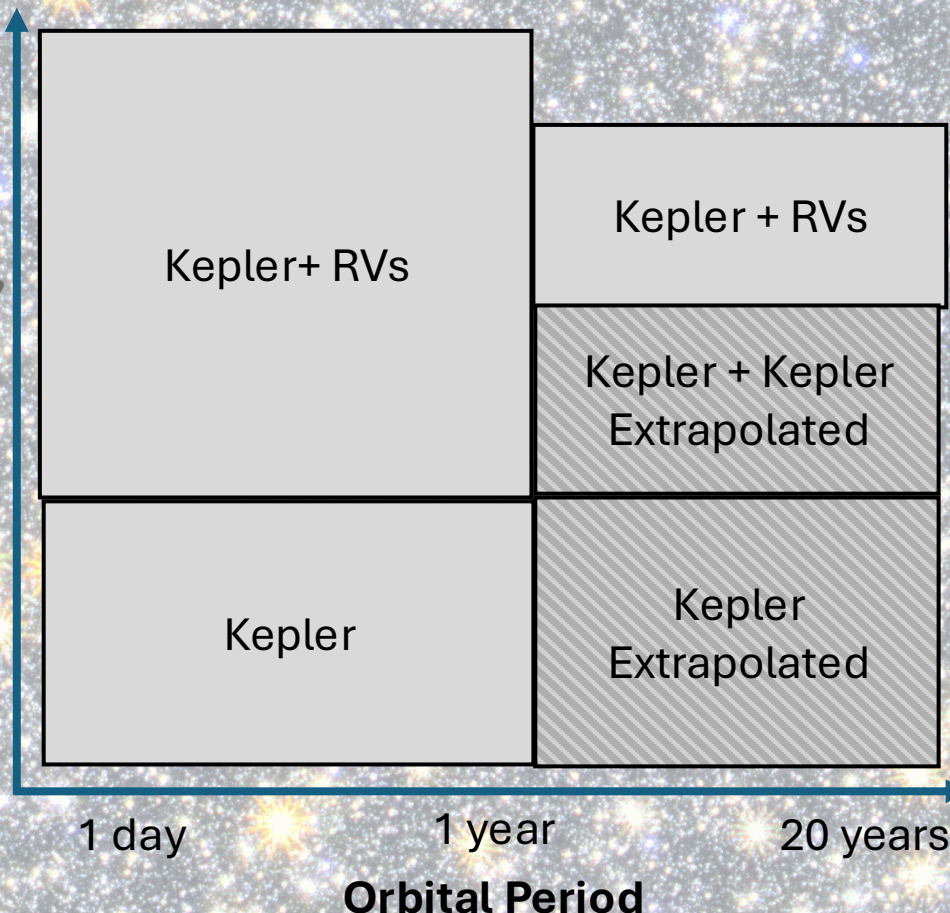
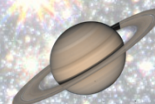
- **FGK Stars**

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Planet Radius



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. Annotations include:

- Number of Stars Searched for Planets**: Points to $N_\star$ with a green checkmark.
- Number of Planets around Star i** : Points to $n_{p,i}$ with a green checkmark.
- Total Number of Planets (i.e., Yield)**: Points to N_p .
- Probability that planet j is detected orbiting star i** : Points to η_j .

Number of Stars Searched for Planets

Number of Planets around Star i

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

Probability that planet j is detected orbiting star i

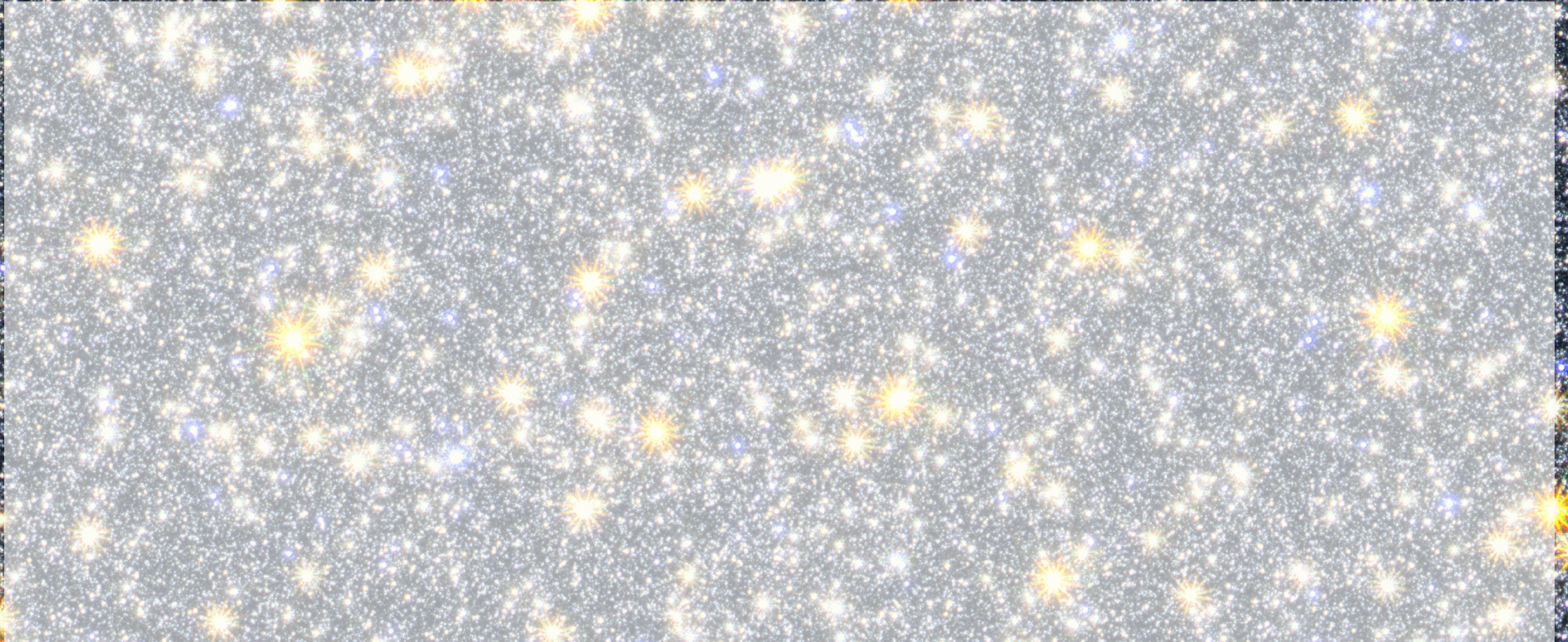
$$N_p = \sum_i N_\star n_{p,i} \eta_j$$



η : Survey Efficiency

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



η : Survey Efficiency

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

**** Probability that a transit occurs**

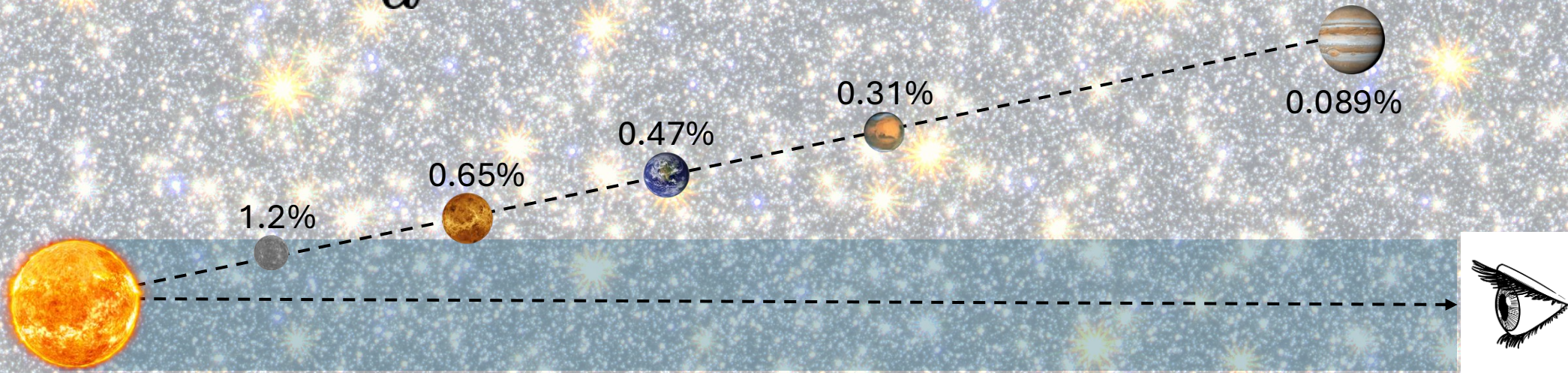
η : Survey Efficiency

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

**** Probability that a transit occurs**

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

Highly biased toward close-in planets



η : Survey Efficiency

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

**** Probability that a transit occurs *while* being observed**

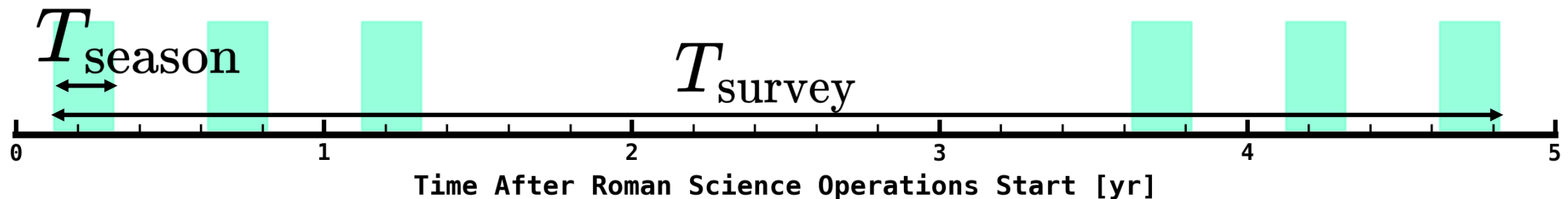
η : Survey Efficiency

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

**** Probability that a transit occurs *while* being observed**

Assume one transit is enough

*It historically
is not!!!*



η : Survey Efficiency

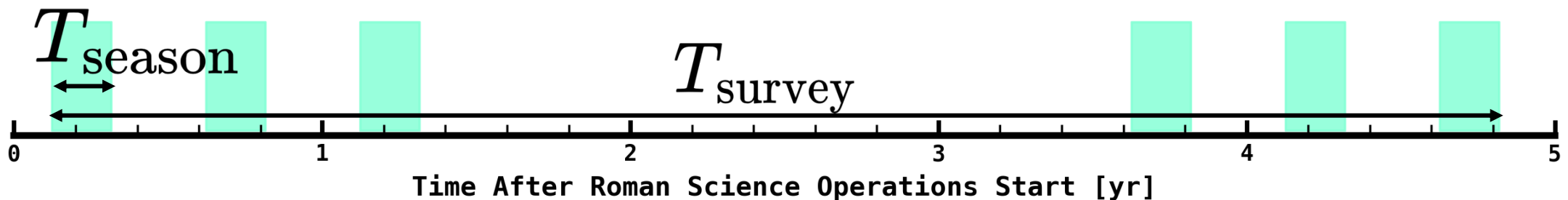
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**** Probability that a transit occurs *while* being observed**

Assume one transit is enough

*It historically
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$$p_{\text{window}}(P < T_{\text{season}}) = 1$$



η : Survey Efficiency

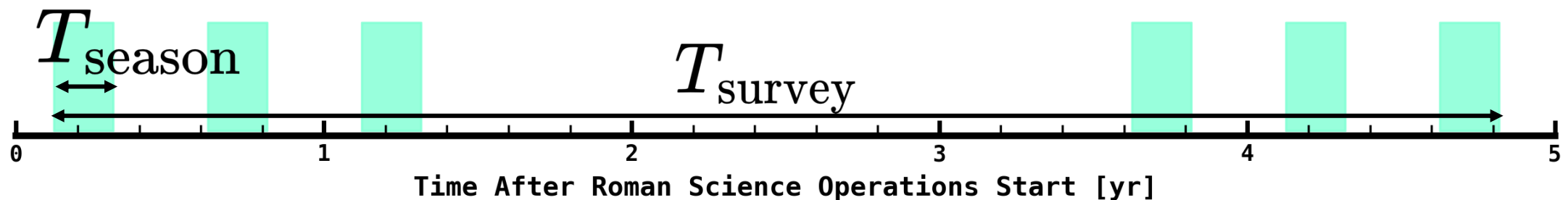
$$\eta = p_{\text{transit}} \times p_{\text{window}} \times p_{\text{detect}}$$

**** Probability that a transit occurs *while* being observed**

Assume one transit is enough *It historically is not!!!*

$$p_{\text{window}}(P < T_{\text{season}}) = 1$$

$$p_{\text{window}}(P > T_{\text{survey}}) = \frac{n_{\text{seasons}} \times T_{\text{season}}}{P}$$



η : Survey Efficiency

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

**** Probability that a transit occurs *while* being observed**

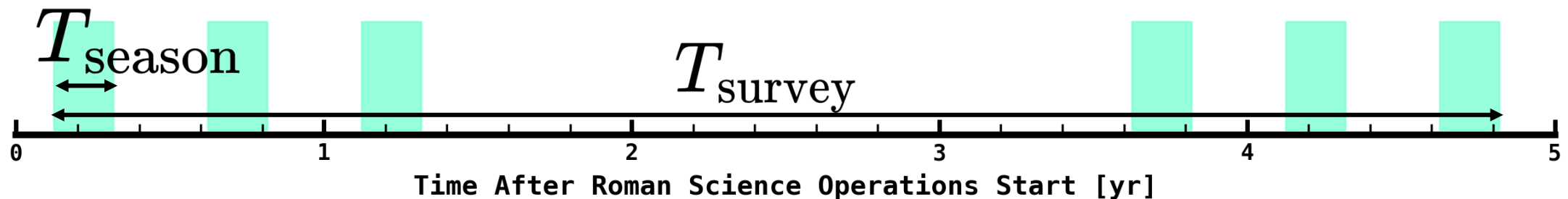
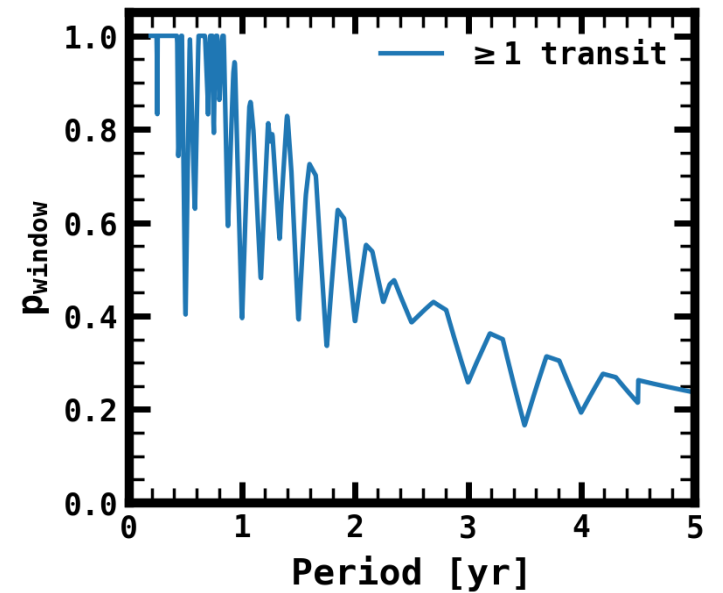
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$$p_{\text{window}}(T_{\text{season}} < P < T_{\text{survey}}) =$$



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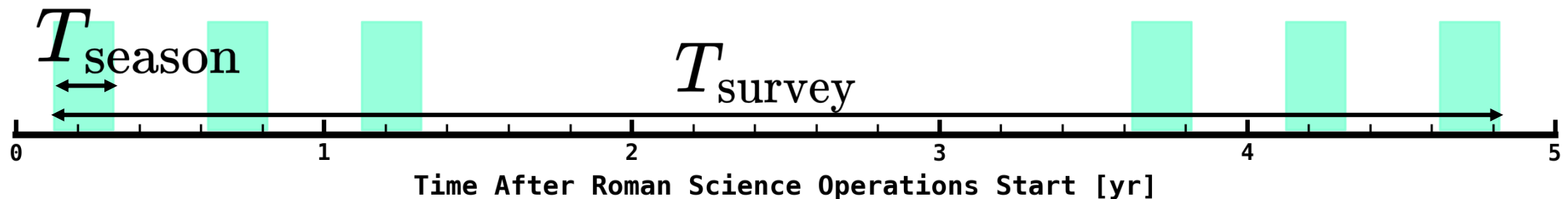
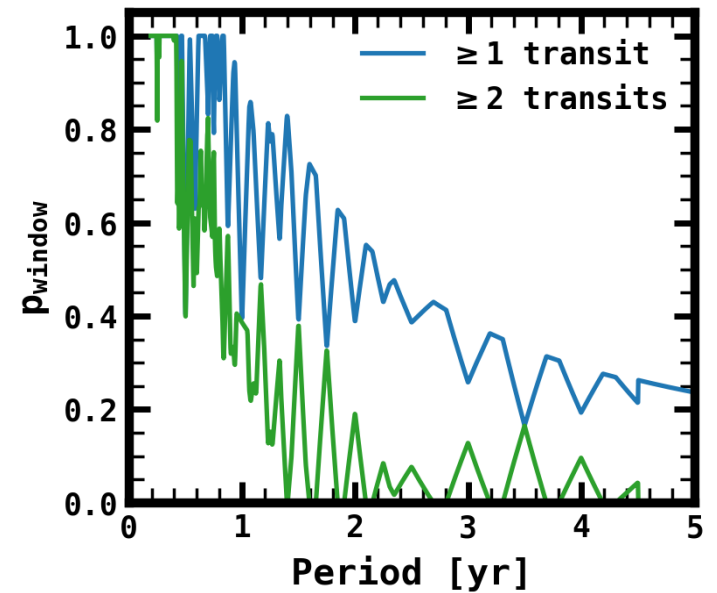
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$$\eta = p_{\text{transit}} \times p_{\text{window}} \times p_{\text{detect}}$$

**** Probability that a transit occurs *while* being observed**

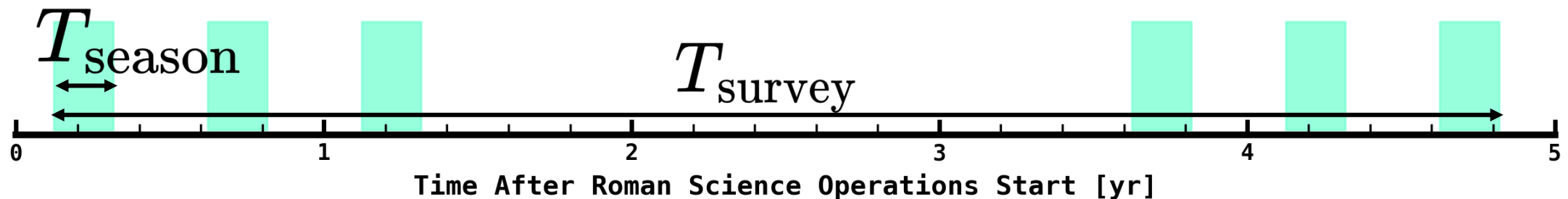
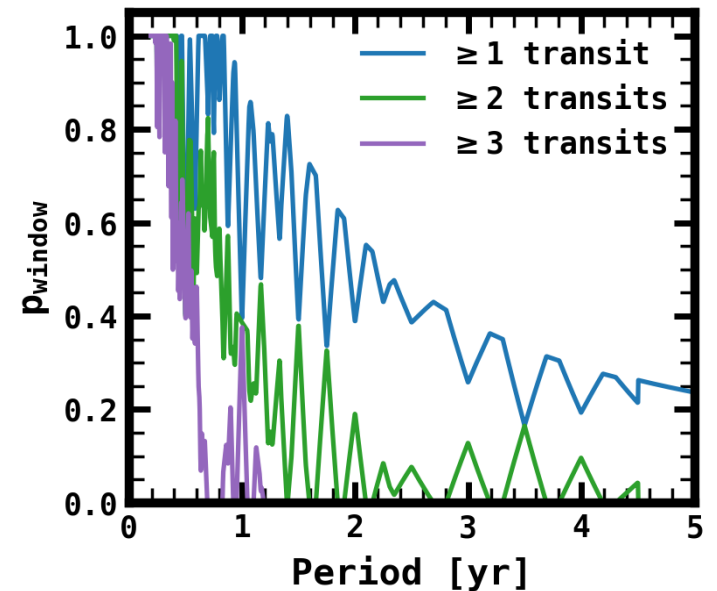
Assume one transit is enough

It historically is not!!!

$$p_{\text{window}}(P < T_{\text{season}}) = 1$$

$$p_{\text{window}}(P > T_{\text{survey}}) = \frac{n_{\text{seasons}} \times T_{\text{season}}}{P}$$

$$p_{\text{window}}(T_{\text{season}} < P < T_{\text{survey}}) =$$



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

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

**** 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

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

η : Survey Efficiency

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

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

Model this process using injection/recovery experiments

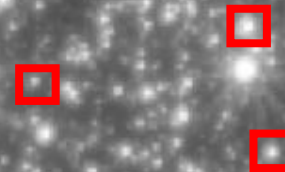
- Must be done at pixel level to model crowding

η : Survey Efficiency

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

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

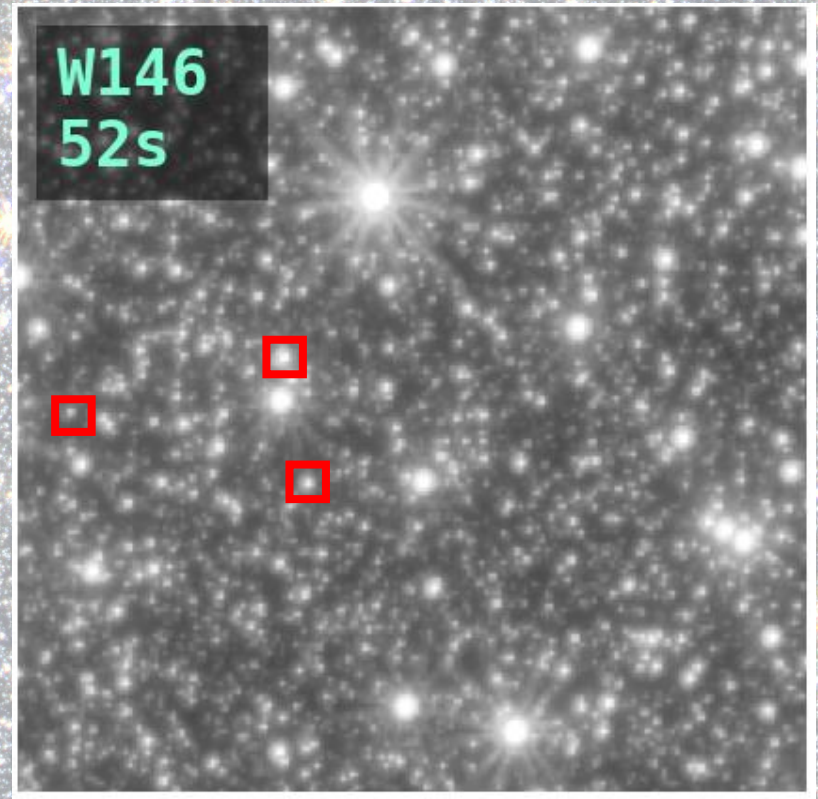
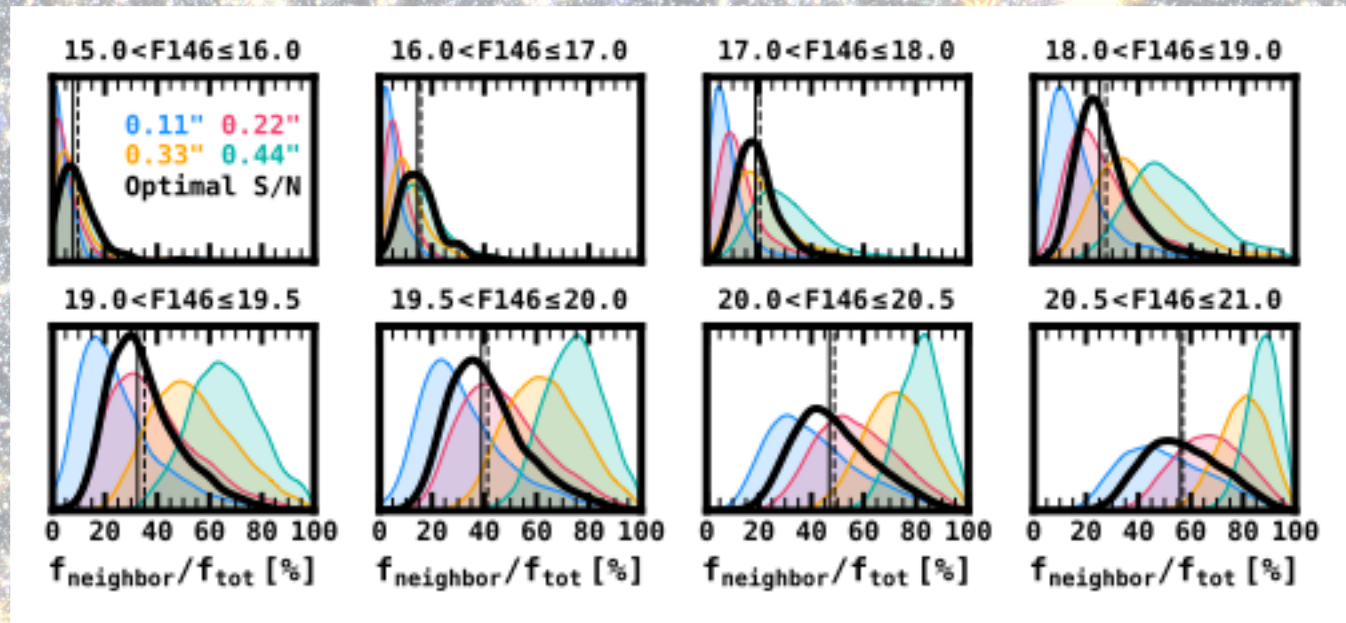
W146
52s



η : Survey Efficiency

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

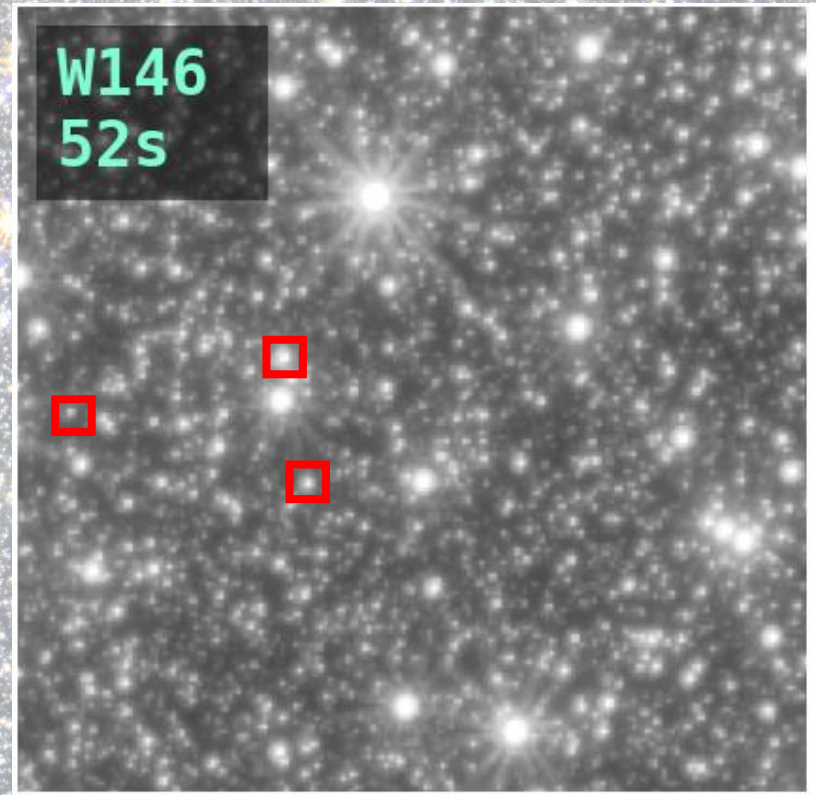
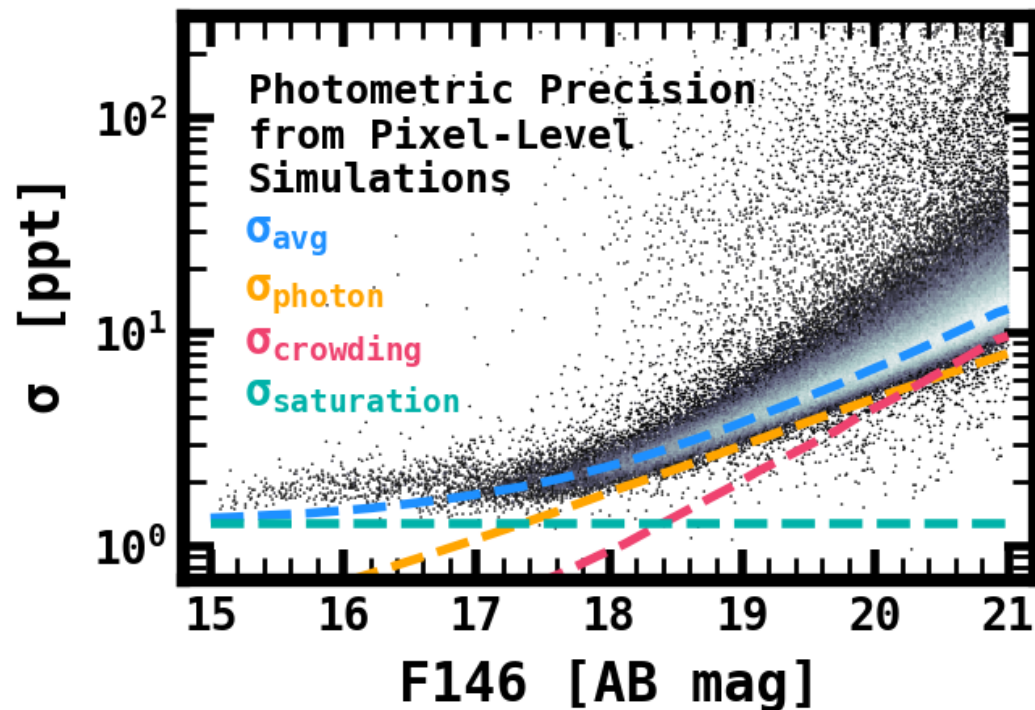
**** Probability that an observed transit is detected**



η : Survey Efficiency

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

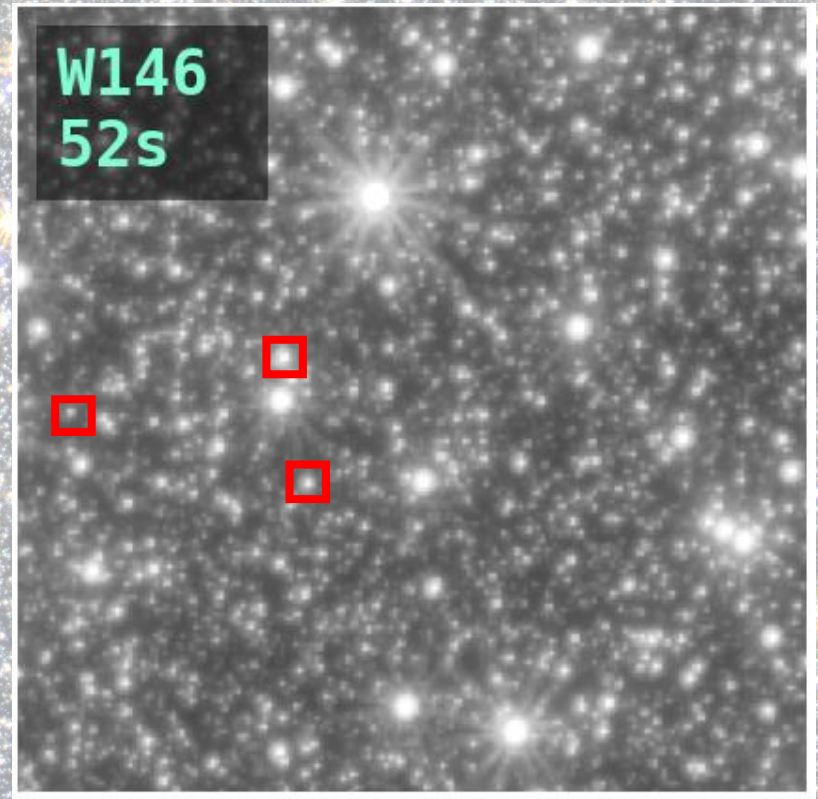
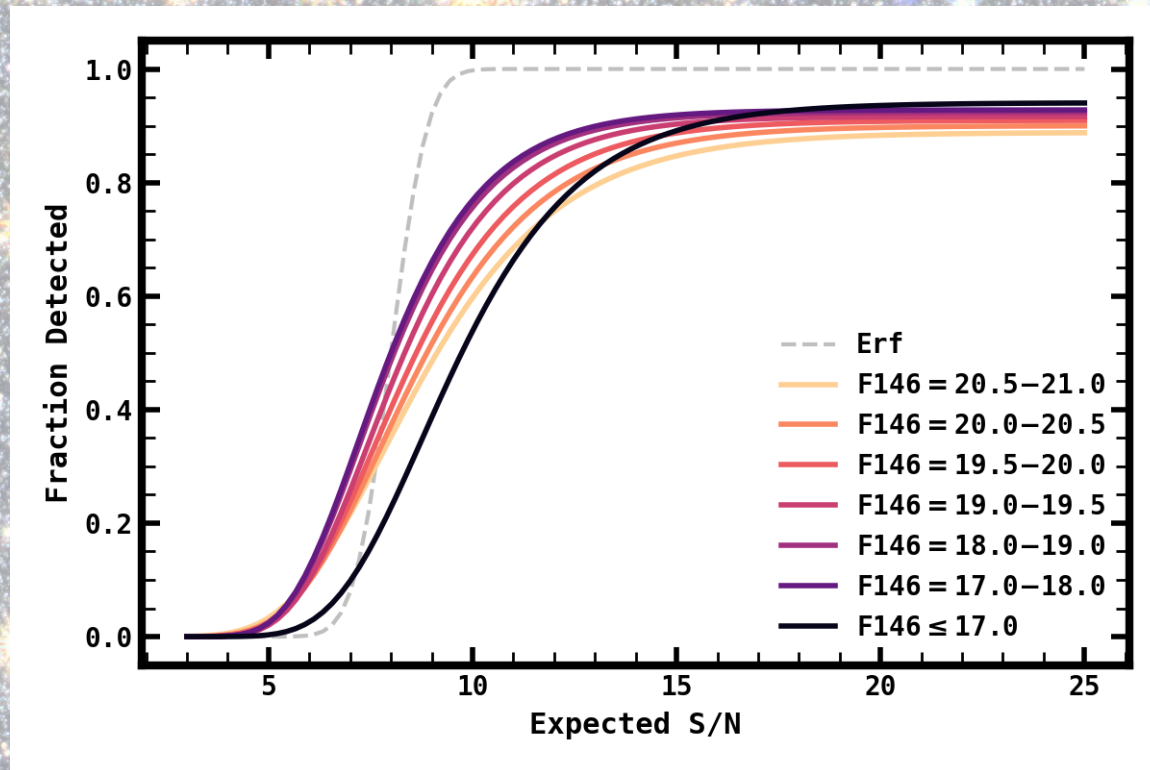
**** Probability that an observed transit is detected**



η : Survey Efficiency

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

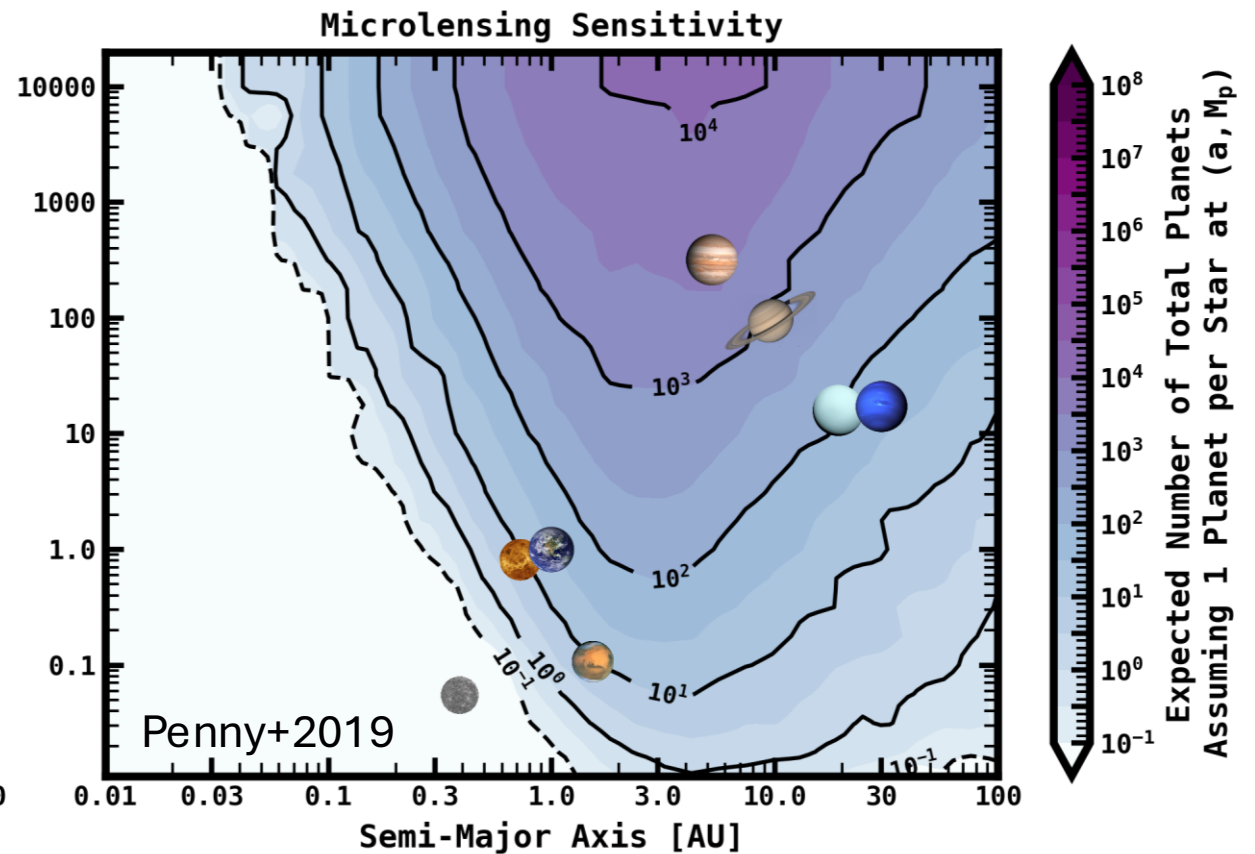
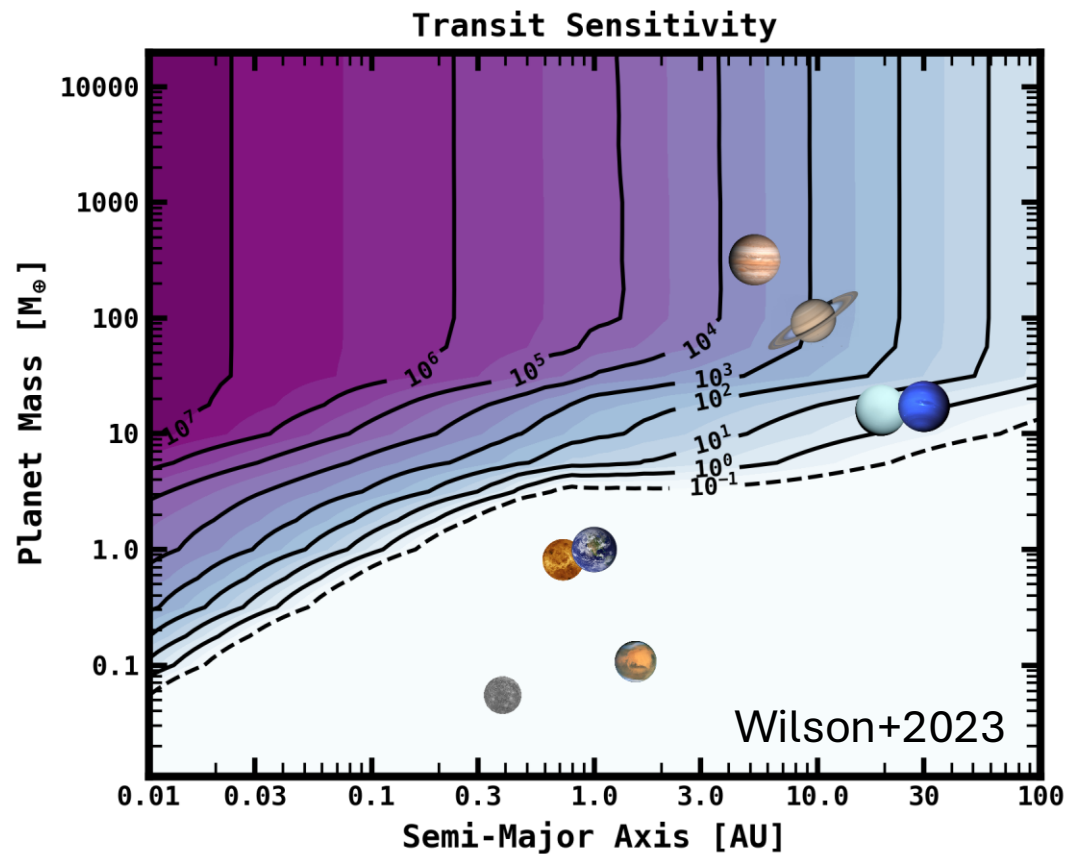
**** Probability that an observed transit is detected**

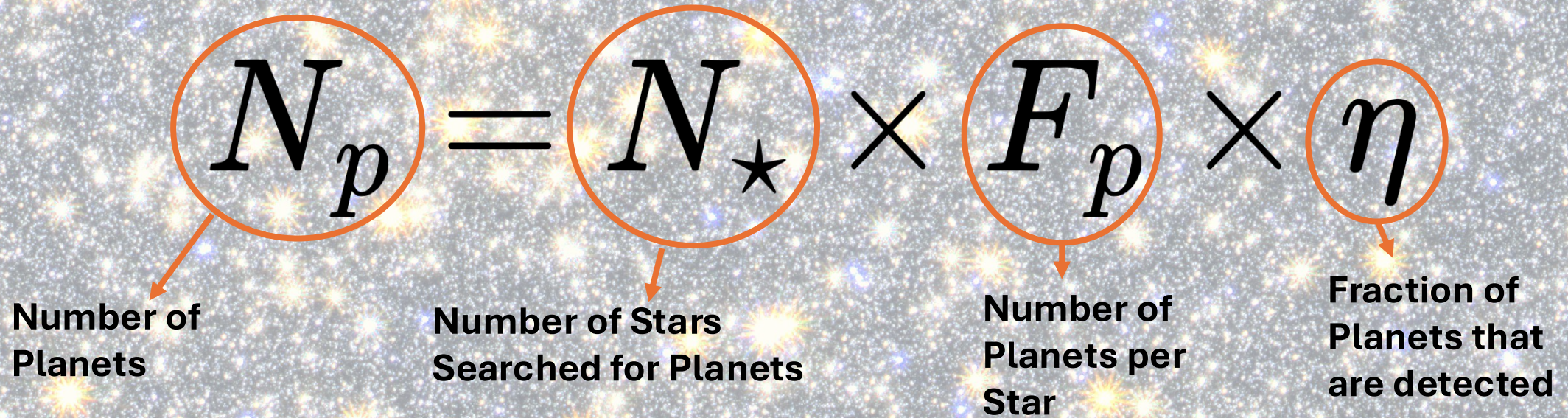


η : Survey Efficiency

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

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





The diagram shows the equation $N_p = N_{\star} \times F_p \times \eta$ where each variable is circled in orange. Arrows point from each circle to its corresponding label below: N_p to "Number of Planets", $N_{\star}$ to "Number of Stars Searched for Planets", F_p to "Number of Planets per Star", and η to "Fraction of Planets that are detected".

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

Number of Planets

Number of Stars Searched for Planets

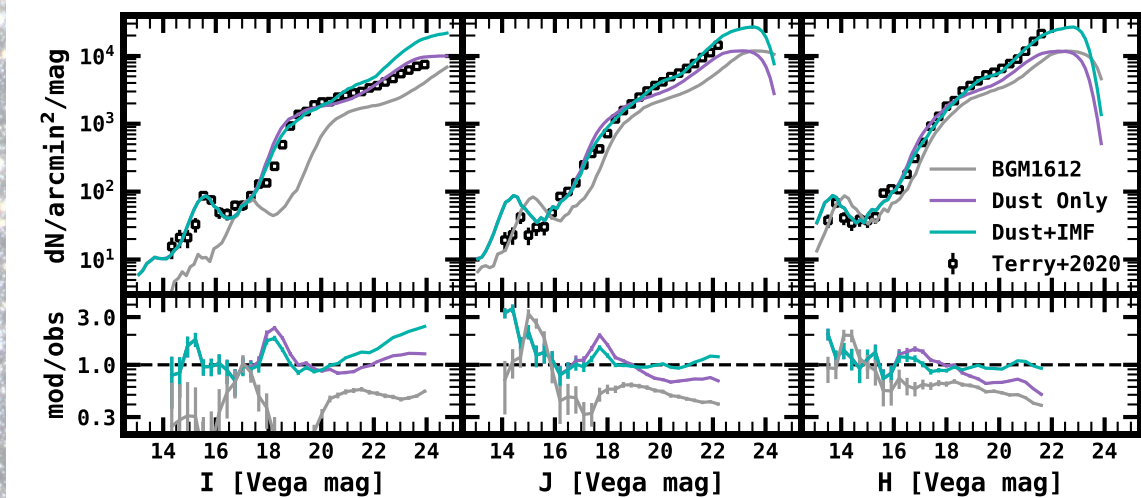
Number of Planets per Star

Fraction of Planets that are detected

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

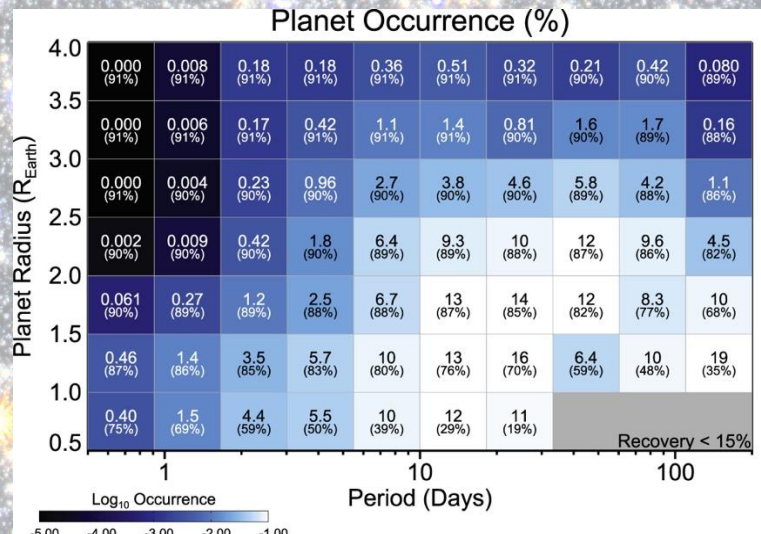
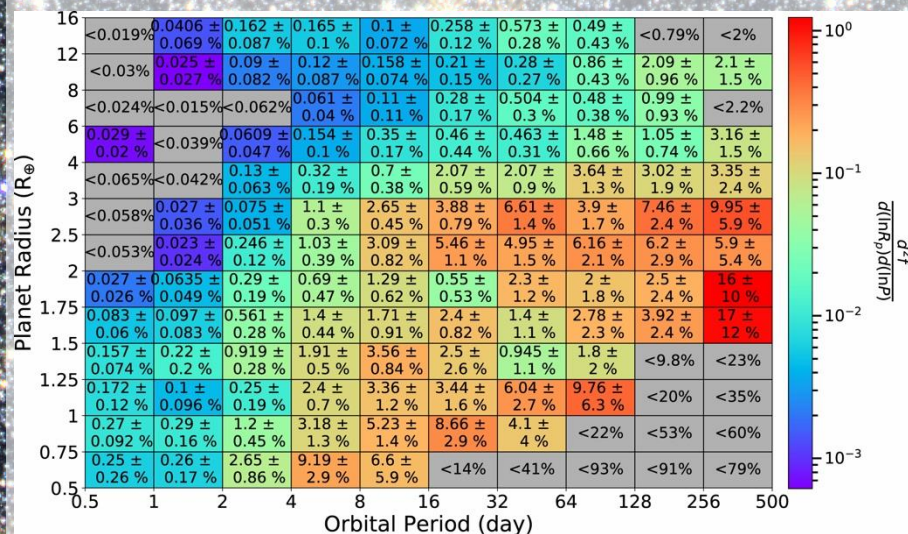
$$N_p = N_{\star} \times F_p \times \eta$$

Number of Stars
Searched for Planets



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

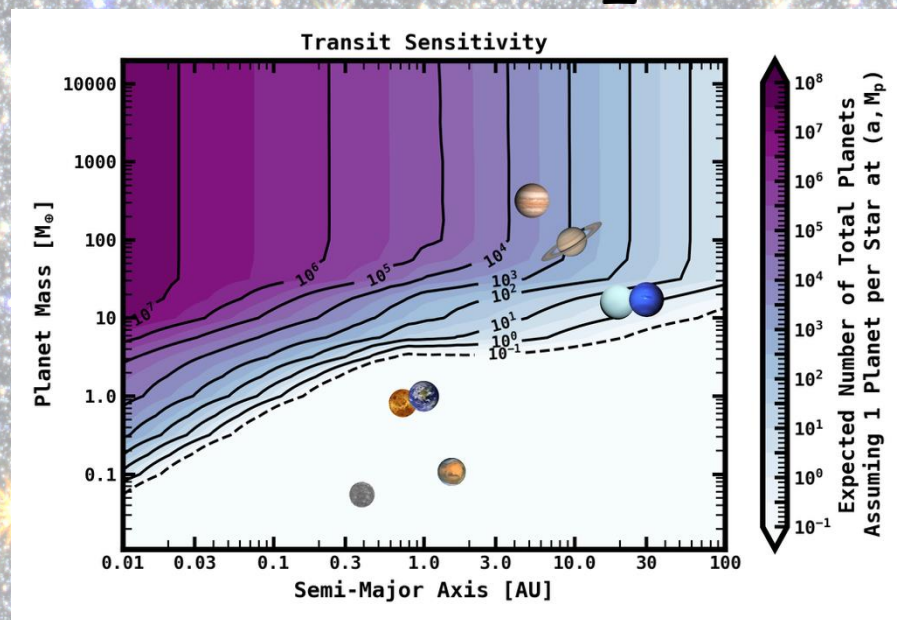
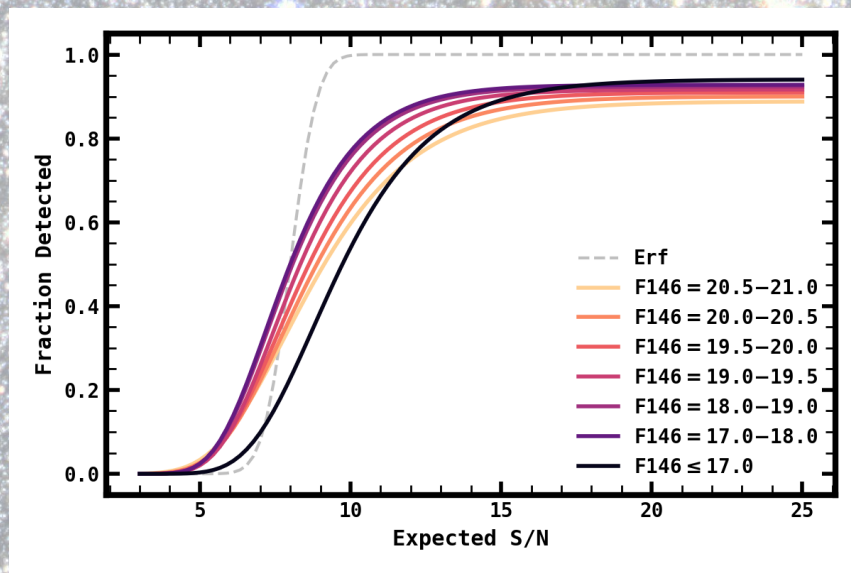
$$N_p = N_{\star} \times F_p \times \eta$$



Number of Planets per Star

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

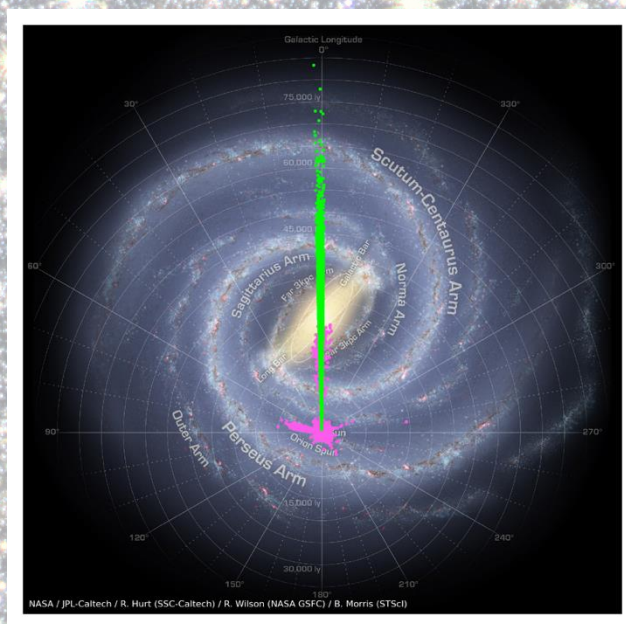
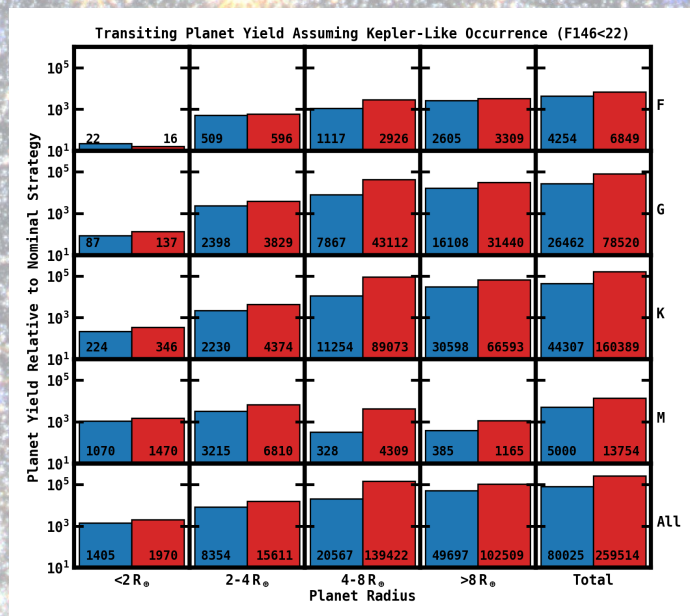
$$N_p = N_{\star} \times F_p \times \eta$$



Fraction of
Planets that
are detected

Yield = ($\sim 10^8$ stars) $\times$ (~ 0.1 - 10 planet/star) $\times$ ($\sim 10^{-1}$ - 10^{-6} detected) =
 $\sim 10^5$ planets detected

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



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