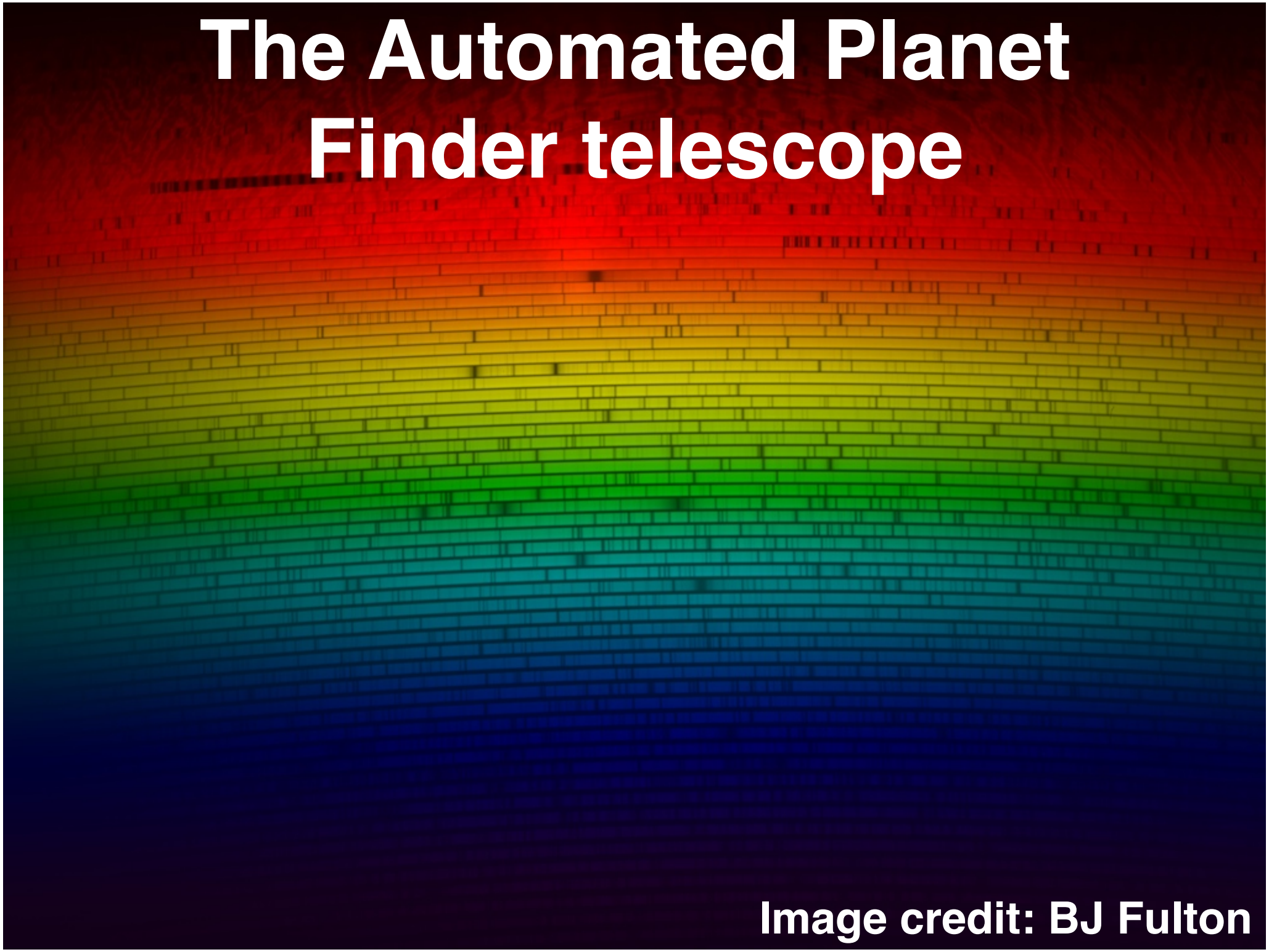
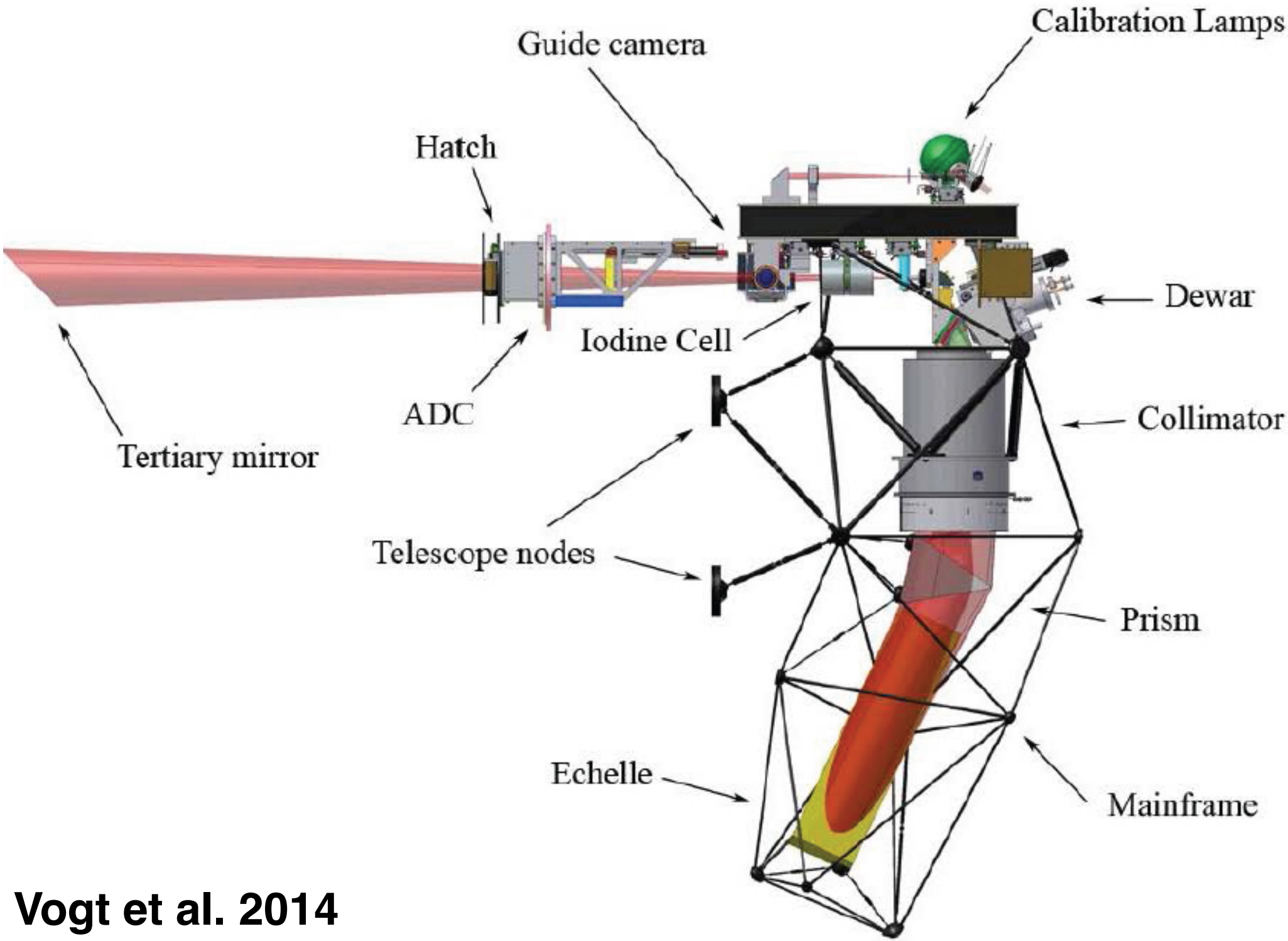
Designing optimal exoplanet mass measurement surveys in the era of TESS

Jennifer Burt (MIT)

Brad Holden (UCO/Lick)
Angie Wolfgang (Penn State)
Luke Bouma (Princeton)

The Automated Planet Finder telescope

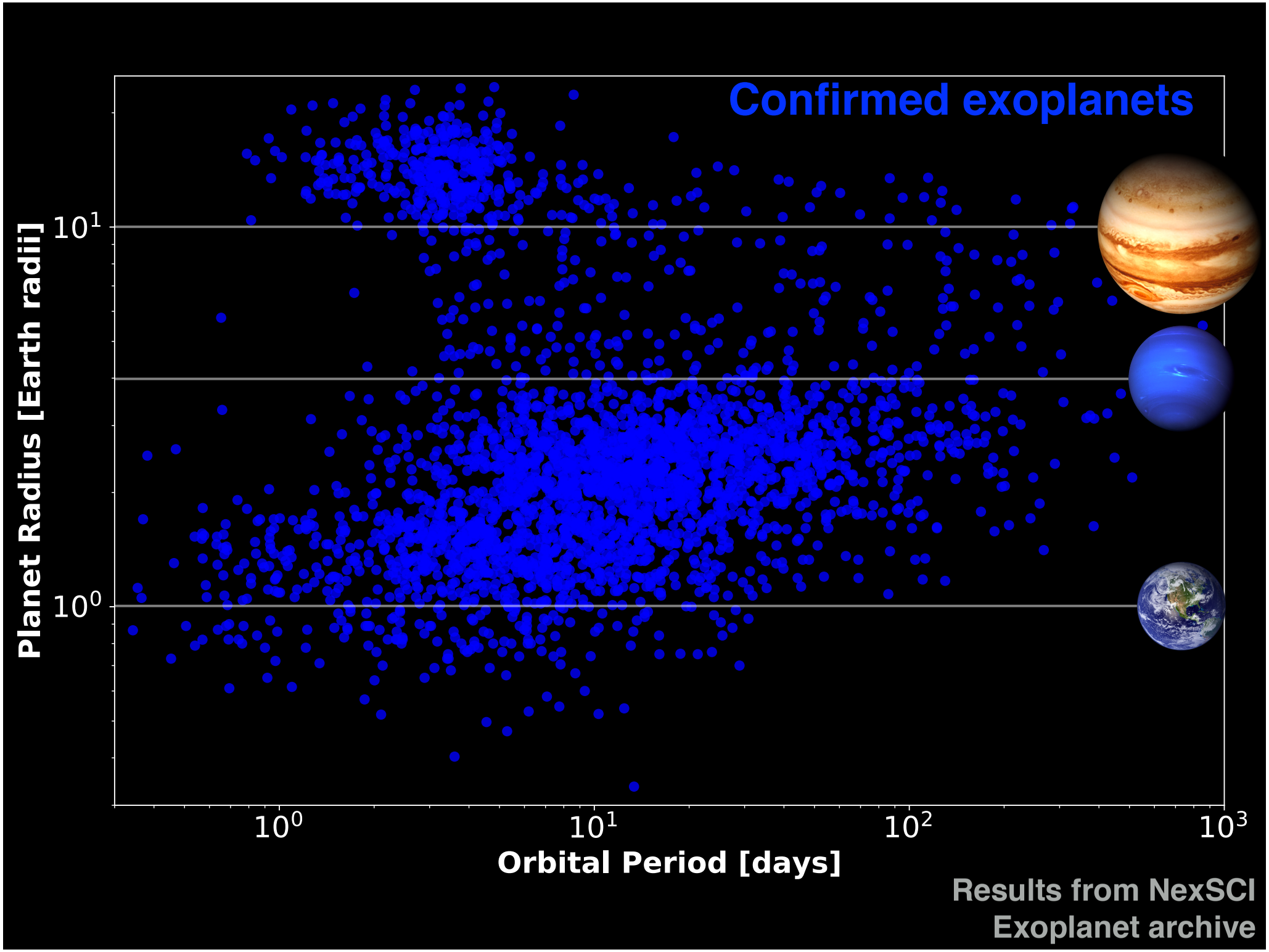

The Automated Planet Finder telescope
Image credit: BJ Fulton

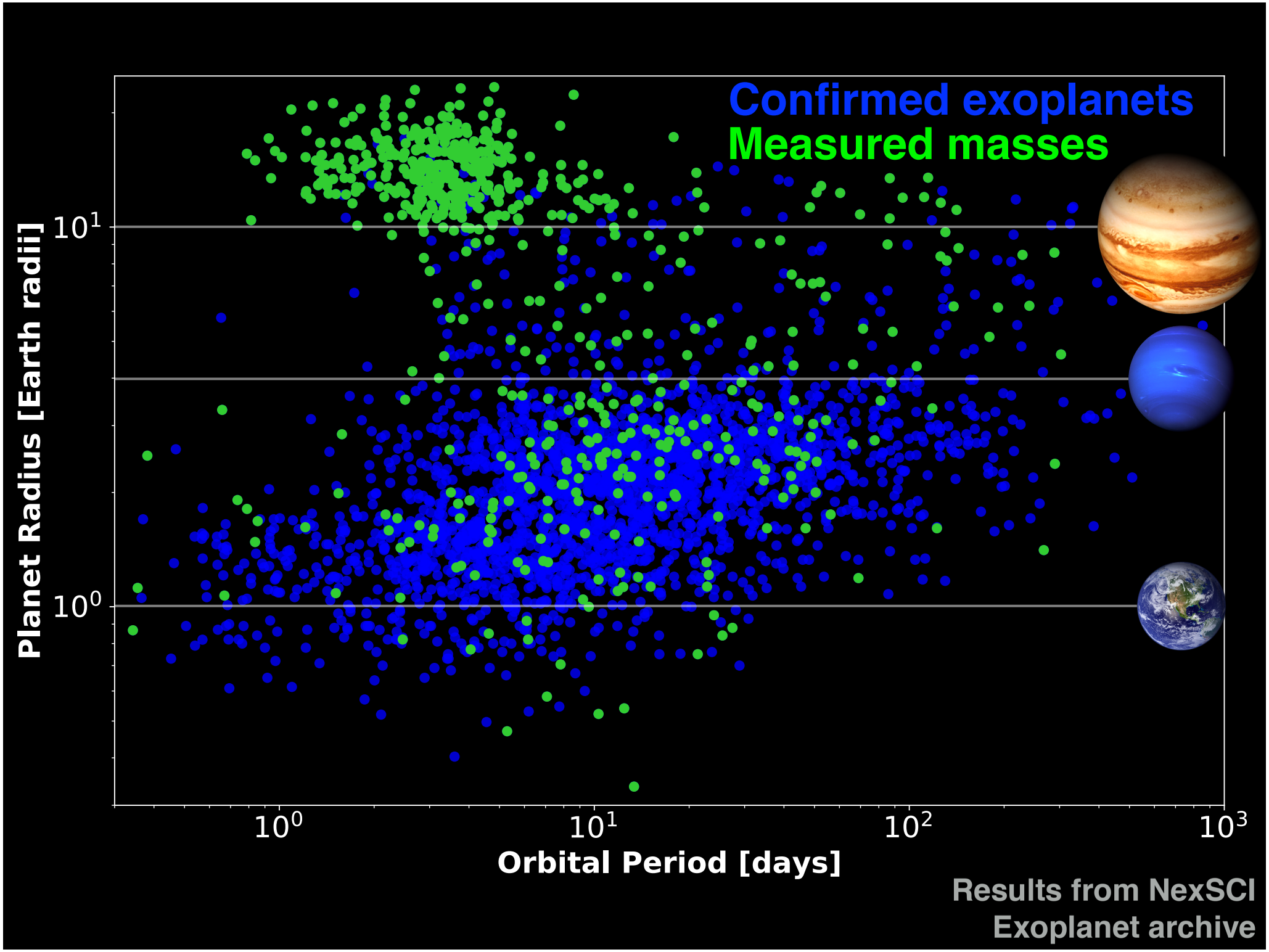


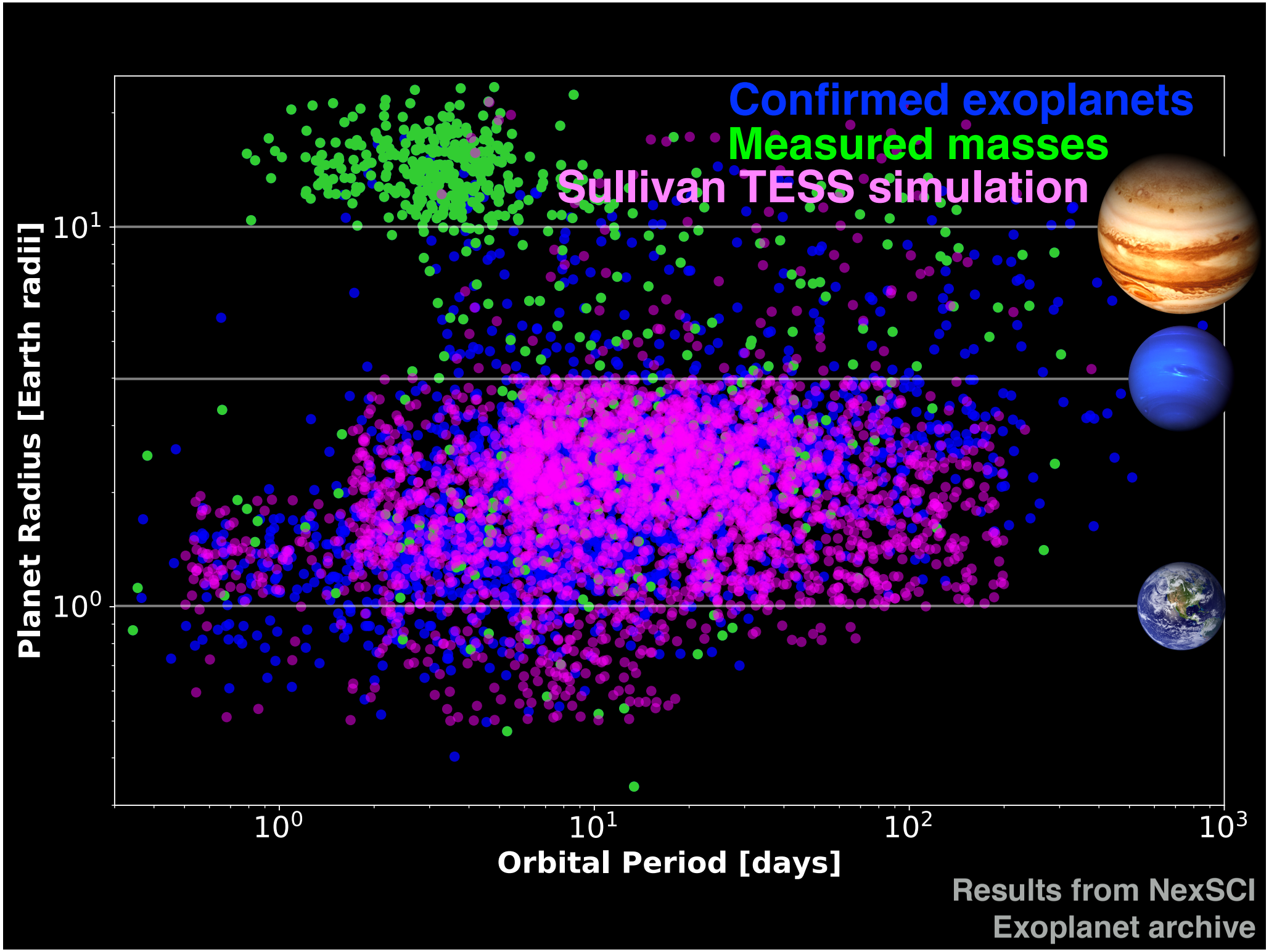
Vogt et al. 2014

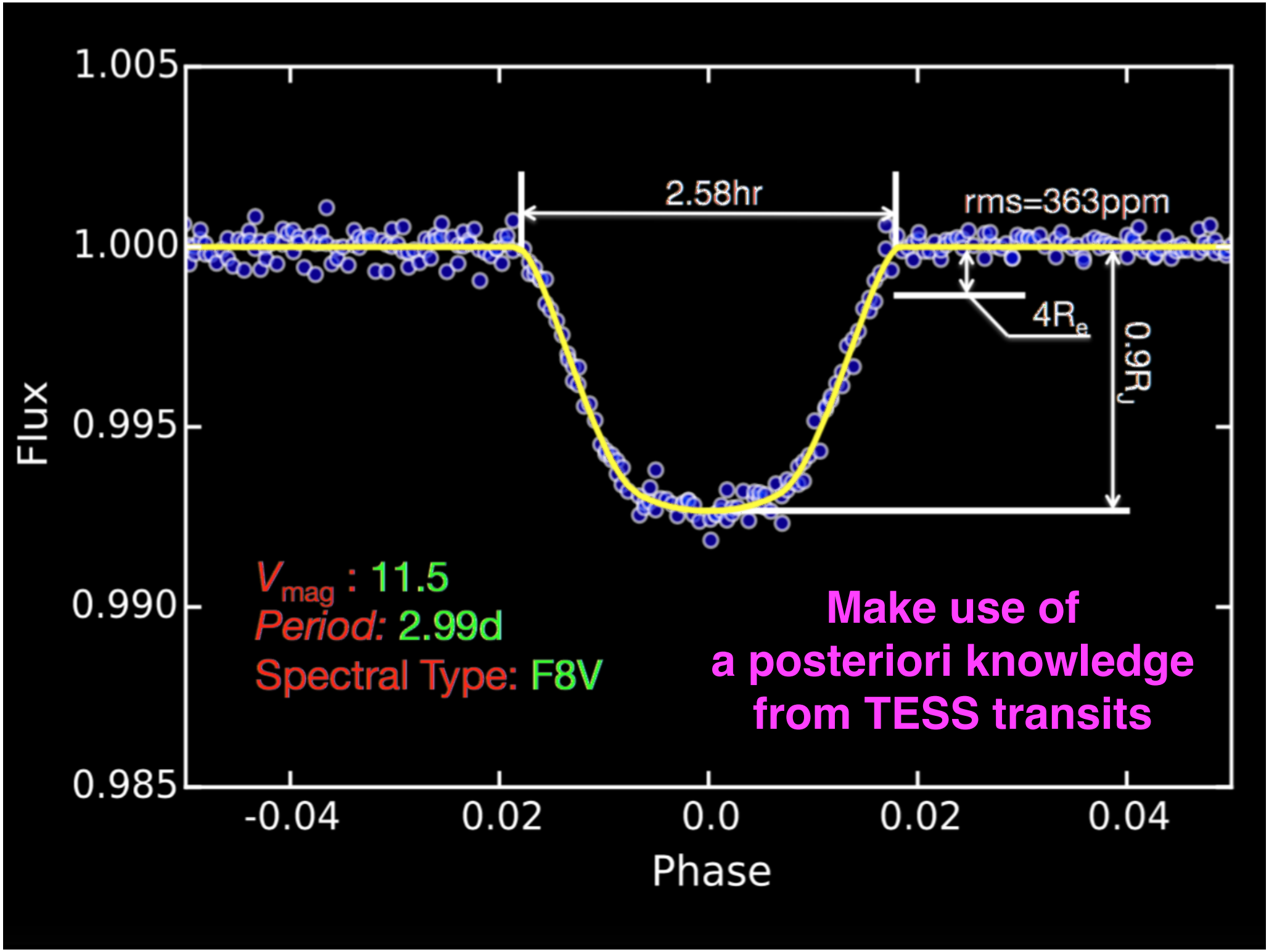
APF observing

See Burt et al. 2015

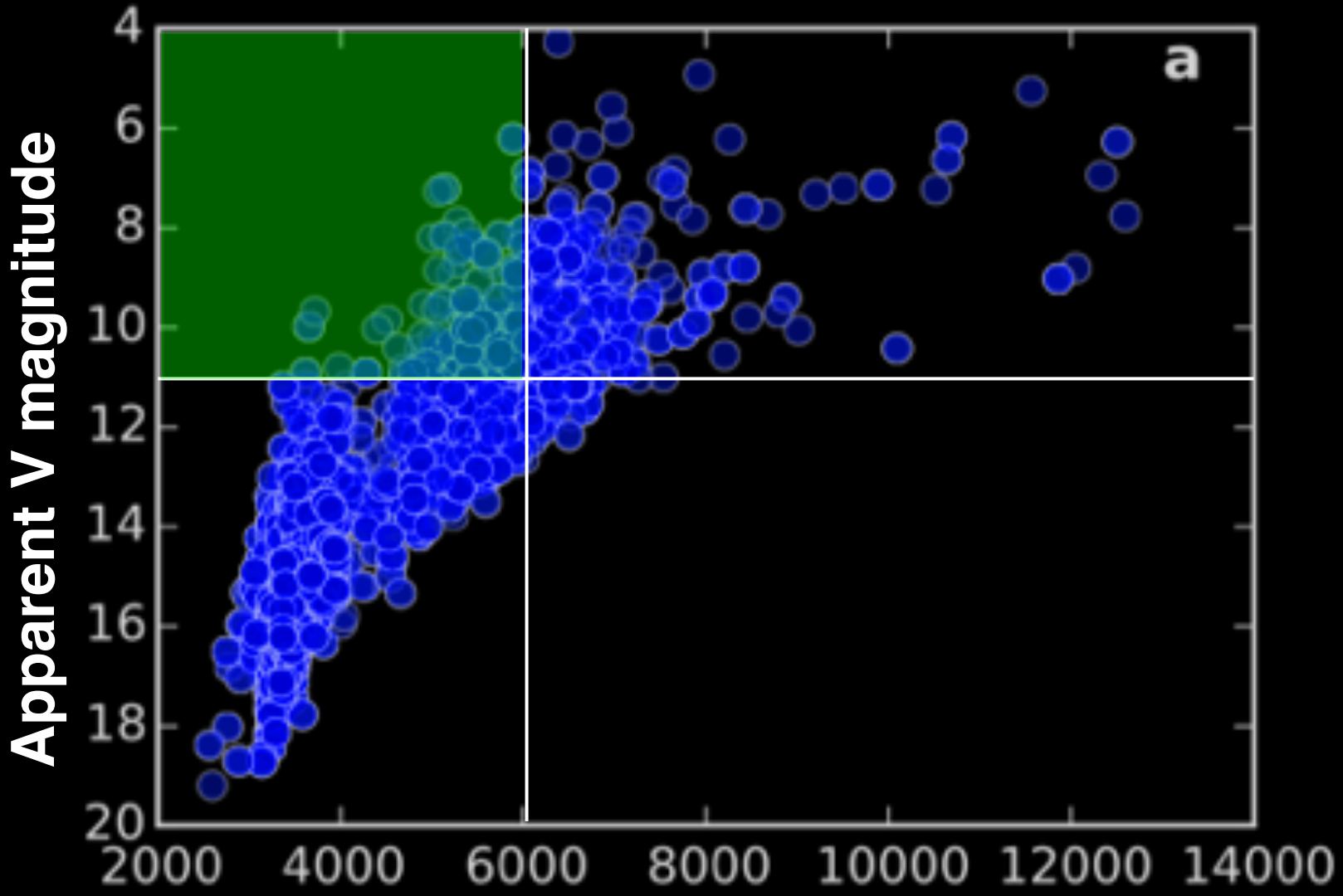

Confirmed exoplanets
Planet Radius [Earth radii]
10^1
10^0
10^0
10^1
10^2
10^3
Orbital Period [days]
Results from NexSCI
Exoplanet archive


Confirmed exoplanets
Measured masses
Planet Radius [Earth radii]
10^1
10^0
10^0
10^1
10^2
10^3
Orbital Period [days]
Results from NexSCI
Exoplanet archive

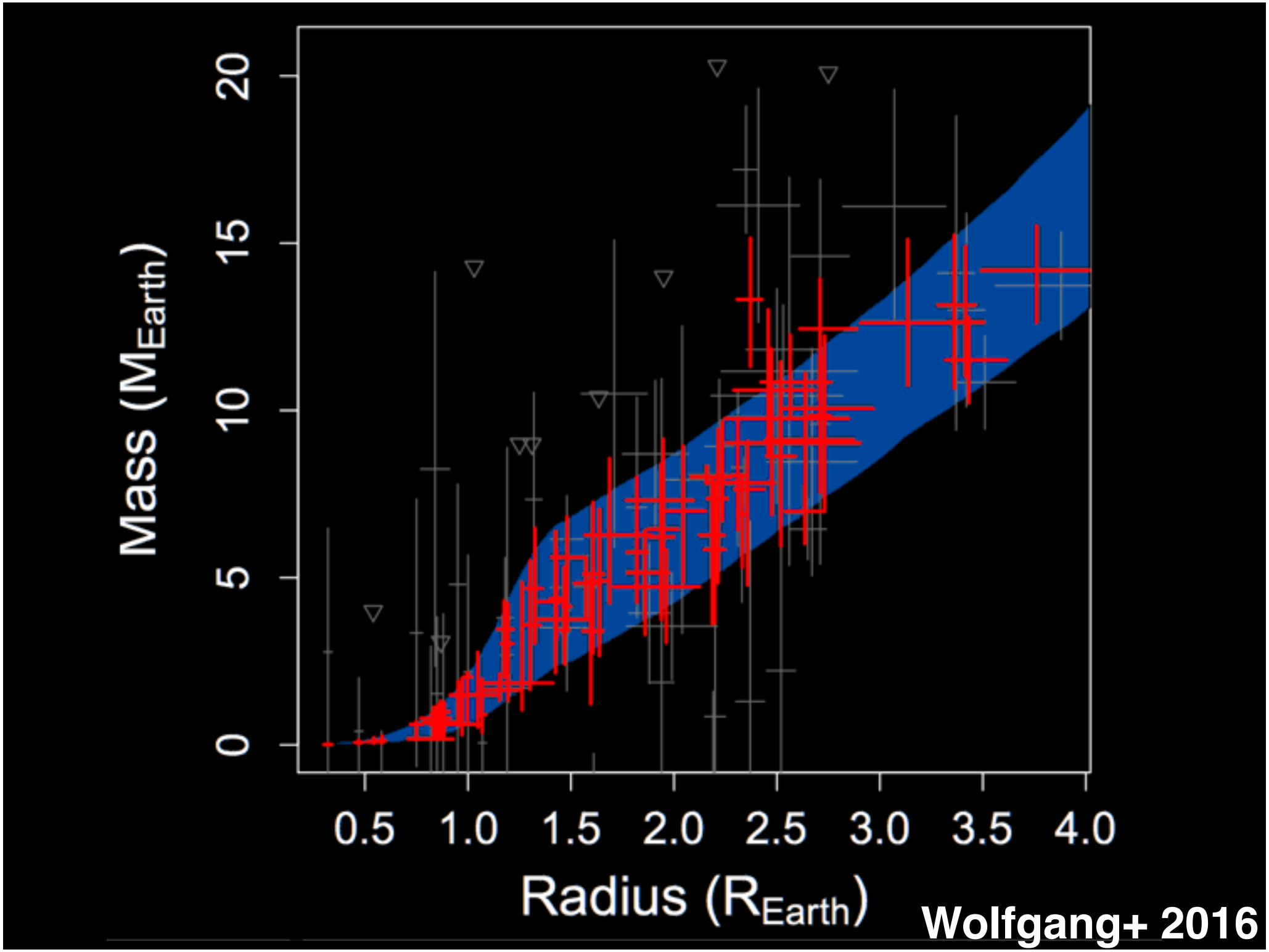

Confirmed exoplanets
Measured masses
Sullivan TESS simulation
Planet Radius [Earth radii]
10^1
10^0
10^0
10^1
10^2
10^3
Orbital Period [days]
Results from NexSCI
Exoplanet archive

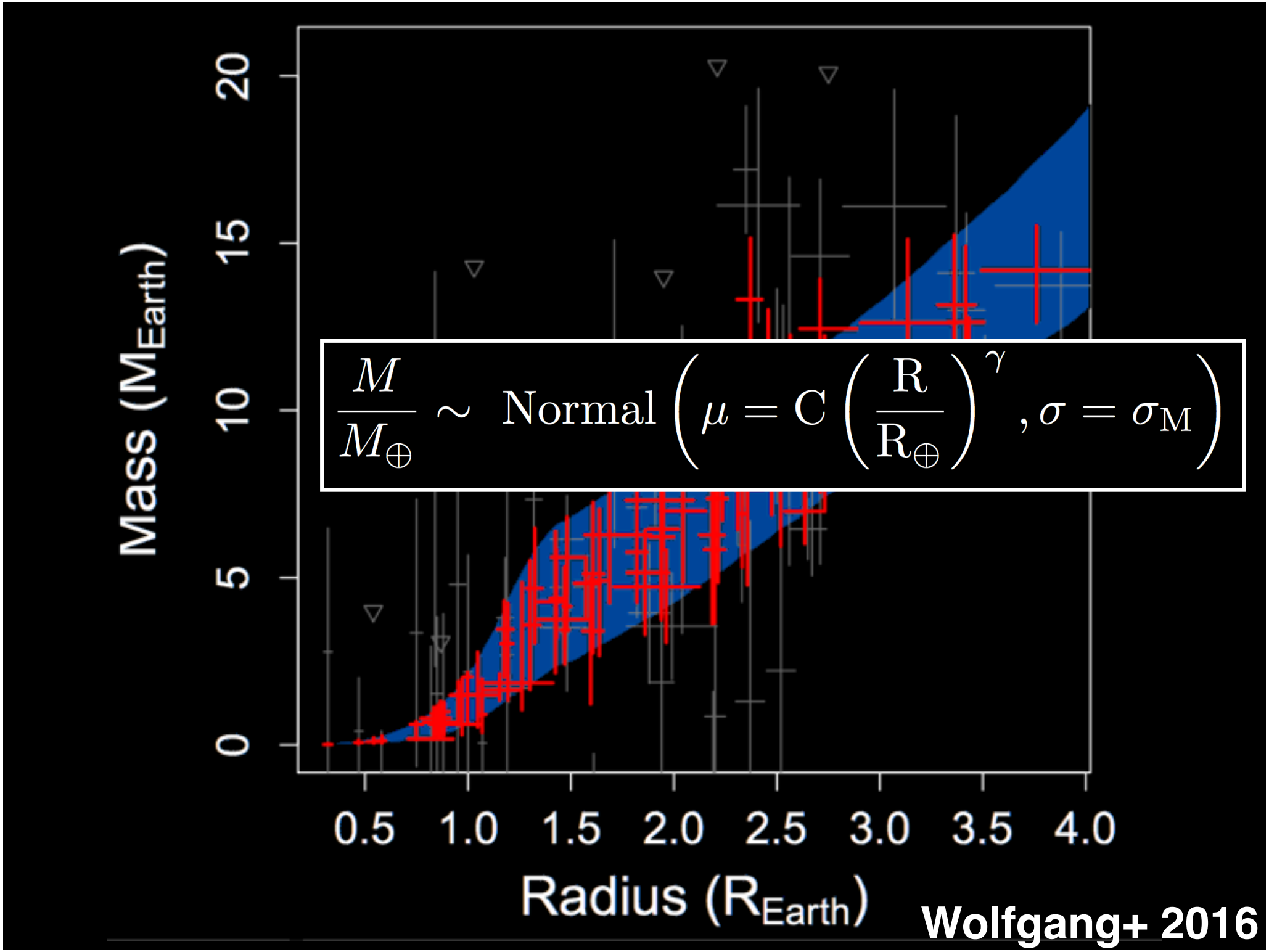

1.005
1.000
0.995
0.990
0.985
Flux
-0.04
0.02
0.0
0.02
0.04
Phase
2.58hr
rms=363ppm
4R_e
0.9R_J
V_mag : 11.5
Period: 2.99d
Spectral Type: F8V
Make use of
a posteriori knowledge
from TESS transits

Simulated TESS host stars



Burt+ 2018


Mass (M_{Earth})
0
5
10
15
20
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Radius (R_{Earth})
Wolfgang+ 2016


$\frac{M}{M_\oplus} \sim \text{Normal}\left(\mu = \text{C}\left(\frac{\text{R}}{\text{R}_\oplus}\right)^{\gamma}, \sigma = \sigma_\text{M}\right)$
Mass (M_{Earth})
0
5
10
15
20
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Radius (R_{Earth})
Wolfgang+ 2016

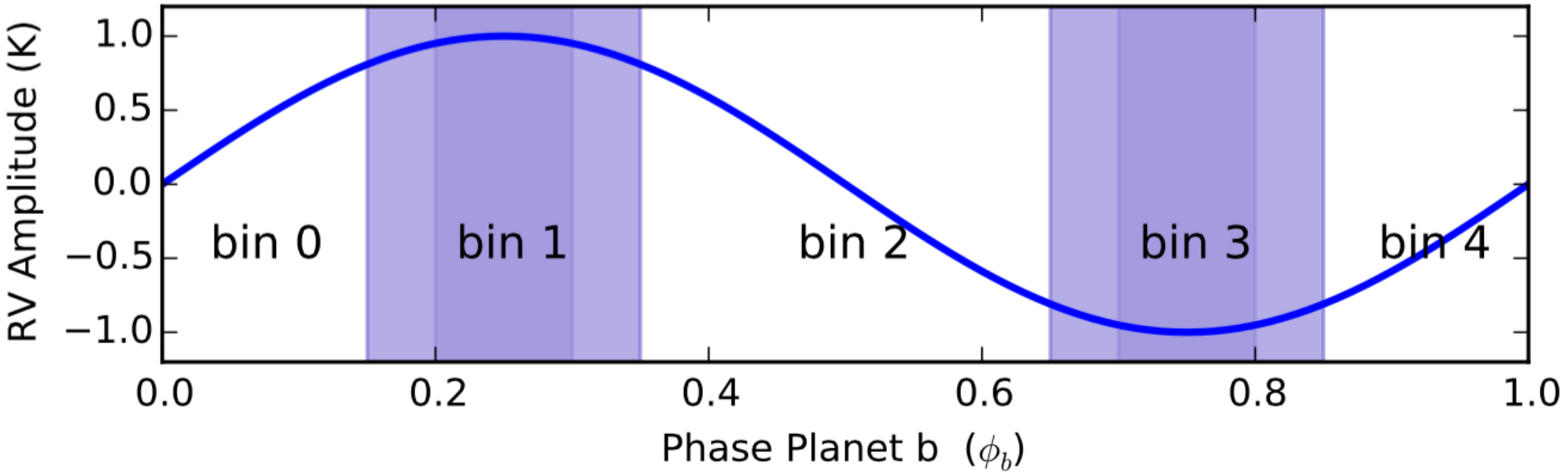
Simulating an RV survey

- 3 year simulated APF survey, beginning after TESS looks at northern hemisphere
- 40% of the telescope's time in whole night segments
- Models seeing/weather based on previous years of data

Simulating an RV survey

Time varying prioritization schemes

- In quadrature
- Uniform
- Out of quadrature
- Random



Calculating RV values

Instantaneous true RV for star
noise signature for star
internal uncertainty
\+ instrumental noise floor

Final RV value for that observation

Stellar Activity

Isaacson & Fischer 2010

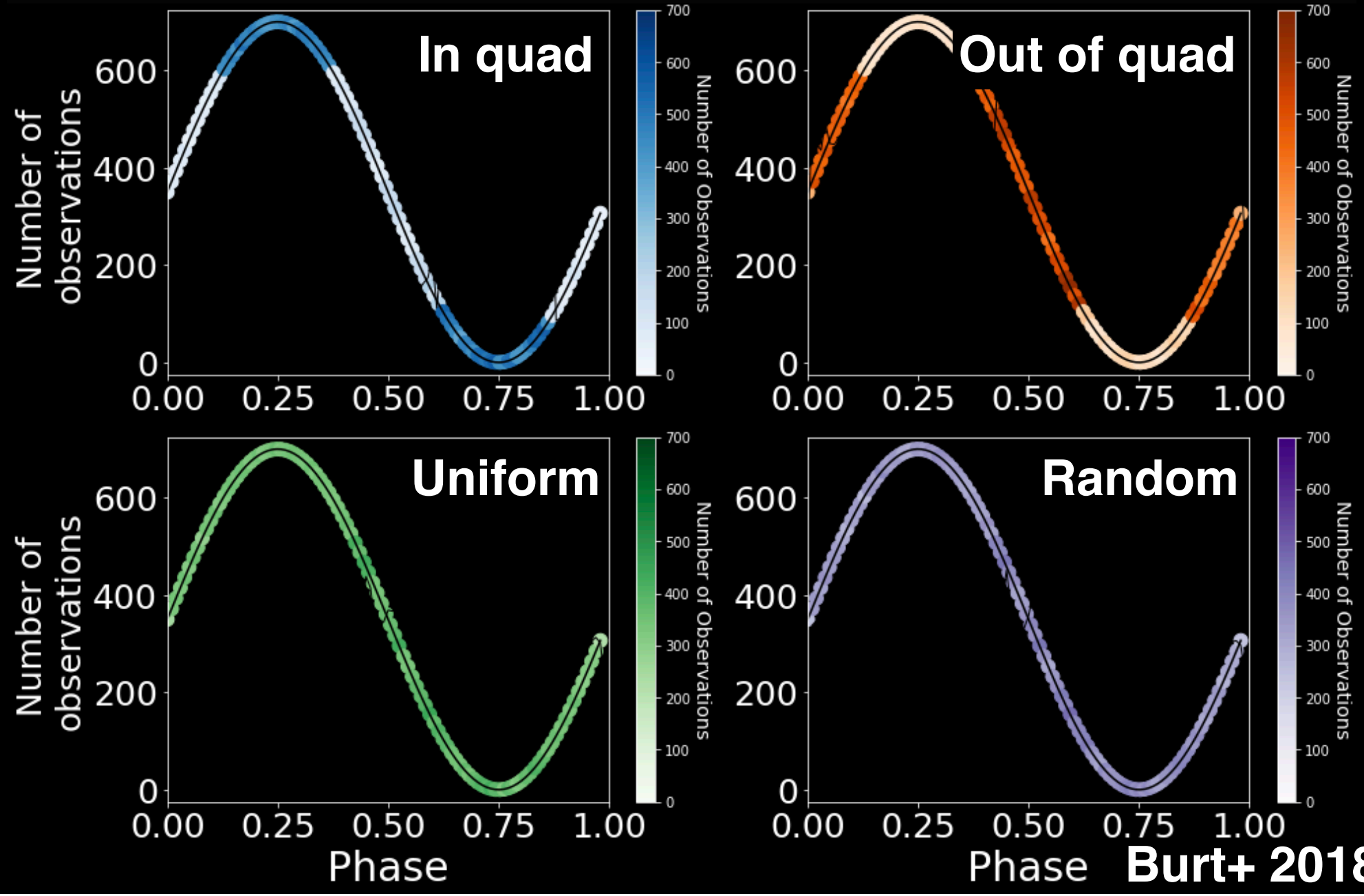
periodic signal
5-15 min

$$\sigma_{star} = \sqrt{\sigma^2_{jitter} + \sigma^2_{puls} + \sigma^2_{rot}}$$

random value
normal distribution

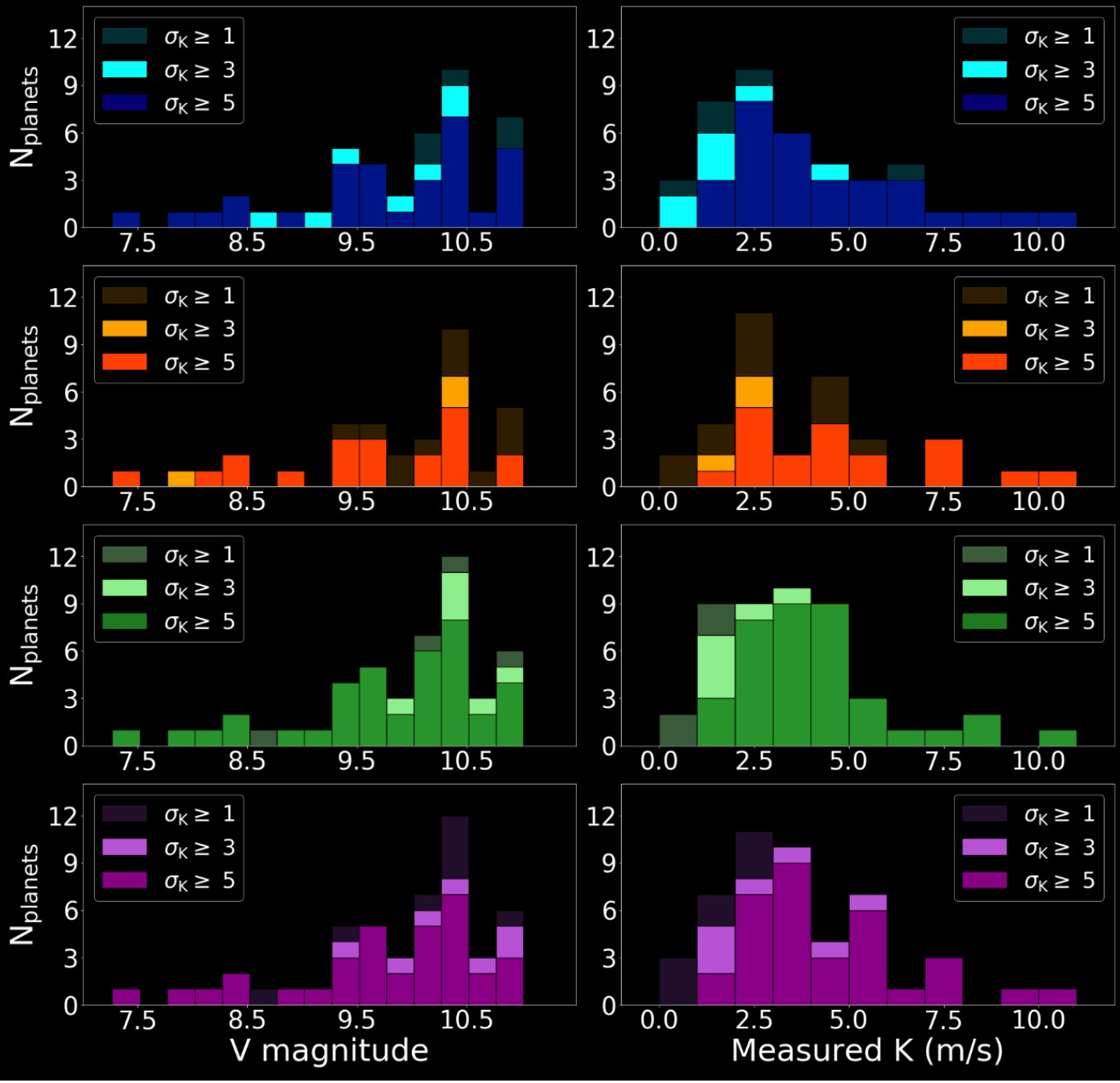
periodic signal
20-40 days

Phase Coverage

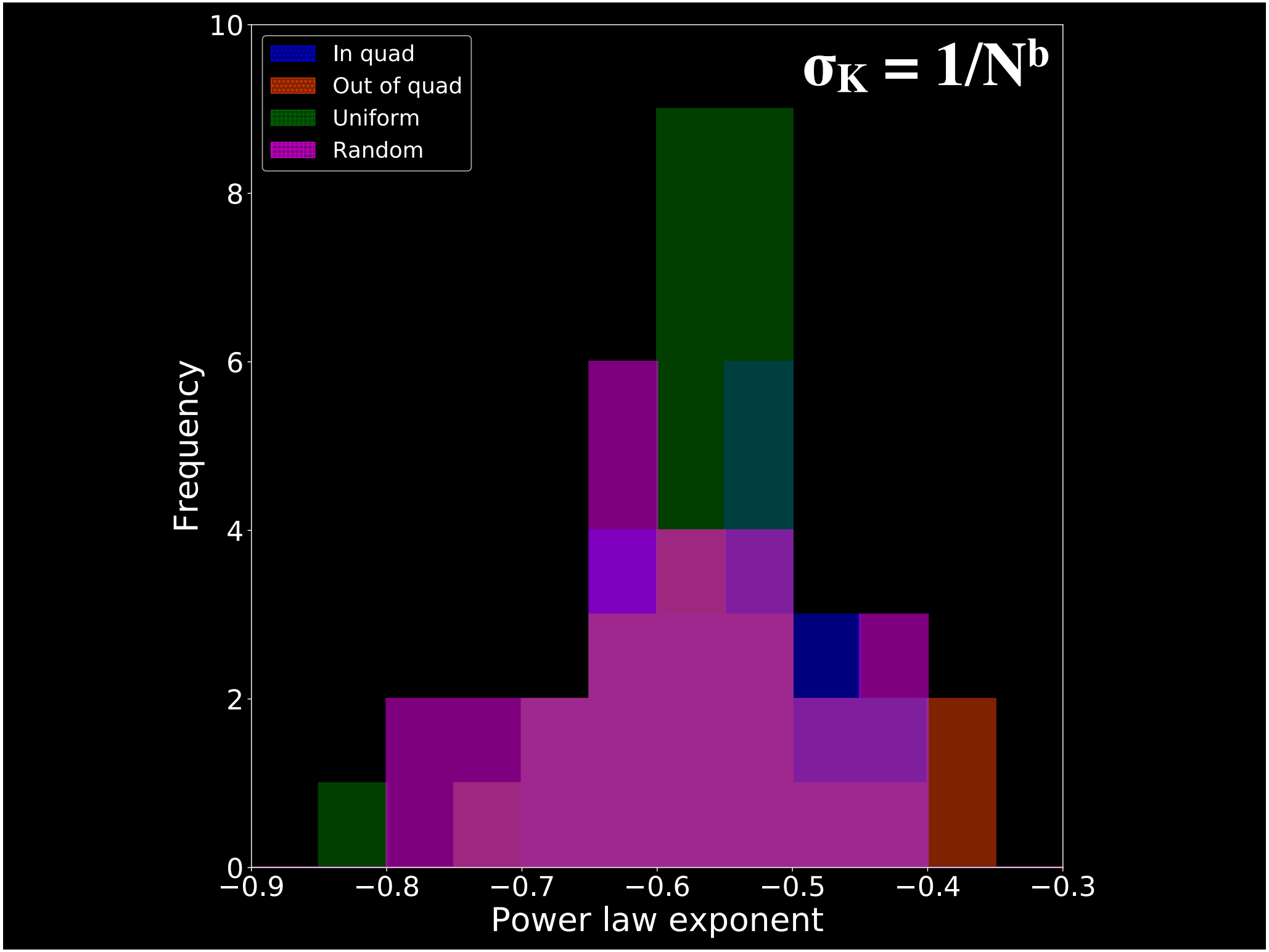


Burt+ 2018

Mass measurements



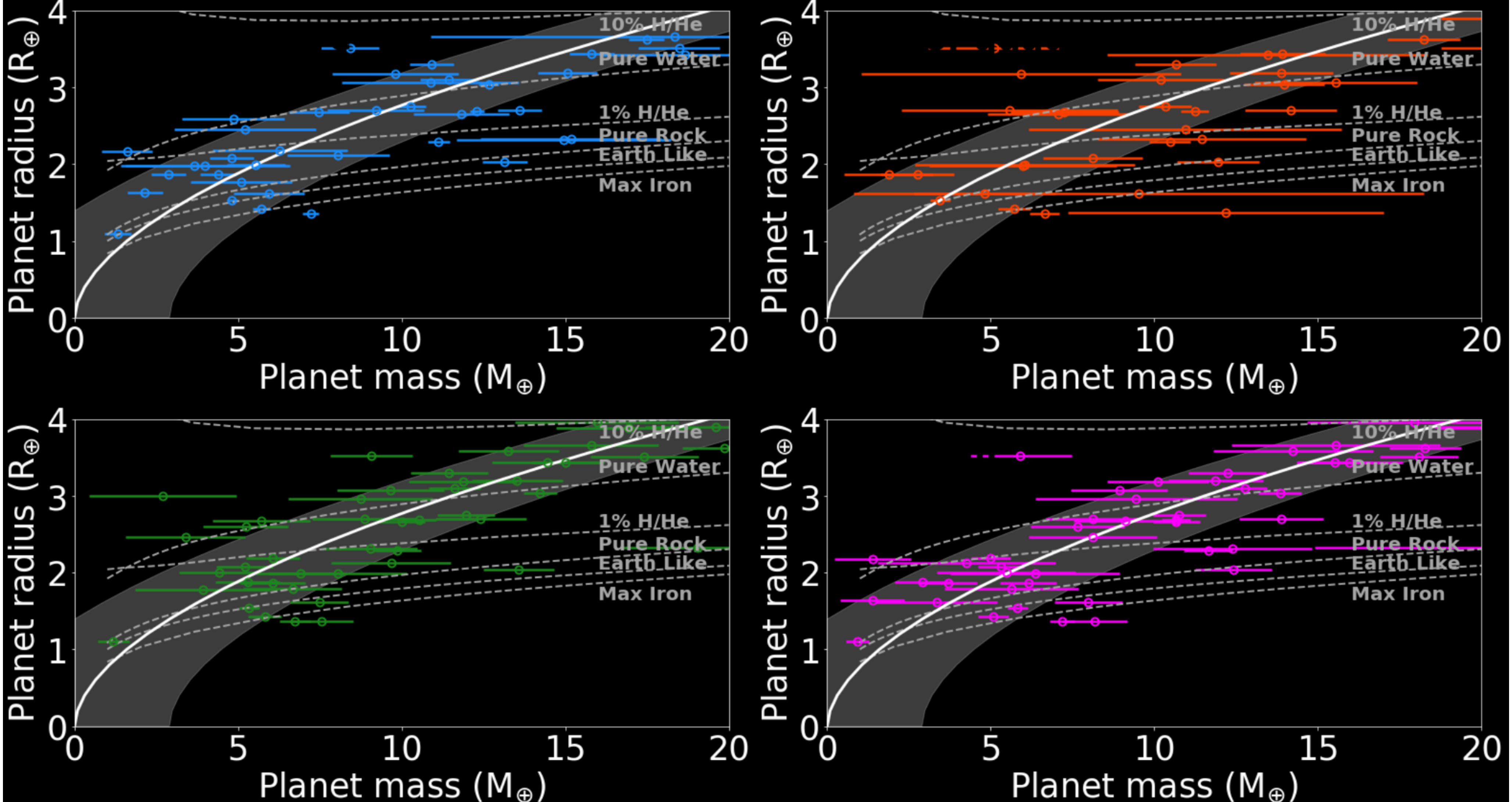
Burt+ 2018


In quad
Out of quad
Uniform
Random
$\sigma_K = 1/N^b$
Frequency
Power law exponent
0
2
4
6
8
10
−0.9
−0.8
−0.7
−0.6
−0.5
−0.4
−0.3

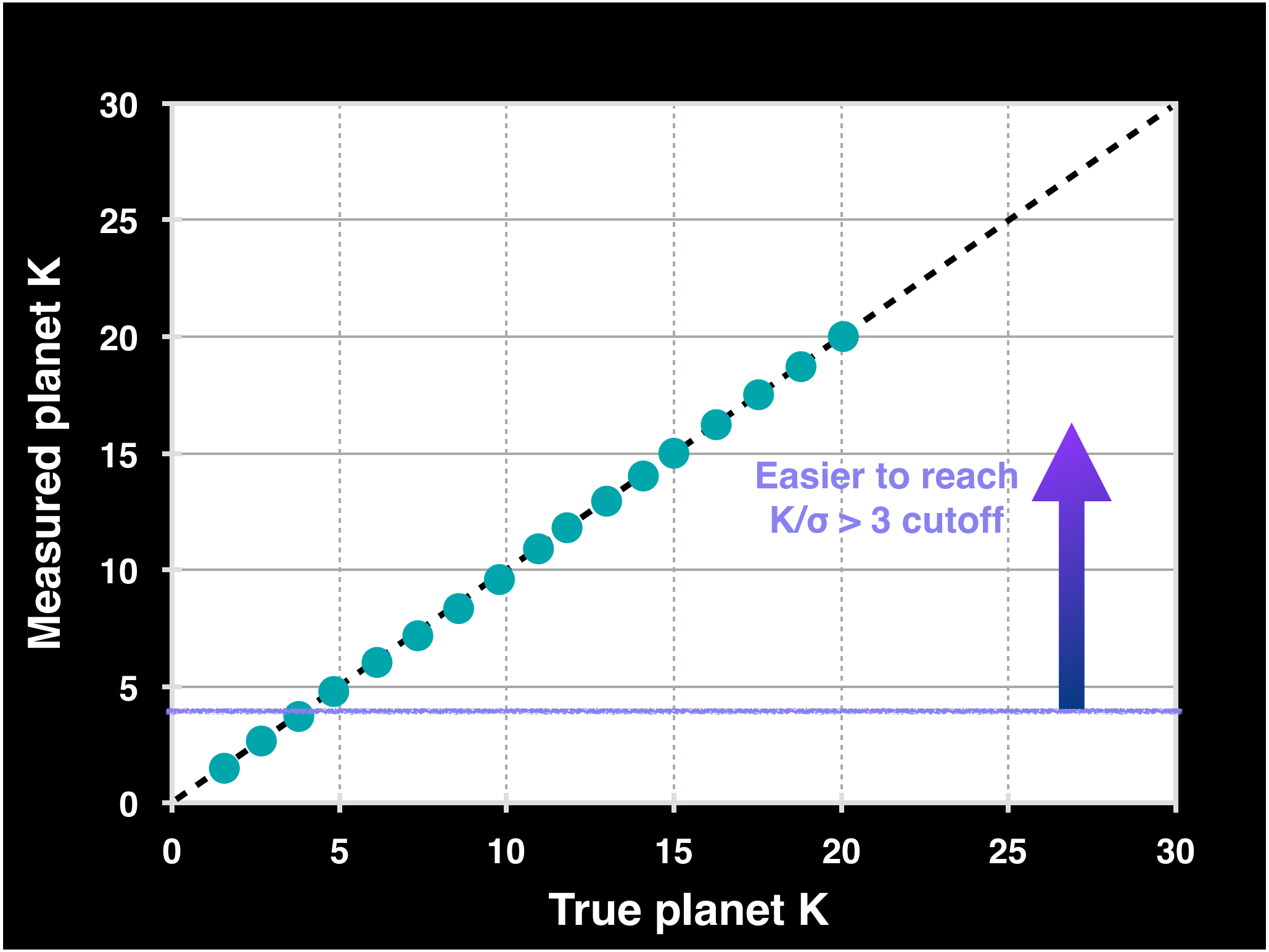
Uniform and random observing schemes perform the best in terms of the number of measured planet masses.

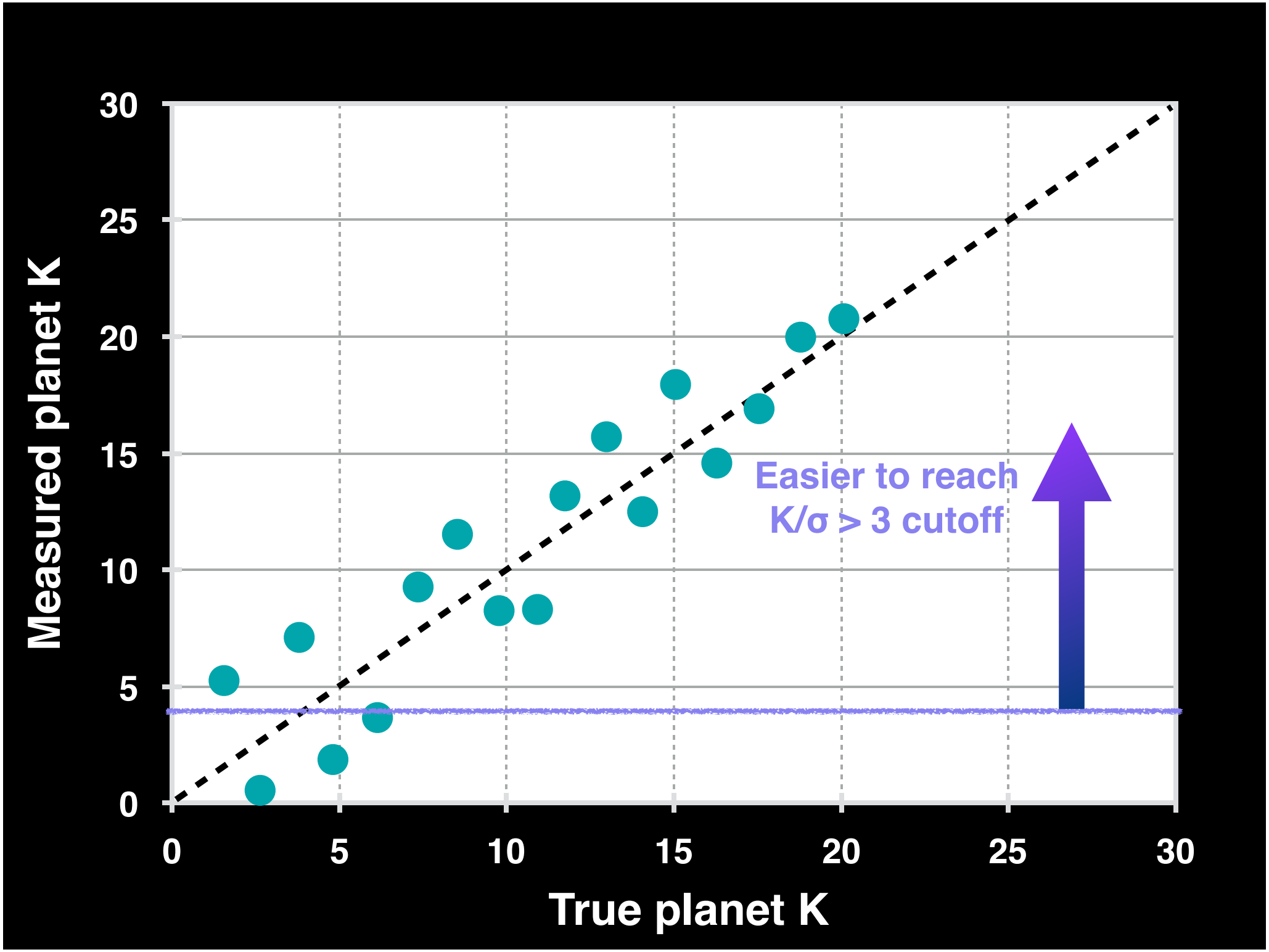
No observing scheme reaches higher semi-amplitude significance values (K/σ_K) significantly faster than the others.

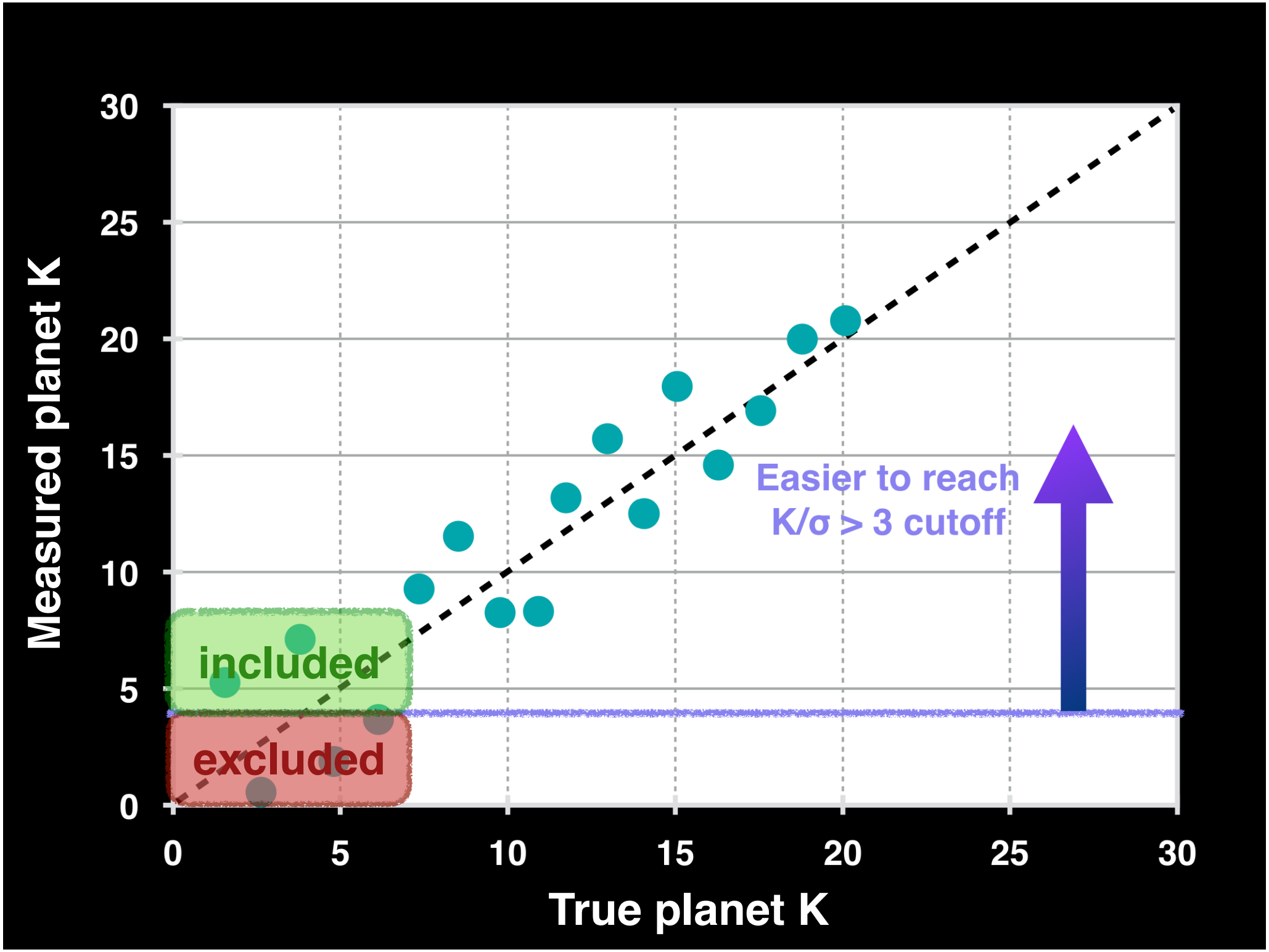
Additions to the M-R diagram

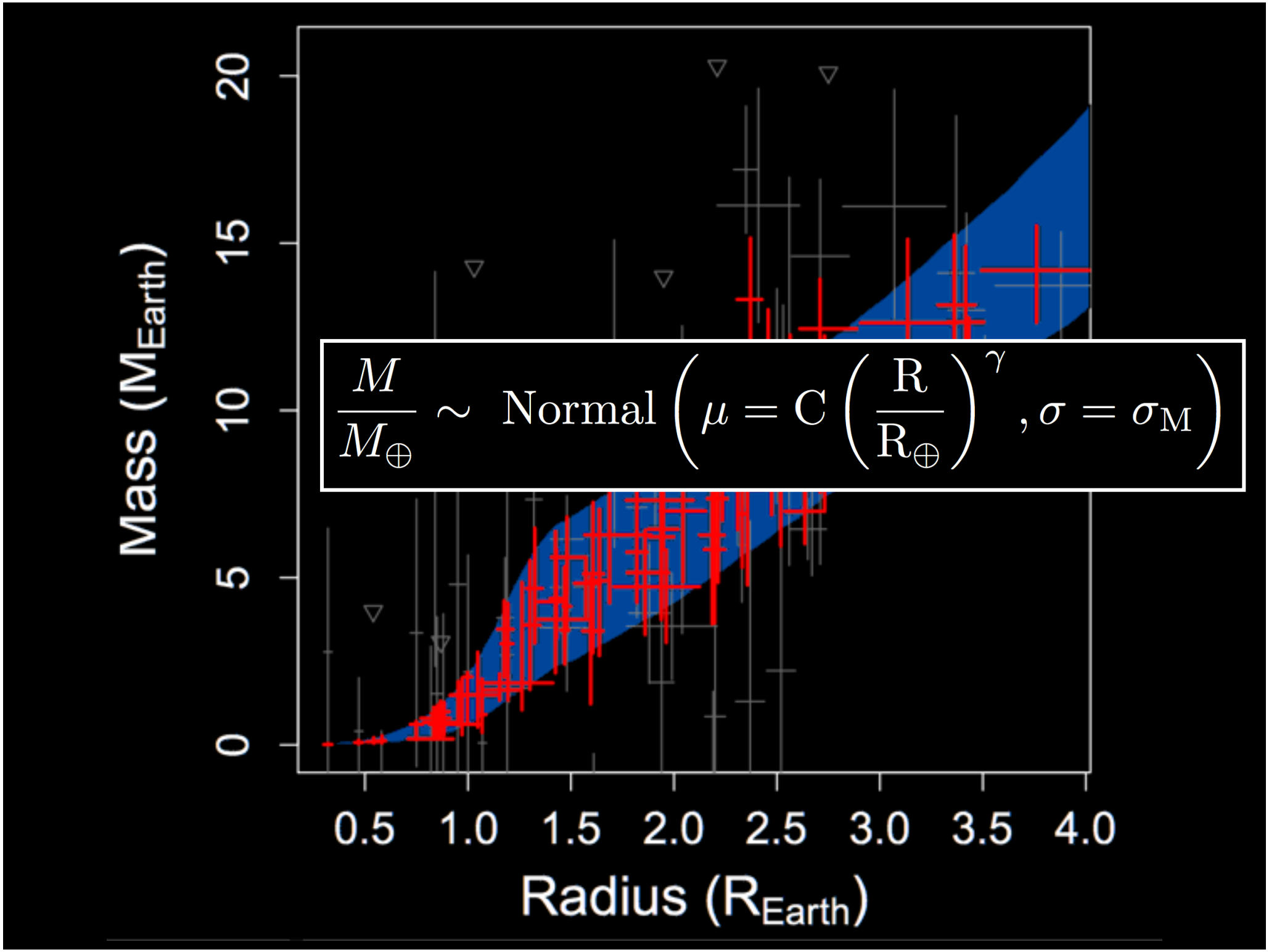


Burt+ 2018


30
25
20
15
10
5
0
Measured planet K
0
5
10
15
20
25
30
True planet K
Easier to reach
K/σ > 3 cutoff


Measured planet K
True planet K
0
5
10
15
20
25
30
Easier to reach
K/σ > 3 cutoff


Measured planet K
True planet K
0
5
10
15
20
25
30
included
excluded
Easier to reach
K/σ > 3 cutoff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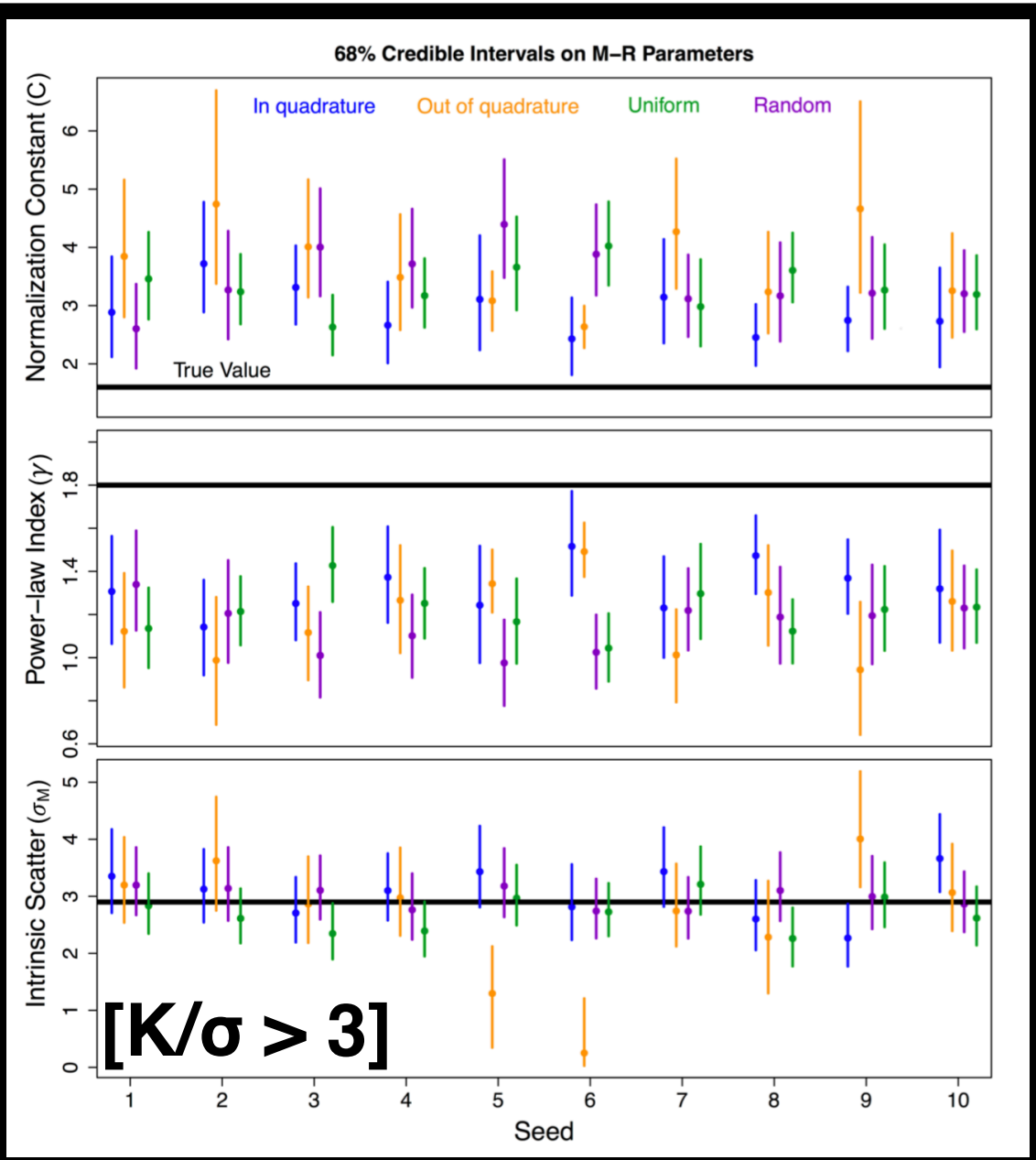
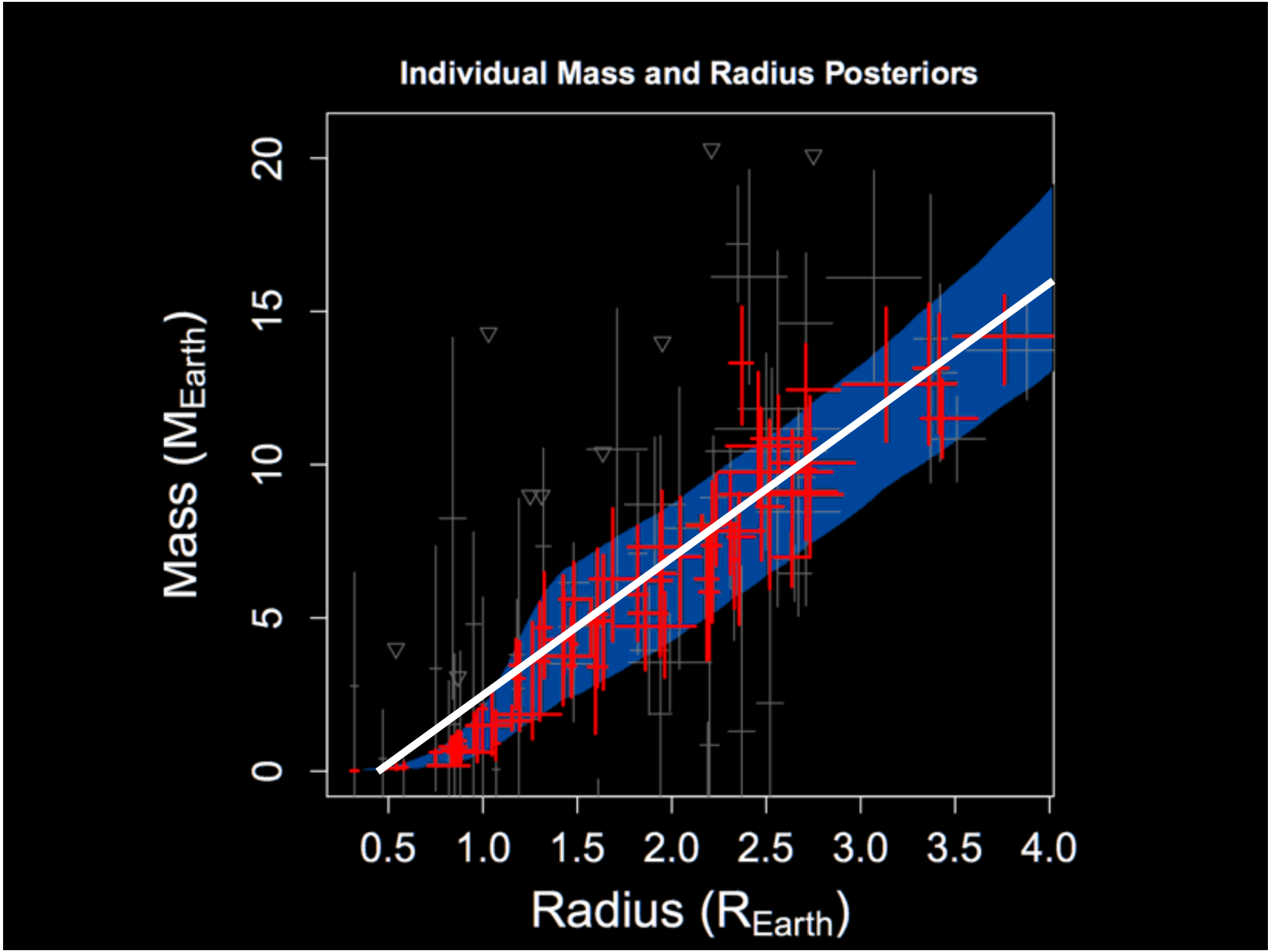
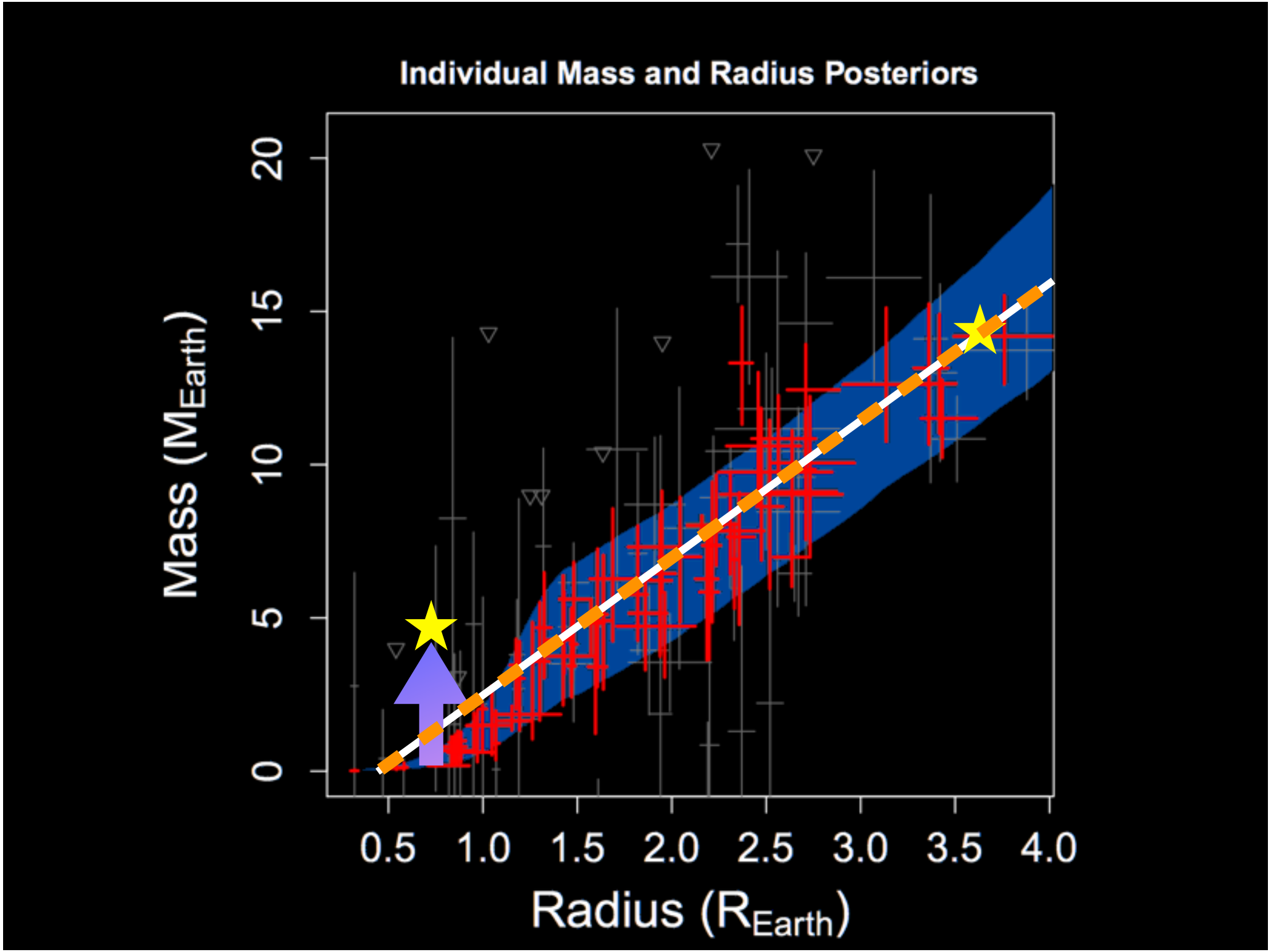
Radius (R_{Earth})

$$\frac{M}{M_\oplus} \sim \text{Normal}\left(\mu = \text{C}\left(\frac{\text{R}}{\text{R}_\oplus}\right)^{\gamma}, \sigma = \sigma_{\text{M}}\right)$$



Burt+ 2018


Individual Mass and Radius Posteriors
Mass (M_{Earth})
0
5
10
15
20
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Radius (R_{Earth})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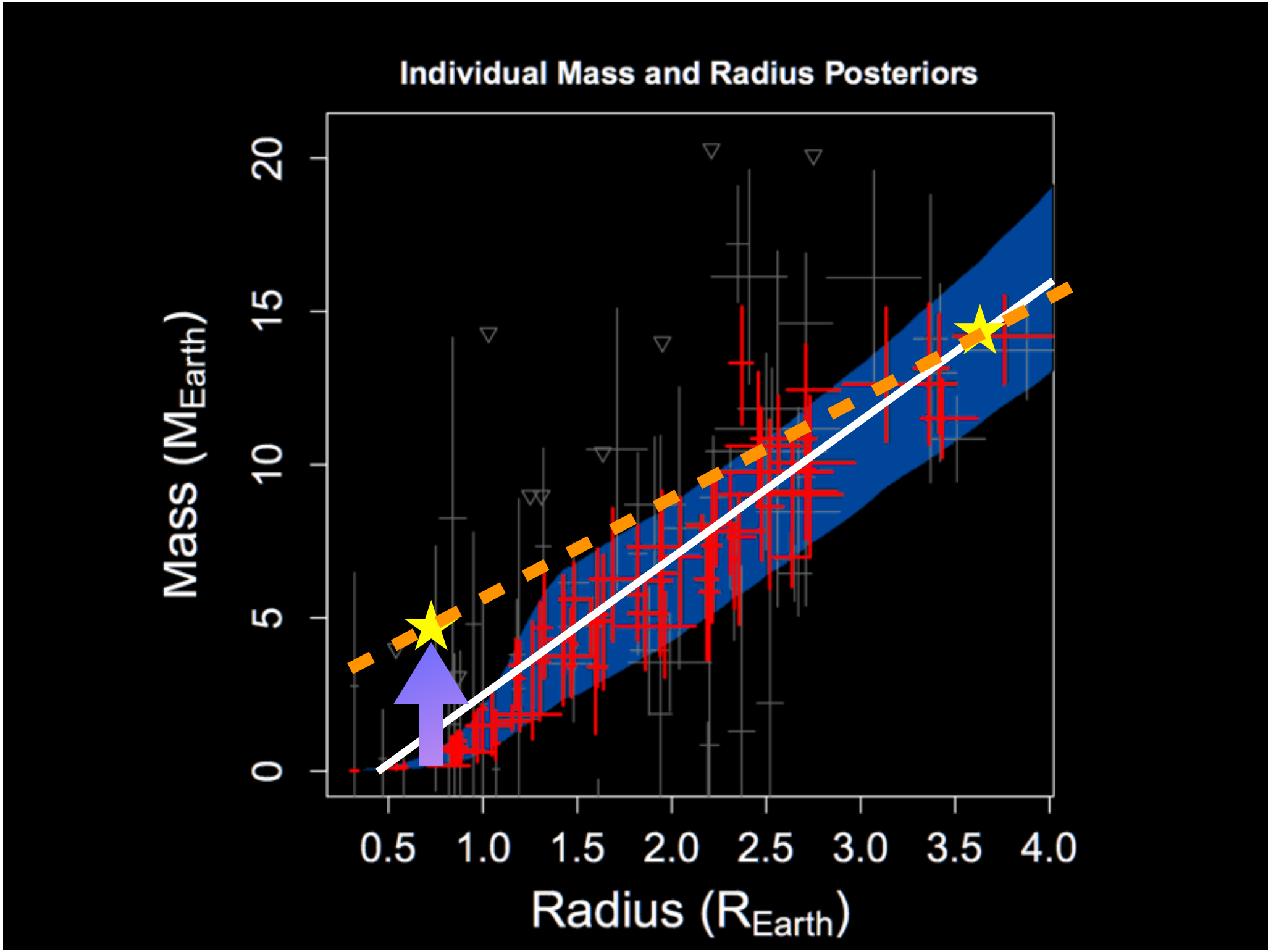
Radius (R_{Earth})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1.5
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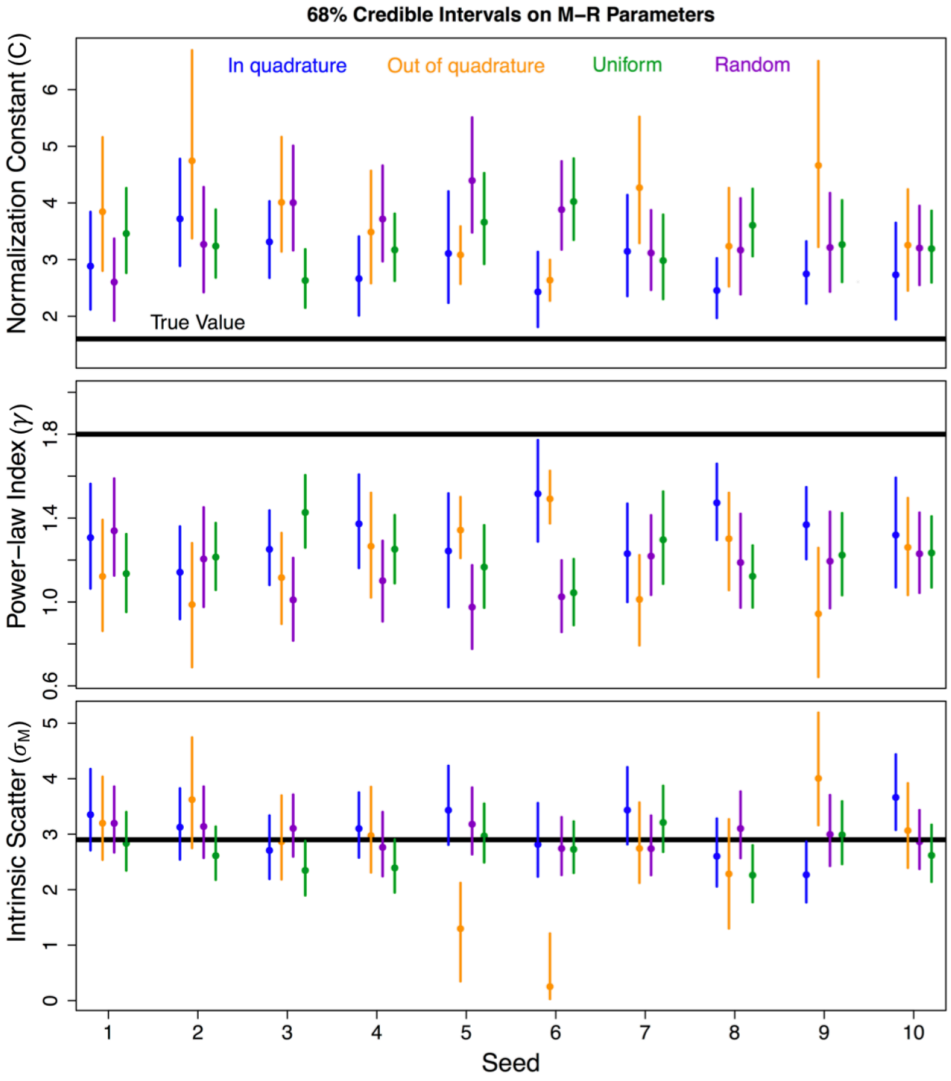
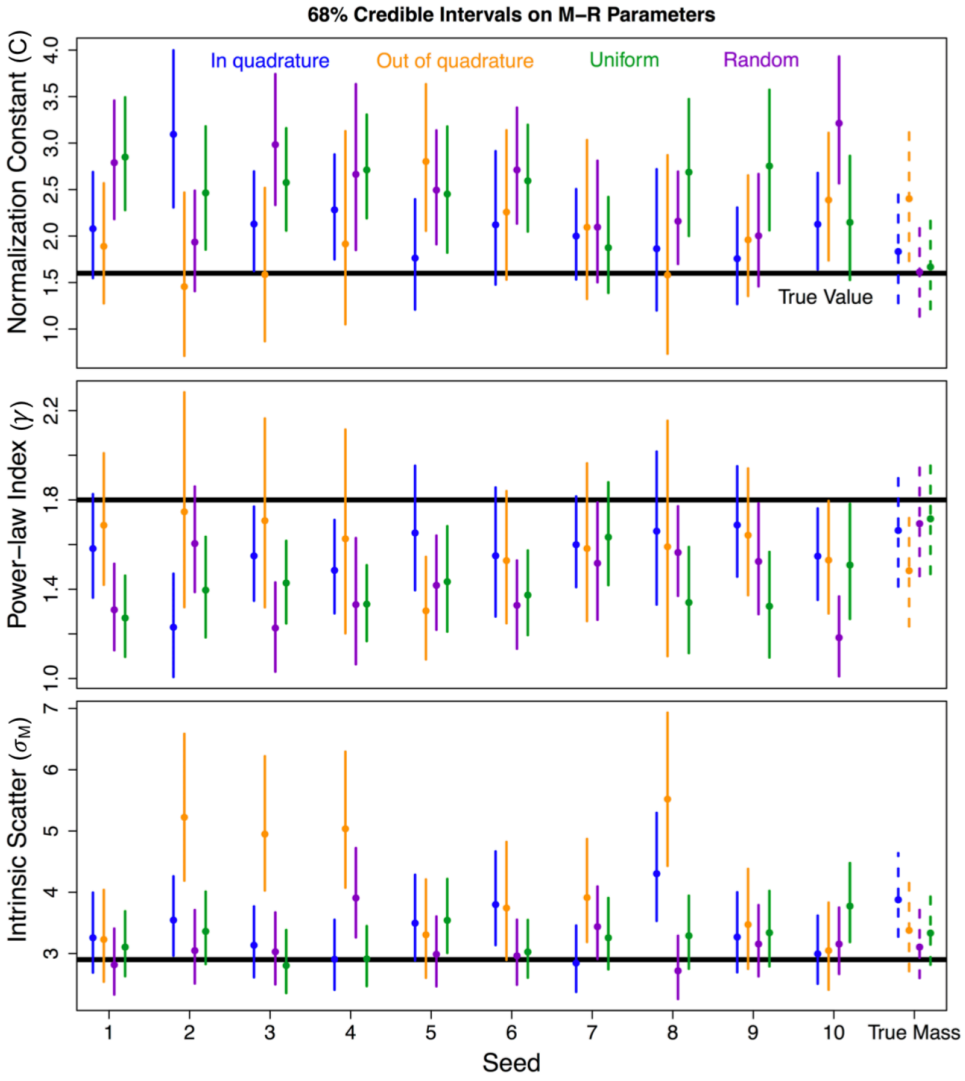
3.5
4.0
Radius (R_{Earth})

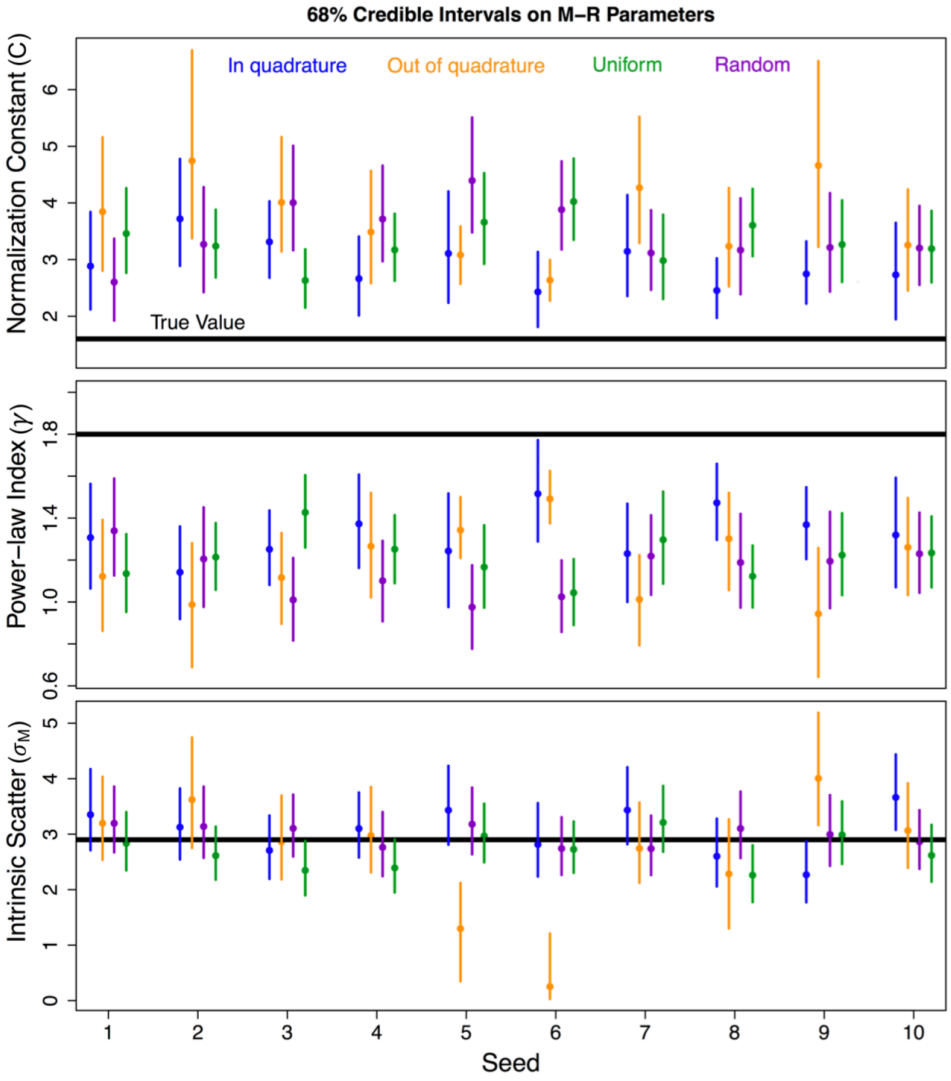


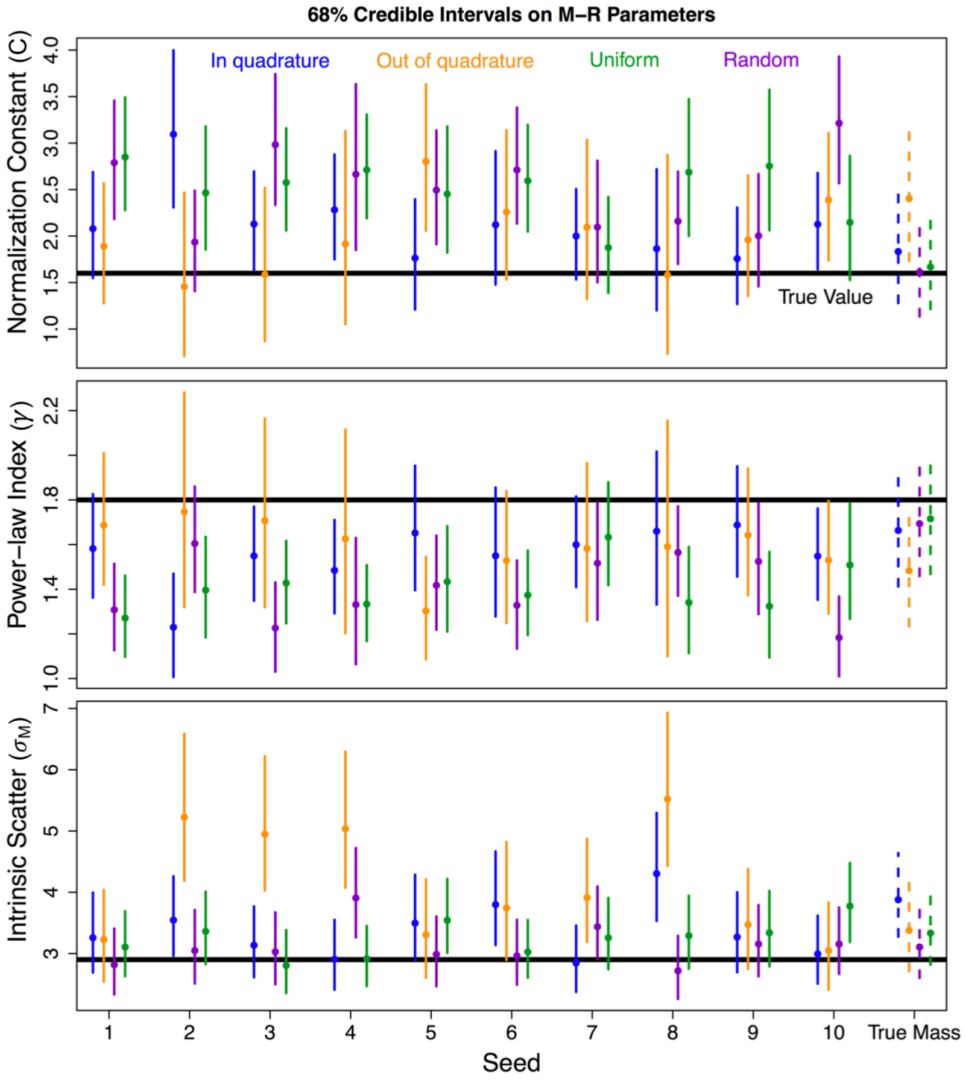


[K/σ > 3]

No cut

Burt+ 2018





[K/σ > 3]

No cut

Burt+ 2018

Groups who aim to analyze empirical mass-radius distributions produced by RV followup should include mass measurements of **all planets** in their sample. Performing population analyses with significance cuts will consistently produce biased results in the extracted M–R relation.

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