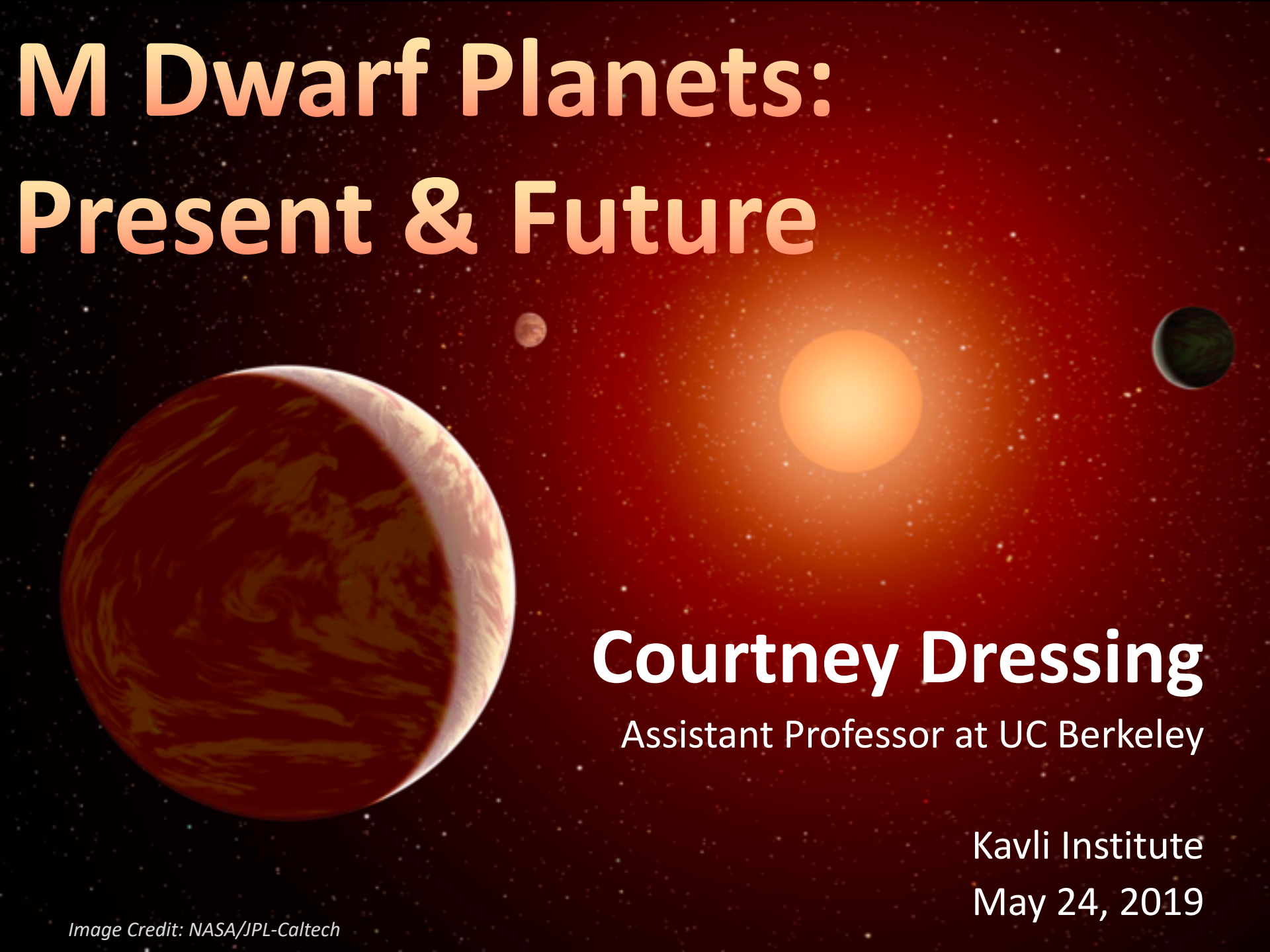
M Dwarf Planets: Present & Future



Courtney Dressing

Assistant Professor at UC Berkeley

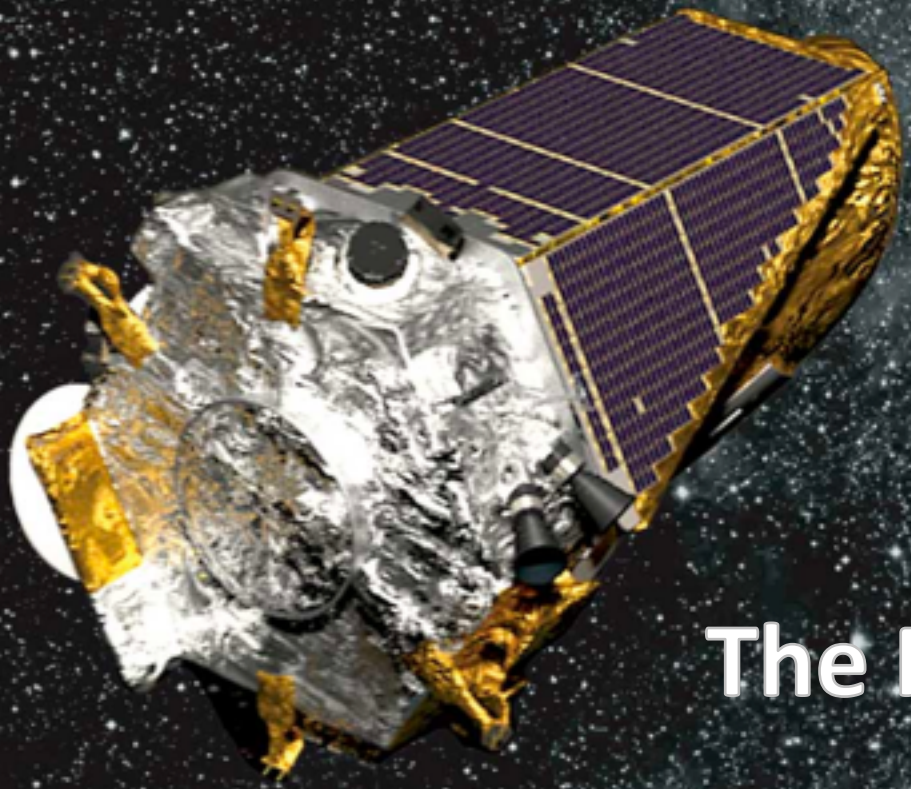
Kavli Institute

May 24, 2019

Image Credit: NASA/JPL-Caltech

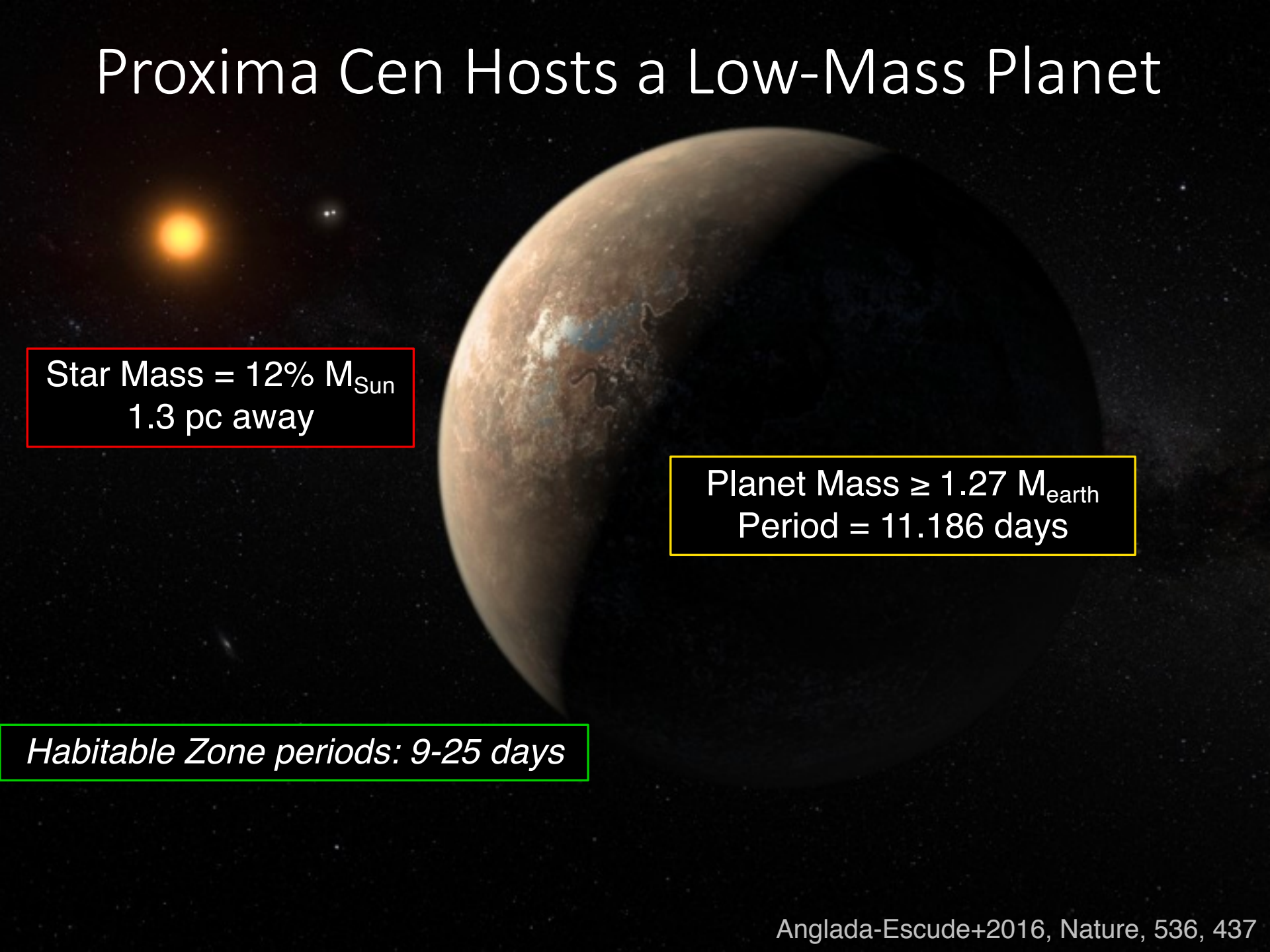
THE PAST

2285 Confirmed Planets
1792 Candidate Planets



The NASA *Kepler* Mission
2009 - 2013

Proxima Cen Hosts a Low-Mass Planet



Star Mass = 12% M_{Sun}
1.3 pc away

Planet Mass ≥ 1.27 M_{earth}
Period = 11.186 days

Habitable Zone periods: 9-25 days

Anglada-Escude+2016, Nature, 536, 437

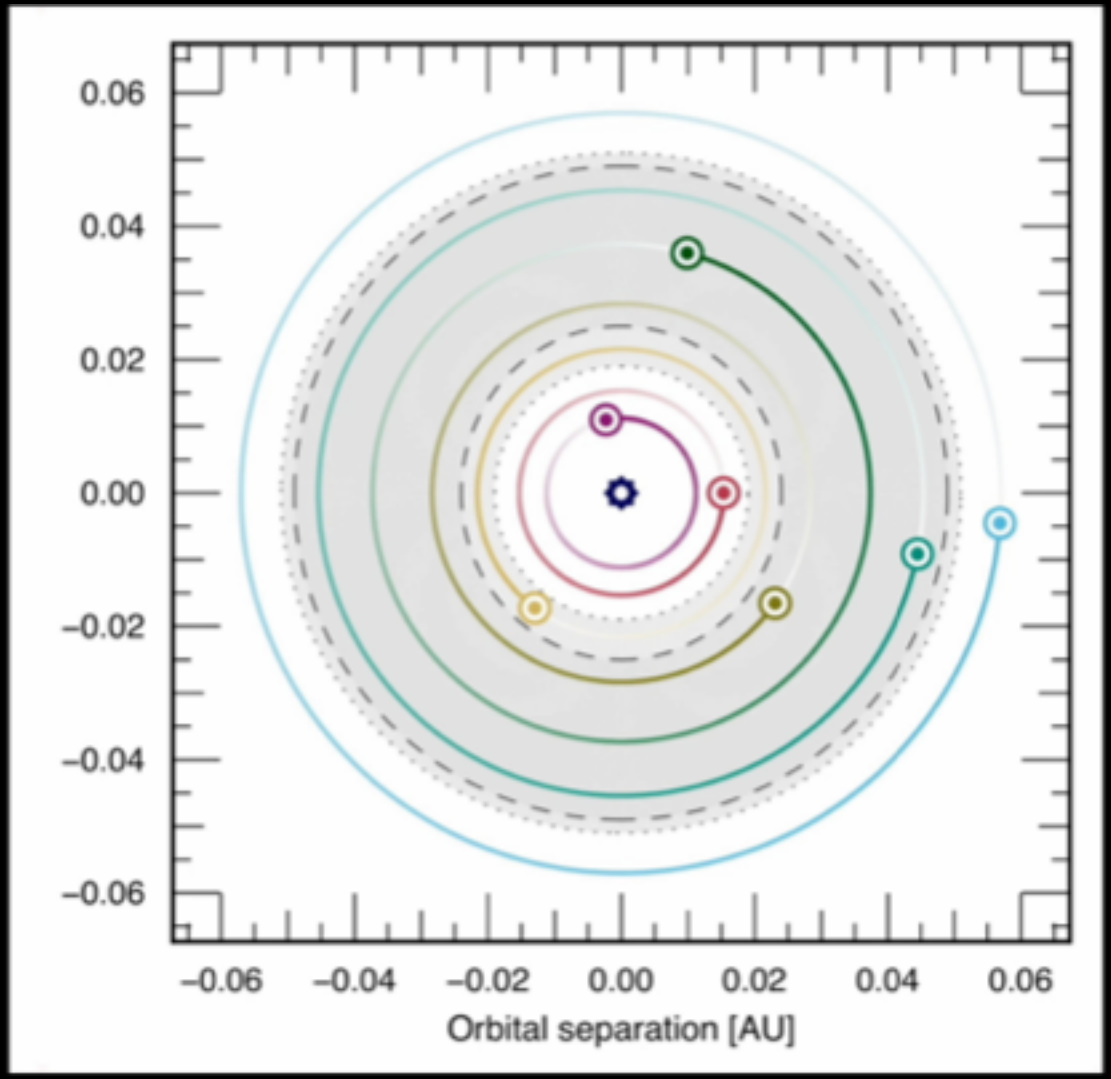
TRAPPIST-1 hosts 7 planets!

Planet b
1.5d
1.1R_{Earth}

Planet c
2.4d
1.1R_{Earth}

Planet d
4.0d
0.8R_{Earth}

Planet e
6.1d
0.9R_{Earth}



Planet f
9.2d
1.0R_{Earth}

Planet g
12.4d
1.1R_{Earth}

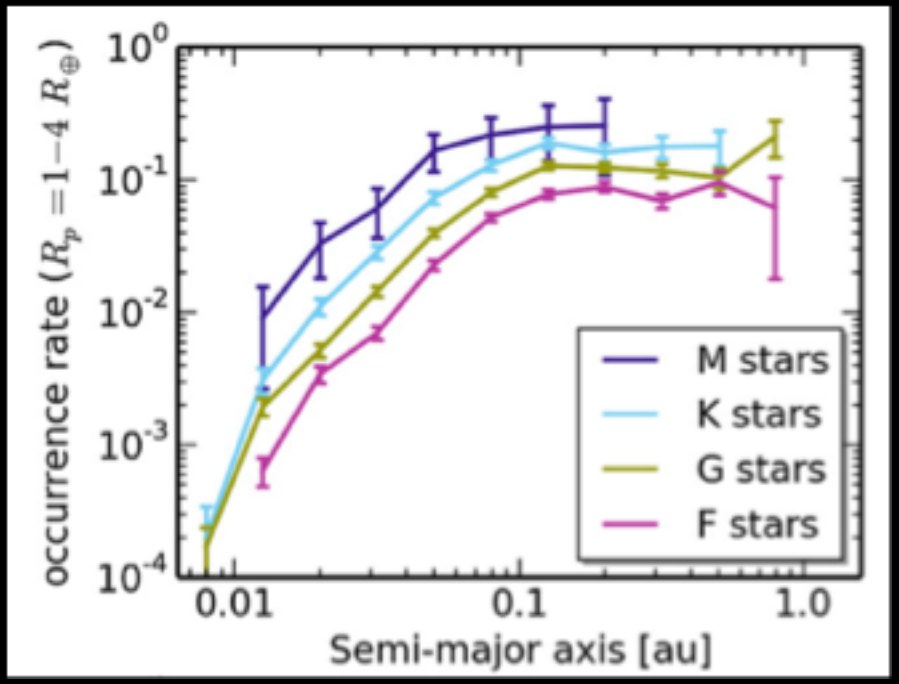
Planet h
18.8d
0.8R_{Earth}

Gillon+2016, 2017

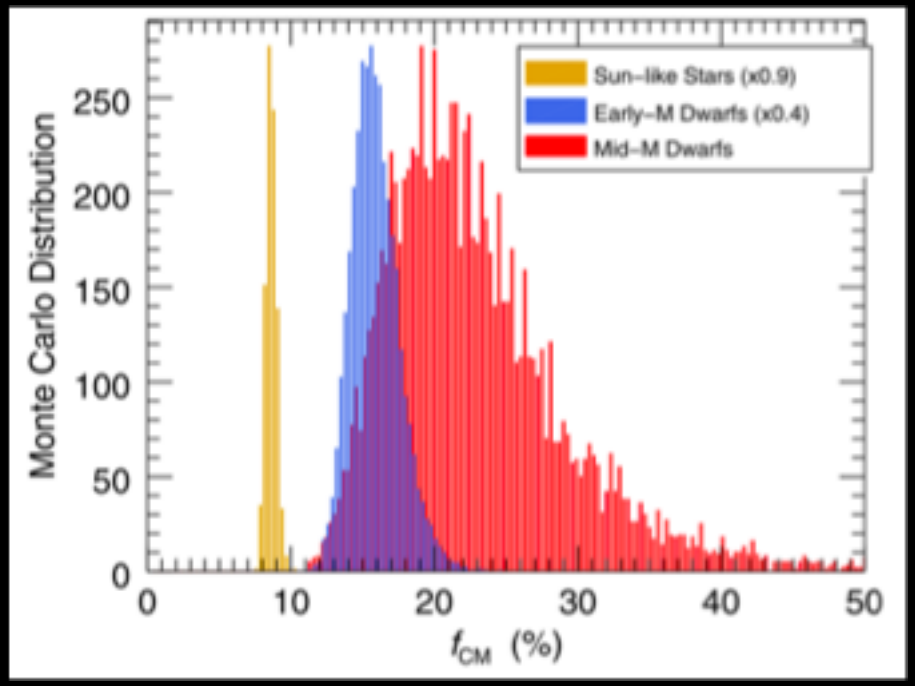
DO THE TINIEST STARS HAVE EVEN MORE CLOSE-IN PLANETS?

Initial Answer:

Yes, Smaller Stars Host More Close-in Planets



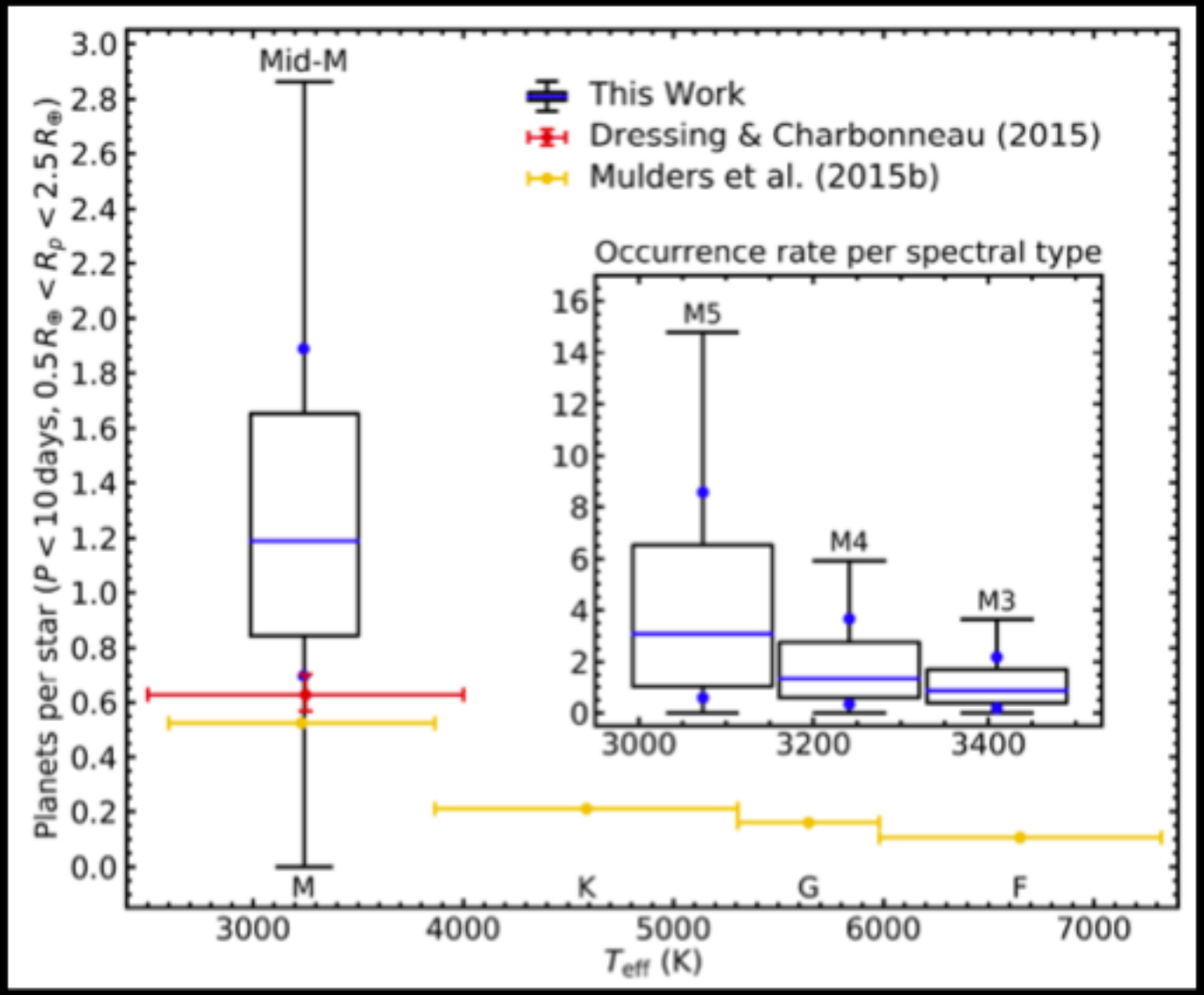
Mulders et al. (2015)



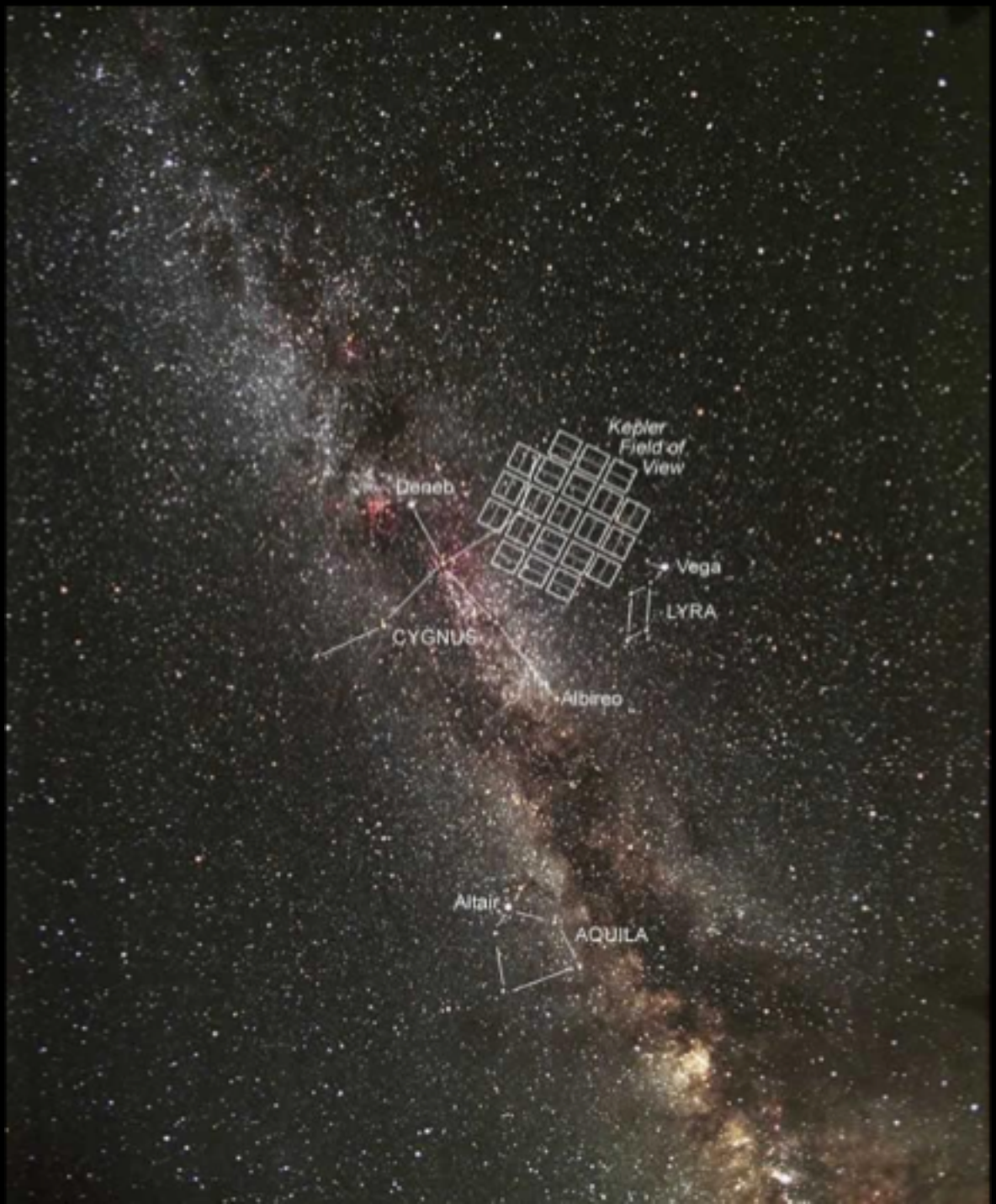
Muirhead et al. (2015)

Updated Answer:

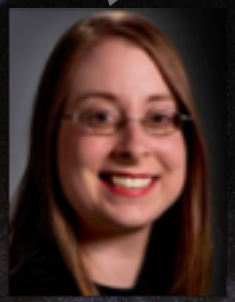
Still Yes! Smaller Stars Host More Close-in Planets



Hardegree-Ullman et al. 2019, arXiv: 1905.05900


Kepler
Field of
View
Deneb
Vega
LYRA
CYGNUS
Albireo
Altair
AQUILA

K2 Expanded the Census of Planets Orbiting Cool Dwarfs



Elianna Schwab Abrahams
(1st year)

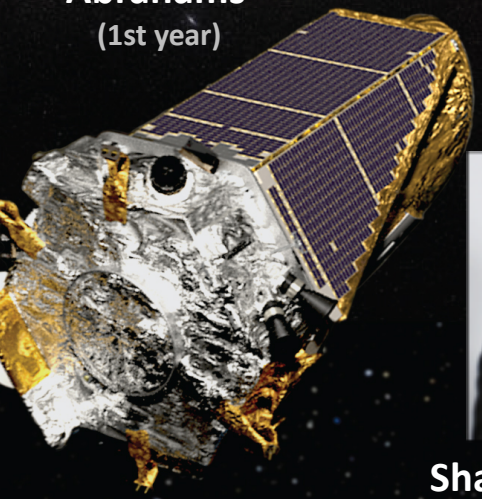
Alexander Ye
(junior)

41%

of K2 targets are small stars

(Huber et al. 2016)

…but many were poorly characterized!



Shashir & Shashank Dholakia
(sophomores)

Makena Fetzer
(junior)

Collaborators: Kevin Hardegree-Ullman, Joshua Schlieder, Elisabeth Newton, Andrew Vanderburg, Adina Feinstein, Girish Duvvuri, Lauren Arnold, Makennah Bristow, Beverly Thackeray, David Ciardi, Ian Crossfield, Liang Yu, Jessie Christiansen, Justin Crepp, Howard Isaacson, Heather Knutson, BJ Fulton, Erica Gonzales, Andrew Howard, Evan Sinukoff, Erik Petigura, John Livingston, Andrew Howard, Mark Evertt, Eliot Horch, Steve Howell

Characterizing Planetary Systems Orbiting Cool Dwarfs Observed by K2

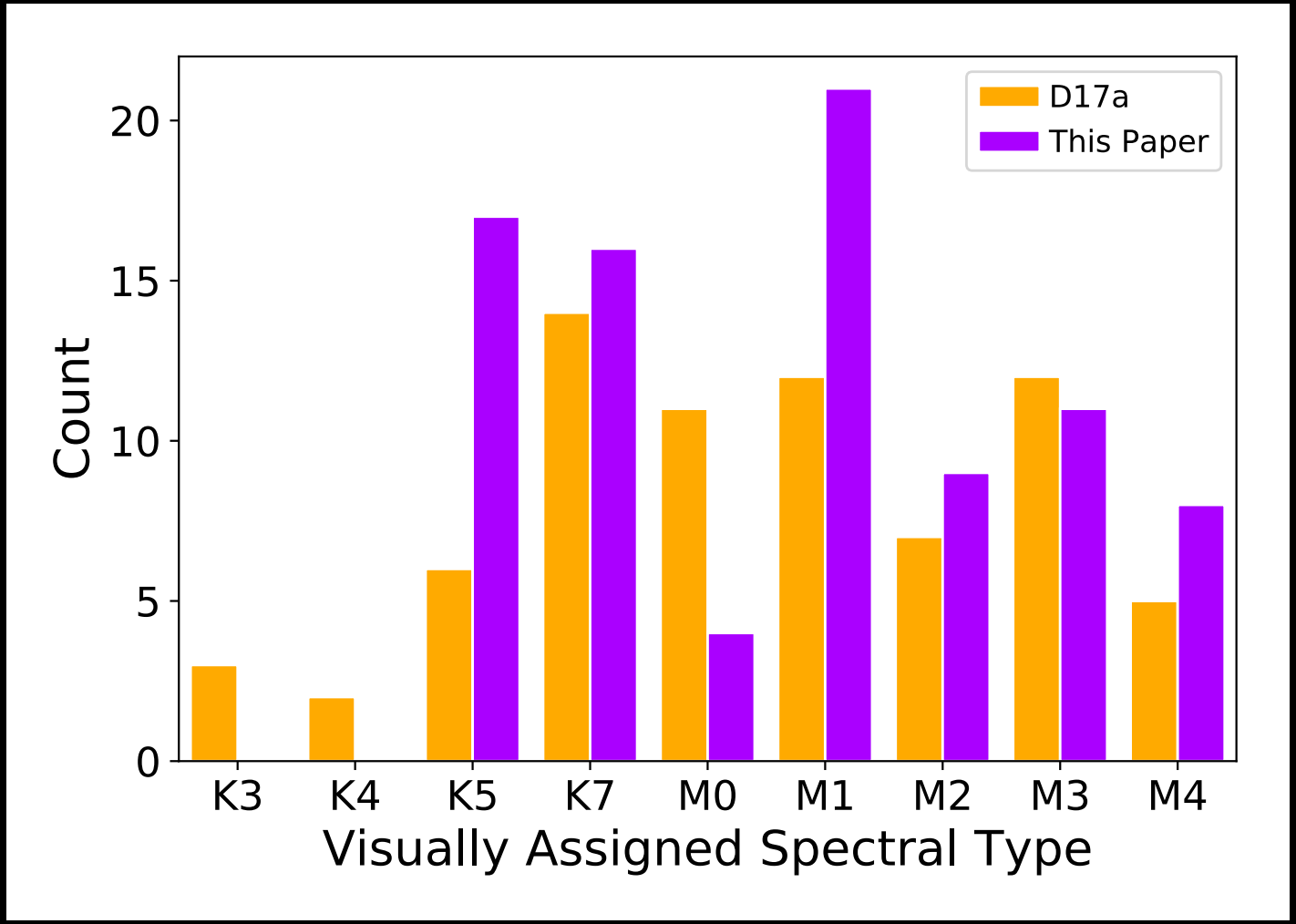
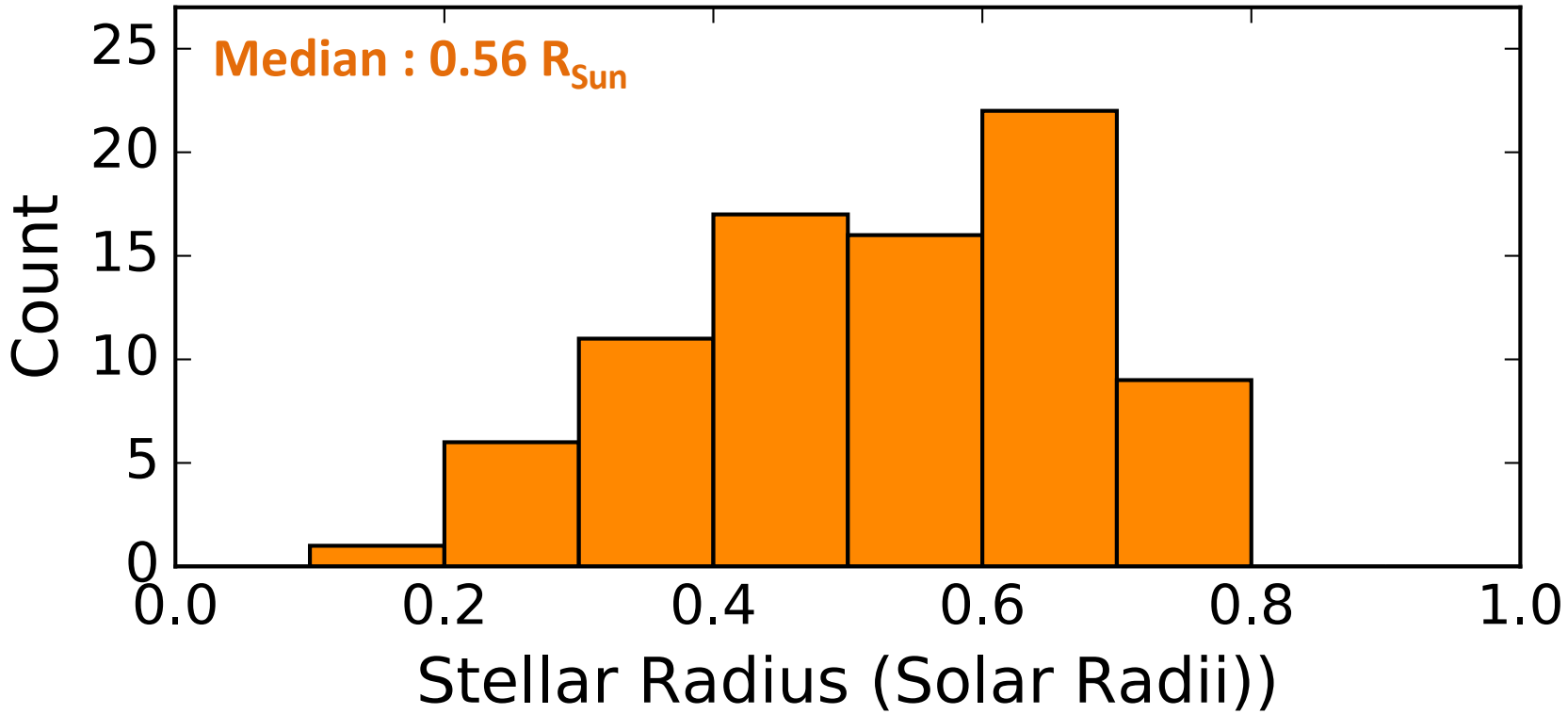


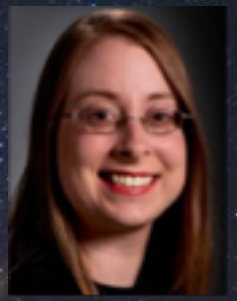
Figure & Purple Sample: Dressing et al. (in review)
Orange Sample: Dressing et al. 2017a, ApJ, 836, 167

Our Typical Targets are Roughly Half the Size of the Sun

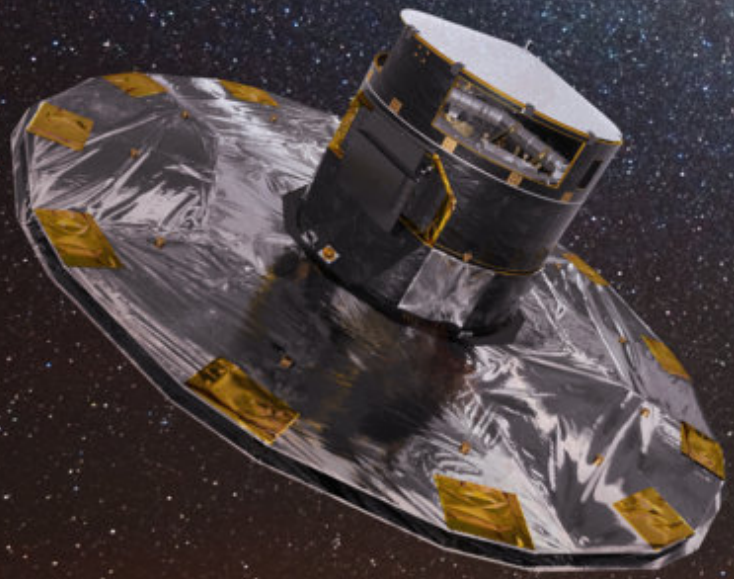


Dressing et al. 2017a, ApJ, 836, 167

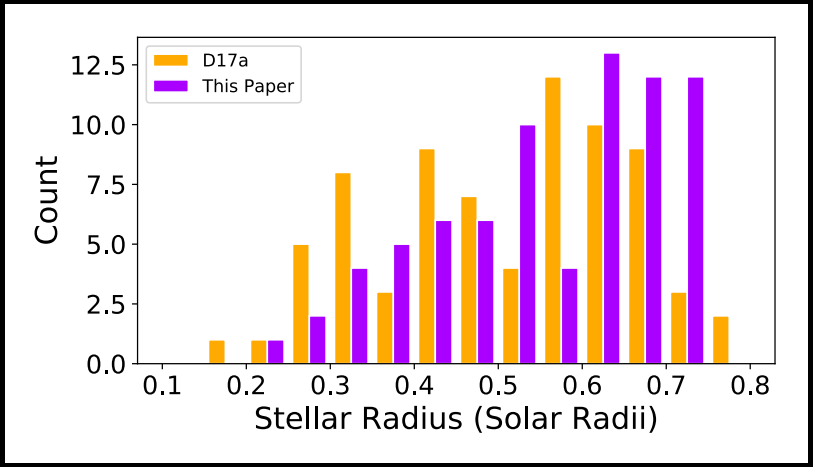
Gaia Parallaxes Constrain Stellar Properties

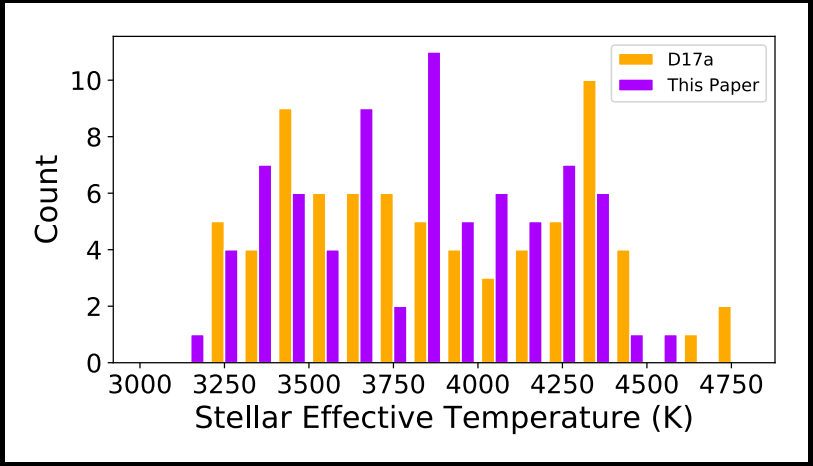


Elianna Schwab Abrahams
(1st year)

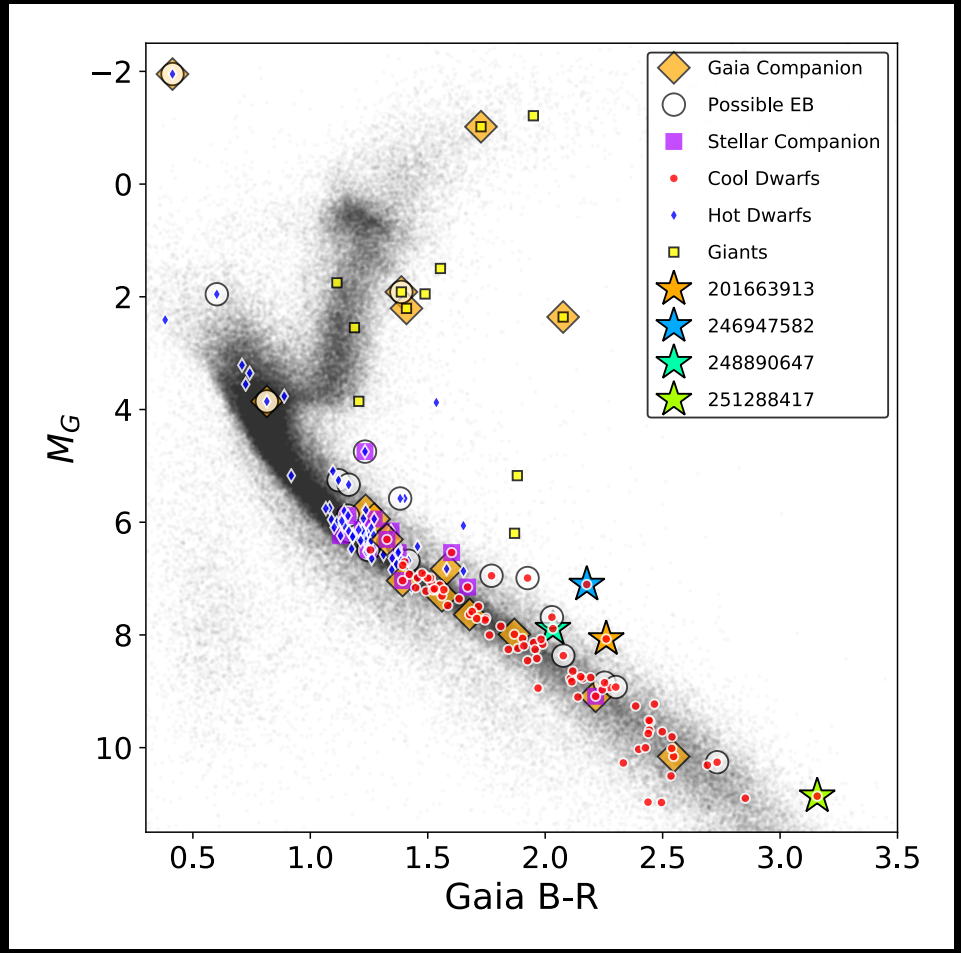


Gaia Parallaxes Constrain Stellar Properties





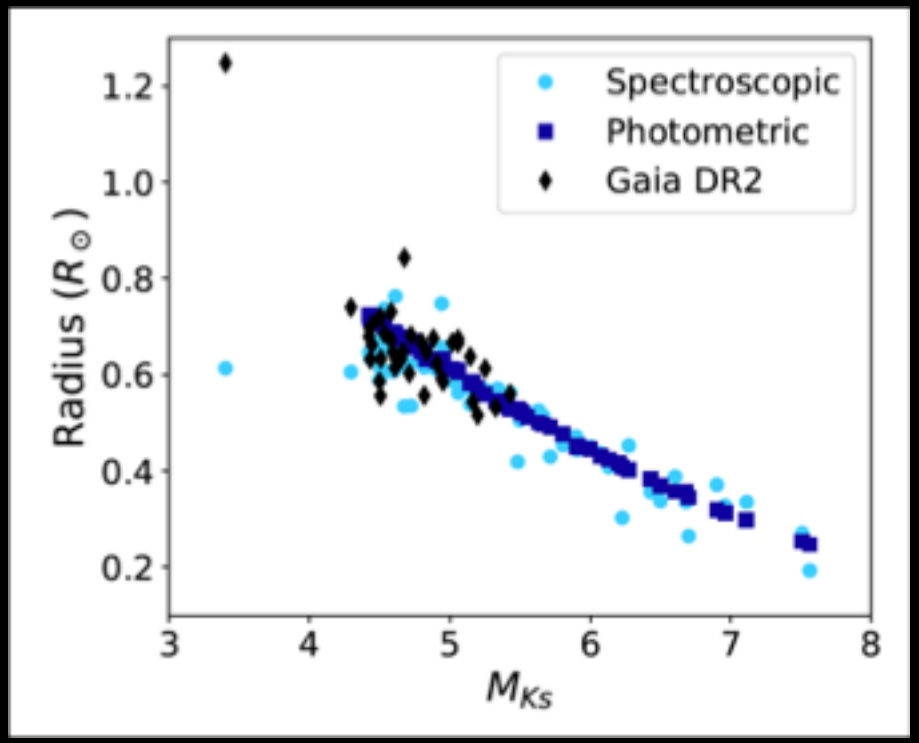
Dressing+ (under review)



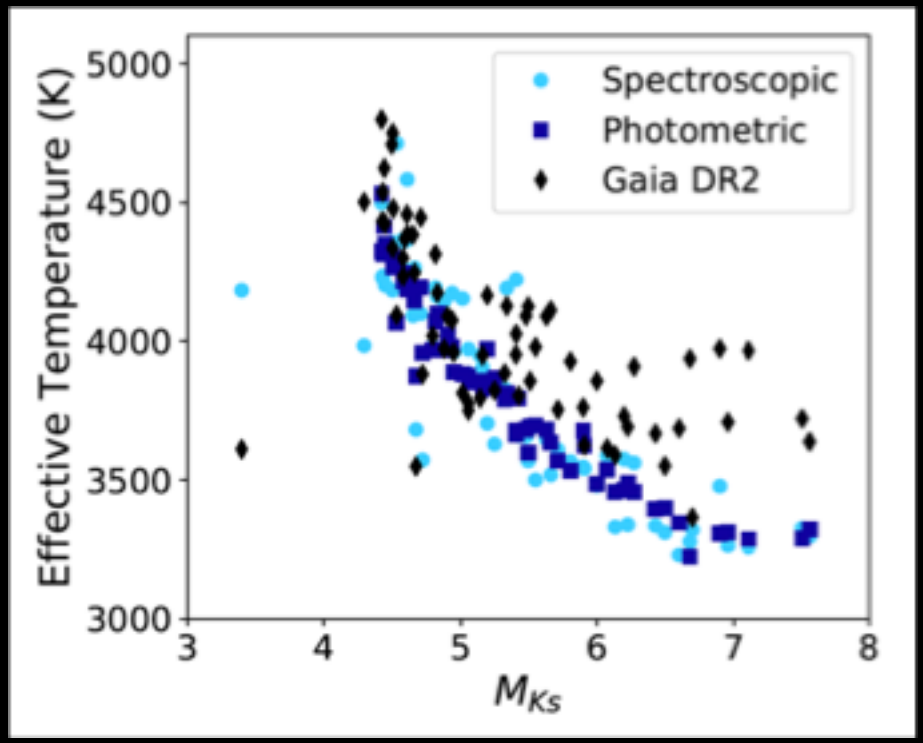
Parallaxes from Gaia DR2
Distances from Bailer-Jones+ 2018

Figure from Dressing+ (under review)

Spectroscopic & Photometric T_{eff} & Radius Estimates Agree Well



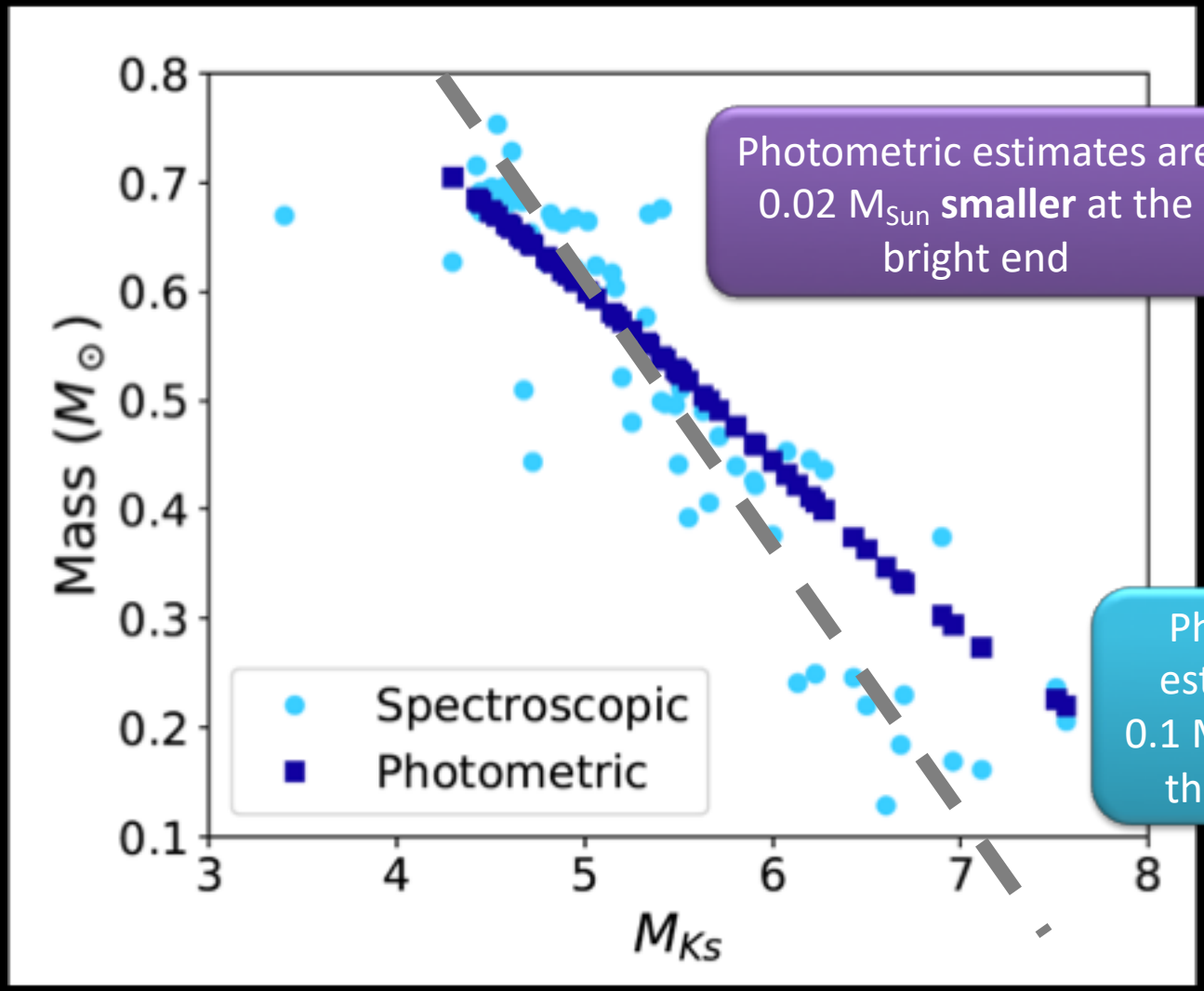
Median Difference
$R_{phot} - R_{spec} = 0.02\ R_{Sun}$



Median Difference
$T_{eff,phot} - T_{eff,spec} = -3K$

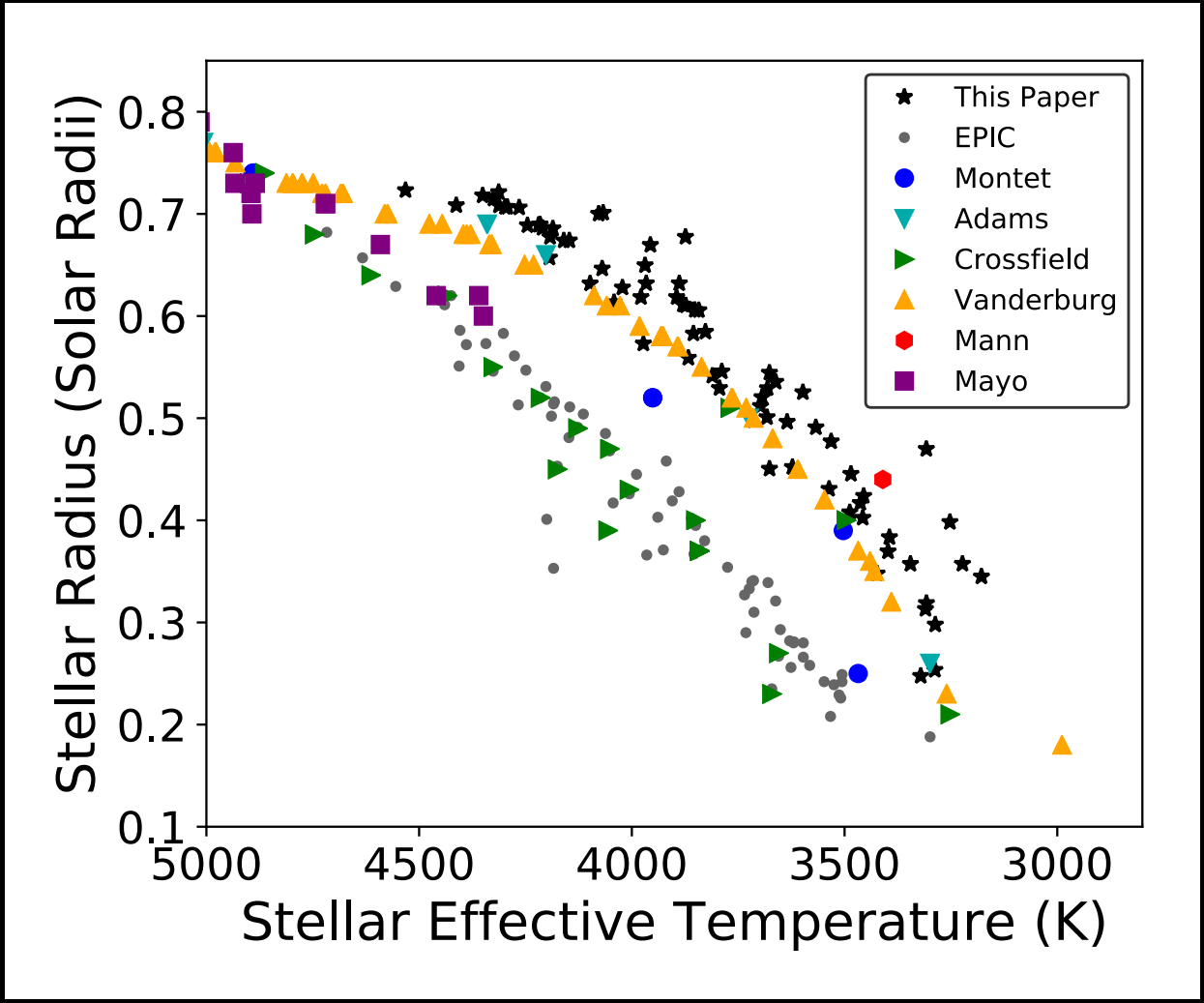
Dressing+ (under review)

…But Photometric & Spectroscopic Masses Display a Magnitude-Dependent Offset



Dressing+ (under review)

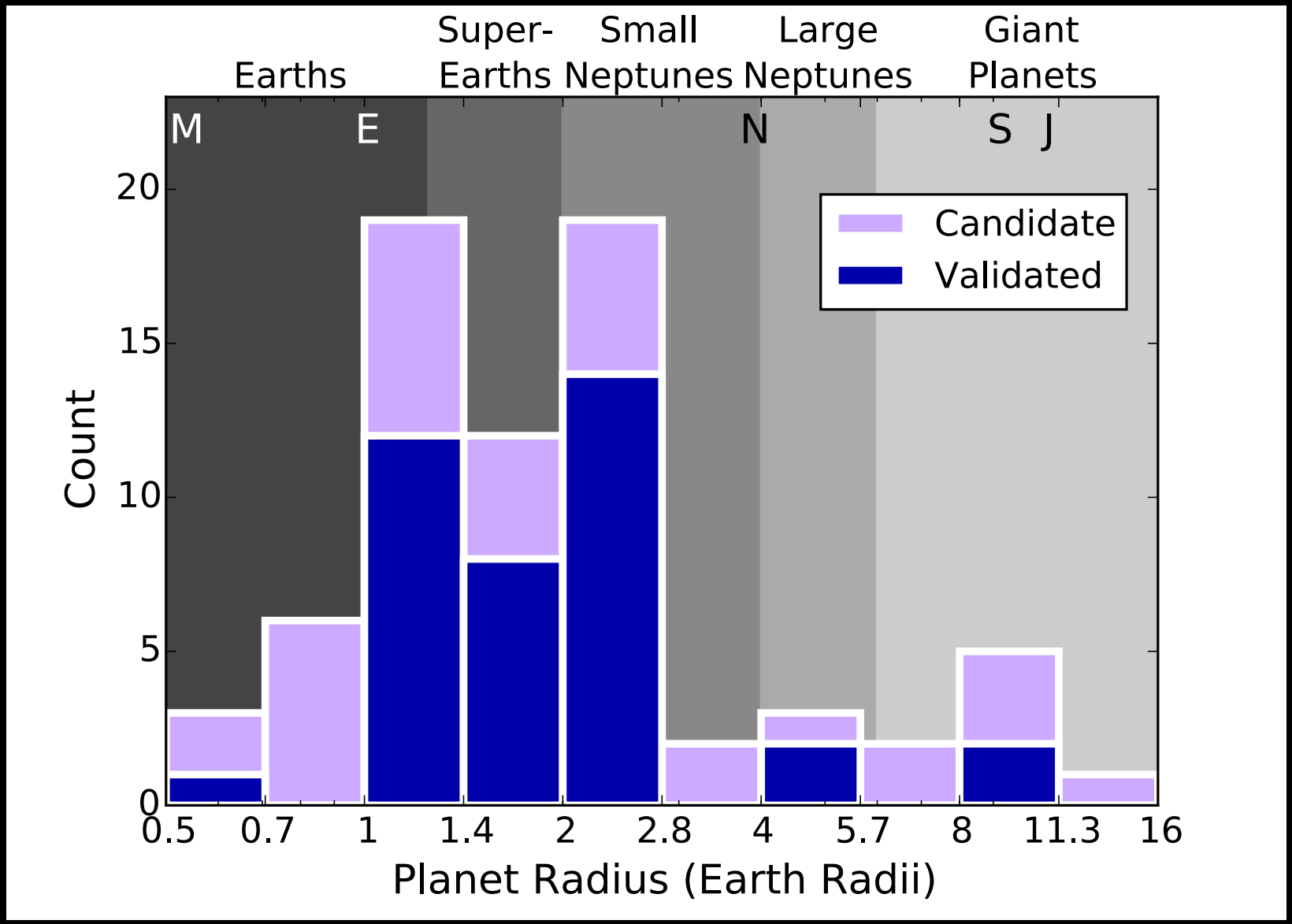
Our Radius Estimates Are Roughly 40% Larger than the EPIC Estimates



EPIC parameters from Huber et al. (2016)

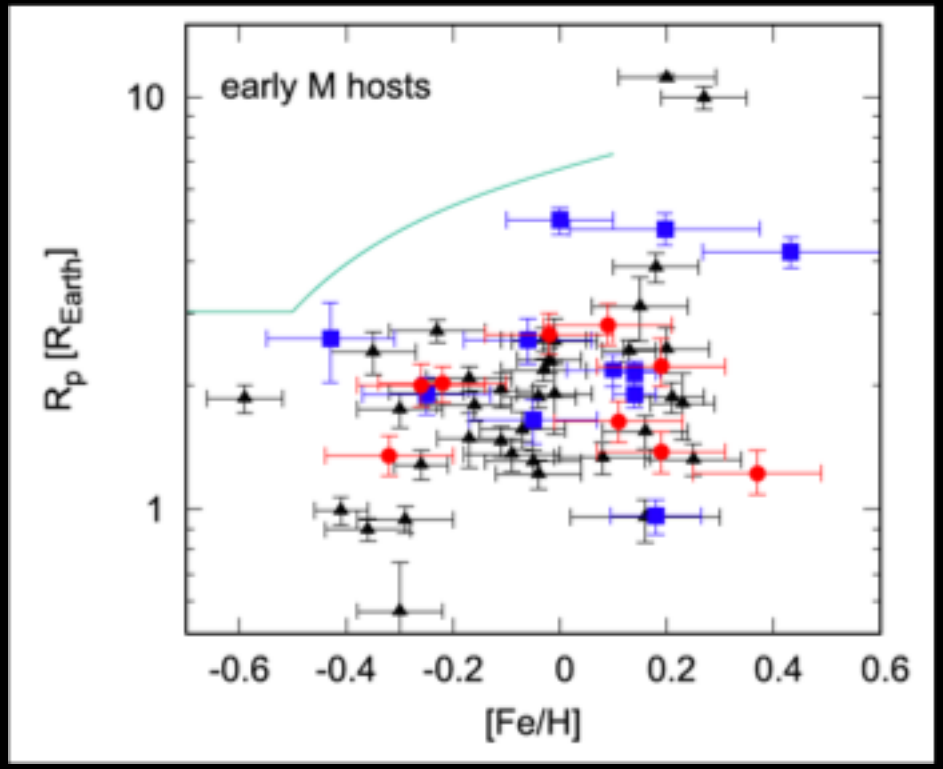
Dressing+ (under review)

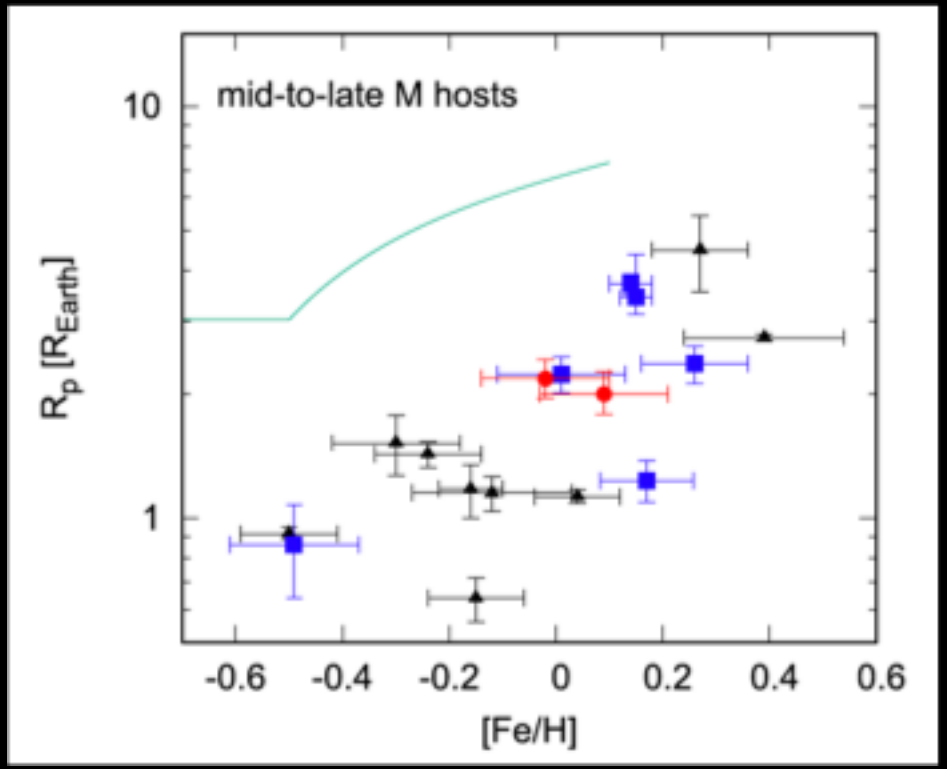
85% Of Planets In Our Sample Are Smaller Than Neptune



Dressing et al. 2017b, AJ, 154, 207

The Largest M Dwarf Planets Tend to Have More Metal-Rich Host Stars

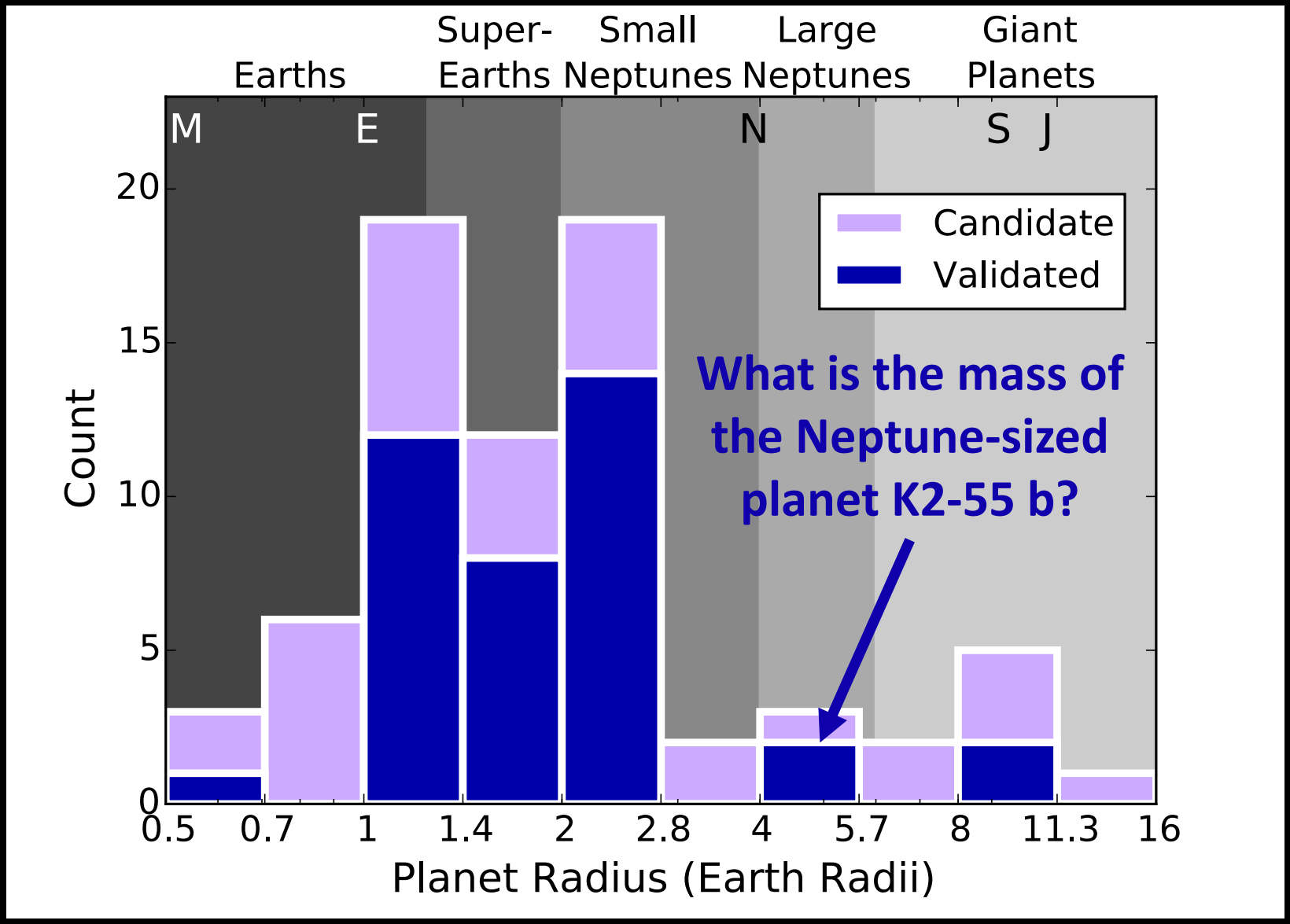




Hirano et al. (2018)

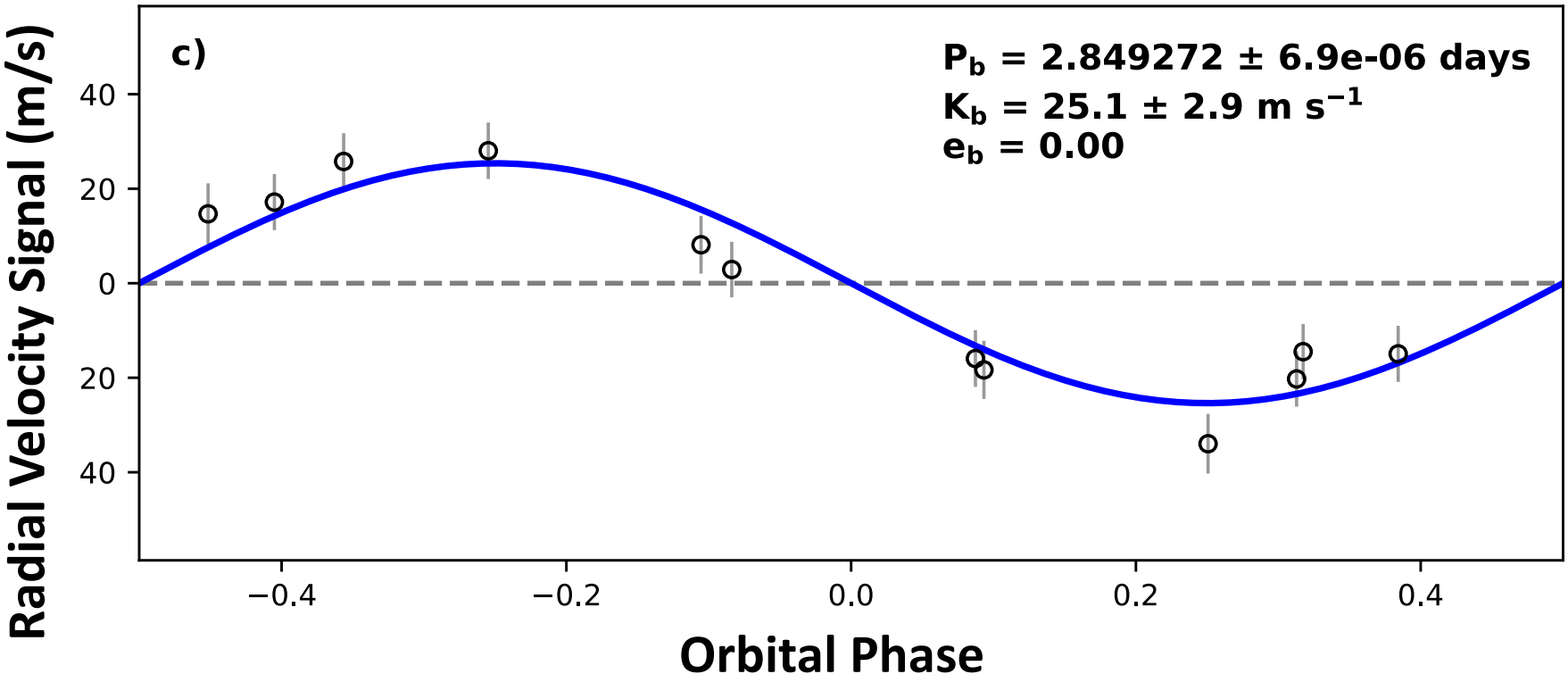
What are the compositions of these planets?

85% Of Planets In Our Sample Are Smaller Than Neptune



Dressing et al. 2017b, AJ, 154, 207

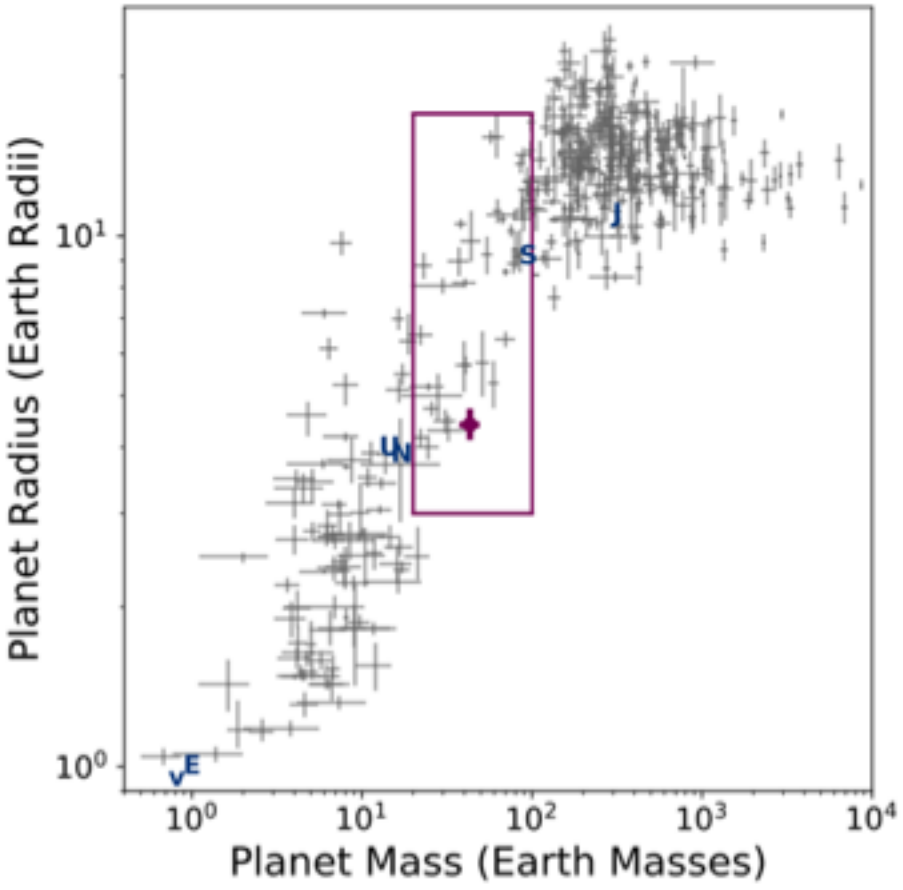
Our Keck/HIRES Observations Revealed the Mass of K2-55b

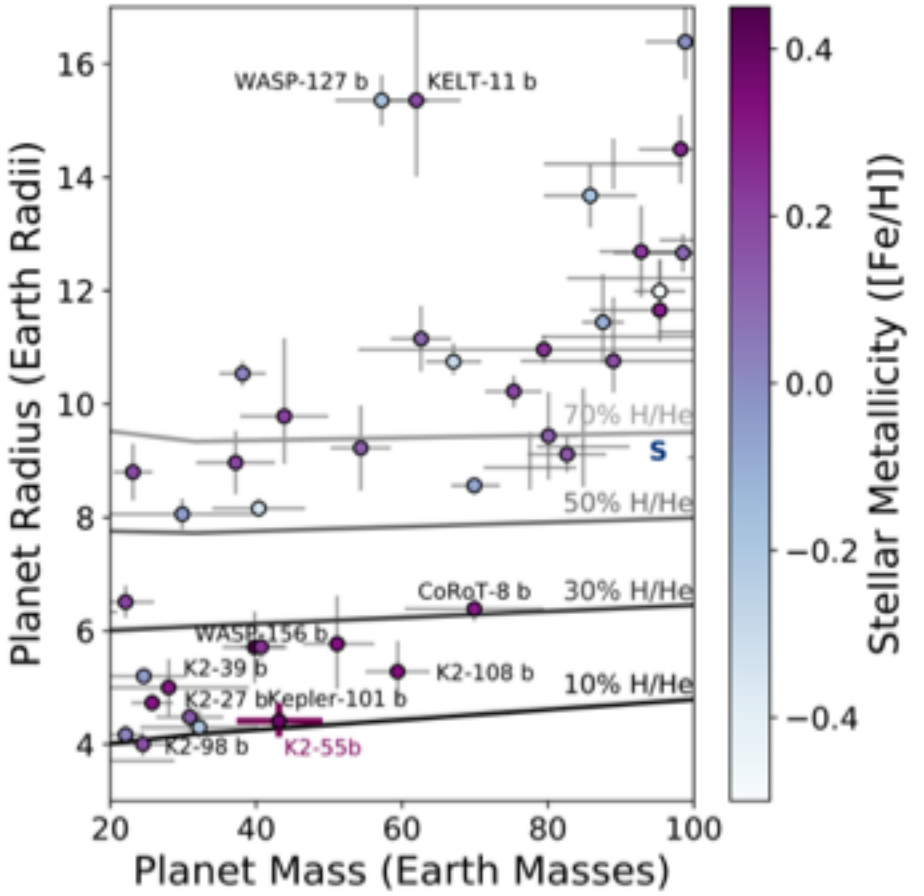


Size: 4.4 Earth radii
(from K2)

Mass: 43 Earth masses
(from Keck)

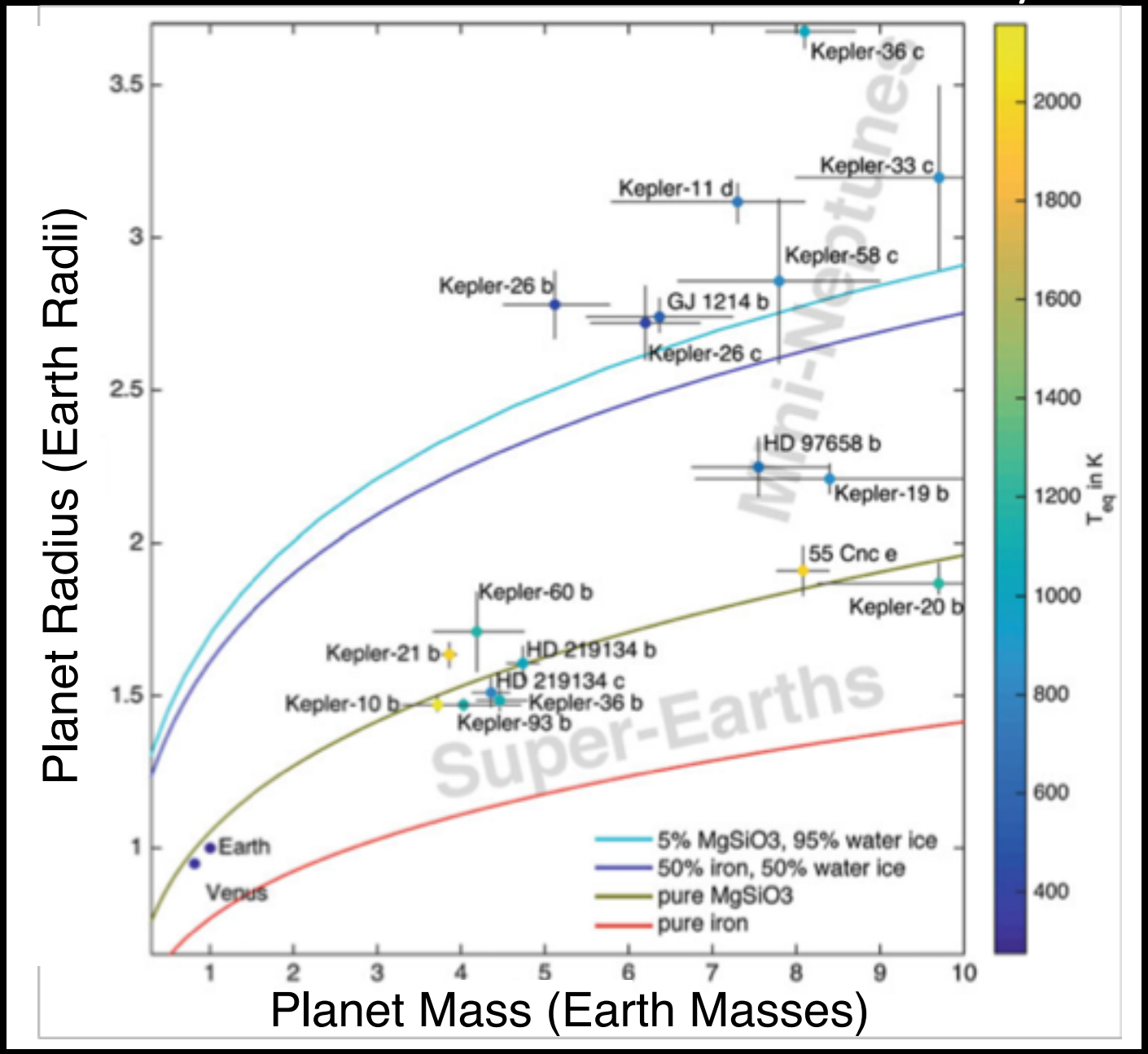
K2-55b is Unusually Dense Compared to Other Neptune-Sized Planets





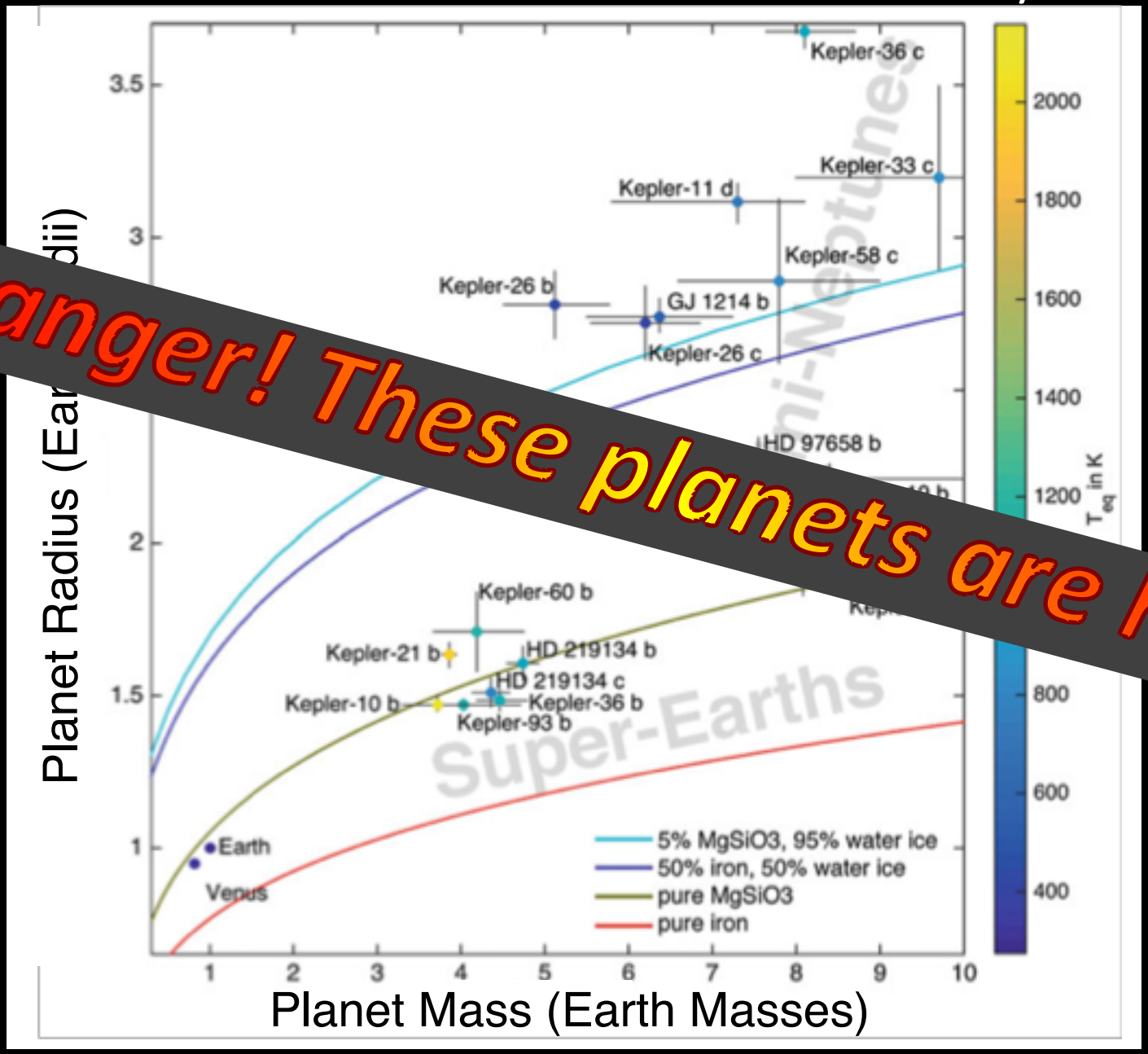
Dressing et al. 2018

Few Small Planets Have Precise Density Estimates



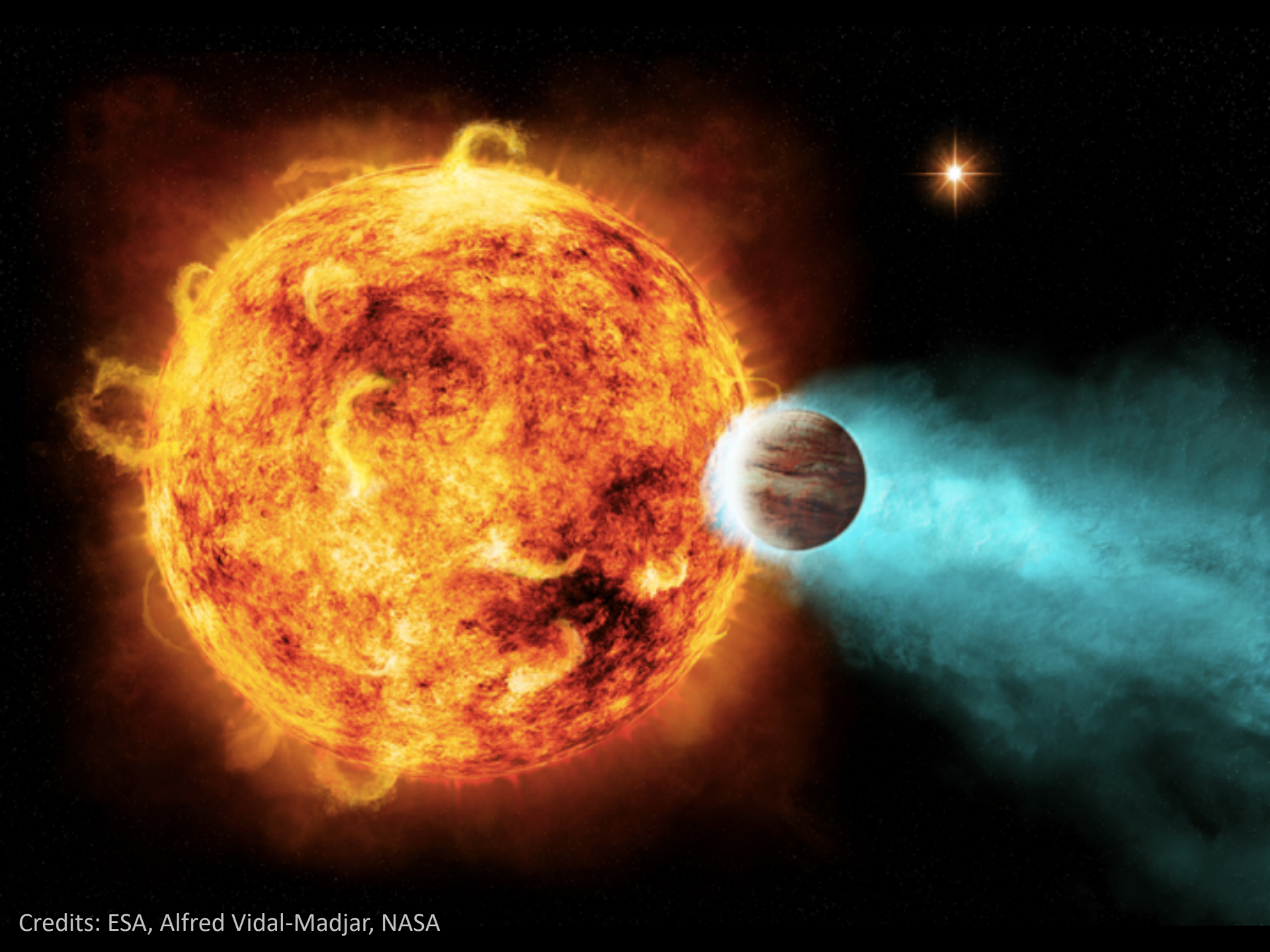
Dorn et al. 2018

Few Small Planets Have Precise Density Estimates



Danger! These planets are hot!

Dorn et al. 2018



Credits: ESA, Alfred Vidal-Madjar, NASA

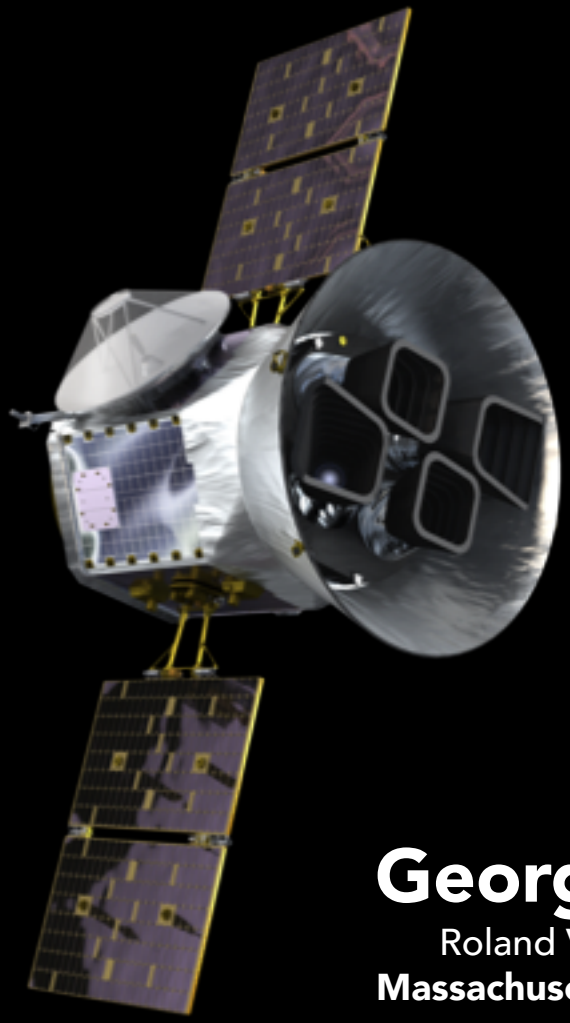
MOST KEPLER & K2 TARGETS ARE FAINT

MOST KEPLER & K2 TARGETS ARE FAINT

We need **brighter** stars to measure masses

The Present

TESS



Explorer Mission

George Ricker (P.I.)

Roland Vanderspek (Deputy P. I.)

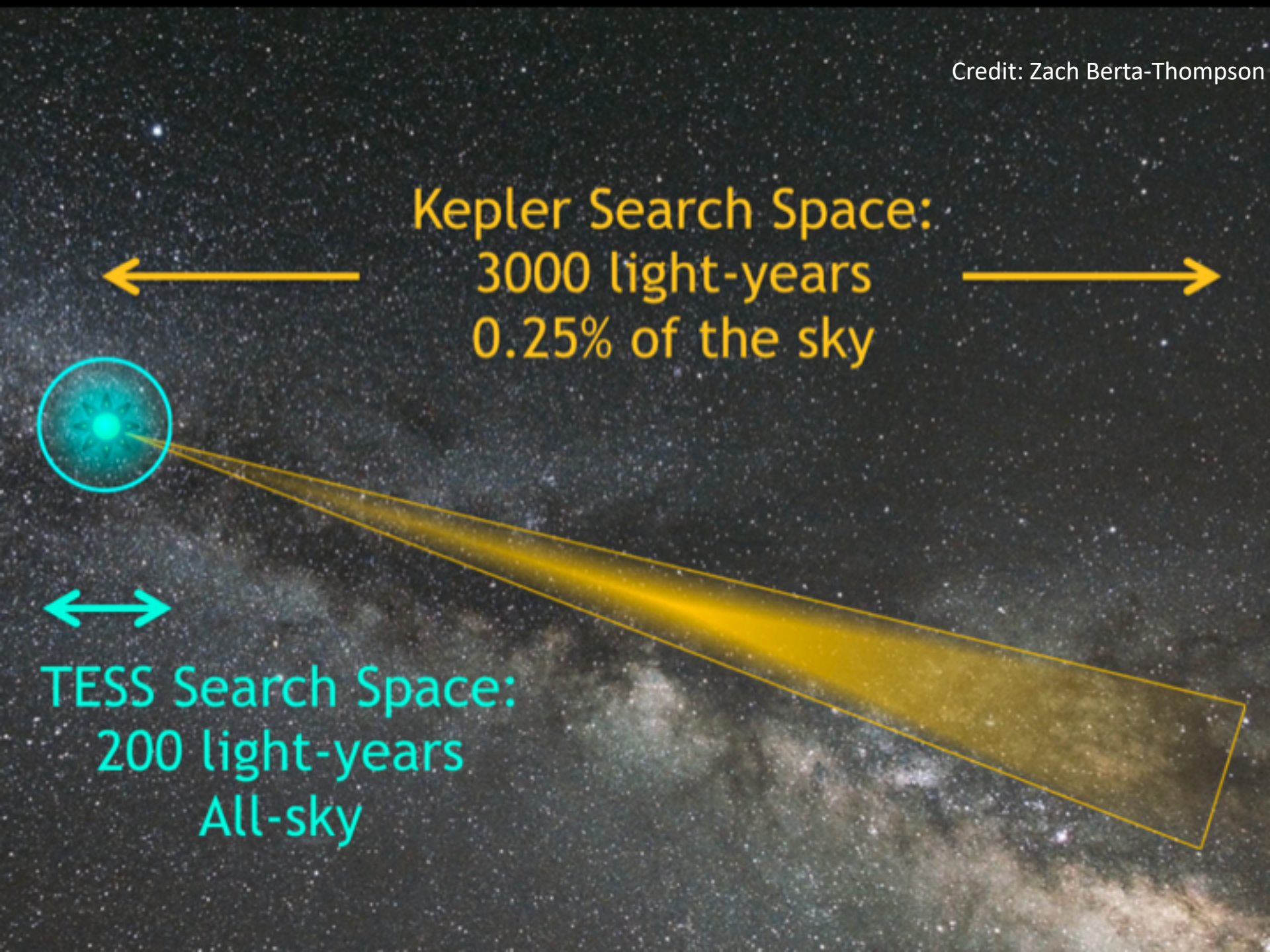
Massachusetts Institute of Technology

science center shared between

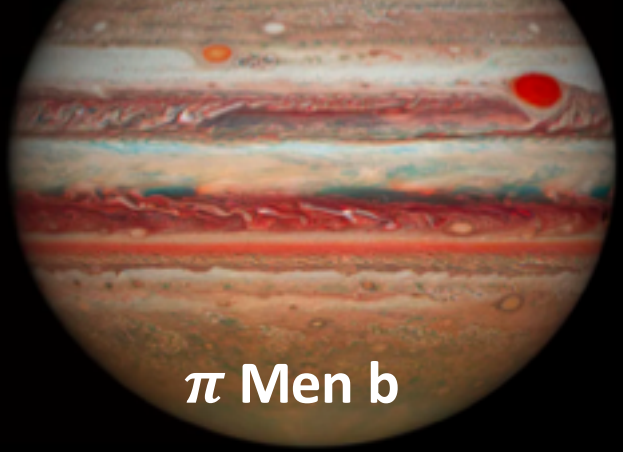
MIT + Harvard/Smithsonian CfA

Ricker et al., JATIS, (2014)


Image credit: NASA TV
TESS
launched in April
to find hundreds of nearby small exoplanets amenable to detailed characterization
NASA
Explorer Mission
Ricker et al., JATIS, (2014)


Credit: Zach Berta-Thompson
Kepler Search Space:
3000 light-years
0.25% of the sky
TESS Search Space:
200 light-years
All-sky

Parameters from Huang et al. 2018



π Men b

$M_p \geq 10.2\ M_\odot$
P = 5.7 yrs
e = 0.6

π Men
(HD 39091)

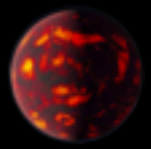
1.1 $M_\odot$
1.1 $R_\odot$
V = 5.7
d = 18.27 pc

π Men c

$R_p = 2.14\ R_E$
P = 6.27 d
$M_p = 4.82\ M_E$

From Gaia *From TESS* *From RV monitoring*

Vanderspek et al. 2019



LHS 3844 b

$R_p = 1.32 \pm 0.02\ R_E$

P = 0.46 d (11 hr)

a = 0.006 AU

T_{eq} = 805 K

$0.15\ M_\odot$

$0.19\ R_\odot$

V = 15.26

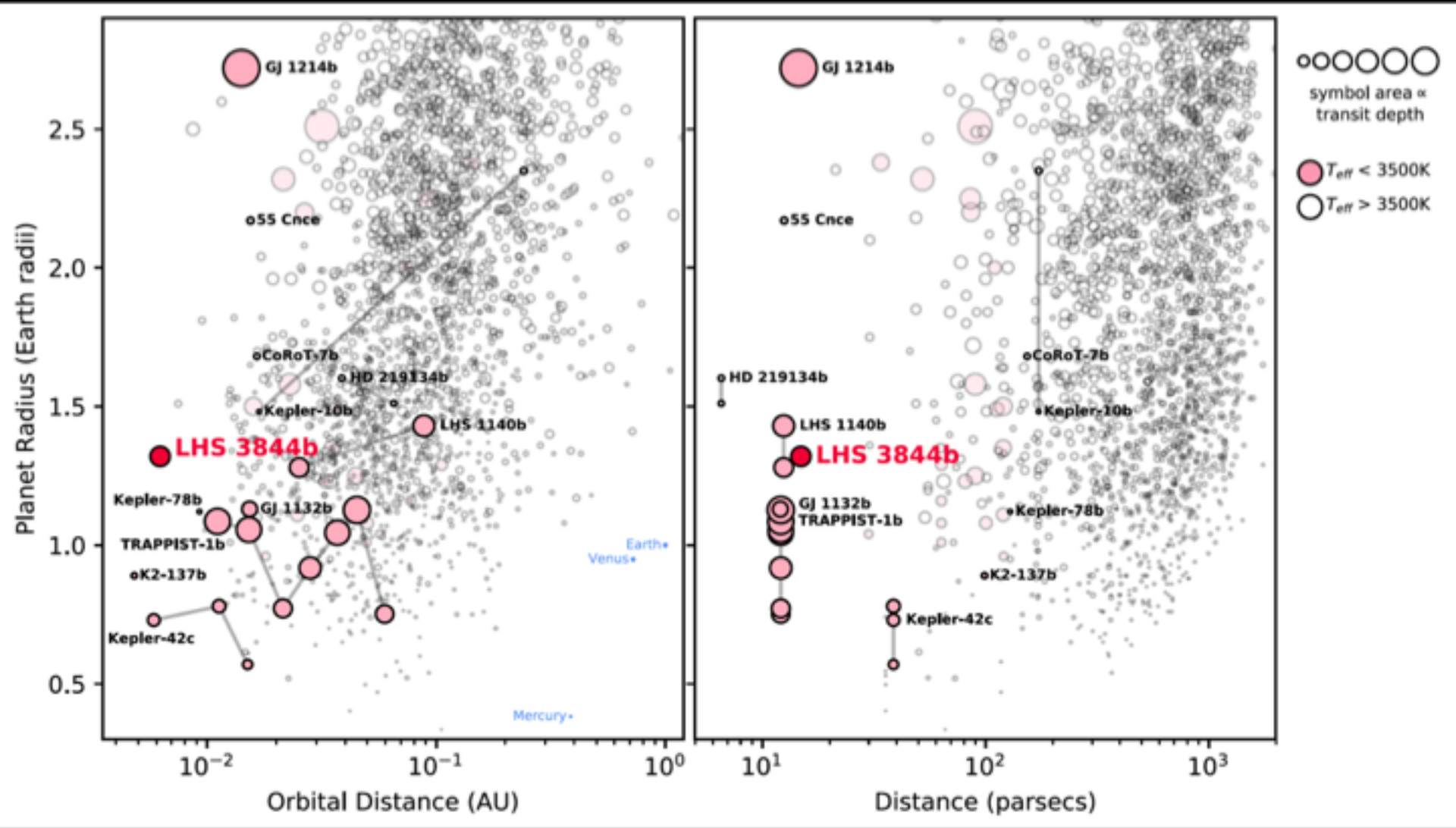
K = 9.1

d = 14.9 pc

From Gaia

From TESS

LHS 3844b:
A Nearby Planet Discovered by TESS

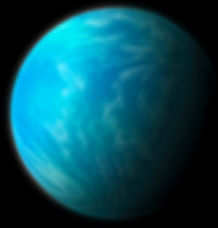


Vanderspek et al. 2019

How many planets will TESS discover?

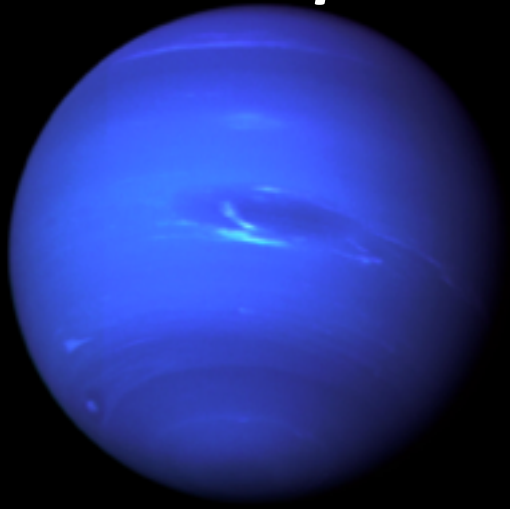
TESS Will Find Thousands of Planets

45 Earths



240 "Super-Earths"

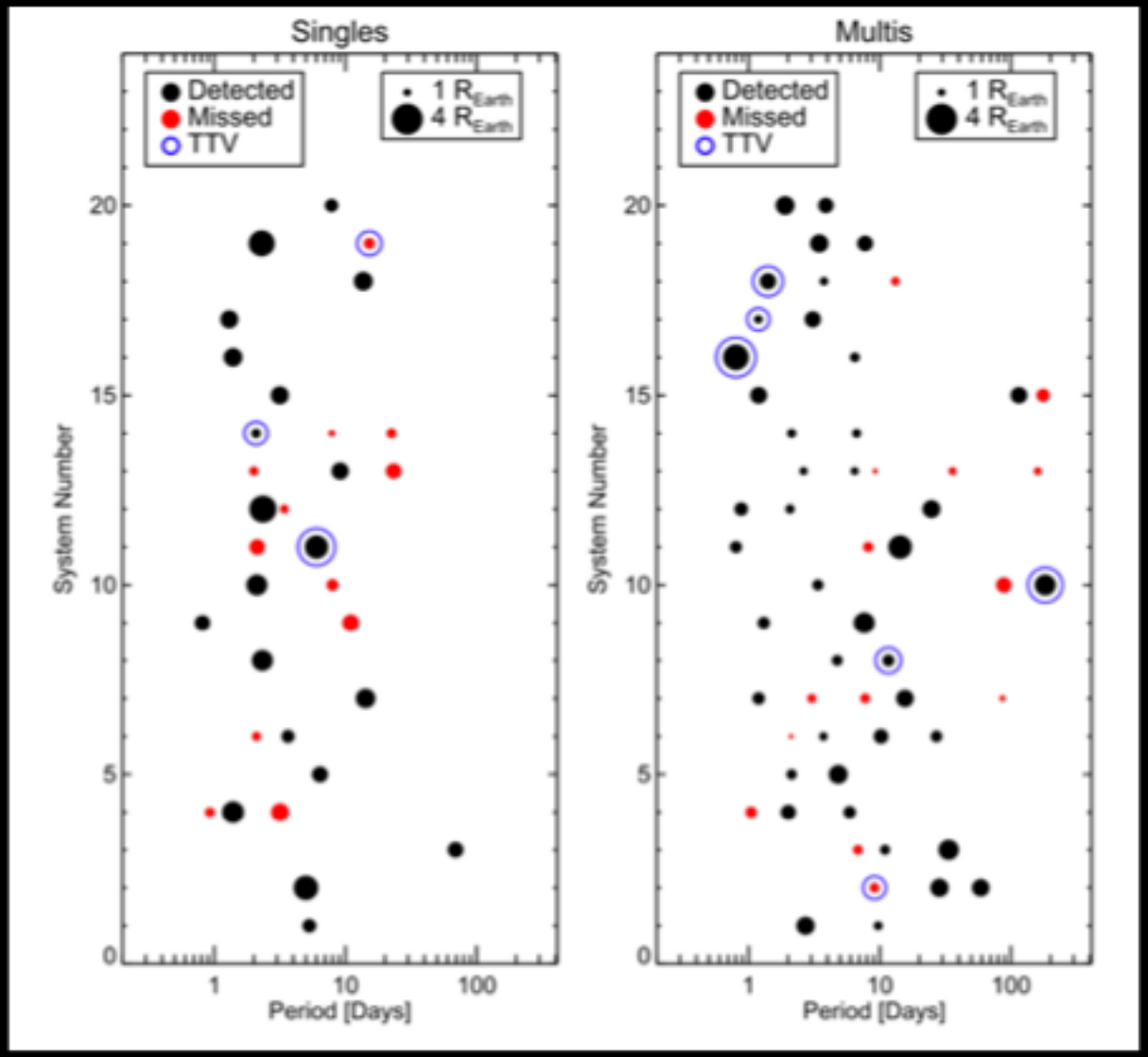
1870 "Sub-Neptunes"



2400 giant planets

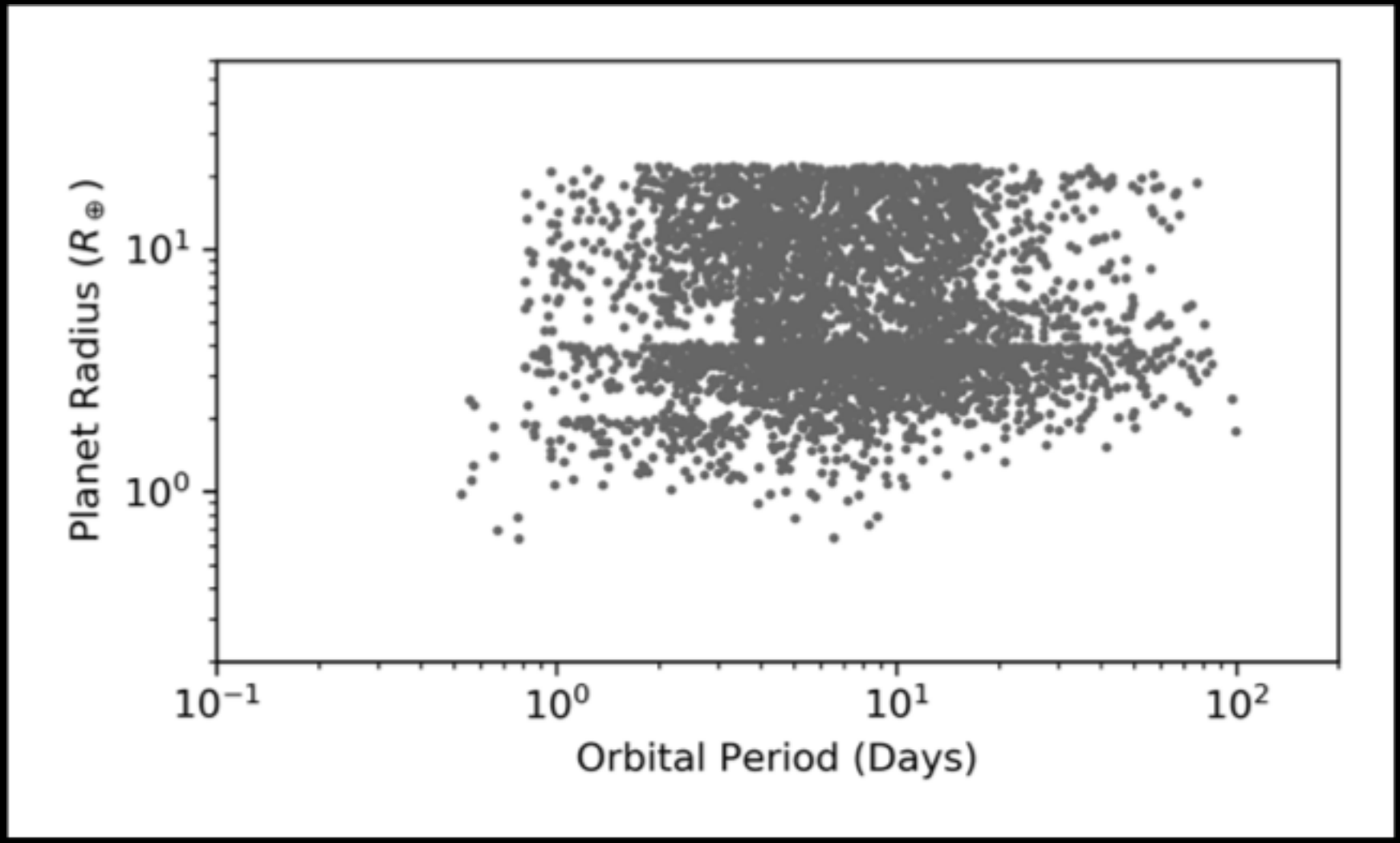
Barclay et al. (2018)

TESS Should Find Many M Dwarf Planets in Multi-Planet Systems



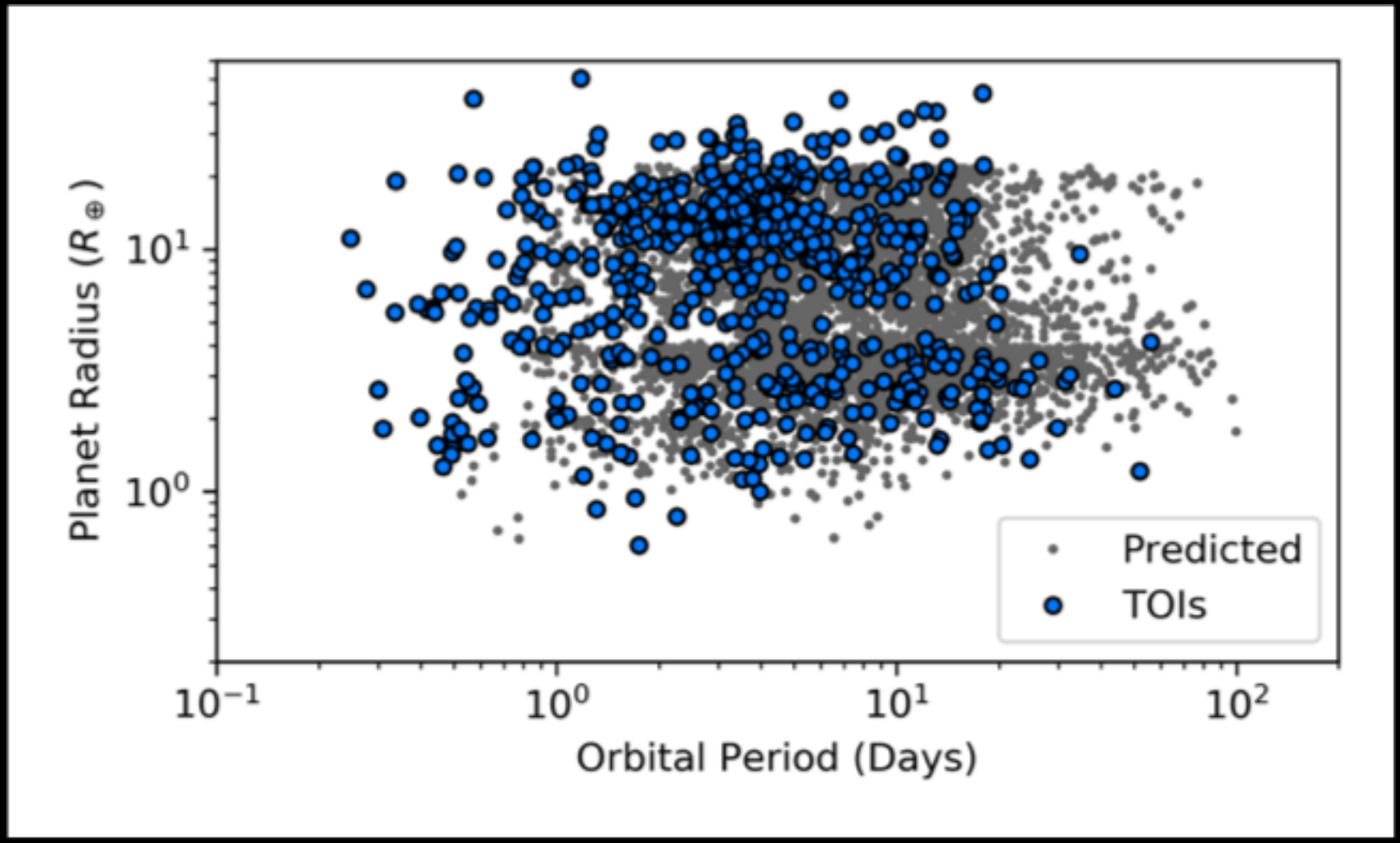
Ballard (2019)

TESS Has Already Found Hundreds of Candidates



Yield Simulation by Barclay et al. (2018)

TESS Has Already Found Hundreds of Candidates

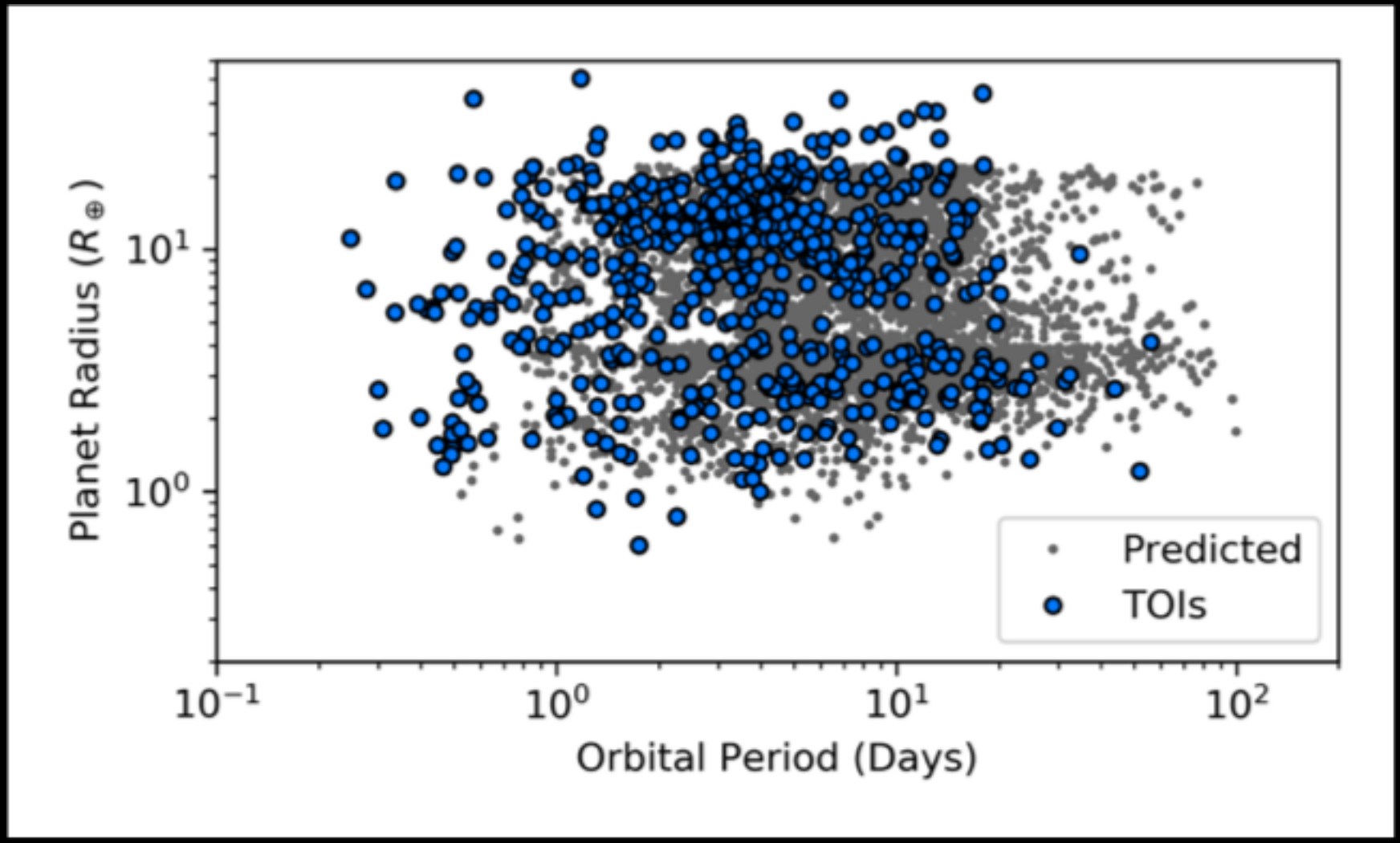


TOIs from NASA Exoplanet Archive

Yield Simulation by Barclay et al. (2018)

Figure by Dressing

TESS Has Already Found Hundreds of Candidates



TOIs from NASA Exoplanet Archive

Yield Simulation by Barclay et al. (2018)

Figure by Dressing

TESS Has Already Found Hundreds of Candidates

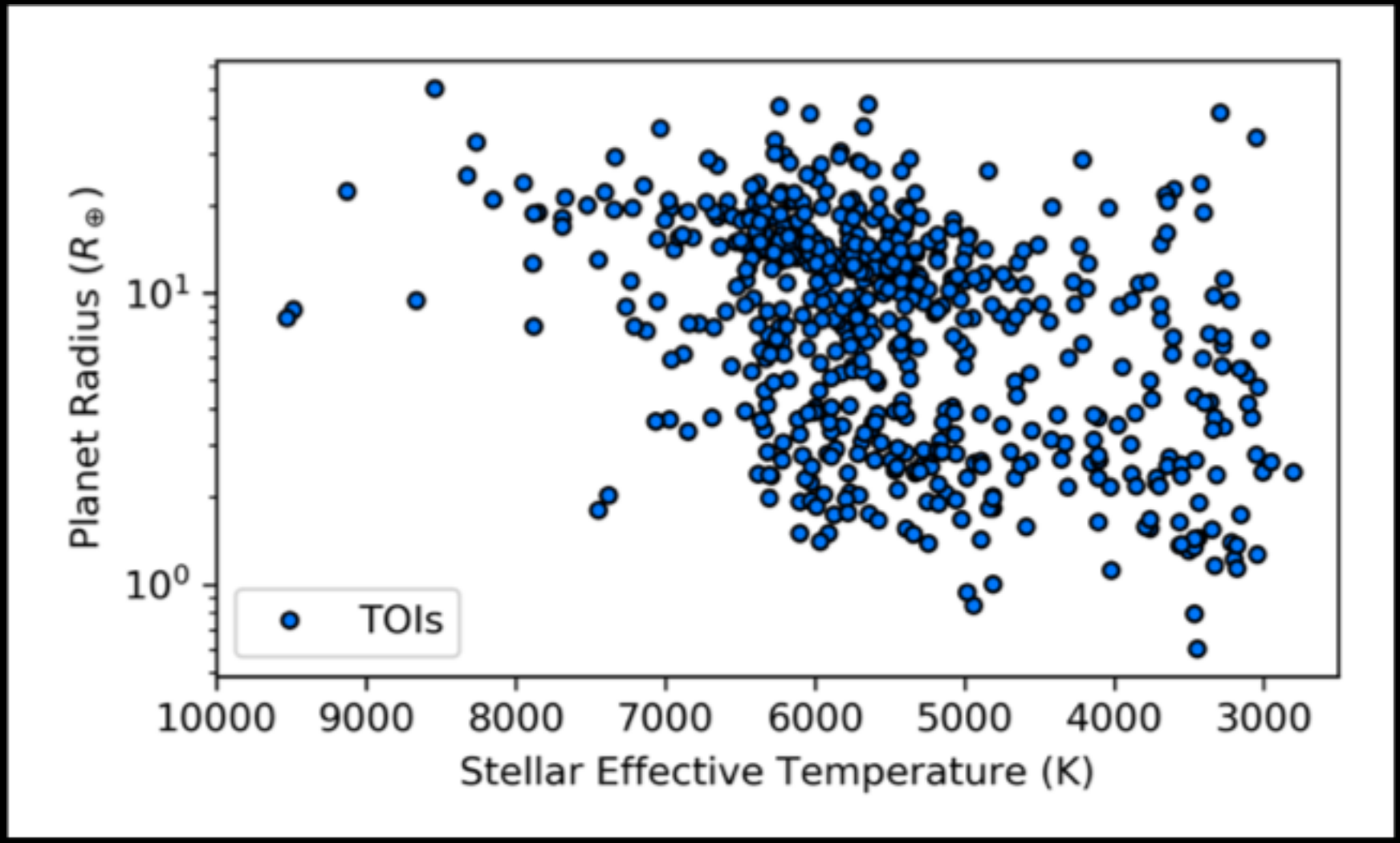


Figure by Dressing

TOIs from NASA Exoplanet Archive

TESS planets will be ideal targets
for RV mass measurement

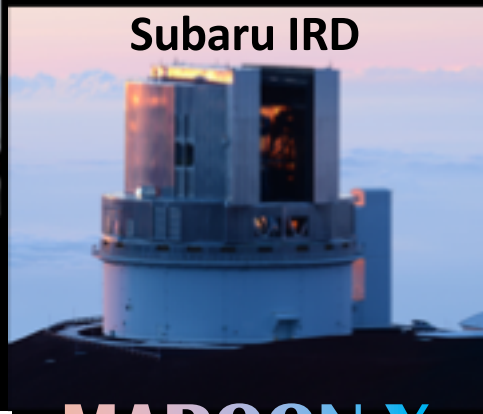

CARMENES


Levy


SPIRou


HPF

TESS planets will be ideal targets for RV mass measurement


Subaru IRD


Keck Planet Finder
HIRES

MAROON-X

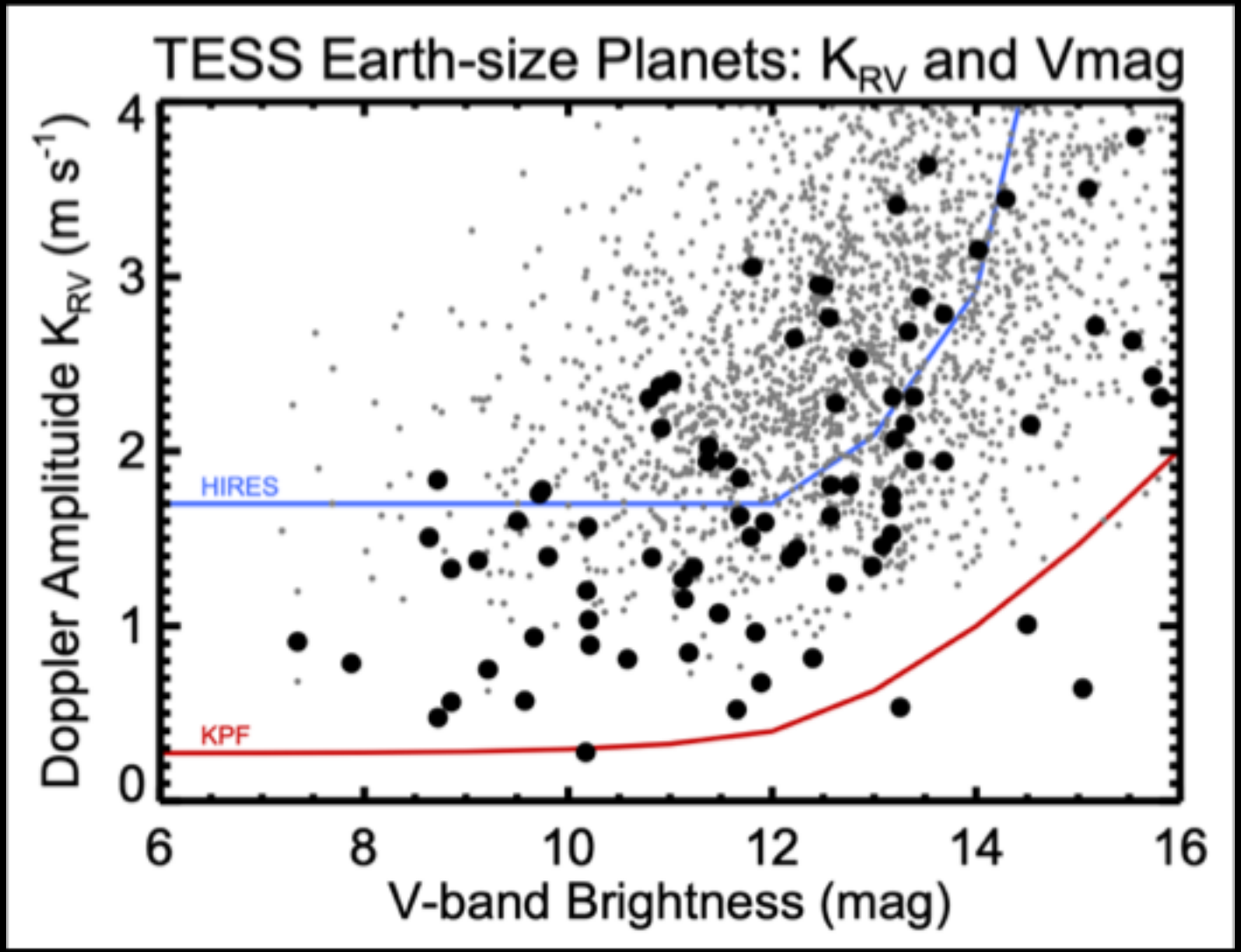

iGRINS


MINERVA Red


HARPS-N

NRES

Keck Planet Finder Would Enable Cutting-Edge Studies of Planet Composition & Habitability



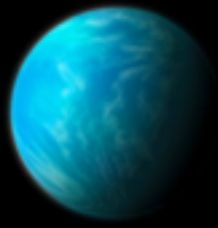
Larger Planet Signals

Brighter Stars

Gibson et al. (2016)

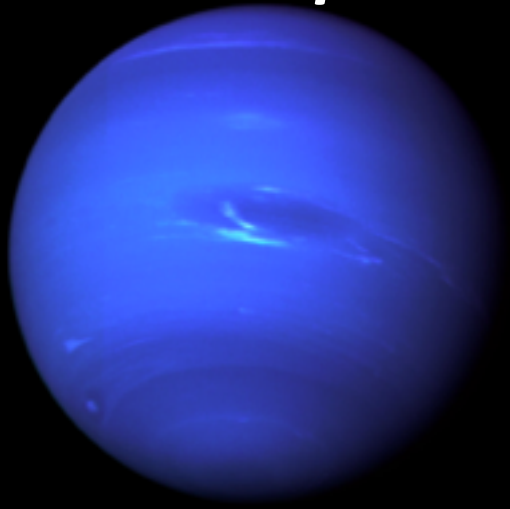
TESS Will Find Thousands of Planets

45 Earths



240 "Super-Earths"

1870 "Sub-Neptunes"



2400 giant planets

Barclay et al. (2018)

Not All Candidate Signals Are Planets

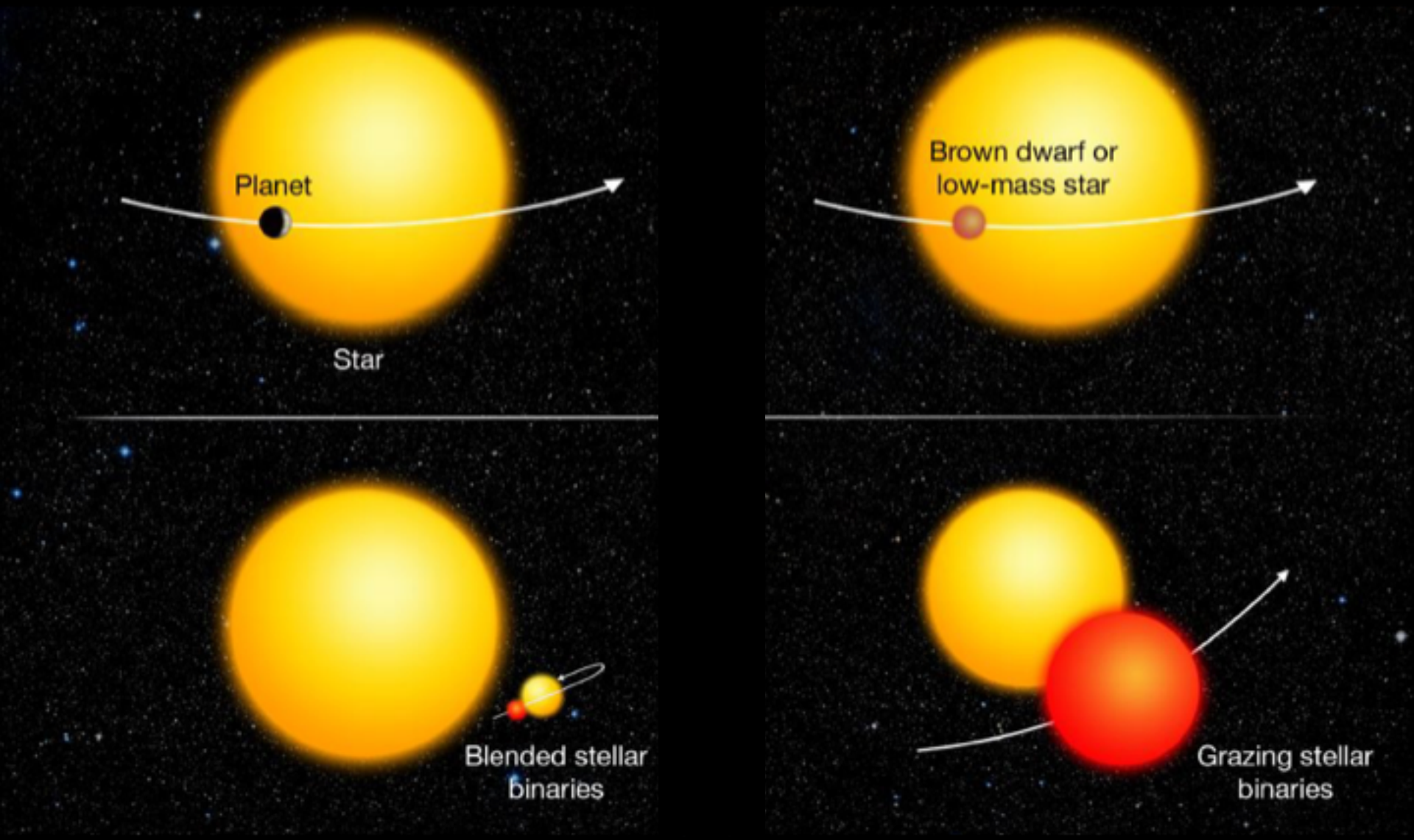
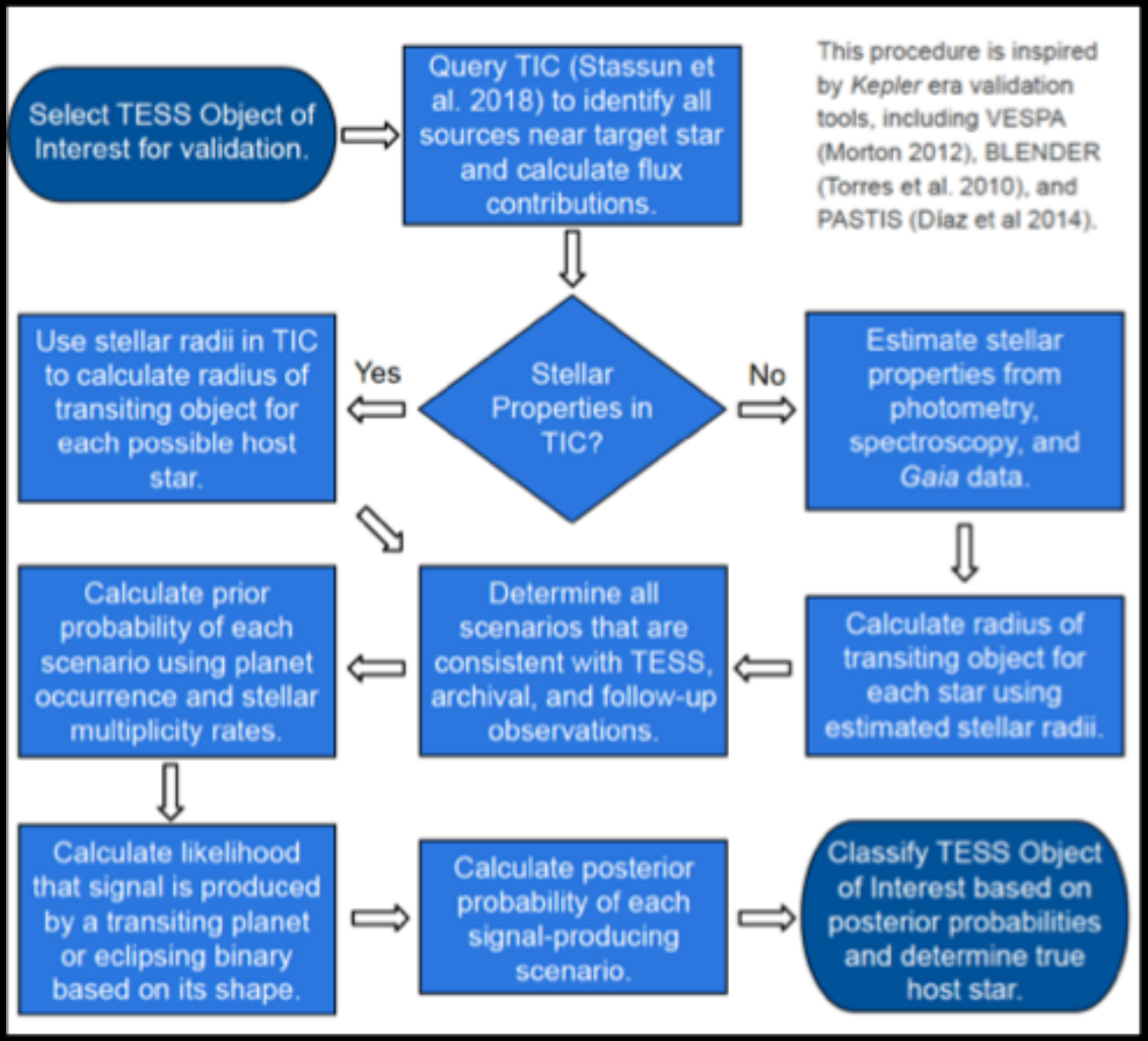


Image Credit: NASA

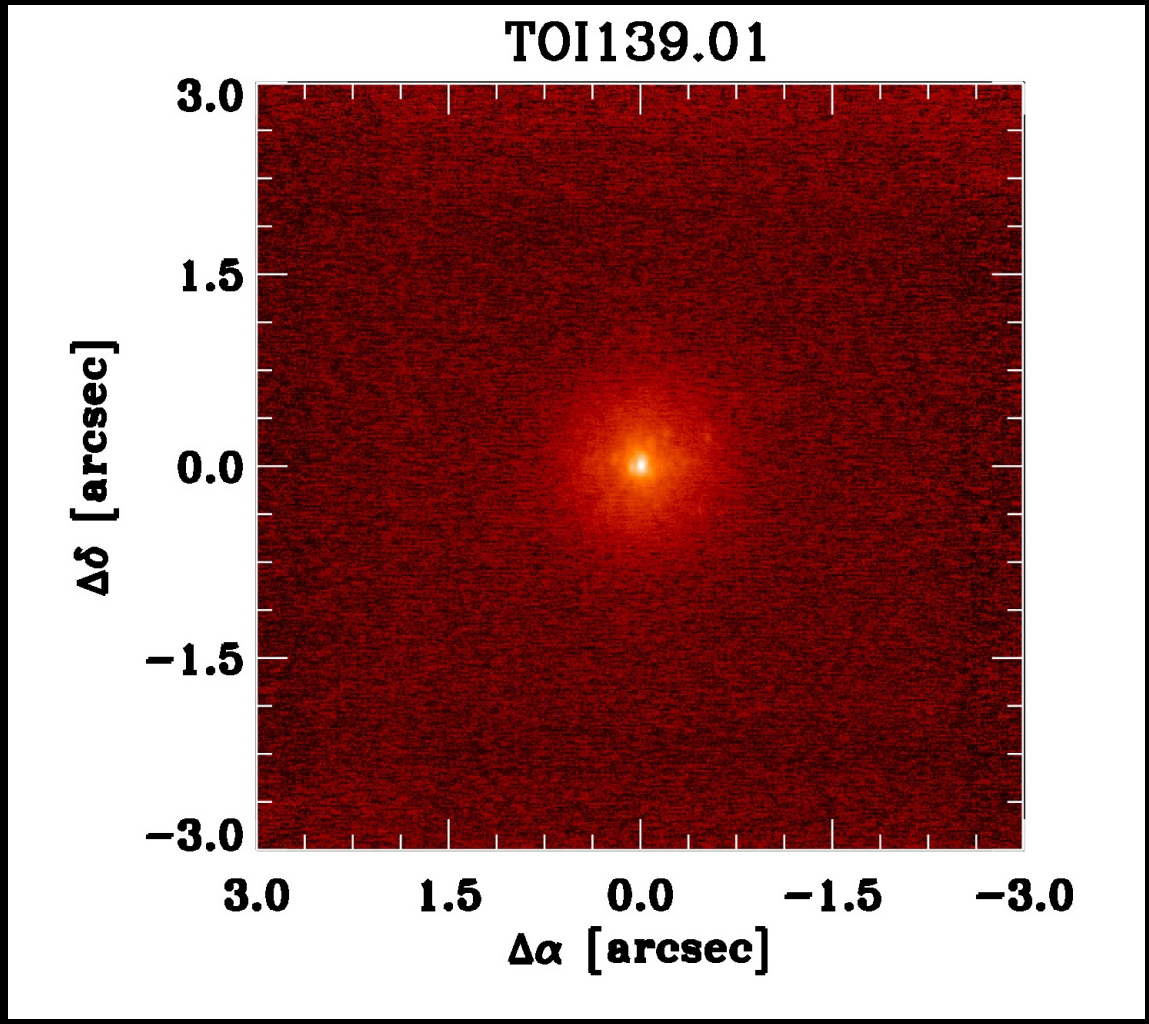
Validation Pipelines Are Essential



Steven Giacalone (UCB 3rd year grad) is building tools to vet TESS planet candidates

Schematic by Giacalone

Adaptive Optics Images with Keck Can Distinguish Between False Positives & Planets



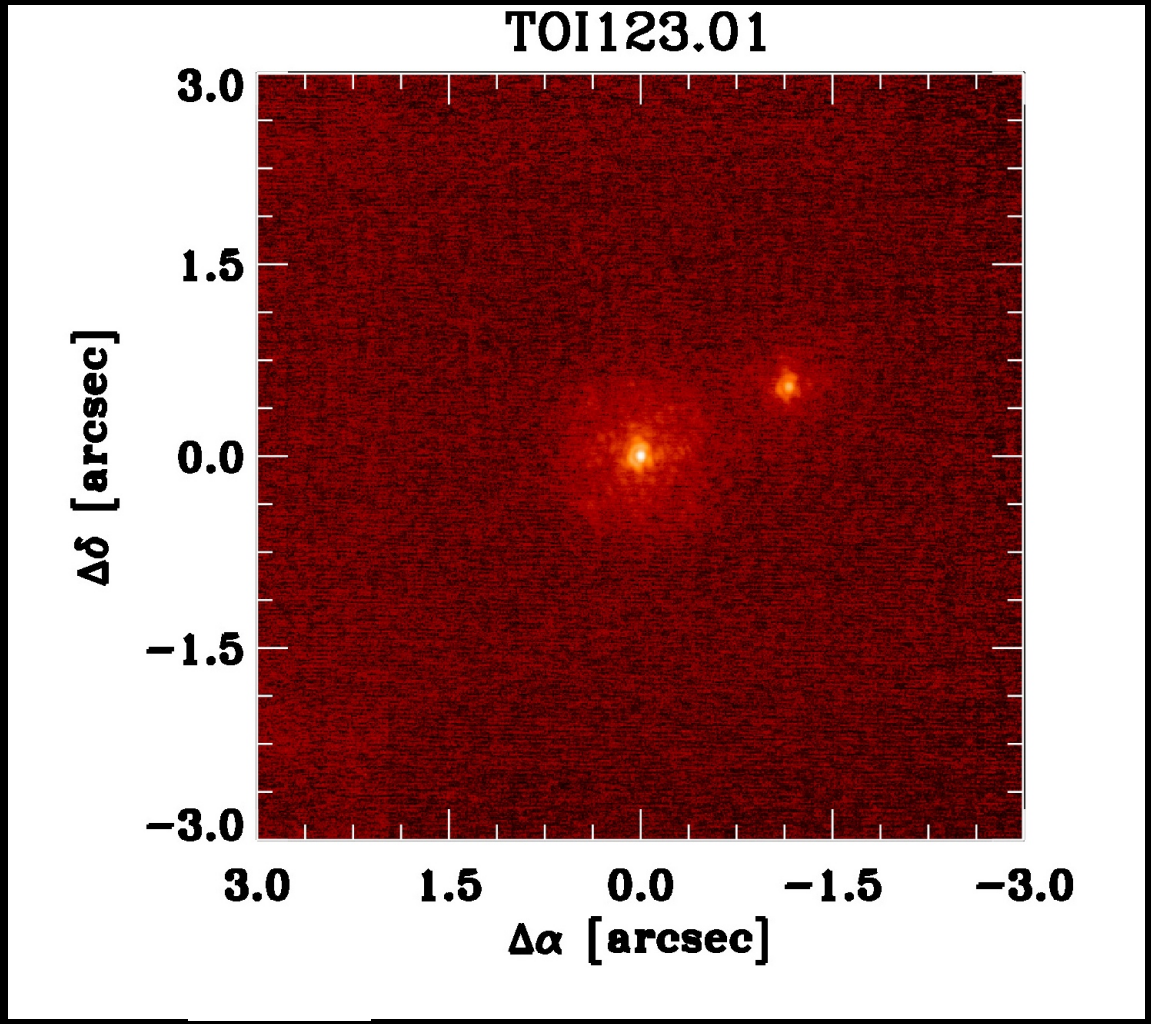
Keck/TESS ToO Program (PI: Beichman)

Figure by D. Ciardi

Adaptive Optics Images with Keck Can Distinguish Between False Positives & Planets

Arjun Savel
(UCB junior)

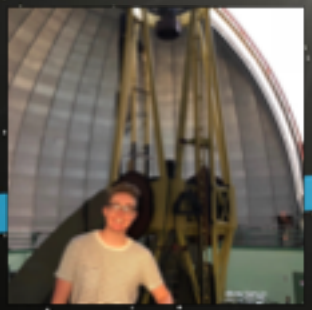
Elliot Cantor
(UCB junior)



Keck/TESS ToO Program (PI: Beichman)

Figure by D. Ciardi

Follow-up Transit Observations will Confirm Transit Times & Recover Single-Transit Events



Jordan Fleming
(3rd year UCB grad)
is analyzing *Spitzer*
observations of
transiting planets

Credit: NASA/JPL

The Next Step:

Characterizing the Atmospheres of Potentially Habitable Planets

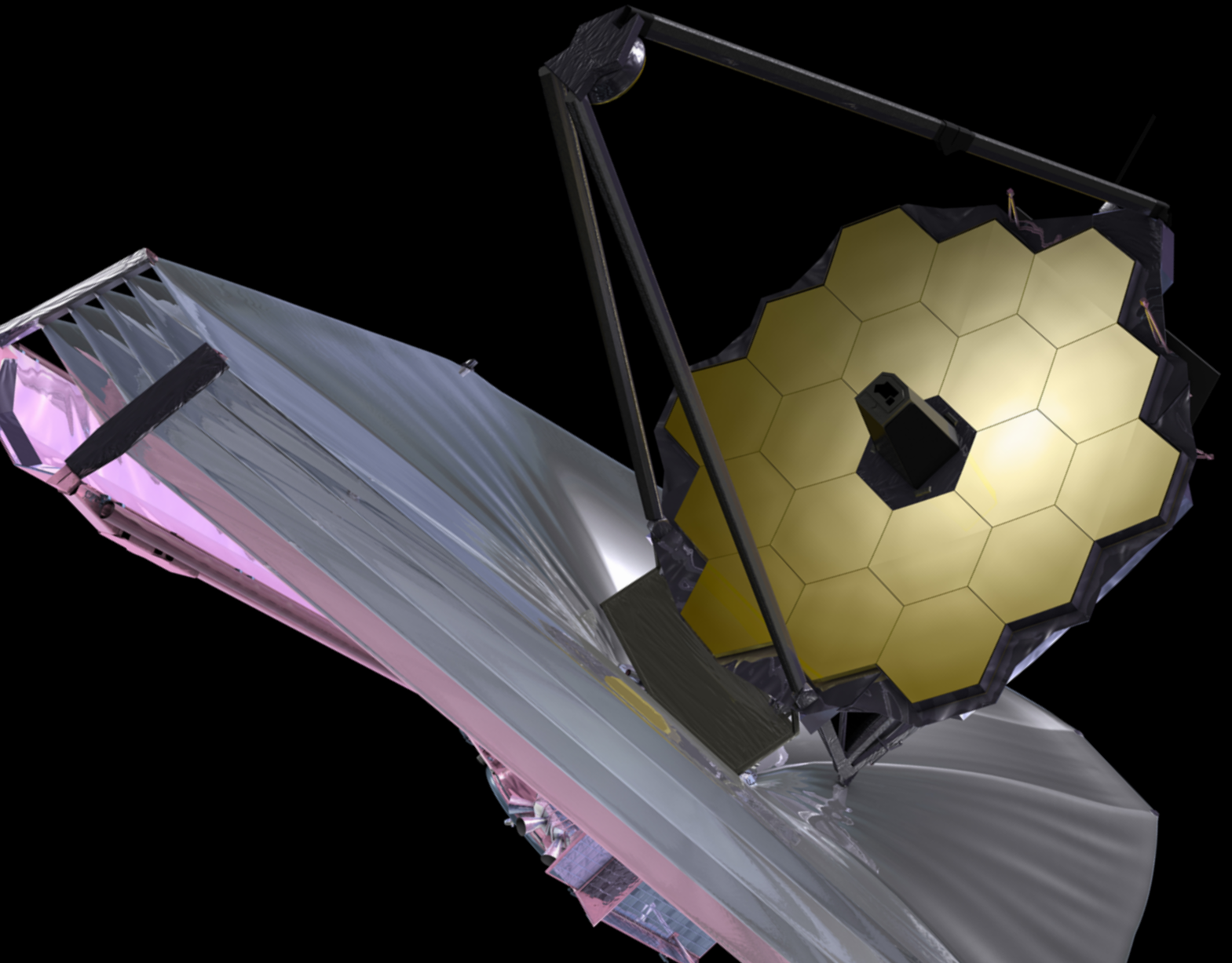
The Future

The Future

Near

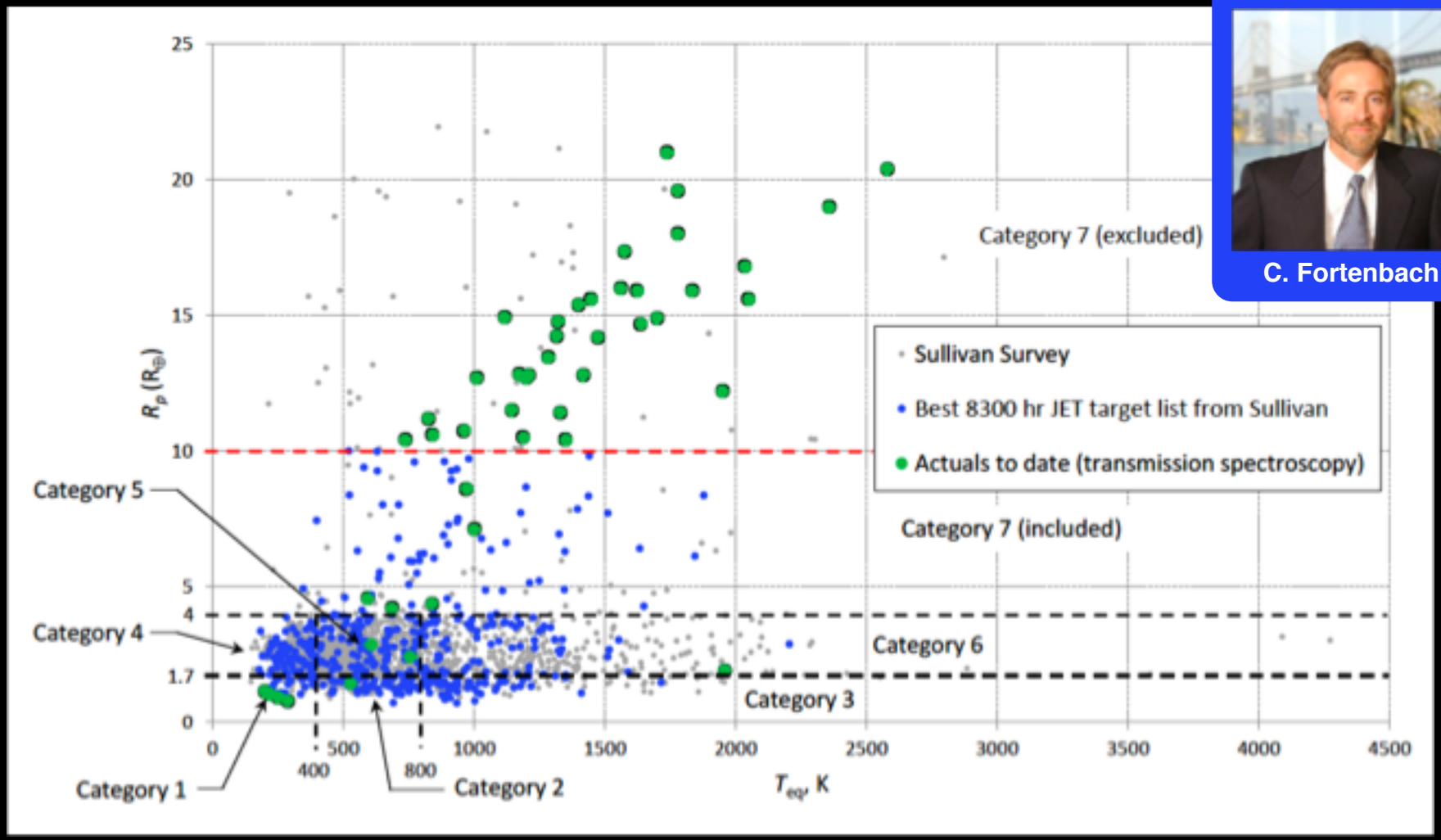
The Hubble Space Telescope

The James Webb Space Telescope



Charles Fortenbach
(SFSU MA Student)
has built a framework
to rank TESS planets
for study with JWST

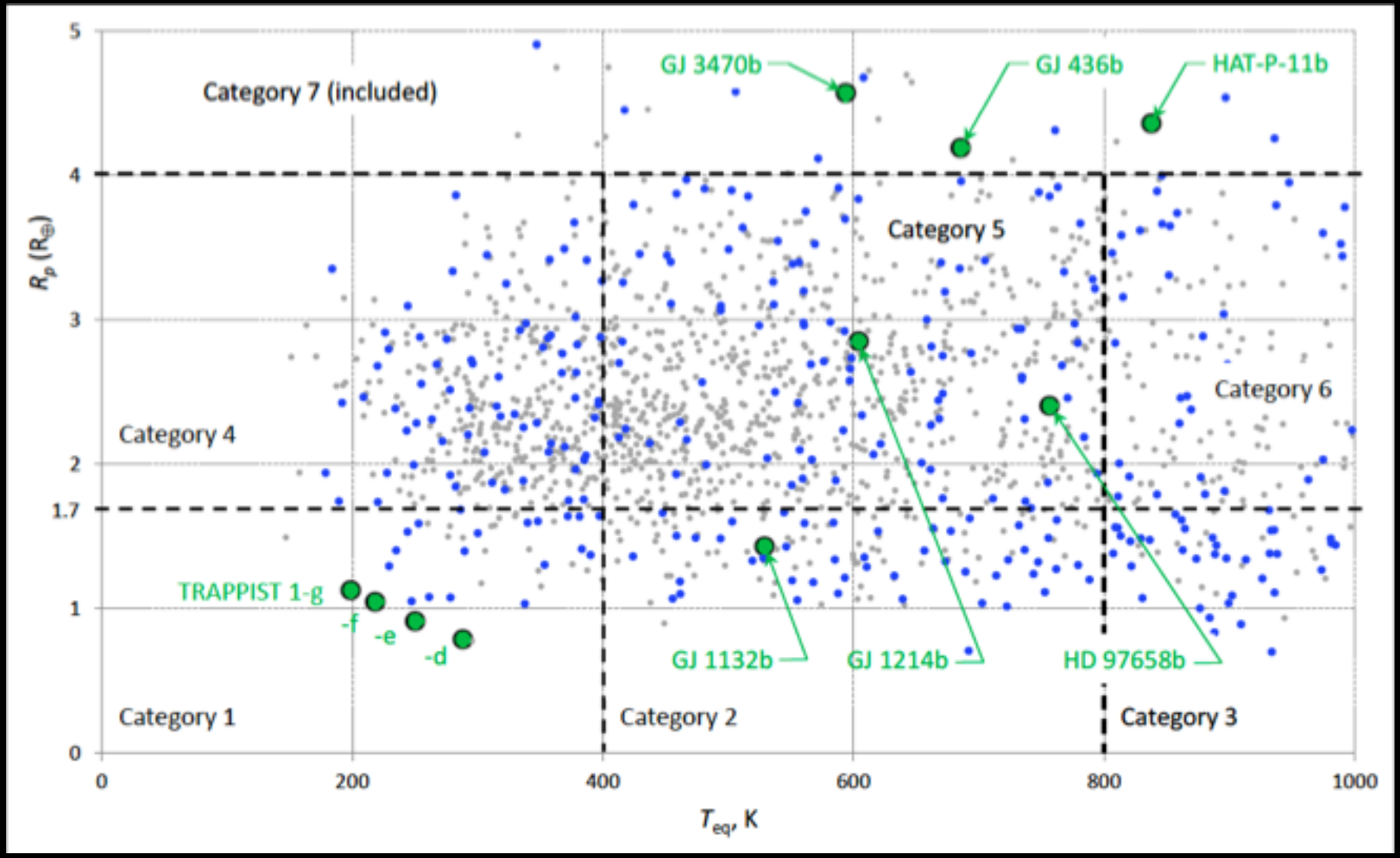
Prioritizing *TESS* Planets for Atmospheric Characterization with *JWST*



C. Fortenbach

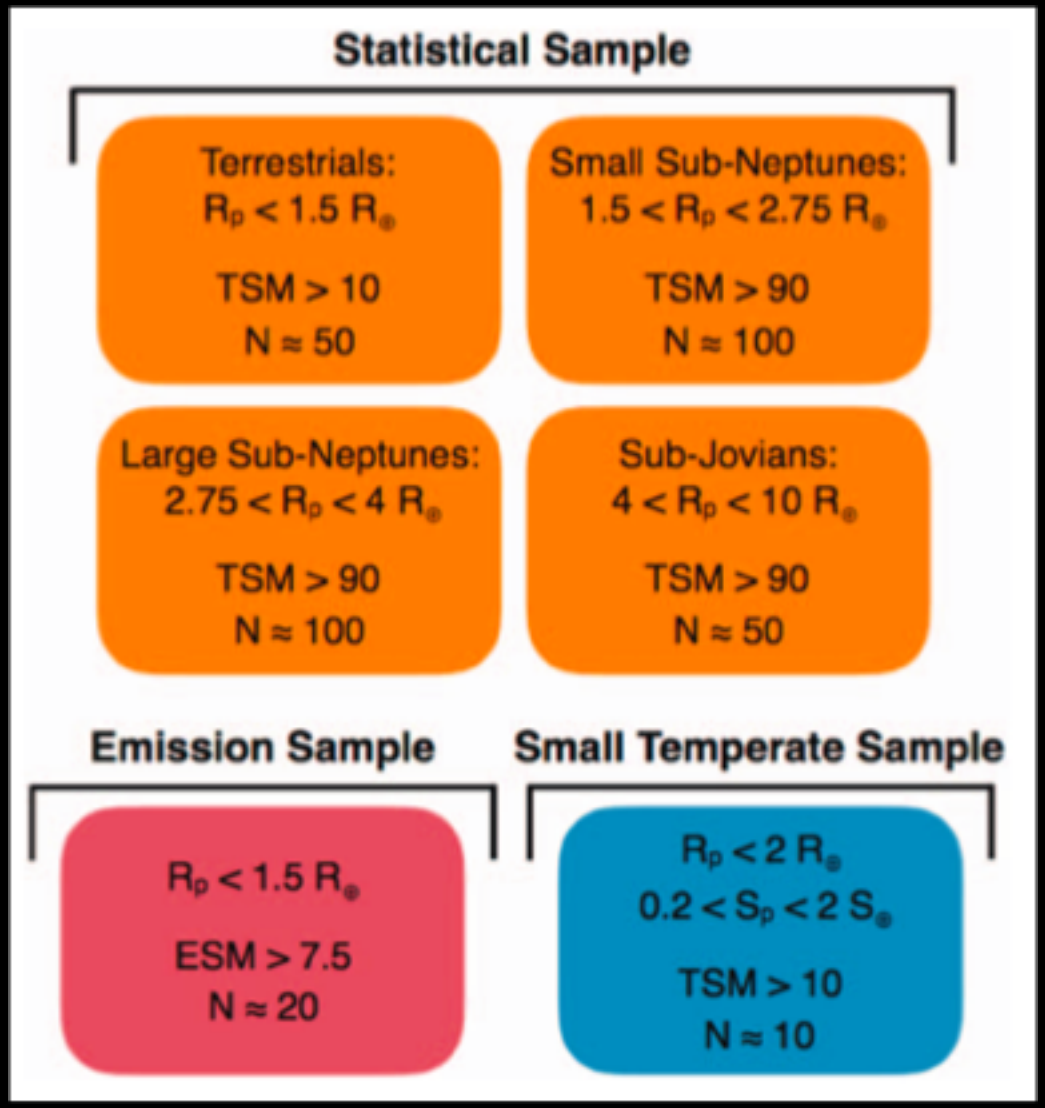
Fortenbach & Dressing (in prep)

Prioritizing *TESS* Planets for Atmospheric Characterization with *JWST*



Fortenbach & Dressing (in prep)

Prioritizing *TESS* Planets for Atmospheric Characterization with *JWST*

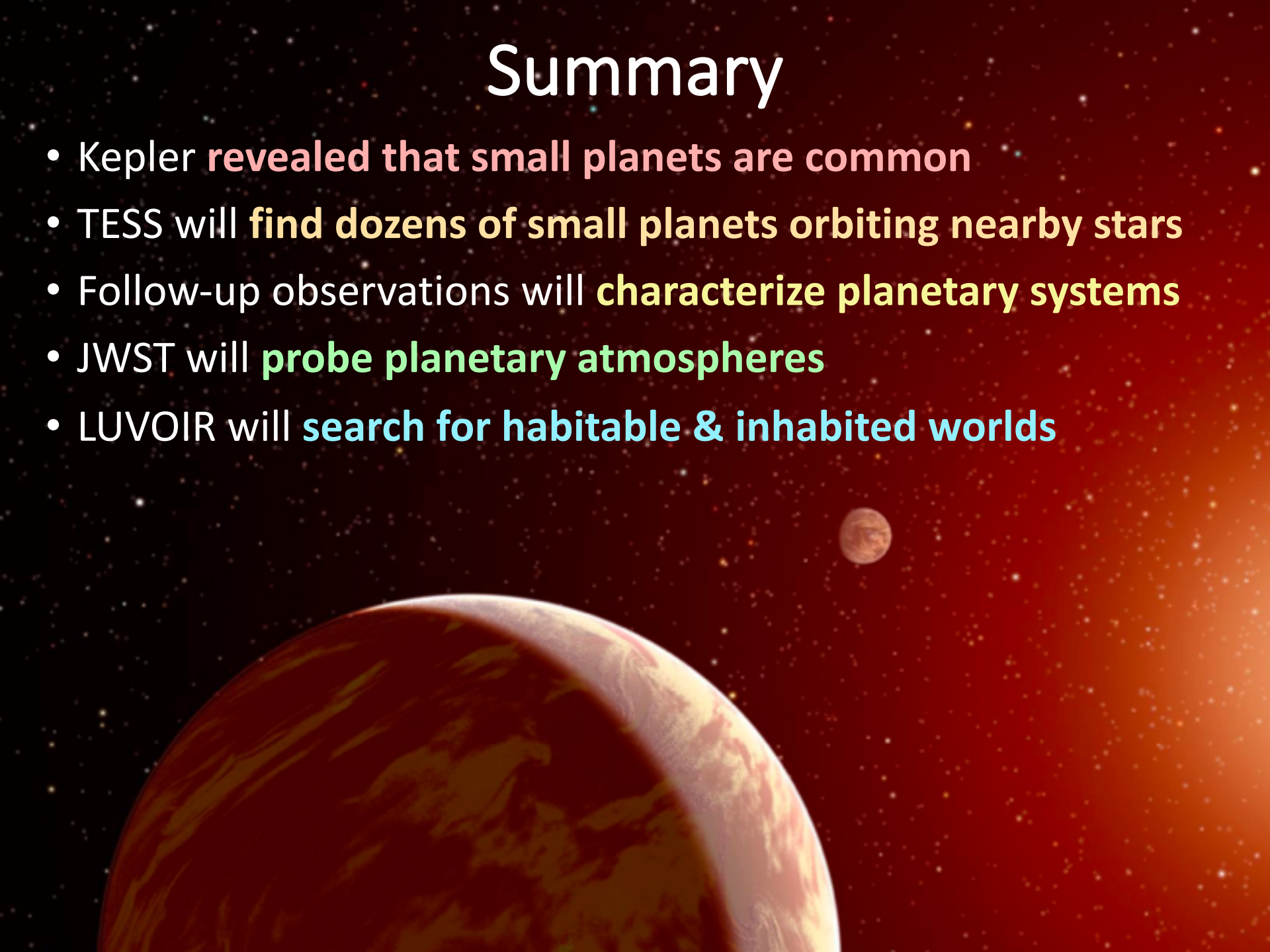


Kempton et al. (2018)

Ground-based observations will complement space-based observations

Summary

- Kepler **revealed that small planets are common**
- TESS will **find dozens of small planets orbiting nearby stars**
- Follow-up observations will **characterize planetary systems**
- JWST will **probe planetary atmospheres**
- LUVOIR will **search for habitable & inhabited worlds**



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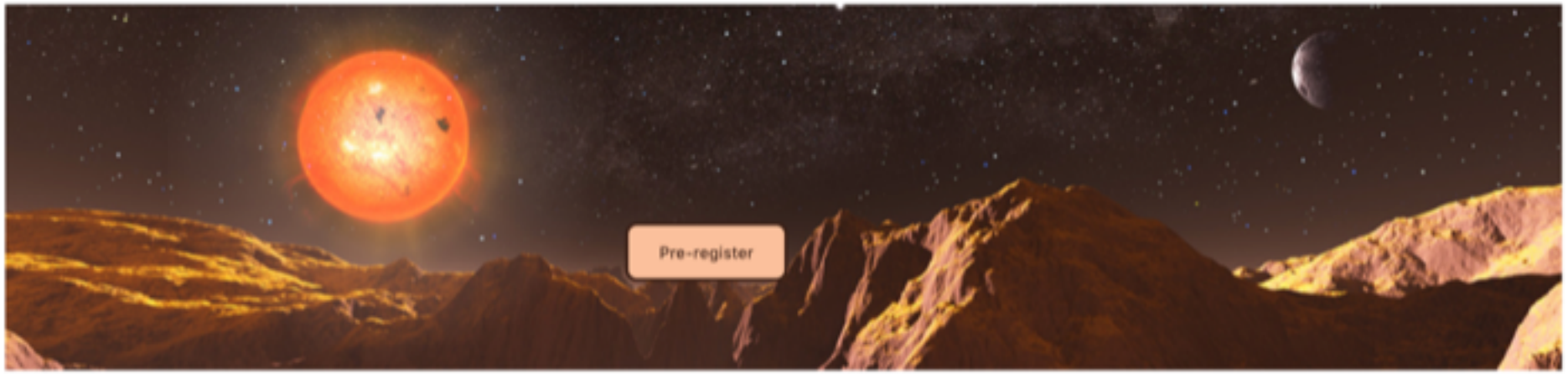
Thanks to my group & collaborators!

SEEC Symposium 2019



SEEC Symposium 2019 | November 4-8, 2019 | NASA GSFC, Greenbelt, MD

Rocky Exoplanets in the Era of JWST: Theory and Observation

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