Finding Planets Around Nearby Stars & A Voice Within Research Collaborations

Courtney Dressing
Assistant Professor at UC Berkeley

Exoplanet Explorers
March 19, 2021

Research funding provided by UC Berkeley, the David & Lucile Packard Foundation, the Sloan Foundation, the Hellman Family Faculty Fund, the NASA TESS Guest Investigator & K2 Guest Observer Programs, NASA FINESST Program, and NSF GRFP

Image Credit: NASA/JPL-Caltech

Big Question #1: ***How Common is Life?***

Big Question #2: ***How can I maintain a scientific identity while working in a large collaboration?***

Globular Cluster Messier 107 (Credit: ESA/NASA)

Collaborations During Graduate School

- Research Group
  - Advisor: David Charbonneau
  - Grad cohort: Zach Berta-Thompson, Sarah Ballard, Elisabeth Newton, Jason Dittmann, Sukrit Ranjan
  - Staff scientists: Jonathan Irwin
- *Kepler* Team
  - Attended team meetings
  - AO Imaging follow-up with Andrea Dupree (CfA)
- HARPS-N Team
  - Weekly in-person collaboration meetings at the CfA
  - Monthly telecons with international collaborators

Collaborations As a Sagan Fellow

- Research Group
  - Met a few times/month with my research sponsor (Heather Knutson)
  - Attended weekly group meetings & chatted with students about their research
  - Worked with Heather to co-advise summer student Girish Duvvuri (now at CU)
- Caltech& NExSci/IPAC
  - Went to other departments/organizations on campus to attend talks
  - Joined *K2* and *Spitzer* collaborations
  - Started working with new people! (e.g., Beichman, Christiansen, Ciardi, Crossfield, Schlieder)
- HARPS-N Team
  - Continued to call in to collaboration meetings
- LUVOIR Science & Technology Definition Team

Collaborations As a Faculty Member

- LUVOIR Science & Technology Definition Team
  - Attended several in person meetings
  - Participated in weekly telecons
  - Helped design LUVOIR & write the final report
- TESS-Keck Survey
  - Attending weekly telecons & less frequent all-hands meetings
  - Helped write & lead telescope proposals
  - Advising students working on papers
  - Co-leading various science cases
- Astro2020 Panel on Exoplanets, Astrobiology, & The Solar System
  - Read many white papers & summarized key findings
  - Attended several in-person meetings & many telecons
  - Helped write our panel report

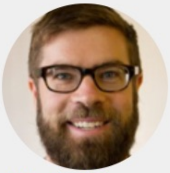
Voting Members of LUVOIR

Non-Voting Members of LUVOIR

International Ex-Officio Non-Voting Members


Martin Barstow
Leicester


Lars Buchhave
Copenhagen


Nicolas Cowan
McGill


José Dias do Nascimento Jr.
Brazilian Federal University


Marc Ferrari
Marseille


Ana Gomez de Castro
Madrid


Kevin Heng
Berne


Thomas Henning
Max Planck


Michiel Min
Netherlands Institute for Space Research


Antonella Nota
ESA


Takahiro Sumi
Osaka

Ex-Officio Non-Voting Members


Shawn Domagal-Goldman
NASA GSFC


Mario Perez
NASA HQ


Michael Garcia
NASA HQ


Susan Neff
NASA GSFC

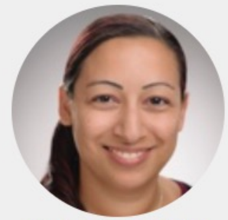

Erin Smith
NASA GSFC

LUVOIR Study Office at Goddard

Study Office


Giada Arney
GSFC


Matt Bolcar
GSFC

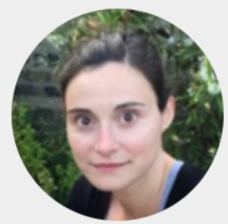

Knicole Colón
GSFC


Julie Crooke
GSFC

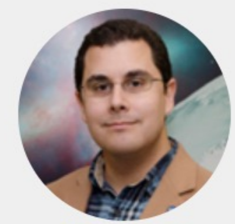

Thomas Fauchez
GSFC


Tyler Groff
GSFC

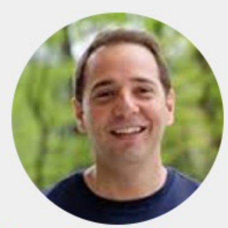

Jason Hylan
GSFC

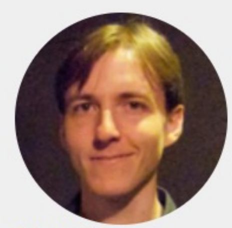

Roser Juanola Parramon
GSFC


Ravi Kopparappu
GSFC


Eric Lopez
GSFC


Avi Mandell
GSFC


Geronimo Villanueva
GSFC


Neil Zimmerman
GSFC

My Research Group: Planets And Life in Space (PALs)

- Graduate Students
  - Steven Giacalone (4th year)
  - Andrew Mayo (3rd year)
  - Emma Turtelboom (2nd year)
  - Caleb Harada (1st year)
- Undergraduate Students
  - Roughly a dozen students who attend group meetings & work on team projects
  - Three students working on individual projects with me
  - Two students working on individual projects with Steven
- Group Structure
  - Weekly group meetings
  - Weekly one-on-one meetings
  - Slack channel
  - Team website
  - Shared Overleaf files for papers & proposals
  - Google drive for notes & presentations

Intermediate Questions & Talk Outline

- **Where are the nearest planets?**
- **What are the properties of those systems?**
- **Which planets are rocky?**
- **How frequent are Earth-like planets?**
- **How common is life?**

Q1. Where are the nearest planets?

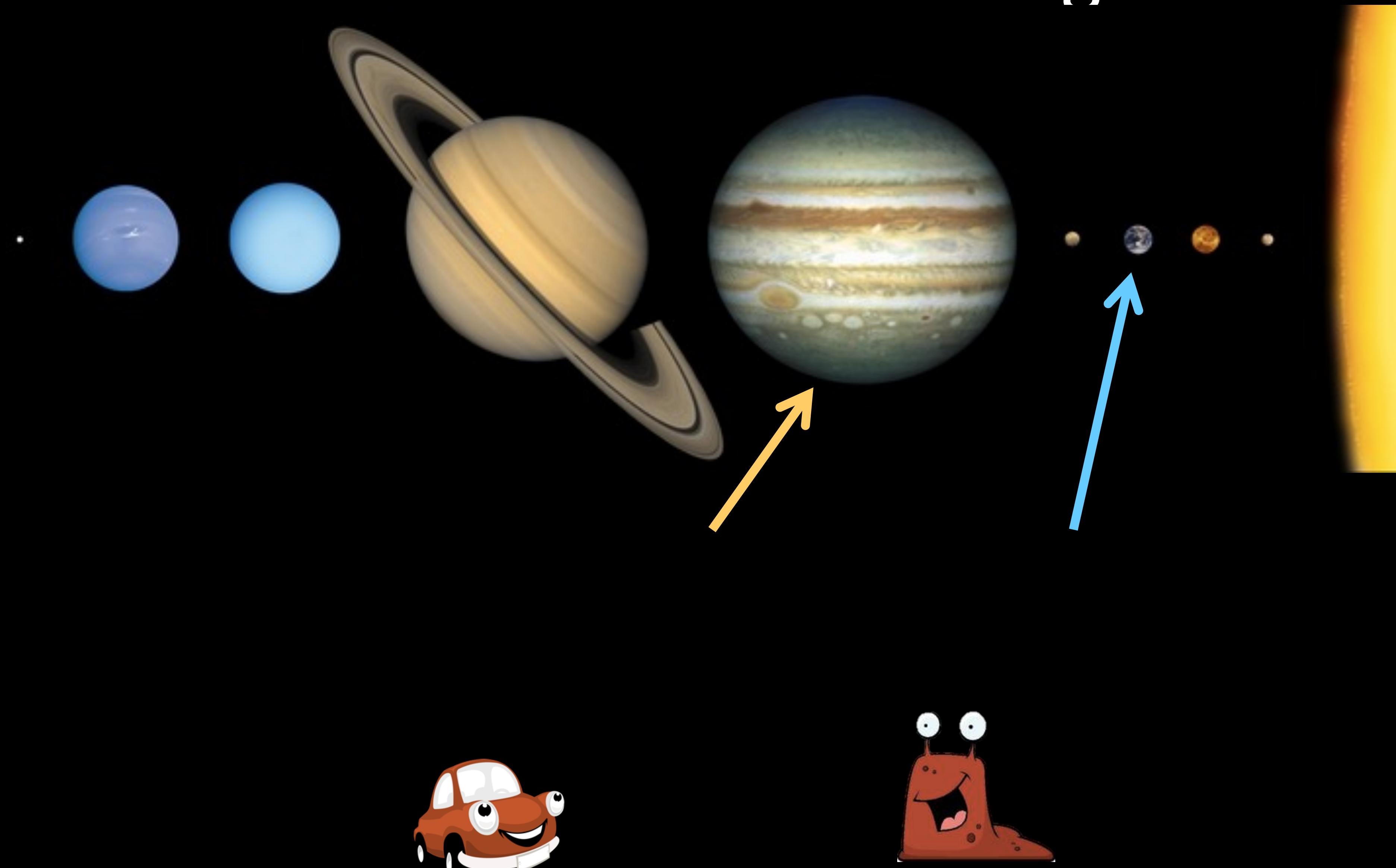
Transit Observations Reveal Planet Sizes

Transit Observations Reveal Planet Sizes

Radial Velocity Observations Reveal Planet Masses

Image credit: NASA/SDO, Scientific American

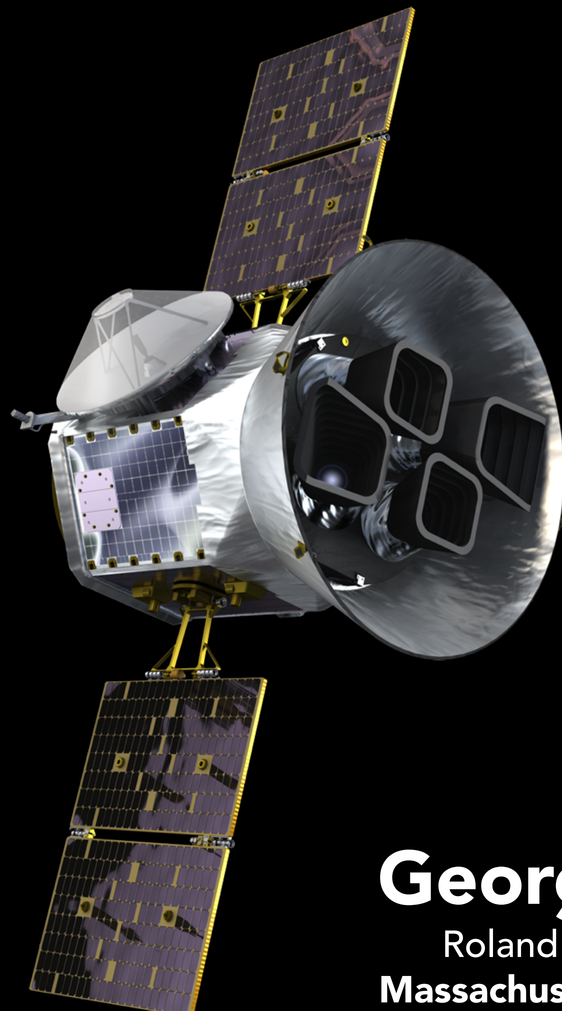
How detectable are these signals?




2285 Confirmed Planets
1792 Candidate Planets
The NASA *Kepler* Mission
2009 - 2013

TESS

Explorer Mission



George Ricker (P.I.)

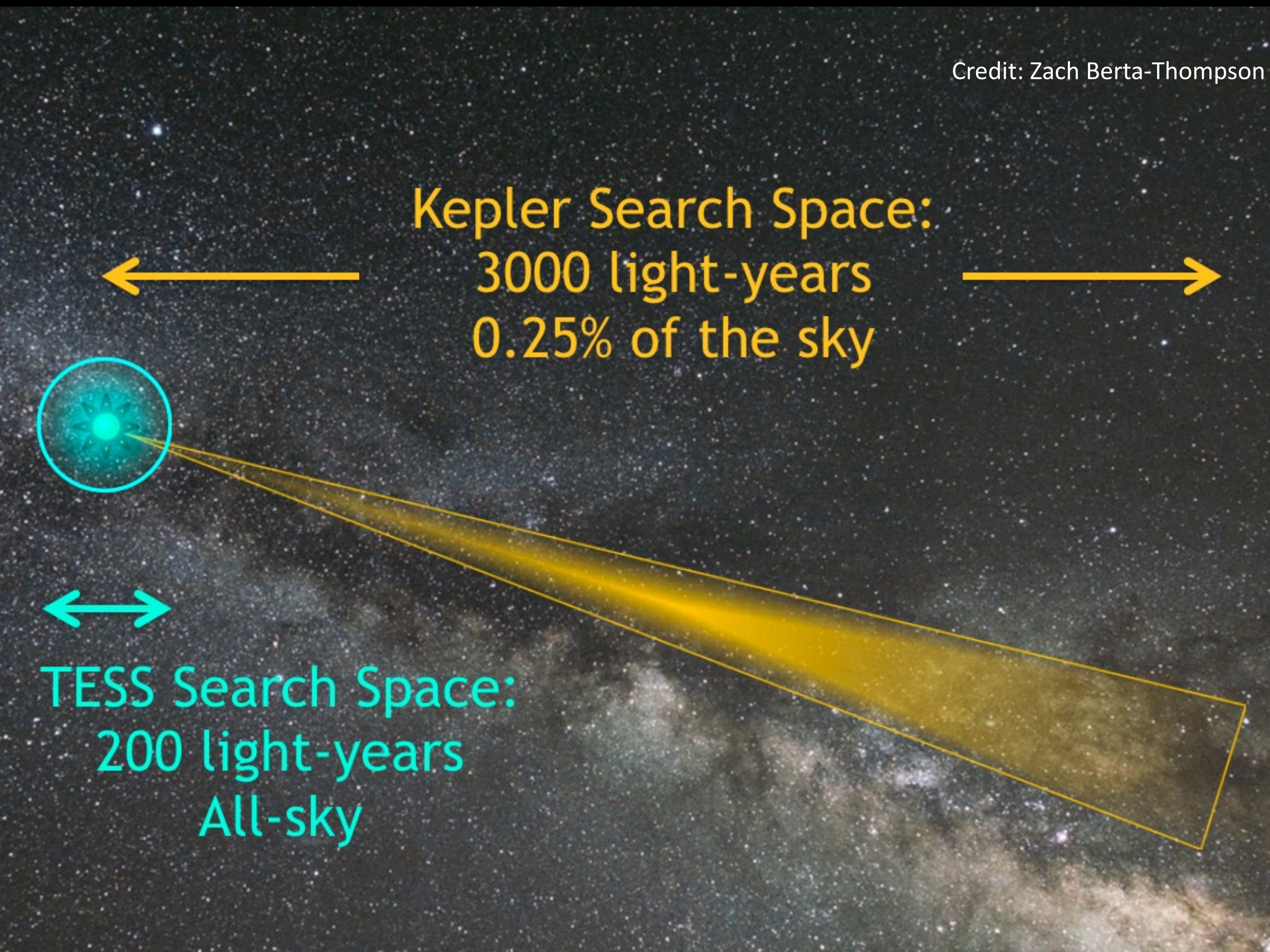
Roland Vanderspek (Deputy P. I.)

Massachusetts Institute of Technology

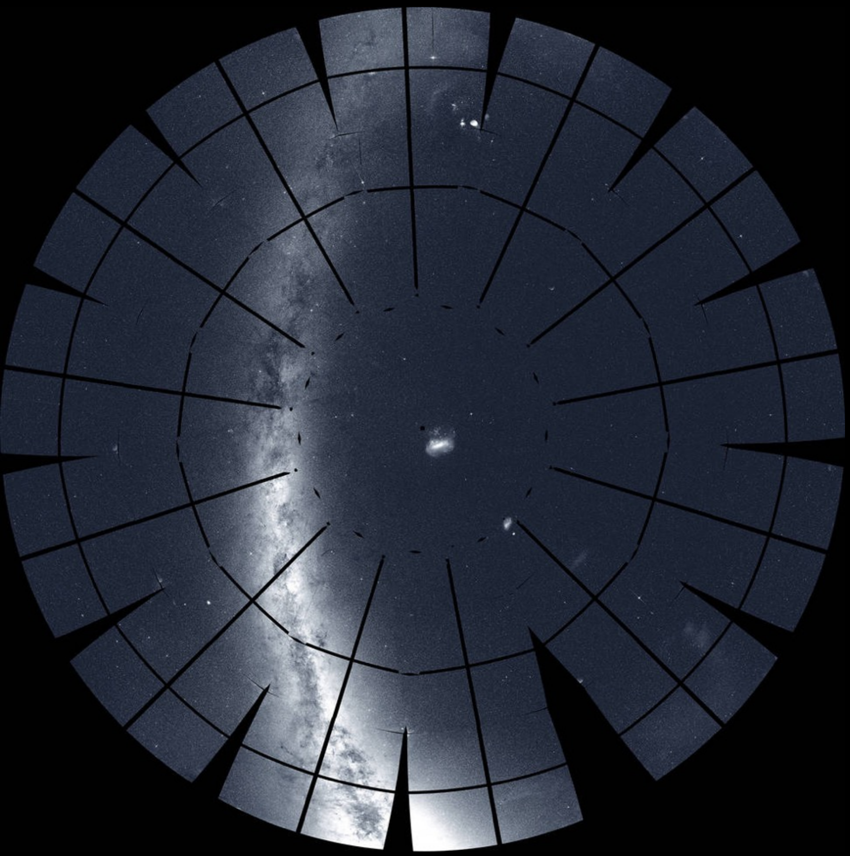
science center shared between

MIT + Harvard/Smithsonian CfA

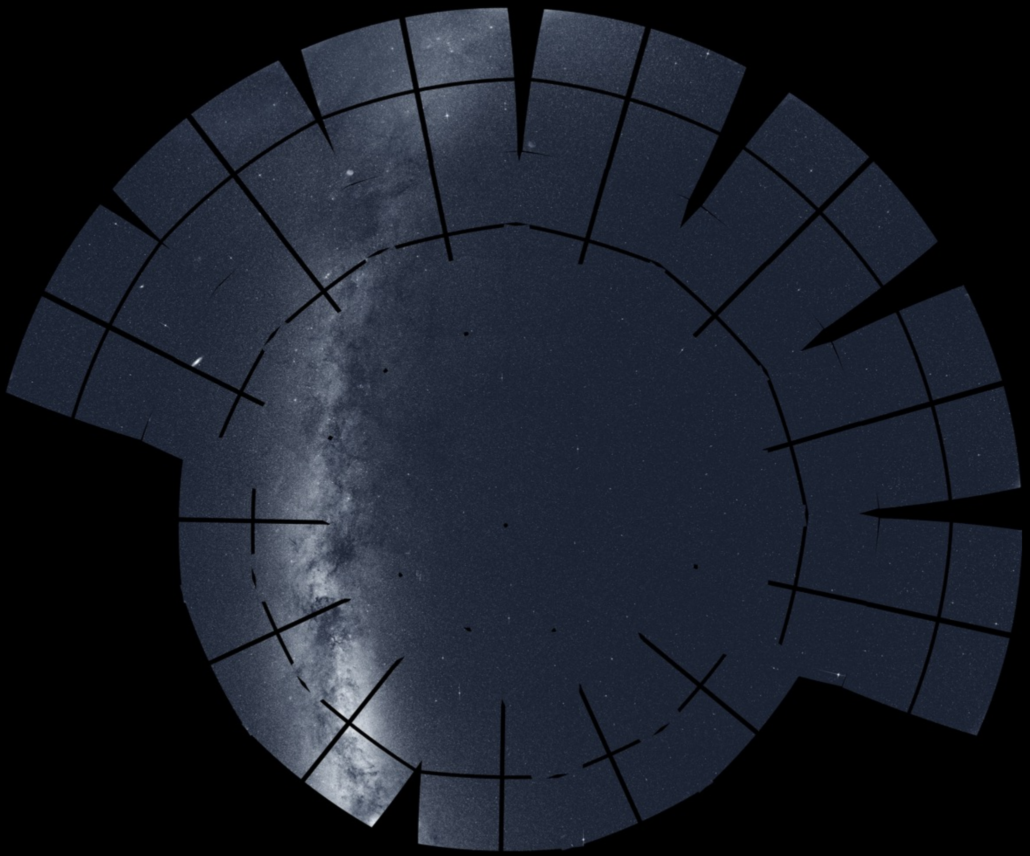
Ricker et al., JATIS, (2014)


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

TESS's Sky Coverage



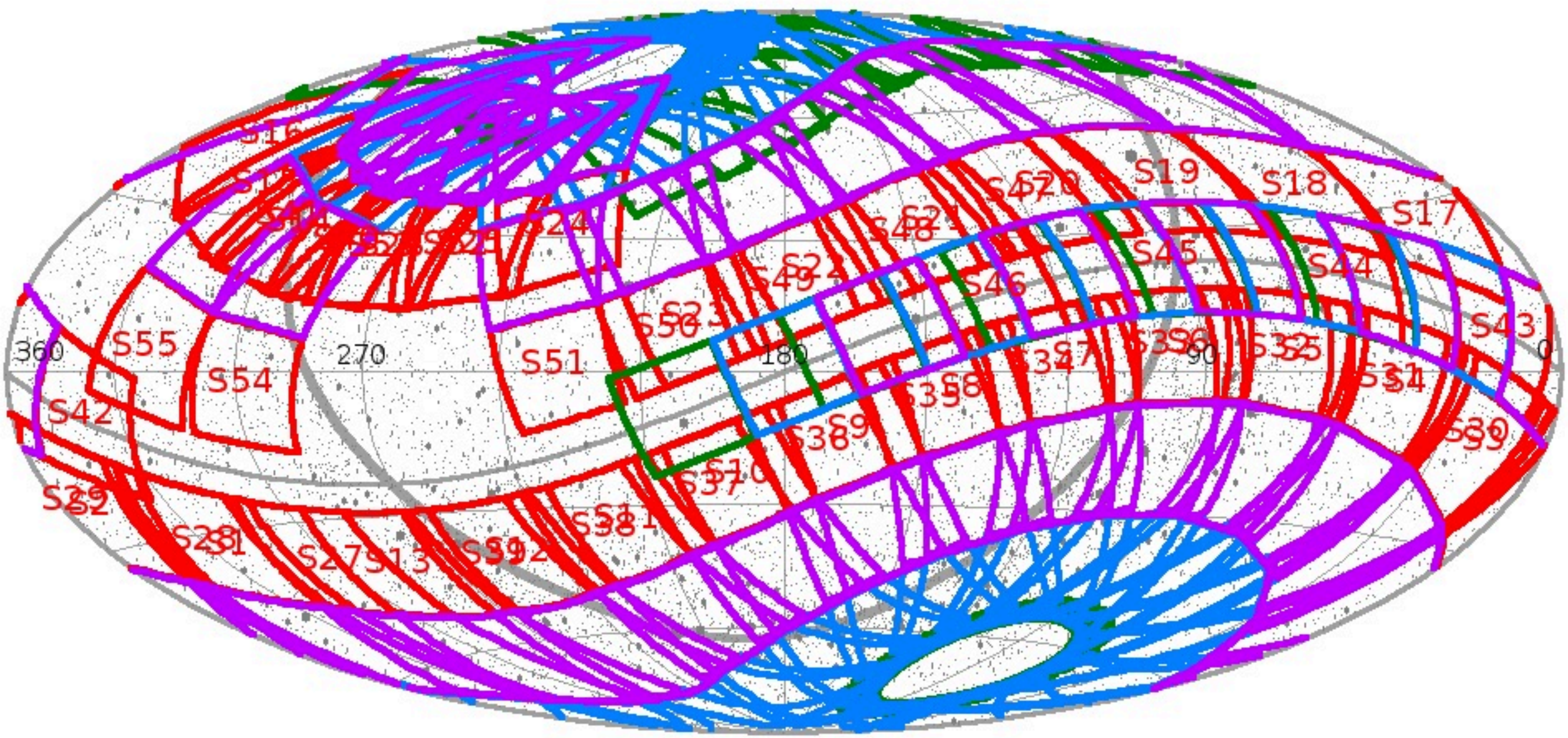
Southern Sky (Year 1)



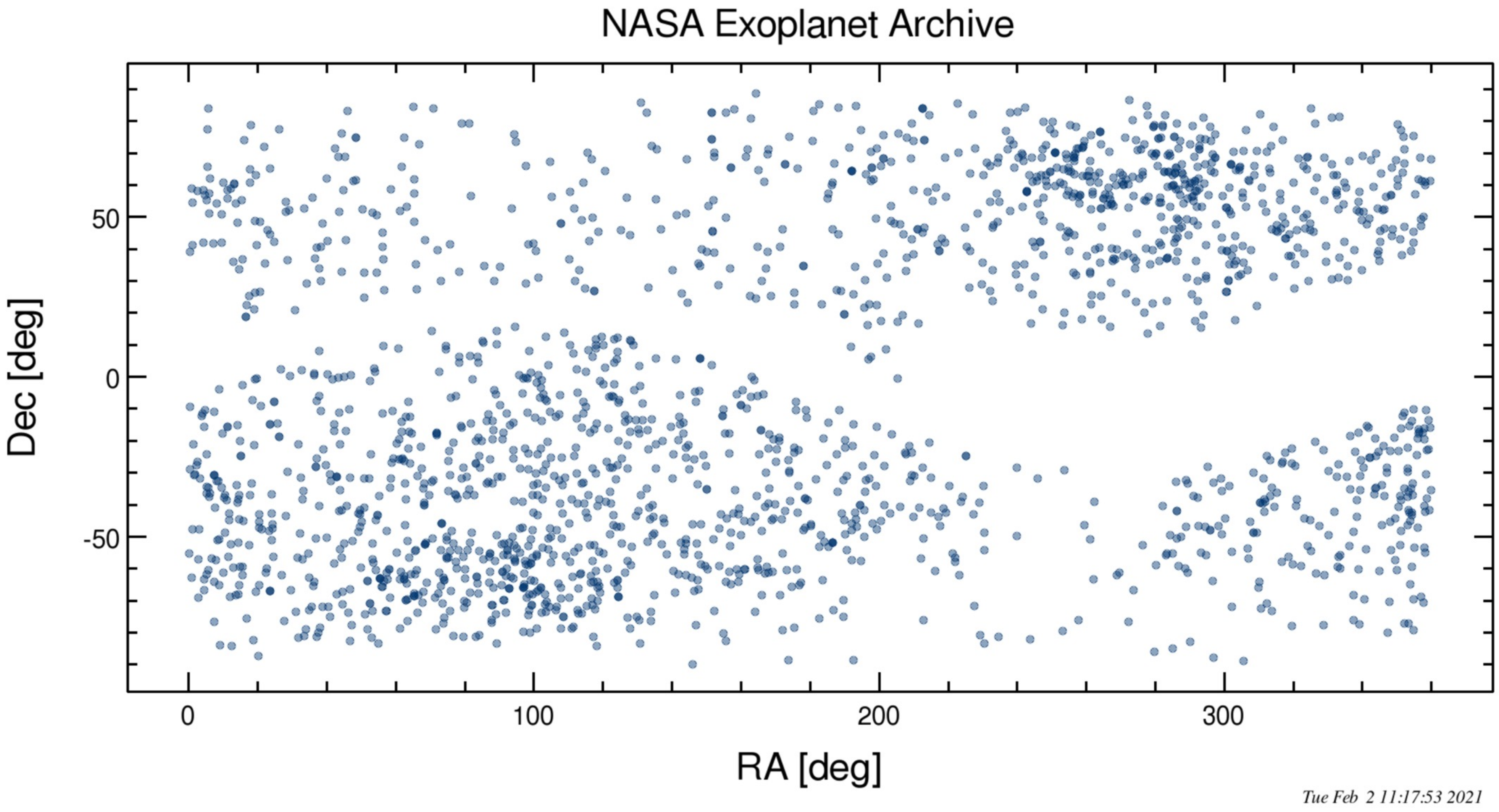
Northern Sky (Year 2)

Image Credits: NASA/MIT/TESS and Ethan Kruse (USRA)

After the Extended Mission, *TESS* will have mapped even more of the sky

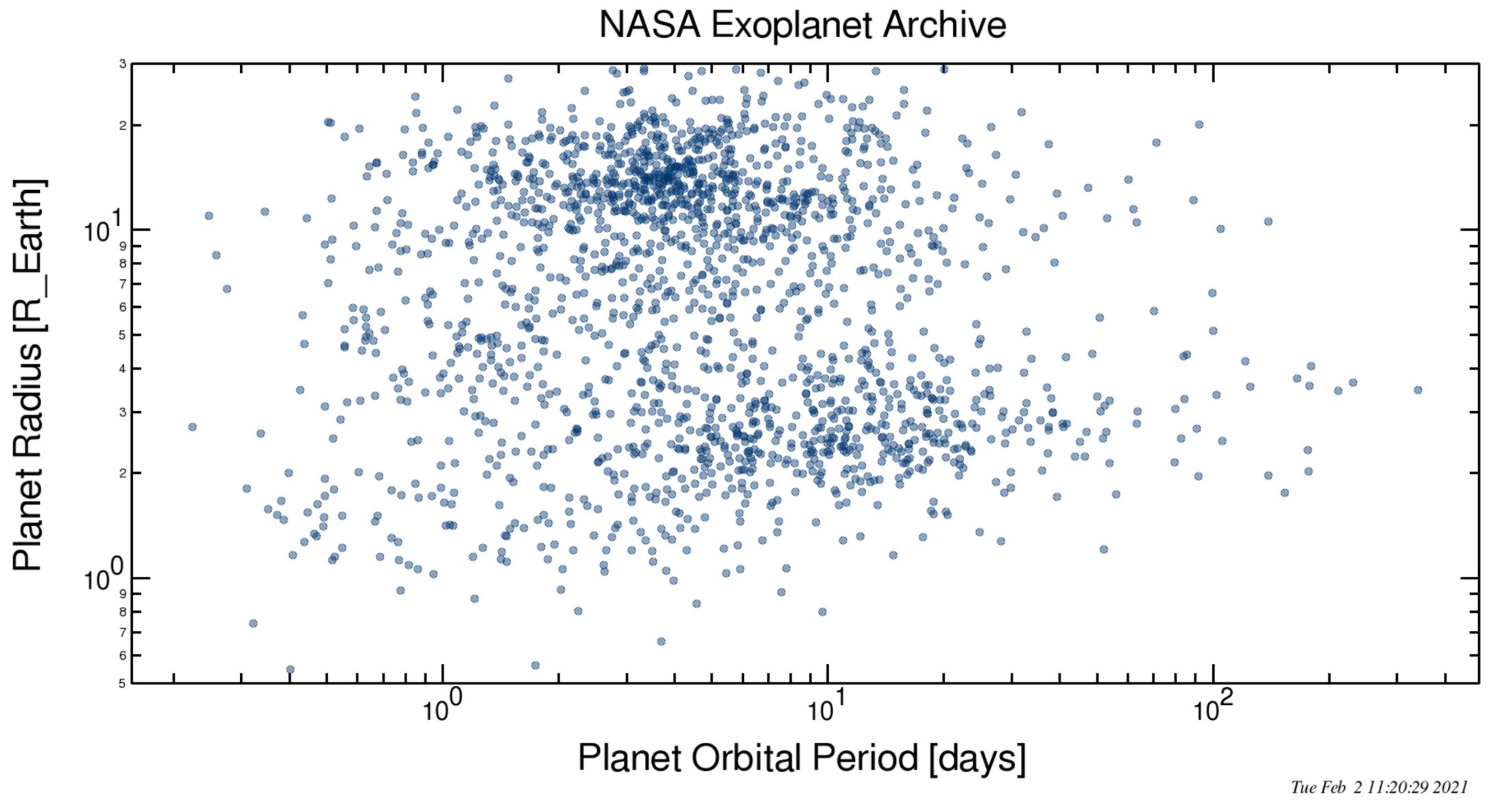


TESS has detected over 2000 Objects of Interest (TOIs)



Plot & Data from NASA Exoplanet Archive

Most *TOIs* have short orbital periods



Plot & Data from NASA Exoplanet Archive

Q2. What are the properties of nearby planets?

Planet characterization requires stellar characterization.

Not All Candidate Signals will be Planets

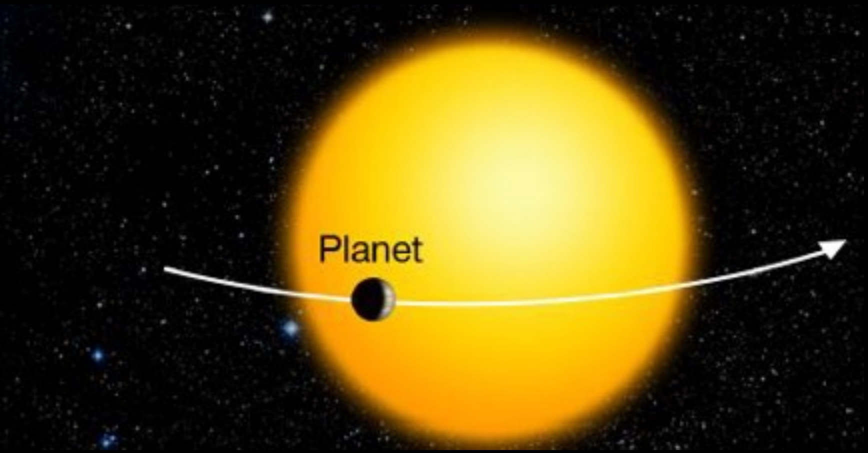
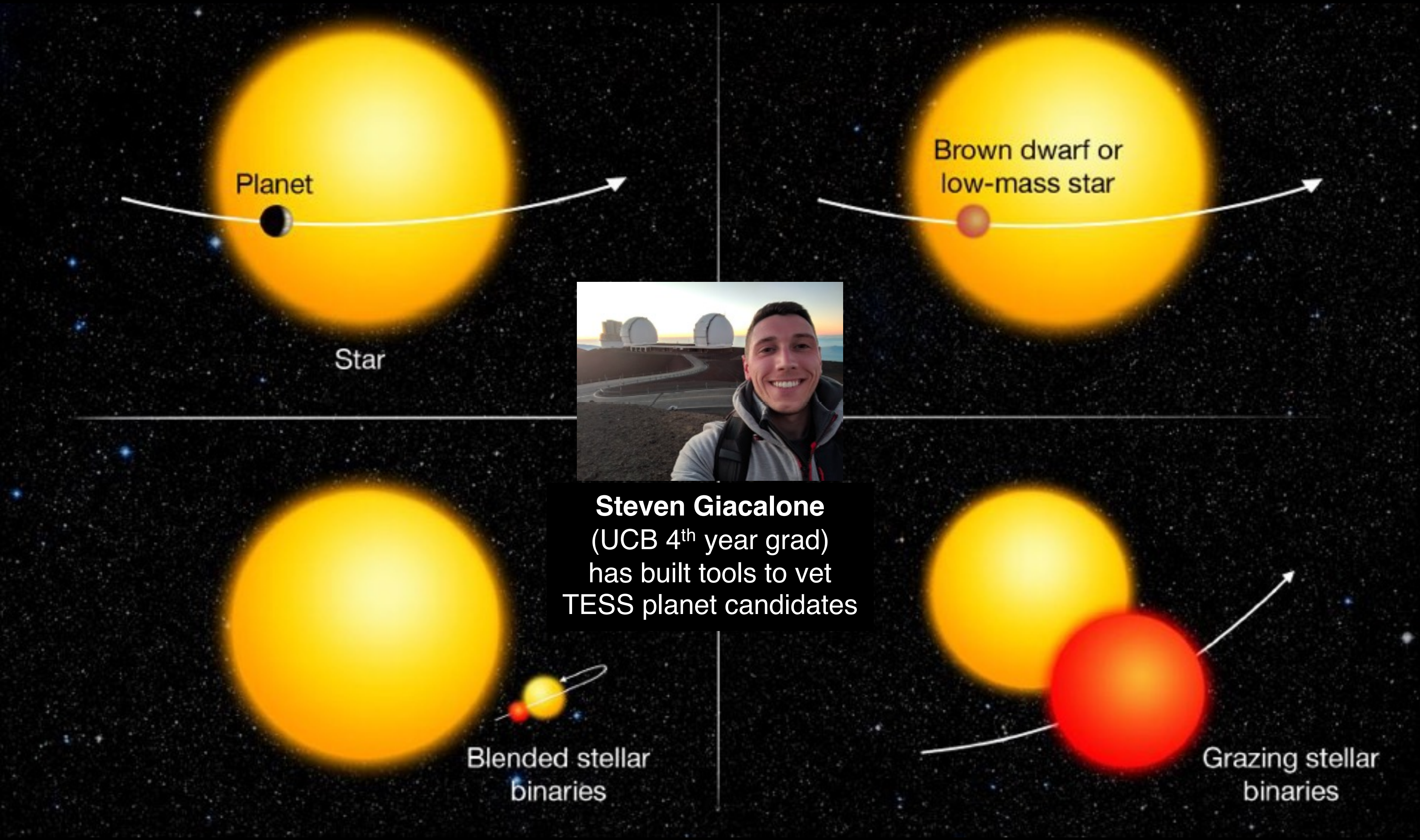


Image Credit: NASA

Not All Candidate Signals will be Planets



Steven Giacalone
(UCB 4th year grad)
has built tools to vet
TESS planet candidates

Image Credit: NASA

TRICERATOPS pipeline described in Giacalone, Dressing et al. 2021 AJ, 161, 24

The Astronomical Journal, 161:24 (27pp), 2021 January
https://doi.org/10.3847/1538-3881/abc6af

Vetting of 384 TESS Objects of Interest with TRICERATOPS and Statistical Validation of 12 Planet Candidates

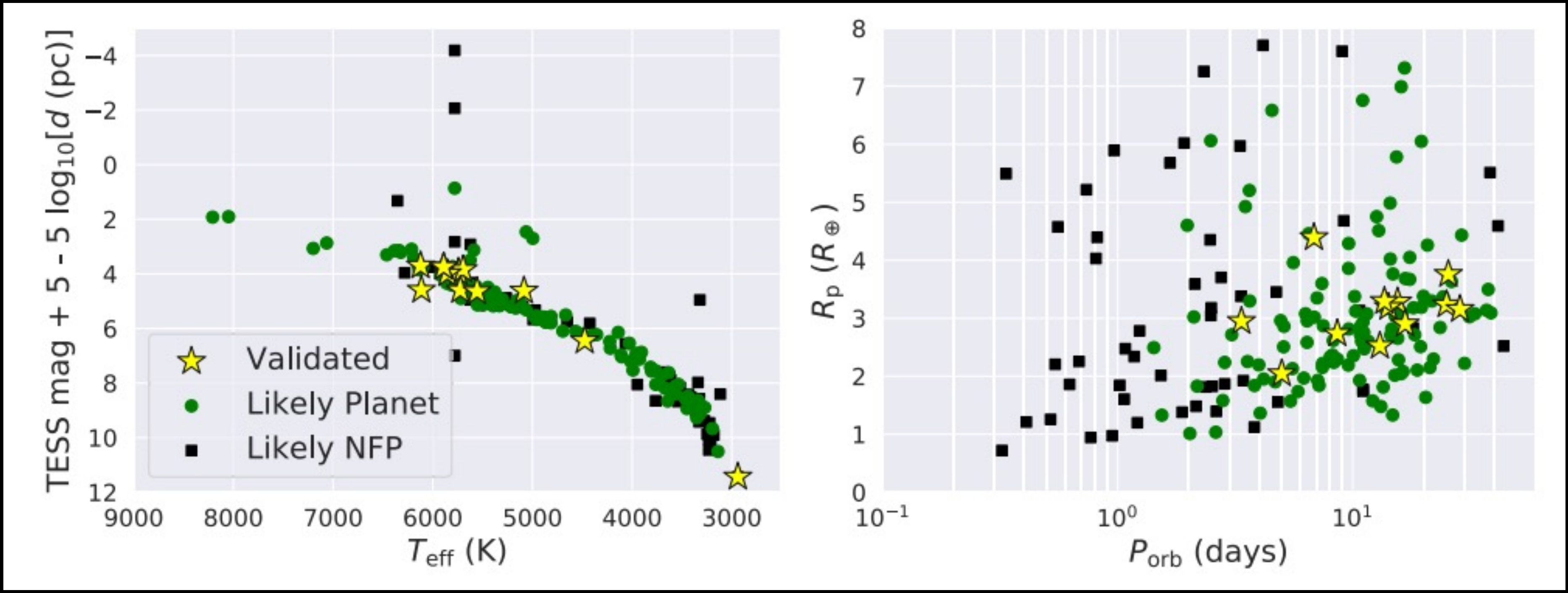
Steven Giacalone[1], Courtney D. Dressing[1], Eric L. N. Jensen[2], Karen A. Collins[3], George R. Ricker[4], Roland Vanderspek[4], S. Seager[4,5,6], Joshua N. Winn[7], Jon M. Jenkins[8], Thomas Barclay[9,10], Khalid Barkaoui[11,12], Charles Cadieux[13], David Charbonneau[3], Kevin I. Collins[14], Dennis M. Conti[15], René Doyon[13], Phil Evans[16], Mourad Ghachoui[12], Michaël Gillon[11], Natalia M. Guerrero[4], Rhodes Hart[17], Emmanuël Jehin[18], John F. Kielkopf[19], Brian McLean[20], Felipe Murgas[21,22], Enric Palle[23,24], Hannu Parviainen[23,24], Francisco J. Pozuelos[11,25], Howard M. Relles[3], Avi Shporer[4], Quentin Socia[26,31], Chris Stockdale[27], Thiam-Guan Tan[28], Guillermo Torres[3], Joseph D. Twicken[8,29], William C. Waalkes[30], and Ian A. Waite[17]

Steven Giacalone
(UCB 4th year grad)

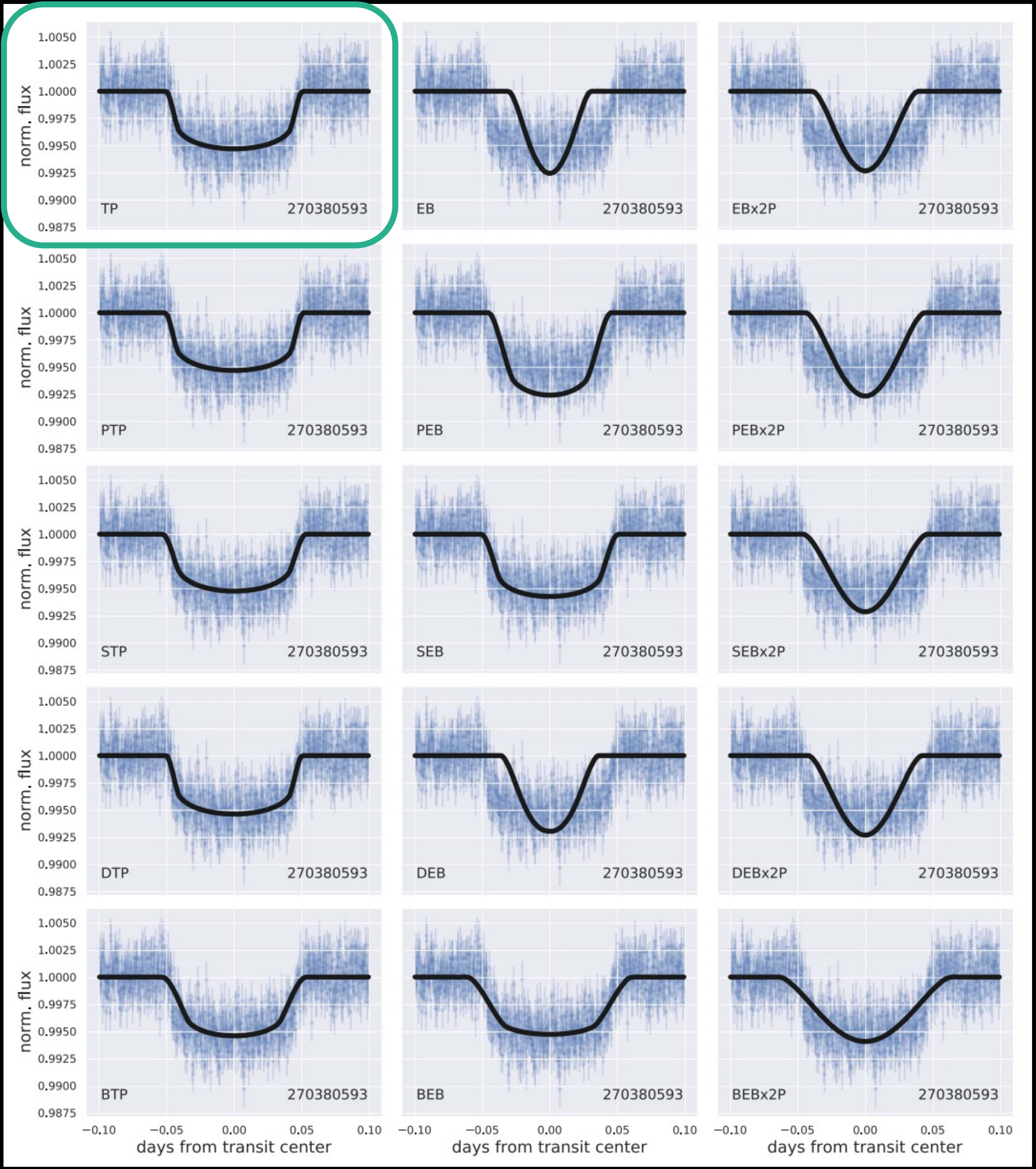
12 Validated TOIs

125 Likely Planets

52 Likely Nearby False Positives



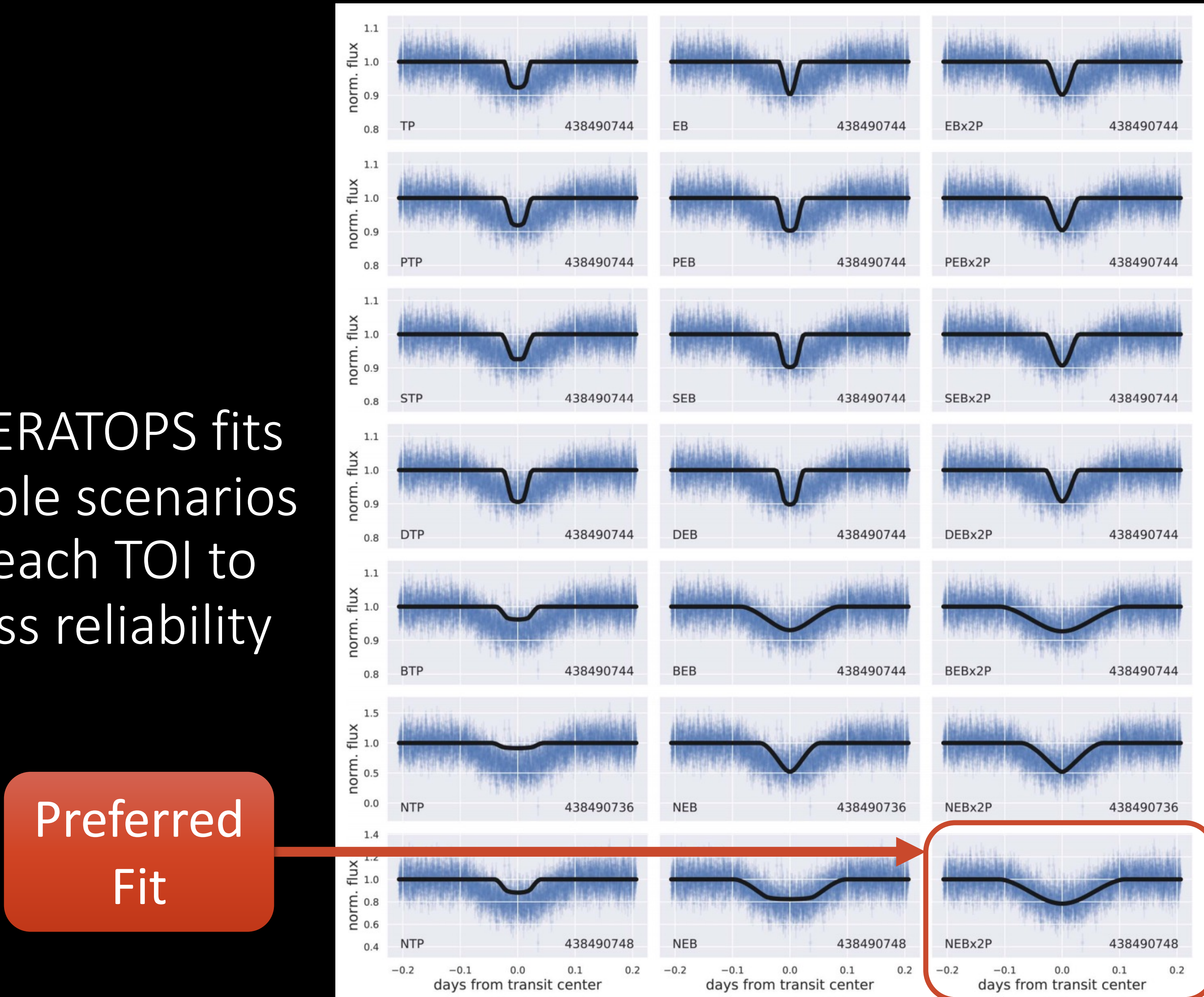
Preferred Fit



TRICERATOPS fits multiple scenarios for each TOI to assess reliability

Giacalone, Dressing et al. 2021 AJ, 161, 24

TRICERATOPS fits multiple scenarios for each TOI to assess reliability

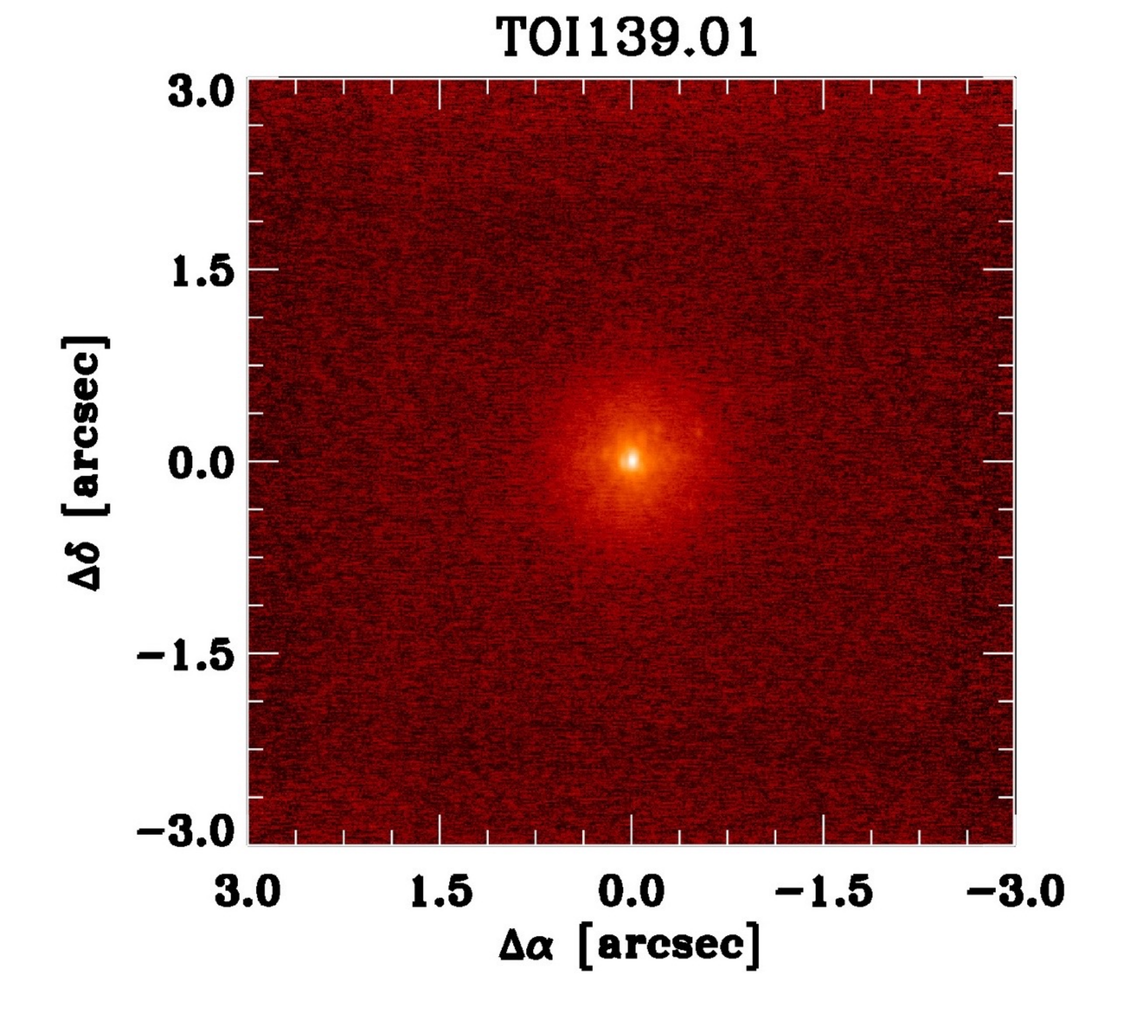


Giacalone, Dressing et al. 2021 AJ, 161, 24

Thank you to TFOP!

Follow-up observations can help distinguish between TESS planets & false positives

No companion star detected. ***Stronger*** support for transiting planet?

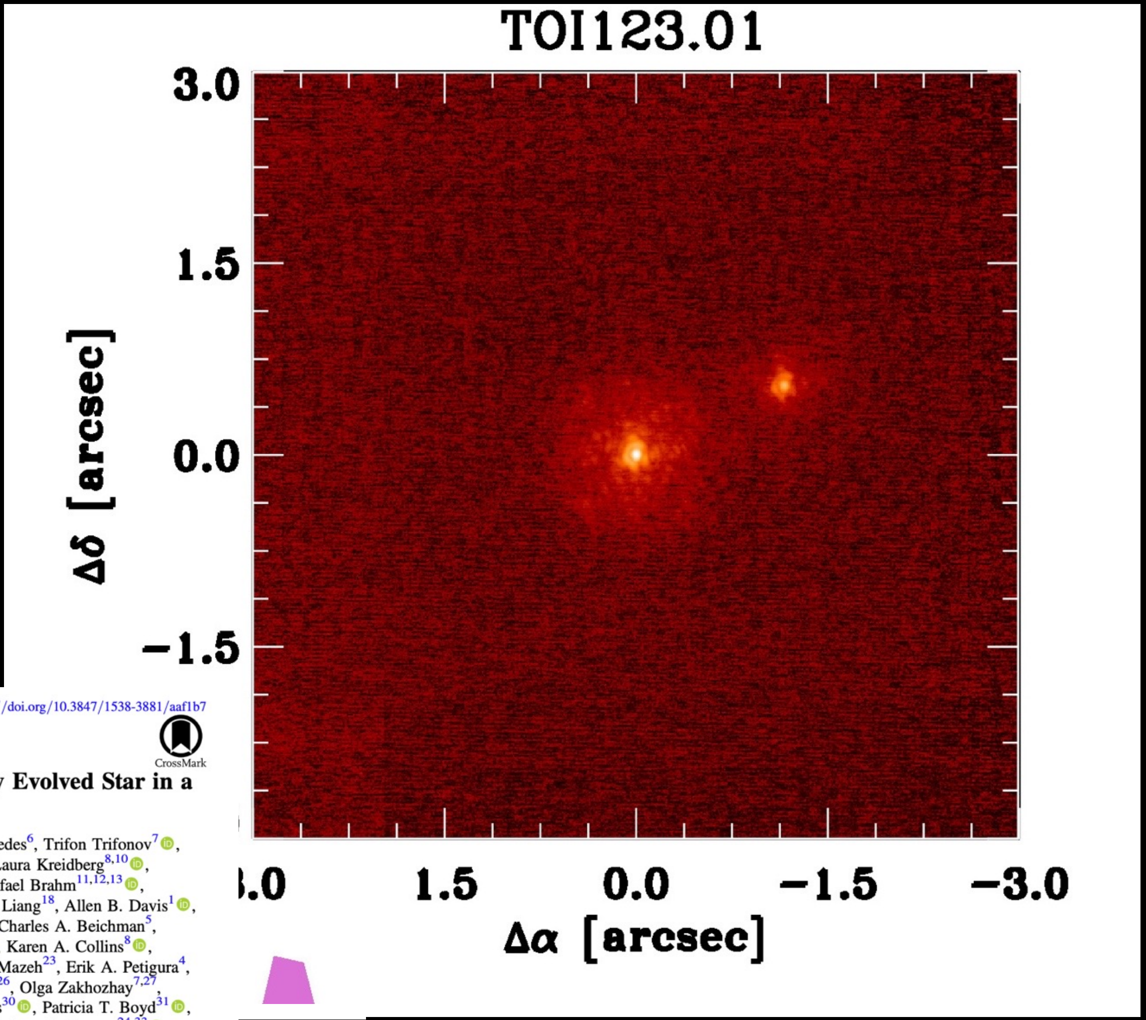


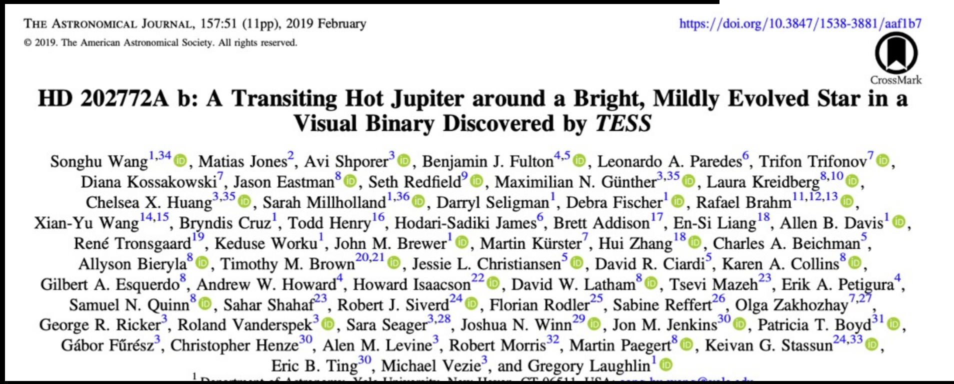
Keck/TESS ToO Program (PI: Beichman)

Figure by D. Ciardi

Follow-up observations can help distinguish between TESS planets & false positives

Companion star detected. ***Weaker*** support for transiting planet?





The Astronomical Journal, 157:51 (11pp), 2019 February
https://doi.org/10.3847/1538-3881/aaf1b7

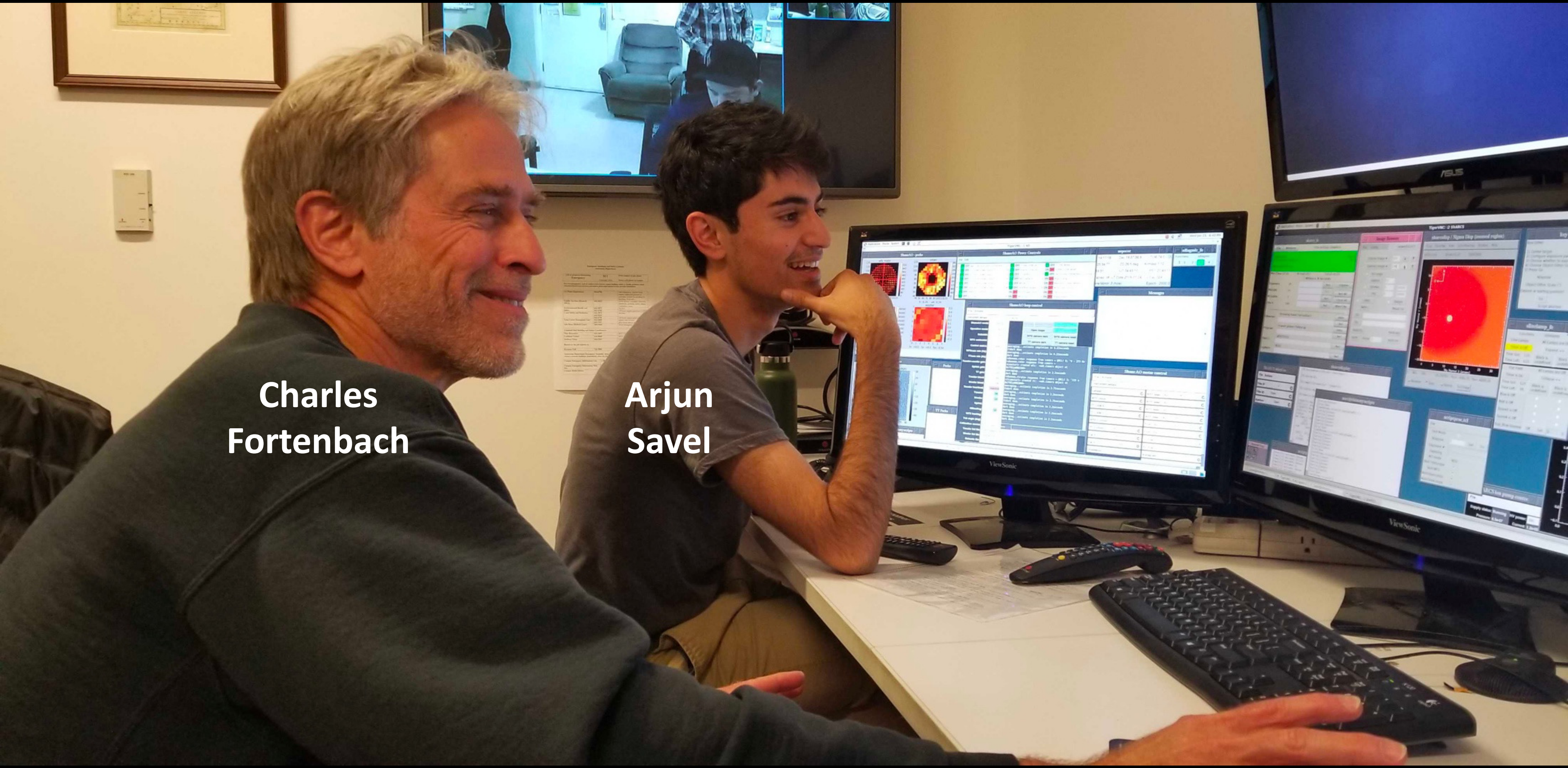
HD 202772A b: A Transiting Hot Jupiter around a Bright, Mildly Evolved Star in a Visual Binary Discovered by *TESS*

Songhu Wang[1,34], Matias Jones[2], Avi Shporer[3], Benjamin J. Fulton[4,5], Leonardo A. Paredes[6], Trifon Trifonov[7], Diana Kossakowski[7], Jason Eastman[8], Seth Redfield[9], Maximilian N. Günther[3,35], Laura Kreidberg[8,10], Chelsea X. Huang[3,35], Sarah Millholland[1,36], Darryl Seligman[1], Debra Fischer[1], Rafael Brahm[11,12,13], Xian-Yu Wang[14,15], Bryndis Cruz[1], Todd Henry[16], Hodari-Sadiki James[6], Brett Addison[17], En-Si Liang[18], Allen B. Davis[1], René Tronsgaard[19], Keduse Worku[1], John M. Brewer[1], Martin Kürster[7], Hui Zhang[18], Charles A. Beichman[5], Allyson Bieryla[8], Timothy M. Brown[20,21], Jessie L. Christiansen[5], David R. Ciardi[5], Karen A. Collins[8], Gilbert A. Esquerdo[8], Andrew W. Howard[4], Howard Isaacson[22], David W. Latham[8], Tsevi Mazeh[23], Erik A. Petigura[4], Samuel N. Quinn[8], Sahar Shahaf[23], Robert J. Siverd[24], Florian Rodler[25], Sabine Reffert[26], Olga Zakhozhay[7,27], George R. Ricker[3], Roland Vanderspek[3], Sara Seager[3,28], Joshua N. Winn[29], Jon M. Jenkins[30], Patricia T. Boyd[31], Gábor Fűrész[3], Christopher Henze[30], Alen M. Levine[3], Robert Morris[32], Martin Paegert[8], Keivan G. Stassun[24,33], Eric B. Ting[30], Michael Vezie[3], and Gregory Laughlin[1]

Keck/TESS ToO Program (PI: Beichman)

Figure by D. Ciardi

Searching for Stellar Companions



Digression: The Importance of Follow-up Imaging for Studies of Planet Occurrence

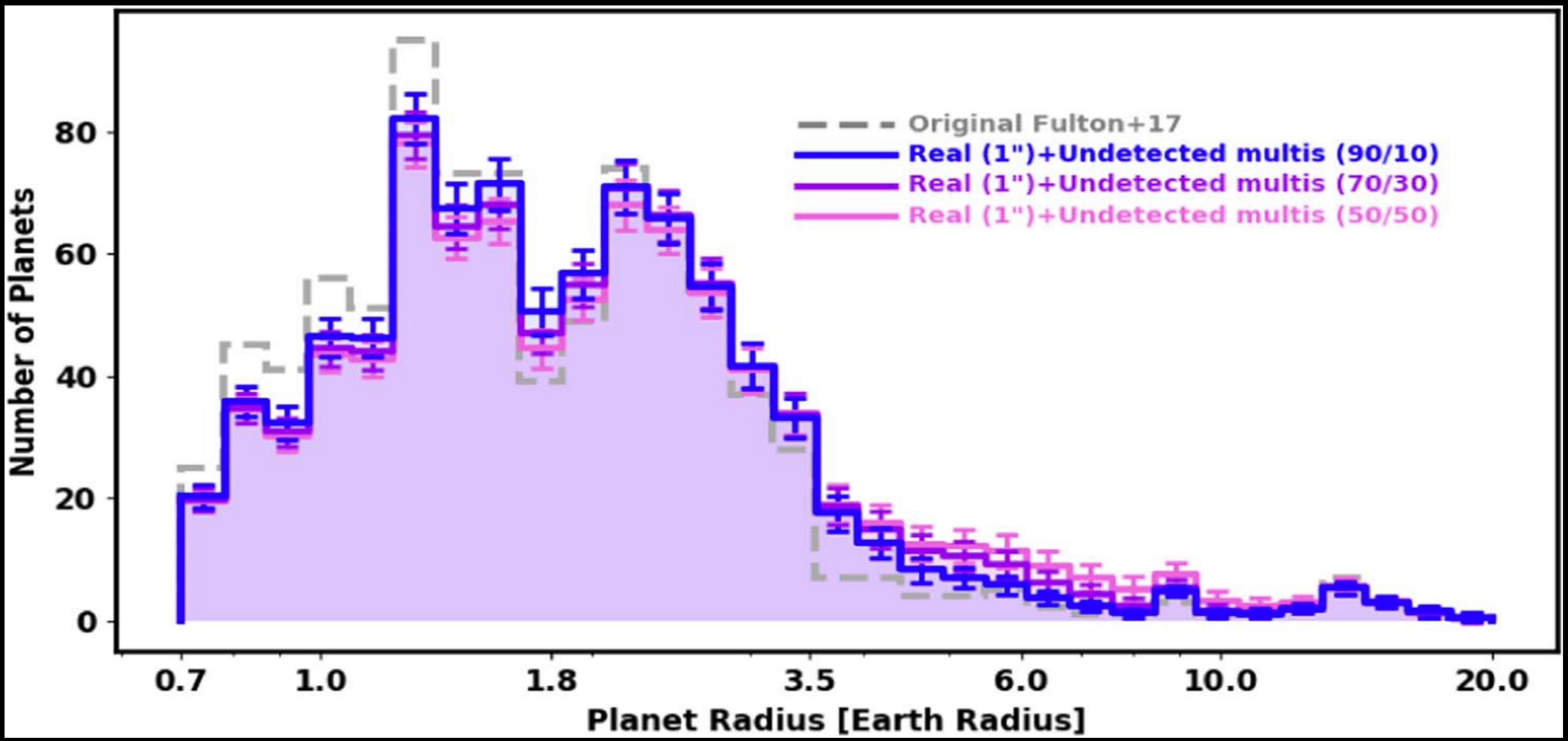
Reliability: *what fraction of candidates are actually planets?*

$$\text{Planet Occurrence Rate} = \frac{\textbf{Planets detected}}{\textbf{Stars searched}}$$

Completeness: *how many real planets were missed?*

Stellar Companions Affect Reliability

- Some “planets” are actually diluted eclipsing binaries
- Real planets may be larger than estimated
- ***This effect is often considered***



Teske et al. (2018)

Stellar Companions Affect Reliability

- Some "planets" are actually diluted eclipsing binaries
- Real planets may be larger than estimated
- ***This effect is often considered***

We are vetting TESS and K2 Objects of Interest by obtaining AO images with Lick/ShARCS, Keck/NIRC2, and Palomar/PHARO.

UCB Team: Arjun Savel (now at UMD), Steven Giacalone, Charles Fortenbach (SFSU), Andy Mayo, Caleb Harada, Emma Turtelboom, Jordan Fleming, Holden Gill

External Collaborators: Lea Hirsch, Jessie Christiansen, David Ciardi, Chas Beichman, Josh Schlieder, Erica Gonzales, Ian Crossfield

Stellar Companions Affect Completeness

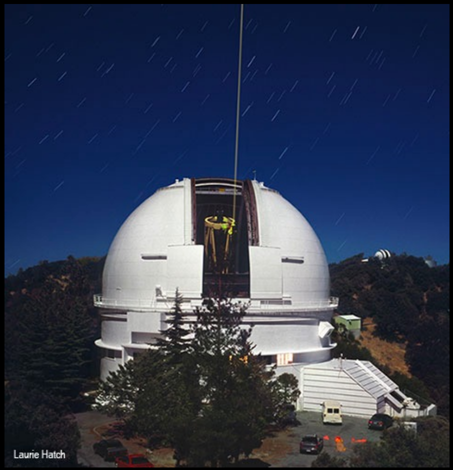
- Stellar companions contribute light to the target aperture and reduce the sensitivity of transit searches
- ***This effect is typically ignored***

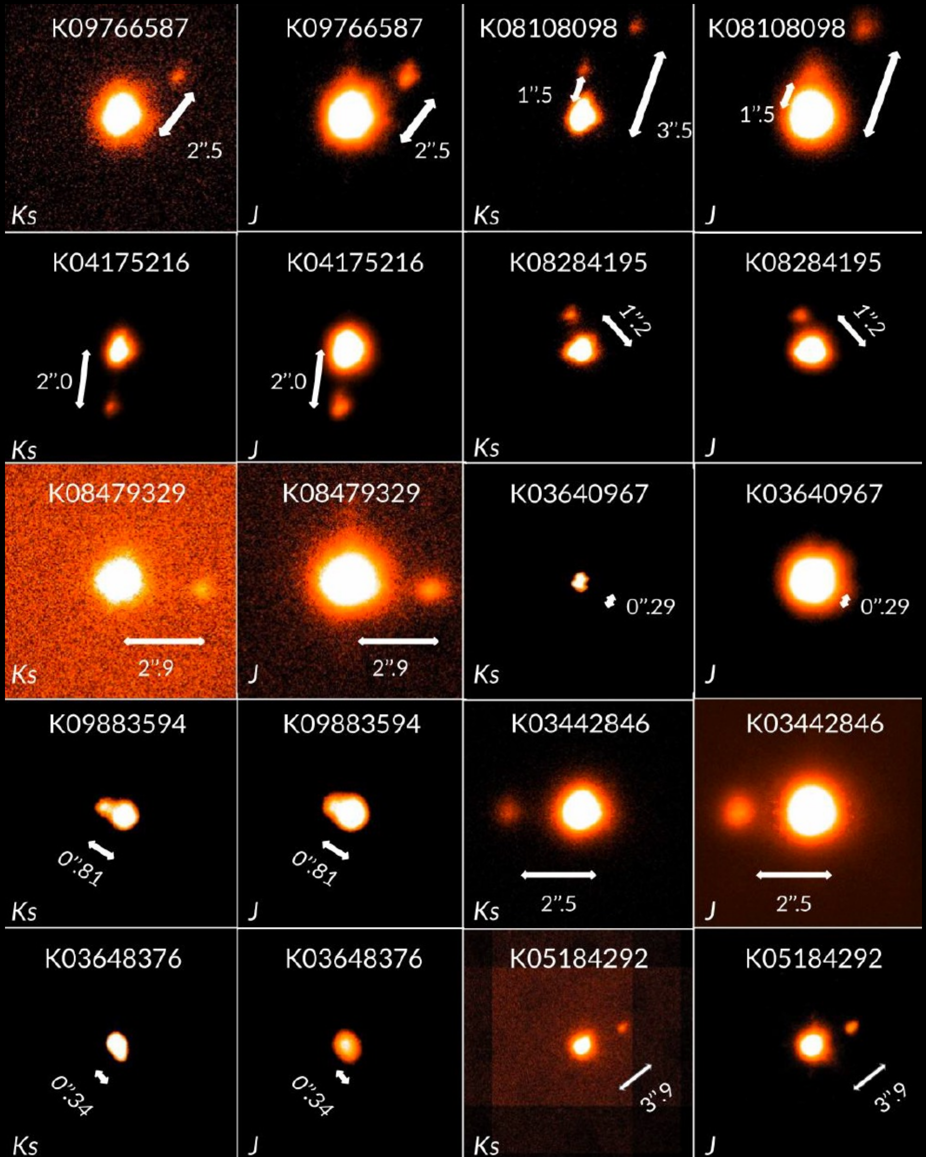
We are refining estimates of the frequency of Earth-like planets by obtaining AO images of Kepler targets that would have been amenable to the detection of potentially habitable planets.

UCB Team: Arjun Savel (now at UMD), Steven Giacalone, Charles Fortenbach (SFSU), Andy Mayo, Caleb Harada, Emma Turtelboom, Jordan Fleming, Holden Gill

External Collaborators: Lea Hirsch, Jessie Christiansen, David Ciardi, Kevin Hardegree-Ullman, Jon Zink

Determining the Multiplicity of *Kepler* Target Stars to Revise Estimates of the Frequency of Earth-like Planets





Arjun Savel
(UCB 2020 graduate; now 1st year grad student at UMD)

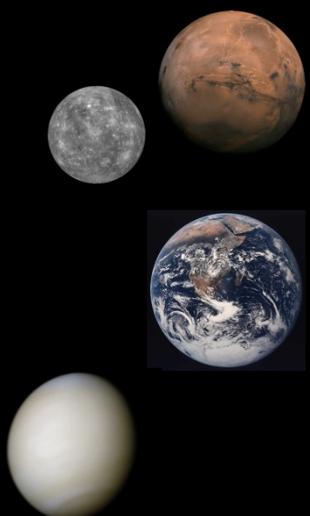
Imaged 71 *Kepler* target stars with Lick/ShARCS

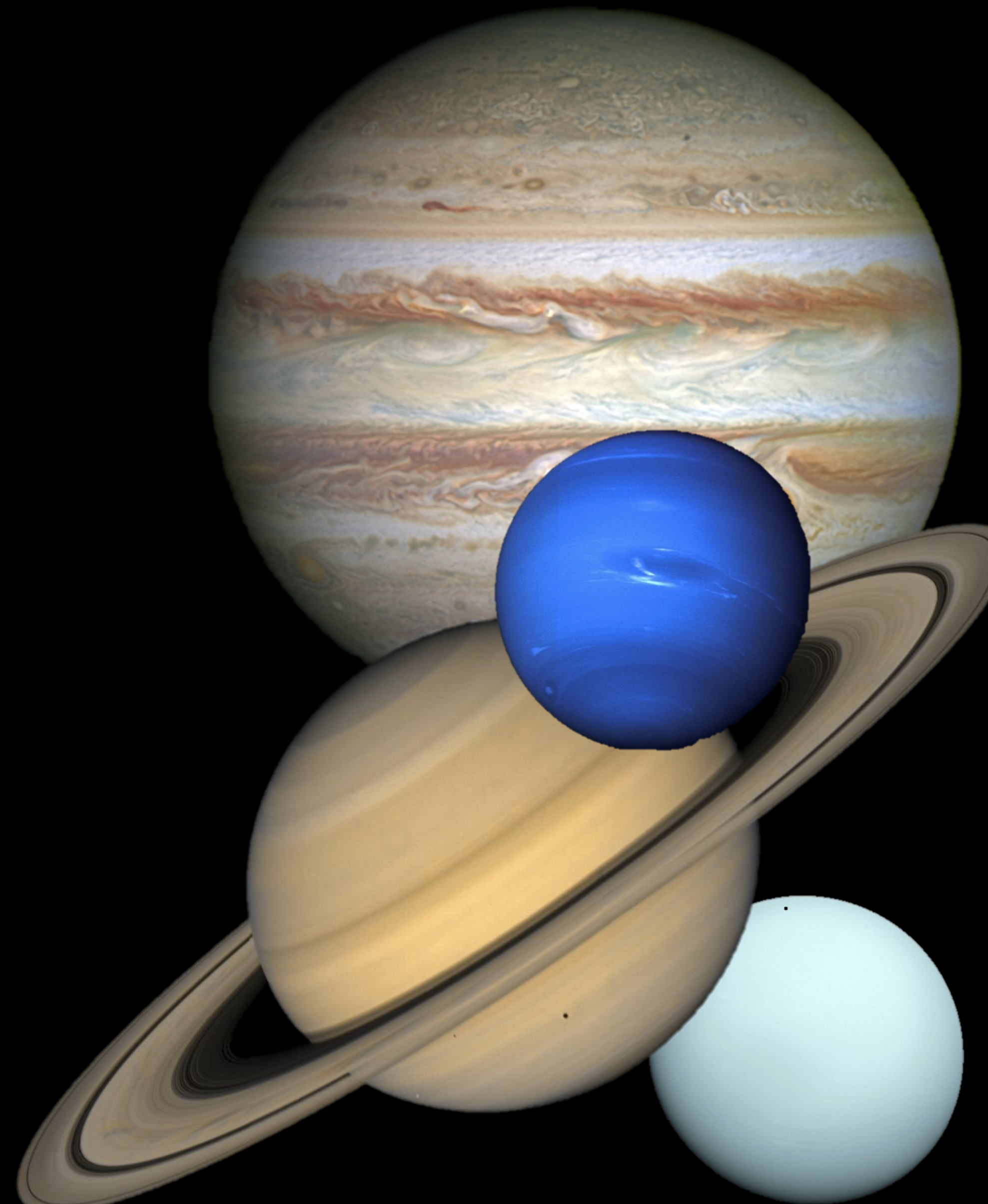
Detected 14 companions within 4” of 13 stars

Savel, Dressing et al. (2020, AJ, 160, 287)

Q3. What are the compositions of these planets?

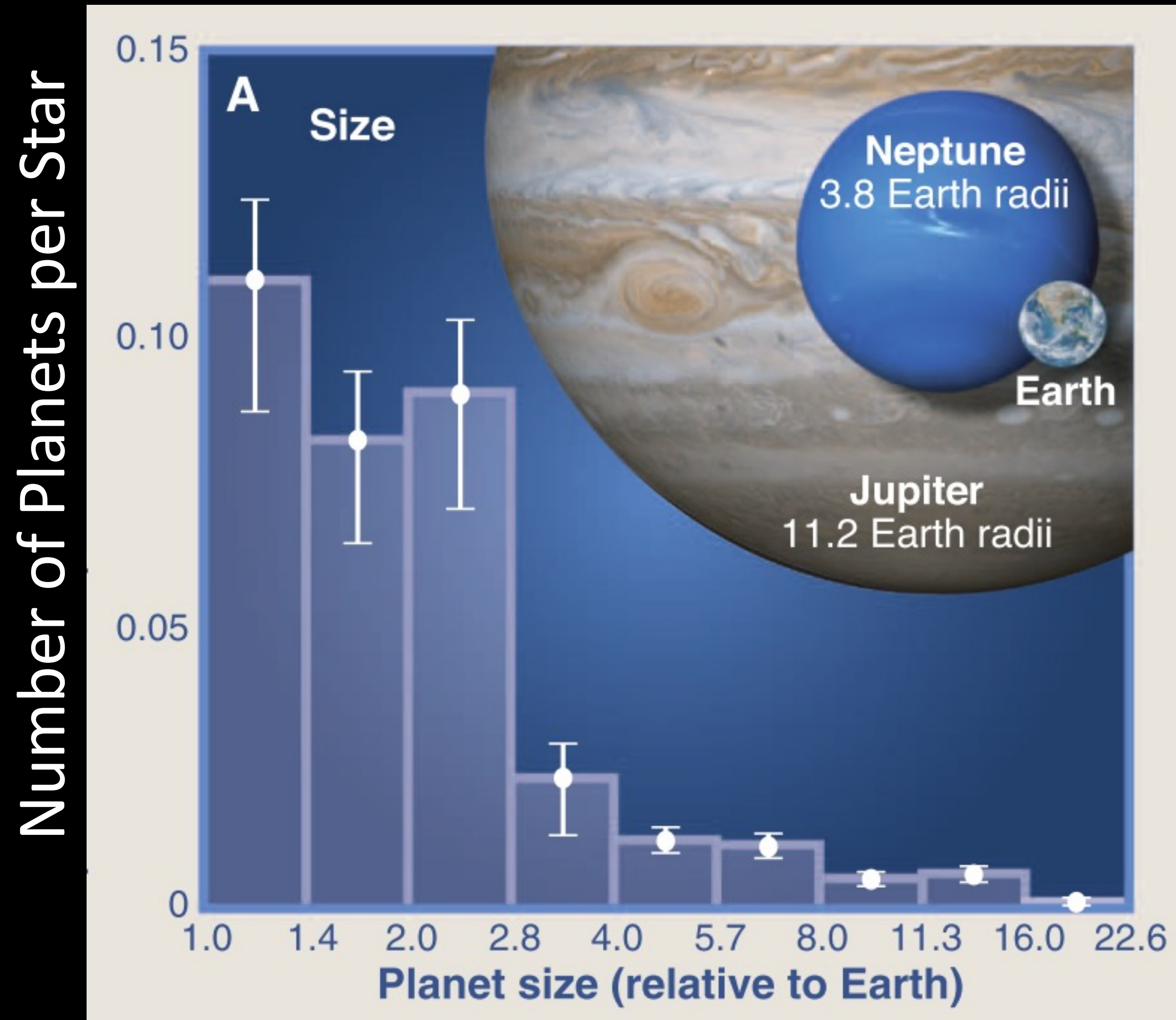
Our Solar System has Two Types of Planets





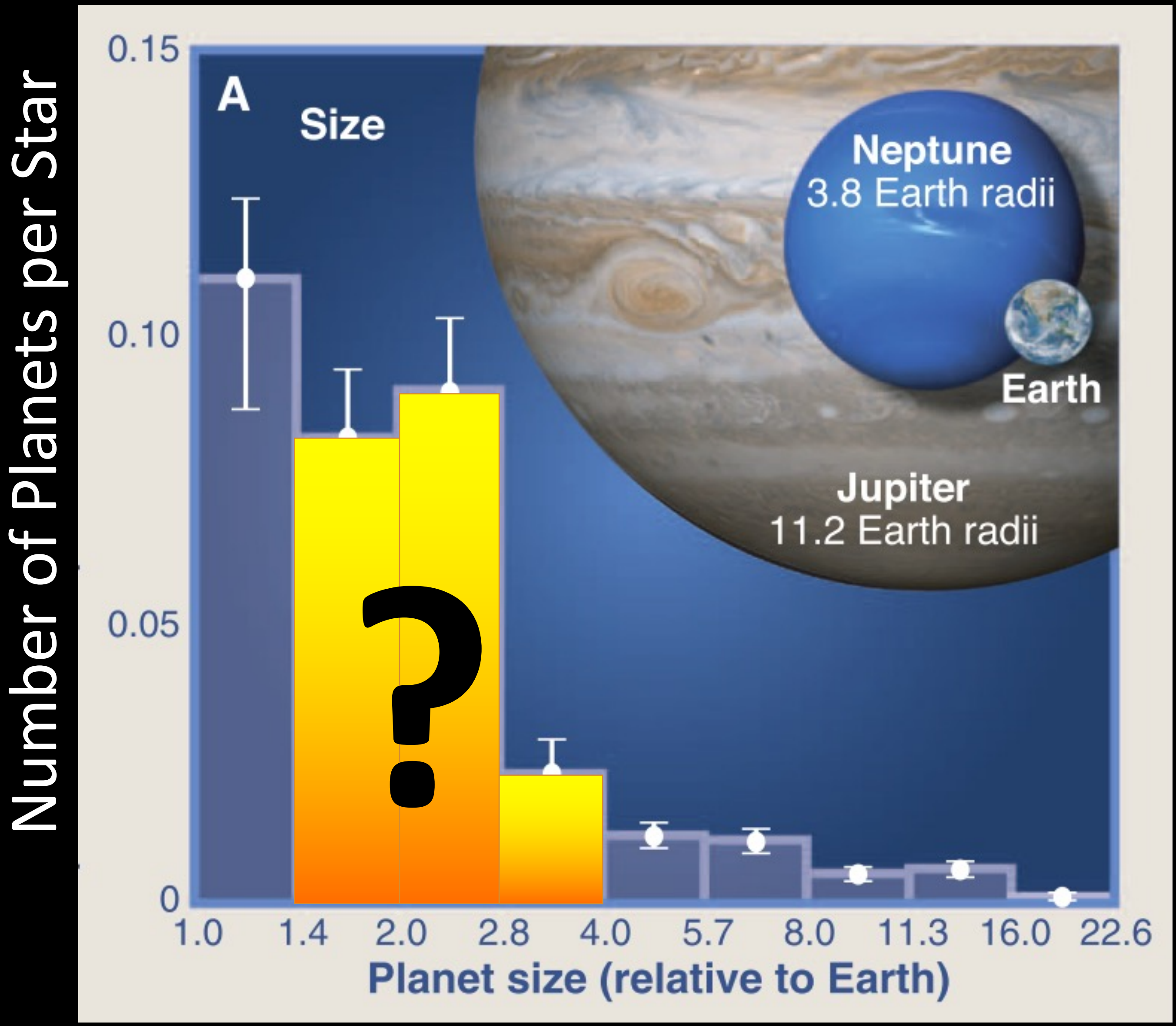
Not to scale

Planets 2-4x Larger than Earth are Common



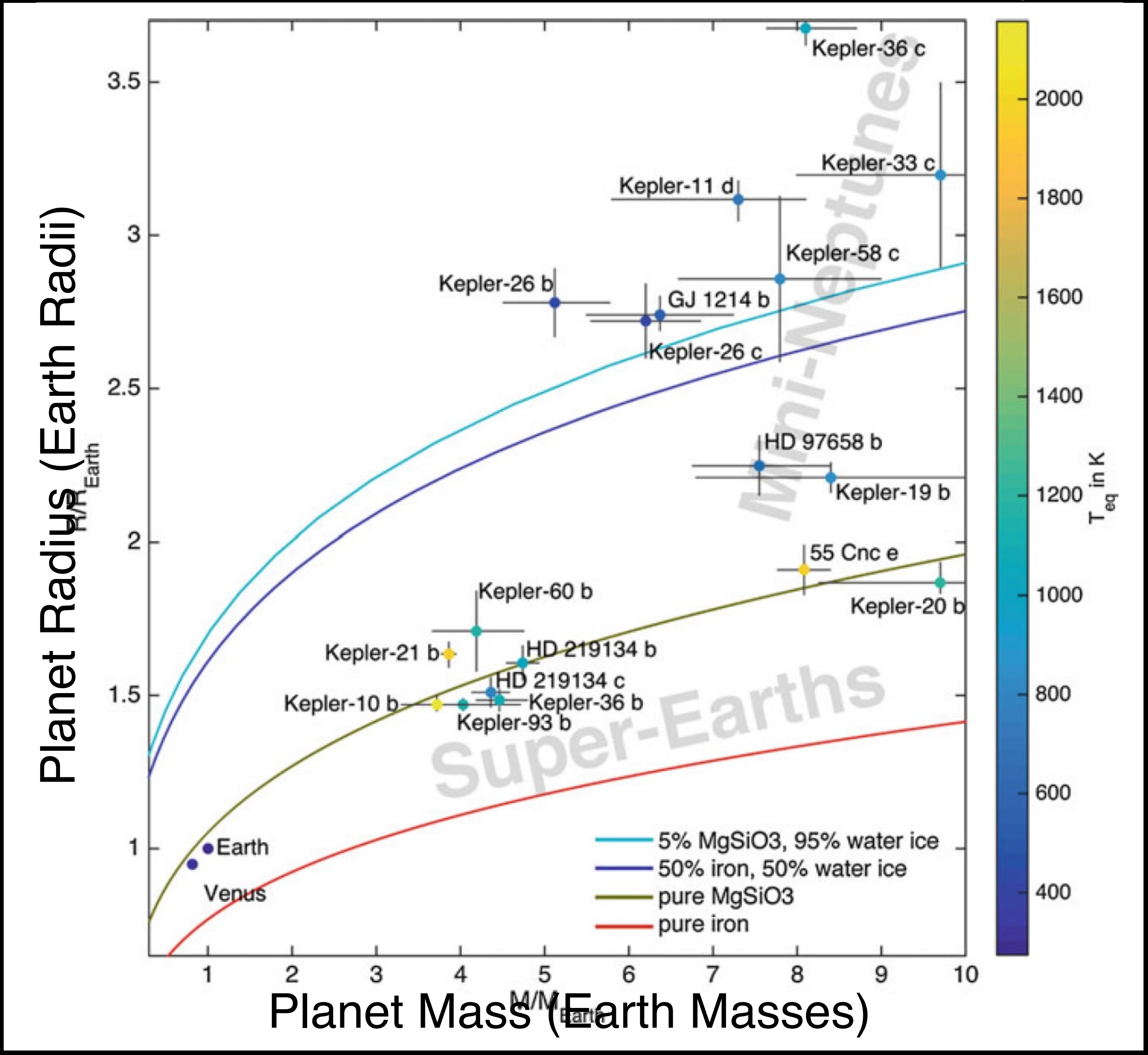
Howard 2013, Science, 340, 572

Planets 2-4x Larger than Earth are Common



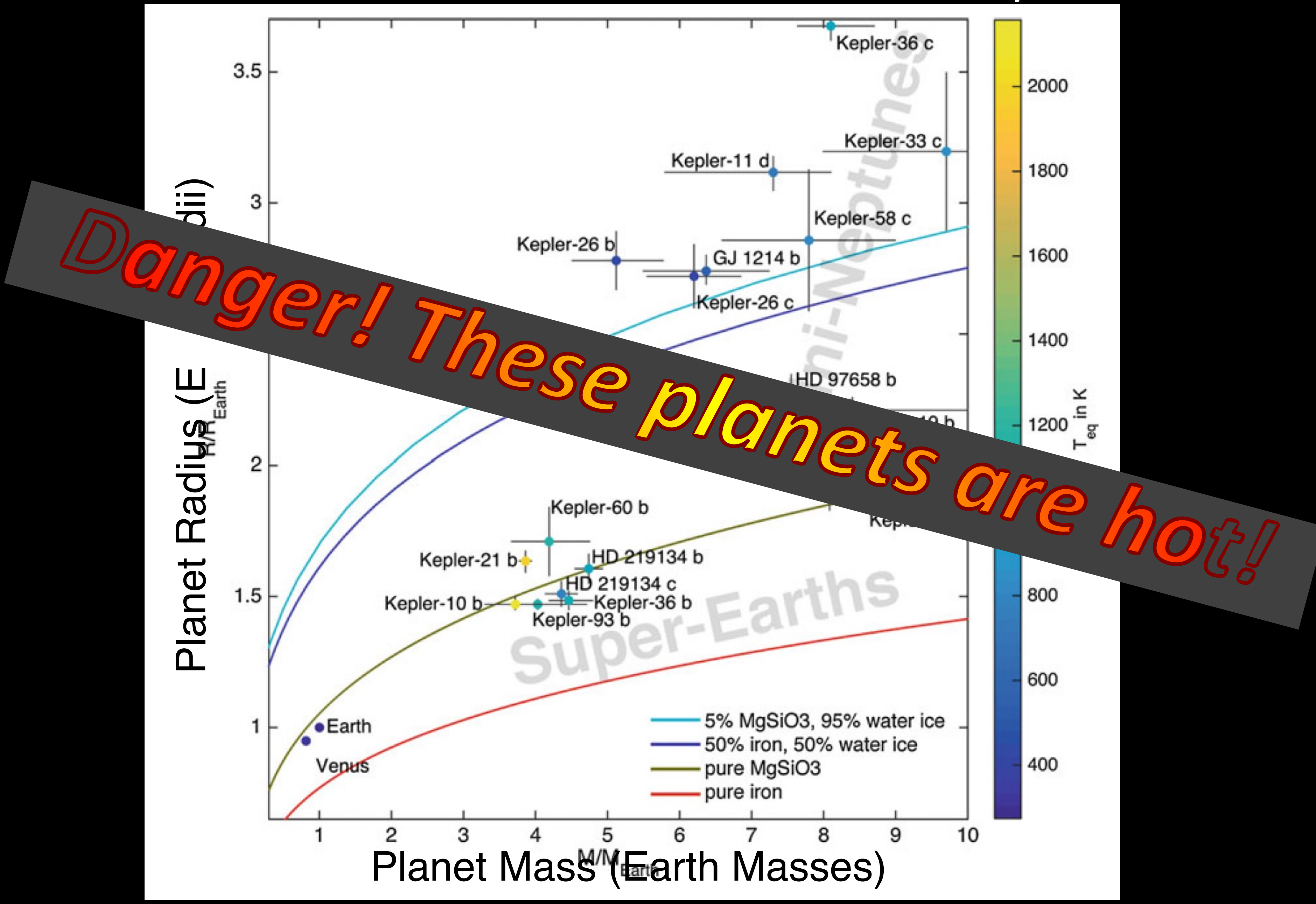
Howard 2013, Science, 340, 572

Few Small Planets Have Precise Density Estimates

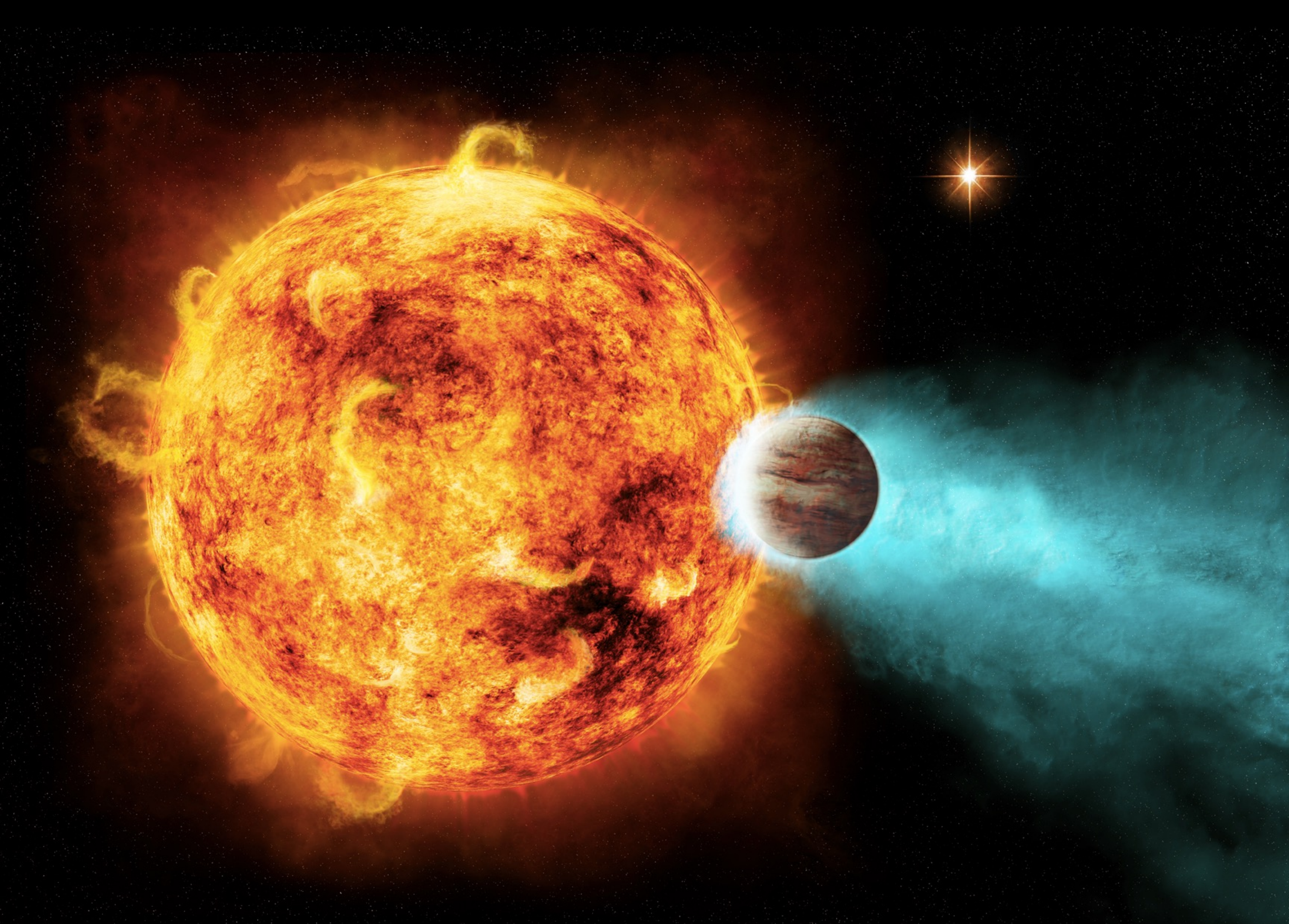


Dorn et al. 2018

Few Small Planets Have Precise Density Estimates



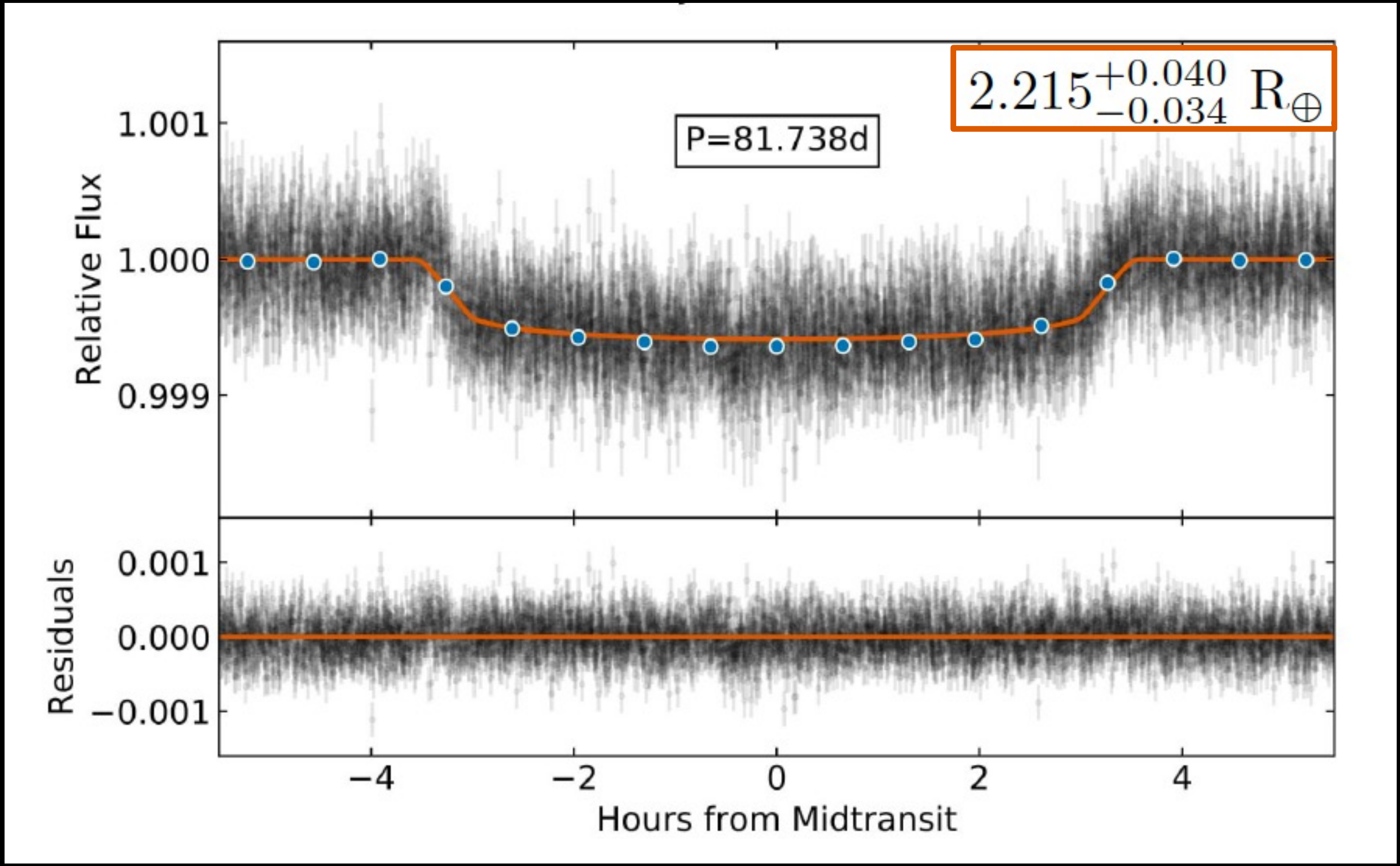
Dorn et al. 2018



Credits: ESA, Alfred Vidal-Madjar, NASA

Kepler-538b: A Sub-Neptune with a Relatively Long Orbital Period

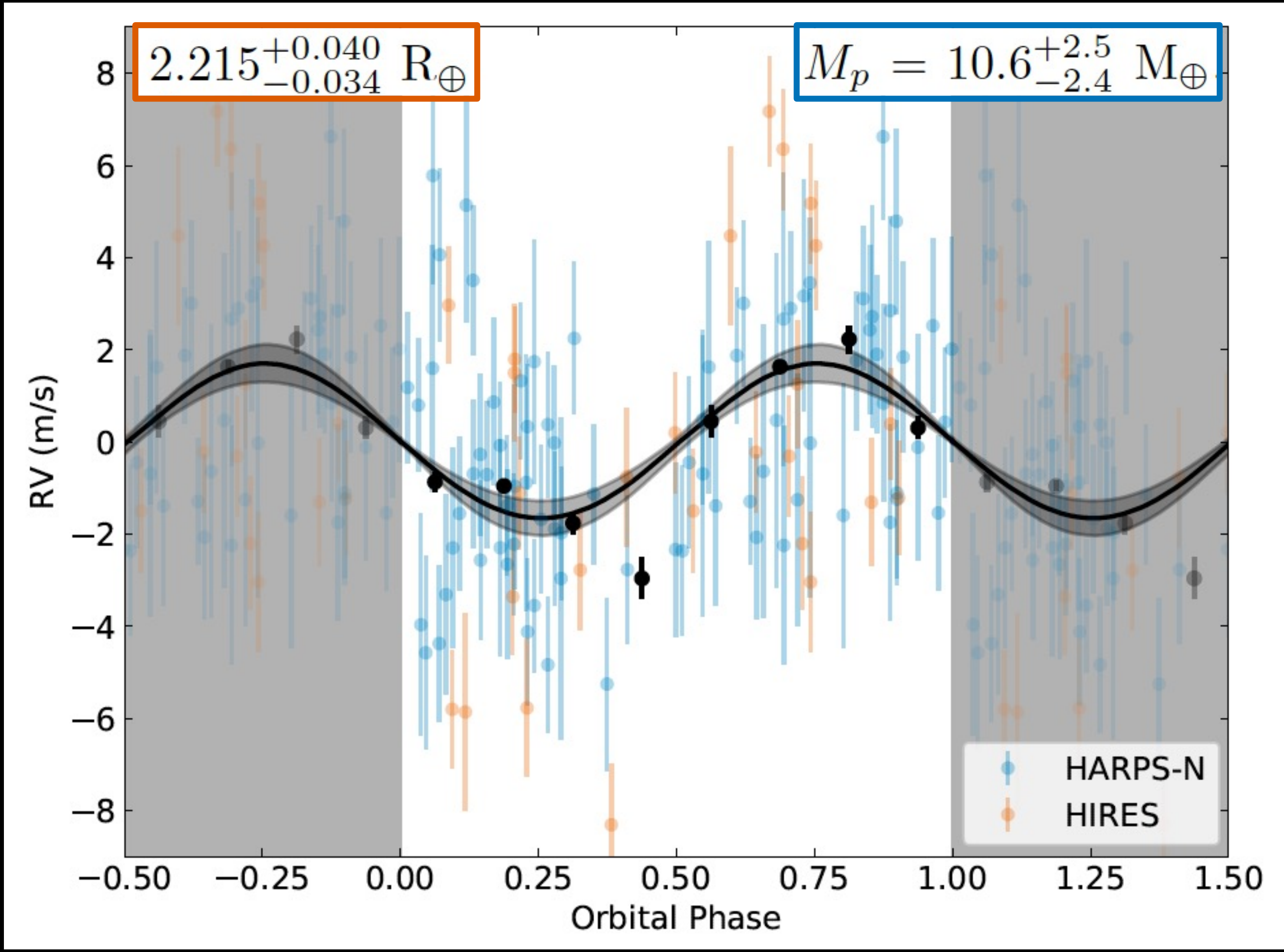
Andy Mayo
(3rd yr UCB grad)



Mayo, Rajpaul, Buchhave, Dressing et al. 2019, AJ, 158, 165

Modeling the RVs of Kepler-538

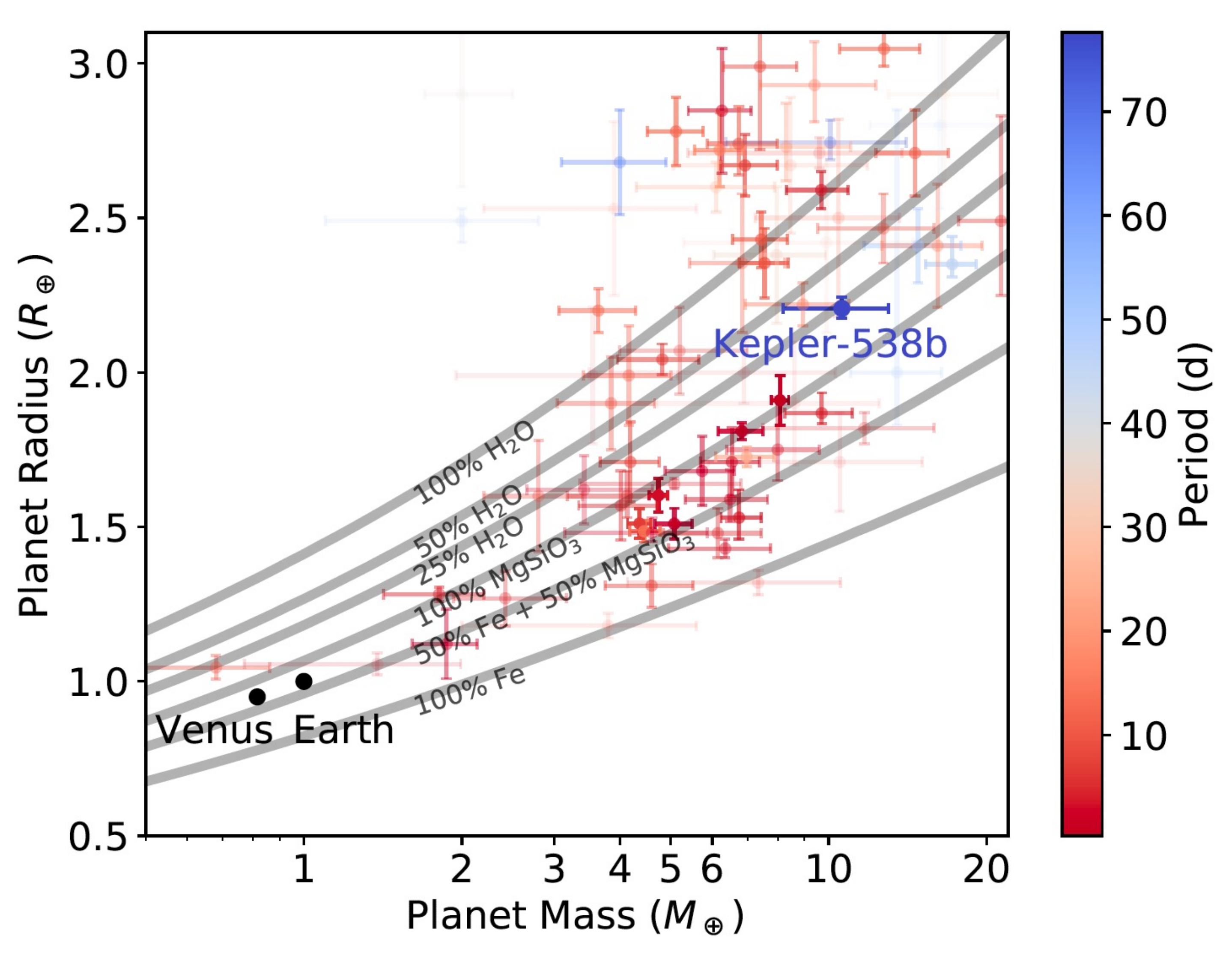
Andy Mayo
(3rd yr UCB grad)



Mayo, Rajpaul, Buchhave, Dressing et al. 2019, AJ, 158, 165

Kepler-538b Is Not Rocky

Andy Mayo
(3rd yr UCB grad)



Mayo, Rajpaul, Buchhave, Dressing et al. 2019, AJ, 158, 165

A Precise Mass Estimate for the Young Sub-Neptune K2-136 c

Mayo, Dressing et al. *(in prep)*

Andy Mayo
(3rd yr UCB grad)

K dwarf in Hyades
(800 Myr; Brandt & Huang 2015)

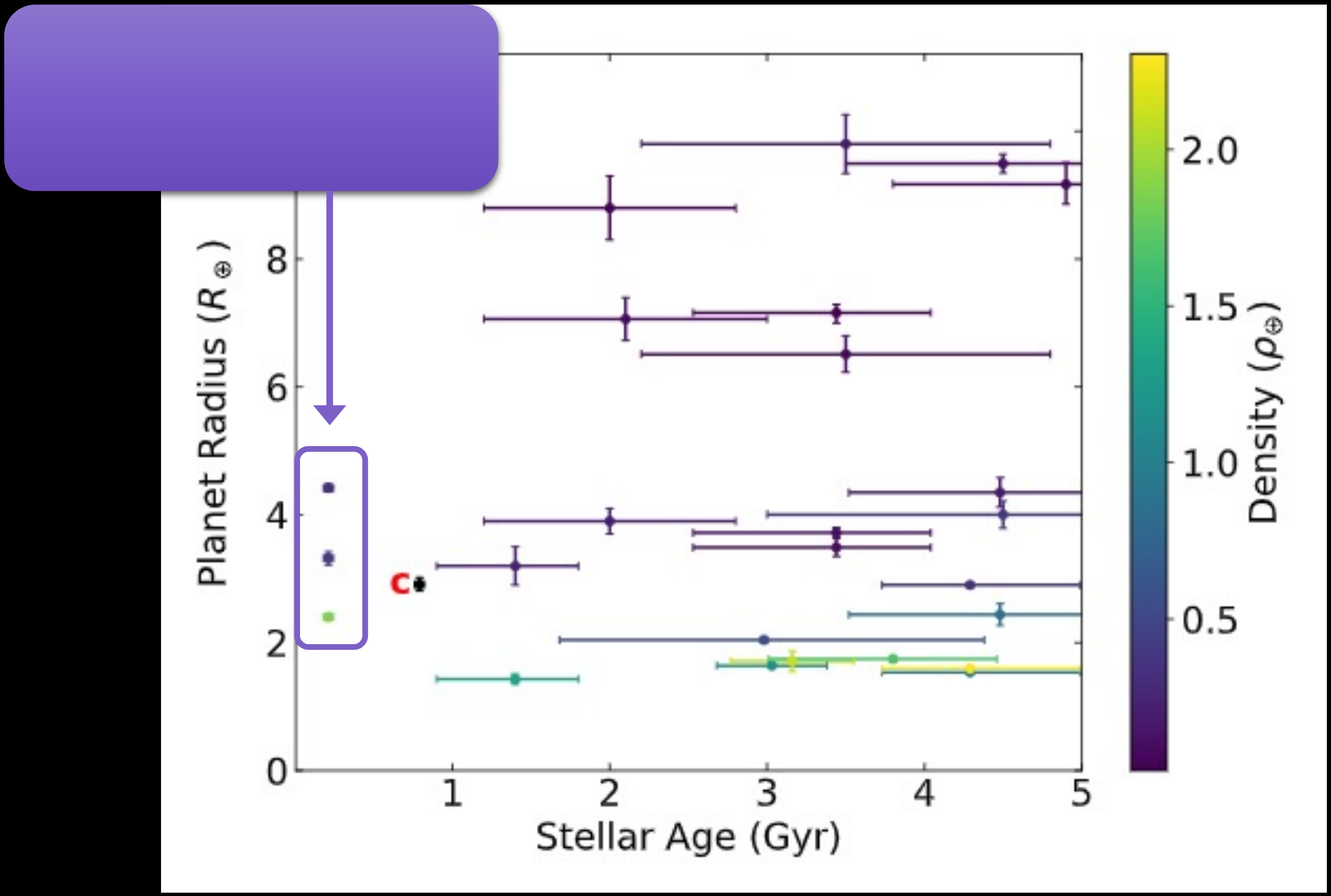
K2-136

$M_c = 15.9 \pm 2.4\ M_{Earth}$

b	c	d
P = 8.0 days	P = 17.3 days	P = 25.6 days
$R = 0.99\ R_{Earth}$	$R = 2.91\ R_{Earth}$	$R = 1.45\ R_{Earth}$

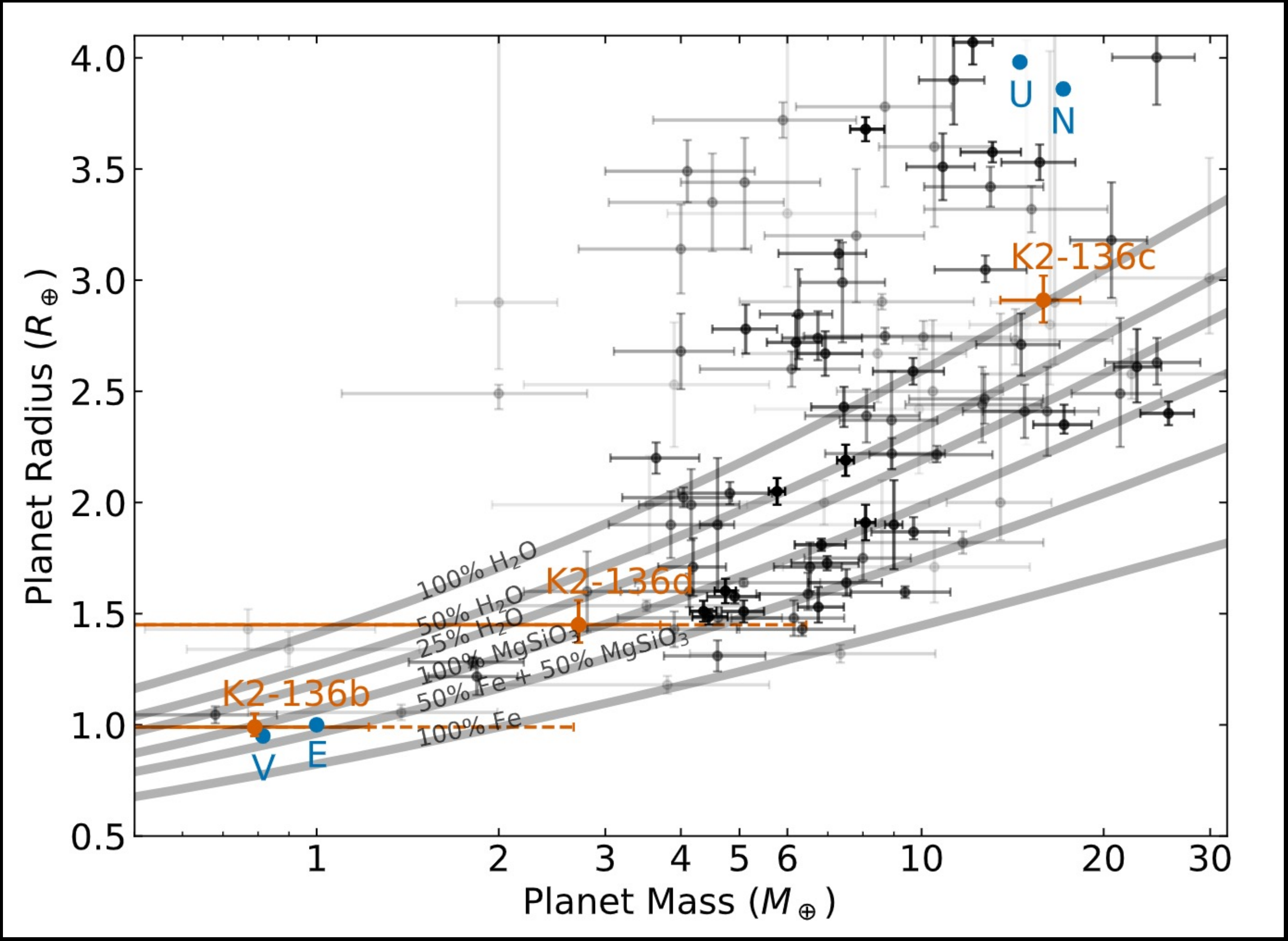
Mann et al. 2018, AJ, 155, 4

Few Young Planets Have Precise Density Estimates



Mayo, Dressing et al. *(in prep)*

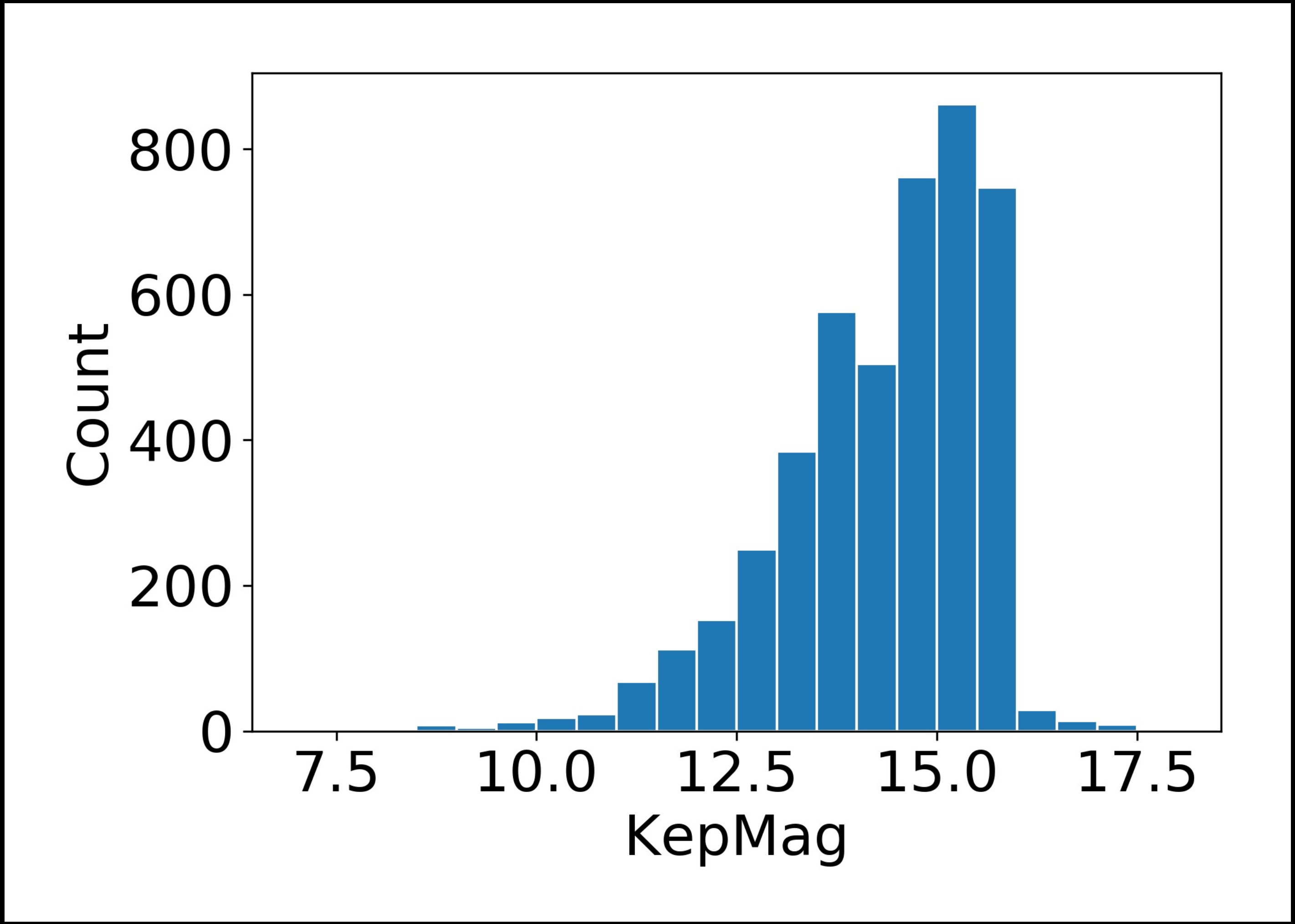
K2-136 c is Roughly Twice As Dense as Neptune



Mayo, Dressing et al. *(in prep)*

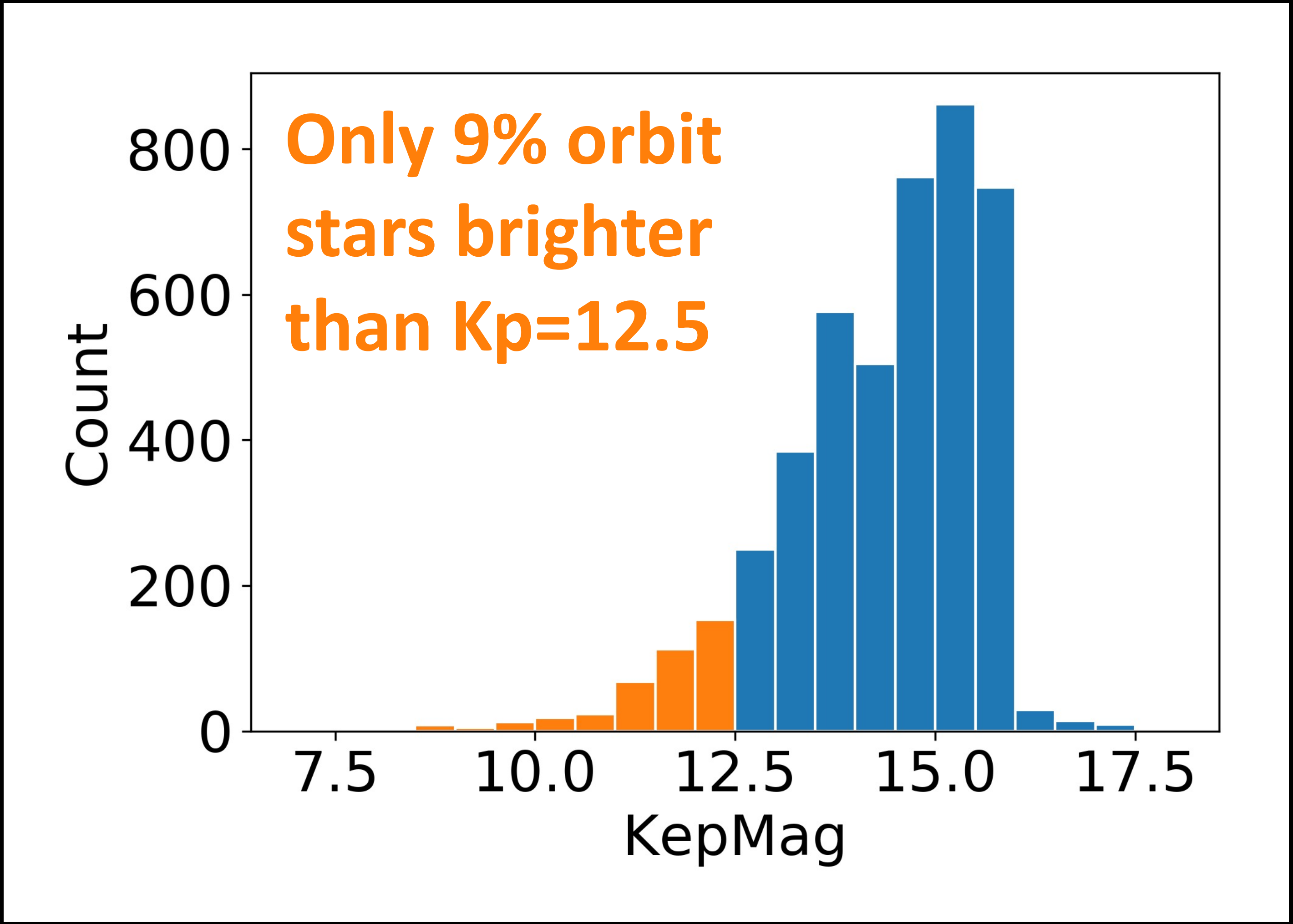
Q3b. Why is the mass-radius diagram so sparsely populated?

Most small planets detected by *Kepler* orbit stars that are too faint for current RV spectrographs



Data from the NASA Exoplanet Archive

Most small planets detected by *Kepler* orbit stars that are too faint for current RV spectrographs



Data from the NASA Exoplanet Archive

TESS planets are ideal targets for RV mass measurement

TESS planets are ideal targets for RV mass measurement

The TESS-Keck Survey (TKS)

A NASA-Keck Key Strategic Mission Support program & UC LMAP

California Institute of Technology • NASA • NASA Exoplanet Science Institute • UC Berkeley • UC Irvine • UC Riverside • UC Santa Cruz University of Hawaii • University of Kansas • W.M. Keck Observatory

We recognize and acknowledge the cultural role and reverence that the summit of Maunakea has within the indigenous Hawaiian community. We are deeply grateful to have the opportunity to conduct observations from this mountain.

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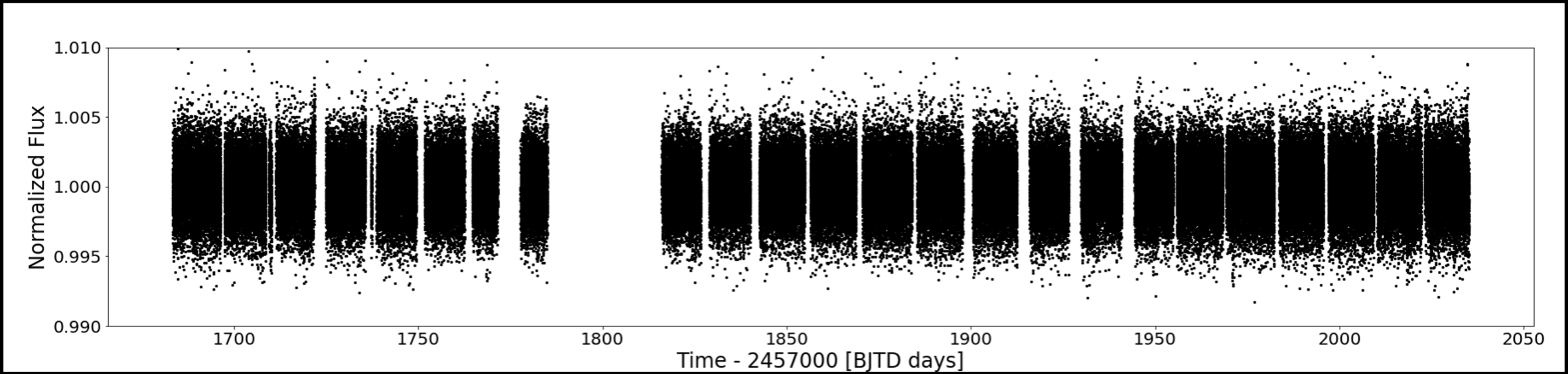
TOI-1246:
4 sub-Neptunes orbiting a K dwarf

Emma Turtelboom
2nd yr grad at UCB
Lead Author

Lauren Weiss
Parrent Fellow at UH

TOI-1246 was heavily observed by TESS



Turtelboom, Weiss, Dressing, TKS in prep

- 12 sectors of TESS photometry collected between July 2019 and April 2020
- 40 RVs collected between Nov 2019 and Oct 2020 using HIRES on Keck I

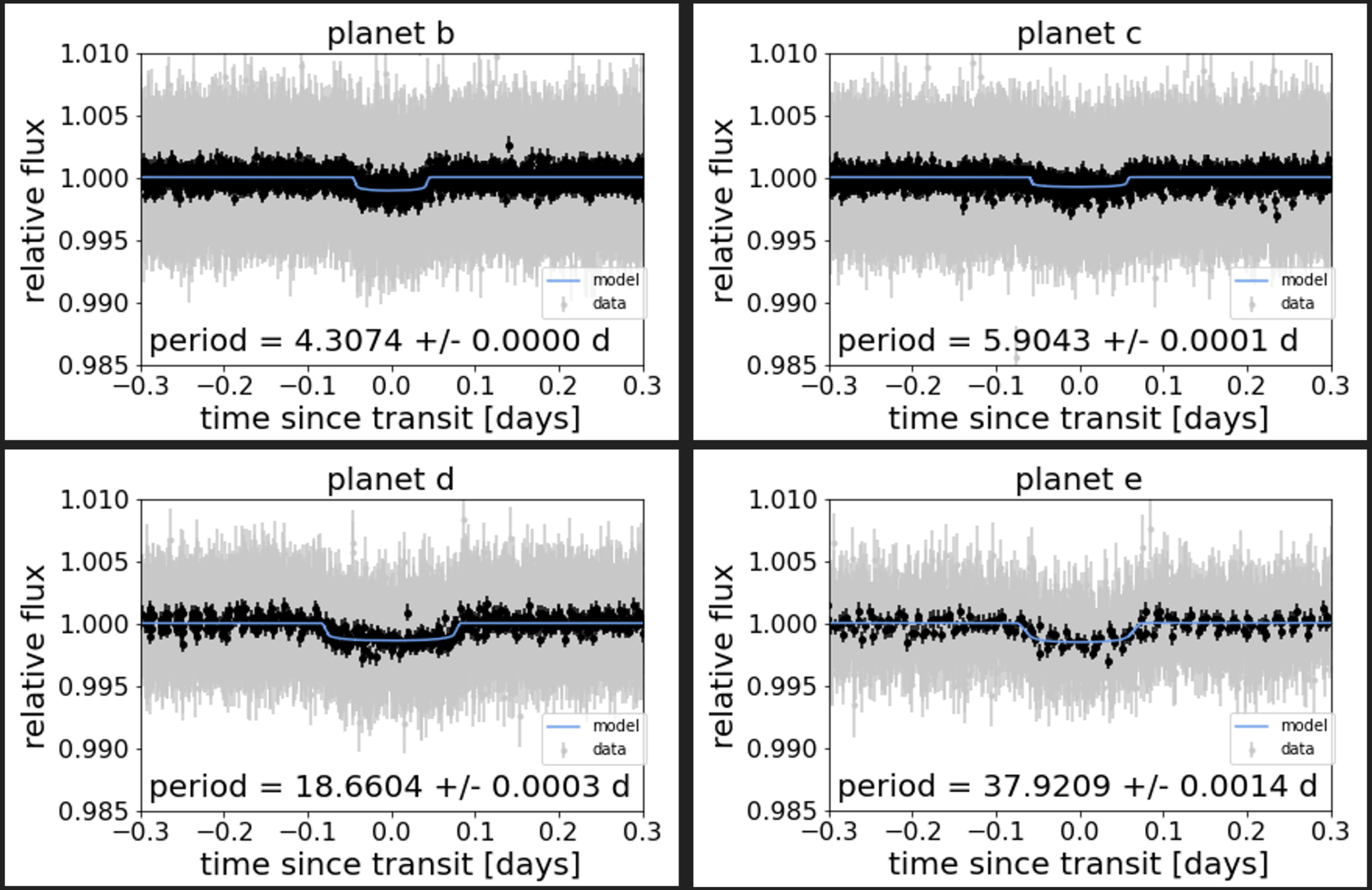
4 transiting sub-Neptunes

2.92 $R_\oplus$

2.77 $R_\oplus$

3.31 $R_\oplus$

3.32 $R_\oplus$



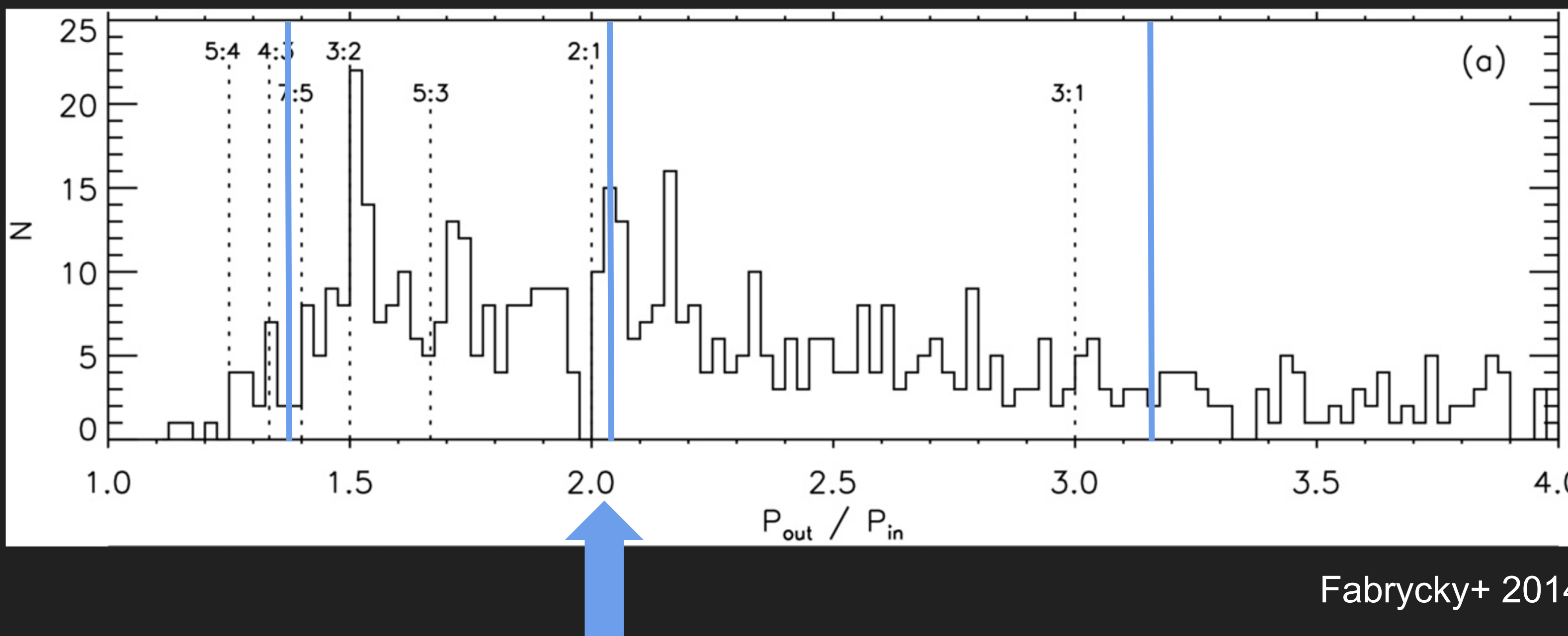
Turtelboom, Weiss, Dressing, TKS in prep

Planets b and e are near 2:1 resonance

planets
c and d

planets
b and e

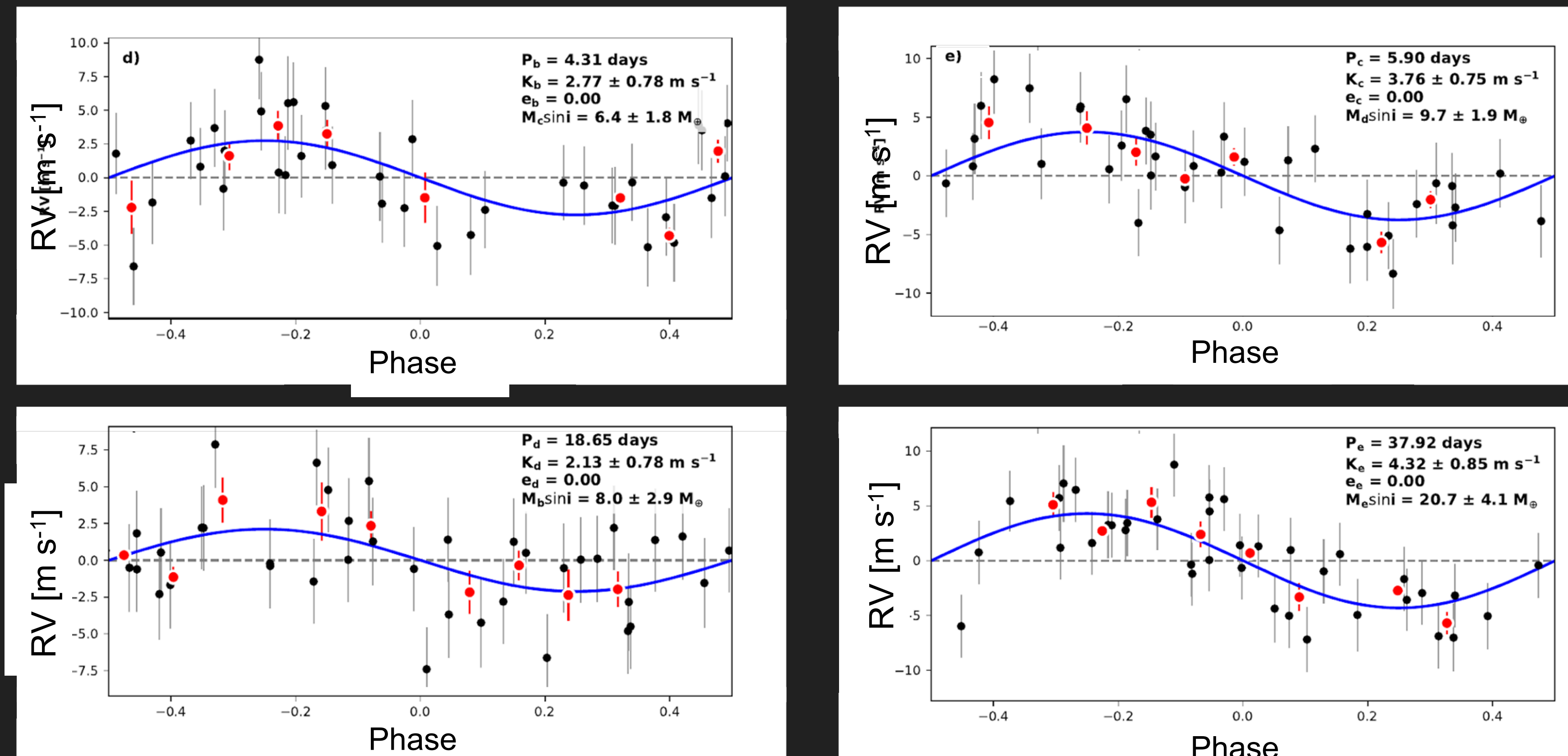
planets
b and c



Fabrycky+ 2014

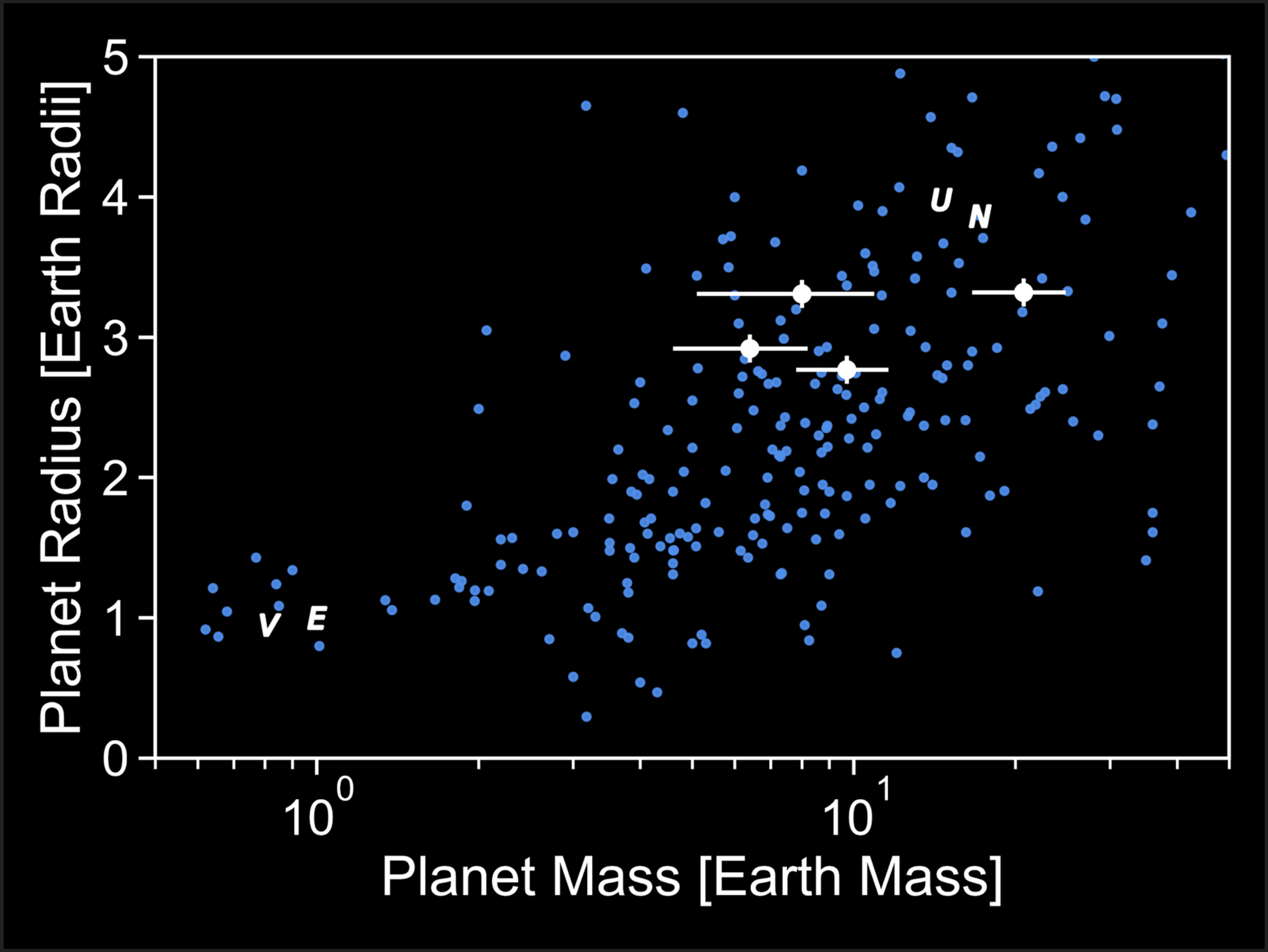
PRELIMINARY

Planet masses range from 6 to 20 $M_\oplus$



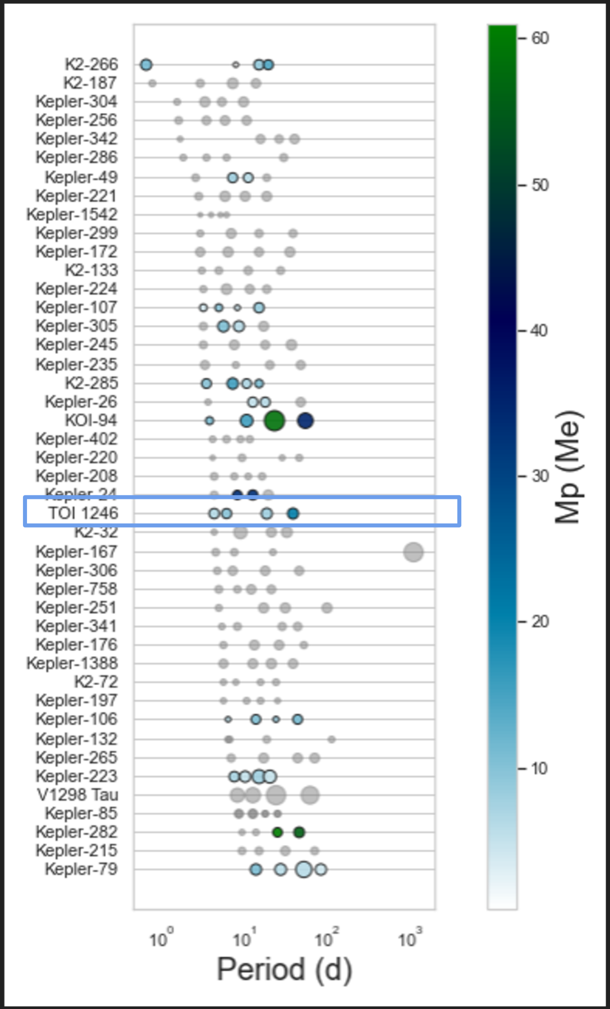
Turtelboom, Weiss, Dressing, TKS in prep

TOI 1246 hosts 4 sub-Neptunes with diverse masses



Turtelboom, Weiss, Dressing, TKS in prep

TOI 1246 is one of only 8 four-planet systems with both measured masses and radii for all four planets



Turtelboom, Weiss, Dressing, TKS in prep

Oceans?

Atmospheric circulation?

Stellar activity?

Atmospheric composition?

Obliquity?

Geological activity?

Magnetic fields?

Q4. How frequent are Earth-like planets?

Surface Temperature?

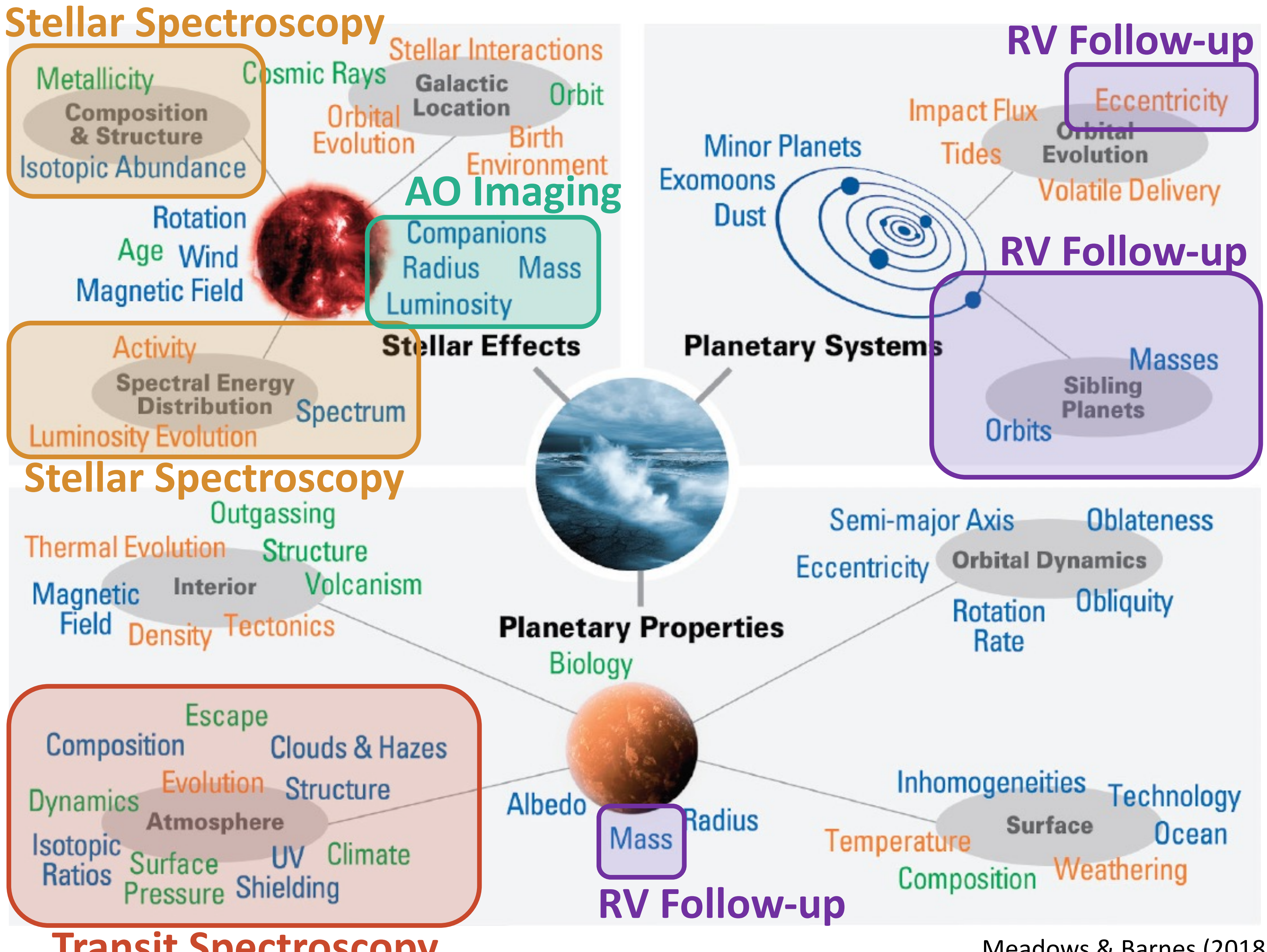
Radius?

Rotation Rate?

Mass?

Age?

Bulk composition?



Meadows & Barnes (2018)

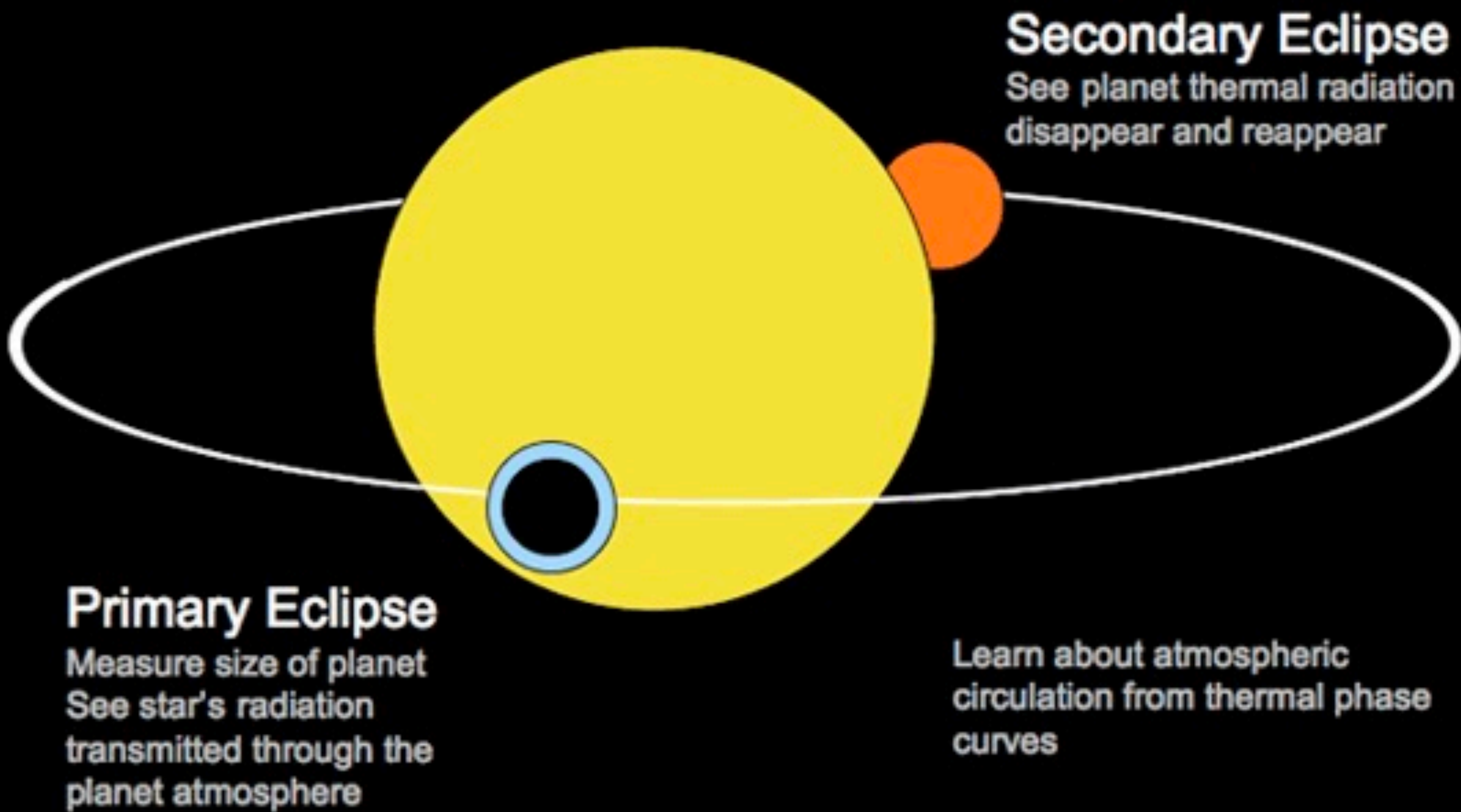
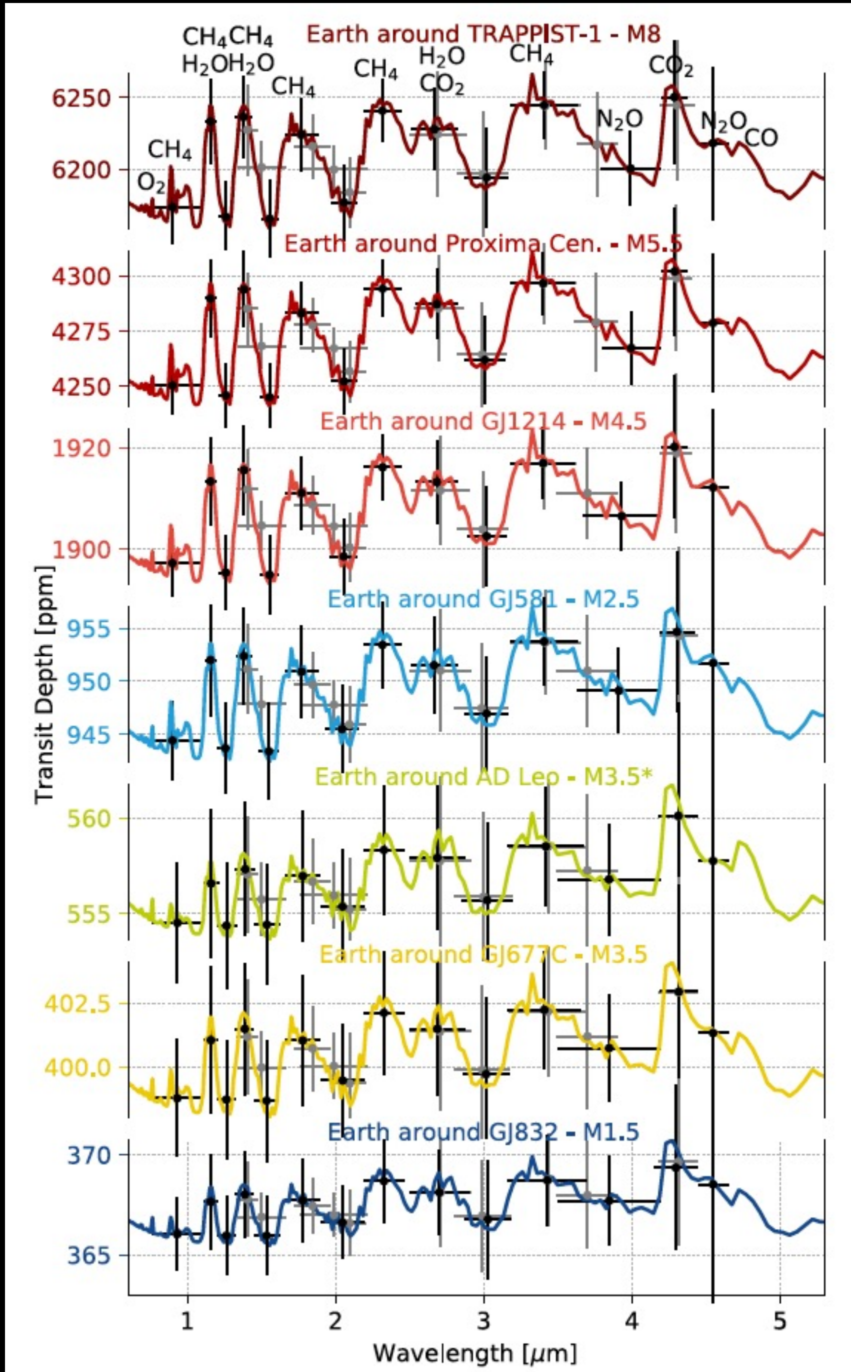


Figure by S. Seager

The Hubble
Space Telescope

The James Webb Space Telescope Will Provide a Closer Look at Planetary Atmospheres

Simulating JWST Observations of Potentially Habitable Planets Orbiting Nearby M Dwarfs



Number of Transits Needed for Detection

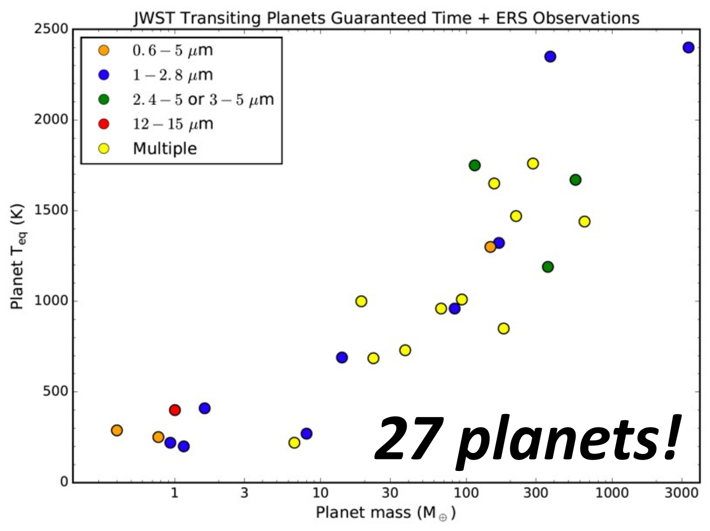
Host star	H_2O	CH_4	CO_2	O_3
GJ 436	31	10	30	209
GJ 1132	14	4	13	142
TRAPPIST-1	12	3	10	172
GJ 1214	17	4	15	171
LHS 1140	25	5	21	354
GJ 3470	91	17	80	792
NLTT 41135	47	9	41	711
K2-18	93	18	80	824
LHS 6343	167	33	140	1332
Kepler-42	168	30	106	2880
K2-25	233	42	184	5887

Wunderlich et al. (2019)

The Exoplanet Community Has Developed a Plan to Optimize JWST Observations of Transiting Planets

Table 1: **Approved GTO and ERS Transiting Planet Programs**

ID	Title and Science Instrument	Team Lead	Hours
1177	MIRI observations of transiting exoplanets	T. Greene	75
1185	Transit Spectroscopy of Mature Planets (NIRCam)	T. Greene	140
1201	NIRISS Exploration of the Atmospheric Diversity of Transiting Exoplanets	D. Lafrenière	201
1224	Transiting Exoplanet Characterization with JWST/NIRSPEC	S. Birkmann	50
1274	Extrasolar Planet Science with *JWST* (NIRCam)	J. Lunine	74
1279	Thermal emission from Trappist1-b (MIRI)	P.-O. Lagage	25
1280	MIRI Transiting Observation of WASP-107b	P.-O. Lagage	11
1281	MIRI and NIRSPEC Transit Observations of HAT-P-12 b	P.-O. Lagage	32
1312	Transit and Eclipse Spectroscopy of a Warm Neptune (NIRISS+NS+MIRI)	N. Lewis	36
1331	Transit Spectroscopy of TRAPPIST-1e (NIRSpec)	N. Lewis	22
1353	Transit and Eclipse Spectroscopy of a Hot Jupiter (NIRISS+NS+MIRI)	N. Lewis	72
1366	The Transiting Exoplanet Community ERS Program (all SIs)	N. Batalha	78
	TOTAL		816



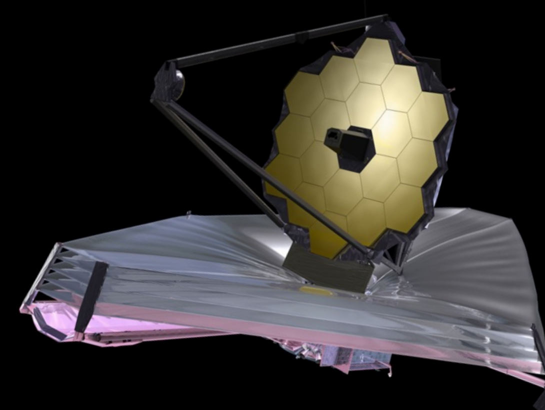
Characterizing Transiting Exoplanets with JWST Guaranteed Time and ERS Observations
(Greene et al. 2019)

Engaging Citizen Scientists to Keep Transit Times Fresh and Ensure the Efficient Use of Transiting Exoplanet Characterization Missions
(Zellem et al. 2019)

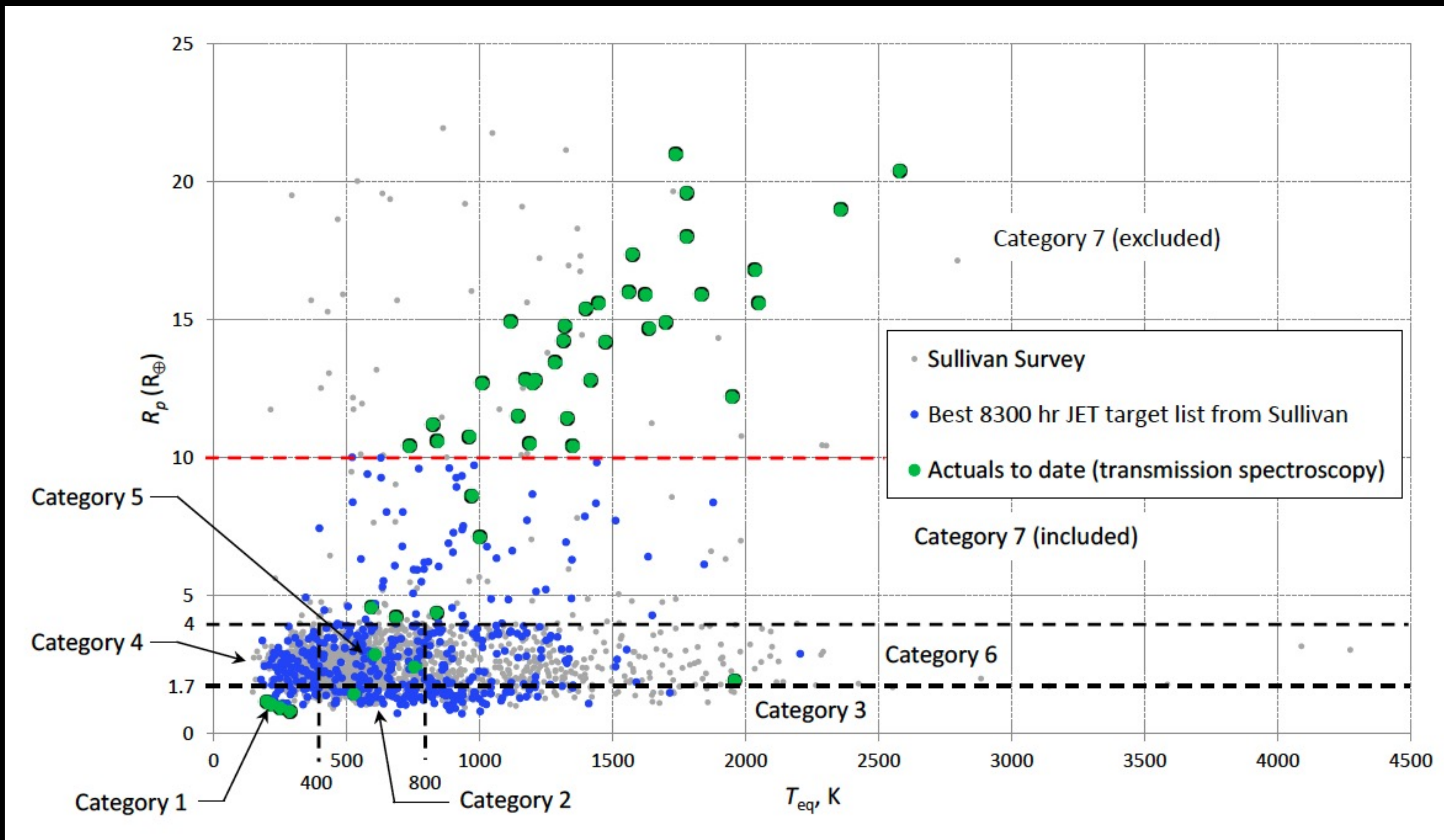
A FRAMEWORK FOR OPTIMIZING EXOPLANET TARGET SELECTION FOR THE JAMES WEBB SPACE TELESCOPE

Charles D. Fortenbach[1] and Courtney D. Dressing[2]

Charles Fortenbach
(SFSU MA Student)



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

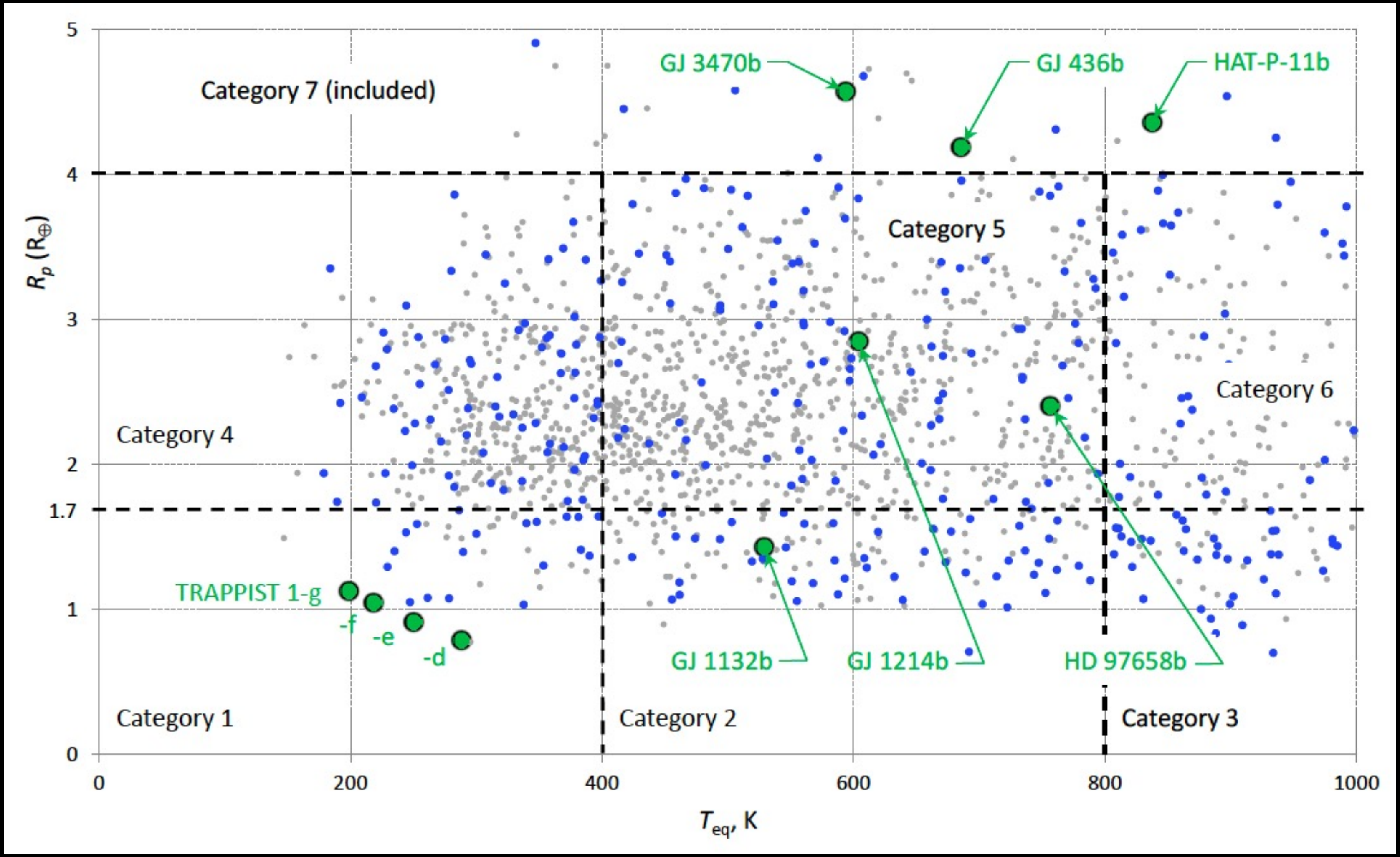


C. Fortenbach

See also Kempton et al. (2018), Louie et al. (2018), Batalha et al. (2018)

Fortenbach & Dressing 2020, PASP,132, 054501

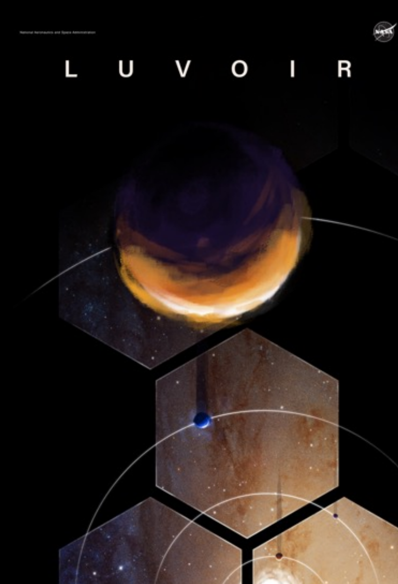
Prioritizing *TESS* Planets for Atmospheric Characterization with *JWST*



See also Kempton et al. (2018), Louie et al. (2018), Batalha et al. (2018)

Fortenbach & Dressing 2020, PASP,132, 054501

Q5. How Common is Life?



LUVOIR IS . . .

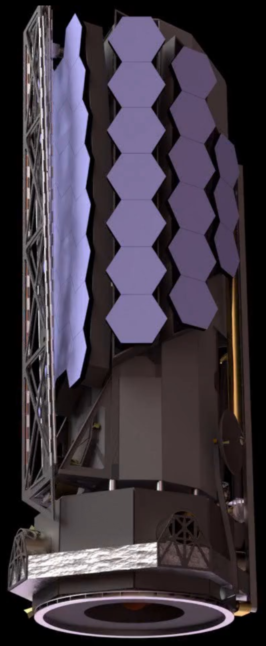
A community-driven, UV/O/IR observatory able to perform direct spectroscopy of dozens of exoEarth candidates, high-fidelity Solar System remote sensing, and transformative astrophysics

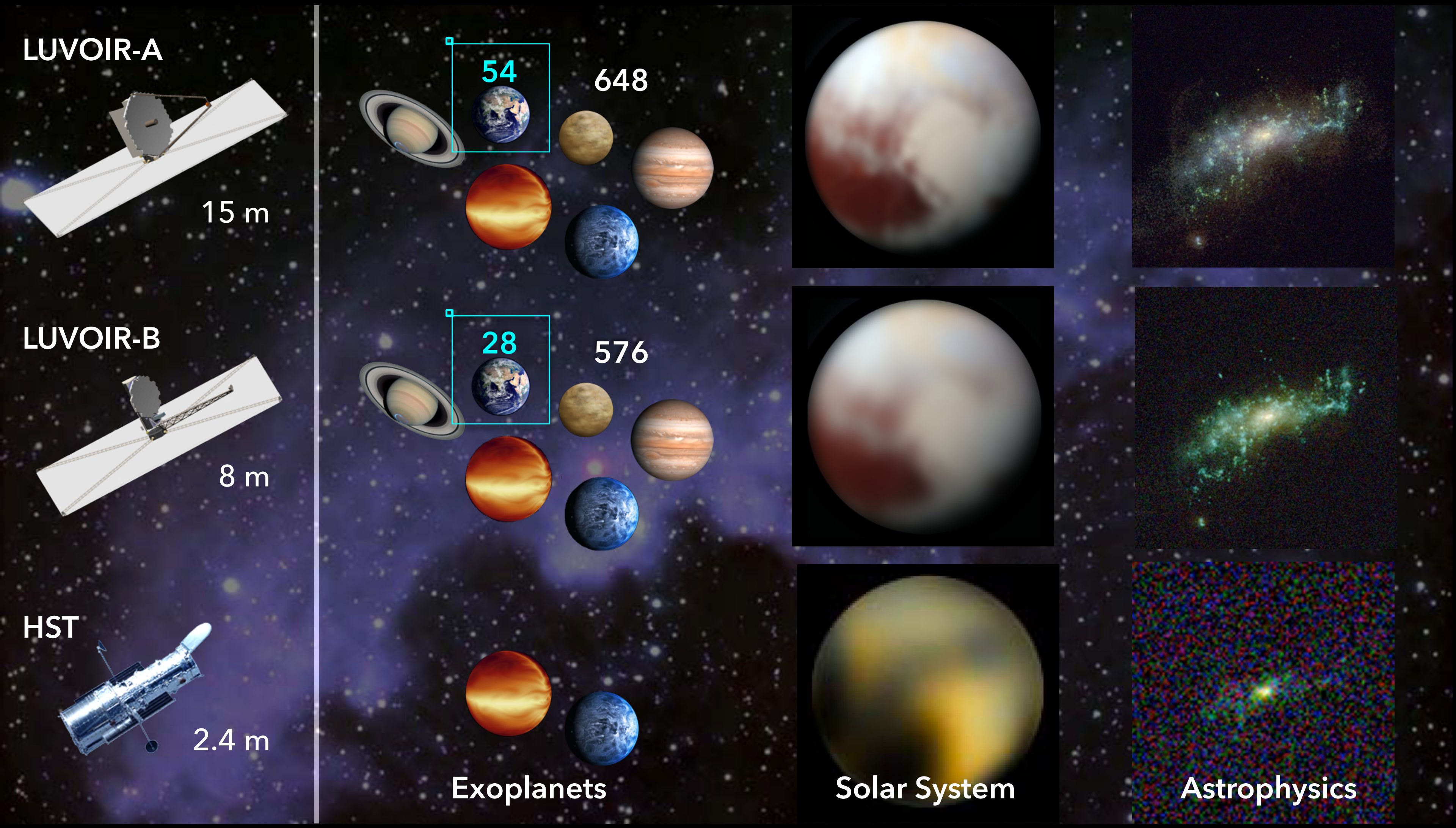
LUVOIR-A

- 15-m, on-axis telesc
  - 120 segments, 1.2
    to-flat
  - 155 m² collecting
  - Four instrument b
    - ECLIPS
    - LUMOS
    - HDI
    - POLLUX

LUVOIR-B

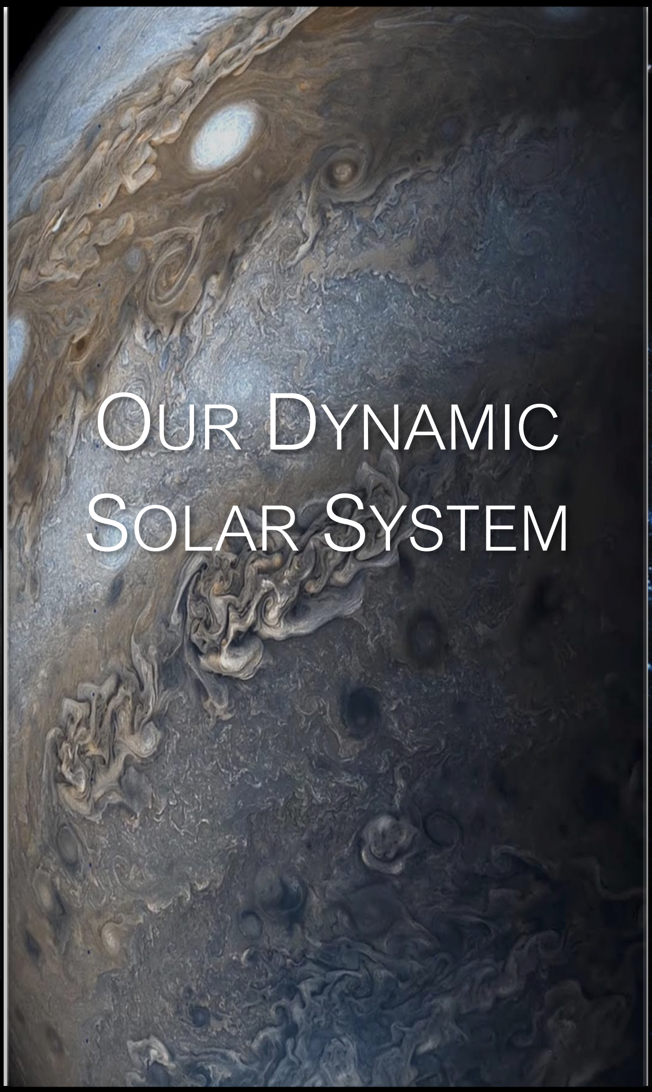
- 8-m, off-axis telescope
  - 55 segments, 0.955-m
  - 43.4 m^2 collecting are
  - Three instrument bays
    - ECLIPS
    - LUMOS
    - HDI

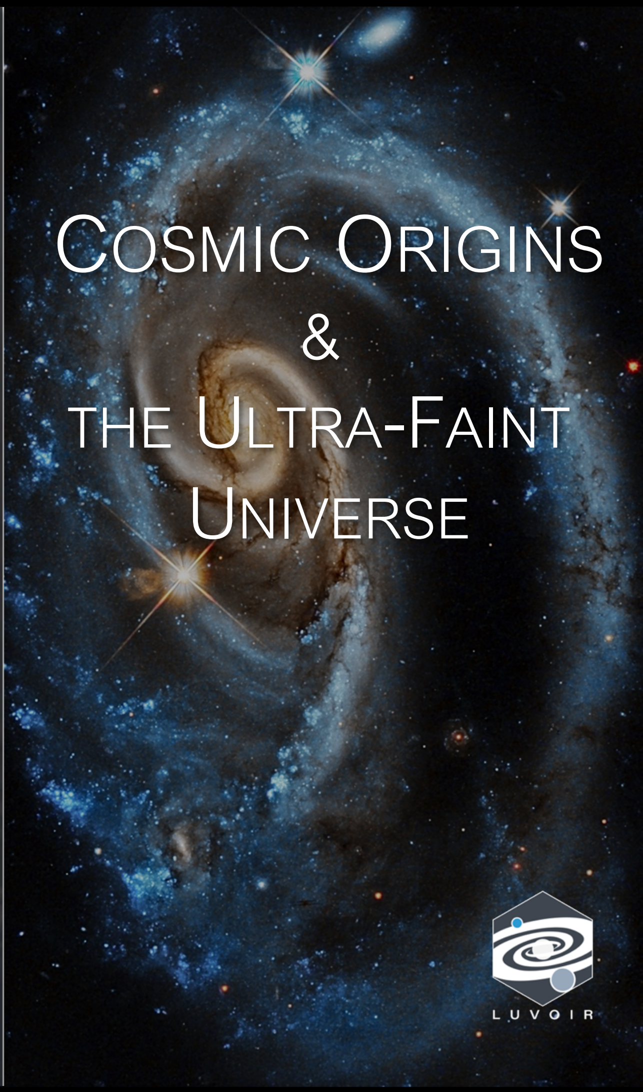




LUVOIR-A
15 m
LUVOIR-B
8 m
HST
2.4 m
54
648
28
576
Exoplanets
Solar System
Astrophysics


Exotic Worlds
The Search
for Life


Our Dynamic
Solar System

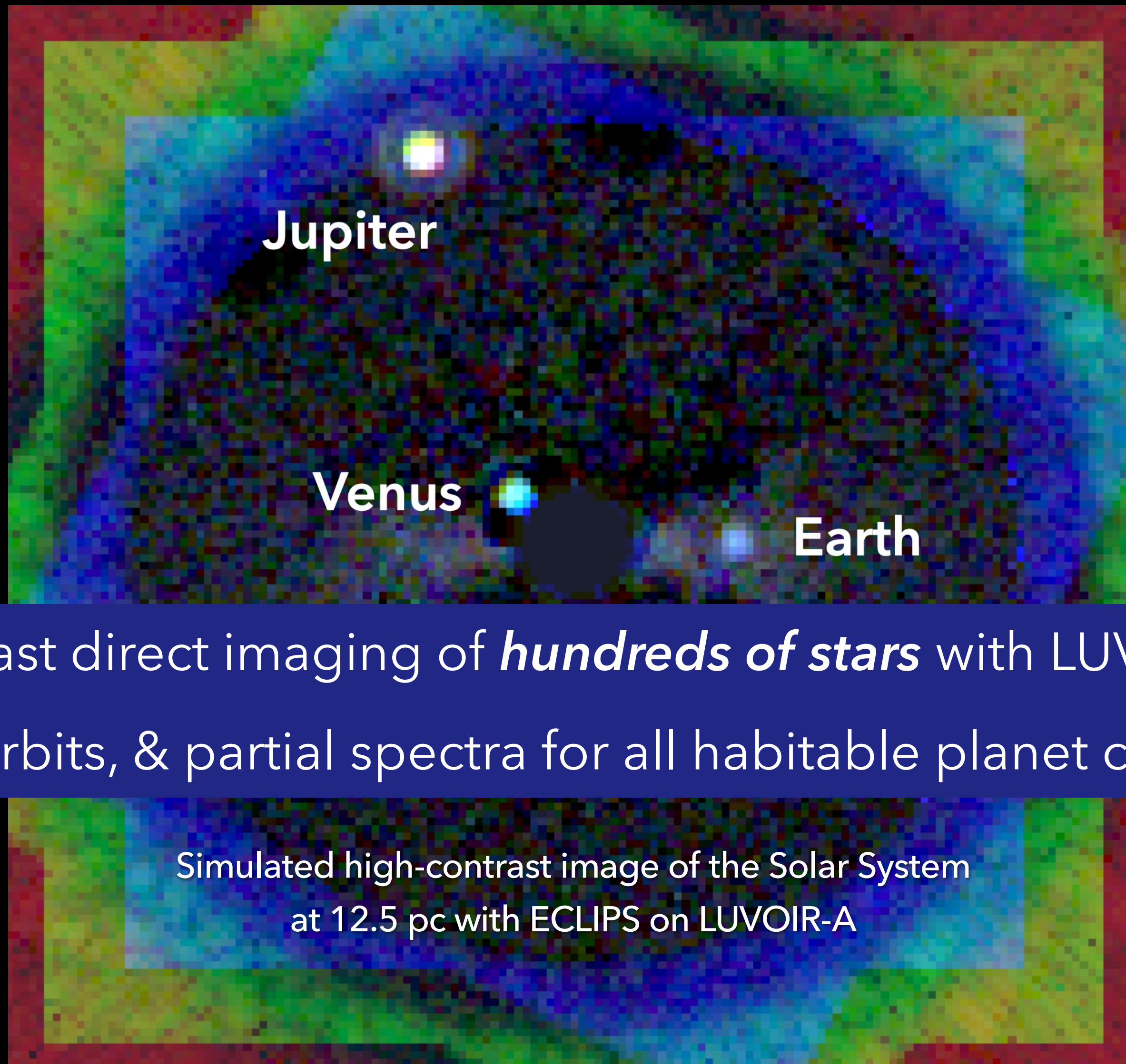

Cosmic Origins
&
the Ultra-Faint
Universe
LUVOIR

Ambitious goal drives telescope size

THE HABITABLE PLANET SURVEY OBSERVATIONS

High-contrast direct imaging of ***hundreds of stars*** with LUVOIR ECLIPS

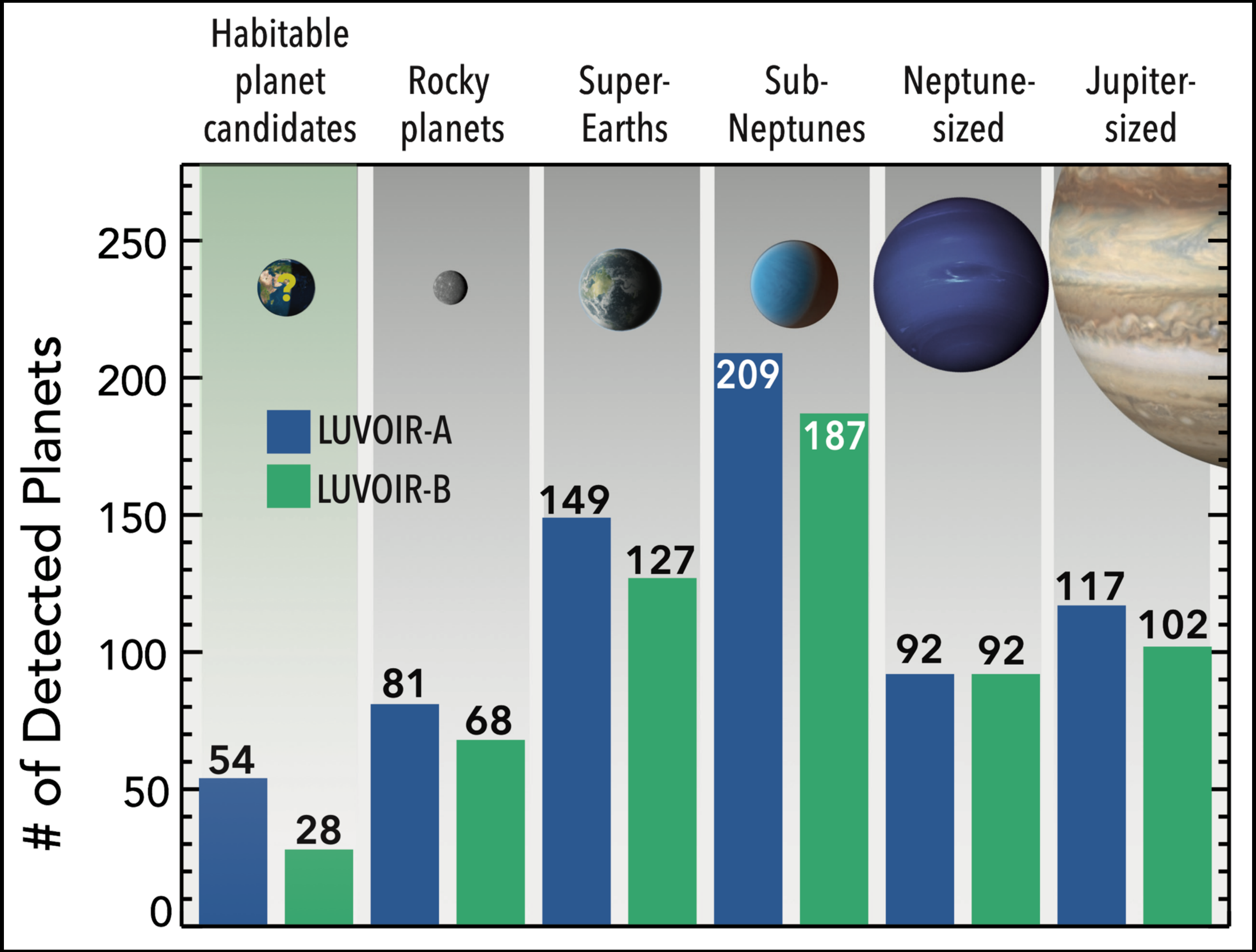
Colors, orbits, & partial spectra for all habitable planet candidates



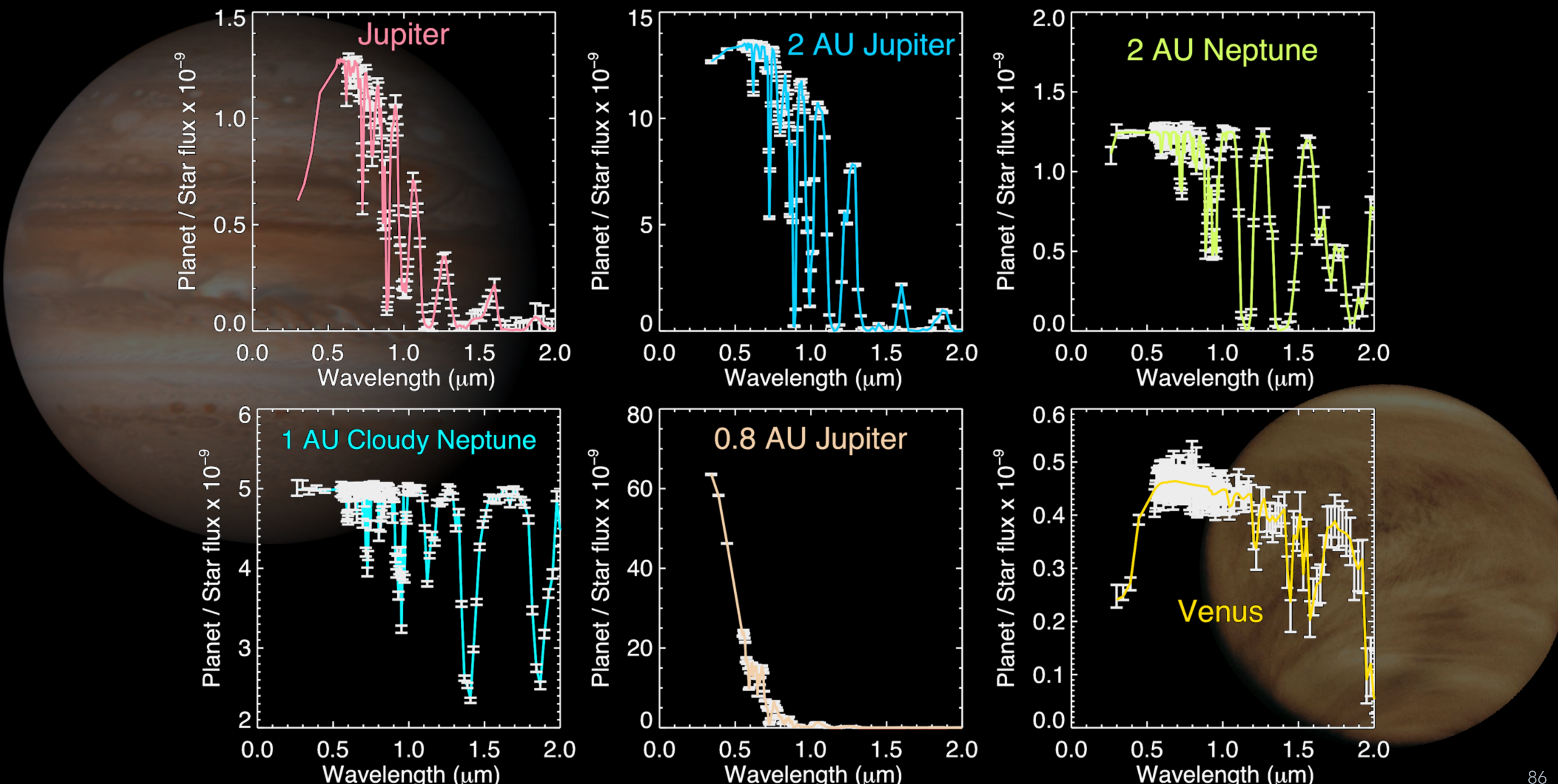
Simulated high-contrast image of the Solar System
at 12.5 pc with ECLIPS on LUVOIR-A

Searching for Signs of Life

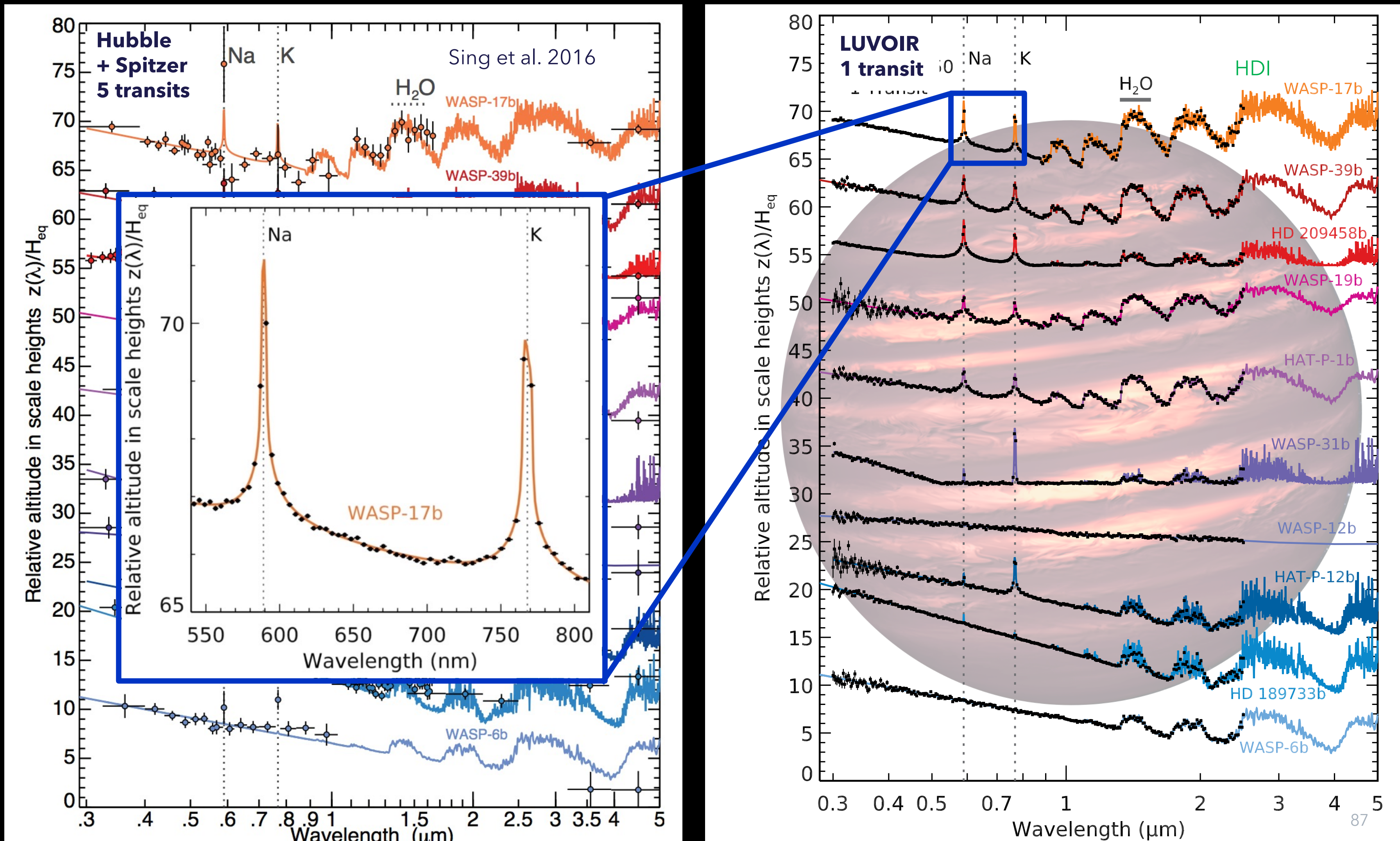
Dozens of habitable candidates, hundreds of planets



LUVOIR Will Observe a Wide Range of Planets



Transmission Spectra with LUVOIR



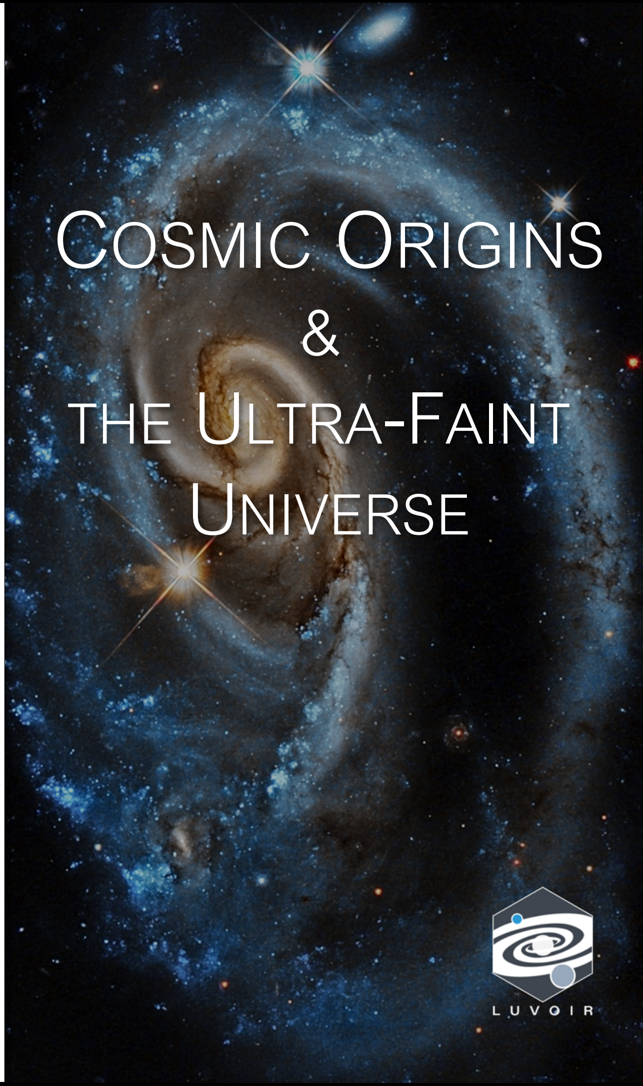
OUR DYNAMIC SOLAR SYSTEM

Flyby-quality observations of Solar System bodies

Jupiter from JUNO at ~ 30 km resolution

Comparable to LUVOIR-A (~ 24 km at opposition)

Cosmic Origins & the Ultra-Faint Universe



SEEKING THE BUILDING BLOCKS OF GALAXIES

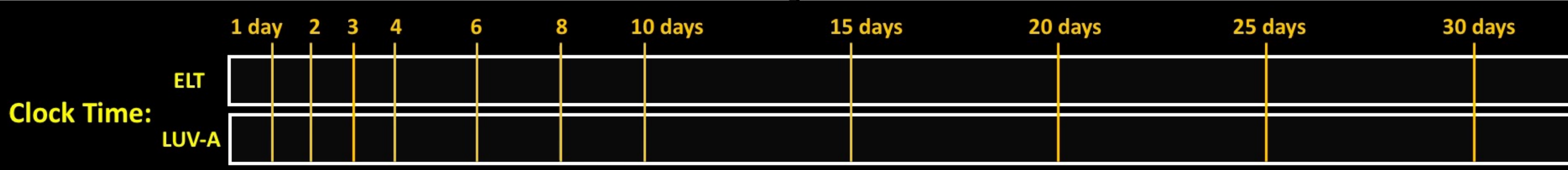
HDI

Exposure Time: 100 seconds

ELT (39 meter) J-band, 5sig lim = 26.77 mag

LUVOIR-A (15 meter) F850LP (z-band), 5sig lim = 28.00 mag

LUVOIR's ***Deep Fields*** – many collected in parallel with deep exoplanets observations - will reach will reach down to the very smallest mass scale galaxy formation




CALIFORNIA
ACADEMY OF
SCIENCES

Research funding provided by UC Berkeley, the David & Lucile Packard Foundation, the Sloan Foundation, the Hellman Family Faculty Fund, the NASA TESS Guest Investigator & K2 Guest Observer Programs, NASA FINESST Program, and NSF GRFP

Summary

Kepler **revealed that small & cool planets are common**

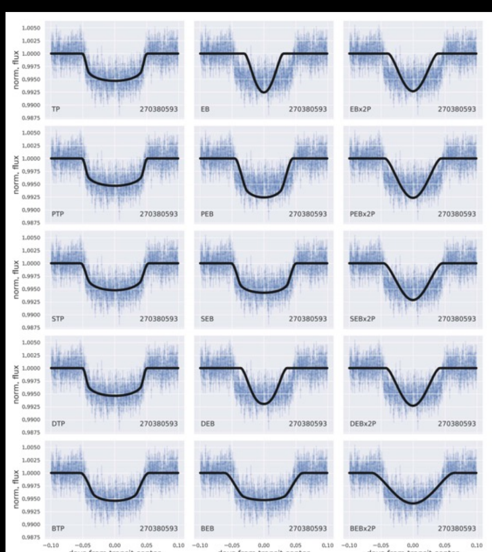
TESS **is finding small planets orbiting nearby stars**

Ground-based facilities are **characterizing planetary systems**

JWST will **probe planetary atmospheres**

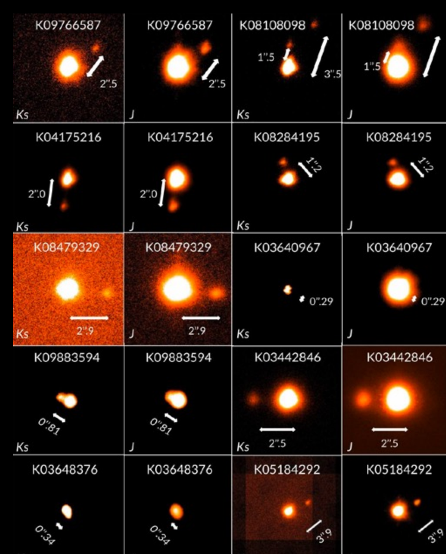
Future instruments will **search for habitable & inhabited worlds**

Estimating Planet Reliability



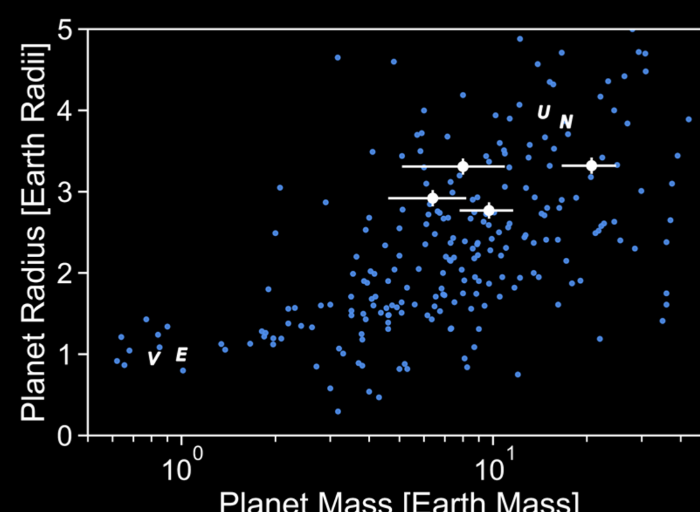
Giacalone et al. (2021)

Validating Planets



Savel et al. (2020)

Exploring Planet Composition



Turtelboom et al. (in prep)

Advice for Working in Collaborations

- Communicate regularly and clearly with your team.
  - Delineate tasks & roles for team members.
  - Hold meetings with pre-determined agendas.
  - Maintain a shared repository of information.
  - Establish useful communication channels (e.g., email lists, Slack workspaces).
- Share your interests with your collaborators.
  - Explain what you want to focus on and why.
  - Convince others that your goals are exciting!
  - Learn about work by your team members.
  - Seek out opportunities for collaboration.
- Speak up for yourself if necessary.
  - Clarify ambiguous messages.
  - Have awkward conversations about publication plans.
  - Pay attention to group dynamics.
  - Ensure that all group members are treated with respect.
- Routinely re-assess your interest in the collaboration.
  - Check your "time budget."
  - Verify that you're still working on topics that you find exciting.
  - Ensure that the collaboration behaves ethically and fairly.

ADDITIONAL SLIDES