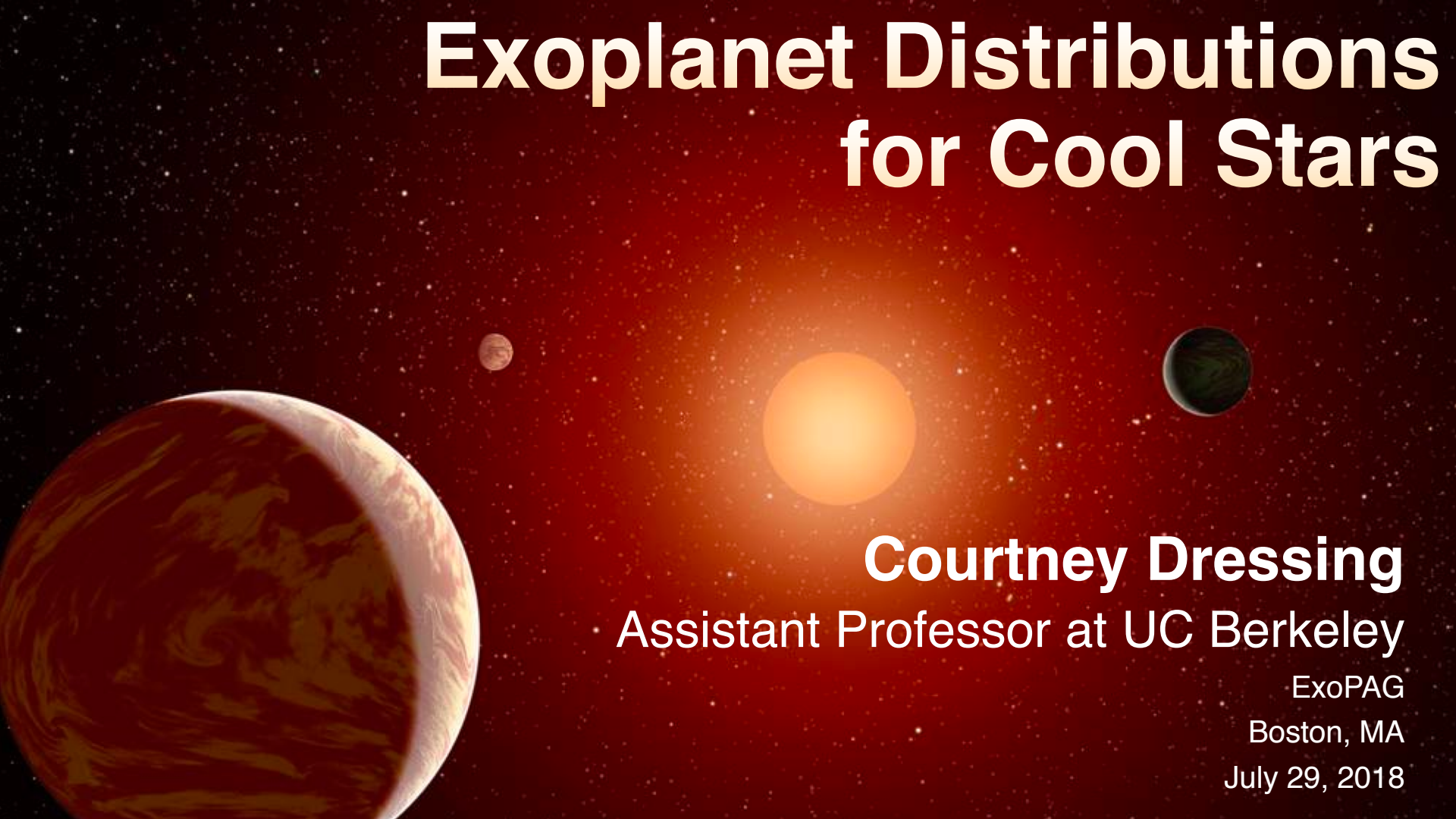
Exoplanet Distributions for Cool Stars



Courtney Dressing

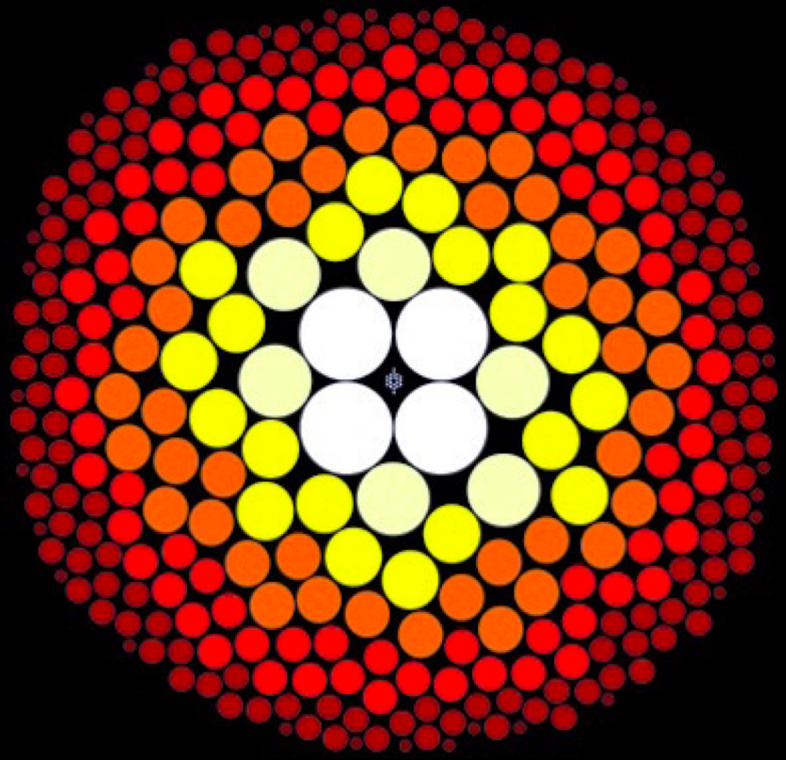
Assistant Professor at UC Berkeley

ExoPAG

Boston, MA

July 29, 2018

Advantage 1: M Dwarfs are Prevalent



75% of stars are M dwarfs

(Winters+2015, Henry+2006)

Image Credit: Henry / RECONS

Advantage #2:
M Dwarfs are Easy Targets

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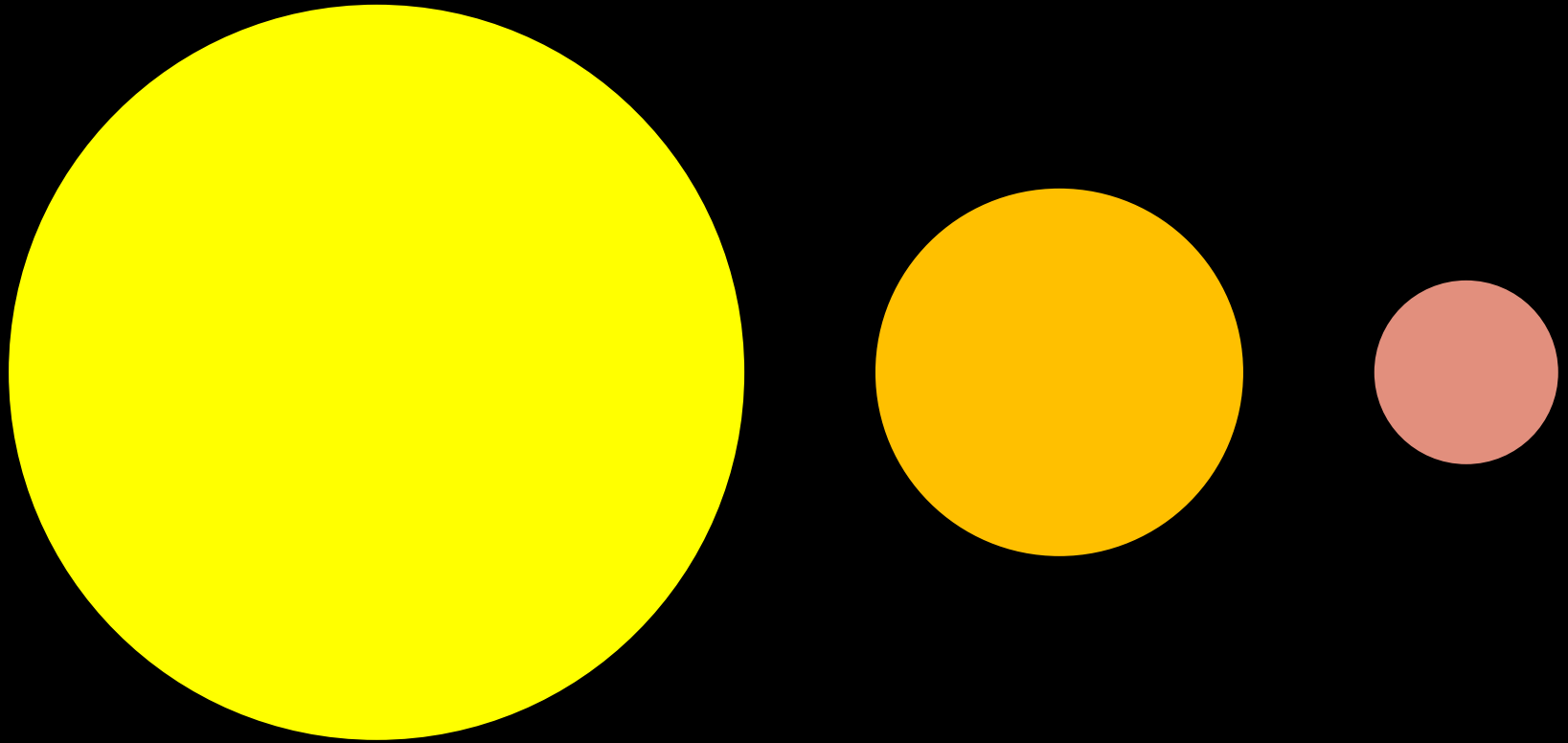
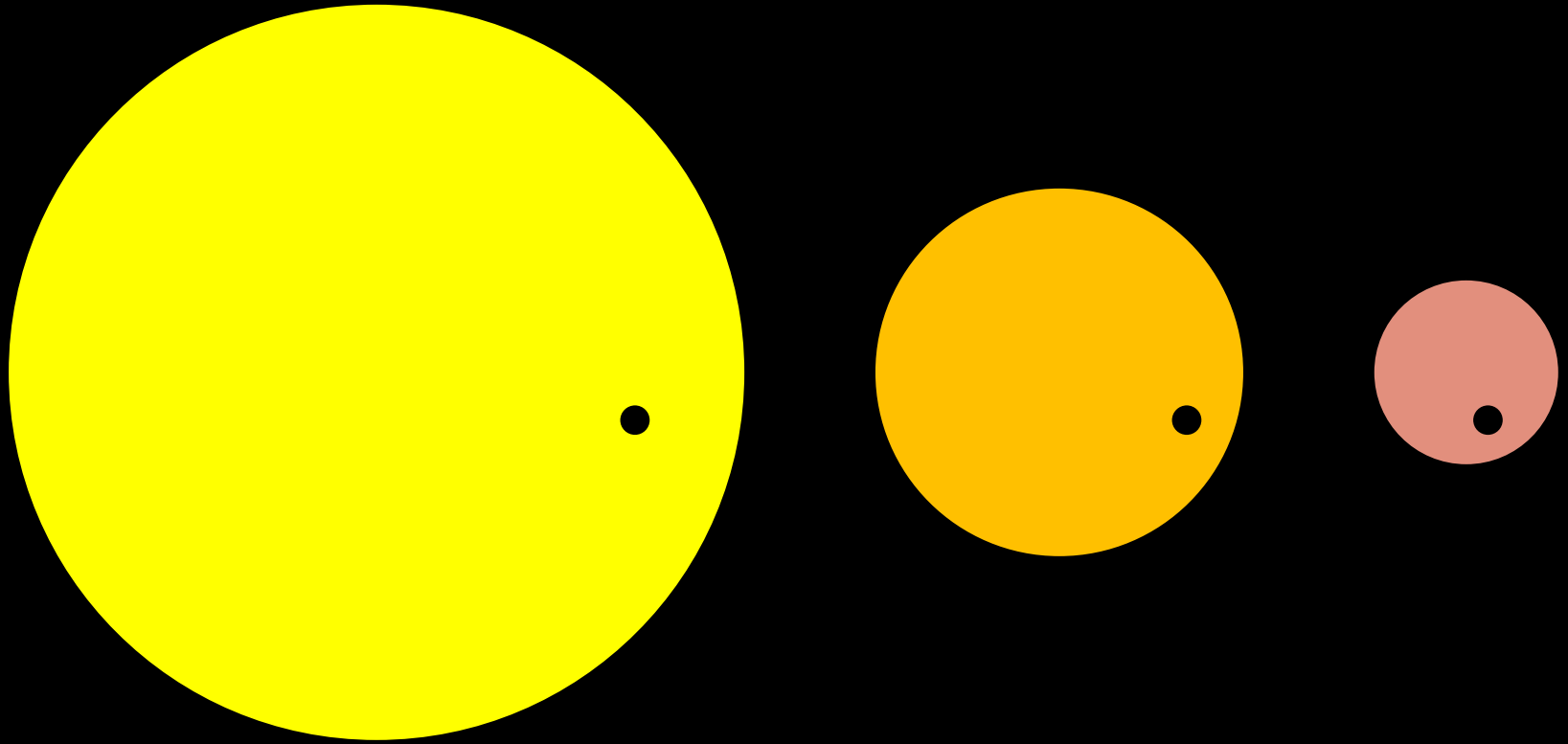


Advantage 2: M Dwarfs are Easy Targets



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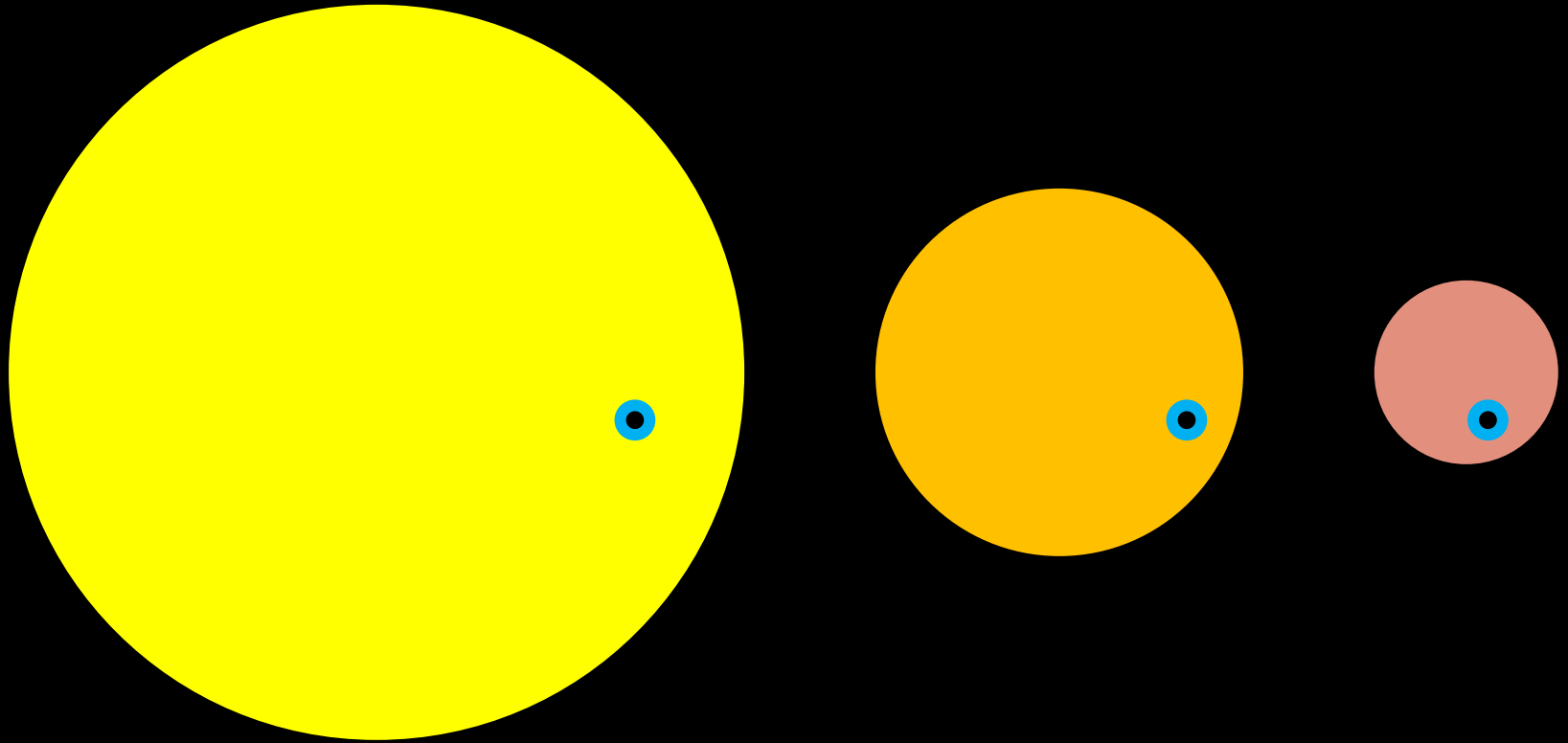
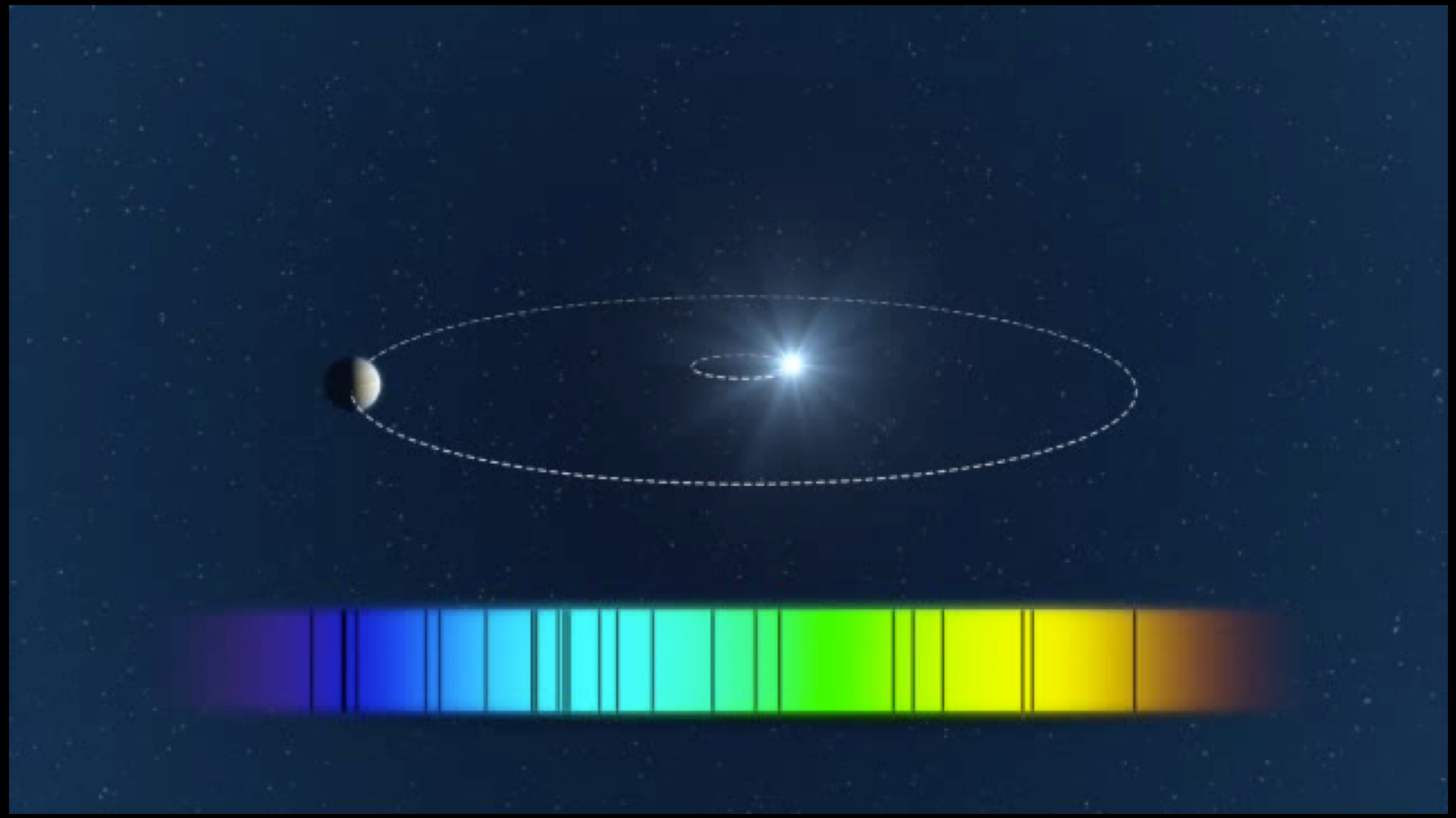


Atmospheric signals are larger

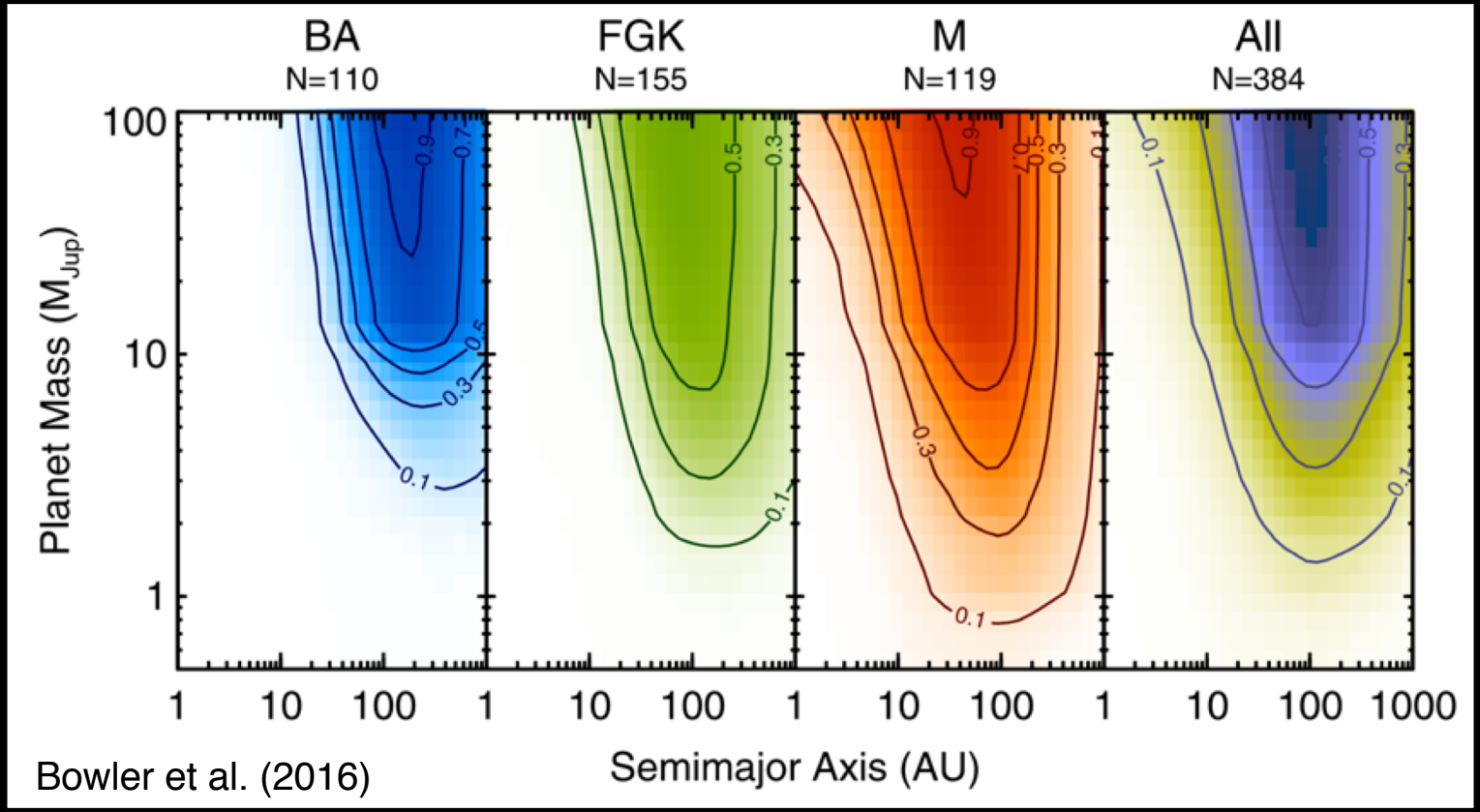
Advantage 2: M Dwarfs are Easy Targets



Credit: ESO

Radial velocity signals are larger

Advantage 2: M Dwarfs are Easy Targets



Bowler et al. (2016)

Planet/star contrast ratios are more favorable

Advantage #3:
Potentially Habitable Planets Have Short Orbital Periods

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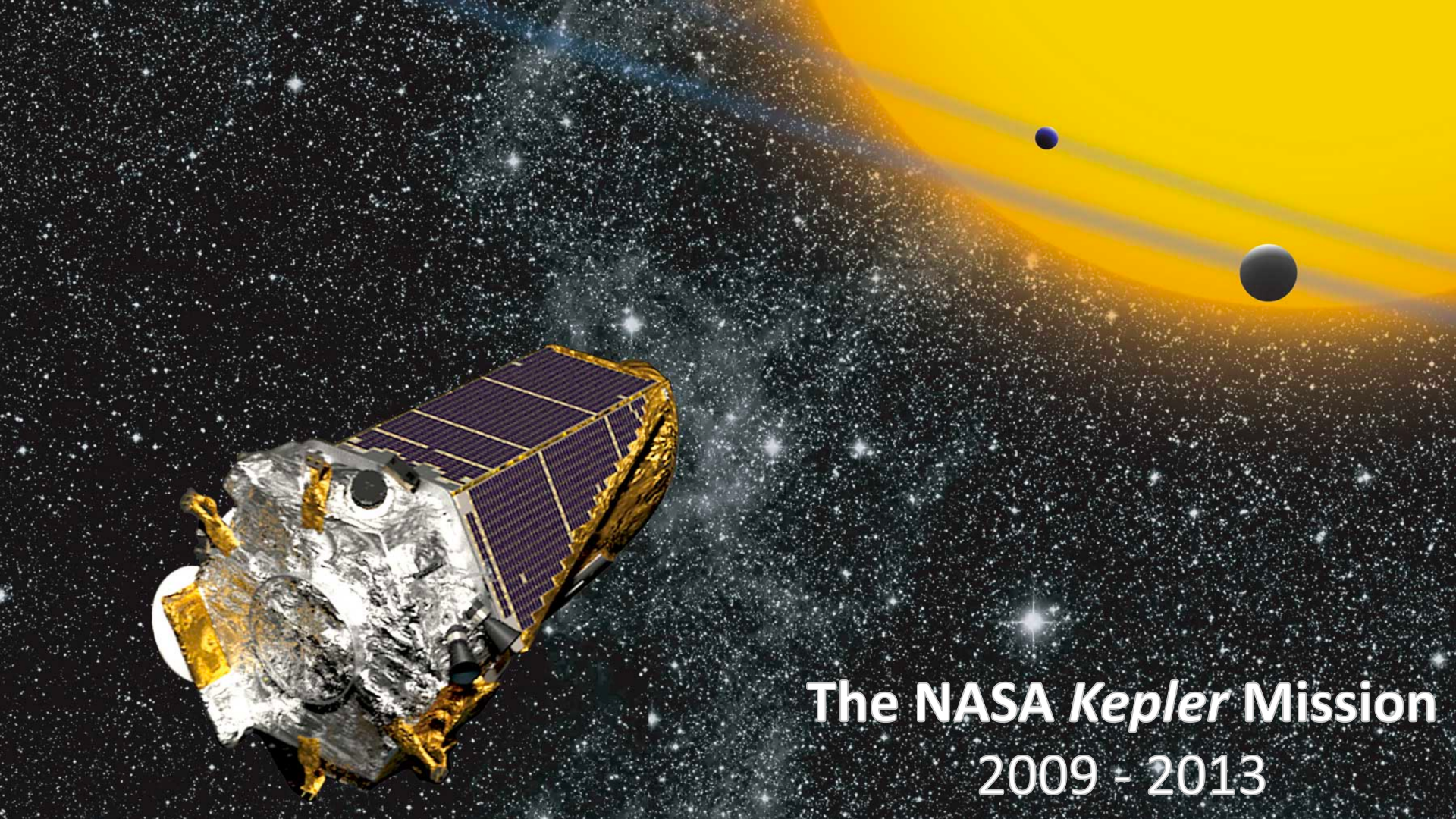
Potentially Habitable Planets Have Short Orbital Periods

Transits are more frequent & more likely

Advantage #4:
Planets Orbiting M Dwarfs are Common


The NASA *Kepler* Mission
2009 - 2013

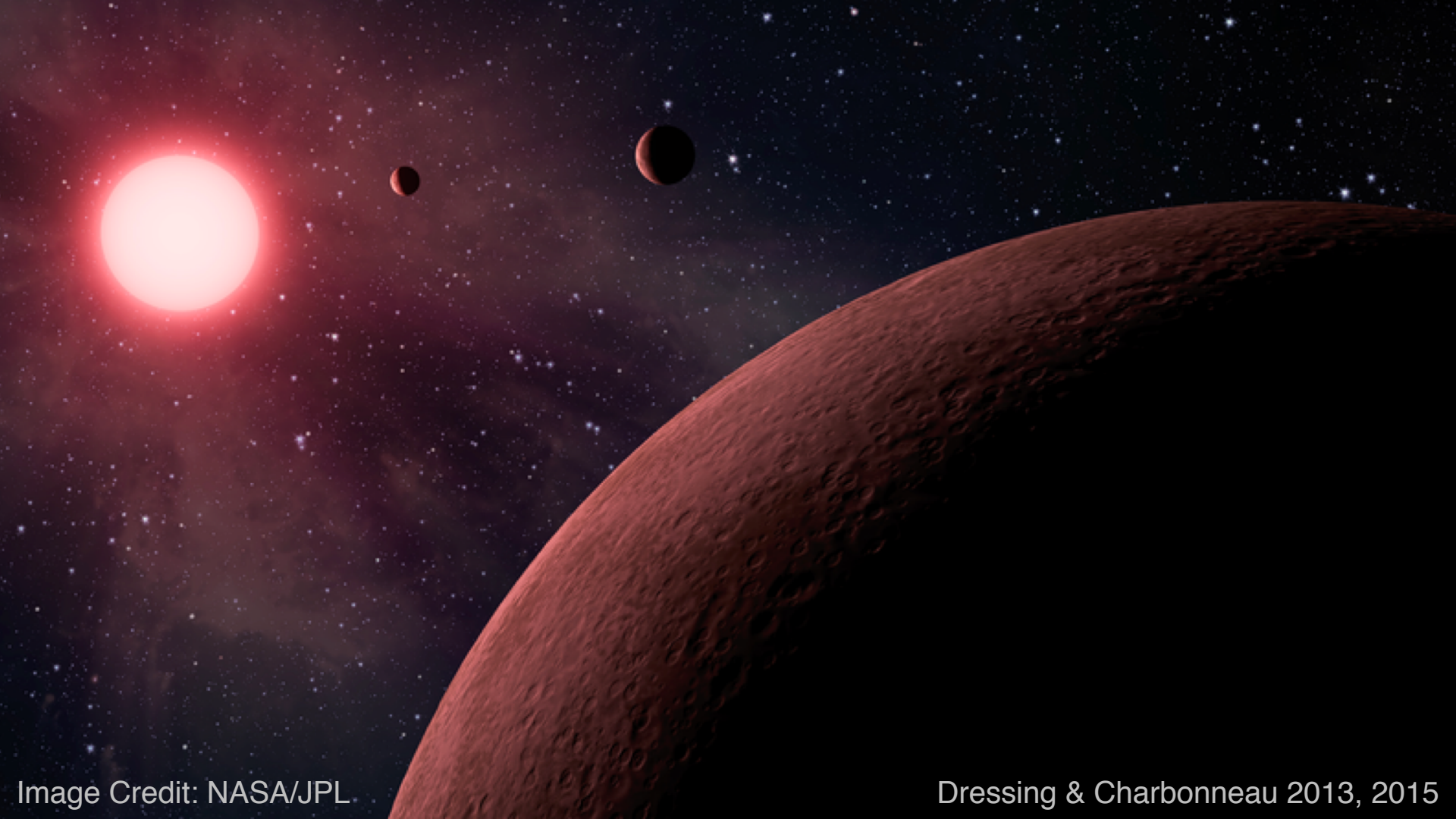
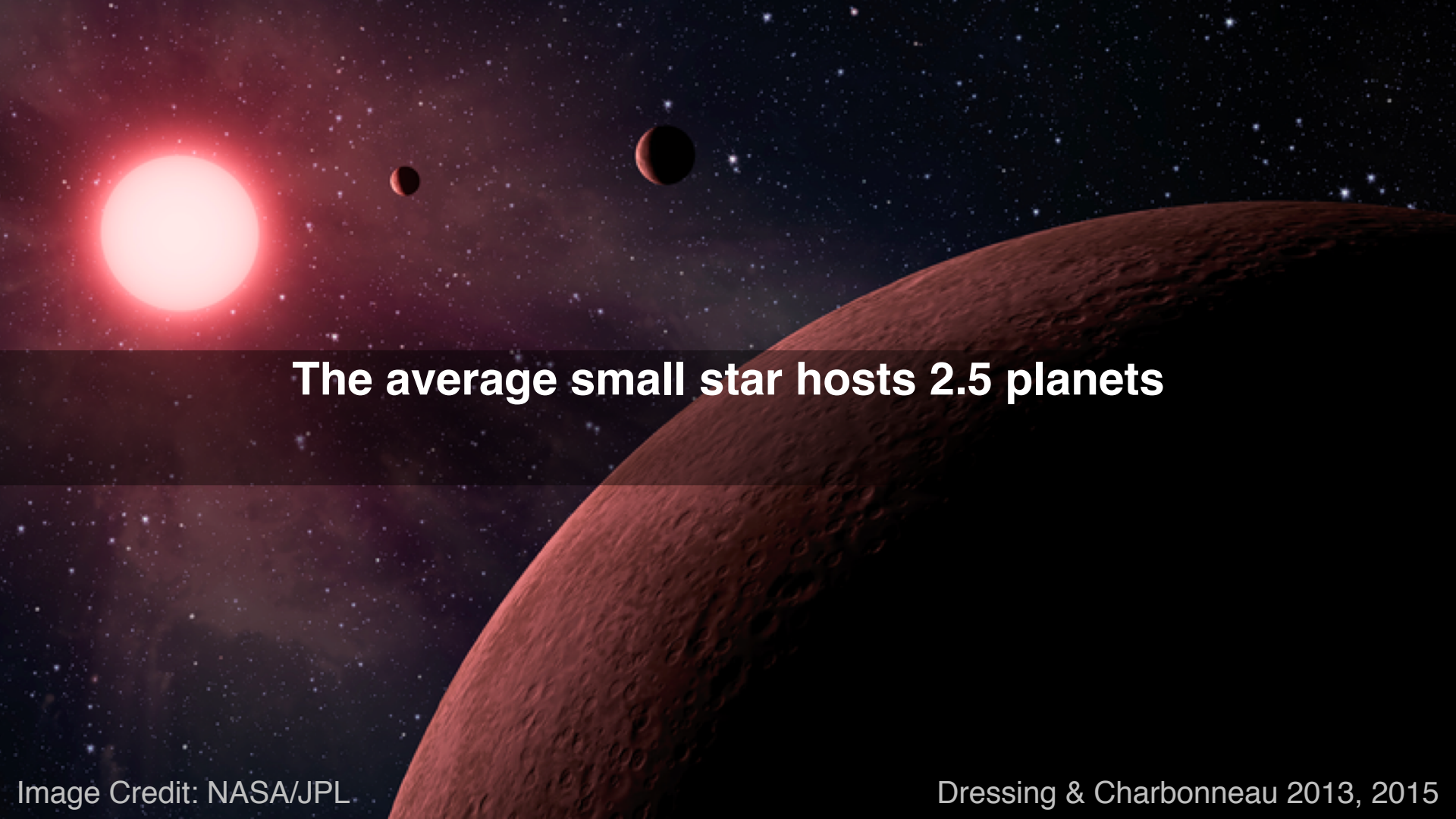


Image Credit: NASA/JPL

Dressing & Charbonneau 2013, 2015



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Dressing & Charbonneau 2013, 2015

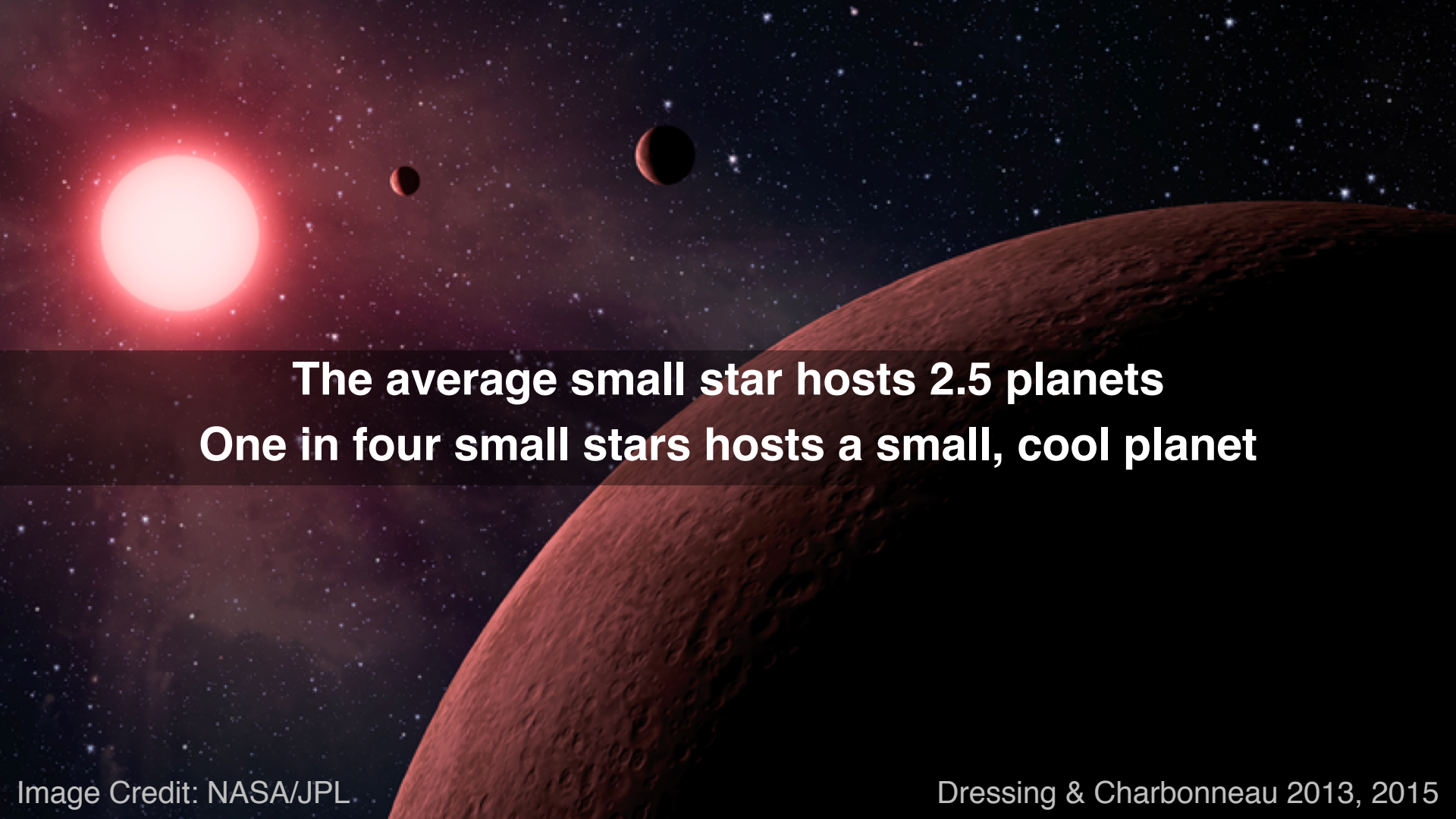
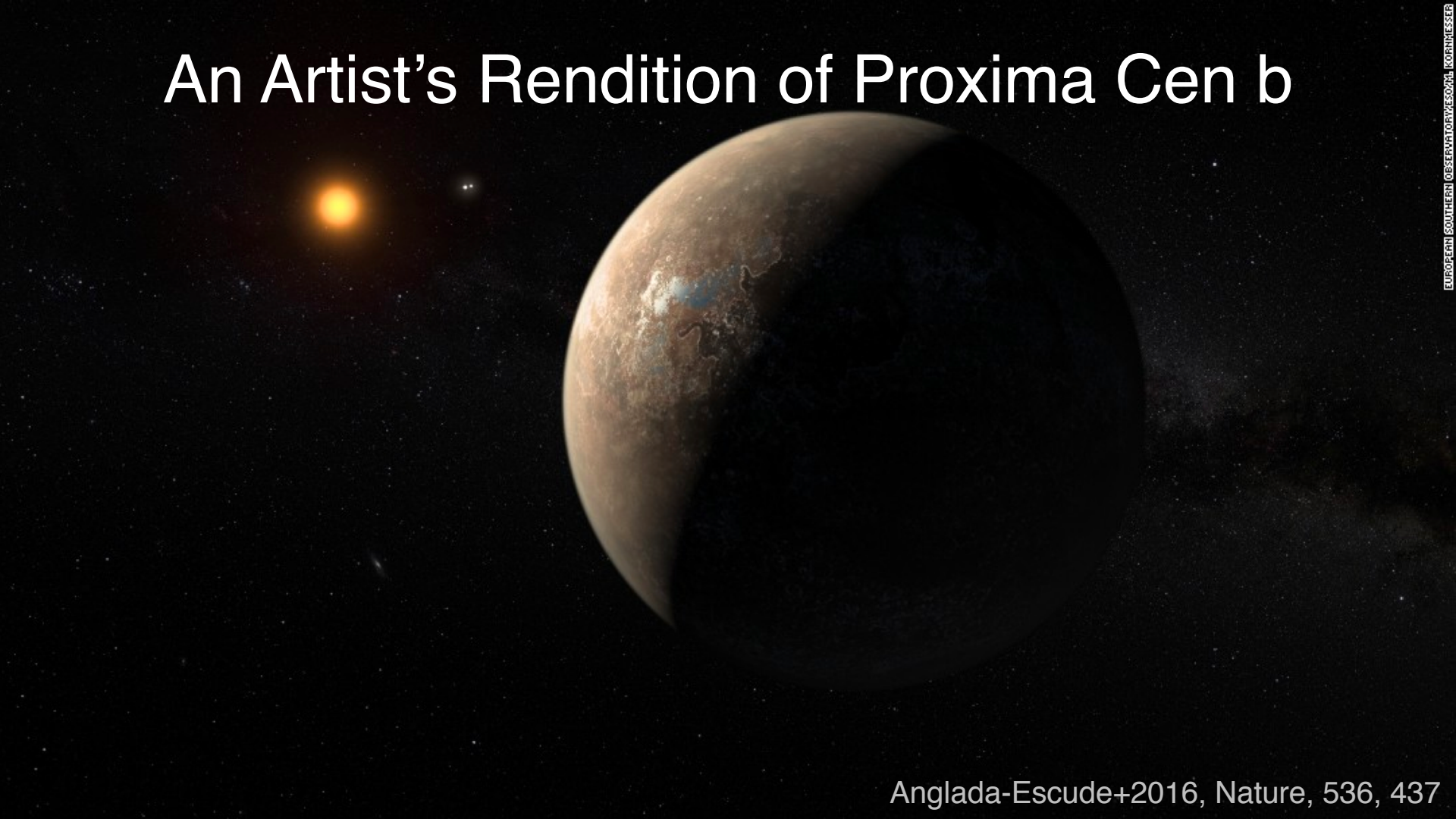


Image Credit: NASA/JPL

Dressing & Charbonneau 2013, 2015

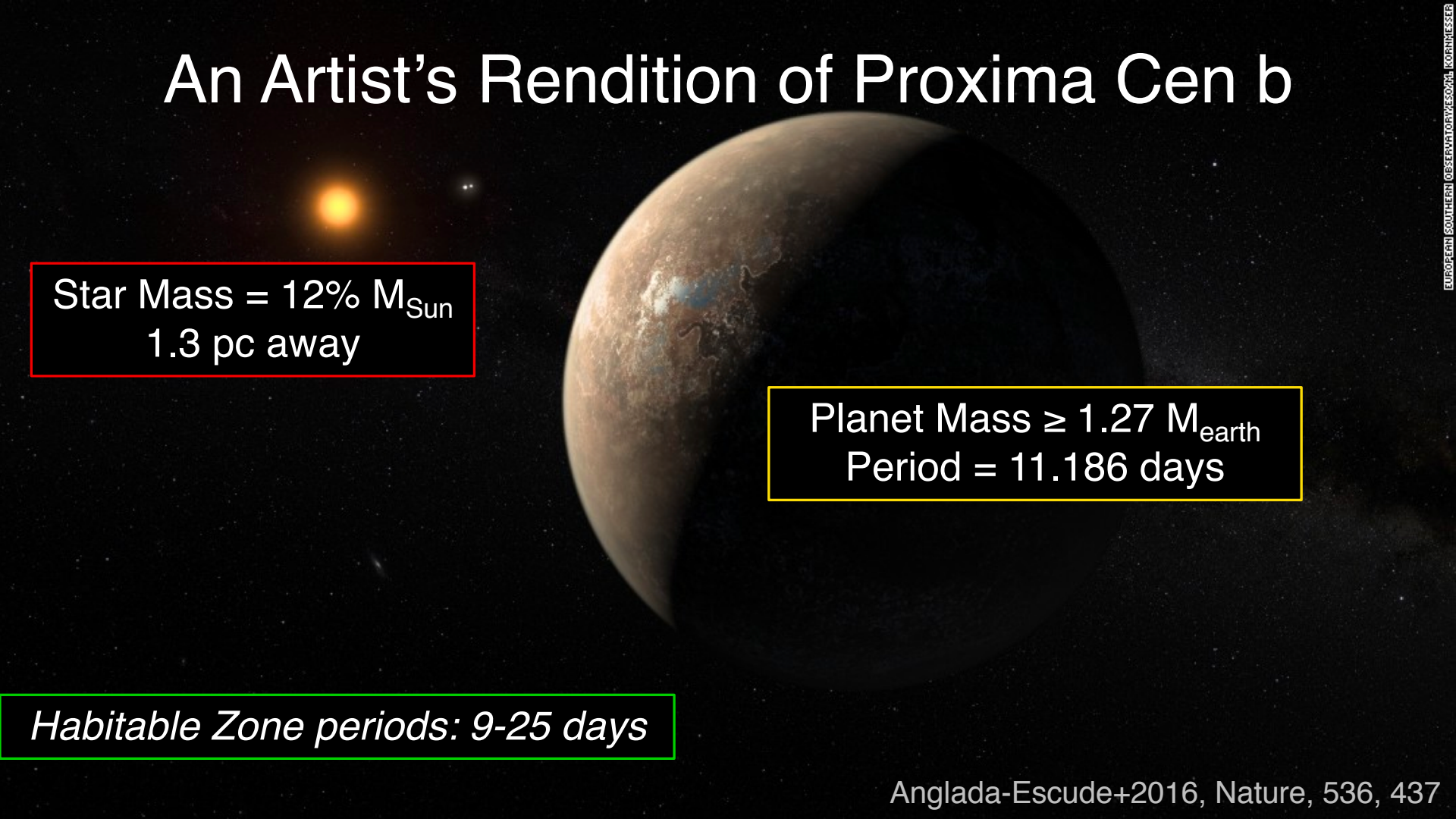
An Artist's Rendition of Proxima Cen b



EUROPEAN SOUTHERN OBSERVATORY/ESO/M. KORNMESSER

Anglada-Escude+2016, Nature, 536, 437

An Artist's Rendition of Proxima Cen b



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

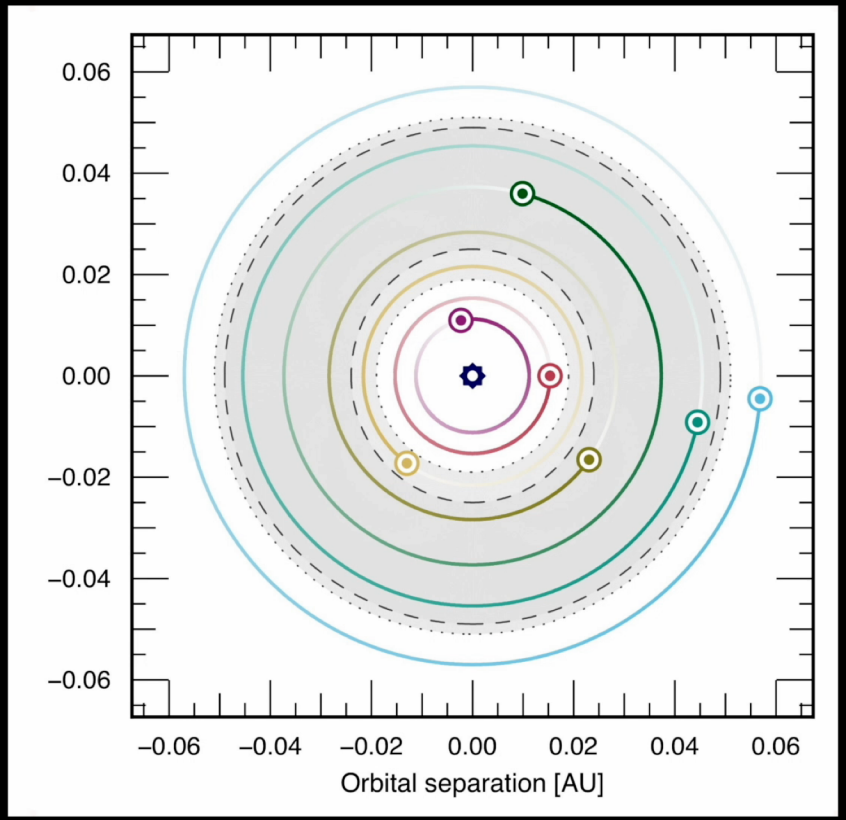
TRAPPIST-1 hosts 7 planets!

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}



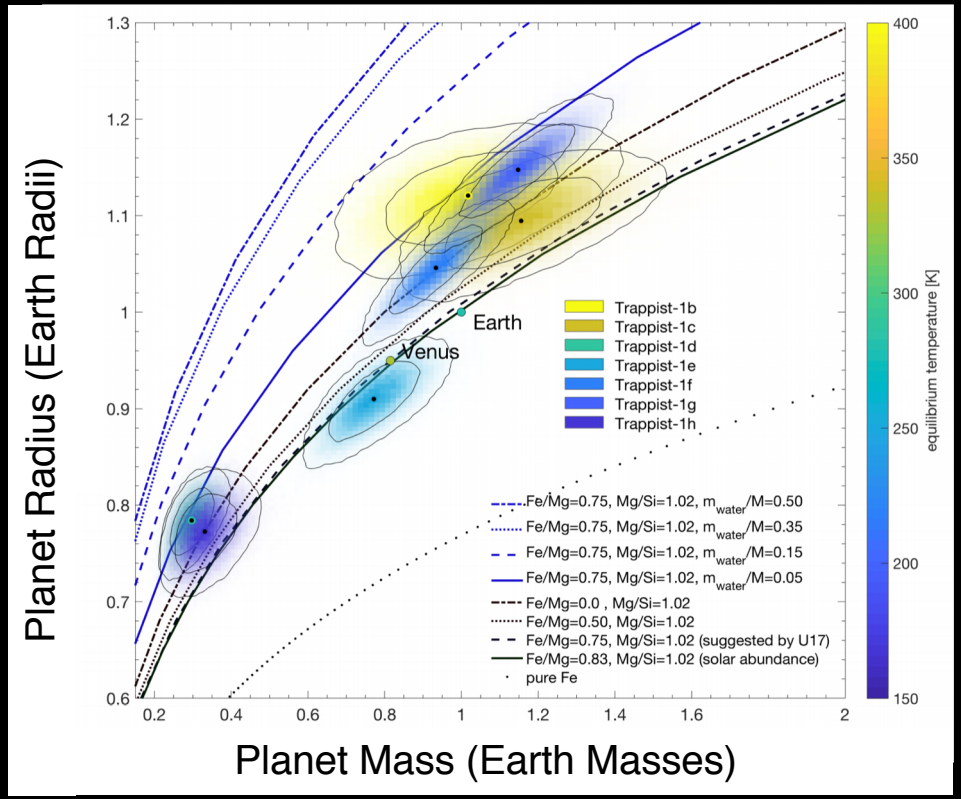
Planet f
9.2d
1.0R_{Earth}

Planet g
12.4d
1.1R_{Earth}

Planet h
18.8d
0.8R_{Earth}

Gillon+2016, 2017

Transit Timing Variations Probe the Compositions of the TRAPPIST-1 Planets



Grimm et al. 2018, A&A, 613, A68

Do the tiniest stars have even more planets?

Initial Answer: Yes, Smaller Stars Host More Planets

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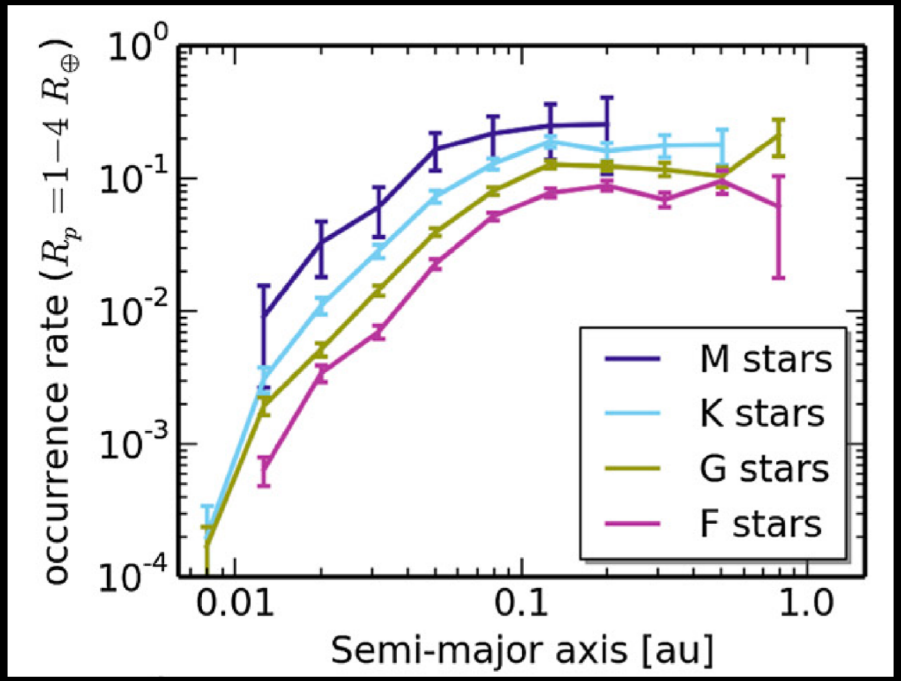

Mulders et al. (2015)

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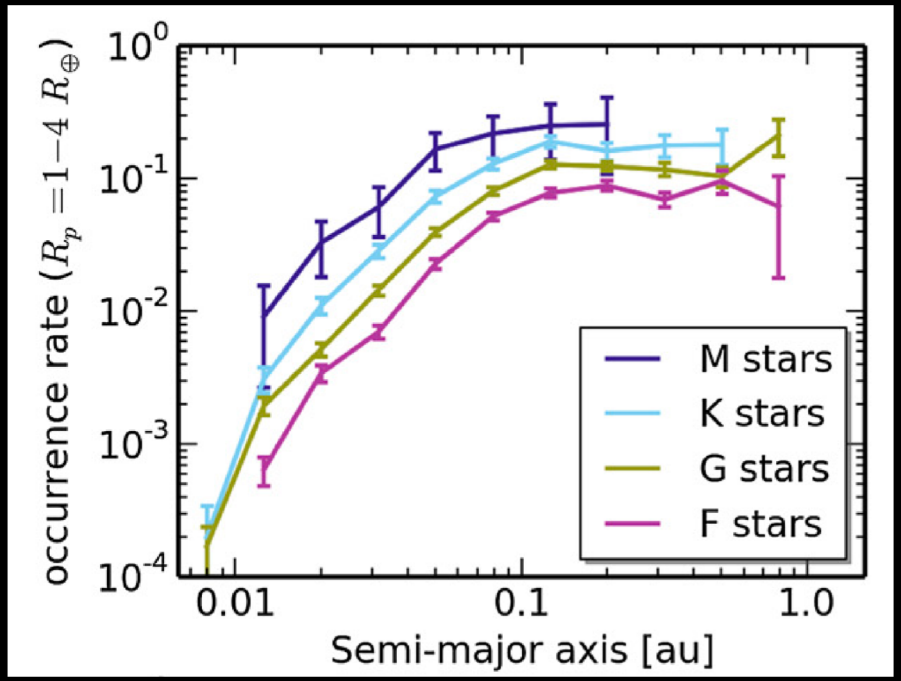

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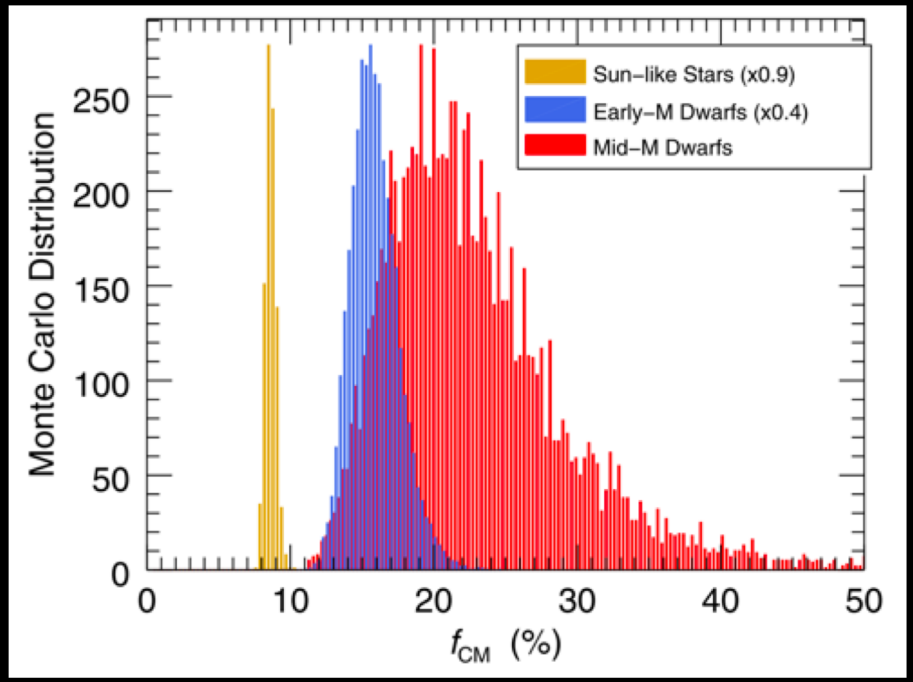
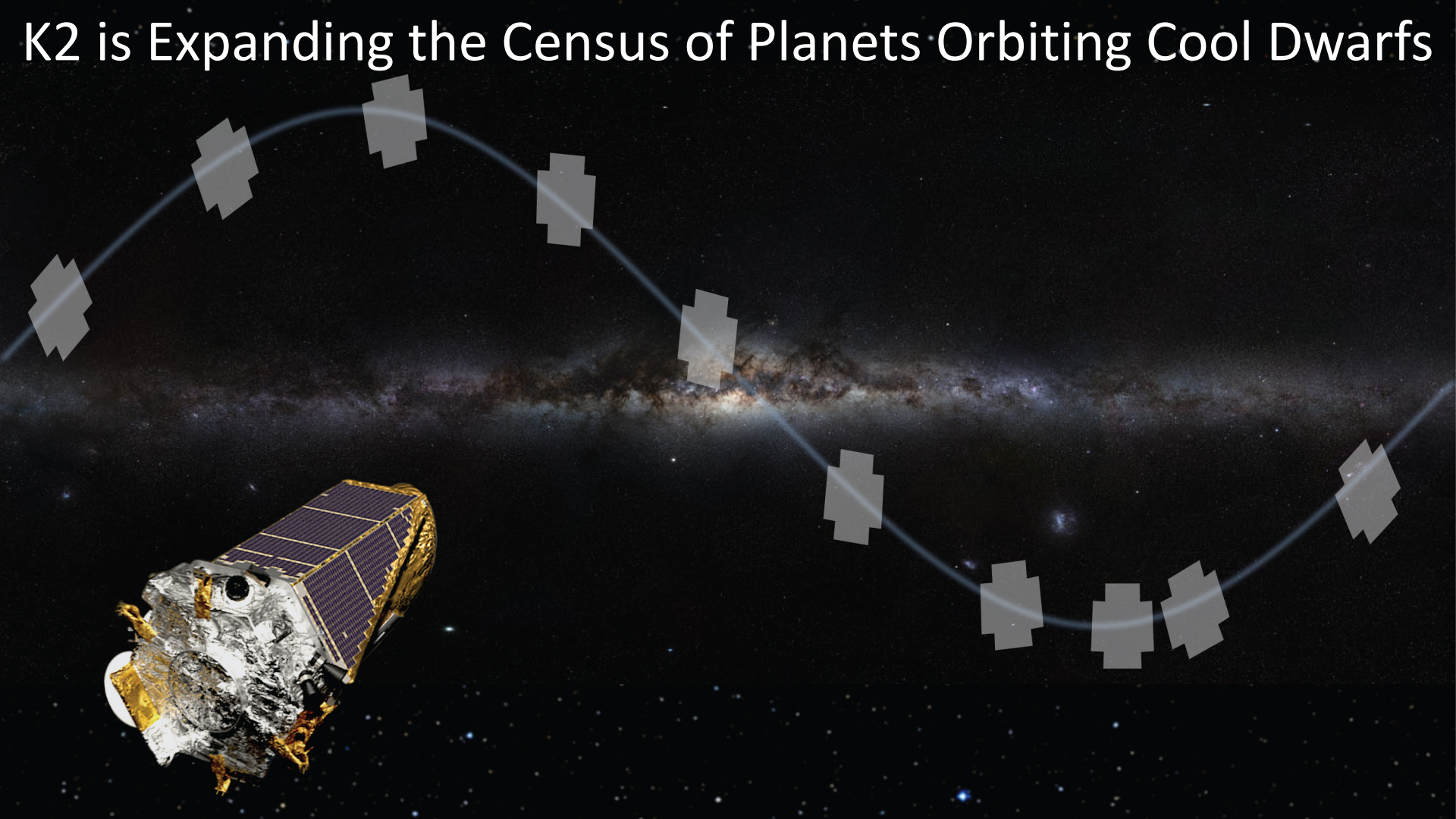


Muirhead et al. (2015)

K2 is Expanding the Census of Planets Orbiting Cool Dwarfs



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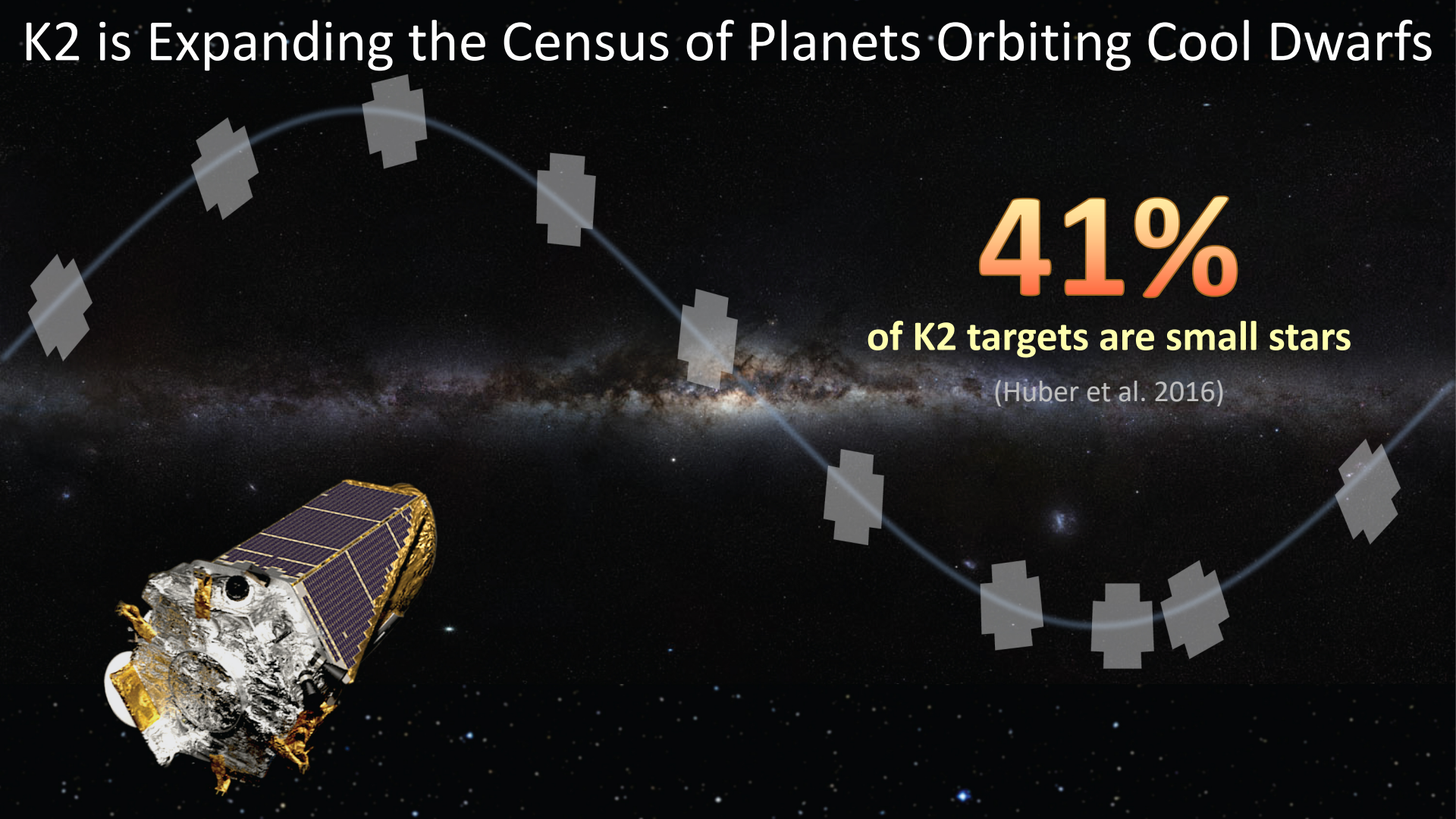

41%

of K2 targets are small stars

(Huber et al. 2016)

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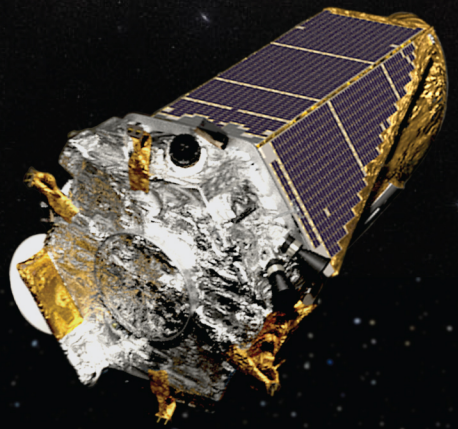

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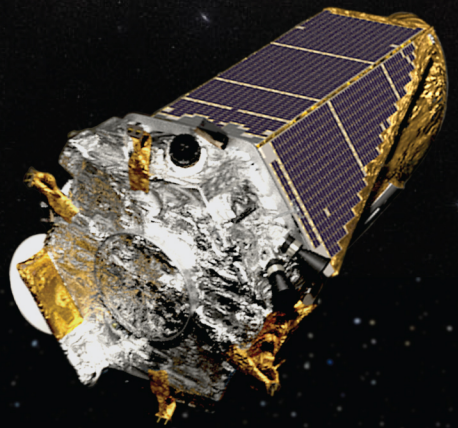

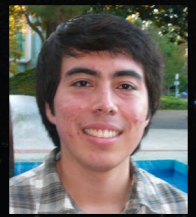

Arturo Martinez

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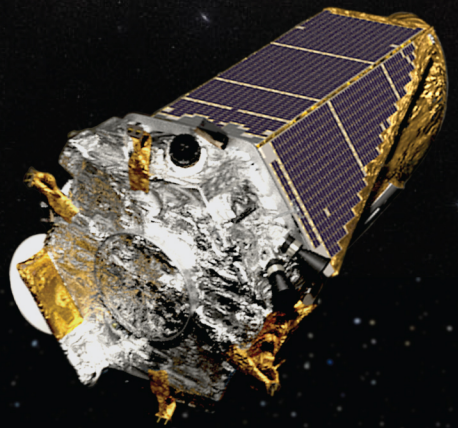
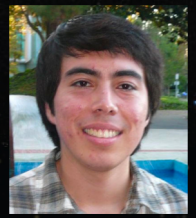
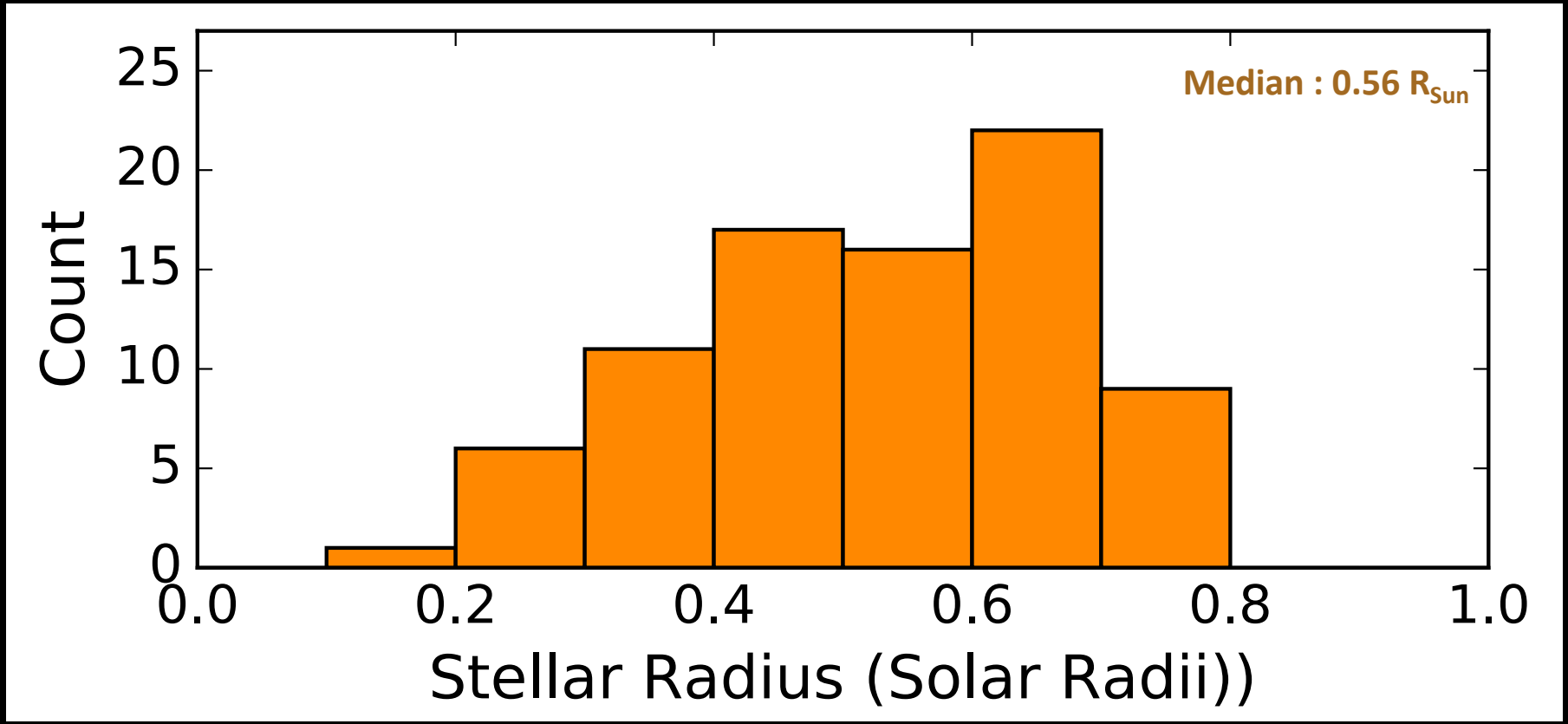




Arturo Martinez

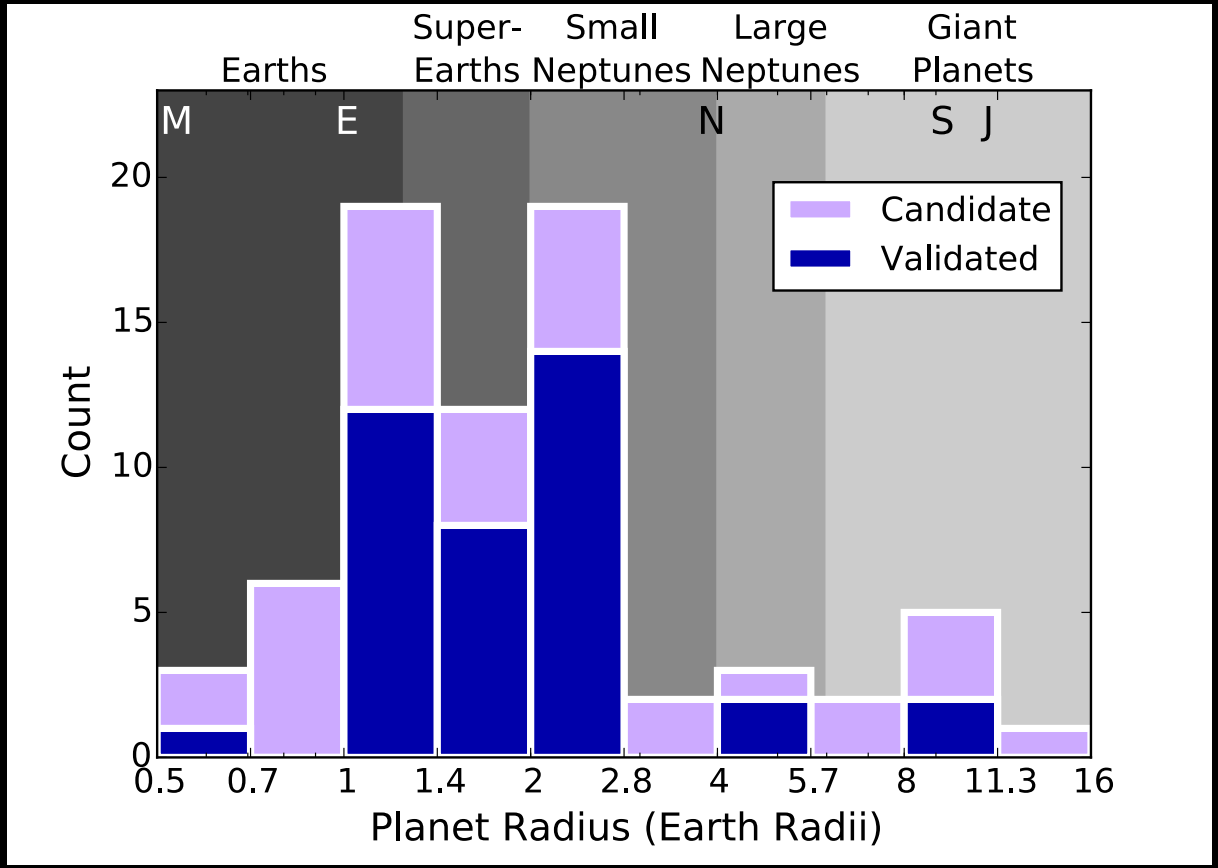
Makena Fetzer

Our Typical Targets are Roughly Half the Size of the Sun



Dressing+ 2017a, ApJ, 836, 167

85% of the Planets & Candidates are Smaller than Neptune



Dressing+ 2017b, AJ, 154, 207

Spectra are Expensive!

How can we classify the full K2 M dwarf sample?

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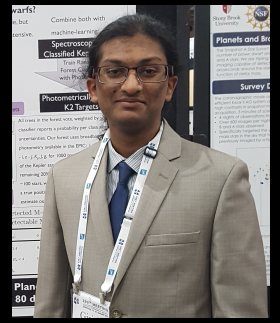
- Trained random forest using spectroscopically-classified stars
- Reported probabilities that individual targets are M dwarfs



G. Duvvuri
CU grad student
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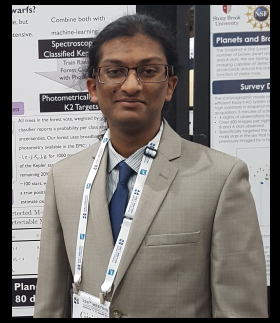

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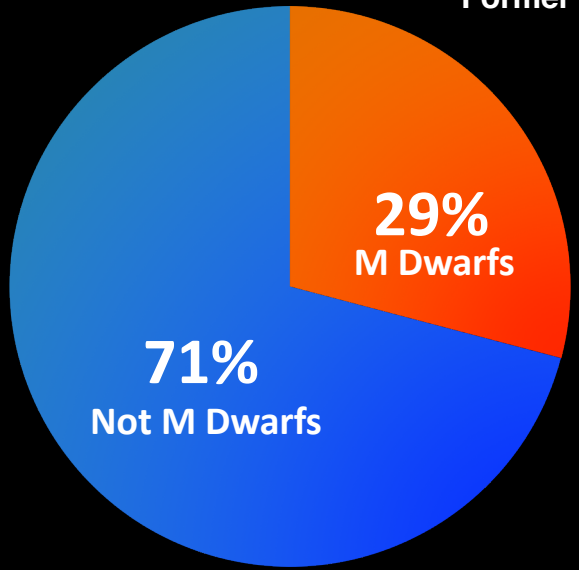
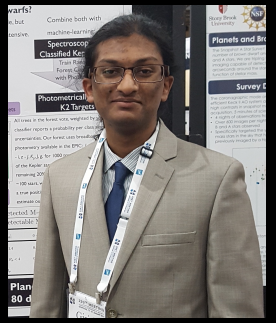


Girish Estimated K2's Sensitivity to Planetary Systems Orbiting M Dwarfs



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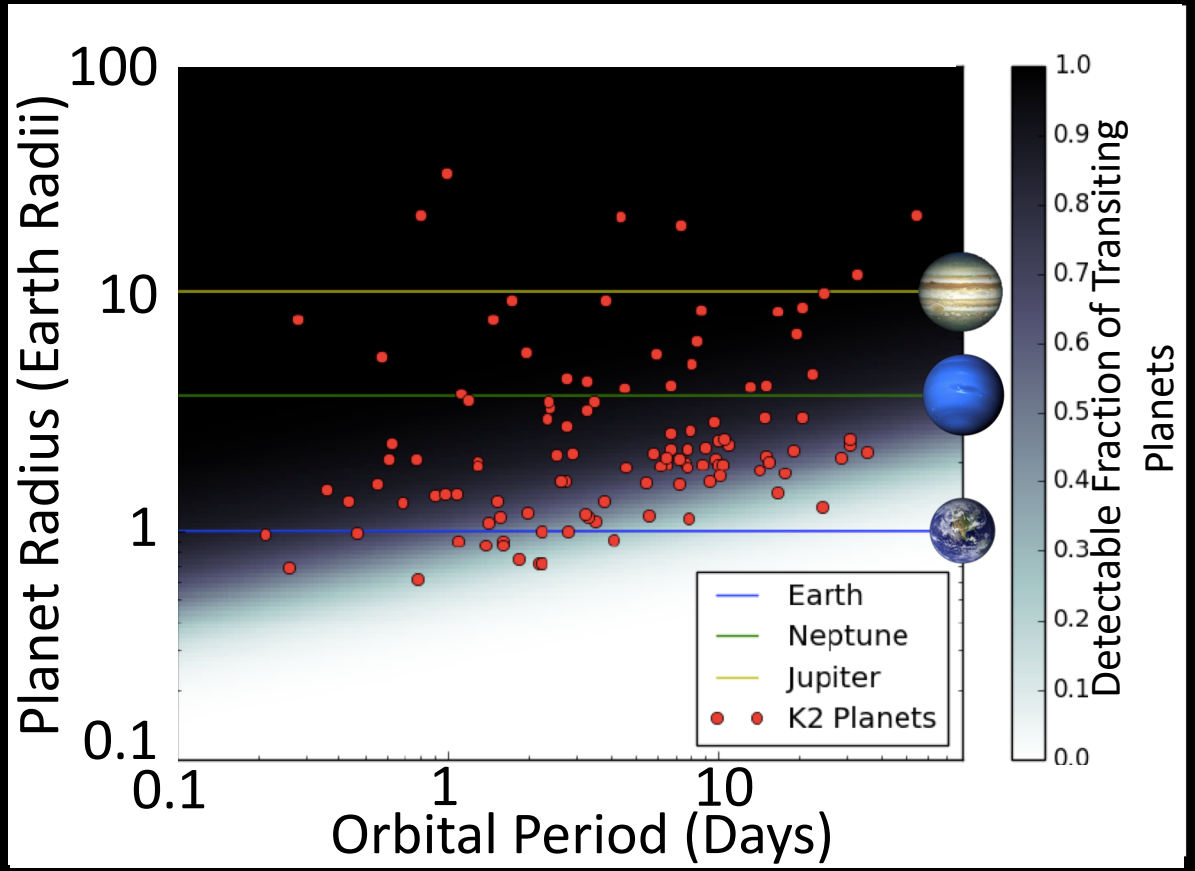

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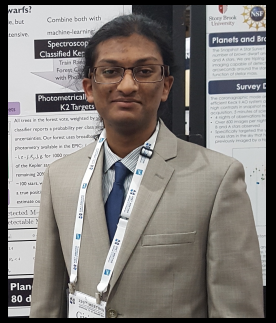

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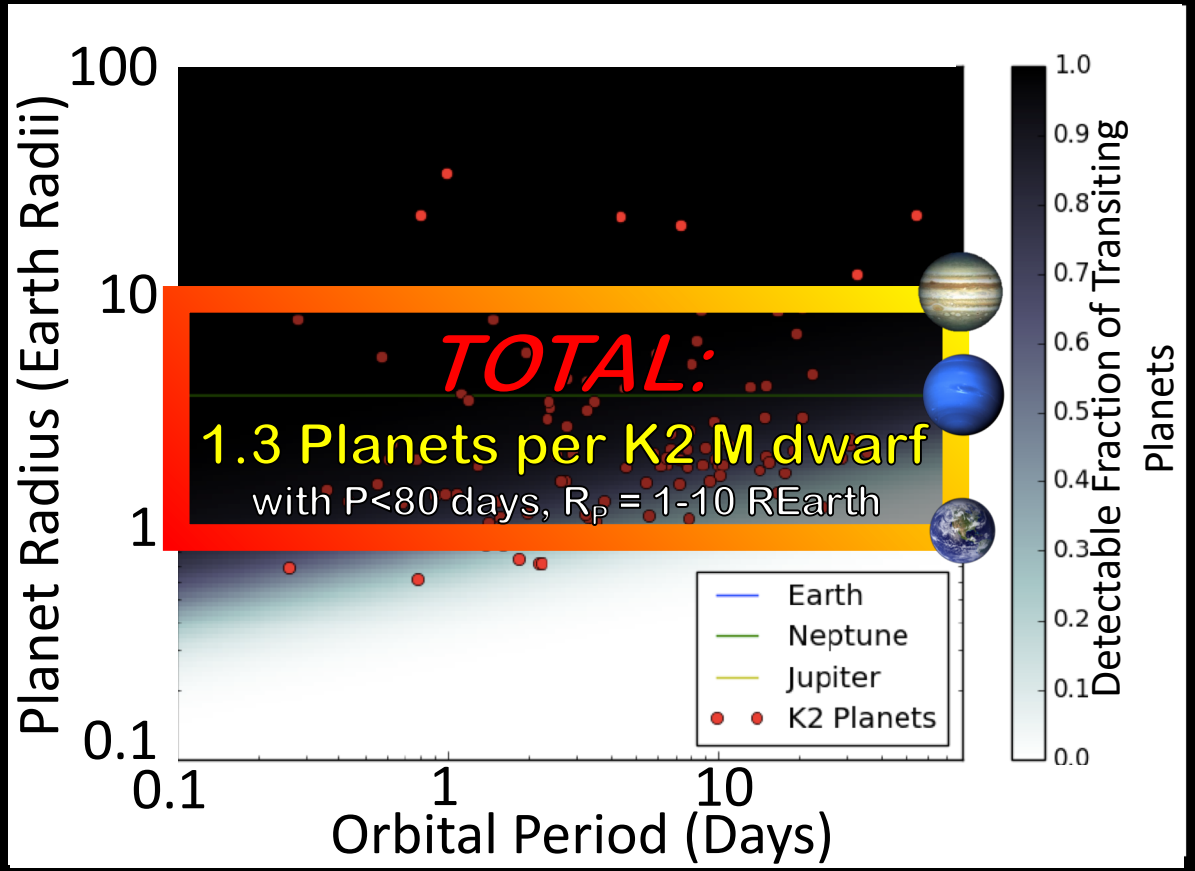

Gaia Parallaxes Constrain Stellar Properties

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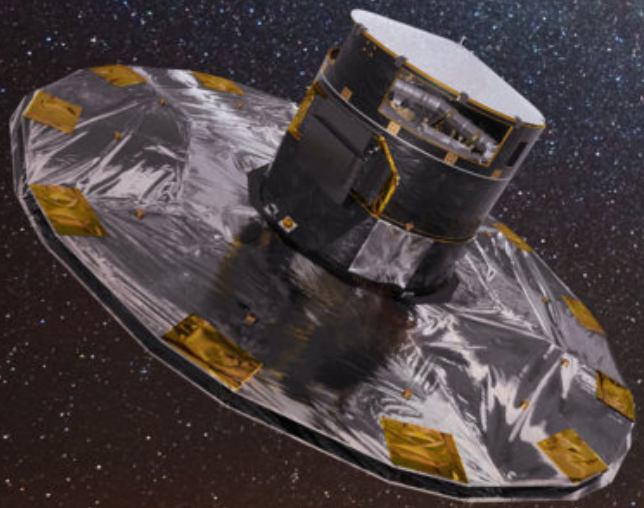
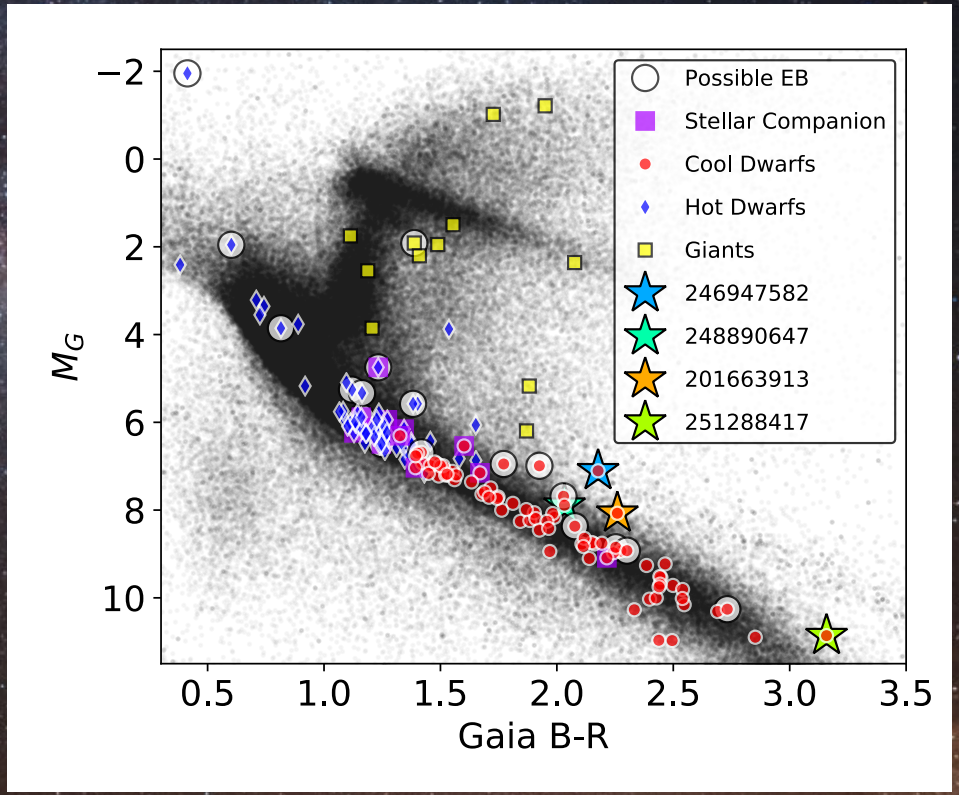
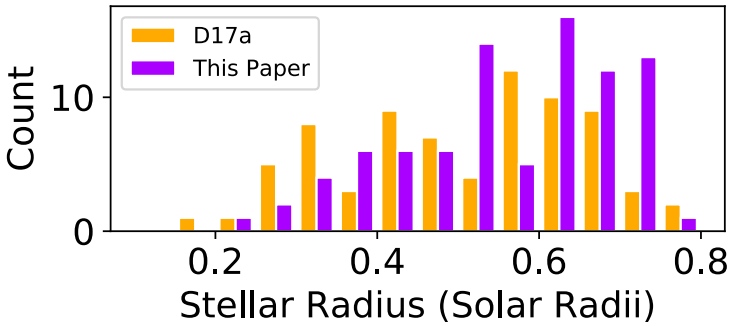
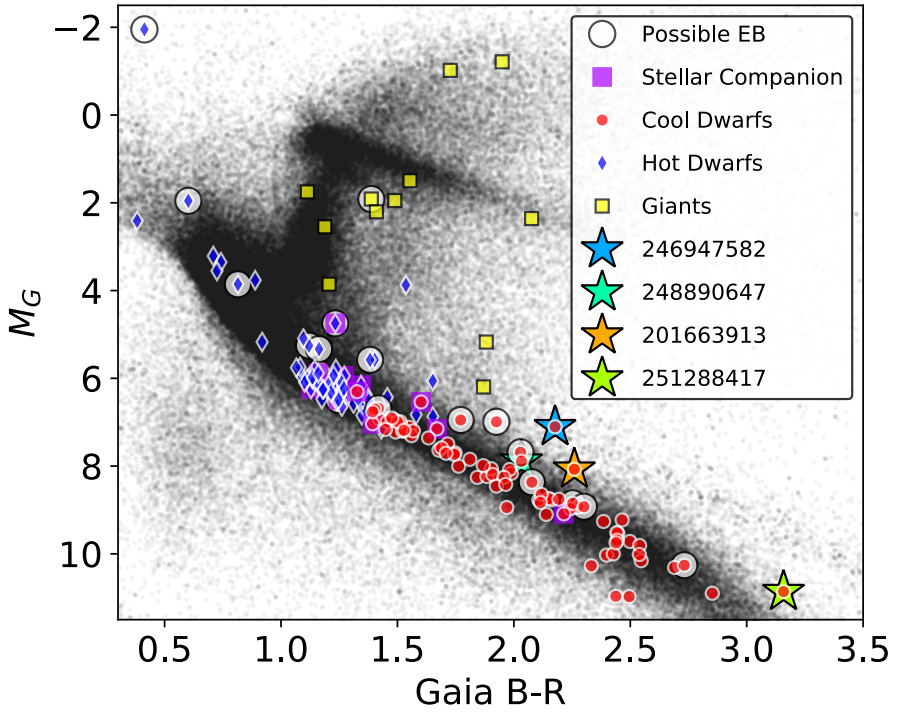




Parallaxes from Gaia; distances from Bailer-Jones+ 2018

Gaia Parallaxes Constrain Stellar Properties



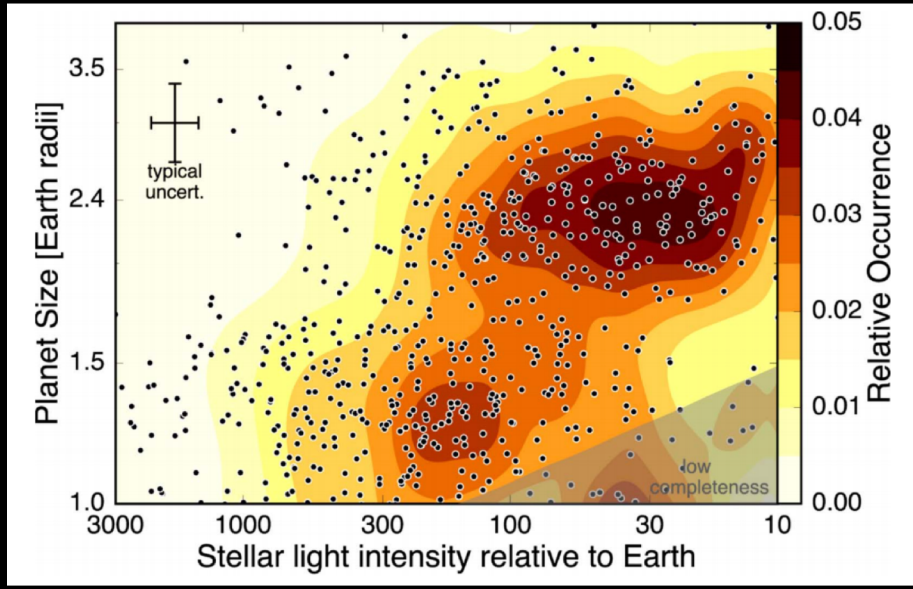


Dressing+ (in prep)

Parallaxes from Gaia; distances from Bailer-Jones+ 2018

How do planets orbiting M dwarfs compare to those orbiting Sun-like stars?

M Dwarf Planets Also Show a Radius Gap



Fulton+ 2018

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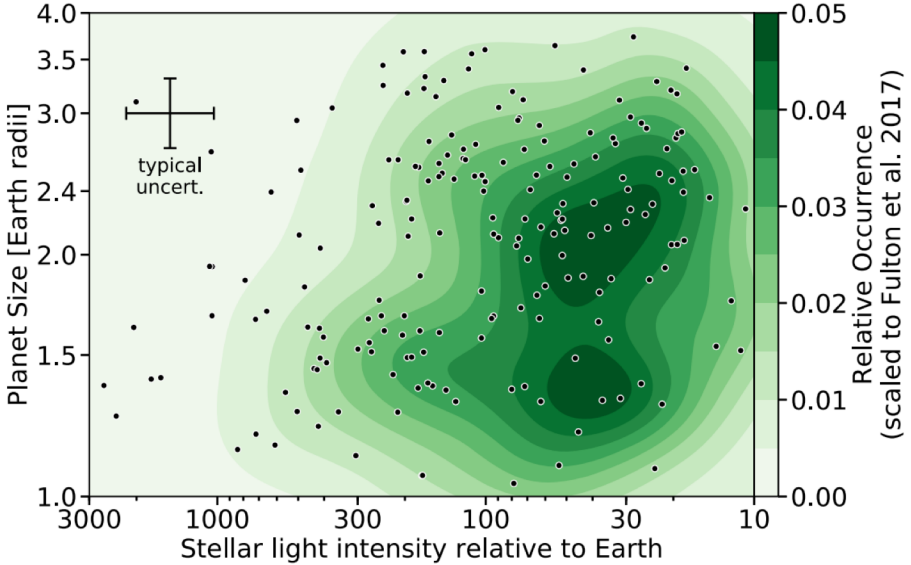
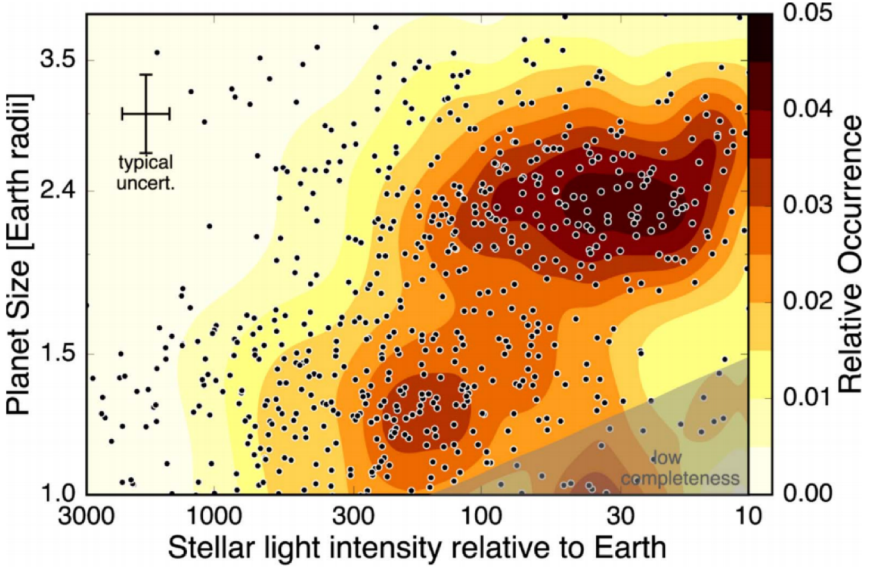
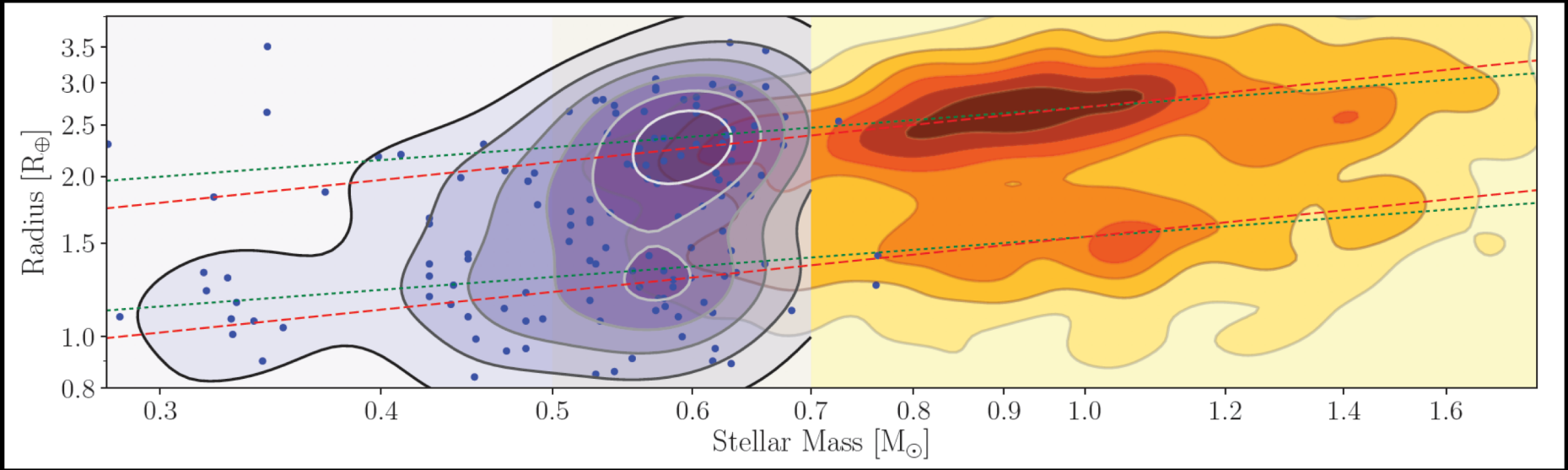


Mayo+ 2018



Fulton+ 2018

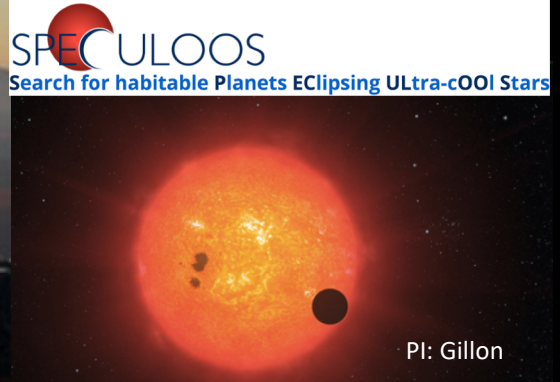
The Location of the Gap May Depend on Stellar Mass



Wu, submitted to AAS journals, arXiv:1806.04693

TRAPPIST-S & TRAPPIST-N

SPECULOOS
Search for habitable Planets EClipsing ULtra-cOOl Stars



Small telescopes are finding small planets orbiting small stars!

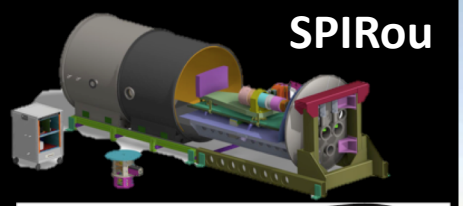
MEarth & MEarth-South

ExTrA

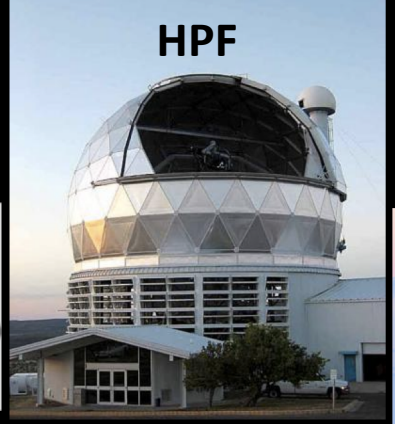
Next-Generation Transit Survey


CARMENES


Levy


SPIRou

espresso


HPF

iSHELL

Subaru IRD

MINERVA

Current & Upcoming RV Spectrographs Targeting Small Stars

NEID


Keck Planet Finder
HIRES

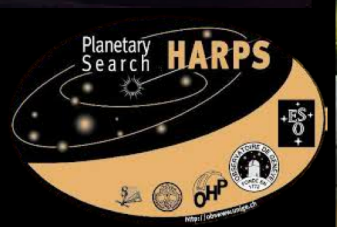
iLocater

MAROON-X

EXPRES
Search for 100 Earths


iGRINS


MINERVA Red

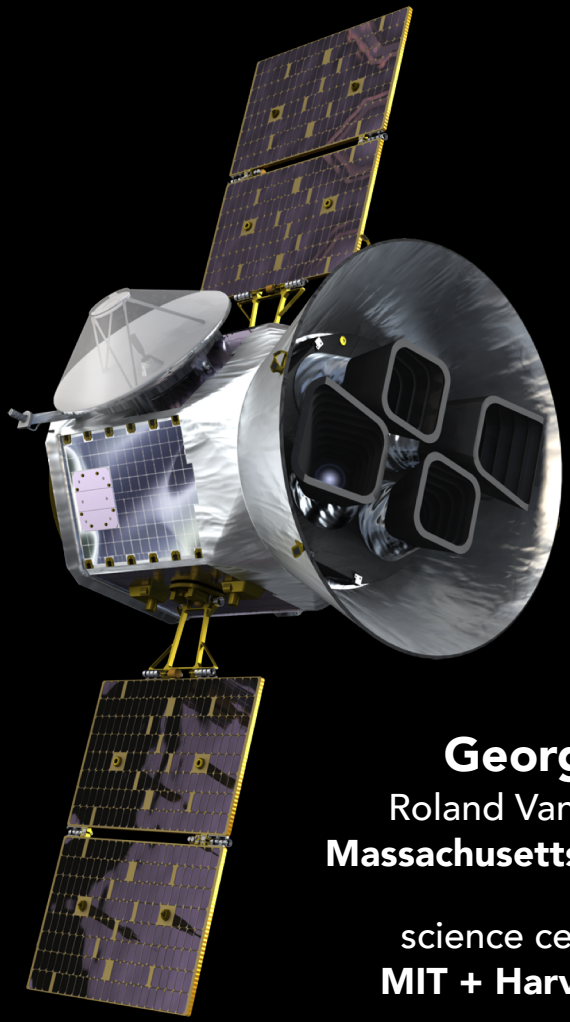



HARPS-N

LCO

NRES

TESS



NASA

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)

TESS will find thousands of planets

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45 Earths

Barclay et al. (2018)

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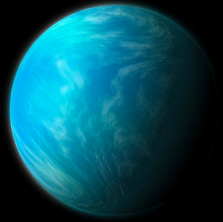
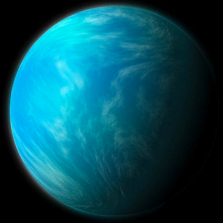


240 "Super-Earths"

Barclay et al. (2018)

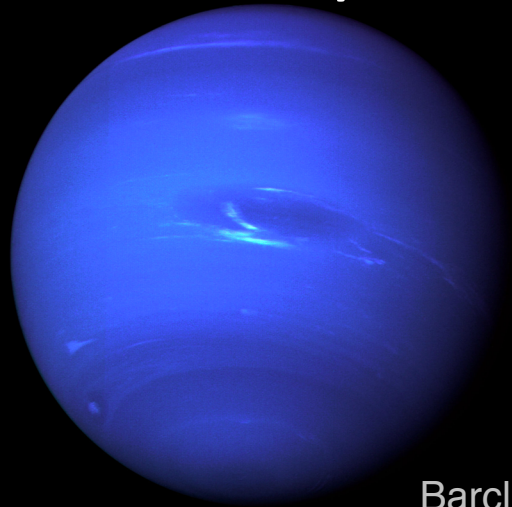
TESS will find thousands of planets

45 Earths



240 "Super-Earths"

1870 "Sub-Neptunes"



Barclay et al. (2018)

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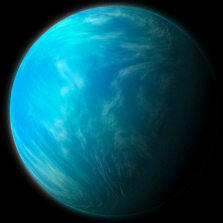

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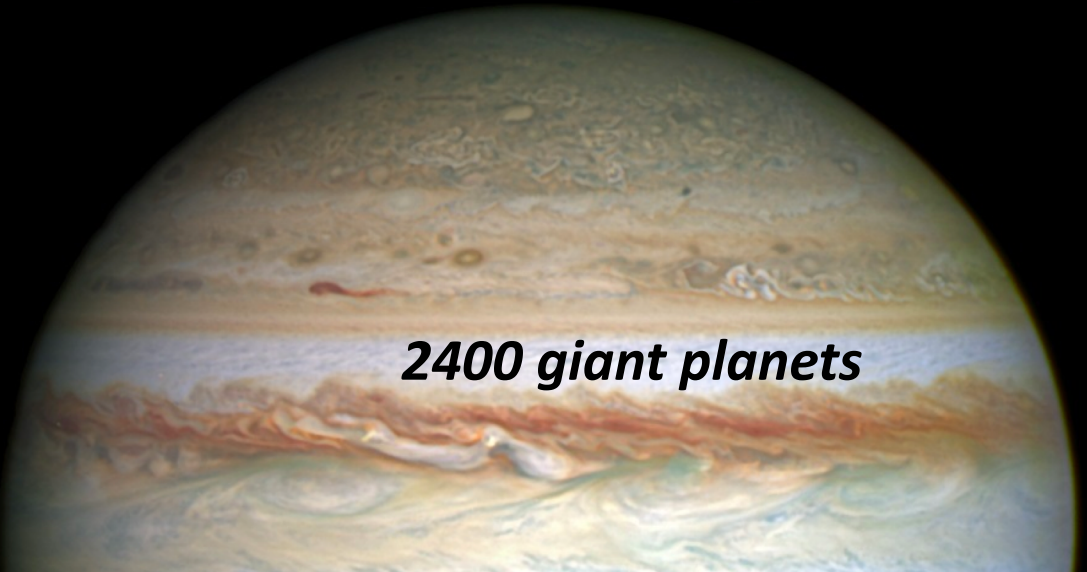
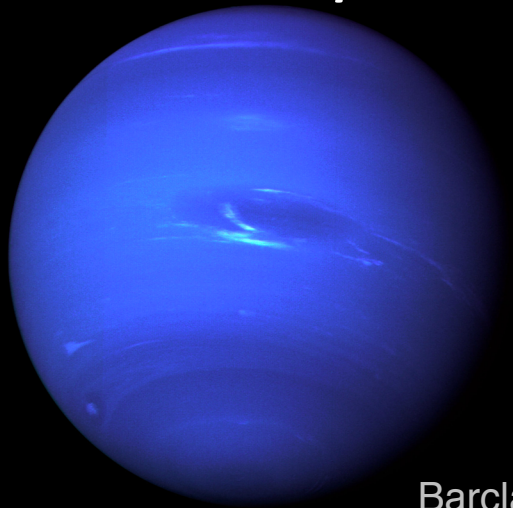
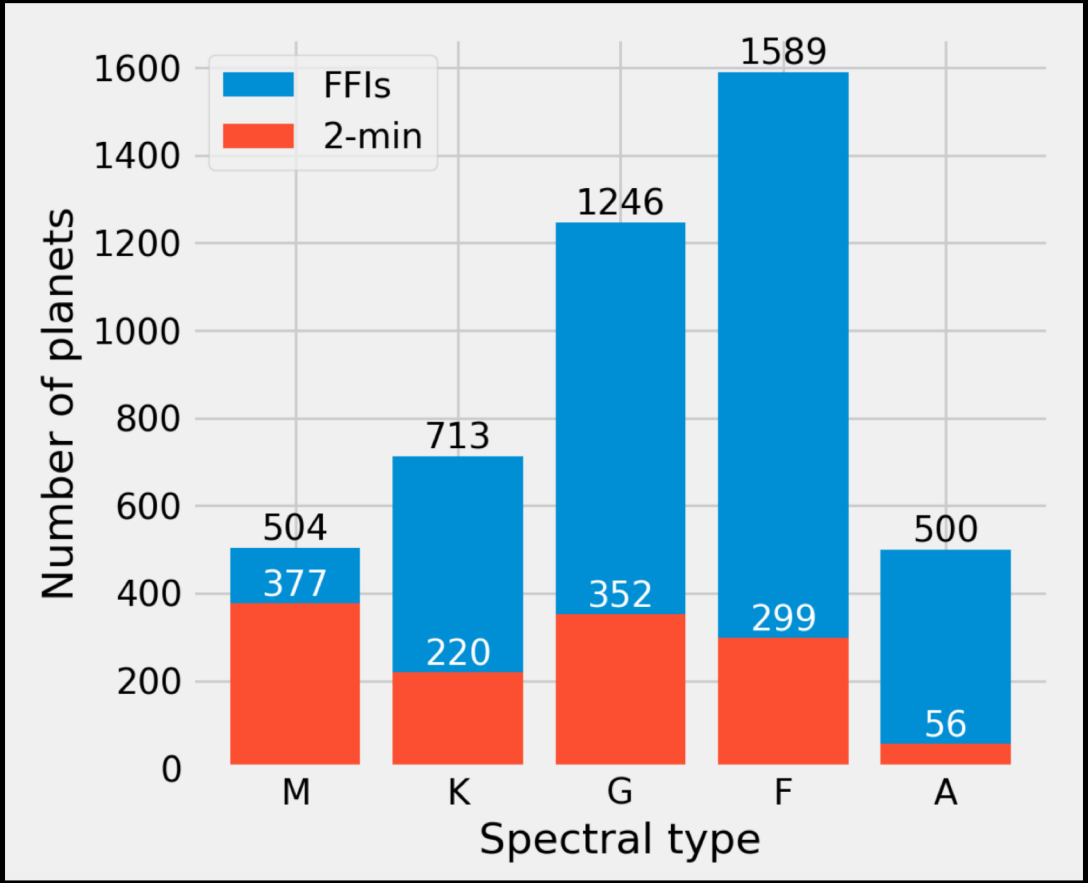


2400 giant planets



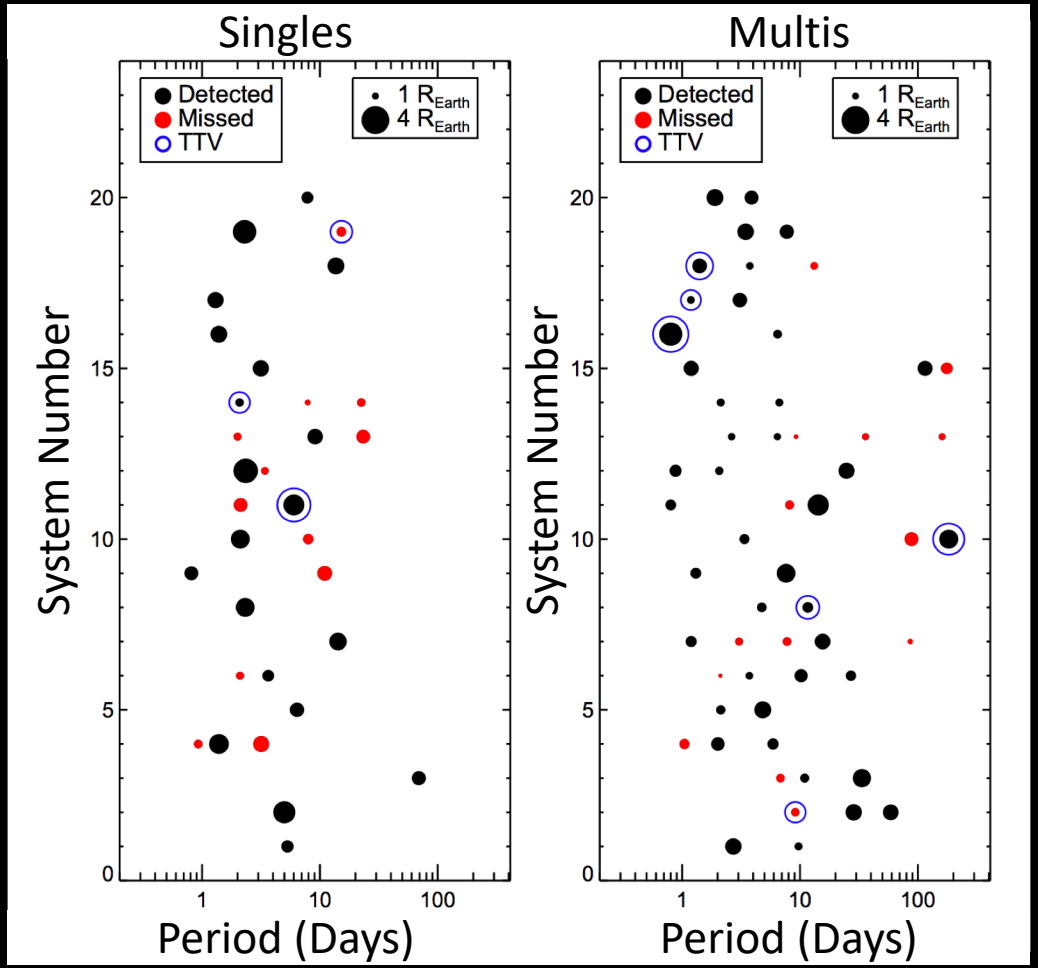
Barclay et al. (2018)

TESS will Find Planets Orbiting a Wide Variety of Stars



Barclay et al. (2018)

TESS M Dwarfs are Likely to Host Additional Planets



Ballard 2018

Not all candidate signals will be planets

Not all candidate signals will be planets

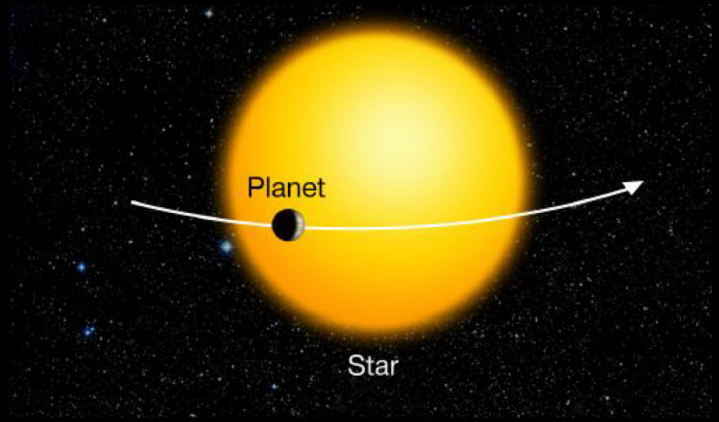


Image Credit: NASA

Not all candidate signals will be planets

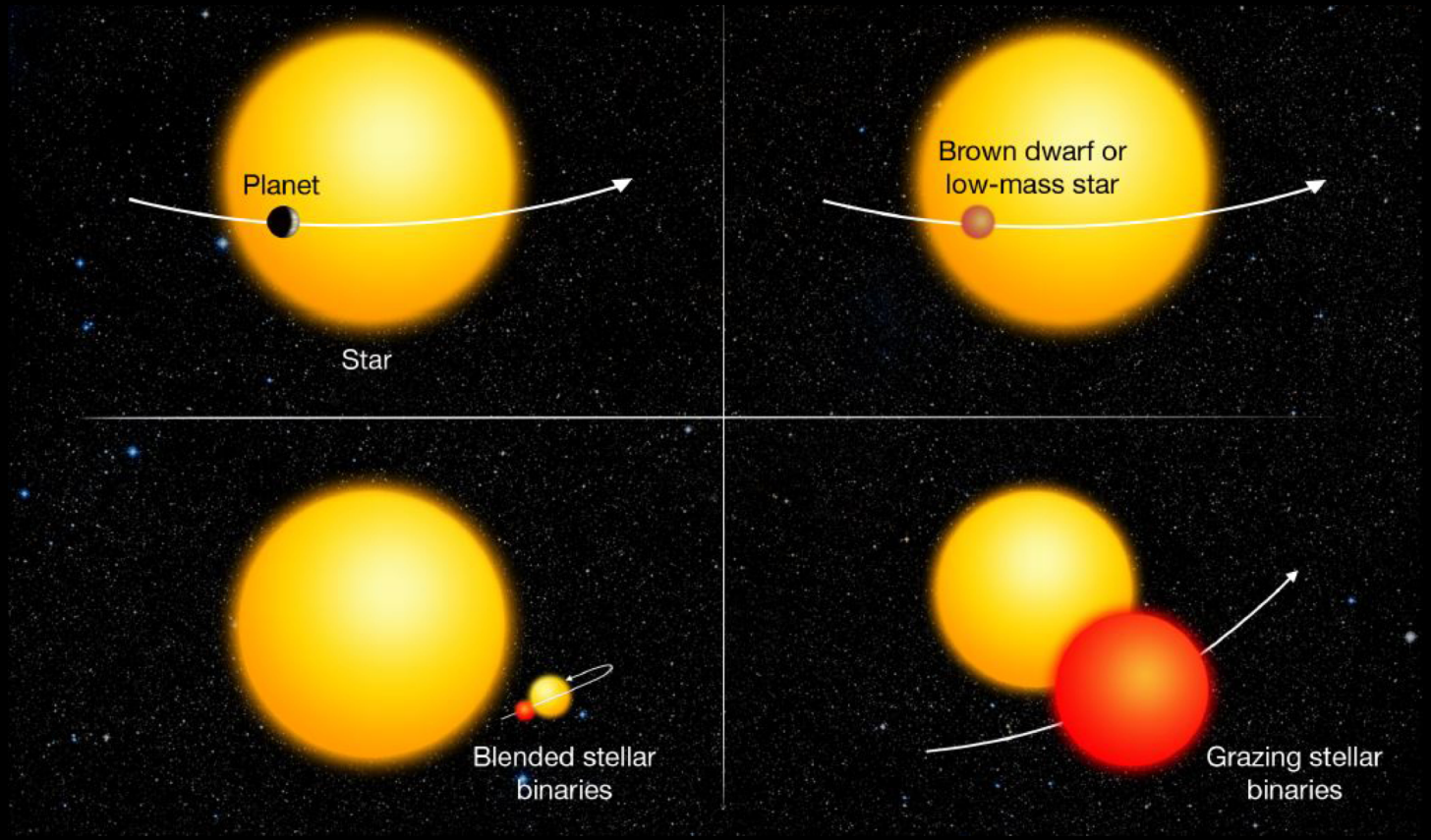


Image Credit: NASA

Not all candidate signals will be planets

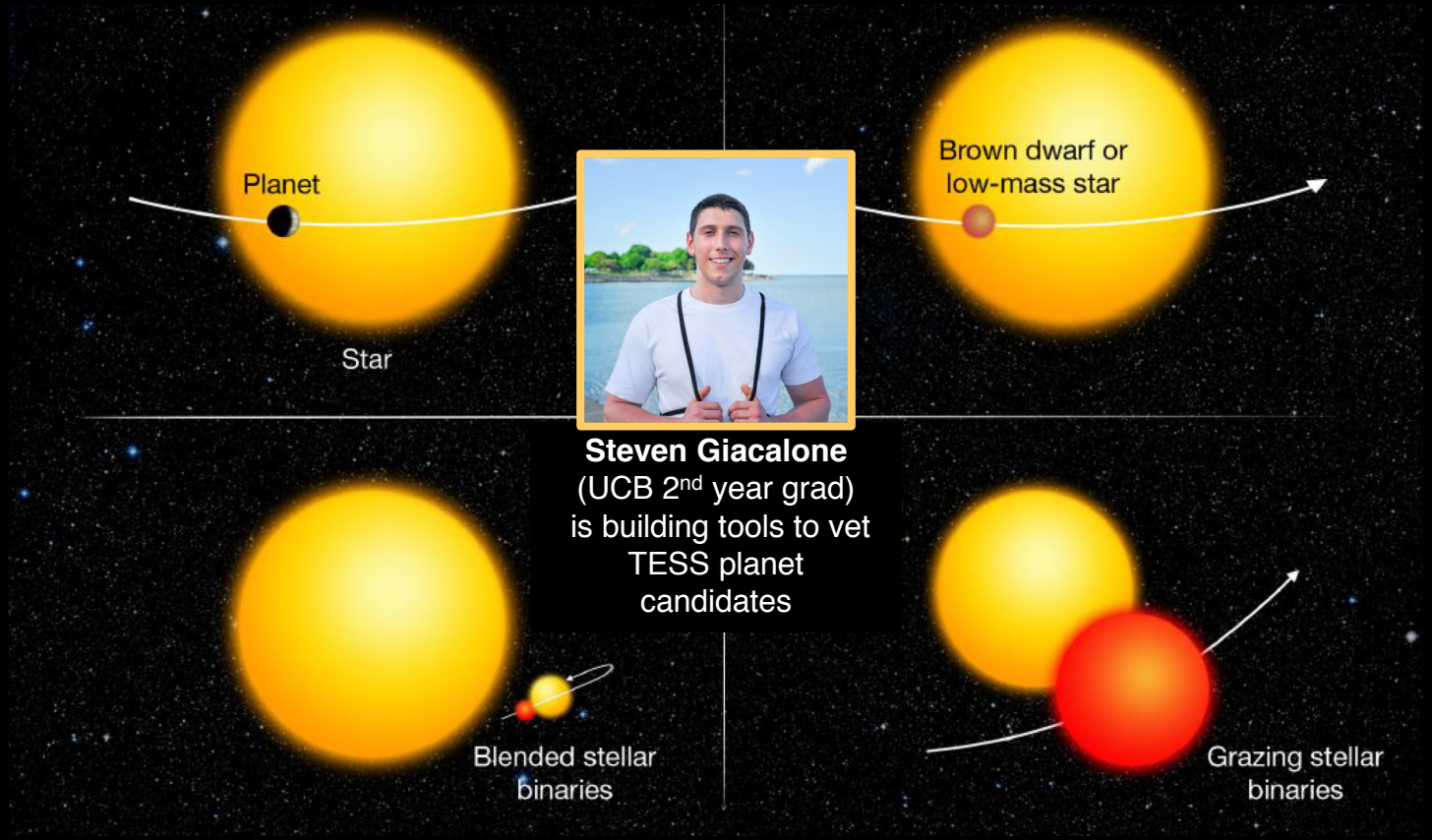
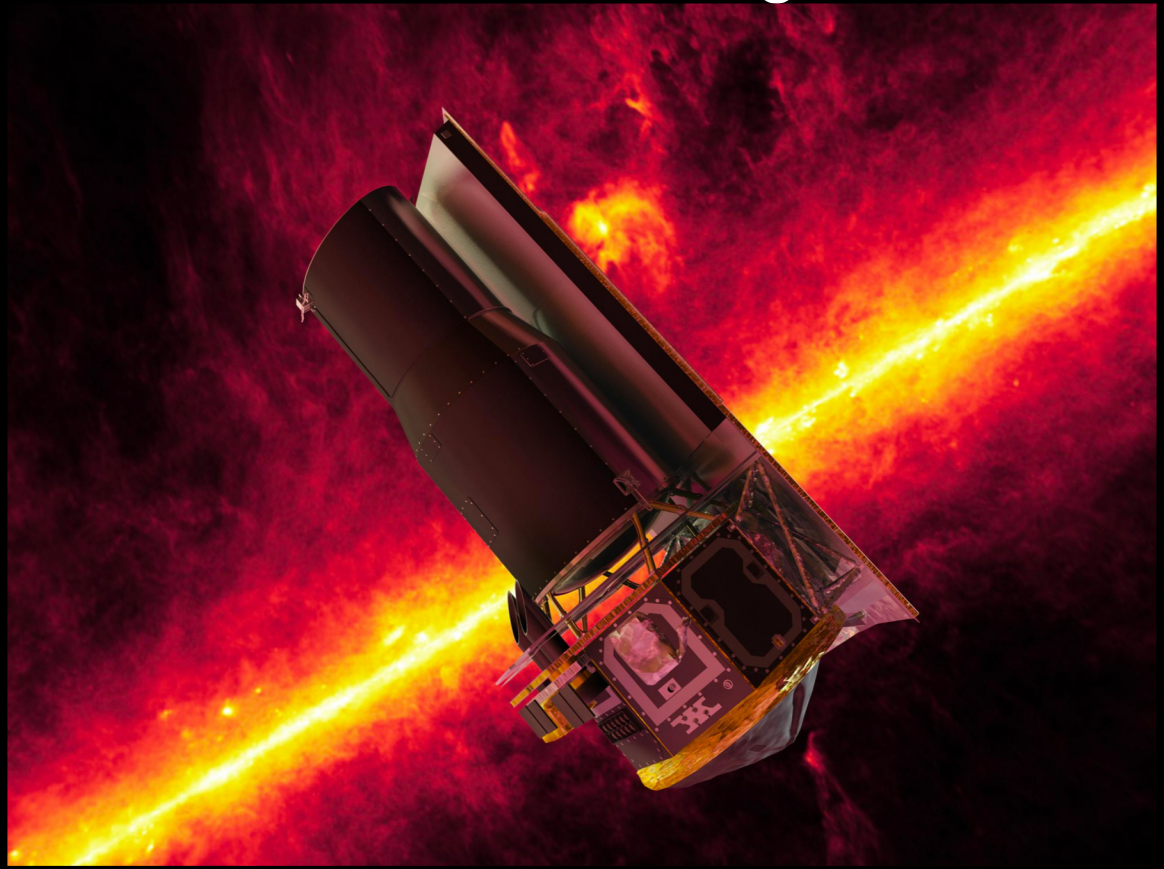


Image Credit: NASA

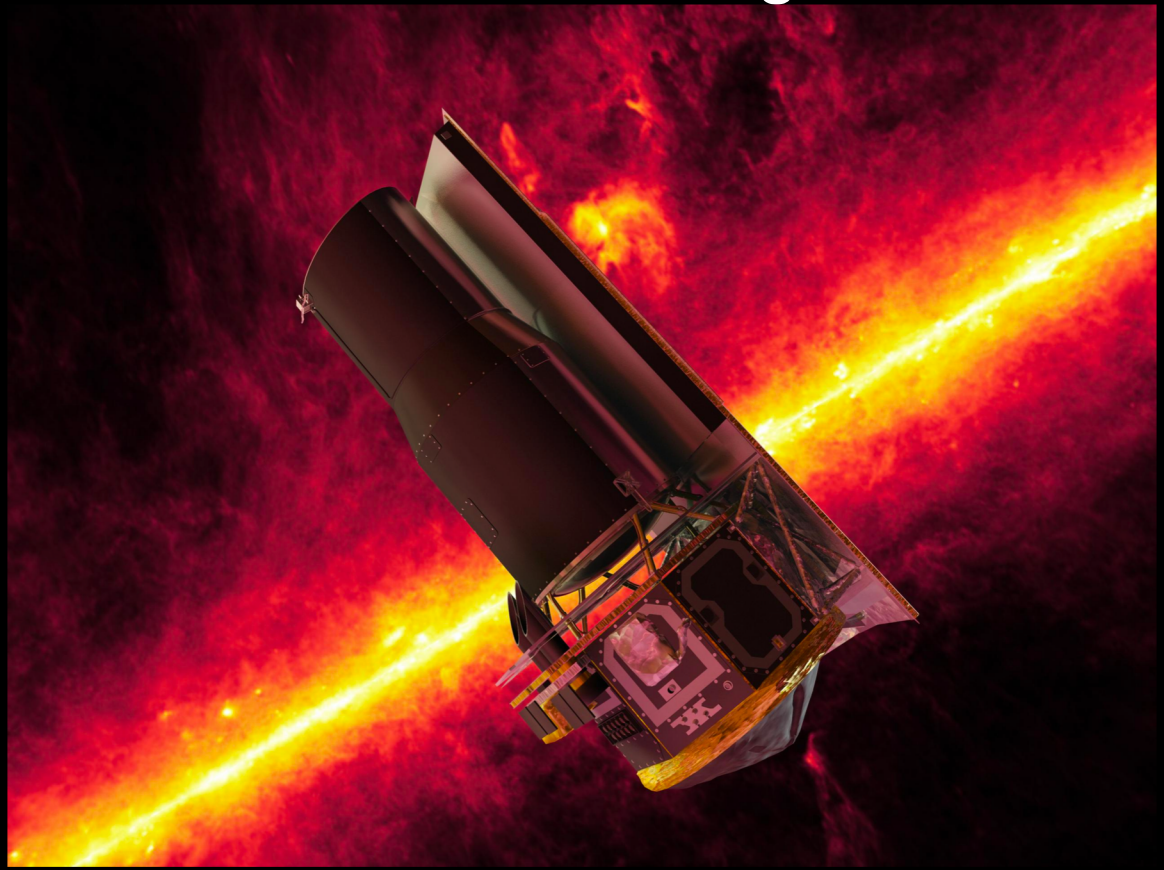
Follow-up Transit Observations will Confirm Transit Times & Recover Single-Transit Events



Credit: NASA/JPL

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

Jordan Fleming
(2nd year UCB grad)
is analyzing *Spitzer* observations of transiting planets



Credit: NASA/JPL

TESS Planets Will be Ideal Targets for Radial Velocity Mass Measurement

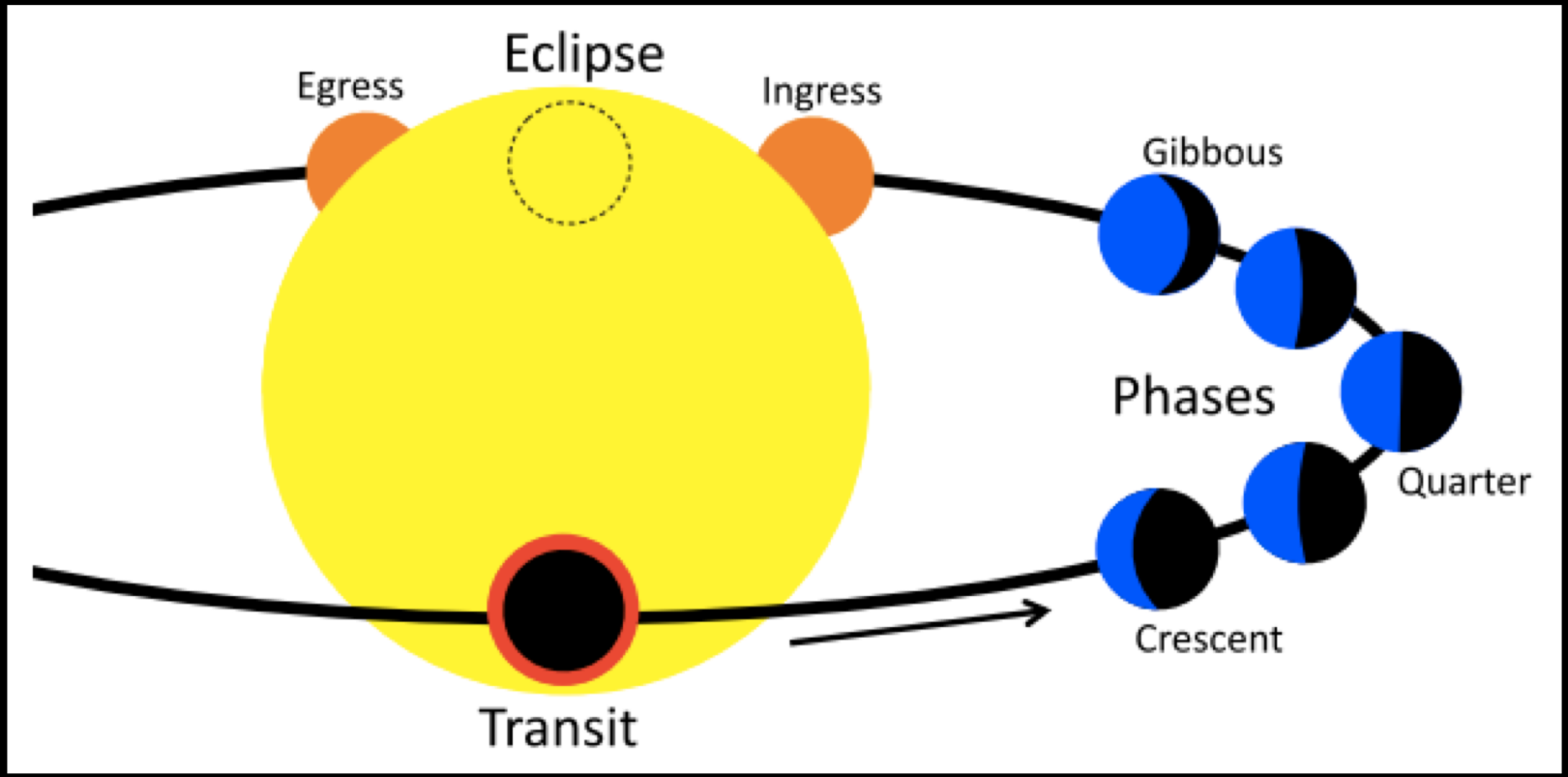
Keck Telescopes on Mauna Kea in Hawaii

TESS Planets Will be Ideal Targets for Radial Velocity Mass Measurement

Andy Mayo
(incoming UCB grad)
will measure masses
of TESS planets

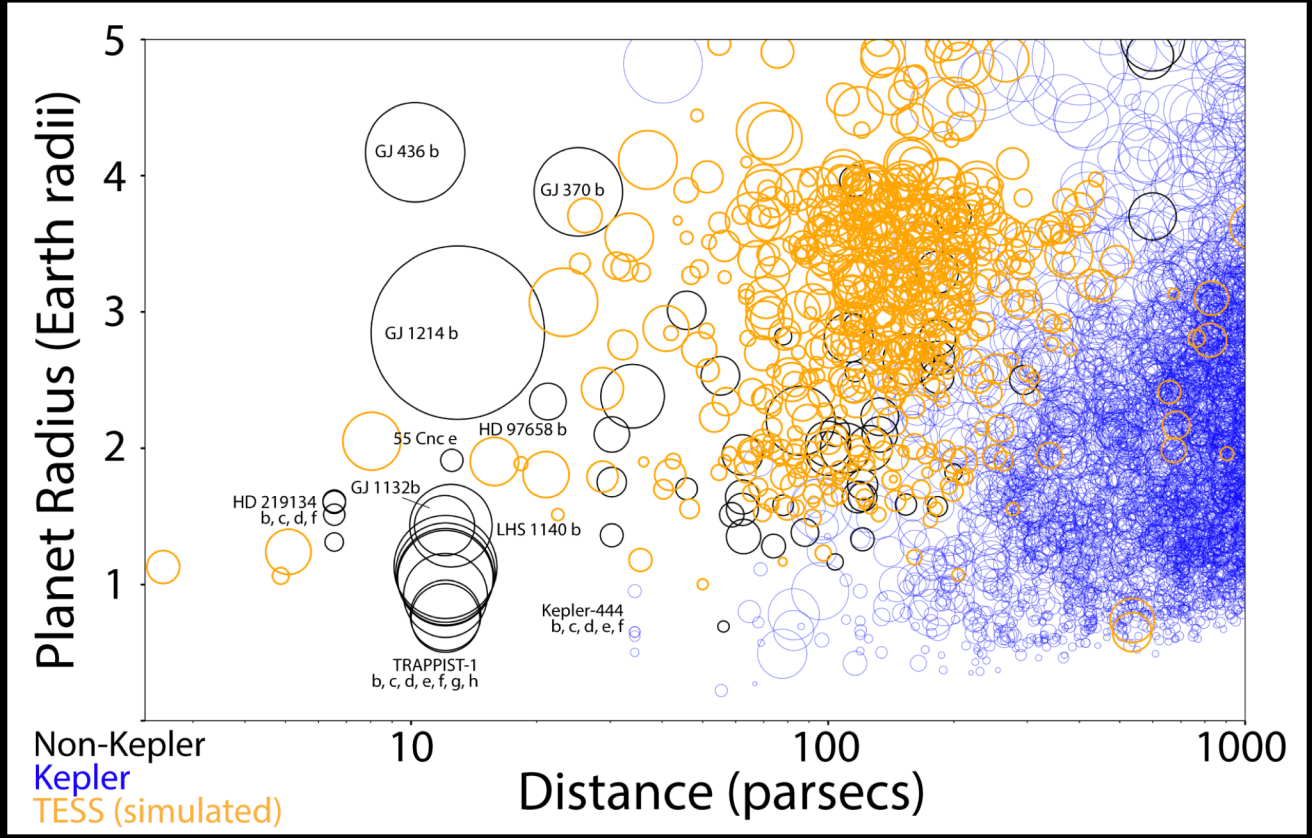
Keck Telescopes on Mauna Kea in Hawaii

Transits, Eclipses, and Phase Curves of Exoplanets Reveal Atmospheric Properties



Cowan et al. 2015, PASP, 127, 311

TESS Planets will be Attractive Targets for Atmospheric Characterization

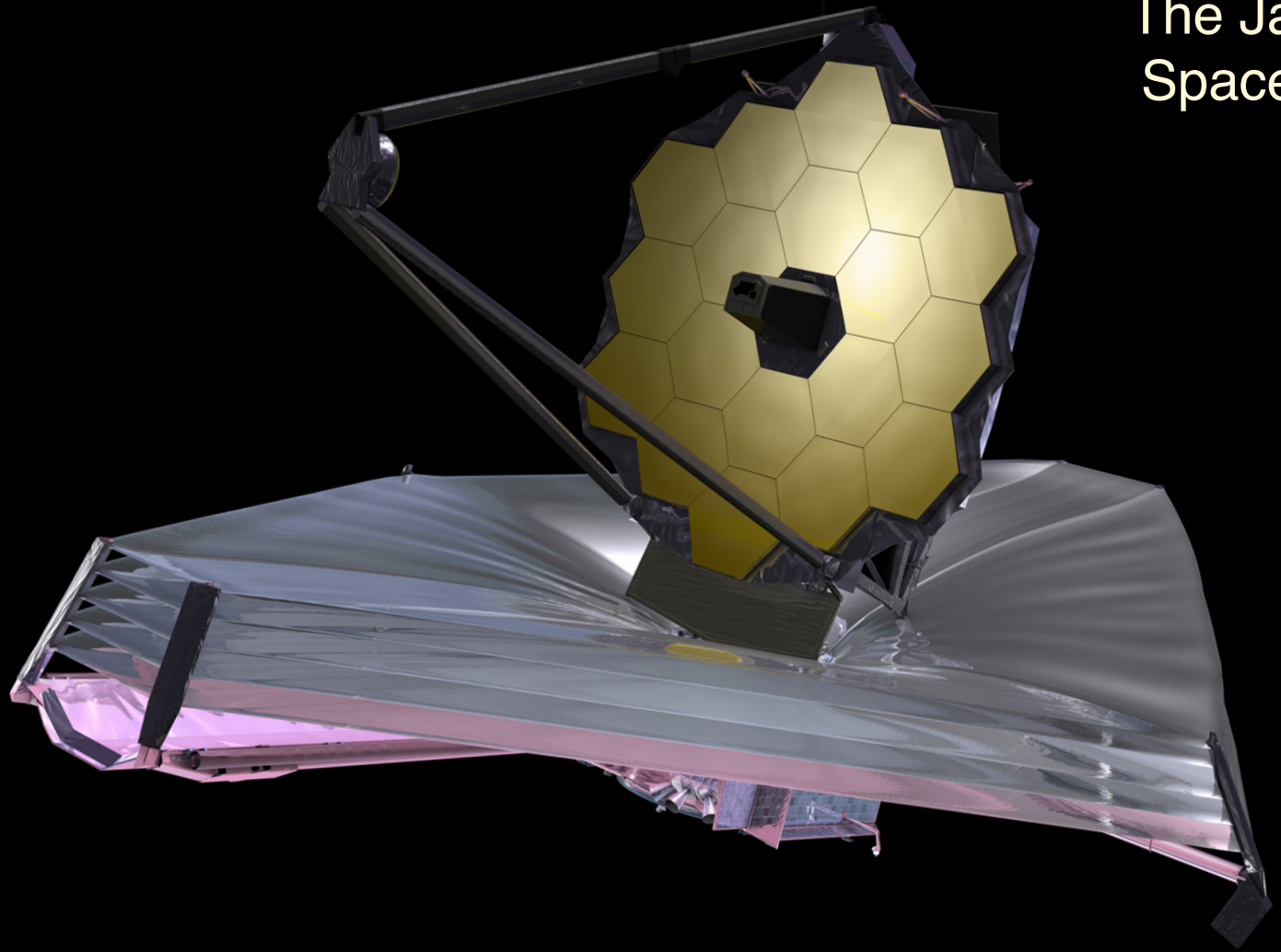


Based on a figure created by Zach Berta-Thompson

Barclay et al. (2018)

The Hubble Space Telescope

The James Webb Space Telescope



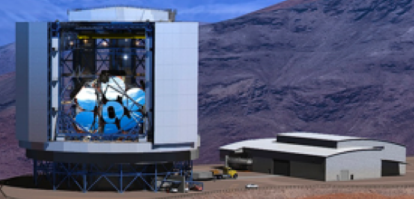
Charles Fortenbach (SFSU MA Student) is building a framework to rank TESS planets for study with JWST

The James Webb Space Telescope

Space-based observations will complement ground-based observations

Giant Magellan Telescope

- Commissioning in 2023
- 24.5-m diameter
- First-light instruments
  - G-CLEF: visible echelle spectrograph
  - GMACS: Visible Multi-Object Spectrograph
- Future instruments
  - GMTIFS: Near-IR IFU & Adaptive Optics Imager
  - GMTNIRS: IR Echelle Spectrograph
  - MANIFEST: Facility Fiber Optics Positioner
  - ComCam: Commissioning Camera



Credit: GMT, rendering by Mason Media

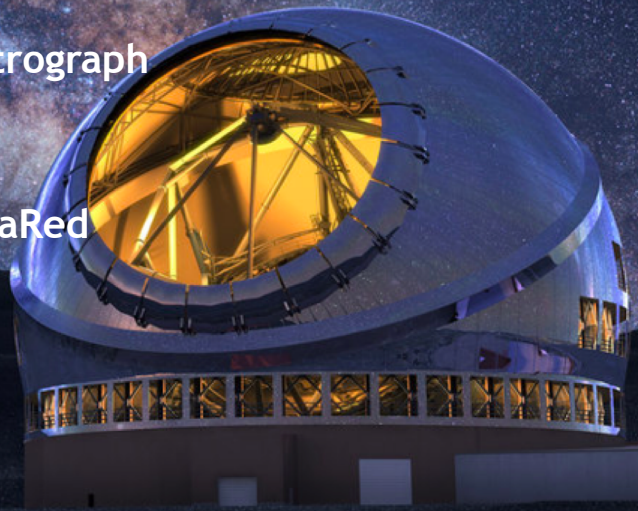
European Extremely Large Telescope

- Operations beginning in 2024
- 39-m diameter
- First-light instruments
  - MICADO (ELT-CAM): diffraction-limited NIR imager
  - HARMONI (ELT-IFU: single-field near-infrared wide-band integral field spectrograph
  - MAORY (MCAO): multi-conjugate adaptive optics system
- Future instruments
  - METIS (ELT-MIDIR): Mid-IR imager & spectrometer
  - ELT-HIRES: high-resolution spectrometer
  - ELT-MOS: multi-object spectrometer

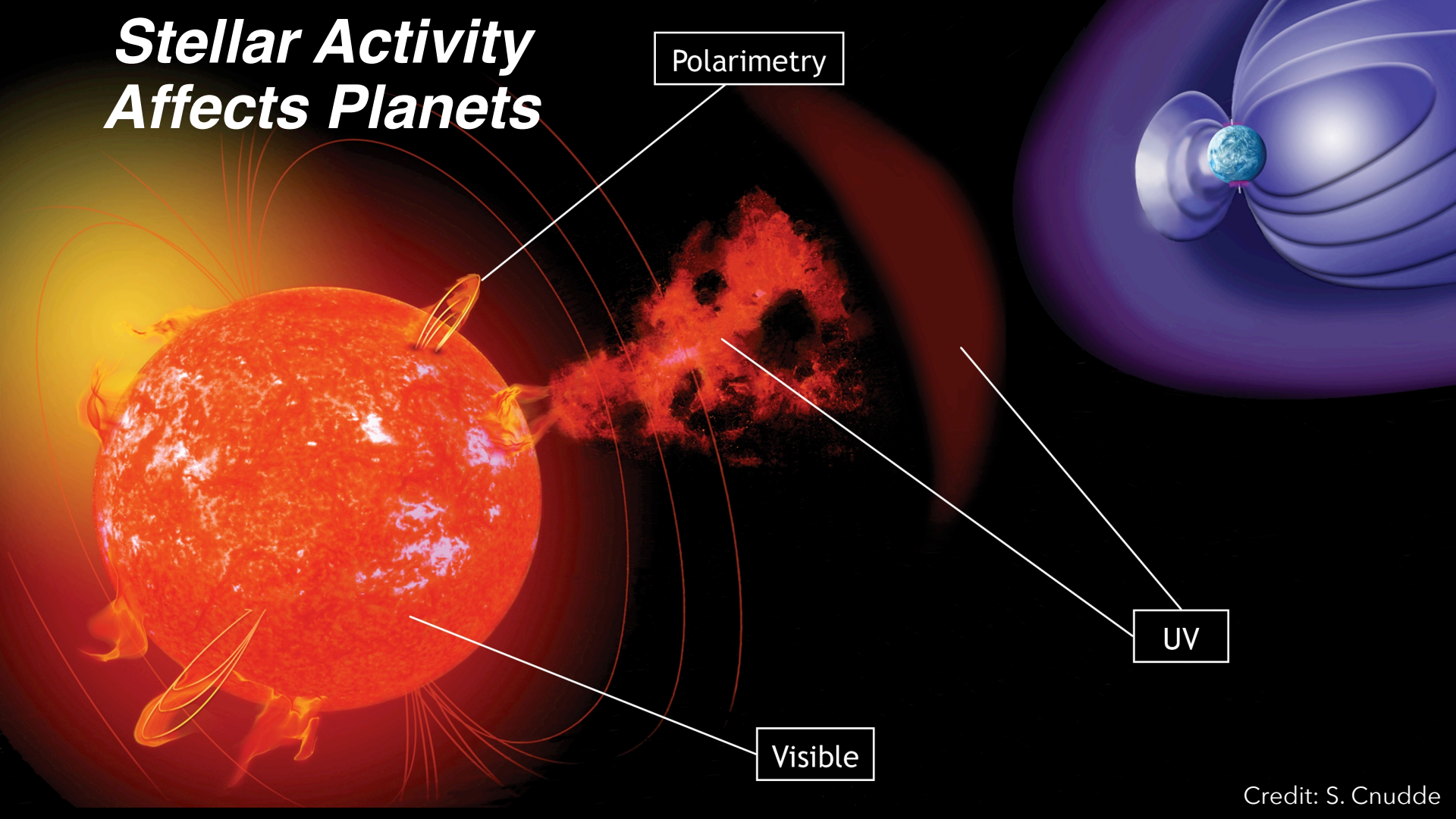
Credit:ESO/L. Calçada

Thirty Meter Telescope

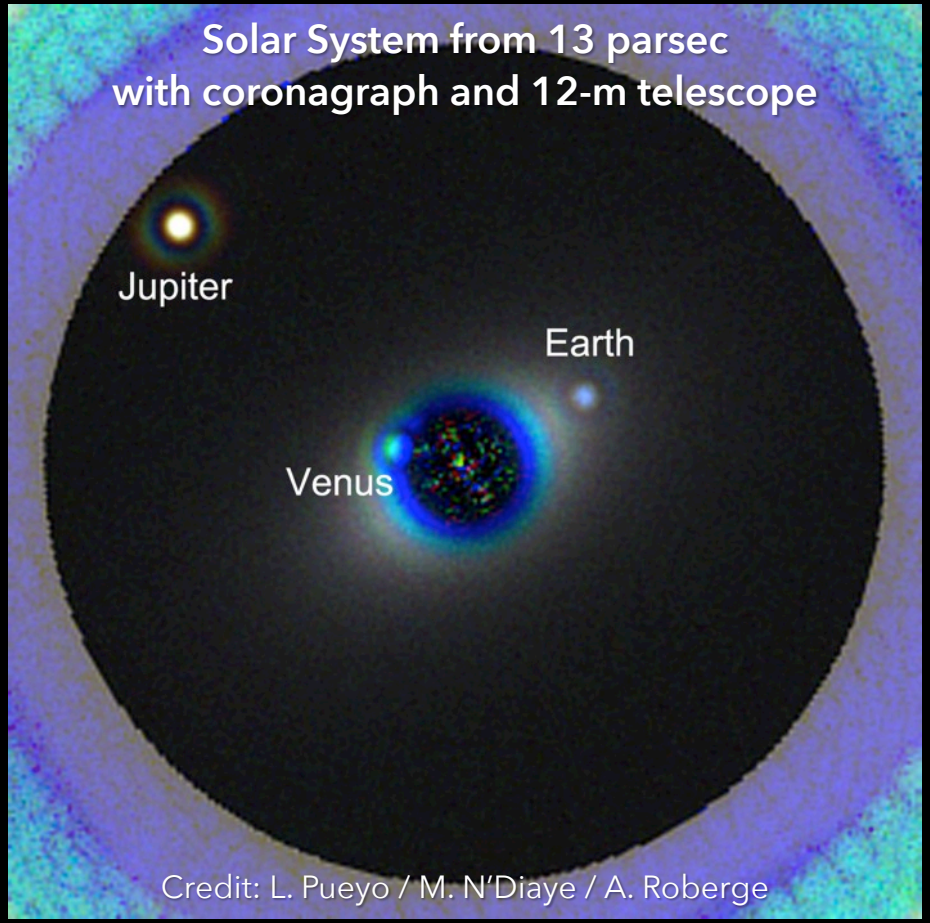
- First Light 2026
- 30-m Diameter
- First-light Instruments
  - WFOS: Wide-field Optical Spectrometer
  - IRIS: Infrared Imaging Spectrograph
  - IRMS: Infrared Multi-object Spectrometer
  - NFIRAOS: Narrow Field InfraRed Adaptive Optics System



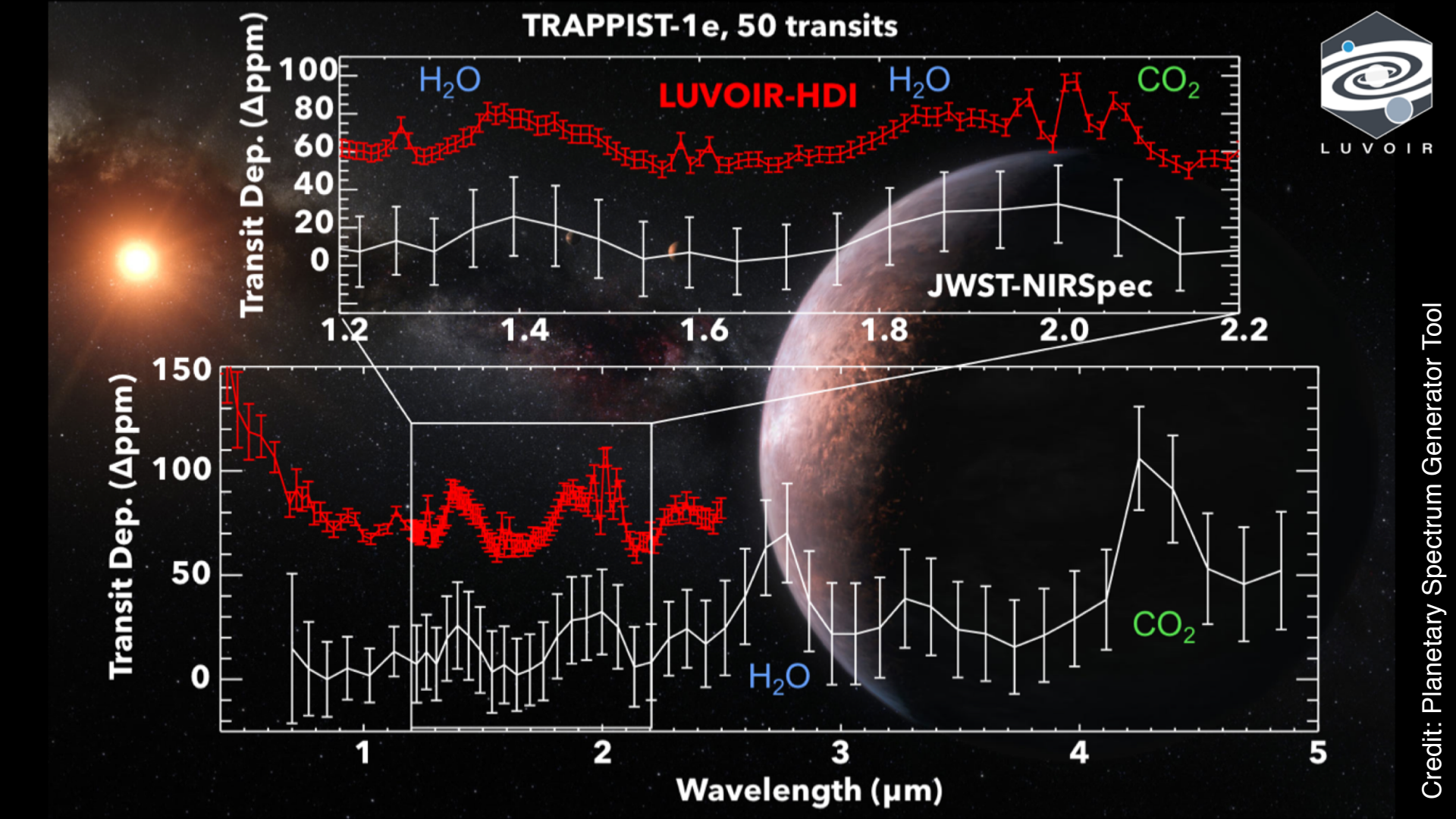
Stellar Activity Affects Planets


Stellar Activity
Affects Planets
Polarimetry
UV
Visible
Credit: S. Cnudde

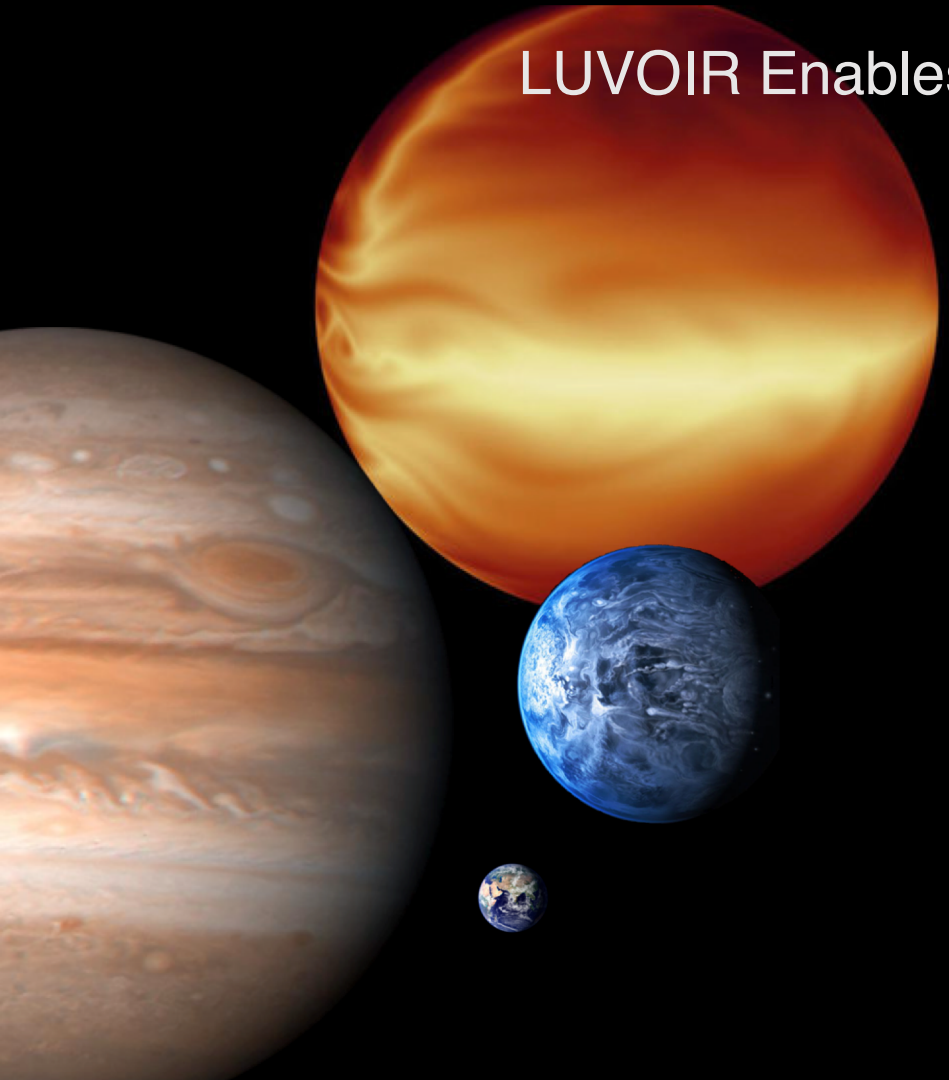
Imaging Earthlike Planets

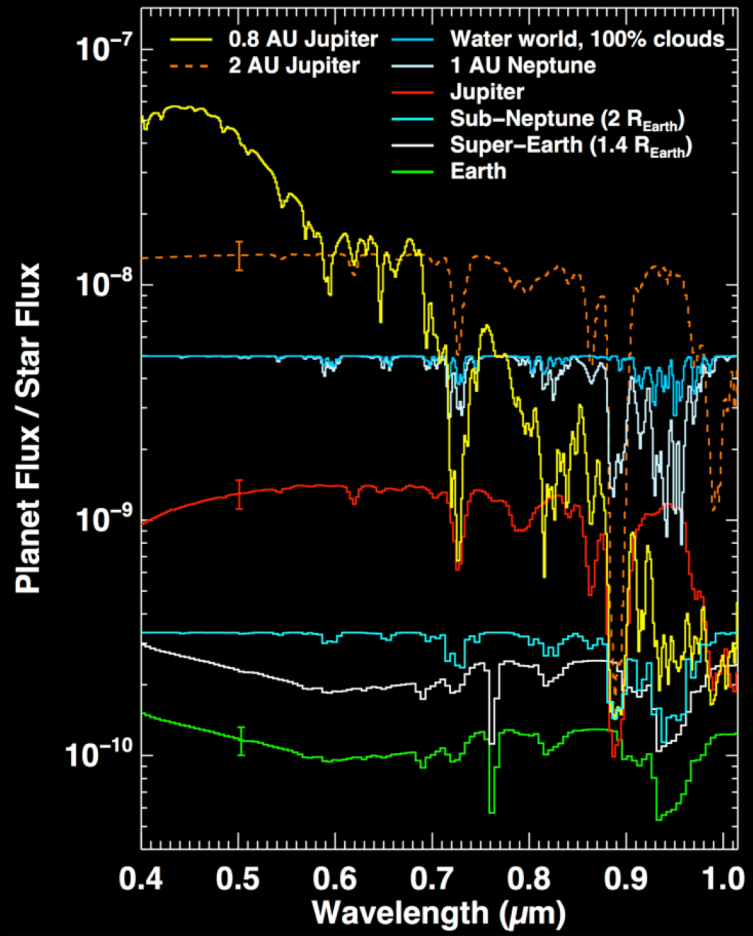


LUVOIR


TRAPPIST-1e, 50 transits
LUVOIR-HDI
JWST-NIRSpec
H2O
H2O
CO2
Transit Dep. (Δppm)
100
80
60
40
20
0
1.2
1.4
1.6
1.8
2.0
2.2
150
100
50
0
1
2
3
4
5
Wavelength (μm)
LUVOIR
Credit: Planetary Spectrum Generator Tool

LUVOIR Enables Exoplanetology





LUVOIR

Design Your Own Observations Using Our Online Tools

http://asd.gsfc.nasa.gov/luvoir/tools/

LUVOIR

Science Design Team Tools Events Participate Resources Technology Press

Tools

This page links to performance simulation and visualization tools for the LUVOIR mission, a future ultraviolet / optical / near-infrared observatory concept.

These widgets are experimental. If they are not working, email Jason Tumlinson (STScI). For the Planetary Spectrum Generator, email Geronimo Villanueva (GSFC).

Coronagraphic Spectra of Exoplanets

Simulate optical/near-IR reflection spectra of various exoplanets with realistic noise.

Multiplanet Yield Tool

Tool for visualizing yields of observed exoplanets (of various types) as function of basic mission parameters.

Planetary Spectrum Generator

Advanced tool for simulating spectra of Solar System bodies (with LUVOIR and other telescopes).

HDI Photometric ETC

Basic exposure time calculator for optical photometry in multi-band images.

LUMOS Spectroscopic ETC

Simple exposure time calculator for UV spectroscopy.

UV MOS Visualizer

See the impact of UV multi-object spectroscopy on the study of stellar clusters and their feedback.

High-Resolution Imaging

Examples of astronomical objects viewed with different sized telescopes.

NASA Goddard SPACE FLIGHT CENTER

Curator: J.D. Myers
NASA Official: Phil Newman

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› Contact NASA
› Page Last Updated: Fri, Dec 01, 2017

Summary

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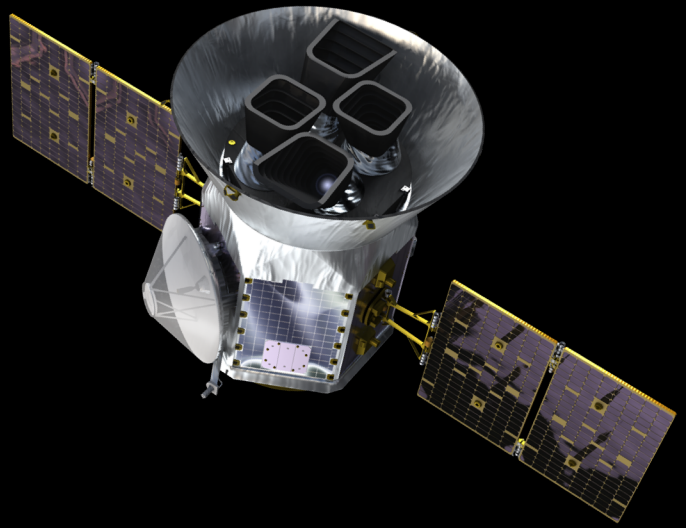
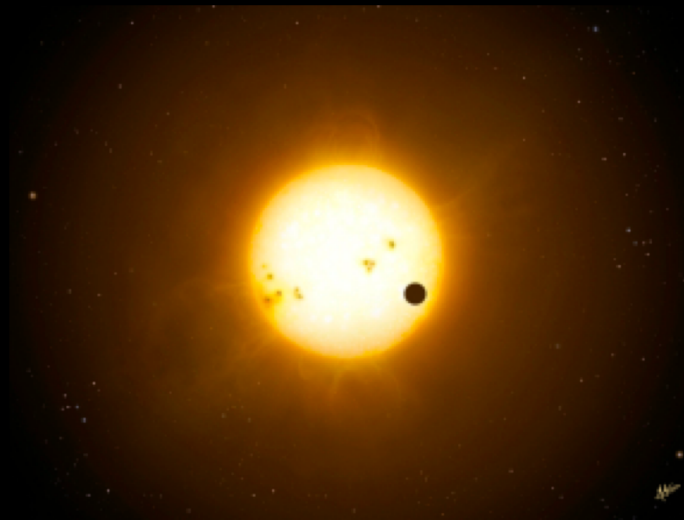
- TESS will **find dozens of small planets orbiting nearby stars**





Summary

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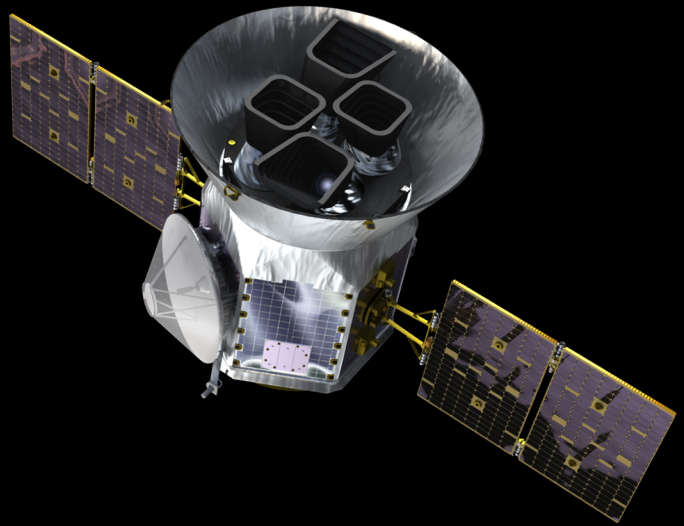
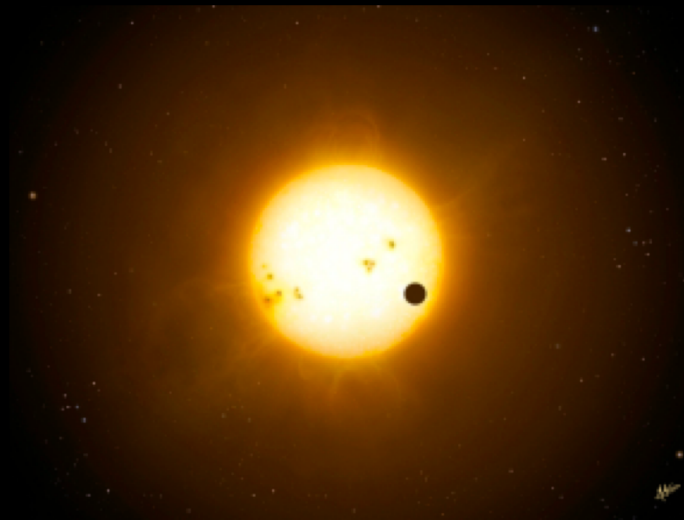
- Ground-based facilities will **characterize planetary systems**





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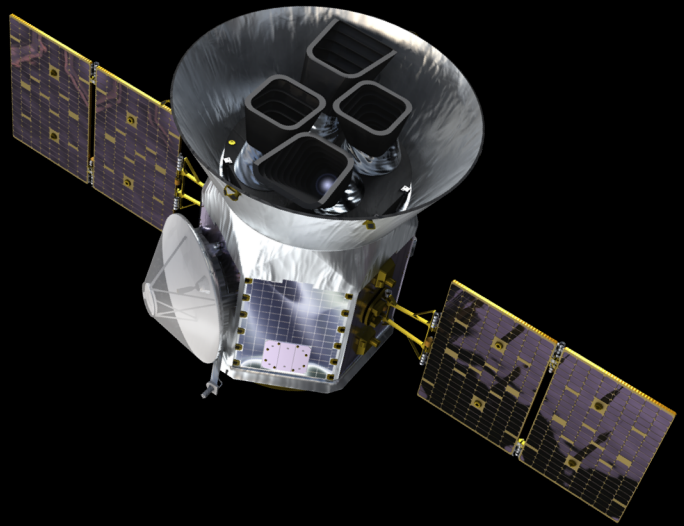

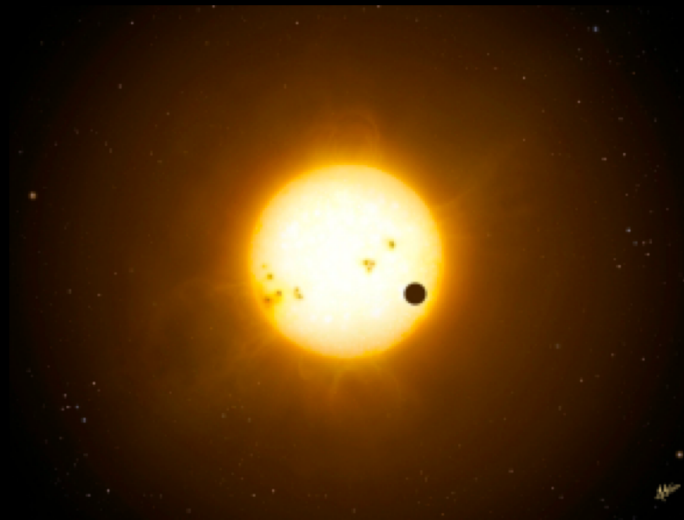

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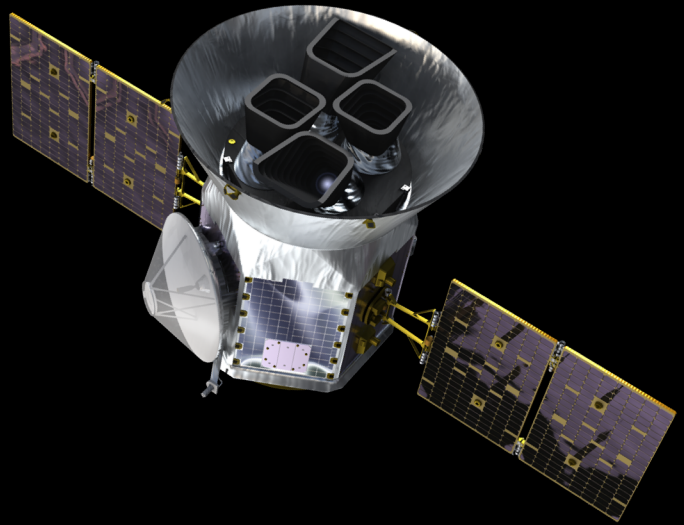
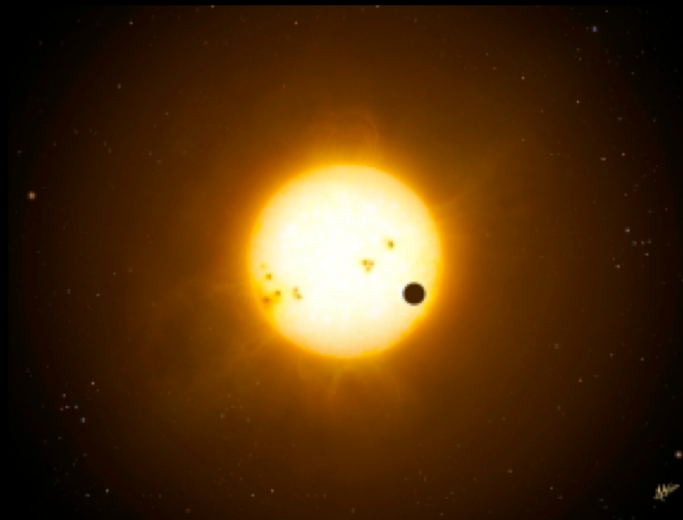
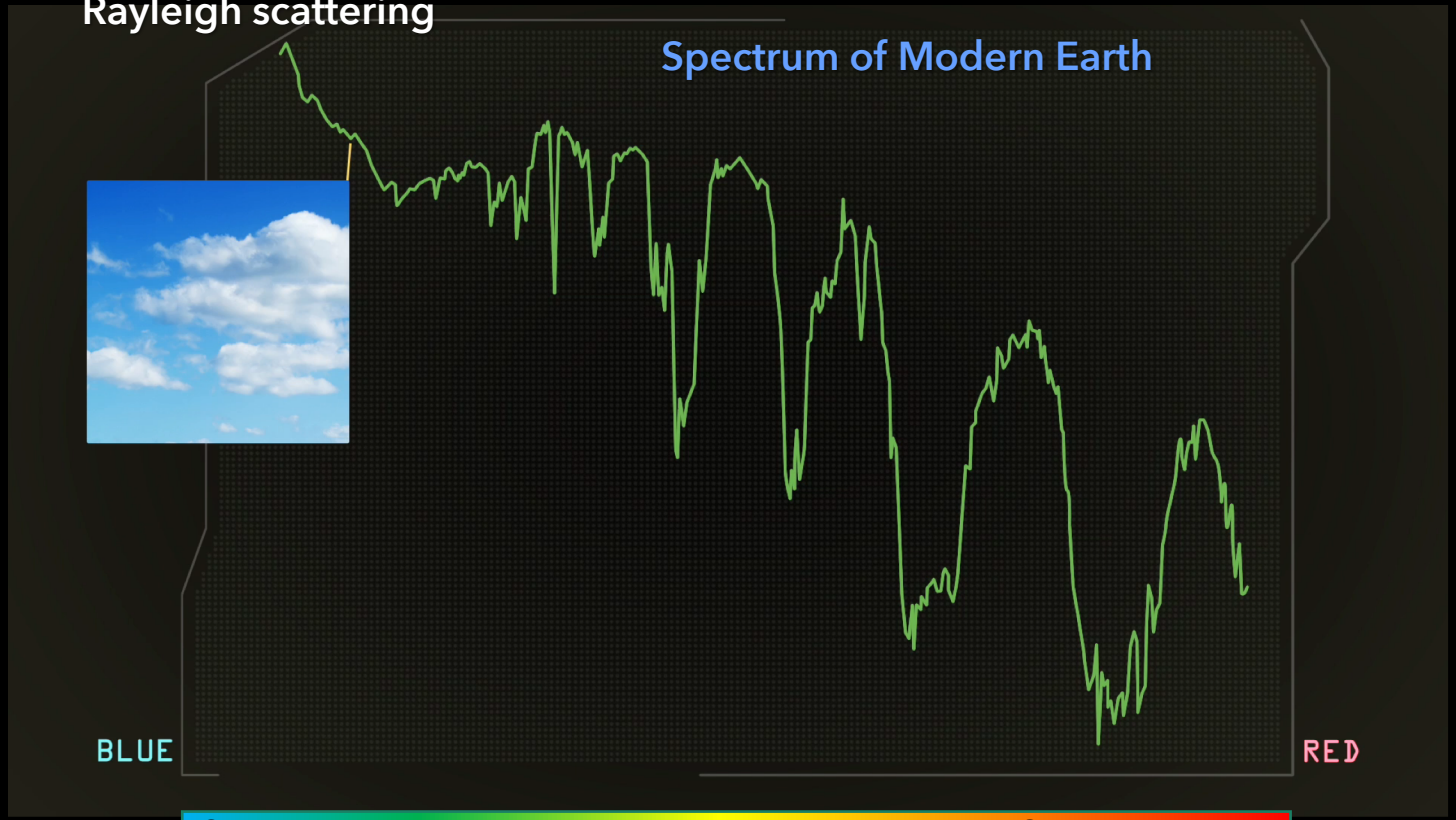
- Future flagships like LUVOIR will **search for habitable & inhabited worlds**





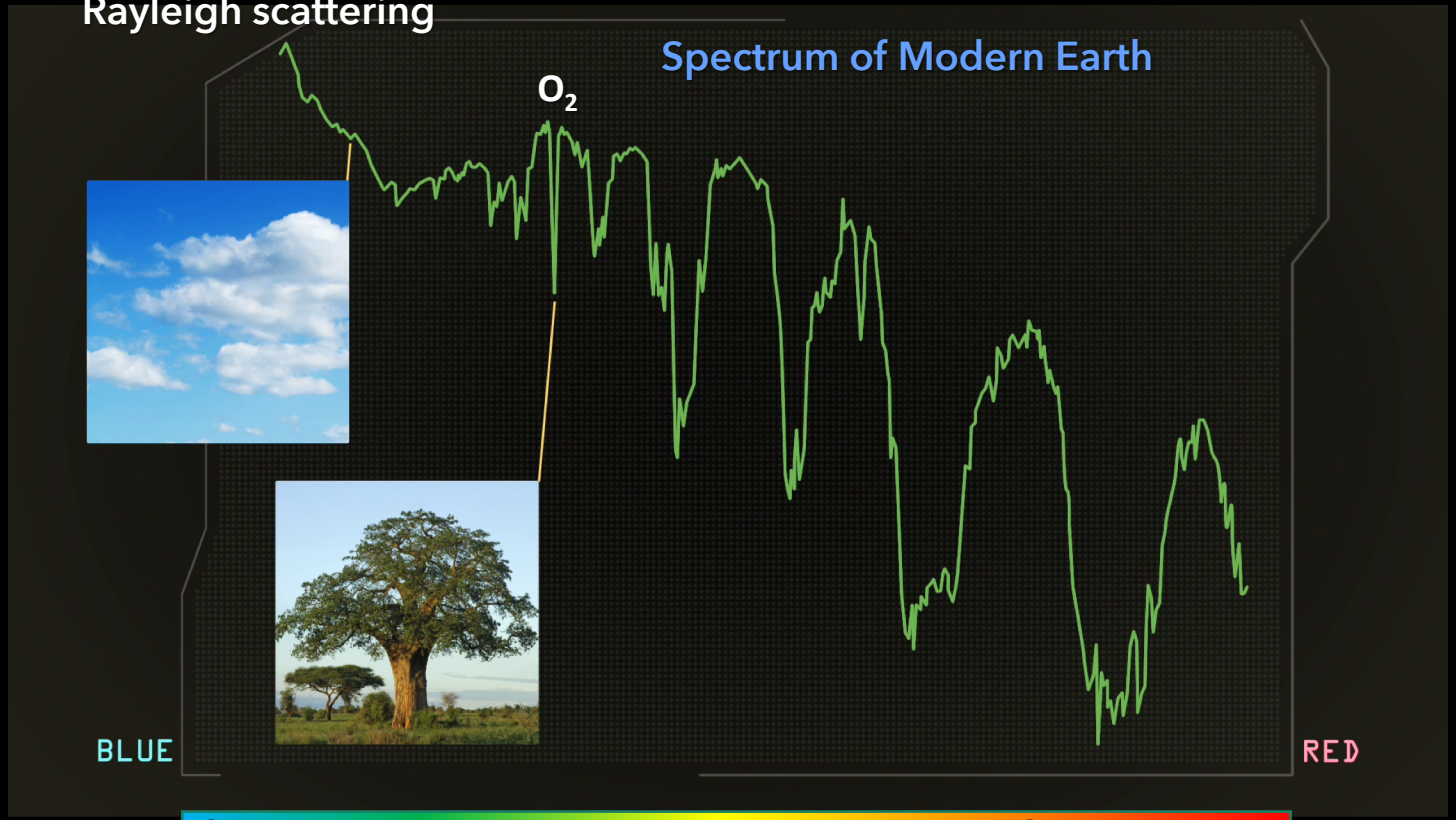
Additional Slides

Searching for Life



LUVOIR

Searching for Life



LUVOIR

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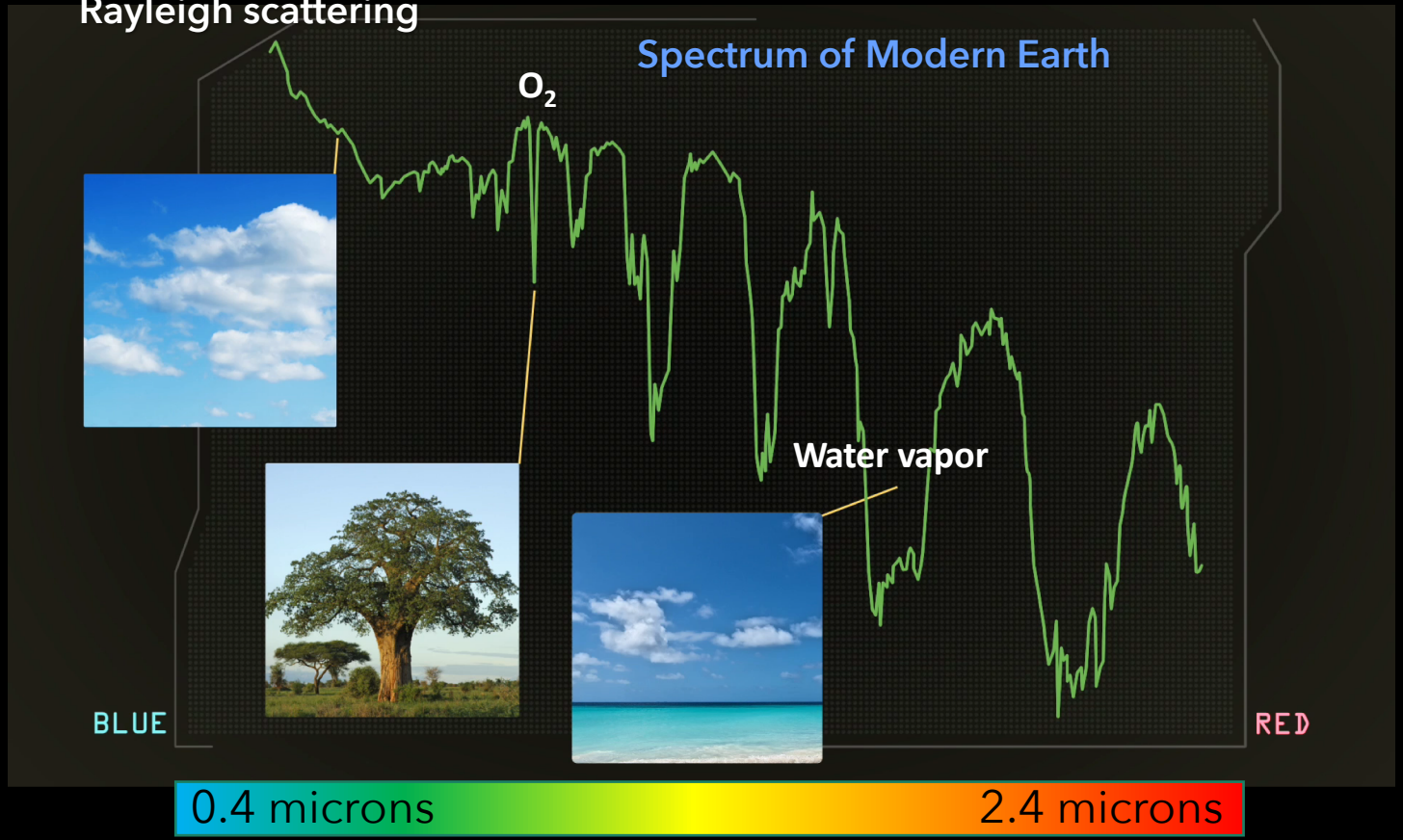

LUVOIR

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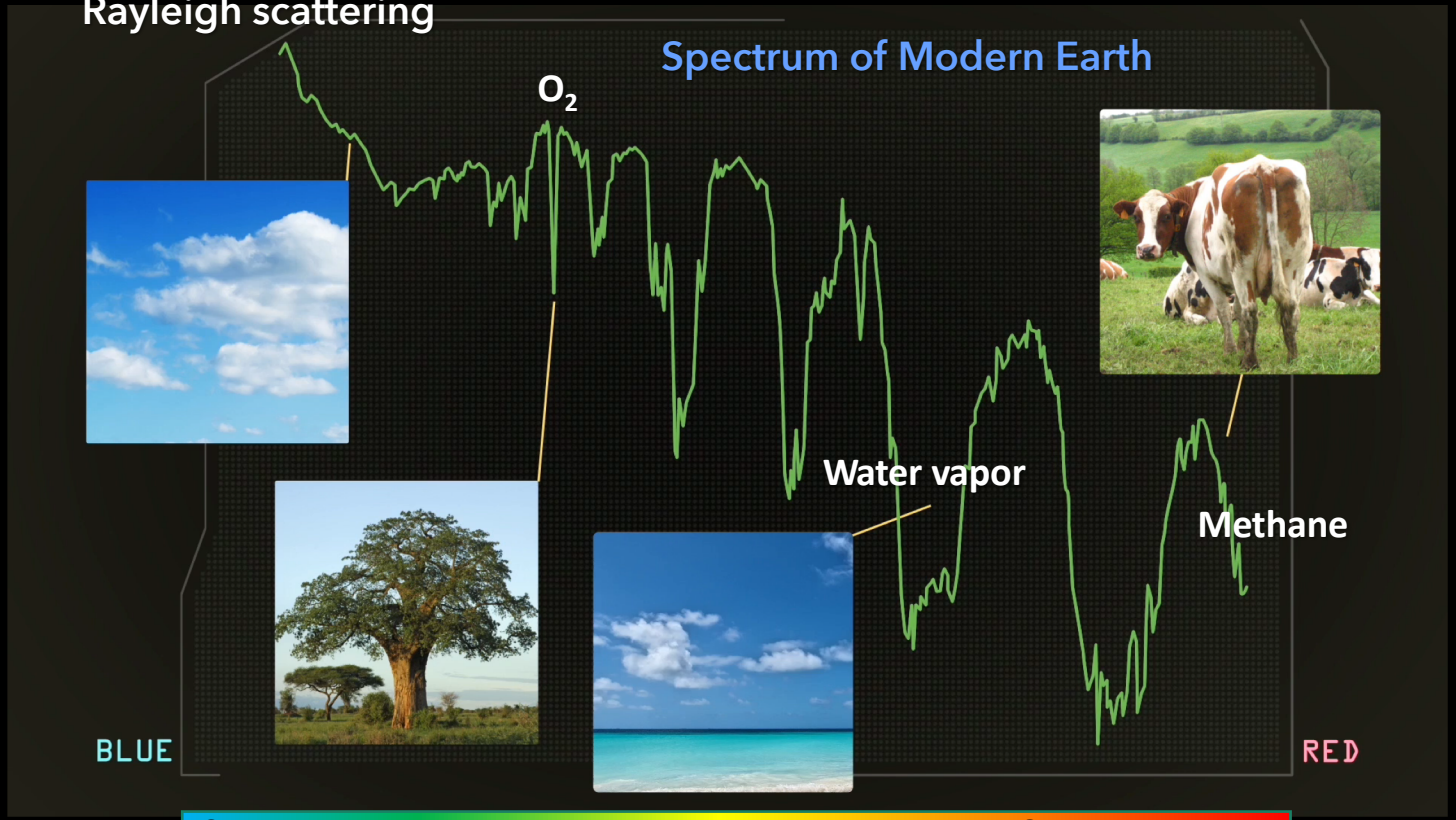
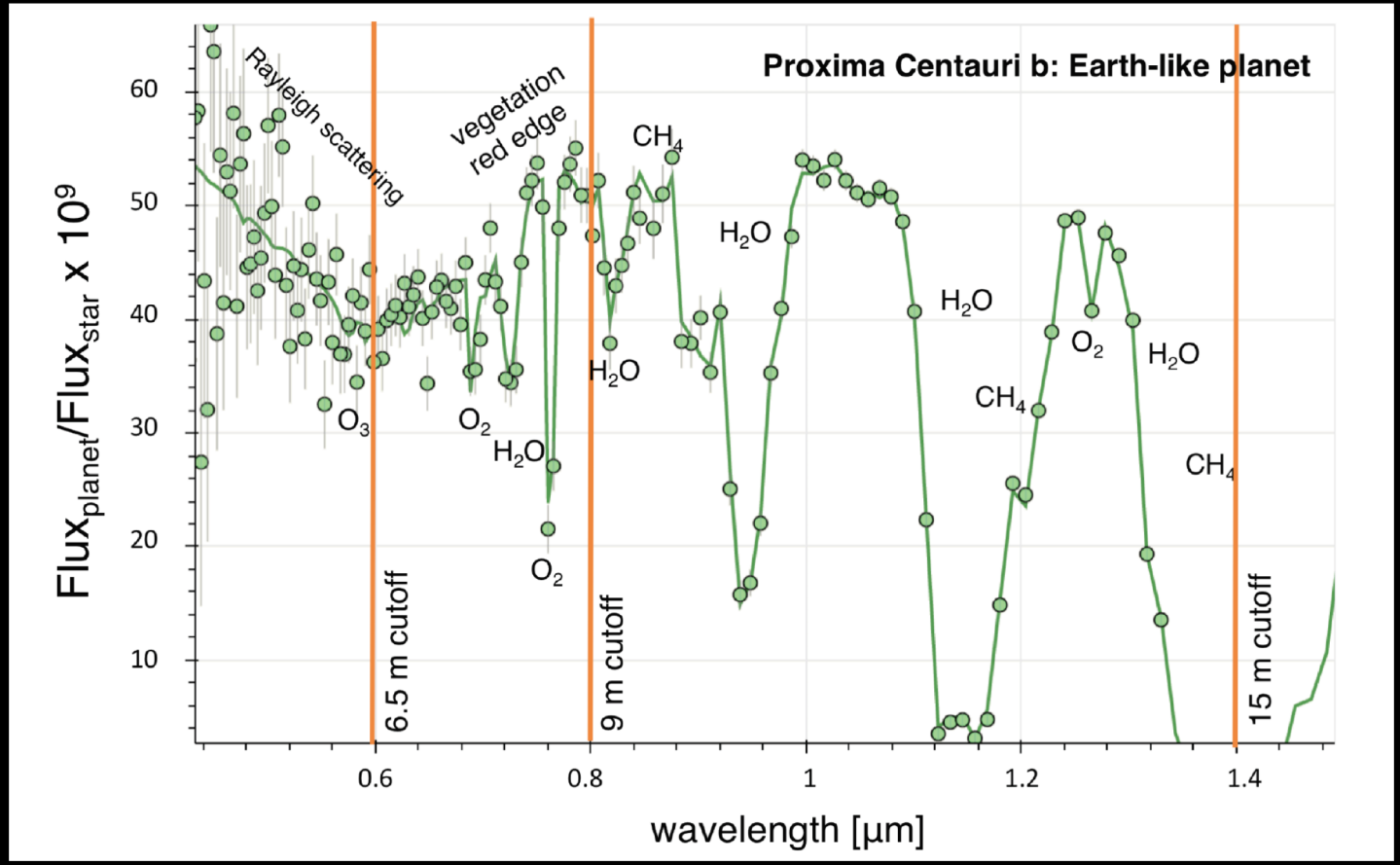


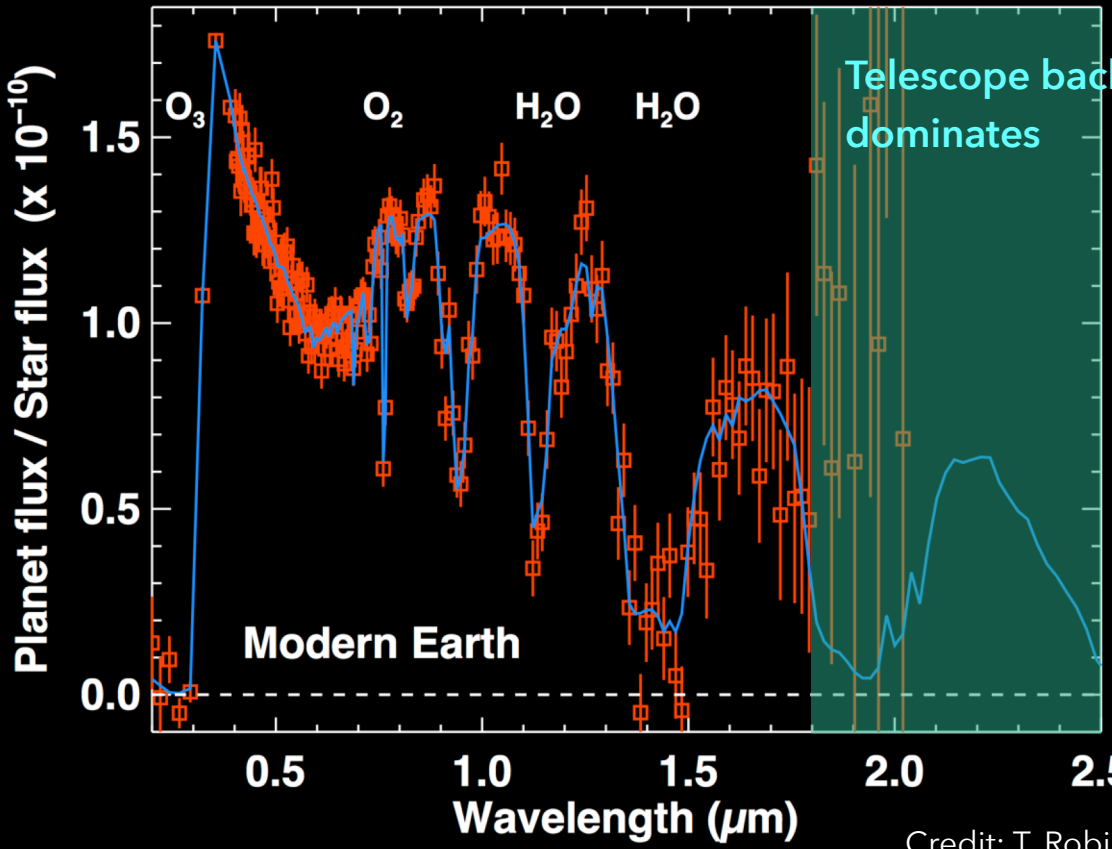
Sample Observation: LUVOIR Spectrum of Proxima Centauri b



LUVOIR

Credit: LUVOIR Tools

Simulated LUVOIR Observation

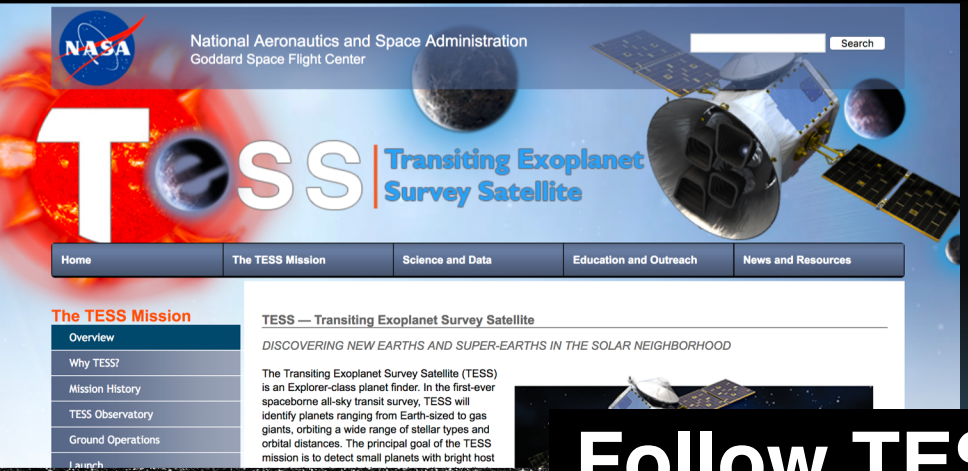


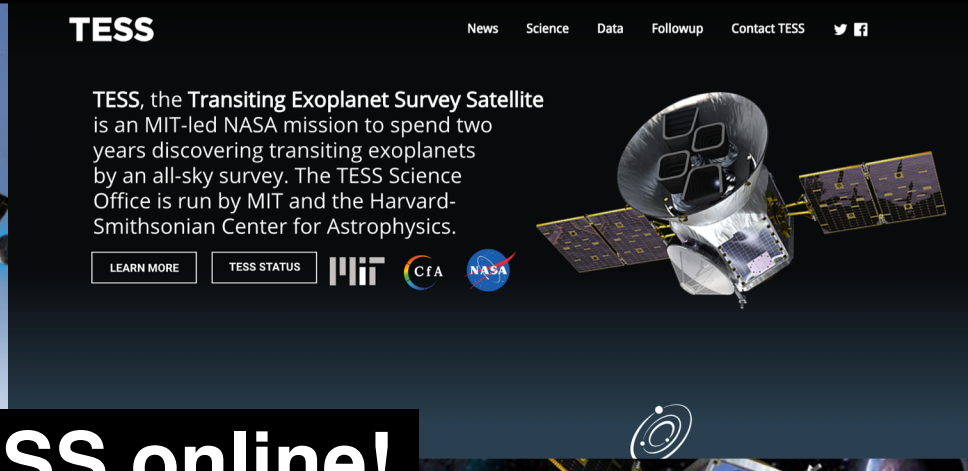
Distance = 10 pc
$D_{telescope}$ = 15-m
$T_{telescope}$ = 270 K
R = 150
Time = 96 hrs per band

Credit: T. Robinson / G. Arney

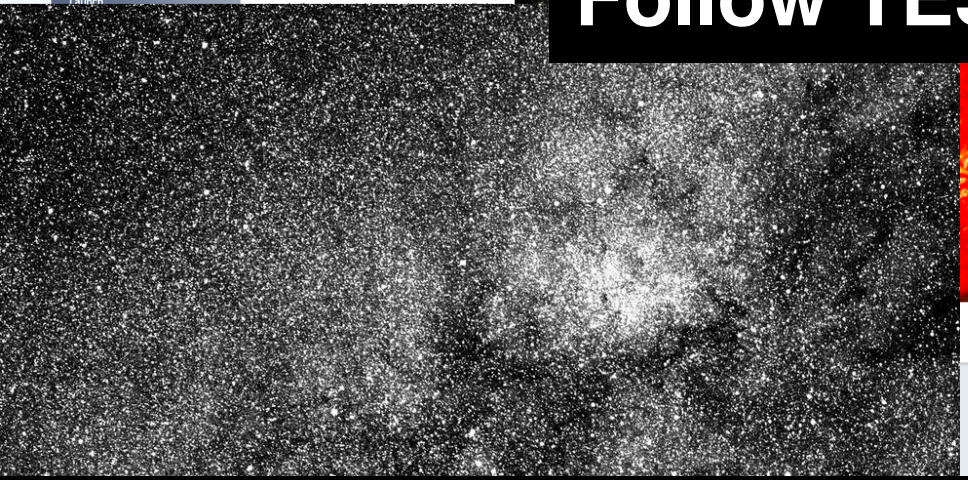
NASA TESS website: https://tess.gsfc.nasa.gov/

MIT TESS website: https://tess.mit.edu/





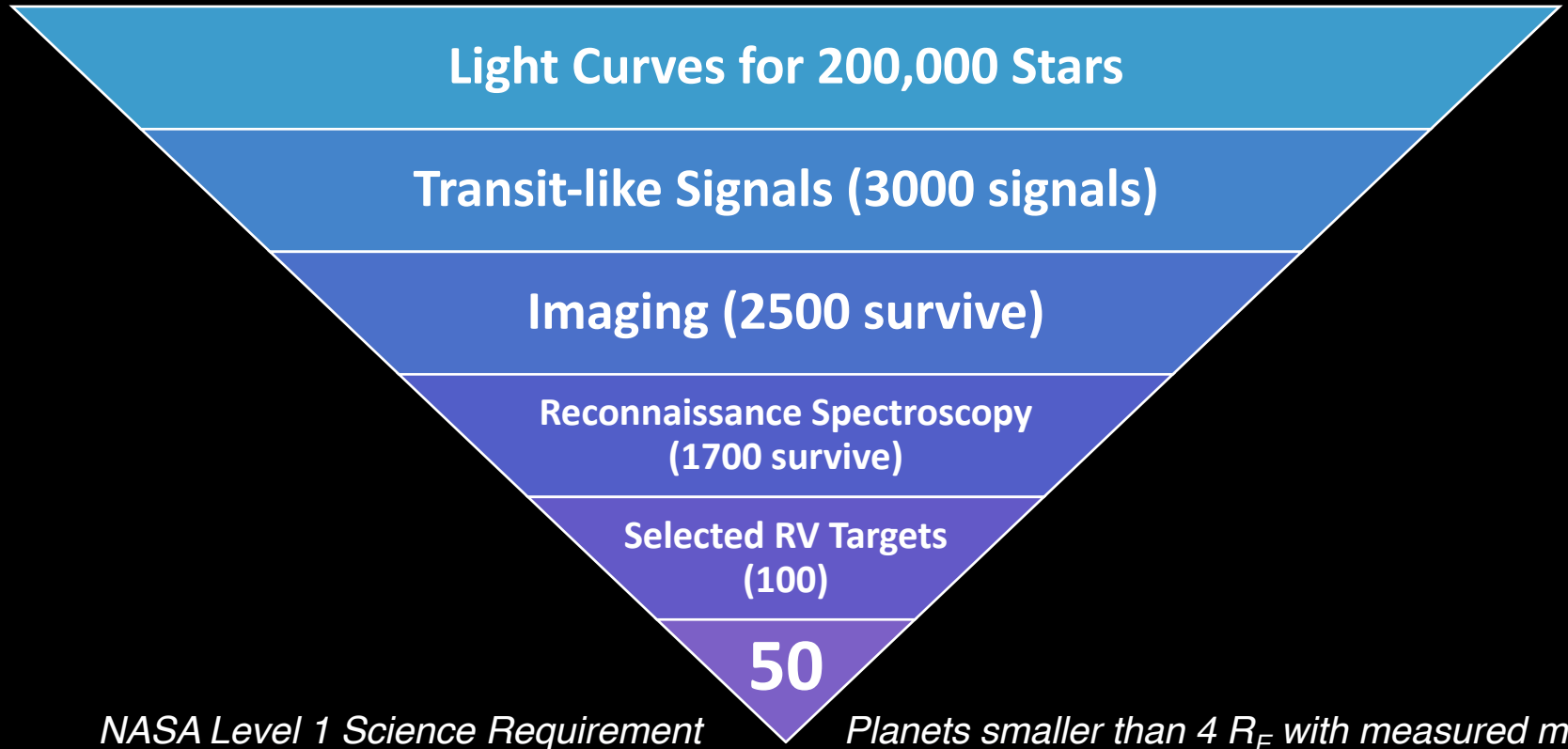
Follow TESS online!



TESS Test Image (Credit: NASA/MIT/TESS)

Twitter: @NASA_TESS, Facebook: NASATESS

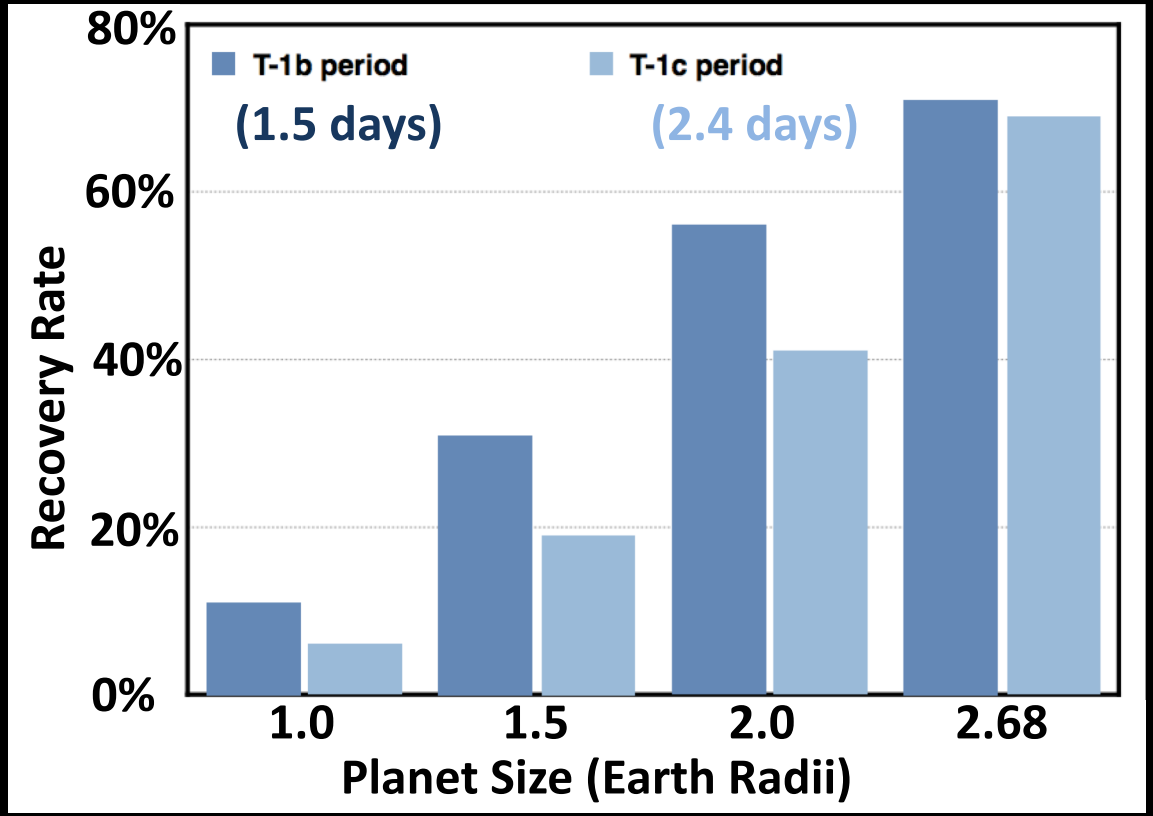
Follow-up Observations Will Be Essential to Identify False Positives



NASA Level 1 Science Requirement

Planets smaller than 4 R_E with measured masses

How Common are Planetary Systems Orbiting Late M Dwarfs?



Demory et al. 2016, ApJL, arXiv:1606.08622

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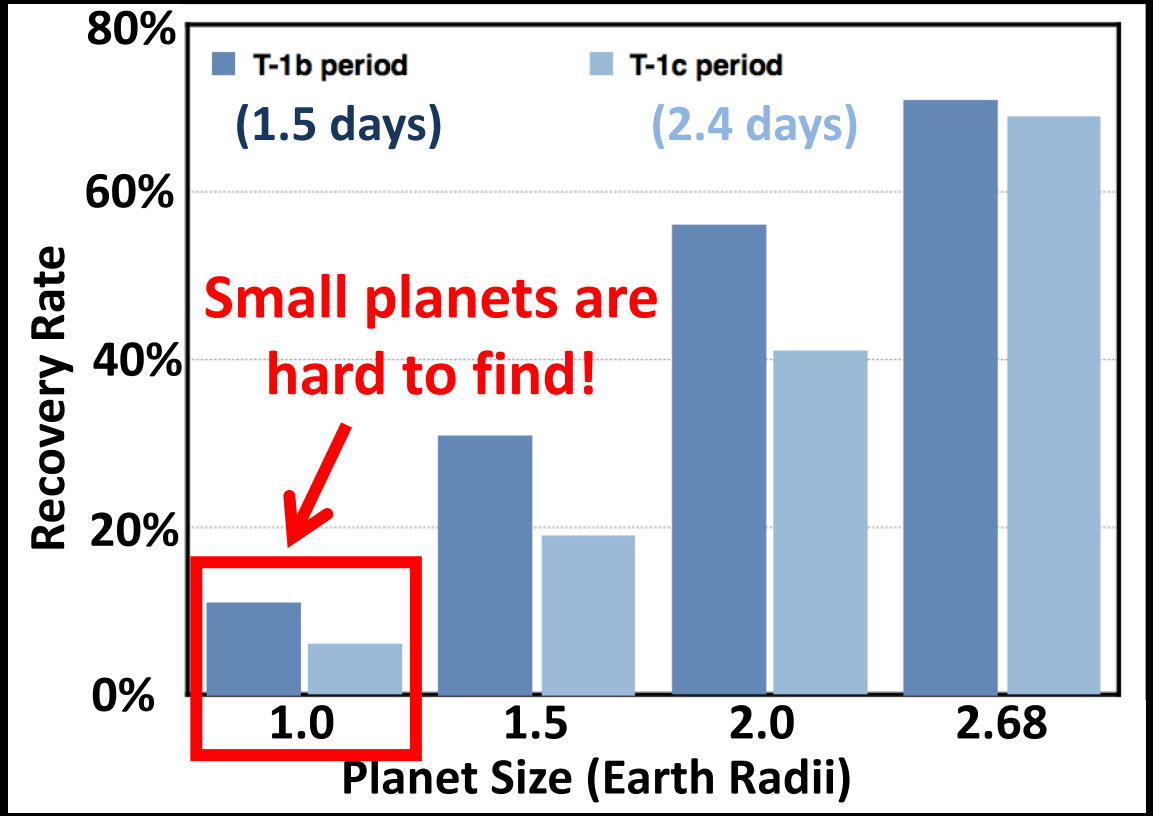

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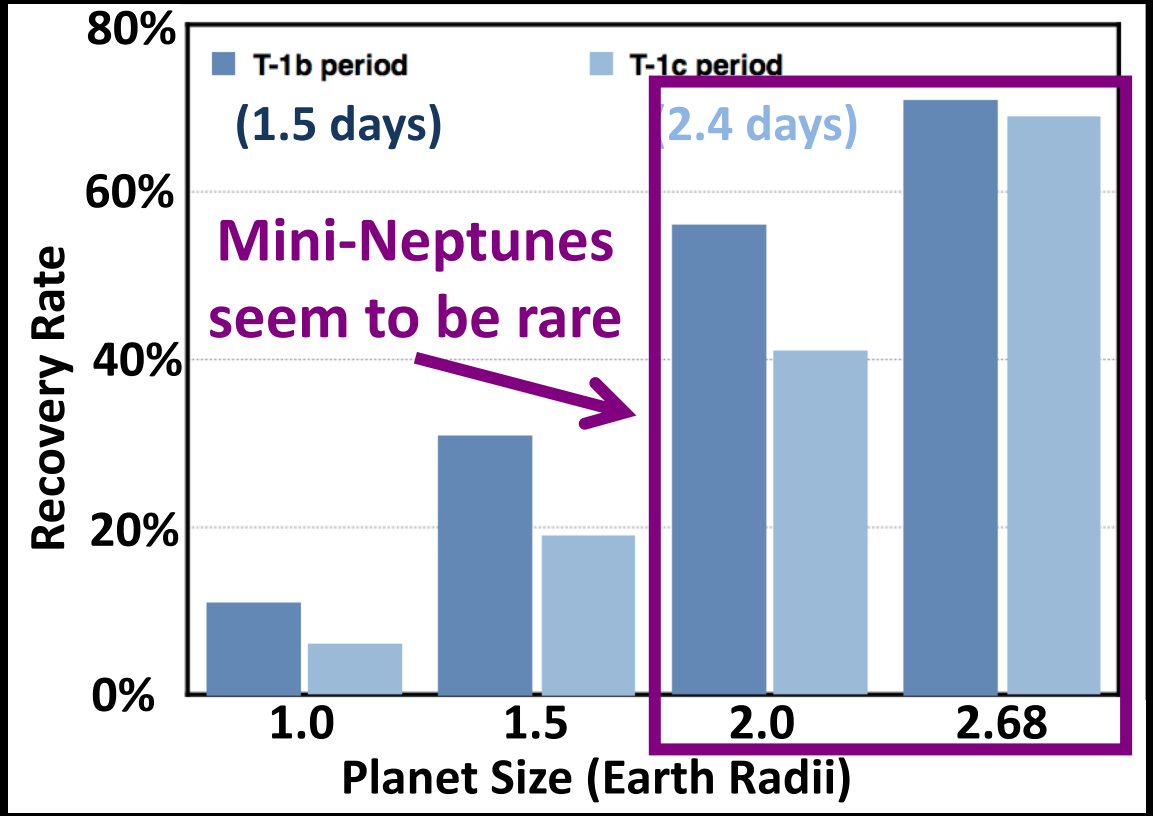
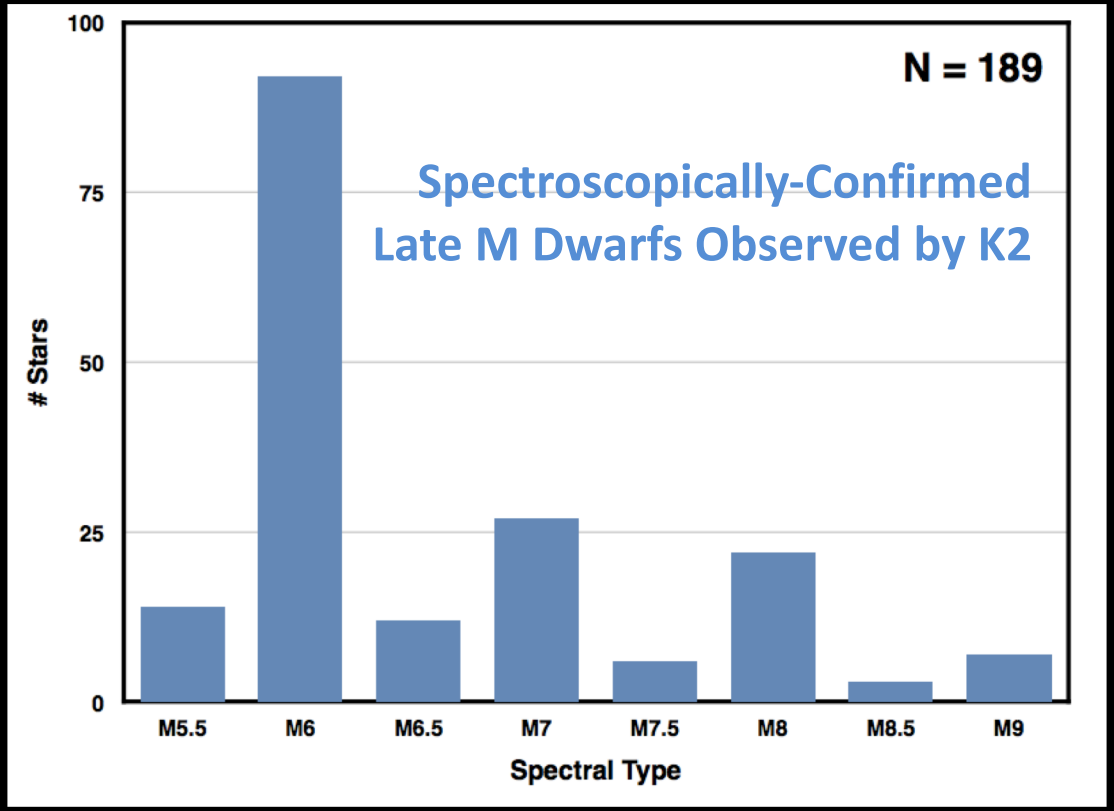


Consistent with Berta-Thompson+ 2013; Dressing + Charbonneau 2013, 2015

Demory et al. 2016, ApJL, arXiv:1606.08622

Studies of Late M Dwarf Planet Occurrence are Limited by Small Stellar Sample Size



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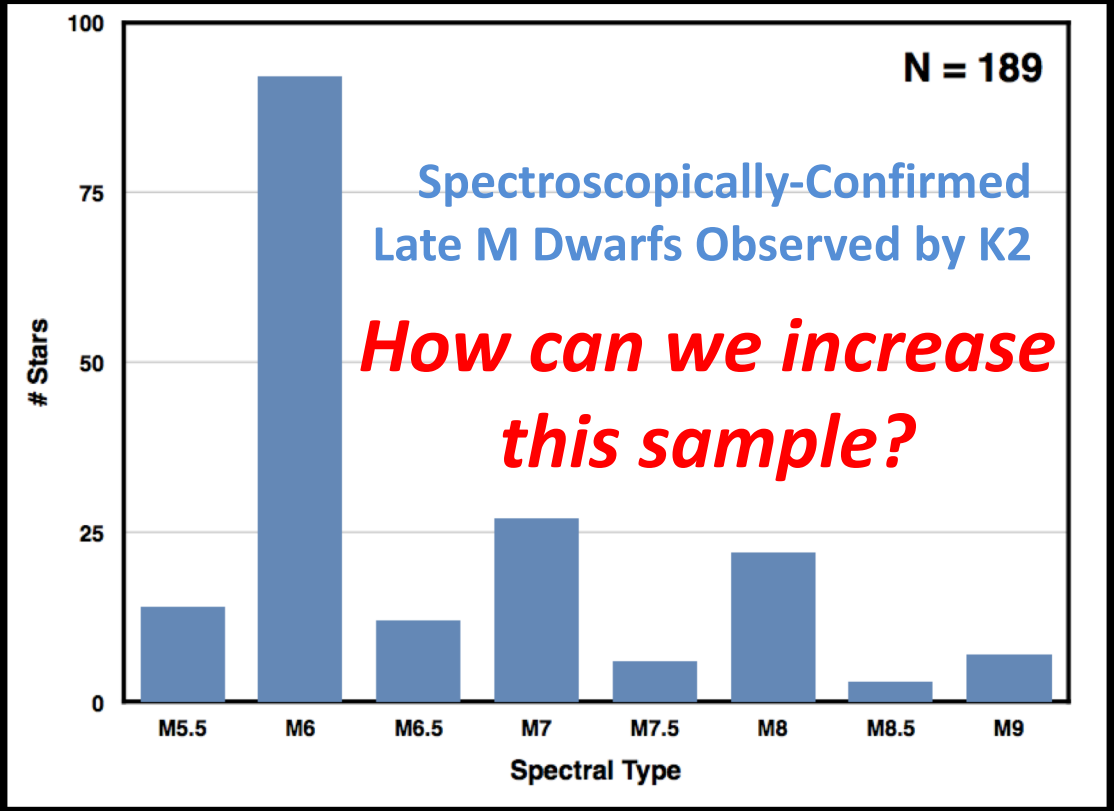
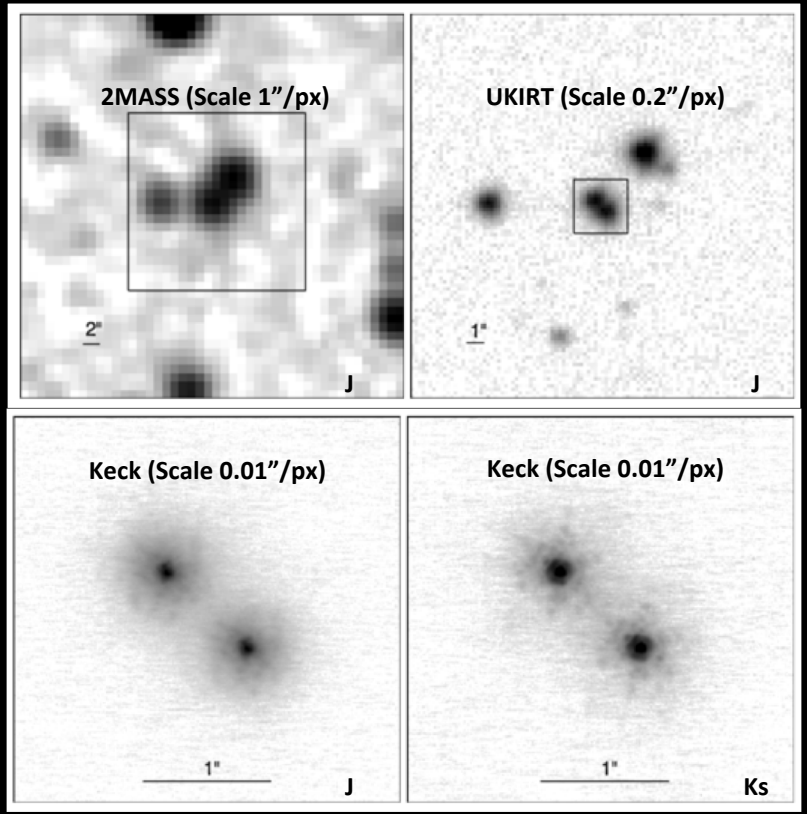


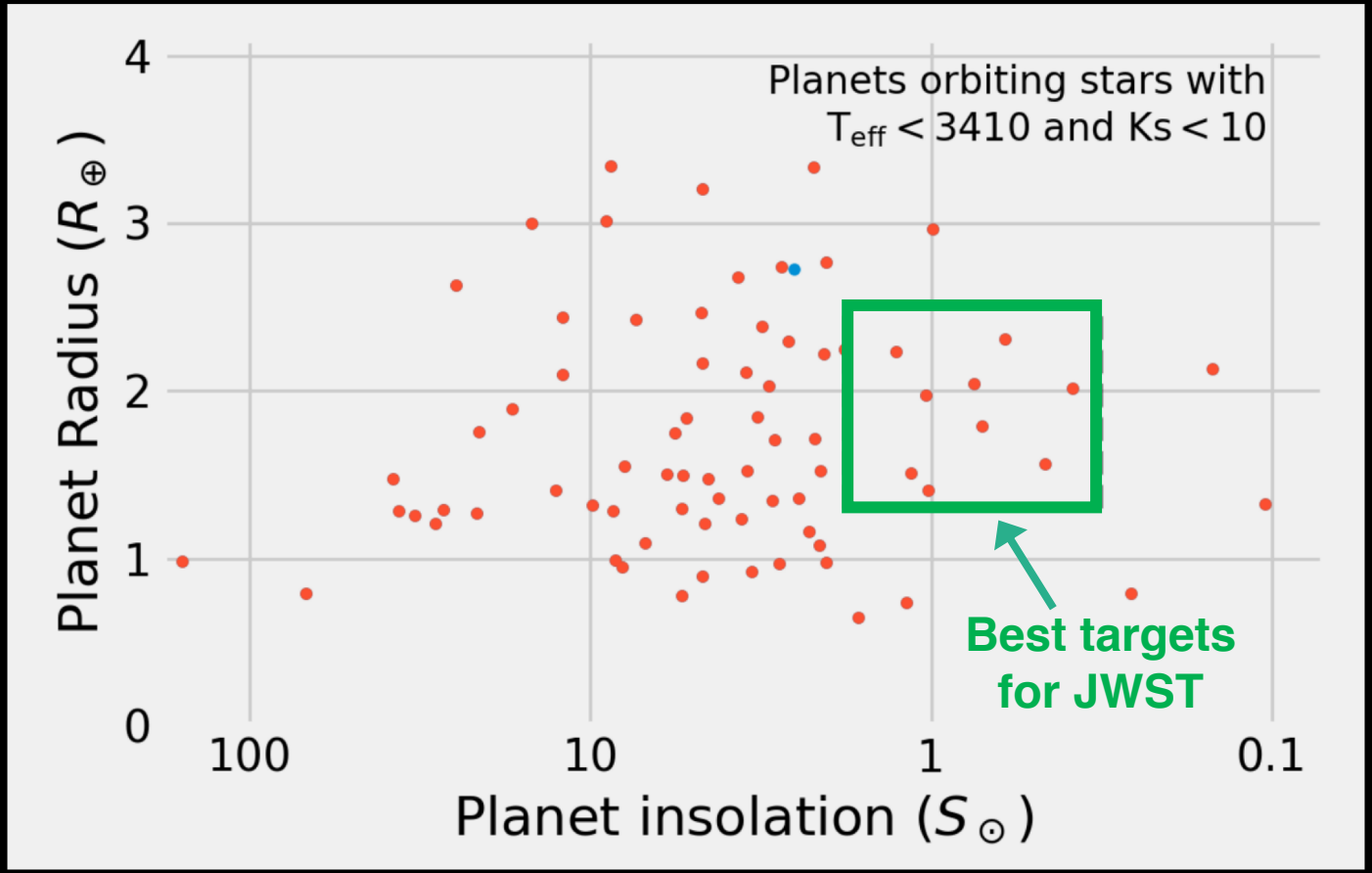
Demory et al. 2016, ApJL, arXiv:1606.08622

TESS Pixels are Large (20” x20”)



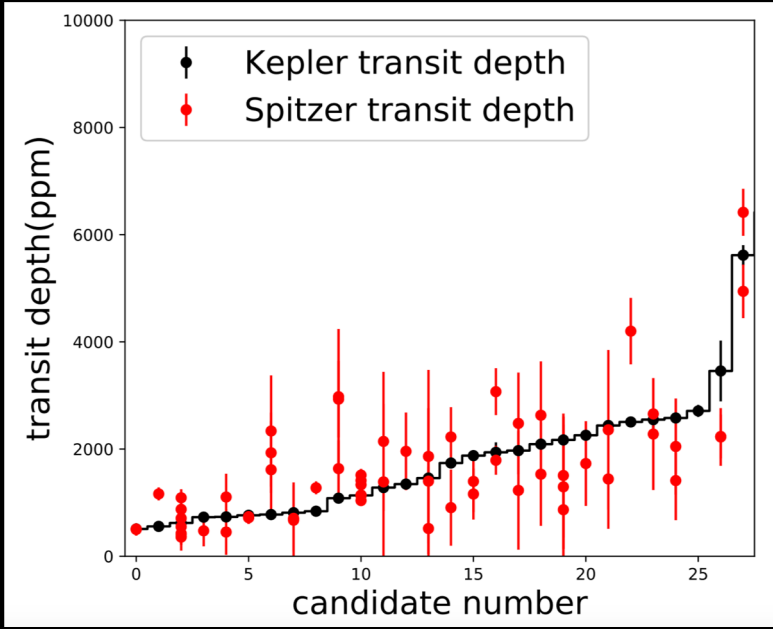
Furlan et al. 2017, AJ, 153, 71

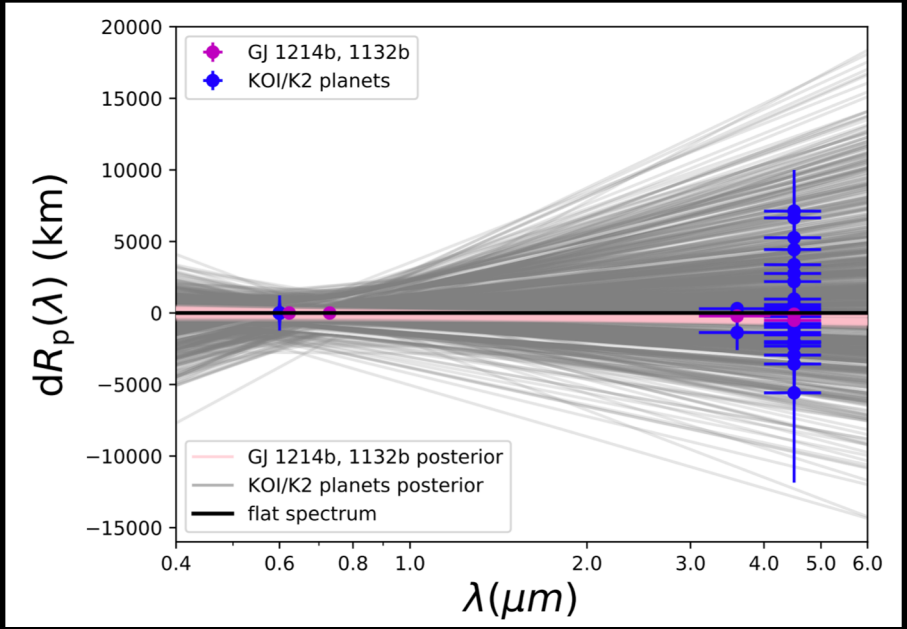
The Coolest TESS Planets will Orbit M Dwarfs



Barclay et al. (2018)

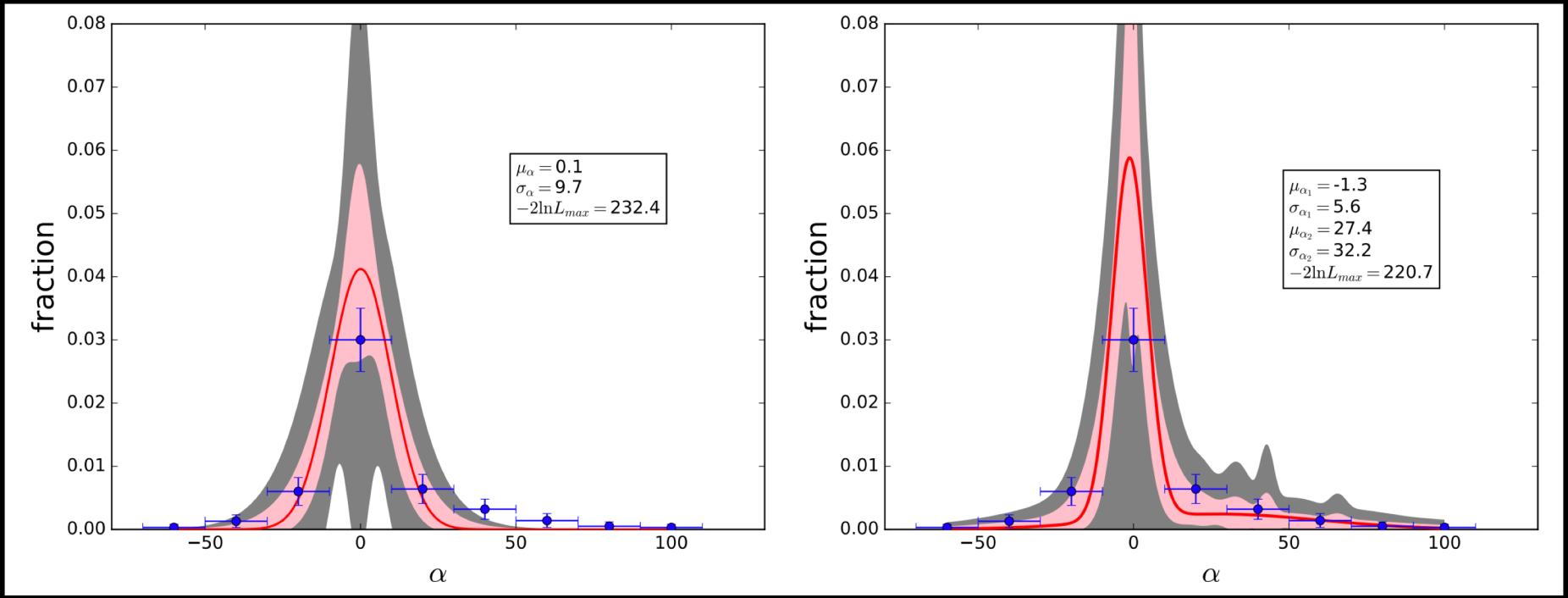
Ensemble Studies of Multiple Planets Can Reveal Population Properties





Guo et al., submitted to ApJ, arXiv: 1804.00071

The Data are Best Explained by a Mixture Model Containing Two Types of Atmospheres



Guo et al., submitted to ApJ, arXiv: 1804.00071

The LUVOIR Architectures

Architecture A

- 15-m diameter telescope
- Fits in 8.4-m fairing
  - *Space Launch System Block 2*
- Bulk of work completed
- Refinements in progress

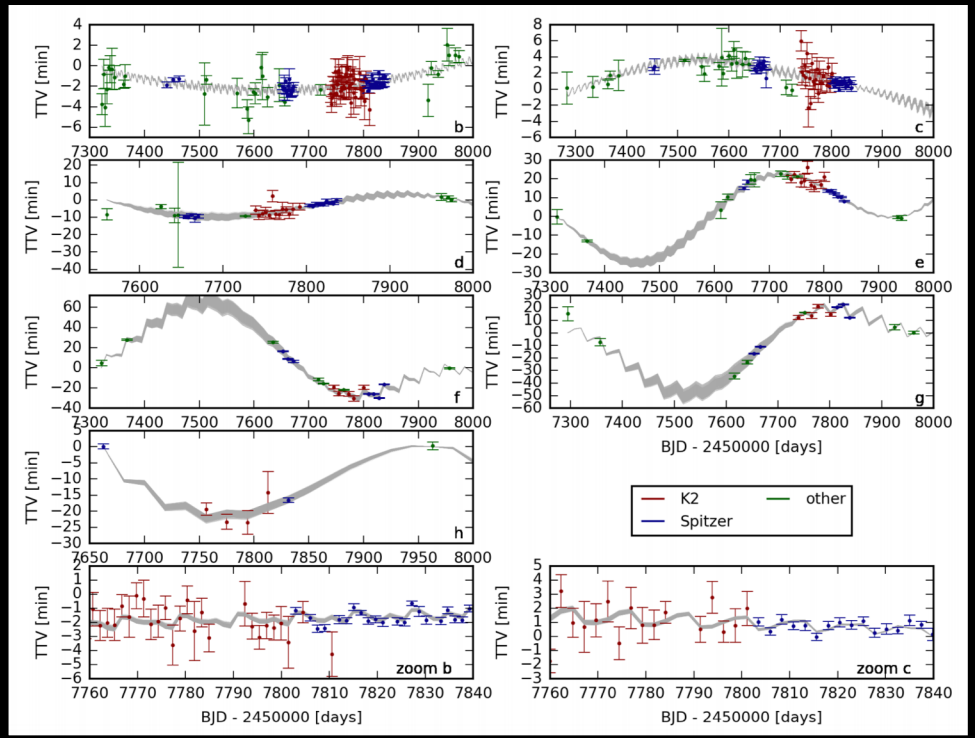
Instruments
ECLIPS A
LUMOS A
High-Definition Imager
POLLUX

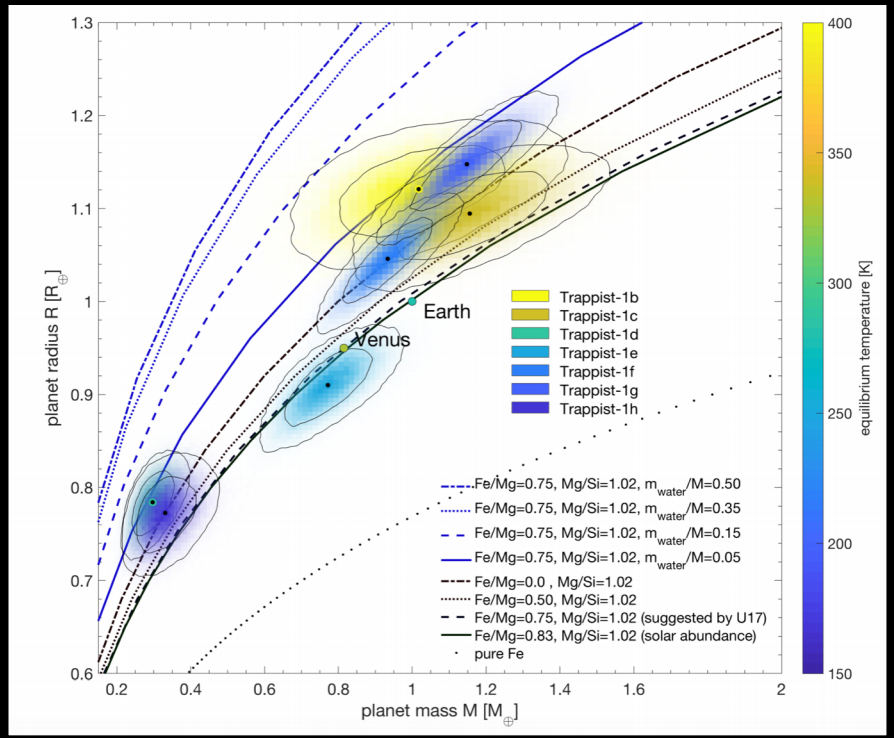
Architecture B

- 8-m diameter telescope
- Fits in 5-m fairing
  - *e.g., Delta IV Heavy, Falcon Heavy*
- Work began in September 2017

Instruments
ECLIPS B
LUMOS B
HDI B

Transit Timing Variations Probe the Compositions of the TRAPPIST-1 Planets





Grimm et al. 2018, A&A, 613, A68