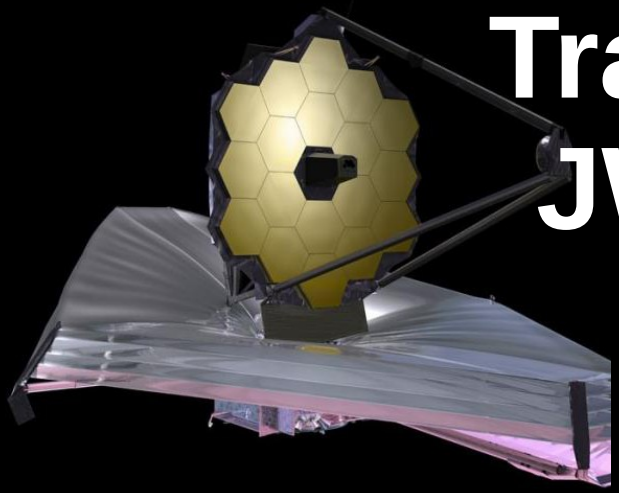
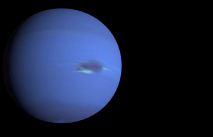
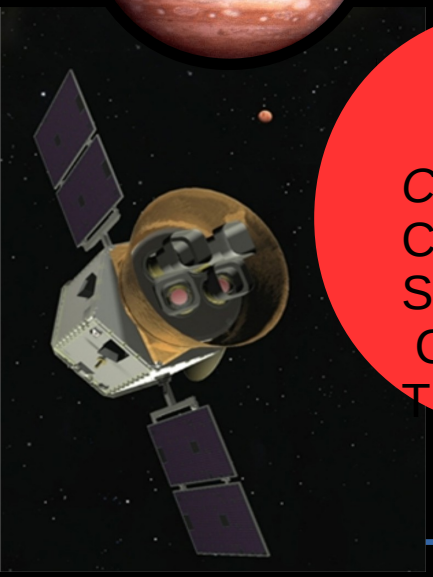
Transiting Targets for JWST Spectroscopy







Ian Crossfield
Sagan Fellow, UA/LPL

2015/10/14

Collaborators: **E. Petigura, J. Schlieder, B. Benneke,** A. Martinez, C. Beichman, A. Howard, H. Knutson, D. Dragomir, E. Sinukoff, BJ Fulton, S. Lepine, H. Isaacson, J. Krick, J. Livingstone, M. Werner, T. Barclay, C. Obermeier, K. Aller, L. Kaltenegger, J. Crepp, J. Christiansen, T. Barman, Th. Henning, B. Hansen, M. Liu, T. Greene, D. Ciardi, N. Deacon, E. Schlafly

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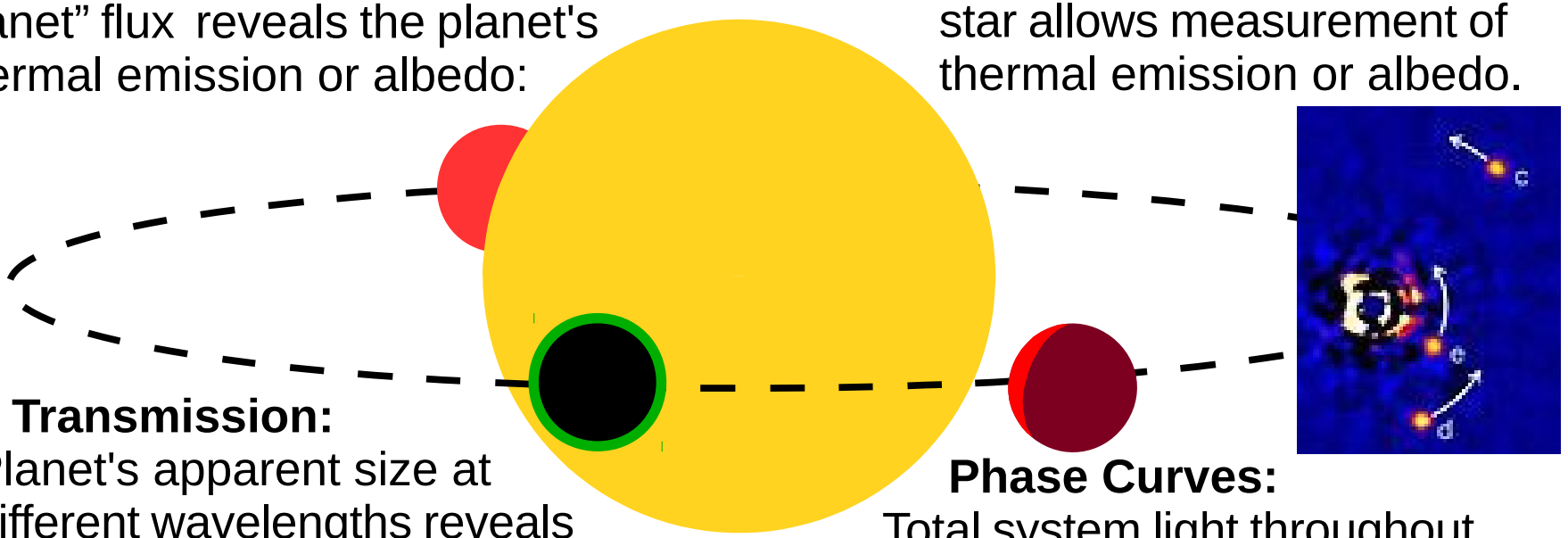
Observations of Exoplanet Atmospheres

Eclipse:
Removing “star” from “star plus planet” flux reveals the planet's thermal emission or albedo:

Direct Imaging:
Spatially resolving planet from star allows measurement of thermal emission or albedo.

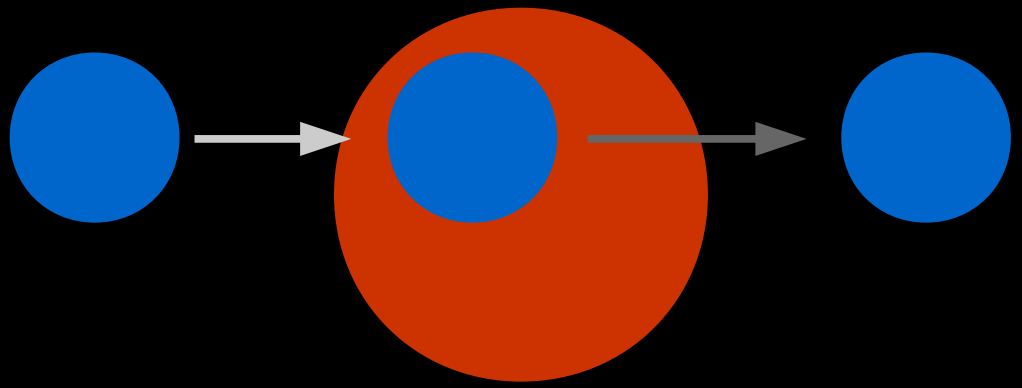


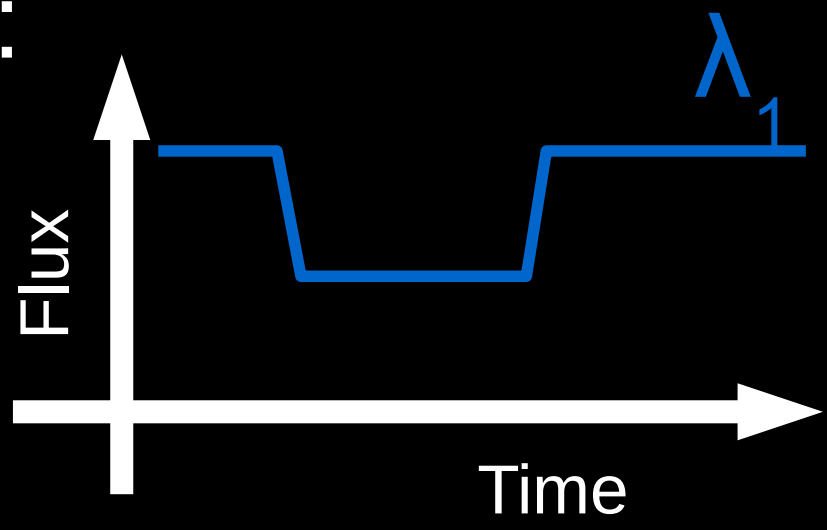
Transmission:
Planet's apparent size at different wavelengths reveals atmospheric opacity and composition.

Phase Curves:
Total system light throughout an orbit constrains atmospheric circulation and/or composition.

Crossfield 2015

Transmission spectroscopy probes exo-atmospheric makeup:





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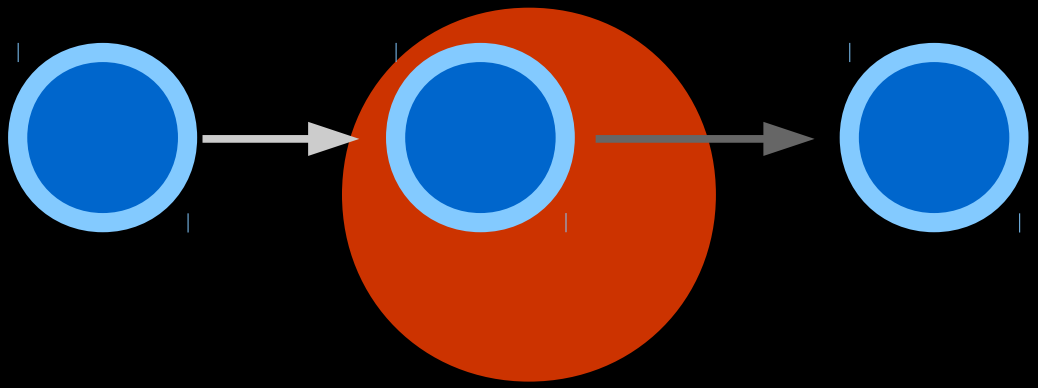

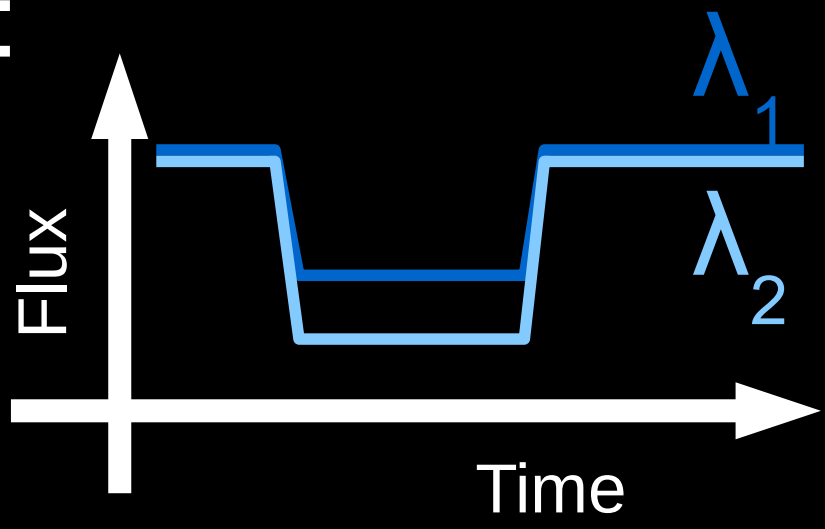

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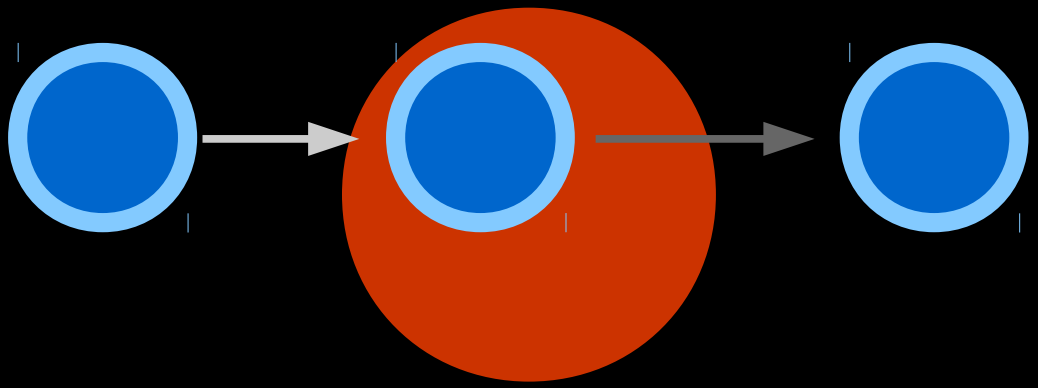

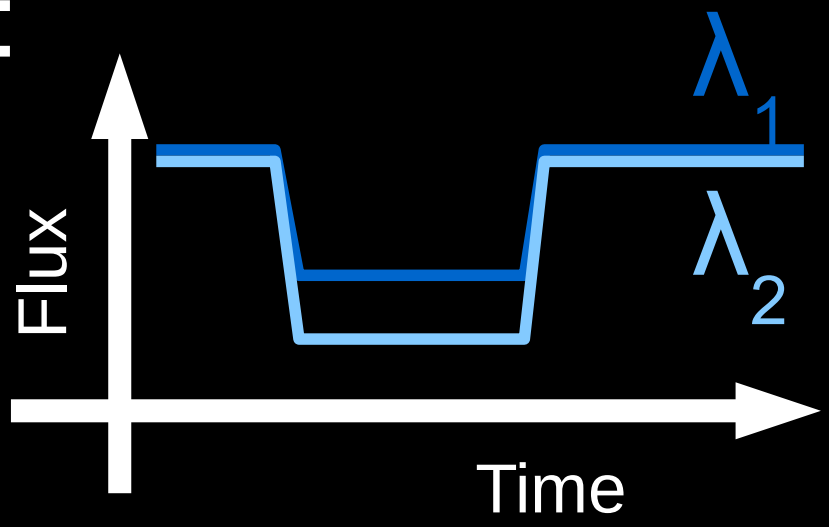

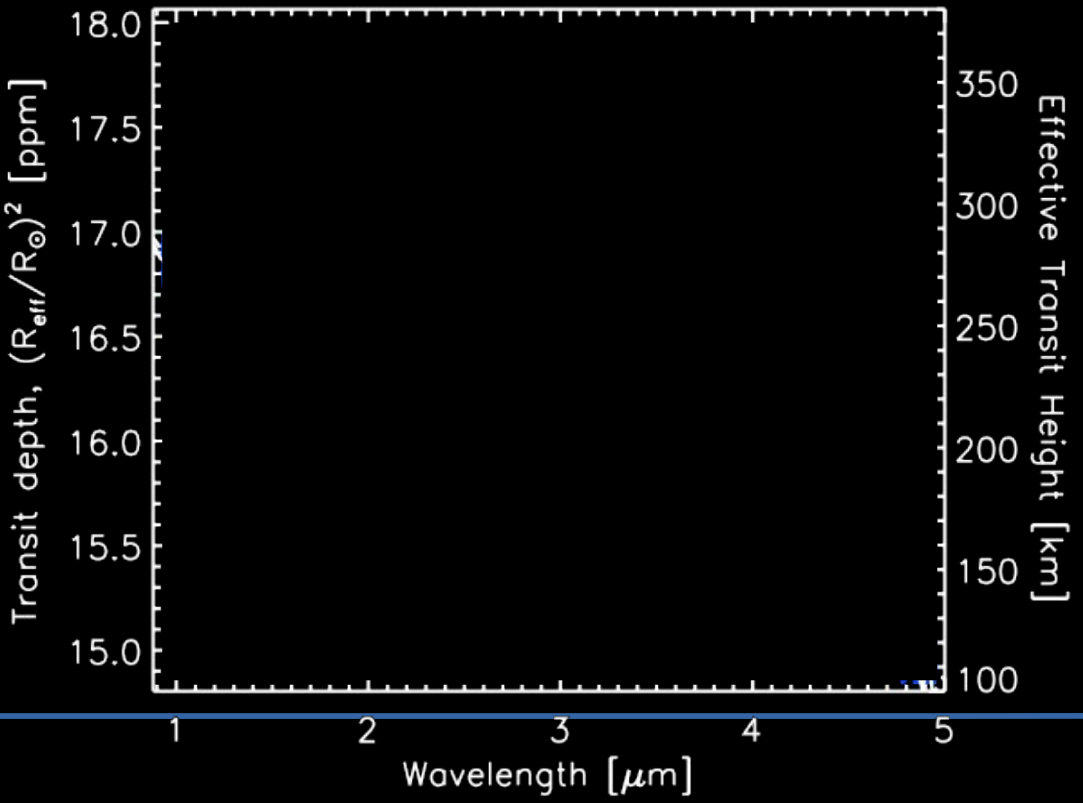

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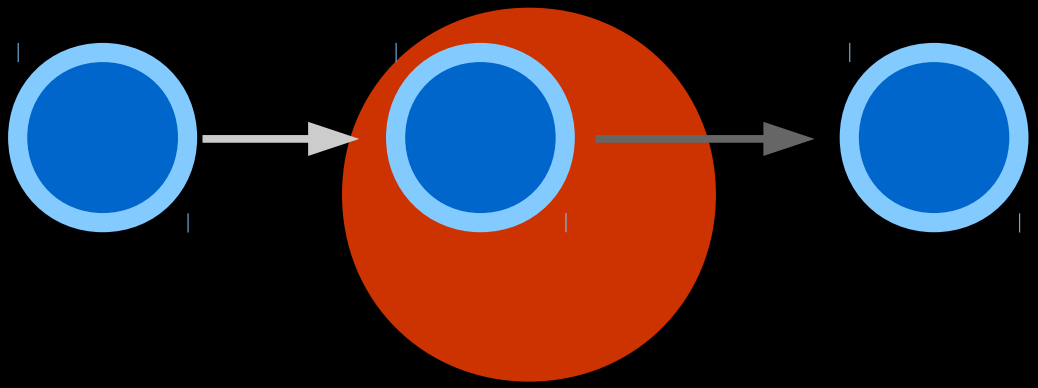

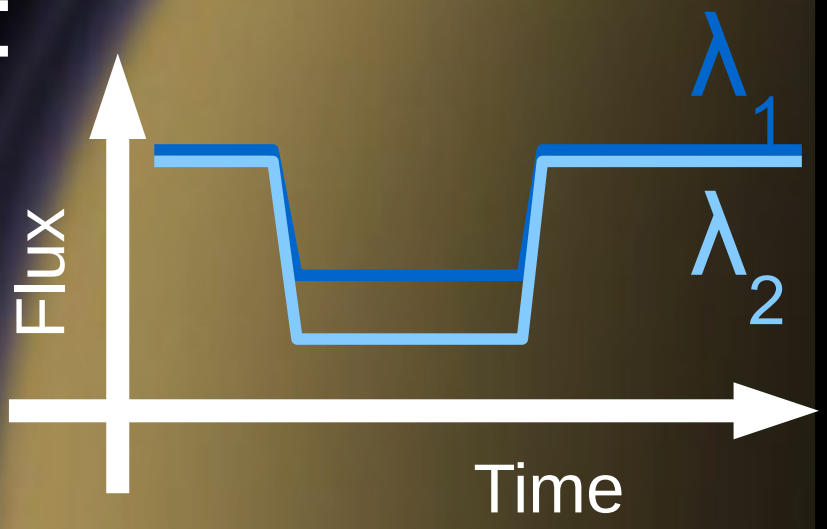

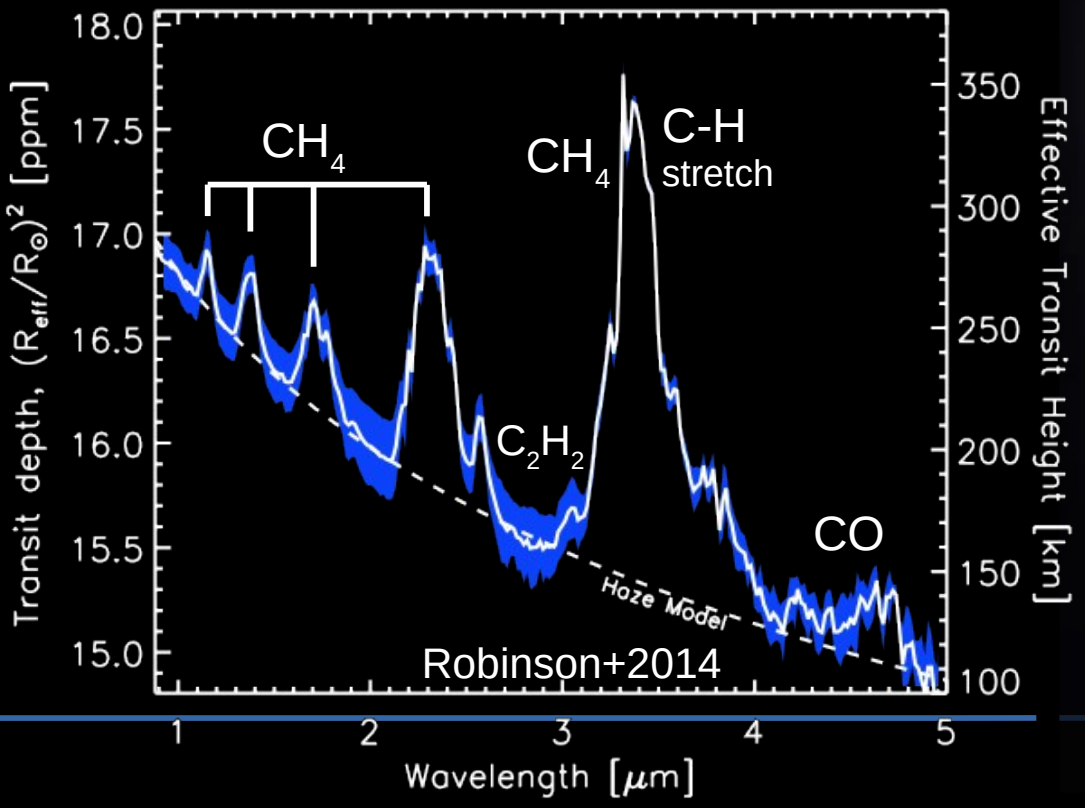

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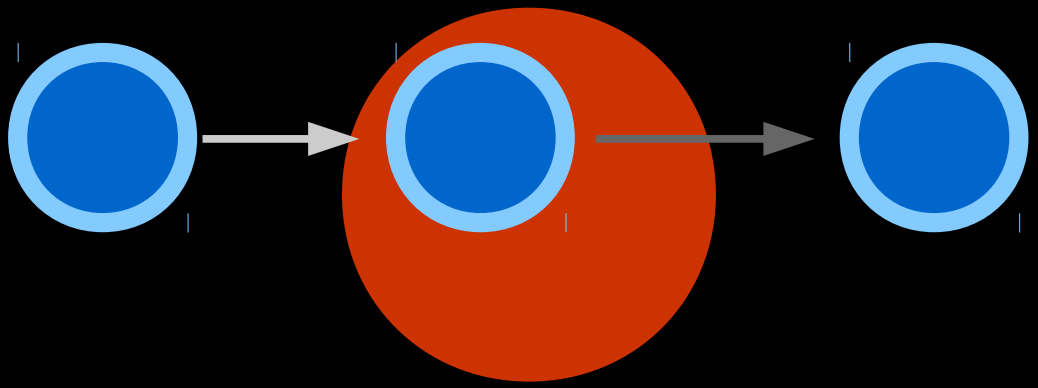
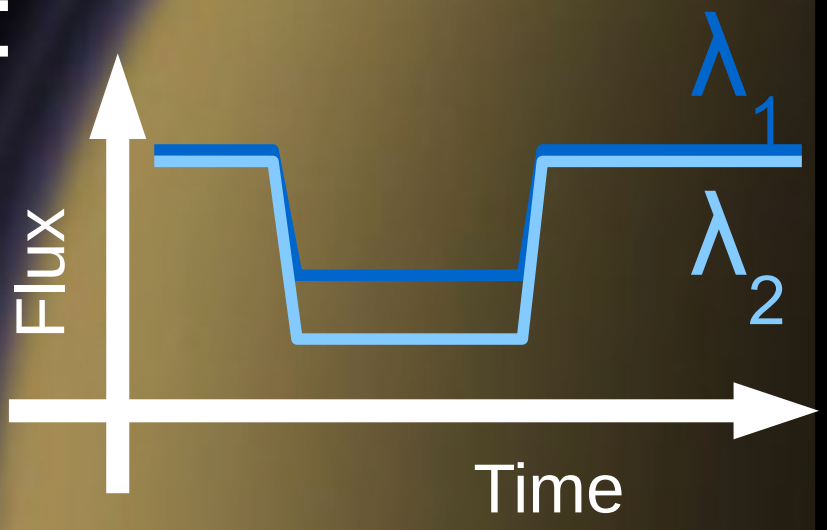
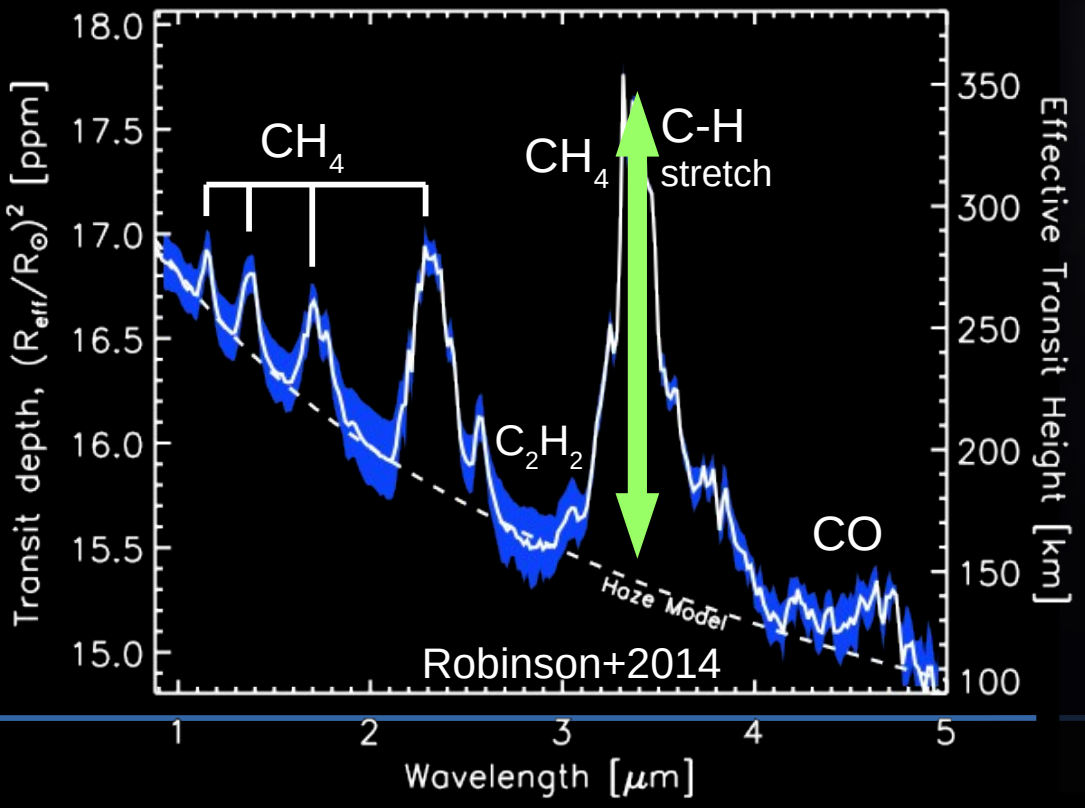
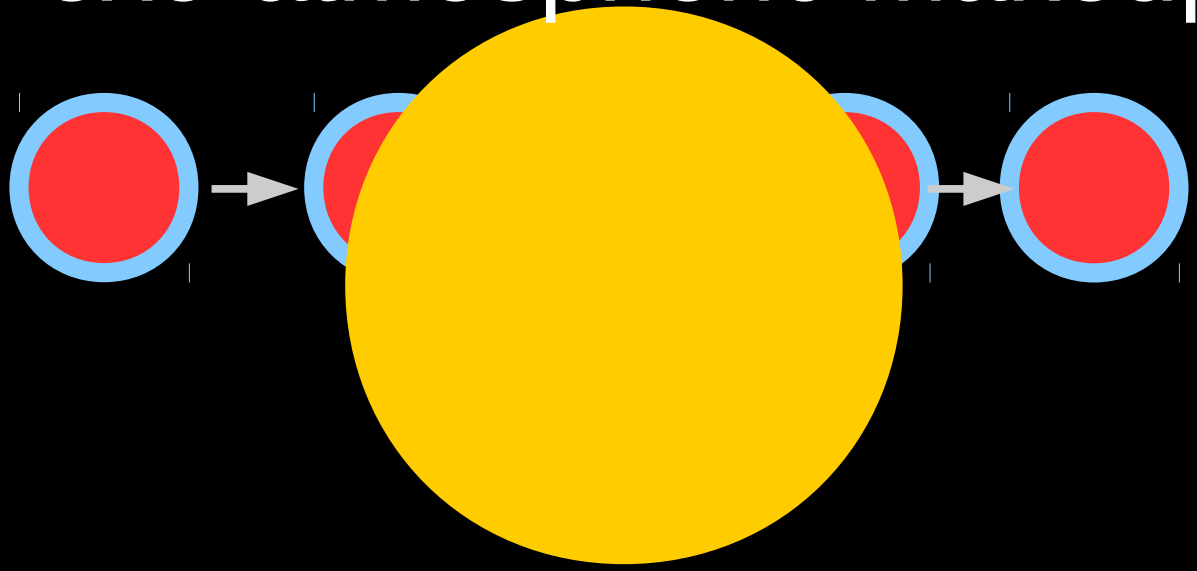


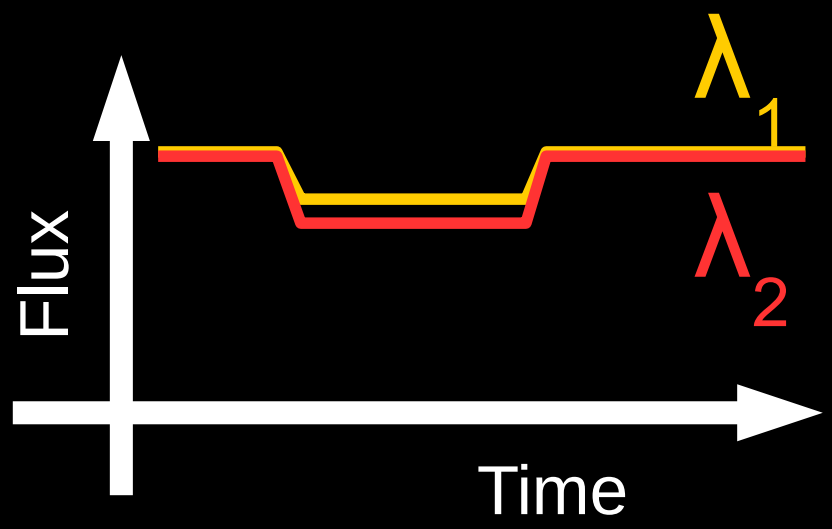




$$\text{signal} \sim \frac{T_p}{\mu_P \rho_p R_*^2}$$

Emission spectroscopy also probes exo-atmospheric makeup:





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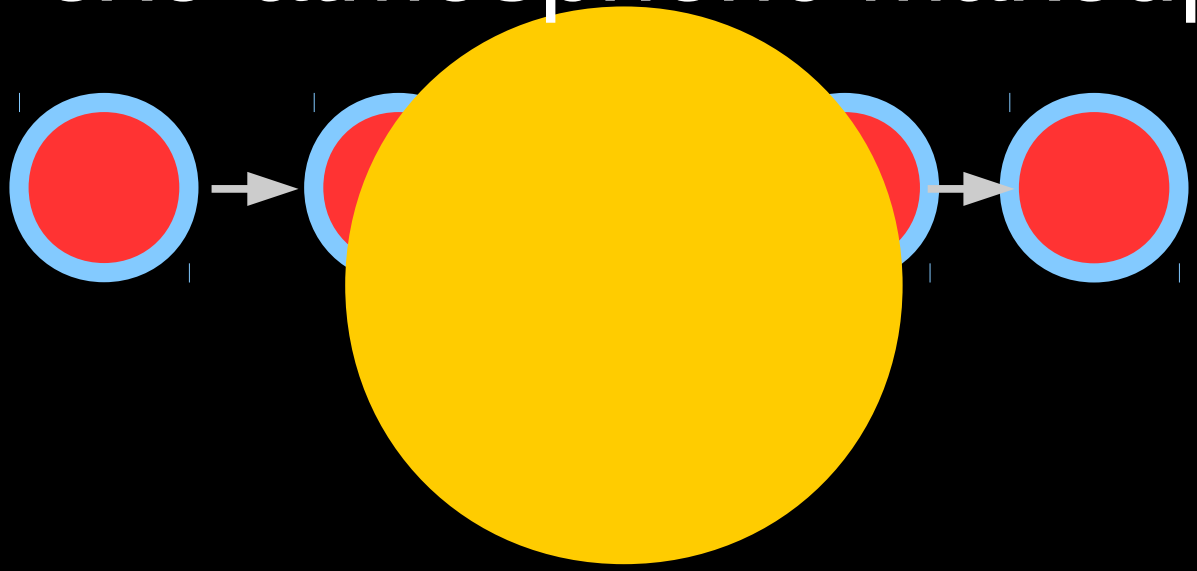
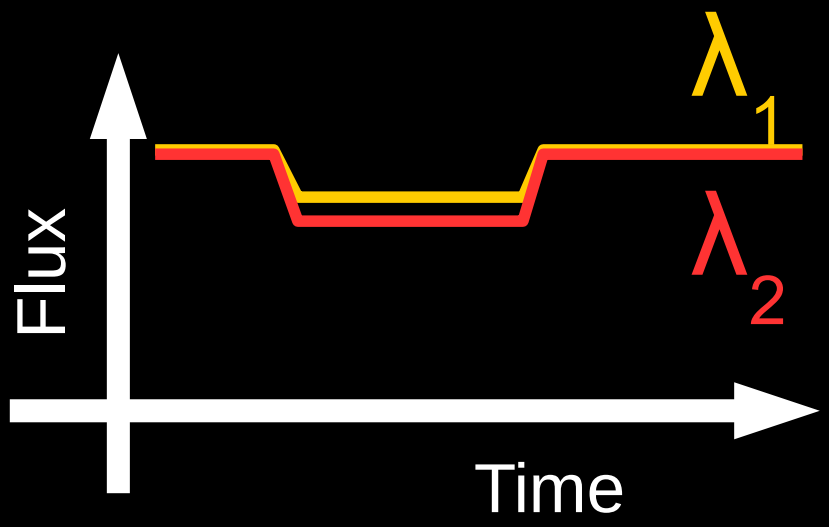
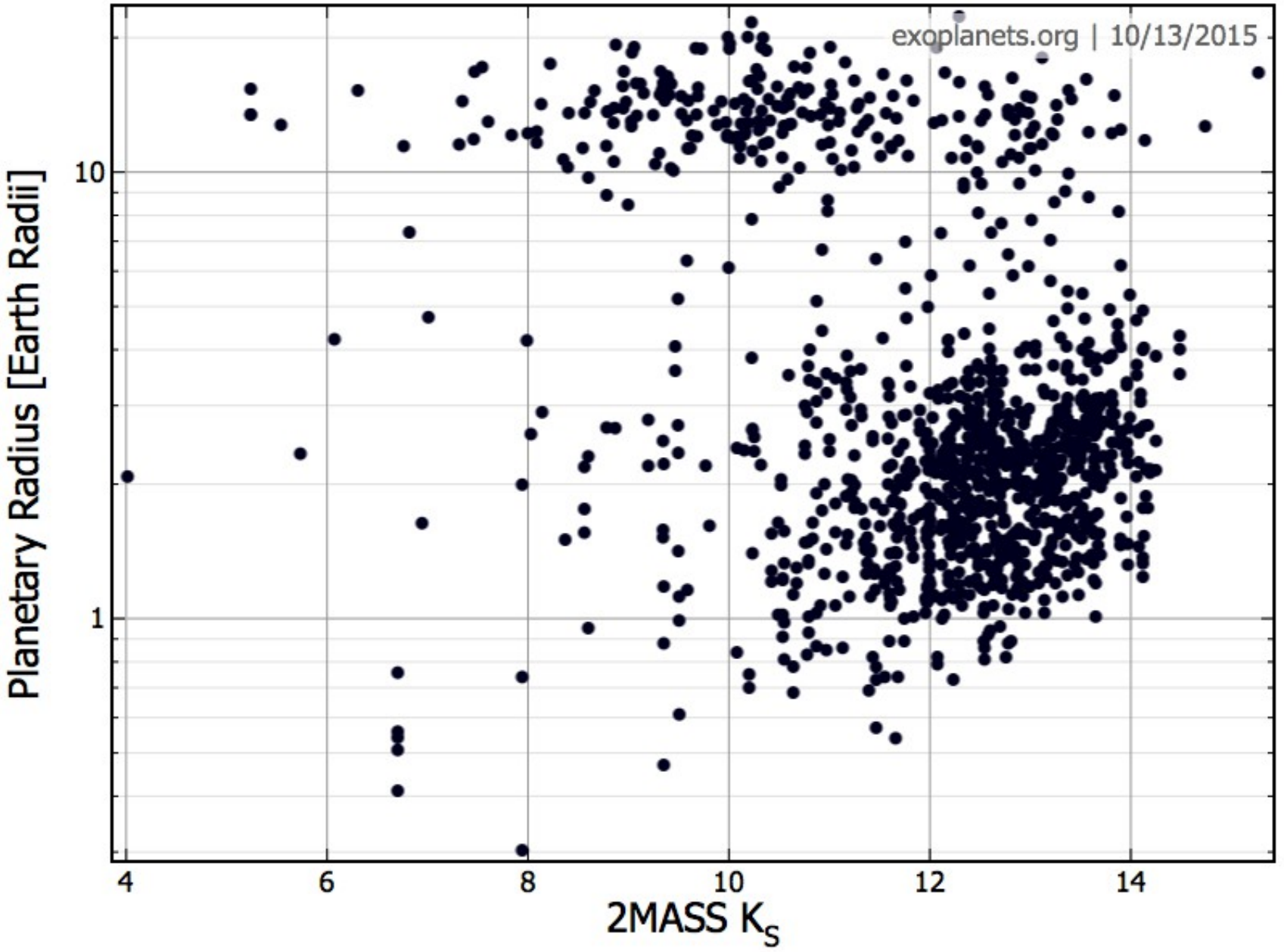




$$\text{signal} \sim \frac{F_\nu(T_p)\, R_p^{\,2}}{F_\nu(T_*)\, R_*^{\,2}} \sim \frac{T_p\, R_p^{\,2}}{T_*\, R_*^{\,2}}$$

Most Known Transiting Planets Orbit Faint Stars:



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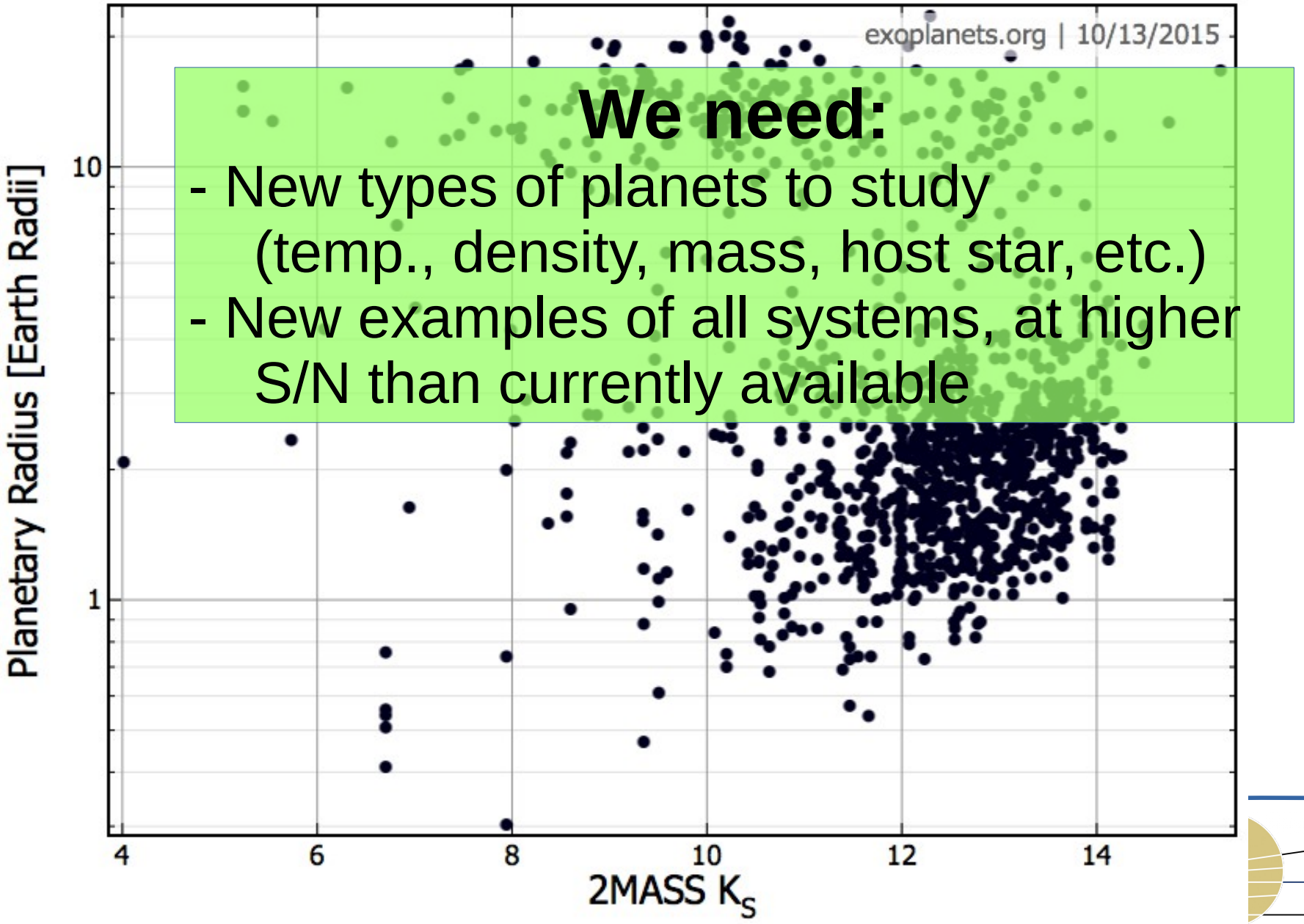

We need:

- New types of planets to study (temp., density, mass, host star, etc.)
- New examples of all systems, at higher S/N than currently available

Lunar and Planetary Laboratory

Transiting Target Timeline

2015

2016

2017

2018

2019

2020

HST Operations

Transiting Target Timeline

2015

2016

2017

2018

2019

2020

HST Operations

Launch, check-out, Cycle 1

Transiting Target Timeline

2015

HST Operations

2016

2017

Calls for GTO, ESR, Cycle 1 Proposals

2018

2019

Launch, check-out, Cycle 1

2020

Transiting Target Timeline

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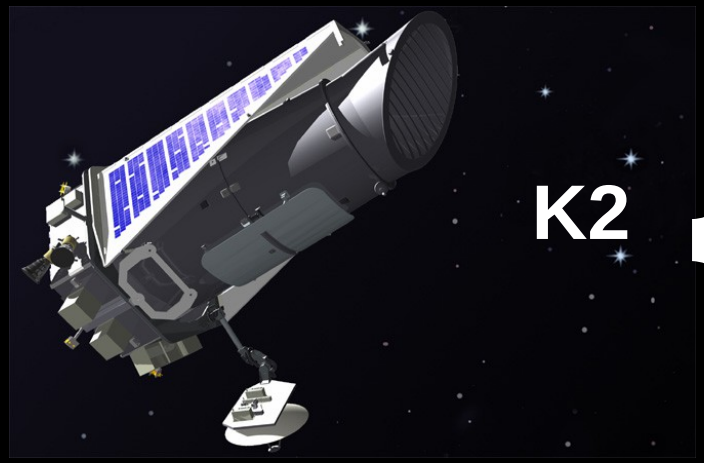
TESS operations

2019

Launch, check-out, Cycle 1

2020

Transiting Target Timeline



K2

2015

2016

2017

2018

2019

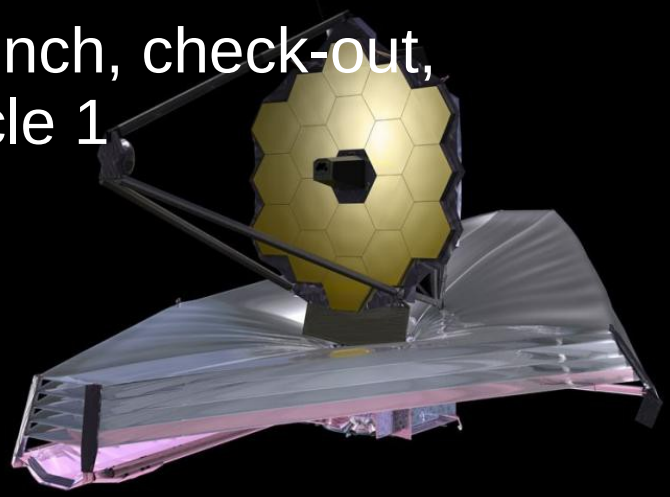
2020

HST Operations

Calls for GTO, ESR, Cycle 1 Proposals

TESS operations

Launch, check-out, Cycle 1



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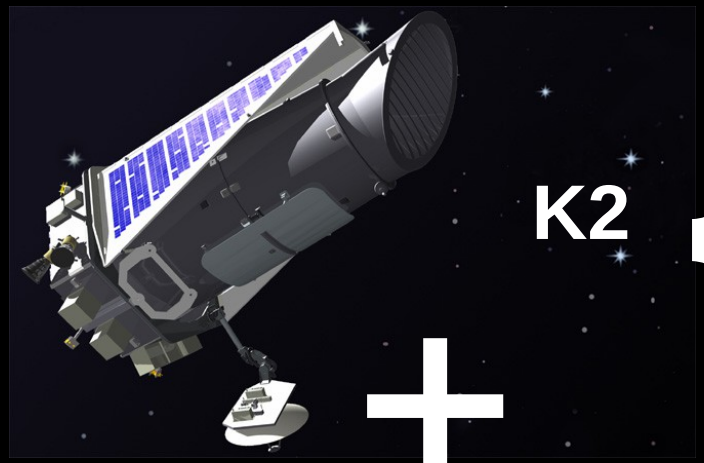

K2

+

CHEOPS,
Mearth, NGTS, ExTrA,
SPECULOOS, MASCARA

2015

2016

2017

2018

2019

2020

HST
Operations

Calls for GTO, ESR,
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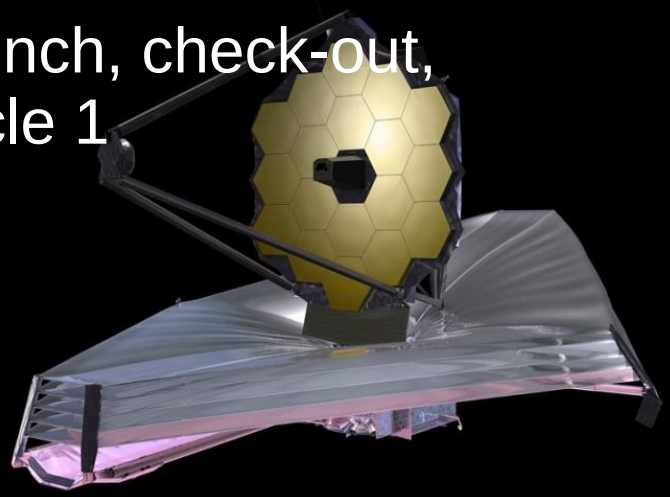
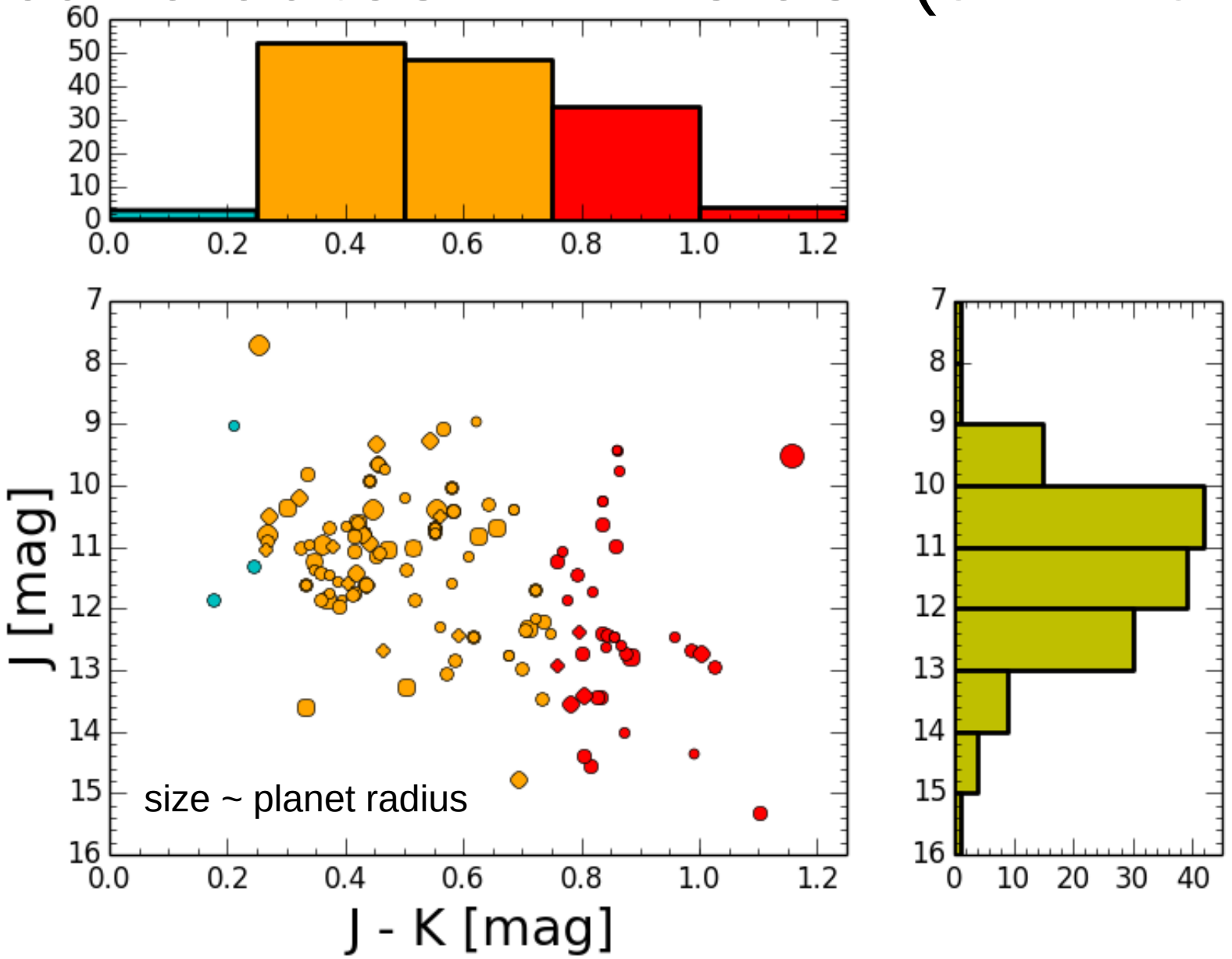
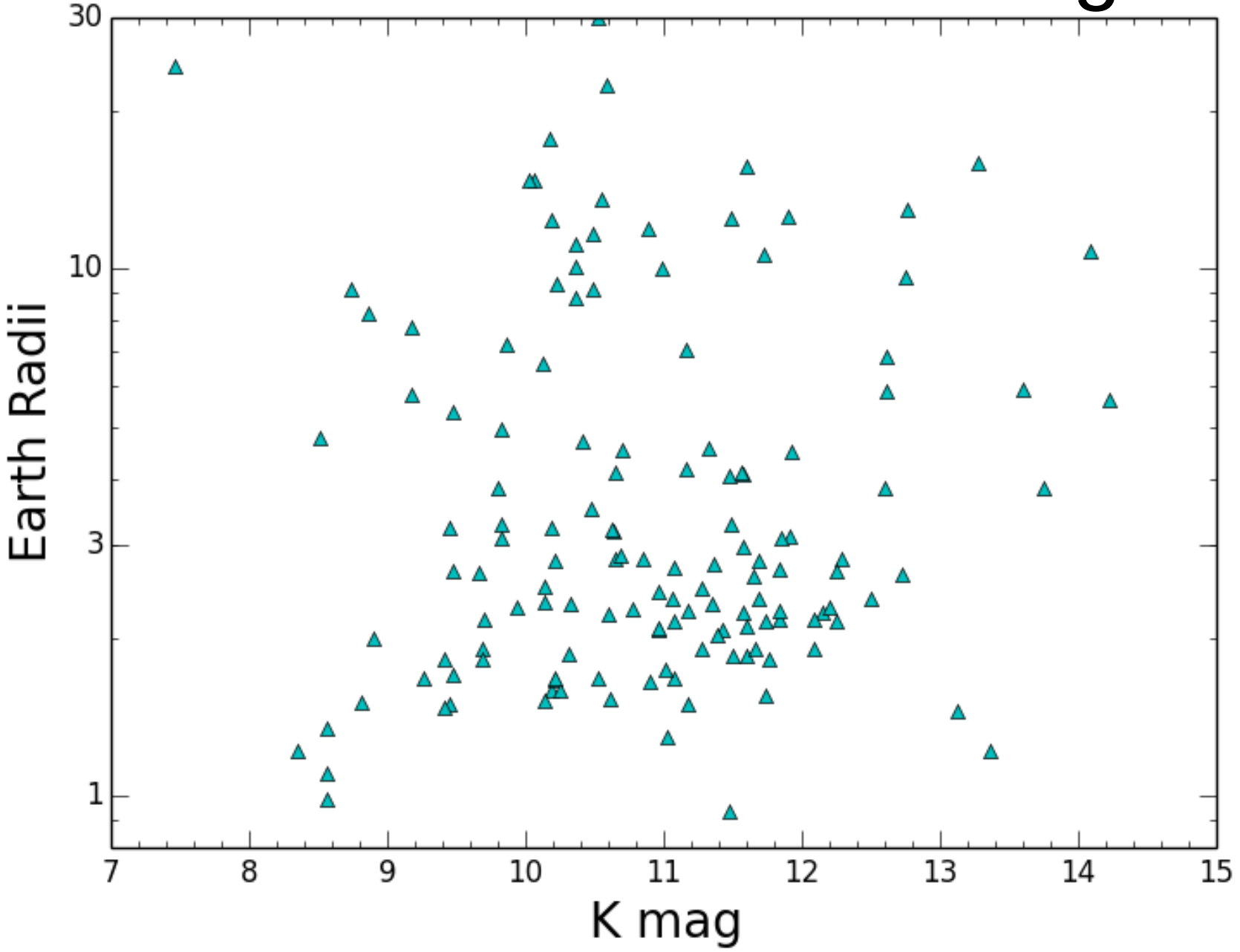
Launch, check-out,
Cycle 1



K2: Our team has found ~150 planet candidates in 4 fields (of 14 total)



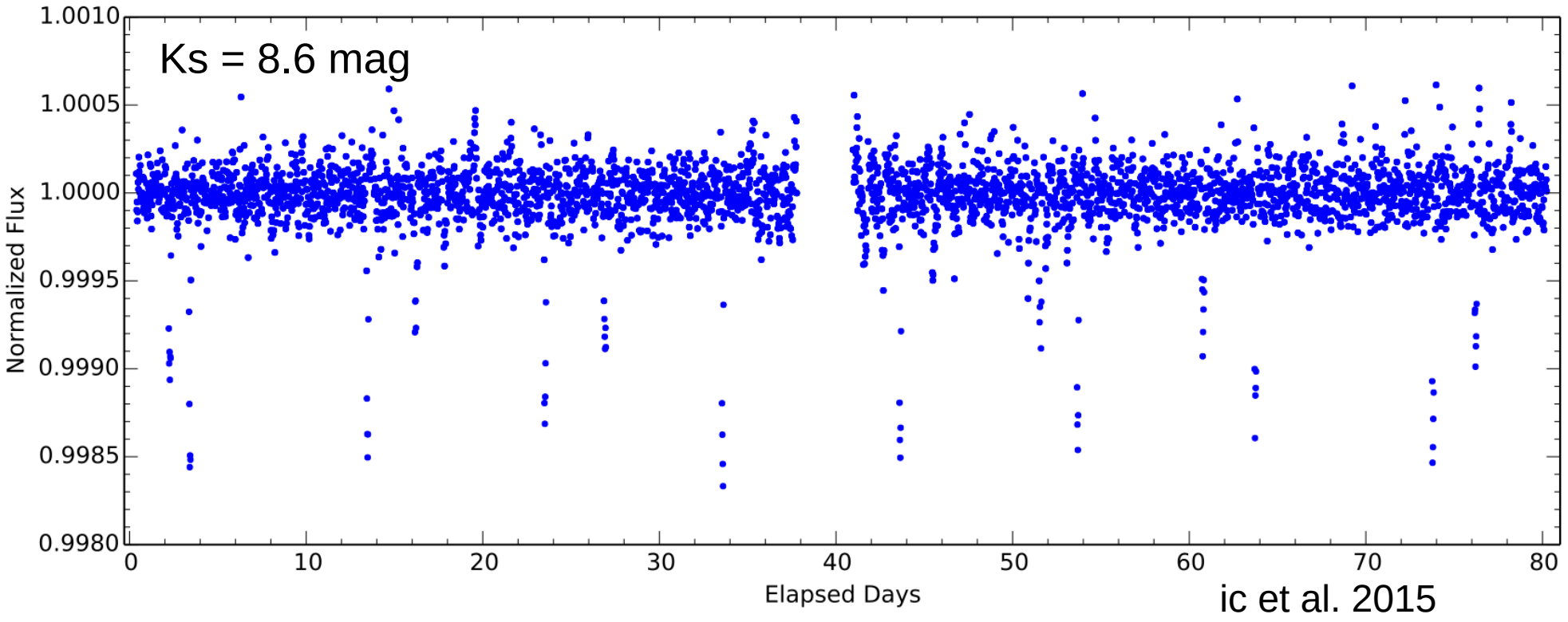
Planet Size vs. Stellar Magnitude



K2–3 bcd: Three small planets transiting a bright M dwarf

A NEARBY M STAR WITH THREE TRANSITING SUPER-EARTHS DISCOVERED BY K2

Ian J. M. Crossfield[1], Erik Petigura[2], Joshua Schlieder[3], Andrew W. Howard[4], B.J. Fulton[4], Kimberly M. Aller[4], David R. Ciardi[5], Sébastien Lépine[6], Thomas Barclay[3], Imke de Pater[2], Katherine de Kleer[2], Elisa V. Quintana[3], Jessie L. Christiansen[5], Eddie Schlafly[7], Lisa Kaltenegger[11], Justin R. Crepp[8], Thomas Henning[7], Christian Obermeier[7], Niall Deacon[9], Brad M. S. Hansen[10], Michael C. Liu[4], Tom Greene[3], Steve B. Howell[3], Travis Barman[1], Christoph Mordasini[7]



ic et al. 2015

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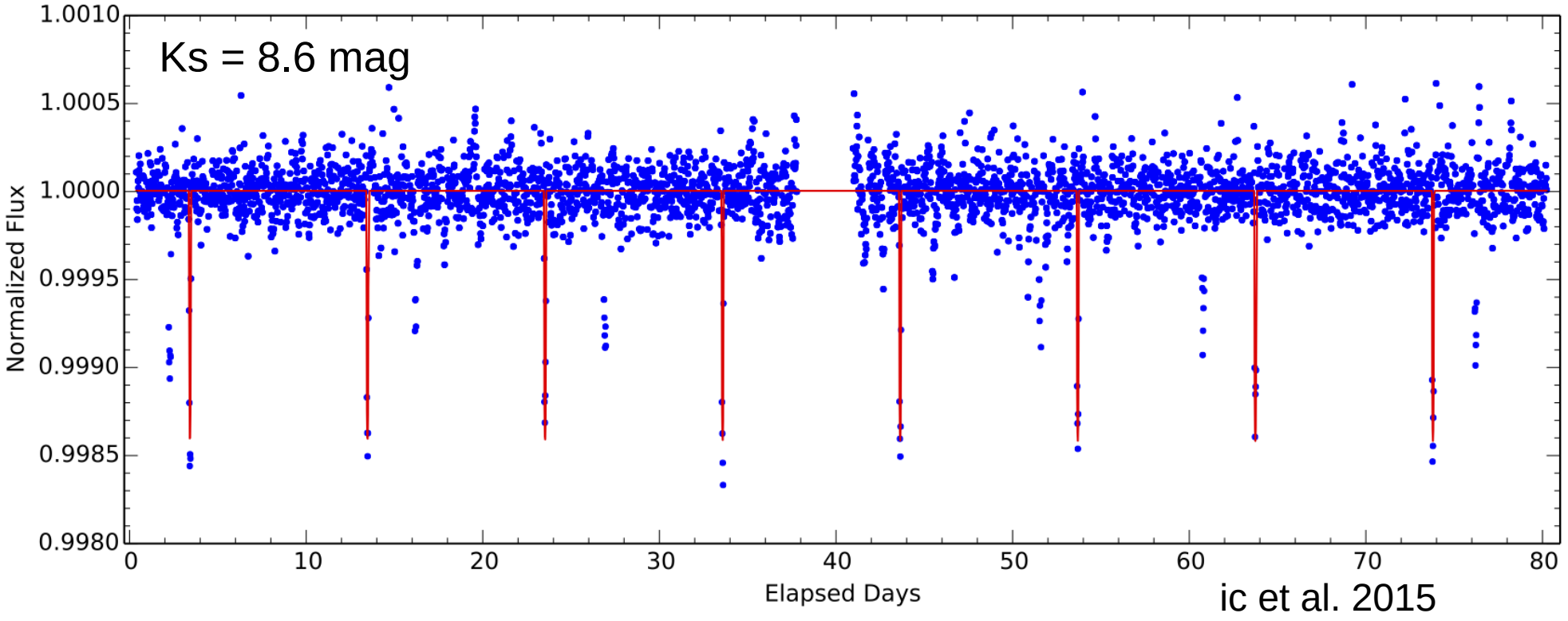

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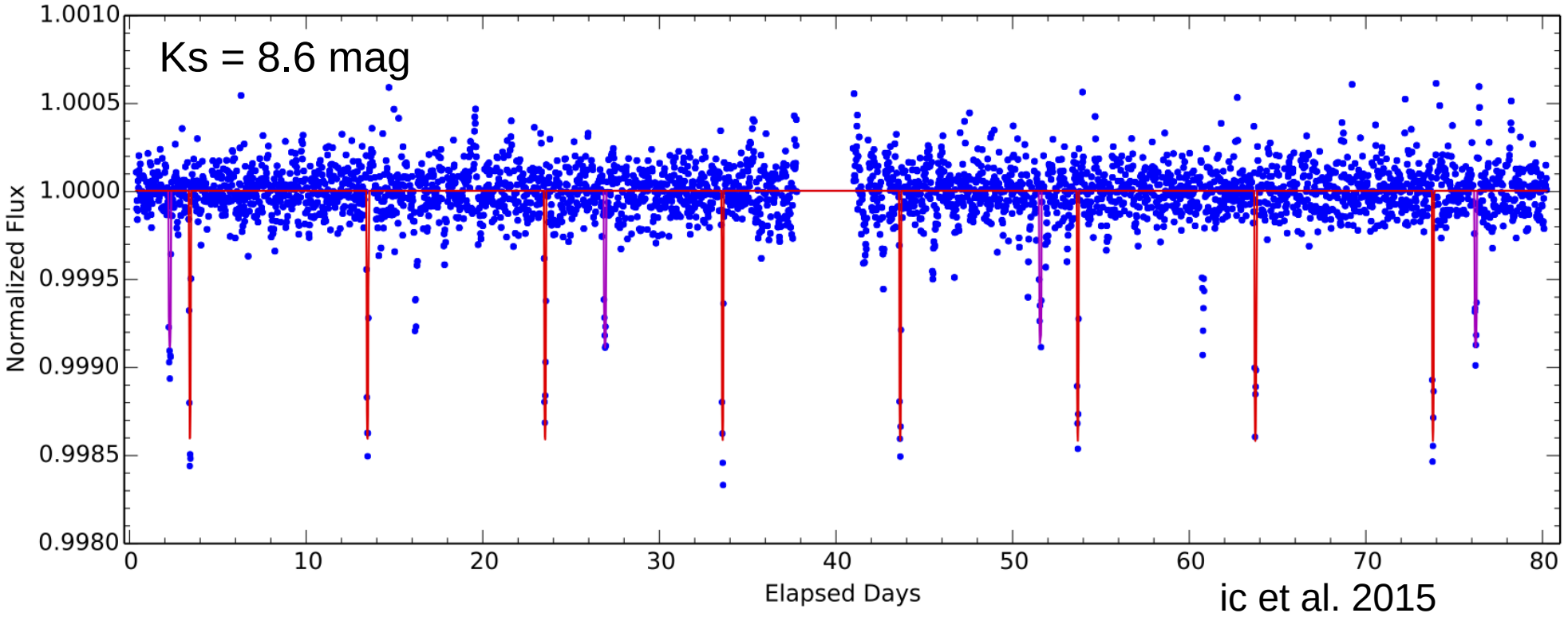

ic et al. 2015

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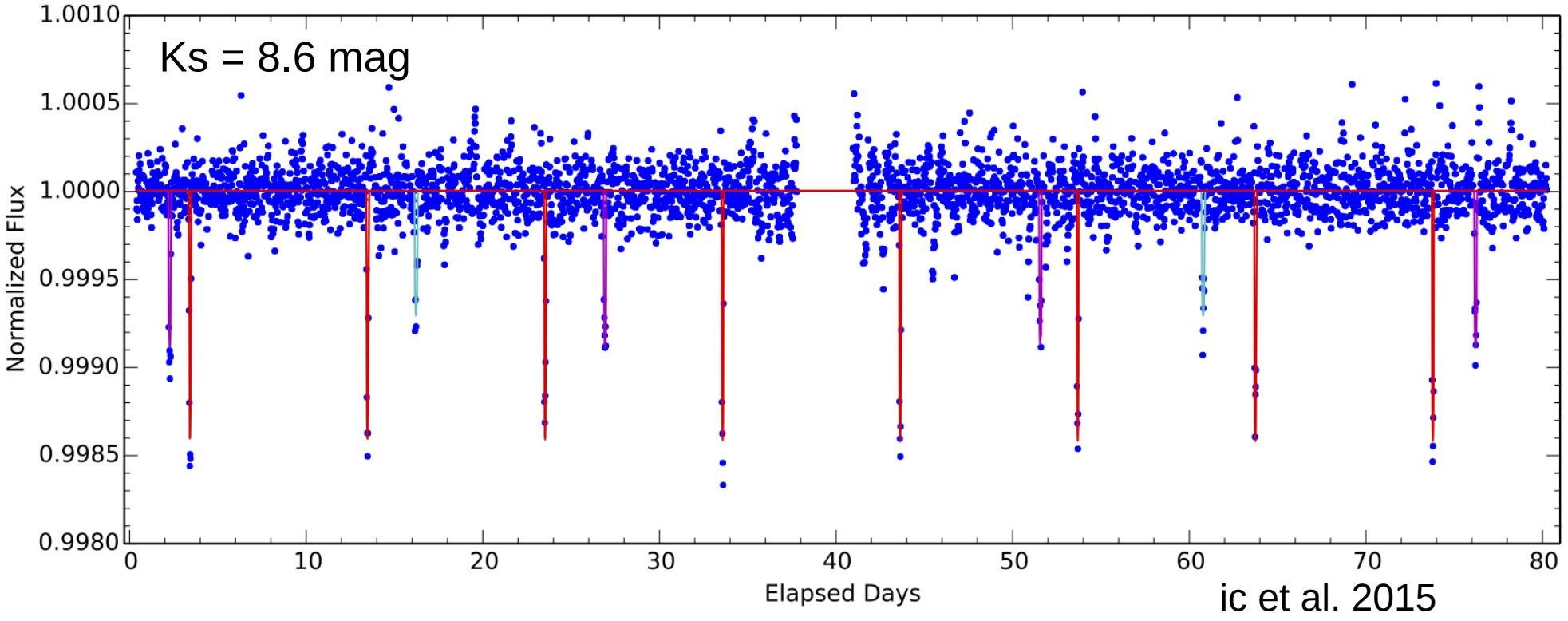

ic et al. 2015

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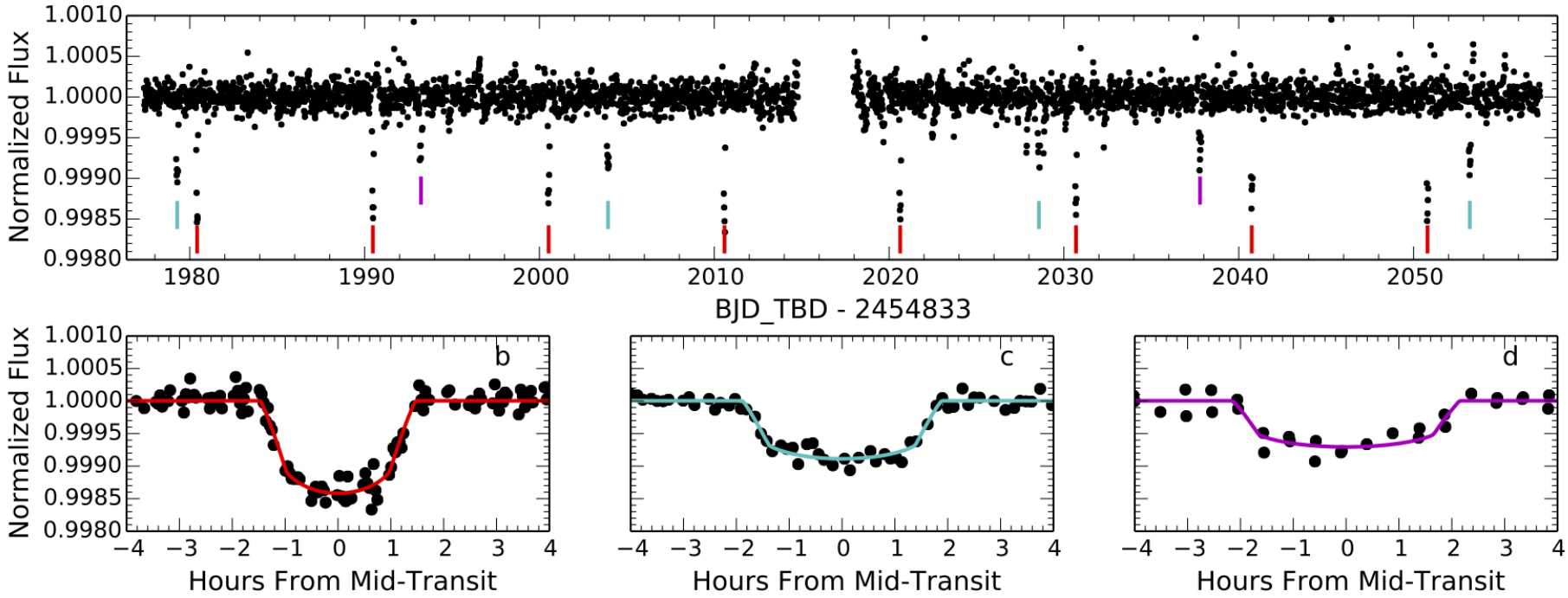
K2–3 bcd: Three small planets

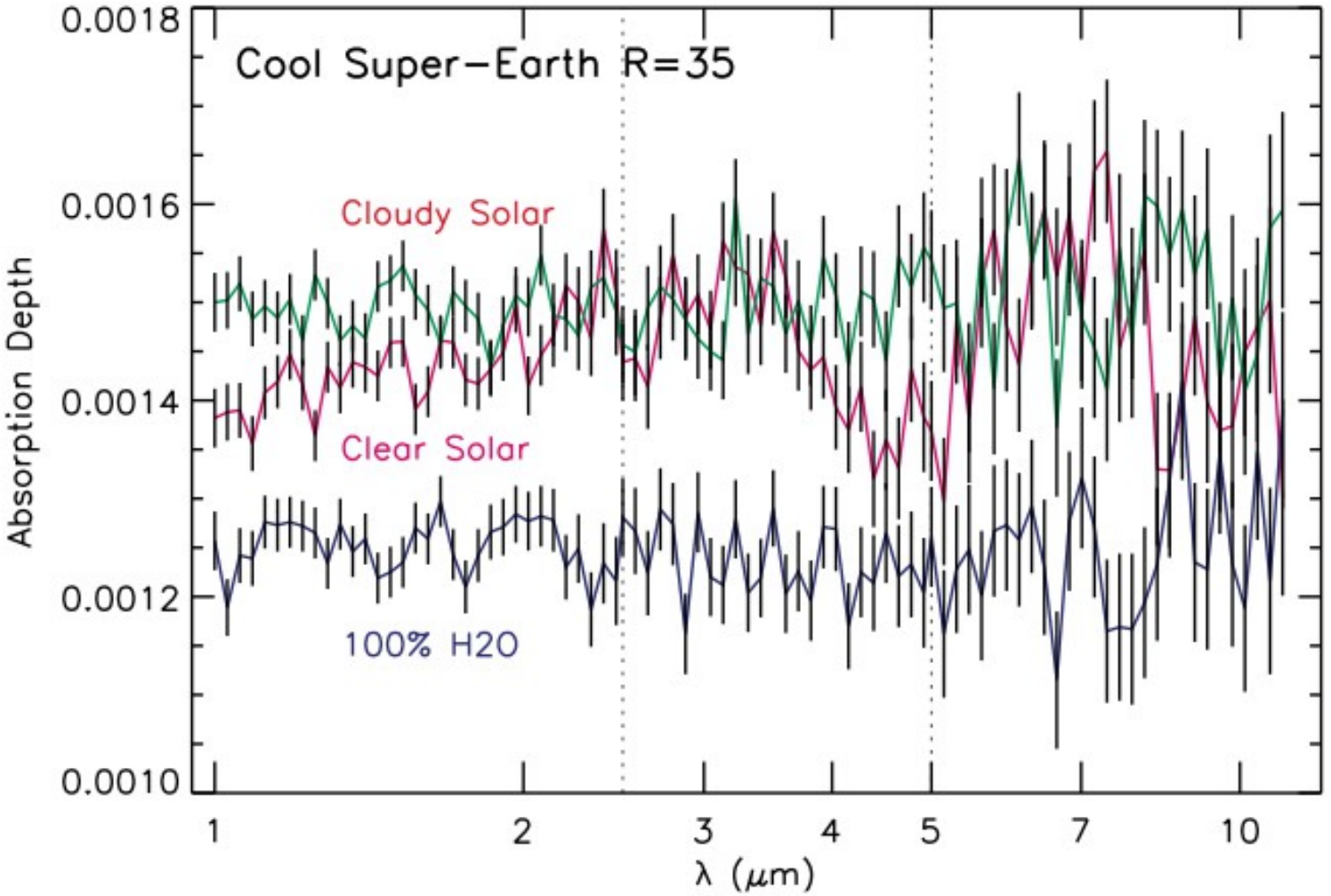


	K2-3b	K2-3c	K2-3d
R_p / R_{Earth}	2.1 ± 0.2	1.7 ± 0.2	1.5 ± 0.1
F_{inc} / F_{Earth}	11 ± 3	3.3 ± 0.9	1.5 ± 0.5

ic et al. 2015

Lunar and Planetary Laboratory

K2-3b: one 1-11 μm transit spectrum would easily distinguish atmospheric makeup



Greene et al., submitted

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More K2 planets (and JWST targets) are on the way:

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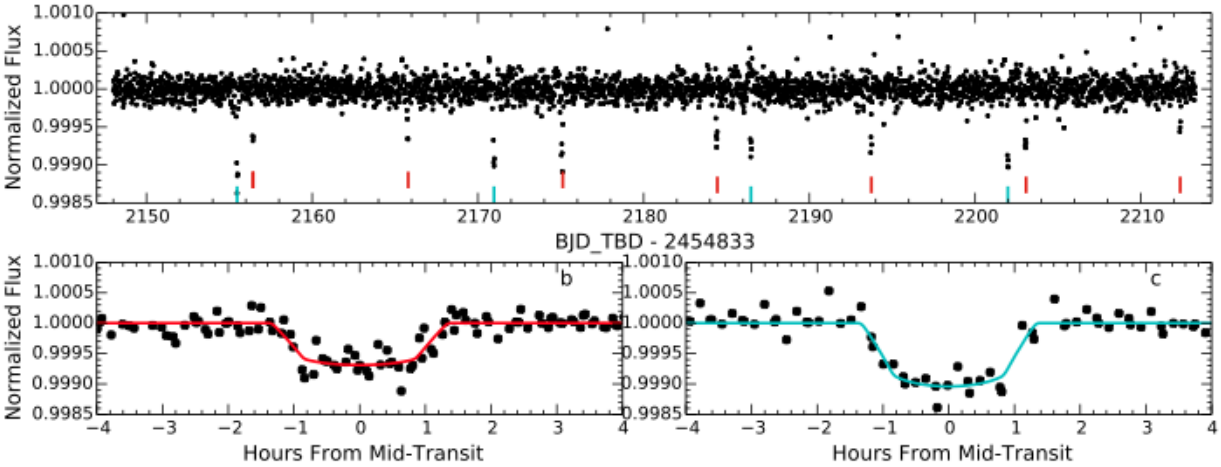

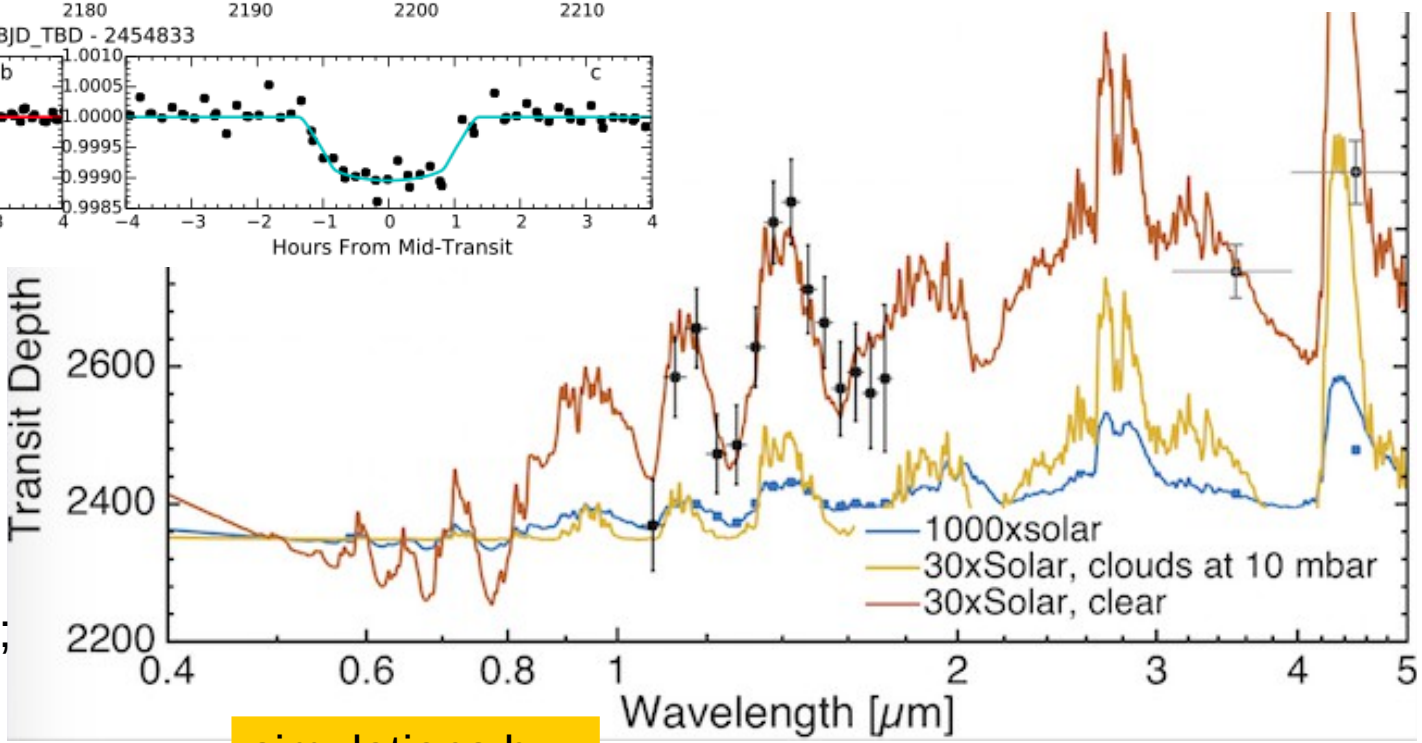

Petigura+2015;
Schlieder et al., submitted;
Sinukoff et al., in prep;
Ciardi et al., in prep

simulations by B. Benneke

Lunar and Planetary Laboratory

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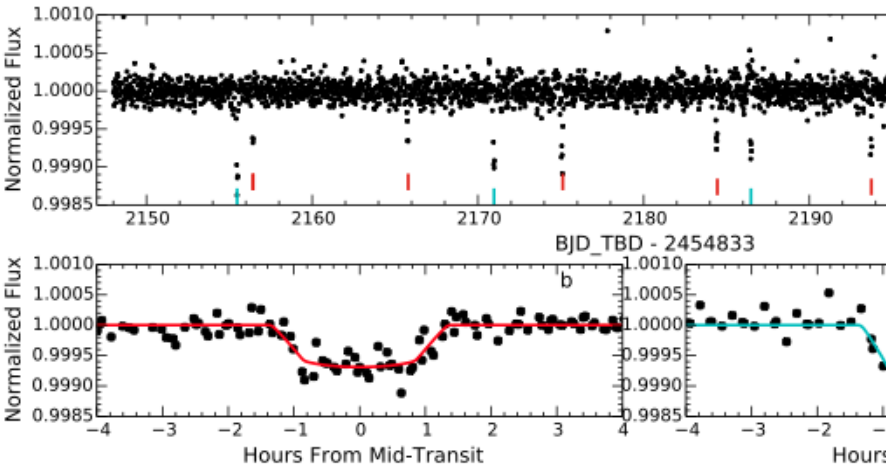

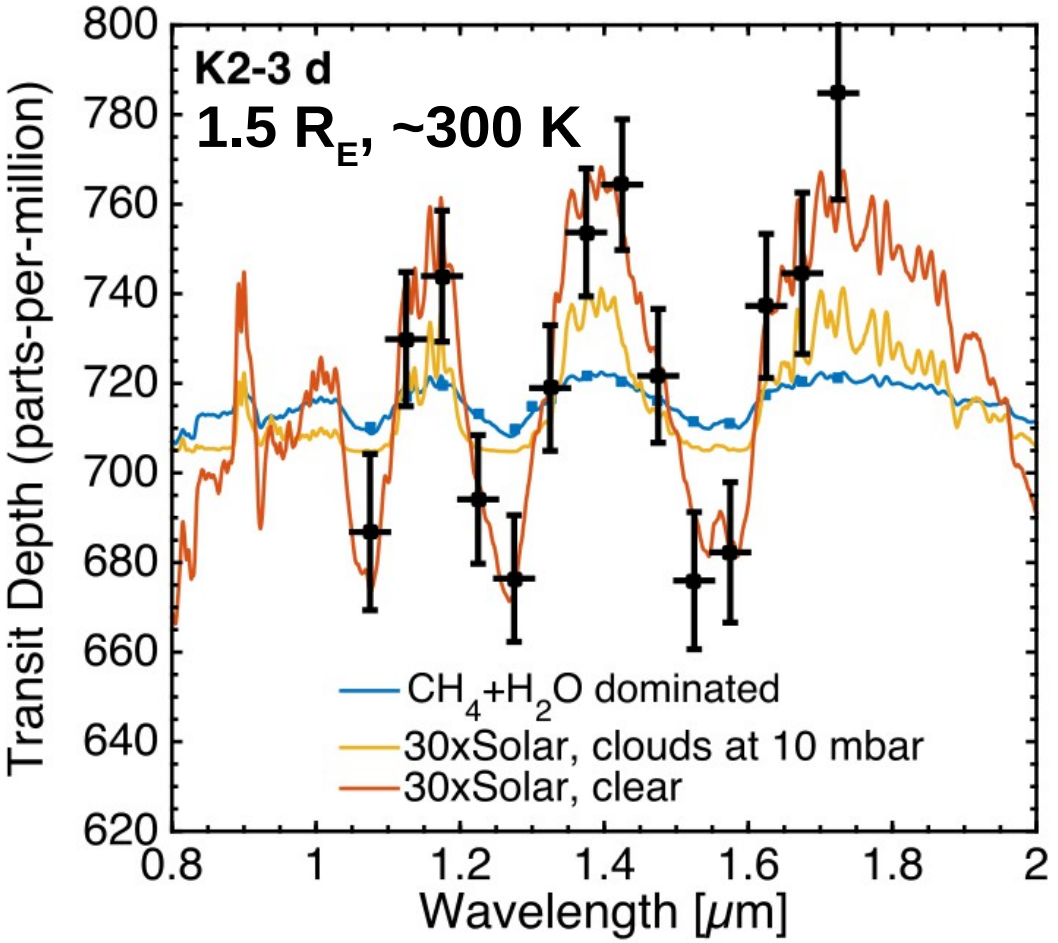

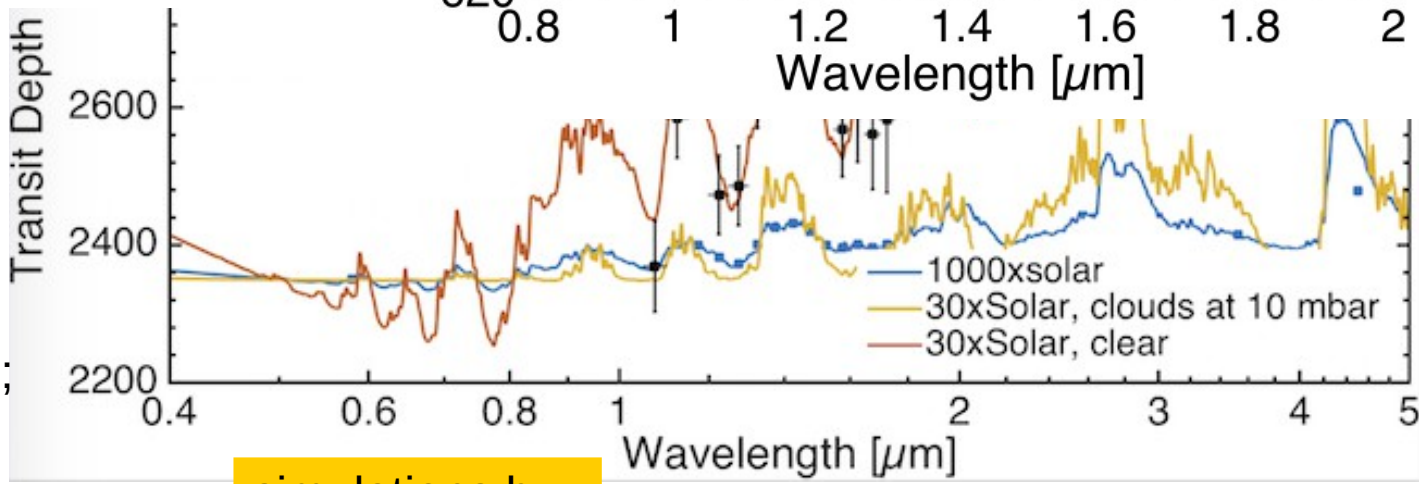

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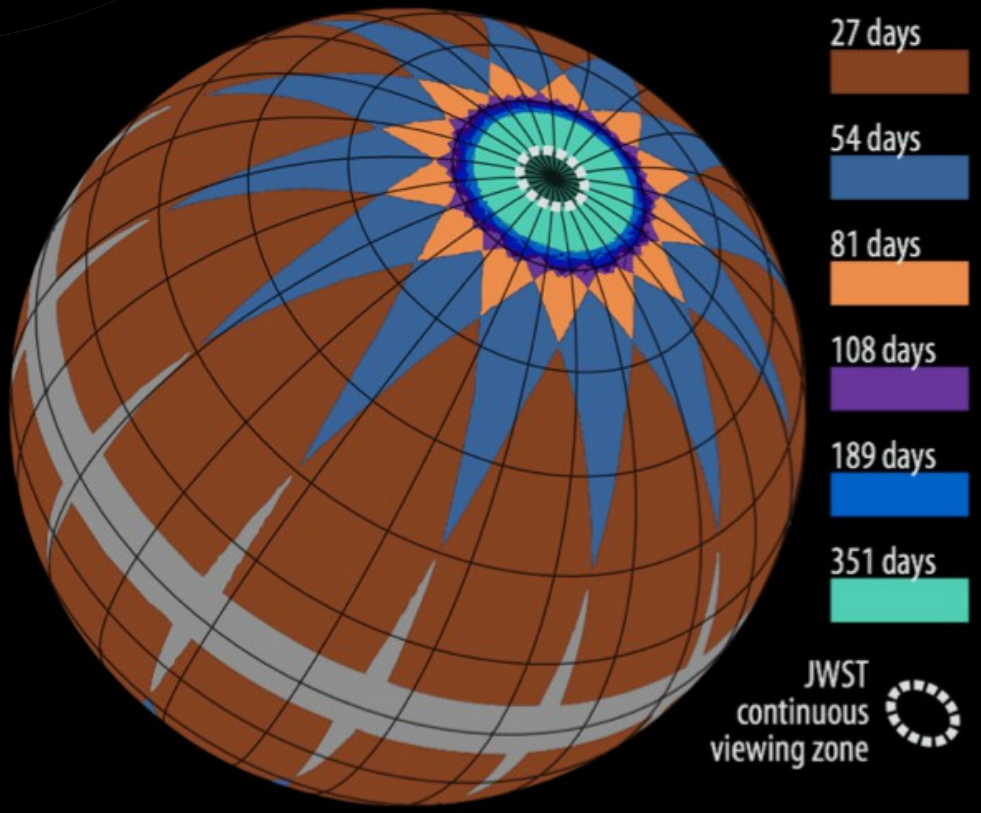
TESS on the horizon



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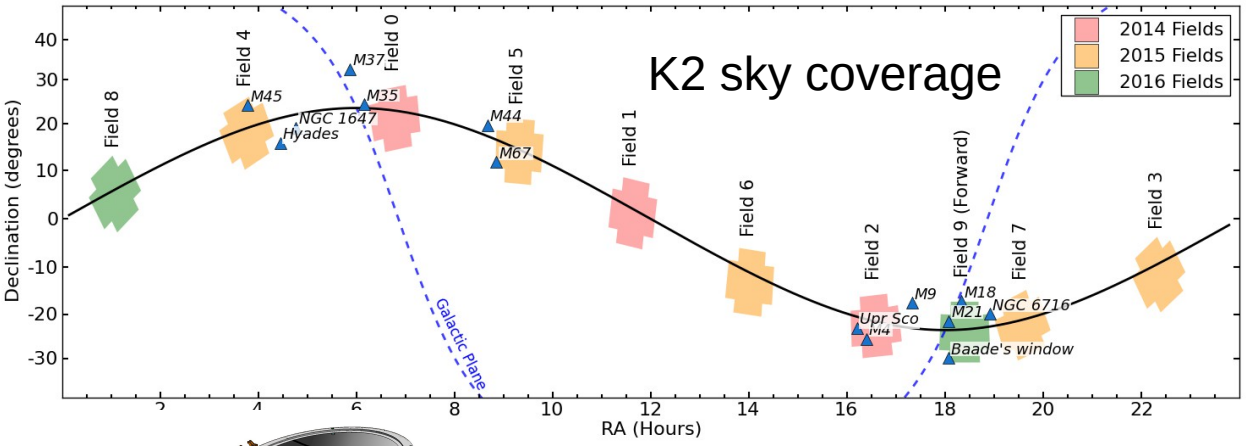
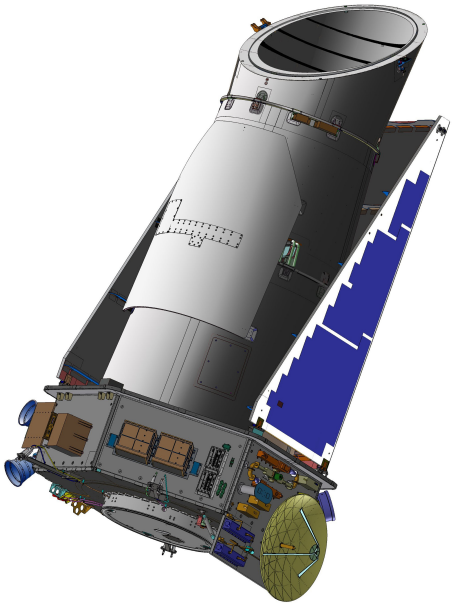
Sky coverage

Kepler
2009-2014

Temporal coverage





K2
2014-2017

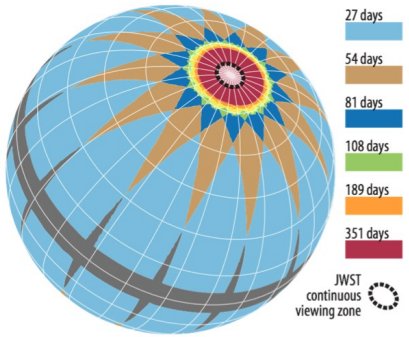
Kepler
2009-2014

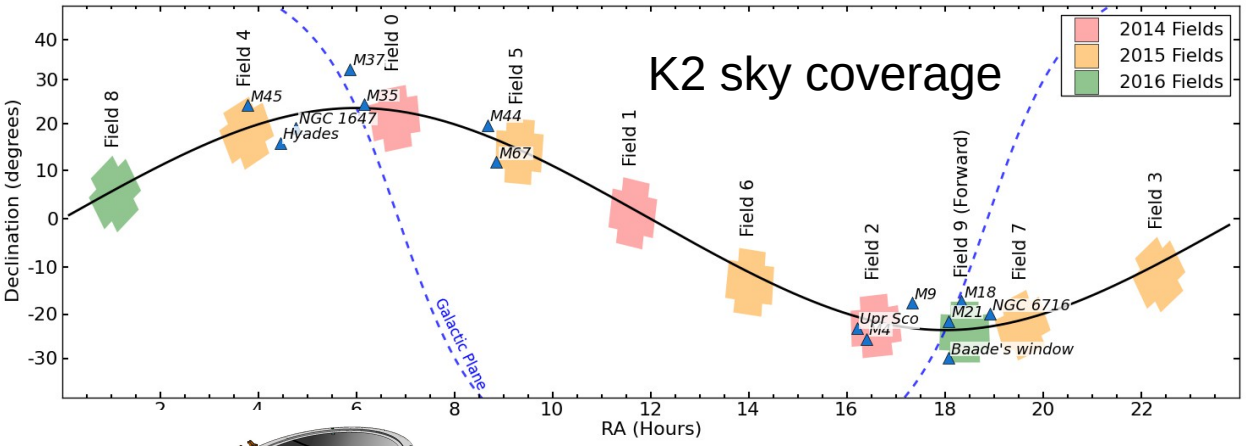
Sky coverage

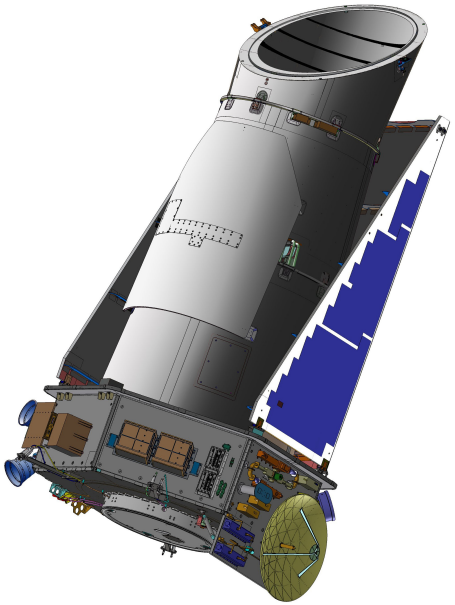
Temporal coverage

Sky coverage

TESS
2017-2019





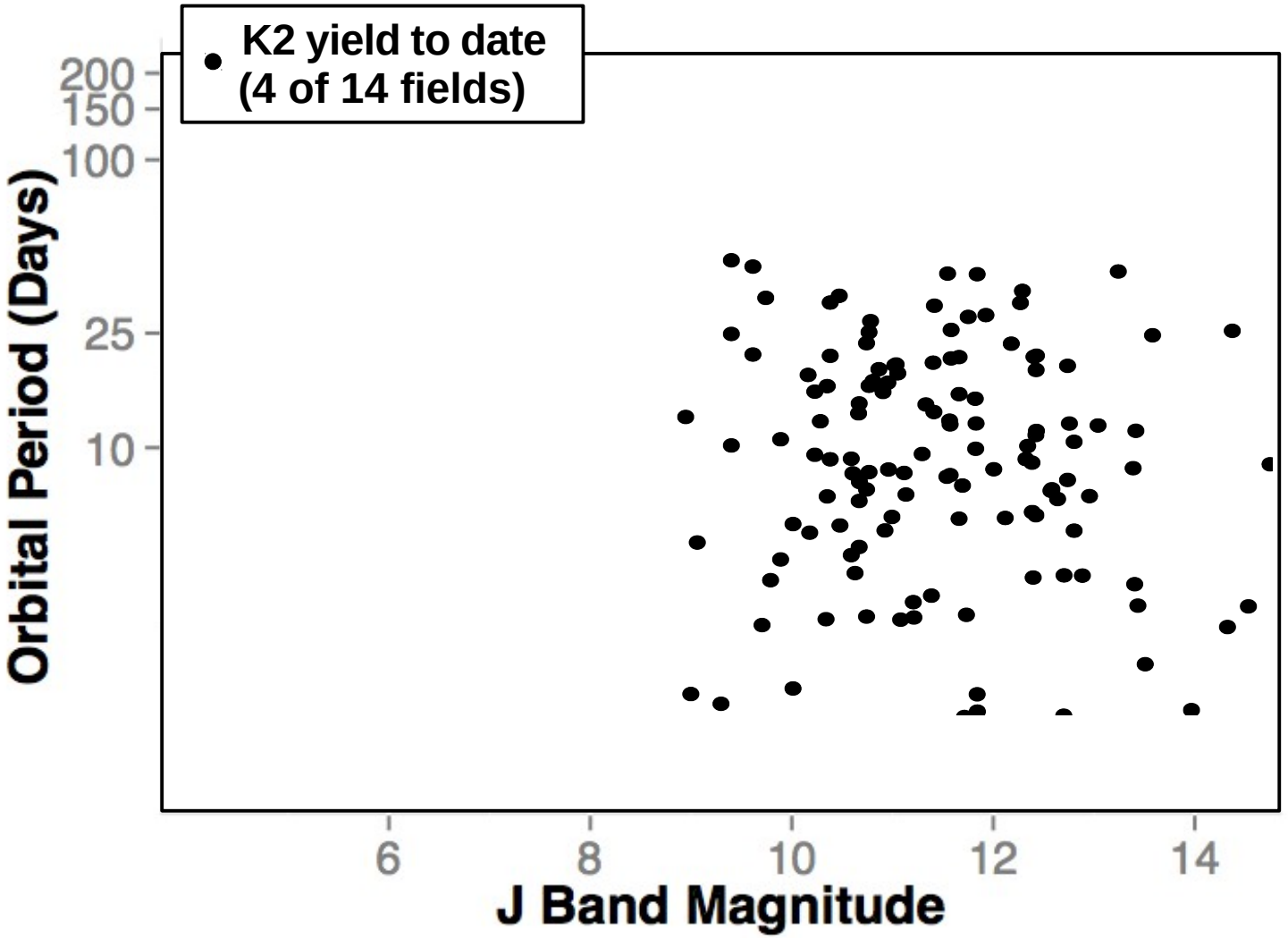


K2
2014-2017

Kepler
2009-2014

Temporal coverage

Expected yields: K2 and TESS



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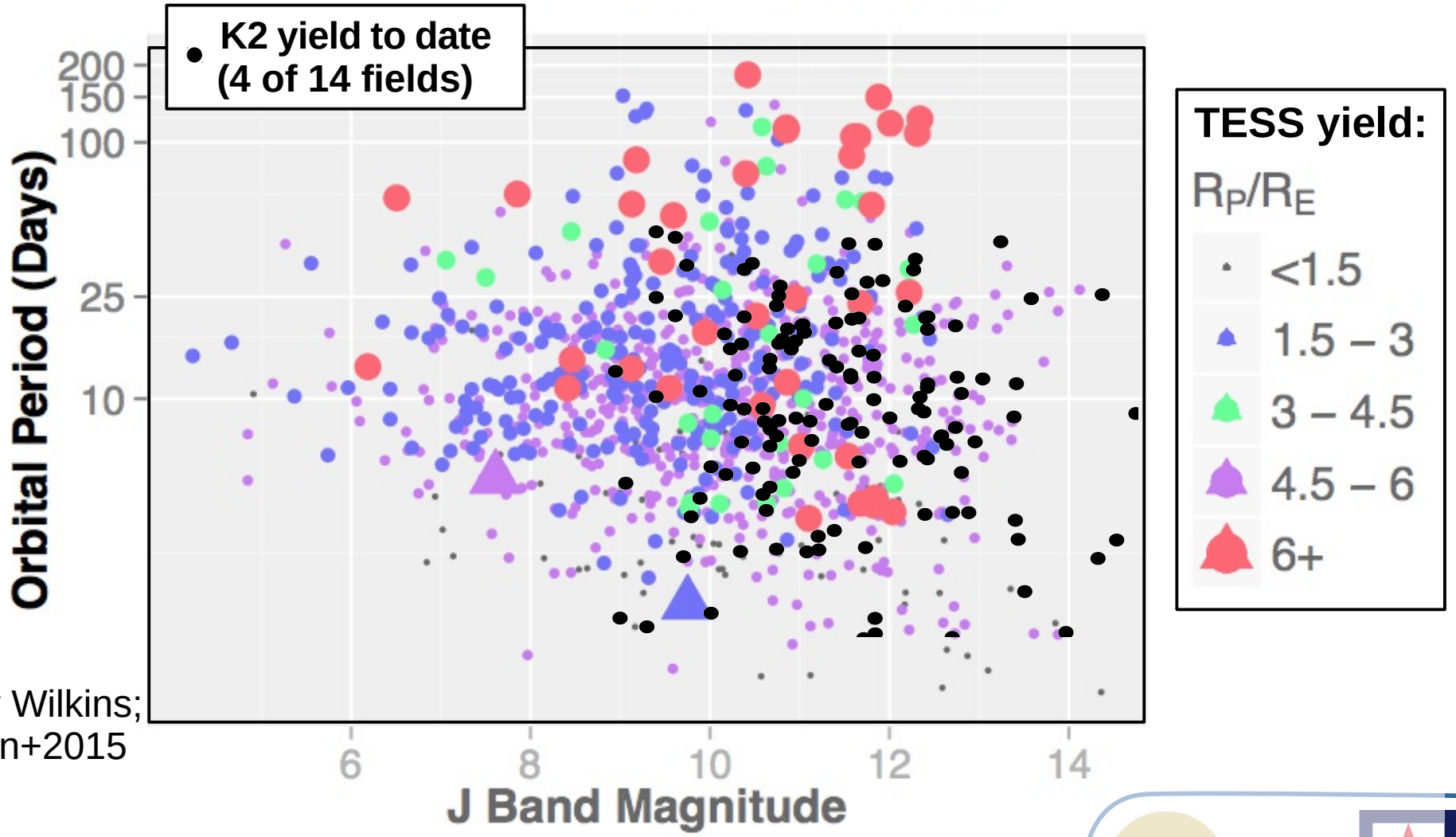
Expected yields: K2 and TESS



Ashley Wilkins; Sullivan+2015

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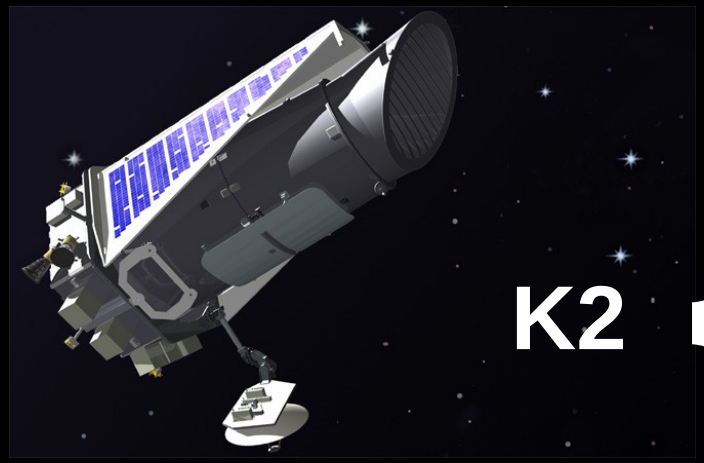
Transiting Target Timeline



K2

2015

2016

2017

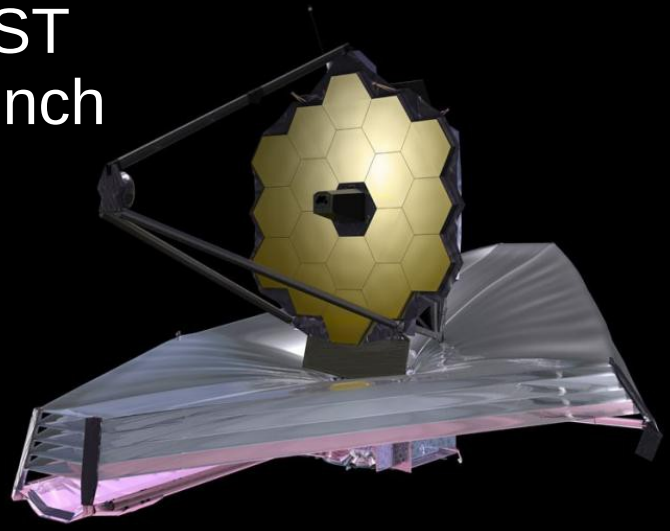
JWST Calls for GTO & Cycle 1 Proposals

TESS operations

2018

2019

JWST Launch



2020

Planets from K2/TESS require additional transits to refine timing:

- Transit surveys measu$P \pm \sigma_P$, $T_T \pm \sigma_{TT}$
- Uncertainty in transit time grows with time

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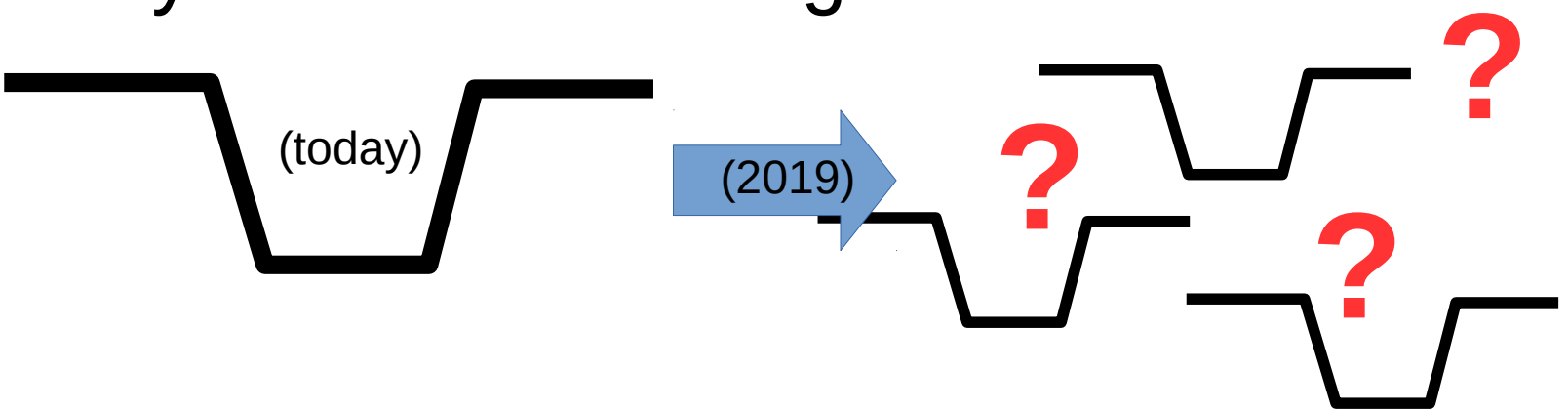

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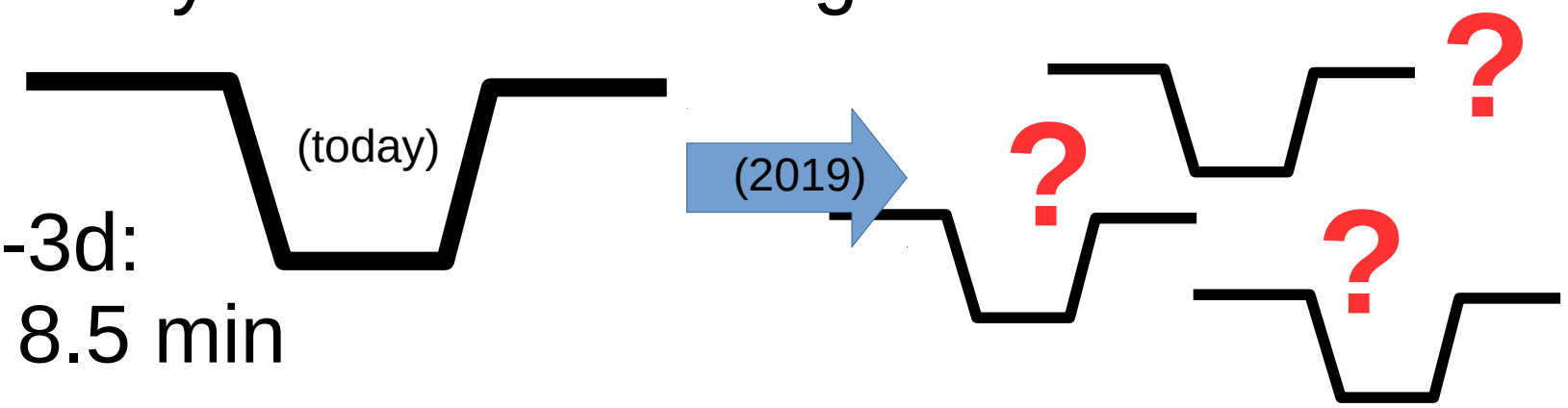
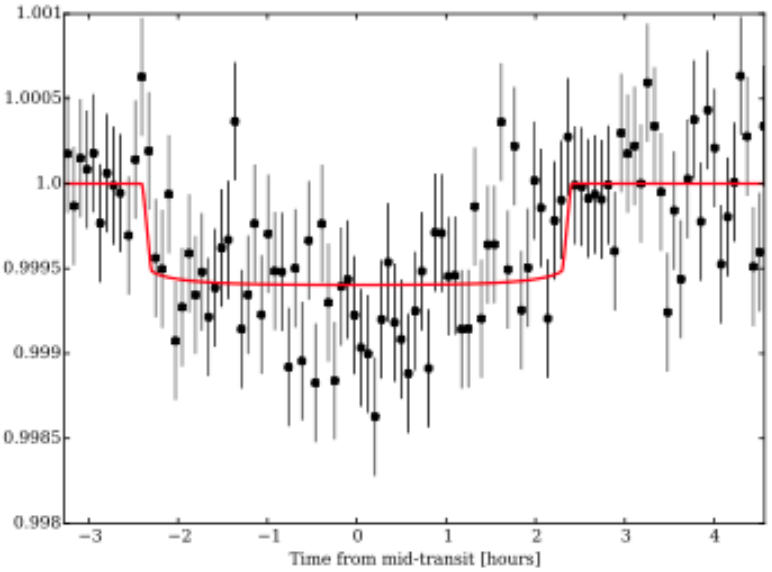
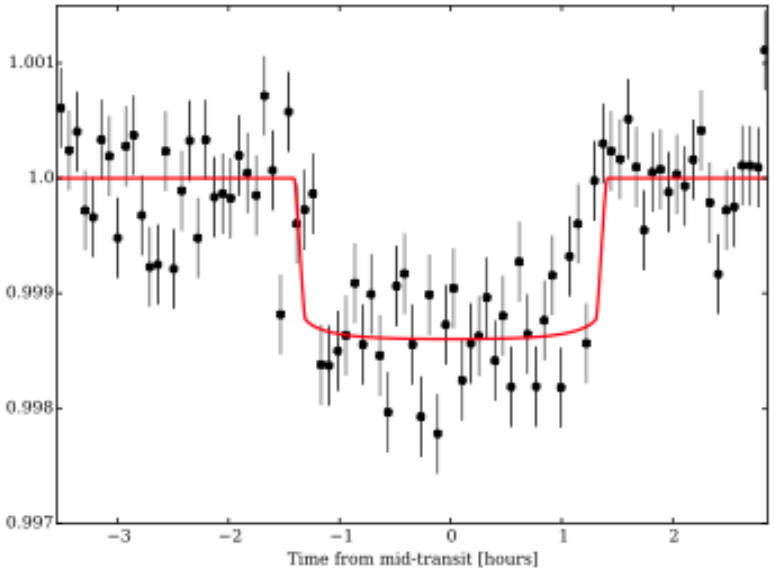


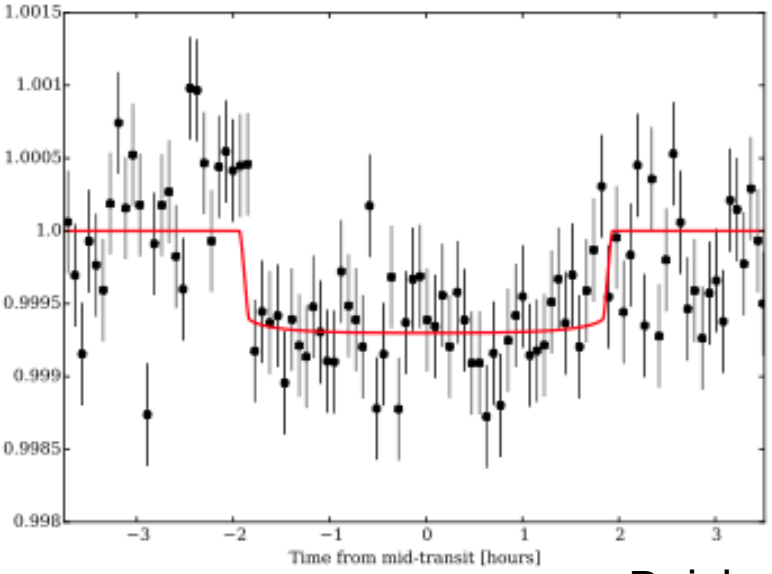
- For K2-3d:
  - σ_P = 8.5 min
  - In mid-2019: timing uncertainty is **±6 hr (1σ)**

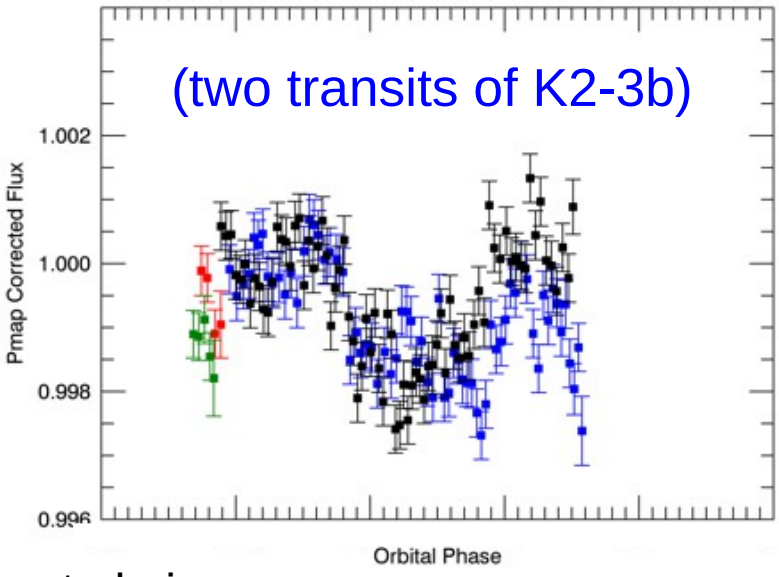
- Pre-JWST transit followup is essential to maximize science return!

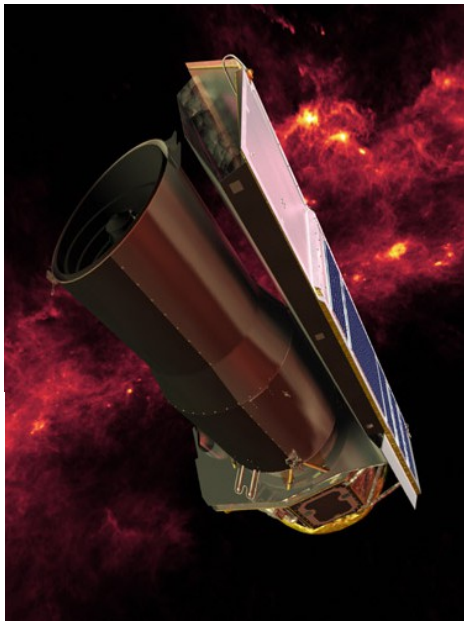
Spitzer transits are underway to ensure precise ephemerides in the JWST era:











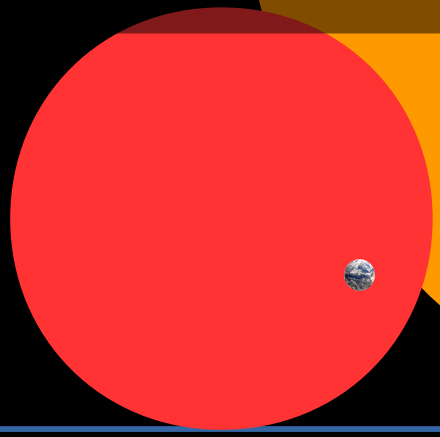
Beichman et al., in prep.

Still to come:

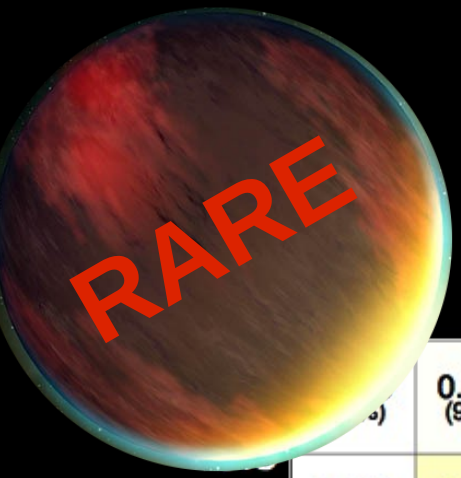
K2: 8-12 more fields
TESS: launch in 2017

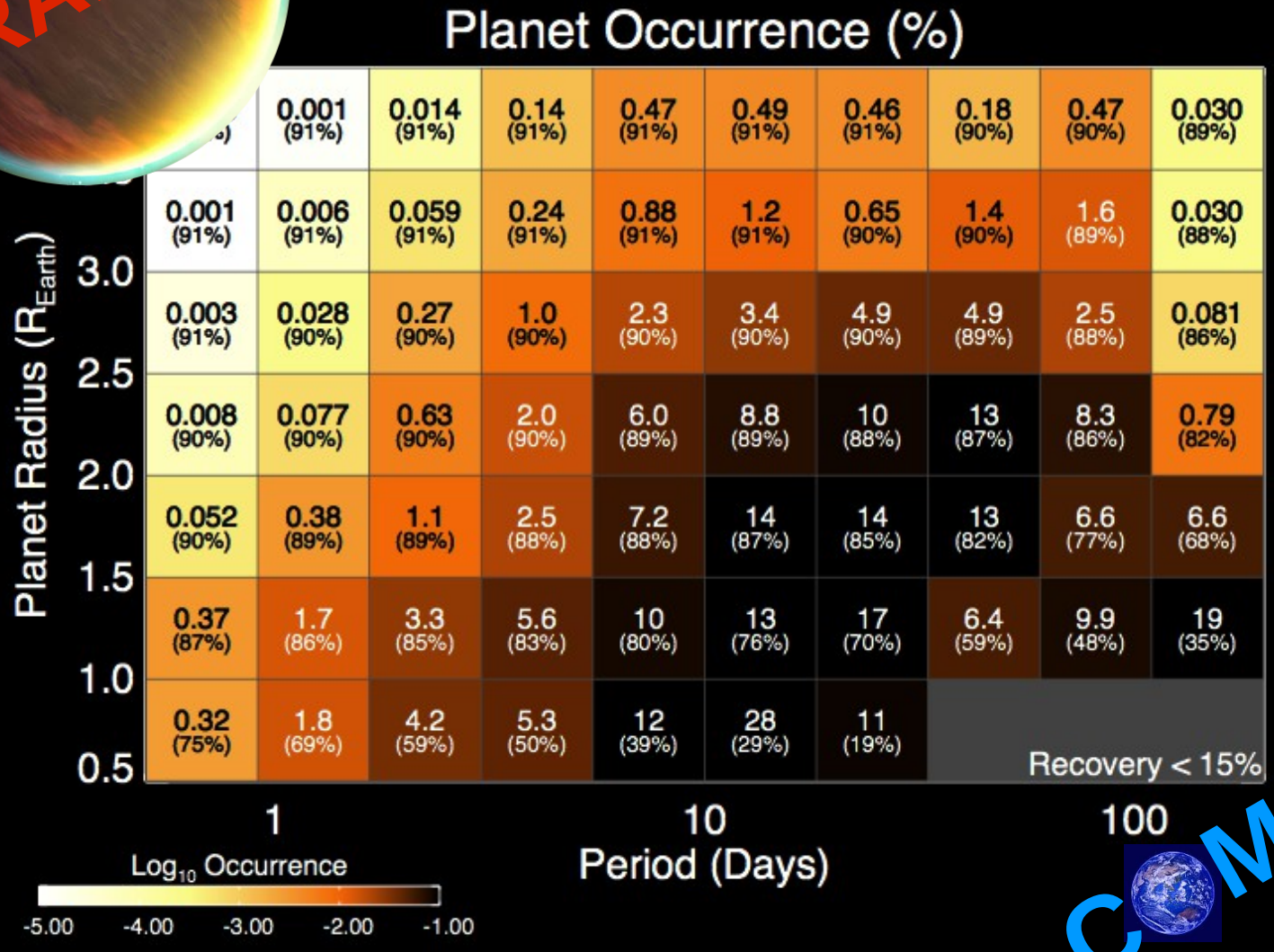
Take-home Points:

- JWST will do amazing exoplanet spectroscopy (see other talks)
- Need to find the best targets!
- K2 is already finding good ones
- TESS targets will be better (but: no GTO/ERS, few GO-1)



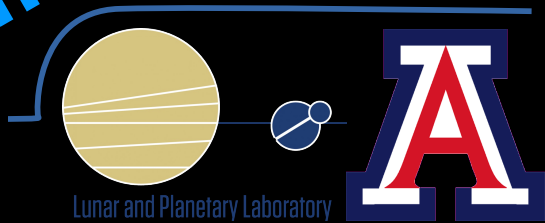
Planet frequency increases toward smaller and cooler planets:
(for both M stars & FGKs)



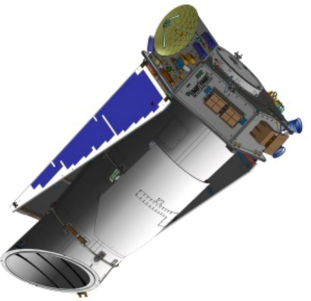


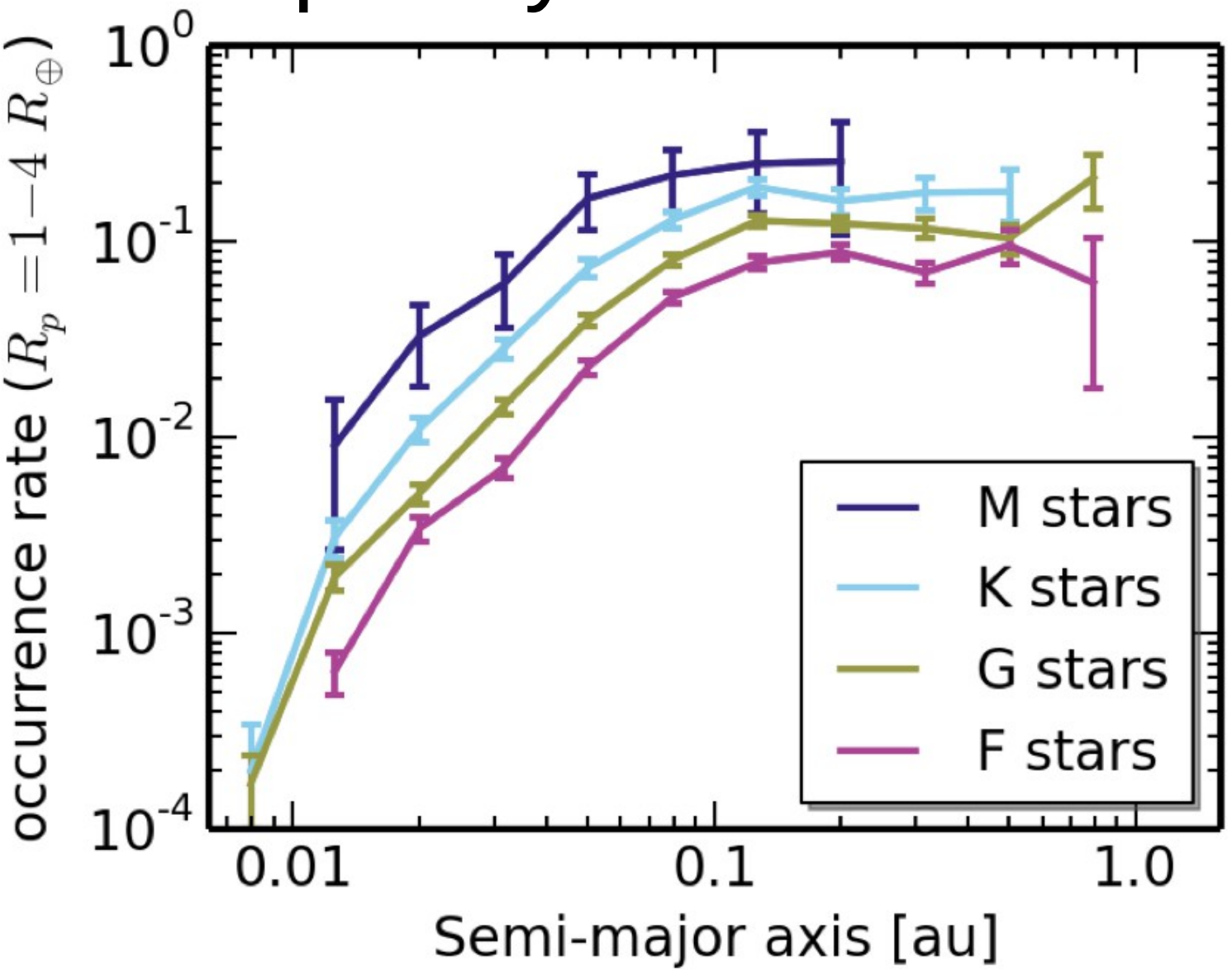
Dressing+2013, 2015,
Howard+2012,
Petigura+2013a,b

COMMON?



Small planets occur 2–3x more frequently around cooler stars:





Mulders+2014

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K2 M Dwarf Advantage: Numbers

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- Kepler sample (Dressing et al. 2015):
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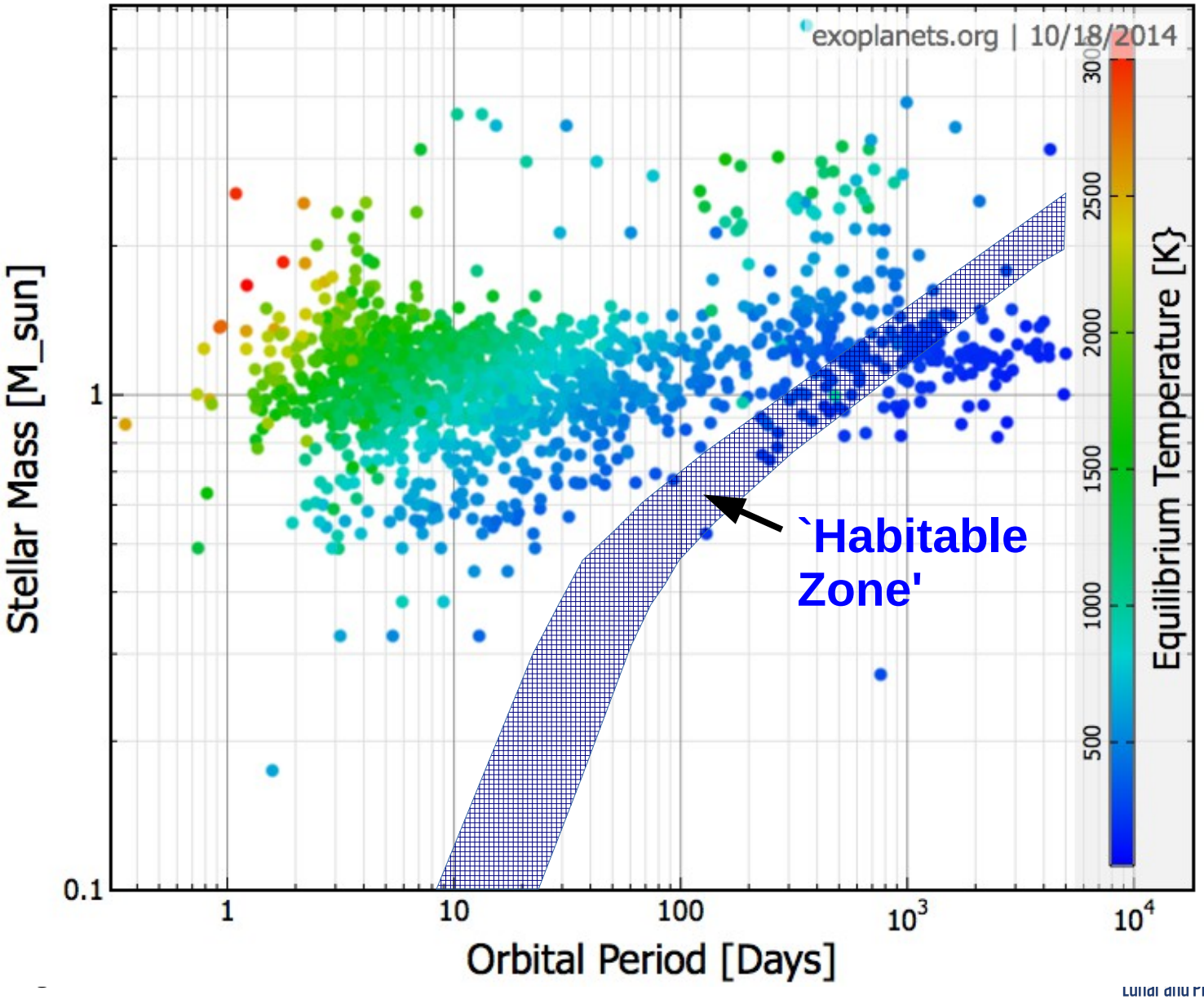
- The K2 M dwarf advantage:
  - 5000*80***10** / 2543*1000*1 ~ **1.5x**

K2 M dwarf advantage: M dwarf Habitable Systems



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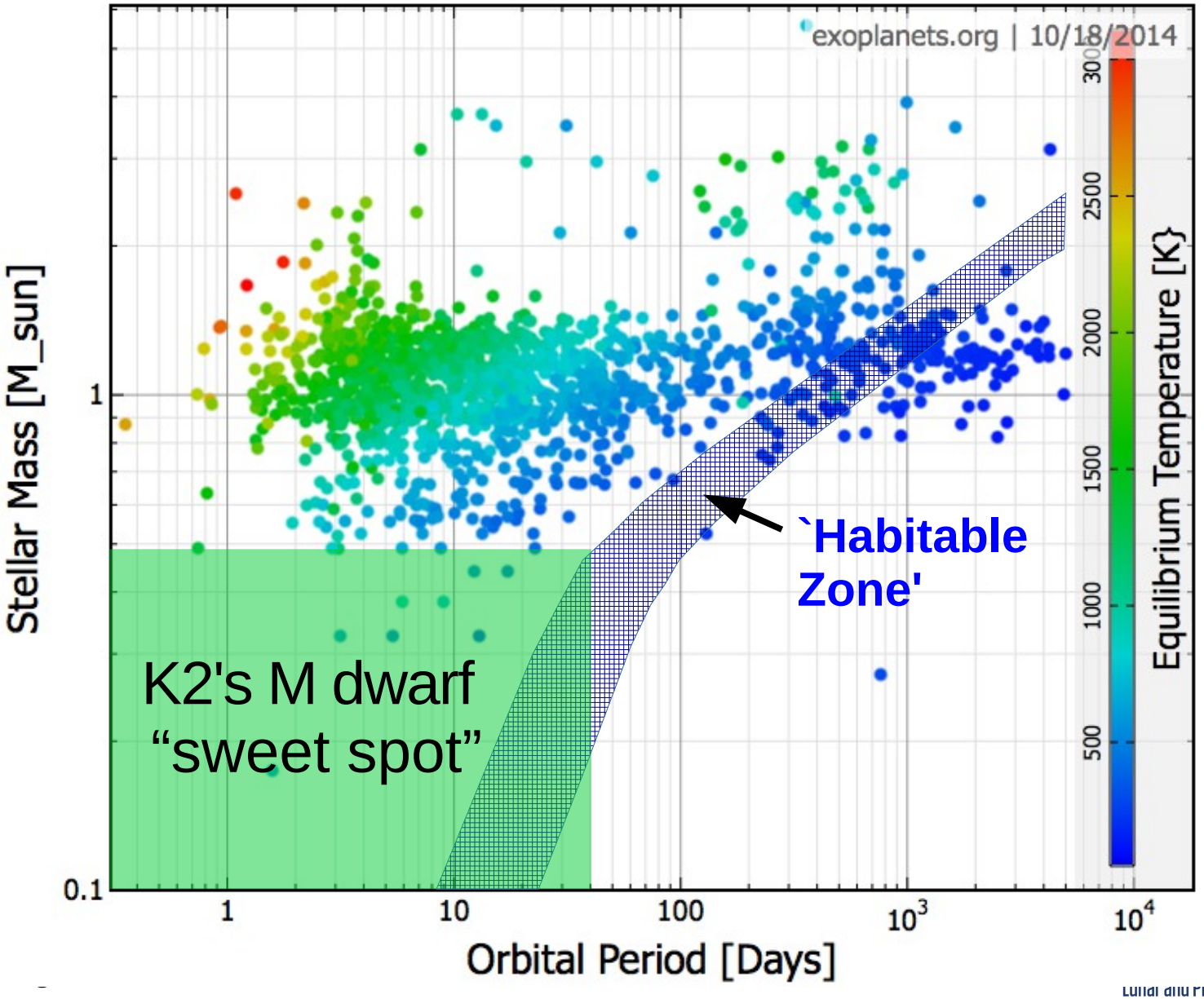

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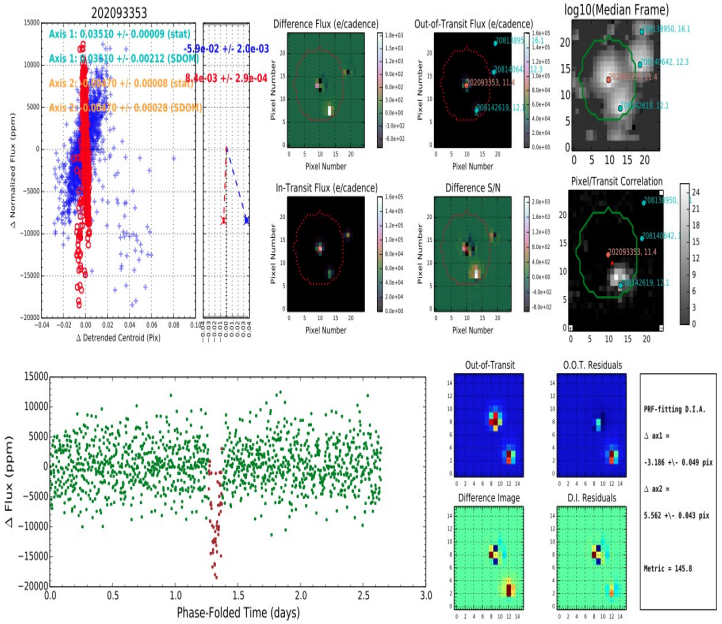
Candidate Validation is Underway:



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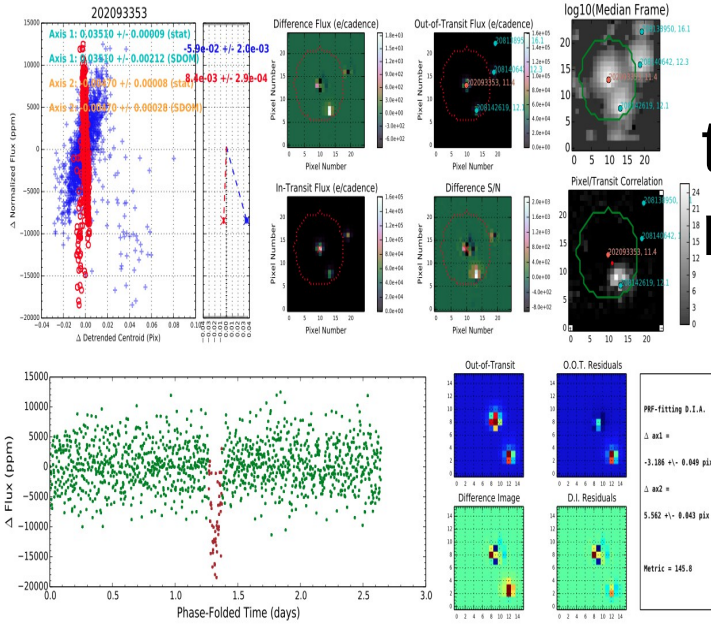

← K2 data analyses: transit fitting, centroid motion, diff. images

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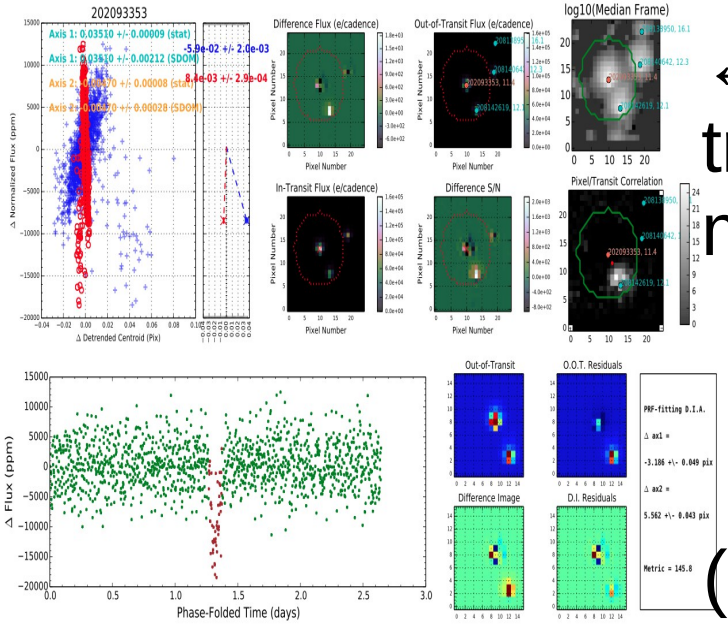

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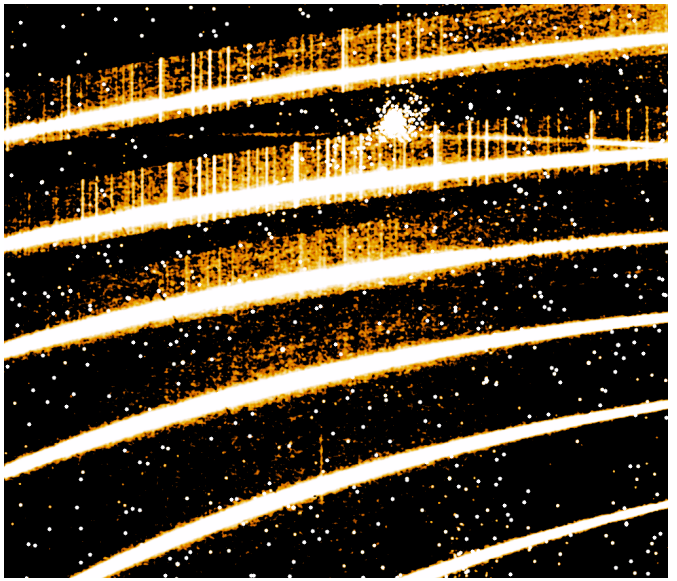
Stellar spectra → give system params (ESO/NTT, 70 nights) and RV masses



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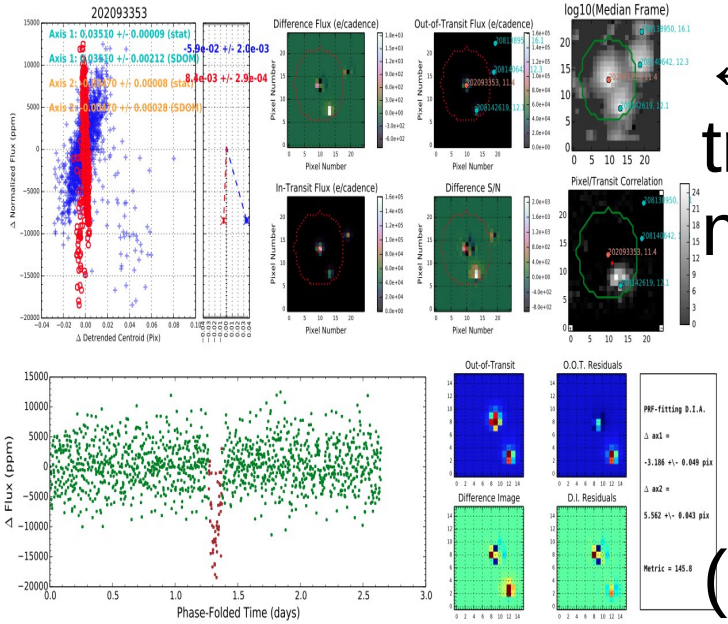

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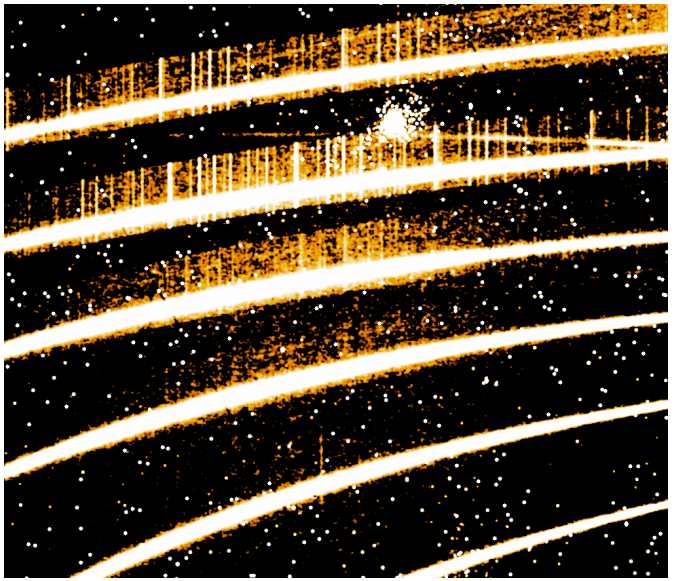

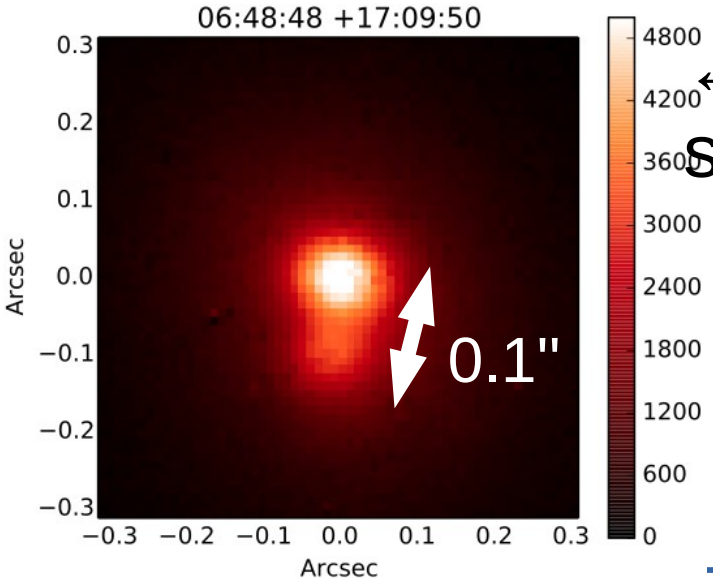

← Adaptive optics search for blends

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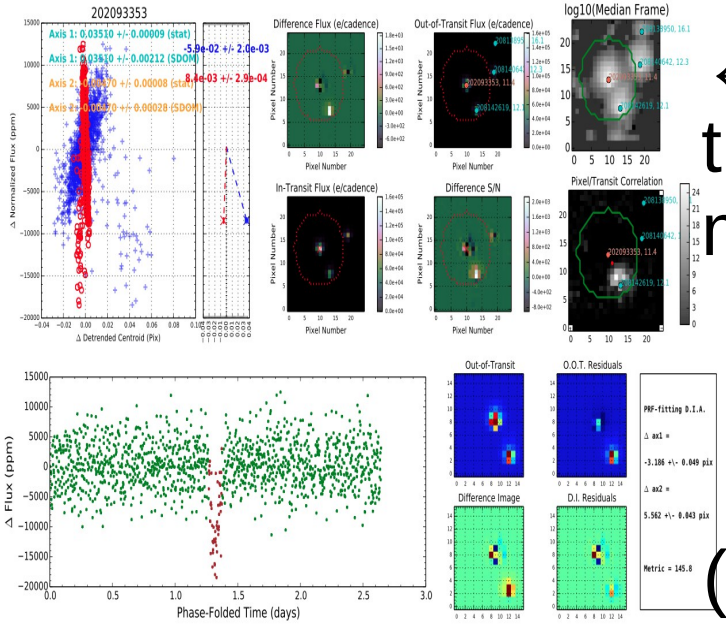

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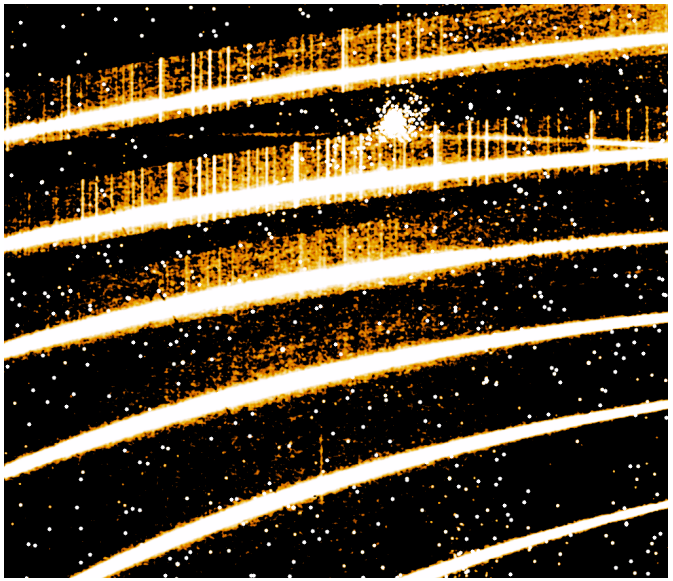
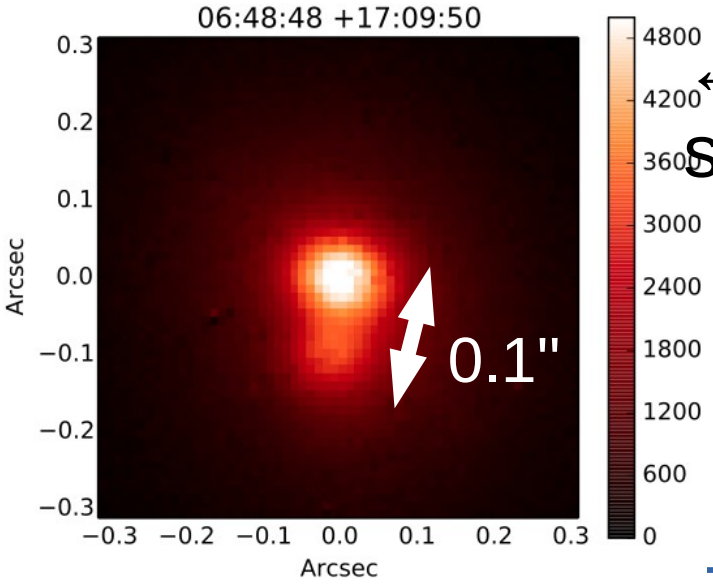
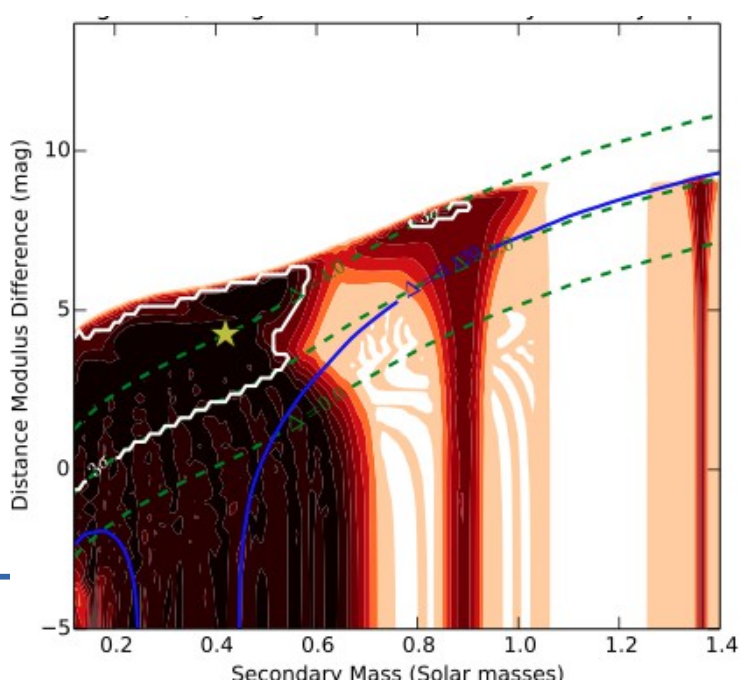


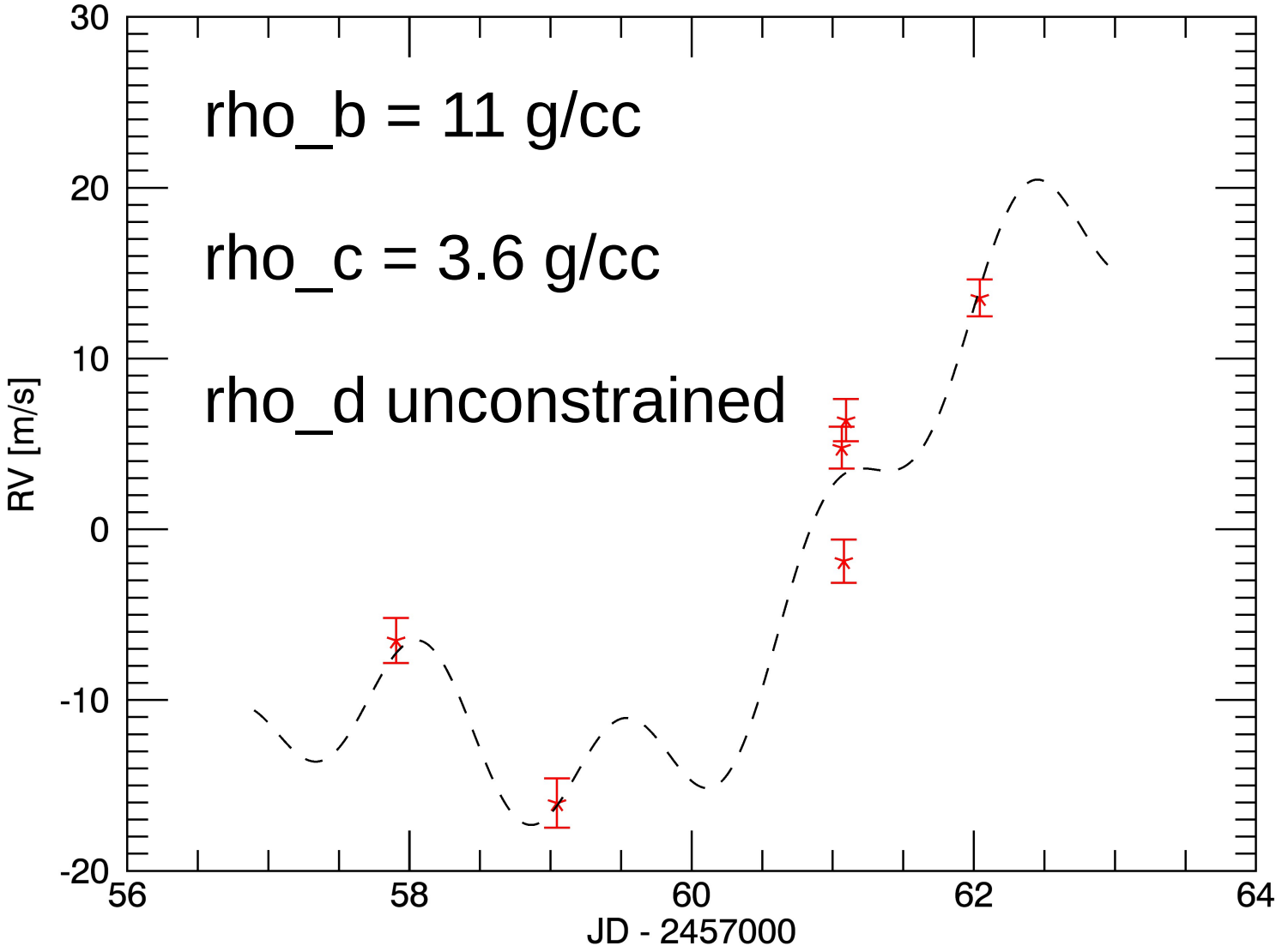


← Adaptive optics search for blends

BLENDER → To quantify false-positive likelihood



Mass/density measurements underway:



- Transiting exoplanet science case & S/N of existing sample
- Twin needs:
  - New types of planets to study
  - New examples of known-type systems, at higher S/N
- Timeline: JWST vs. TESS, and K2+others
- K2:
  - 1-slide mission background, observing strategy
  - Progress to date
  - Our discoveries, etc.
- Others: Mearth, MASCARA, SPECULOOS, ExTrA, NGTS...
- TESS:
  - Strategy
  - Anticipated yield