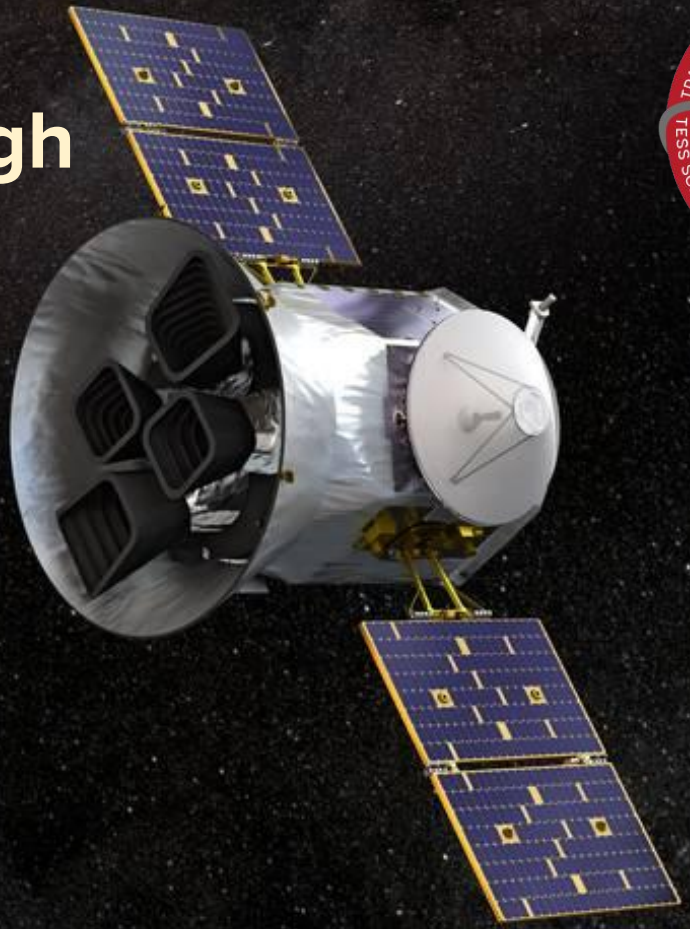
Diamonds in the Rough

Finding Thousands of New Planet Candidates Around Faint Stars

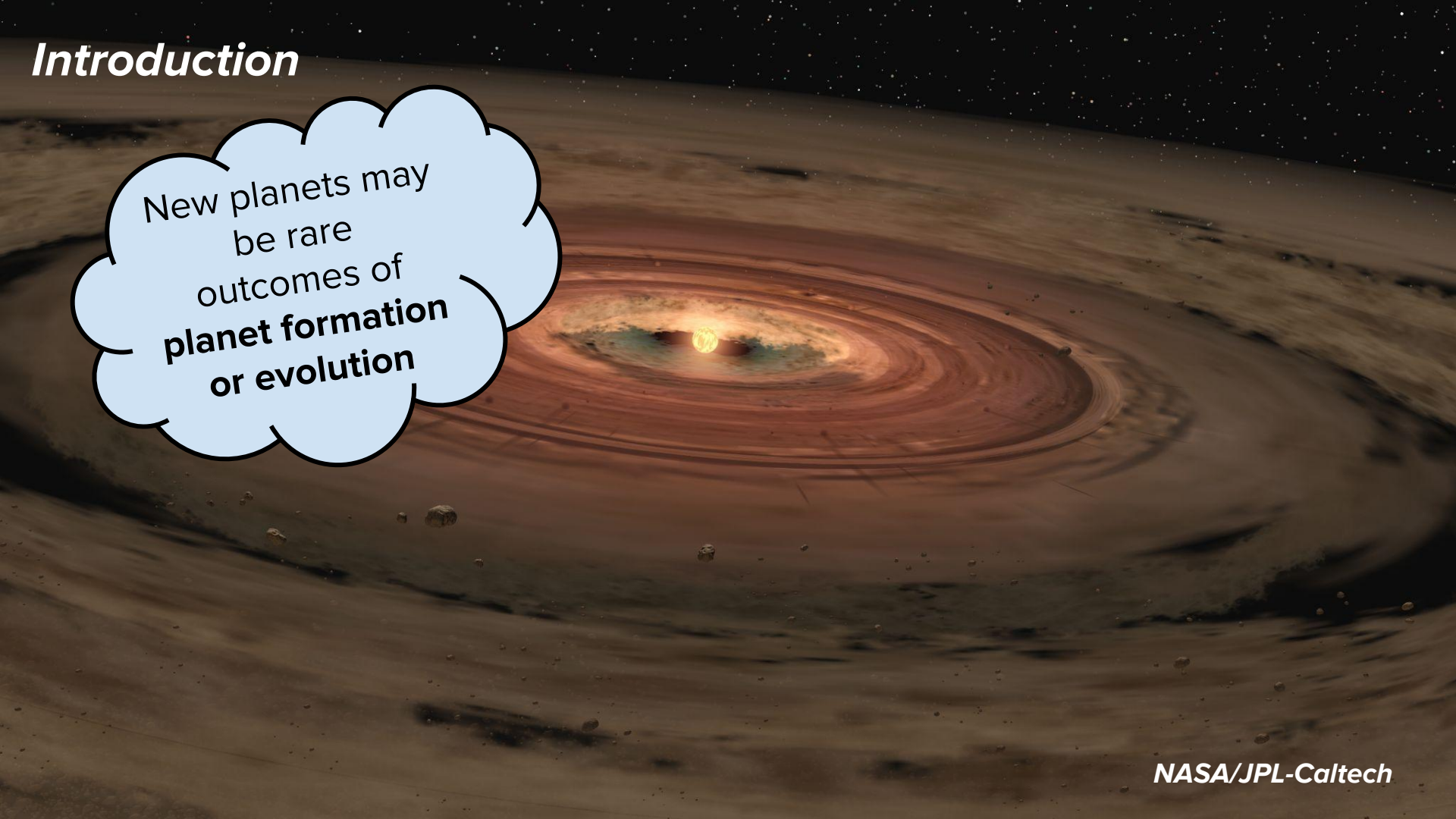
Michelle Kunimoto
TESS Postdoctoral Scholar, MIT

ExoExplorers Series
May 12, 2023



NASA

Introduction



NASA/JPL-Caltech

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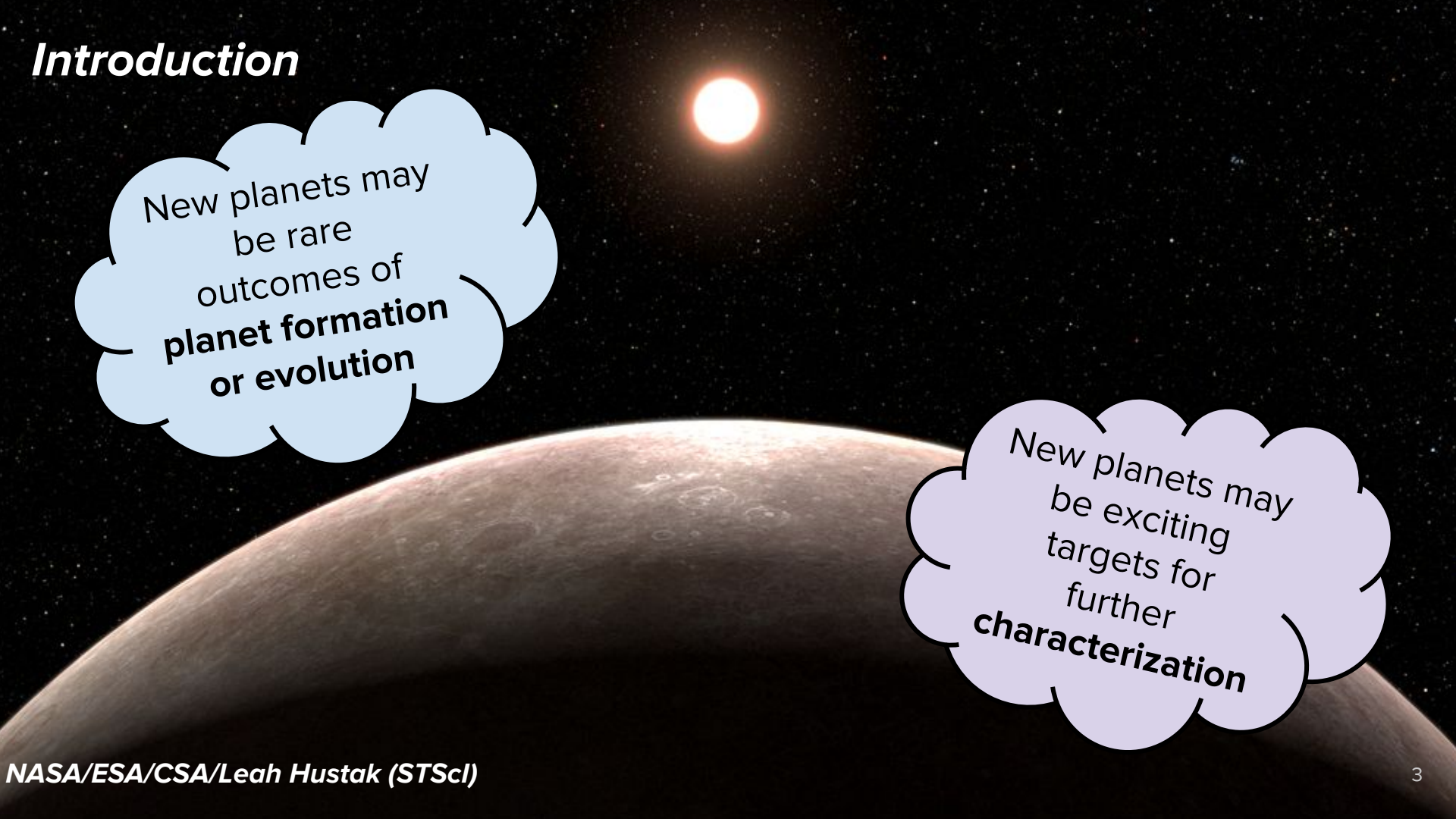
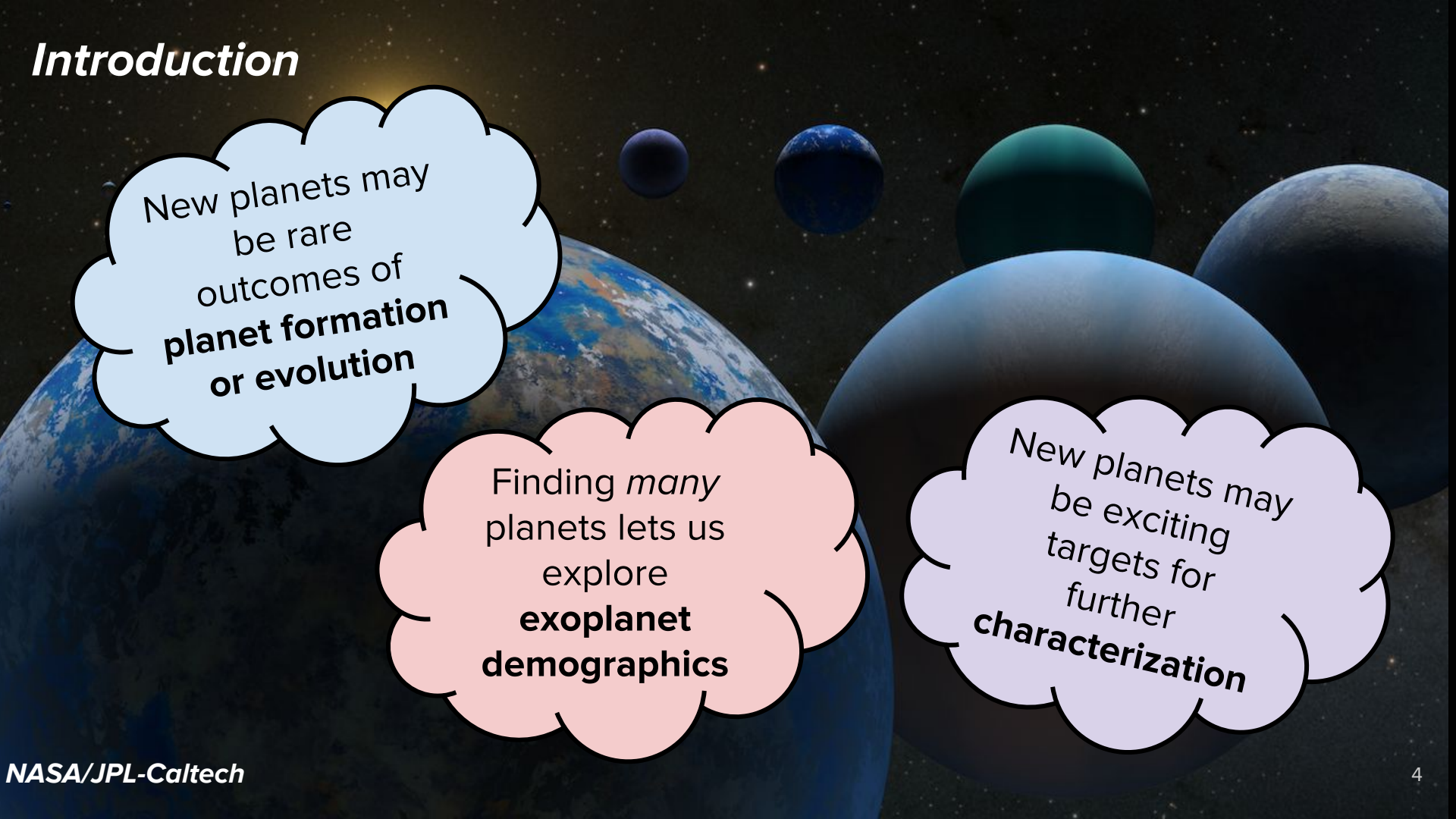


NASA/ESA/CSA/Leah Hustak (STScI)

Introduction



NASA/JPL-Caltech

Introduction

New planets may be rare outcomes of **planet formation or evolution**

We could find **another planet like Earth**

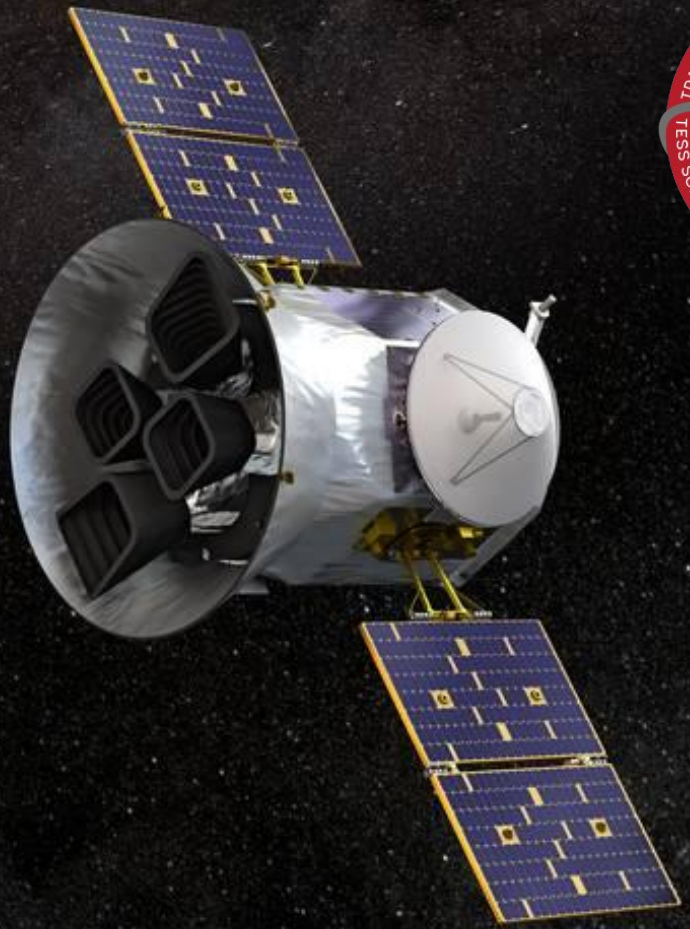
Finding many planets lets us explore **exoplanet demographics**

New planets may be exciting targets for further **characterization**

Background

NASA's Transiting Exoplanet Survey Satellite (TESS)
2018 - Present

All-sky survey designed to find exoplanets around nearby, bright stars amenable to follow-up



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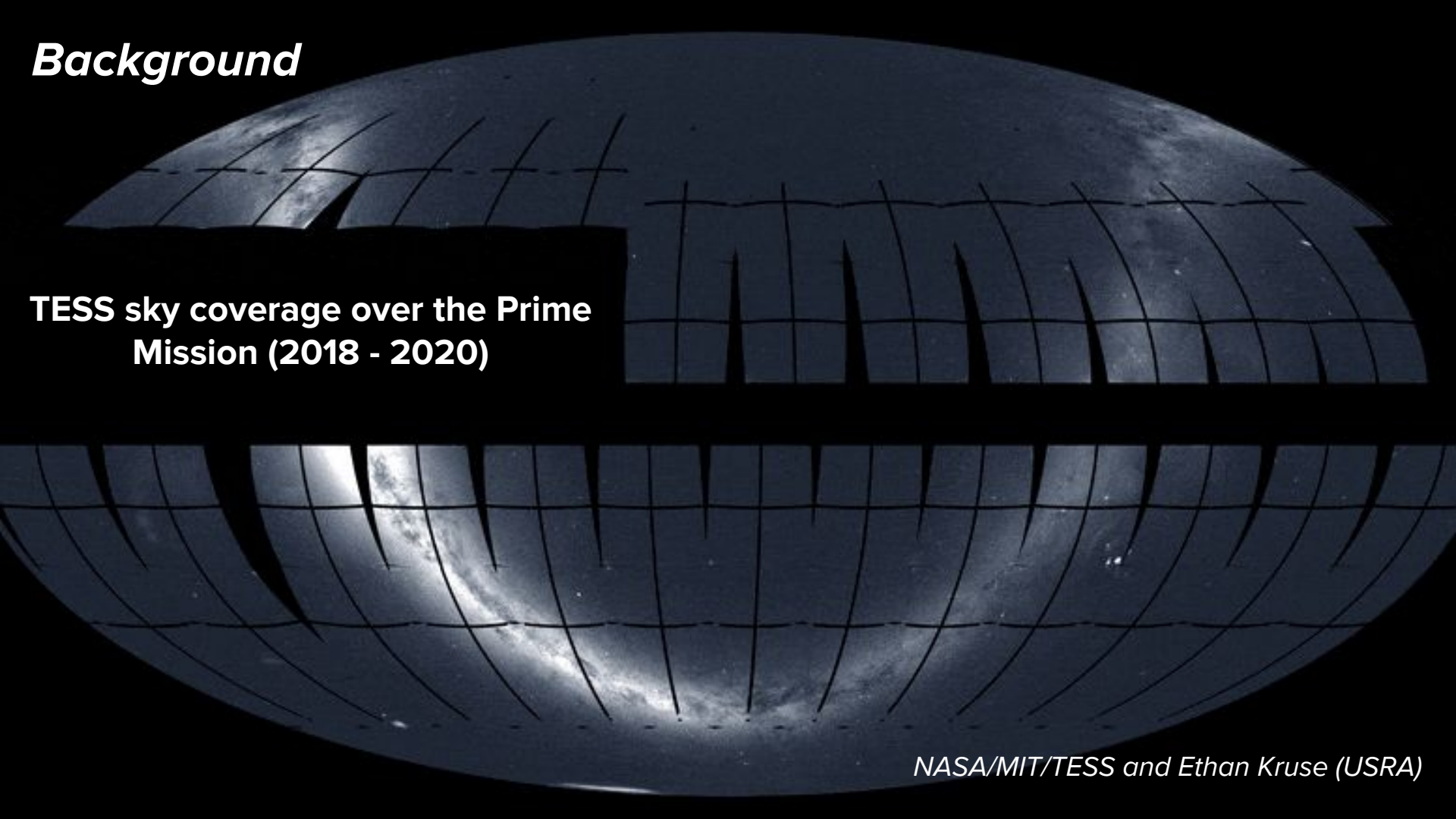

TESS sky coverage over the Prime Mission (2018 - 2020)

NASA/MIT/TESS and Ethan Kruse (USRA)

Background

MIT's Quick-Look Pipeline (QLP) team uses TESS FFIs to find planets:

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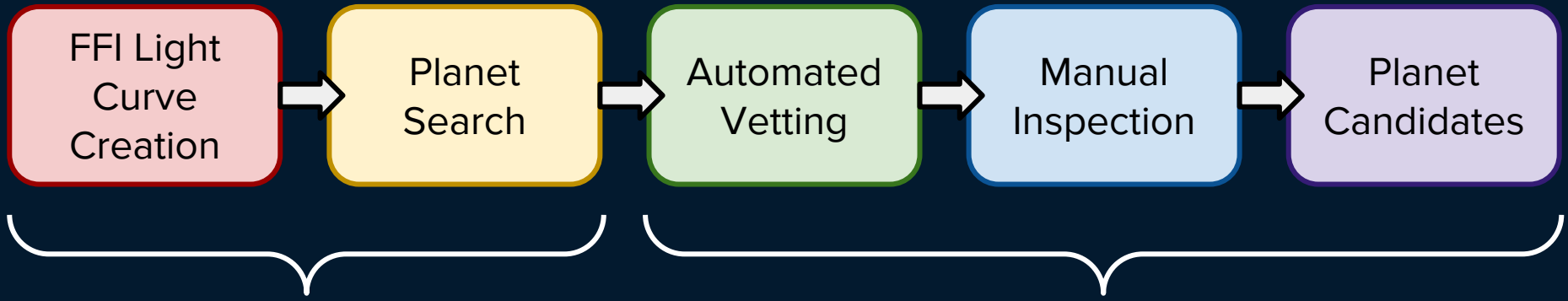

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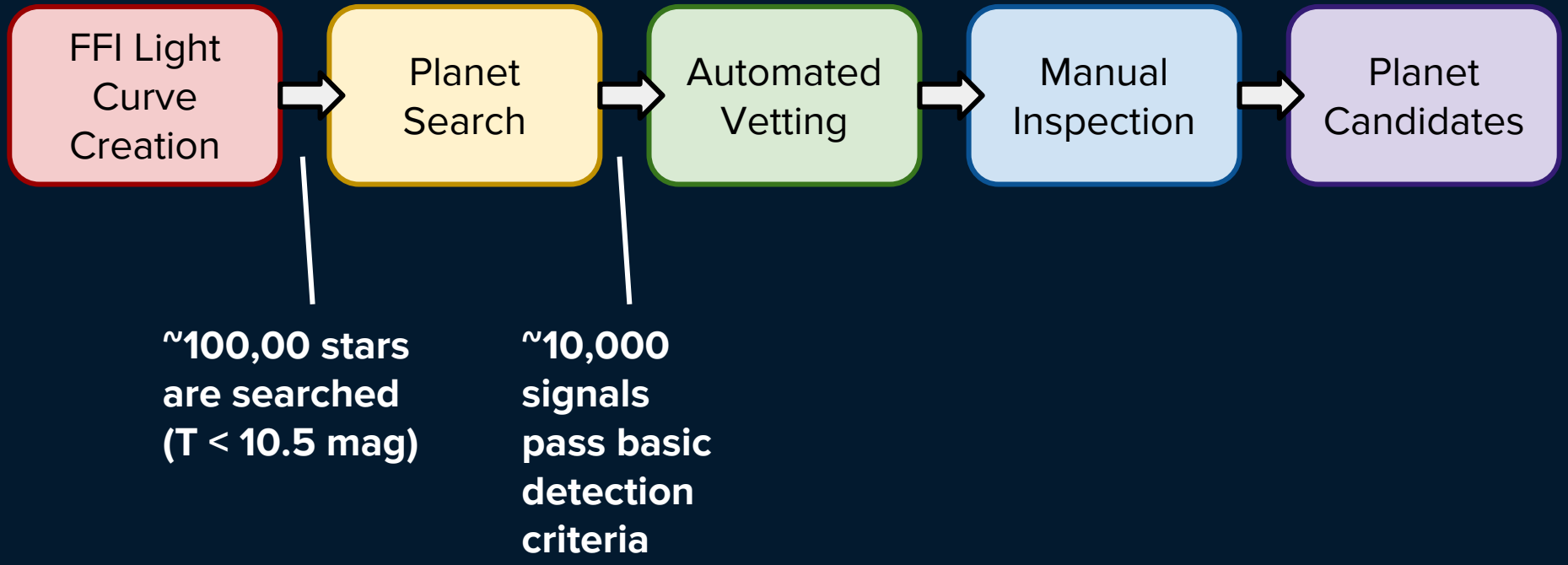

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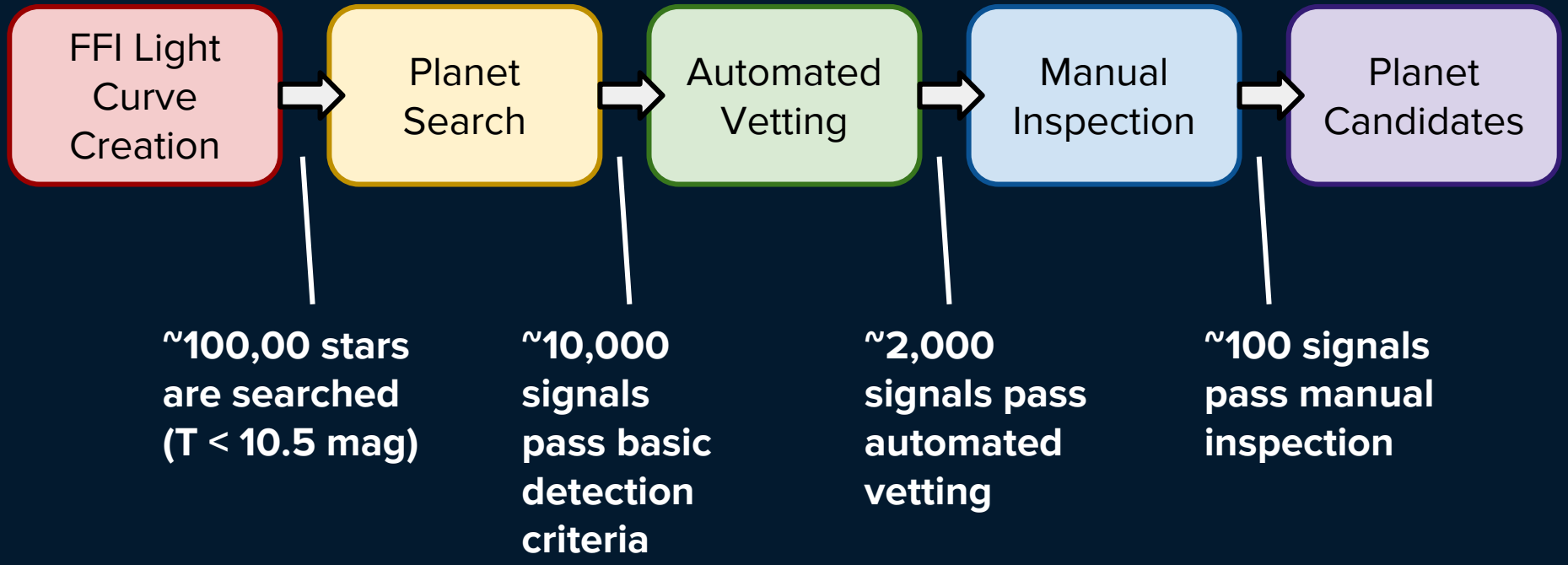

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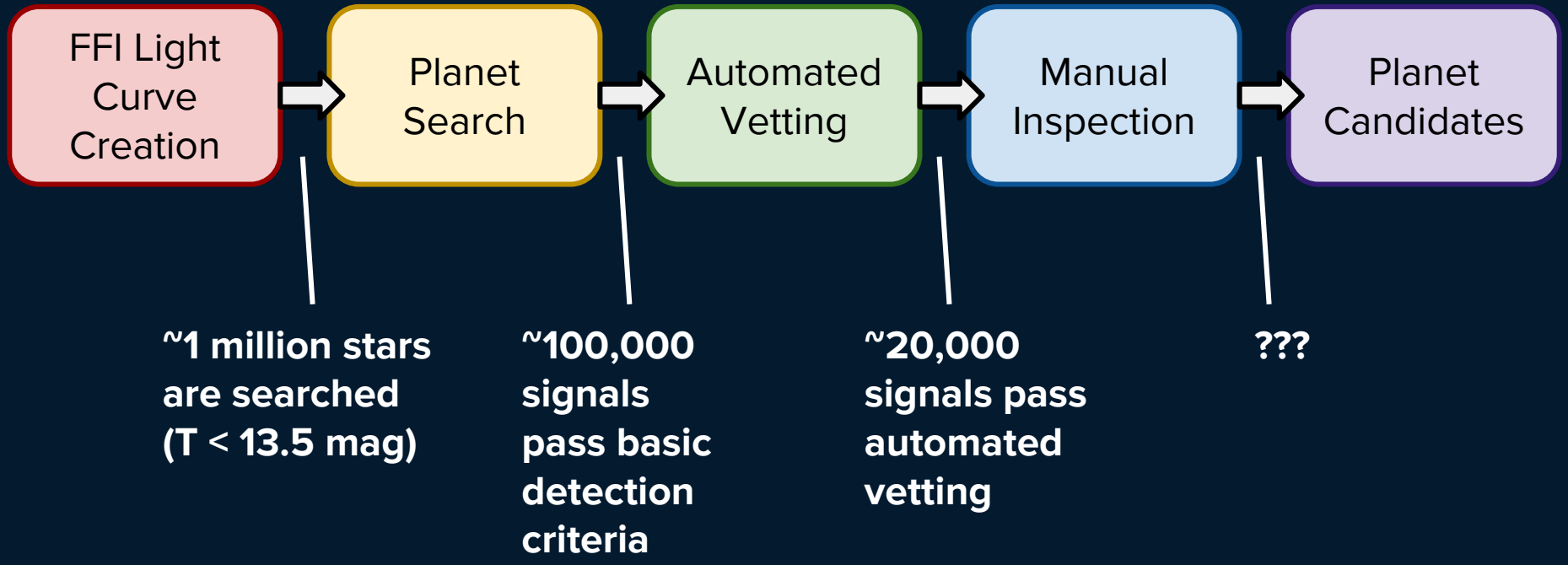

Motivation

More efficient automated vetting is needed for large-scale TESS planet searches!

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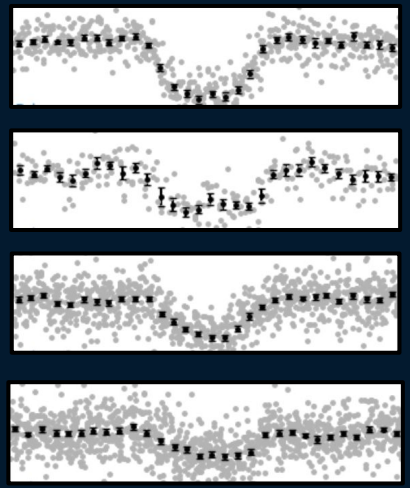
More efficient automated vetting is needed for large-scale TESS planet searches!

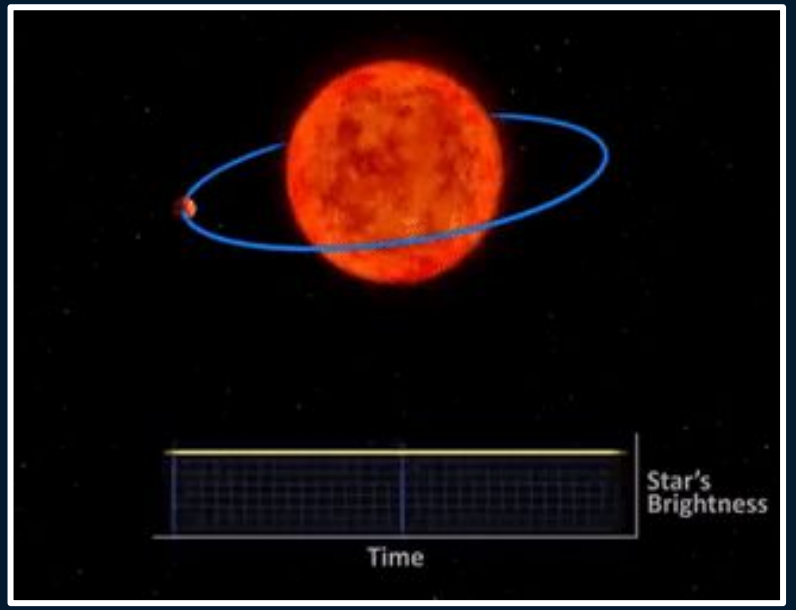
- there is no fully automated vetting pipeline available for TESS planet searches
- what worked for Kepler won't necessarily work for TESS
- humans are inherently biased
- fully automated vetting is needed for robust statistical studies of exoplanet populations (demographics)

Methodology

Signals detected in a planet search can be classified into three major categories:

Planets





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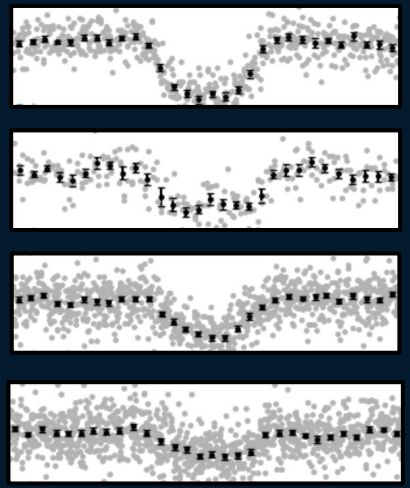
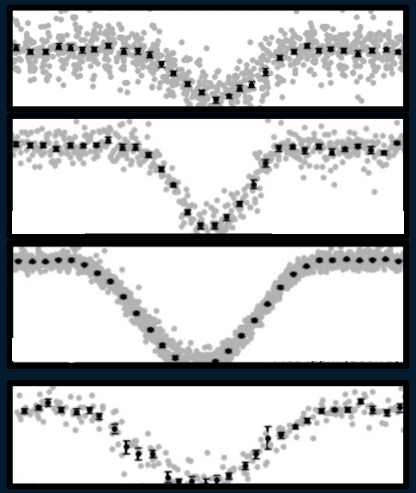
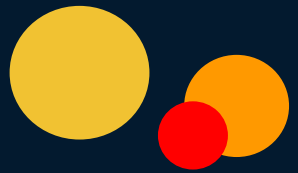


False Positives



Eclipsing binaries (EBs)



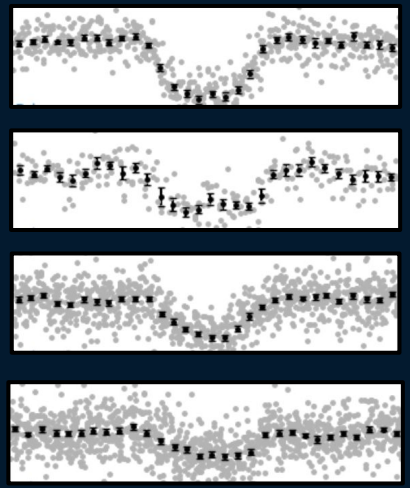
Hierarchical triple eclipsing binaries (HEBs)

Nearby eclipsing binaries (NEBs)

Methodology

Signals detected in a planet search can be classified into three major categories:

Planets



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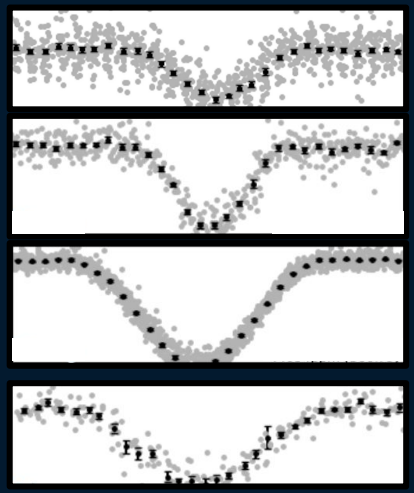
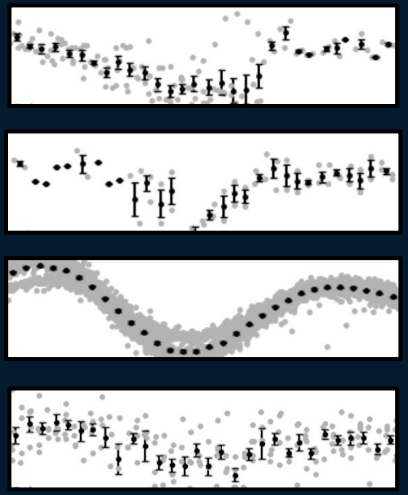


False Alarms



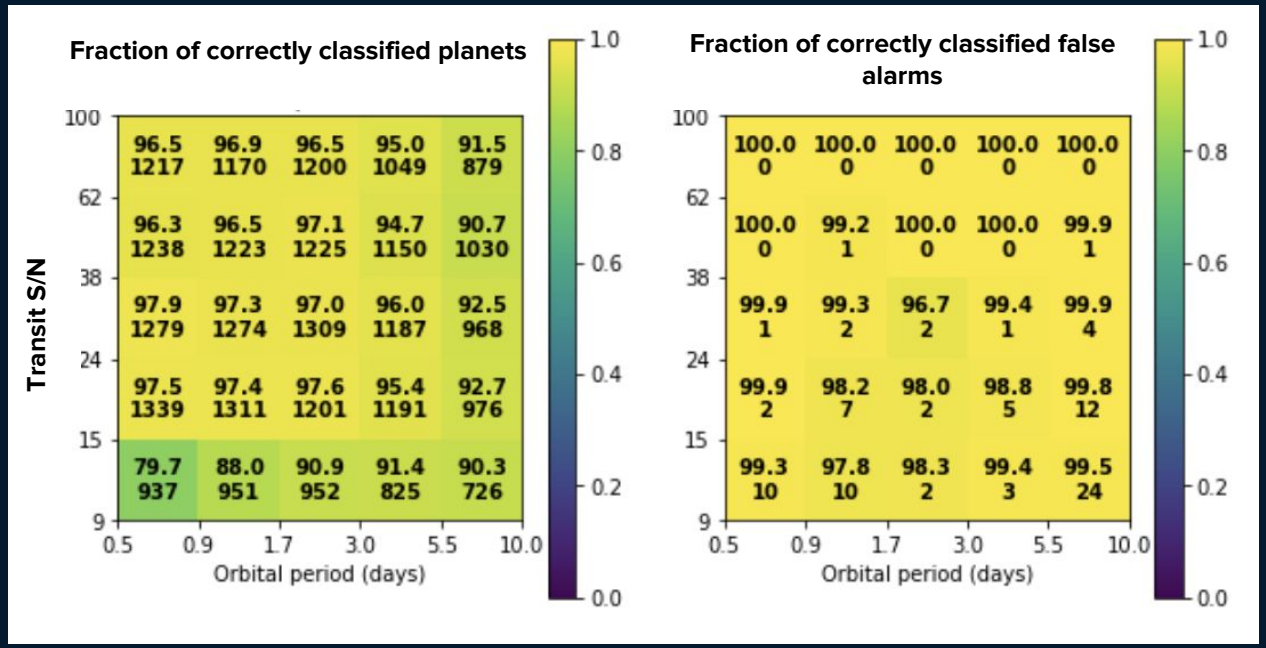
Methodology

Current series of tests, inspired by the Kepler *Robovetter* (Coughlin et al. 2017; Thompson et al. 2018) but fine-tuned for TESS

- **Model fits:** straight line, trapezoid, transit model, sinusoid
- **Model-shift uniqueness tests:** assesses the uniqueness of events, including secondaries
- **Odd-even depth comparison tests:** compare depths of odd/even events
- **V-shape test:** checks if an object is both grazing and large
- **Individual event tests:** checks consistency and validity of individual events
- **Difference images:** pixel-level data products to identify off-target signals
  (in collaboration with **Dr. Steve Bryson**, NASA Ames)
- **... many others ...**

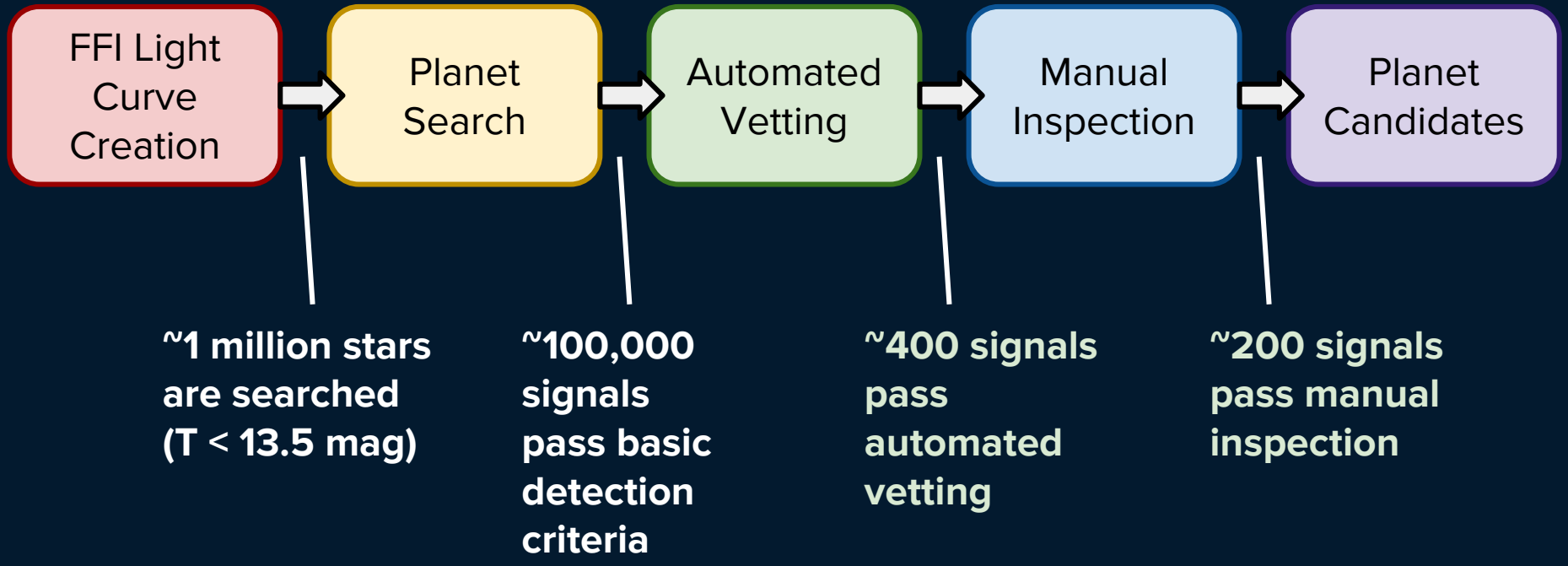
Methodology

The performance of the vetting pipeline has been tested on simulated planets and false alarms:



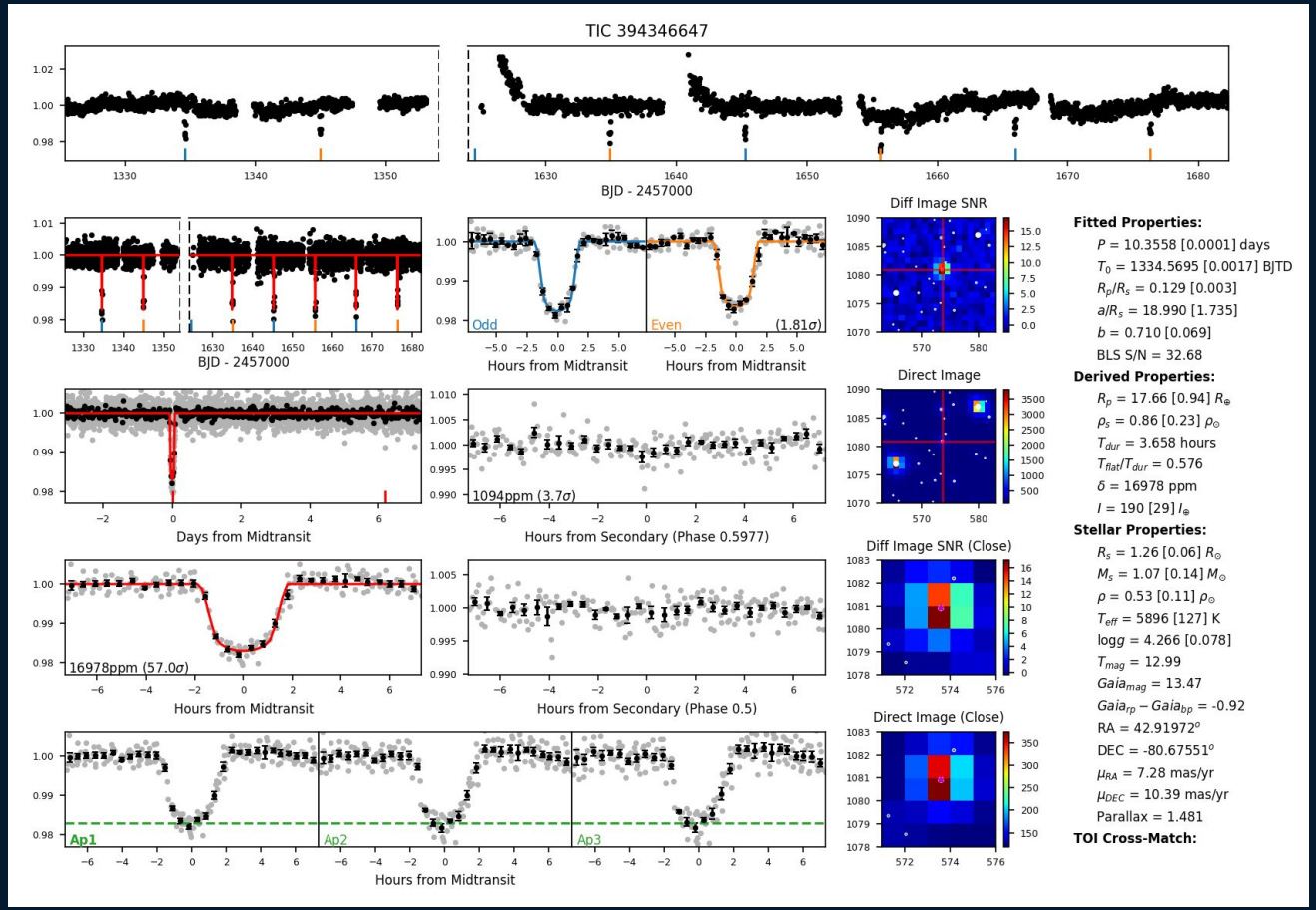
Methodology

After implementing these tests into the pipeline:

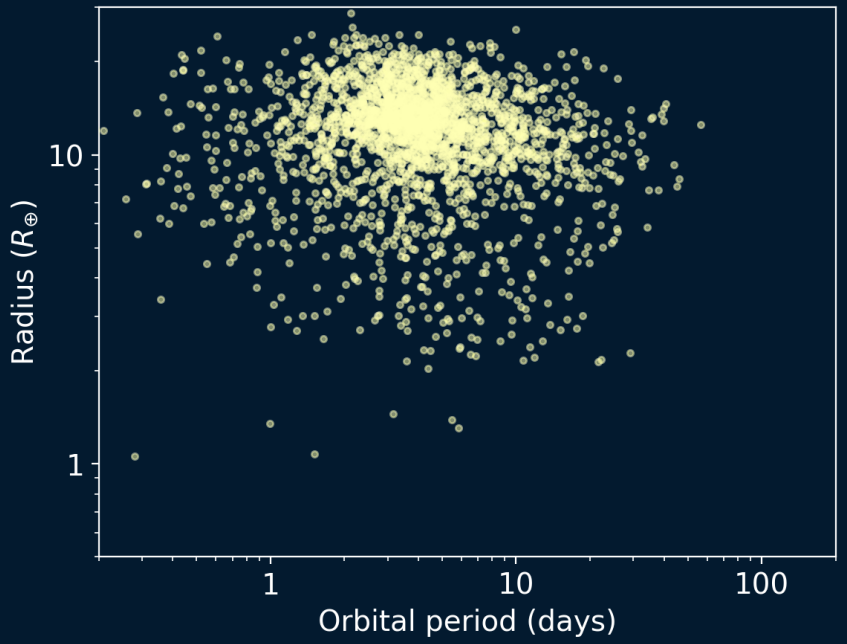


Methodology

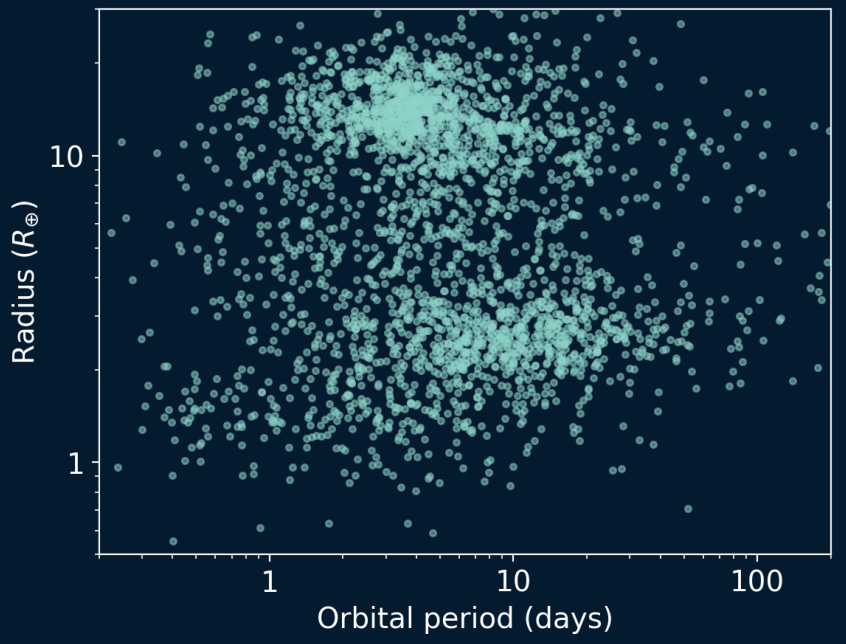
Reviewed all signals and refined vetting algorithm with fellow postdoc Tansu Daylan (MIT/Princeton)



Results

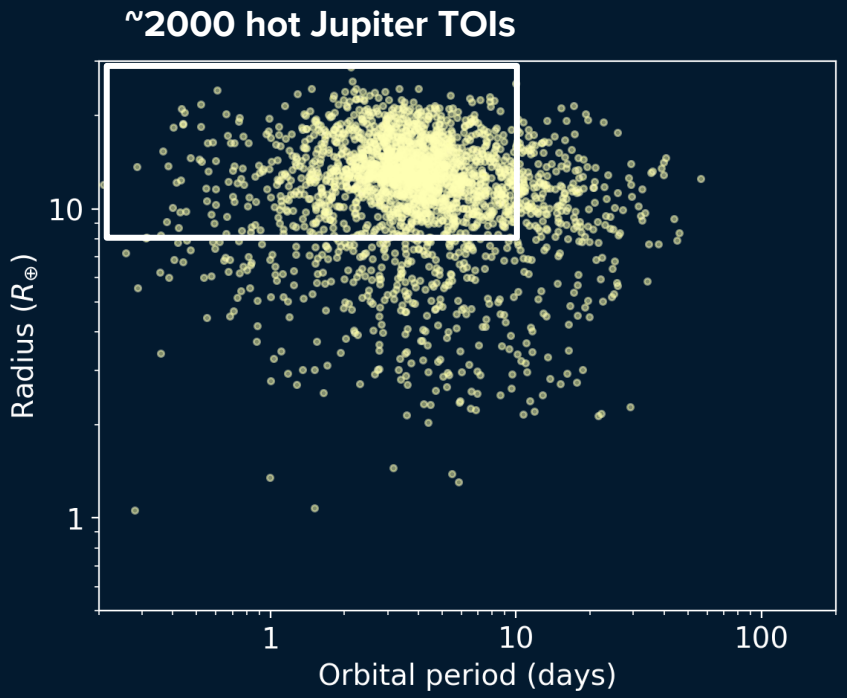


“Faint Star” TOIs (2922)



Other TOIs (3664)

Results



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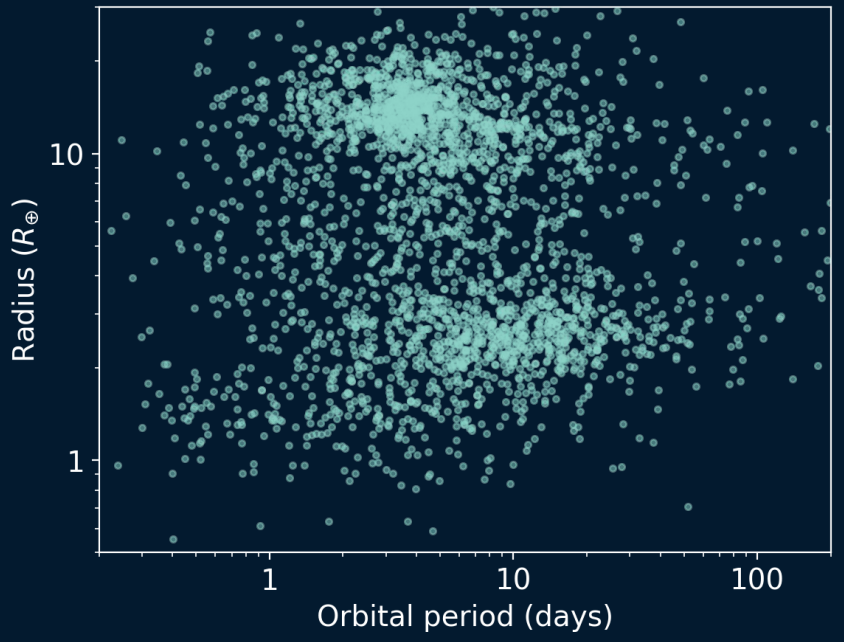

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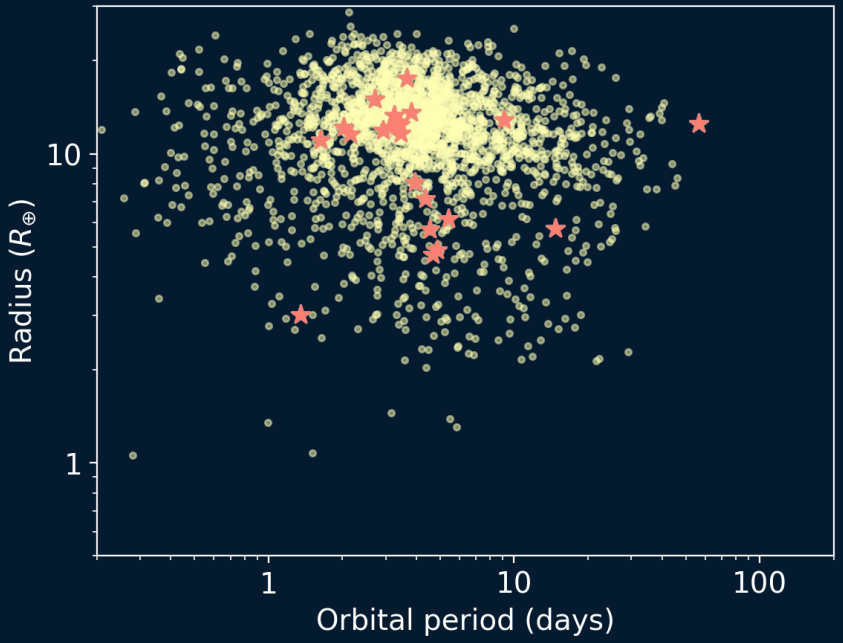

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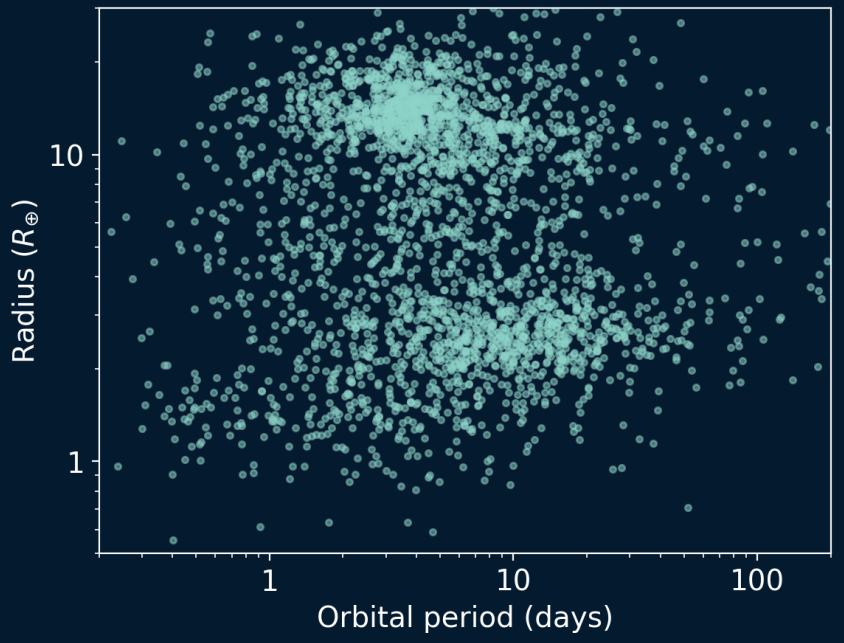

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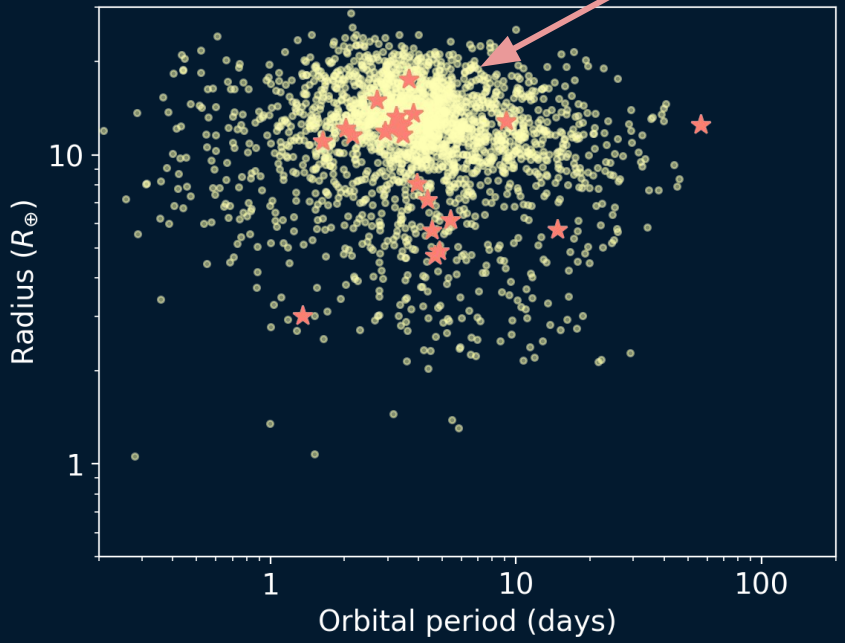
Results

Several of these confirmed giants orbit M dwarfs



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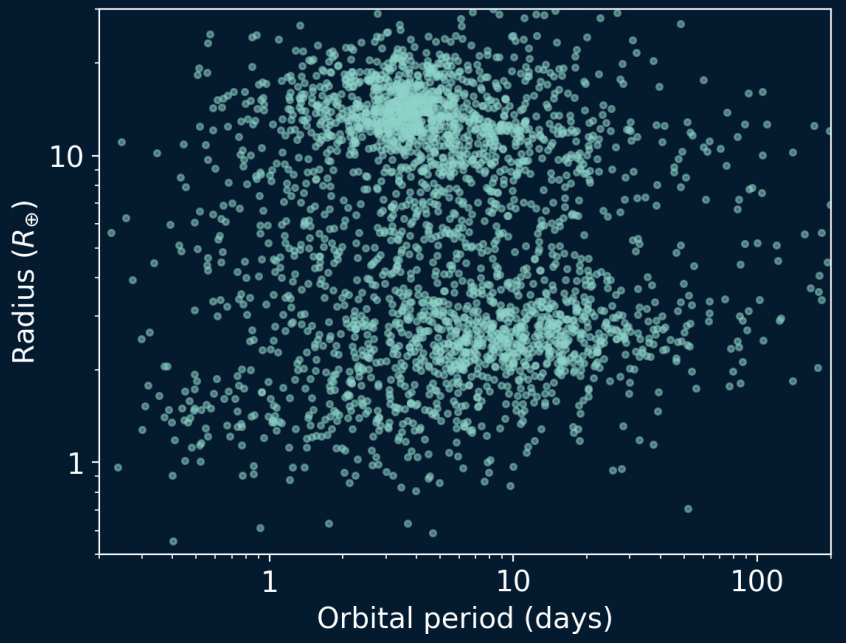

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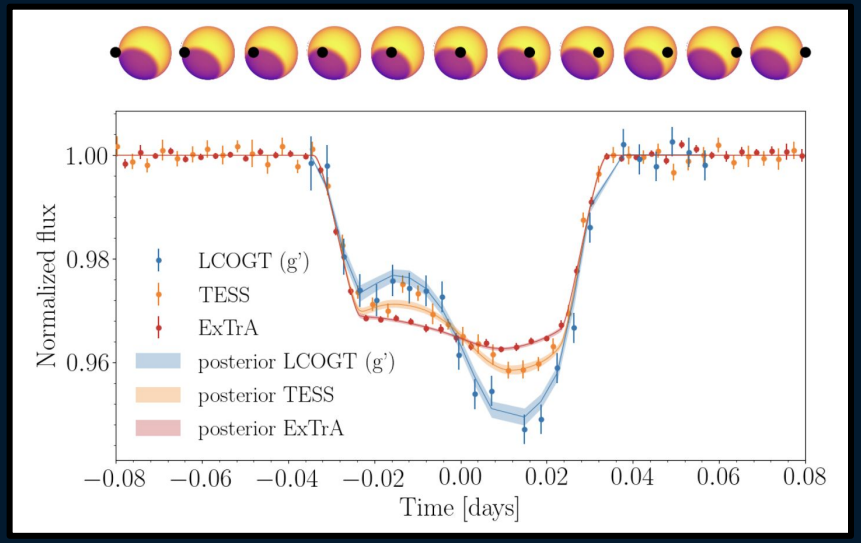
Highlighted Discoveries



TOI-3884 b: First sub-Saturn found transiting a mid-M dwarf (Almenara [+ Kunimoto] et al. 2022)

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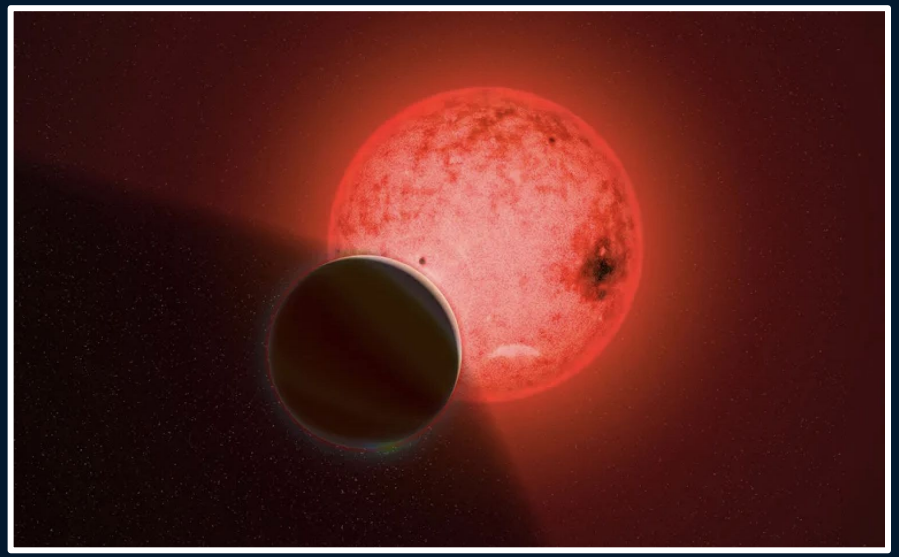


TOI-3884 b: First sub-Saturn found transiting a mid-M dwarf (Almenara [+ Kunimoto] et al. 2022)

TOI-5205 b: First Jupiter found transiting a mid-M dwarf (Kanodia et al. 2023)

Astronomers Discover Bizarre "Forbidden" Planet That Should Not Exist

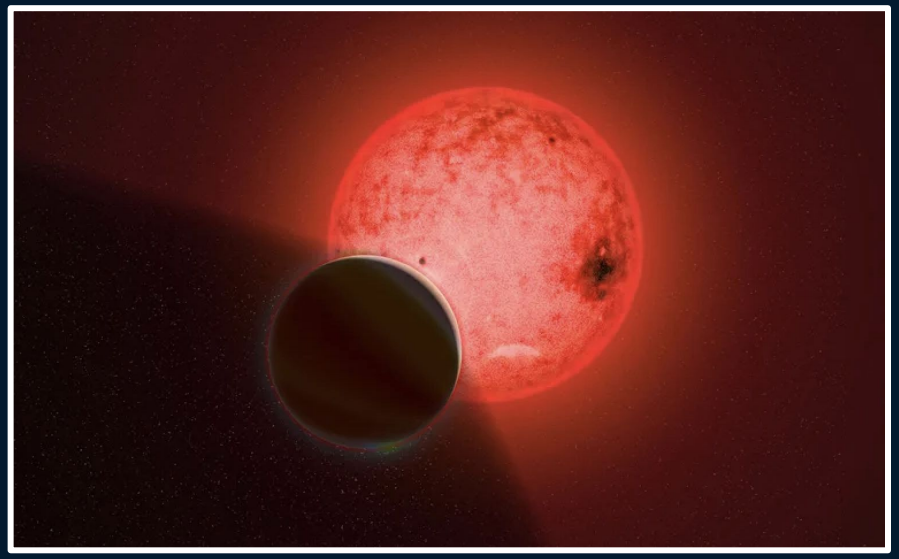
TOPICS: Astronomy Astrophysics Carnegie Institution For Science Exoplanet TESS

By CARNEGIE INSTITUTION FOR SCIENCE FEBRUARY 25, 2023

Scitech Daily

Katharine Cain/Carnegie Institution for Science

Highlighted Discoveries



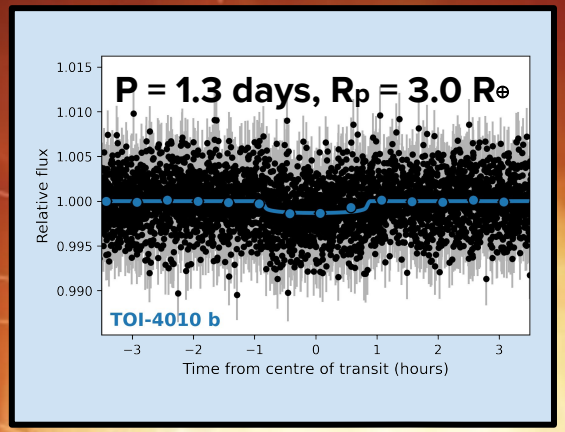
TOI-3884 b: First sub-Saturn found transiting a mid-M dwarf (Almenara [+ Kunimoto] et al. 2022)

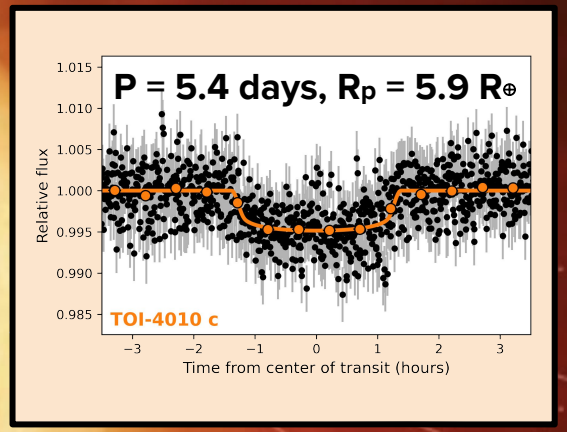
TOI-5205 b: First Jupiter found transiting a mid-M dwarf (Kanodia et al. 2023)

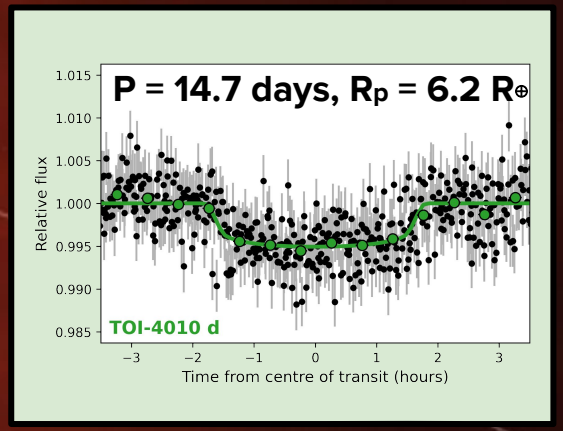
TOI-3757 b: Lowest density transiting planet known to orbit an M dwarf (Kanodia et al. 2022)

Katharine Cain/Carnegie Institution for Science

Highlighted Discoveries



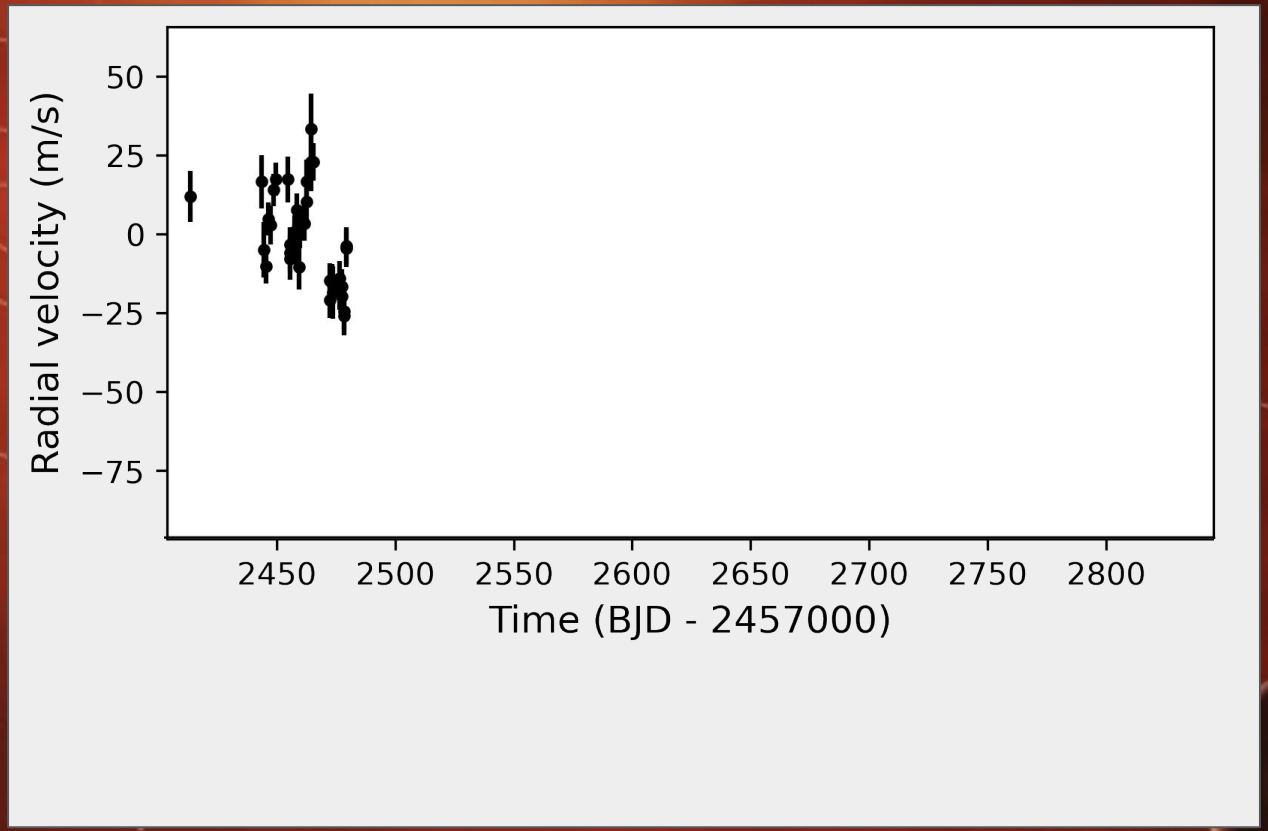




TOI-4010: Metal-rich K-dwarf ([Fe/H] = +0.37)

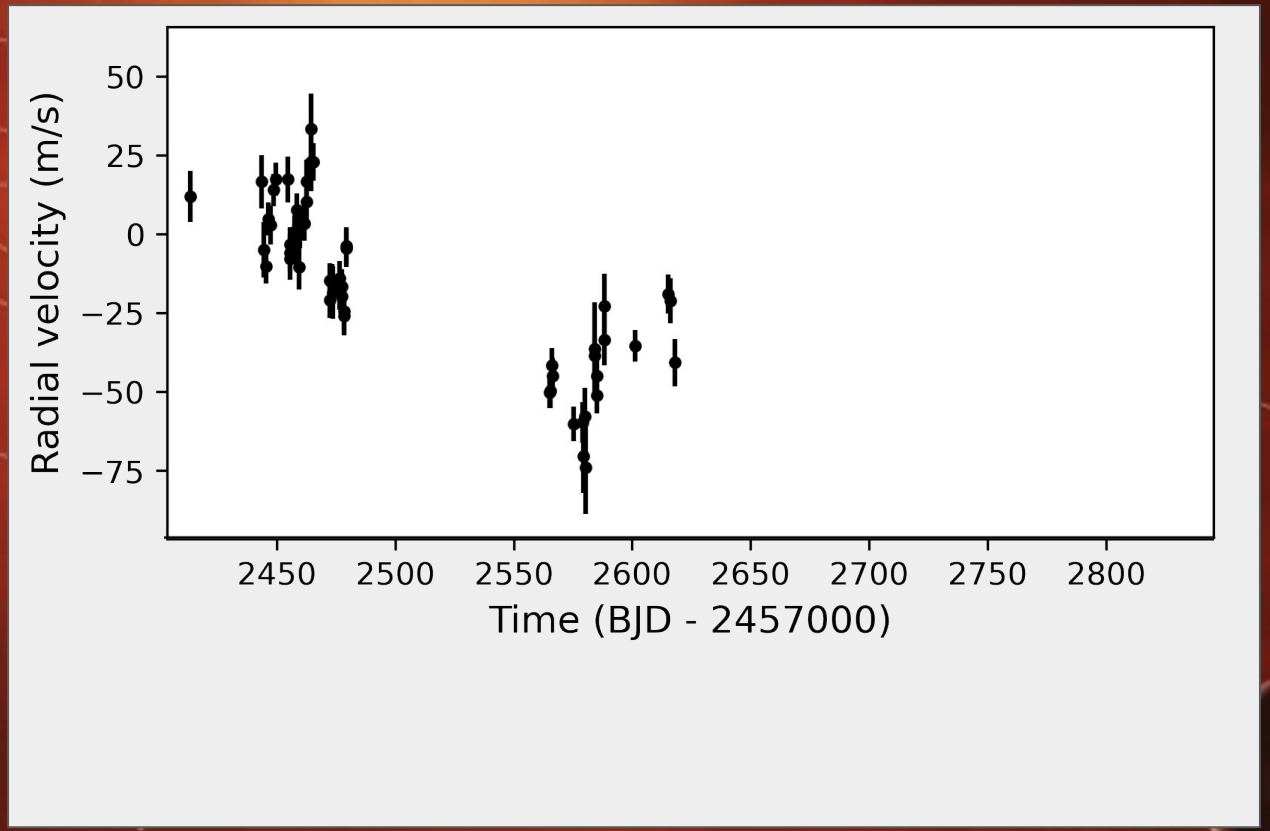
Mark Garlick/SPL

Highlighted Discoveries



112 HARPS-N RVs: July 2021 - January 2023

Highlighted Discoveries



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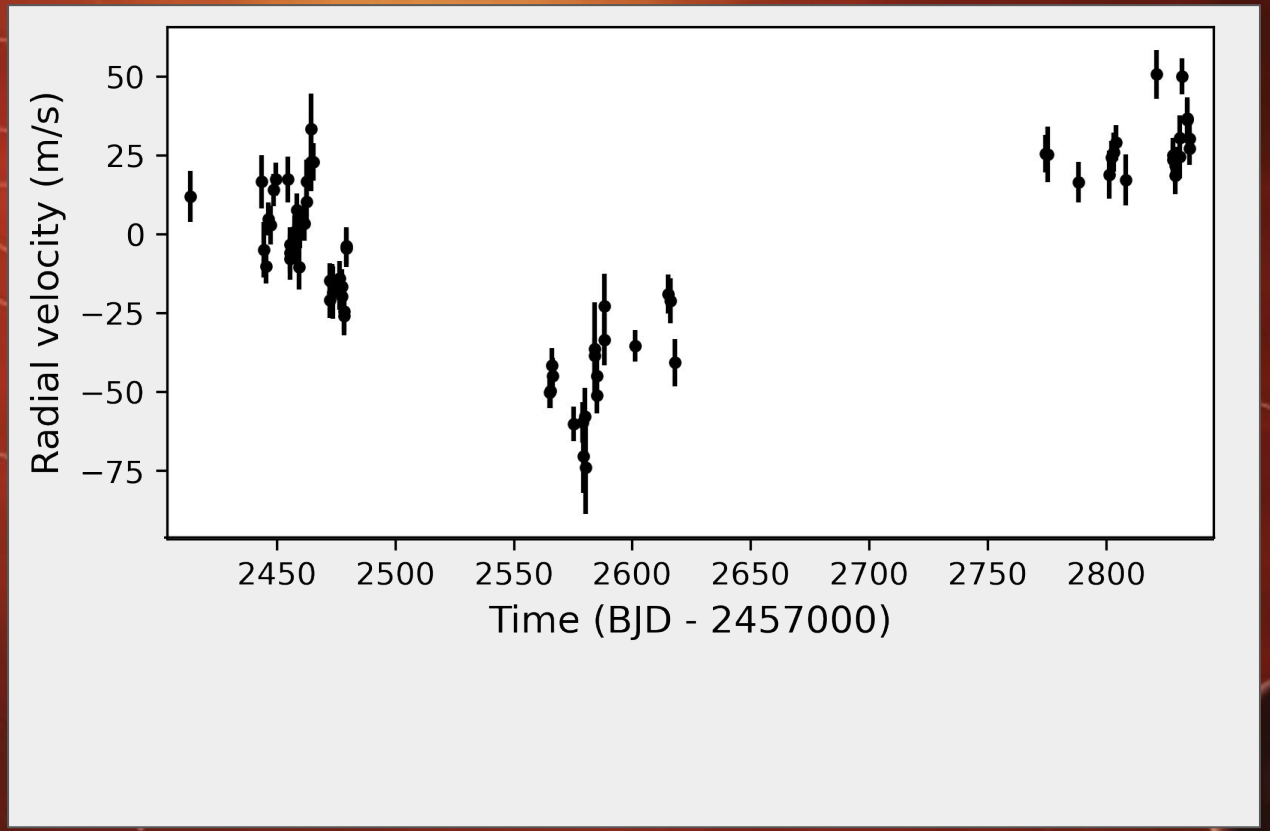

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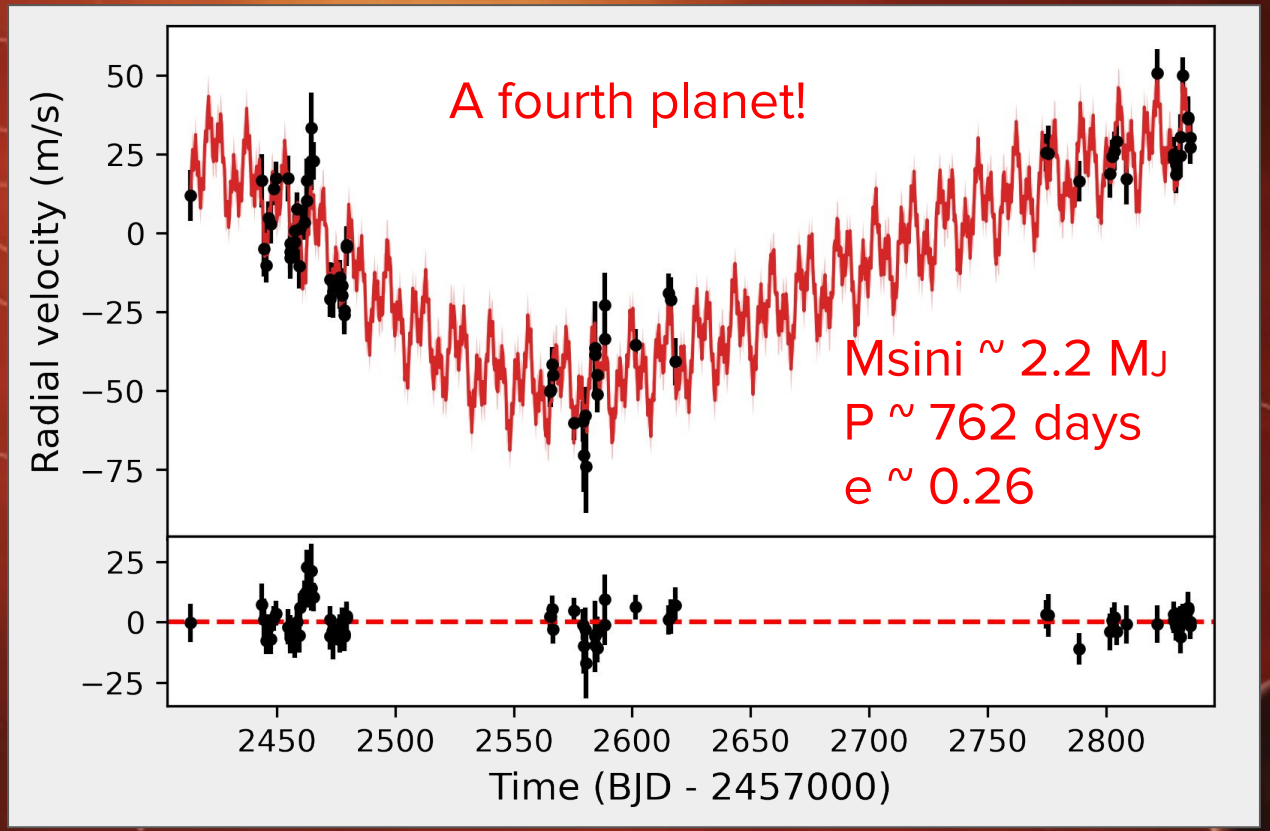

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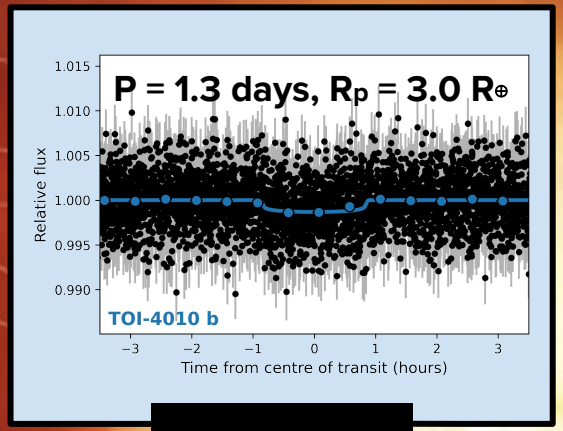
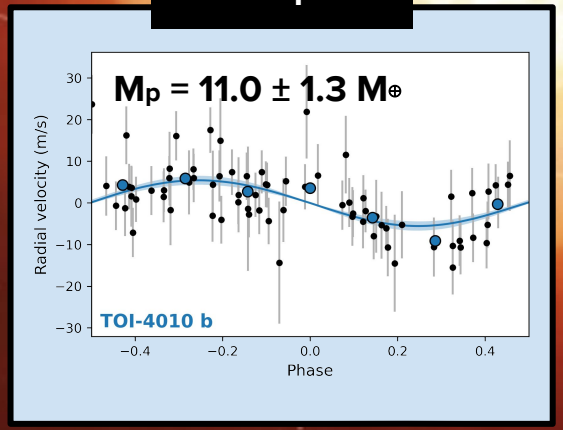
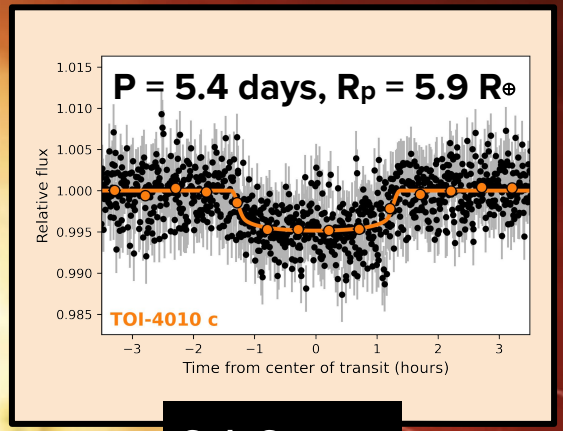
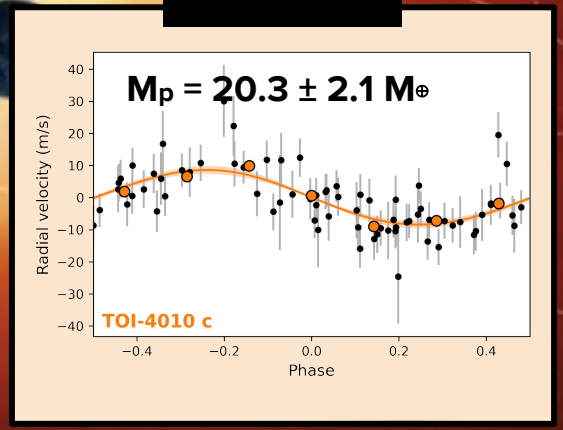


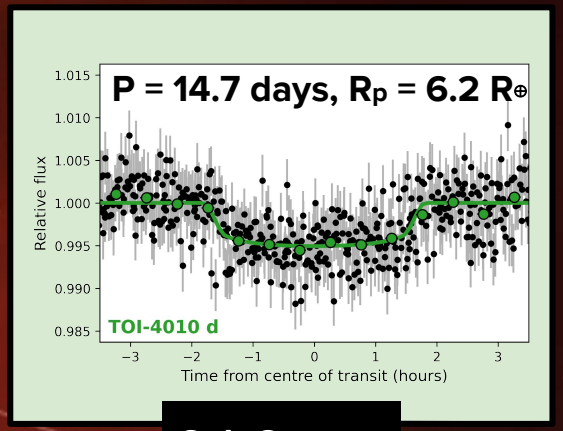
Sub-Neptune





Sub-Saturn





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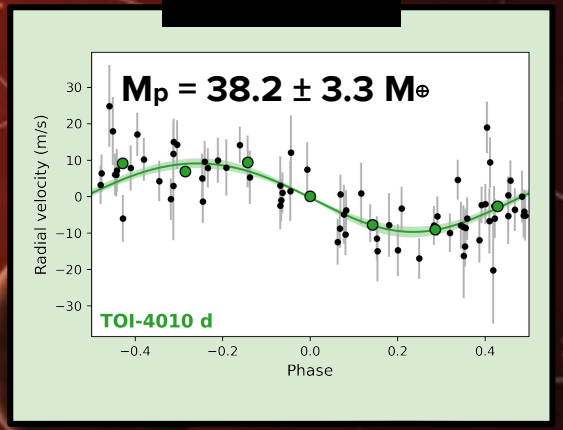
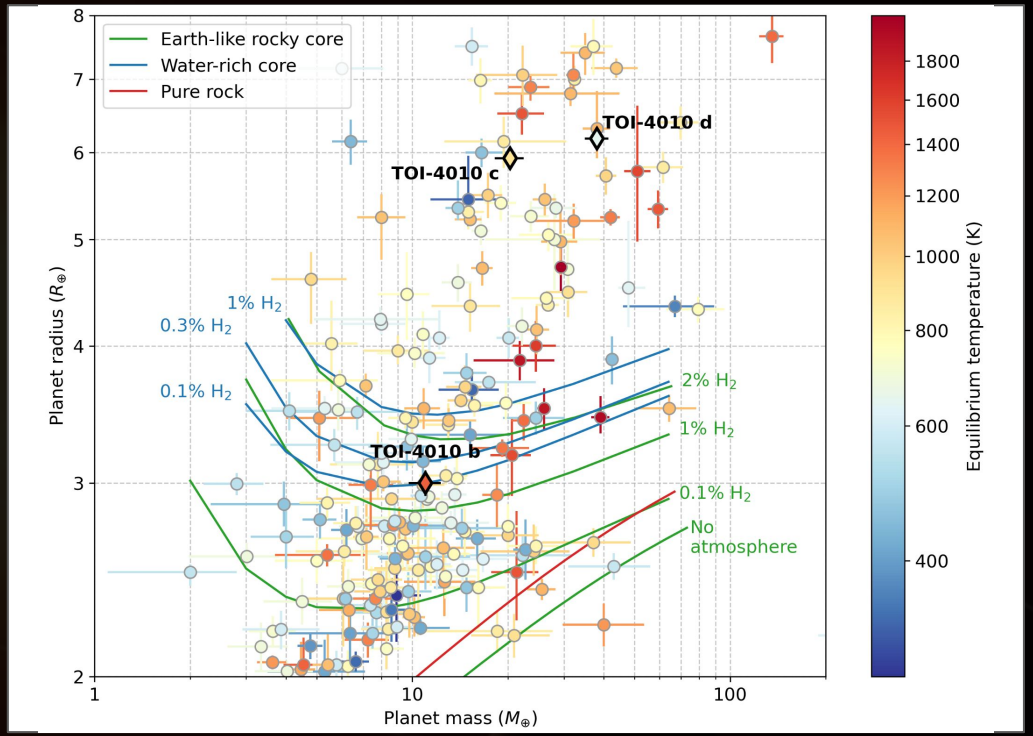


Highlighted Discoveries

Cool things about TOI-4010

1. Comparative Planetology

TOI-4010 has THREE large planets in close-in orbits, all with atmospheres



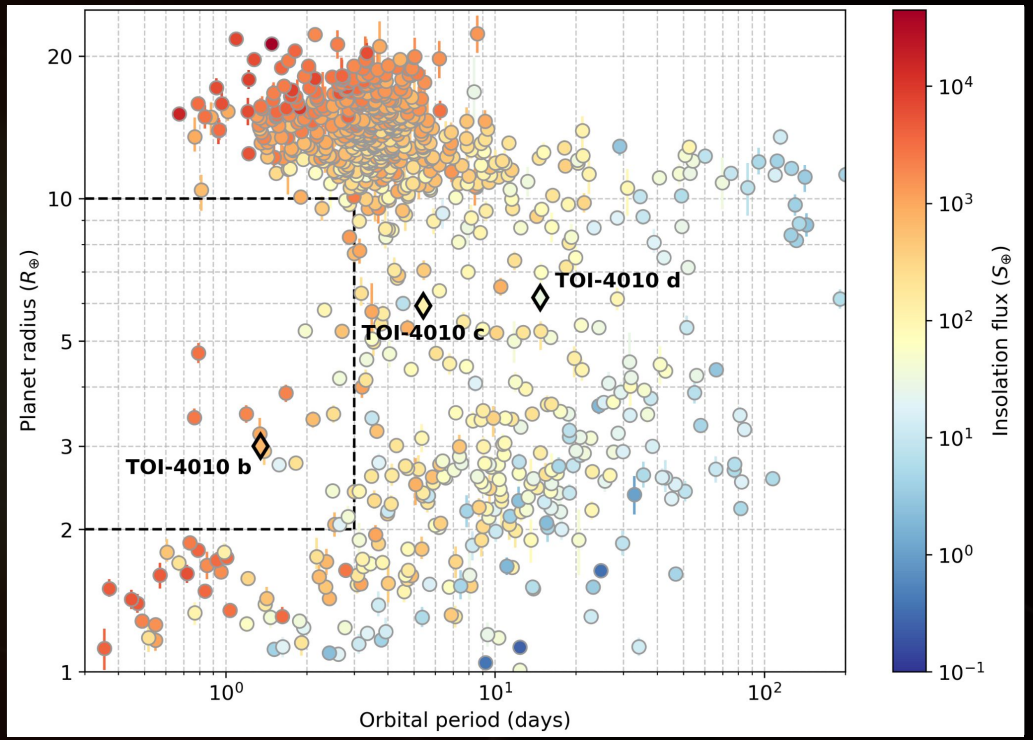
Mass-radius curves from Zeng et al. (2018)

Highlighted Discoveries

Cool things about TOI-4010

2. A planet in the hot Neptune desert

TOI-4010 b is one of the only hot Neptunes in a multi-planet system

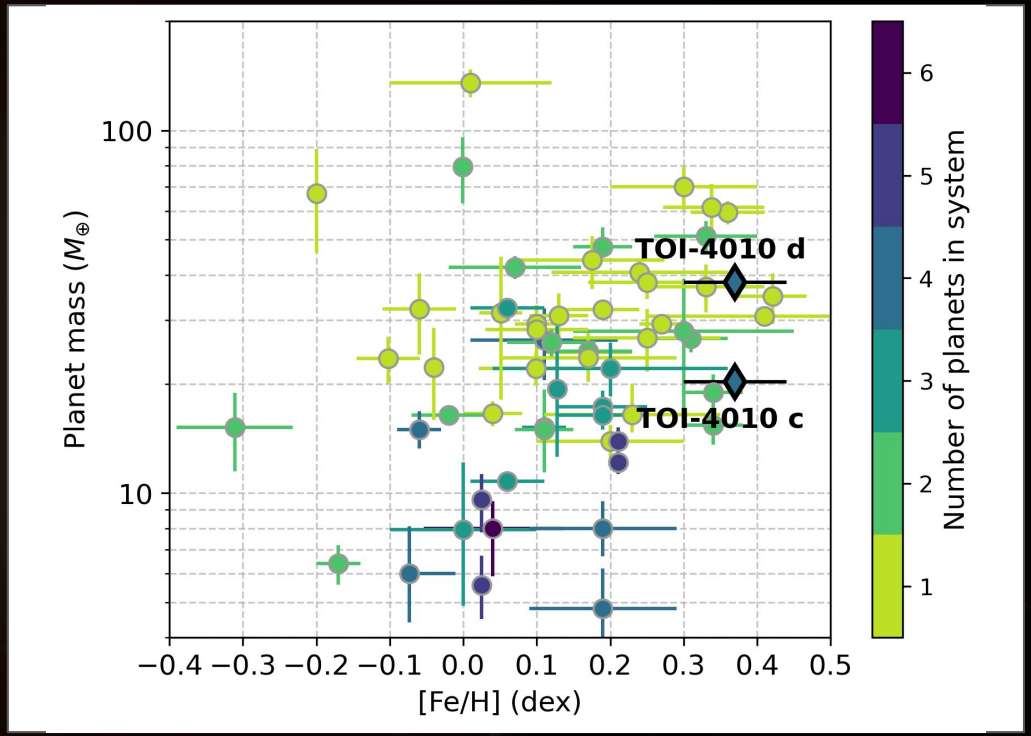


Planets in the NASA Exoplanet Archive with density measured to better than 50% precision

Cool things about TOI-4010

3. Particularly massive sub-Saturns

TOI-4010 d is one of the most massive sub-Saturns found in a multi-planet system

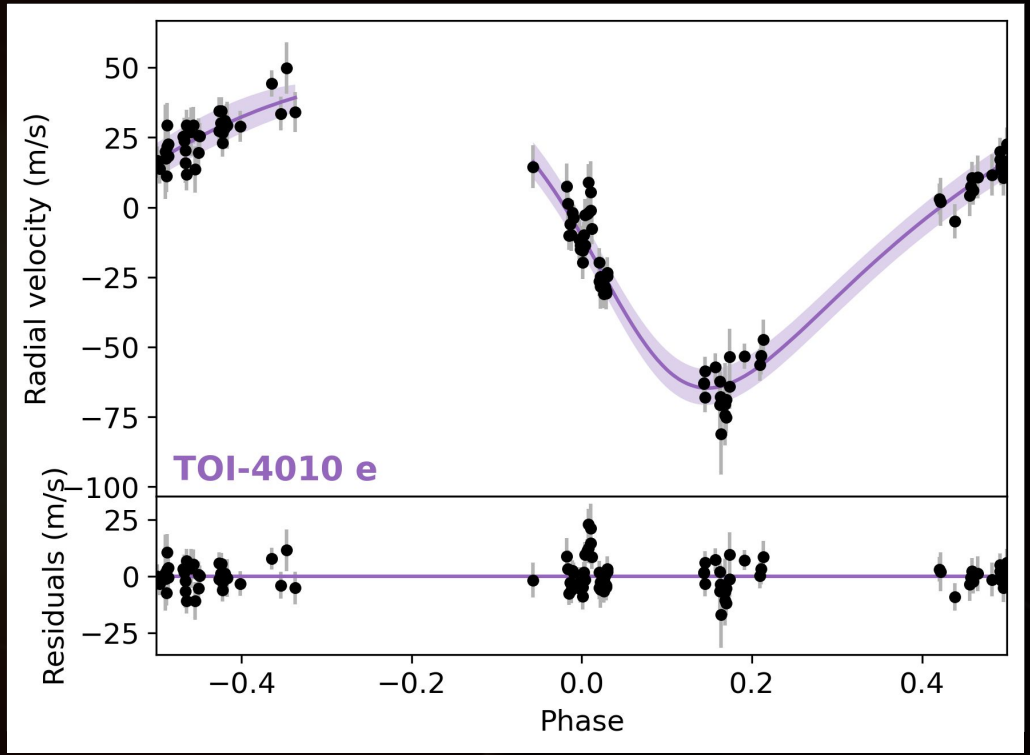


Mass-host star metallicity diagram for sub-Saturns (4 - 8 $R_\oplus$)

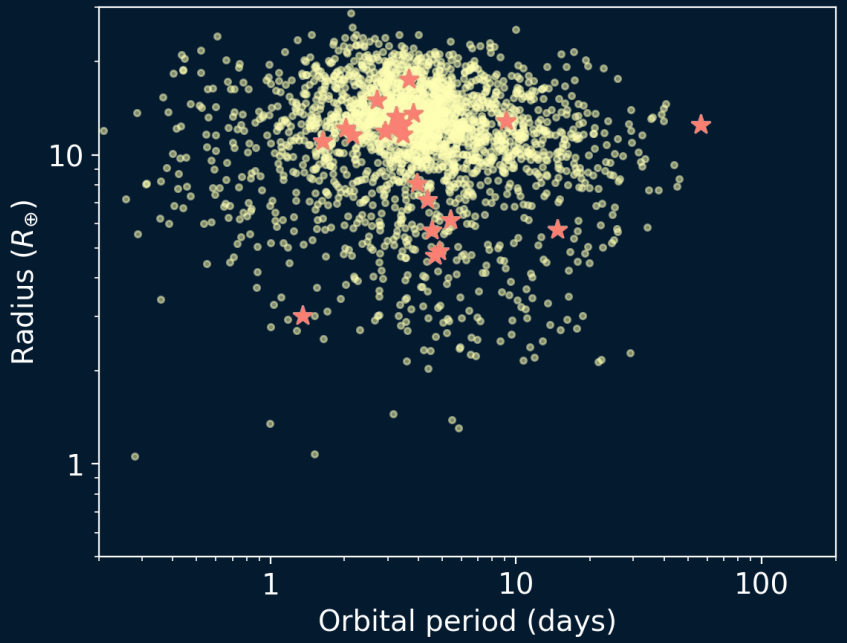
Cool things about TOI-4010

4. Moderately eccentric super-Jupiter companion

Still monitoring RVs to complete the orbit and determine the correct period



Summary & Future Plans



- automated vetting is needed for large-scale planet searches
- I'm close to a fully automated TESS vetting pipeline, with applications to both planet searches and exoplanet demographics
- will be made publicly available for use by the exoplanet community
- 2922 TOIs so far - many more upcoming!
  - several TOIs are rare outcomes of planet formation and promising targets for follow-up