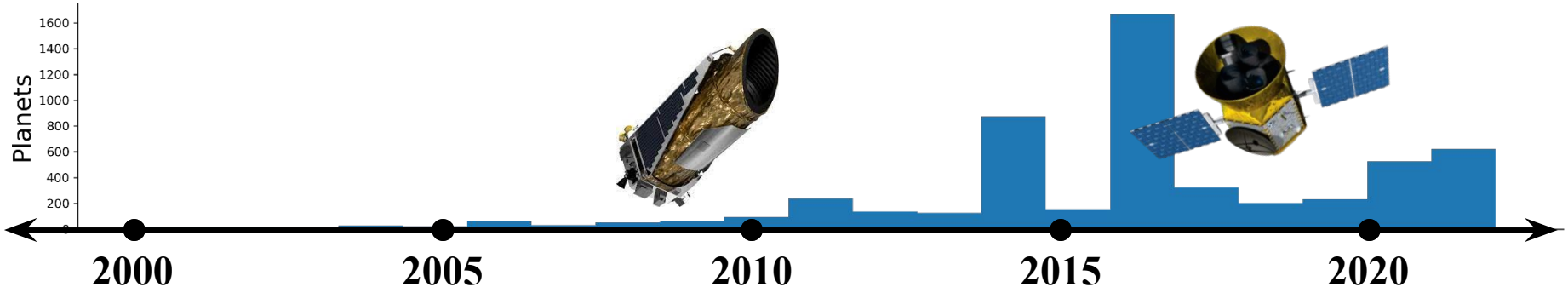
Exploring Exoplanetary Systems with the TESS-Keck Survey

Alex Polanski
and the TKS and CPS Team

Transitioning into a new Era

Our field has made massive strides in past two decades.



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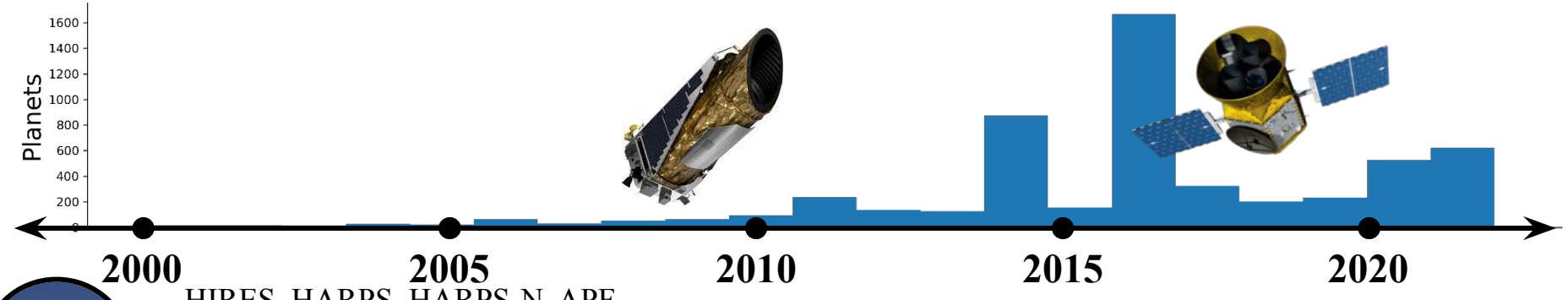

HIRES, HARPS, HARPS-N, APF

Long-term Radial Velocity Monitoring

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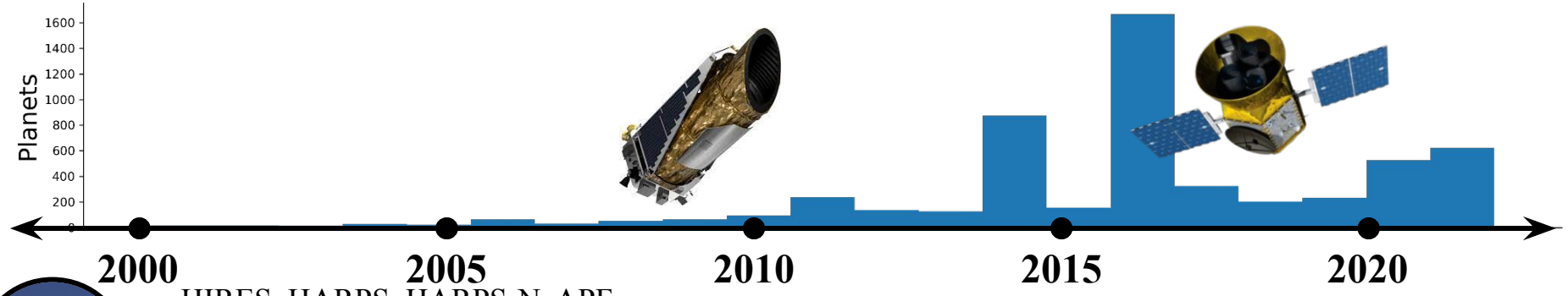

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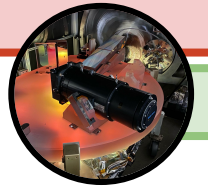
Long-term Radial Velocity Monitoring

KPF, EXPRES
NEID, ESPRESSO,
HPF…



The combination of new RV instrumentation and the maturation of long RV surveys means are we in the best position to investigate system architectures.

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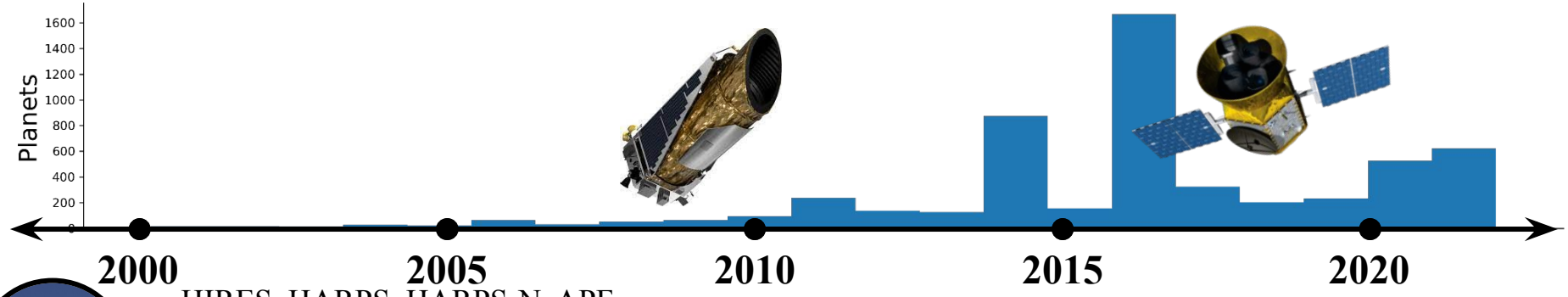

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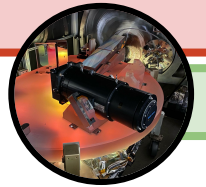

KPF, EXPRES
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TFOP

TESS Follow-up Observation Program

TESS-Keck Survey

A NASA-Keck Strategic Mission Support Program

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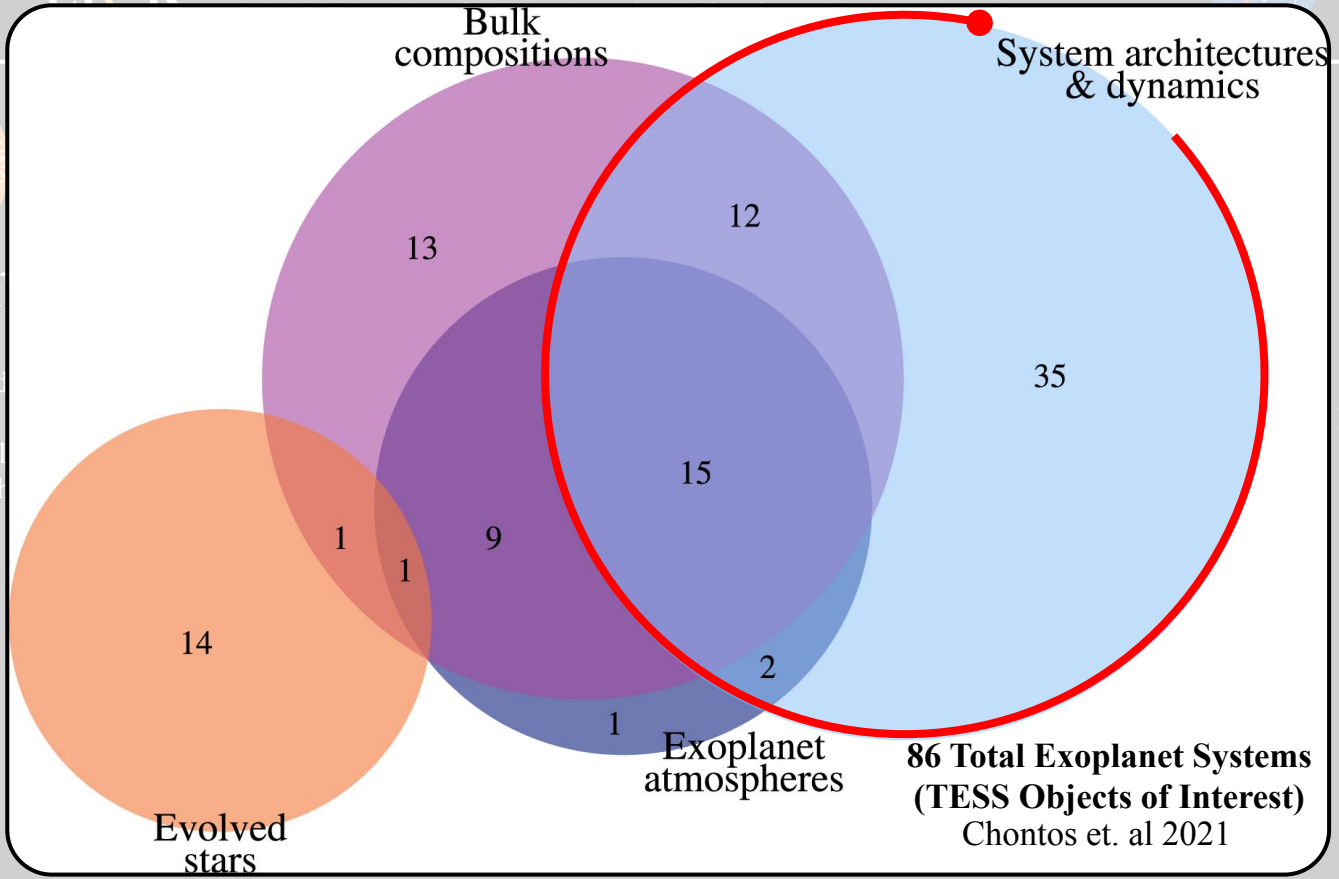


* TKS Co-I

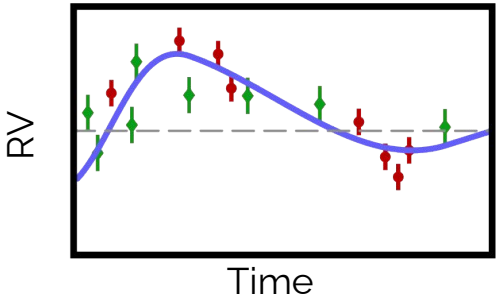
The TKS Mass Catalog

Polanski et al. (*submitted*)

Full Data Release

Nearly 10,000 radial velocity points from both Keck/HIRES and the Automated Planet Finder (APF, Lick Observatory)

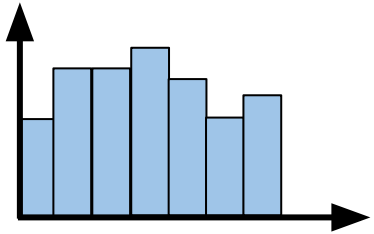
Uniform RV Analysis



We perform a standardized analysis of all survey data to produce mass constraints for 126 planets.

The largest uniform RV analysis of TESS planets to date.

Assessment of Survey Performance



Take the opportunity to assess how well our survey achieved the goals we set out 3 years ago.

RV Observations and System Architectures

Detecting Non-Transiting Planets

Resolving Orbital Eccentricity

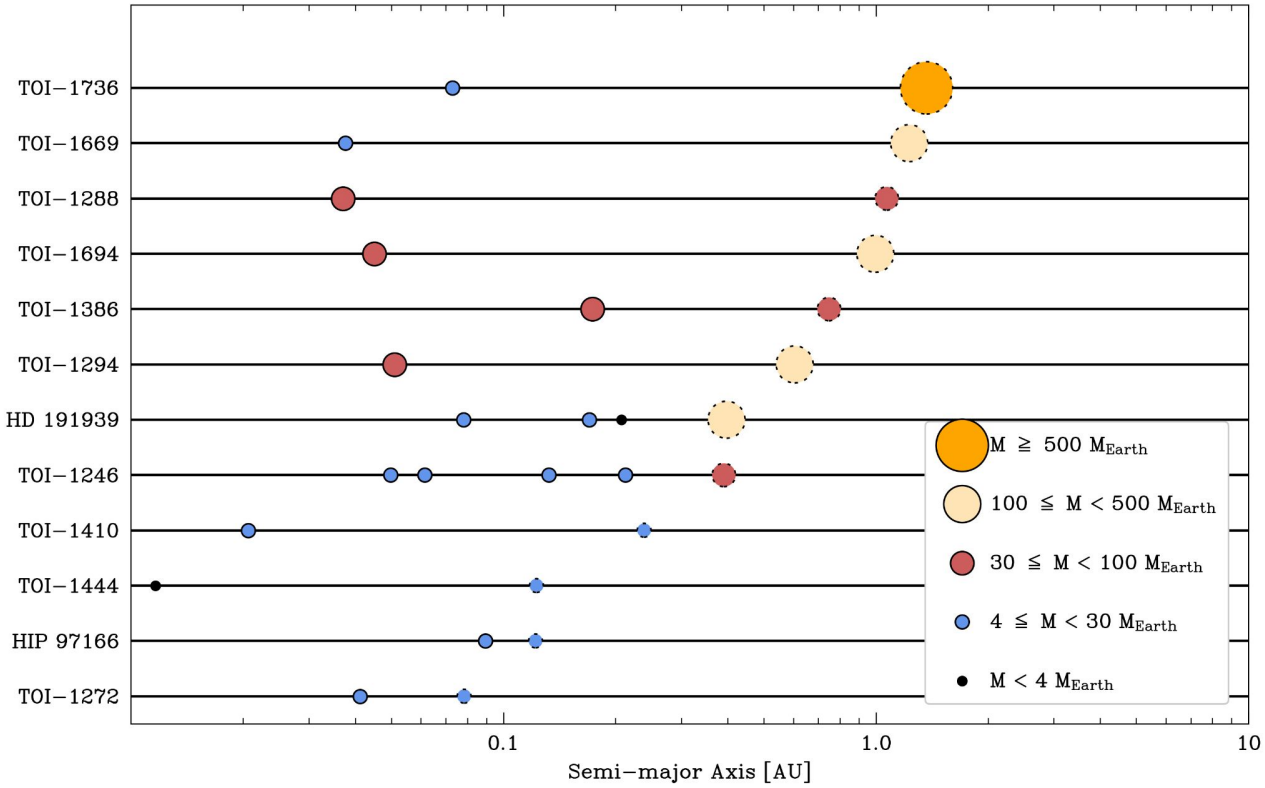
Measuring Planet Masses

RV Observations and System Architectures

Detecting Non-Transiting Planets Resolving Orbital Eccentricity Measuring Planet Masses

TKS detected non-transiting planets in 12 of the 86 TOIs surveyed.

- ➢ Almost exclusively in systems with a single transiting planet (10/12). **Systems with large mutual inclinations?**



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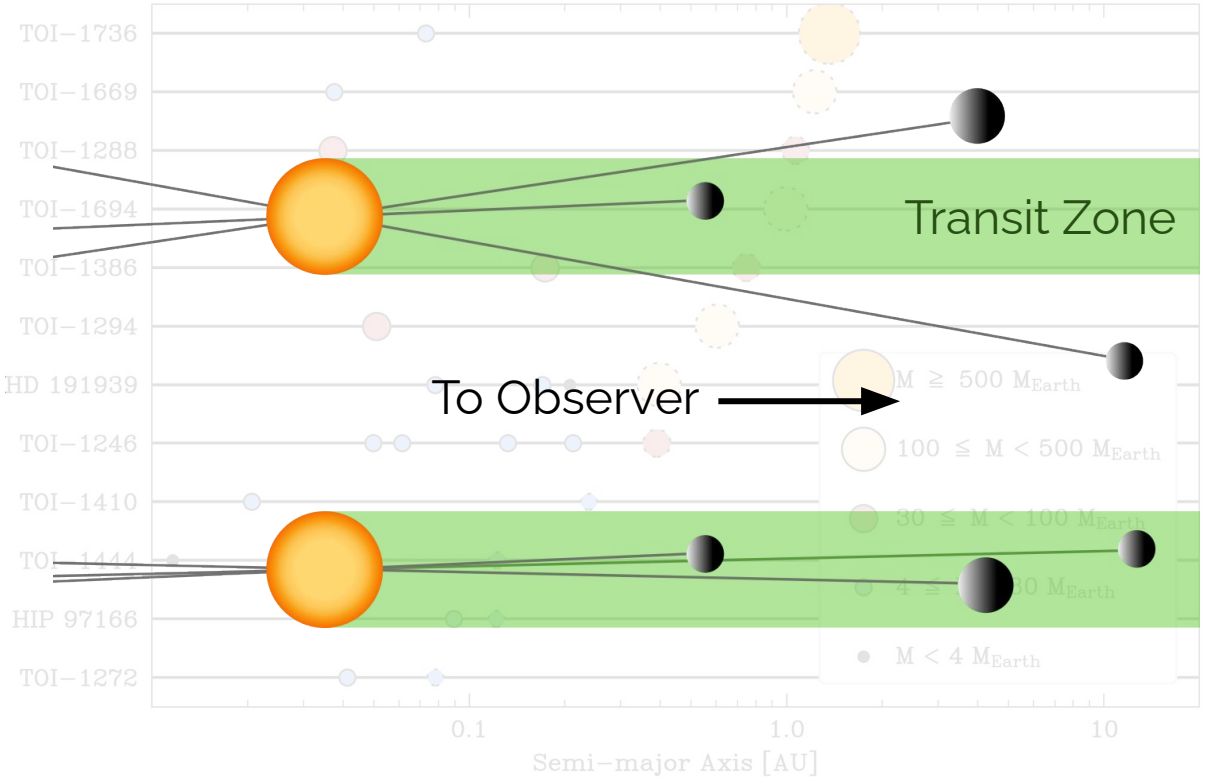

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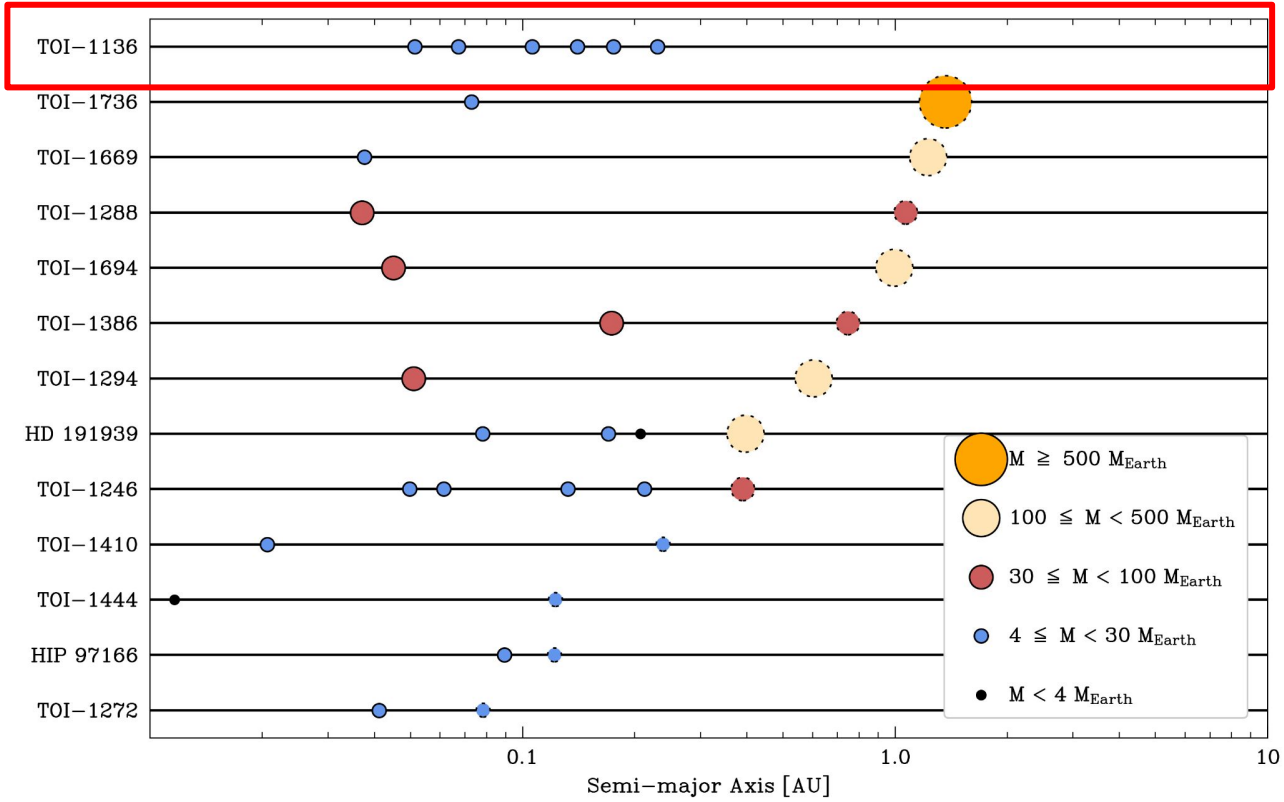

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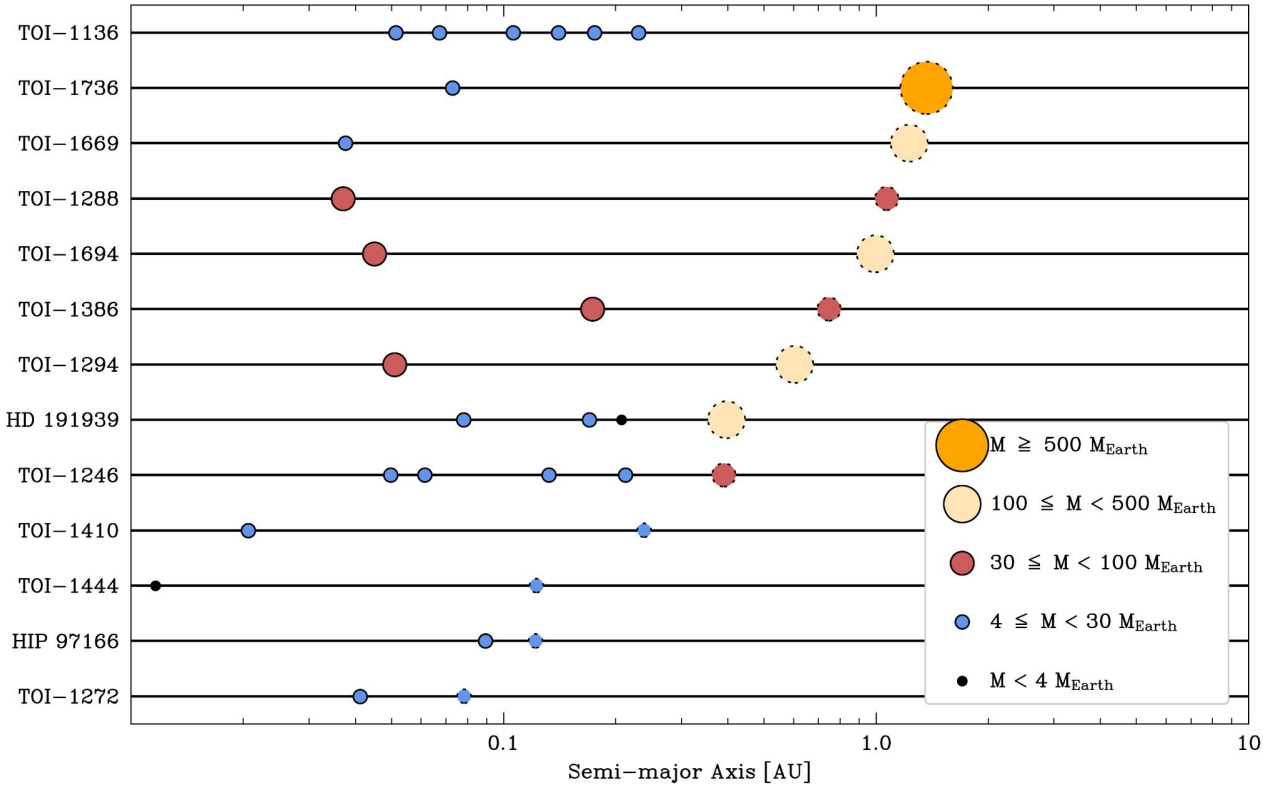
- Many of our detections are higher in mass.



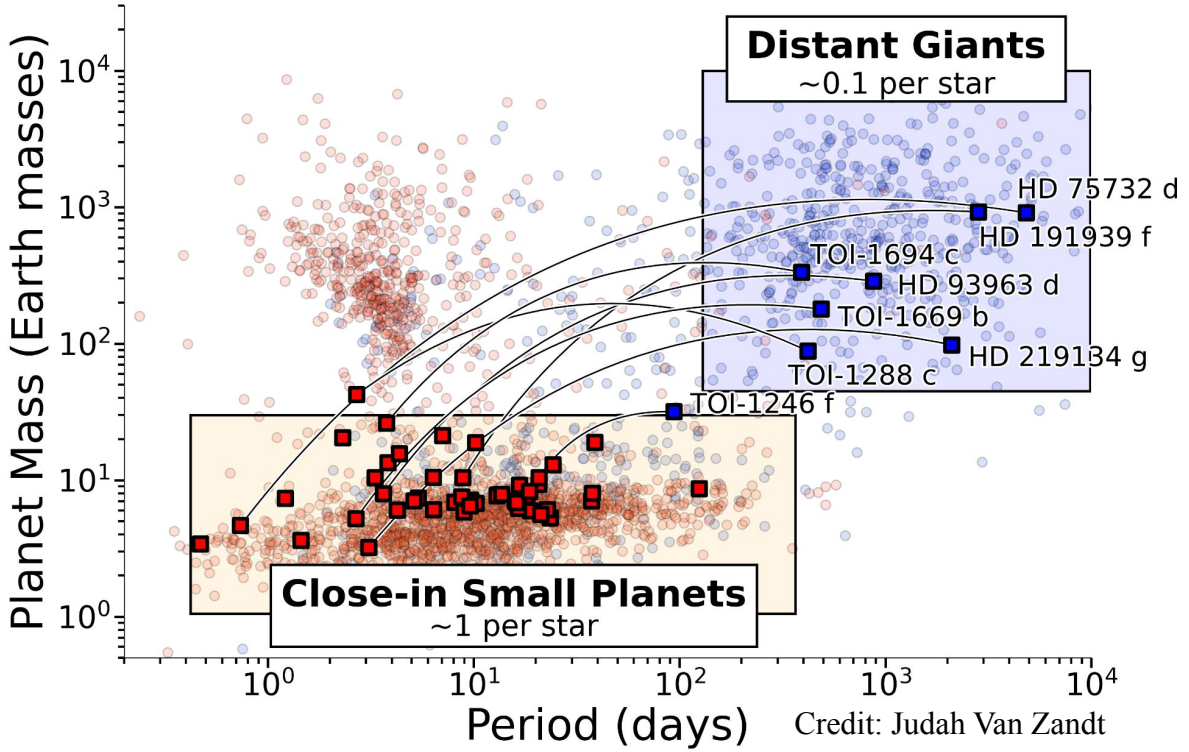
RV Observations and System Architectures

Detecting Non-Transiting Planets Resolving Orbital Eccentricity Measuring Planet Masses

Distant Giants Program:

- 47 small-planet hosts observed for with 3 years with monthly RV cadence.
- 7 Jovian analogs, 1 sub-Jovian, 7 linear trends.

Work being done by Judah van Zandt (UCLA)

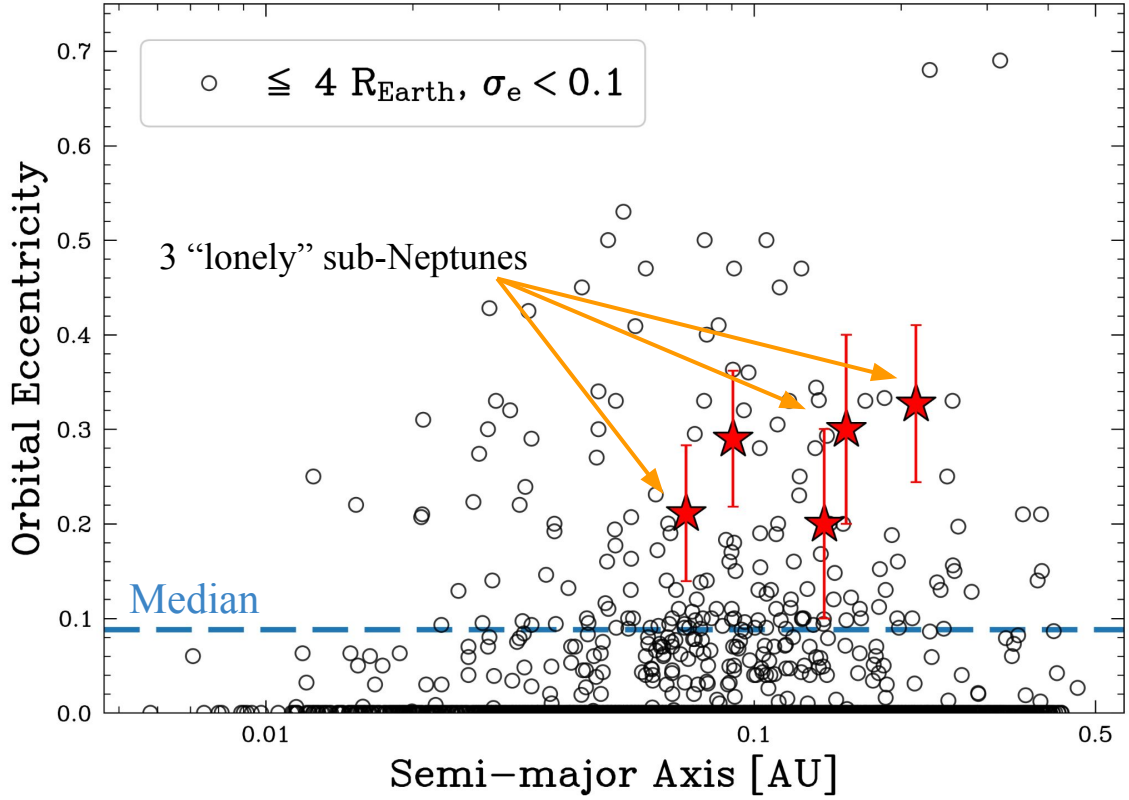


RV Observations and System Architectures

The eccentricity of planets are records of their orbital evolution.

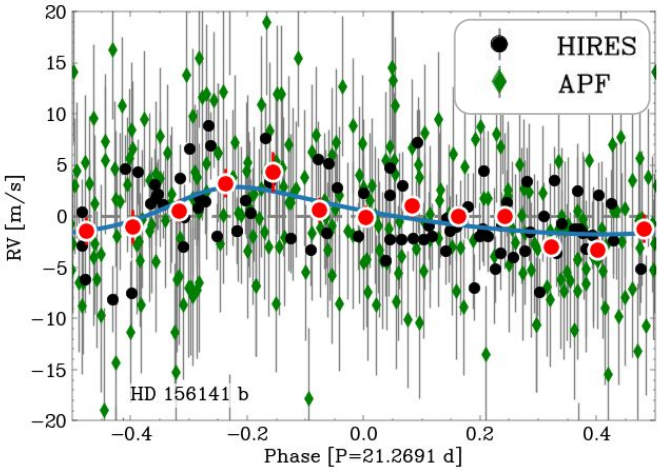
We were able to constrain non-zero eccentricities for 5 small planets (< 4 R_{Earth}):

- ➢ Two of these systems have additional sub-Neptunes
- ➢ Remaining three are "lonely" with hints of long-term trends. Indications of cold Jupiters? (see Bitsch & Izidoro 2023)

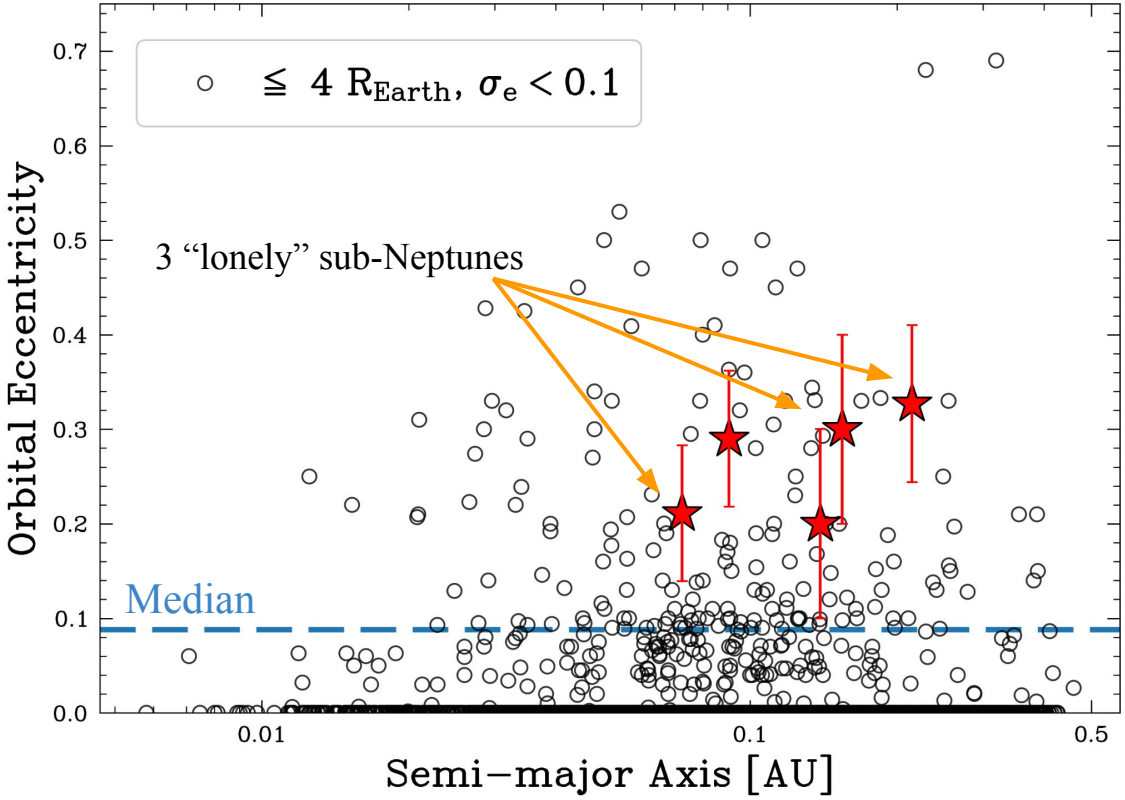


RV Observations and System Architectures

Detecting Non-Transiting Planets | **Resolving Orbital Eccentricity** | Measuring Planet Masses



High-cadence APF RVs provided tighter constraints on orbital eccentricity by providing fuller RV phase coverage.



RV Observations and System Architectures

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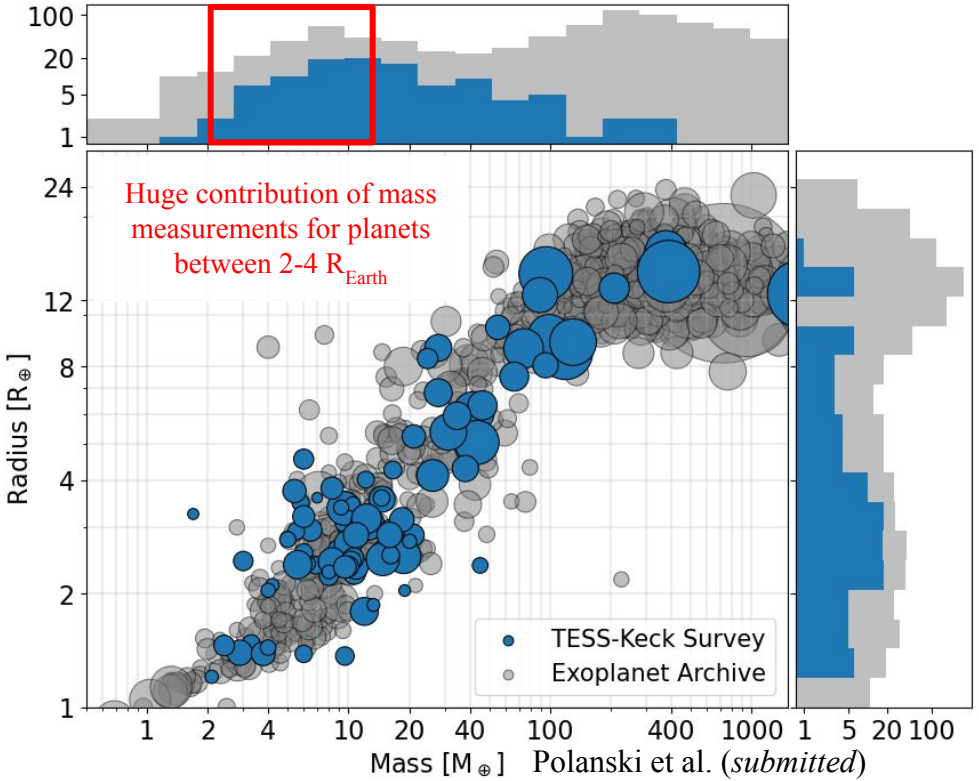

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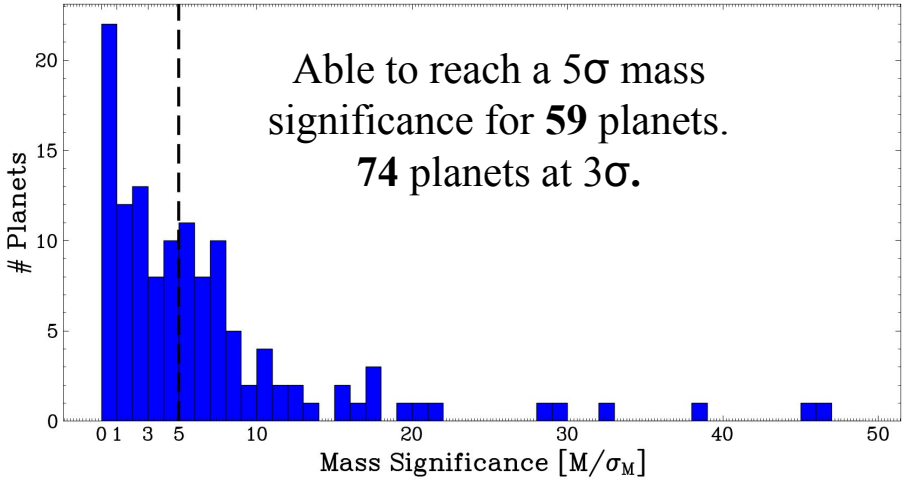

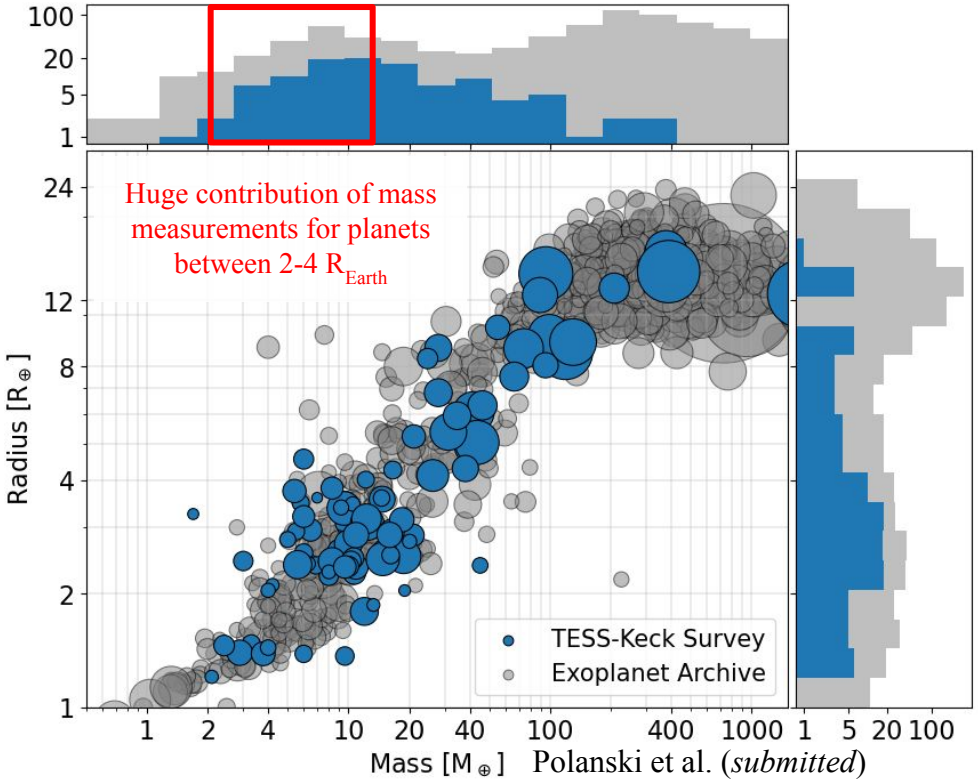

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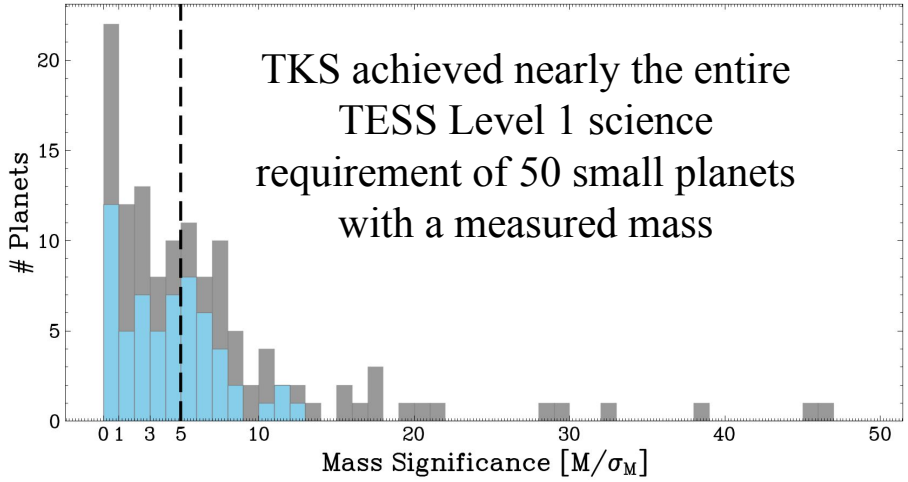
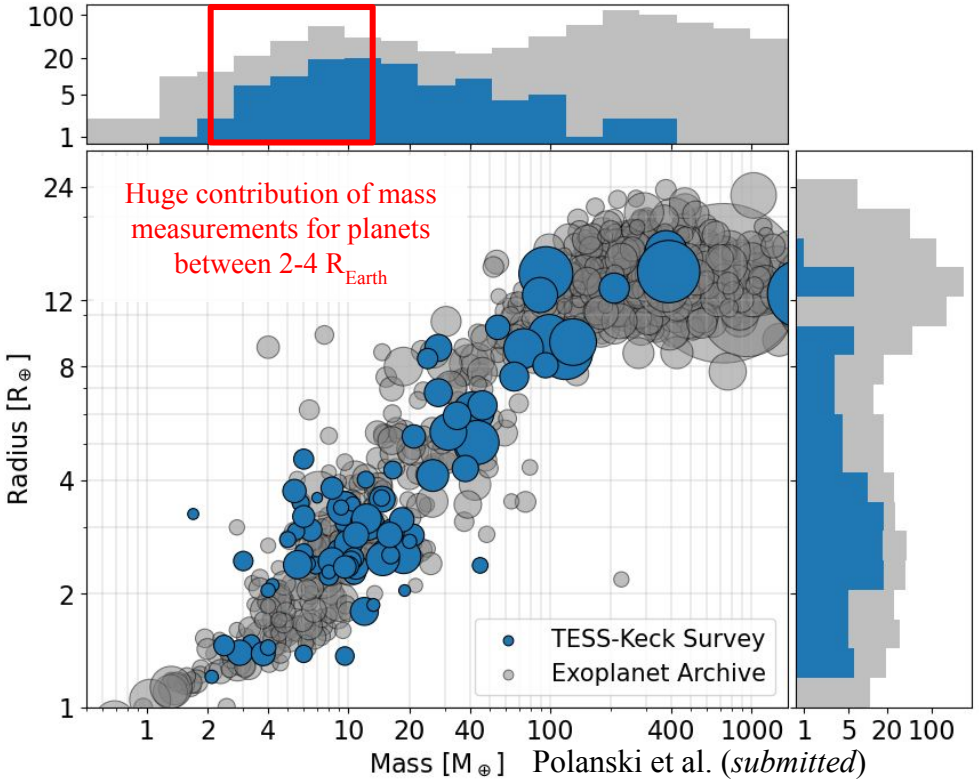
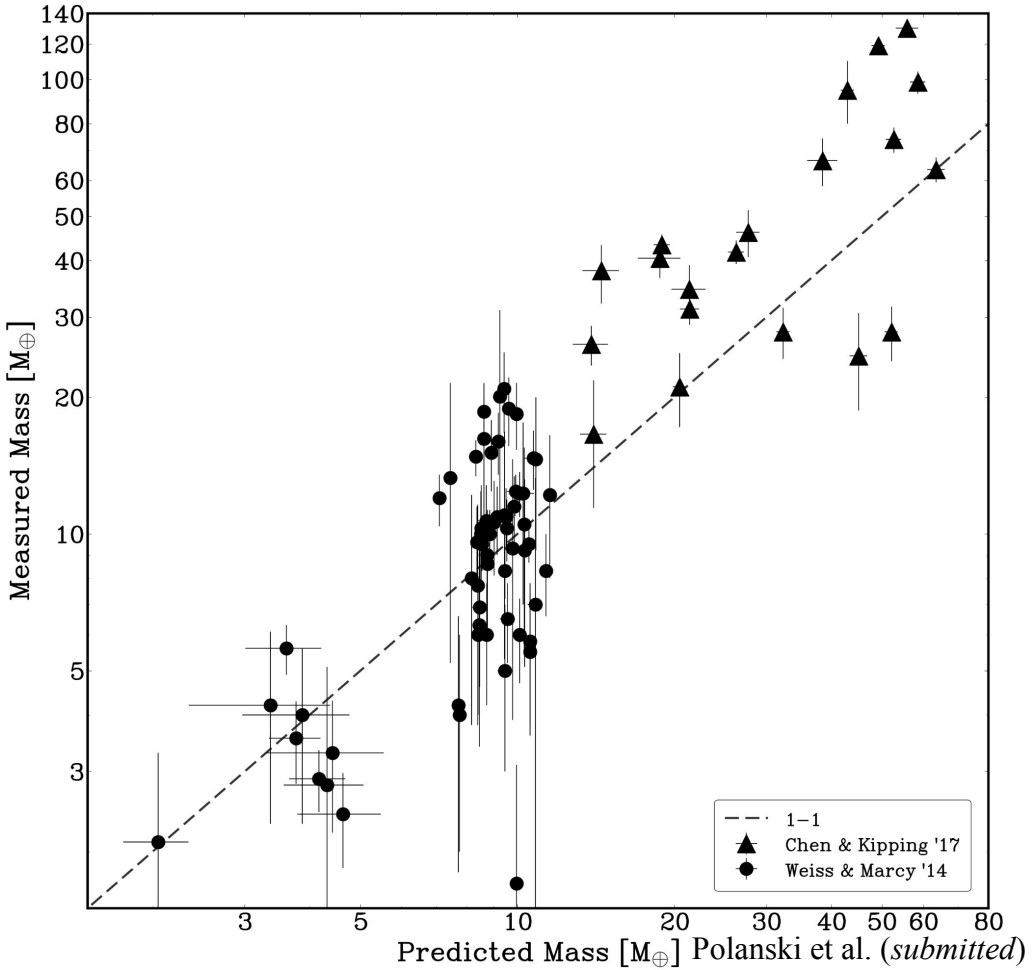




Testing Empirical Mass-Radius Relations

We can use TKS masses to test if mass-radius relations are still holding up.

- Weiss & Marcy for planets < 4 R_{Earth}
- Chen & Kipping for planets > 4 R_{Earth}



Polanski et al. (*submitted*)

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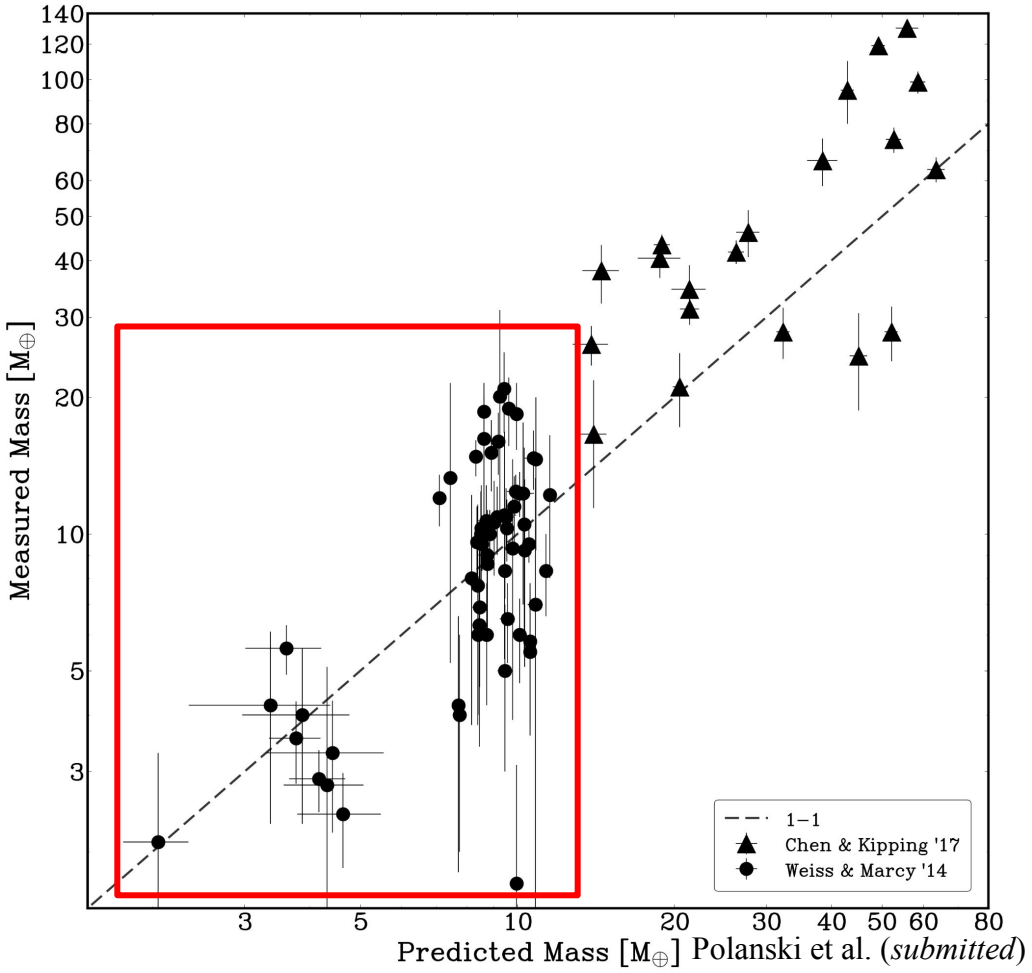
WM'14 is able to predict TESS planet masses well and with a similar amount of RMS scatter as seen in their *Kepler* sample.



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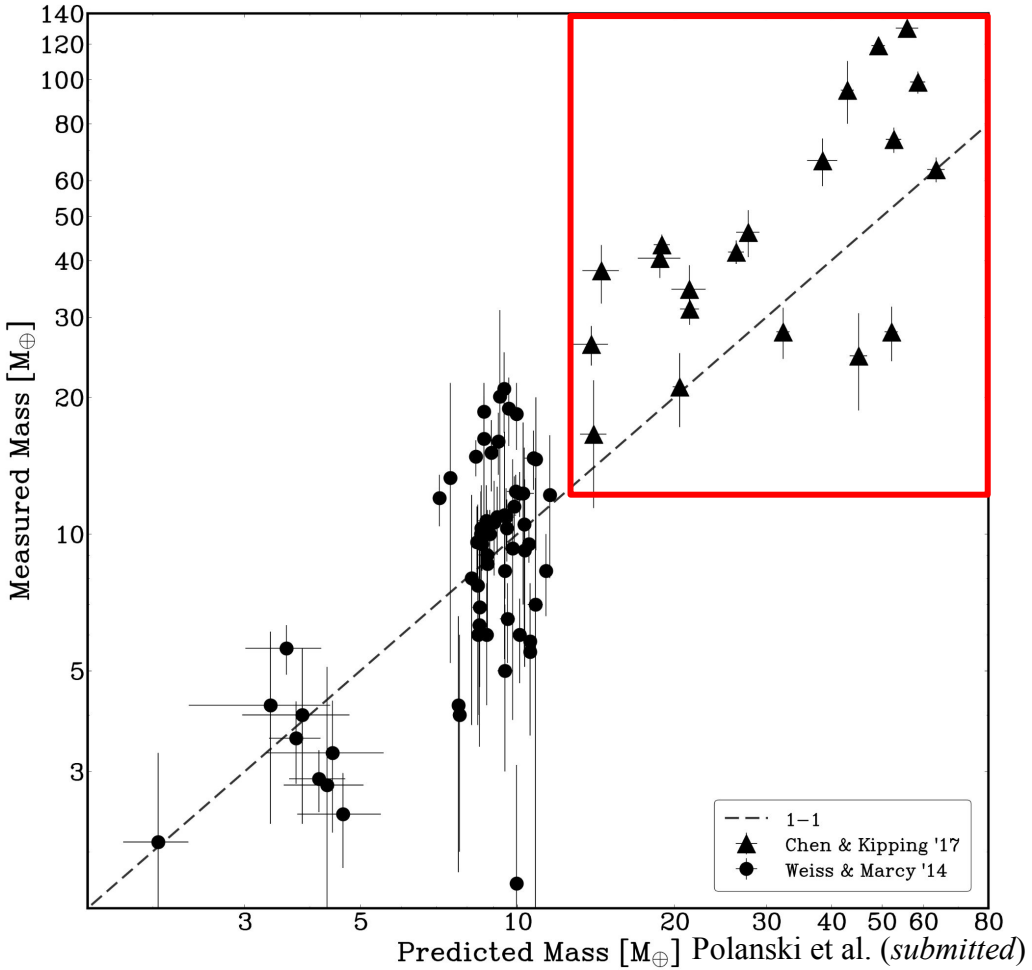
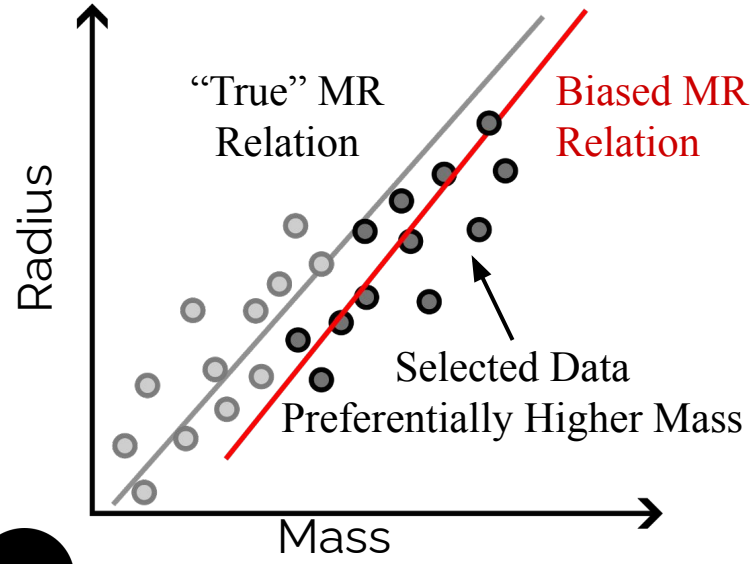
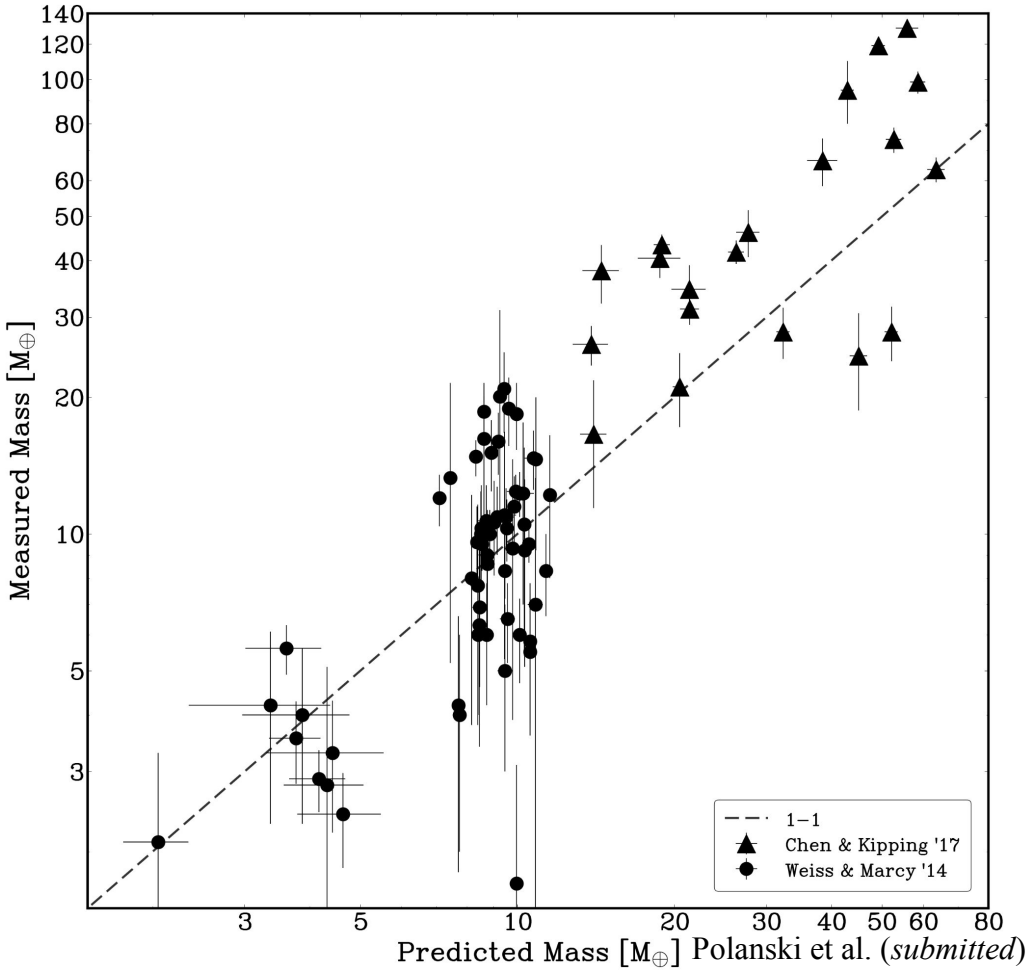
CK'17 tend to *underestimate* planet mass by a factor of ~2.



Testing Empirical Mass-Radius Relations

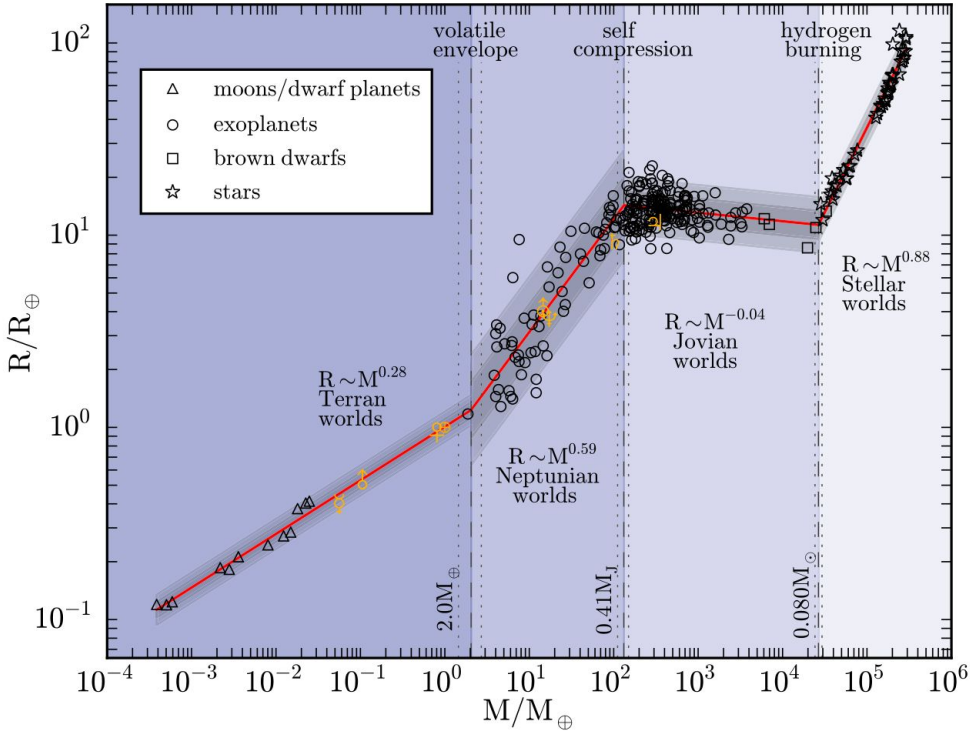
Wouldn't Chen and Kipping 2017 be suffering from publication bias?
See Burt et. al 2018 or Montet 2018





The Need for Updated Mass Radius Studies

Pre-TESS MR Relations are outdated - we're now benefiting from a massive increase in the number of well-characterized planets.



Chen & Kipping 2017

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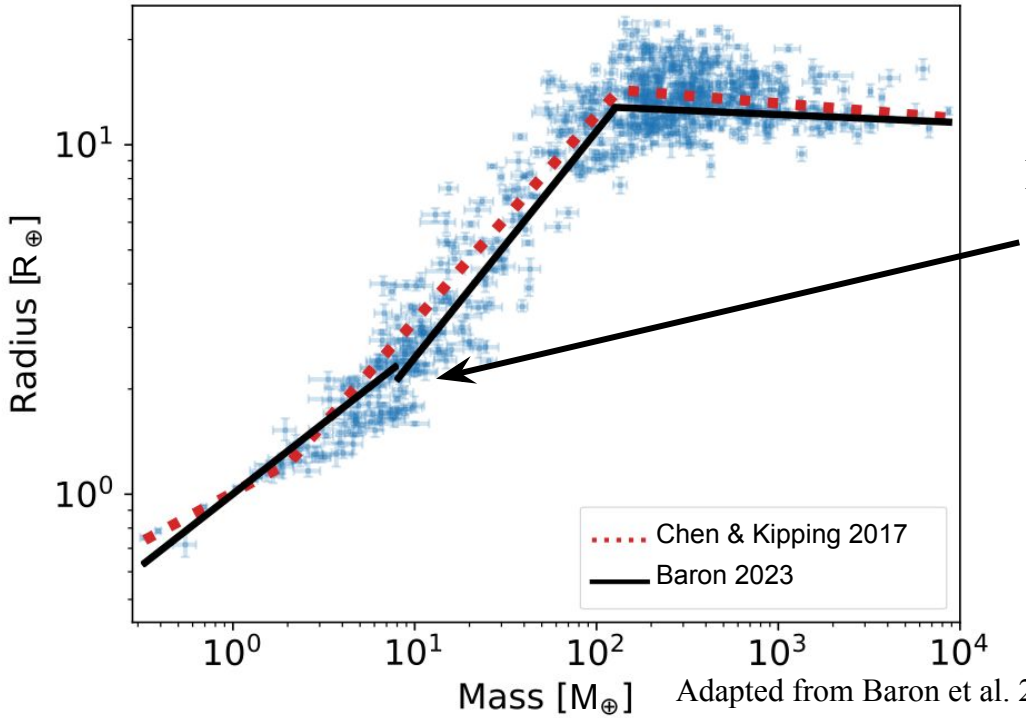
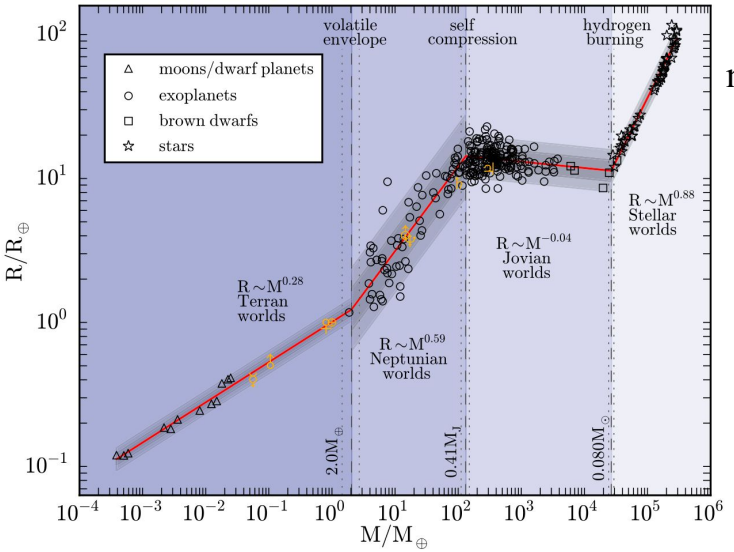


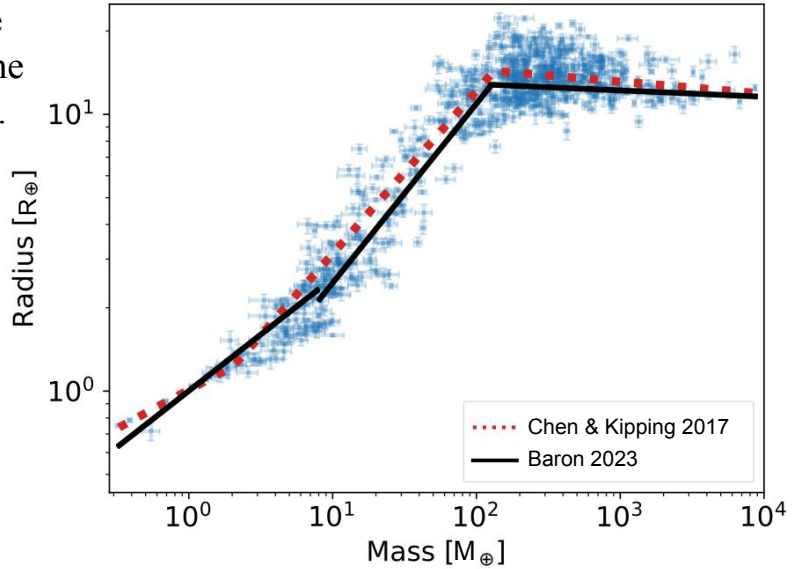
Break point at higher mass results in a steeper MR slope.

Adapted from Baron et al. 2023

The Need for Updated Mass Radius Studies



More than double the number of planets in the Neptunian range now.



We will be discovering more non-transiting planets…not just with RVs: Roman!

Multi-dimensional MR Relations, in conjunction with methods to constrain inclination, will be critical to characterizing these new planets.

Acknowledgments

Much of the data used in astronomical research, especially research on exoplanets, is obtained using observatories in Hawai'i. These telescopes reside on the mountain of Mauna Kea; a place of significant cultural importance to native Hawaiians. We are deeply grateful to have the opportunity to conduct observations from this mountain.

I also want to thank the Co-Is and many observers, especially junior researchers, who spent hundreds of hours collecting the data that made this survey possible.

Summary & Take Aways

- This is an exciting time to study exoplanet architectures - many pieces are starting to come together!
- The TESS Keck-Survey is contributing to our understanding of how systems arrange themselves:
  - 12 systems with non-transiting planets, many of which are single-transiting planet TOIs
  - Able to resolve the eccentricity of 5 additional small planets - the APF was crucial to do this!
  - **We present the TKS Mass Catalog: the Largest uniform RV analysis of TESS-discovered planets to date providing mass constraints for 126 planets.**