Study Analysis Group 8: Requirements & Limits of Future Precise Radial Velocity Measurements

Co-Chairs:

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ExoPAG 10 – 6 June 2014

SAG 8 Charter

This group will evaluate the future role of RV measurements in the exoplanet field, both scientific and programmatic, and will attempt to analyze the resources required to fulfill this goal.

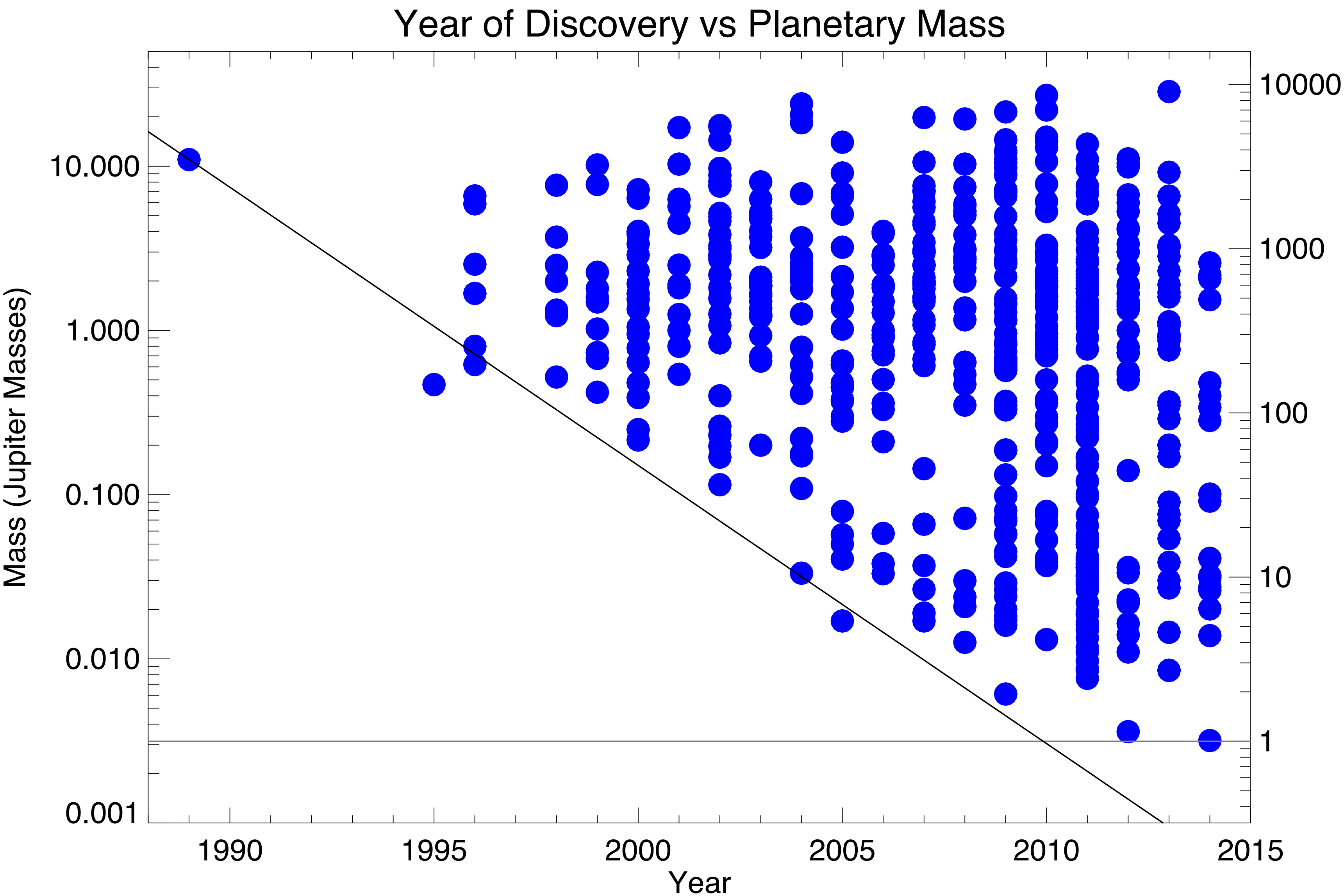
See our ExoPAG 6 presentation for the full charter

SAG 8 Sermon

- The demands on telescope time for NASA mission support, especially for systems of small planets, will exceed the number of nights available using instruments now in operation by a factor of at least several for TESS alone. Pushing down towards true Earth twins will require more photons (i.e. larger telescopes), more stable spectrographs than are currently available, better calibration, and better correction for stellar jitter.

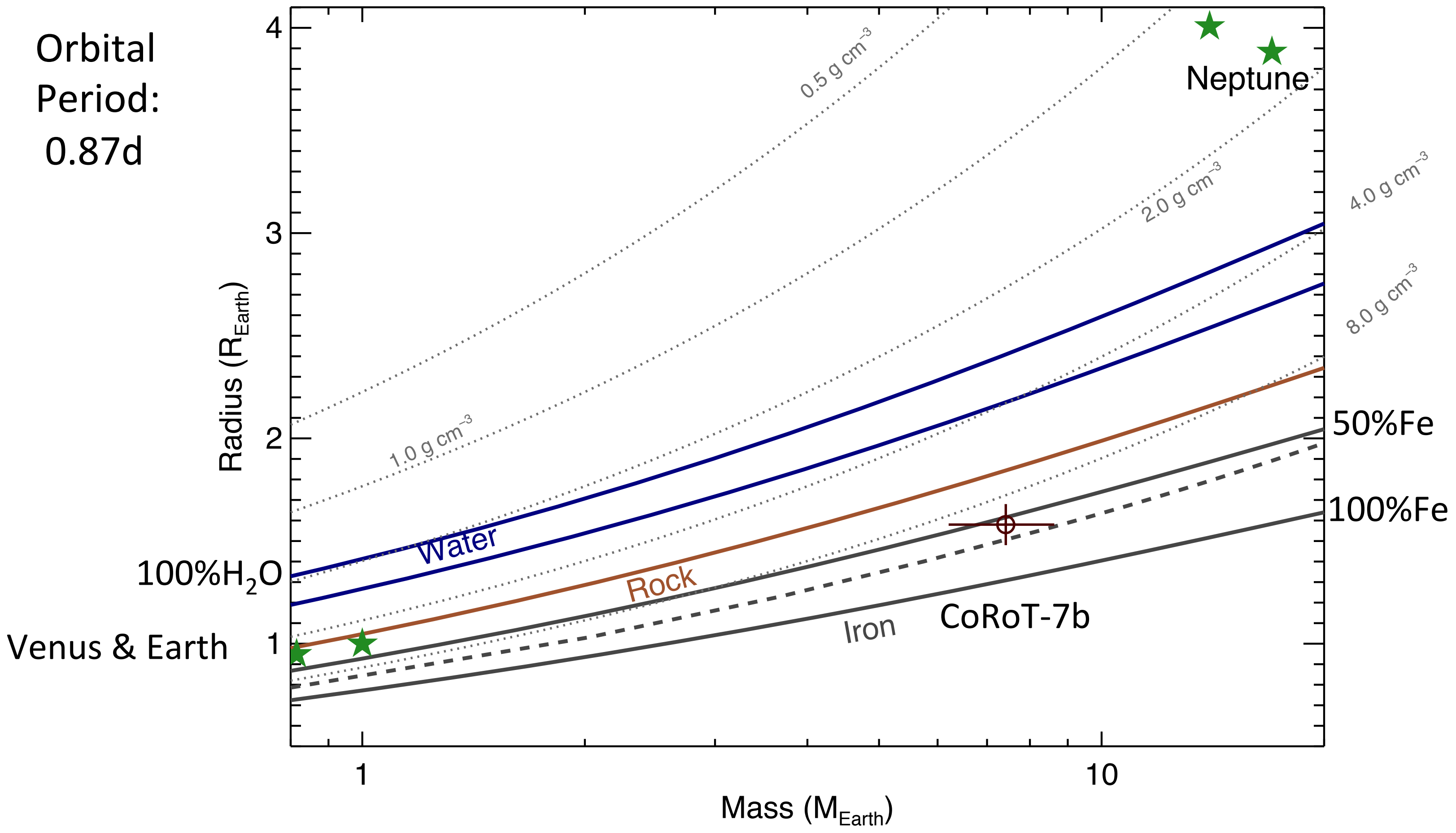
Summary of PRV support for NASA mission science objectives

Mission	Target identification for mission science yield optimization	Follow-up validation & characterization of low mass transiting exoplanets	Exoplanet mass & orbit determination
Kepler		✓	✓
TESS	✓	✓	✓
JWST	✓	✓	✓
AFTA/Coronagraph/ probe direct imaging	✓		✓
Future Flagship direct imaging	✓		✓



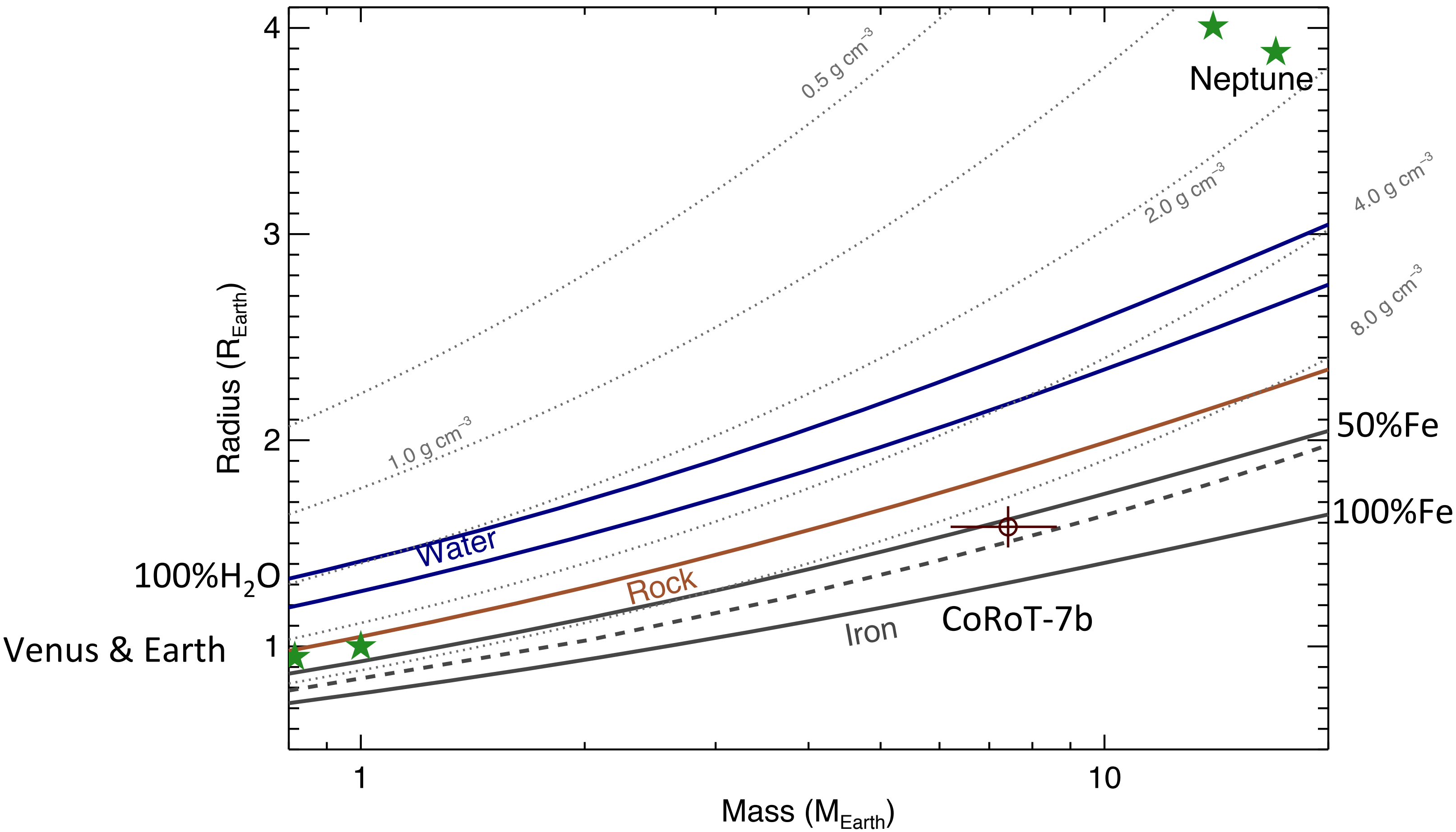
Year of Discovery vs Planetary Mass
Mass (Jupiter Masses)
10.000
1.000
0.100
0.010
0.001
Mass (Earth masses)
10000
1000
100
10
1
1990
1995
2000
2005
2010
2015
Year

Mass vs Radius Diagram for Small Planets

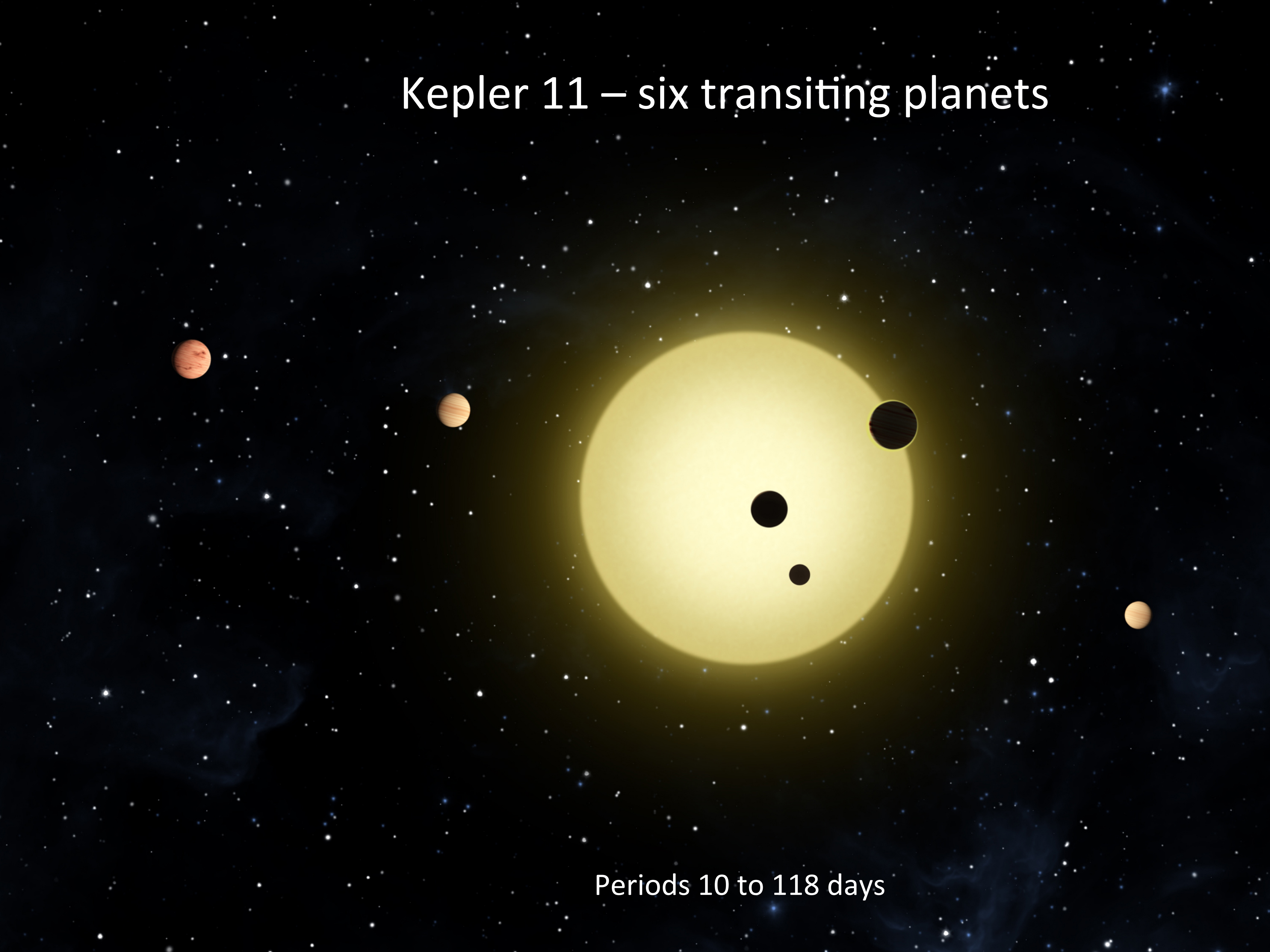


CoRoT-7b: The First Rocky Planet

CoRoT-7 is an active star with velocity jitter

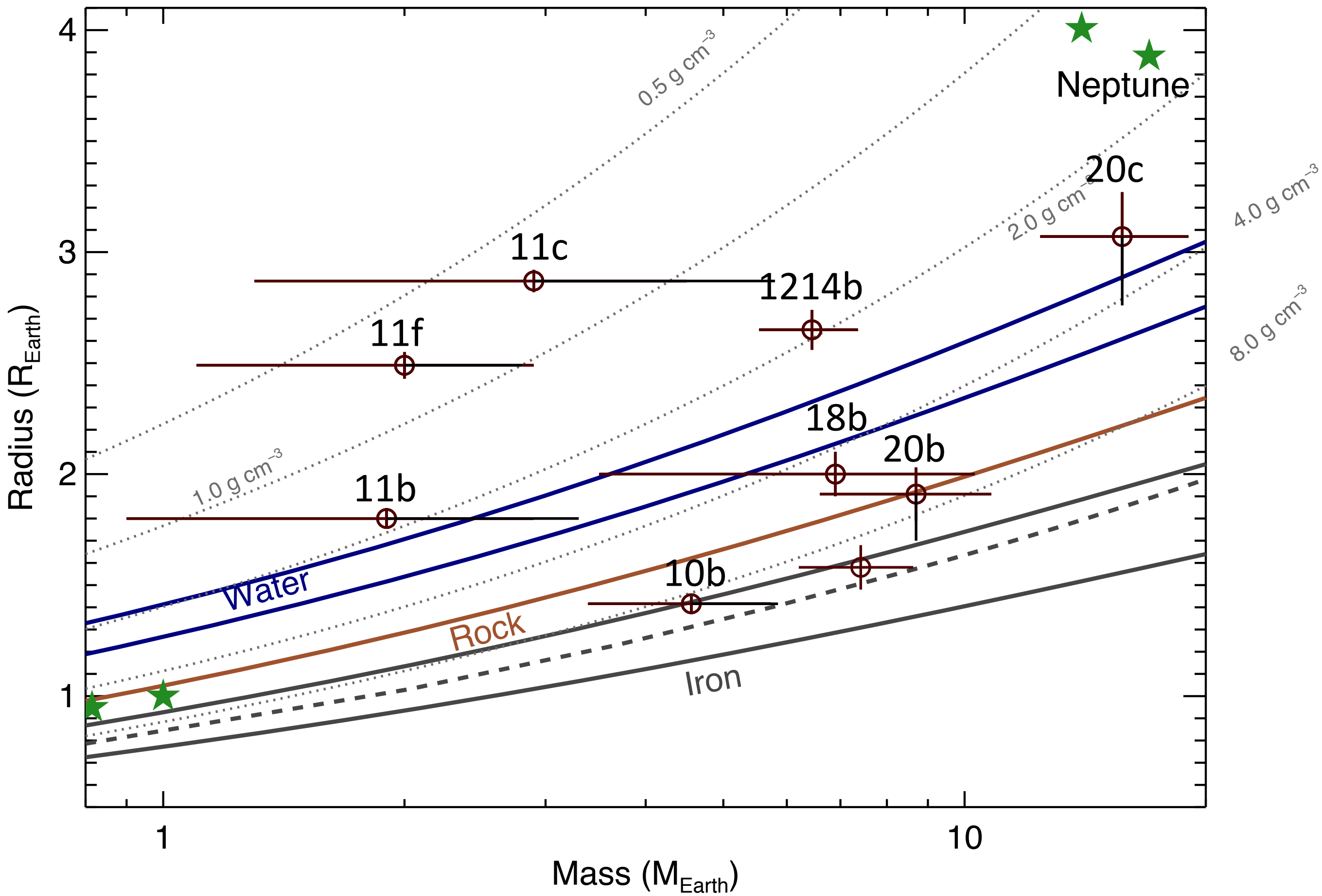


Pre-whitening for rotation (Dumusque et al. 2012; Boisse et al. 2011; Queloz et al.2009), correlation with activity (Boisse et al. 2009), velocity differences (Hatzes et al. 2010), correlation with photometry (Aigrain et al. 2012), jitter as correlated noise (Feroz & Hobson 2013, Haywood et al. 2014)


Kepler 11 – six transiting planets
Periods 10 to 118 days

Kepler-10b (rocky) and the puzzle of Kepler-11 (puffy)

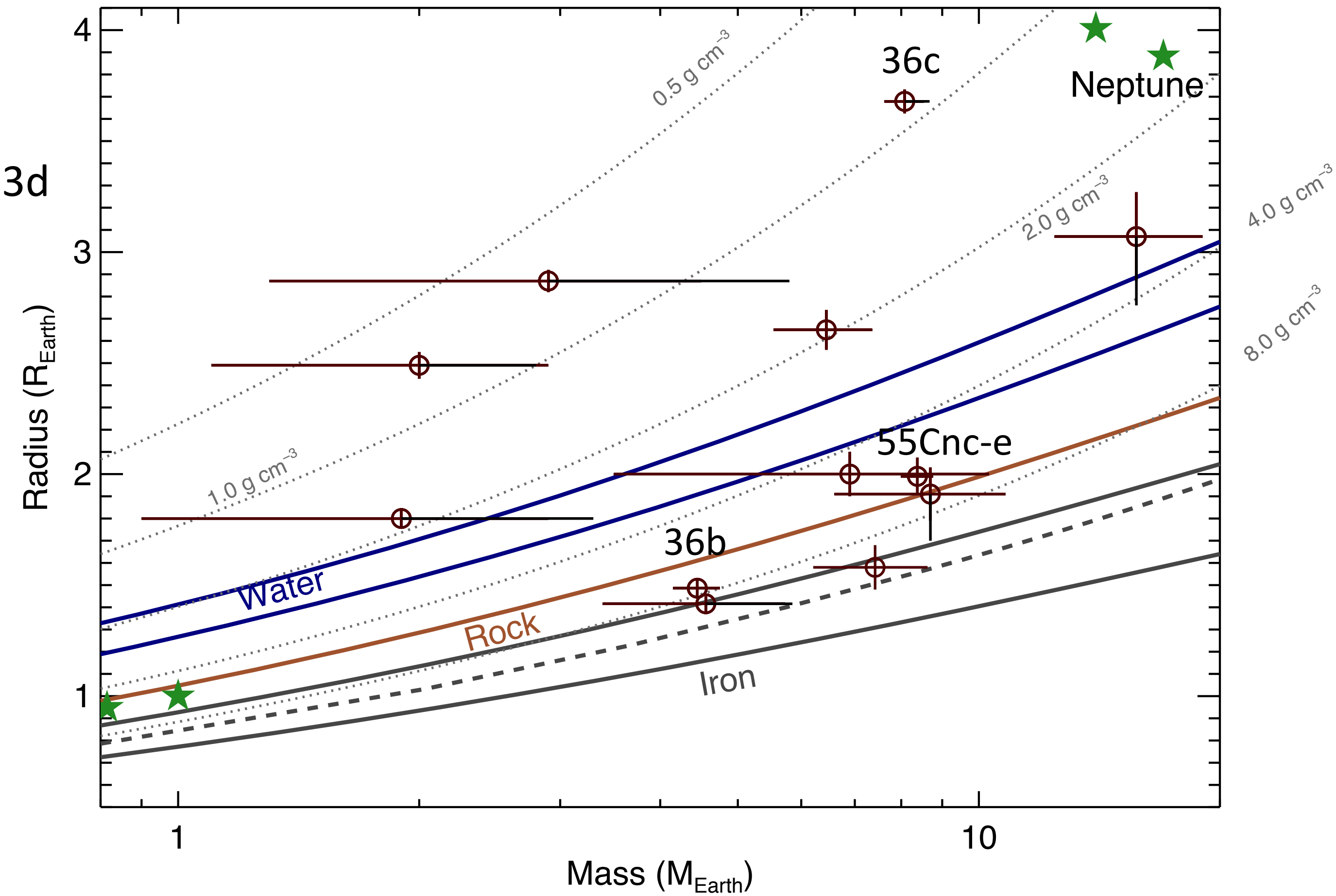
Periods:
10b: 0.84d
11b: 10.3d
11c: 13.0d
11f: 46.6d
18b: 3.5d
20b: 3.7d
20c: 10.9d
1214: 1.6d



Kepler-10: Batalha et al. 2011, ApJ 729, 27
Kepler-11: Lissauer et al. 2011, Nature 470, 53

Kepler-36b and c in 6:7 MMR, masses from TTVs
Densities differ by a factor of 8

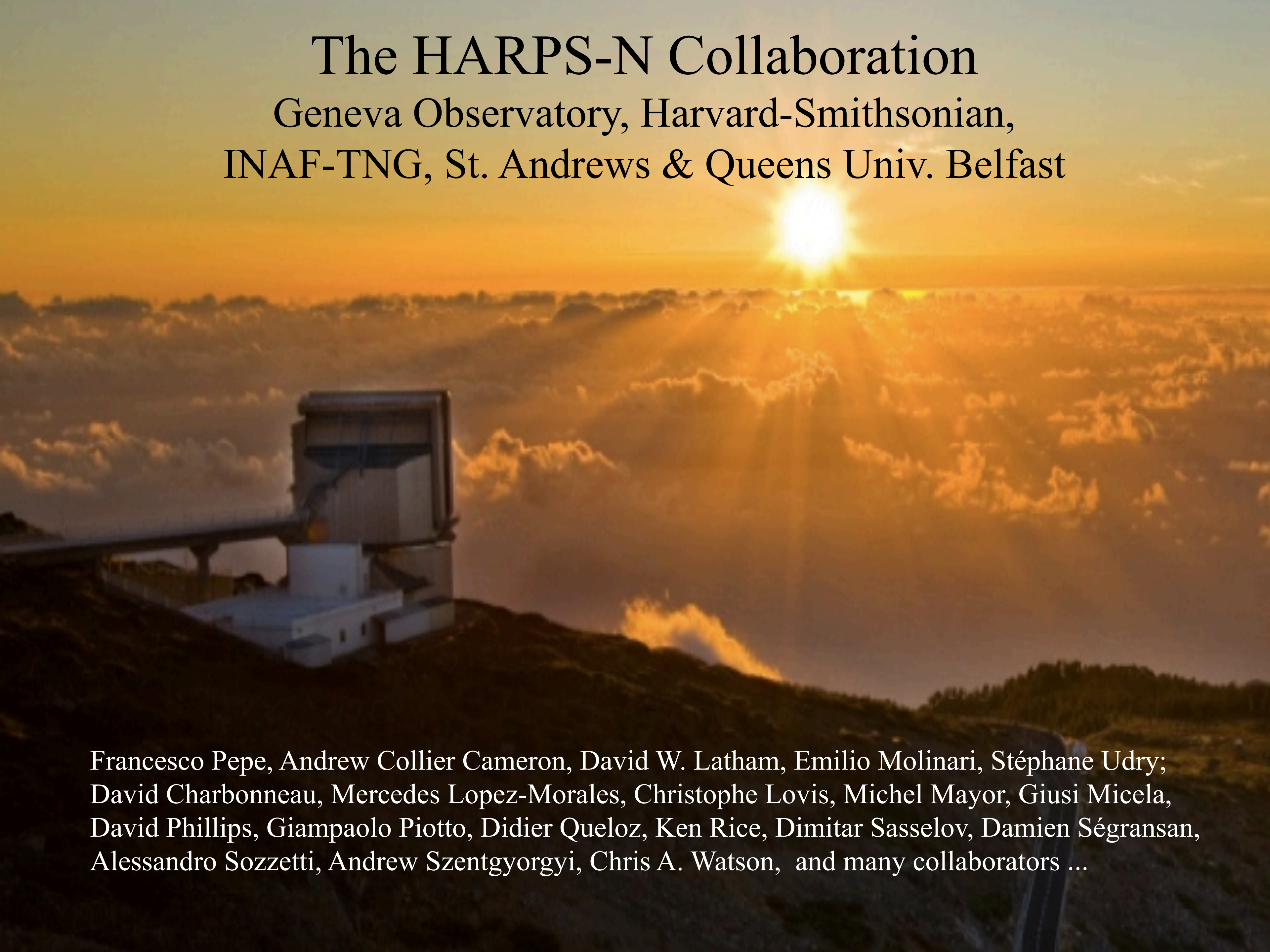
Periods:
36b: 13.8d
36c: 16.2d
55 Cnc: 0.73d



55 Cancri planetary system found first by RVs: V=6th mag

The HARPS-N Collaboration

Geneva Observatory, Harvard-Smithsonian,
INAF-TNG, St. Andrews & Queens Univ. Belfast



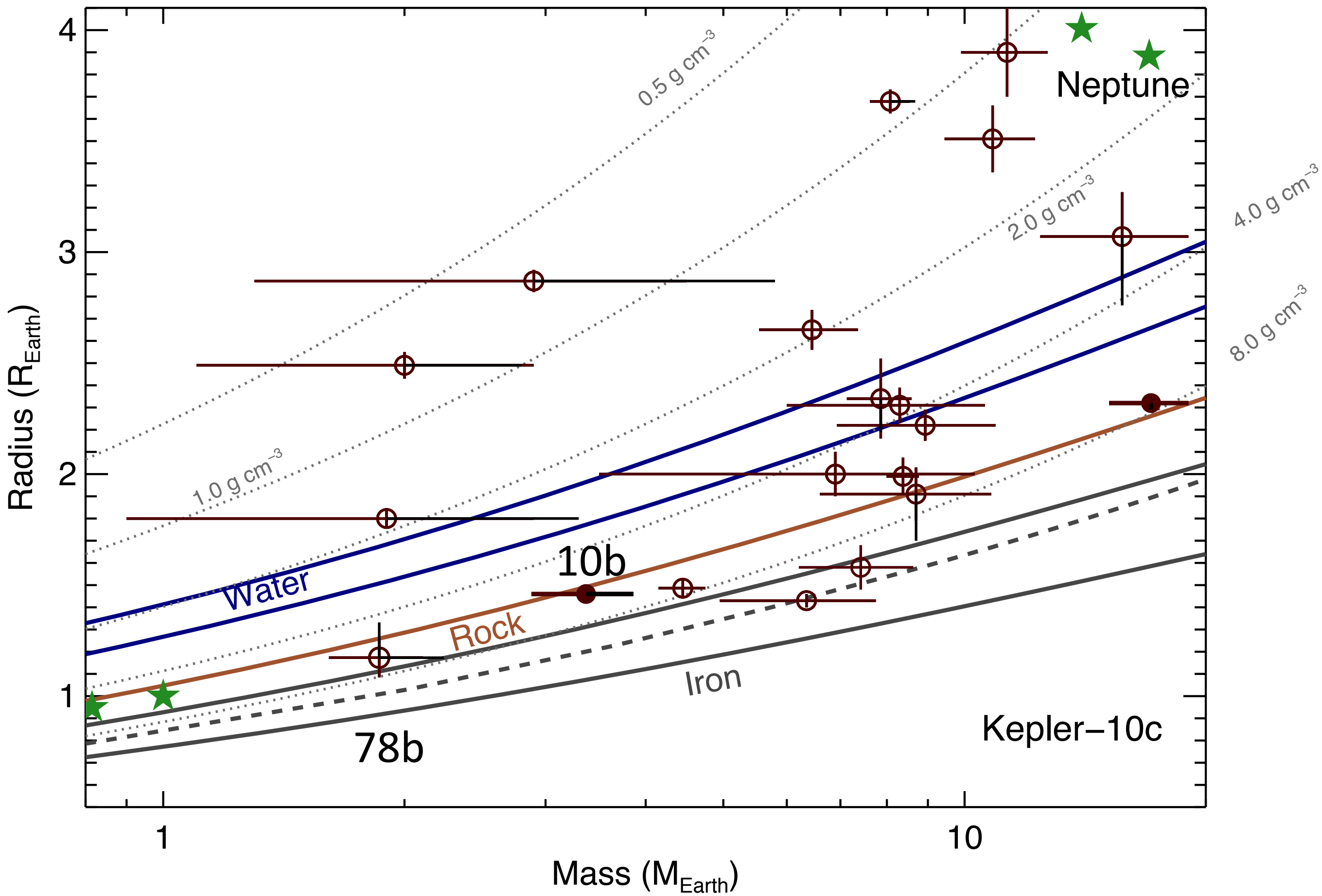
Francesco Pepe, Andrew Collier Cameron, David W. Latham, Emilio Molinari, Stéphane Udry;
David Charbonneau, Mercedes Lopez-Morales, Christophe Lovis, Michel Mayor, Giusi Micela,
David Phillips, Giampaolo Piotto, Didier Queloz, Ken Rice, Dimitar Sasselov, Damien Ségransan,
Alessandro Sozzetti, Andrew Szentgyorgyi, Chris A. Watson, and many collaborators ...

80 nights per year for 5 years:

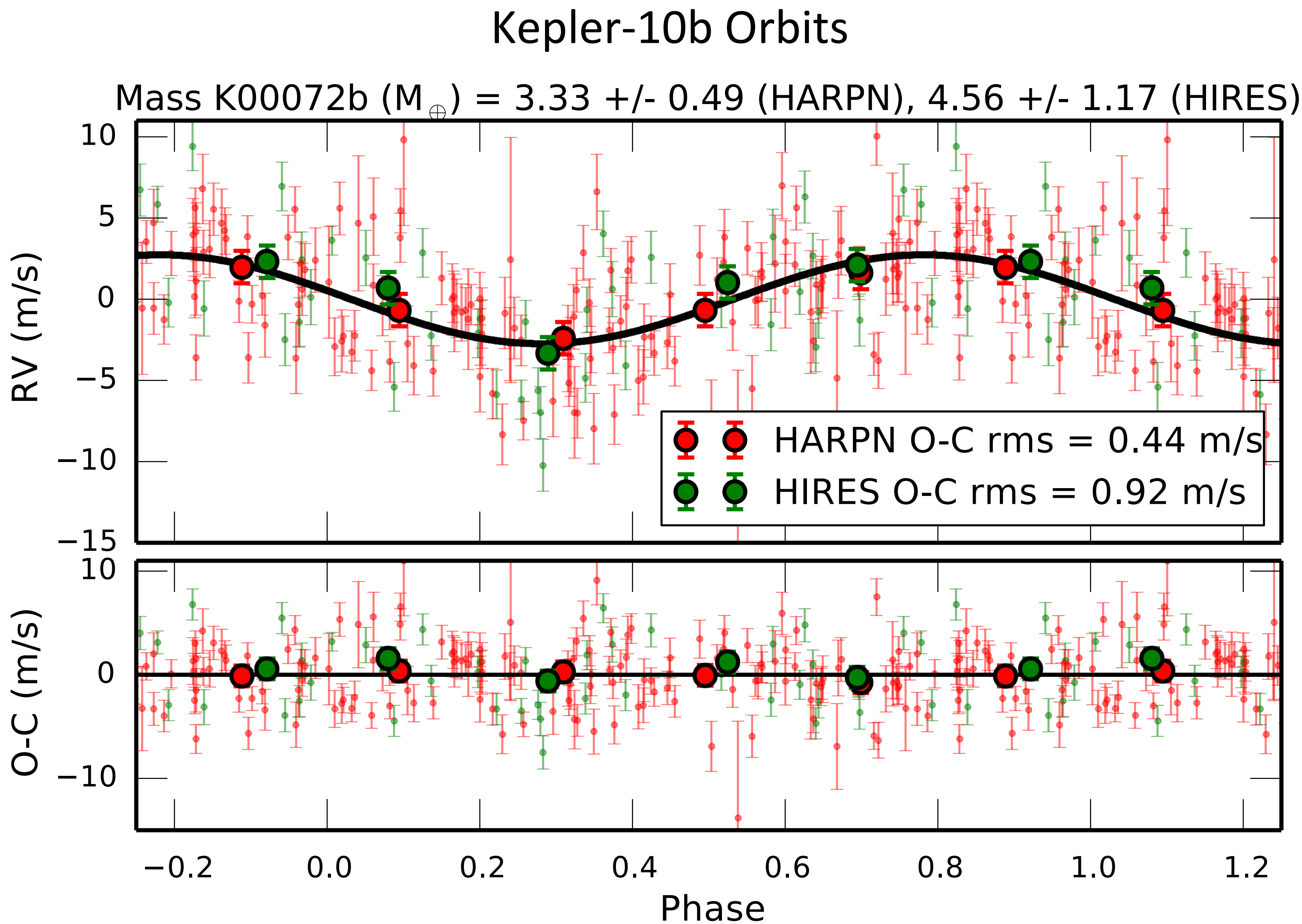
1. Masses of small Kepler planets
2. Rocky Planet Search

Kepler-78b: Observed Independently by HIRES & HARPS-N Results Agreed, Papers Submitted Simultaneously

Periods
78b: 8.5hr
10b: 20hr



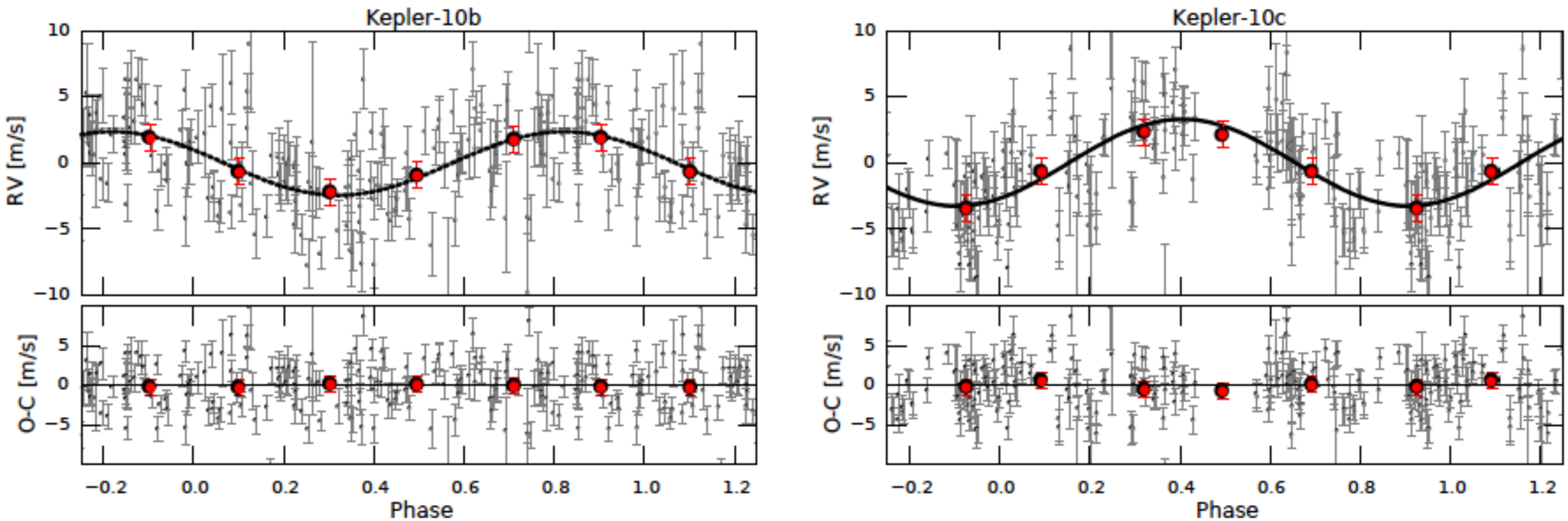
Kepler-10b: four times as many HARPS-N observations
Mass error half as big (15%), now closer to Earth-like density



Credit: Xavier Dumusque

Kepler-10b: *P* = 0.84d

Kepler-10c: *P*=45d

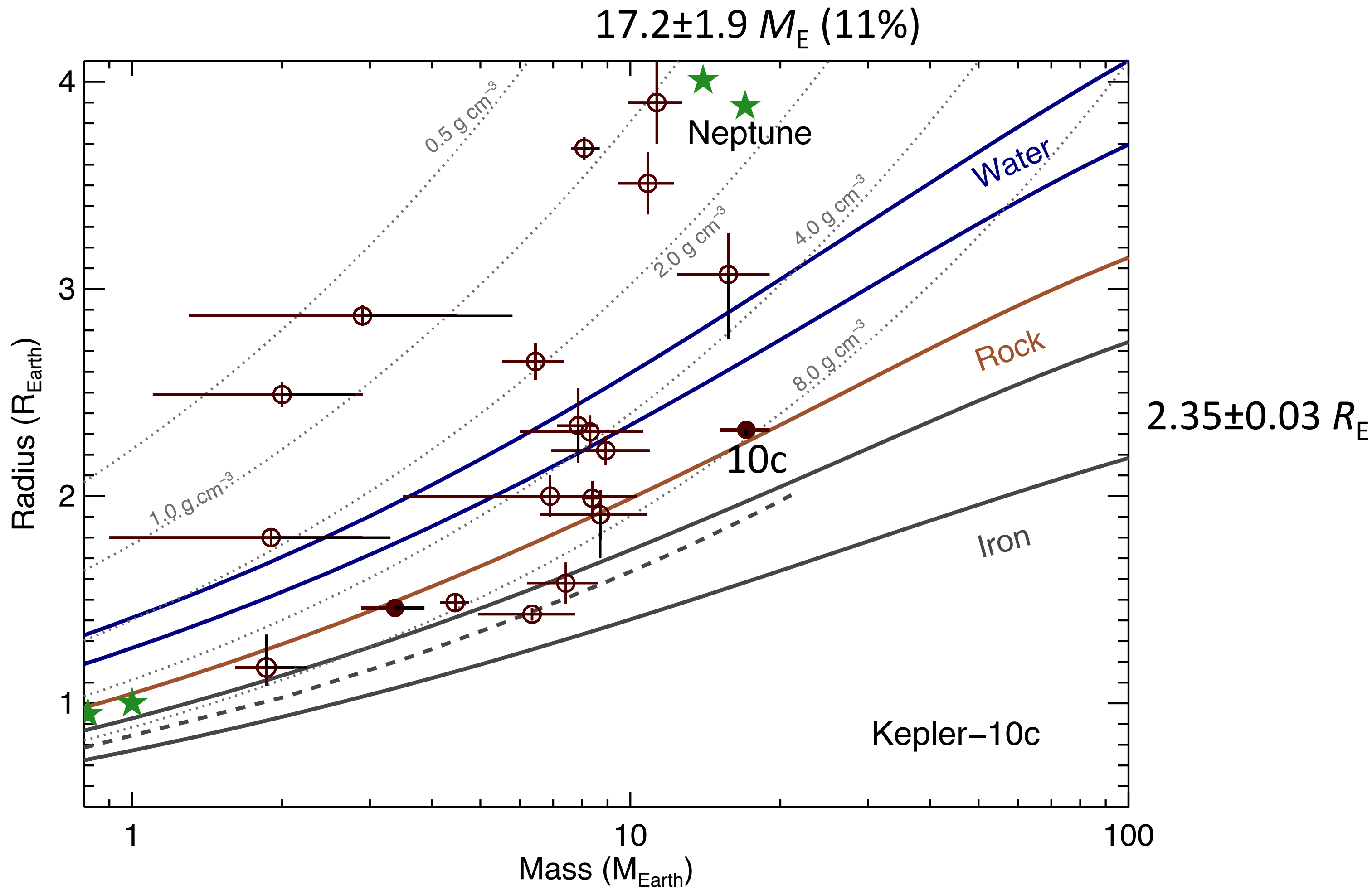


$R = 1.47\ R_E$
$M = 3.33\ M_E$ (15%)
$\rho = 5.8$ g/cc

$R = 2.35\ R_E$
$M = 17.2\ M_E$ (11%)
$\rho = 7.1$ g/cc

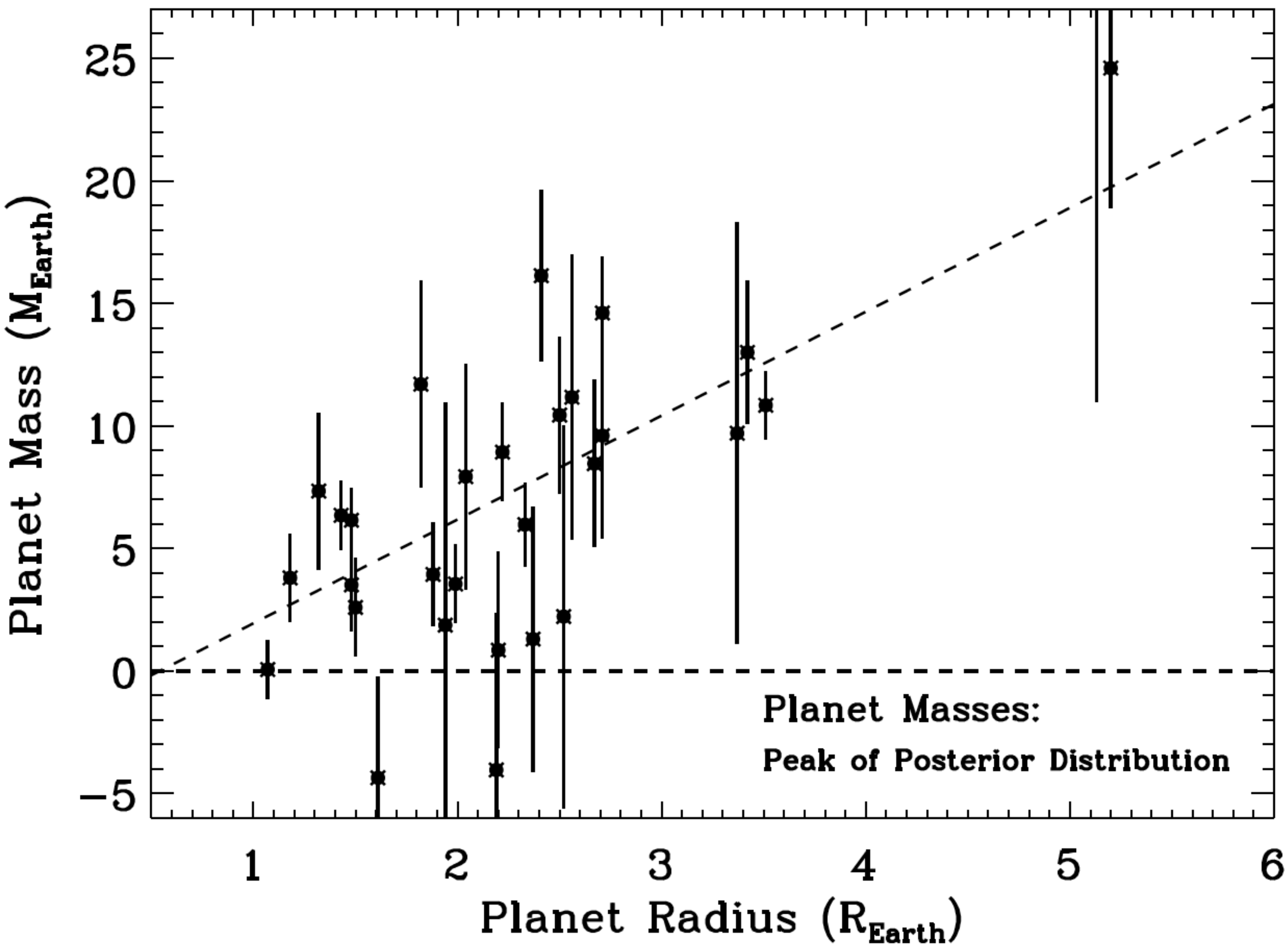
Dumusque et al. 2014, ApJ in press

Kepler-10c: a rocky planet as massive as Neptune



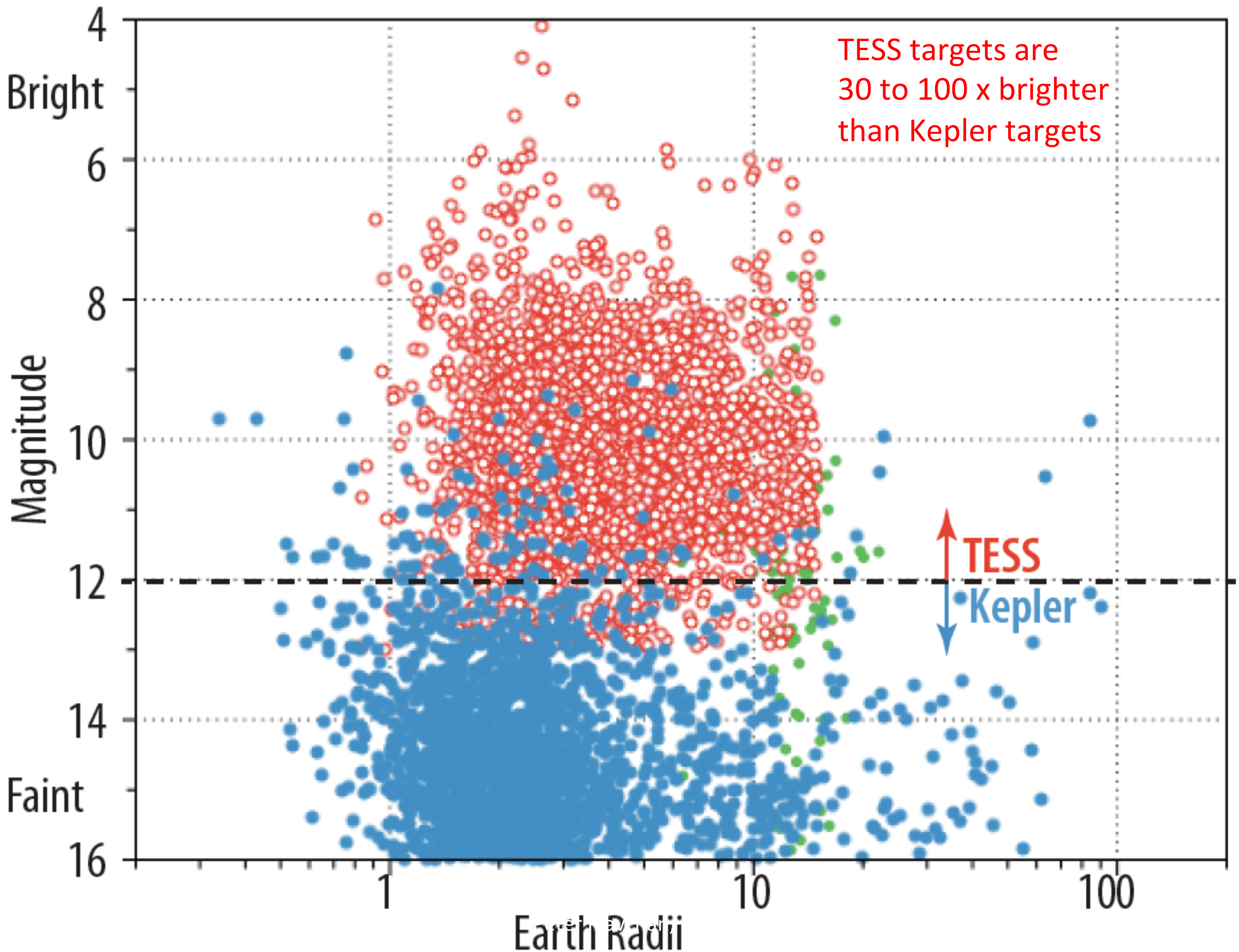
Are there more of these?

Mass vs. Radius for 30 planets followed up with HIRES on Keck1 over four seasons
16 have masses better than 2 sigma, 14 better than 1 sigma
Role of the transit ephemeris is critical



The TESS Advantage

- Planet candidates will be 30 to 100 times brighter



TESS targets are
30 to 100 x brighter
than Kepler targets
TESS
Kepler
Bright
Faint
Magnitude
4
6
8
10
12
14
16
1
10
100
Earth Radii

The TESS Advantage

- Planet candidates will be 30 to 100 times brighter
- Commitments from both HARPS & HARPS-N
  - HARPS time contingent on ESO TAC
  - HARPS-N contingent on renewed International Agreement
  - Nominally 90 nights per year dedicated to TESS follow-up
    - Only sufficient to follow up some of easiest rocky candidates
- New infrared spectrometers promise to help
  - TPF (Hobby-Eberly), Carmenes (Calar Alto), SPIRou (CFHT), etc

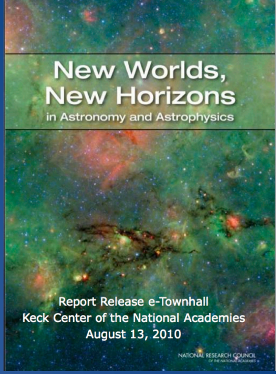
TFOP PRV Assets

MASS: Measuring Instrument	Telescope	Band	PRV [m s^{-1}]	Available	Leads	Observing Time [hr]	Commitment	Funding
HARPS-N	TNG 3.6m N	Opt	0.7	Now	Latham, Sasselov	960	Collaboration	Partial
HARPS	ESO 3.6m S	Opt	0.7	Now	Udry, Pepe	720	TACs	Collab
SOPHIE	OHP 2m N	Opt	3	Now	Bouchy	1500	TACs	Collab
LCOGT	1-m network S	Opt	3	2015	Brown	720	Committed	Partial
HDS	Subaru 8.2m N	Opt	3	Now	Narita	100	TACs	Collab
IRD	Subaru 8.2m N	IR	1-3	2015	Narita	100	TACs	Collab
HRS	HET 9.2m N	Opt	3	2014	Cochran	200	TACs	Collab
CARMINES	Calar Alto 3.5m N	OPT/IR	1-3	2015	Quirrenbach	200	TAC	Collab
ESPRESSO	VLT 8.2m S	OPT	0.1	2016	Pepe, Udry	?	TACs	Collab
SPIRou	CFHT 3.6m N	OPT/IR	1-3	2017	Doyon	?	TACs	Collab
SPIRou	NTT 3.6m S	Opt/IR	1-3	2017	Hebrard	?	TACs	Collab
					Total Hours ≃	**4500**		

Three Hypothetical Scenarios
To support NASA missions with PRVs

- Dedicated 4-m with optical HARPS-like 50 cm/s
  - Masses and densities for TESS transiting planets
  - PRV survey of candidates for AFTA-type mission
- Access to 10-m with 5 cm/s performance
  - Push towards orbits for true Earth twins
  - Requires much better correction of stellar jitter
- Access to 4-m with infrared 50 cm/s
  - Masses for habitable planets around M dwarfs

Astro 2010 NWNH Report



- "The first task on the ground is to **improve the precision radial velocity** method by which the majority of the close to 500 known exoplanets have been discovered. … Using existing large ground-based or new dedicated mid-size ground-based telescopes equipped with a **new generation of high-resolution spectrometers in the optical and near-infrared**, a velocity goal **of 10 to 20 centimeters** per second is realistic." – page 7-8
- To prepare for direct imaging, "**NASA and NSF should support an aggressive program** of ground-based high-precision radial velocity surveys of nearby stars to identify potential candidates" - page 1-8

AFTA-type Coronograph Mission

- PRV survey of nearest stars for best targets
  - DRM studies underway in SAG 9
    - For known RV planets
- Long-term PRV monitoring required
  - Very high precision and stability needed
  - Volunteers from the community unlikely
    - Many potential targets have been observed, but not published
    - Can those results be harvested?
    - How to merge results from different instruments?

SAG 8 Status

- Slow progress this spring
- Draft executive summary
- Detailed outline
- Lots of draft text, but many place holders
  - Peter has enlisted “volunteer” experts
    - Asks for 30 June submission deadlin
- It’s already too long