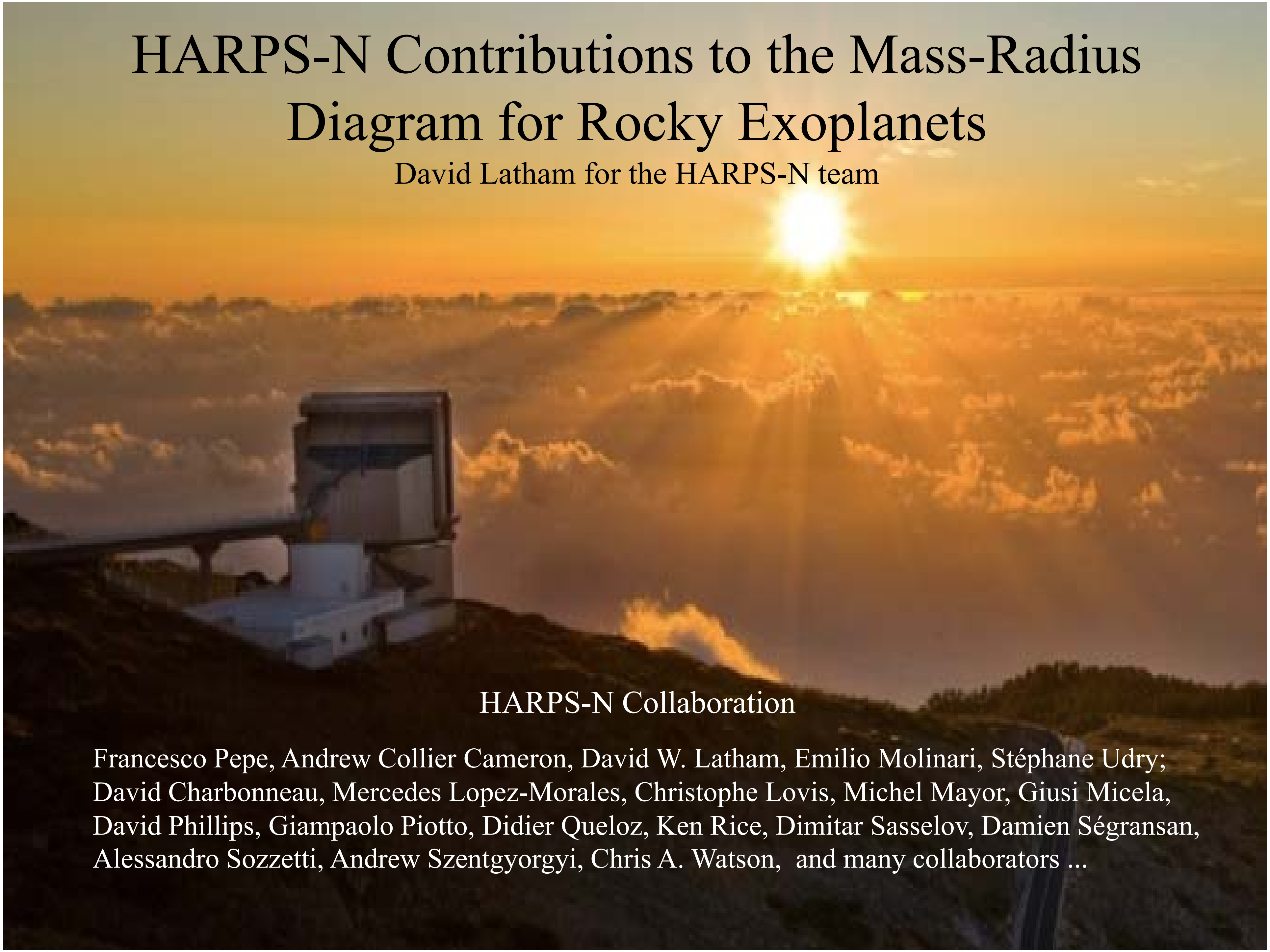
HARPS-N Contributions to the Mass-Radius Diagram for Rocky Exoplanets

David Latham for the HARPS-N team



HARPS-N Collaboration

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 ...

The Legacy of Kepler

- Planets smaller than 4 Earth radii are common
  - Most FGK dwarfs host 1.25 – 3.5 R_E planets
- Many compact/flat systems of small planets
  - Photo-dynamical and TTV analyses are powerful
- Circumbinary planets are not rare
  - Star and planet formation
- Stellar astrophysics: four-year light curves
  - Asteroseismology, stellar variability, …
- Inspiration for future missions

Un-fulfilled Promise

- Discovery/characterization of true Earth twins
  - Frequency of Earth-size planets "η Earth"
- Targets for spectroscopy of atmospheres
- Composition and structure of "rocky" planets
  - Masses and bulk properties of small planets

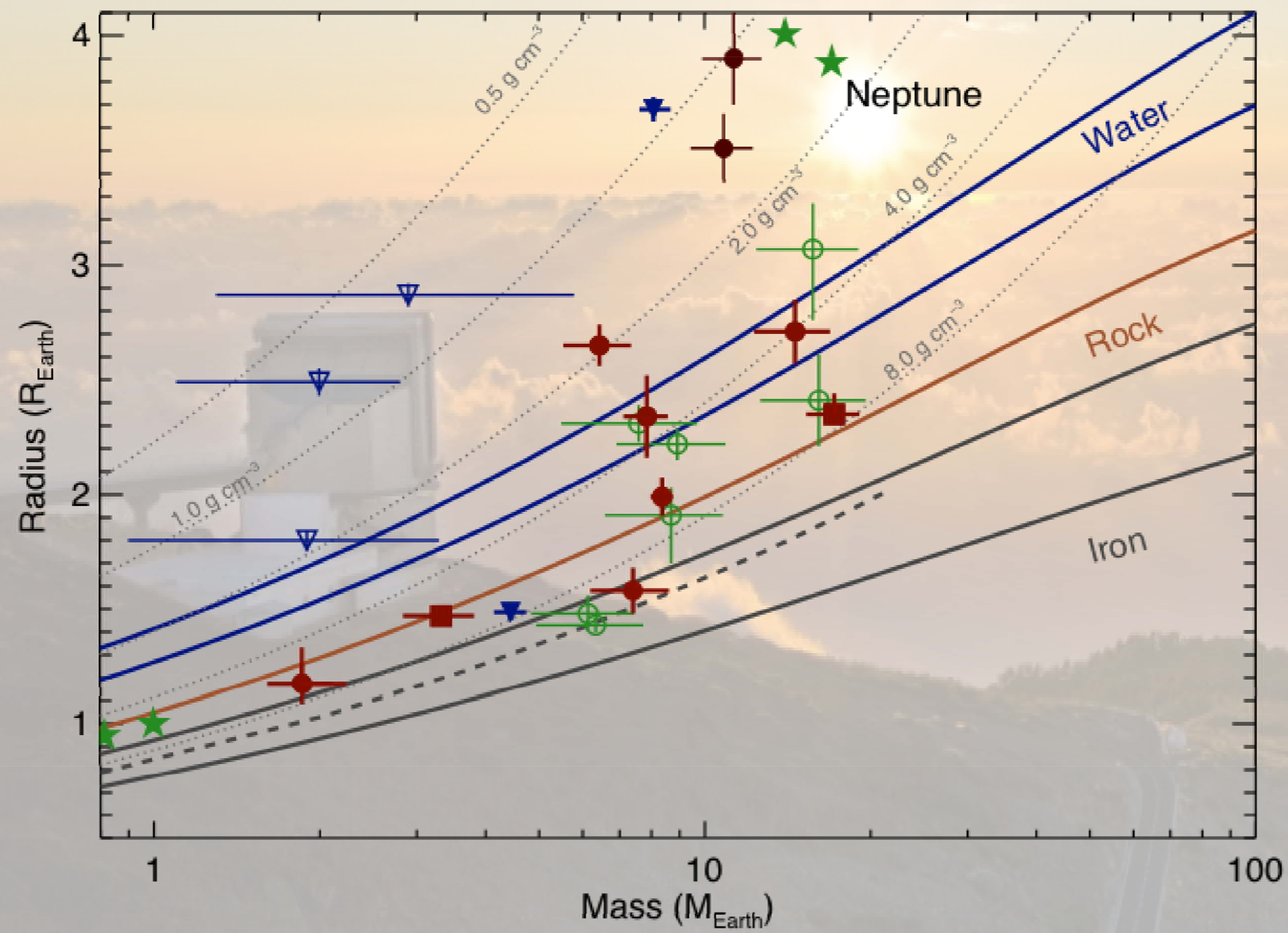
Some questions that require masses

- How large, or how massive, can a planet be and still be Earth-like, with a composition dominated by silicate rock, and iron, and only a thin, secondary atmosphere?
- How small, or how low in mass, can a planet be and yet have retained a substantial primordial envelope of hydrogen and helium similar to Neptune and Uranus?
- Is there a unique relationship between radius and mass, or, if not, what is the relative population of rocky, icy, and gaseous planets as a function of radius from 1 – 3 R_E?
- What is the dependence of these fractional occurrence rates upon the properties of the star, notably its mass, metallicity, and age?
- Does the relationship depend upon the orbital period, and/or the presence of other planets in the system?

HARPS-N Strategy (then)

- GTO program: 80 nights/year, 5 years
  - Rocky Planet Search, ~dozen quiet/bright FGK
  - Masses of small Kepler planets
- Original proposal called for 10% masses
- Science operations started August 2012
- First full Kepler season: science team favorites
  - Kepler-10 (25% HIRES mass)
  - Kepler-78 (Target of opportunity)

Mass accuracy better than ±20%: red; ±30%: green



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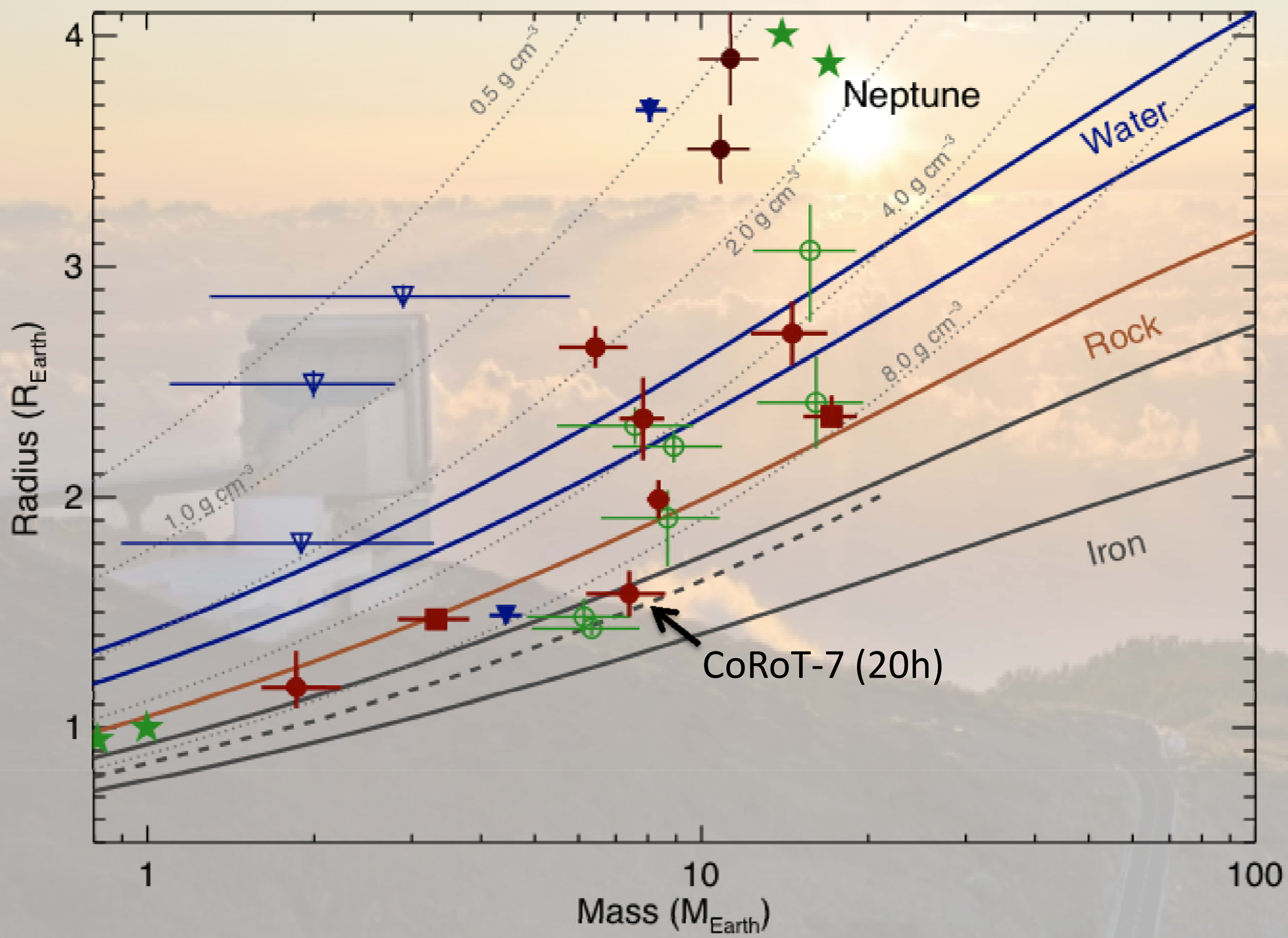


Kepler-11: Lissauer et al. 2011, 2013

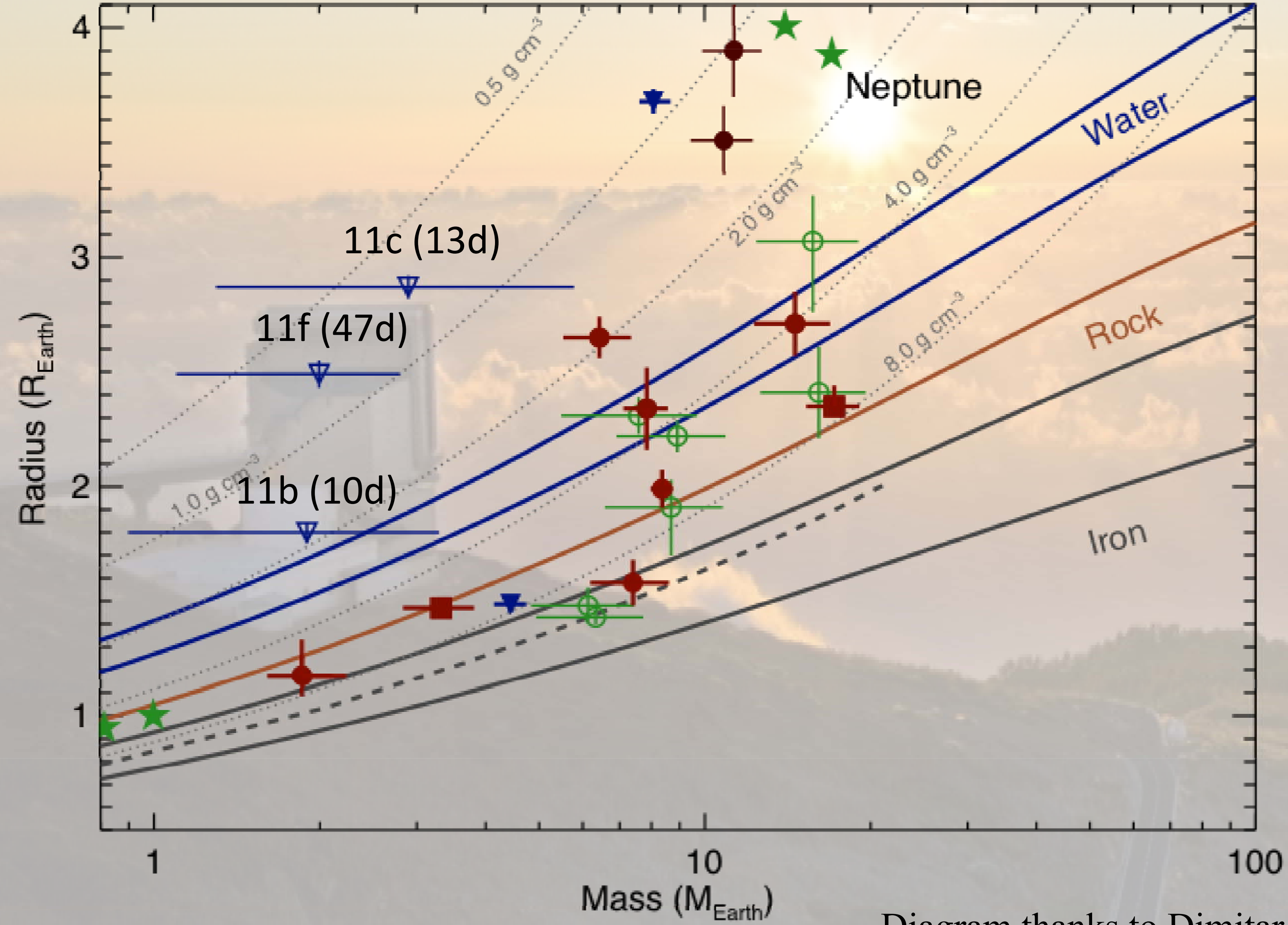
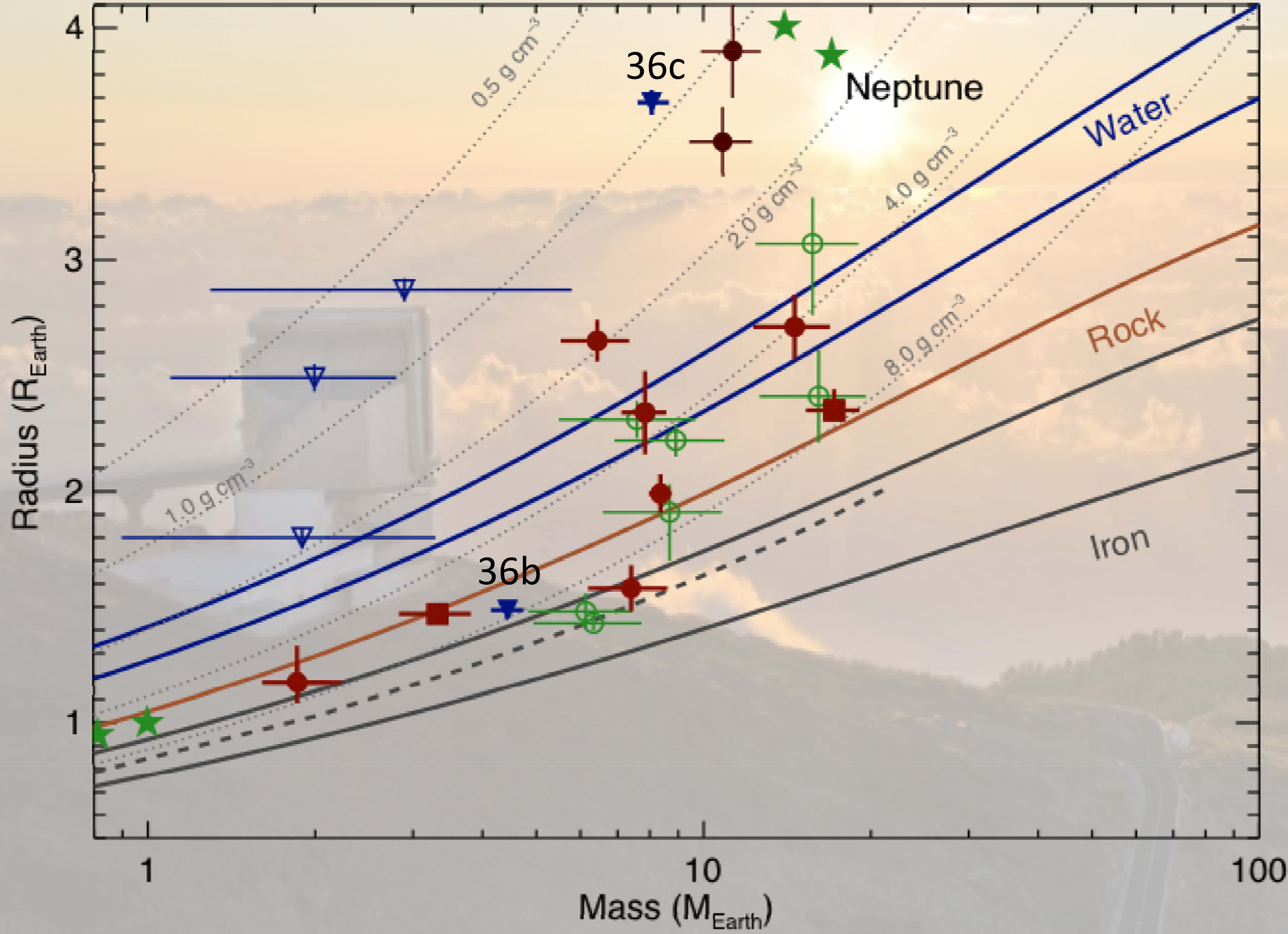
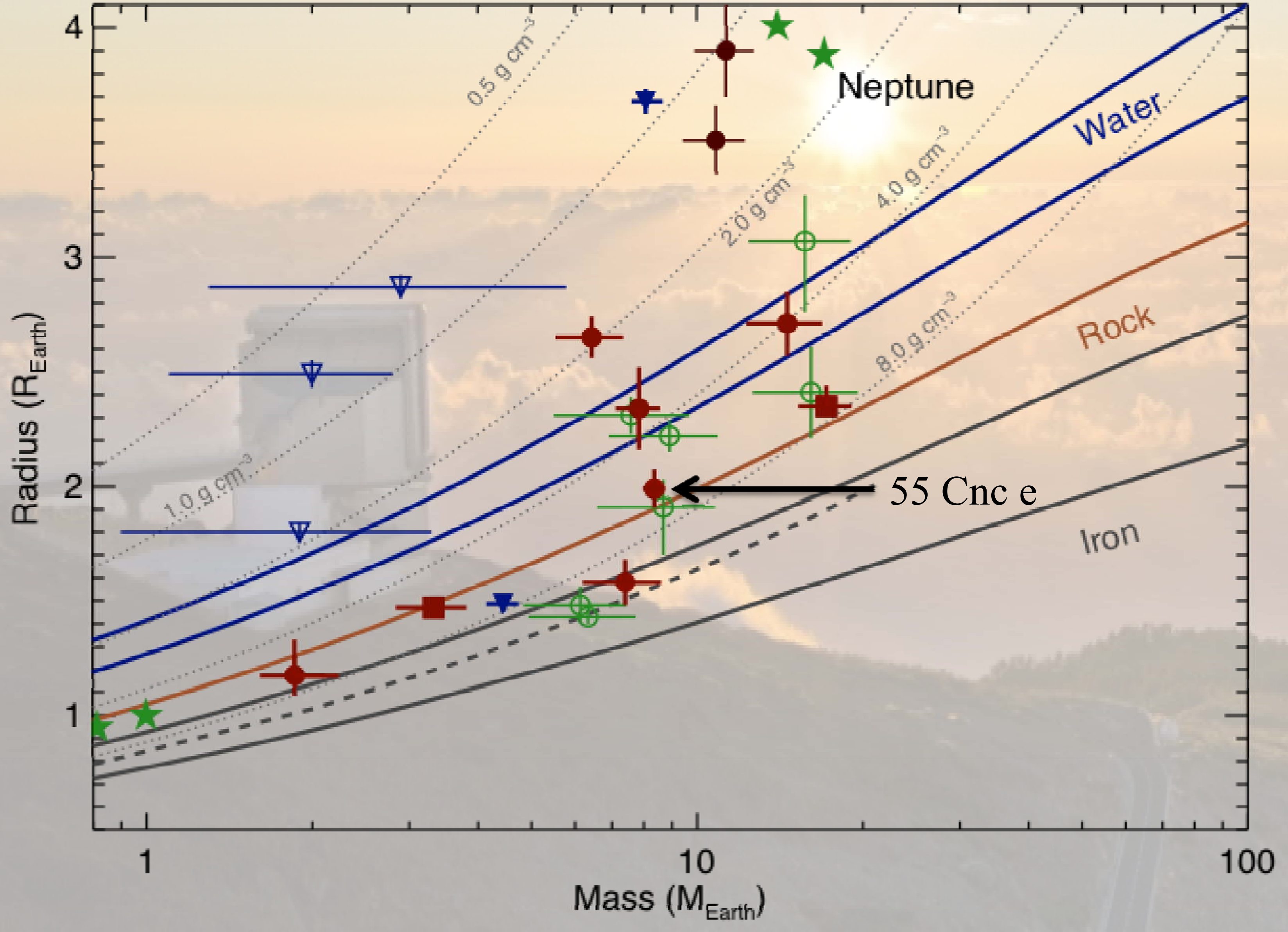


Diagram thanks to Dimitar

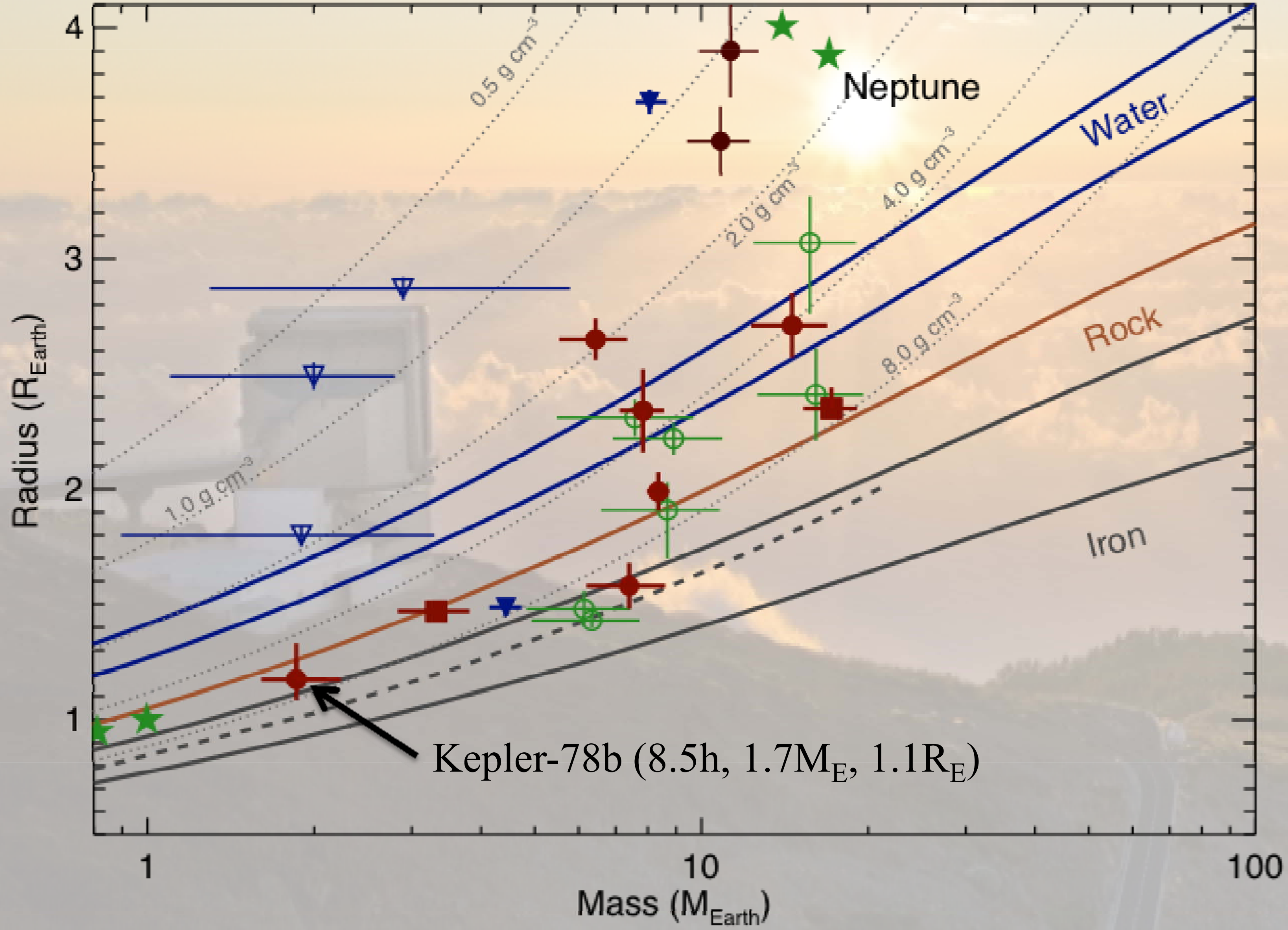
Kepler-36b (13.8d) & c (16.2d); Carter et al. 2012



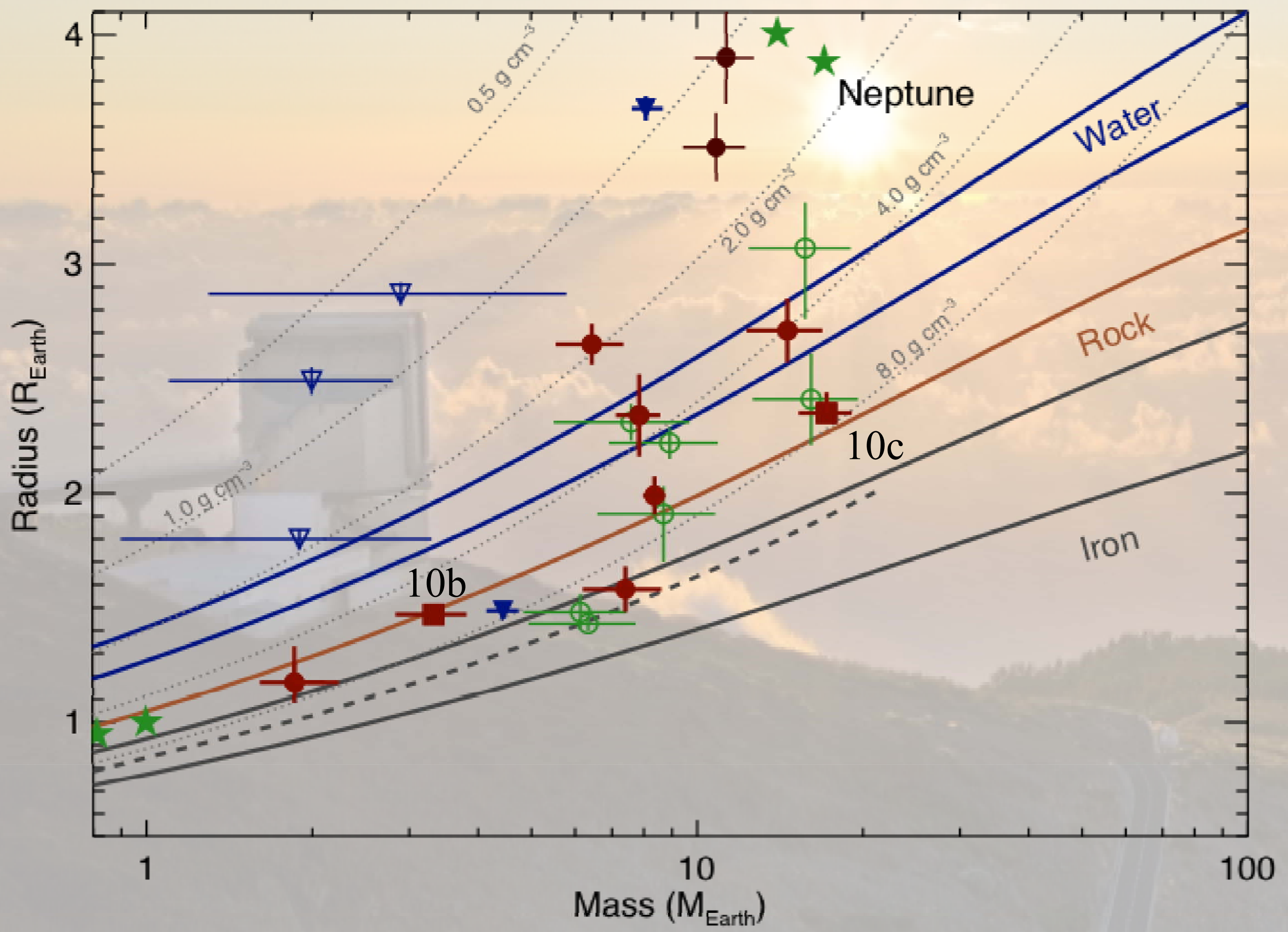
55 Cnc e (18h): Dawson & Fabrycky 2010, Winn et al. 2011



Sanchis-Ojeda et al. 2013, Howard et al. 2013, Pepe et al. 2013



Kepler 10: Batalha et al. 2011, Dumusque et al. 2014



Kepler-10b = KOI-72b

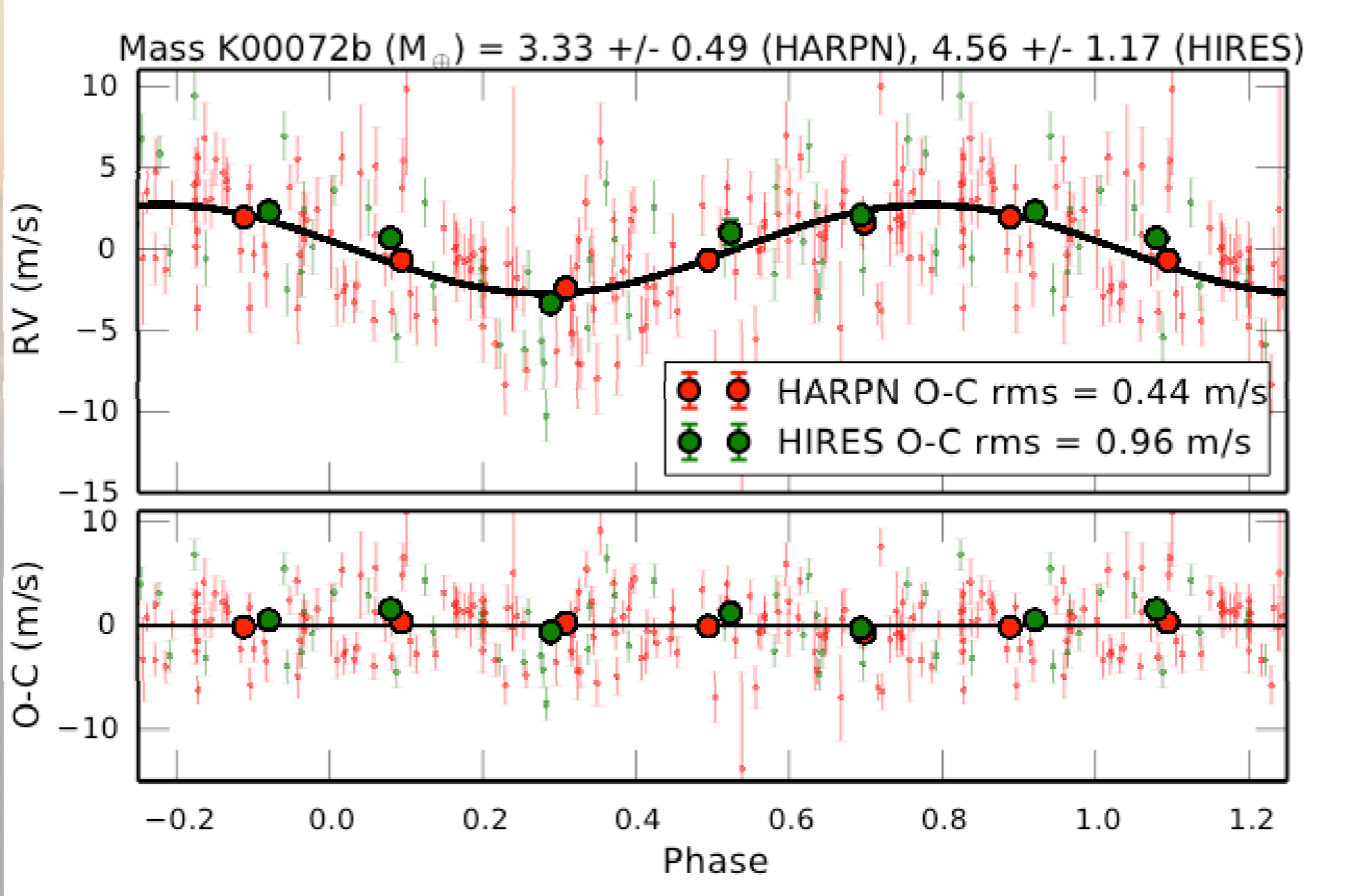
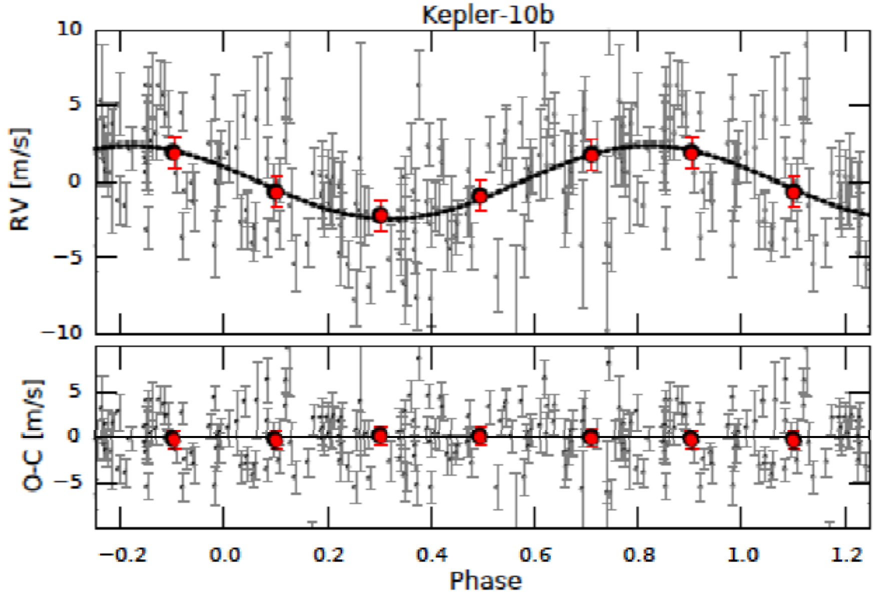
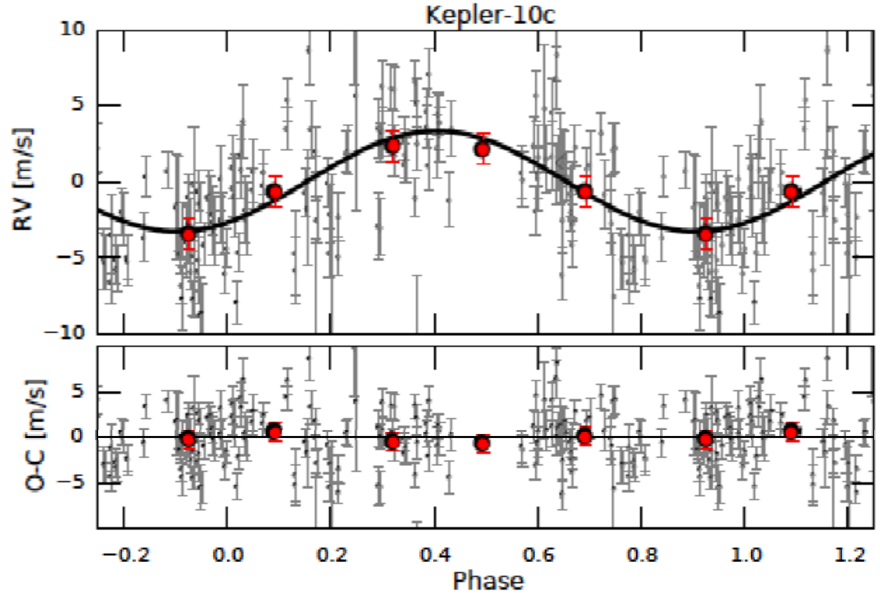


Diagram thanks to Xavier

Kepler-10b: $P = 0.84$d

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 729, 27

HARPS-N Strategy (now)

- Add 10 to 20 masses good to 15%, $R_P < 3R_E$
  - V < 13.5 mag, P < 50d
  - Reliable stellar parameters (asteroseismic favored)
  - Previous masses worse than 15%
  - Quiet Kepler photometry
    - Lomb-Scargle amplitude < 0.025% (~1m/s jitter)
    - F8 Flicker limit on granulation noise
    - Photometric rotation period > 10d
    - Orbital period avoids rotation period and harmonics
  - 23 priority-ordered candidates
- Observe nightly: better average of stellar signals
  - Oscillations, granulation, activity (if any)

Start of 2014 Kepler season: binned HIRES=green, HARPS-N=red

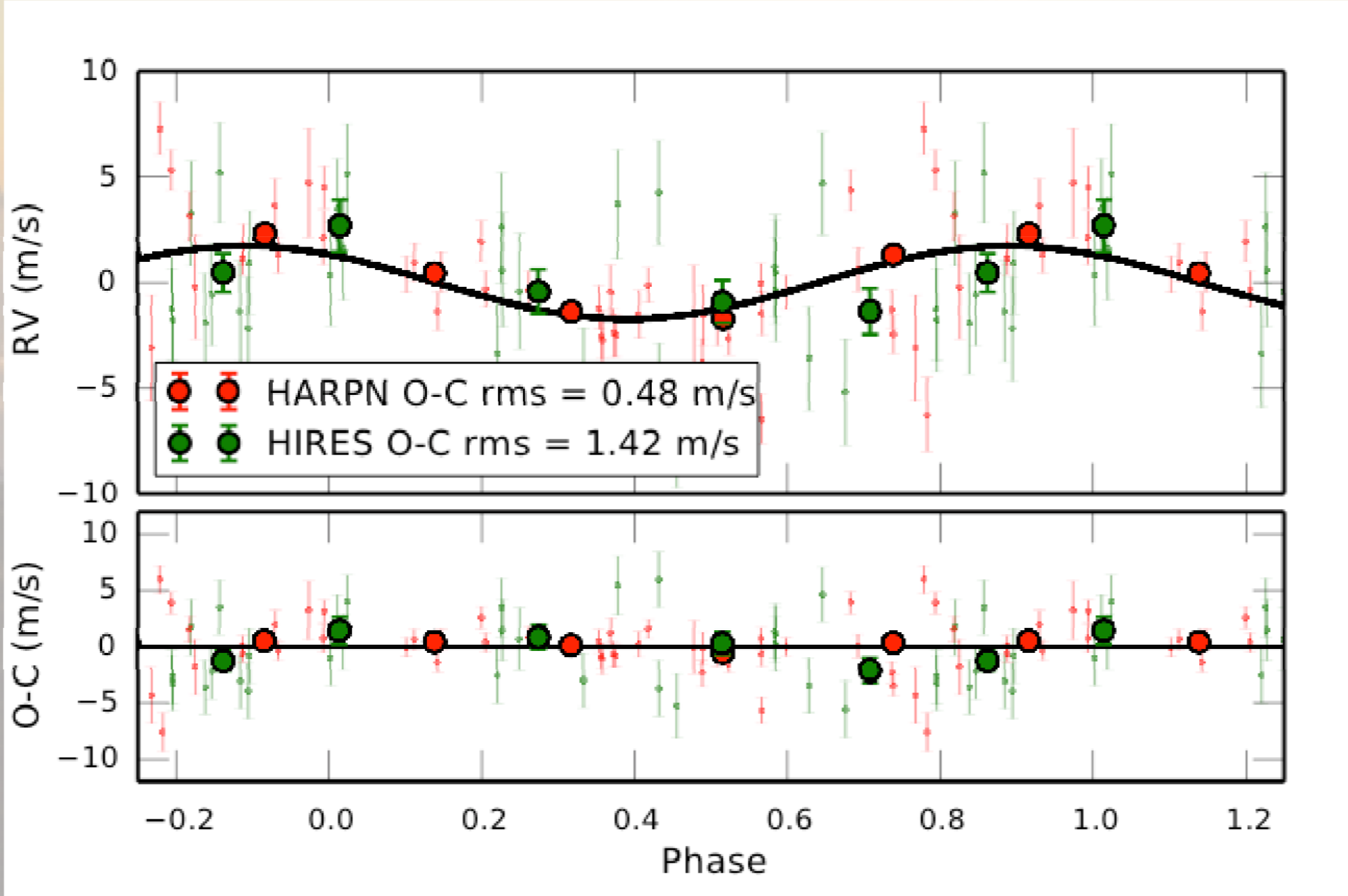


Diagram thanks to Xavier

Present status: HARPS-N mass error now ±15%
Nightly observations allow better jitter correction

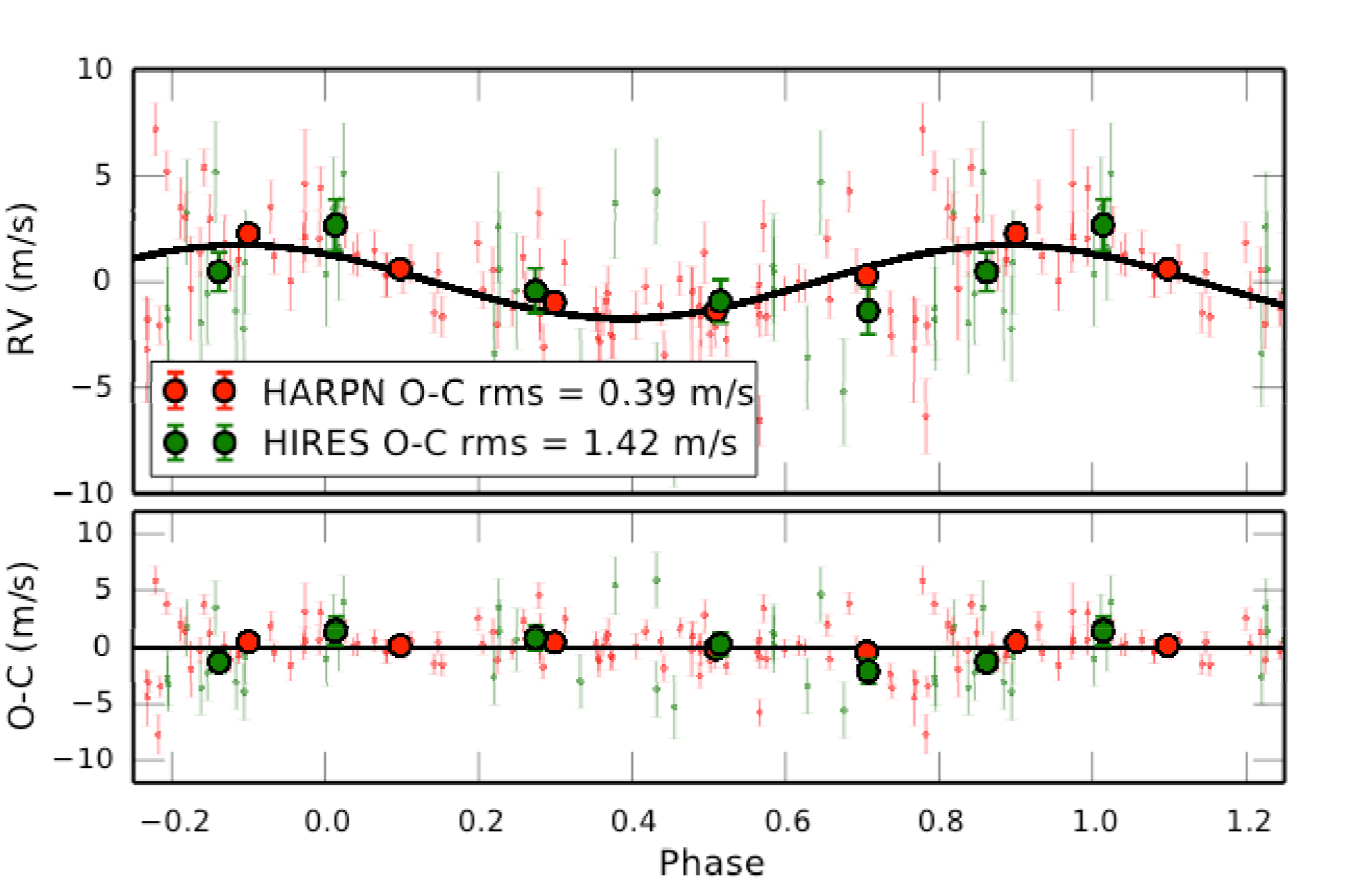


Diagram thanks to Xavier


Stay tuned for some new mass results from HARPS-N
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