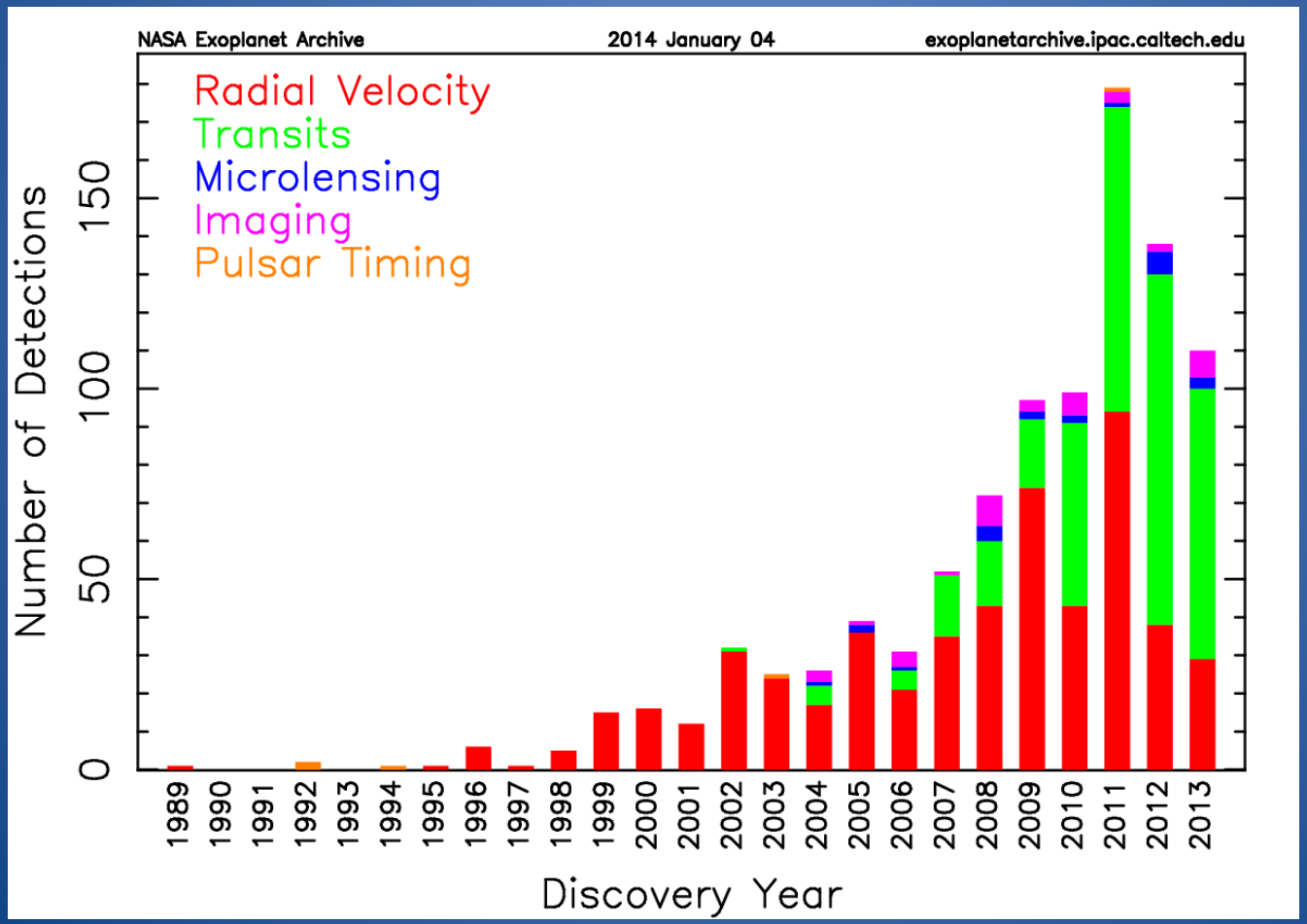
Study Analysis Group 8: Requirements & Limits of Future Precise Radial Velocity Measurements

Co-Chairs:
Peter Plavchan (plavchan@ipac.caltech.edu)
NASA Exoplanet Science Institute, Caltech
Dave Latham (latham@cfa.harvard.edu)
Harvard-Smithsonian CfA

RV SAG8 Goals

Precise radial velocity measurements are the workhorse technique in the exoplanet field, for both detection and characterization of exoplanets.



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RV SAG8 Goals

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

"… to search for planetary bodies and Earth-like planets in orbit around other stars." (U.S. National Space Policy, June 28, 2010)

→ See ExoPAG 6 talk for full charter

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RV SAG8 current status

Some draft text is written, and community input is being sought on the report sections.

Given the wealth of previous community input on the subject, the challenge is to keep the report manageable!

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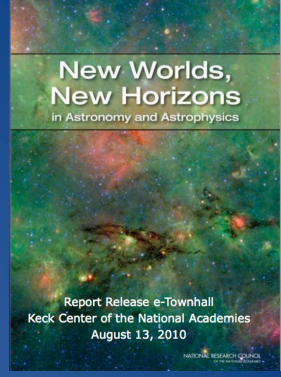
Previous Sources of Community Input

See ExoPAG 6, 7, & 8 talks:

- **PRV mini-workshops @ ExoPAG 6,7**
- 2010 US National Space Policy
- 2011 NASA Strategic Plan
- 2013 Program Plan for Exoplanet Exploration (ExEP)
- 2010 Astro Decadal Survey
- 2011 NSF Portfolio Review
- 2008 Exoplanet Task Force (ExoPTF)
- 2008 Exoplanet Community Report chapter on PRVs by Guillermo Torres
- 2011 Penn State RV Workshop Community Response to Astro 2010 Decadal Survey
- 2010 ESA Roadmap

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

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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	✓		✓

White Paper "Thesis"

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.

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

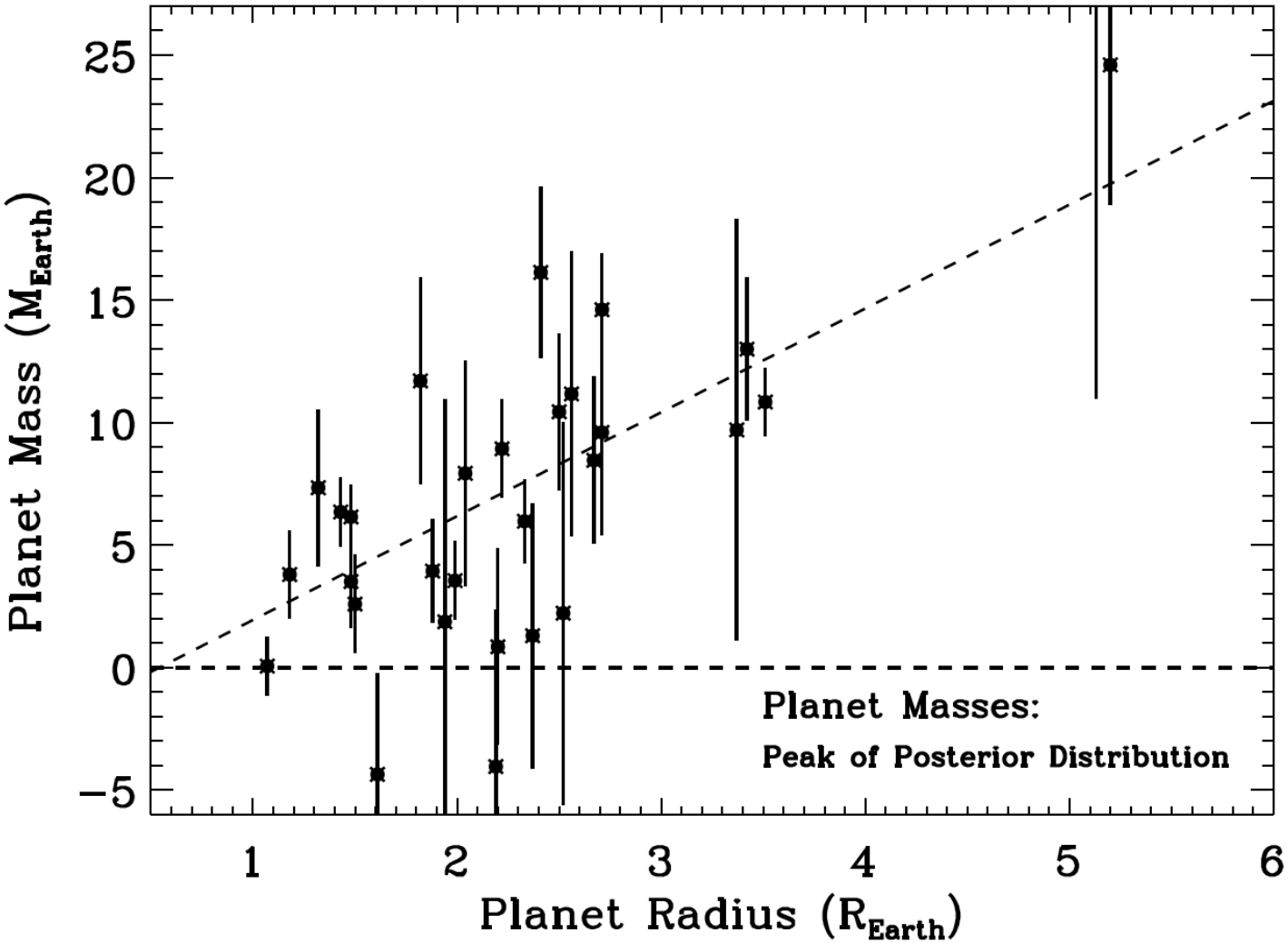
Dedicated 4-m with HARPS-like 50 cm/s

- State of the art still defined by α Cen Bb
  - Four years and 450 observations with original HARPS
  - Corrections need to reveal orbital motion:
    - Orbital motion of α Cen B with α Cen A - 187 m/s
      - Raw rms of 2.9 m/s after this correction
    - Magnetic cycle - 2.0 m/s
    - Activity effects - 1.9 m/s
- Orbital semi-amplitude – 0.5 m/s
  - Not yet a confirmed planet
    - Transit ephemeris would provide strong independent evidence

Kepler Experience with HIRES

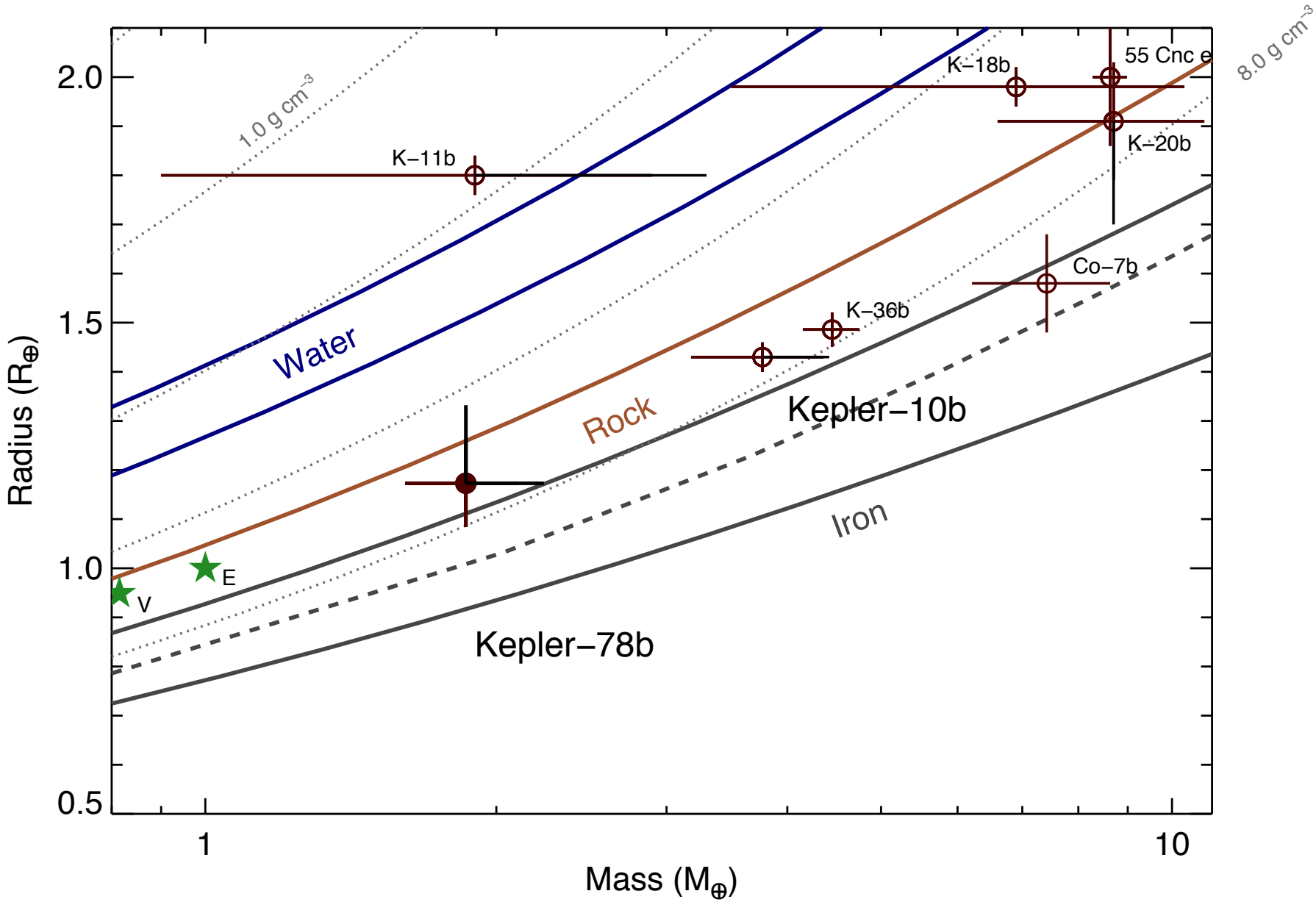
- Four seasons of HIRES following up small planets
  - Three- or four-sigma masses for Kepler 10b and 78b
    - Kepler 10b: V = 11, P = 0.84 d, M = 4.6 ± 1.2 M_{Earth}, K = 3.3 m/s, N_{obs} = 42
    - Kepler 78b: V = 12, P = 0.36 d, M = 1.69 ± 0.41 M_{Earth}, K = 1.66 m/s, N_{obs} = 84
  - 49 candidates around 22 stars, detectable if rocky
    - Roughly 100 nights NASA plus California time
  - Better than two-sigma masses for 16, one-sigma for 14

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



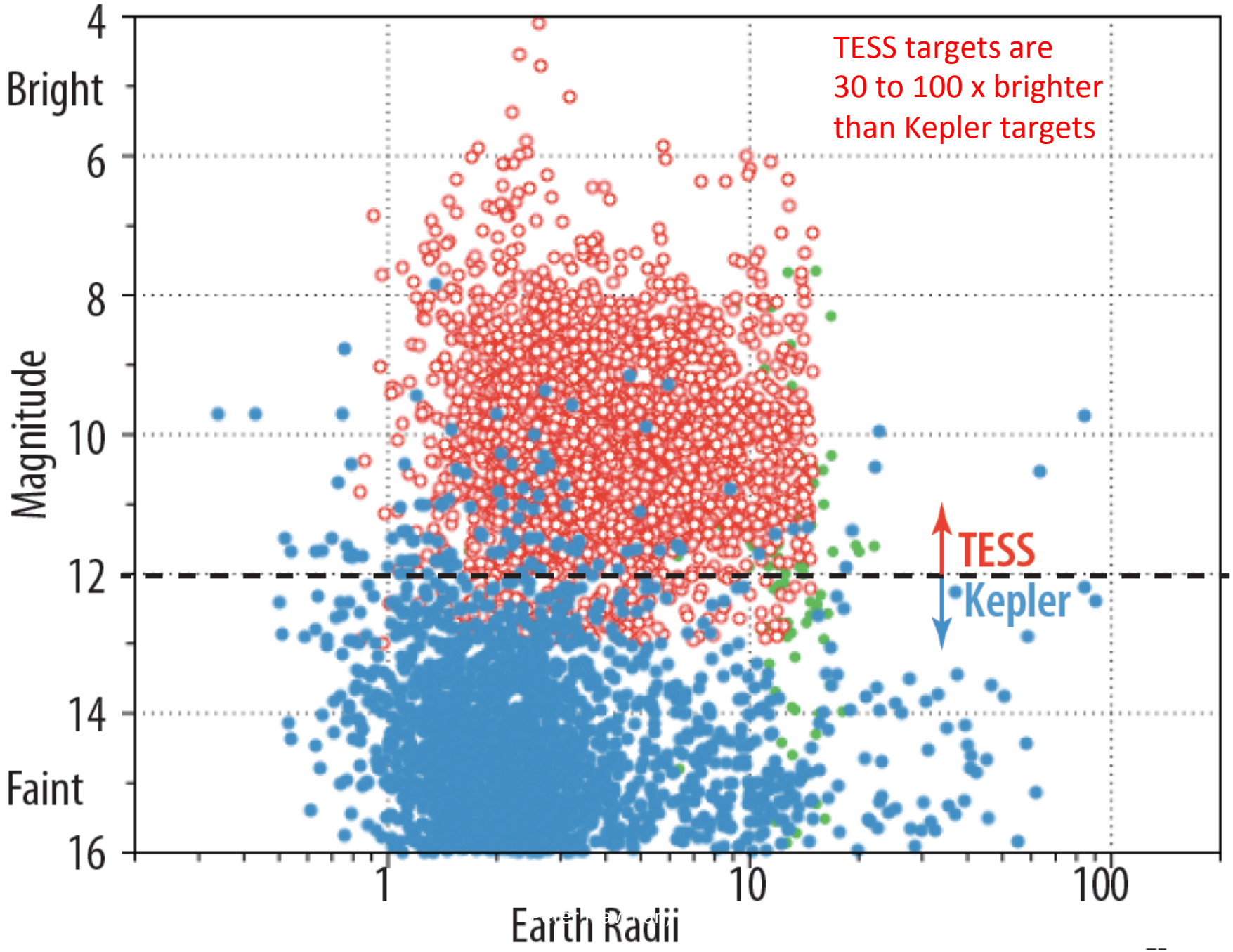
Kepler Experience with HARPS-N

- Four seasons of HIRES following up small planets
  - Three- or four-sigma masses for Kepler 10b and 78b
    - Kepler 10b: V = 11, $P = 0.84$ d, $M = 4.6 \pm 1.2$ M_{Earth}, $K = 3.3$ m/s, $N_{obs} = 42$
    - Kepler 78b: V = 12, $P = 0.36$ d, $M = 1.69 \pm 0.41$ M_{Earth}, $K = 1.66$ m/s, $N_{obs} = 84$
  - 49 candidates around 22 stars, detectable if rocky
    - Roughly 100 nights NASA plus California time
  - Better than two-sigma masses for 16, one-sigma for 14
- 1.5 seasons of HARPS-N following a dozen small planets
  - Six-sigma masses for Kepler 10b and 78b
    - Kepler 10b: $M = 3.31 \pm 0.49$ M_{Earth}, $N_{obs} = 137$, $K = 2.47$ m/s
    - Kepler 78b: $M = 1.86 \pm 0.32$ M_{earth}, $N_{obs} = 137$, $K = 1.96$ m/s


Radius ($R_\oplus$)
Mass ($M_\oplus$)
2.0
1.5
1.0
0.5
1
10
1.0 g cm^{-3}
8.0 g cm^{-3}
Water
Rock
Iron
K−11b
K−18b
55 Cnc e
K−20b
Co−7b
K−36b
Kepler−10b
Kepler−78b
V
E

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 community instruments may help
  - TPF (Hobby-Eberly), Carmenes (Calar Alto), SPIRou (CFHT), etc

AFTA-type Coronograph Mission

- PRV survey of nearest stars for best targets
  - Study underway in SAG 9
  - Long-term needed to extend out to wider orbits
    - 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?

Cost Analysis (ballpark estimates)

- Hardware investment
  - HARPS-N budgeted at $7M
  - Next generation calibration sources at $1-2M (LFC)
  - Assume existing telescope at no cost
- Operations $2M per year
- Software and data management ??

Access to 10-m with 5 cm/s

- Espresso on VLT and G-Clef on GMT
  - Espresso first light 2016
  - G-Clef first light 2021, $30M budget
- Next generation spectrometer for Keck?
- Investment in treating stellar jitter needed