INAF - Osservatorio Astrofisico di Torino

HARPS-N GTO: status and prospects

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Meeting INAF - Macroarea 2, Bologna 15-16/06/2016

Intriguing questions

- What are the likely compositions of small planets ($R_p < 3\ R_\oplus$)?

- Do the interior structures of rocky planets correlate with stellar metallicity (considered as a proxy for solids inventory in the protoplanetary disc)?

- Can low-mass planets accrete a H/He envelope?

- What are the main mechanisms responsible for the diversity of small planet densities? (Photoevaporation caused by stellar XUV flux? Impacts between protoplanetary embryos? Diversity of atmospheres formed through degassing during planetary-accretion process?)

- Are water-rich super-Earths abundant? Important constraints on the formation of super-Earths (beyond the snow line or "in situ")

- What are the occurrence rates of small-size/low-mass planets as a function of stellar and planetary parameters?

- How do planet formation and evolution affect the architecture of planetary systems with low-mass planets?

Intriguing questions

Radial-velocity (RV) follow up of Kepler small-size planetary candidates to determine their mass/density

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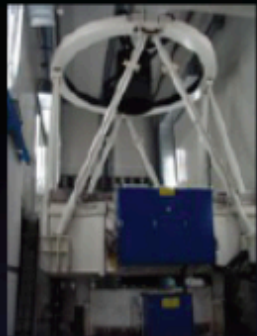
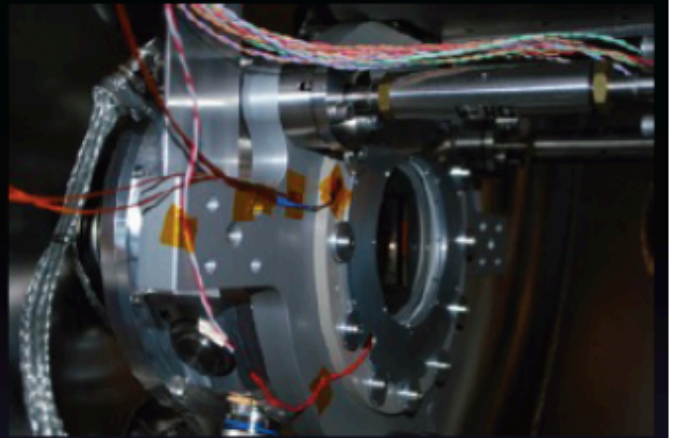
Search for low-mass planets around nearby and bright stars through the Doppler method (Rocky Planet Search programme)

HARPS-N

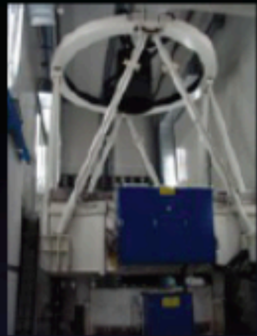



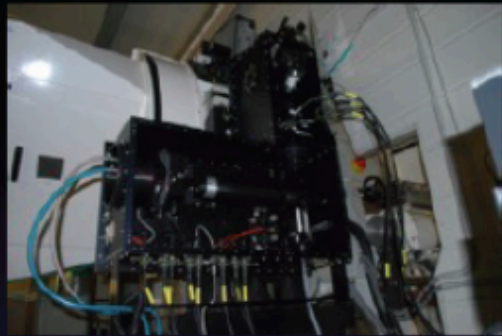


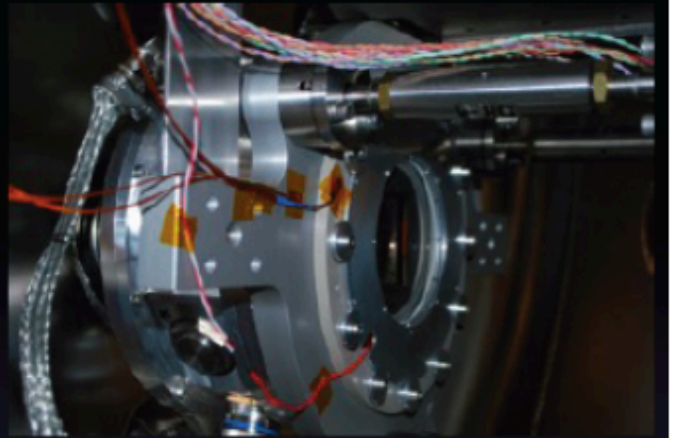

Partnership between Geneva Observatory, Harvard-Smithsonian Center for Astrophysics, Italian National Institute for Astrophysics, Univ. of St. Andrews, Edinburgh, and Queens Univ Belfast.

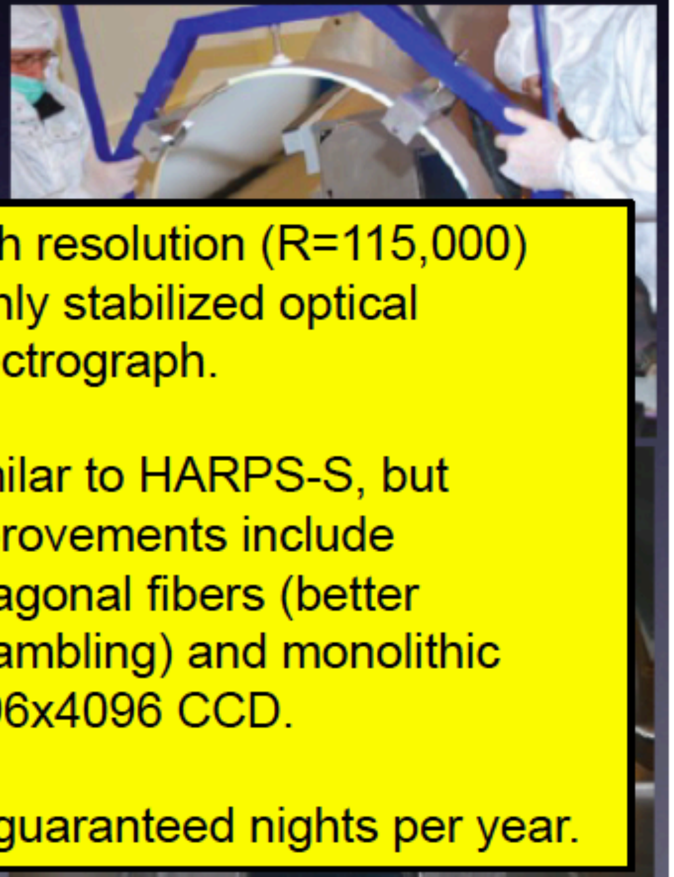
Located at 3.6m Italian Galileo Telescope on the island of La Palma, Spain.

HARPS-N









High resolution (R=115,000) highly stabilized optical spectrograph.

Similar to HARPS-S, but improvements include octagonal fibers (better scrambling) and monolithic 4096x4096 CCD.

80 guaranteed nights per year.

Characterisation of planetary systems with small/low-mass planets

• Analysis of the HARPS-N spectra to determine stellar atmospheric parameters (T_{eff}, [Fe/H], logg)

• Parameters of the host stars ($M_{\star}$, $R_{\star}$, age) from stellar atmospheric parameters, stellar evolutionary tracks, and
- asteroseismology (for the brightest stars)
- stellar density from the transit fitting as a proxy for luminosity

• Periodogram and Bayesian (MCMC) analyses of Kepler and/or HARPS-N data to derive system (orbital and physical planet) parameters

• Simultaneous modelling of planetary and activity signals in RV time series of magnetically active stars

Some exciting results

Two infernal Earths

Kepler-78b
P_{orb} = 8.5 hr
R_p = 1.16 ± 0.19 $R_\oplus$
M_p = 1.86 ± 0.31 $M_\oplus$
ρ_p = 5.6 ± 0.7 g/cm^3

Kepler-10b
P_{orb} = 20.1 hr
R_p = 1.47 ± 0.03 $R_\oplus$
M_p = 3.33 ± 0.49 $M_\oplus$
ρ_p = 5.8 ± 0.8 g/cm^3

rocky planets with possible lava oceans at their surface (T_{eq} > 2000 K)

Pepe et al. 2013, Nature
Dumusque, Bonomo et al. 2014

The first megaEarth

Kepler-10c
P_{orb} = 45.3 d
R_p = 2.35 ± 0.07 $R_\oplus$ M_p = 17.2 ± 1.9 $M_\oplus$
ρ_p = 7.1 ± 1.0 g/cm^3

rocky bulk composition + solid high-pressure H_2O or a very thin H/He envelope

Dumusque, Bonomo et al. 2014

The first super-Neptune in a "reversed" planetary system

Kepler-101b
P_{orb} = 3.49 d
R_p = 5.8 ± 0.8 $R_\oplus$
M_p = 51 ± 5 $M_\oplus$
ρ_p = 1.4 ± 0.6 g/cm^3

60% of its mass in heavy elements

Kepler-101c
P_{orb} = 6.03 d
R_p = 1.25 ± 0.18 $R_\oplus$
M_p < 3.8 $M_\oplus$
ρ_p < 10.5 g/cm^3

Likely rocky: no H/He envelope

Bonomo, Sozzetti et al. 2014

Two small planets with distant companions but different composition

Kepler-93b
P_{orb} = 4.73 d
R_p = 1.48 ± 0.02 $R_\oplus$
M_p = 4.02 ± 0.68 $M_\oplus$
ρ_p = 6.9 ± 1.2 g/cm^3

rocky planet

Kepler-454b
P_{orb} = 10.57 d
R_p = 2.37 ± 0.13 $R_\oplus$
M_p = 6.84 ± 1.40 $M_\oplus$
ρ_p = 2.8 ± 0.8 g/cm^3

significant fraction of volatiles

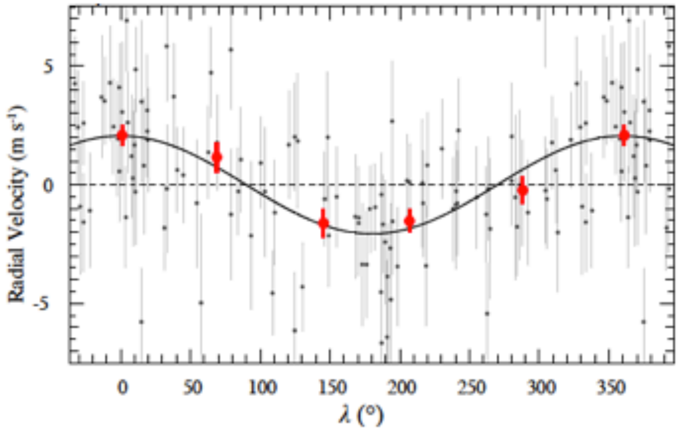
Dressing et al. 2015; Gettel et al. 2016

Some exciting results

Kepler-78b

P_{orb} = 0.35 d, K = 1.96 m/s

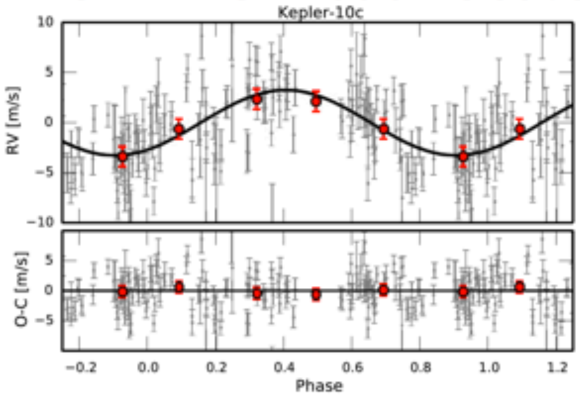
109 HARPS-N radial velocities



Kepler-10c

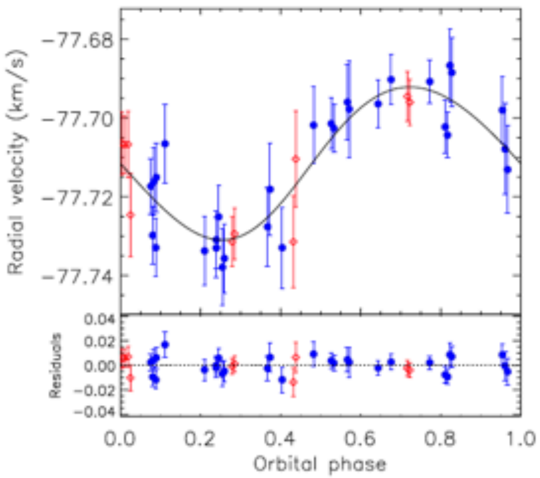
P_{orb} = 45.3 d, K = 3.3 m/s

148 HARPS-N radial velocities



Kepler-101b

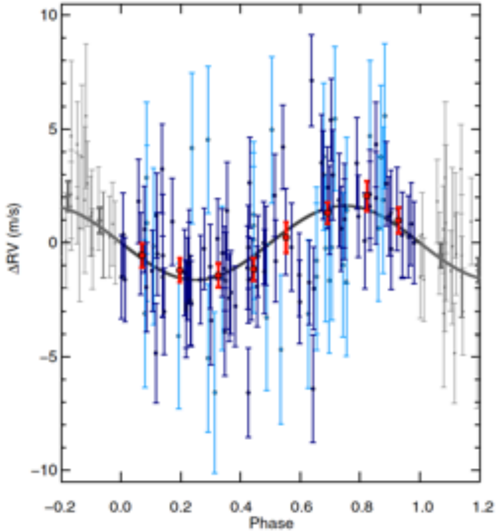
P_{orb} = 3.49 d, K = 19.4 m/s



40 HARPS-N RVs

Kepler-93b

P_{orb} = 4.73 d, K = 1.6 m/s



dark blue circles: 86 HARPS-N RVs

light blue circles: 32 HIRES RVs

HD 219134b: the closest transiting super-Earth

The closest star with a transiting planet (d=6.5 pc, V=5.57, K3V)

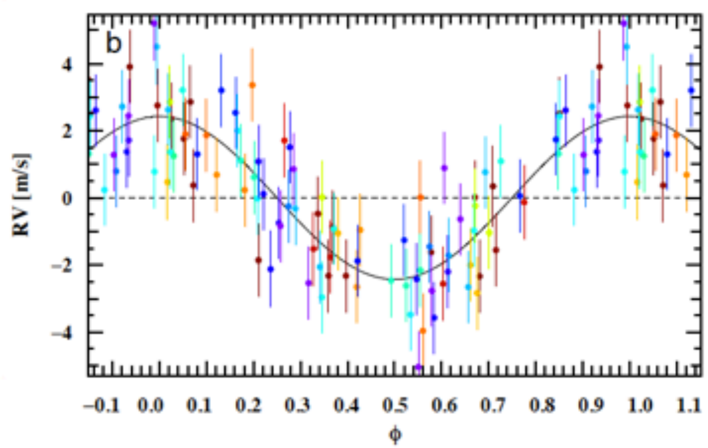
Motalebi et al. 2015

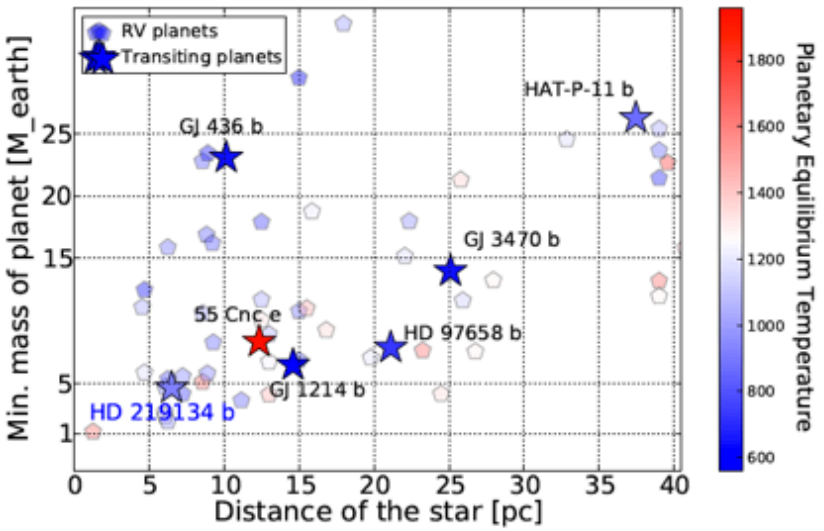
- First detected in a multiple planetary system with HARPS-N RVs taken within the GTO RPS programme (P_{orb}=3.09 d)

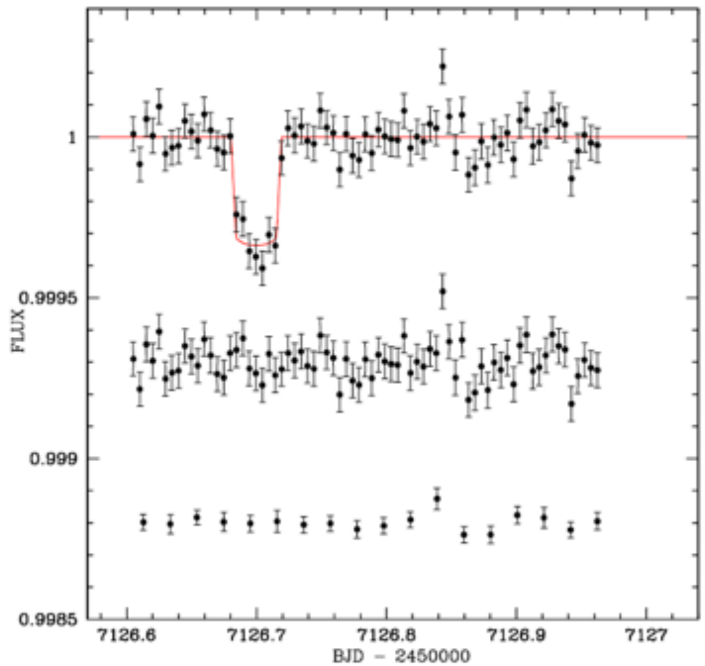
- Transit probability = 9.5% ➪ DDT (9.5 hr) Spitzer/IRAC (4.5 μm) on 14/04/2015

- the inner super-Earth seen transiting its star...

- $R_p = 1.61 \pm 0.09\ R_\oplus$ $M_p = 4.46 \pm 0.47\ M_\oplus$ ➪ ➪ $\rho_p = 5.89 \pm 1.17\ g/cm^3$ ➪ rocky composition

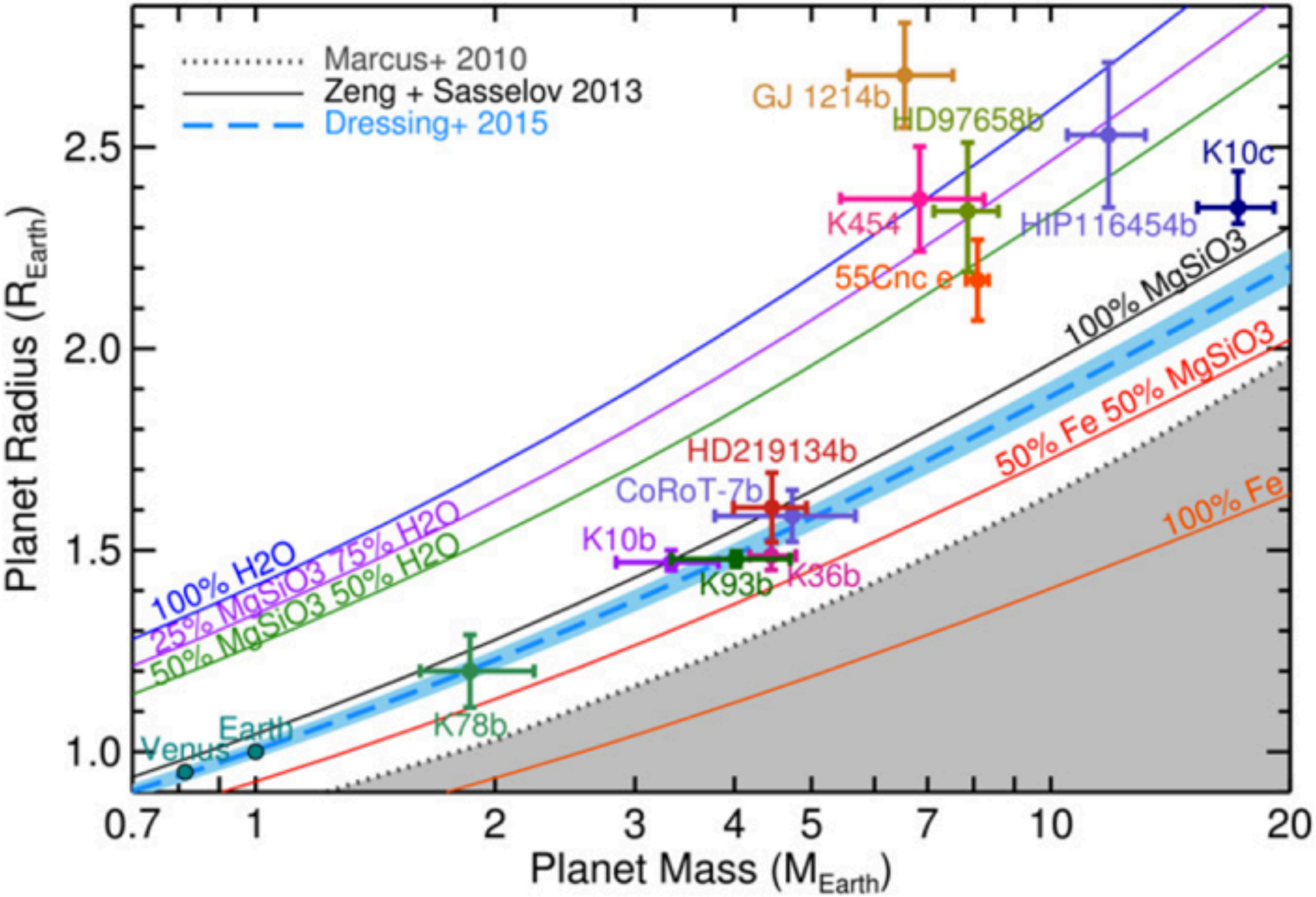






The composition of small planets

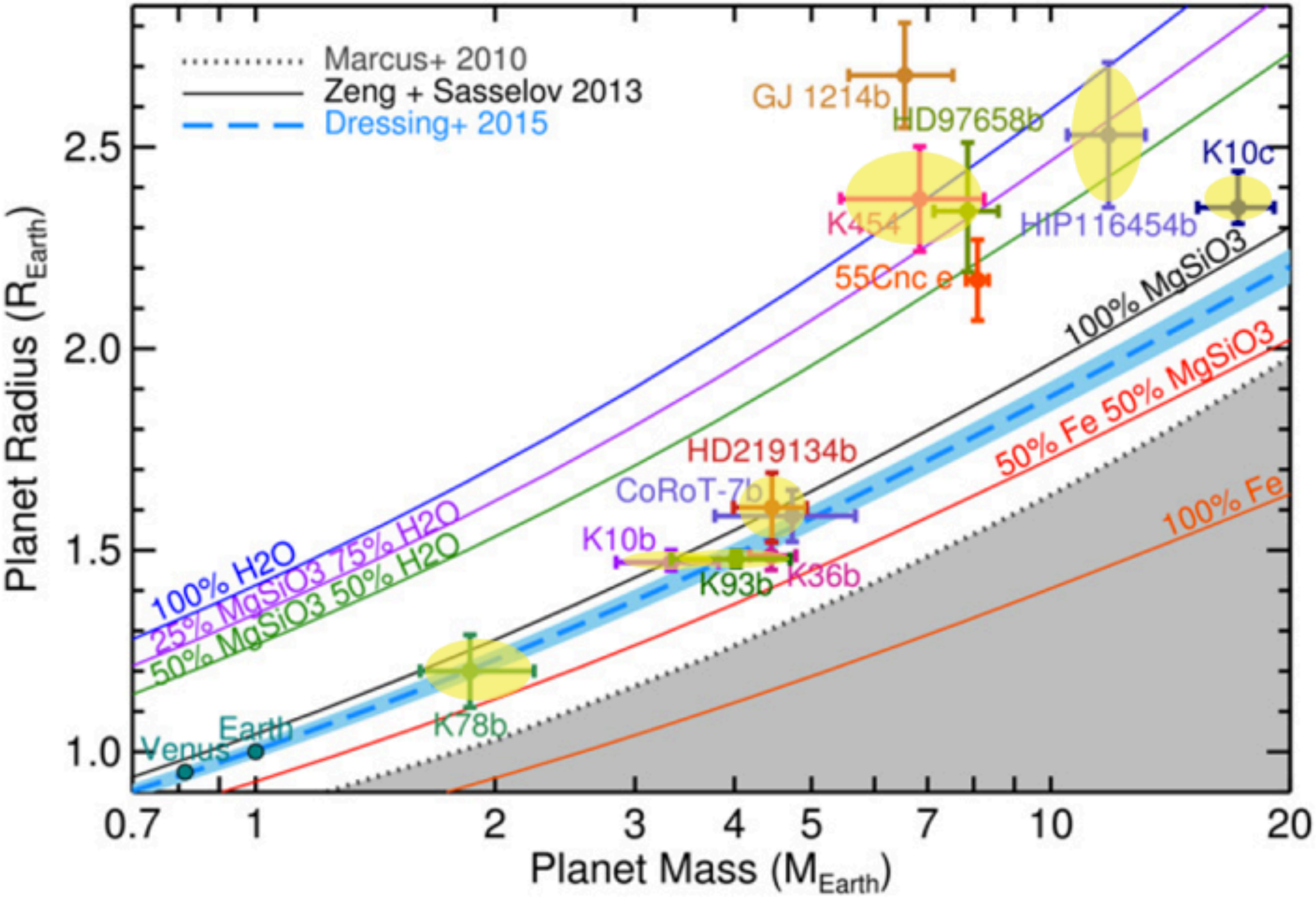
Gettel et al. 2016



- M_p-R_p diagram for planets with $R_p < 2.7\ R_\oplus$ and $\sigma_{Mp}/M_p < 20\%$

- Solid lines: theoretical M_p-R_p curves for planets with different compositions (Zeng & Sasselov 2013)

The composition of small planets



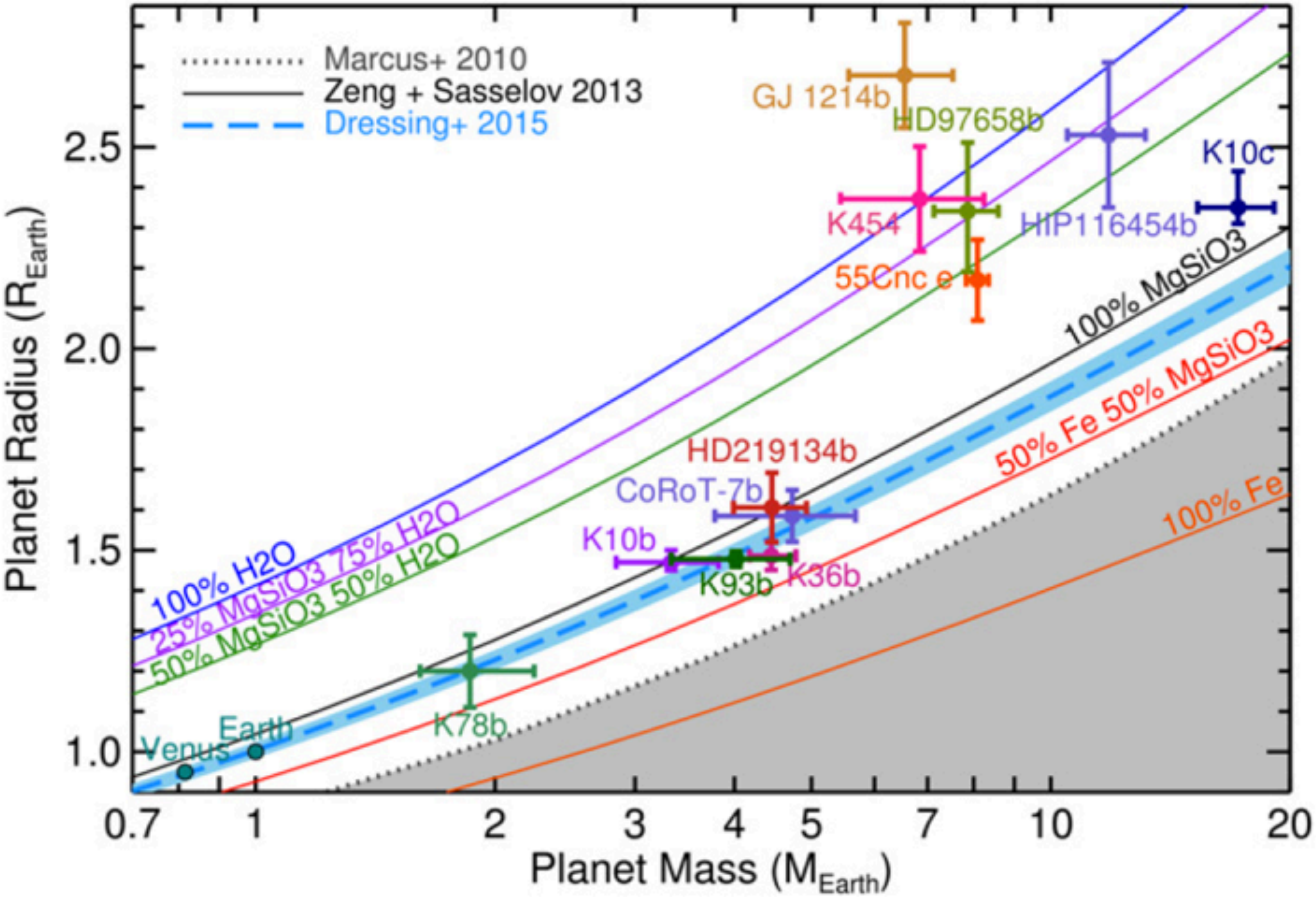
- M_p-R_p diagram for planets with $R_p < 2.7\ R_\oplus$ and $\sigma_{Mp}/M_p < 20\%$

- Solid lines: theoretical M_p-R_p curves for planets with different compositions (Zeng & Sasselov 2013)

- 60% (7/12) of small planets with $R_p < 2.7\ R_\oplus$ and $\sigma_{Mp}/M_p < 20\%$ have been characterised by the HARPS-N/GTO Consortium (yellow ellipses)

The composition of small planets

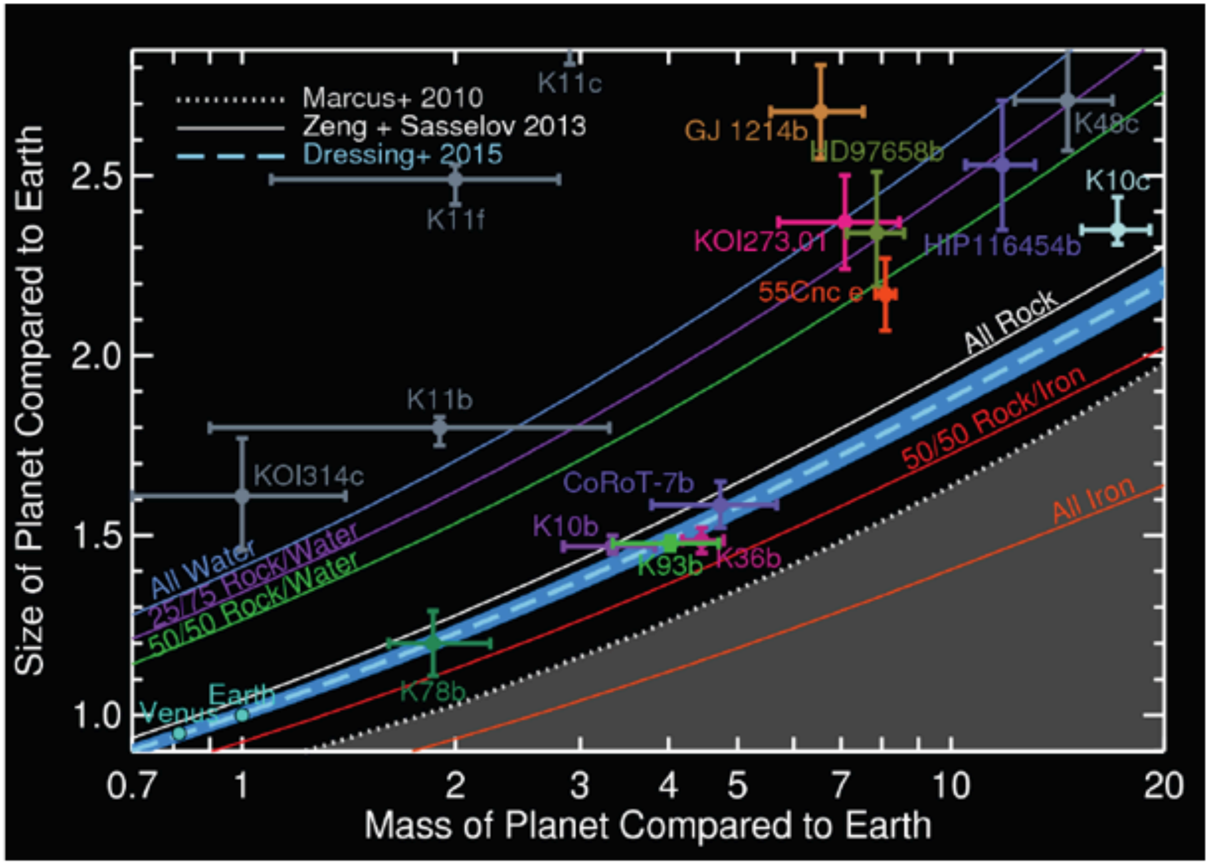
Gettel et al. 2016



- Dashed blue line indicates an Earth-like composition: all dense planets with $M_p \lesssim 6\ M_\oplus$ are well-described by the same fixed ratio of iron to magnesium silicate (17% Fe and 83% $MgSiO_3$, Dressing et al. 2015)

- More massive ($M_p \gtrsim 6\ M_\oplus$) have significant fractions of volatiles and/or H/He envelopes.

The composition of small planets



courtesy:
D. Charbonneau

- Puffy planets with $M_p \lesssim 6\ M_\oplus$ mainly characterised with Transit Timing Variations (e.g., Kepler-11, KOI-314)

- Large mass uncertainties from TTVs with the exception of the Kepler-36 planets

- The RV method is the most efficient in determining precise masses and densities of the majority of small transiting planets

Forthcoming results: stay tuned!

Precise M_p and R_p measurements for six Kepler/K2 planets in four planetary systems

- Buchhave et al., 2016, submitted
- Lopez-Morales et al. 2016, to be submitted
- Malavolta et al. 2016, to be submitted
- Sozzetti et al. 2016, in preparation

Collaboration with GAPS (M dwarf sub-programme) to observe jointly two small planets transiting in the Habitable Zone of M dwarfs to (try to) measure their mass!

Ongoing analyses, in one case several issues with the RV jitter caused by stellar magnetic activity, even if at low level (stellar P_{rot} not far from P_{orb}).

HARPS-N/GTO short-term prospects

Need for extension of the agreement between INAF and the HARPS-N Consortium

Formation, evolution, and composition of mini-Neptunes, super-Earths, and Earth-sized planets

RV follow up of K2 planetary candidates; already started, to be continued till 2018/2019

RV follow up of TESS planetary candidates possibly re-observed with CHEOPS; timespan: 2018-2024

Some of the well-characterised K2 and TESS/CHEOPS low-mass planets will be valuable candidates for atmospheric characterisation with JWST (need for accurate measures of M_p and planetary surface gravity to estimate the atmospheric scale heights)

a large diversity in the properties of the atmospheres of small planets is expected

HARPS-N/GTO short-term prospects

Need for extension of the agreement between
INAF and the HARPS-N Consortium

Composition of super-Earths and Earth-sized planets in the Habitable Zone of nearby early M dwarfs (rocky or water worlds?)

RV follow up of K2 planetary candidates; already started, to be continued till 2018/2019

RV follow up of TESS planetary candidates possibly re-observed with CHEOPS; timespan: 2018-2024

A handful of them might be valuable candidates for atmospheric characterisation in the search for biomarkers with JWST and E-ELT (need for accurate measures of M_p and planetary surface gravity to estimate the atmospheric scale heights)

HARPS-N/GTO long-term prospects

In case of prolonged extension of the agreement between
INAF and the HARPS-N Consortium

Formation, evolution, and composition of mini-Neptunes, super-Earths, and Earth-sized planets

Composition of super-Earths and Earth-sized planets in the Habitable Zone of nearby early M dwarfs (rocky or water worlds?)

RV follow up of PLATO planetary candidates
timespan: 2024-2030

Some of the well-characterised low-mass planets will be valuable candidates for atmospheric characterisation with E-ELT (need for accurate measures of M_p and planetary surface gravity to estimate the atmospheric scale heights)

Conclusions

- Rocky group with $M_p < 6\ M_\oplus$ (and $\sigma_{Mp}/M_p < 20\%$) displays no intrinsic scatter from an Earth-like composition (60% of them characterised by the HARPS-N Consortium).
  Warning: these planets are generally highly irradiated

- More and more accurate and precise R_p and M_p measurements of rocky planets are needed to see whether possible deviations would correlate with stellar metallicity.

- Planetary interior structures and M_p-R_p relationships at different orbital distances, up to the Habitable Zones (HZ):
  - any strong correlation between the presence of H/He envelopes and the distance from the host star? Constraints on the processes of accretion and retention of these gaseous envelopes
  - Constraints on the formation of super-Earths (beyond the snowline if they are water-rich)
  - nature of small planets in the HZ: rocky planets, water worlds, H/He volatiles?

- Prospects of the HARPS-N/GTO for the next 15 yr in case of (multiple?) extensions of the agreement with INAF
  - RV follow up of TESS small-size planetary candidates, even in the HZ of nearby M dwarfs (with possible photometric follow up by CHEOPS)
  - RV follow up of PLATO small-size planetary candidates up to the HZ of nearby M dwarfs

- Valuable candidates for atmospheric characterisation and search of biomarkers (for a handful of them) with JWST and E-ELT