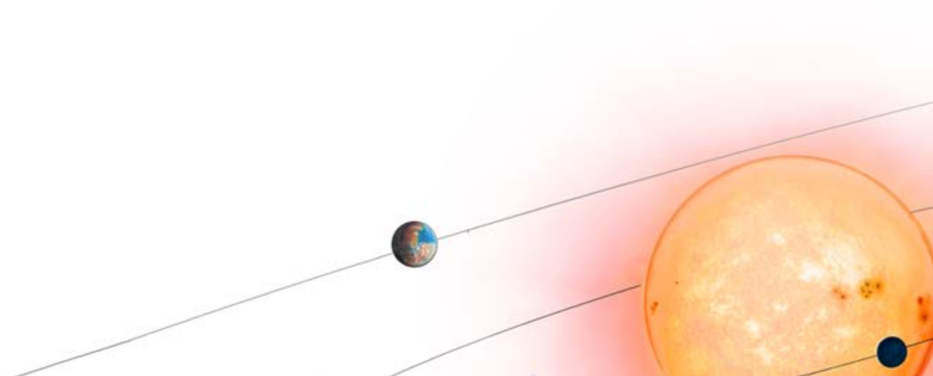
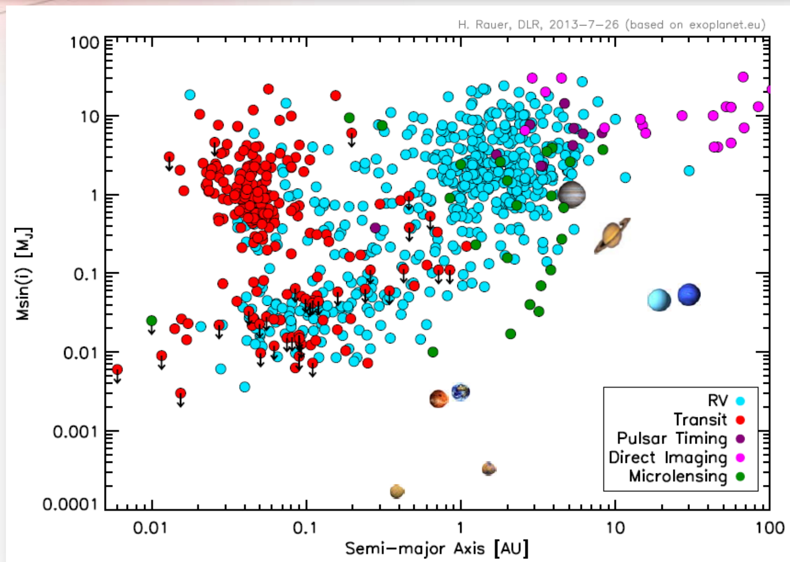
PLATO 2.0

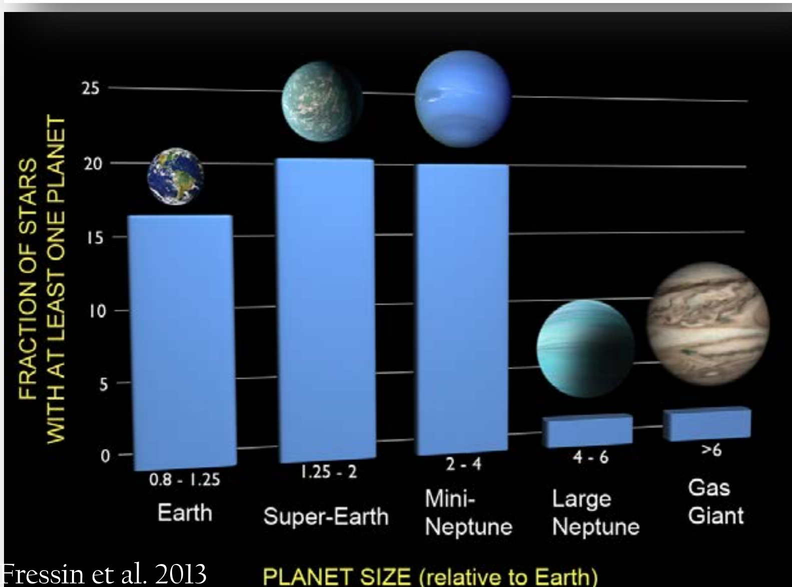
Science objectives and consortium overview

Heike Rauer and the PLATO Team



From planet frequency to planet characterization





Fressin et al. 2013

The next step: characterization!

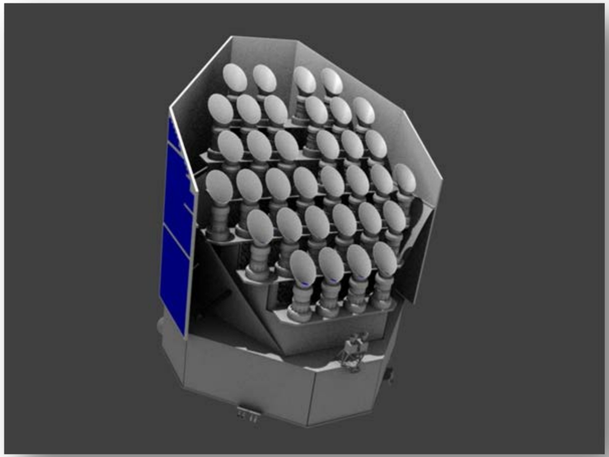
What is characterizing a planet?

- Host star and Orbit → incident stellar flux
- Mass, Radius → mean densitiy, bulk composition
- Atmosphere → scale height, composition
- Age → evolution
- Biosphere → life

The PLATO 2.0 Mission

Mission proposal for ESA M3 launch selection

- PLATO will provide a large catalogue of highly accurate bulk planet parameters:
  - radii (transit)
  - masses (RV follow-up)
  - mean densities
  - ages (astroseismology)
  - well-known host stars



- Focus on warm/cool Earth to super-Earths, up to the habitable zone of solar-like stars
- Focus on solar-like host stars to put the Solar System into context
- Observe bright stars for feasible RV follow-up and targets for atmosphere spectroscopy by e.g. JWST, E-ELT, future space missions
- Provide a huge legacy for planetary, stellar and galactic sciences

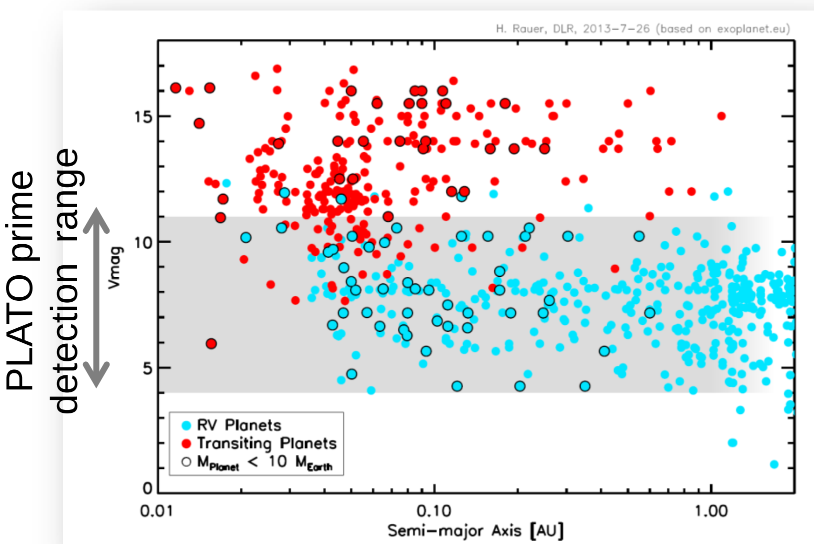
The Method

Characterize bulk planet parameters

Accuracy for Earth-like planets around solar-like stars:

- radius ~2%
- mass ~10%
- age known to 10%

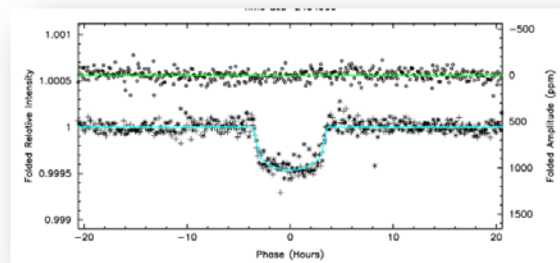
bright host stars:



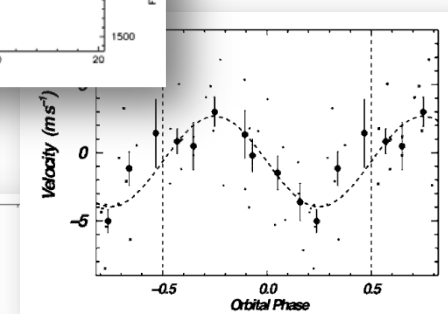
Techniques

Example: Kepler-10 b

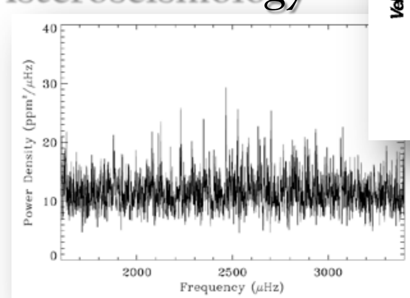
Photometric transit



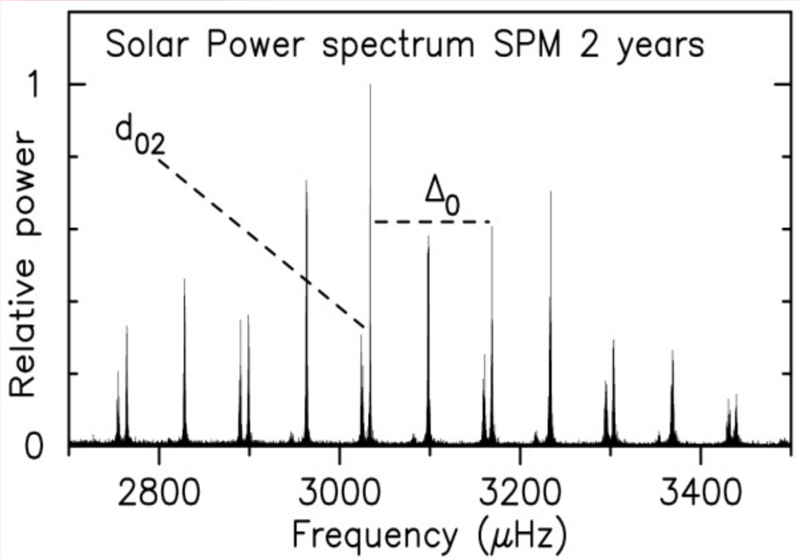
RV – follow-up



Asteroseismology



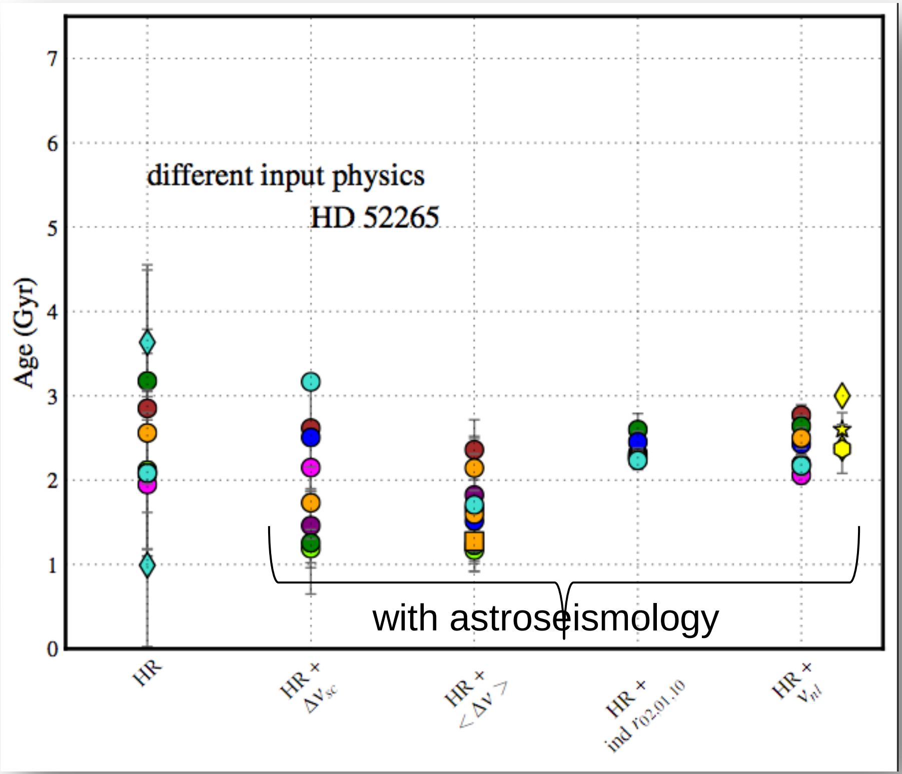
Asteroseismology
mass and age of host stars



1. Large separations $\Delta_0 \propto \sqrt{M/R3}$
   → mean density
2. Small separations d_{02}
   → probe the core → age
3. Inversions + mode fitting

   → consistent ρ, M, age

Astroseismology with PLATO 2.0 for ~85,000 stars with mag ≤11

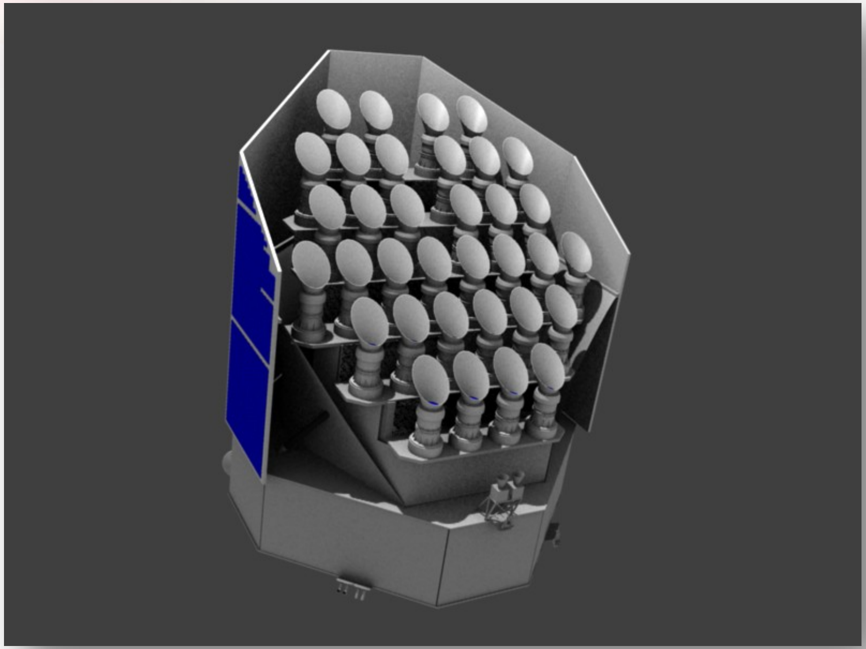


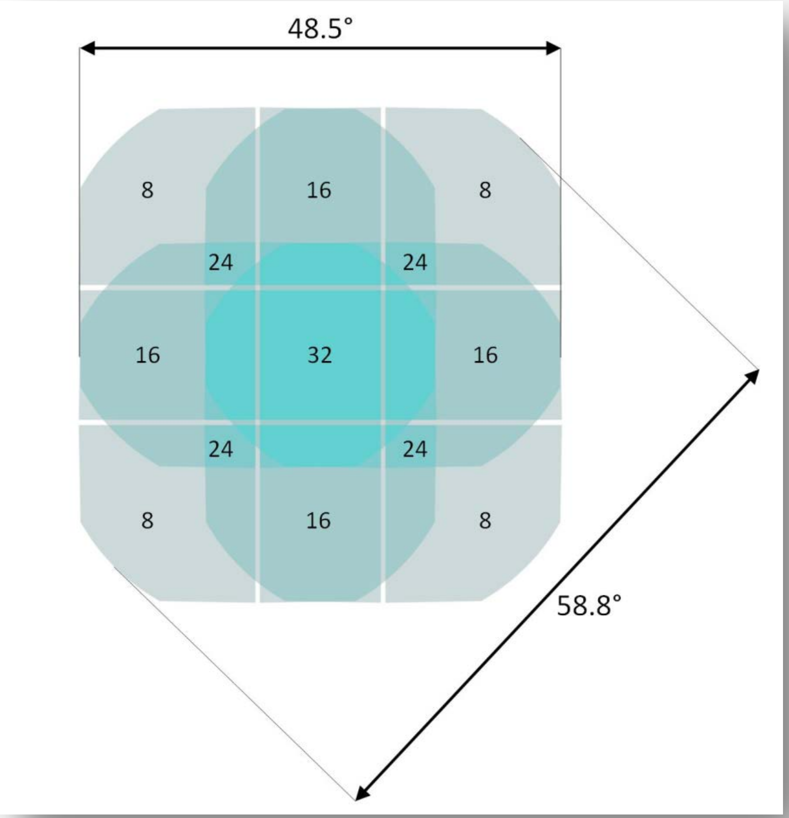
For example: analysis of HD52265

(Lebreton & Goupil, in prep.):

- ‚classical‘ analysis (e.g. gyrochronology, H&K lines, Li, X luminosity, fixed α): 0.5 – 4.2 Gyr
- Astroseismology: 2.1 – 2.6 Gyrs

PLATO instrument

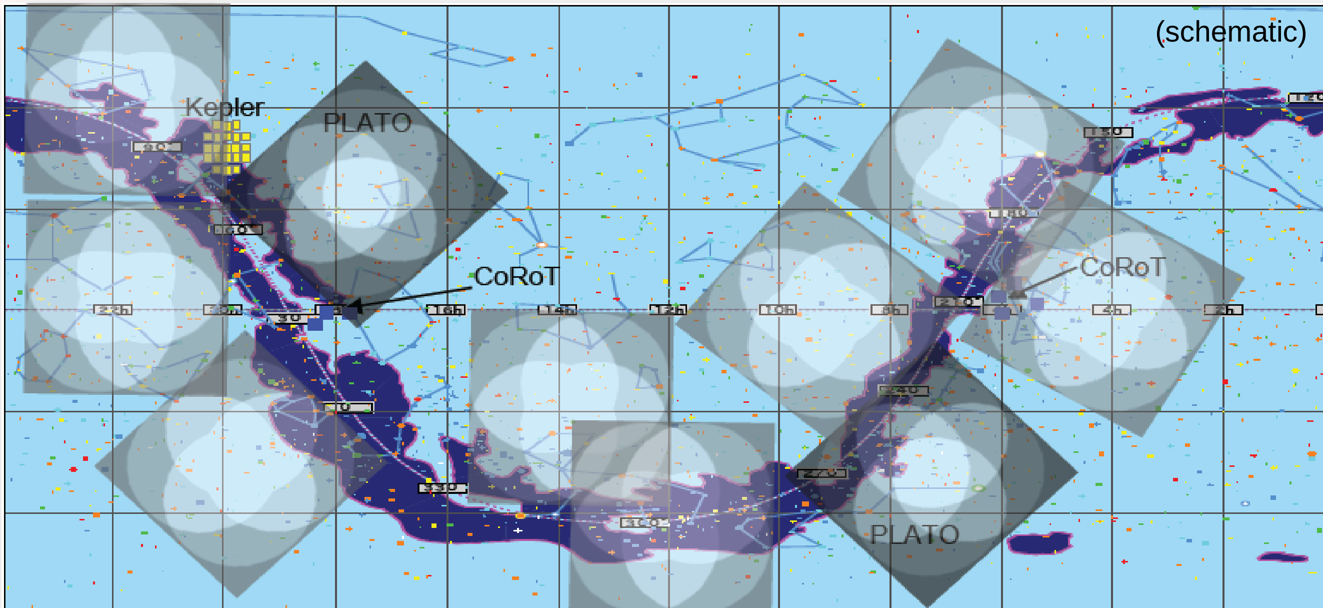




- 32 « normal » cameras, cadence 25 sec
- 2 « fast » cameras : cadence 2.5 sec, 2 colours
- dynamical range: $4 \leq m_V \leq 16$

- Cameras are in groups
- Offset to increase FoV

Observing strategy



High-number detections need wide field, large orbits need long pointings. PLATO optimizes via:

- 6 years nominal science operation
- 2 long pointings of 2-3 years + step-and-stare phase (2-5 months per pointing)

Target bright stars:

- 4-11 mag for super-Earths detection and full planet and host star characterization
  → survey ~85,000 stars
- 11-13 mag for super-Earths detection
  → survey in total1,000,000 stars

PLATO 2.0 Science objectives

Key questions and themes:

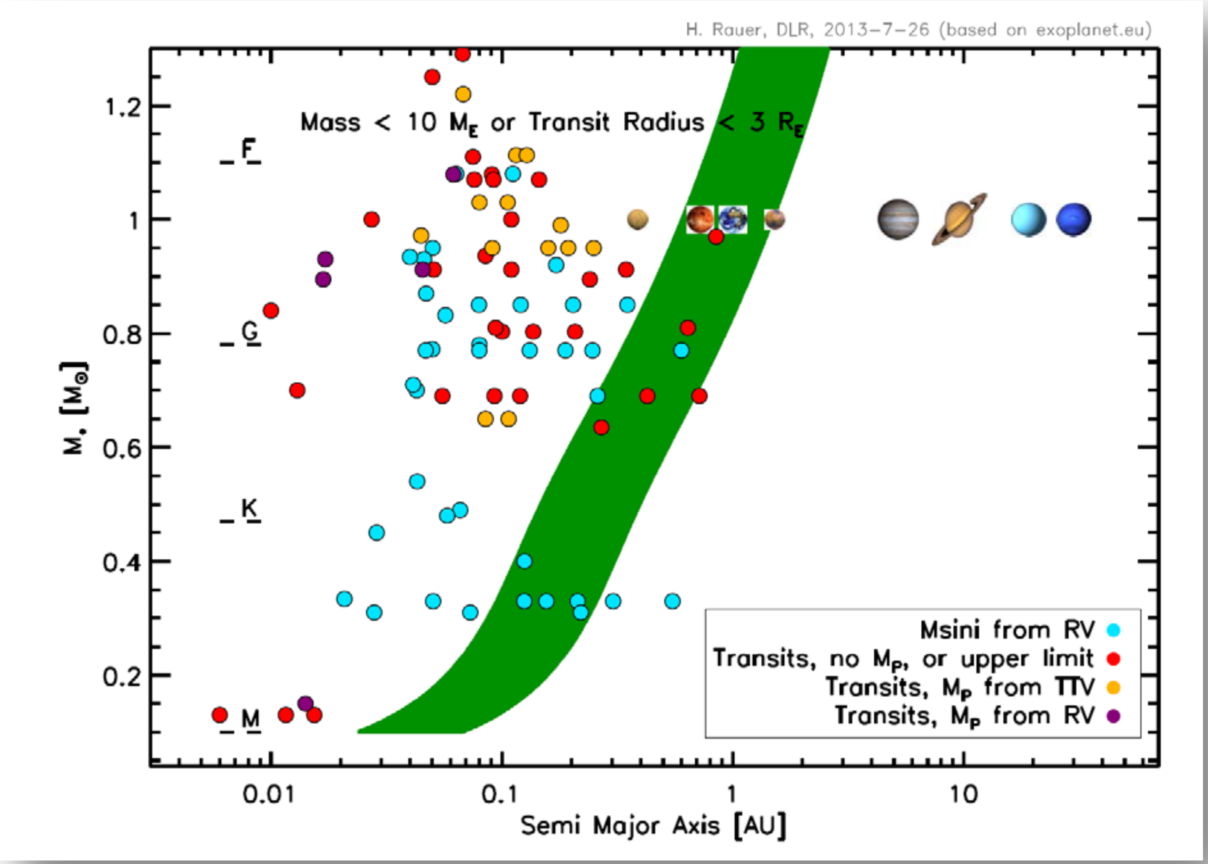
- **Is our Solar System special? Is there another system like ours?**
- **How do planetary systems form?**
- **How do planets and systems evolve?**
- **How abundant are low-mass planets with atmospheres?**
- **Advance stellar science**
- **Galactic structure and evolution**

PLATO 2.0 Science objectives

- Determine diversity of bulk planet properties up to Earth-like planets at ~1AU
- Detect exomoons, planetary rings, Trojan planets; planets around giants and cool dwarfs
- Detect and characterize planets around stars with different metallicity, age, activity, system architectures, …
- Correlate planet bulk properties and system architectures with age (young and old stars)
- Constrain which planets likely have atmospheres
- Improve stellar models via astroseismology
- Probe galaxy structure and evolution using red giants
- Calibrate stellar gyrochronology
- …

Bulk properties of Earth-like planets up to the HZ

Status super-Earths detection and characterization



Bulk properties of Earth-like planets up to the HZ

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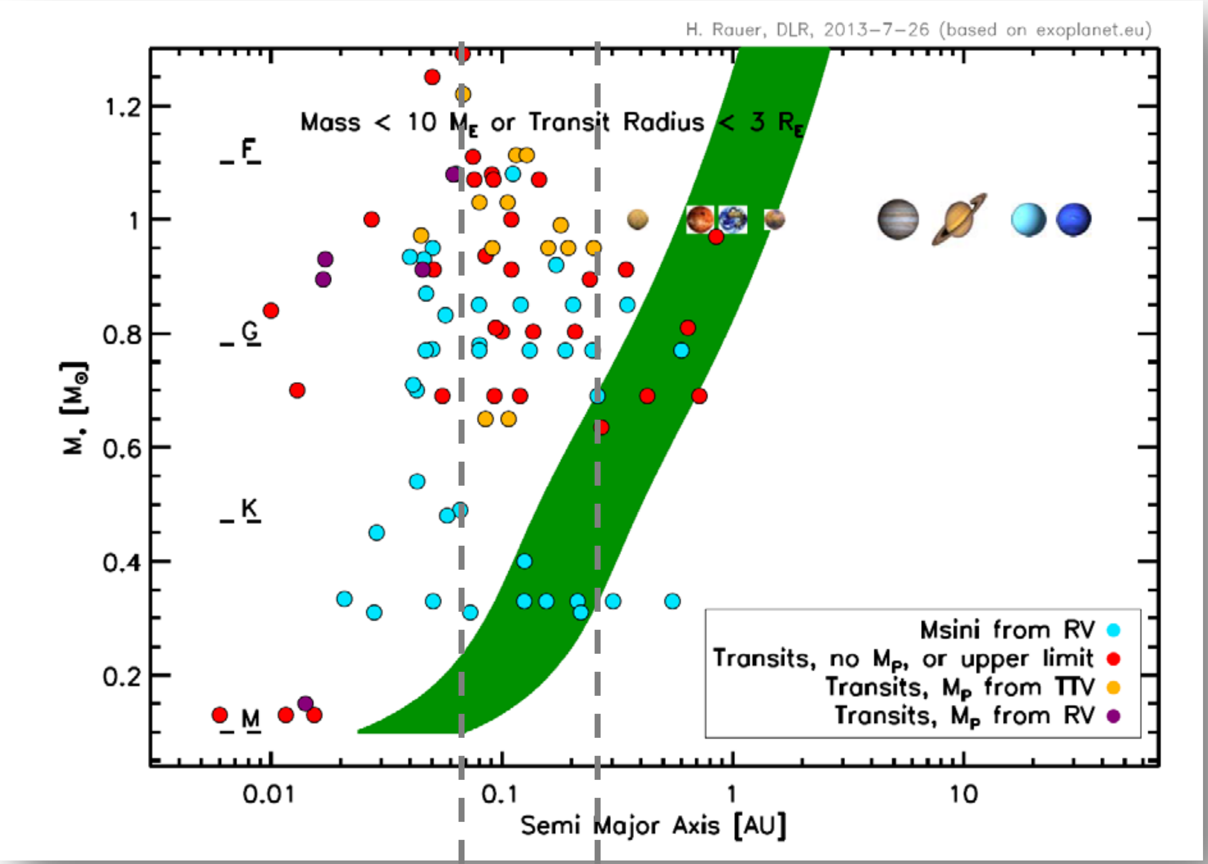
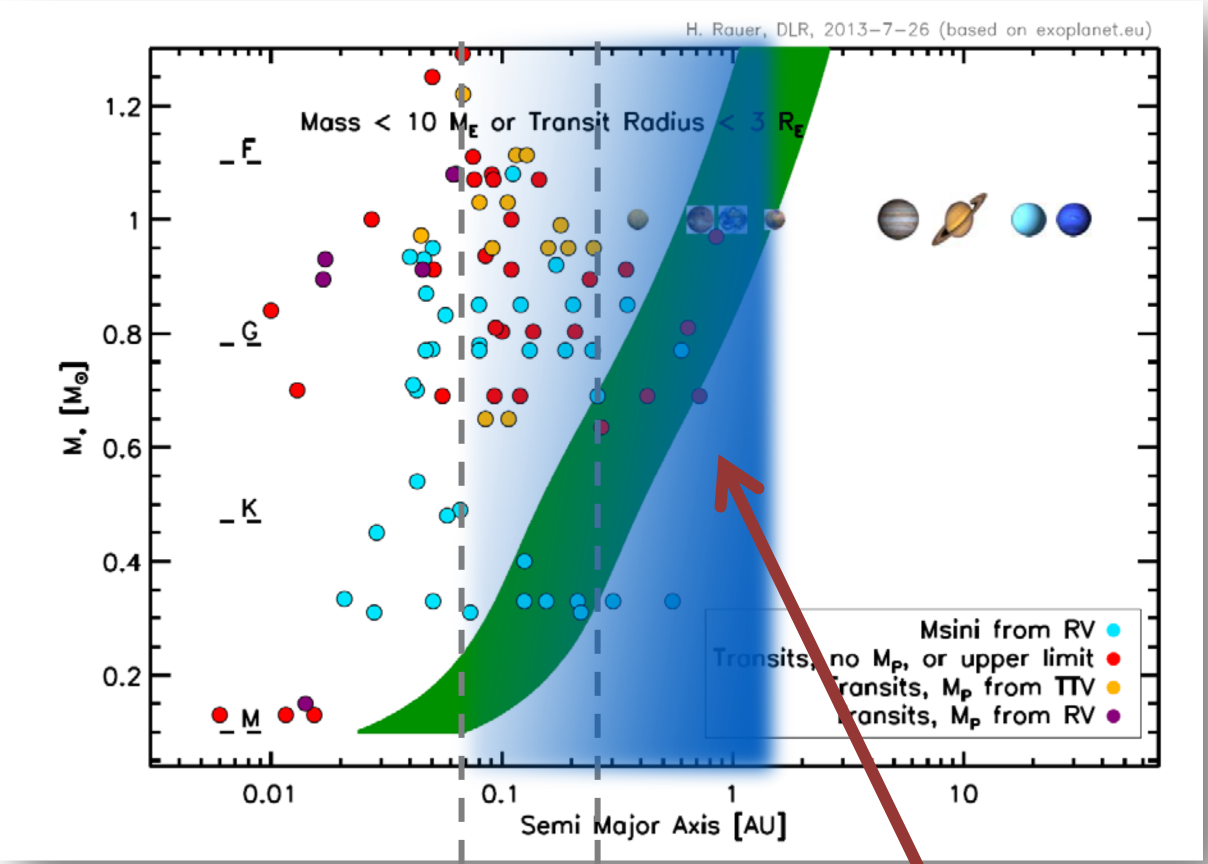


Transits and mass from RV

Mass from TTVs

Bulk properties of Earth-like planets up to the HZ

Status super-Earths detection and characterization

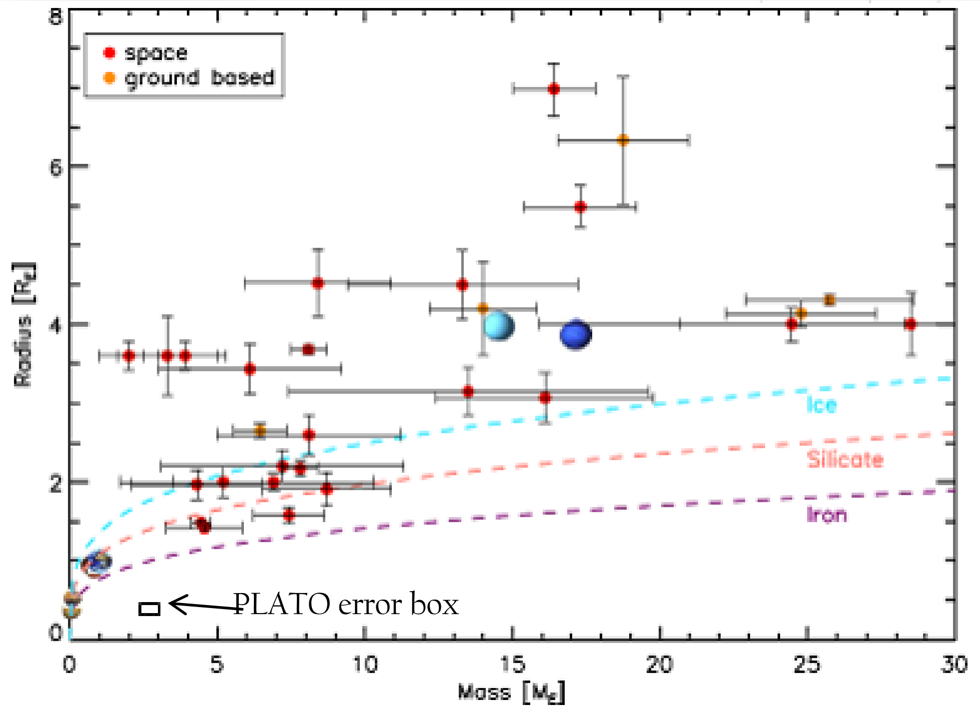


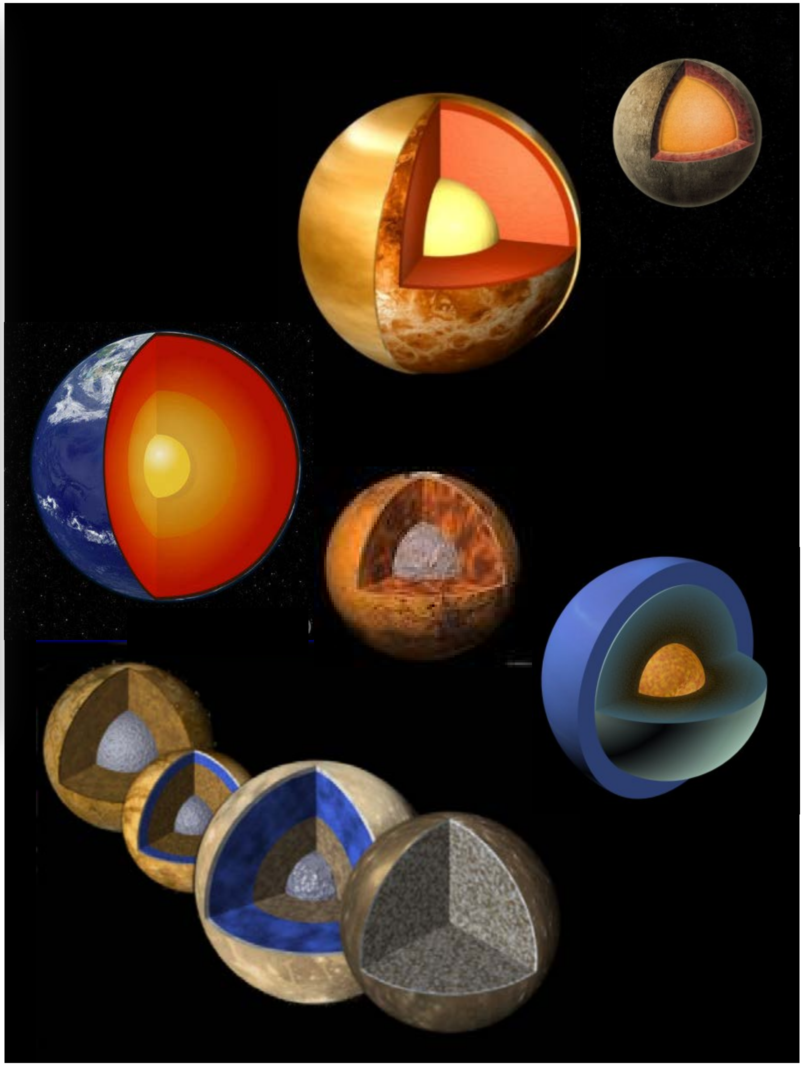
Transits and mass from RV

Mass from TTVs

Main target range for PLATO 2.0 characterization (transit + RV)

Diversity of bulk proerties





- Radii (masses) can differ by factor ~2 for the same mass (radius)
- Constraining composition of small planets requires accurate parameter measurements:

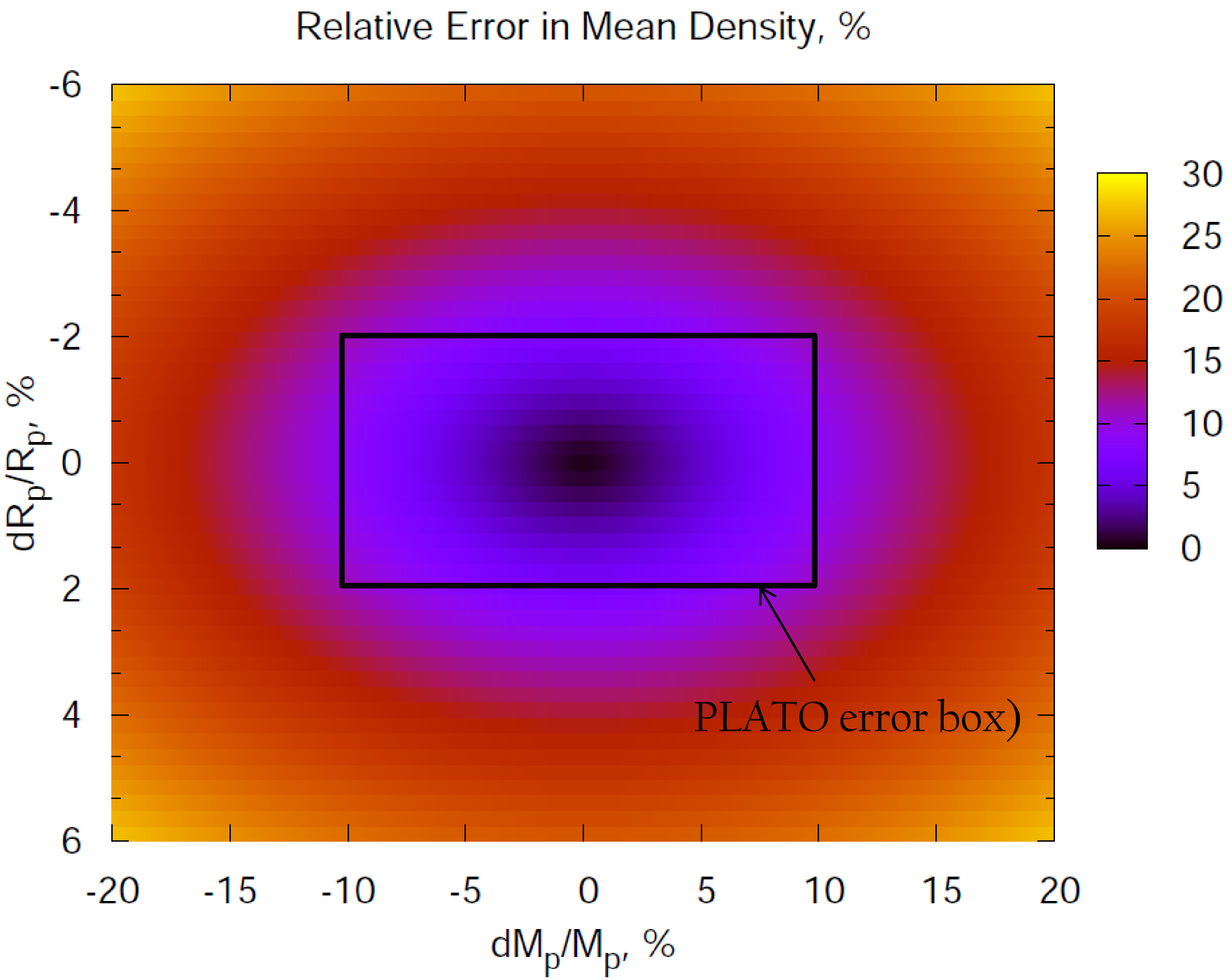
radius ~2%, mass ~10%

Mean density

How accurate?

- Mass-radius relationship
  $R_p \equiv cM_p^{\beta}$
- Super-Earths

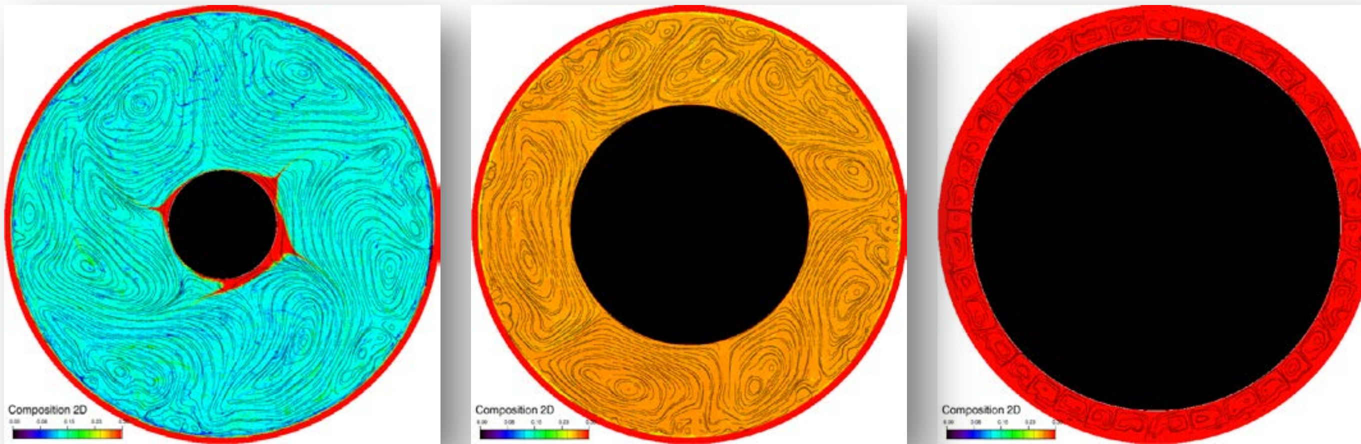
$$\beta = \frac{1}{4}$$

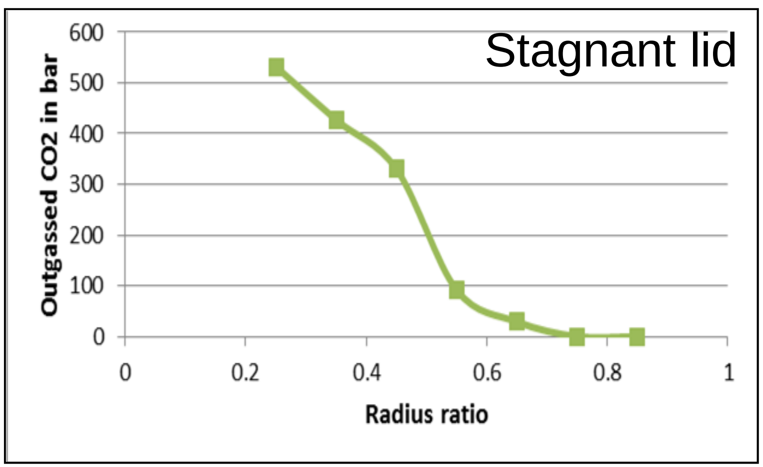


Sohl et al., in press

Atmosphere - interior

Planets with 1 Earth radius, but different mass (±20%) hense density



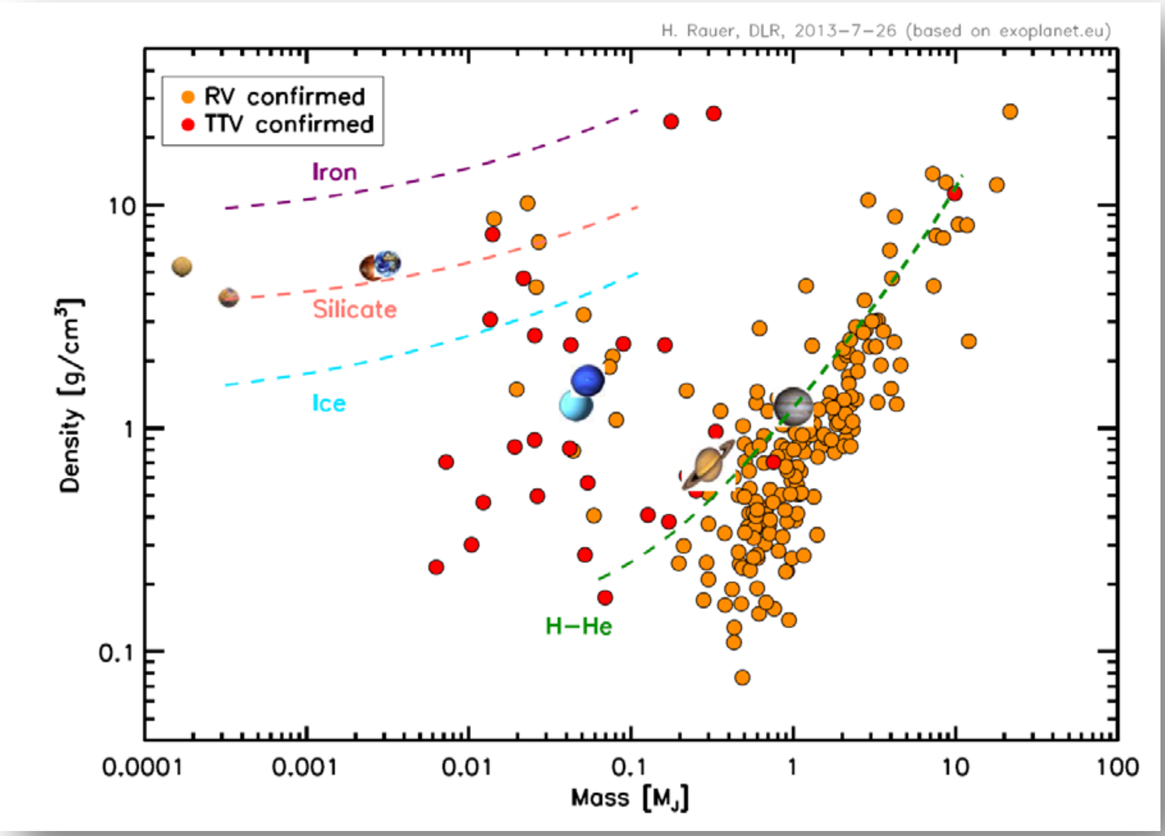


Noack et al., 2013, submitted

- Iron to silicate ratio is related to formation scenarios
- Atmosphere outgassing rates differ for stagnant lid and plate tectonic mode dominated planets
- PLATO 2.0 can provide bound on interior-surface- atmosphere relationships due to a large sample of well-known low-density planets

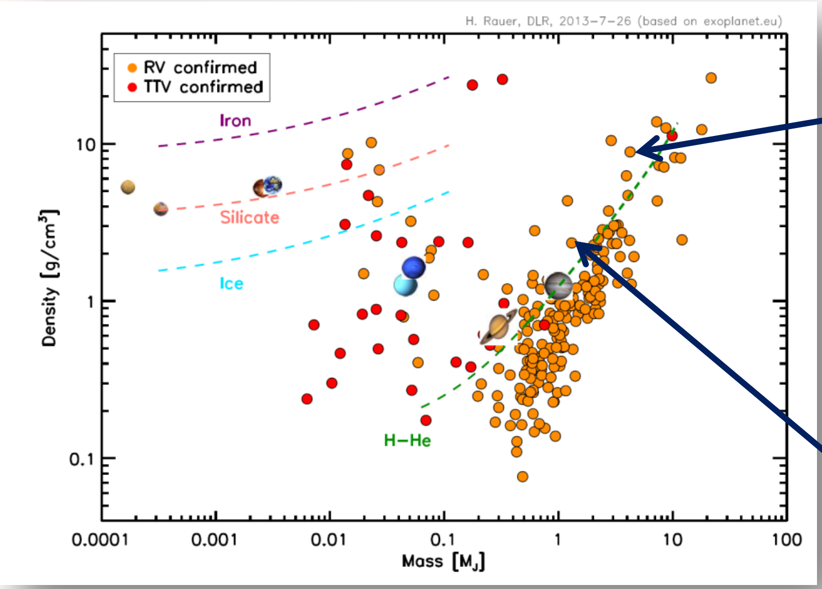
Planet formation and evolution

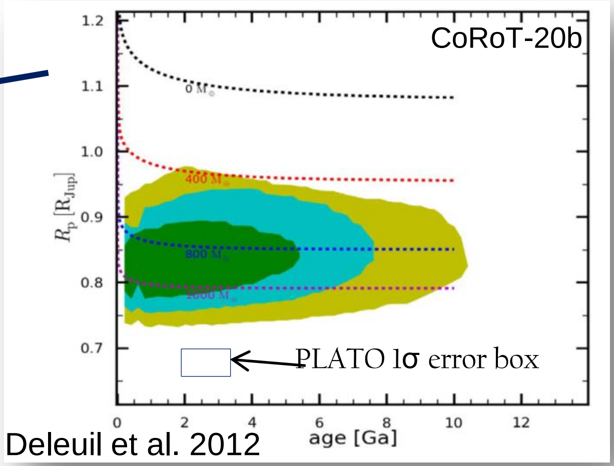
Planets with measured mass and radius:

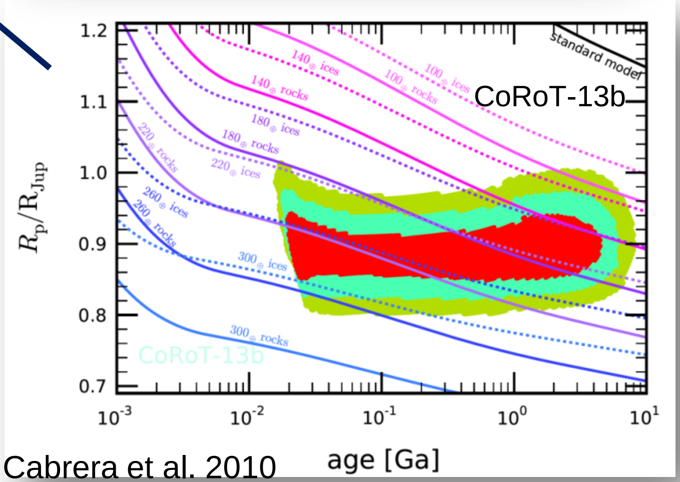


- Not all density-mass combinations are realized. How about small, terrestrial planets?
- One order-of-magnitude diversity in mean density found for a given mass. What is the composition and internal structure?
- What is the observed critical core mass?
- Can super-massive rocky planets exist? How are they formed?

Planet formation and evolution

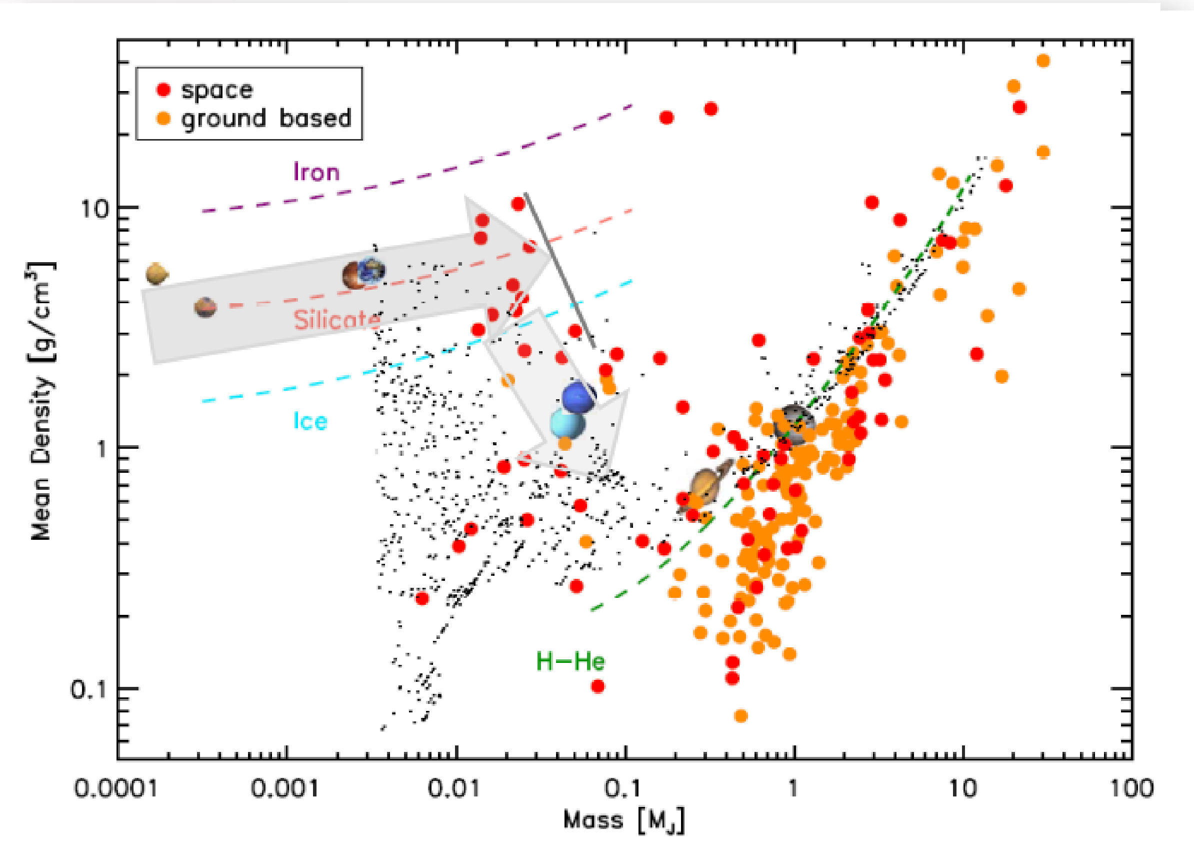






- Gas giants contract with age
- A population of gas giants with heavy cores has been found
- How are planets with such massive cores formed?

Planet formation and evolution



Black dots: Planet synthesis population (Mordasini et al., 2013)

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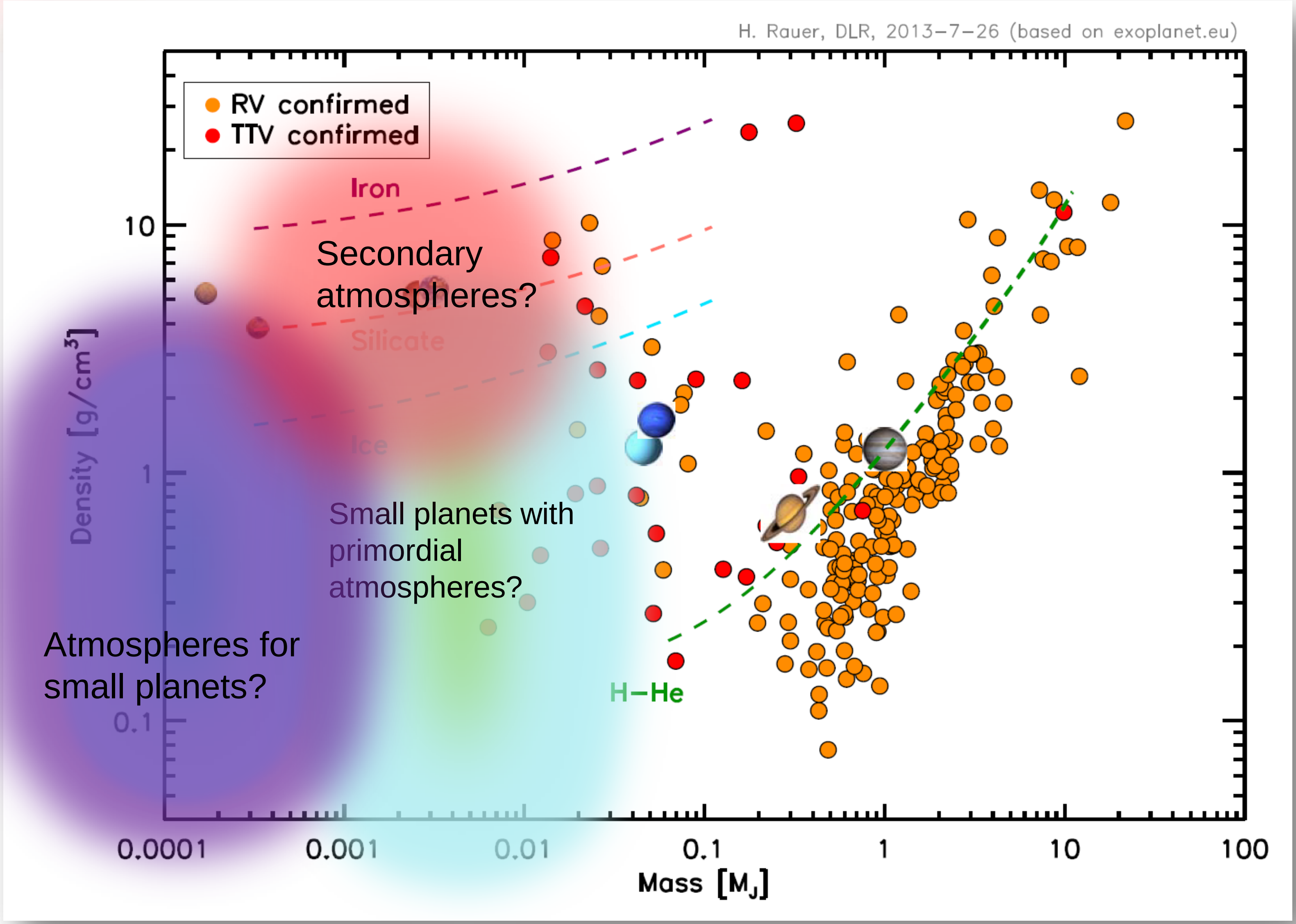
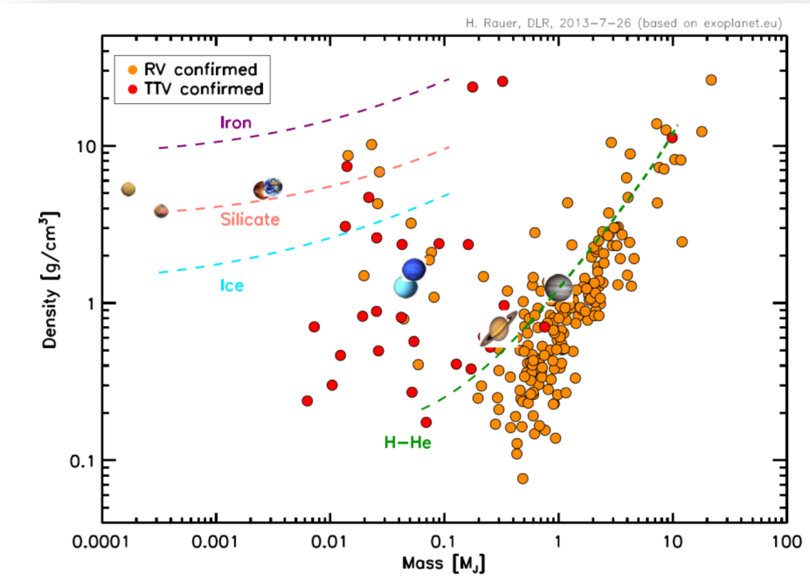
- One order-of-magnitude diversity in mean density found for a given mass. What is their composition and internal structure?
- What is the observed critical core mass?
- Can super-massive rocky planets exist? How are they formed?
- Do large numbers of low-mass planets with H-atmospheres exist?

Small Planets with atmospheres

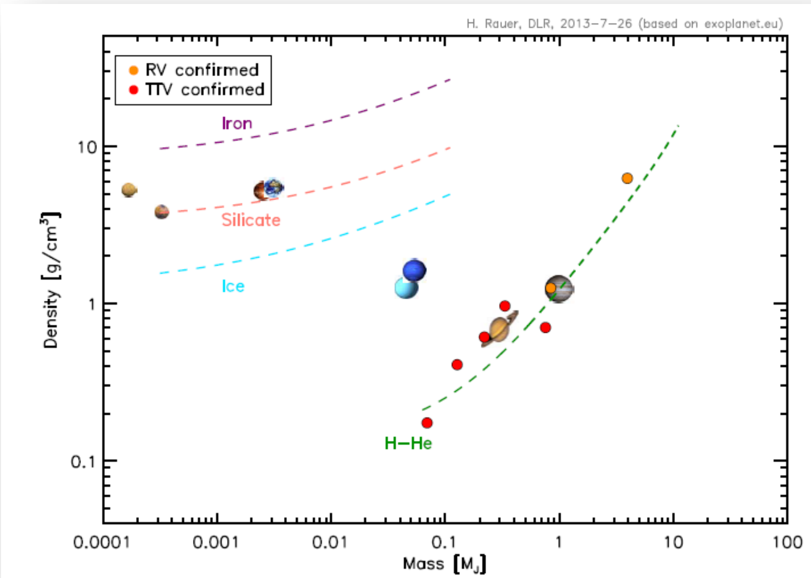


Planets at intermediate distances

All known planets with measured mean densities.



Exolanets with measured mean densities and P≥50 days

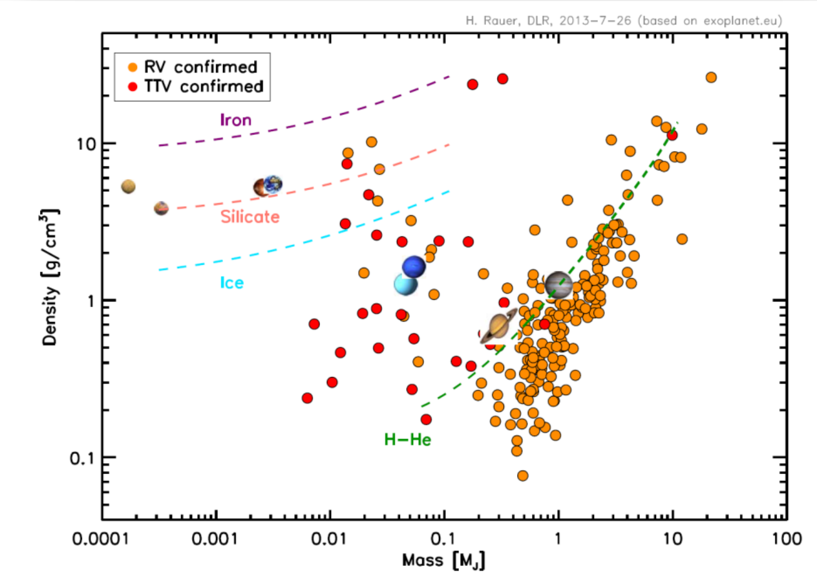


Planets at intermediate distances:

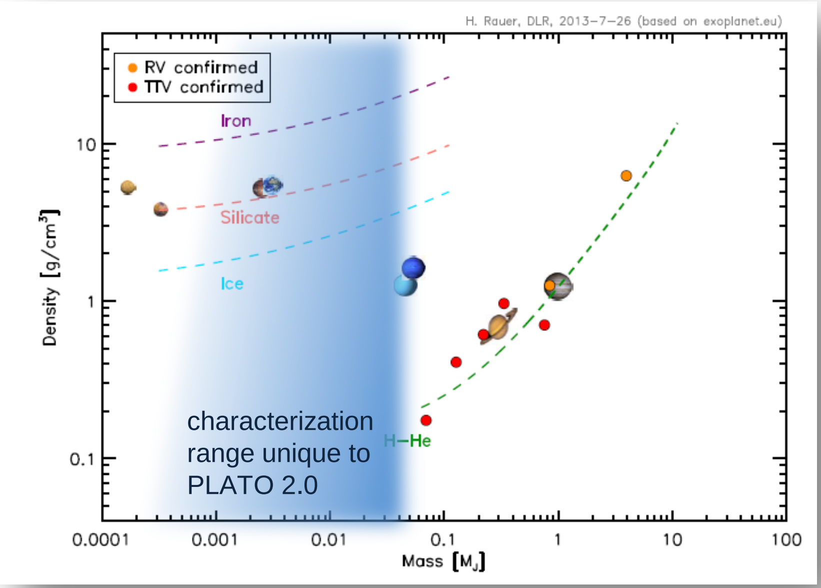
- are less affected by stellar radiation and winds (e.g. heating, atmospheric losses, …)
- allow for temperate climate, hence habitable conditions.
- are less affected by tidal forces (e.g. dynamical evolution)
- probe different regions for planet formation and migration

Planets at intermediate distances

All known planets with measured mean densities.



Exoplanets with measured mean densities and **P≥50 days**



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Detection and characterization performance for Earth-like planets

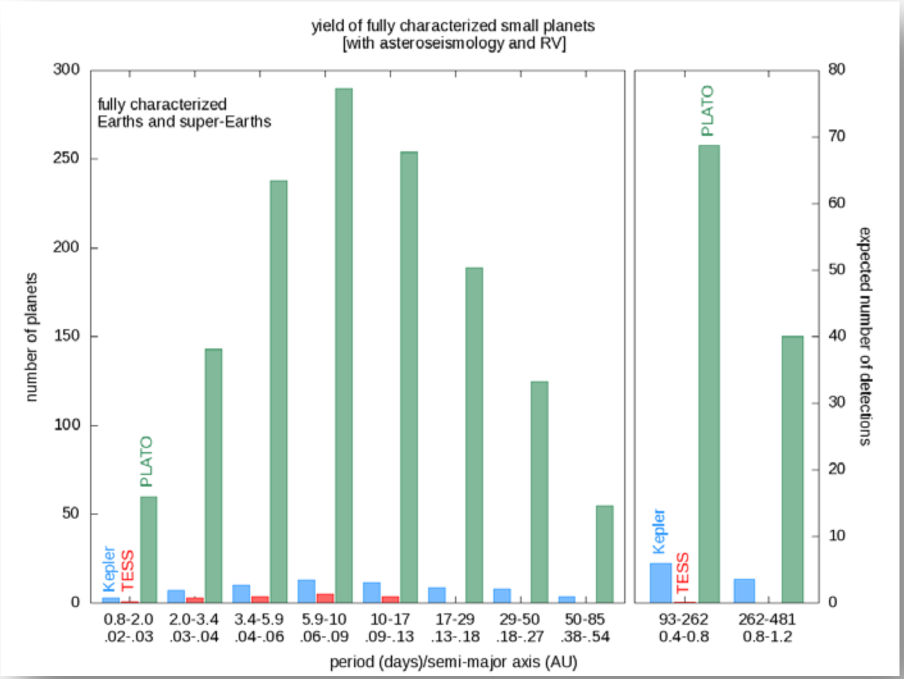
Planet detection and **characterization performance of PLATO 2.0** for Earth-like planets (**≤2 R_{earth}**), hence **transit + bright RV target + astroseismology:**

- For short-periods, P<50 days and in HZ of cool dwarfs:

  >1000 super-Earths transits

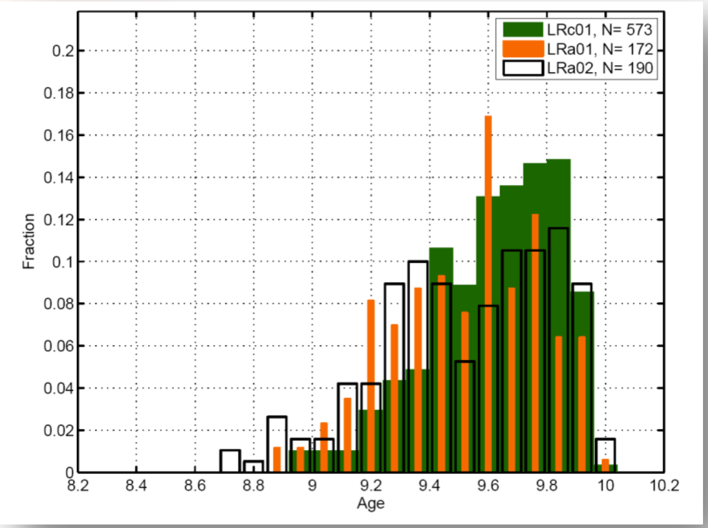
- In HZ of Solar-like stars (>0.8 AU):

  ~40-100 super-Earths transits

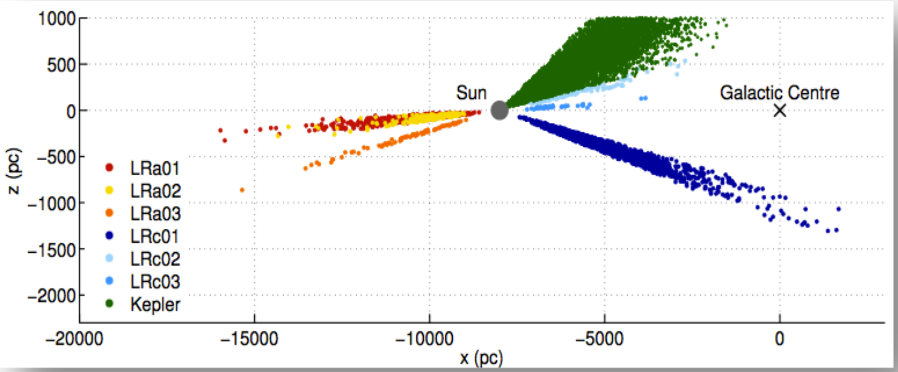


- RV follow-up coordinated during PLATO 2.0 mission will focus on scientifically favored targets. (see talk by Stephane Udry)
- Huge legacy for further planet characterization

Galactic structure



Miglio et al. (2012, 2013)



Miglio et al. (2012, 2013)

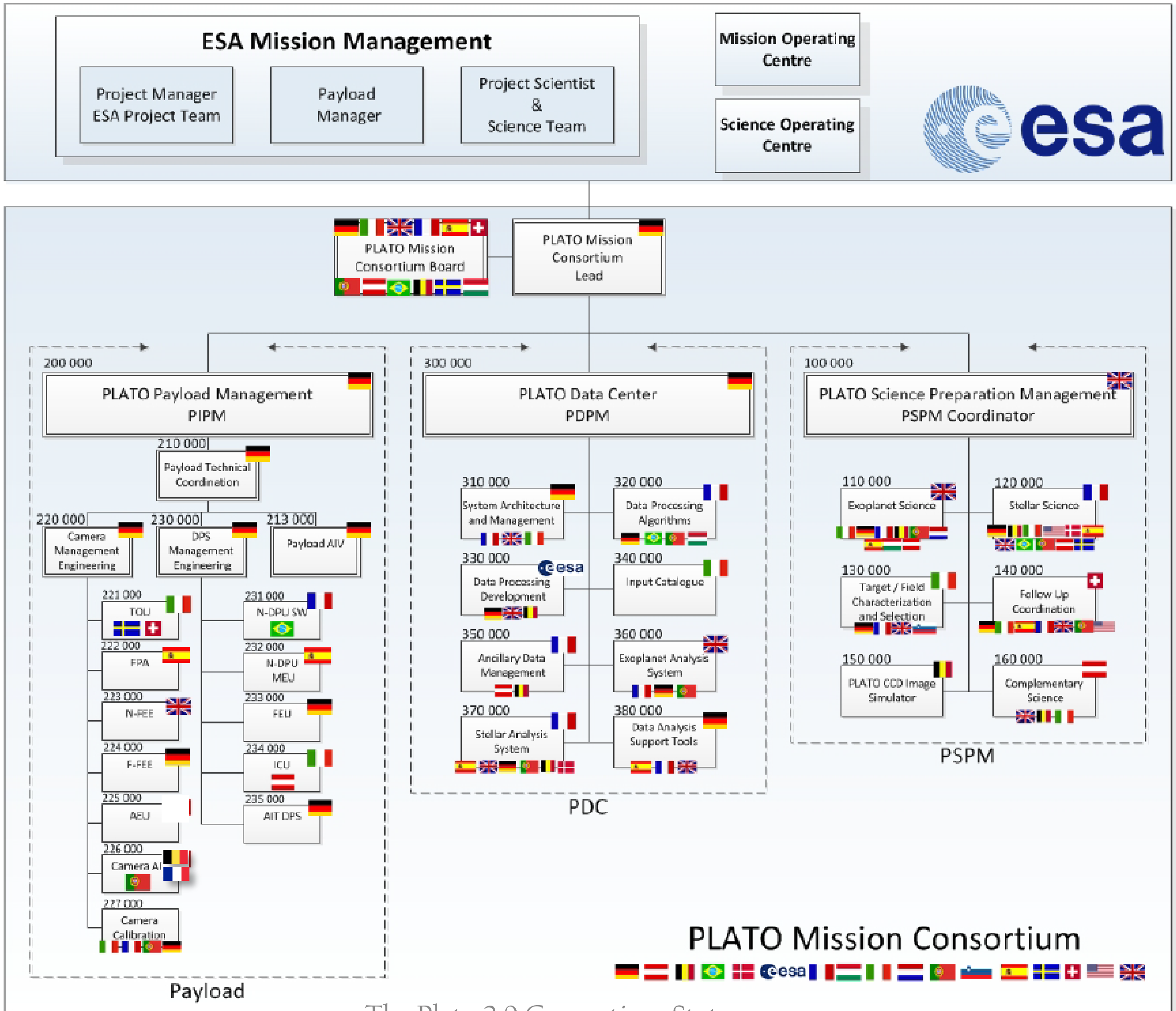
- Probe structure and evolution of our galaxy by measuring stellar distances (from Gaia) and ages (from PLATO red giant stars)
- Calibrate gyrochronology of stars via age-rotation relationship by age from astroseismology and rotation periods from spots
- Perform asteroseismology of blue super-giants (progenitors of core-collapse super-novae) to understand chemical enrichment of galaxies

The PLATO Consortium

Main Partners:

- Austria
- Belgium
- Brazil
- Denmark
- France
- Germany
- Hungary
- Italy
- Portugal
- Spain
- Sweden
- Switzerland
- United Kingdom

Consortium Structure



How to be involved and support the PLATO 2.0 mission

- Become part of the PLATO 2.0 team and contribute to
  - **Payload activities** (contact Heike Rauer, Institute for Planetary Research, DLR)
  - **PLATO Data Center activities** (contact: Laurent Gizon, MPI for Solar System Research)
  - **PLATO Science Preparation activities** (contact: Don Pollacco, Univ. Warwick)

- Become co-author on publication on PLATO 2.0 science

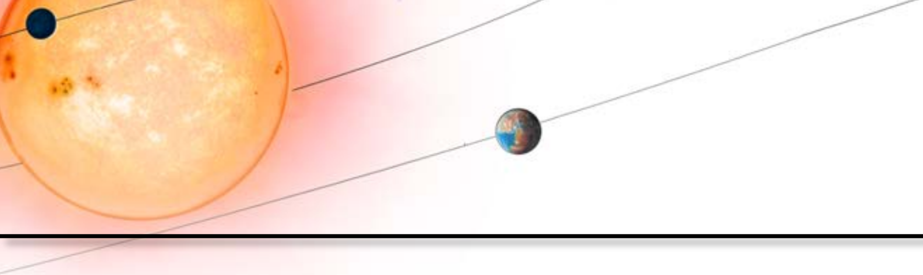
  (draft available for further contributions)

- More information on PLATO 2.0 at:

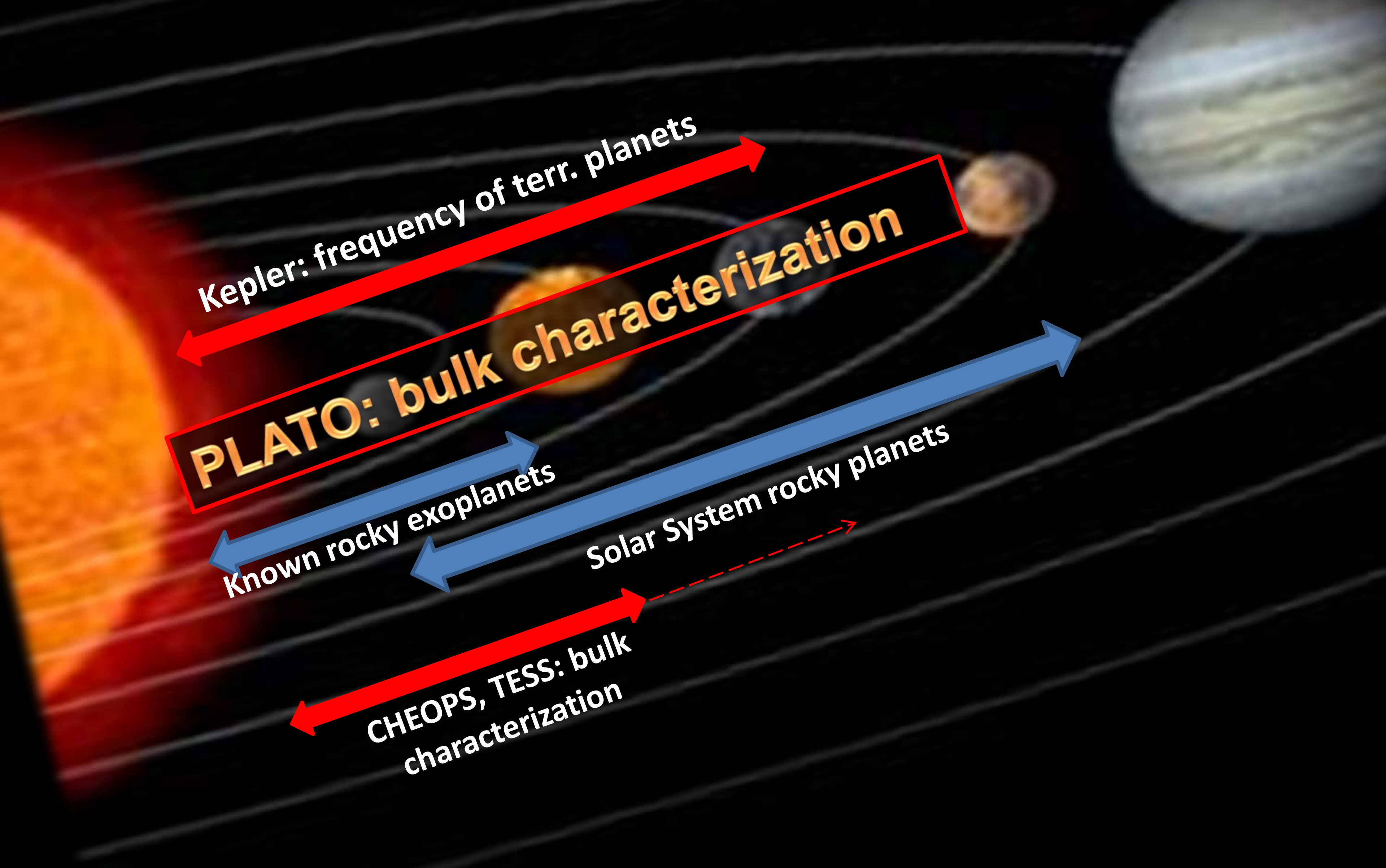
  http://sci.esa.int/plato/

  and

  www.oact.inaf.it/plato/PPLC/



Characterize diversity



Additional slides. Not used.

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- **How do planetary systems form?**
- **How do planets and systems evolve with age?**
- **How many low-mass planets have atmospheres?**
- **Advance stellar science**
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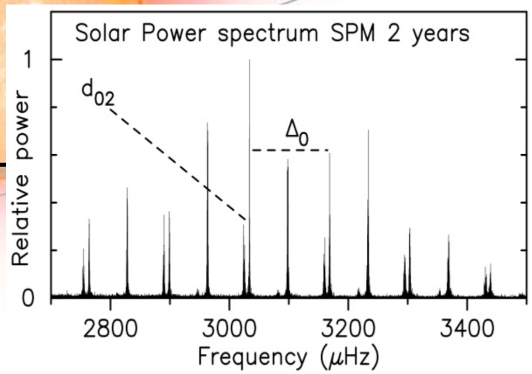
Asteroseismology
mass and age of host stars



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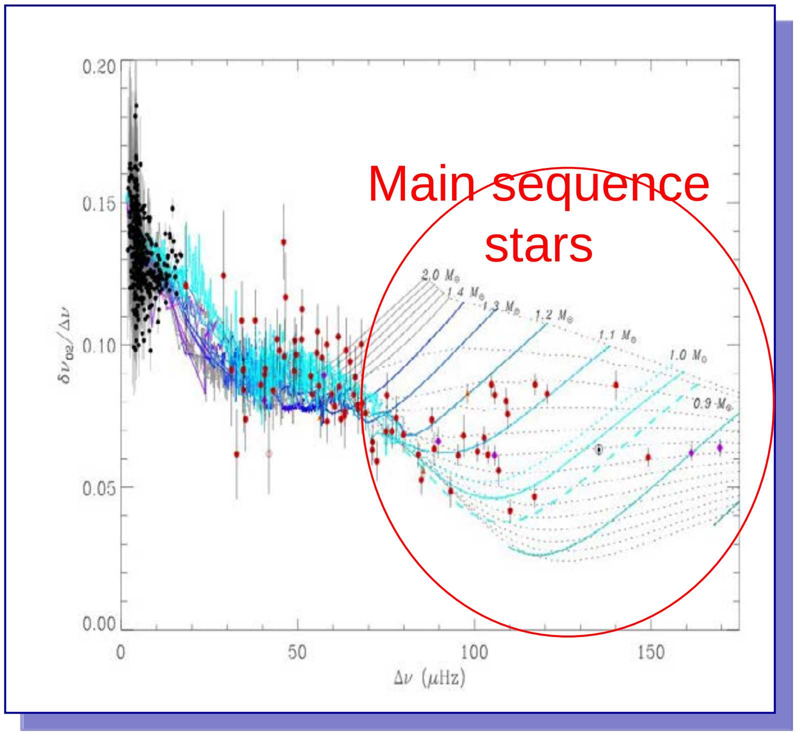


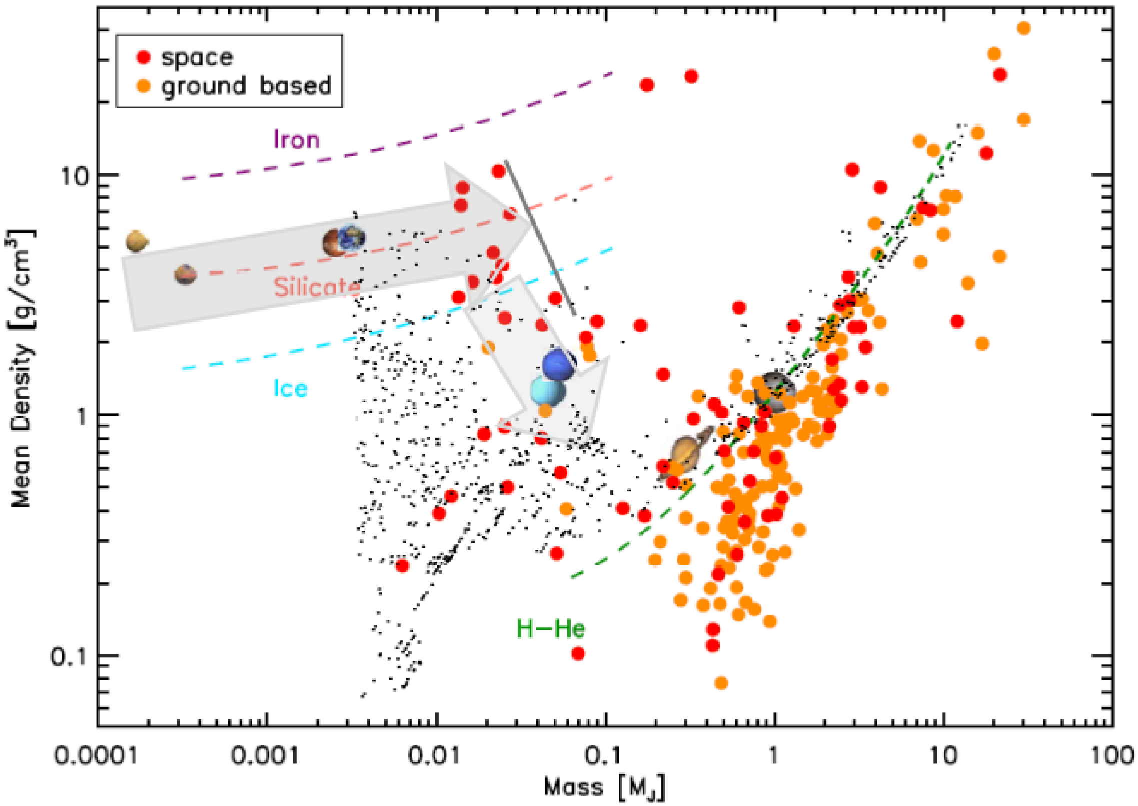
Normalized mean small separation as a function of the mean large separation and evolutionary tracks (blue solid lines). Horizontal dotted lines are isochrones in 1 Gyr steps (White et al. 2011)

Asteroseismology has been successfully applied to bright Kepler stars, showing how powerful this technique is.

PLATO will improve the achieved accuracies to:

- Uncertainty in Mass ≤ 2%
- Uncertainty in Age ~ 10%

Planet formation and evolution



Planet synthesis population from: Mordasini et al., 2013)

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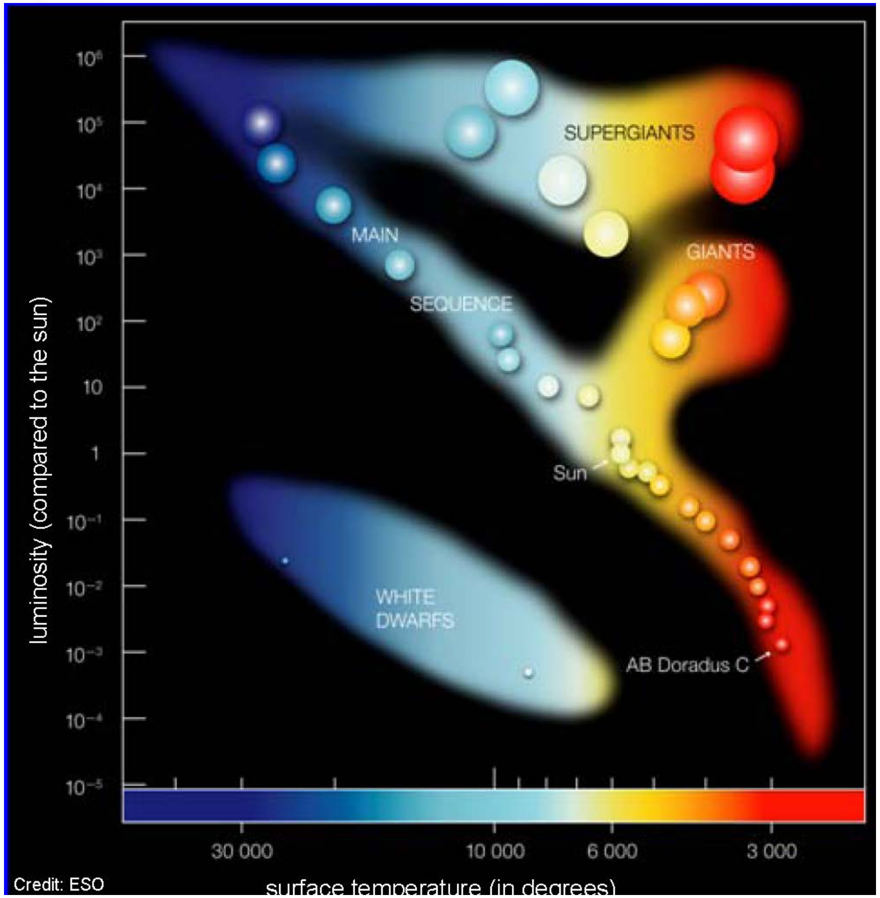
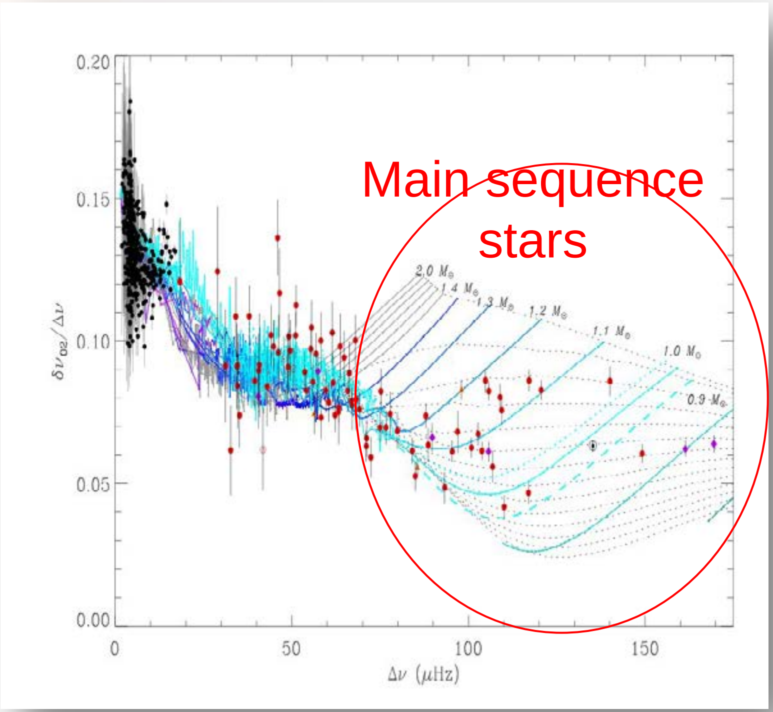
Improve stellar models



Asteroseismology

mass and age of host stars



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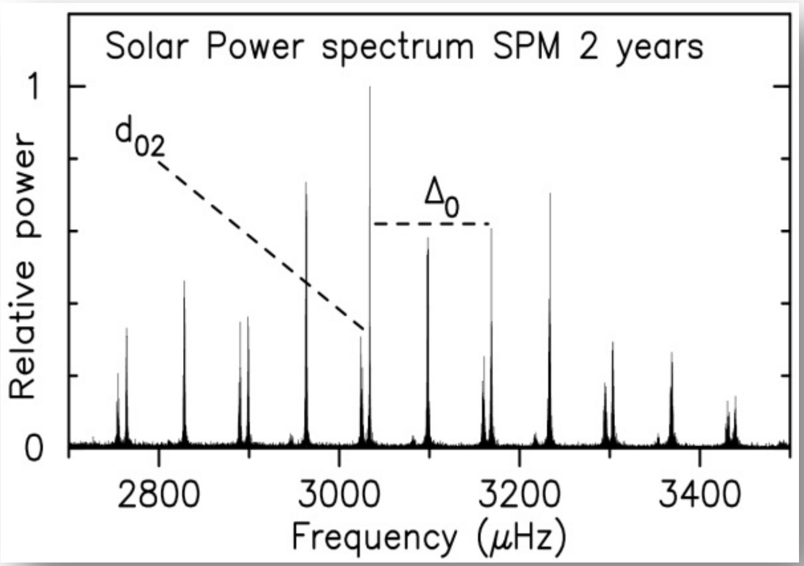

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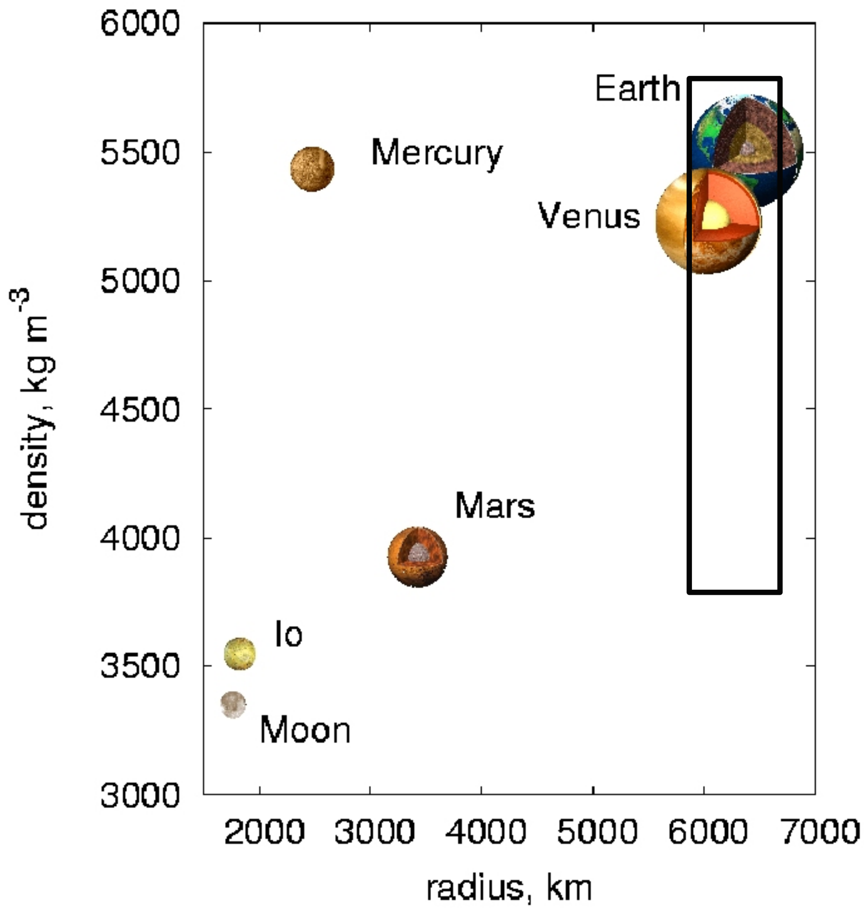
Mean density and composition



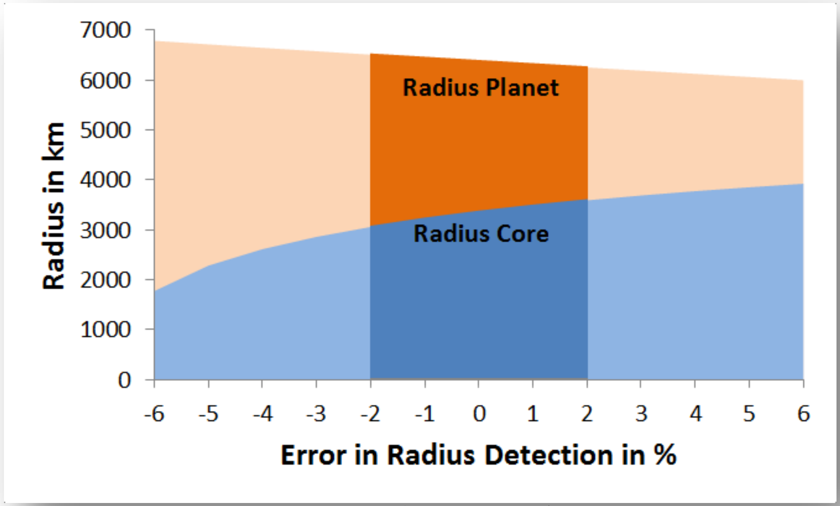
Current uncertainties in mean density of super-Earths:

- ~±6% in radius
- ~±20% in mass

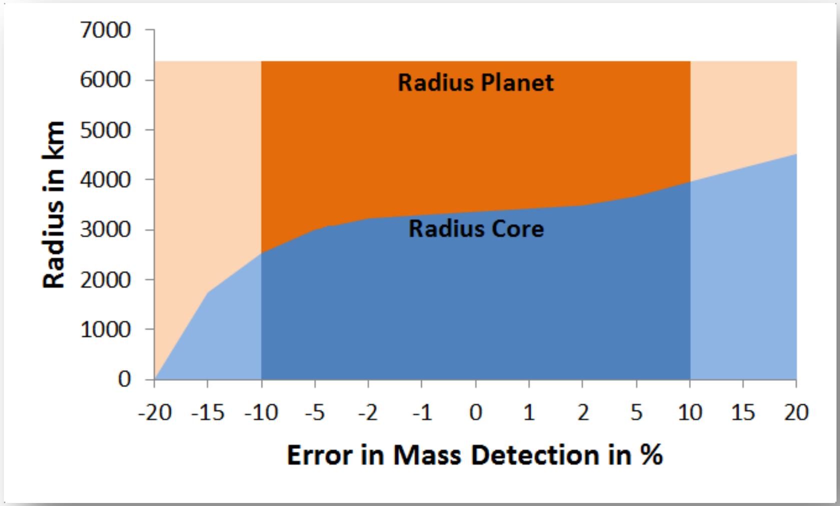
Constrain planet interior

- Planet interior models can be constrained if reasonable assumptions can be made, e.g.: assume a silicate-Fe mixture

1 Earth mass planet



1 Earth size planet



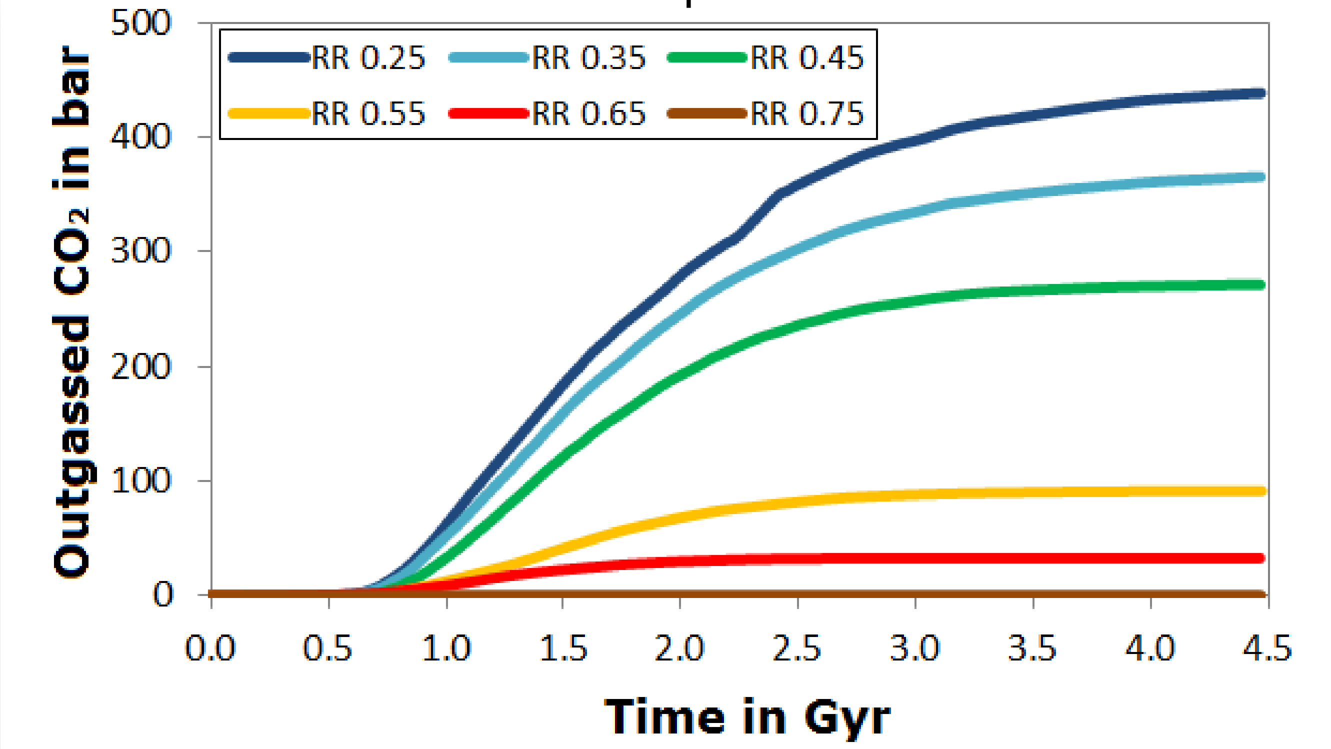
Noack et al. 2013, submitted

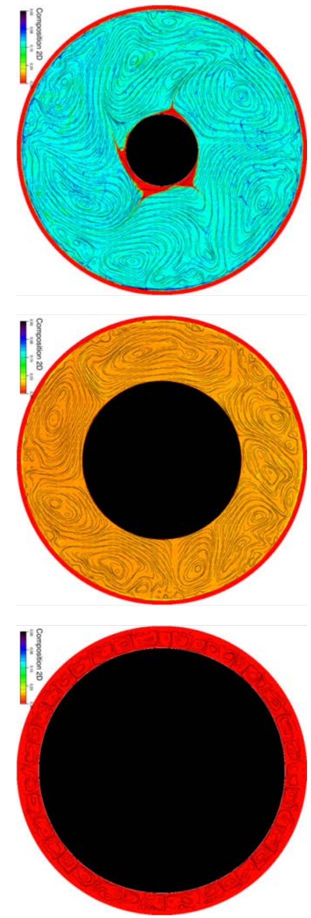
→ With PLATO accuracies core-mantle ratios can be well constraint
→ Allows us to study link to terrestrial planet atmospheres when combined with spectroscopic follow-up

Interior - atmosphere

For example assume the following scenario: Earth radis planet, stagnat-lid regime

ratio of core radius to planet radius

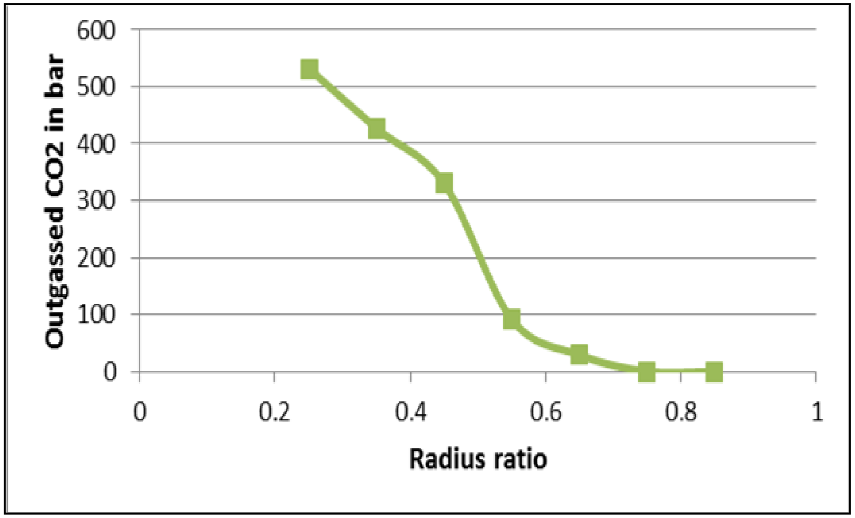




Noack et al. 2013, submitted

→ Needs accurate radii and masses of terrestrial planet samples to constrain core/mantle ratio

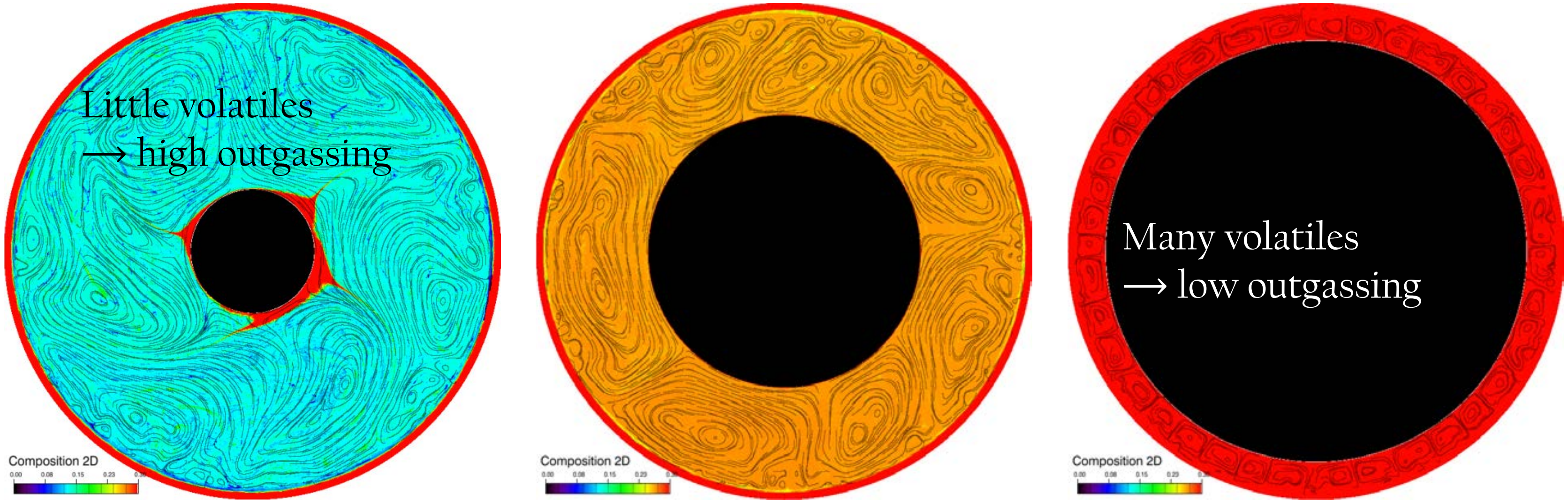
Limited atmospheric CO_2 from outgassing rates



Interior dynamics modeling of an Earth-sized, Earth-like stagnant-lid planet:

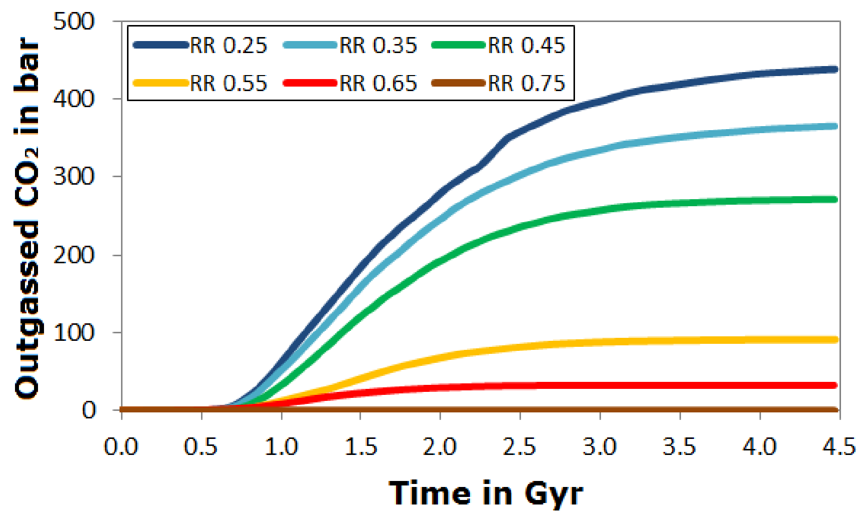
- Large core/planet radius ratio ⟶ little/no outgassing, due to pressure dependence of solidus

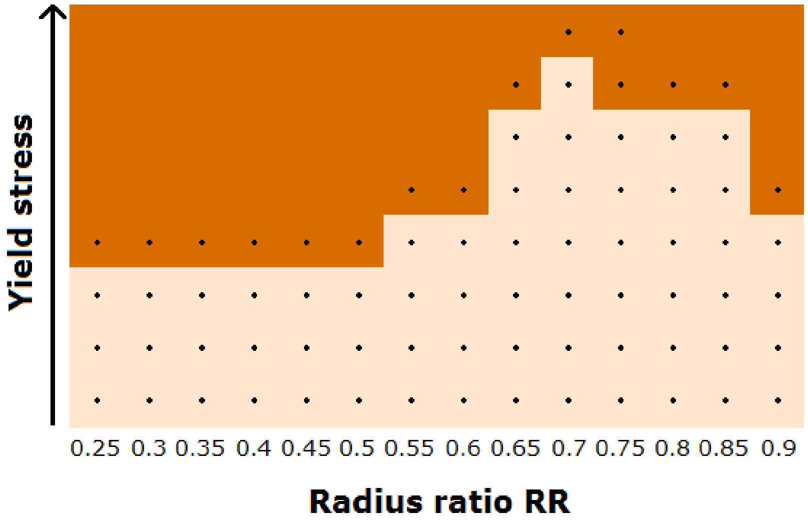
Mantle volatiles after 4.5 Gyrs of thermal evolution:



Noack et al., 2013, submitted

Interior-atmosphere relationship for stagnant lid planets





Noack et al. submitted