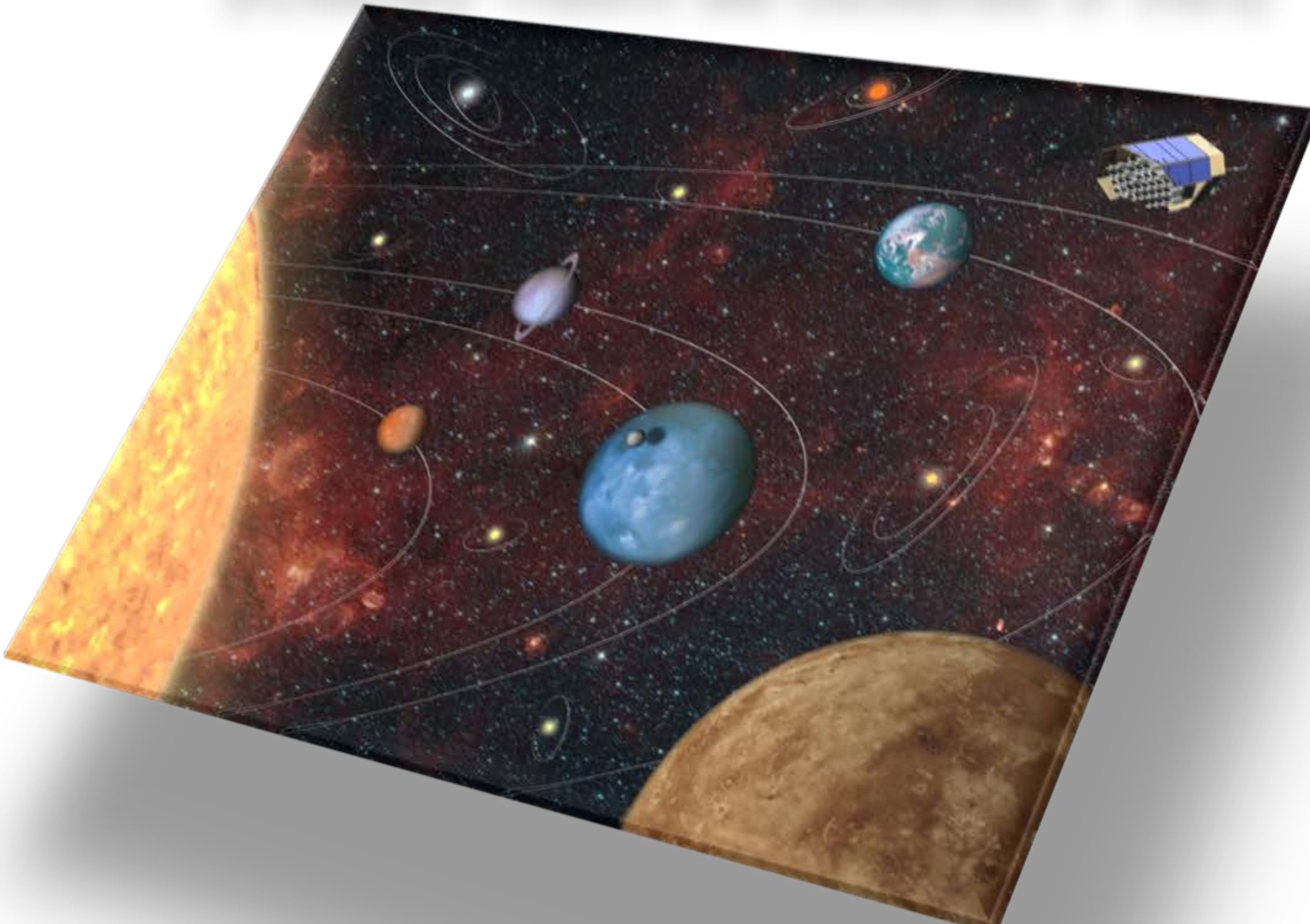
PLATO 2.0

(PLAnetary Transits and Oscillations of stars)



Heike Rauer (Principal Investigator)
Don Pollacco (Science coordinator)
and the PLATO Team

Outline

- Introduction
- PLATO 2.0 science:
  - Planet diversity and implications for:
    - habitability & life
    - planet formation
    - comparative planetology
  - Stellar science
- PLATO 2.0 mission:
  - How we do it

PLATO 2.0 Scientific Motivation

- How do planets and planetary systems form and evolve?
- Is our Solar System special? Are there other systems like ours?
- What makes planets habitable?
- Is the Earth unique or can life also developed elsewhere?

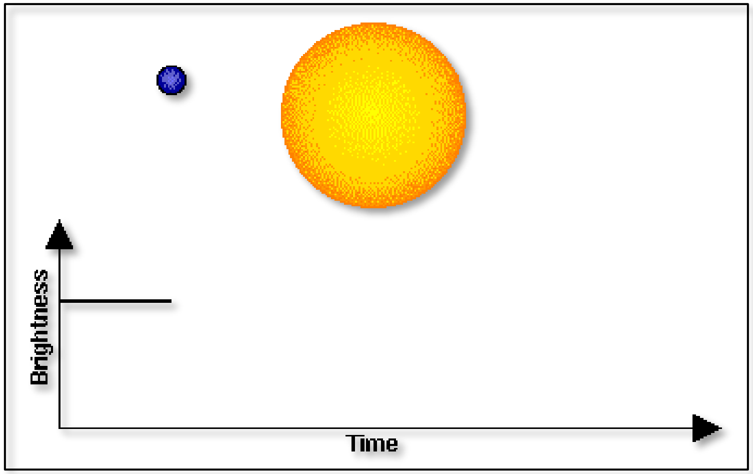
<u>PLATO 2.0 addresses the ESA Cosmic Vision science questions:</u>

- **What are the conditions for planet formation and the emergence of life?**
- **How does the Solar System work?**

PLATO 2.0 follows the recommendations of ESA's Exoplanet Roadmap Advisory Team (EPRAT)

Methods for detection and bulk characterization of planets

Transit Method

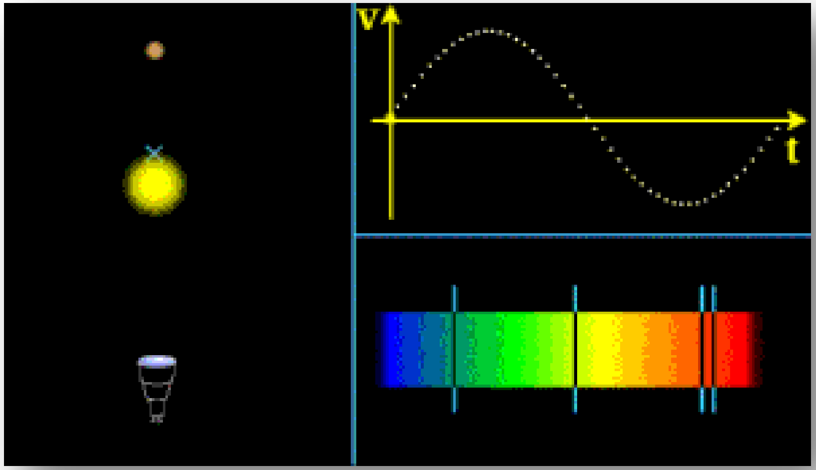


→ Orbit parameters

→ Orbital inclination, ***i***

→ Planet radius

Radial velocity method

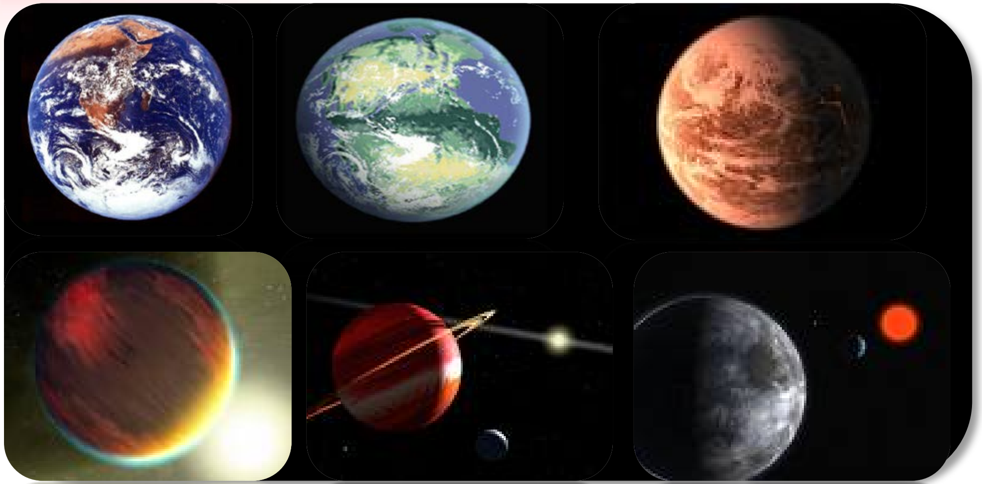


→ Orbital parameters

→ Minimum planet mass, ***m* sin *i***

True planet mass and mean density

PLATO 2.0: Exoplanets and Stars



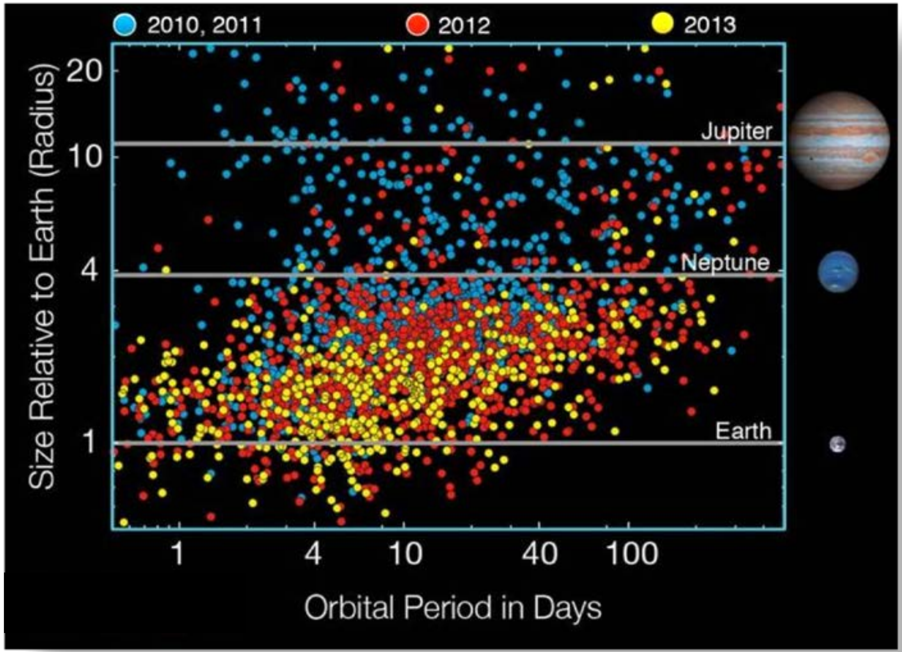
Characterization of exoplanets ... needs characterization of stars

- **Mass + radius → mean density**
  (gaseous vs. rocky, composition, structure)
- **Orbital distance, atmosphere**
  (habitability)
- **Age**
  (planet and planetary system evolution)

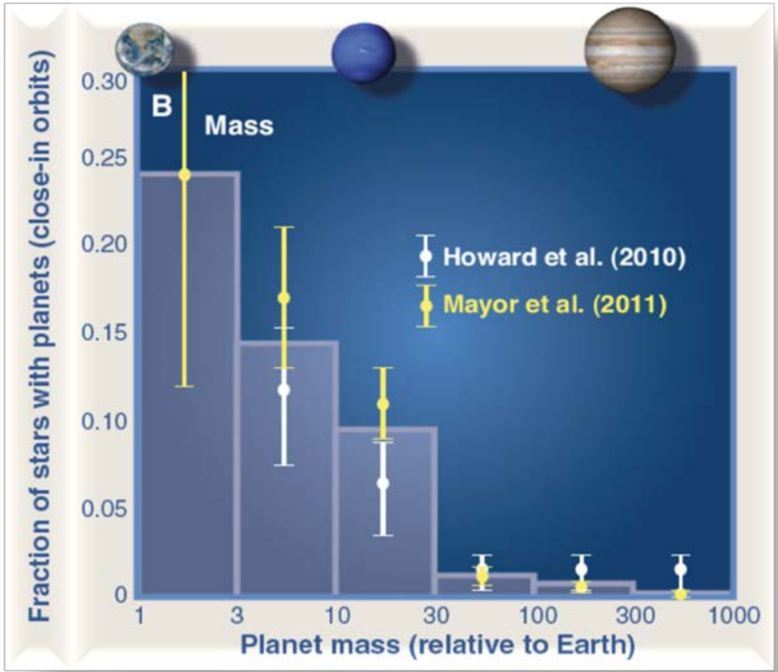
- **Stellar mass, radius**
  (derive planet mass, radius)
- **Stellar type, luminosity, activity**
  (planet insolation)
- **Stellar age**
  (defines planet age)

Planet detection today

Kepler planet candidate statistics



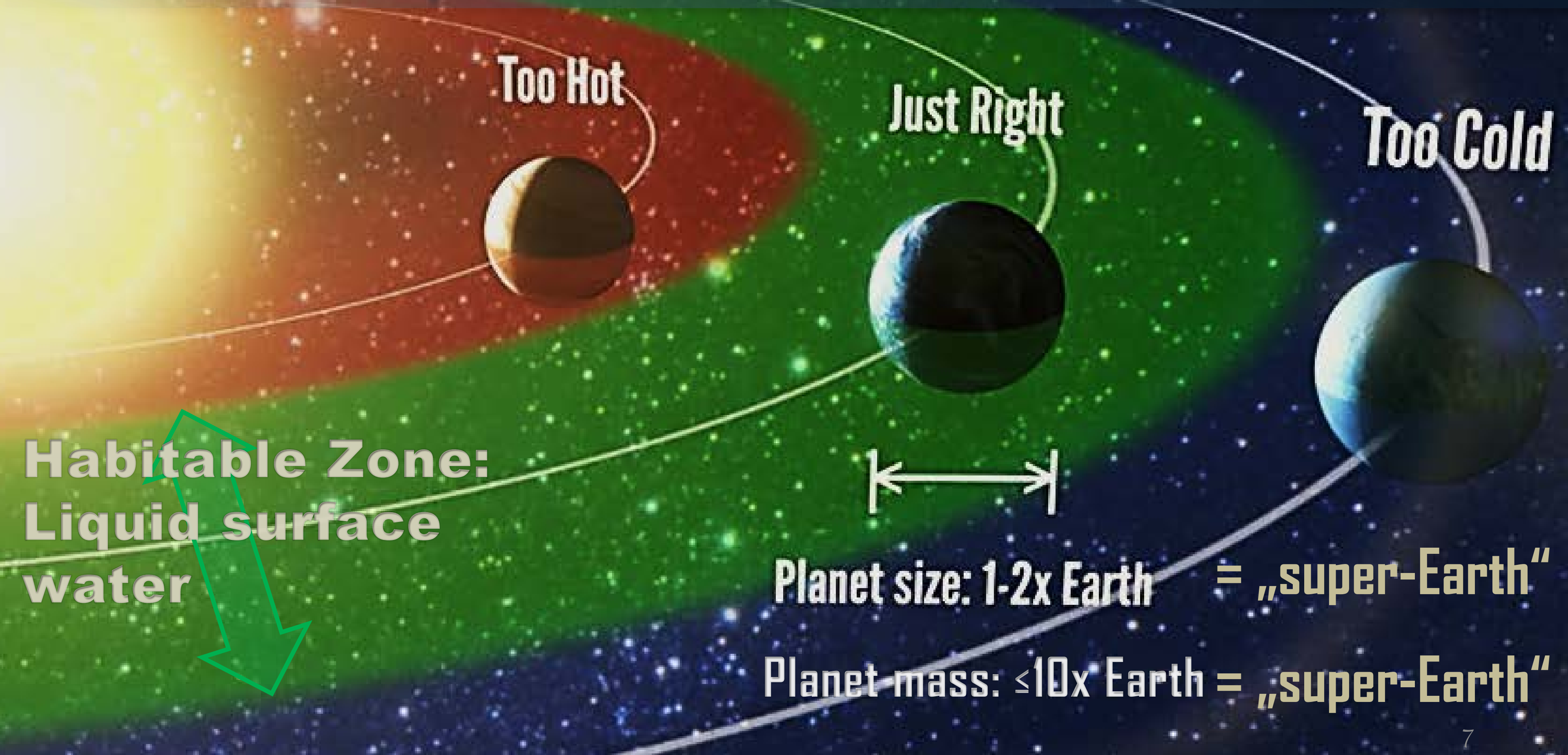
Radial velocity surveys



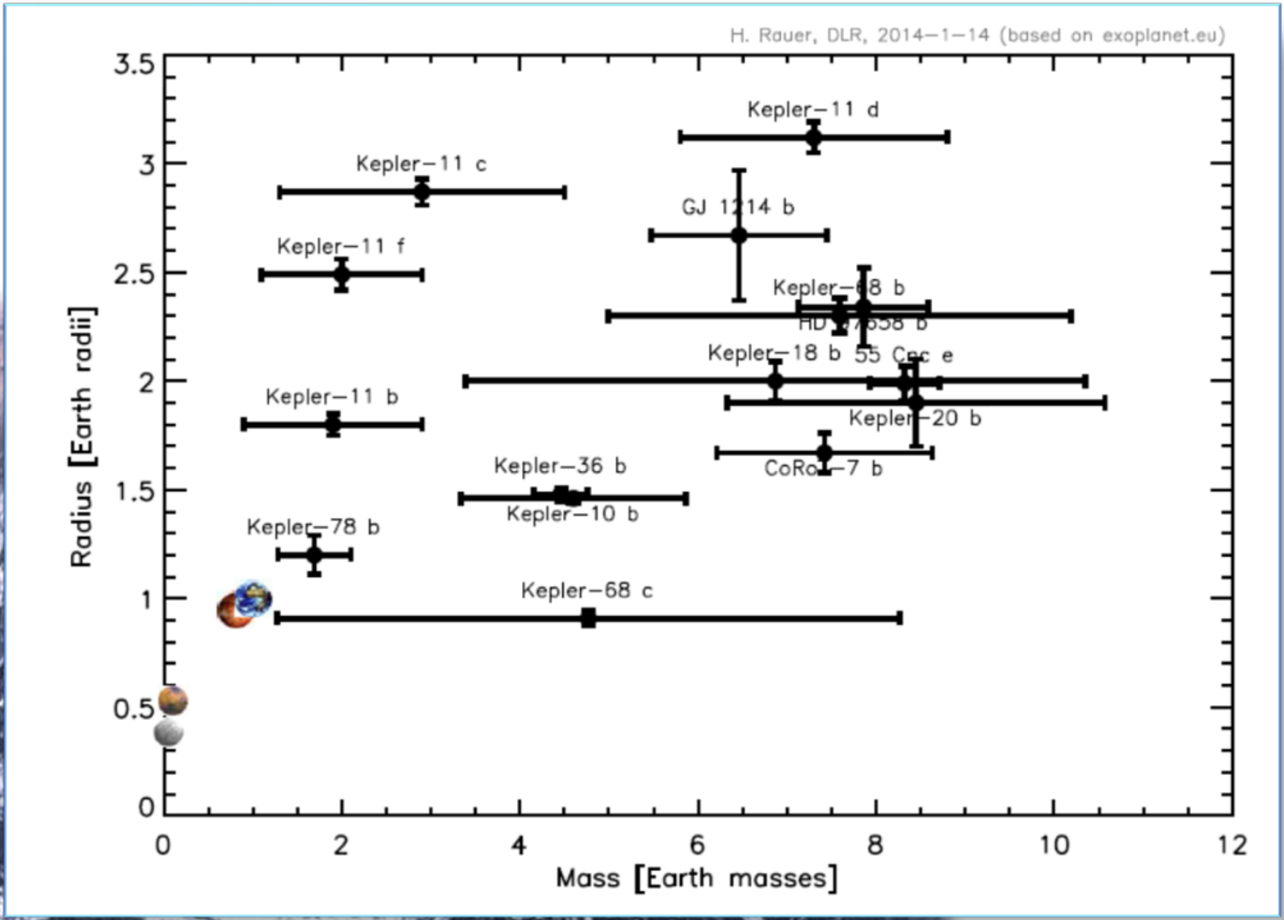
- Current status: ~3000 planet candidates and ~1000 confirmed exoplanets
- *Kepler* mission and radial-velocity surveys → small and low-mass planets are numerous

However, only few detections of small planets in the habitable zone, and no characterization.

PLATO 2.0 science: Planet diversity and implications for habitability & life



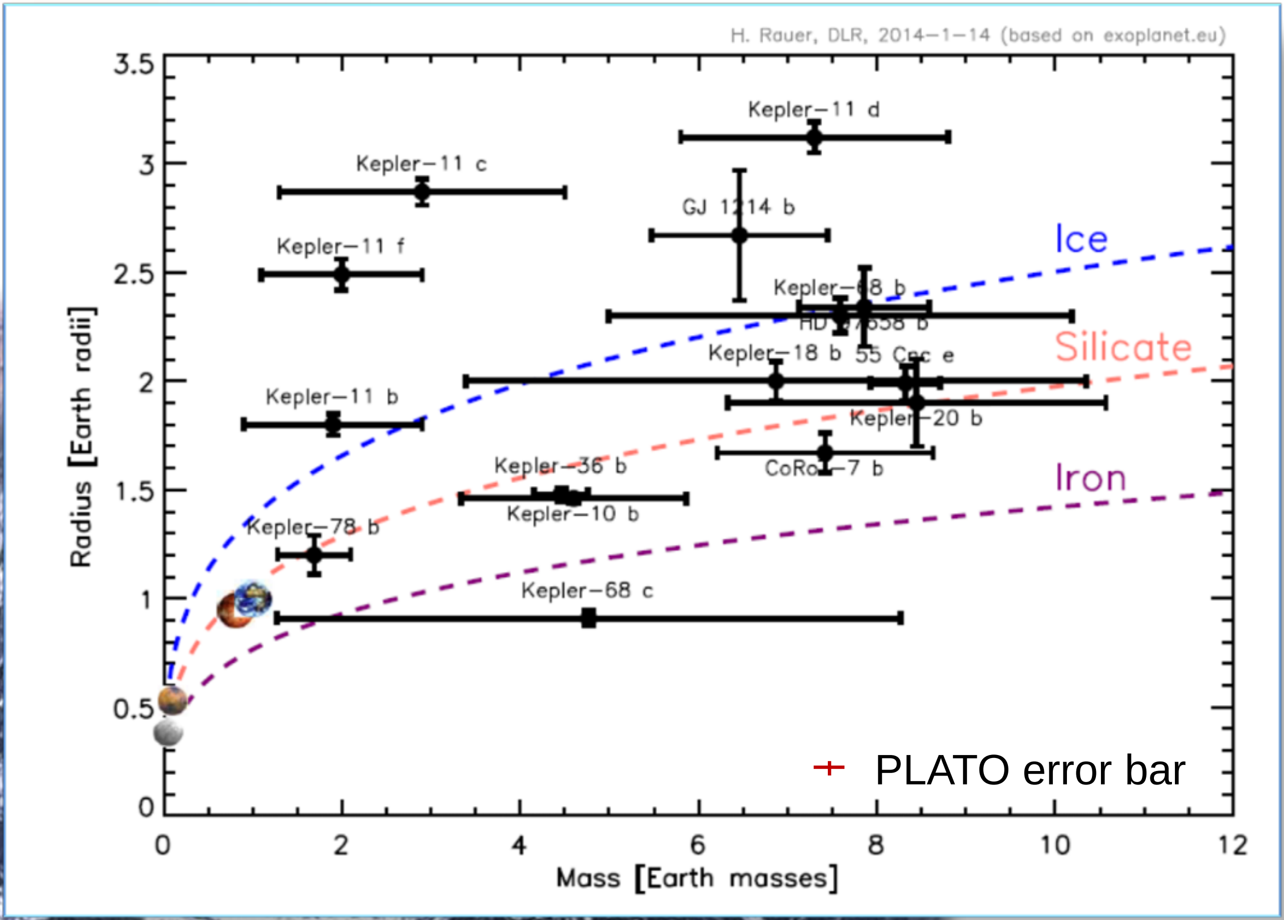
Diversity of „super-Earths"



Wagner et al., 2012

- Masses vary by a factor of ~4 (with large errors)
- Radii vary by a factor of ~3

Diversity of „super-Earths“



Wagner et al., 2012

- Masses vary by a factor of ~4 (with large errors)
- Radii vary by a factor of ~3

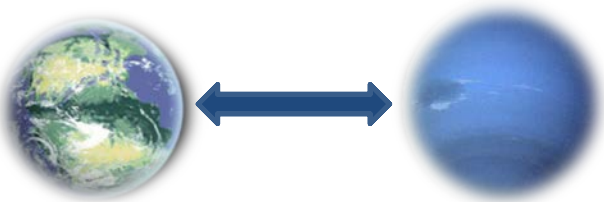
→ **We need both**: Accurate masses & radii to separate terrestrial from mini-gas planets.

„Super-Earths“: diversity and implications on habitability

Solar System planets are NOT the general rule:

small ≠> rocky, large ≠> gaseous

- Small exoplanets are very diverse:
  from Earth-like to mini-gas planets

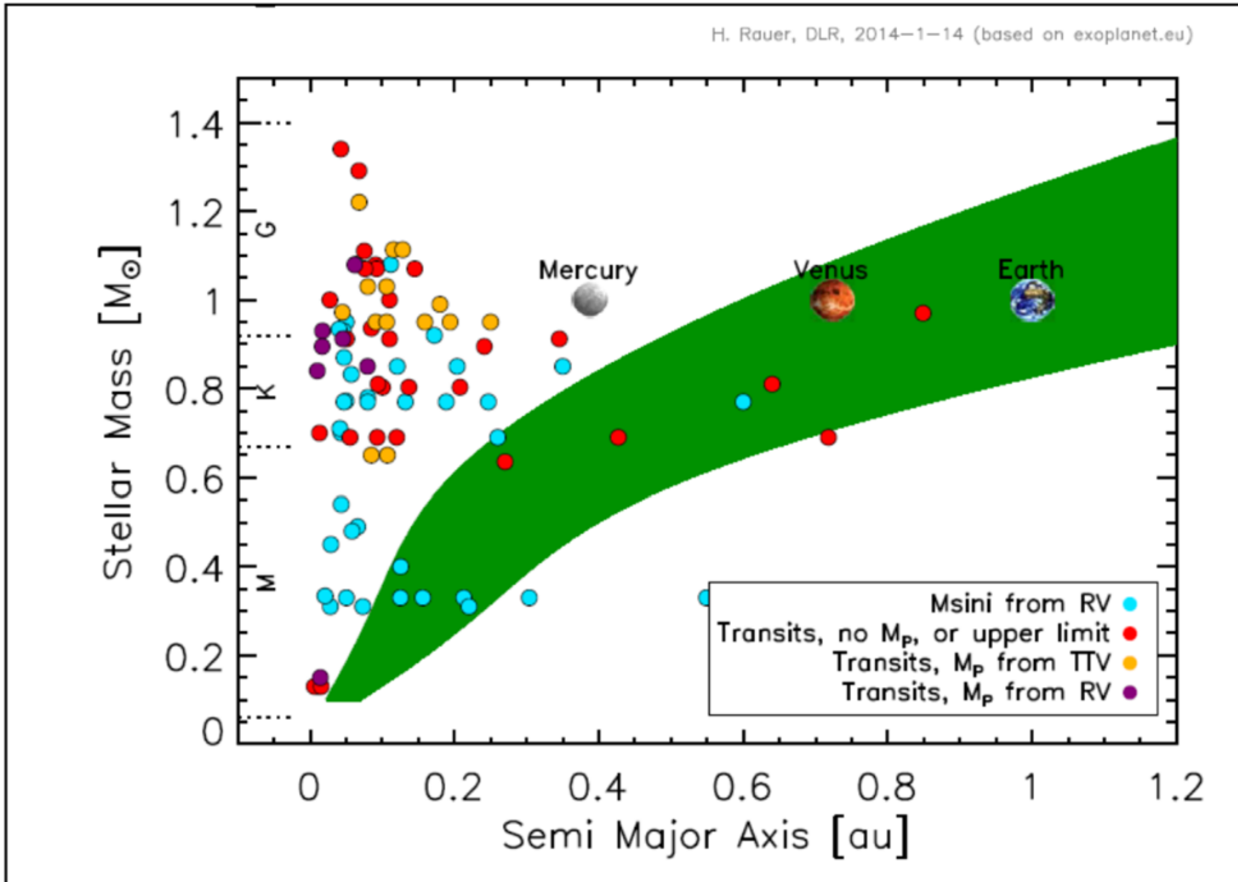


- Mini-gas planets are likely not habitable
- Silicate-iron planets are prime targets for atmosphere spectroscopy

→ PLATO 2.0 will identify potentially habitable planets
→ PLATO 2.0 will characterize targets for atmosphere spectroscopy

Status: Characterized „super-Earths" in their habitable zone

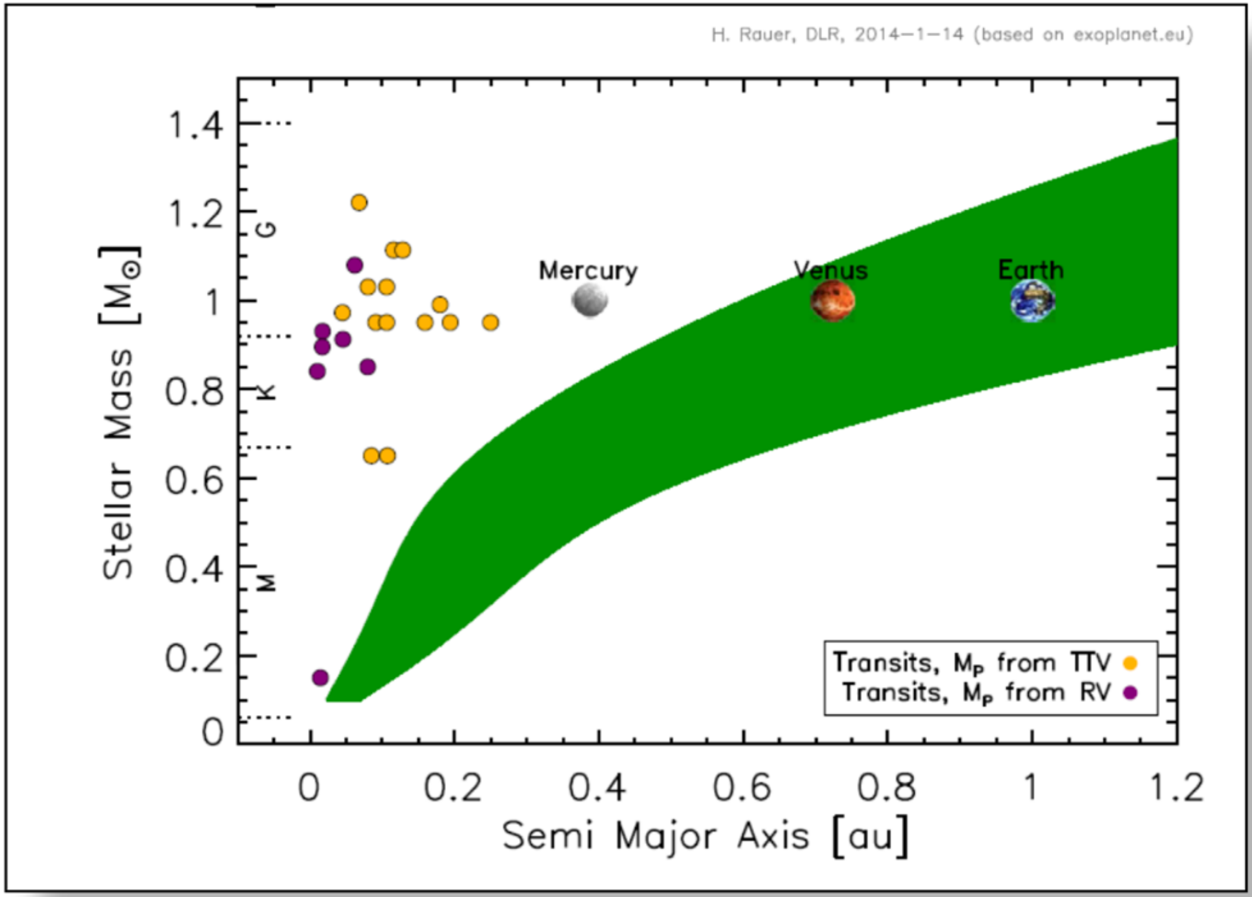
Detected super-Earths



- Goal: Detect and characterize super-Earths in habitable zones
- Status: very few small/light planets in habitable zones detected

Status: Characterized „super-Earths" in their habitable zone

„Super-Earths" with characterized radius and mass

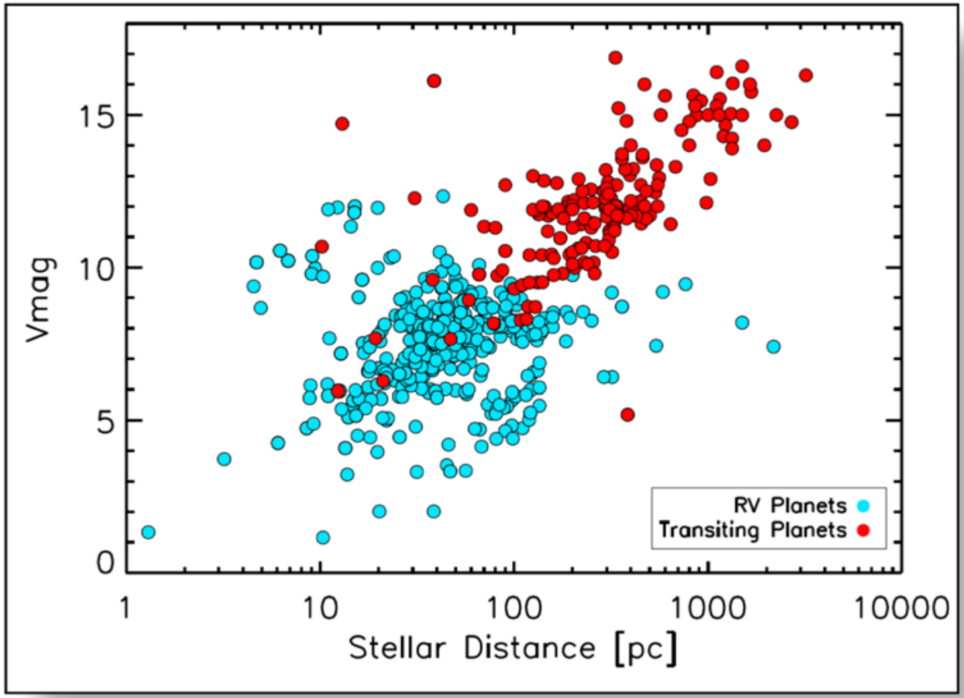


- Goal: Detect and characterize super-Earths in habitable zones
- Status: very few small/light planets in habitable zones detected

→ No characterized „super-Earths" in its habitable zone

The need for bright stars

Known planets from radial velocity and transit surveys



Why have so few targets been characterized?

→ Transit surveys targeted faint and distant stars to maximize detection performance.

→ Radial velocity surveys need bright stars (≤11 mag) to keep telescope resources limited.

Lessons learned:
→ Future transit missions must target bright stars

Upcoming transit missions

Transit missions until 2020 monitoring bright stars:

- **TESS** (NASA): scan the whole sky, **~1 month/field**, 2% of the sky covered for 1 year → **focus on short-period planets**

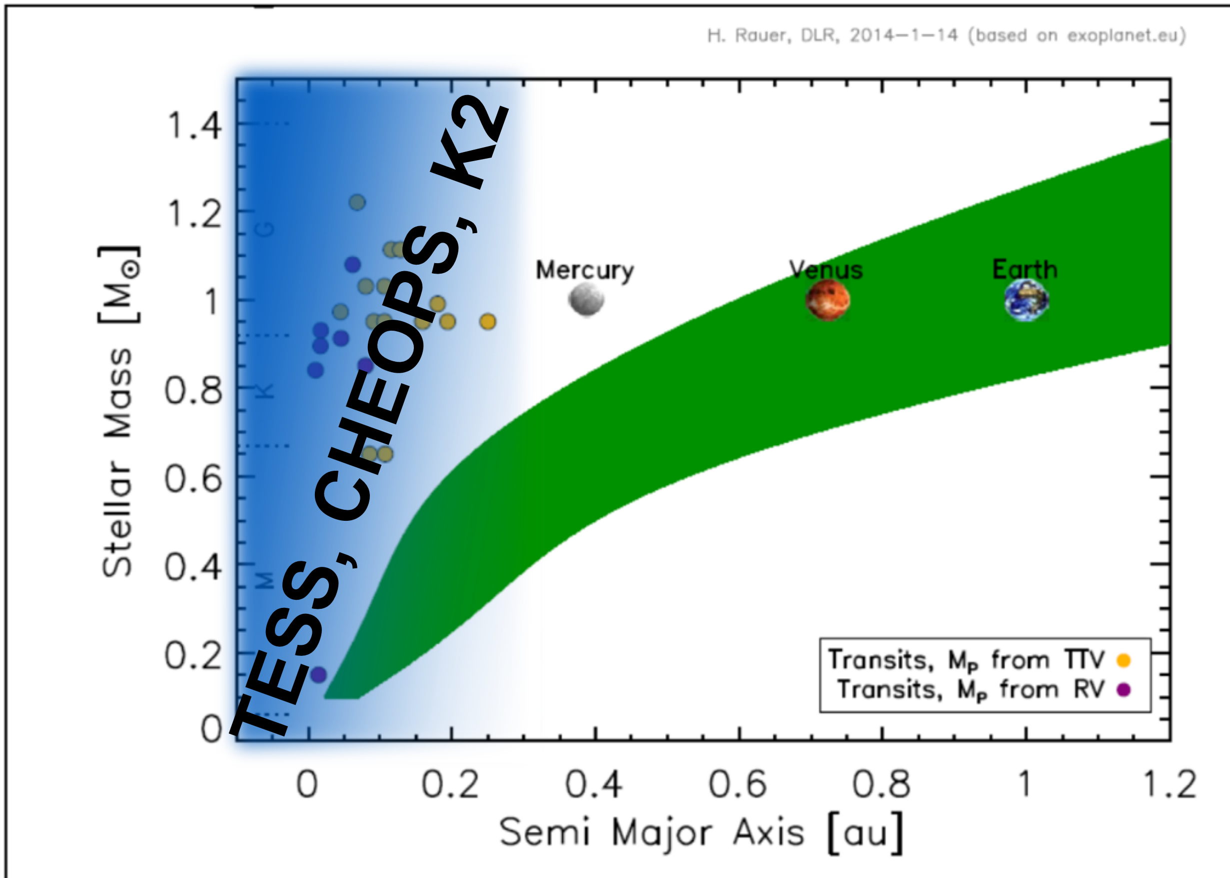
- **CHEOPS** (ESA): follow-up of detected (RV-)planets, biased towards **short-period planets** by transit probability

- **K-2** (Kepler 2) (NASA): observe fields in the ecliptic plane for **~40-80 days/field** → **mainly short-period planets**

→ upcoming transit missions
focus on planets with orbital periods up to ~ 80 days

Prospects: Characterized „super-Earths" in their habitable zone

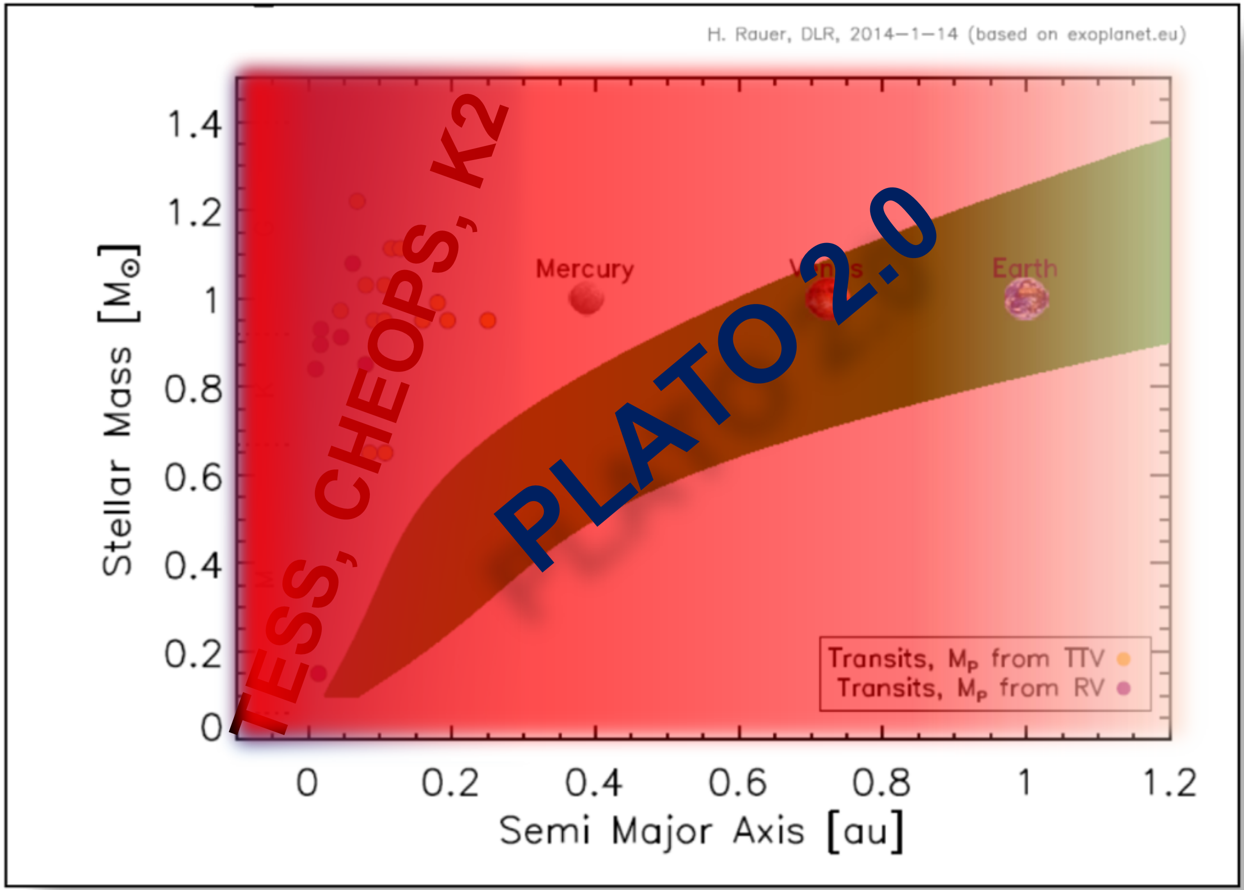
„Super-Earths" with characterized radius and mass



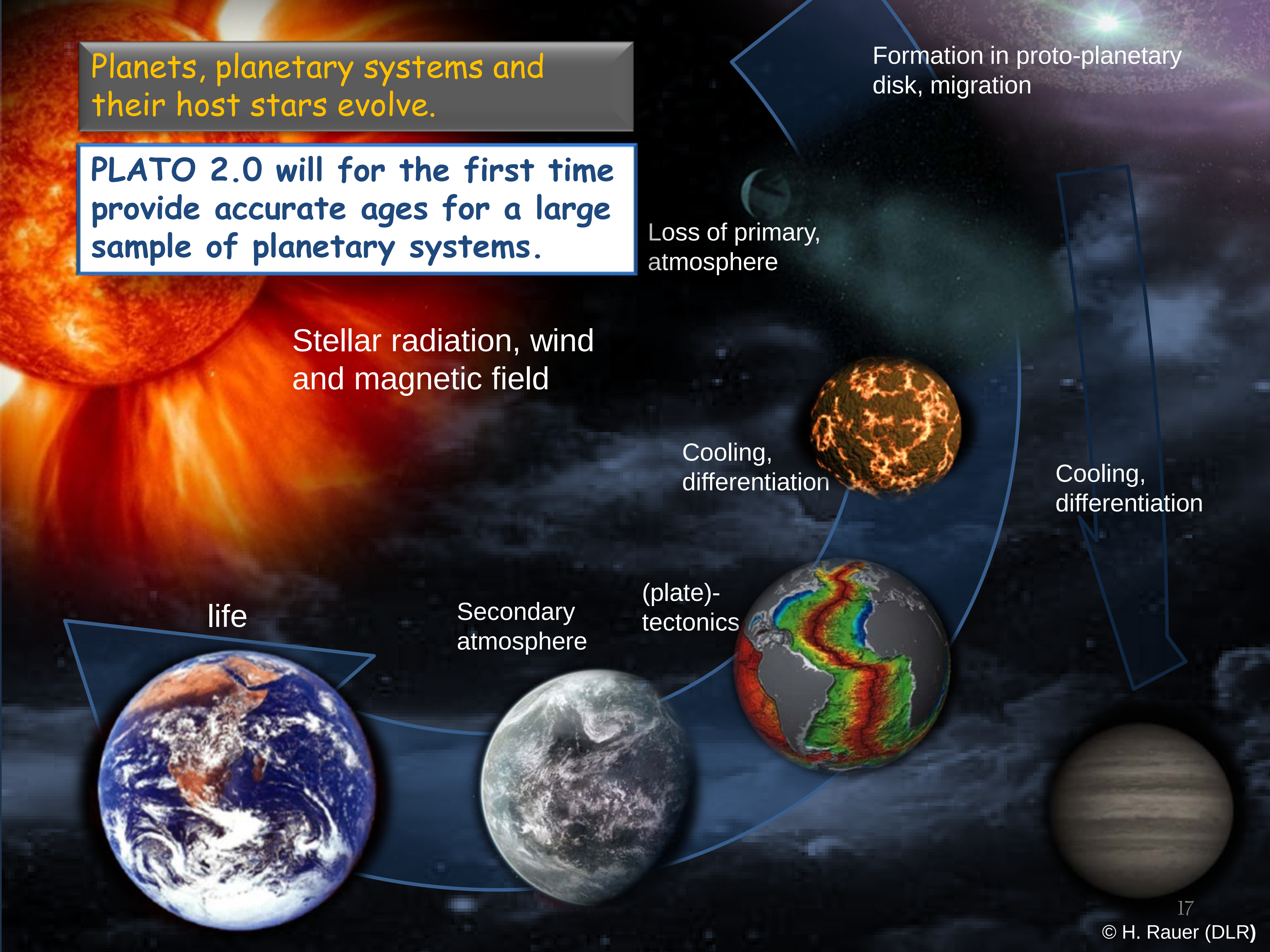
- No rocky planets in the habitable zone known with certainty
- TESS, CHEOPS, K2 will cover orbital periods up to ~80 days
- In Solar-System analogues: No planets characterized outside Mercury's orbit without PLATO 2.0!

Prospects: Characterized „super-Earths" in their habitable zone

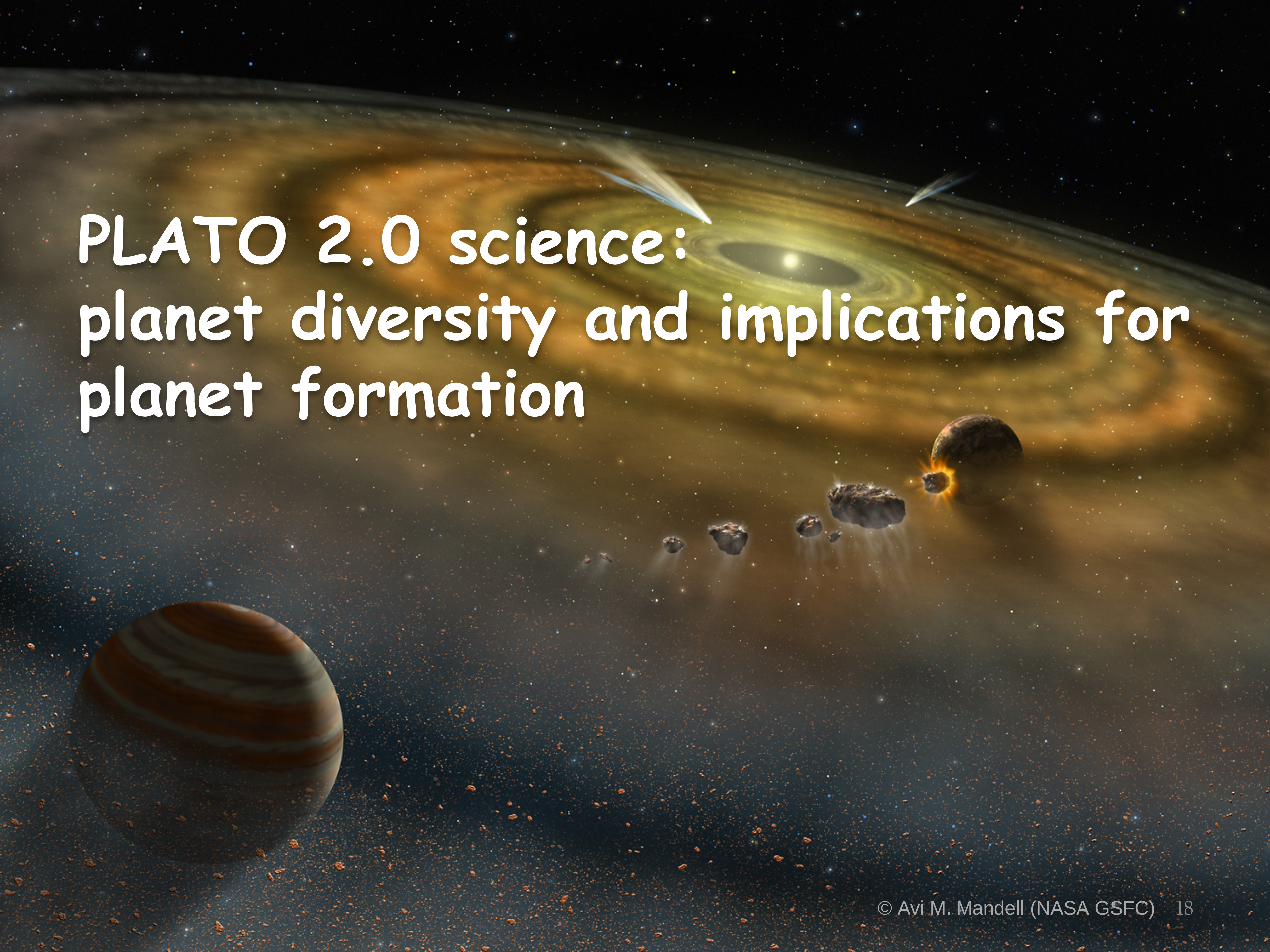
„Super-Earths" with characterized radius and mass



PLATO 2.0 will detect and bulk characterize small planets up to the habitable zone of solar-like stars.

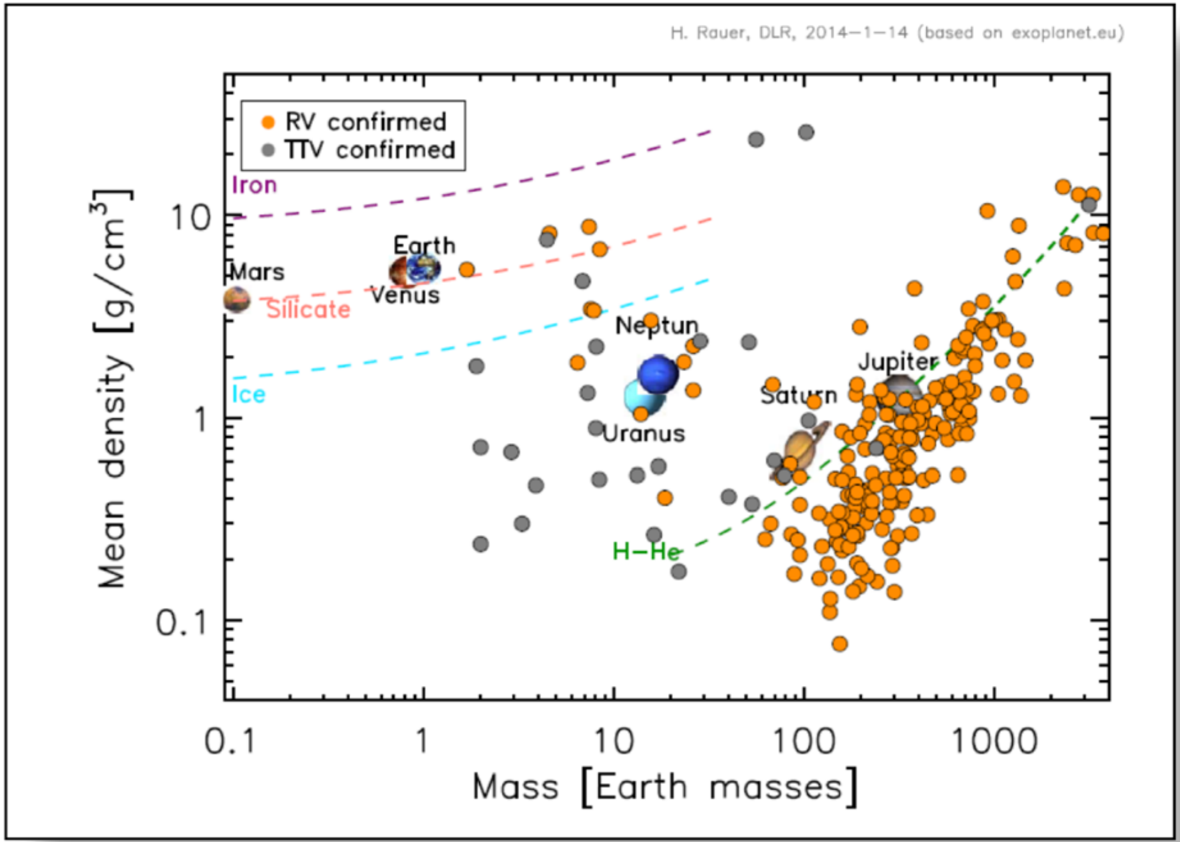

Planets, planetary systems and their host stars evolve.
PLATO 2.0 will for the first time provide accurate ages for a large sample of planetary systems.
Formation in proto-planetary disk, migration
Loss of primary, atmosphere
Stellar radiation, wind and magnetic field
Cooling, differentiation
Cooling, differentiation
(plate)-tectonics
Secondary atmosphere
life

PLATO 2.0 science: planet diversity and implications for planet formation



Planet diversity and planet formation

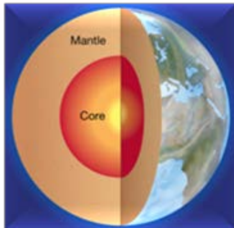
- Mean density varies by two orders of magnitude for a given mass
- Planets of Earth mass and below remain to be detected and characterized



Planet diversity and planet formation

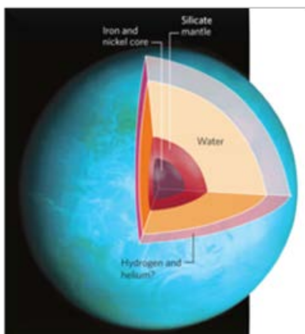
Earth

5.5 g/cm^3



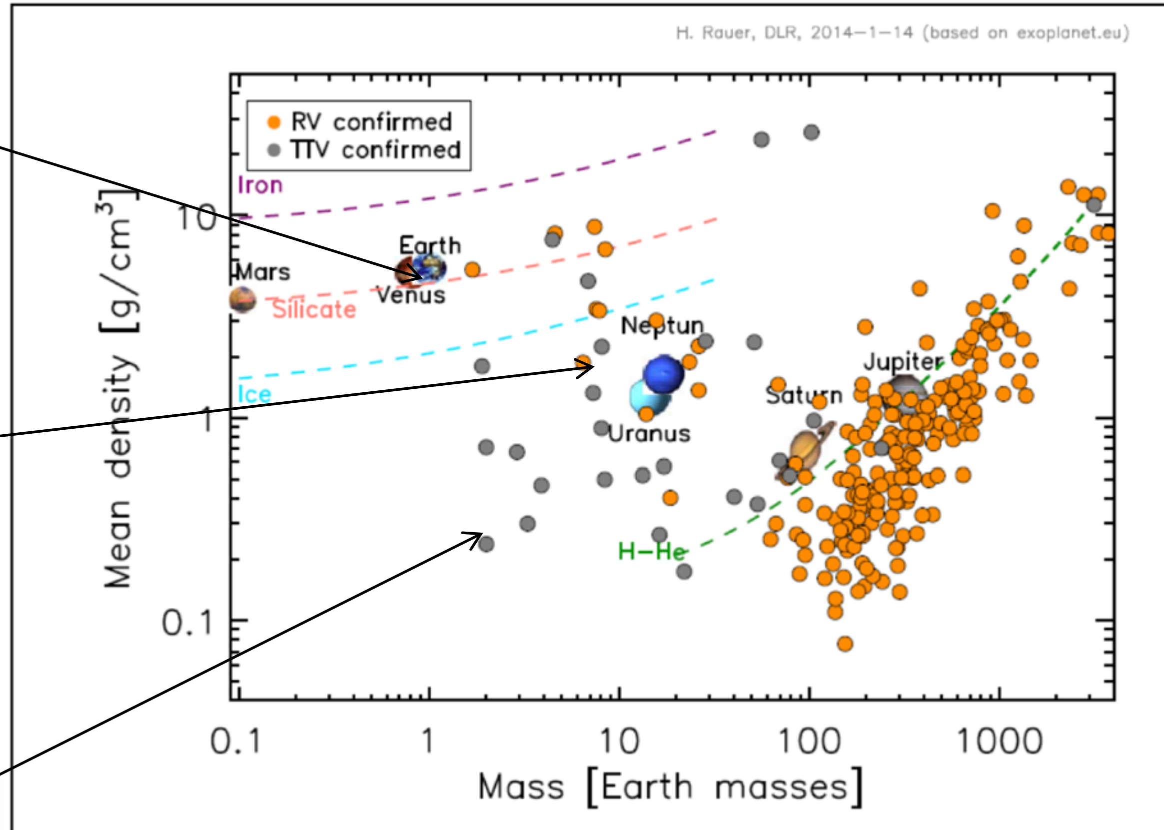
GJ1214b

1.6 g/cm^3



Mini gas planets

<~1 g/cm^3

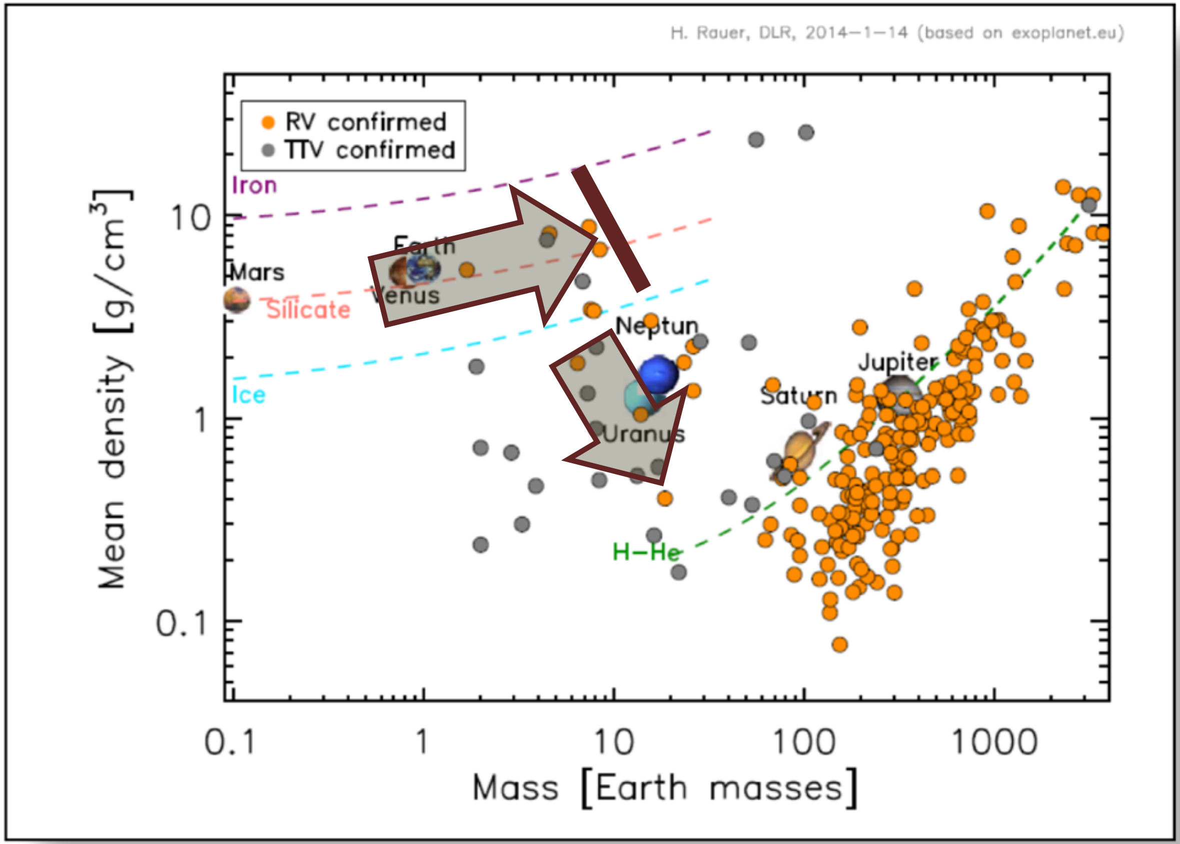


Low-mass planets have a range of compositions and interior structures for similar masses.

Planet diversity and planet formation

Test planet formation models:

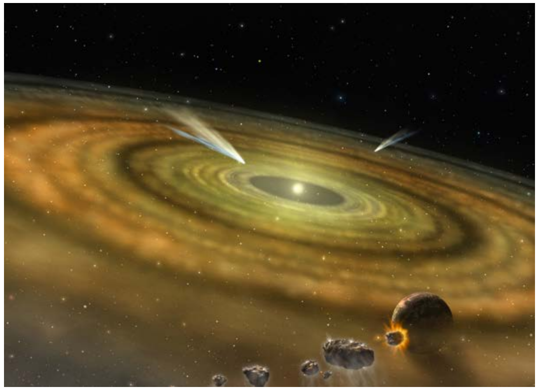
- What is the observed critical core mass?
- Can super-massive rocky planets exist? How are they formed?
- Are light planets with H_2-dominated atmospheres common?

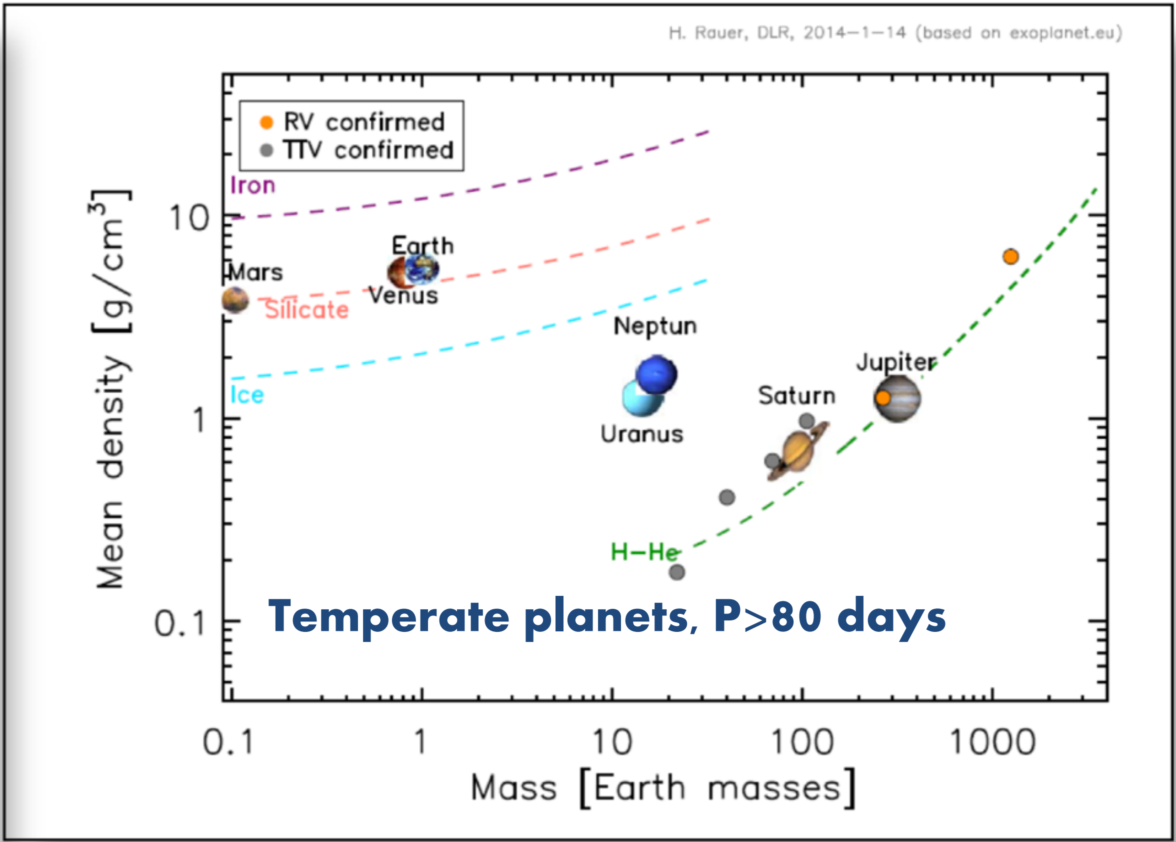


Planet diversity and planet formation

PLATO 2.0 will provide thousands of characterized planets at intermediate orbital distances, down to Earth size/mass.

→ Study planets where they form!

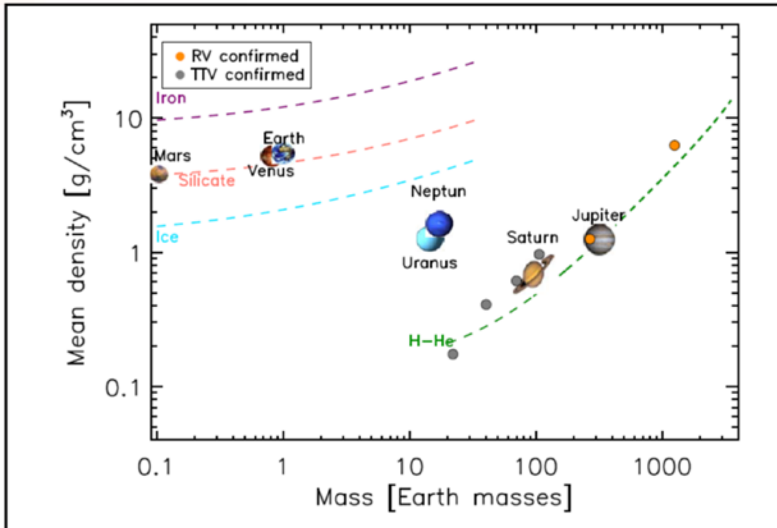




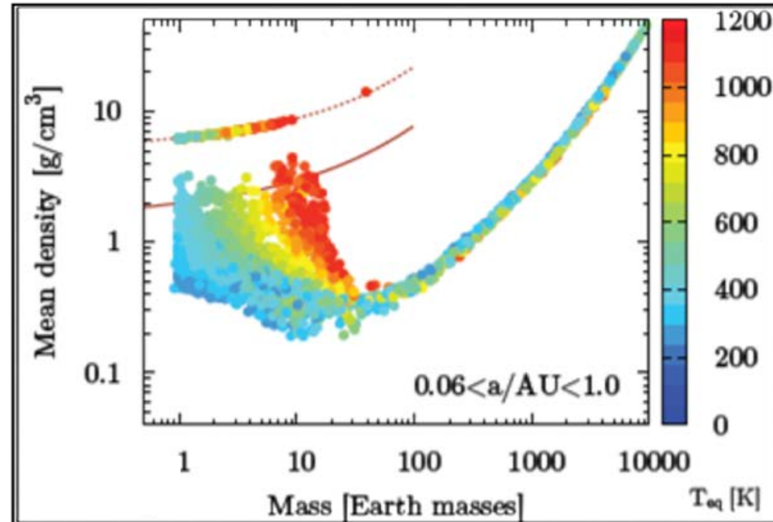
→ No characterized (radius, mass,density) low-mass planets outside a Mercury-like orbit today.

Planet diversity and planet formation

Observations



Planet formation model predictions



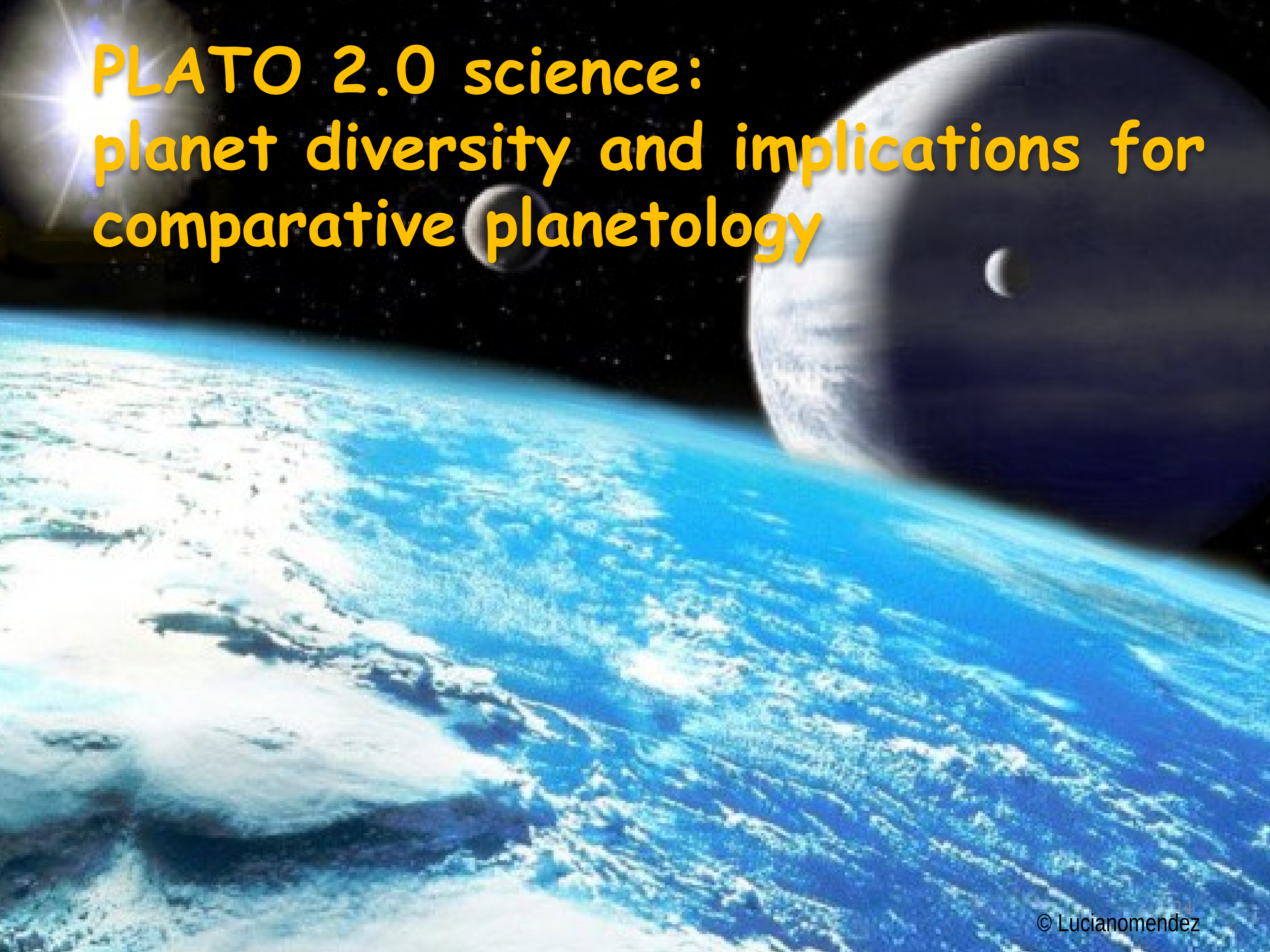
Mordasini et al.

PLATO 2.0 will allow us to:

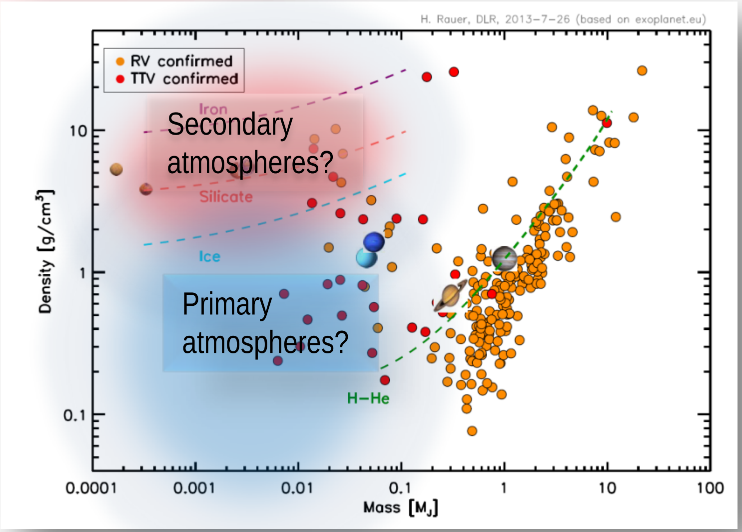
- Measure how planet density and mass vary with
  - orbital distance and planetary system architectures
  - host star parameters (spectral type, composition, age…)

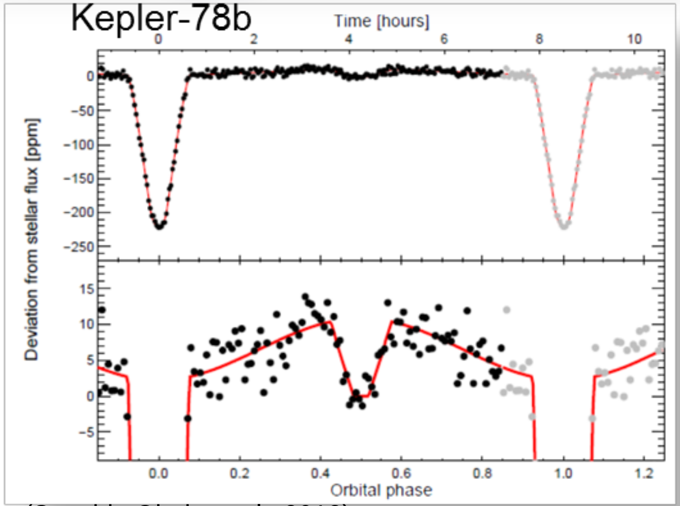
→ gain new insights into planet formation and evolution processes

PLATO 2.0 science: planet diversity and implications for comparative planetology



Planet diversity & comparative planetology





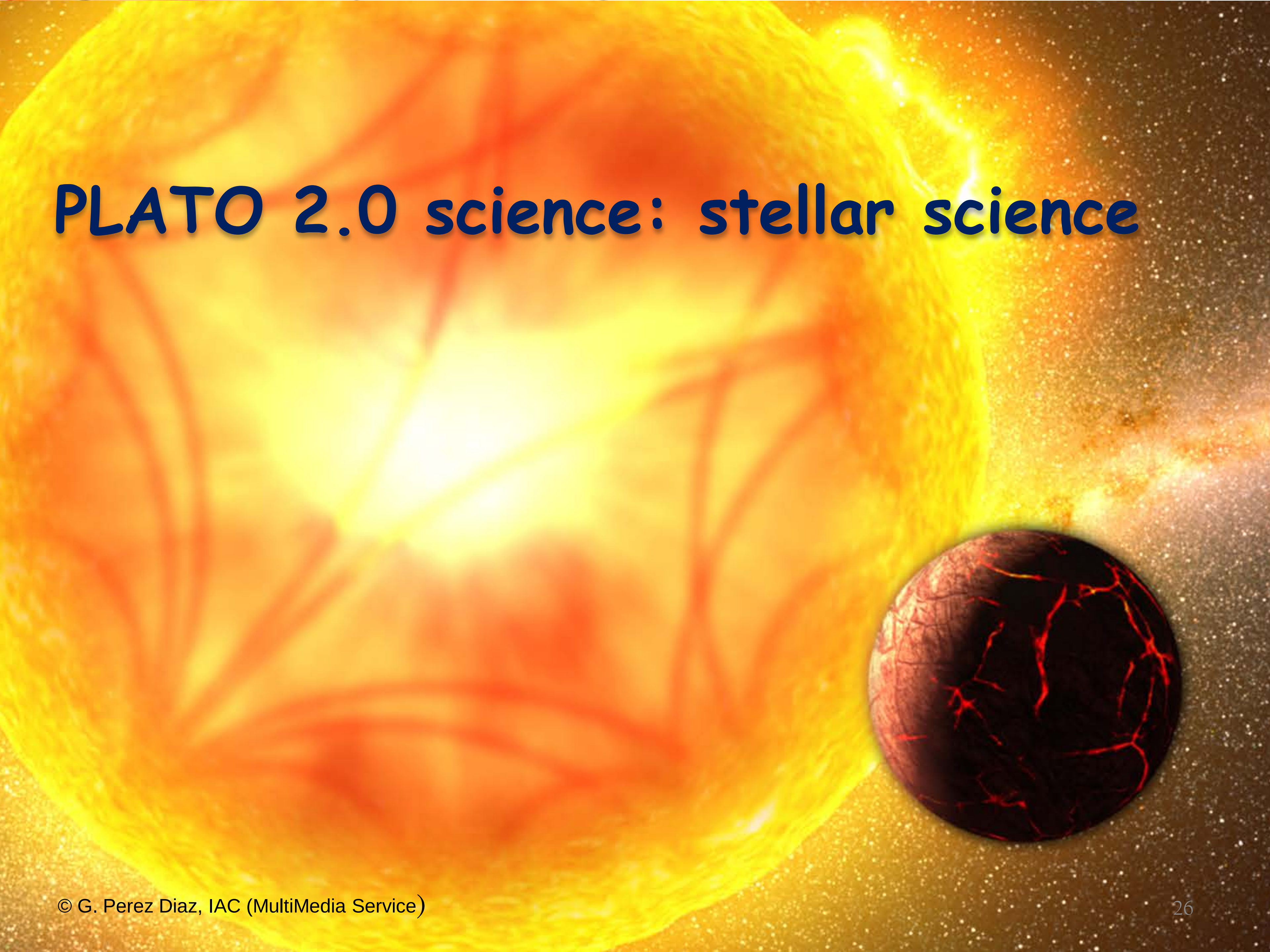
(Sanchis-Ojeda et al., 2013)

PLATO 2.0 will provide planets with:

- mean density
  → composition and structure (rocky, mini-gas)
  → constrain atmosphere scale heights
- albedo and its diversity
  → indicative for clouds, hazes
- accurate ages
  → evolutionary pathways
- characterized host stars
  → incident flux, stellar activity

PLATO 2.0 will
→ explore the wealth of planets, systems, host stars
→ provide well-characterized targets for atmosphere spectroscopy

PLATO 2.0 science: stellar science



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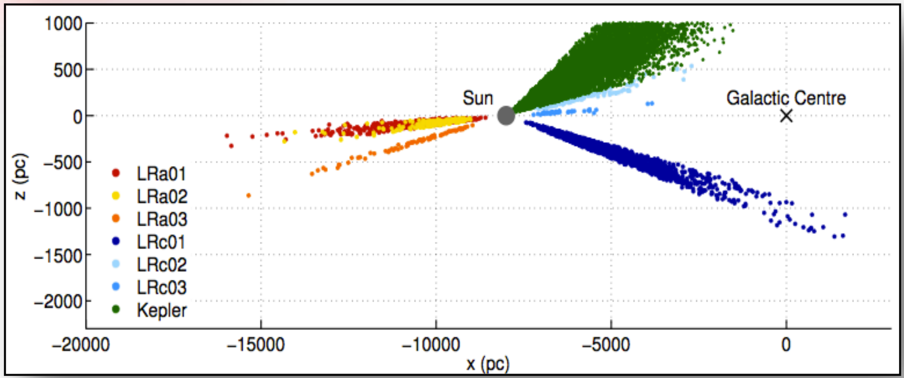
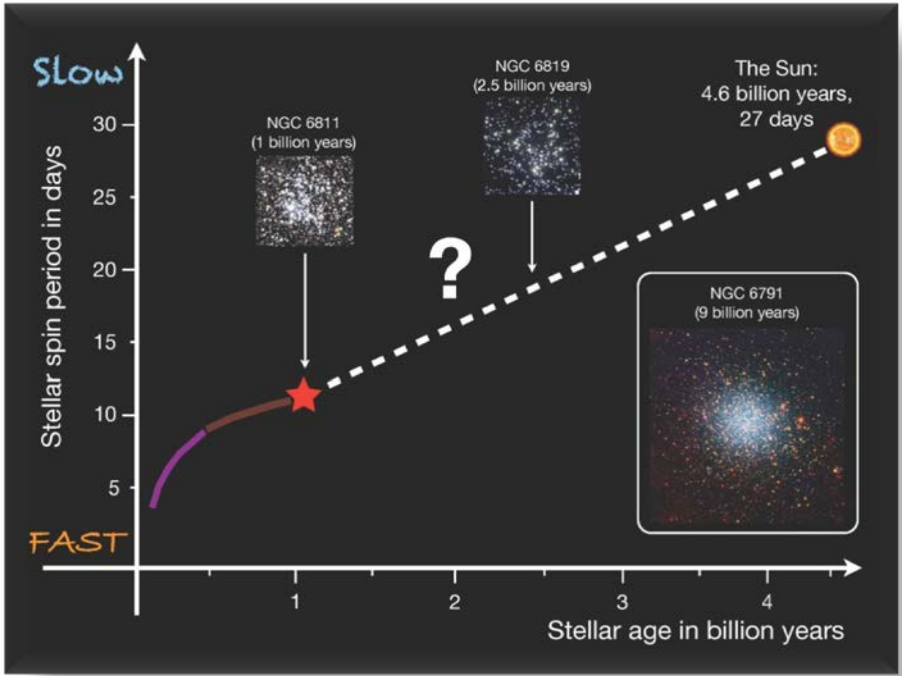
Structure and evolution of the galaxy with PLATO 2.0



Miglio et al. (2013)



Meibom et al. (2011)

- Gyrochronology of stars via age-rotation relationship:
  → seismic age versus rotation period from spots

- PLATO 2.0 & Gaia:
  - seismic + astrometric distances
  - seismic age-metallicity relations for giants

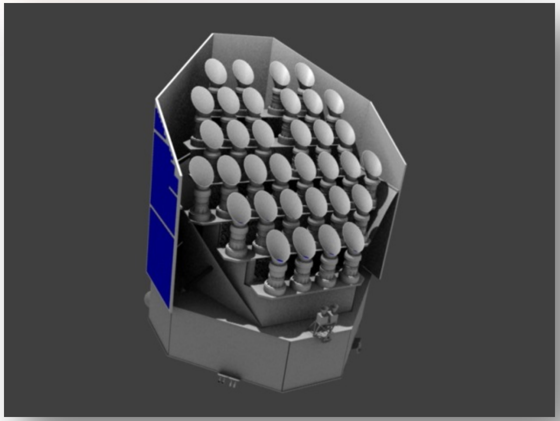
  → Provide accurate ages
  → Calibrate stellar evolution theories
  → Calibrate Galactic age-metallicity relationship

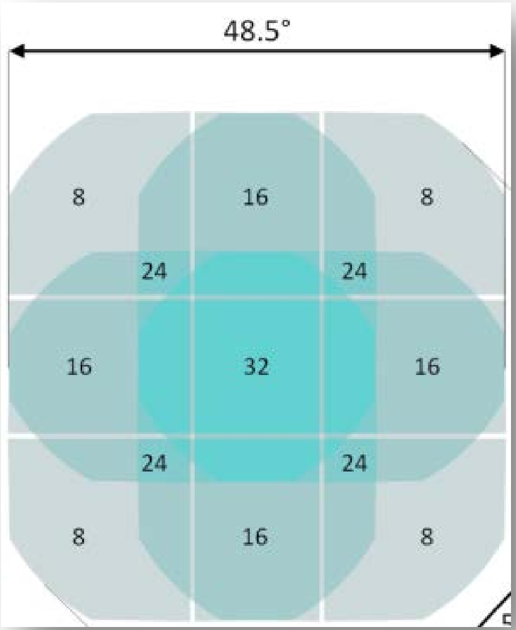
  → Probe the structure and the evolution of our Galaxy

PLATO 2.0 mission: How we do it

PLATO 2.0 instrument

Two designs studied:

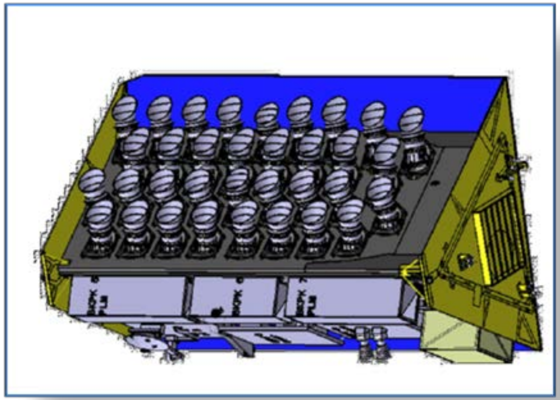




Multi-telescope approach:

- *Large FOV (Large number of bright stars)*
- Large total collecting area *(provides high sensitivity allowing asteroseismology)*
- Redundancy

- Cameras are in groups
- Offset to increase FoV



- 32 «normal» 12cm cameras, cadence 25 s, white light
- 2 «fast» 12cm cameras, cadence 2.5 s, 2 colours
- dynamical range: $4 \leq m_V \leq 16$
- L2 orbit
- Nominal mission duration: 6 years
- Field-of-View: 48.5° x 48.5° (2250 square degrees)

PLATO 2.0 instrument

Two designs studied:

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number

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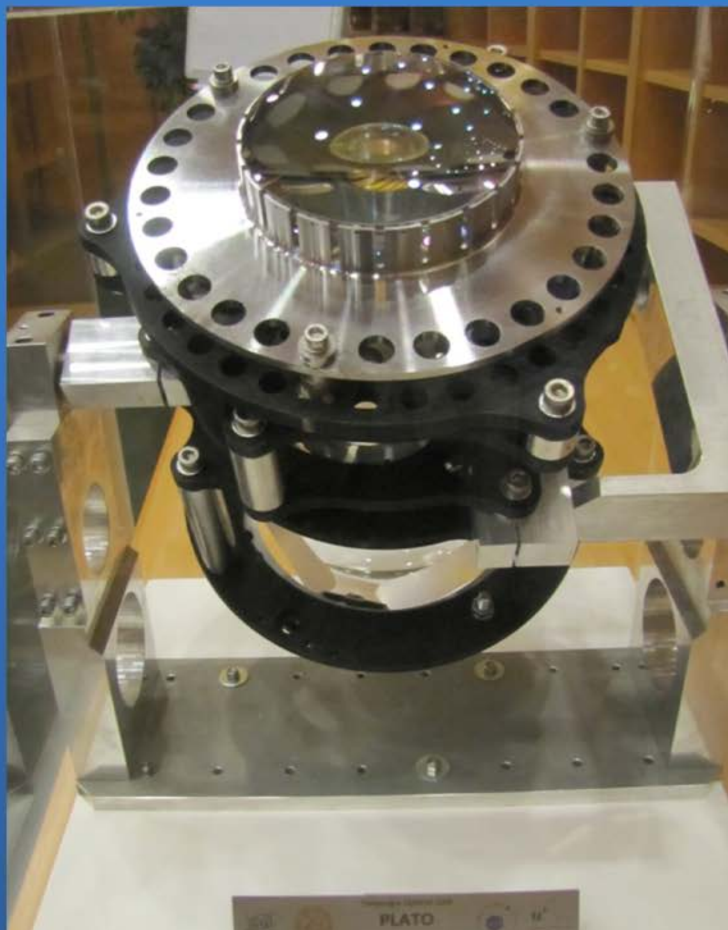


BreadBoard of one PLATO 2.0 Telescope

- Aspheric feasibility demonstrated
- CaF lenses demonstrated
- Alignment in warm demonstrated

- Field-of-View: 48.5° x 48.5° (2250 square degrees)

The Method

Characterize bulk planet parameters

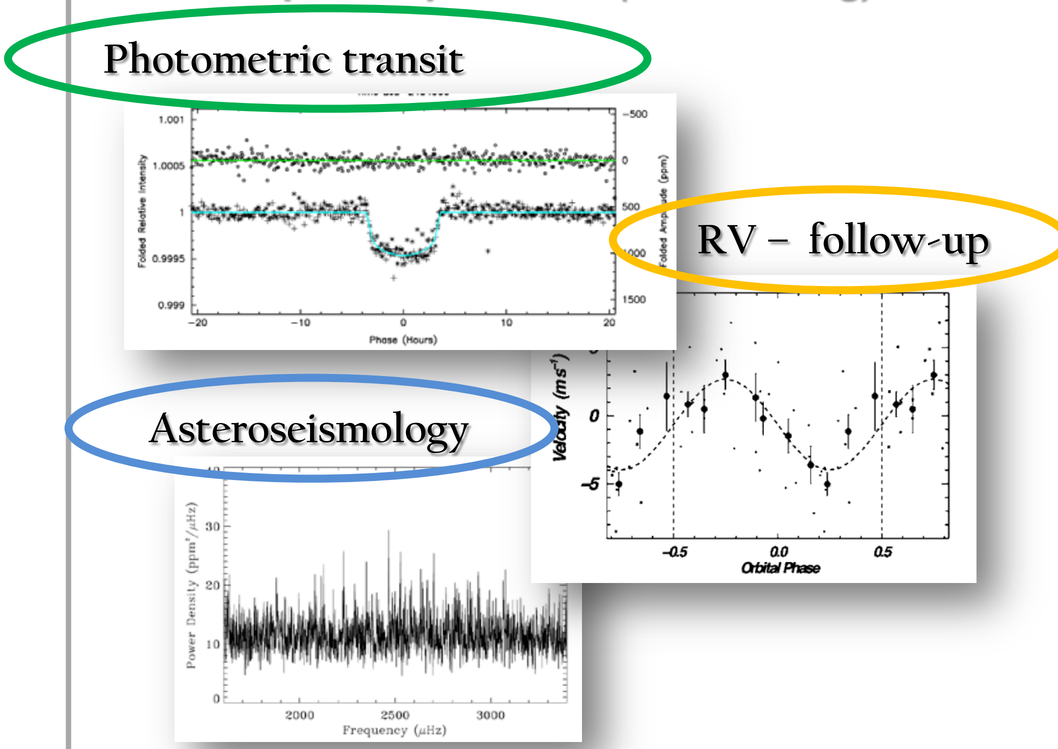
Accuracy around solar-like stars for PLATO 2.0:

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

For bright stars (4 – 11 mag)

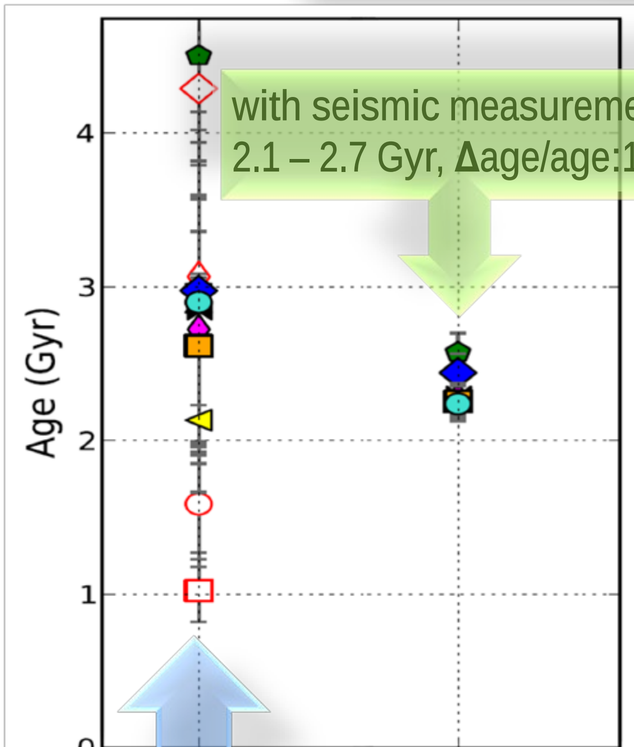
Techniques

Example: Kepler-10 b (V=11.5 mag)



Asteroseismology

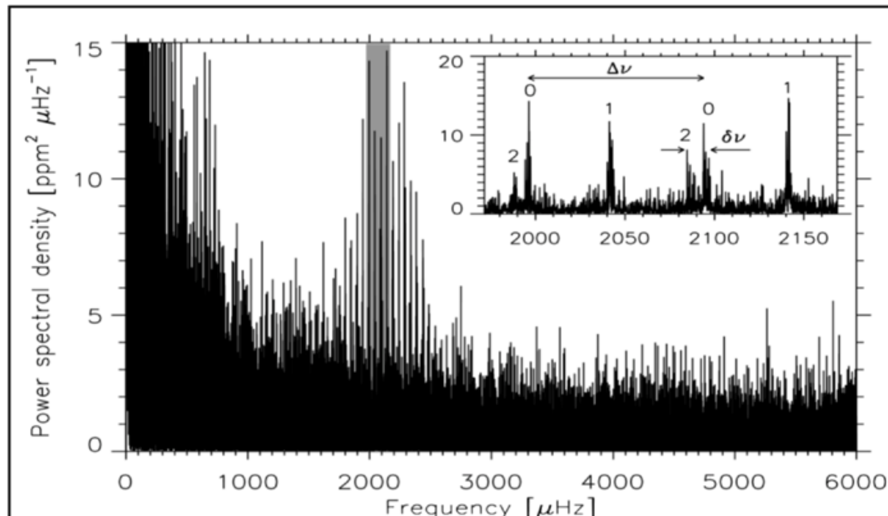
CoRoT and Kepler have demonstrated that the required accuracies can be met



with seismic measurement, 2.1 – 2.7 Gyr, Δage/age:13%

no seismic measurement, 0.8 – 5.9 Gyr, Δage/age: 75%

Example: HD 52265 (CoRoT), a G0V type, planet-hosting star, 4 months data

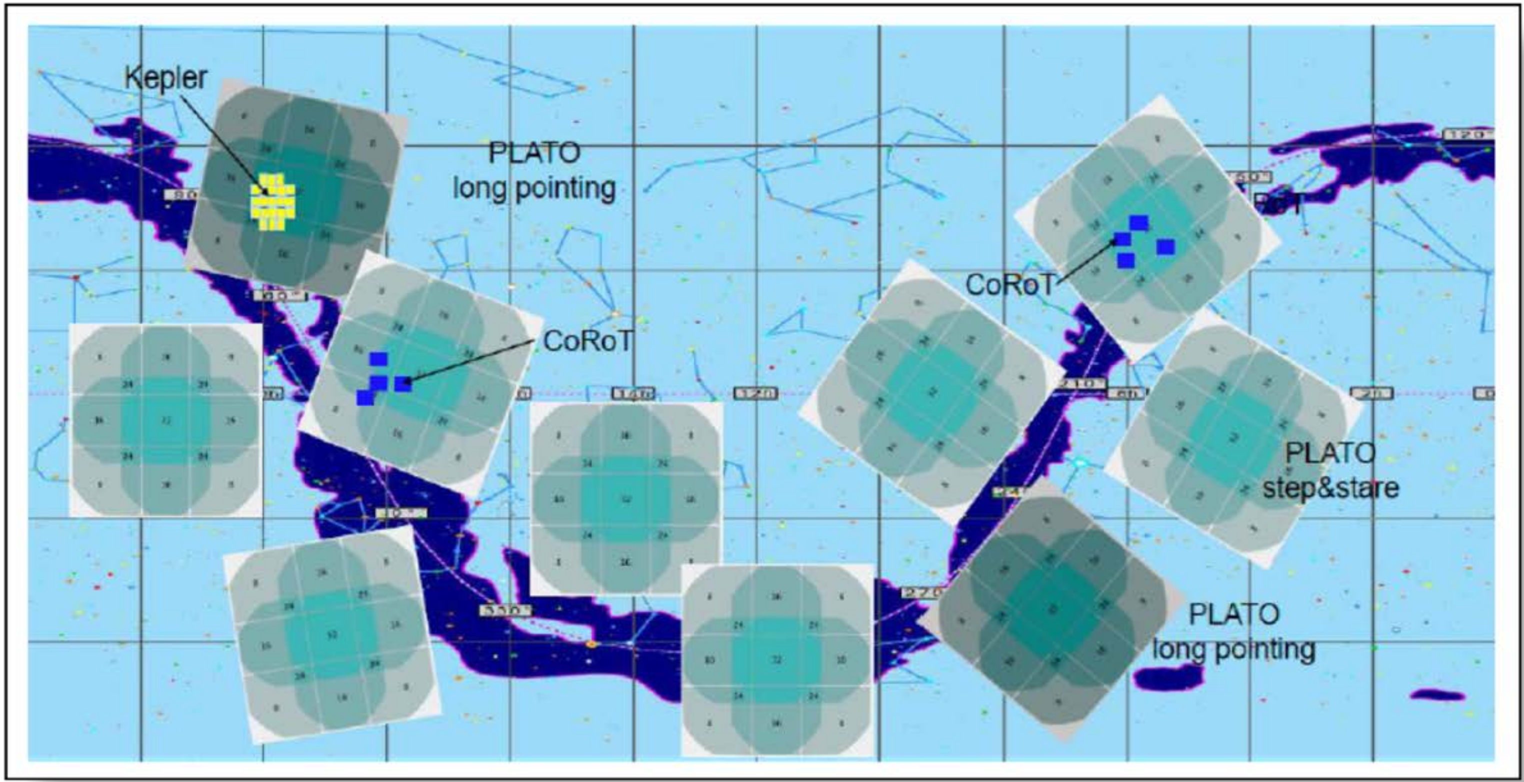


(Gizon et al. 2013)

Seismic parameters: Radius: $1.34 \pm 0.02\ R_{sun}$,
Mass: $1.27 \pm 0.03\ M_{sun}$,
Age: 2.37 ± 0.29 Gyr

Baseline observing strategy

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



→ covers ~50% of the sky

PLATO 2.0: Number of Light Curves

For the baseline observing strategy:

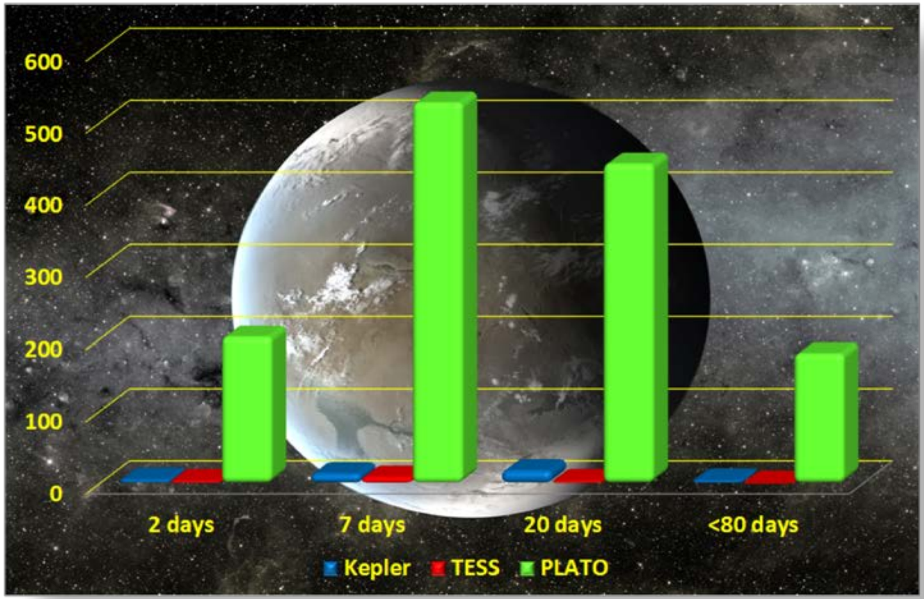
Noise level	Magnitude limit	4300 deg^2 (long stare fields)	20,000 deg^2 (plus step and stare fields)
(ppm/√hr)	m_V	Number of cool stars	Number of cool stars
34	11	**22,000**	**85,000**
80	13	**267,000**	**1,000,000**

Detection of Earth-sized planets
+ asteroseismology
+ radial velocity

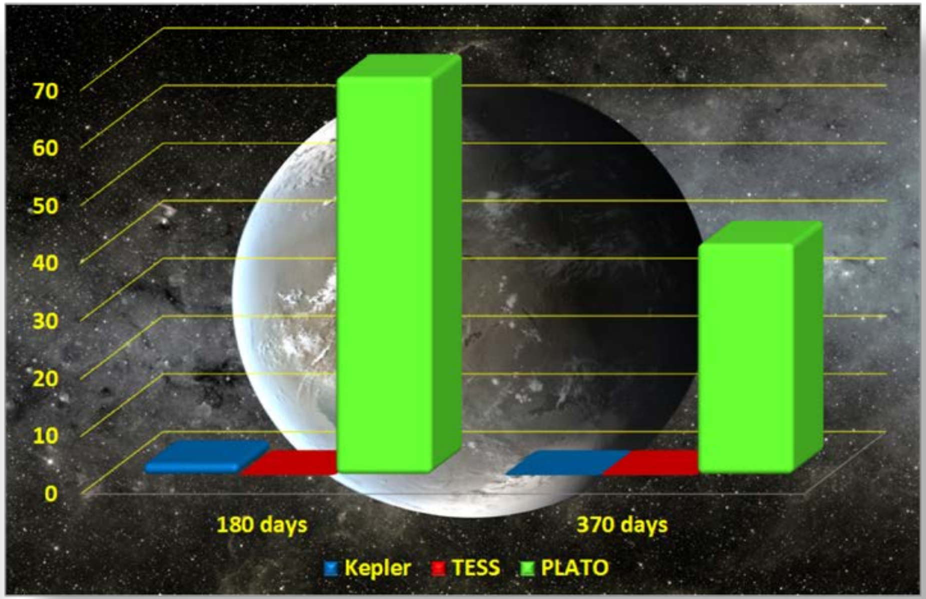
+ Detection of Earth-sized planets
+ ...

PLATO 2.0: Potential for characterized 'super-Earths'

Short-period planets



Habitable zone of solar-like stars

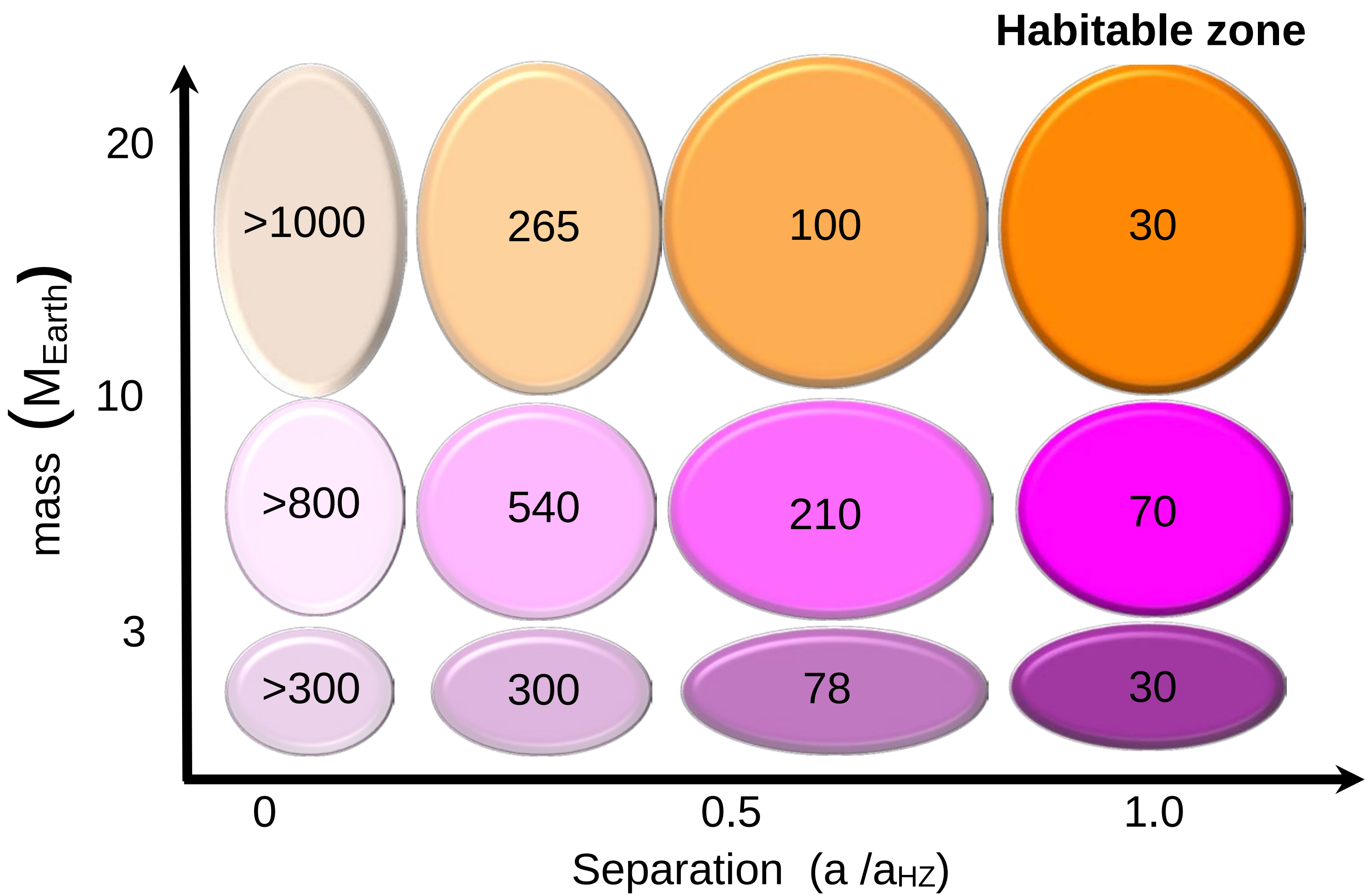


Earth to super-Earth detections around stars bright enough for RV follow-up and asteroseismology

PLATO 2.0 will provide >1000 Earths to „super-Earths" for characterization

Total numbers of characterized planets in core sample

Number of characterized planets (**Earth to Neptune mass**) after detailed model of radial velocity efforts and the impact of stellar activity:



Follow-up time needed

Full follow-up of the expected planet yield from core sample

Radial velocity precision	Telescope	Type of objects	Example time distribution
10m/s	1-2m	Giant planets on short/medium orbits	50 nights/yr for 6 yrs on 3 tel.
1m/s	4m	Giant planets, long orbits. Super-Earths on short medium orbits	40 nights/yr for 6 yrs on 3 tel.
<20cm/s	8m	Earths/Super-Earths on long orbits	40 nights/yr for 6 yrs on 1 tel.

Few hardest cases (eg faintest hosts with Earths in the habitable zone) will need E-ELT

Follow-up time needed

Full follow-up of the expected planet yield from core sample

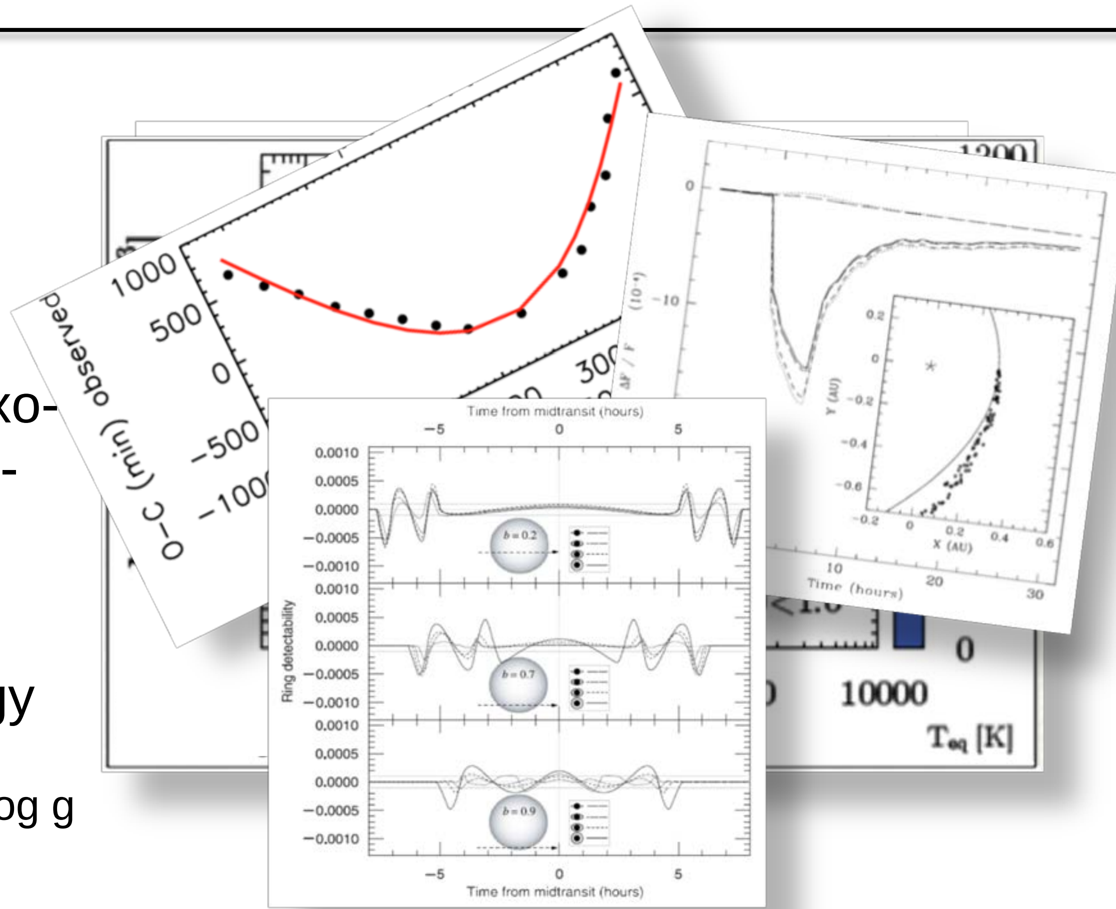
Radial velocity precision	Telescope	Type of objects	Example time distribution
10m/s	1-2m	Giant planets on short/medium orbits	50 nights/yr for 6 yrs on 2 tel.
[illegible]	[illegible]	[illegible] medium orbits	[illegible]
<20cm/s	8m	Earths/Super-Earths on long orbits	40 nights/yr for 6 yrs on 1 tel.

Follow-up is tractable with existing/planned facilities with reasonable allocation of time

Few hardest cases (eg faintest hosts with Earths in the habitable zone) will need E-ELT

PLATO 2.0 Science and Legacy

- Understanding rocky planet diversity
- Test formation and evolution Models
- Circumbinary planets, exo-moons/rings/comets/mis-aligned planets
- Stellar and Galactic evolution → Gaia synergy
  Gaia: radius, distance, proper motion, luminosity, T_{eff}, log g
  PLATO 2.0: masses, ages



→ 1 000 000 high quality light curves of stars
→ Decades of work in Exoplanet and Stellar astrophysics
→ PLATO 2.0 data are open access to the community

PLATO 2.0 Community

The PLATO community includes scientists across different research fields:

- Planet and planetary system formation, evolution, habitability, interior, atmospheres, star-planet interactions
- Stellar evolution, activity, clusters, …
- Evolution of our Galaxy

In total >500 scientists from 21 countries

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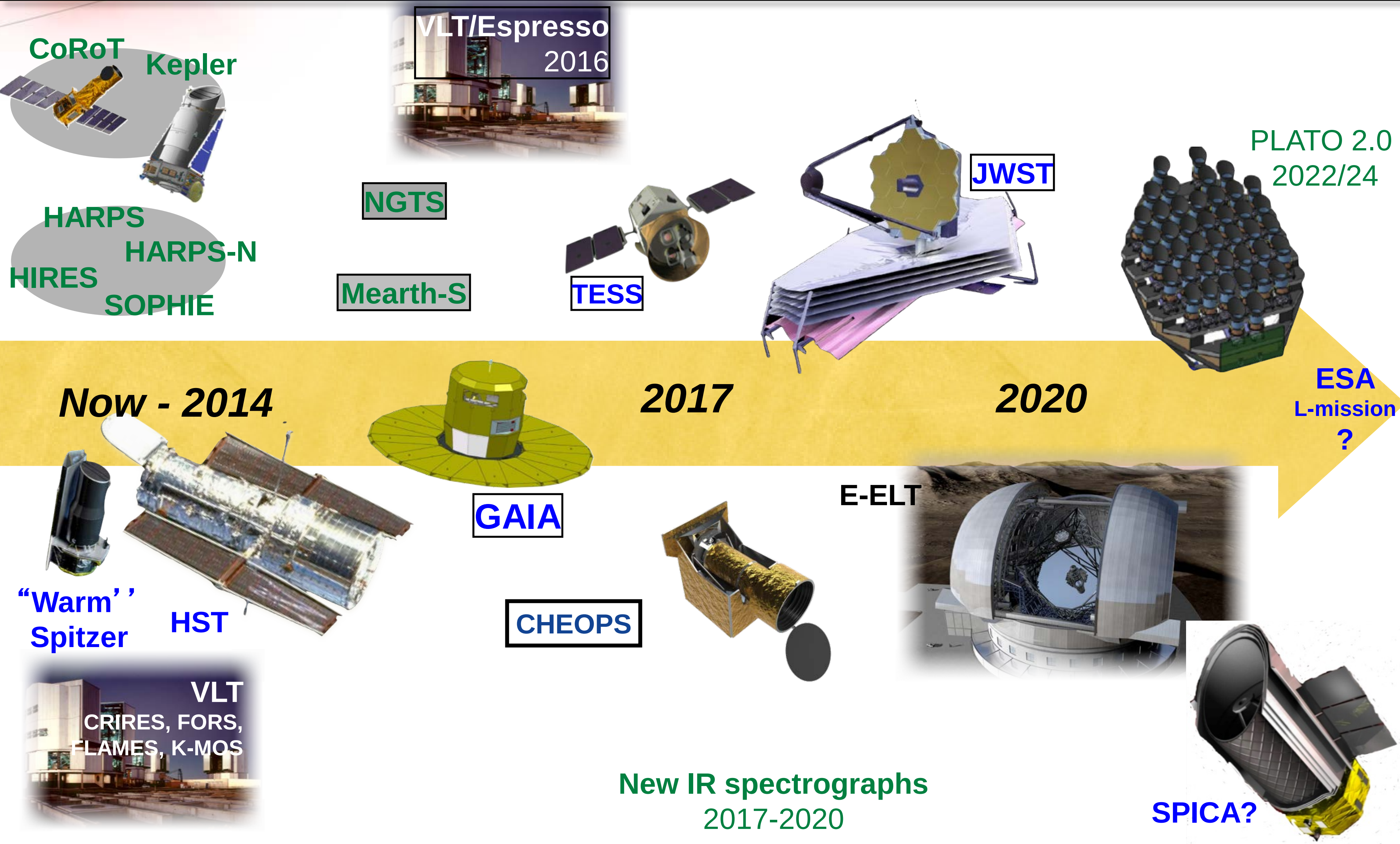
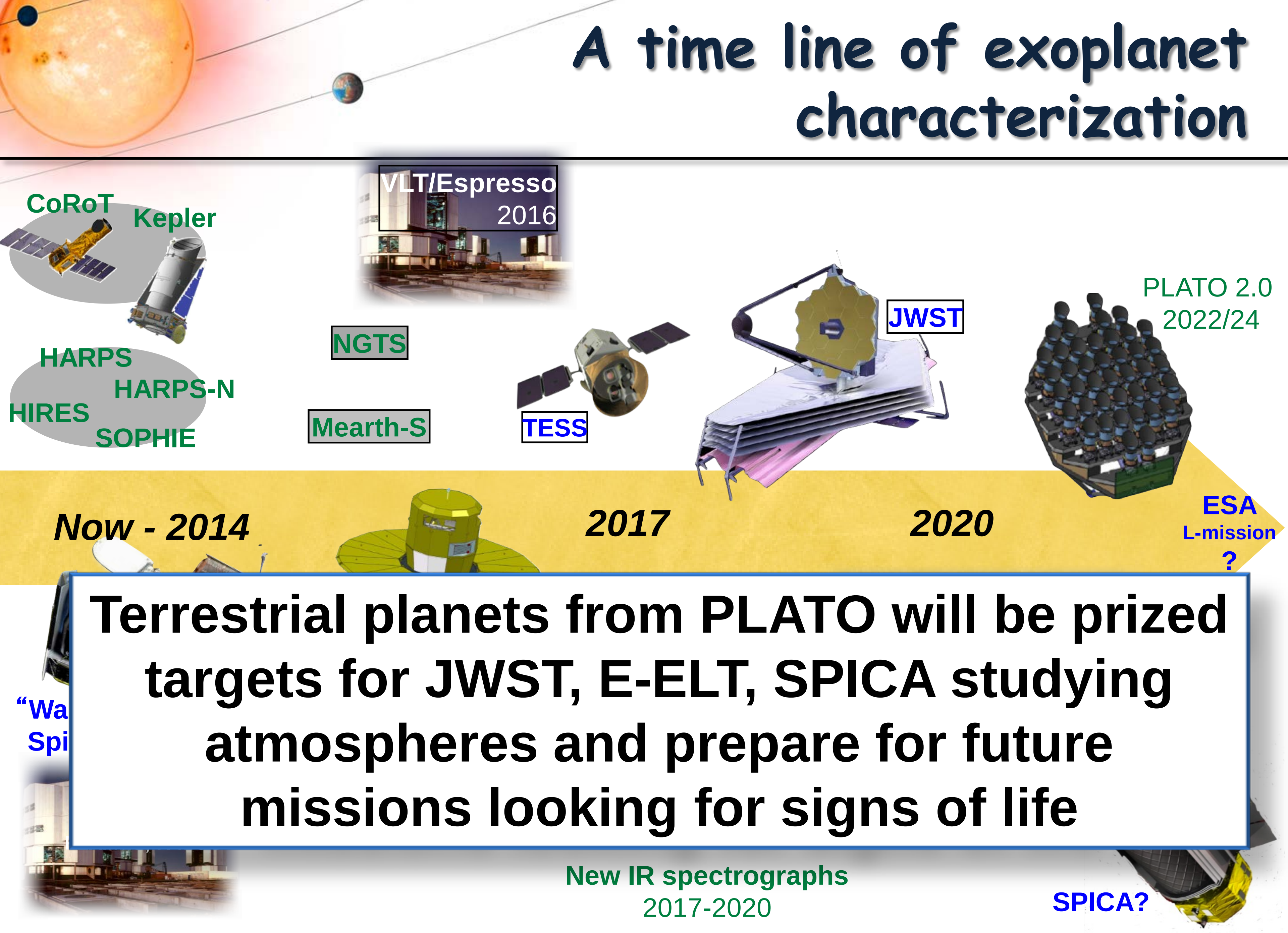
A time line of exoplanet characterization

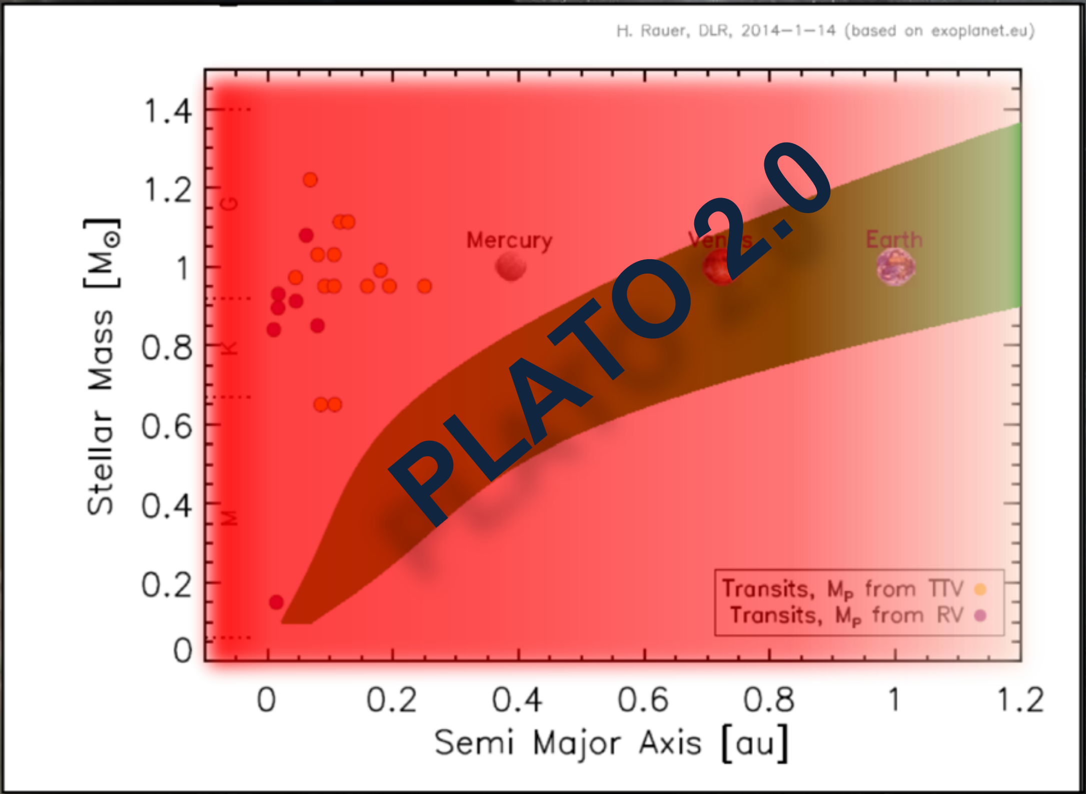




A time line of exoplanet characterization
CoRoT
Kepler
VLT/Espresso
2016
HARPS
HARPS-N
HIRES
SOPHIE
NGTS
Mearth-S
TESS
JWST
PLATO 2.0
2022/24
Now - 2014
2017
2020
ESA
L-mission
?
Terrestrial planets from PLATO will be prized targets for JWST, E-ELT, SPICA studying atmospheres and prepare for future missions looking for signs of life
New IR spectrographs
2017-2020
SPICA?

PLATO 2.0: The Habitable Zone Explorer

We shall not cease
from exploration.
In the end of all our
exploring will be to
arrive where we
started.
T.S. Eliot



PLATO 2.0 will transform our knowledge of habitable zone rocky planets and pave the way for the detection of life beyond the Solar System