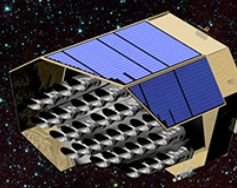
Habitable Zone Planets:
PLATO, and the search for Earth 2.0

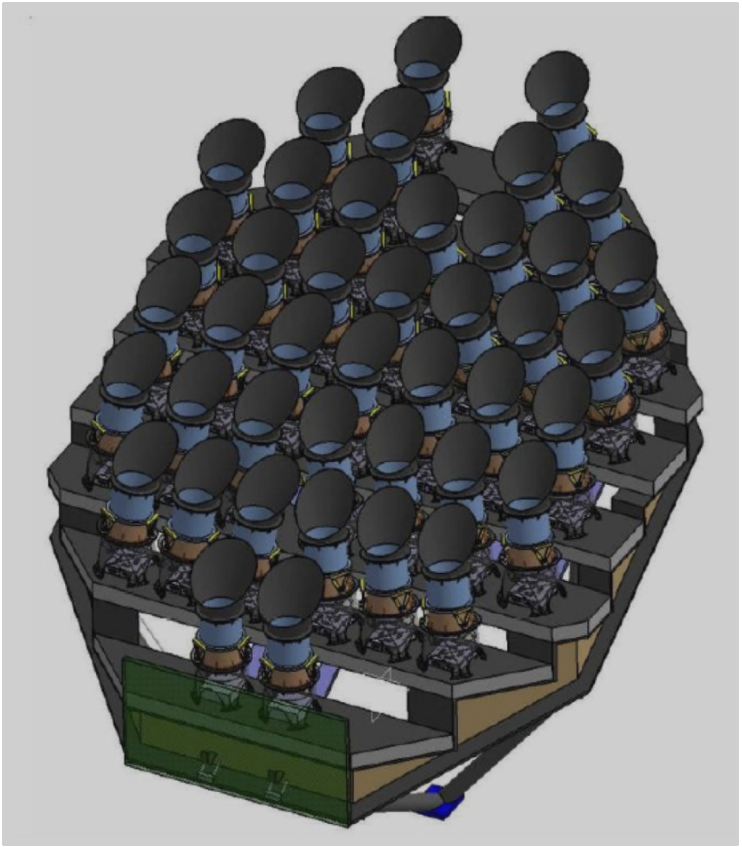


David Brown (University of Warwick)

Jet Propulsion Laboratory
4th June 2015

Overview

- Historical context and background
- Scientific motivation
- PLATO science:
  - Planet diversity
  - Planet habitability
  - Planet formation
  - Comparative planetology
  - Stellar science
- PLATO mission
  - Current status



An historical perspective

"There are infinite worlds both like and unlike this world of ours…"

Epicurus (c 300 BC)

"There are countless suns and countless earths all rotating around their suns in exactly the same way as the seven planets of our system… The countless worlds in the universe are no worse and no less inhabited than our Earth"

Giordano Bruno, 1584
in *De l'infinito Universo et Mondi*

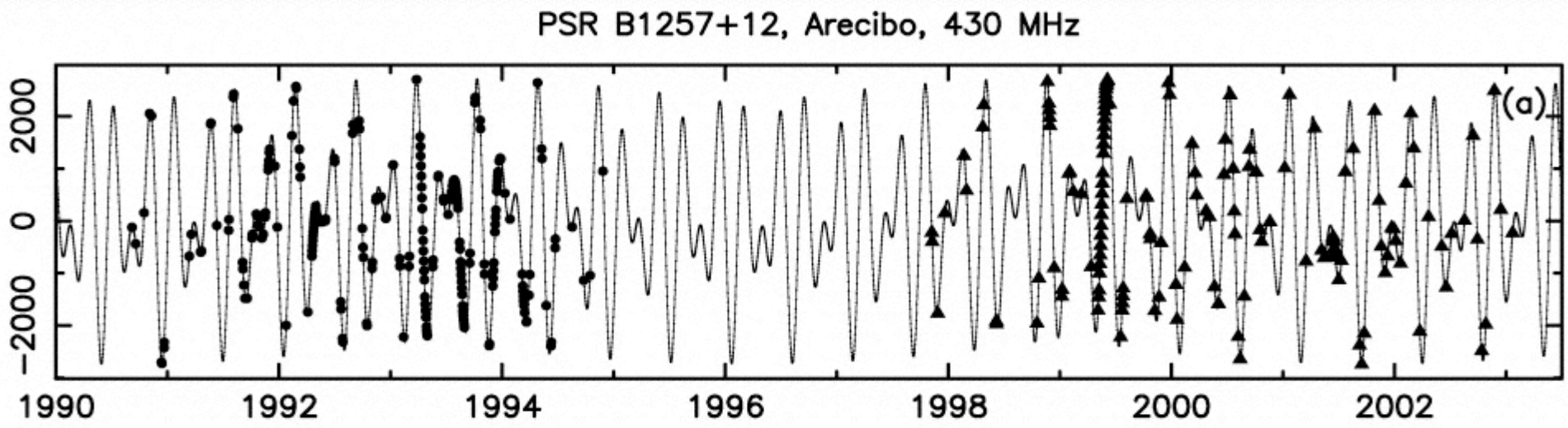
An historical perspective

- A number of disputed claims were made throughout the 19th and 20th centuries
  - 70 Ophiuci (1855) - discredited
  - Barnard's star (1969) - discredited
  - Gamma Cephei (1988) - confirmed
  - PSR 1829-10 (1991) - retracted

- Greater caution with claims of planet detection follows:
  - "*This leads to the suggestion that the companion is probably a brown dwarf, and may even be a giant planet.*"
    - (Latham et al. 1989)
  - "*This object might be a gas-giant planet that has migrated to this location through orbital evolution, or from the radiative stripping of a brown dwarf.*"
    - (Mayor & Queloz et al. 1995)

First confirmation

- First genuine planets came from an unlikely source
  - Pulsar timing (Wolszczan & Frail 1992)



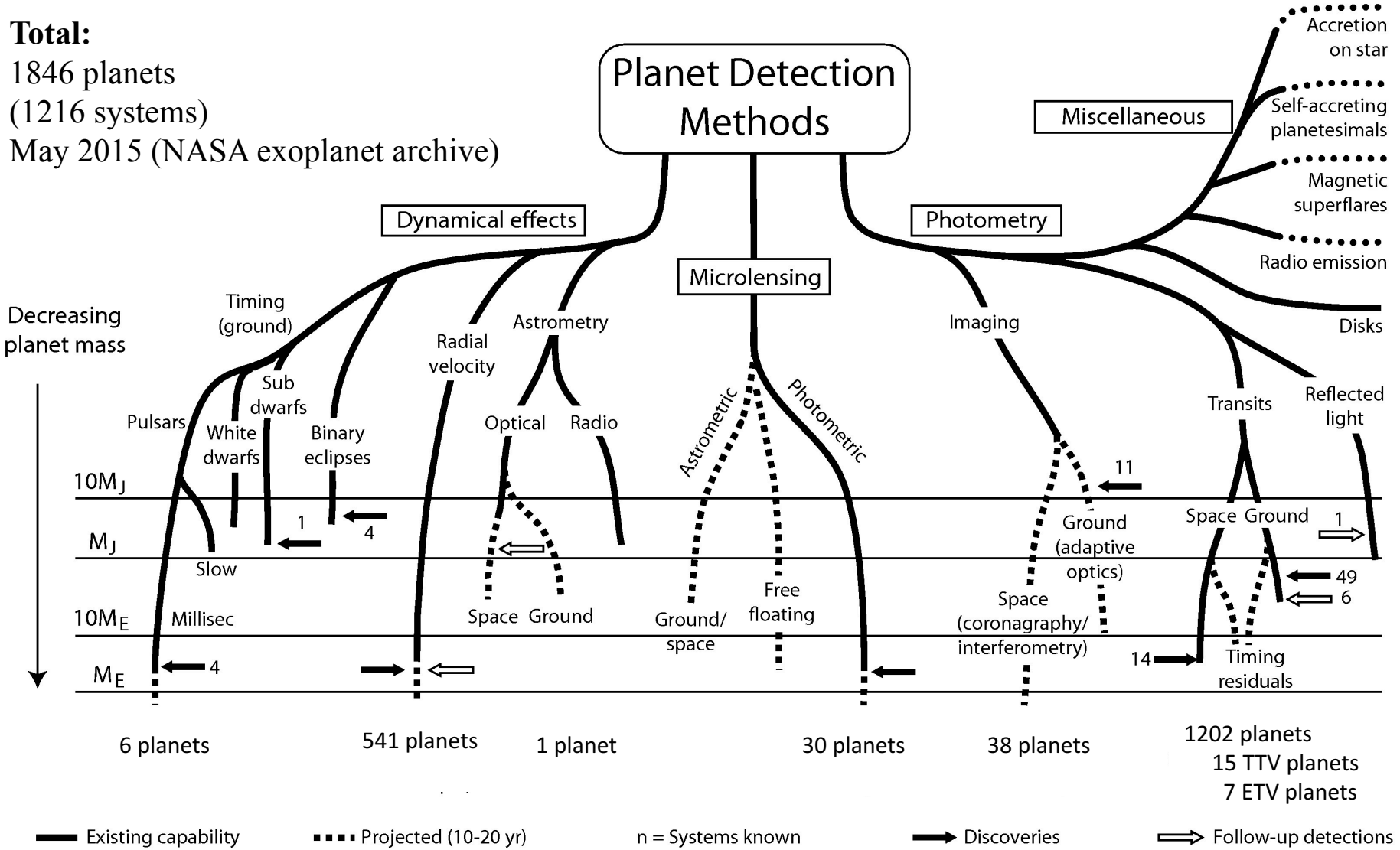
Konacki & Wolszczan (2003)

- First planet around main sequence star
  - 51 Peg b (Mayor & Queloz 1995)

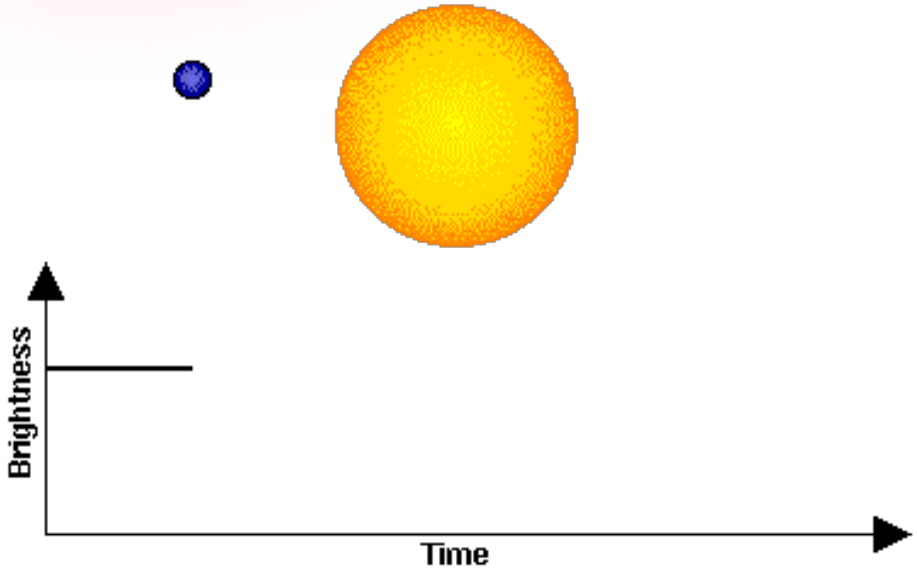
Detection methods

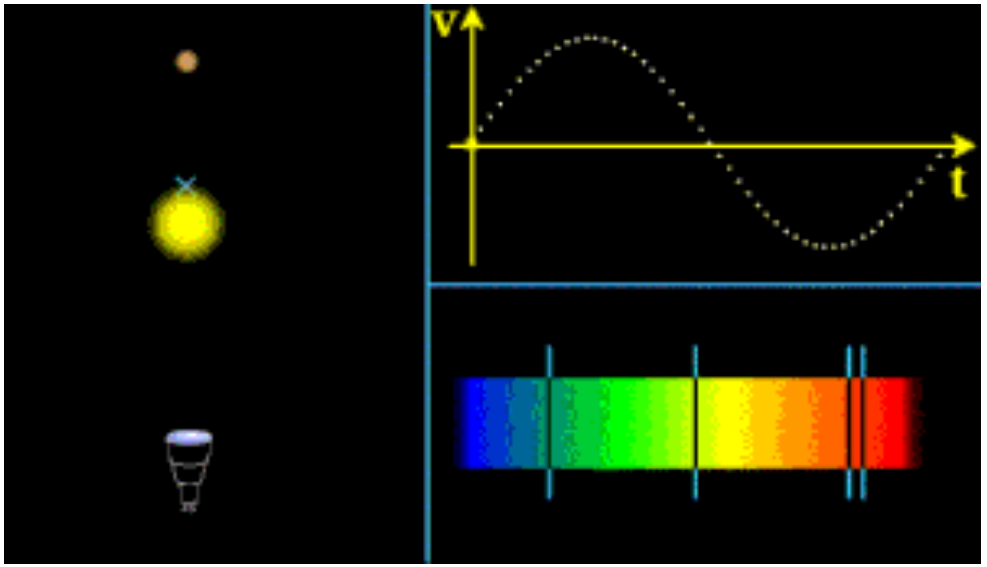
Schuh (2010), updated from Perryman (2000)

Total:
1846 planets
(1216 systems)
May 2015 (NASA exoplanet archive)



Detection methods





Transits provide:

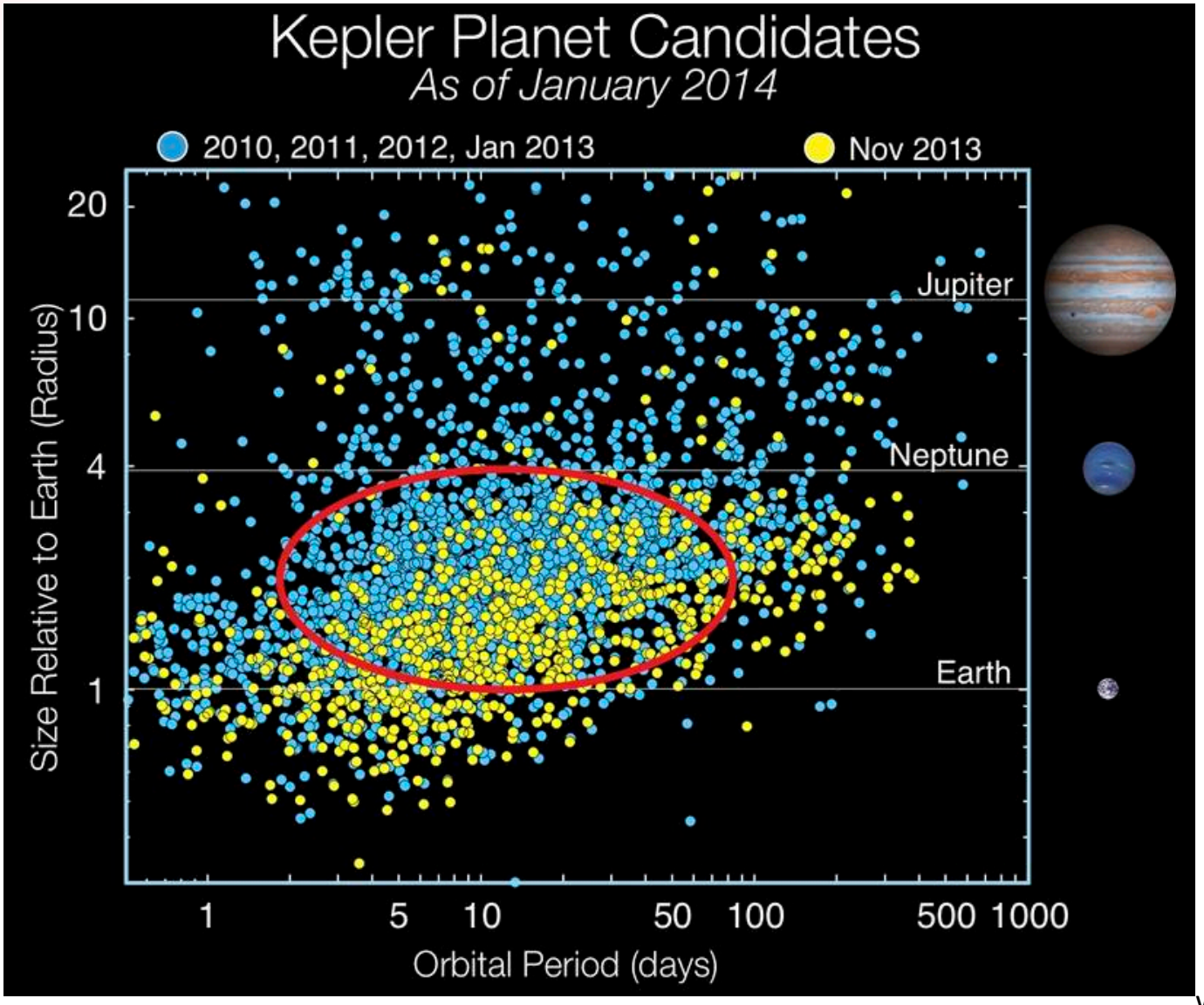
- Orbit parameters
- Orbital inclination, ***i***
- Planet radius

Radial velocities provide:

- Orbital parameters
- Minimum planet mass

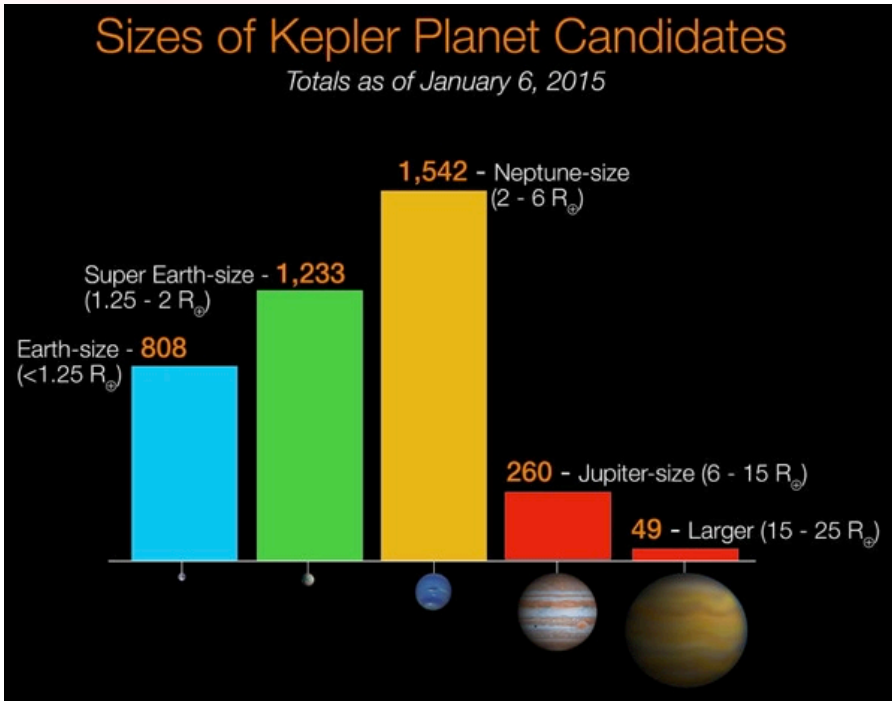
  m* sin *i

Planet population



www.nasa.gov

Planet population



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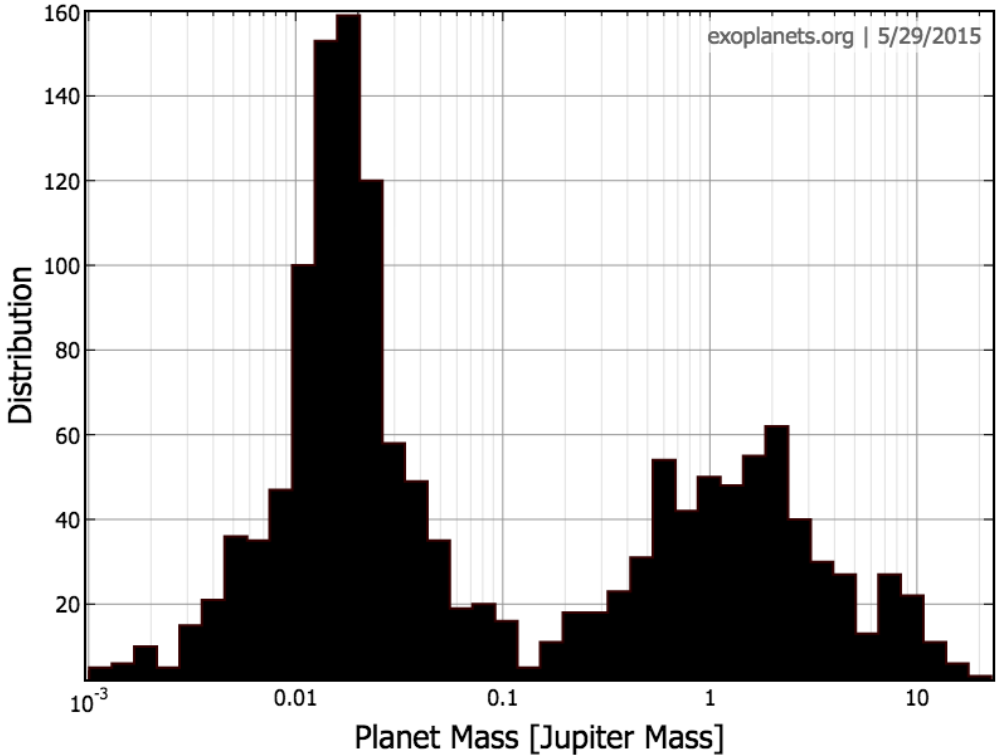


Planet population

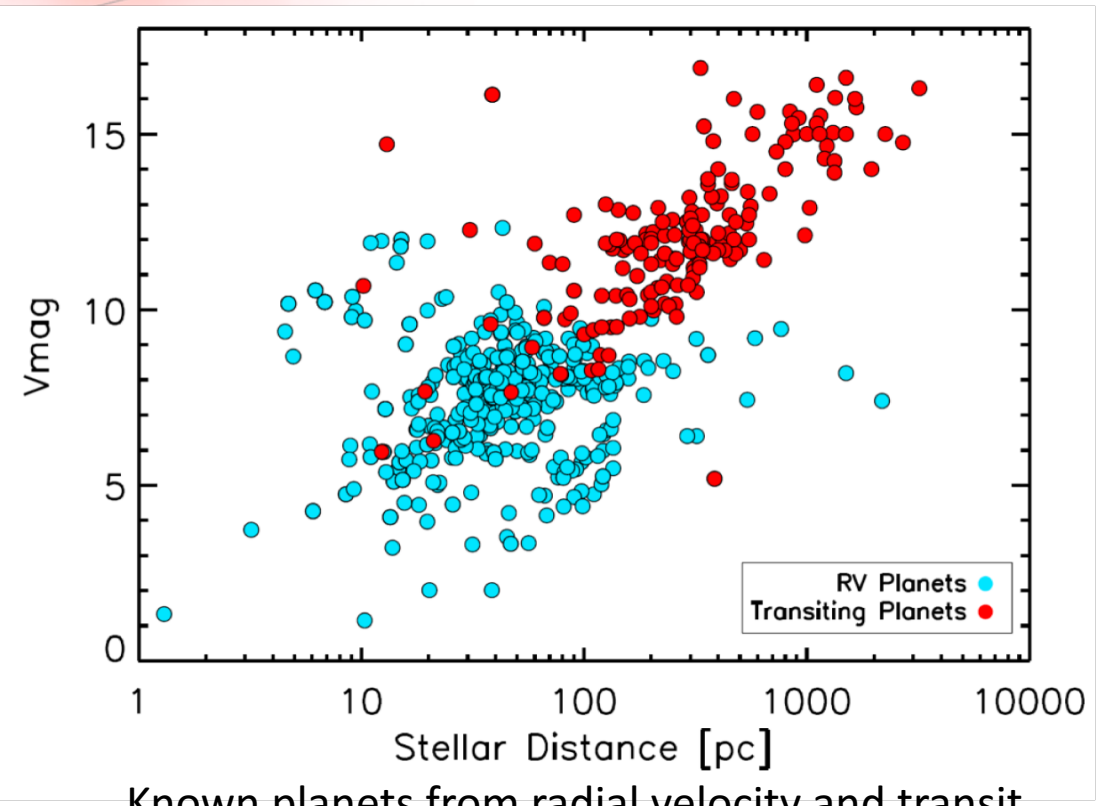
- Current status:
  - ~1500 confirmed exoplanets
  - ~3000 exoplanet candidates

- Combination of *transits* and *RVs* gives the greatest information.

- *Kepler,* and RV surveys, show that small and low-mass planets are numerous

However:
- Few detections of small planets in the habitable zone.
- **Very little characterization**.

The need for bright stars



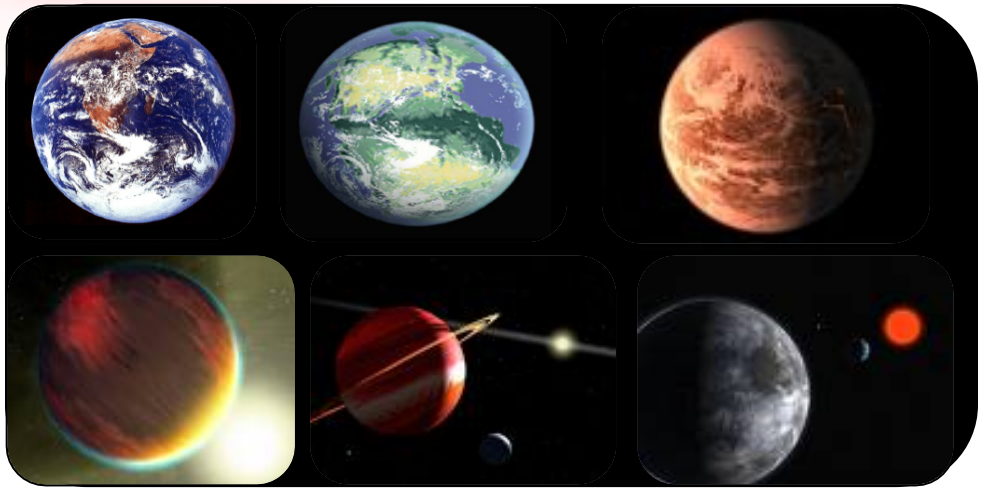
Known planets from radial velocity and transit surveys

Why have so few targets been characterised?

- Transit surveys tend to target faint stars to maximize detection performance.
- Radial velocity surveys need bright stars (≤11 mag) to limit telescope time.

Future transit missions **must** target bright stars

Exoplanets and stars



Characterization of exoplanets ……

- Mass + radius ⇒ mean density
  - Gaseous vs. rocky; composition; structure
- Orbital distance, atmosphere
  - Habitability
- Age
  - Planetary system evolution

needs characterisation of stars

- Stellar mass, radius
  - Derive planet mass & radius
- Stellar type, luminosity, activity
  - Planet insolation
- Stellar age
  - Defines planet age

Upcoming transit missions

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

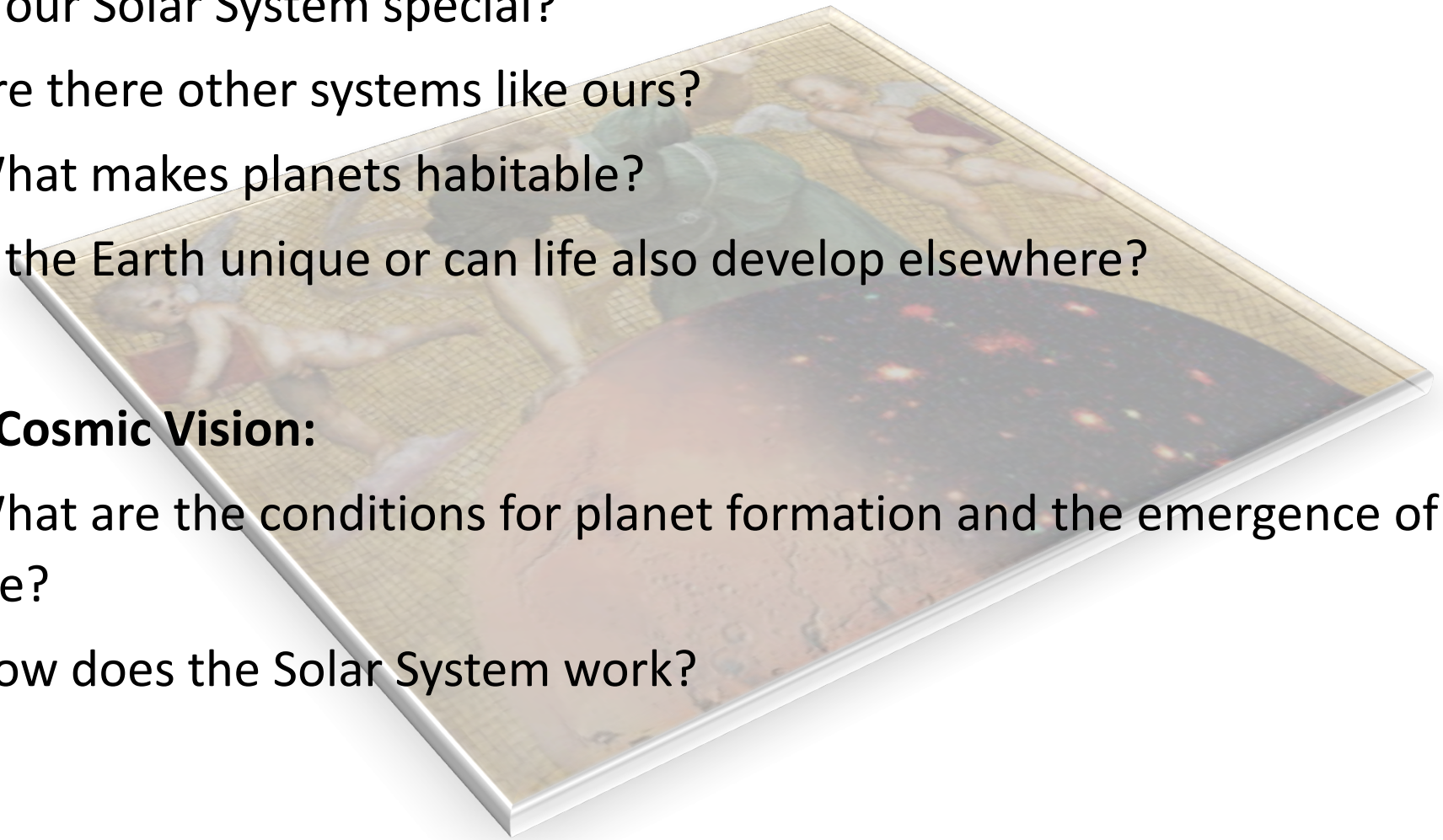
- **CHEOPS** (ESA): follow-up of detected (RV-)planets
  biased towards **short-period planets** by transit probability

- **K2** (NASA): observe fields in the ecliptic plane for **~80 days/field**
  ⇒ **mainly short-period planets**

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

Scientific Motivation

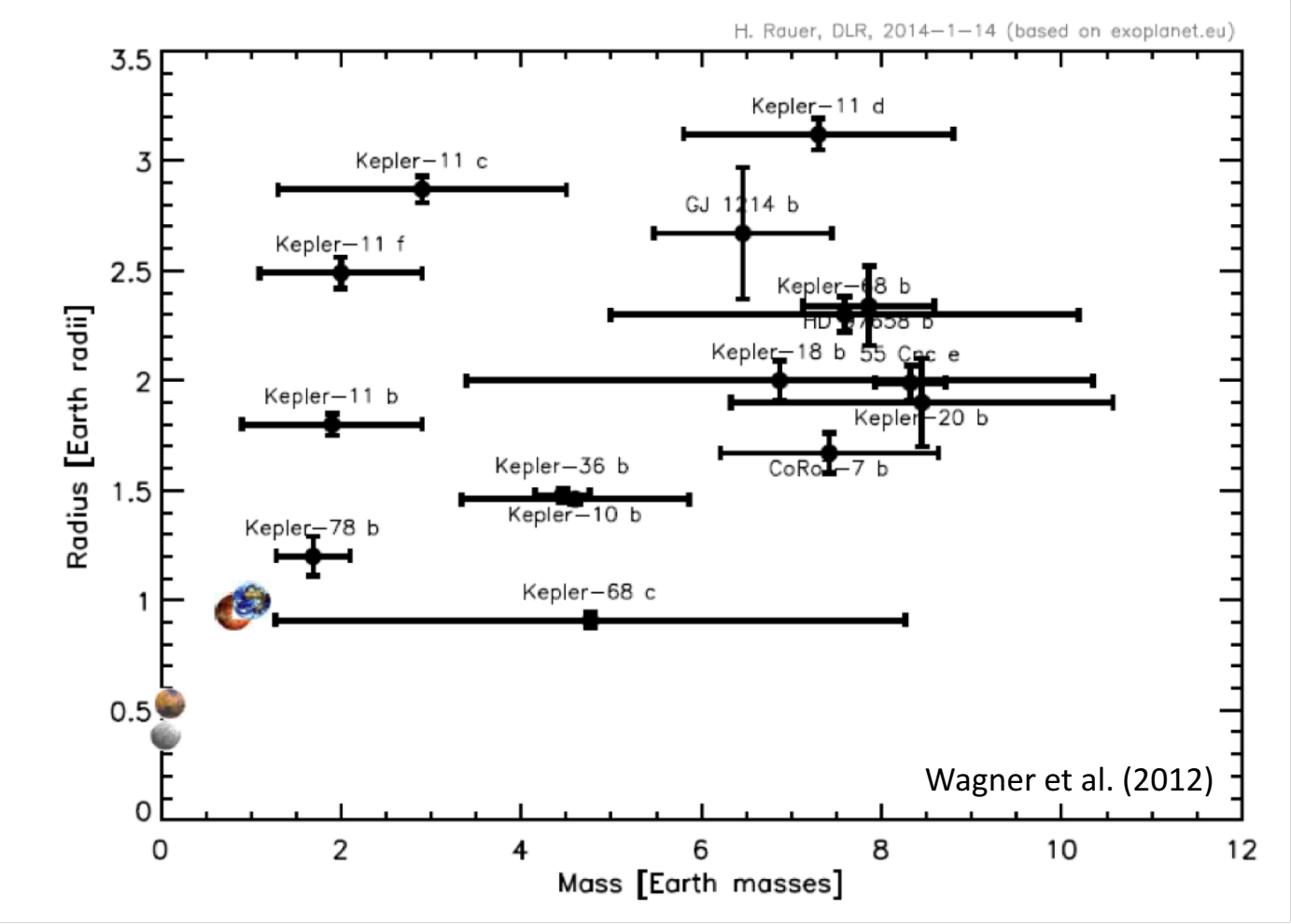
- How do planets and planetary systems form and evolve?
- Is our Solar System special?
- Are there other systems like ours?
- What makes planets habitable?
- Is the Earth unique or can life also develop elsewhere?



ESA Cosmic Vision:

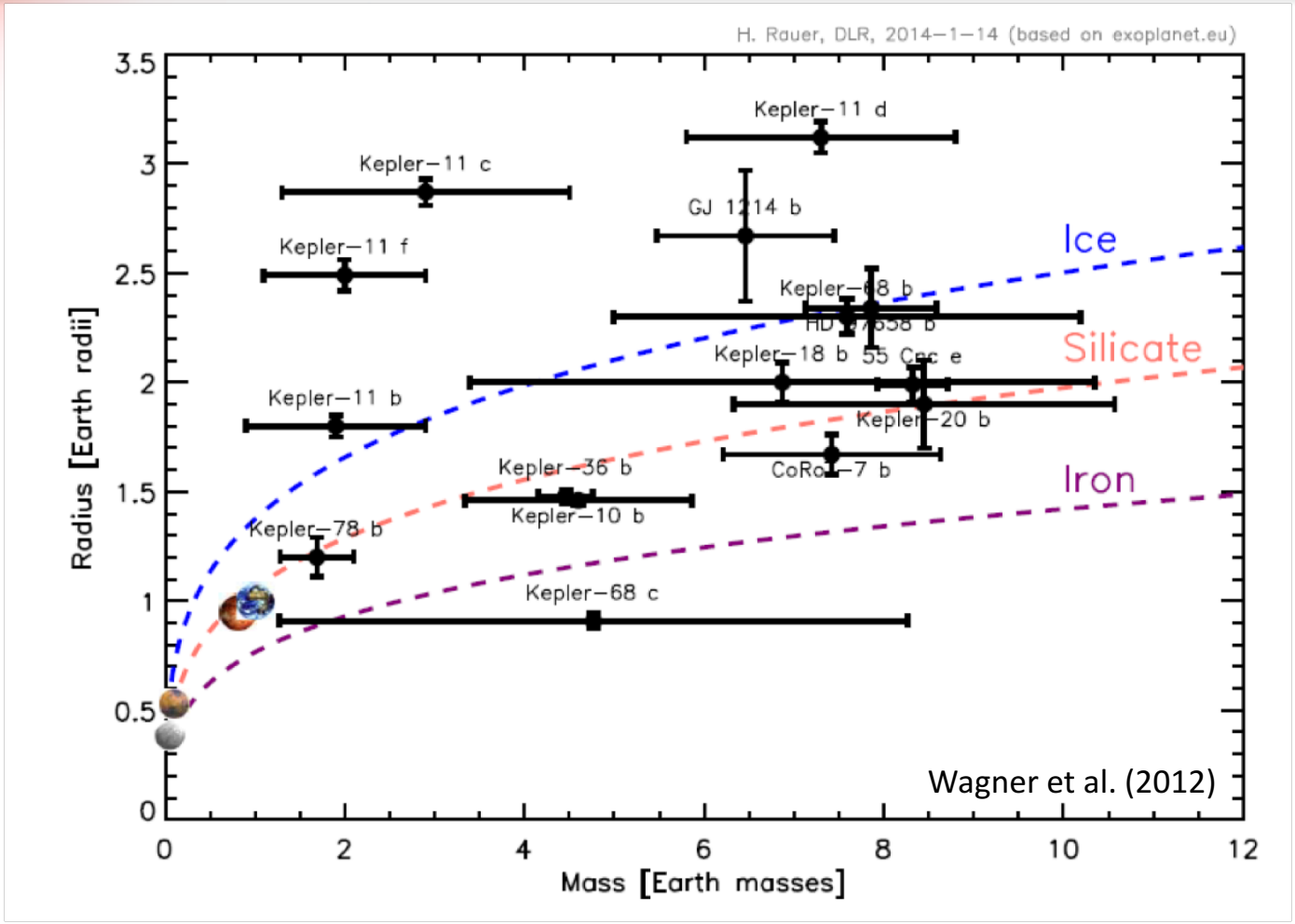
- What are the conditions for planet formation and the emergence of life?
- How does the Solar System work?

Diversity of “super-Earths”



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

Diversity of “super-Earths”



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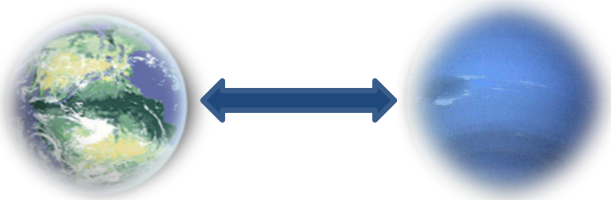
Diversity of "Super-Earths":
Implications for habitability

Solar System planets are NOT the general rule:

small ≠ rocky large ≠ gaseous

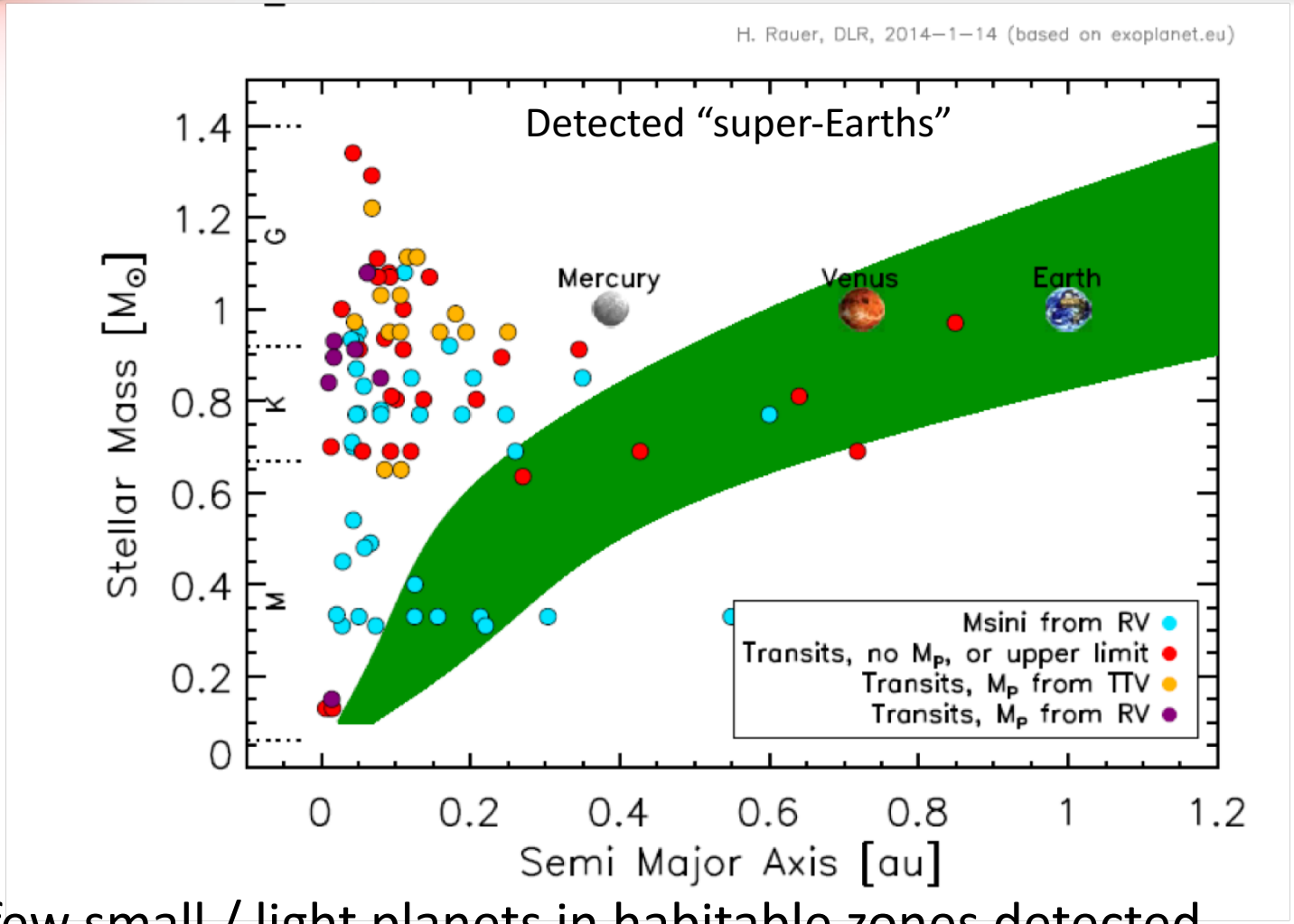
- Small exoplanets are very diverse:
  from Earth-like to mini-gas planets



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

We need **both** precise masses **and** radii to separate terrestrial from mini-gas planets.

Characterized “super-Earths”
in the habitable zone?



- Very few small / light planets in habitable zones detected.
- No *characterized* “super-Earths” in habitable zone.
- TESS, CHEOPS, and K2 will cover orbital periods up to ~80 days.

Characterized “super-Earths”
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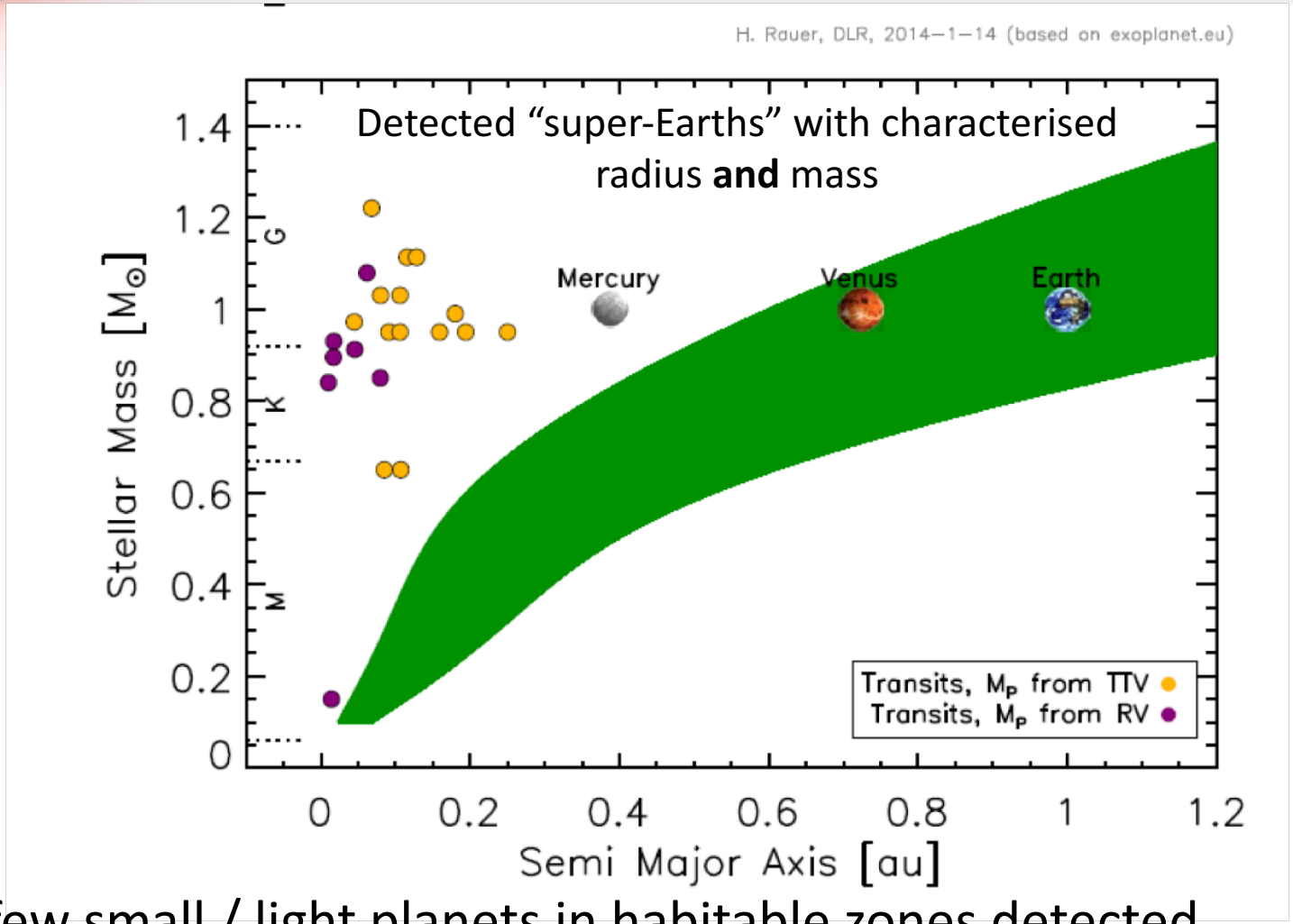

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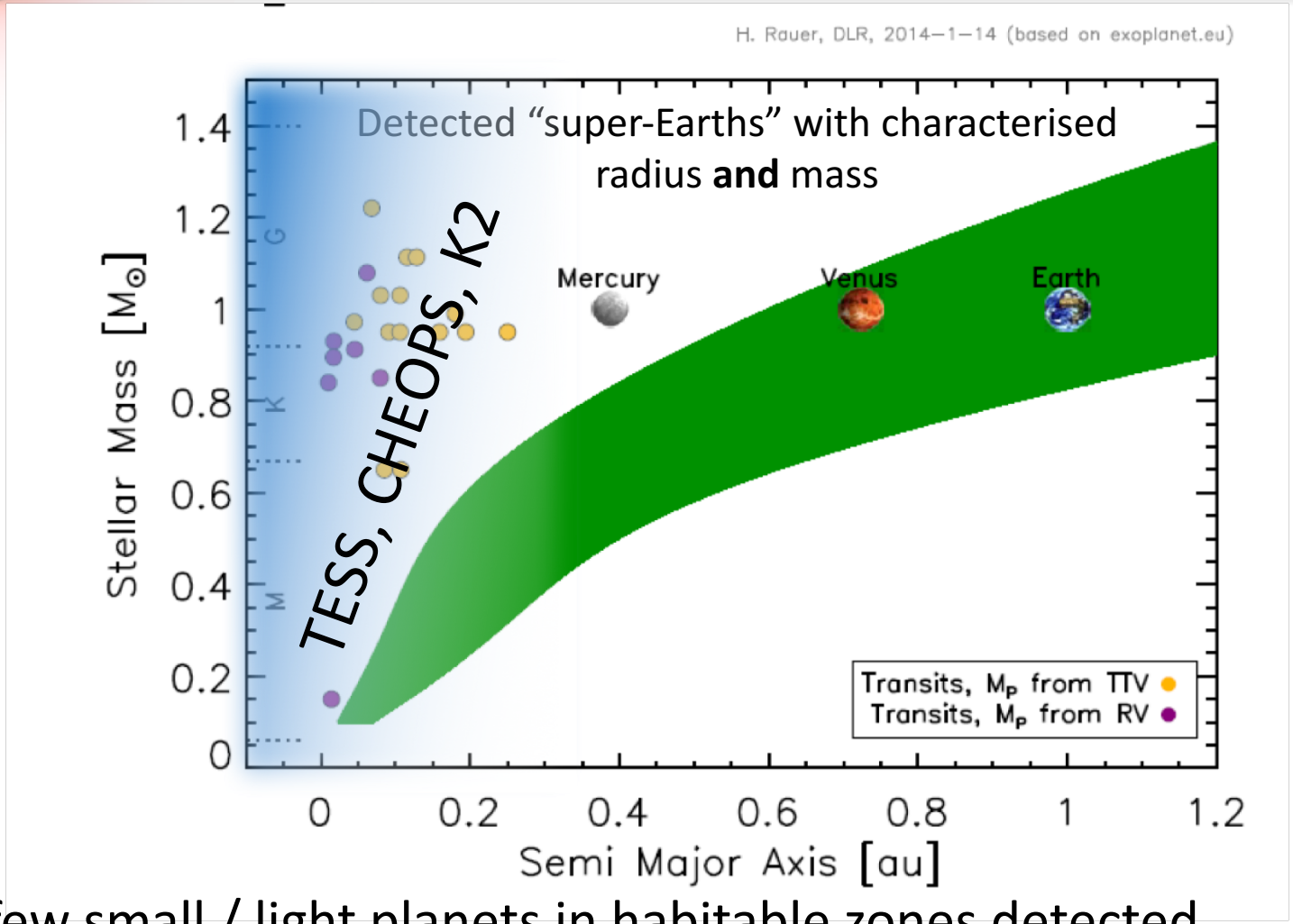

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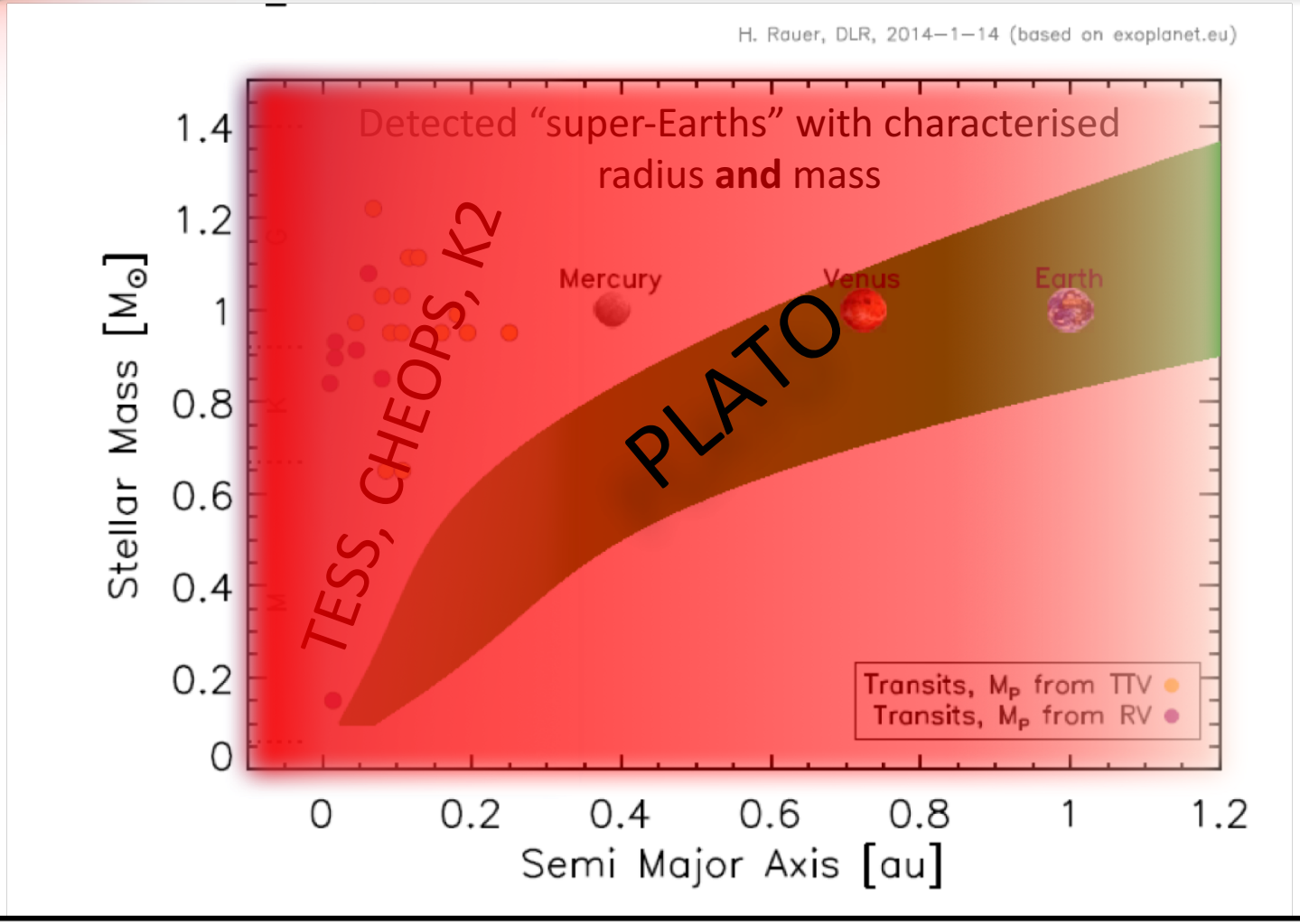
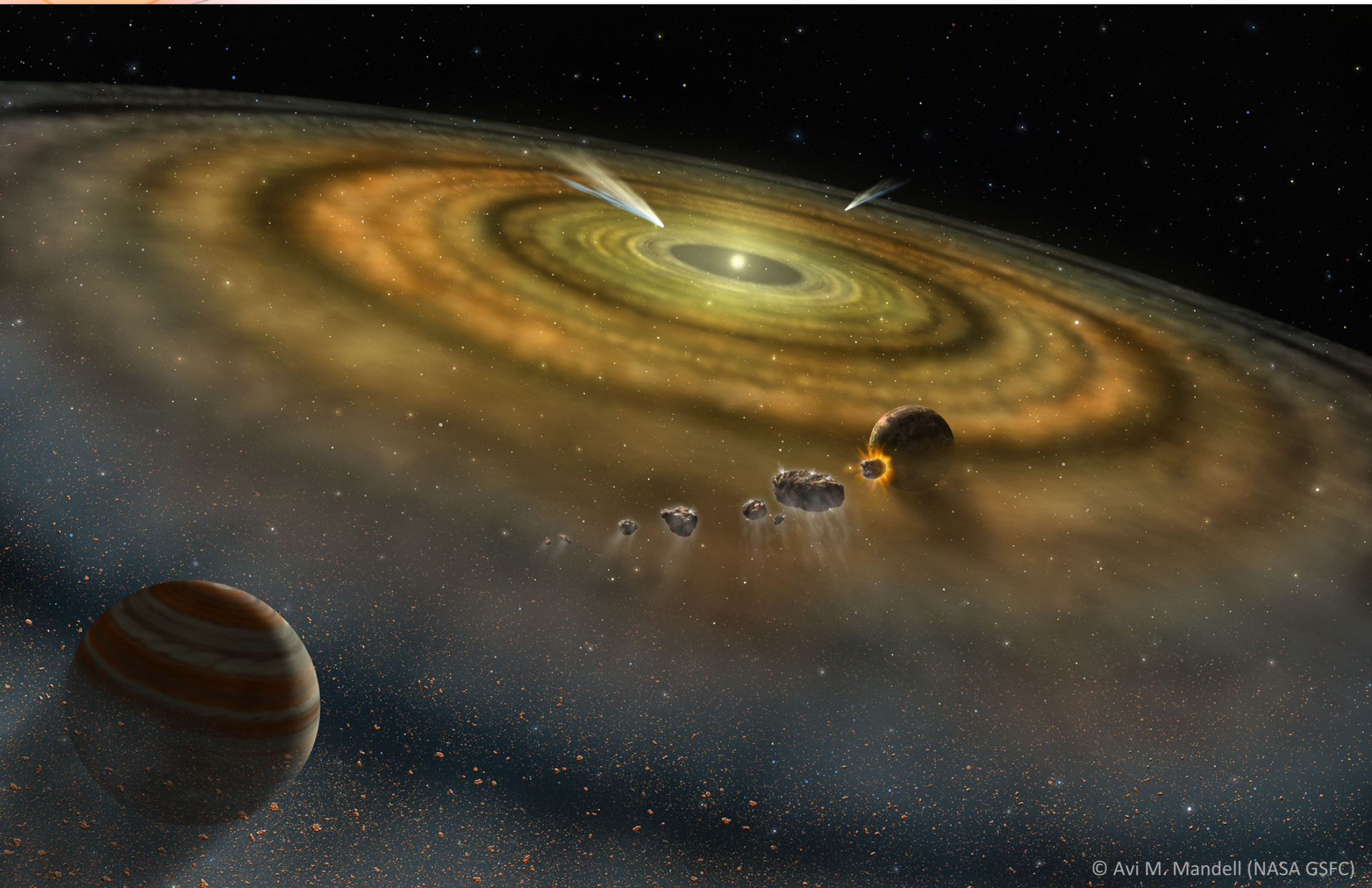


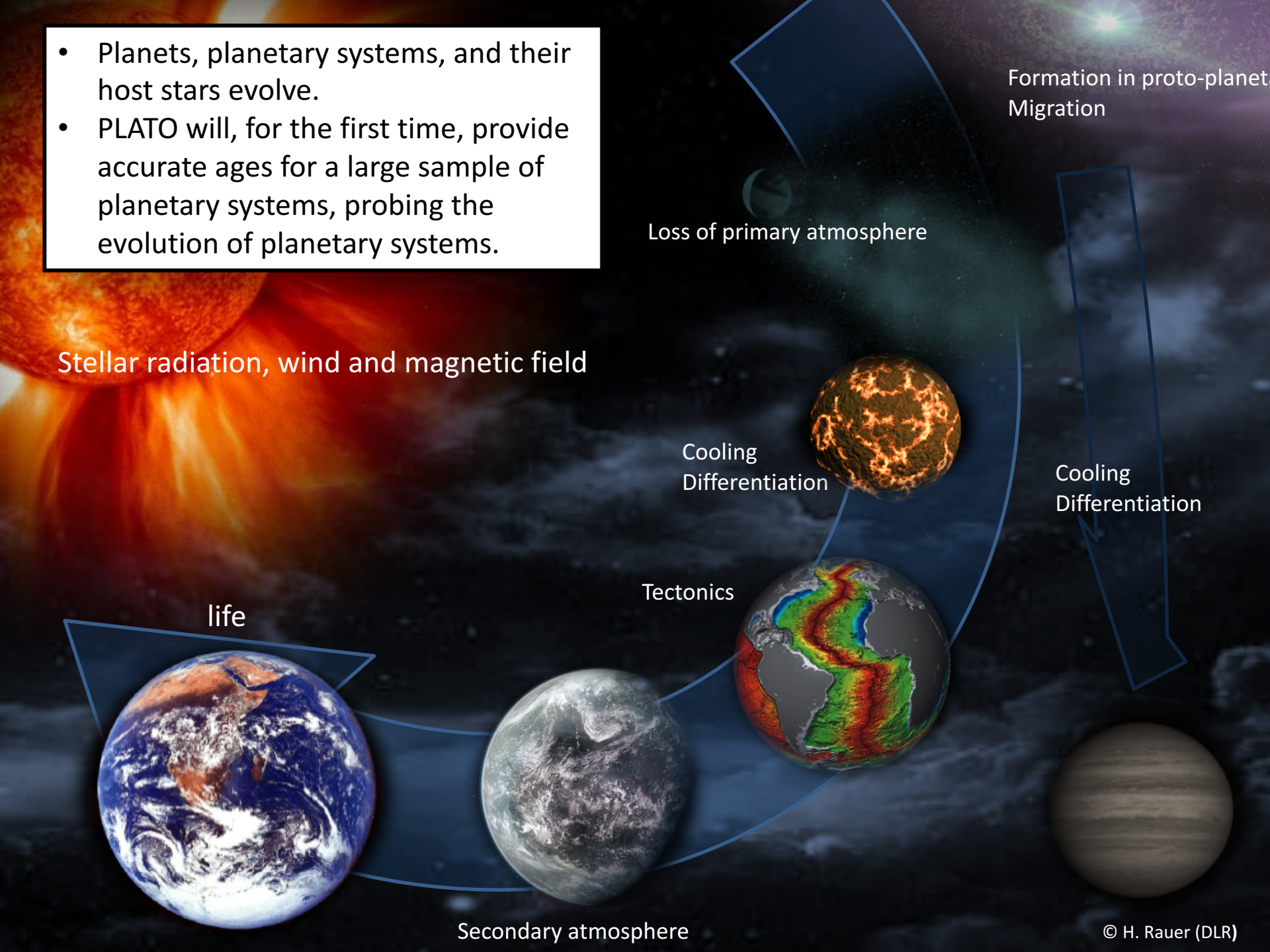
PLATO will detect and bulk characterize small planets up to the habitable zone of solar-like stars.

PLATO Science:

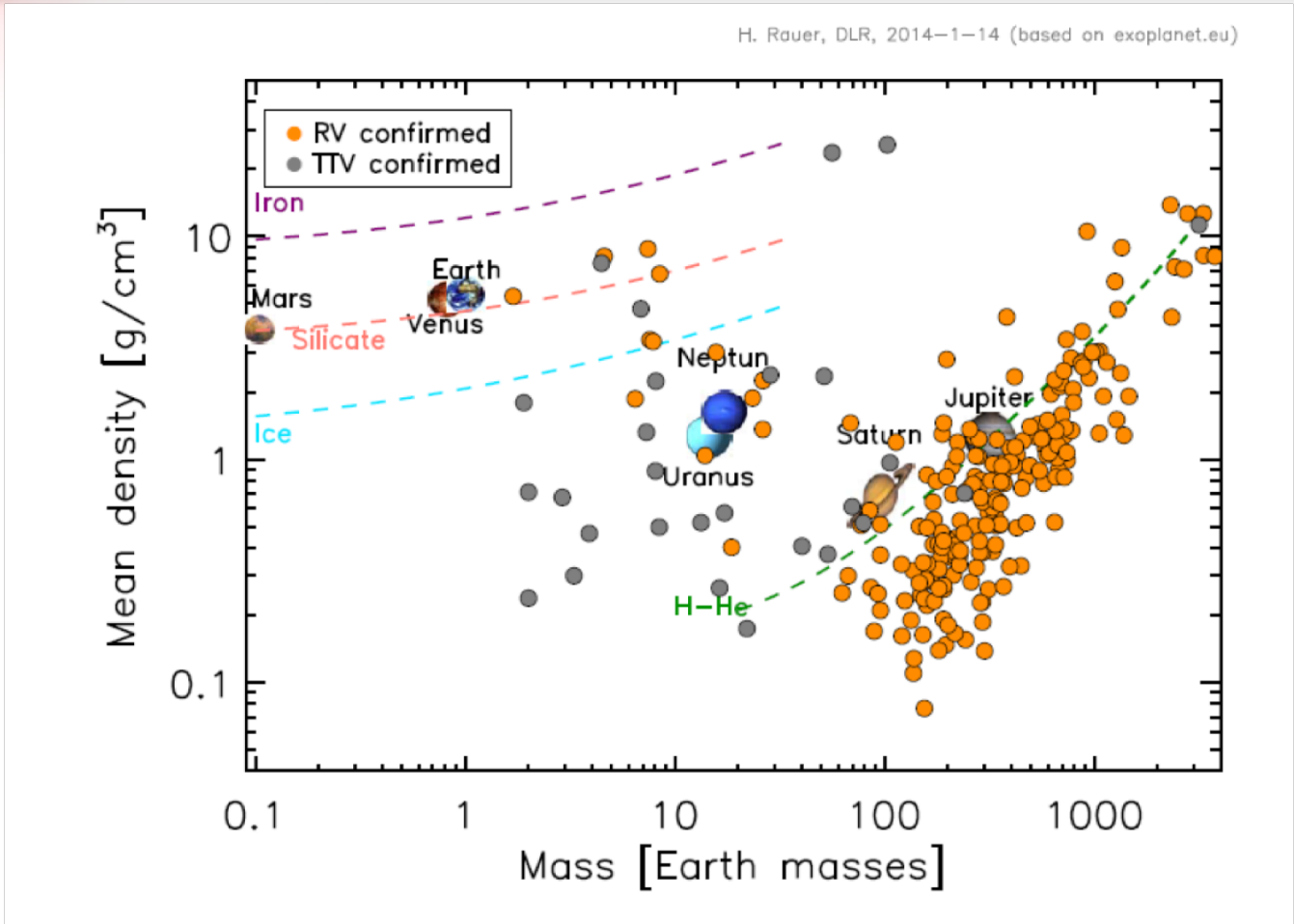
Planet diversity and indications for formation



- Planets, planetary systems, and their host stars evolve.
- PLATO will, for the first time, provide accurate ages for a large sample of planetary systems, probing the evolution of planetary systems.



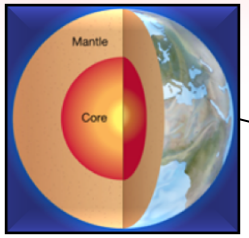
Planet diversity and planet formation



- Mean density varies by two orders of magnitude for a given mass.
- Low-mass planets have a range of compositions and interior structures for similar masses.

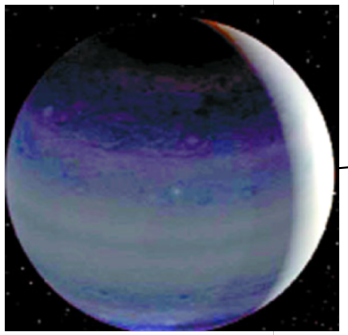
Planet diversity and planet formation

Earth

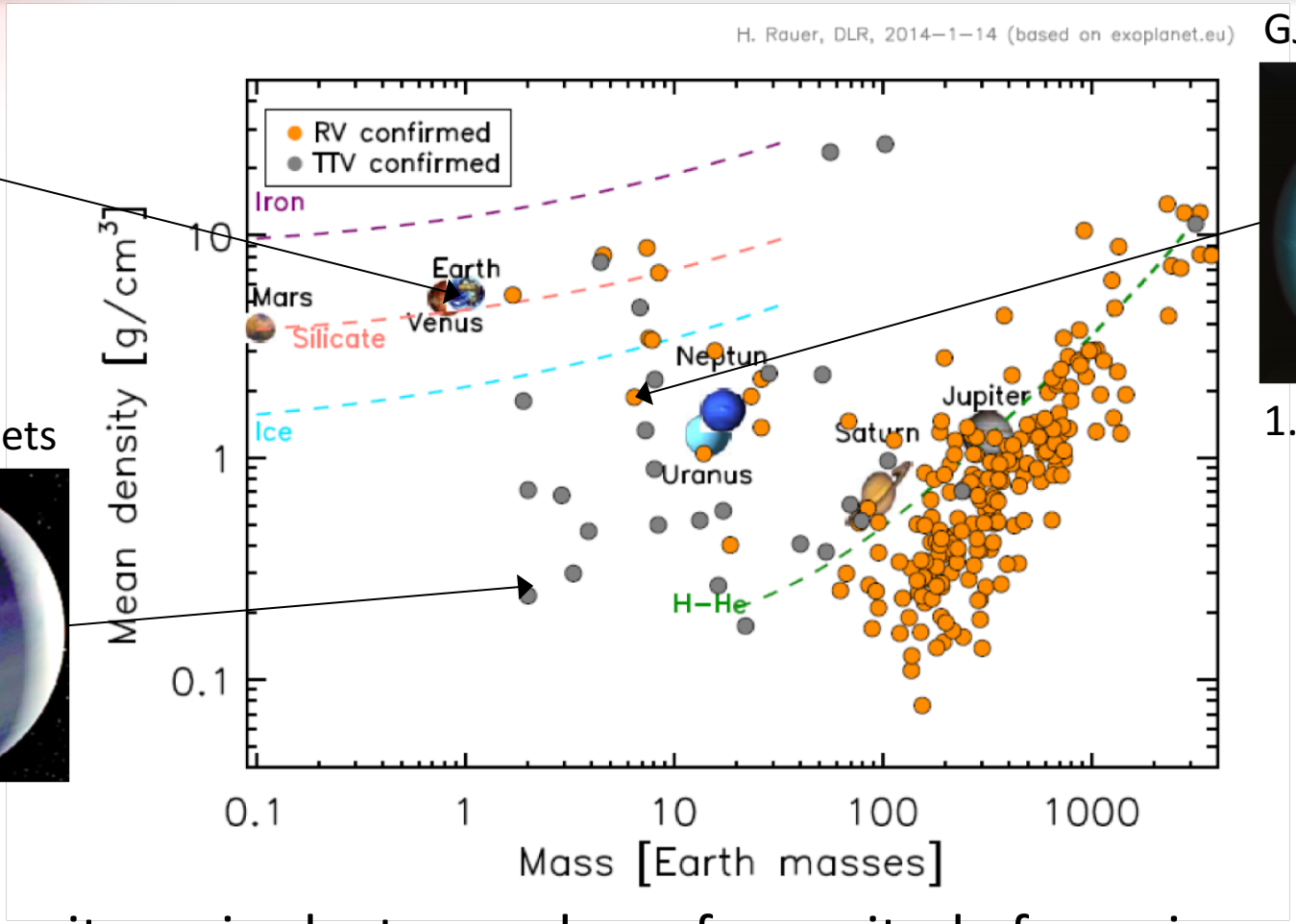


5.5 g/cm^3

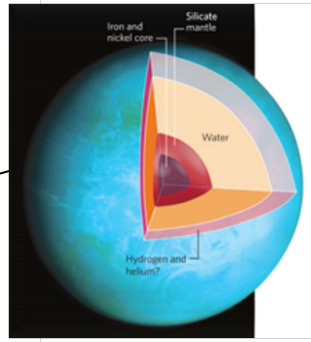
Mini gas planets



<~1 g/cm^3



GJ1214b



1.6 g/cm^3

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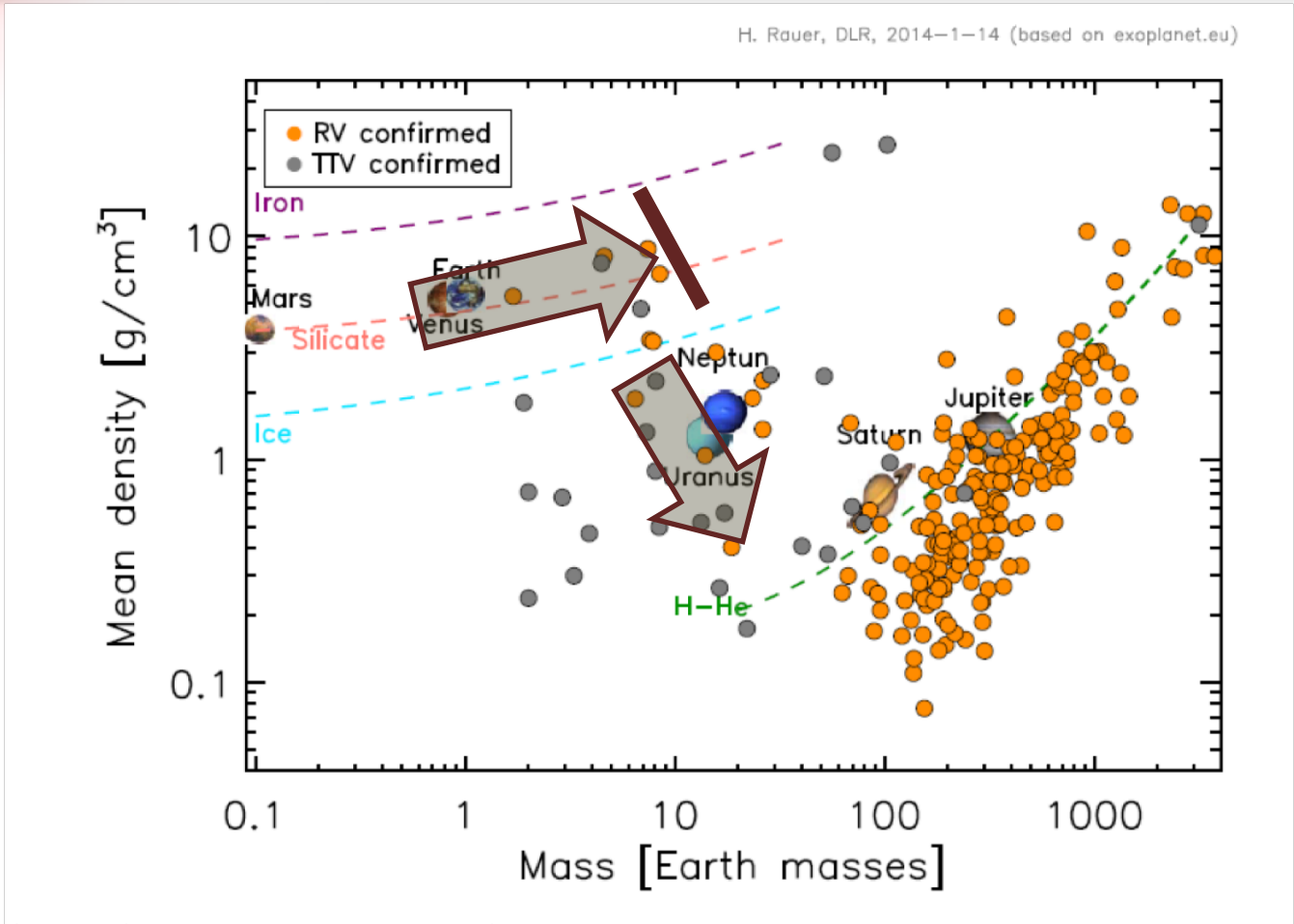
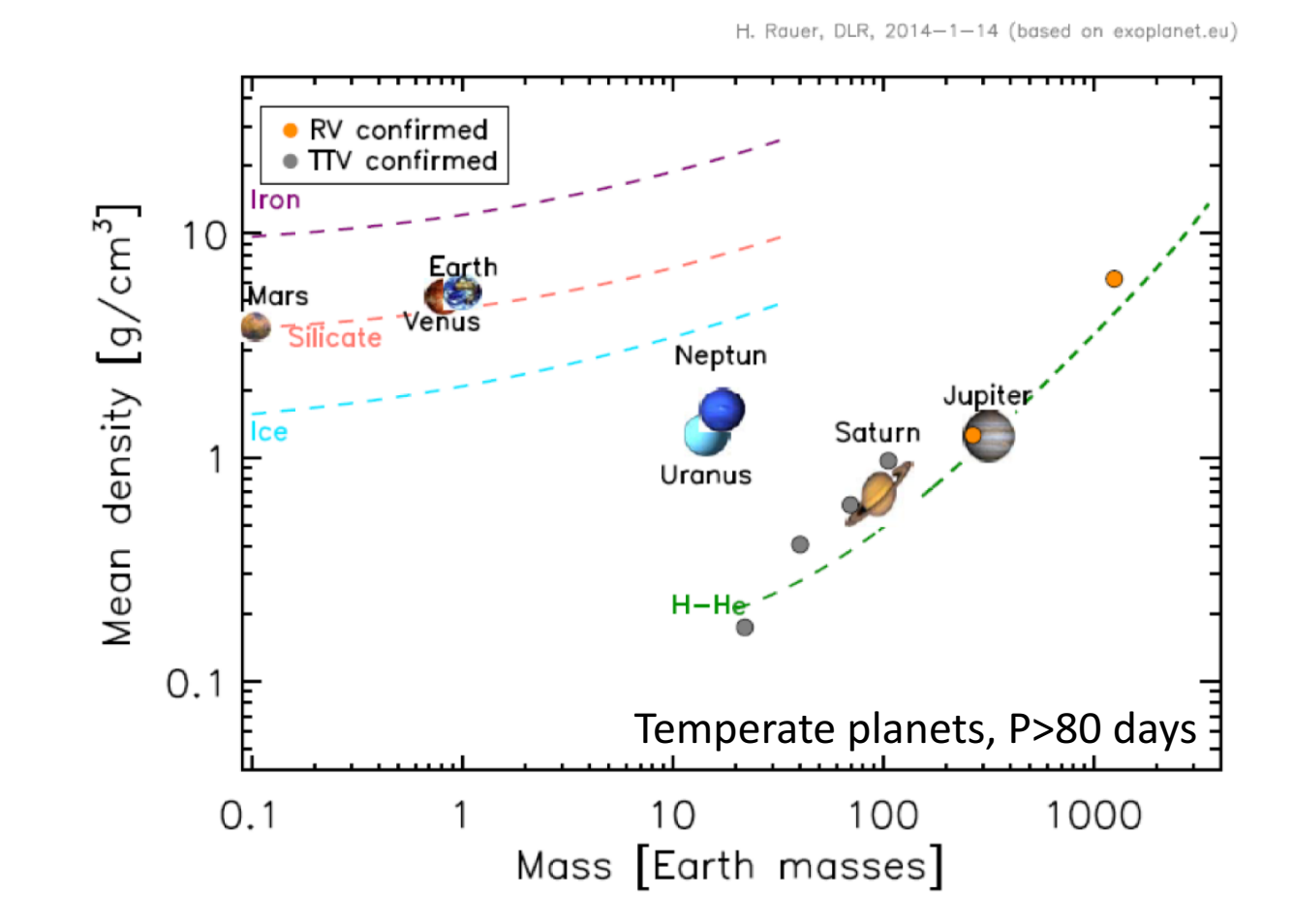
Planet diversity and planet formation



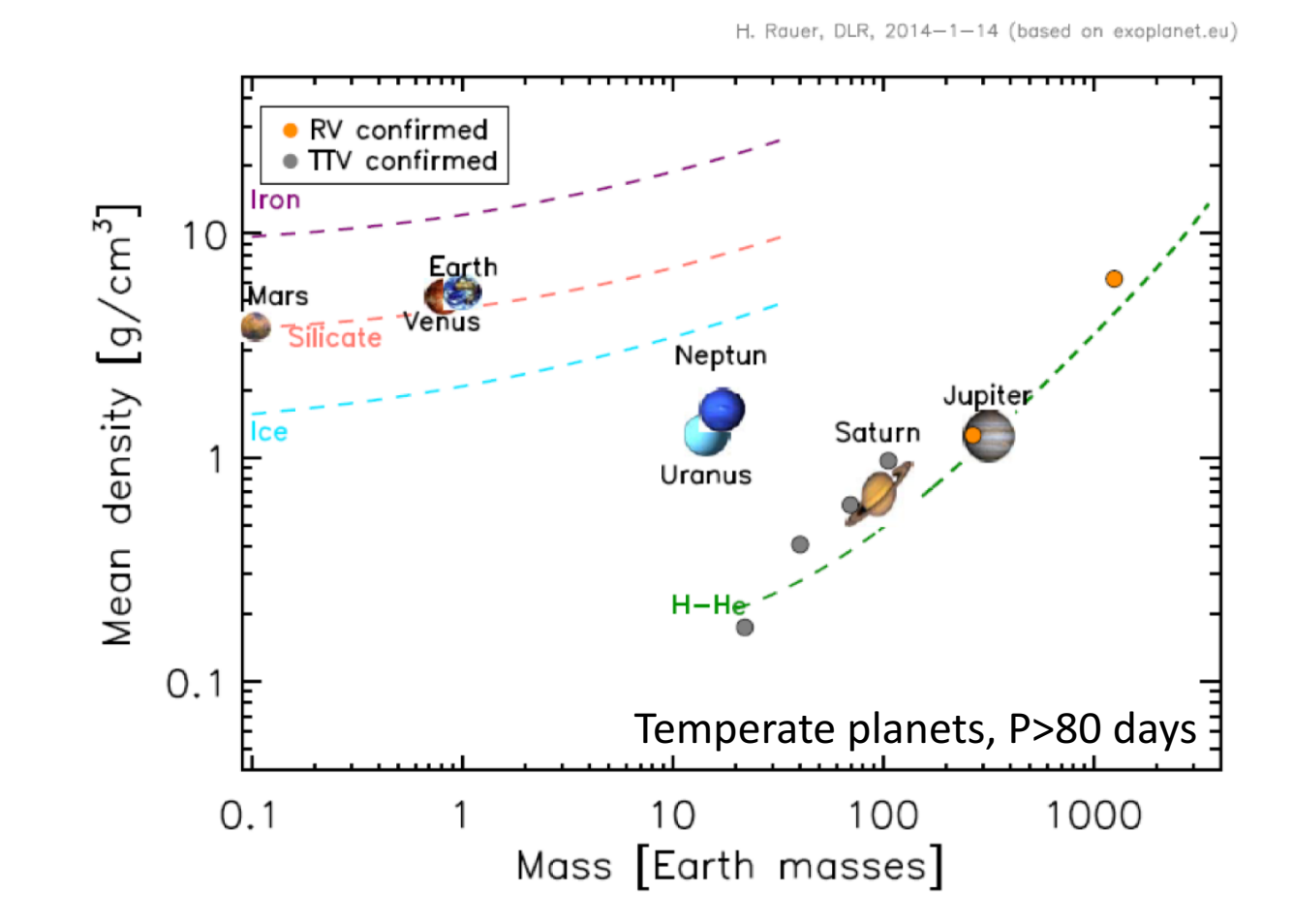
- What is the observed critical core mass?
- Can super-massive rocky planets exist? How are they formed?
- Are light planets with H_2-dominated atmospheres common?

Planet diversity and planet formation



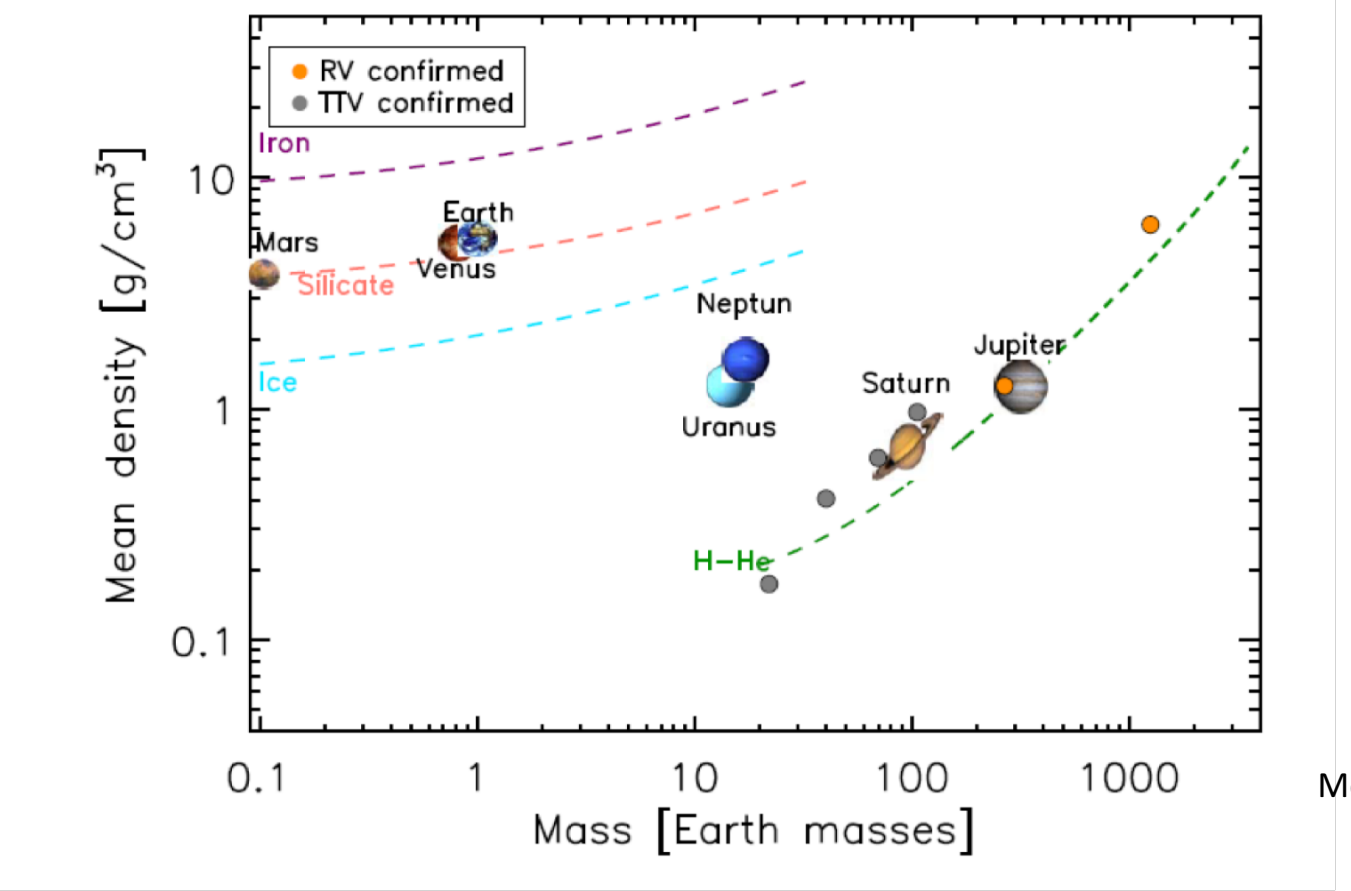
- No *characterized* (radius, mass, density) low-mass planets outside a Mercury-like orbit today.

Planet diversity and planet formation



- PLATO will provide thousands of characterized planets at intermediate orbital distances, down to Earth size/mass.
  - This will allow the study of planets **where they form**!

Planet diversity and planet formation



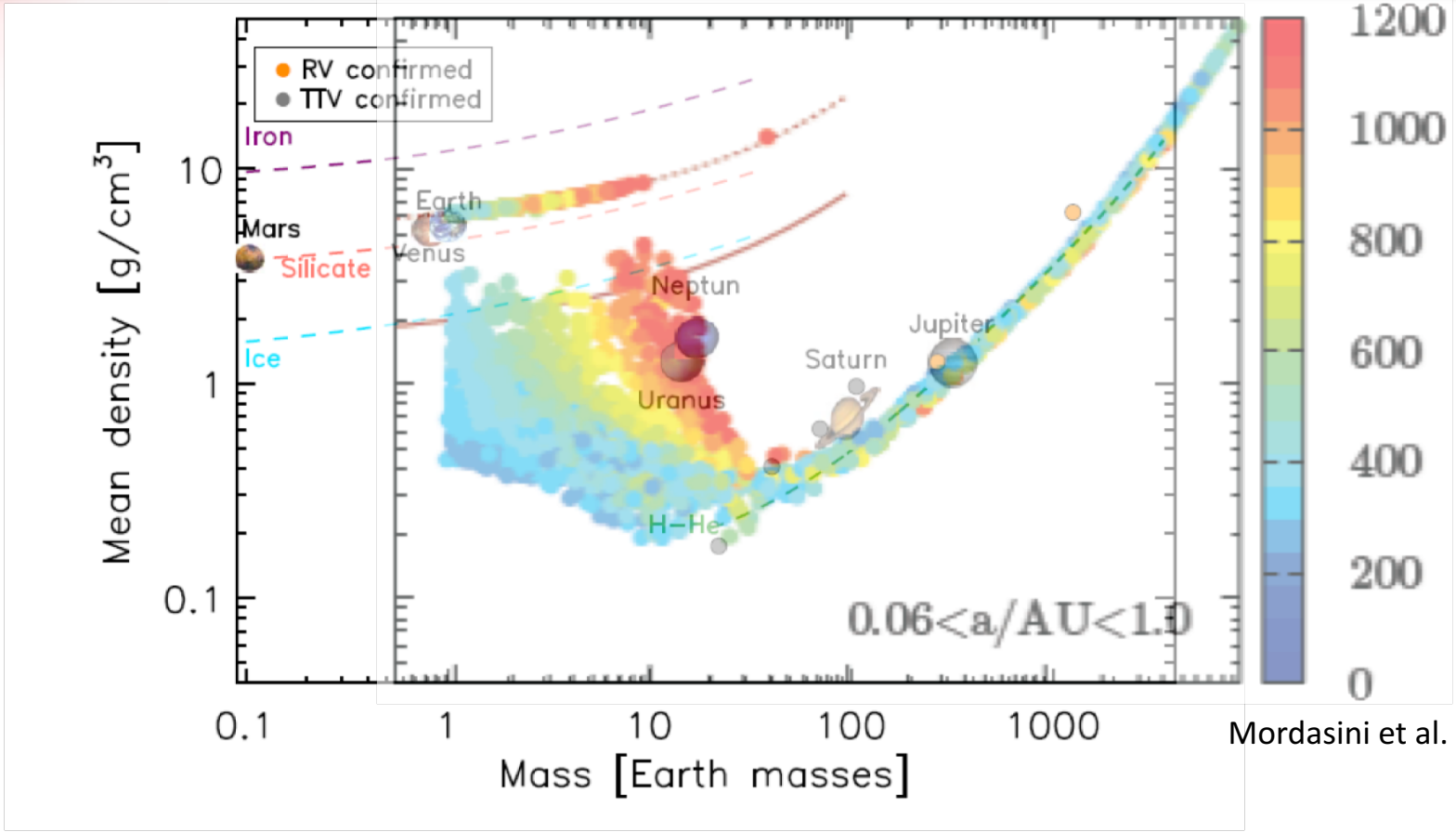
Mordasini et al.

PLATO will measure how planet density and mass vary with

a) orbital distance and planetary system architectures

b) host star parameters (spectral type, composition, age, etc.)

Planet diversity and planet formation



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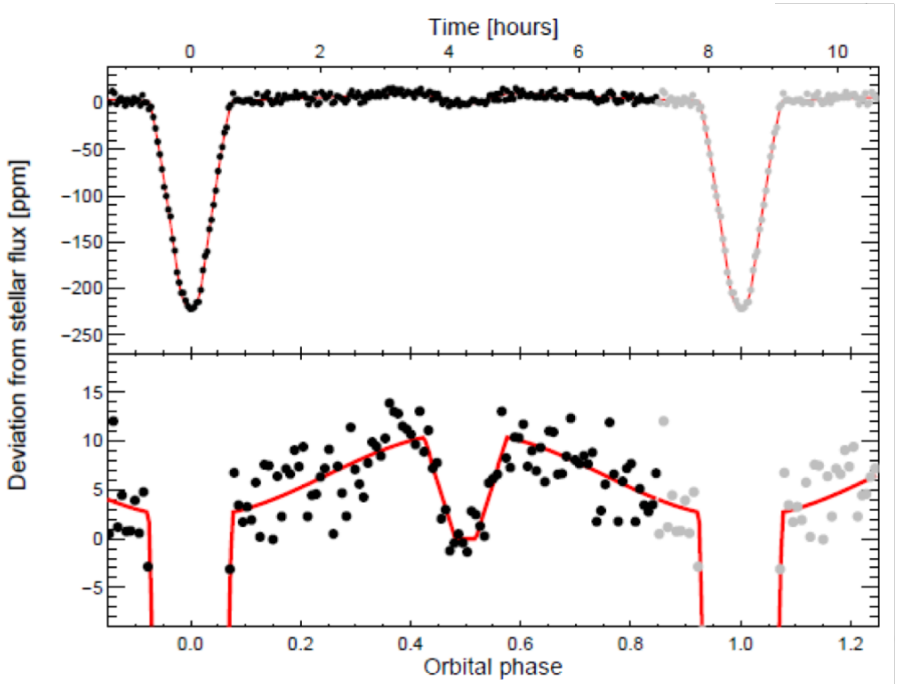
Planet diversity & comparative planetology

Kepler-78



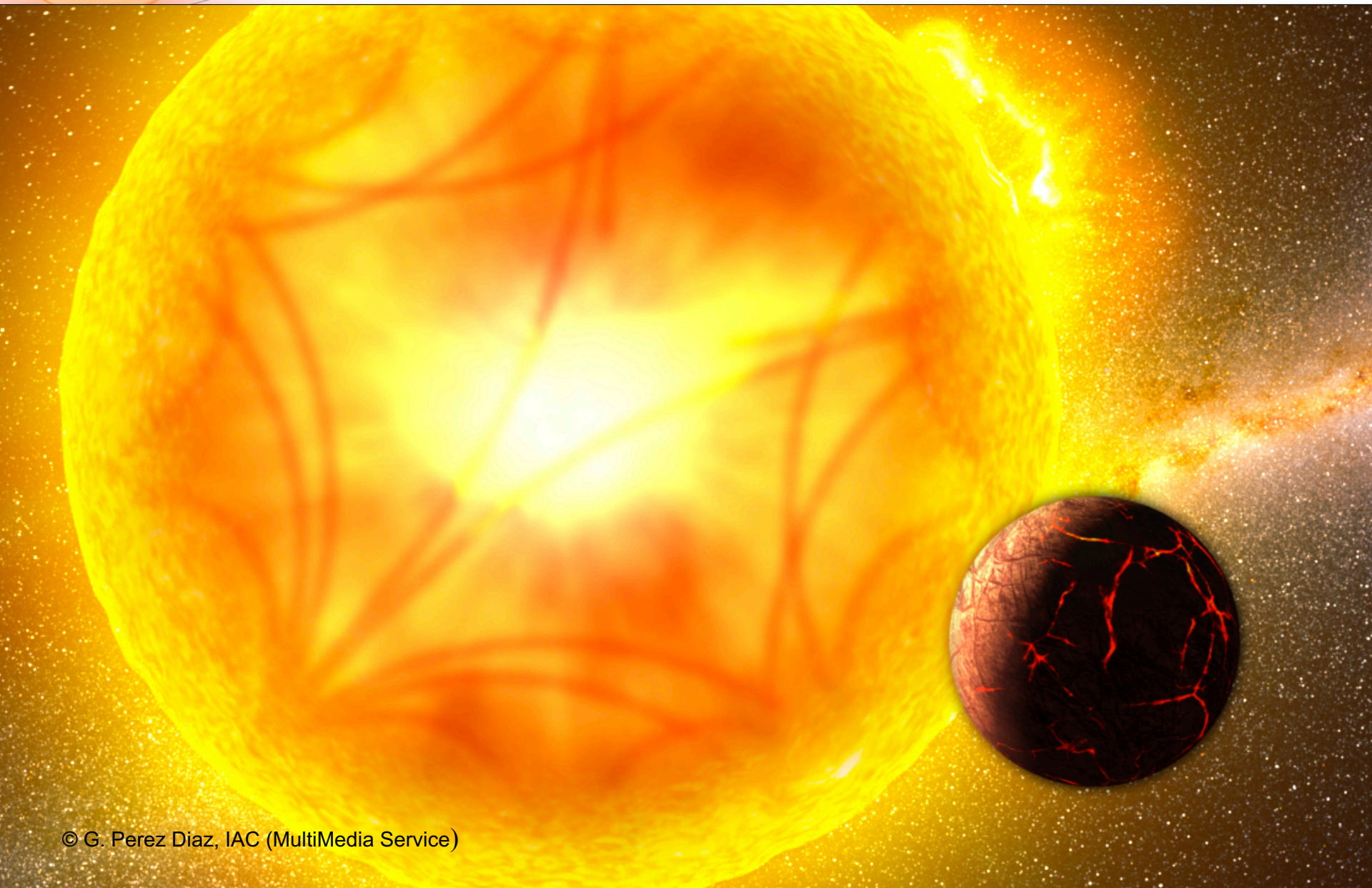
Sanchis-Ojeda et al. (2013)

PLATO will provide planets with:

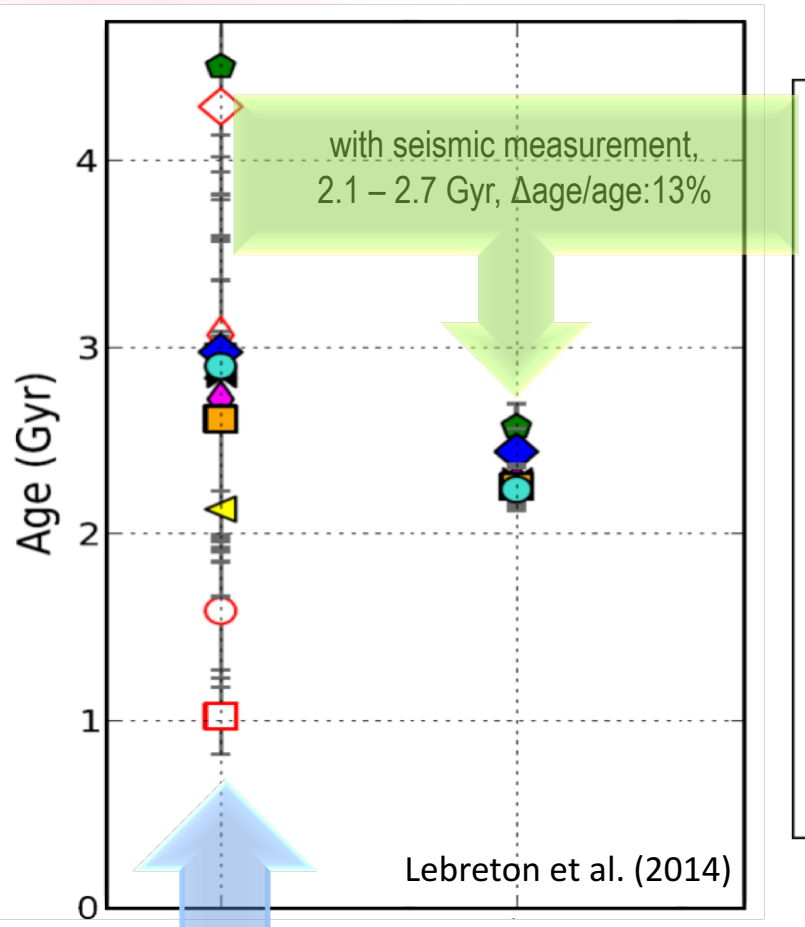
- Mean density
  - ⇒ Indicates bulk composition
  - ⇒ Constrains atmospheric scale height
- Albedo and its diversity
  - ⇒ Indicator for clouds and hazes
- Accurate ages
  - ⇒ Evolutionary pathways
- Characterized host stars
  - ⇒ Incident flux, stellar activity

PLATO Science:

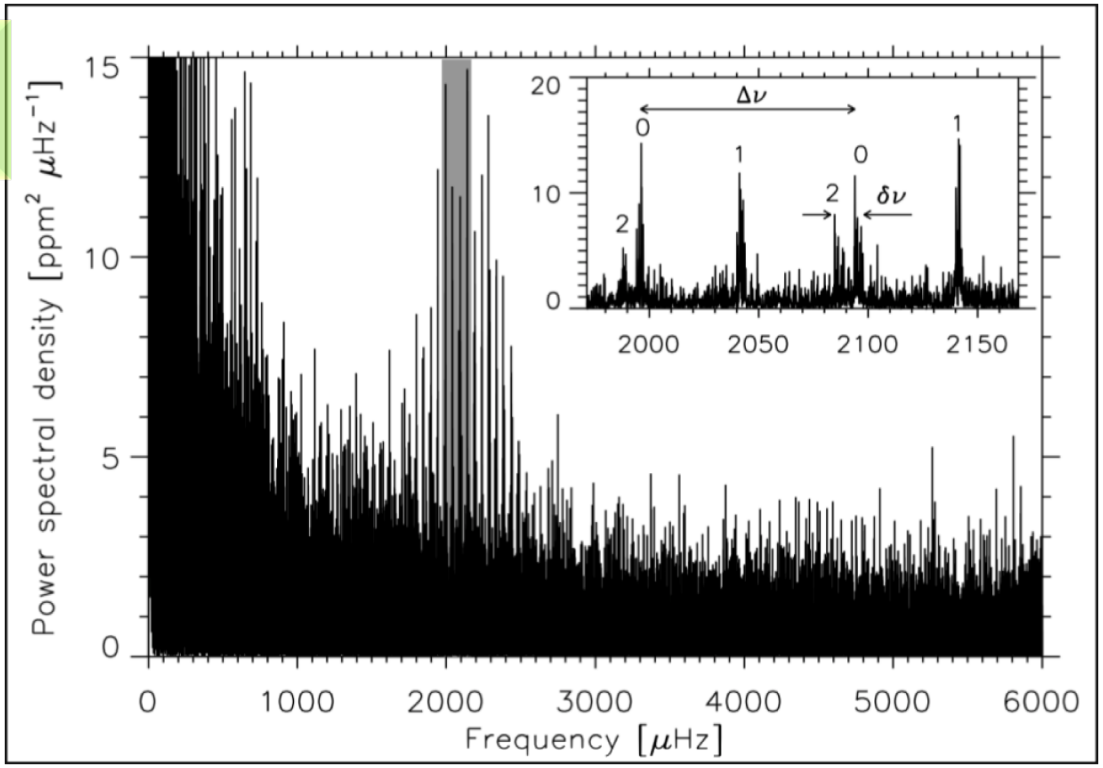
Stellar Science



Asteroseismology



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



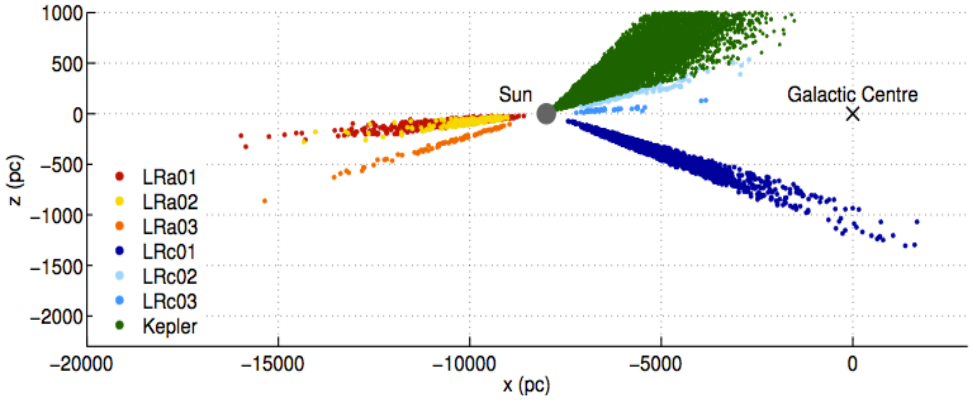
Gizon et al. (2013)

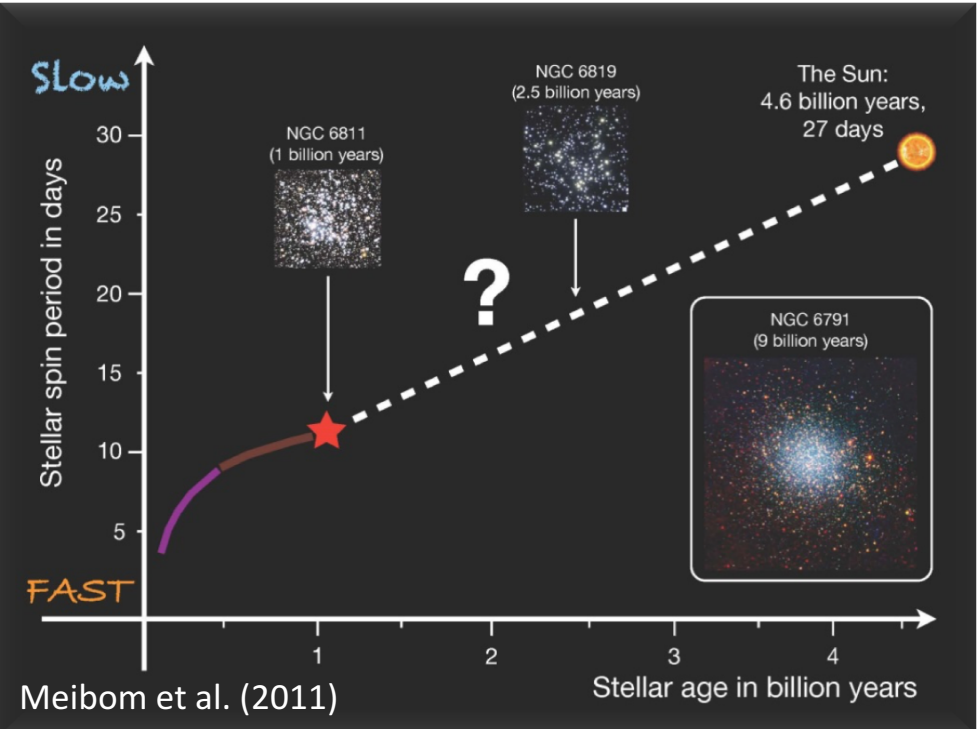
Seismic parameters:

- Radius: 1.34 ± 0.02 R_{sun}
- Mass: 1.27 ± 0.03 M_{sun}
- Age: 2.37 ± 0.29 Gyr

Galaxy structure and evolution

Miglio et al. (2013)



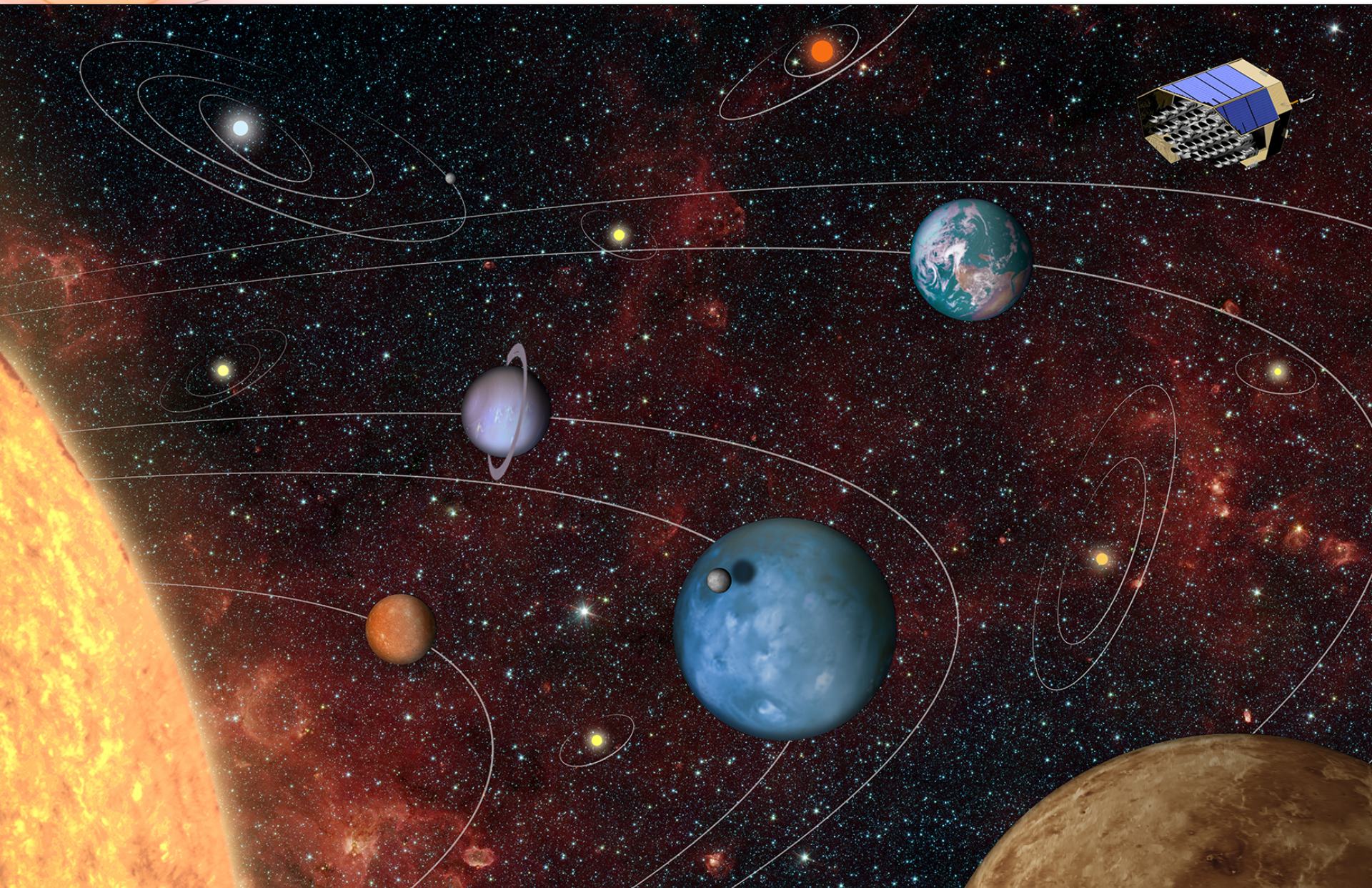


Meibom et al. (2011)

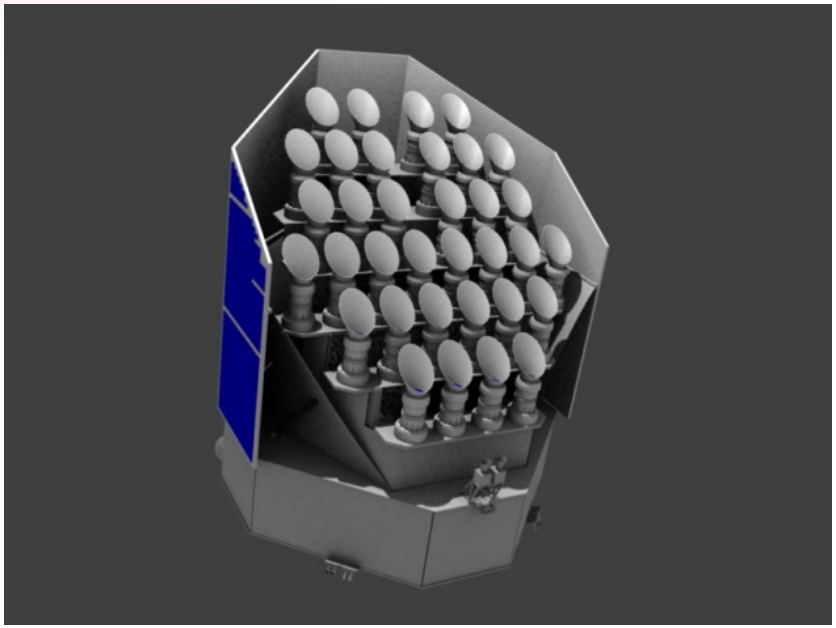
- Gyrochronology of stars via age-rotation relationship:
  ⇒ seismic age versus rotation period from spots
- PLATO & Gaia:
  - seismic + astrometric distances
  - seismic age-metallicity relations for giants

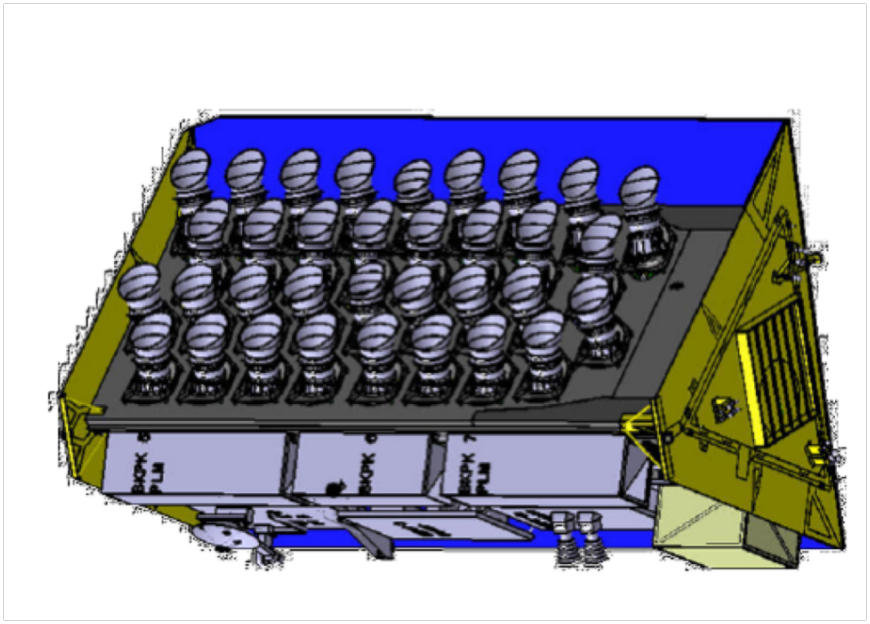
⇒Provide accurate ages
⇒Calibrate stellar evolution theories
⇒Calibrate Galactic age-metallicity relationship

PLATO Mission



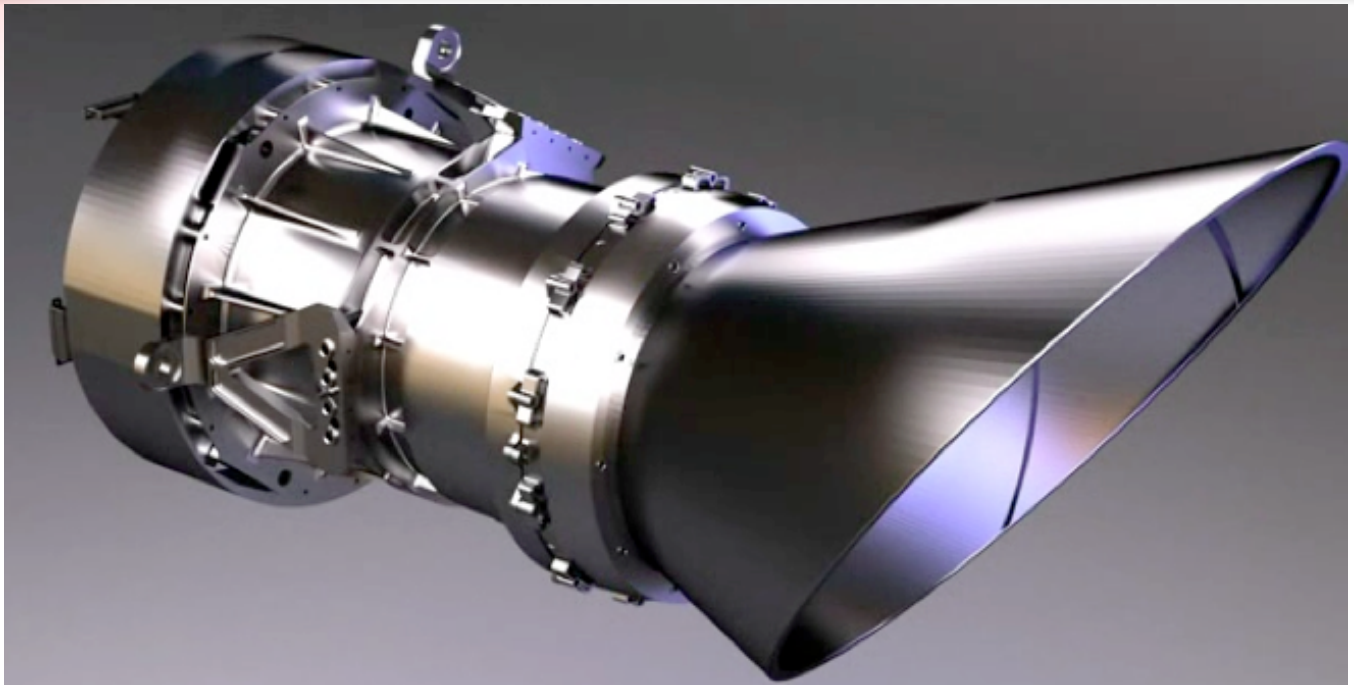
PLATO spacecraft



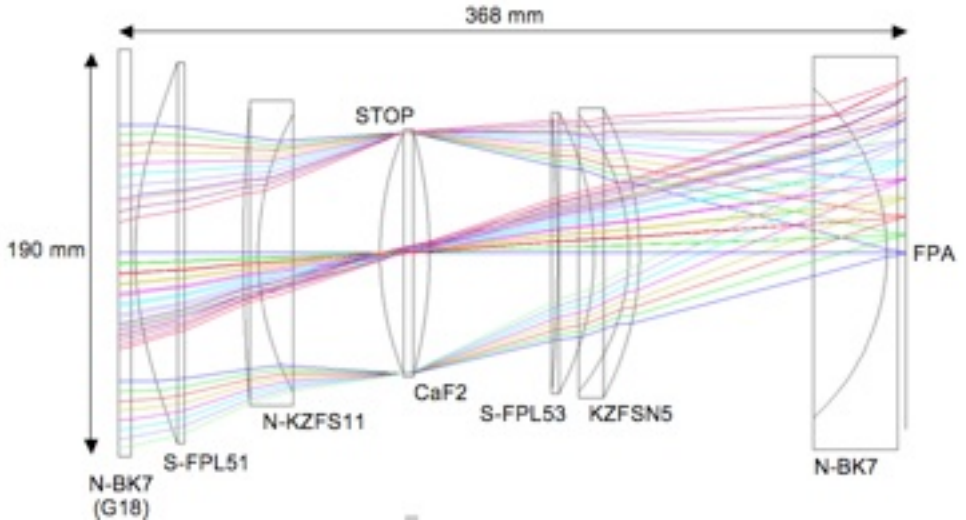


- 32 ‘normal’ cameras, cadence 25s, white light
- 2 ‘fast’ cameras, cadence 2.5s, 2 colours
- Dynamical range: $4 \leq m_V \leq 16$
- L2 orbit
- Field-of-View: 48.5° x 48.5° (2250 square degrees)
- **K-band telemetry**

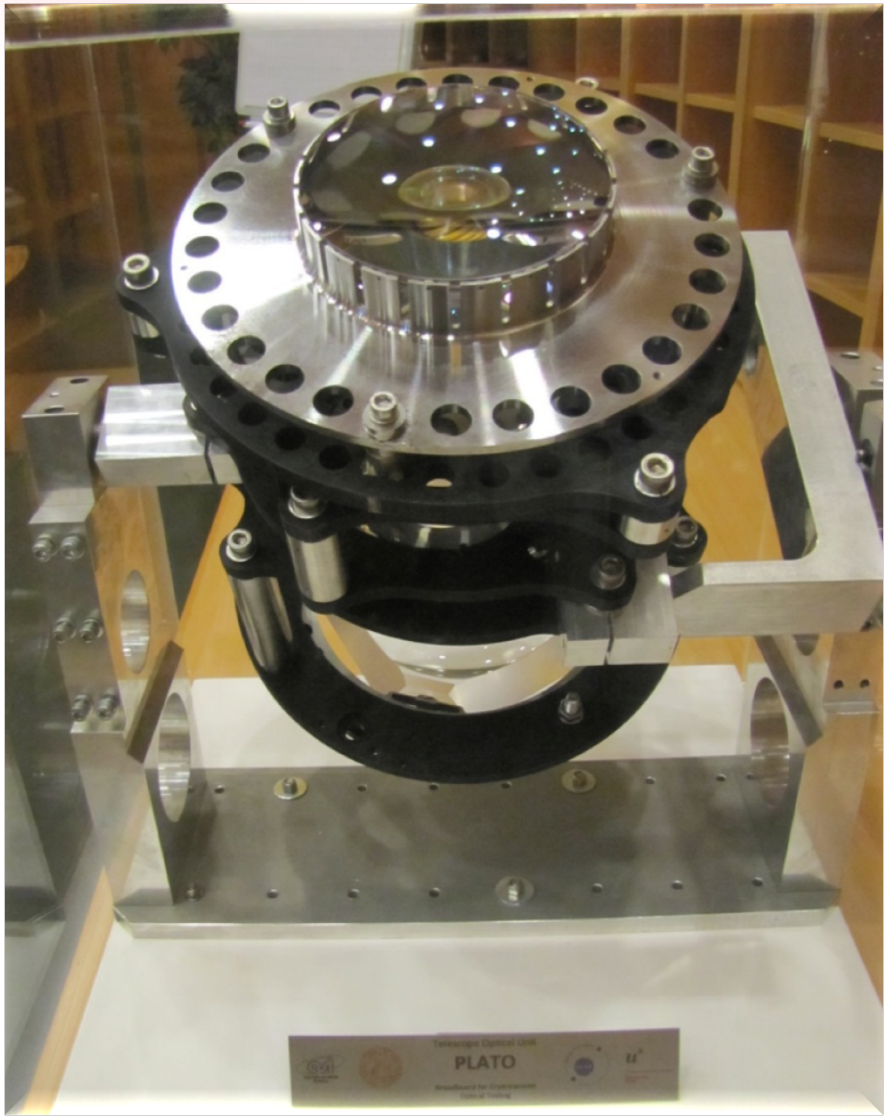
PLATO telescopes



- 6 lenses
- Pupil diameter of 12cm
- 4 ccds / camera
  - Pixel size of 18µm
  - Plate scale 15” / px
  - 500-1050nm



PLATO telescopes

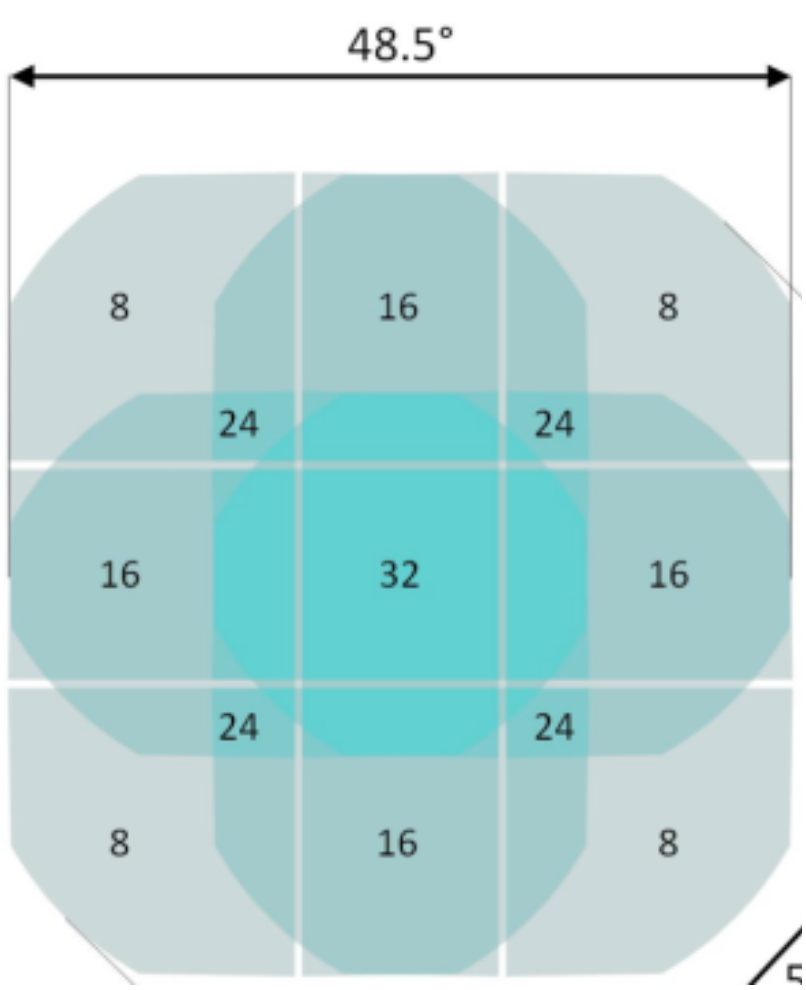


- Aspheric feasibility has been demonstrated
- CaF_2 lenses have been tested
- Vibrational and thermal tests have been passed.

- For testing details, see:
  - Farinato et al. (2010)
  - Magrin et al. (2010)
  - Bergomi et al. (2012)

Prototype of one PLATO telescope

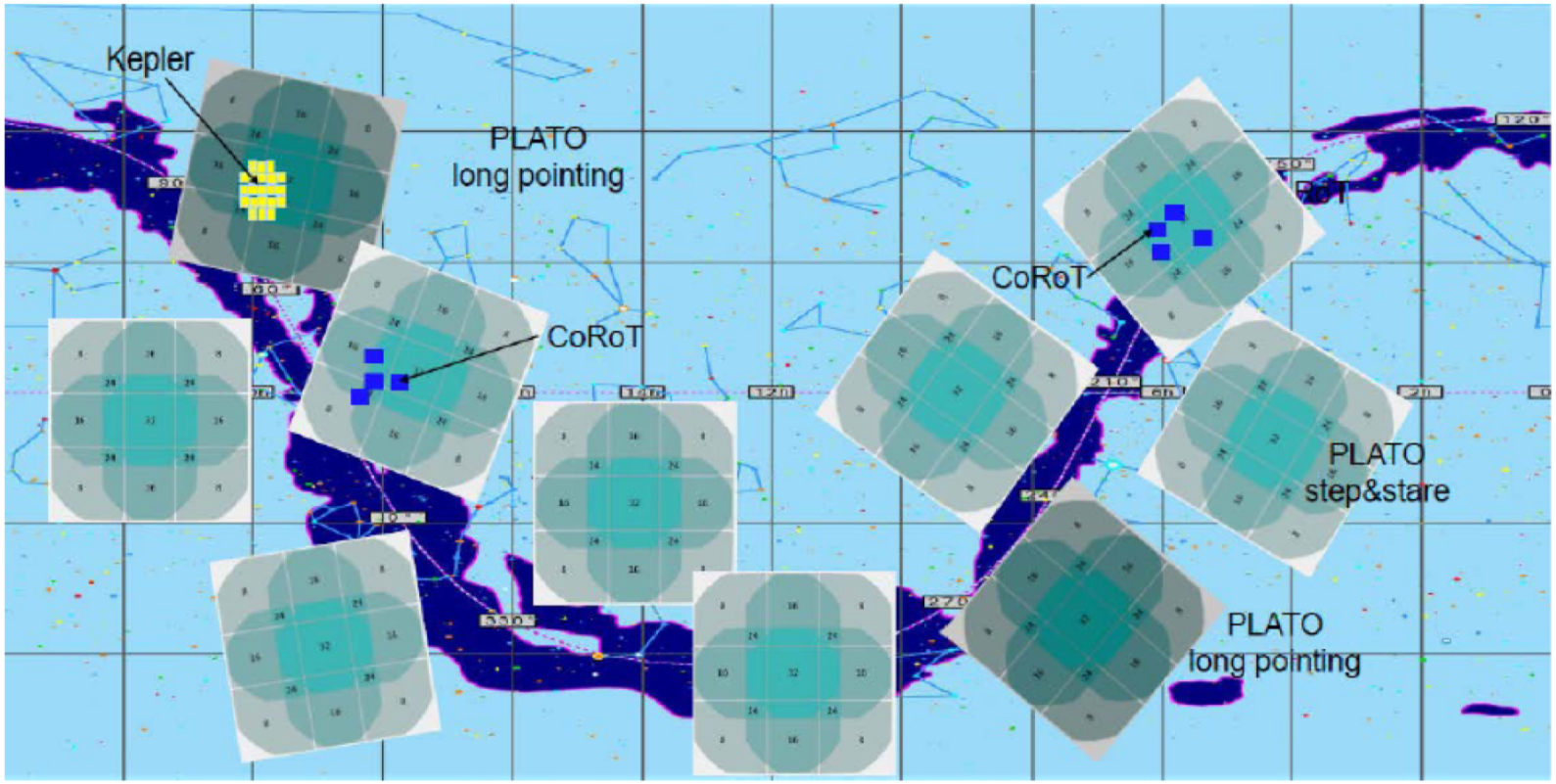
PLATO instrument



Multi-telescope approach:

- Large FOV
  ⇒ large numbers of bright stars
- Large total collecting area
  ⇒ provides high sensitivity allowing asteroseismology
- Provides redundancy
- Cameras are in groups, offset to increase field of view.

Baseline Observing Strategy



- 6 years nominal science operation
  - 2 long pointings of 2-3 years
  - Step-and-star phase of 2-5 months / pointing
- Cover ~40% of the sky

Complementarity of methods

Characterize bulk planet parameters

Precision around solar-like stars for PLATO:

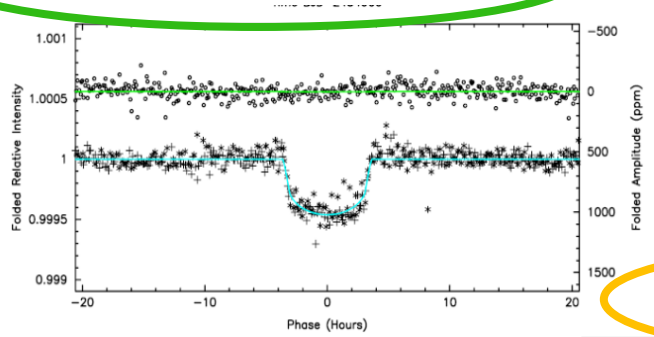
- radius ~2%
- mass ~10%
- age known to ~10%

For bright stars (4 – 11 mag)

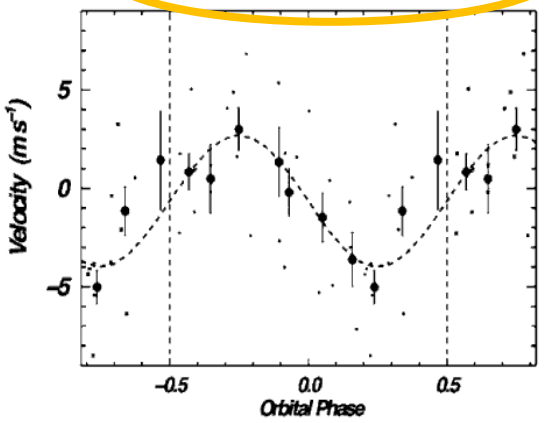
Techniques

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

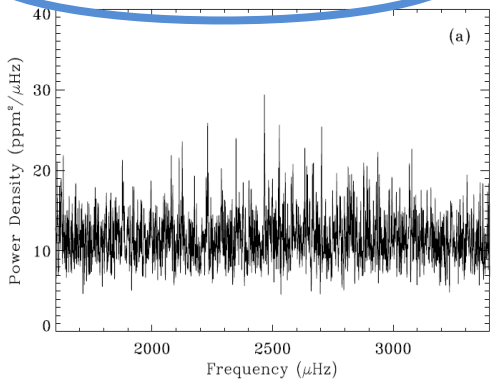
Photometric transit



RV – *follow-up*



Asteroseismology



Stellar samples

Five stellar samples for planet searches:

	# stars	Classification	Spectral Type	Noise per hour	Magnitude
P1	20,000	Dwarf & sub-giant	Later than F5	34ppm	$8 \leq m_V \leq 11$
P2	1,000	Dwarf & sub-giant	Later than F5	34ppm	$m_V < 8$
P3	3,000	Dwarf & sub-giant	Later than F5	34ppm	$m_V < 8$
P4	5,000	M-dwarfs		80ppm	$m_V < 16$
P5	250,000	Dwarf & sub-giant	Later than F5	80ppm	$8 \leq m_V \leq 13$

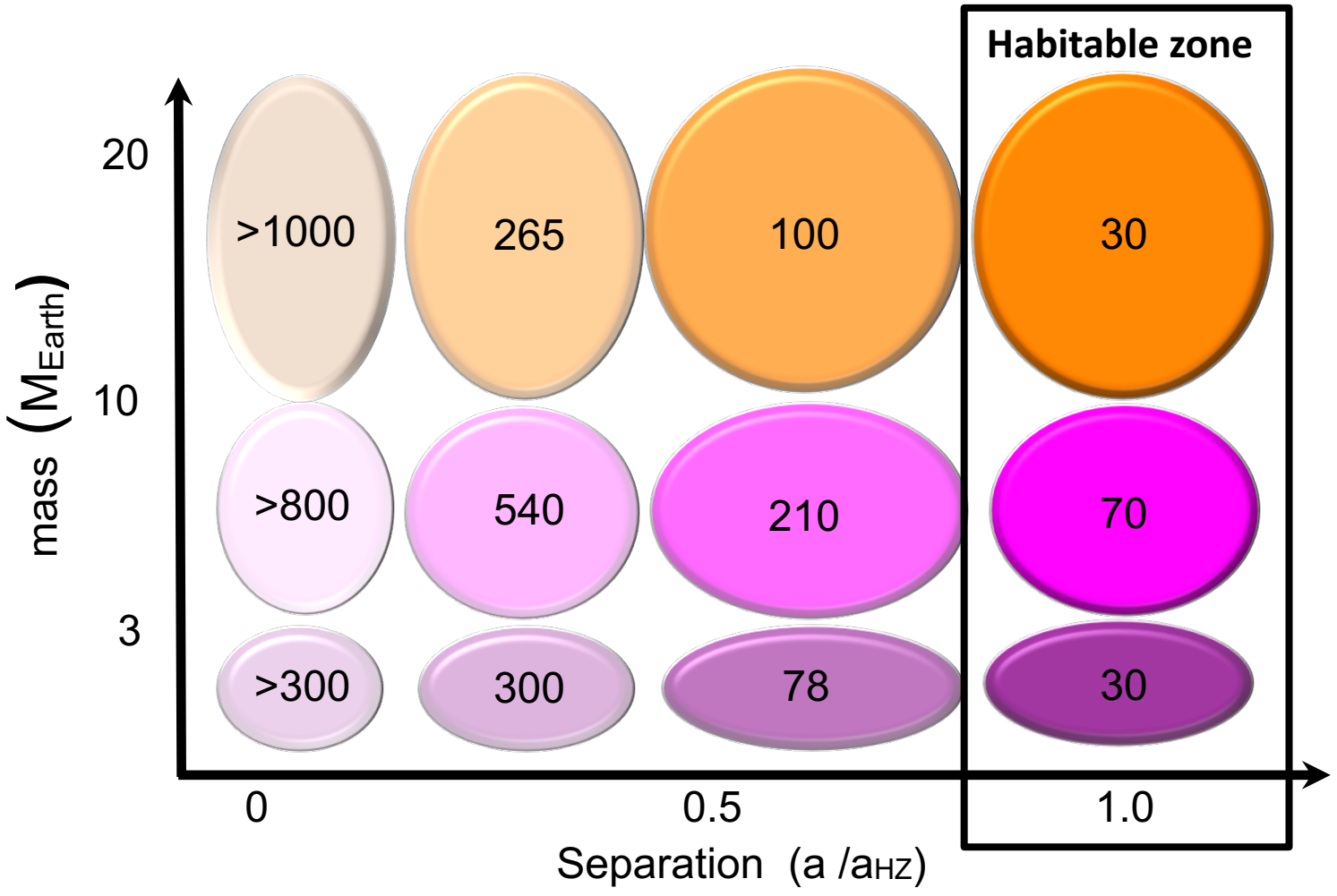
Notes: P2 is a sub-sample of P3.

: P2 and P3 are sub-samples of P1

: Numbers are for the two long-pointings *combined*.

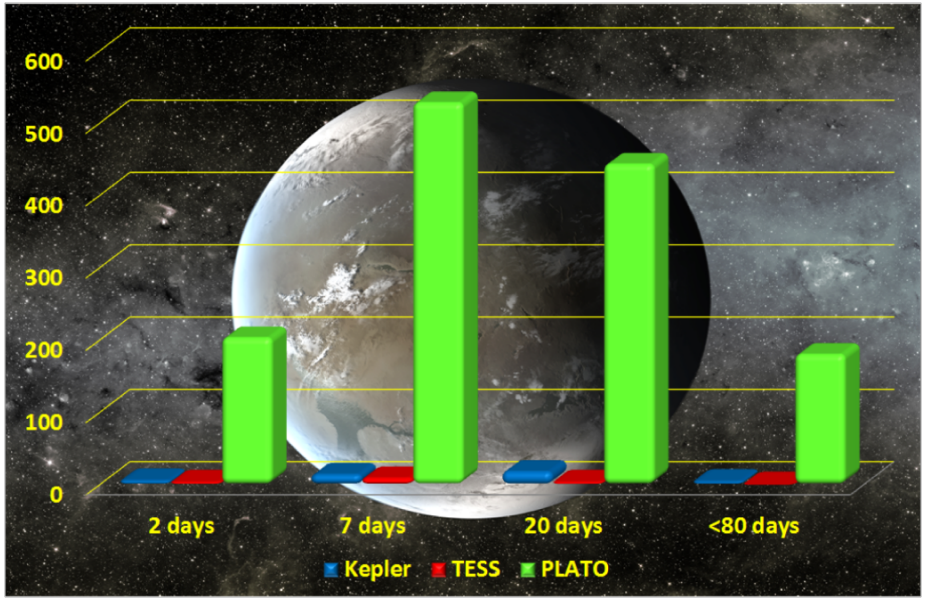
Total number of characterised planets in core sample

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

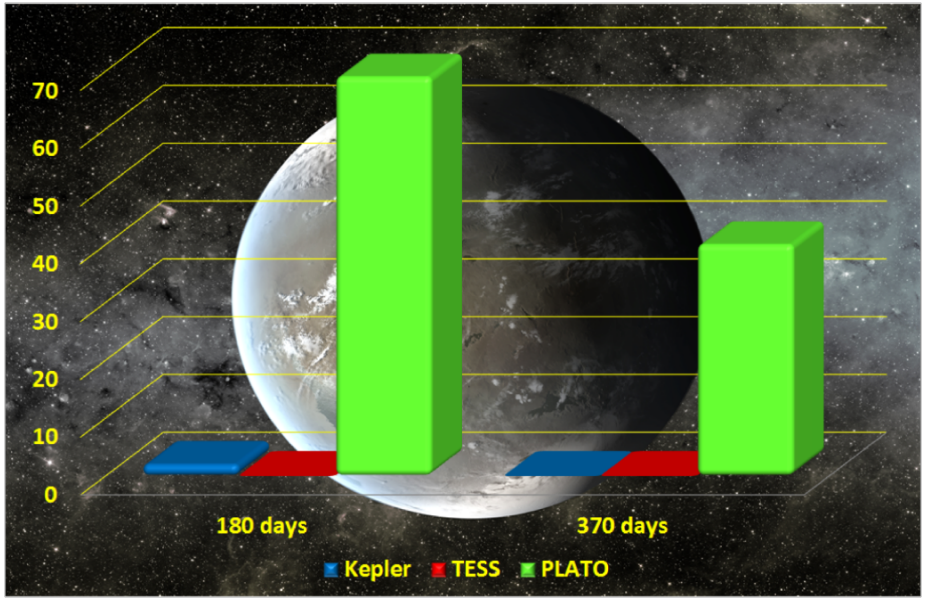


Potential for characterised “super-Earths”

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 will provide >1000 Earths to “super-Earths” for characterization

Follow-up requirements

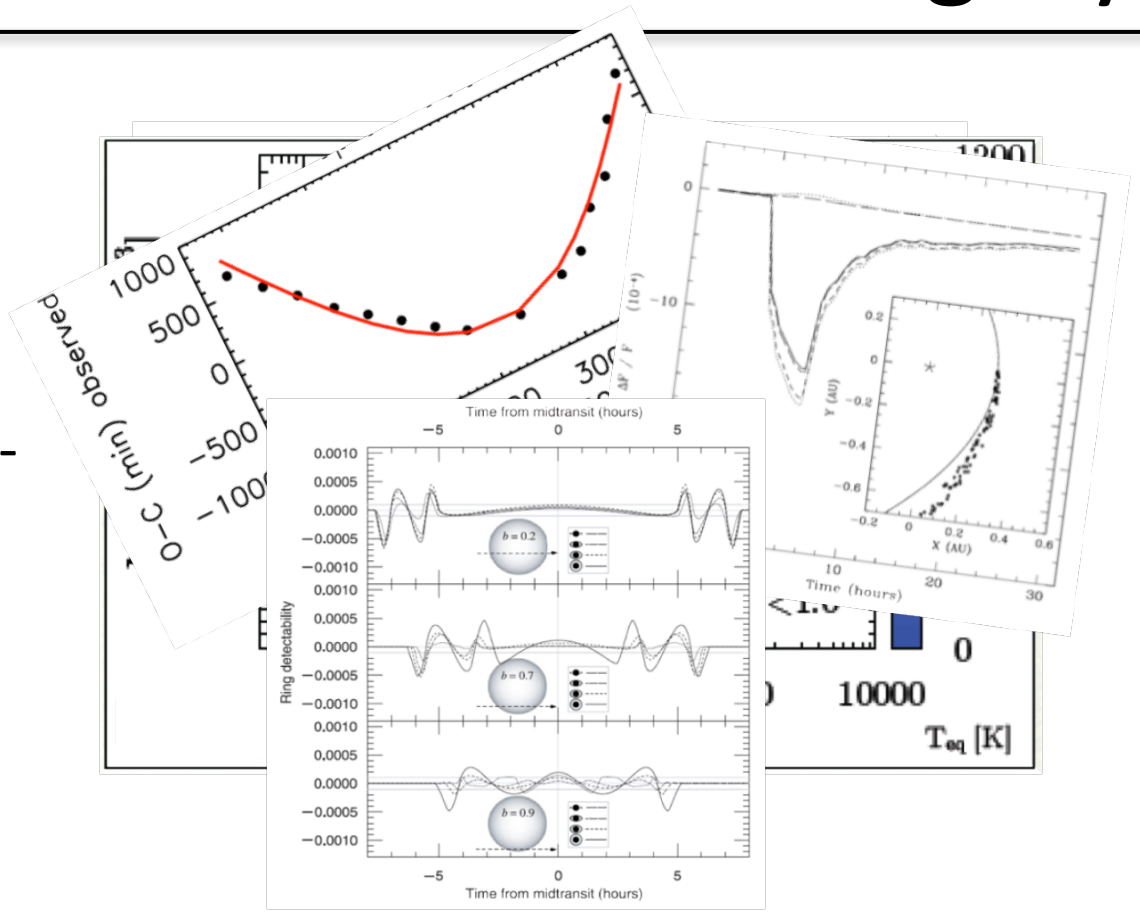
RV precision	Telescope size	Planets	Time required
10 m/s	1-2m	Giant planets on short-medium orbits	50 nights / year 9 years 2 telescopes
1 m/s	4m	Giant planets on long orbits "Super-Earths" on short-medium orbits	50 nights /year 9 years 2 telescopes
<20 cm/s	8m	Earths / "Super-Earths" on long orbits	50 nights / year 9 years 1 telescopes

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

Though the hardest cases (e.g. faint, Solar-type stars, with Earths in the HZ) will need the E-ELT

Science and Legacy

- Understanding of rocky planet diversity
- Formation and evolution models
- Circumbinary planets, exo-moons/rings/comets/mis-aligned planets
- Synergy with Gaia
  - Gaia: radius, distance, proper motion, luminosity, T_{eff}, log g
  - PLATO: masses, ages



1,000,000 high quality light curves of stars
Decades of work in Exoplanet and Stellar astrophysics
PLATO data will be open access to the community

PLATO community

Australia: Martin Asplund (ANU/MPA), P. Cally (Monash Univ.), L. Casagrande (Mt. Stromlo Obs.), D. Stello (Univ. Sydney), R. Mardling (Monash Univ.); **Austria:** J. Alves (Univ. Vienna), R. Dvorak (Univ. Venna), M. Guedel (Univ. Vienna), Th. Kallinger (Univ. Vienna), F. Kerschbaum (Univ. Vienna), M. Khodachenko (OEAW), K.G. Kislyakova (OEAW), F. Kupka (Univ. Vienna), R. (Univ. Vienna), H. Lammer (SSI Graz), Th. Lüftinger (Univ. Vienna), M. Netopil (Univ. Vienna), R. Ottensamer (Univ. …

The PLATO community includes scientists across different research fields:

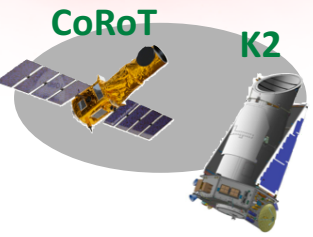
- Planet and planetary system formation, evolution, habitability, interior, atmospheres, star-planet interactions
- Stellar evolution, activity, clusters, …
- Evolution of our Galaxy

… Padova, INAF-OATO), M. Rosaria D'Antonio (ASDC), D. De Martino (INAF-OAC), S. Desidera (INAF-OAPD), S. Di Franco (Univ. Florence), M. Dima (INAF-OAPD), A.M. Di Giorgio (INAF-IAPS), M.P. Di Mauro (INAF-IAPS), J. Farinato (INAF-OAPD), E. Flaccomio (INAF-OAPA), M. Focardi (Univ. Florence), P. Giommi (ASDC), L. Girardi (INAF-OAPD), G. Giuffrida (ASDC), M. Ghigo (INAF-OAB), V. Granata (Univ. Padova), A.F. Lanza (INAF-OACT), M.G. Lattanzi (INAF-OATO), G. Leto (INAF-OACT), D. Magrin (INAF-OAPD), L. Malavolta (Univ. Padova), M. Marconi (INAF-OAC), G. Marcucci (Univ. Florence), P. Marigo (Univ. Padova), P.M. Marrese (ASDC), F. Marzari (Univ. Padova), D. Mesa (INAF-OAPD), S. Messina (INAF-OACT), M. Munari (INAF-OACT), U. Munari (INAF-OAPD), V. Nascimbeni (OAPD-INAF), R. Orfei (INAF-IAPS), S. Ortolani (Univ. Padova), E. Pace (Univ. Florence), I. Pagano (INAF-OACT), F. Palla (INAF-OAA), …

In total >500 scientists from 21 countries

… Ljubljana); **Spain**: C. Allende (IAC), P. J. Amado (IAA-CSIC), R. Alonso (IAC), A. Claret (IAA), H. Deeg (IAC), A. Garcia Hernández (IAA-CSIC), R. Garrido (IAA-CSIC), J.I. Gonzáles-Hernández (IAC), P. Klagyivik (IAC), S. Meszaros (IAC), M. Mas-Hesse (CAB-INTA), A. Moya (CAB), R.U. O'Callaghan (CAB-INTA), A.Serenelli (ICE), I. Skillen (Isaac Newton Group), E. Solano (INTA), J. Carlos Suarez (IAA-CSIC), H. Voss (DAM); **Sweden**: A. Brandeker (Stockholm Univ.), R.P. Church (Lund Obs.), M.B. Davies (Lund Obs.), S.Feltzing (Lund Obs.), A. Johansen (Lund Obs.), O. Kochukhov (Univ. Uppsala), G. Olofsson (Stockholm Univ.); **Switzerland**: Y. Alibert (Univ. Bern), W. Benz (Univ. Bern), C. Charbonnel (Obs. Geneva), R. Diaz (Univ. Geneva), P. Eggenberger (Univ. Geneva), D. Ehrenreich (Univ. Geneva), W. Hayek (AF-Consult Baden), K. Heng (Univ. Bern), Ch. Lovis (Univ. Geneva), D. Naef (Univ. Geneva), F. Pepe (Univ. Geneva), D. Segransan (Univ. Geneva), St. Udry (Obs. Geneva); **UK**: S. Aigrain (Univ. Oxford), M. Burleigh (Univ. Leicester), W. Chaplin (Univ. Birmingham), A. Collier Cameron (Univ. St Andrews), Y. Elsworth (Univ. Birmingham), D.W. Evans (Univ. Cambridge), F. Faedi (Univ. Warwick), R. Fares (Univ. of St Andrews), R. Farmer (Open Univ.), Y. Gomez (Warwick University), E. Gonzalez-Solares (Univ. Cambridge), C. Haswell (Open Univ.), S. Hodgkin (Univ. Cambridge), M. Irwin (Univ. Cambridge), U. Kolb (Open Univ.), A. Miglio (Univ. of Birmingham), R. Nelson (Univ. London), M. Niederste-Ostholt (Univ. Cambridge), A. Norton (Open Univ.), D. Pollacco (Univ. Warwick), I.W. Roxburgh (Univ. London), G. Rixon (Univ. Cambridge), M. Salaris (Univ. Liverpool), J. Southworth (Keele Univ.), A. Smith (University College London), M. Thompson (Univ. Sheffield), Y. Unruh (Imperial College London), D. Walton (University College London), N. Walton (Univ. Cambridge), C. Watson (Univ. Belfast), R. West (Univ. Warwick), P. Wheatley (Univ. Warwick); **USA:** S. Basu (Yale Univ.), A. Bhagatwala (Stanford Univ.), E. Depagne (Las Cumbres Obs.), J. Fortney (Univ. Santa Cruz), S. Hanasoge (Princeton Univ.), M. Havel (ORAU), J. Jenkins (SETI Inst.), D. Latham (Harvard Univ.), J. Linsky (Colorado Univ.), S. Mathur (SSI), N. Nettelmann (Univ. of Santa Cruz), M. Pinsonneault (Ohio State Univ.), I. Ramirez (Univ. Texas), Ch. Sotin (JPL), R. Trampedach (Univ. Colorado), Amaury Triaud (MIT)

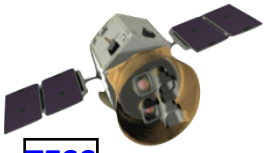
A timeline of exoplanet characterisation

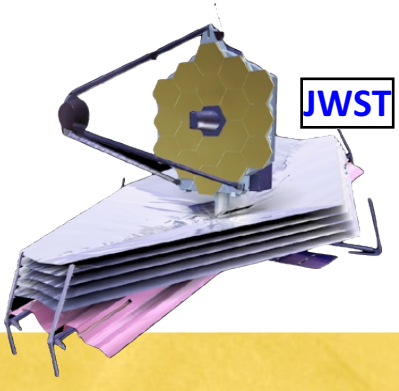


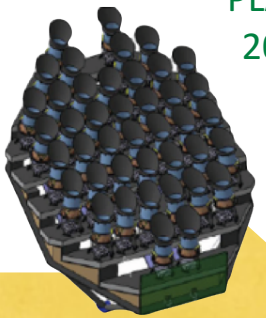
HARPS
HARPS-N
HIRES
SOPHIE

NGTS

Mearth-S







Now - 2015

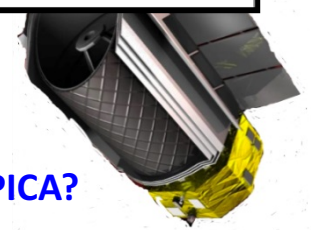
2017

2020

ESA
L-mission
?

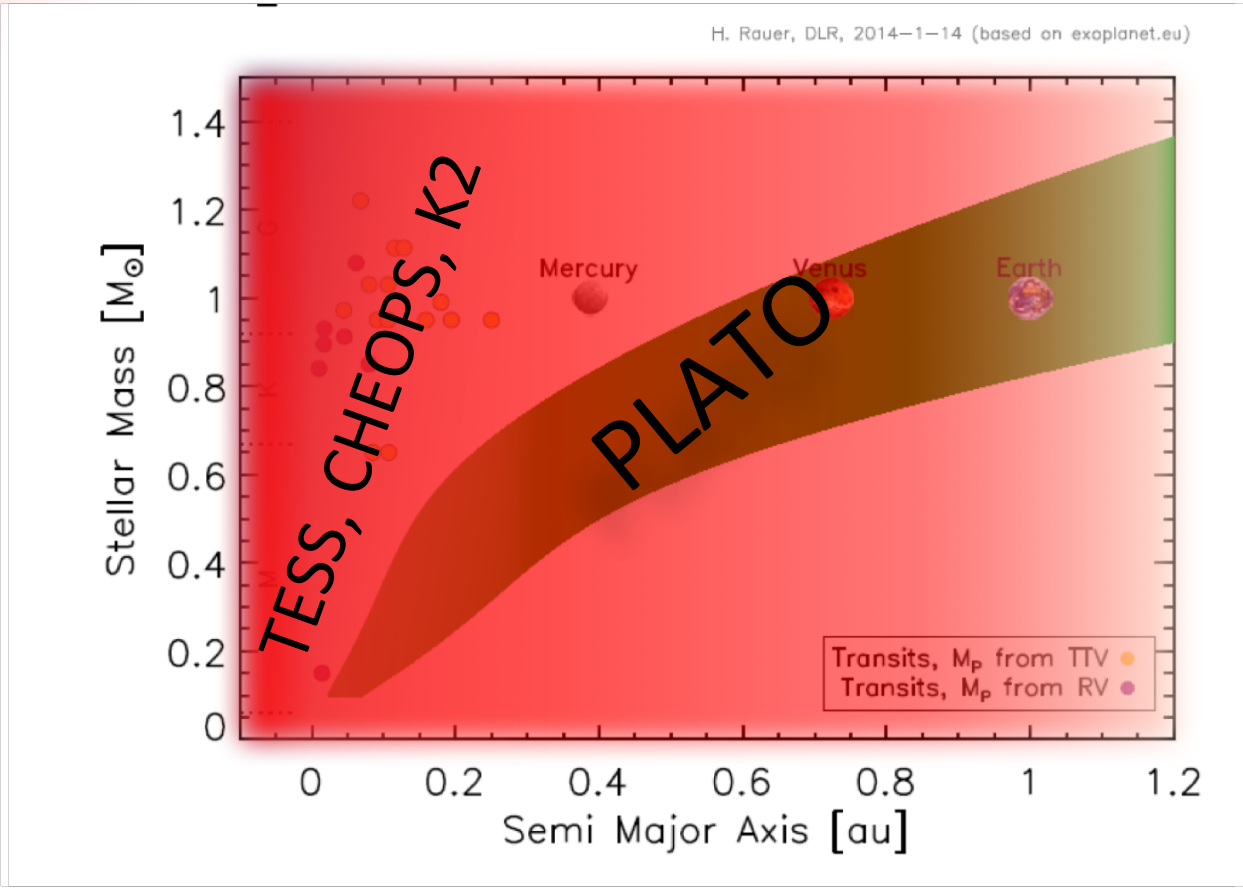
Terrestrial planets from PLATO will be prized targets for JWST, E-ELT, SPICA studying atmospheres and prepare for future missions looking for signs of life

New IR spectrographs
2017-2020



SPICA?

PLATO:
The habitable zone explorer



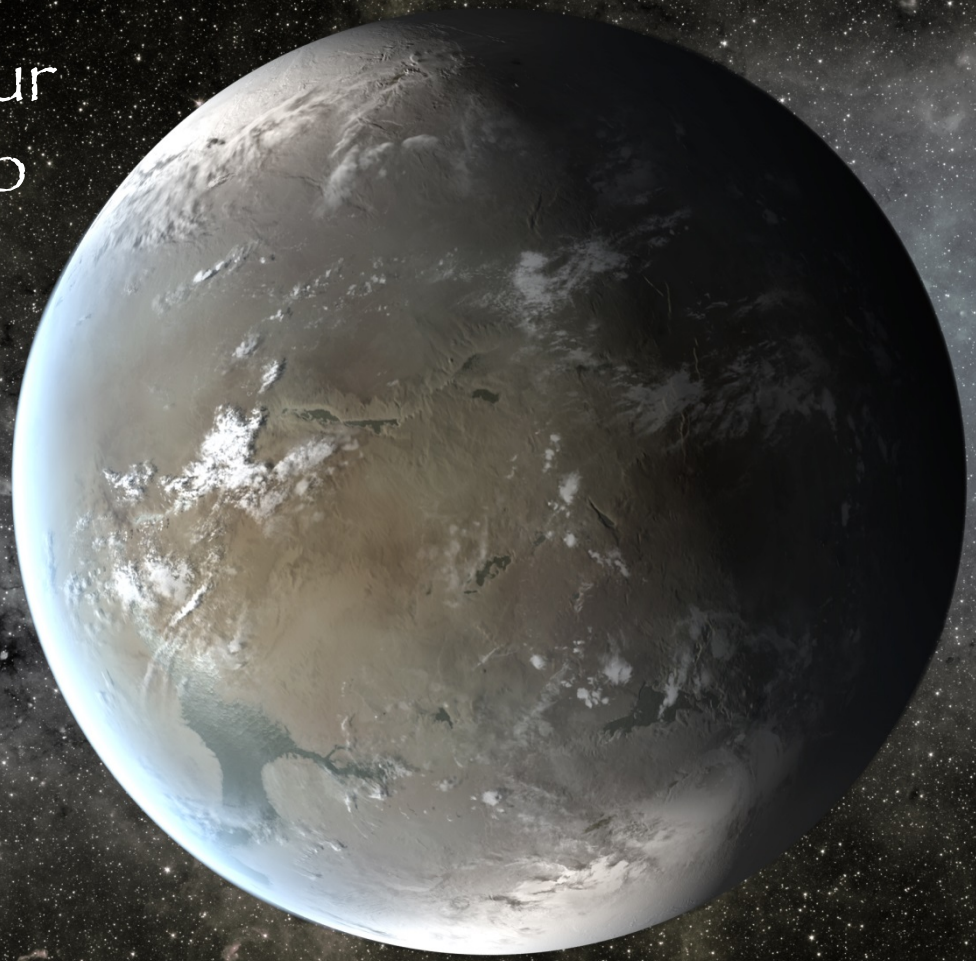
PLATO will transform our knowledge of habitable zone rocky planets and pave the way for the detection of life beyond the Solar System.

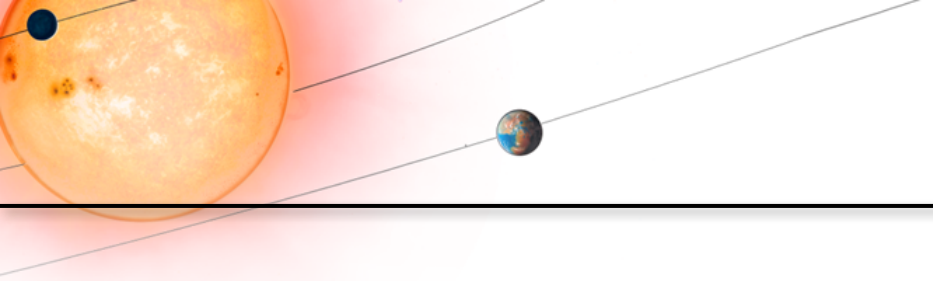
PLATO:

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





Main site: oact.inaf.it/plato/PPLC/Home.html

PSPM: warwick.ac.uk/plato-science

Stellar Science: ias.u-psud.fr/PLATO_STESCI/PLATO_STESCI_OBJ.html

Follow-up: obswww.unige.ch/plato-follow-up/

Complementary Science: fys.kuleuven.be/ster/Projects/plato-cs/