The PLATO Mission

Synergies with Gaia

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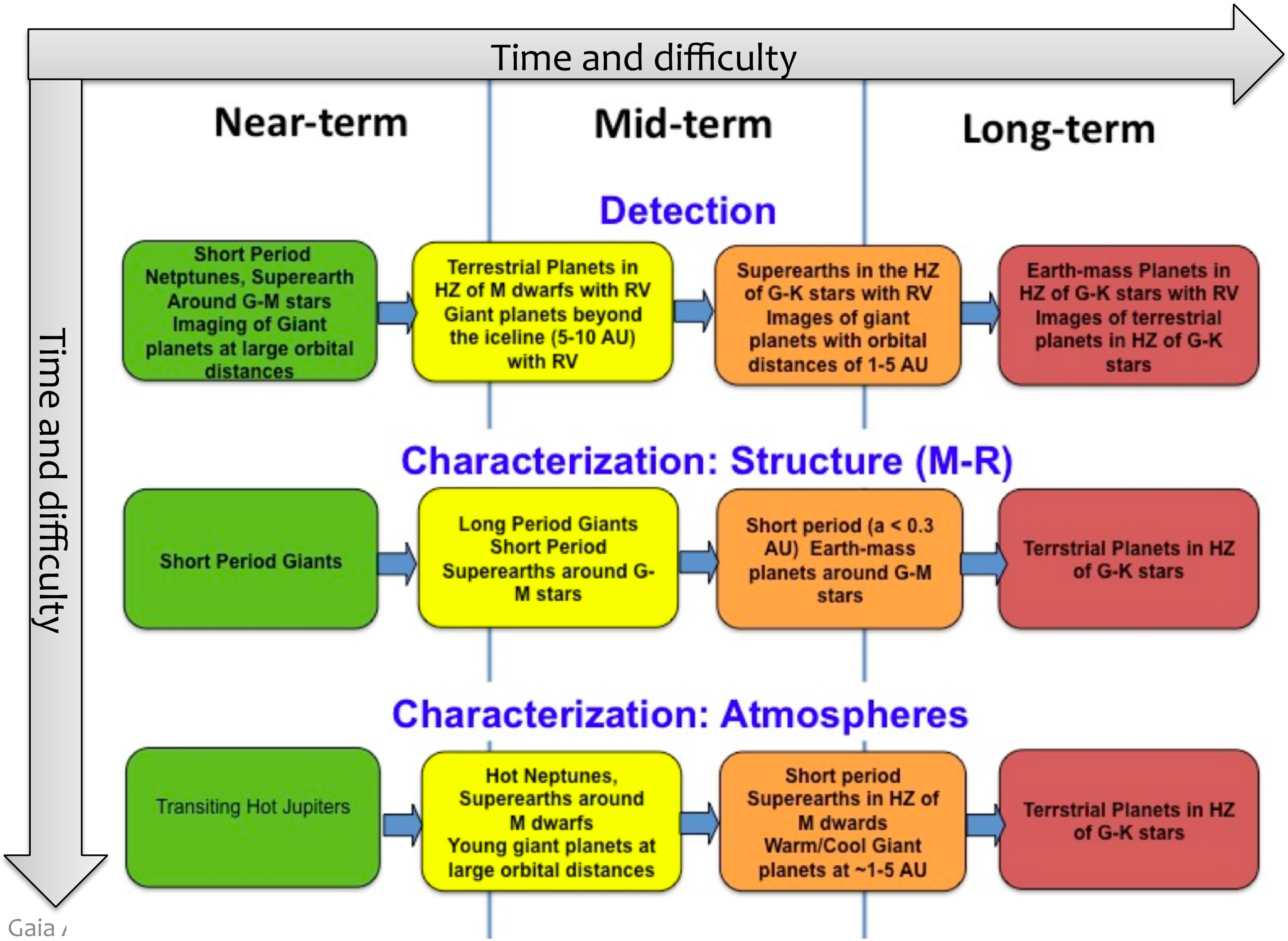
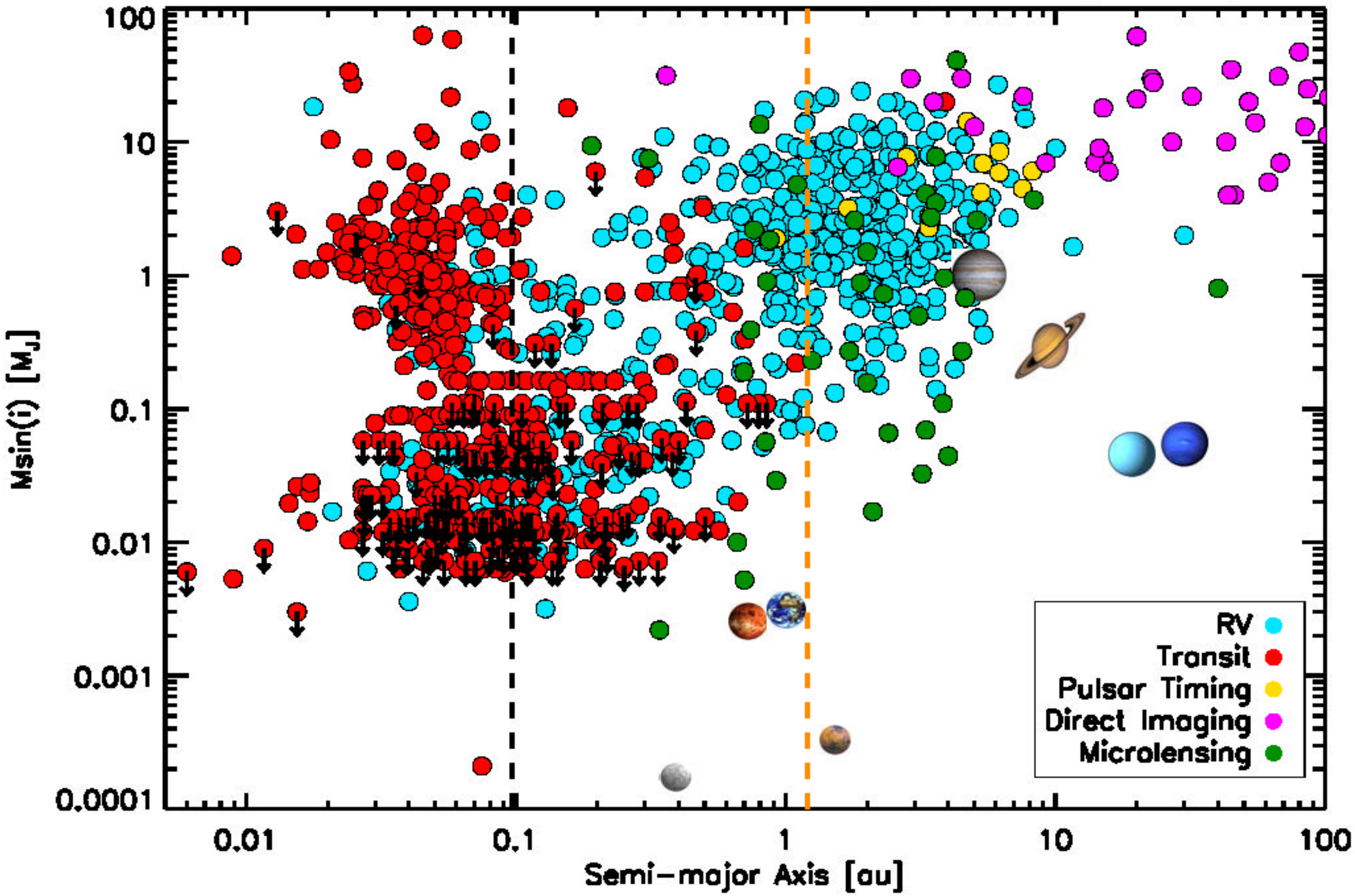
The EP-RAT Roadmap

ESA EXOPLANET ROADMAP ADVISORY TEAM – Oct 2010



~3500 planets in ~2600 planetary systems



Updated to Sept. 2016 from Rauer et al. 2014)

The Kepler revolution

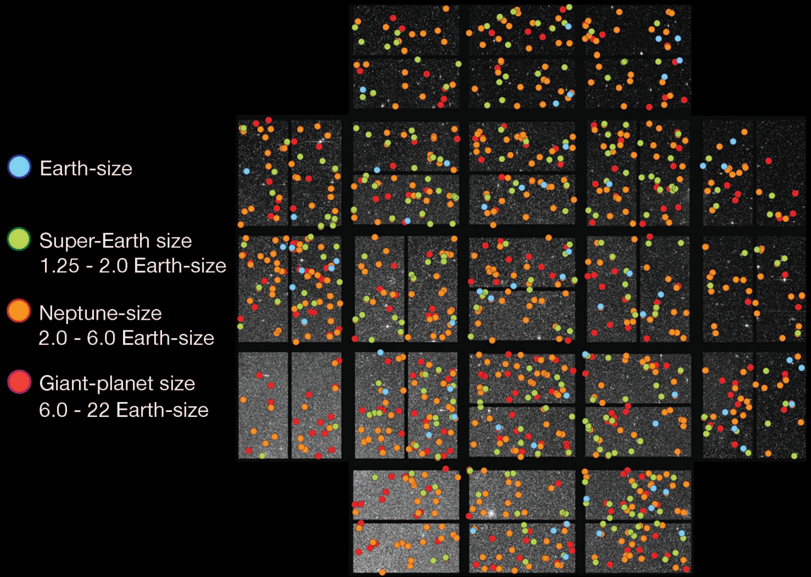
- Launched in 2009
- Still working as K2

- FoV ~100 sqdeg
- (0.25 % of the sky)

- ~ 145 000 stelle

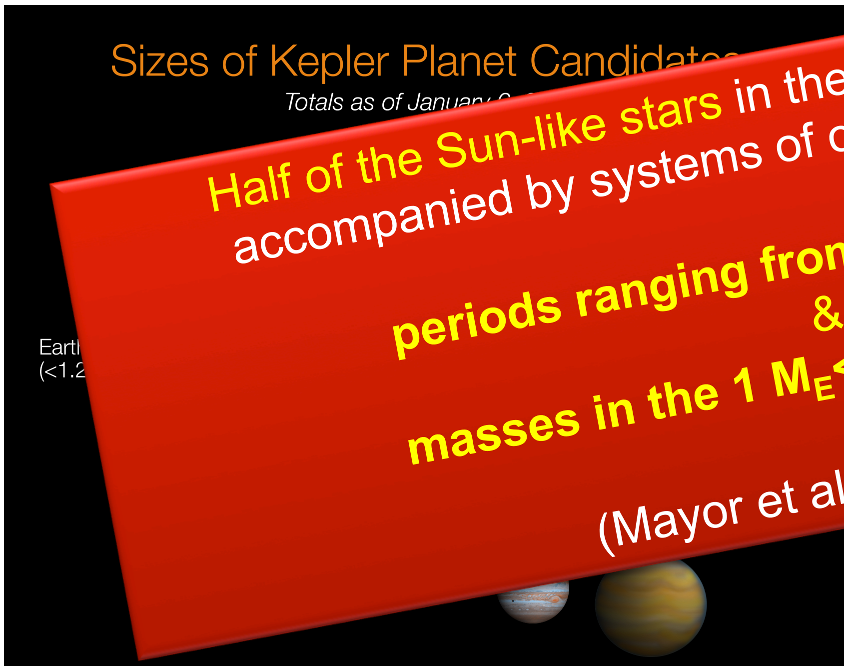
➡ 4706 planet candidates
➡ 2330 confirmed planets

http://kepler.nasa.gov

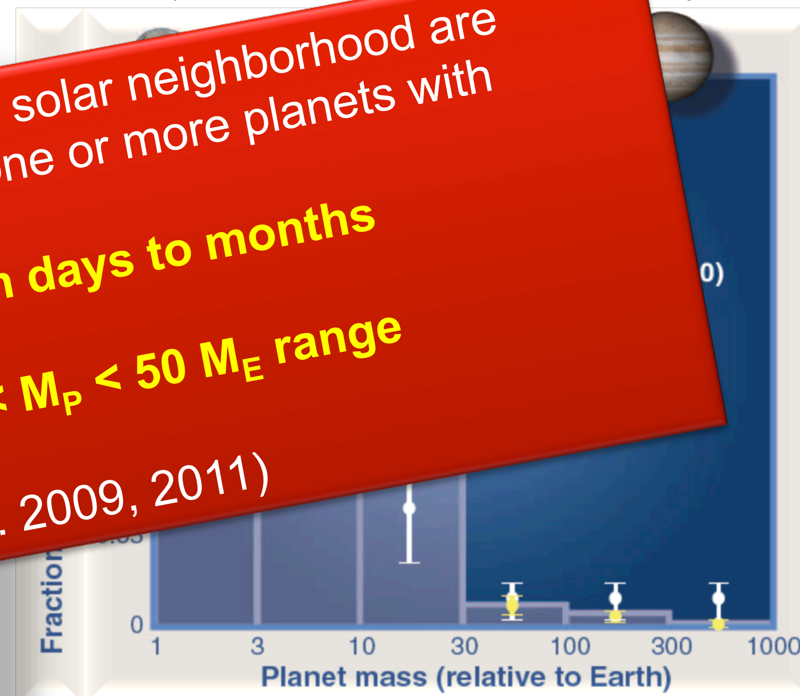


Small planets are common

Size from Kepler



Mass from Radial Velocity Survey



Half of the Sun-like stars in the solar neighborhood are accompanied by systems of one or more planets with

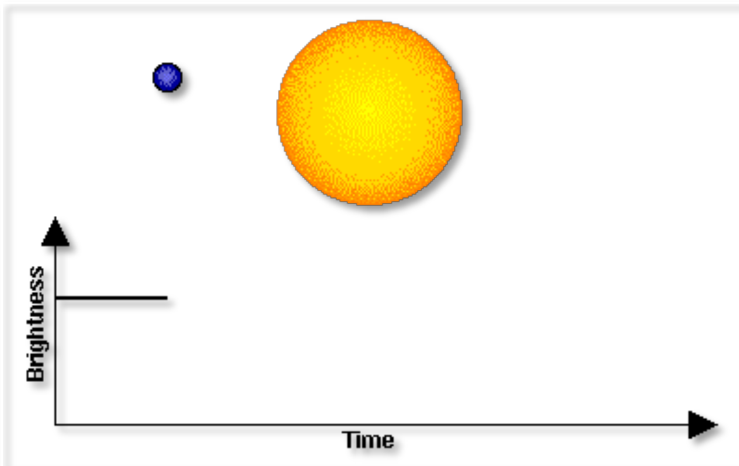
periods ranging from days to months
&
masses in the 1 $M_E < M_P < 50\ M_E$ range

(Mayor et al. 2009, 2011)

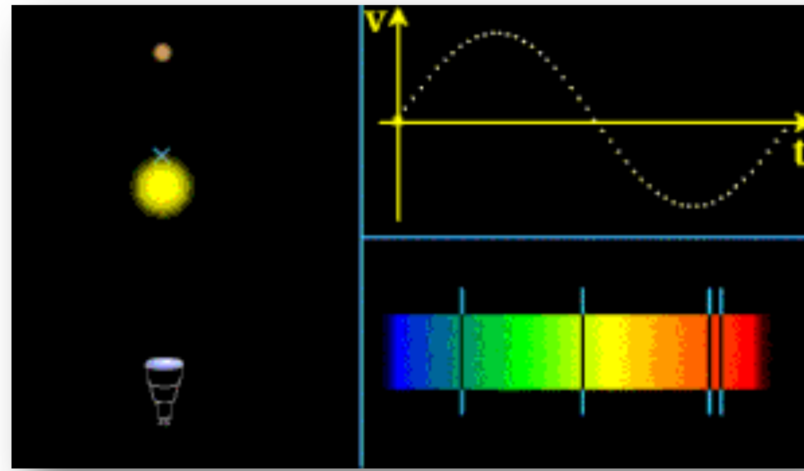
BUT mass and radius mostly come from different techniques: few objects with both measurements

RV & Transits: the power of complementarity

Transit Method



Radial velocity method



$$K = \left(\frac{2\pi G}{P}\right)^{1/3} \frac{M_P \sin i}{(M_\star + M_P)^{2/3}} \frac{1}{\sqrt{1-e^2}}$$

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

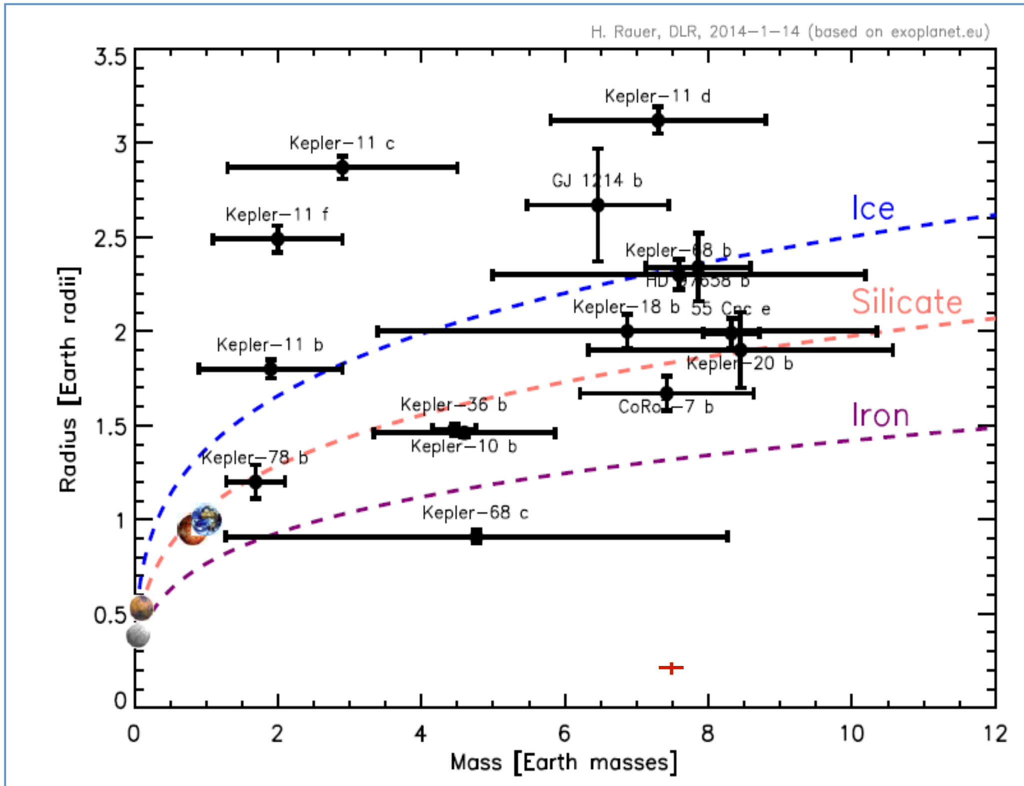
$$\frac{\Delta F}{F} = \left(\frac{R_p}{R_*}\right)^2$$

- Orbital parameters
- Minimum planet mass, $M_p \sin i$

$$K \propto M_p / M_*^{2/3}$$

True planet mass and mean density

From CoRoT, Kepler and Most
→ Diversity of super-Earths



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

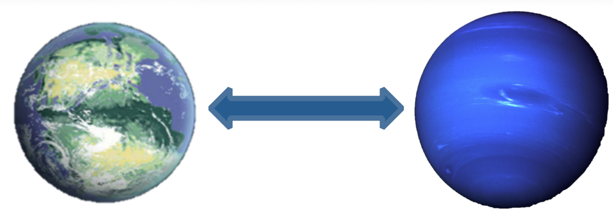
→ **Accurate masses & radii are required to separate terrestrial from mini-gas planets**

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



Searching for Habitability requires:

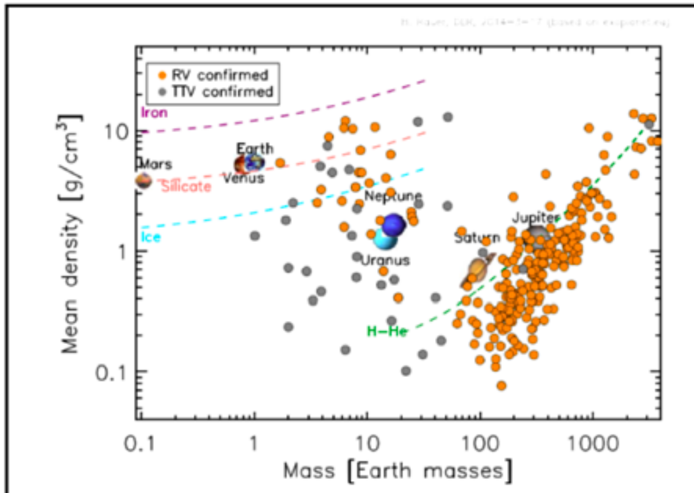
➢ accurate mean densities to identify terrestrial planets

➢ bulk characterize targets for atmosphere spectroscopy follow-up

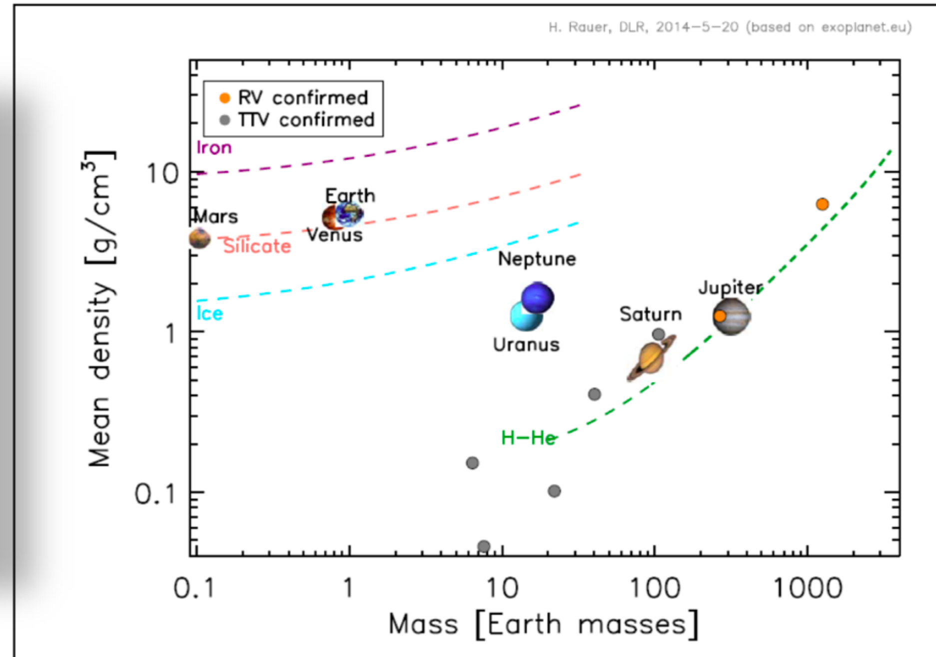
A biased view

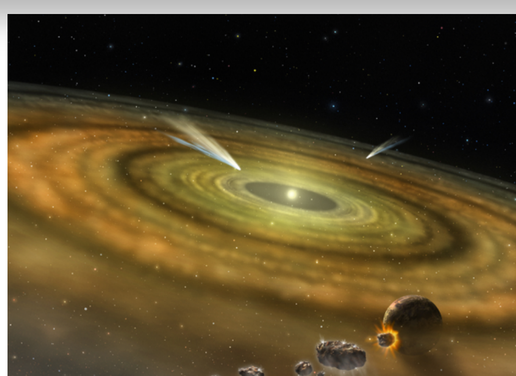
Our knowledge on planet nature is limited to close-in planets so far.

All planets



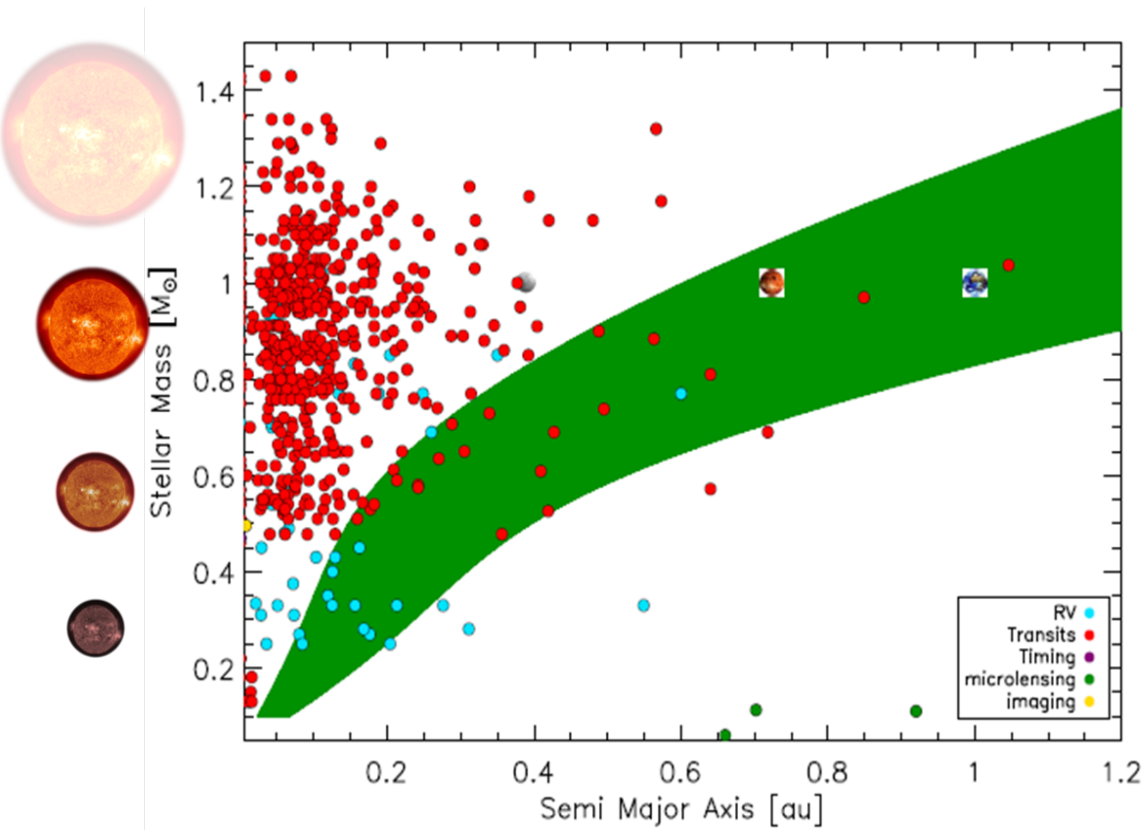
Planets with P>80 days





Super-Earths in the habitable zone

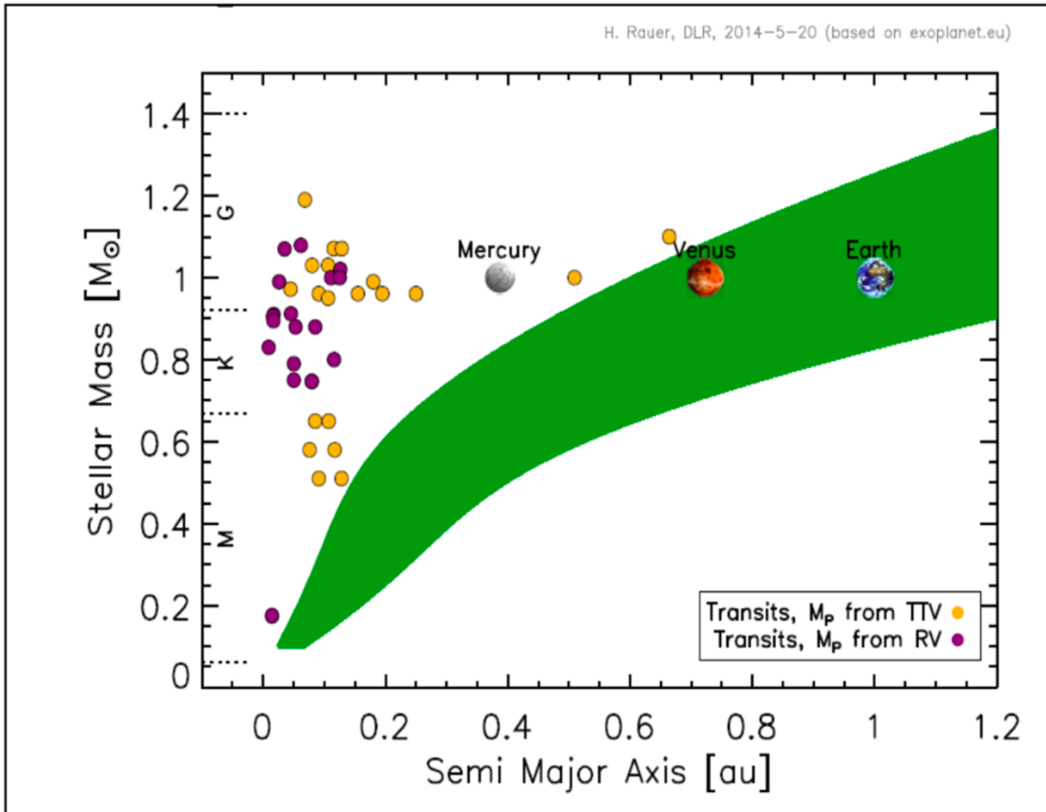
Detected super-Earths



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

Super-Earths in the habitable zone

Super-Earths with measured radius and mass

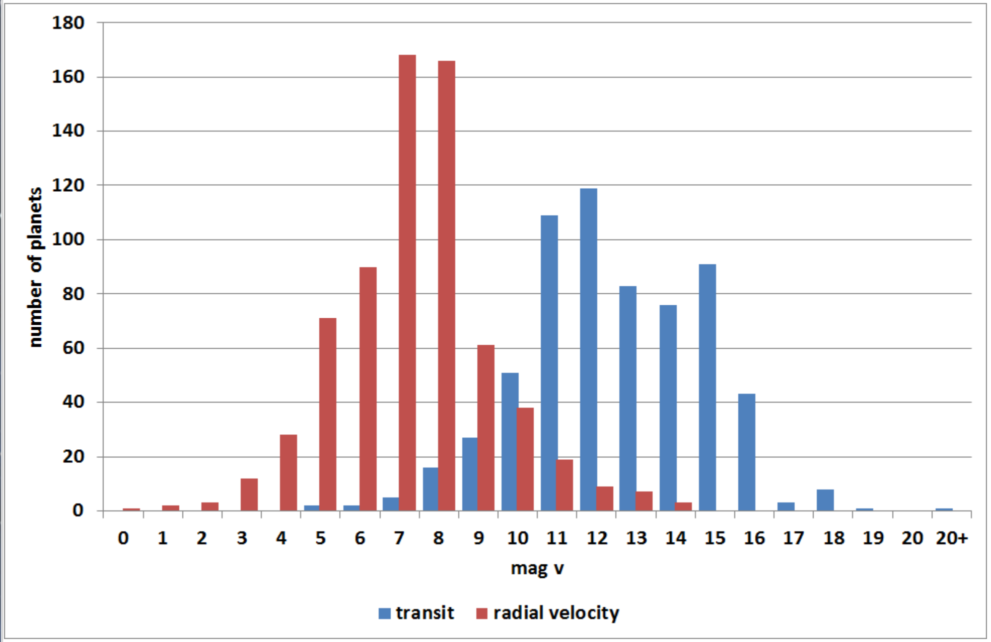


- Goal: Detect and characterize super-Earths in habitable zones
- Status: very few small/ light planets in habitable zones detected

No „super-Earths“ with known mean density in the habitable zone !

The need for bright stars

Known planets from radial velocity and transit surveys

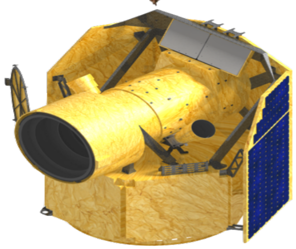


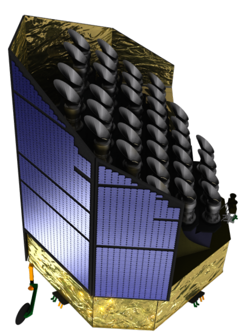
Why have so few targets been characterized?

- 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!

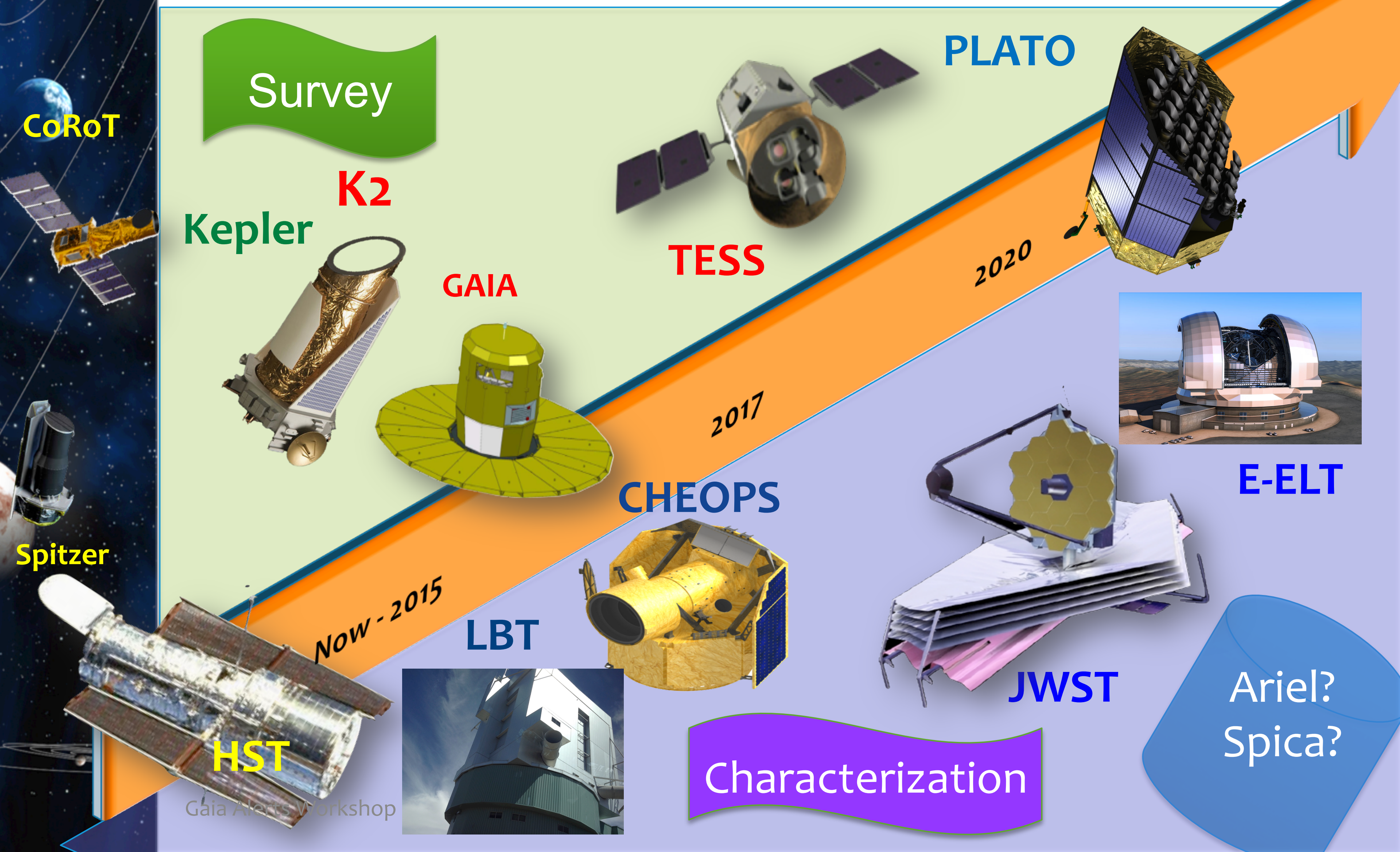
Transit missions: What's next?





K-2 (Kepler 2) (NASA)	observe fields in the ecliptic plane for ~80 days/field
CHEOPS (ESA, launch 2018):	follow-up, radii of detected (RV) planets,
TESS (NASA, launch 2017):	scan the whole sky, ~1 month/ field, ~2% of sky at poles for 1 year
PLATO (ESA, launch 2025)	detect and characterize (density, age) terrestrial planets around solar-like stars up to the habitable zone

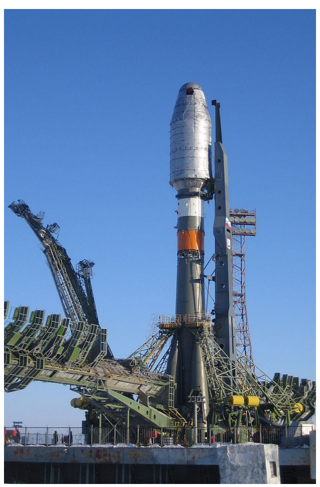
Missions and Observatories for Exoplanets

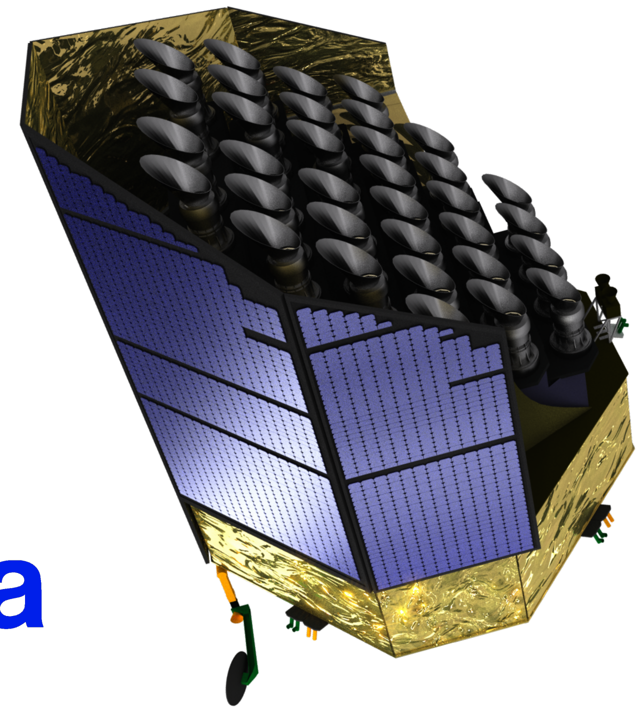


PLATO

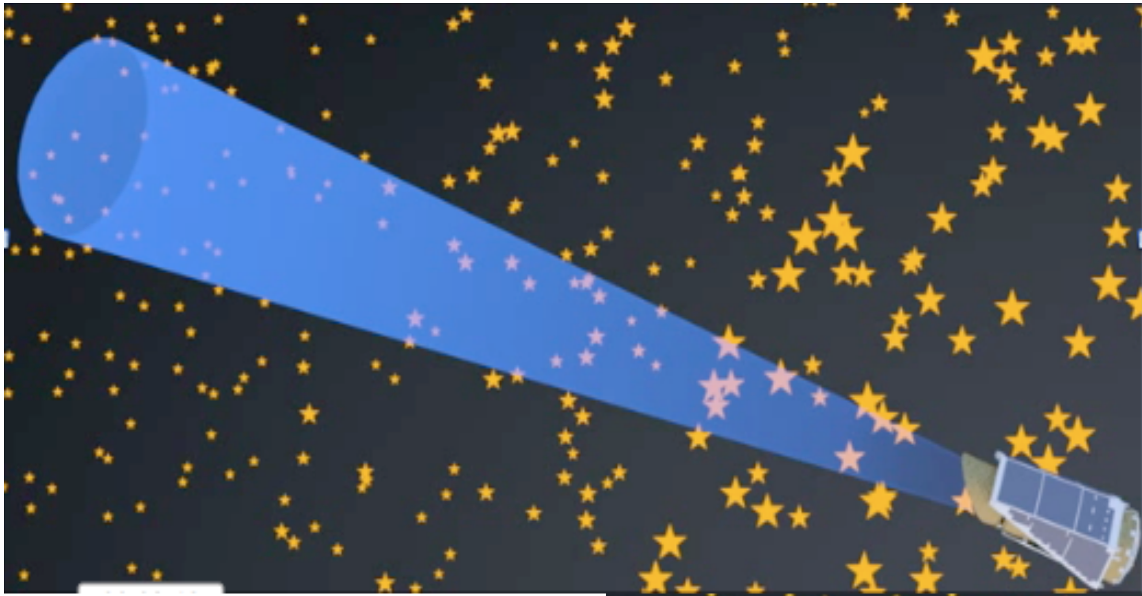
PLAnetary Transits & Oscillations of Stars

- M class mission (M3)
- Budget envelope ~ 650 M€ (≤ 500 M€ from ESA)
- Launch: 2025 – Launcher Soyuz Fregat from Kourou
- Baseline Operation: 4.25 (+2) yrs
  - Consumables for 8 years





Large FoV concept



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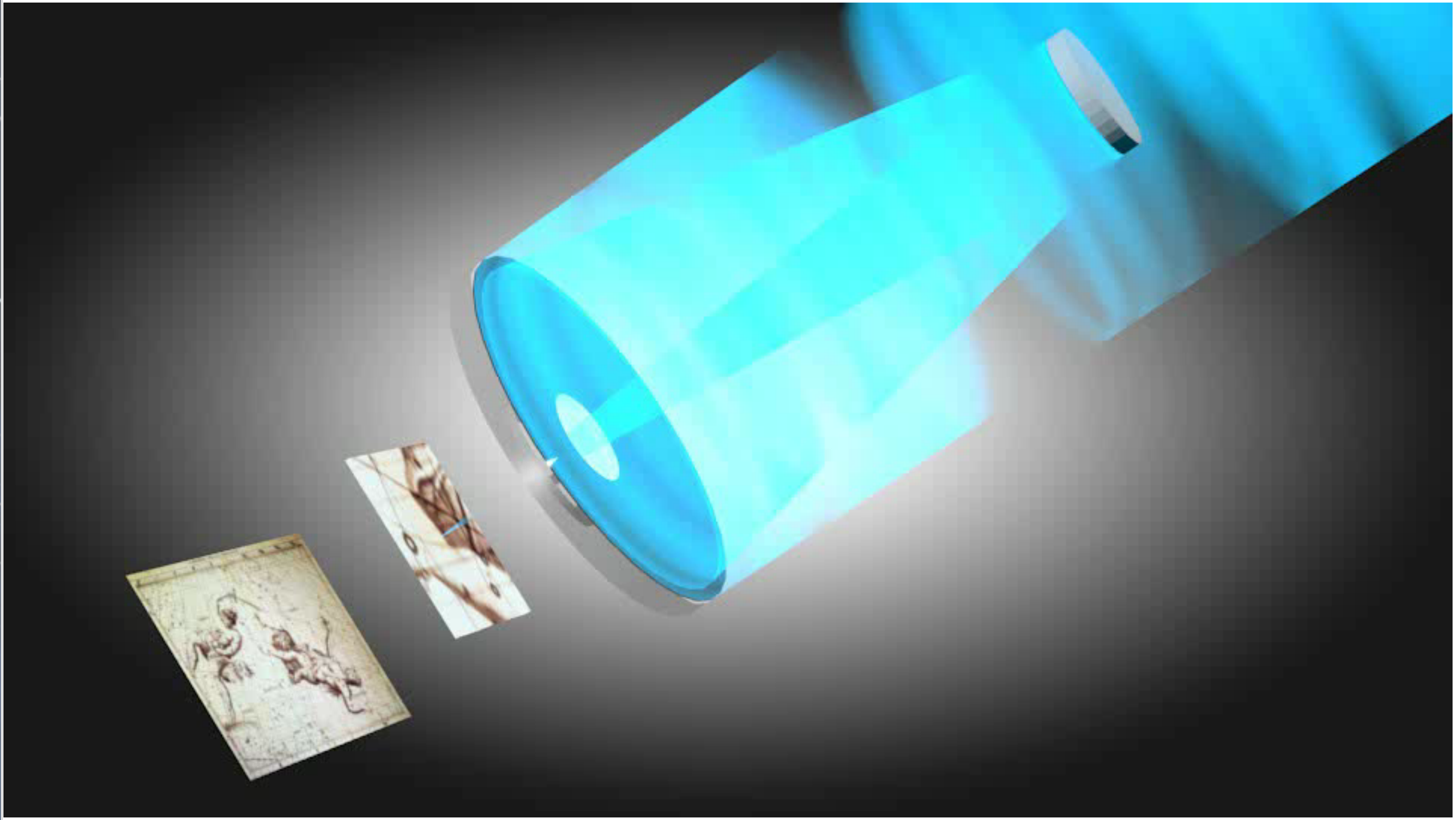
Searching for transits of Bright Stars ➔

➔ large FoV!

Segmentation is the only possible solution



One PLATO telescope

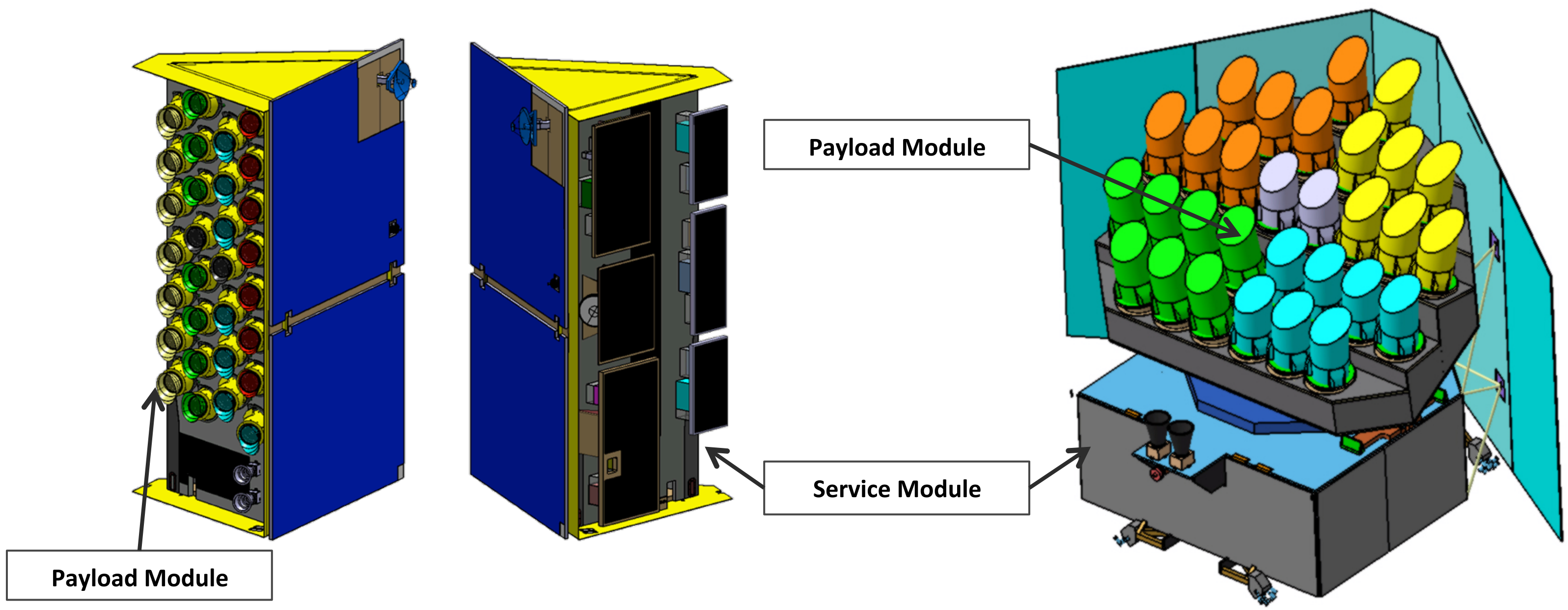
FoV~ ~1037 sqdeg (~10 times Kepler area) – like a circle of 39 deg diameter

PLATO Satellite

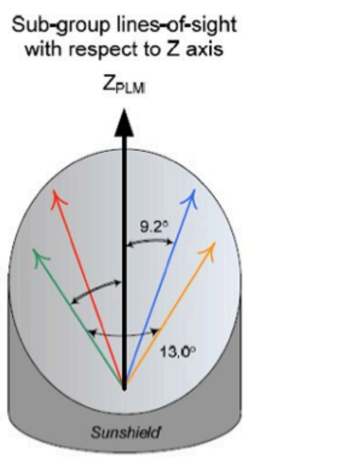
Two competitive industry studies ongoing until end 2016.

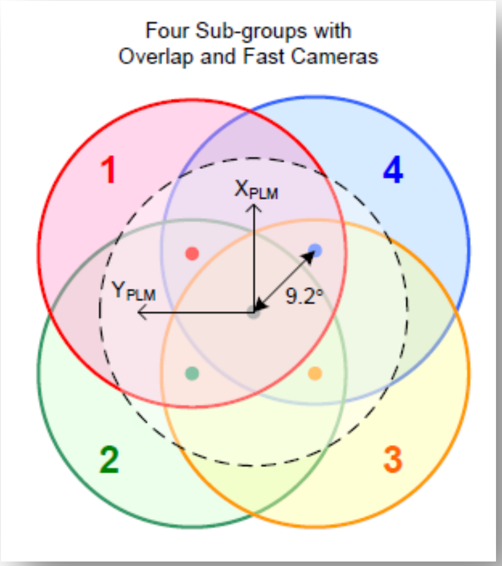
- 3-axis stabilised
- Mass ~ 2000 kg
- Pointing error: 0.2 arcsec $Hz^{-1/2}$ over time scales of 25 s to 14 hours.

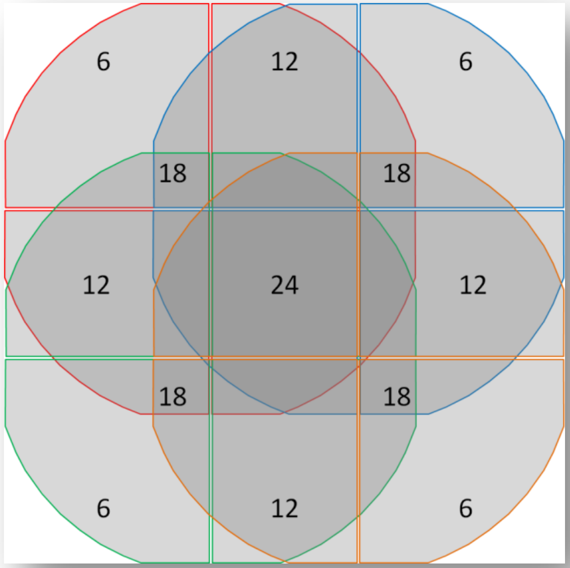
Airbus **OHB**



Telescopes on the satellite





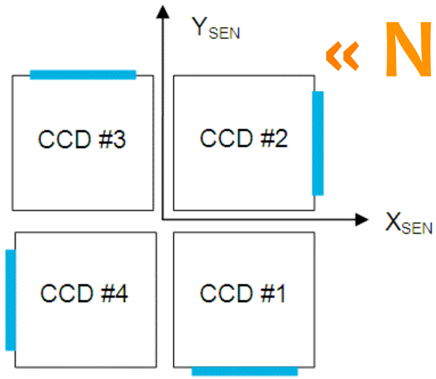


- 24 (4x7) "Normal" telescopes, 25 s cadence
- 2 "Fast" telescopes, 2.5 s cadence
- Instantaneous FoV~ 2232 deg^2 (22 times Kepler area)

Equivalent pupil size:

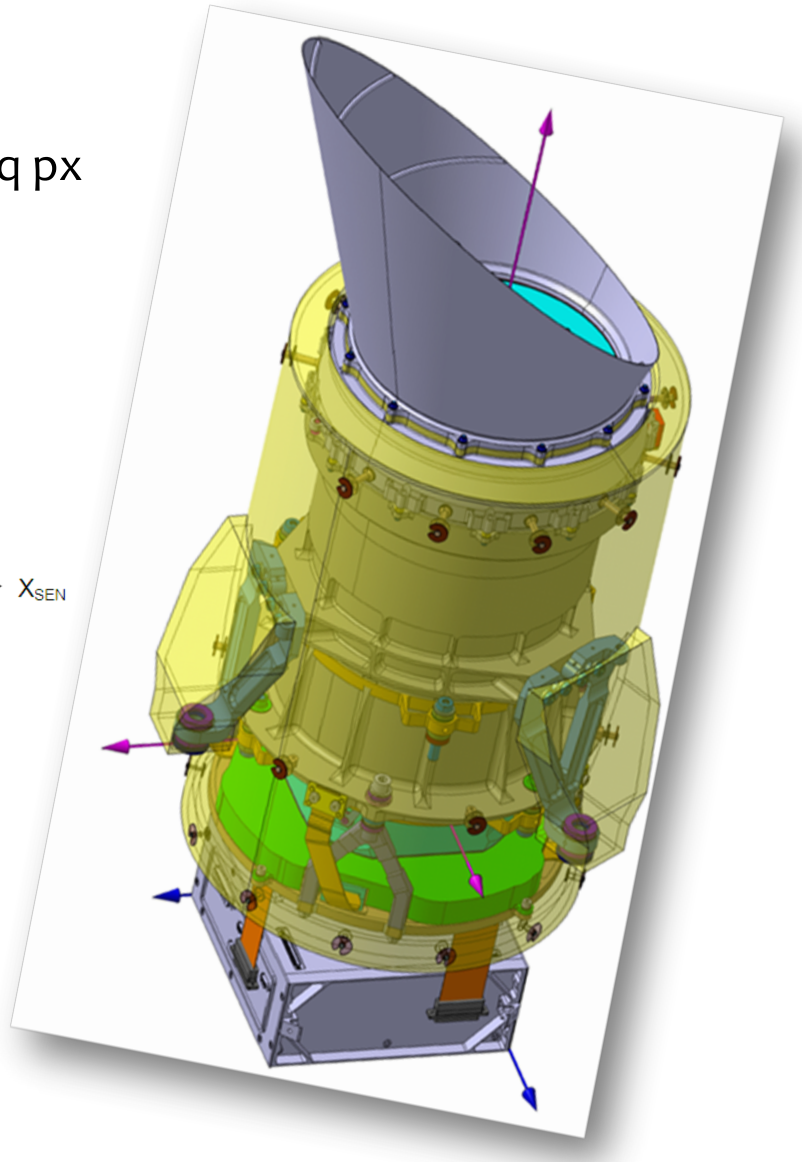
- 587.9 mm for 24 cam
- 509.1 mm for 18 cam
- 415.7 mm for 12 cam
- 293.9 mm for 6 cam

Fast and Normal Telescopes

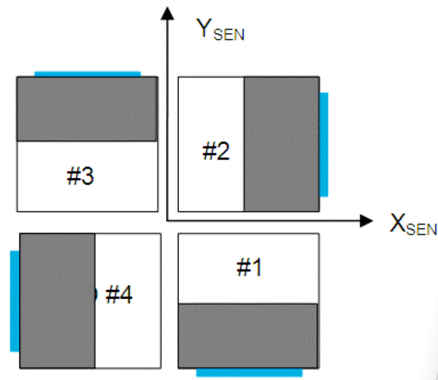


« Normal »

Full frame CCD
4510 × 4510 18 µm sq px
$m_V > 8$
t=25 s



« Fast »



Frame transfer CCD
4510 × 2255 18 µm sq px
m_V ~4–8
t=2.5 s **AOCS**

- ✓ 104 CCDs → ~ 0.70 sq meter
- ✓ 1 FEE / camera;
- ✓ 1 DPU / 2 cameras;
- ✓ 2 ICUs in cold redundancy

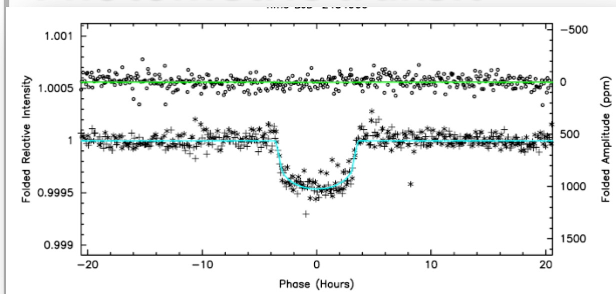
PLATO Science Goals

from the SMP

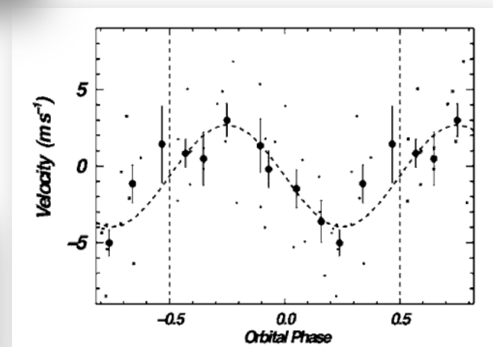
- Determine planet bulk properties (**mass, radius and mean density**)
- Study how planets and planet systems **evolve with age**
- Study the typical **architectures of planetary systems**
- Analyse the correlation of planet properties and their frequencies with stellar parameters (e.g., stellar metallicity, stellar type)
- Analyse correlations with the environment in which they formed
- Identify targets for spectroscopy to investigate planetary atmospheres
- Study the internal structure of stars and how it evolves with age
- + guest observer program (complementary and legacy science topics).

The Method

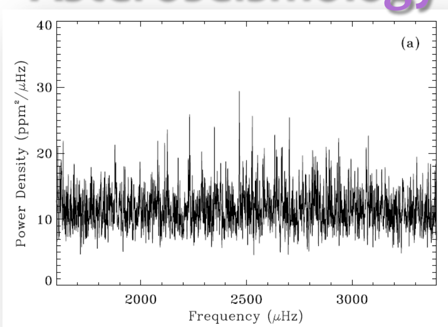
Photometric transit



RV – follow-up



Asteroseismology



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

- radius ~2%
- Mass ~10%
- Age ~10%

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

Stellar samples

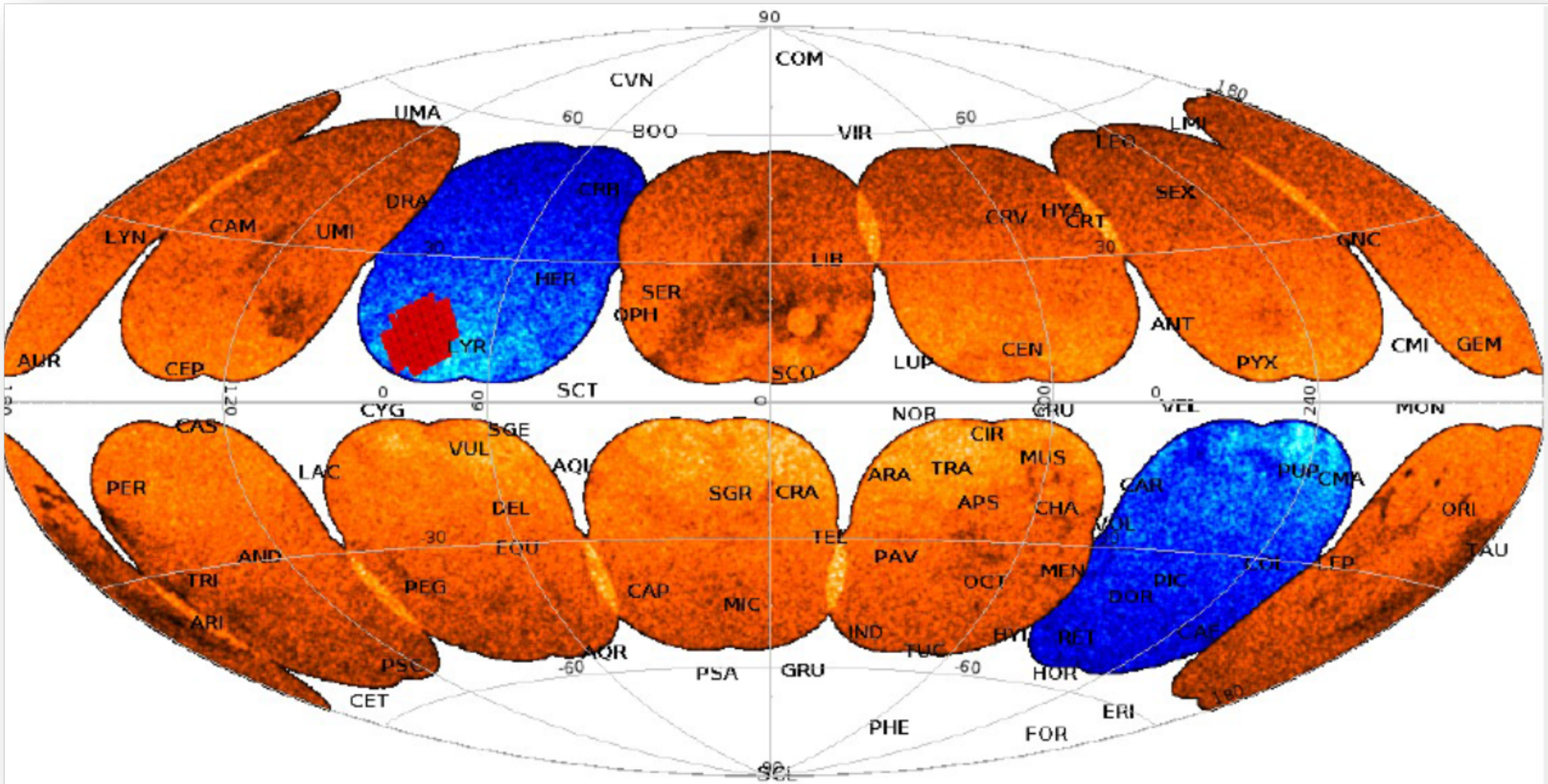
	Sample 1 (P1)	Sample 2 (P2)	Sample 4 (P4)	Sample 5 (P5)
Stars	≥ 15 000 (goal 20 000)	≥ 1000	≥ 5000	≥ 245 000
Spectral type	Dwarf and subgiants F5-K7	Dwarf and subgiants F5-K7	M dwarfs	Dwarf and subgiants F5-K7
Limit *V*	11	8.2	16	13
Random noise (ppm in 1 hr)	34	34	800	
Observation phase	LOP	LOP	LOP	LOP
Sampling time (s)				
Initial measurement	-	-	-	≤ 600
Centroid measurements	-	-	-	≤ 50 for 5% of targets
Transit oversampling			-	≤ 50 for 10% of targets
Imagettes	25	2.5	25	25 for > 9000 targets
Wavelength	500–1000 nm	500–1000 nm	500–1000 nm	500–1000 nm

Note: 8% of the telemetry dedicated to general (public) programs.
Open call for proposals issued by ESA (time tbd)

Observing Strategy

The observing duty cycle will be ≥ 93% per target in a year

The PLATO sky



→ ~50% sky coverage

Ground stations

- X and K-band telecommunications,
- ~ 435 Gb per day
- Ground station contact for 4 hours several times per week.

Data products

- Validated Imagettes
- Validated light curves
- Validated centroid curves

- Planetary transit candidates and their parameters
- Asteroseismic mode parameters
- Stellar rotation and Activity
- Stellar masses, radii and ages
- Living catalogue of confirmed planetary systems and their characteristics using light curves and transit time variations

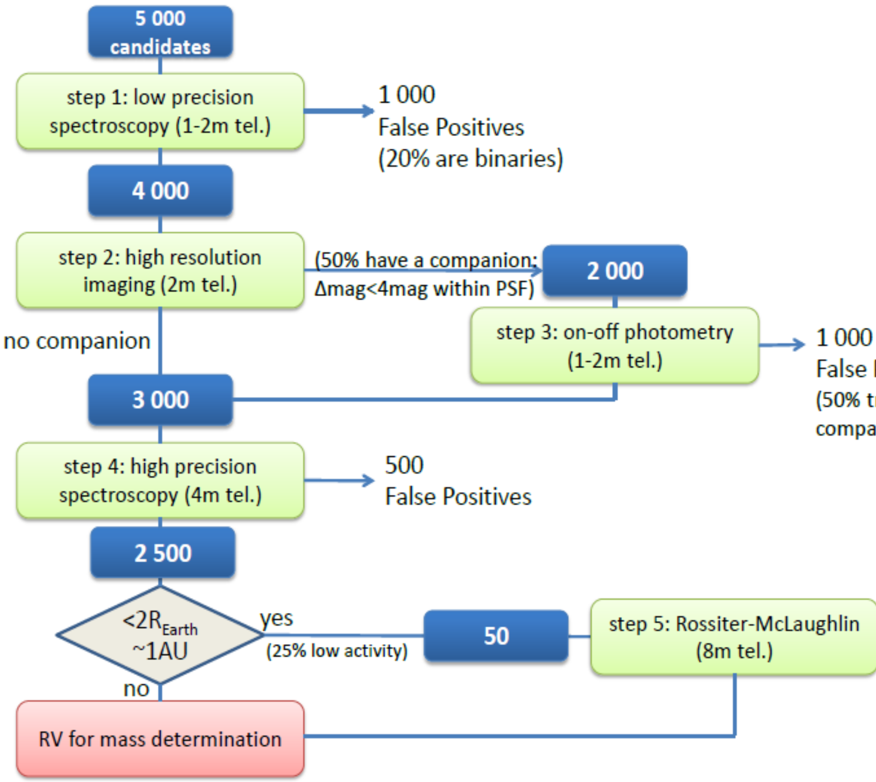
L0 → L1 → L2 → Lg → L3

- Calibrated Light curves
- Calibrated Imagettes
- Centroid curves

- Follow-up ground-based observations

- Living catalogue of confirmed planetary systems and their characteristics using new ground-based follow-up observations (Lg)

Ground-based observations (Lg)



- Ground-based observations for filtering false planet transits
  - Low-precision spectroscopy (1-2 m);
  - High-res imaging (2 m);
  - On-off transit photometry (1-2 m);
  - High-res spectroscopy (4-8 m);
  - Rossiter-McLaughlin obs. (8 m).
- Ground-based observations for the characterisation of planets
  - High-res spectroscopy (1-2 m, 4 m & 8 m);
  - Rossiter-McLaughlin obs. (8 m).

Ground-based Observation Programme

Made by a GOP Team

ESA will take the lead in establishing agreements and managing relations with main ground-based facilities such as (but not only) the European Southern Observatory (ESO).

Based on an ESA-ESO agreement, access to ESO ground-based facilities for the observation of the PLATO candidates in the "prime sample" will be through a competitive selection process for likely one or more ESO Large Programmes.

T...					...tal ...hts
1-2 ... spe...					
1-2 ... imag...					
1-2 m...				-	~ 70
1-2 m... spectr...			~ 3	~30	~ 30
4 m, hi... spectro...		~ 140	~ 100	~ 900	~ 1040
8 m, hig...resolution spectroscopy	~ 5	~ 35	~ 80	~ 720	~ 755

Few hardest cases (e.g., faintest hosts with Earths in the habitable zone) will need E-ELT

Expected Yield

	Stellar Sample	24 N-cam (2+2)	24 N-cam (3+1)	24 N-cam (3+2+1)
All planets, all orbital periods, $V \leq 13$	P1+P5	~4 600	~11 000	~13 000
All planets, all orbital periods, $V \leq 11$	P1+P5 bright	~1 200	~2 700	~3 300
Small planets ($R < 2\,R_E$), all orbital periods, $V \leq 11$	P1+P5 bright	~770	~1 800	~2 200
Small planets ($R < 2\,R_E$), in HZ, $V \leq 11$	P1+P5 bright	6 - 280	3 - 140	6 - 280

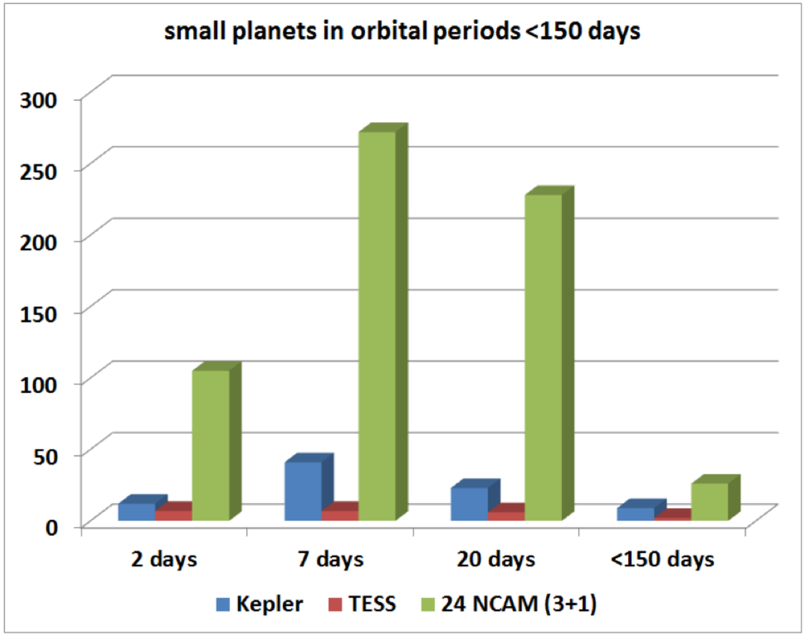
Between 300,000 and ~1,000,000 high precision stellar light curves (depending on the final observing strategy)

huge legacy for stellar and galactic science

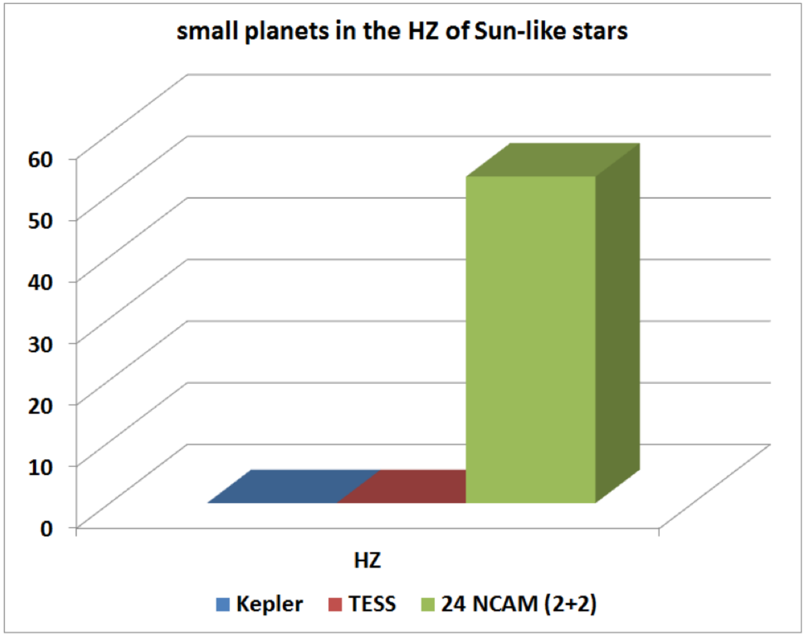
Expected Yield

Expected detection yield of small planets ($R<2R_E$) fully characterized with asteroseismology

3yr LP + 1 yr S&S



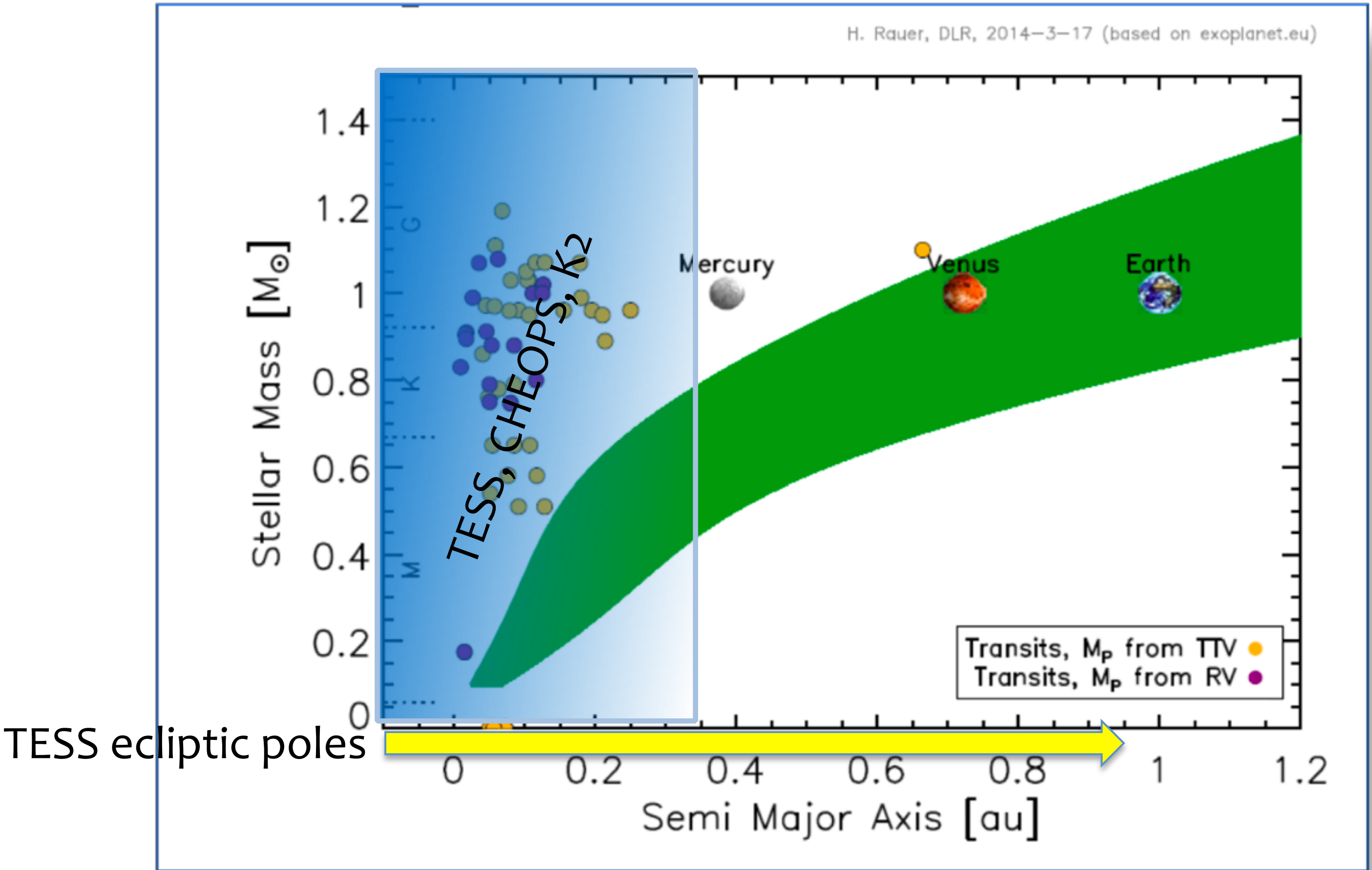
2x2yr LP (baseline)



Kepler data from Lundkvist et al. (2016)
TESS data from Campante et al. (2016)

Prospects for characterized super-Earths in the habitable zone

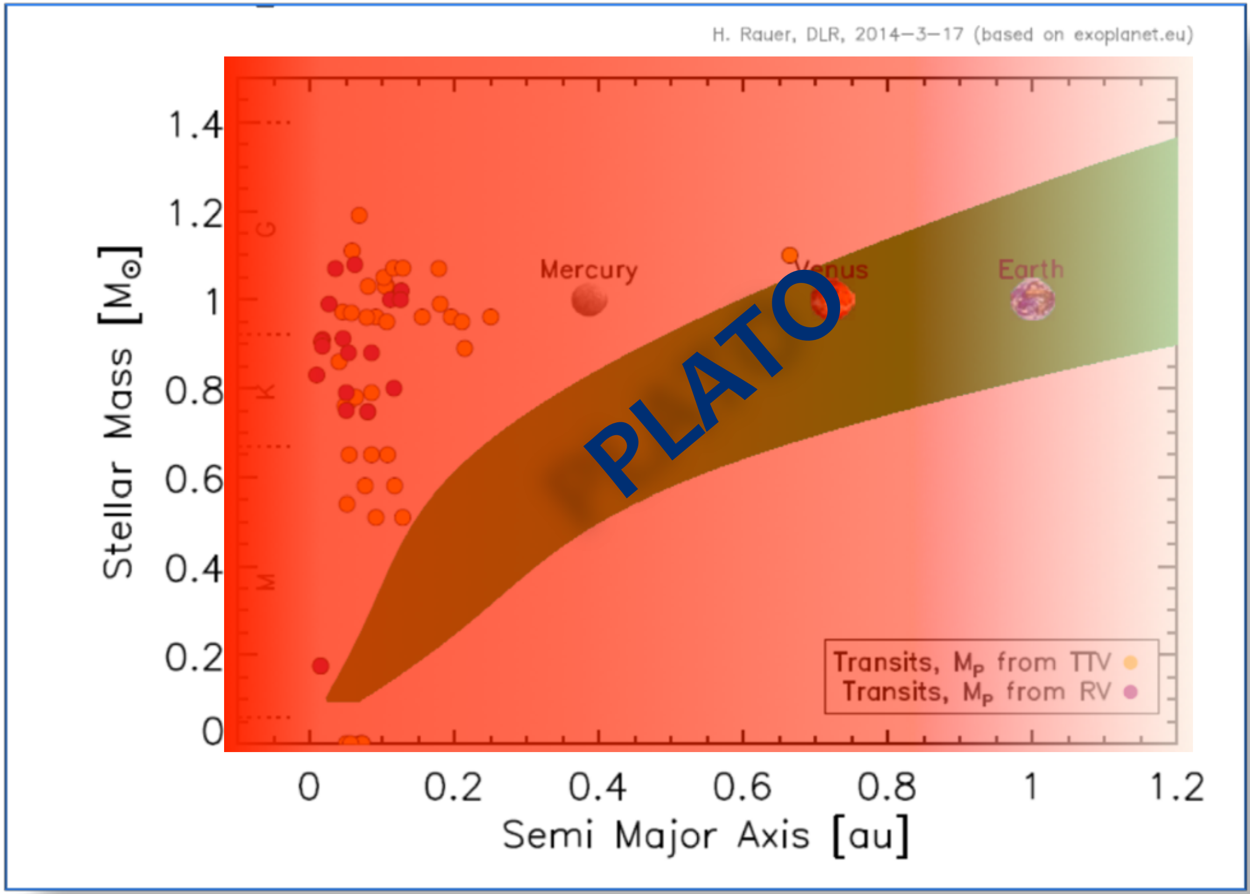
„Super-Earths" with measured radius and mass



TESS, CHEOPS, K2 will mainly cover orbital periods up to ~80 days

PLATO will measure the density of Super-Earths with P> 80 g

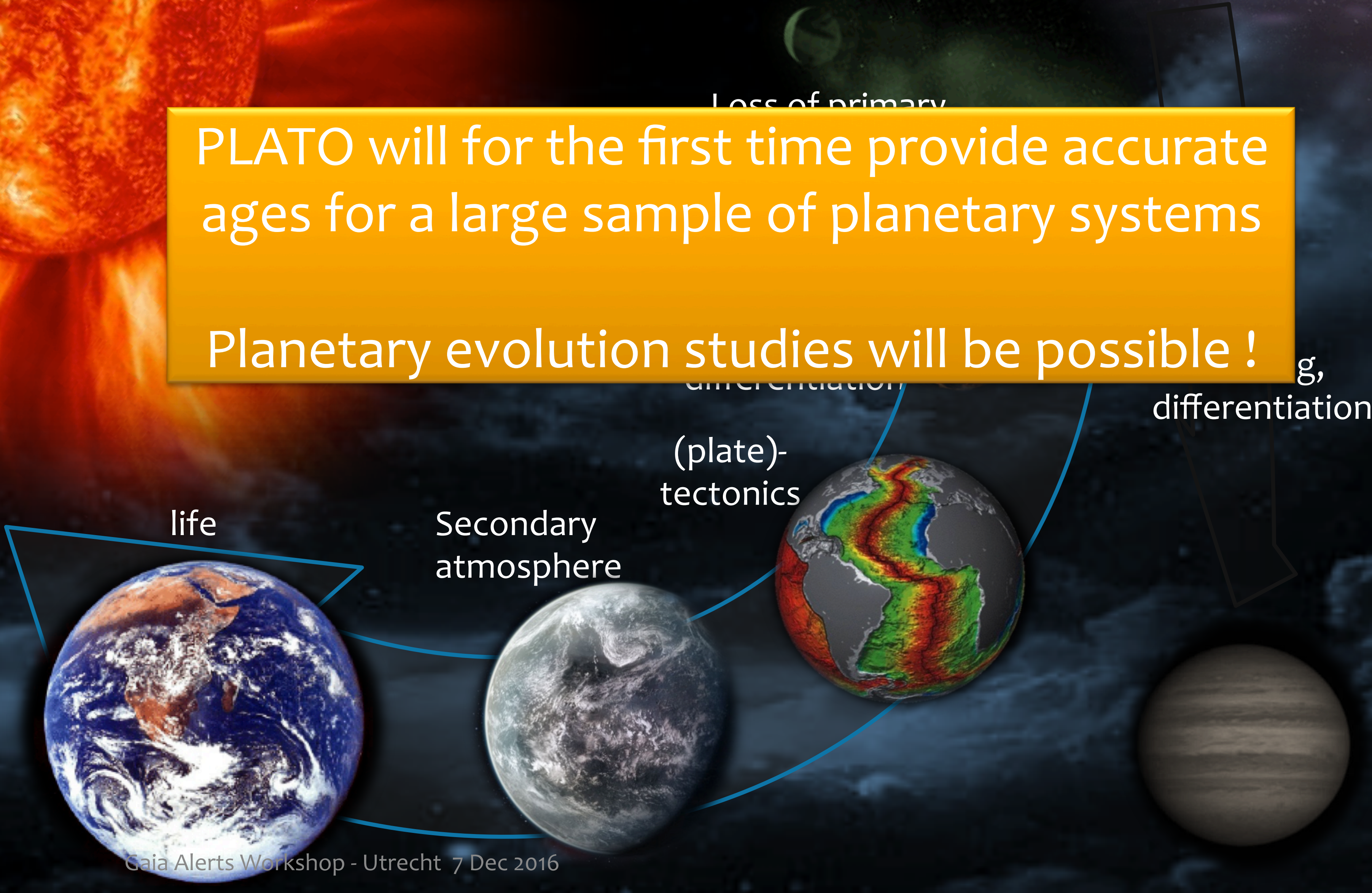
„Super-Earths“ with measured radius and mass



Planets, planetary systems and their host stars evolve

PLATO will for the first time provide accurate ages for a large sample of planetary systems

Planetary evolution studies will be possible !



PLATO & GAIA

Input Catalogue

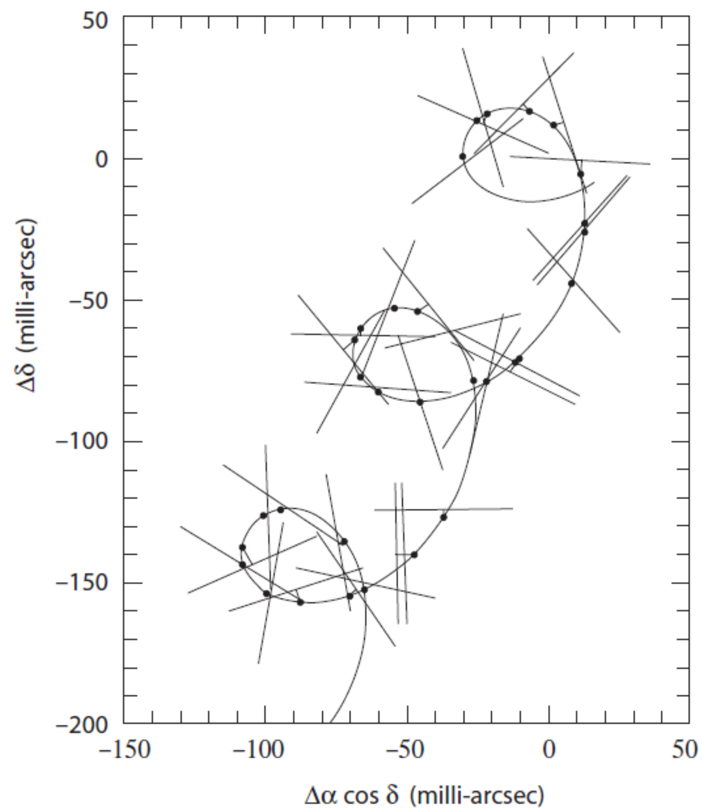
- PLATO will observe stars at 4<*V*<16 ➔PLATO targets will also be observed by *Gaia*.
- **Gaia photometry** is able to provide a "clean" sample of main-sequence dwarfs later than F5, with only ~1% "contamination" from cool giants
- Contamination ~ 0.1%, using Teff and log(g) from **Gaia spectro-photometry**

Complementary measurements

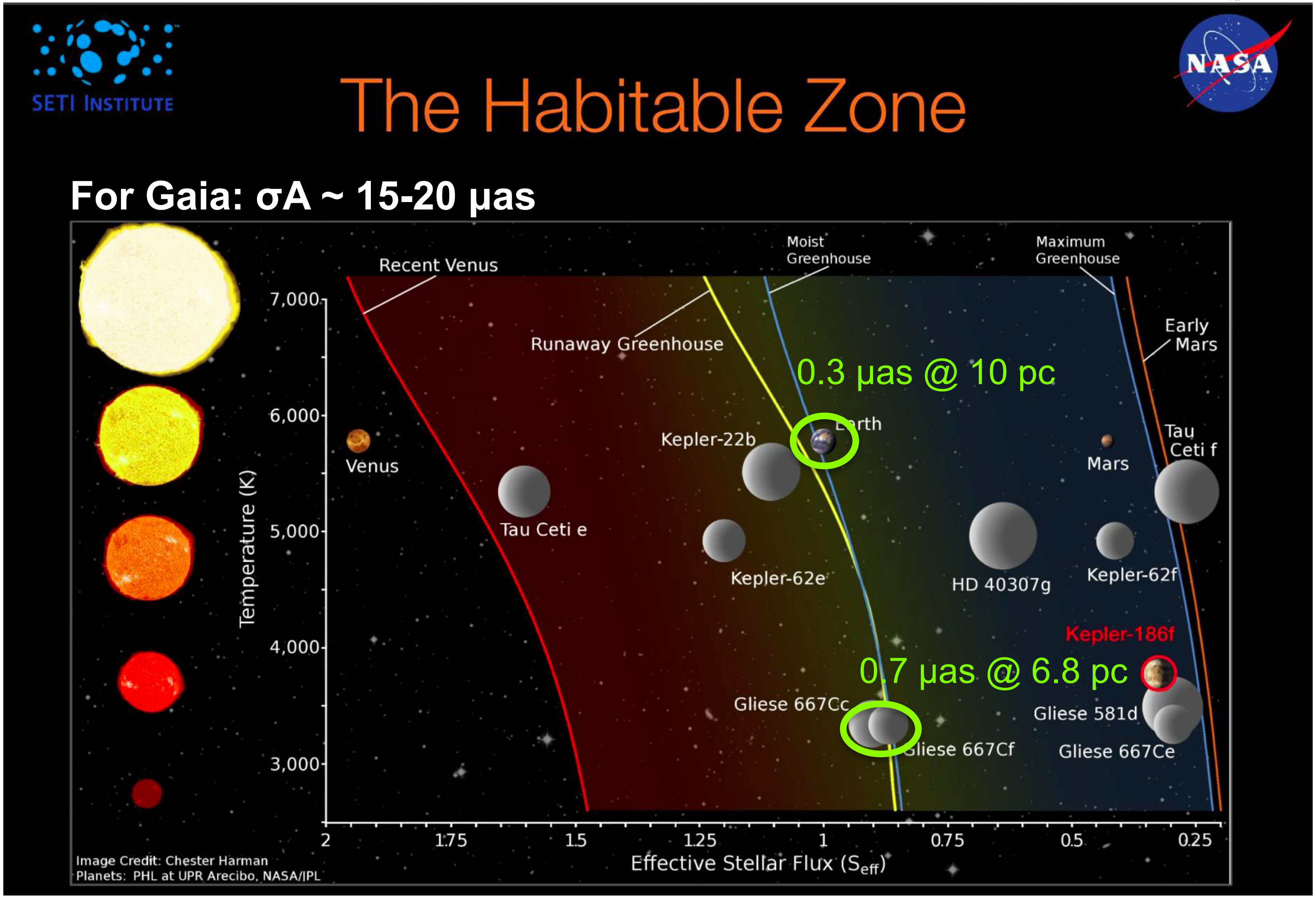
- *Gaia* ➔ absolute high-precision stellar luminosity
- + Teff (from ground-based high-res spectroscopy) ➔stellar radii at a precision of 1–2%.

Gaia planets

- The astrometric detection method is biased towards massive, cool planets hosted by low-mass, nearby stars (a poorly explored region, so far)
- GAIA is expected to discover ~25,000 such planets, of which 25-40 transiting (Perryman+ 2014); ~1,000 will be brighter than G~8.
  - **2-3 M_J planets at 2<a<4 AU are detectable out to~200 pc around solar analogs**
  - **Saturn-mass planets with 1<a<4 AU are measurable around nearby (<25 pc) M dwarfs**
- Direct dection of transiting hot Jupiters through GAIA photometry, on the other hand, will be marginal (Dzigan+ 2012)



Habitable Earths: Not for Gaia



Sozzetti, 2014

Are PLATO alerts possible?

- Preselected targets
- Download of telemetry typically every 24 hrs

- Alerts cannot be drivers, but it can be explored whether or not alerts could be feasible.

The EP-RAT Roadmap

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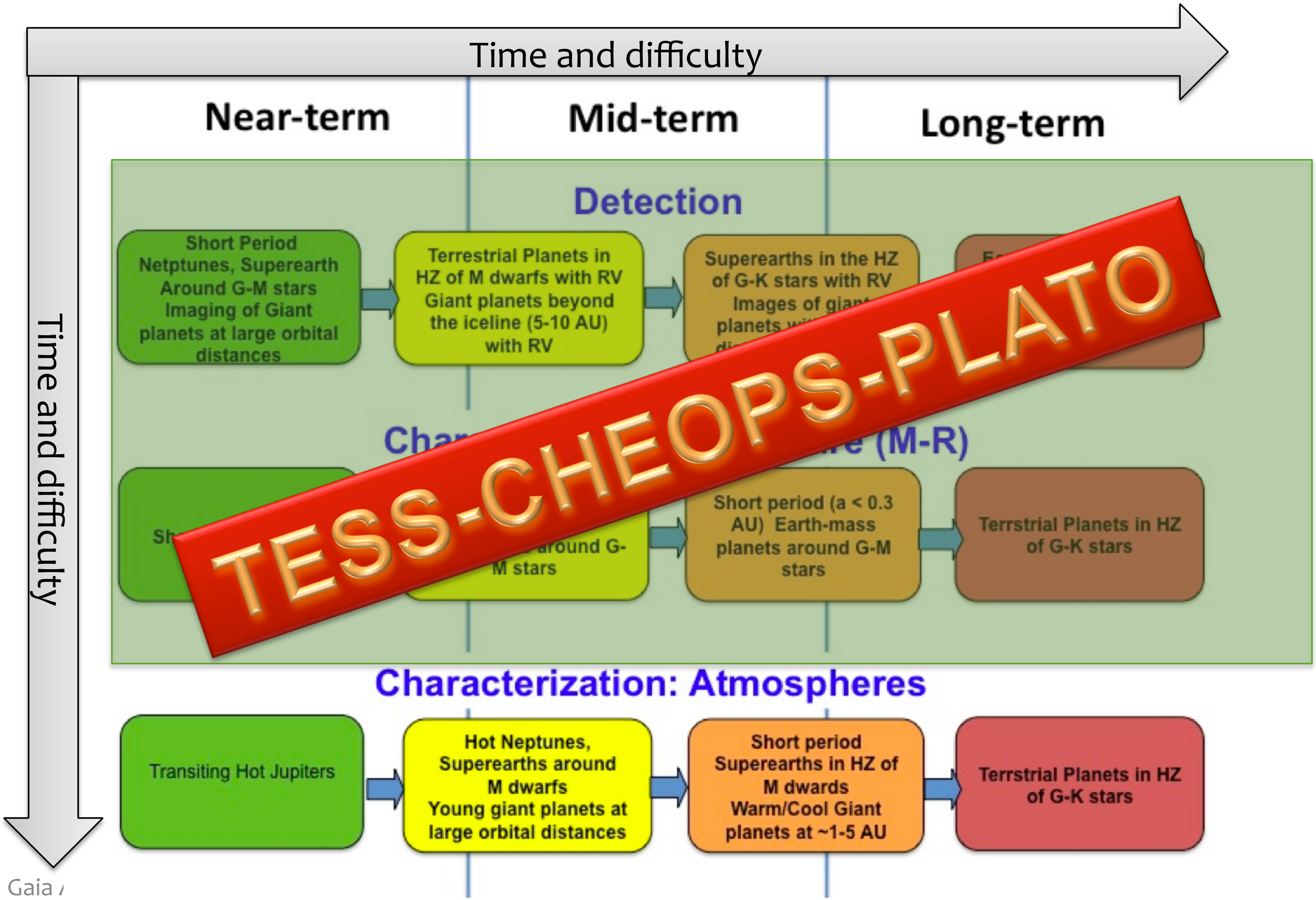
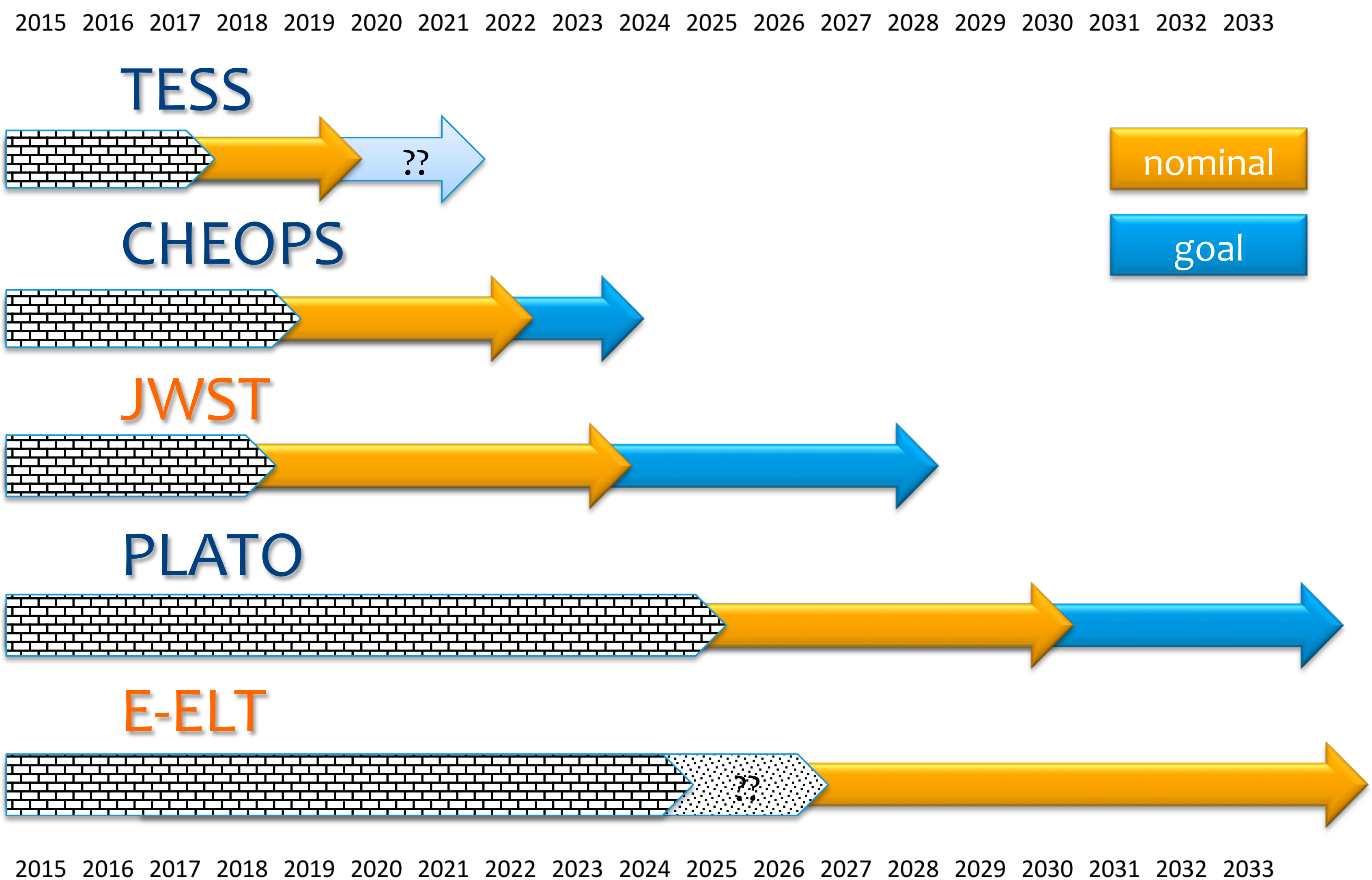


Gaia /


2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033
TESS
??
CHEOPS
JWST
PLATO
E-ELT
??
nominal
goal
2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033

PLATO Status

- ✓ Payload PHASE B2 in progress
- ✓ Mission Adoption in February 2017
- ✓ iPDR: Feb 2018

Launch in 2025

The PLATO Community

About 500 scientists involved all over Europe

A new PLATO Consortium website under construction on wordpress!

http://www.pla

//www.oact.inaf.it/plato/Plato-Italia/Home.html