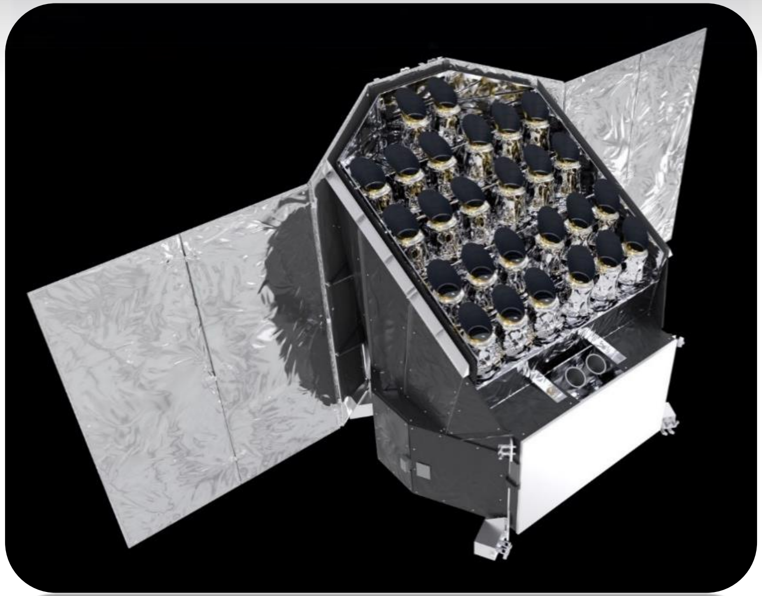
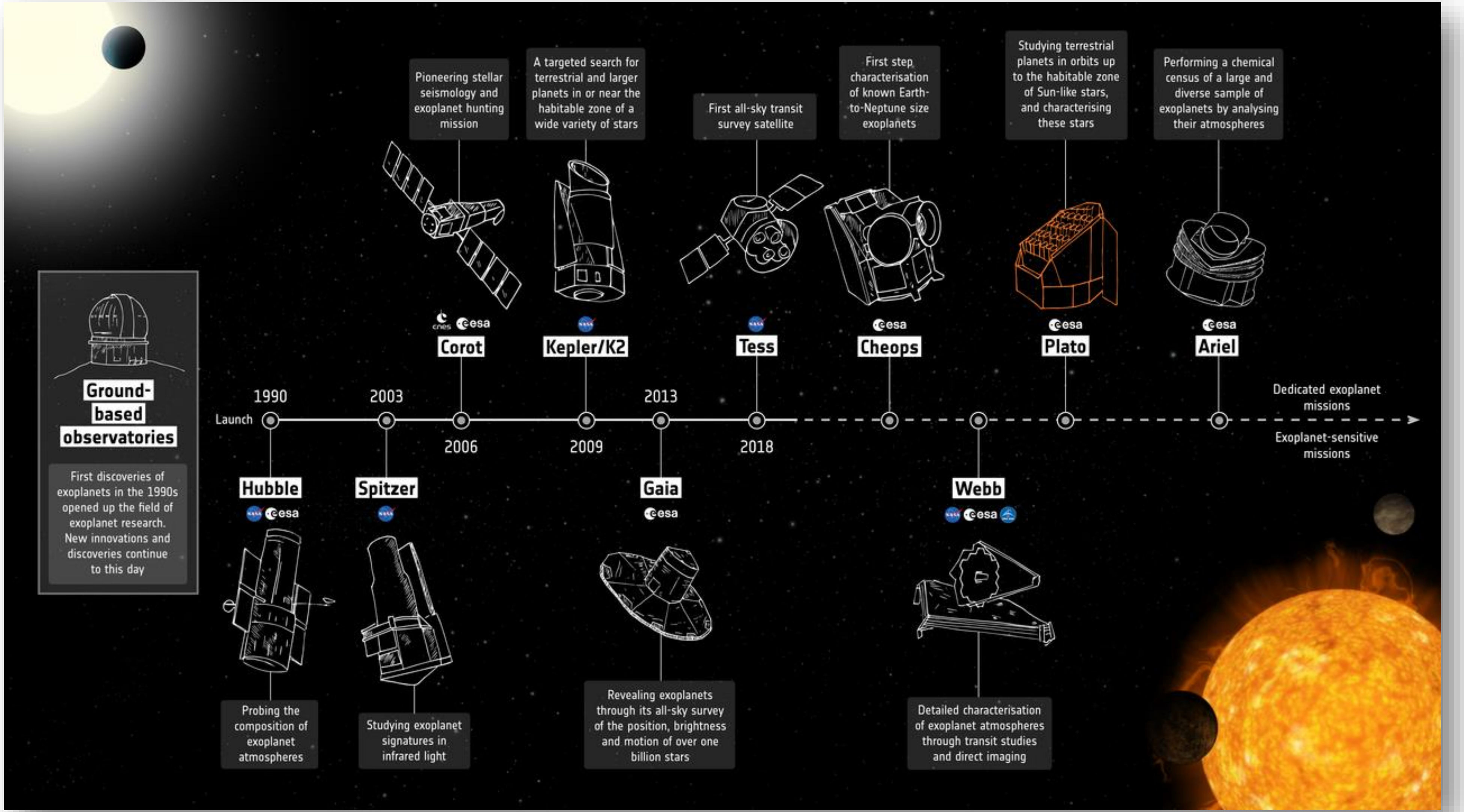


The benefits of space missions in detecting transits of exoplanets: The CHEOPS and PLATO projects

Heike Rauer
Institute of Planetary Research, DLR, Berlin, Germany

with inputs from Monika Lendl, Université de Genève
and the CHEOPS and PLATO Teams

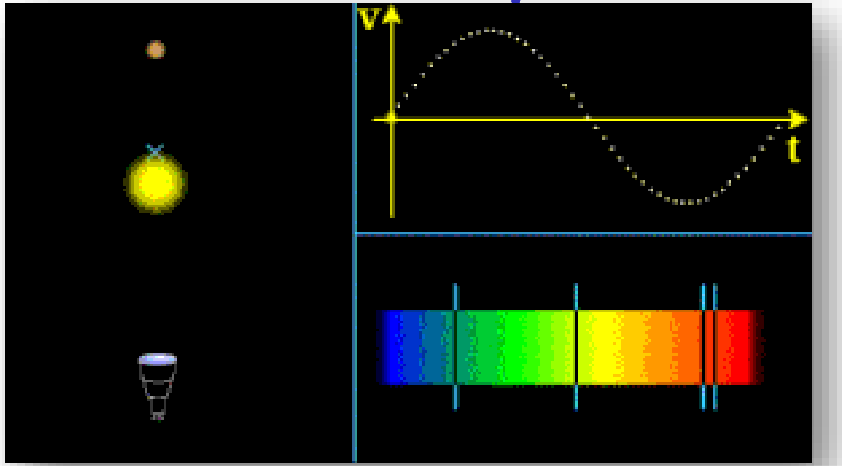
Exoplanet missions



- PLATO is ESA´s M3 mission
- Launch planned for end 2026
- Launch into an orbit around L2

Methods for detection and bulk characterization

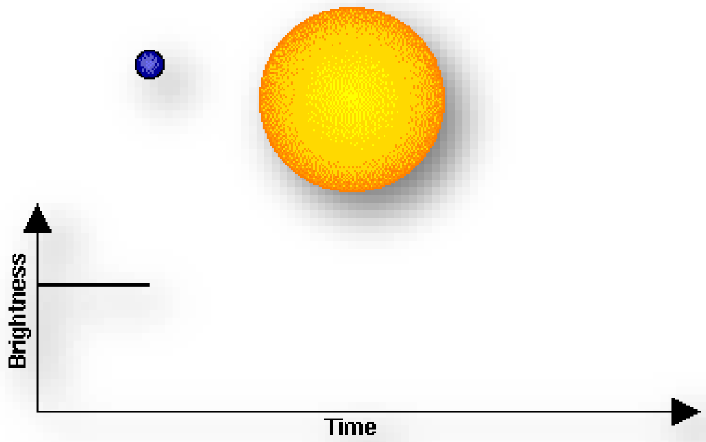
Radial velocity method



→ Orbit parameter

→ minimum planet mass
(m *sin* i)

Transit method



→ Orbit parameter

→ Inclination **i**

→ **Planet radius**

True planet mass and mean density

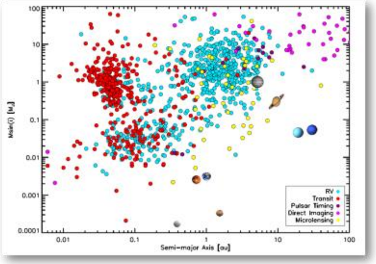
Exoplanets via transits

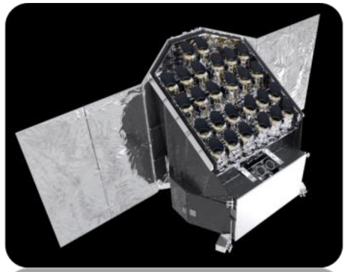
Two research goal for exoplanet detections via the transit method:

- Precise characterization of individual targets to identify their specific nature
  → Better understand geophysical parameters of planets

CHEOPS: precise radii for known exoplanets

- Statistical information of a large number of targets to identify characteristics of planet populations
  → Better constrain planet formation and evolution theories

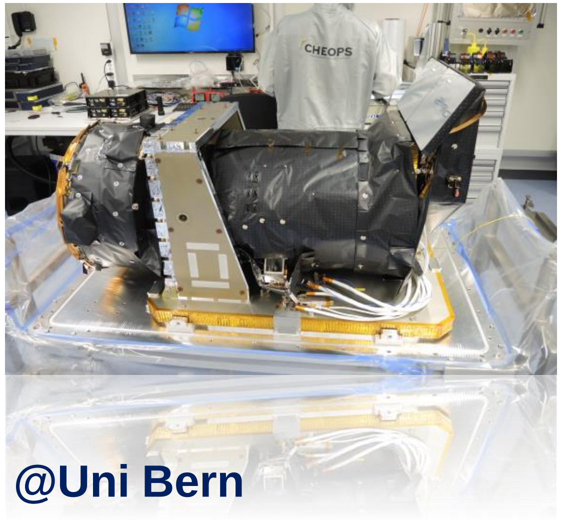


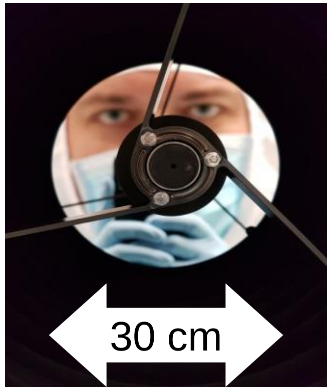


PLATO: exoplanet detections as well as precise radii, masses and ages

CHEOPS

30cm telescope for ultra-high
precision photometry





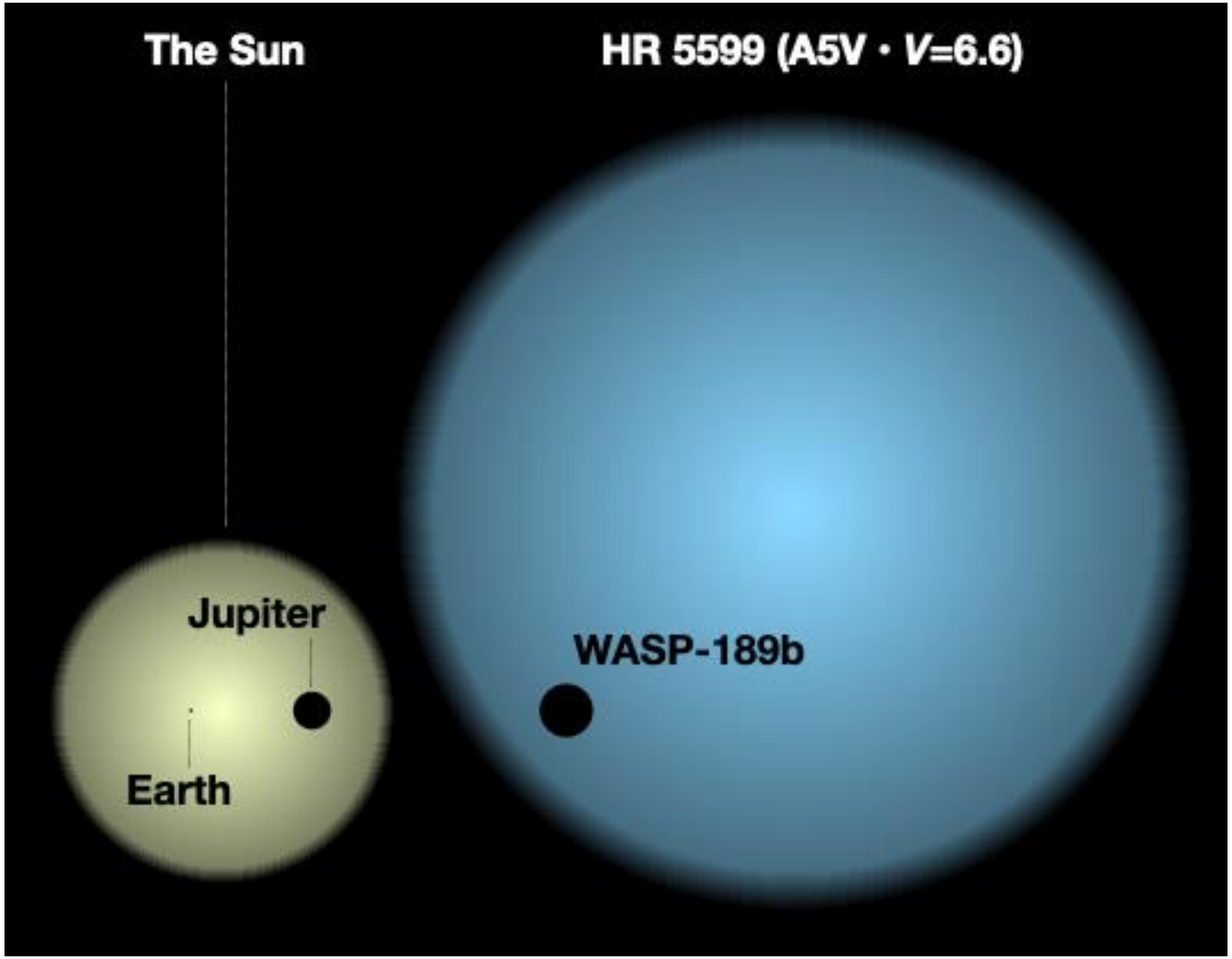
Operating since spring 2020!

Goals:

★ ***20 ppm per 6 hours for V = 6-9 stars***
Detect transits of Earth-size planets around Solar-type stars

★ ***85 ppm per 3 hours for V = 9-12 stars***
Measure precise radii for super-Earths and mini-Neptunes

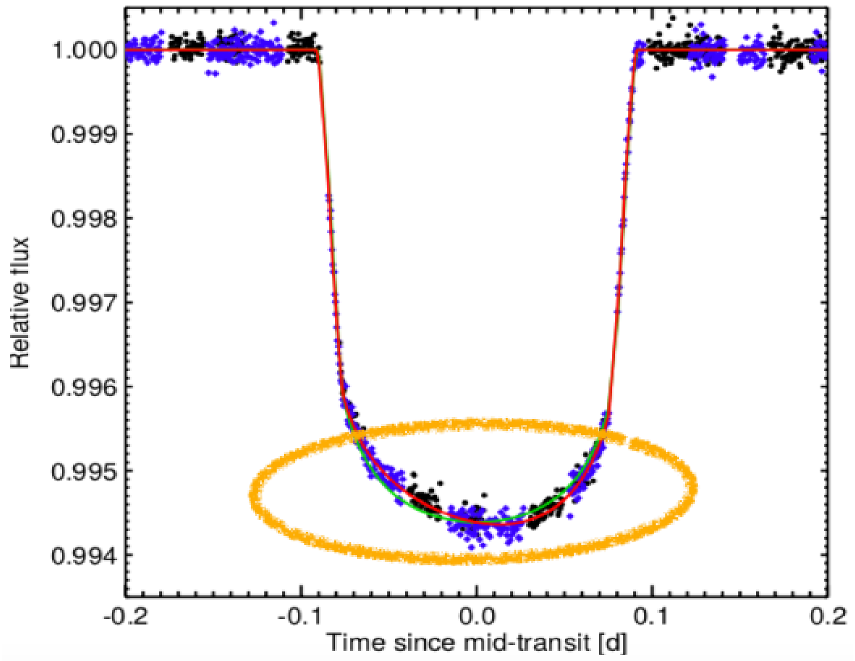
WASP-189b

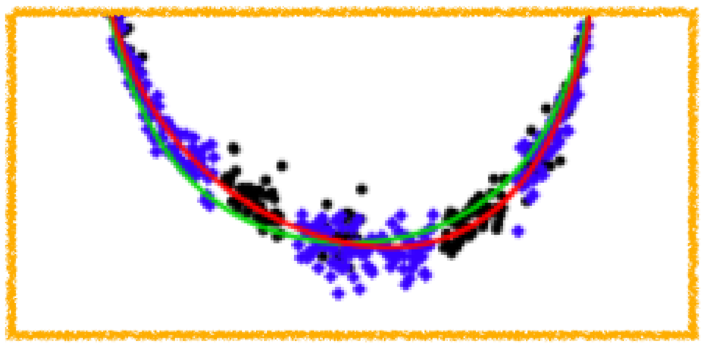


Ultra-hot Jupiter
T_{eq} = 3400 K
2 M_J
1.6 R_J

✓ 4 occultations
✓ 2 transits

WASP-189b transits

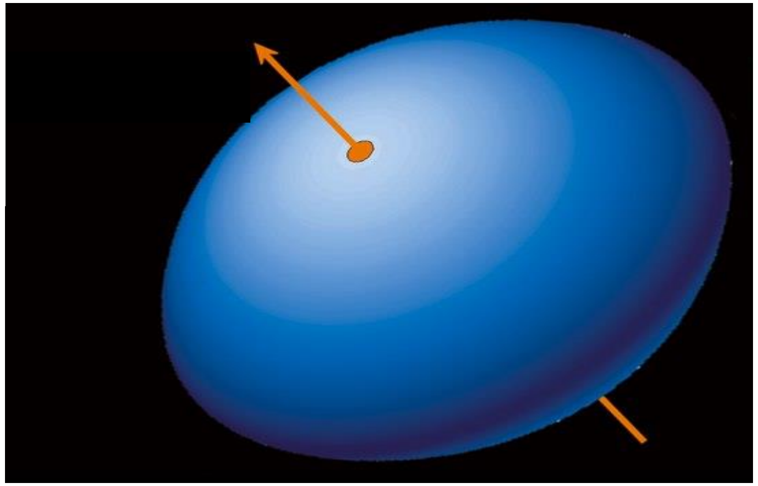




Asymmetric

Gravity darkened host star

Strongly misaligned orbit



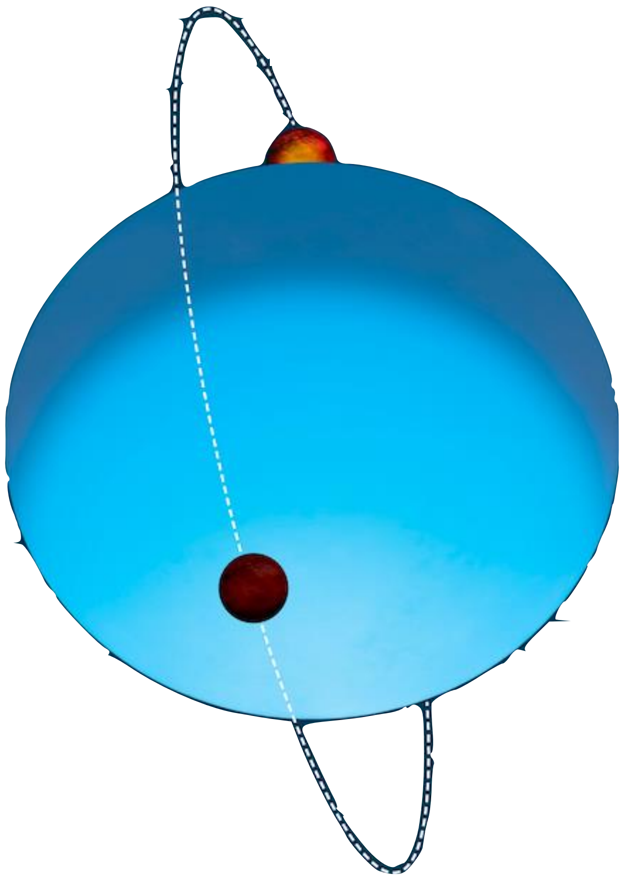
Obliquity:

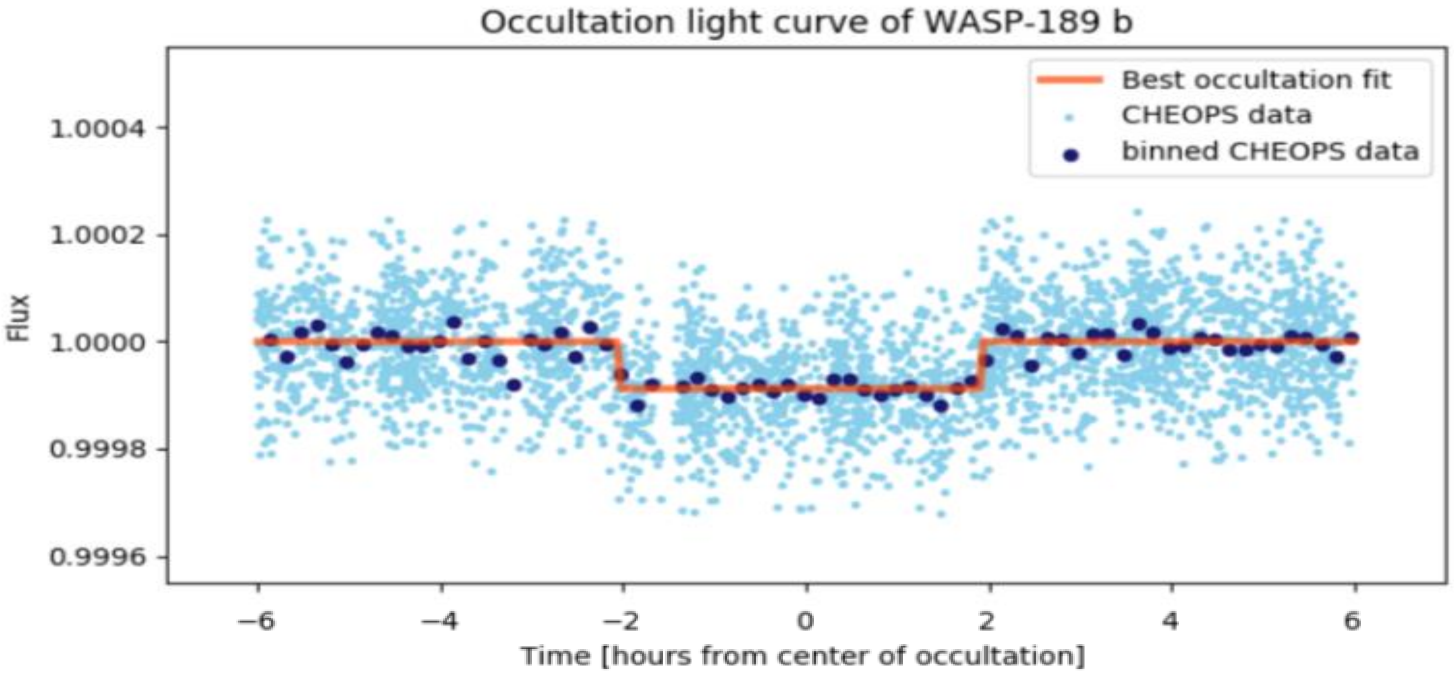
85 ± 4.3 deg

Stellar Inclination:

75.5 ± 3 deg

WASP-189b





A planet with a clear, hot dayside in a polar orbit.

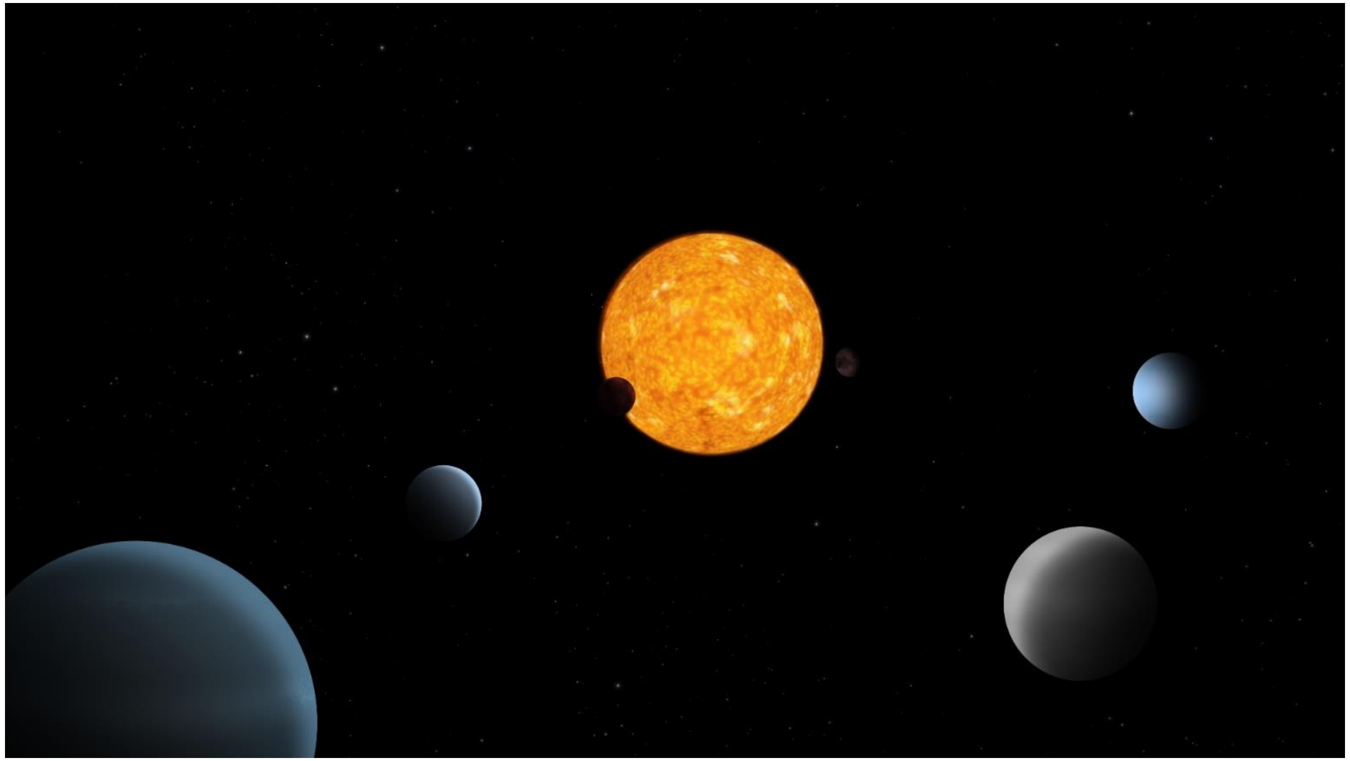
$T_{day,Ag=0}$ = 3435 ± 27 K

1-hour RMS: 5.7 ppm

Lendl et al. 2020

a unique planetary system characterized with CHEOPS

TOI 178 is one of the few (<10) known systems hosting 6 or more planets



It has the unique property of hosting five planets in a 2:4:6:9:12 chain of Laplace resonances.

The inner planet is outside of any resonance, for reasons unknown to us.

Laplace resonances are fragile:

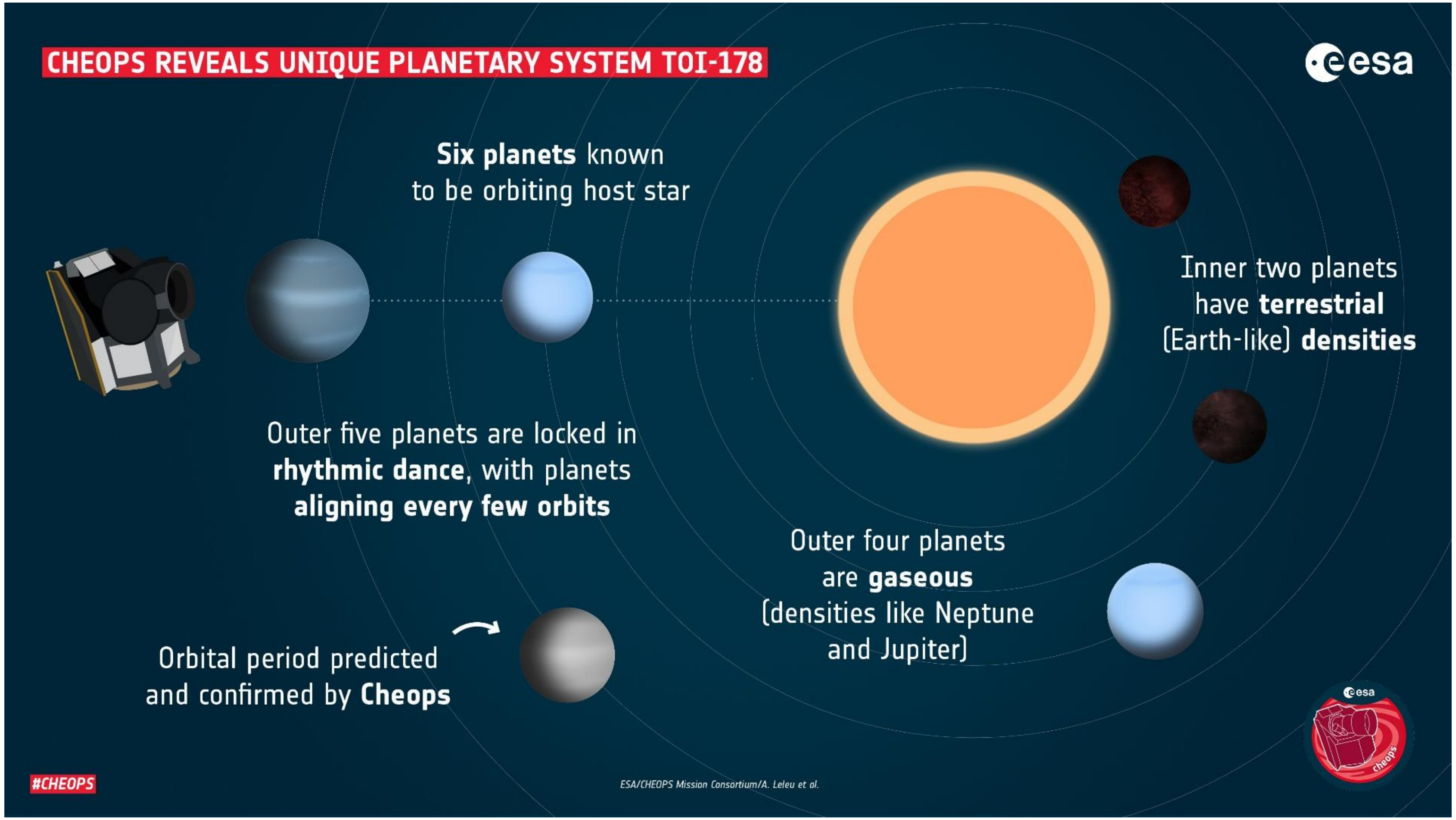
- No significant scattering or collisional event has taken place since the formation of the TOI 178 system

Laplace resonances are rare (we know of 6 among thousands of systems):

- The TOI 178 system is unlike any other Laplace resonances known to date

a unique planetary system characterized with CHEOPS

TOI 178 is one of the few (<10) known systems hosting 6 or more planets



NASA's TESS mission discovered 3 planets in 2018.

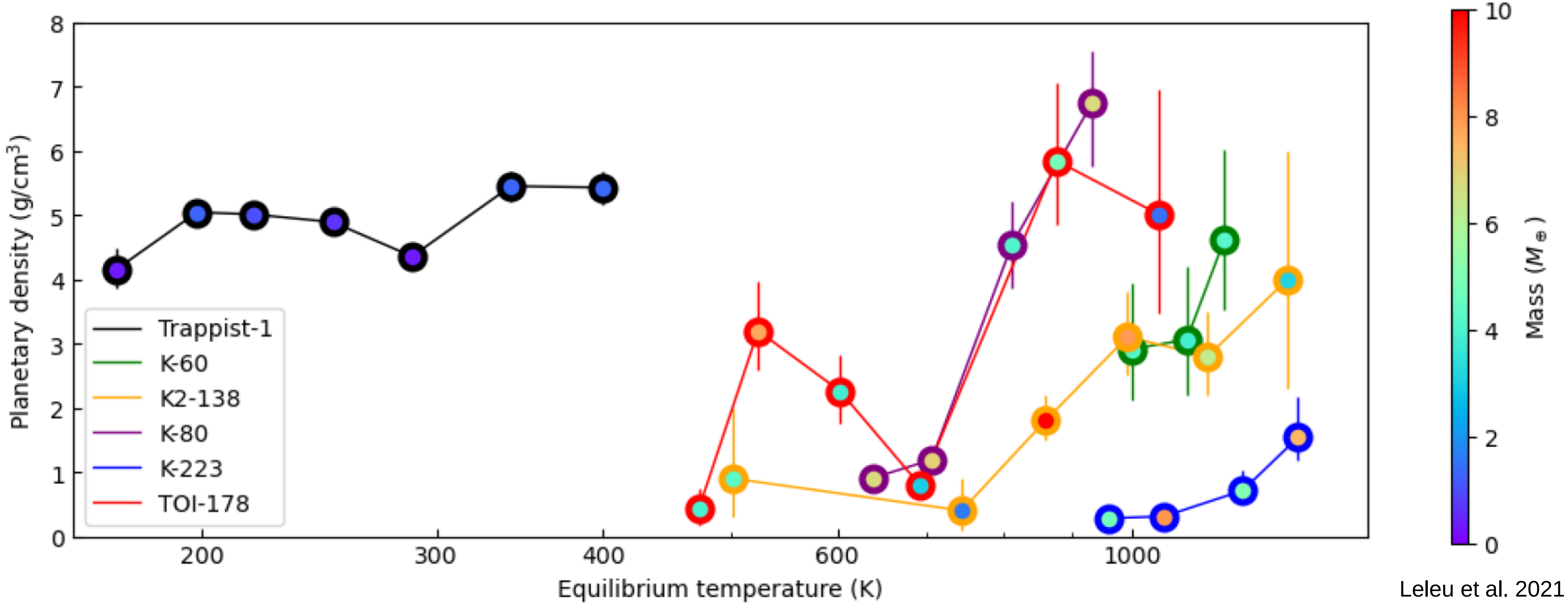
in 2020 ESA's CHEOPS mission:

- Confirmed the existence of two additional inner planets in the system.
- Revealed the true nature of the orbital architecture, the 2:4:6:9:12 chain of Laplace resonances.

Several European teams took part in the characterization of the system: CHEOPS, ESPRESSO, NGTS, and SPECULOOS

A unique planetary system characterized with CHEOPS

6 known multiple planetary systems hosting Laplace resonances



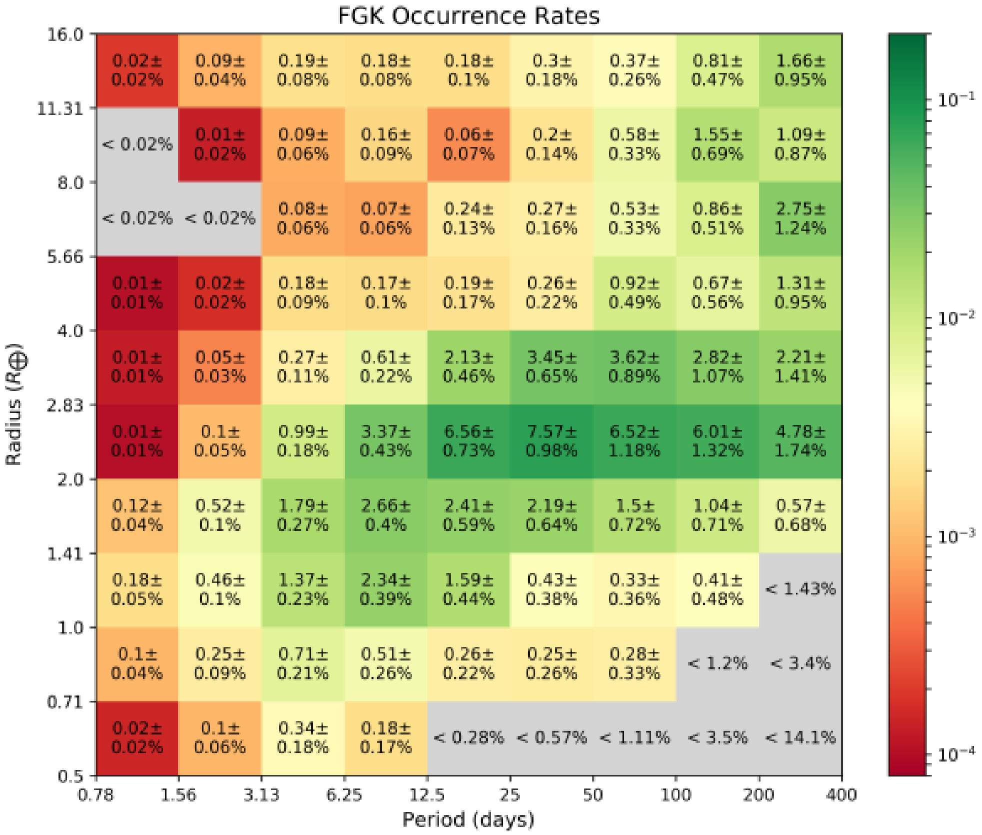
Leleu et al. 2021

The ordered orbital configuration of TOI 178 is at odds with the density variations in the system.

We still investigate today how this system was shaped and what does it tell us about the general processes of planetary formation and evolution, including our own solar system

The statistical point of view…

Small planet occurance rates from the Kepler mission



Kinumoto&Mathews, 2020,arXiv:2004.05296v2

And: eta-Earth from Kepler mission ranging from 0.37 to 0.88 planets per star (depending on definition of HZ) (Bryson et al., 2020, arXiv:2010.14812)

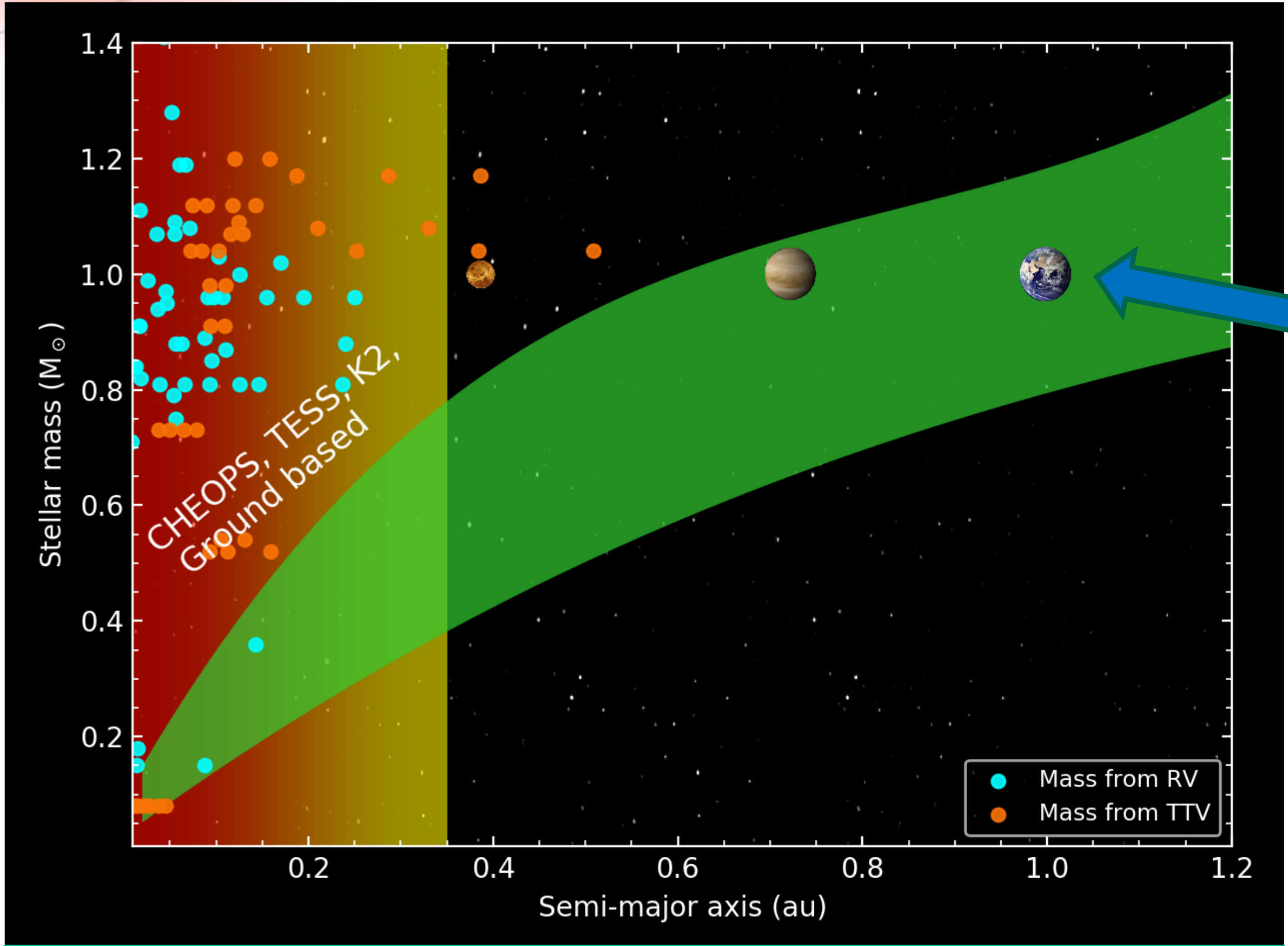
How many stars have small planets?:

- The kepler mission showed us that basically every star has a planet.
- 17% of dwarf stars may have a super-earth.
- But: The occurance rates for small planets in the habitable zone are not well known yet.

→ Main search range for PLATO

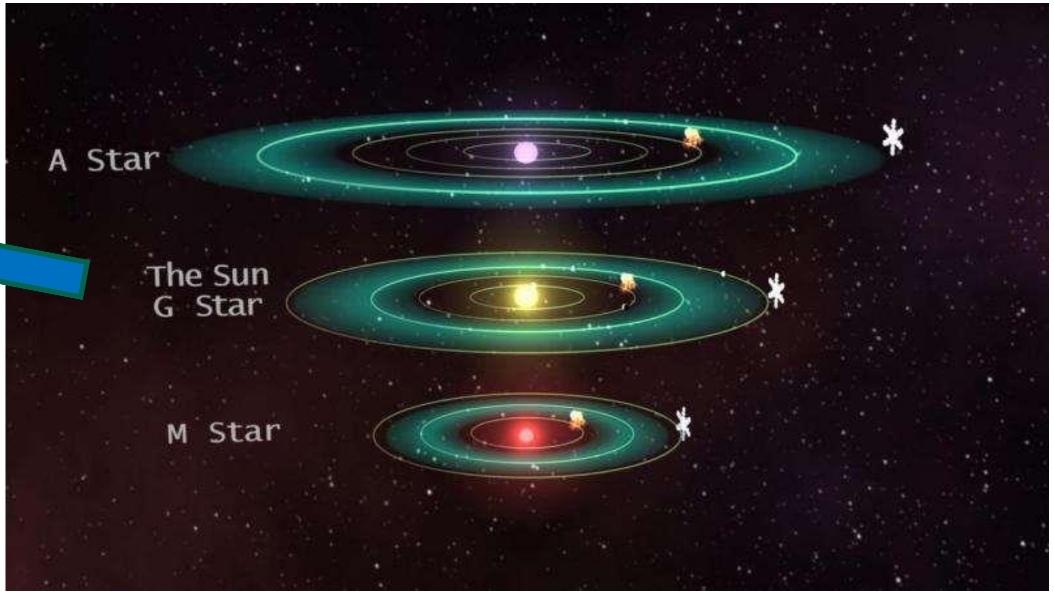
The PLATO Mission

Following CHEOPS and TESS...



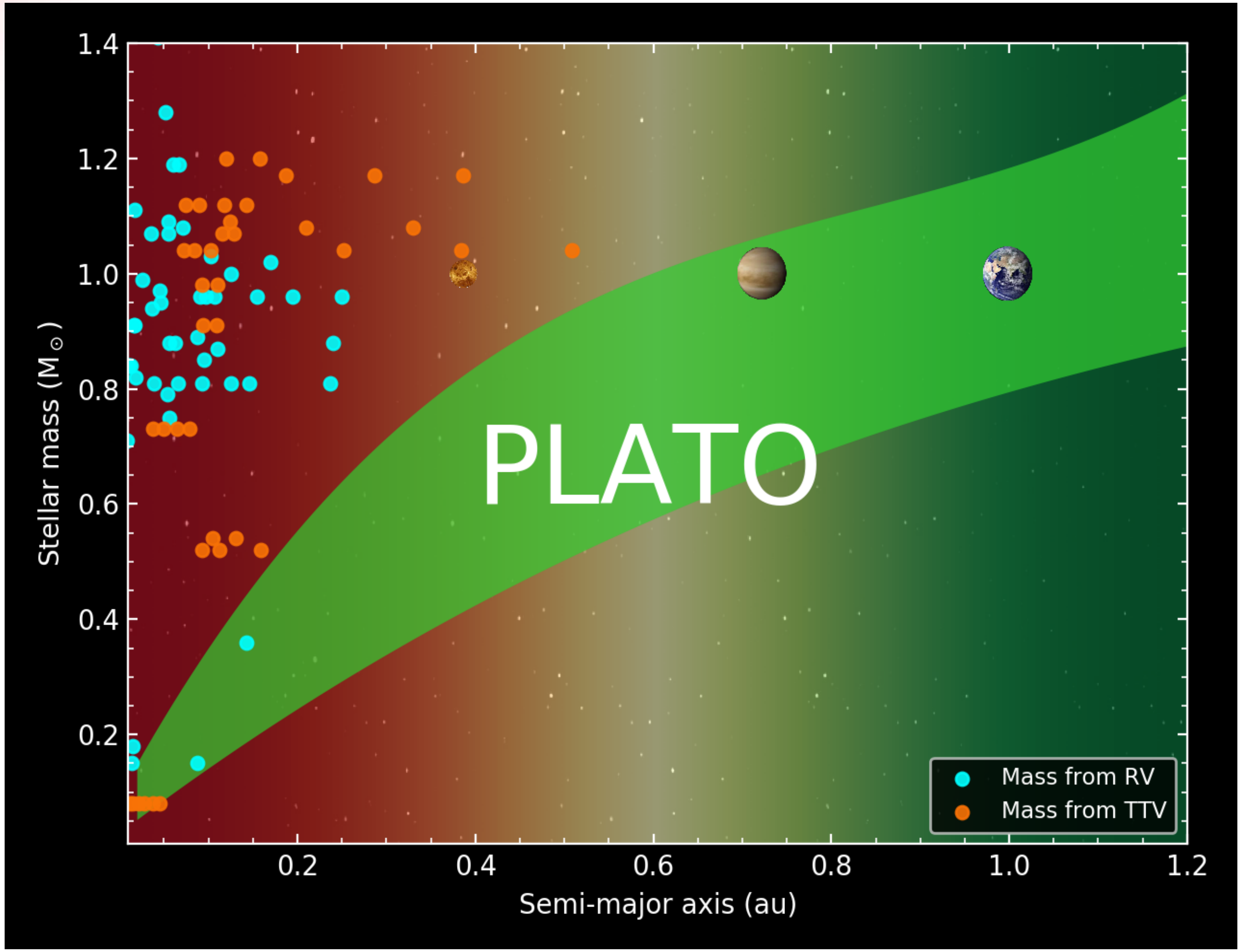
Dots: Small planets with measured radius and mass.
(less than twice the Earth and less than 10 Earth masses)

The habitable zone for different types of stars:



No characterized rocky planets in the habitable zone of Sun-like stars are known!

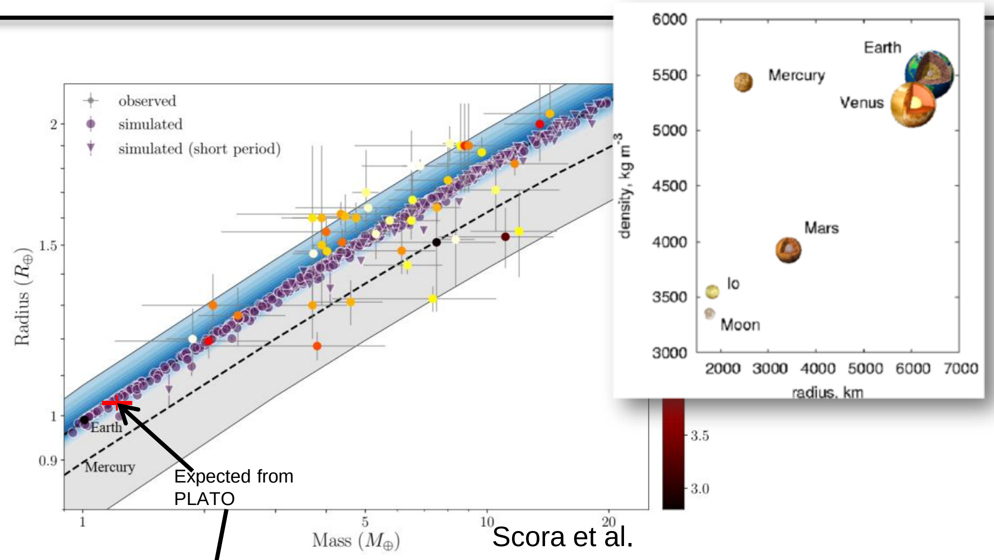
Characterisation of super-Earths around solar-like stars



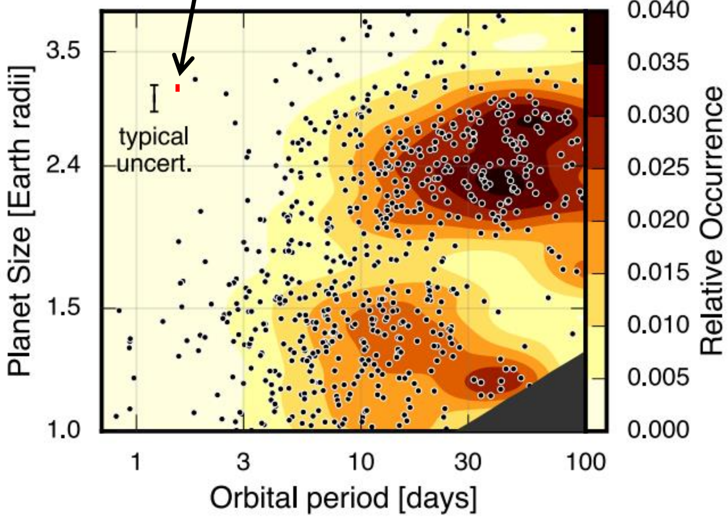
$1 < M_{planet} \leq 10 M_E$
$R_{planet} \leq 2 R_E$

Science Objectives

- Determination of prime properties (**mass, radius, mean density**) of exoplanets with high precision, including terrestrial planets in the habitable zone of Sun-like stars
- Study planetary evolution (**system ages**)
- Internal structure of stars via asteroseismology
- Identification of good targets for spectroscopic follow-up of planet atmospheres (JWST, ARIEL, …)



Scora et al. 2019



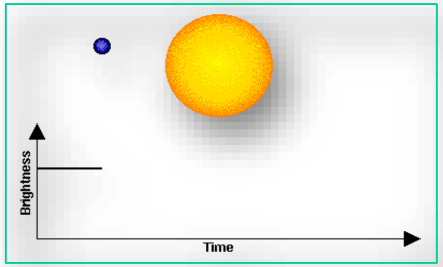
Fulton & Petigura 2019

The PLATO Mission

Goals and Methods

Prime mission goals:

- Detect a large number of extrasolar transiting planets, including **Earth-sized planets up to the habitable zone of solar-like stars**
- Determine precise **planetary radii, masses**, hence **mean densities**
- Investigate seismic activity in stars, enabling the precise characterisation of the planet host star, including its **age**

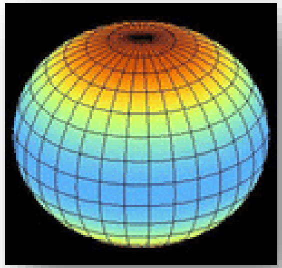


Transit detection

→ Planet/star radius ratio

→ Inclination

+

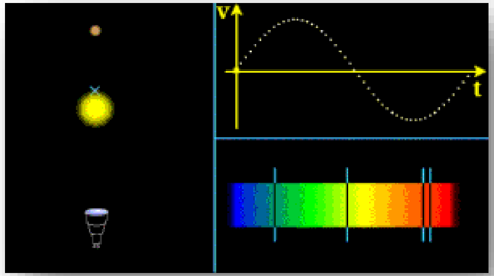


Asteroseismology

→ Stellar radius, mass

→ Stellar age

+

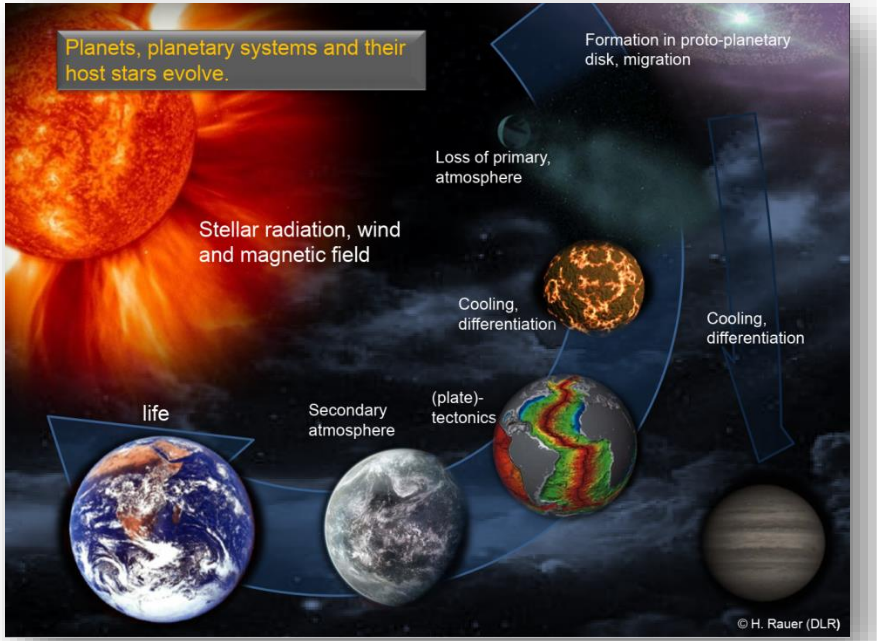


Ground-based observations

→ Planet mass

→ Mean density

→ Age



The PLATO Mission

- **Payload design drivers:**
  - **Planet detection**

    → large number of target stars
  - **Planet and star characterization**

    → bright target stars → wide field-of-view

  → **multi-camera approach:**
    - 24 normal cameras (photometry)
    - 2 fast cameras (fine-guidance, photometry (red and blue))

ESA/ATG medialab

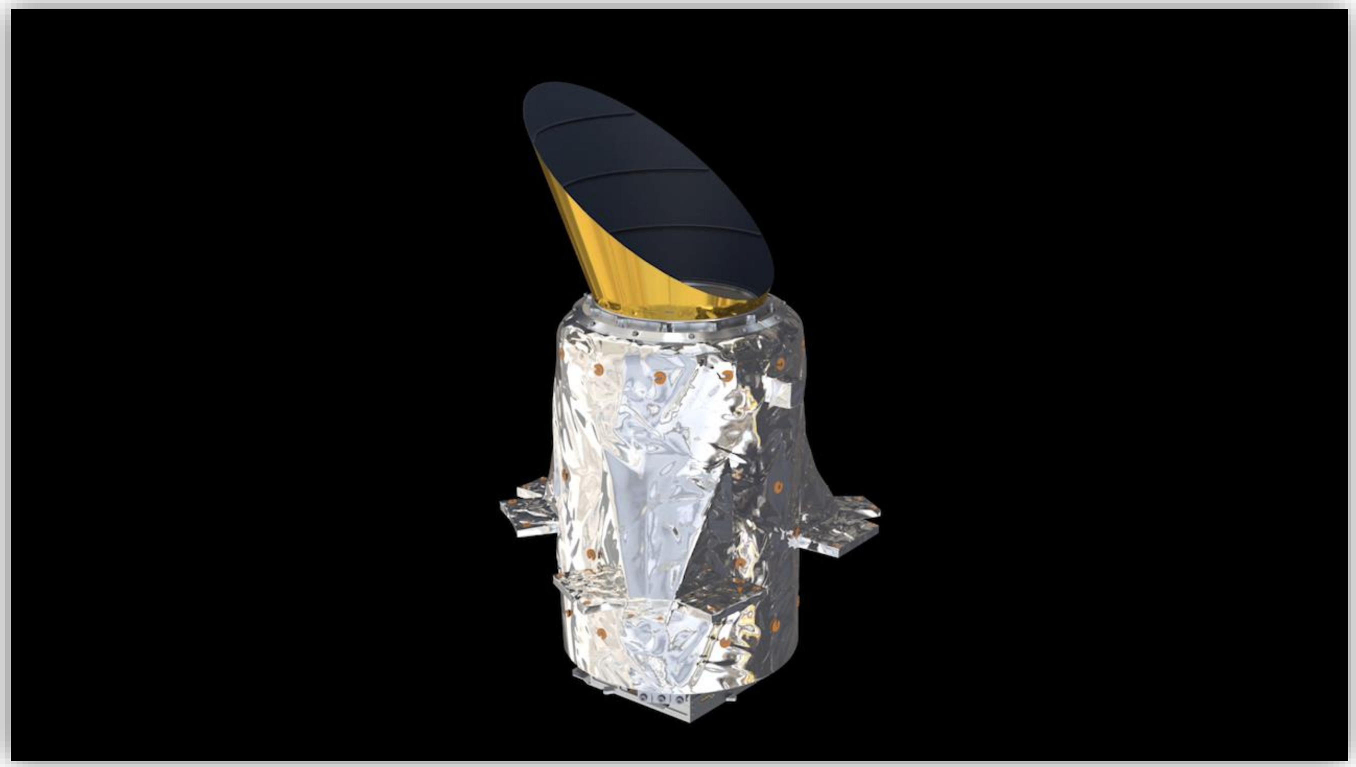
PLATO payload

24 Normal cameras:

- 12cm aperture telescopes
- range: ~8 ≤ m_V ≤ 11 (13)
- FOV payload ~49°x 49°
- Each camera has 4 x CCD, each 4510×4510px
- Pixels size: 18 µm square
- read-out cadence: 25 sec
- operate in “white light” (500 – 1050 nm)

2 Fast cameras:

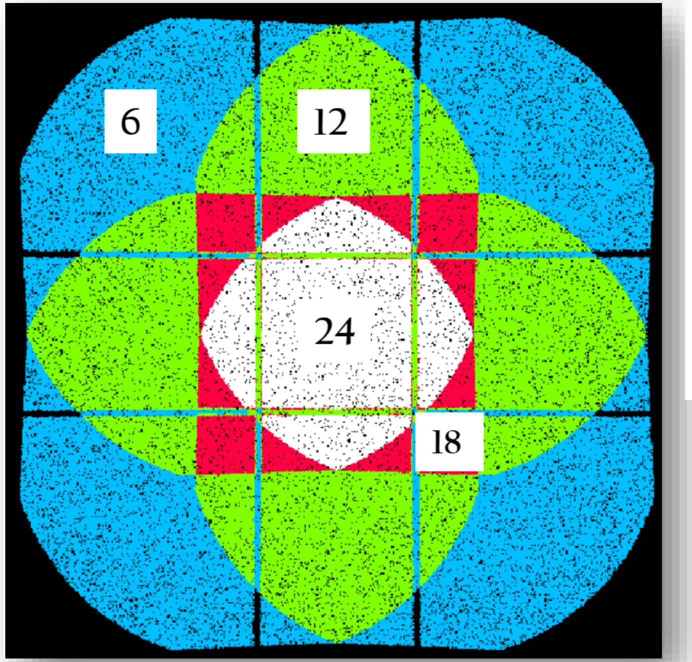
- Bright stars (<~8 mag)
- read-out cadence: 2.5 sec
- one „red“ & one „blue“ camera

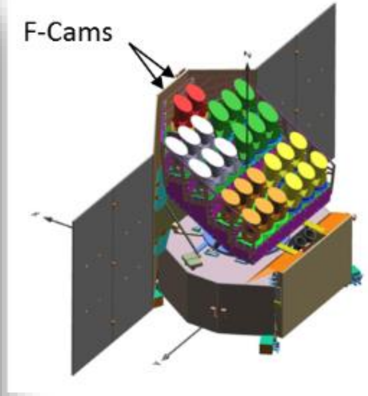


ESA/ATG medialab

ESA/ATG medialab

The instrument field of view is **2 200 square degrees** (vs 105 deg^2 Kepler)



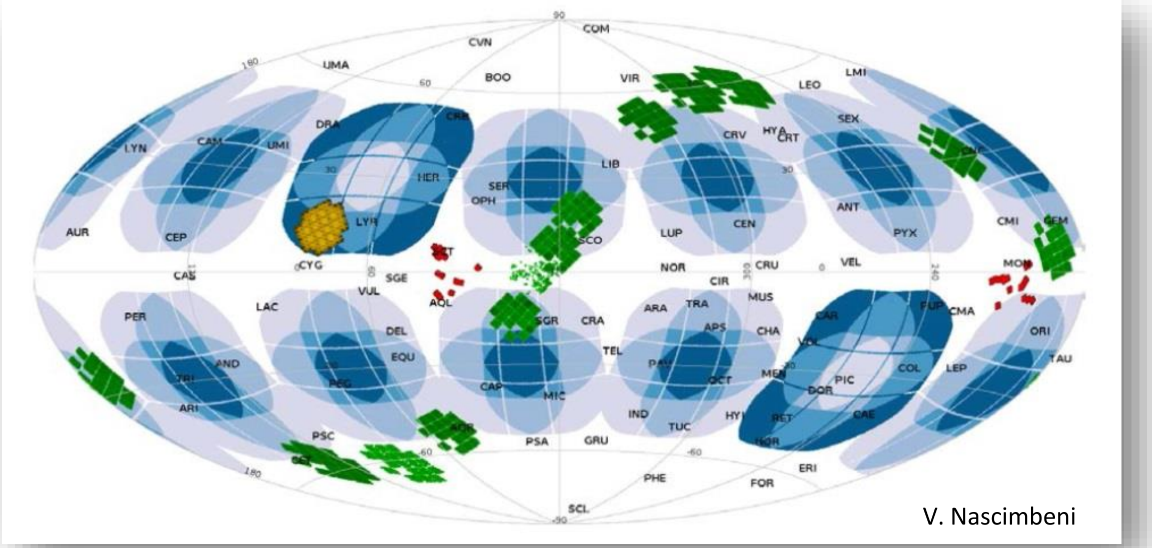


The FoV is spread over:
~2 billion pixels (2 000 Mpx vs 98 Mpx for Kepler)
~6 600 cm^2 of sensitive area (2x Gaia)

PLATO Baseline Observing Scenario

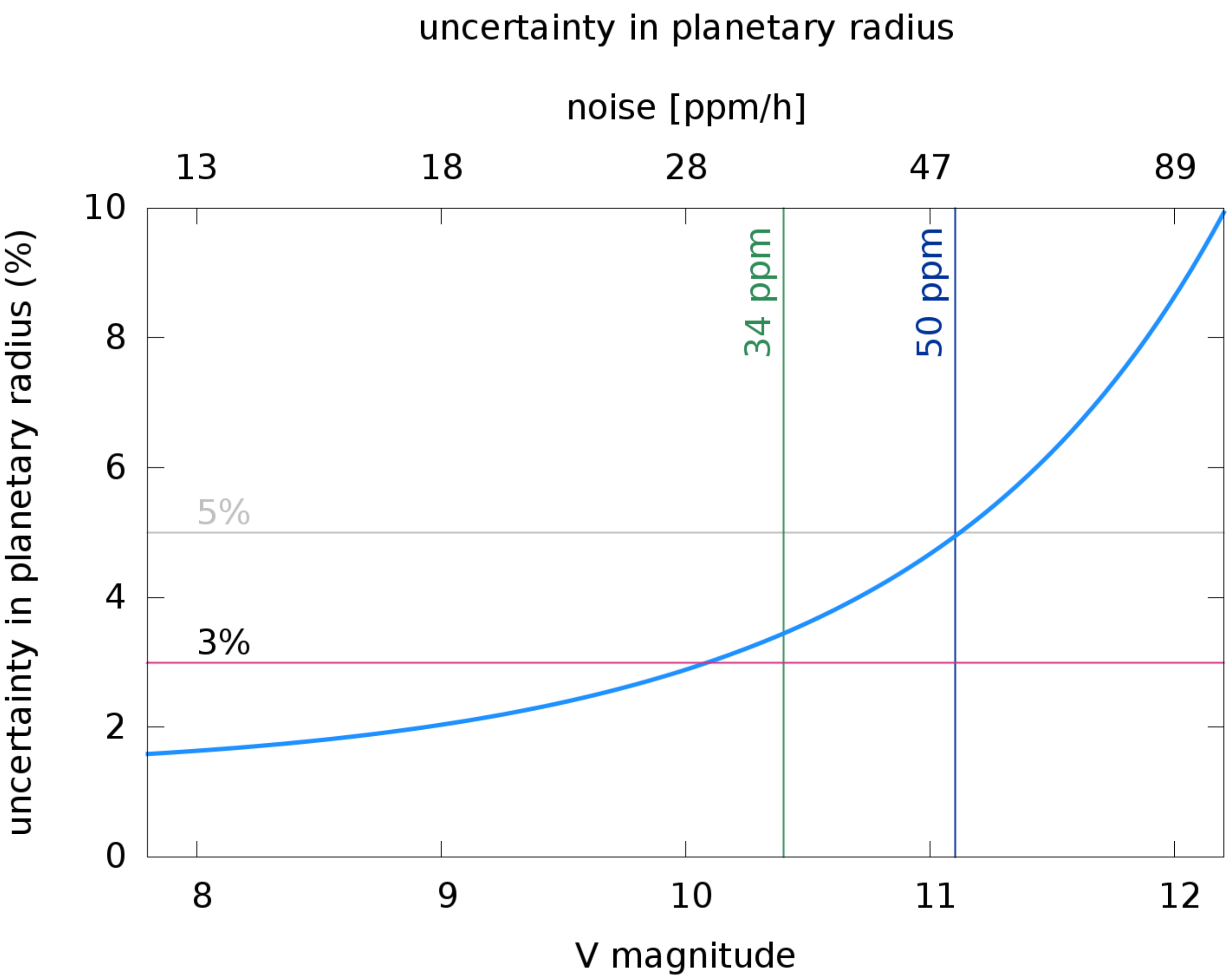
- Launch end 2026 into orbit around L2 Earth-Sun Lagrangian point.
- Mission science operations: 4 years duration.
- Satellite/instrument designed to last with full performance for 6.5 years.
- Consumables will last 8 years.

- **Observing strategy:**
  - **Baseline:**
    2 long pointings of 2 years
  - Alternative:
    3 years + 1 year step-and-stare phase
  - And then: ask for extended mission if needed.



- The final observing strategy will be fixed 2 yrs before launch and can be adapted during the mission.

Planetary radius precision



Expected radius precision:
Based on instrument design requirements for characterization of small planets:

→ 3% planet radius precision for stars <10.3 mag (Earth around Sun case)

→ 5% radius precision for stars >10.3 up to about 11 mag

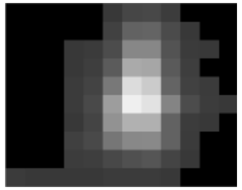
202

Courtesy Sz. Csizmadia and the PLATO performance team

Stellar samples

- PLATO has a set of lightcurve samples defined with different precision.
- The main samples are:
  - **Core sample:** ~15 000 dwarf and sub-giant stars (F5 to K7) with <11 mag
    - 34 ppm in 1 hour for <10mag; 50 ppm for <11 mag

    → high precision planet and stellar parameters (radii, asteroseismology)

  - **„Statistical“ sample**: >245 000 dwarf and sub-giant stars with <13 mag

    → statistics, good planet radii precision; but no asteroseismology, no RV

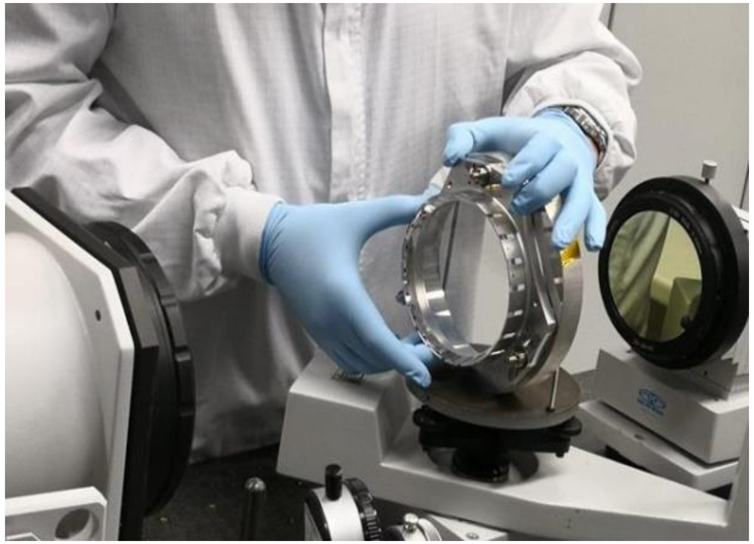
  - >5 000 late type stars (M dwarfs)

- **Expected Planets**
  - >4 000 (goal 7 000) detected planetary systems
  - >100 with highest planet parameter precisions, **including habitable zone planets**

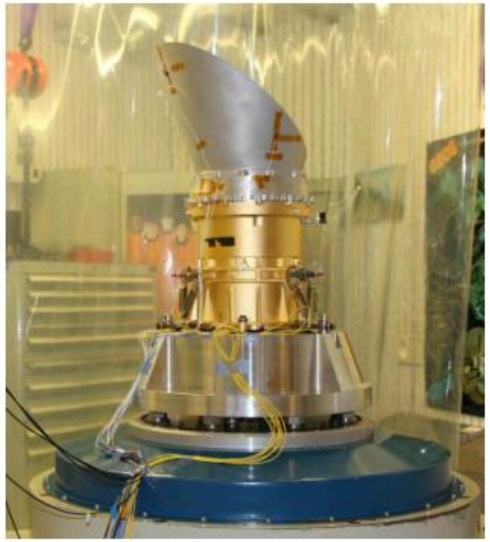
Payload going into Phase C…

Model of camera baffle

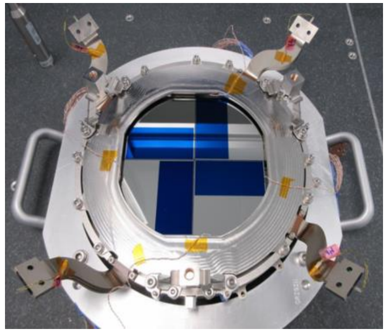
Camera lens….



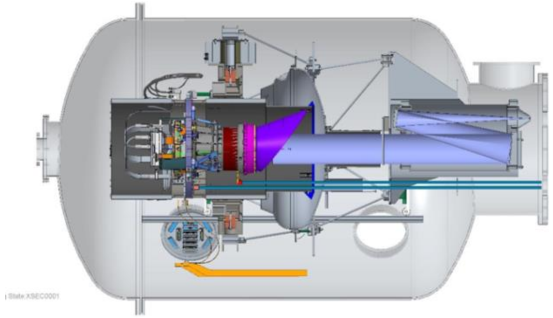
Tube and baffle



Integration procedure test for CCDs in focal plane



Design of one out of three test houses



A ets

1861

Nicolas Camille Flammarion, 1861

Exoplanets remains a fascinating research field.