Detection and characterization of exoplanets from space

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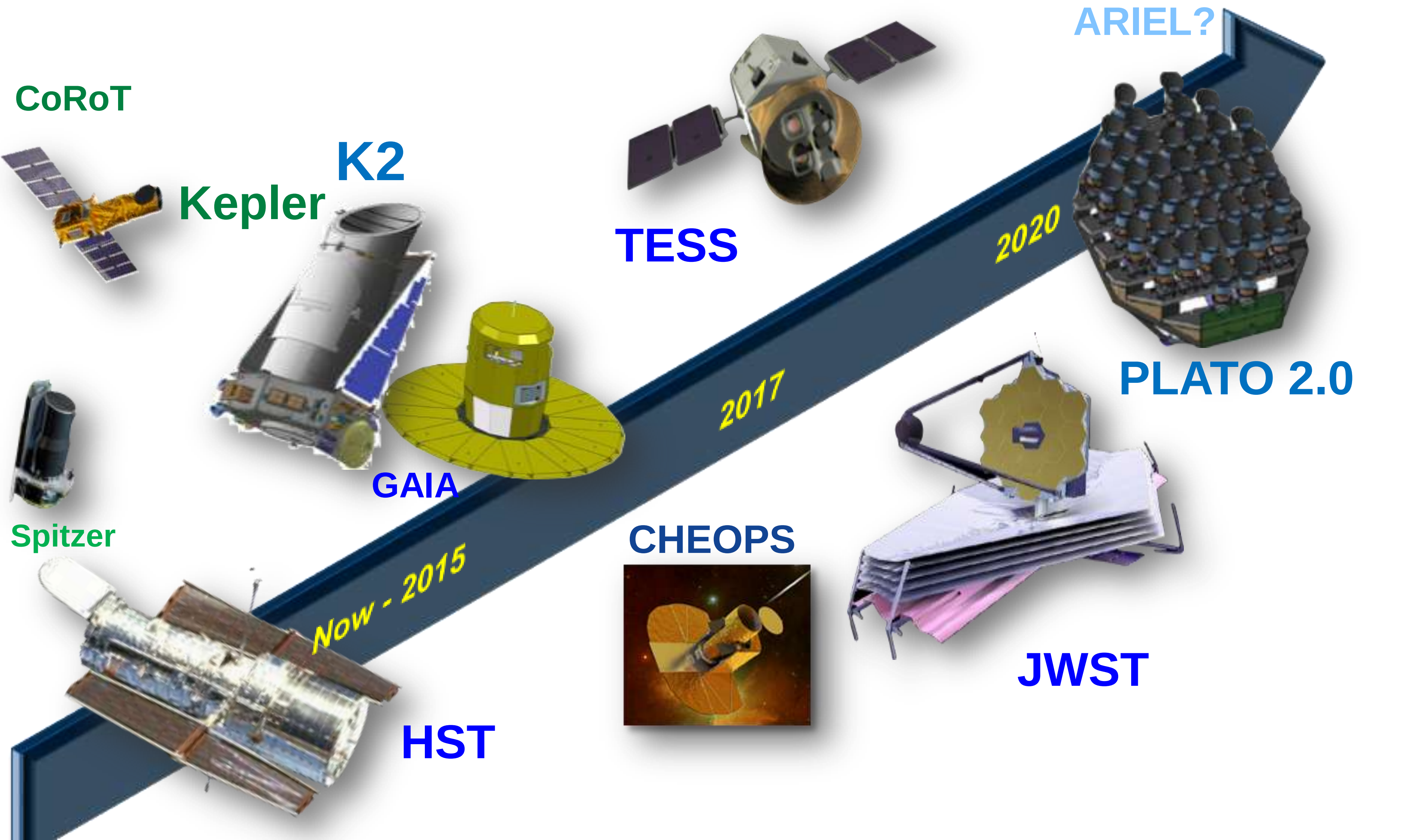
Exoplanet Space Missions and Space Observatories

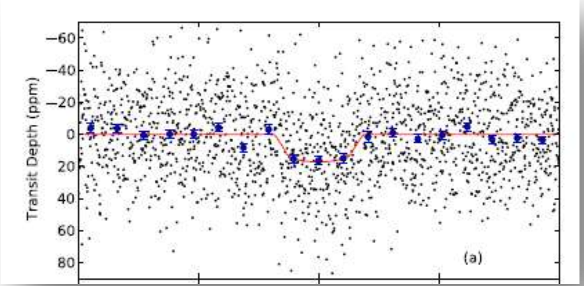


Space-based detection and characterization: Some examples: Detection

- **Terrestrial planets**
- **Temperate transiting planets**
- **Co-planar systems**
- **Statistics**

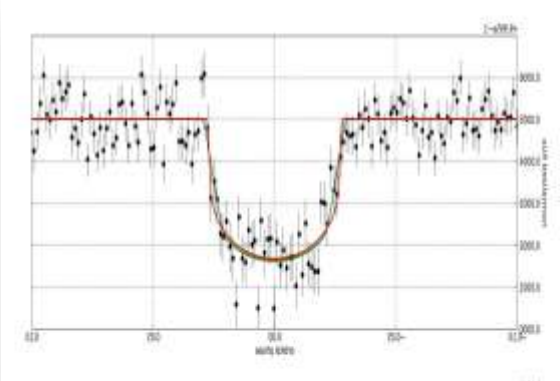
Kepler-37b

0.3 Re, Barclay et al. 2013



CoRoT-7b

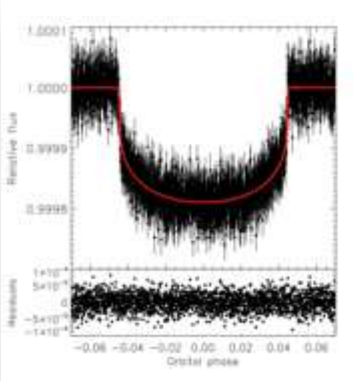
(Leger et al. 2009, Barros et al. 2014)

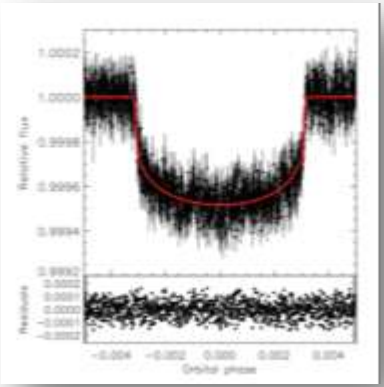


- Radius: 1.5Re
- Density: 8.1 g/cm3
- Period: 0.85 days)

Kepler-10b and -10c

(Batalha et al. 2010)



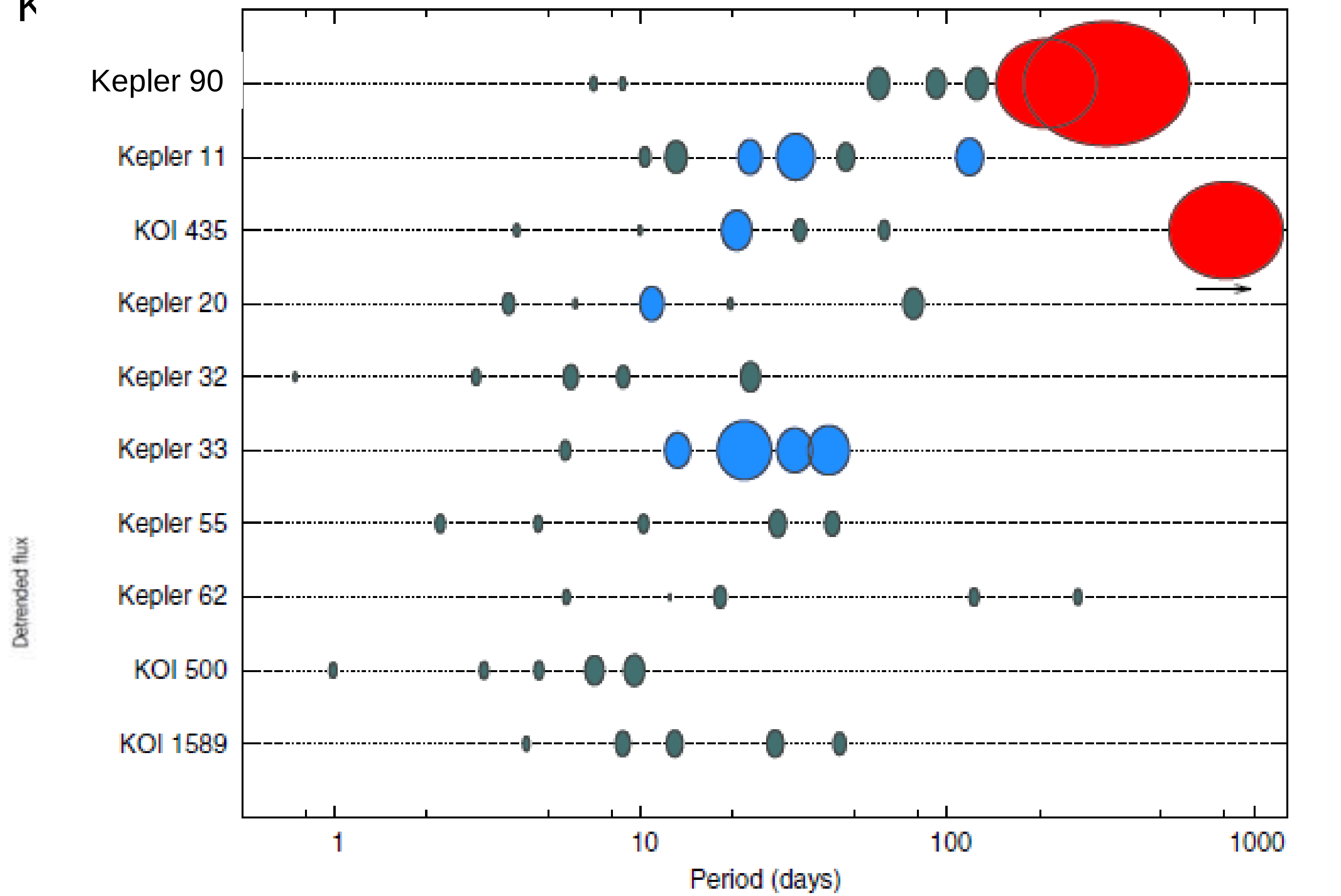


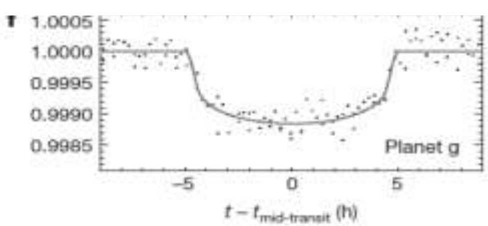
- Radius: 1.7Re
- Density: 5.1 g/cm3
- Period: 0.84 days)

- Radius: 2.3Re
- Density: 7.1 g/cm3
- Period: 45 days)

Co-planar transiting systems

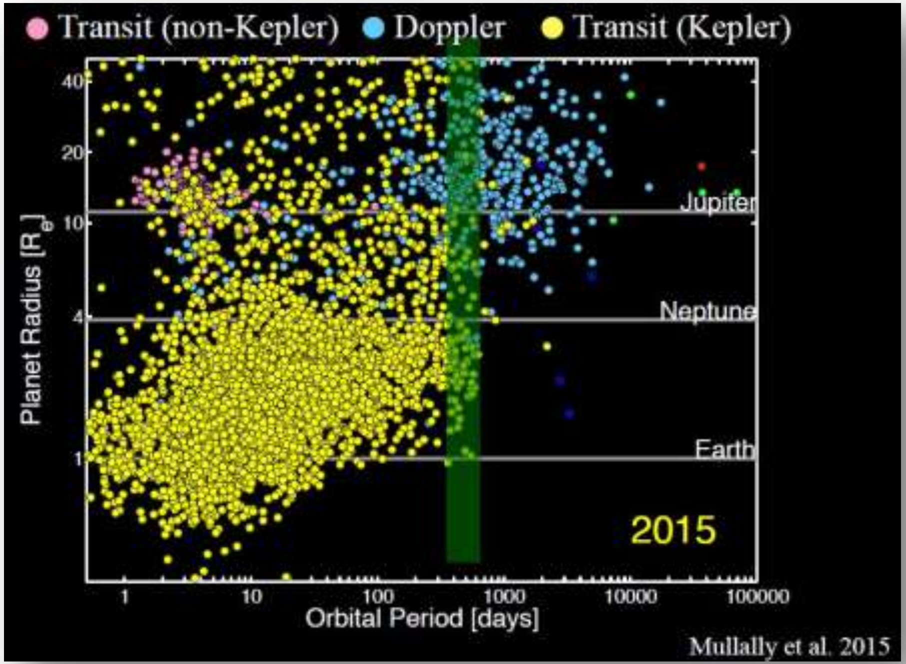
K ... em



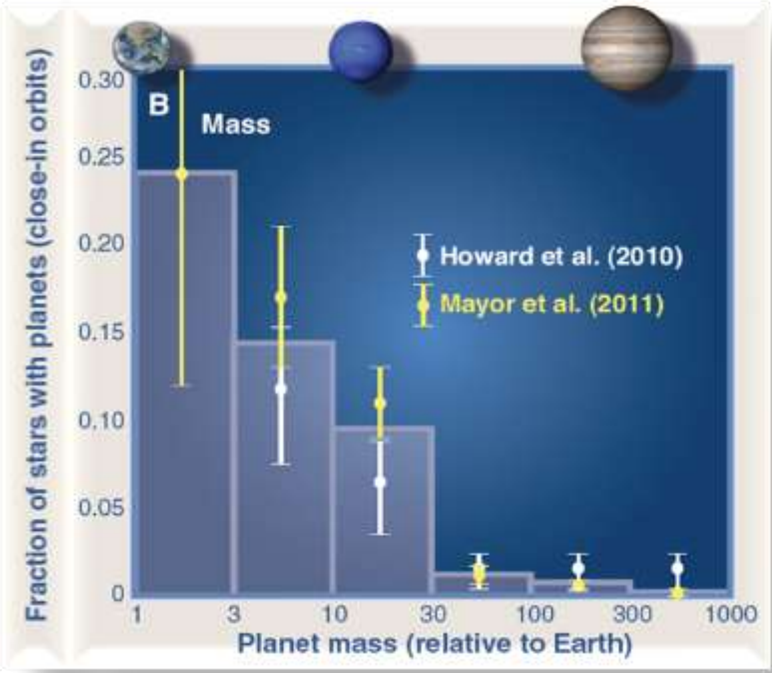


Planet detection statistics

Kepler planet candidate statistics



Radial velocity surveys



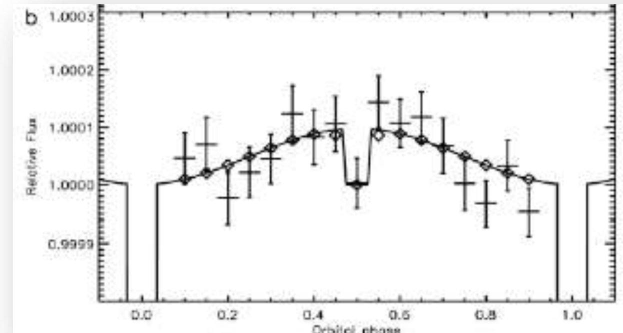
- *Kepler* mission and radial-velocity surveys tell us:

  → small and low-mass planets are numerous

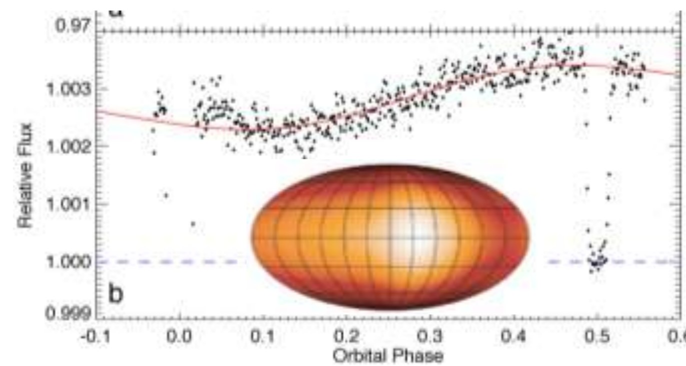
Space-based detection and characterization: Some examples: Characterization

- Atmosphere spectroscopy
- Secondary eclipse
- Phase curves
- Albedos
- Clouds
- …

CoRoT-1b
(Snellen et al. 2009)

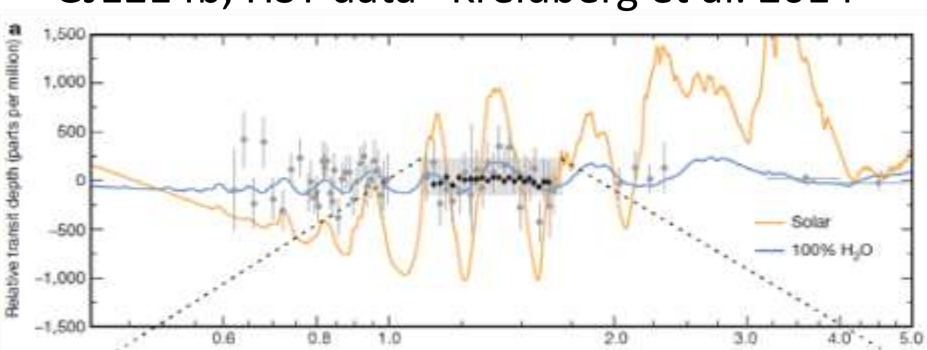


Spitzer: HD189733b



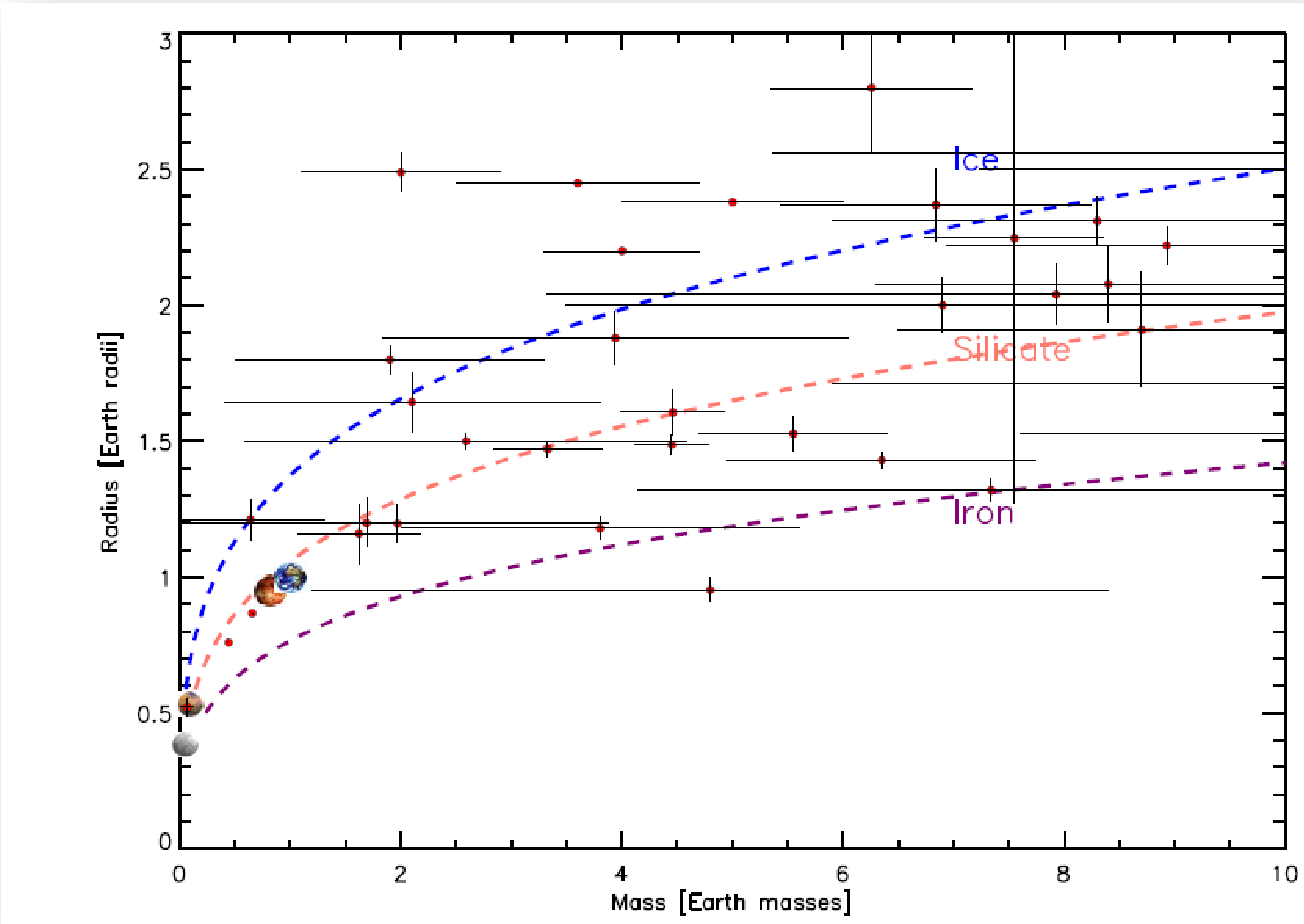
Knudsen et al. 2007

GJ1214b, HST data Kreidberg et al. 2014



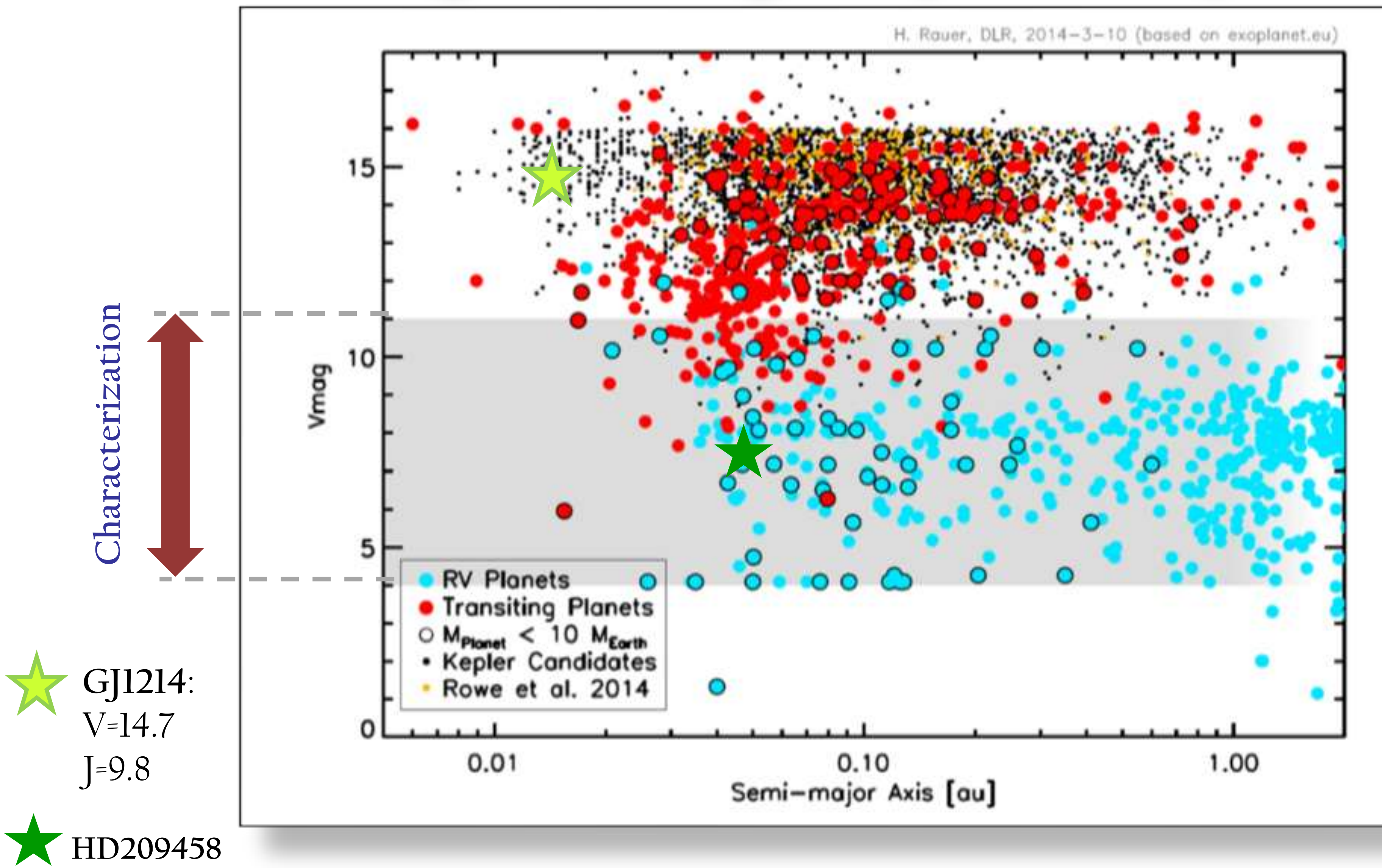
Mass-Radius in the super-Earth domain

Super-Earths: Rp ≤ 3 Rearth; Mp ≤ 10 Mearth

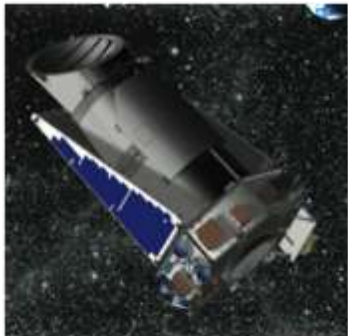


- → Dashed lines: planets of different compositions.
- → Simplified cases of pure compositions. In reality there will be mixtures.

Magnitude range of past surveys

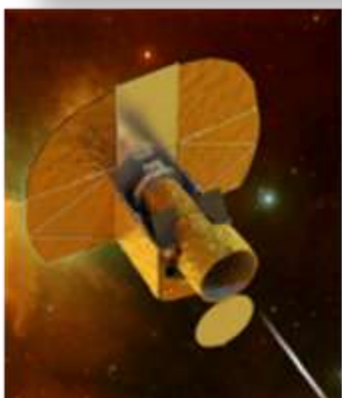


What's next?: Space-based



K-2 (Kepler 2)
(NASA)

observe fields in the ecliptic plane for ~80 days/field
95 cm aperture, Earth trailing
7 – 17 mag
(Koch et al., 2010)



CHEOPS
(ESA, launch 2017)

follow-up, accurate radii
30 cm aperture, Earth orbit
6 - 12 mag
(CHEOPS Red Book)

TESS
(NASA, launch 2017)

scan the whole sky, ~1 month/field,
~2% of sky at poles for 1 year
10 cm aperture, 4 telescopes, Earth-Moon orbit
4 – 13 mag
(Ricker et al., 2014)

cheops

ESA’s first small scientific satellite (S1)

Joint mission ESA/Switzerland

PI: W. Benz, Univ. Bern, CH

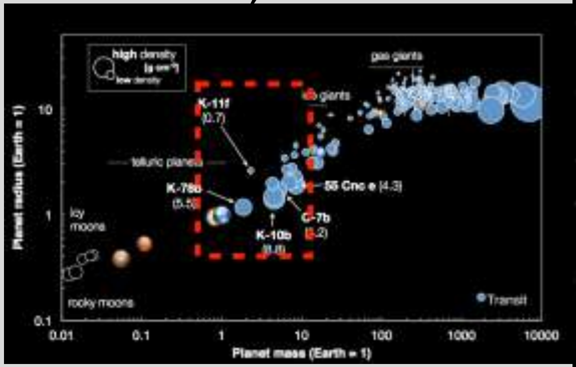
Selected December 2012, adopted June 2014, launch-ready end 2017

CHEOPS

CHARACTERISING EXOPLANET SATELLITE

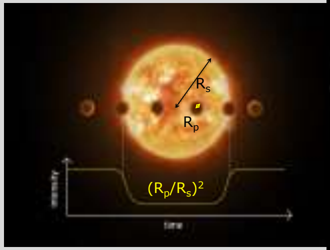
CHEOPS science - I

- Mission dedicated to the search for exoplanet transits of local, bright stars already known to host exoplanets:



  - Detection and characterisation of transiting exoplanets with masses < 30 M_{earth} through wideband transit photometry
 (radius better than 10%)

  - Follow-up, pointed observations:
    - Known exoplanets → Follow-up mission → pointed observations, know <u>where</u> and <u>when</u> to point



    - Bright host stars (V<12) → precise mass measurements available /feasible, detailed knowledge of the star

Credit: K. Isaak

CHEOPS science - II

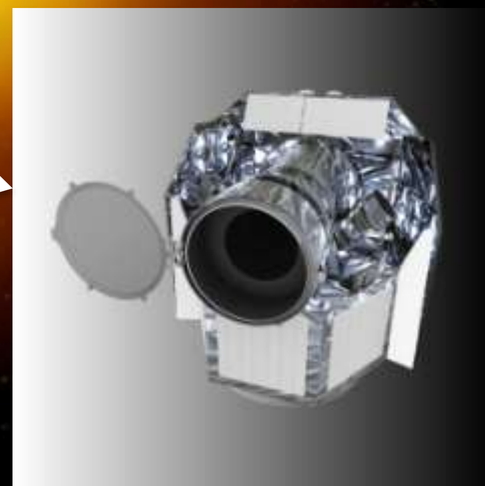
- First-step characterisation of super-Earths and Neptunes: precision masses+radii → measurement of bulk density
  - Insight into physics and formation of planets
  - Identification of planets with atmospheres
  - Constraints on planet migration
- Identification of golden targets for spectroscopic characterisation
- Probing atmospheres of hot-Jupiters using phase curve measurements
  - Study of physical mechanisms and efficiency of energy transport

Credit: K. Isaak

CHEOPS Targets

Ground-based transit surveys
eg. NGTS

TESS (launch 2017)



Ground-based RV surveys
Eg. HARPS, HARPS-N, HIRES, SOPHIE
(on going) ESPRESSO *(2017)*

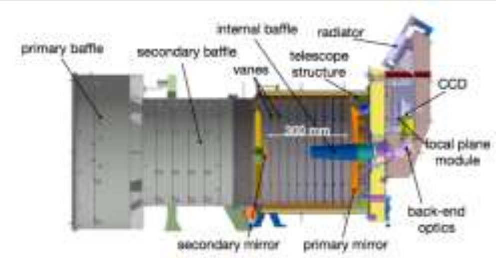
Open-time proposals (20%)

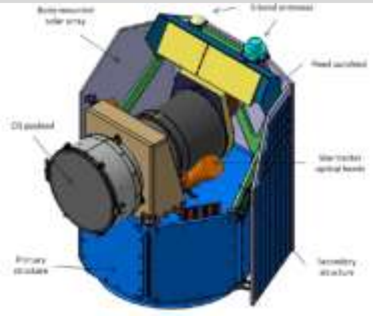
Kepler/K2 survey

CHEOPS in a nutshell

- **Payload**:
  - Single-band high-precision photometer (0.4-1.1 um)
  - Single CCD, 1k x 1k pixels, 13 um pitch, -40 deg C
  - Compact Ritchey-Chrétien telescope, dia.=320 mm
  - Entrance baffle provides high stray-light rejection
  - Defocussed PSF minimises impact of spacecraft jitter

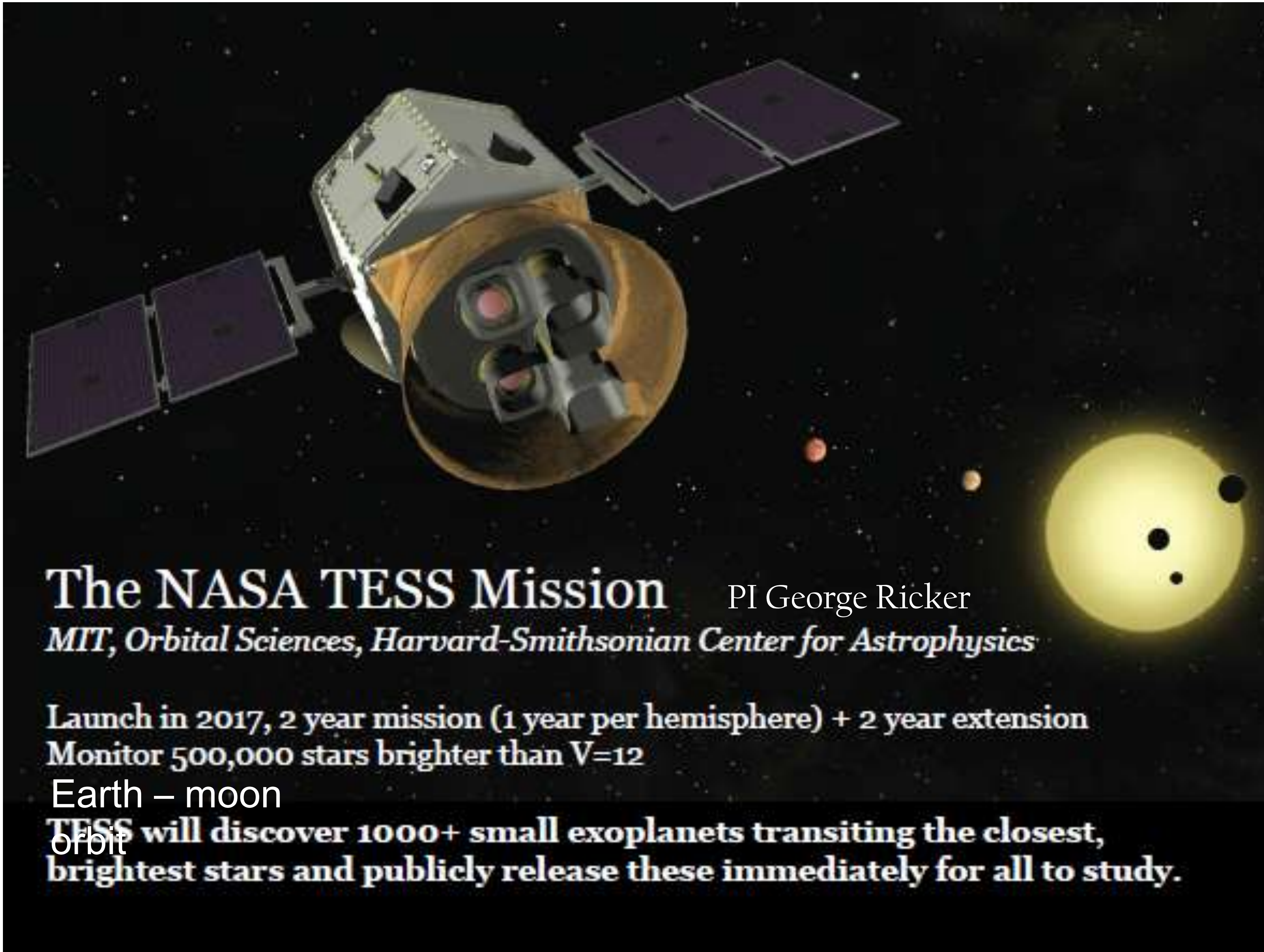
  60 kg / 60 W / 1 Gb downlink budget per day





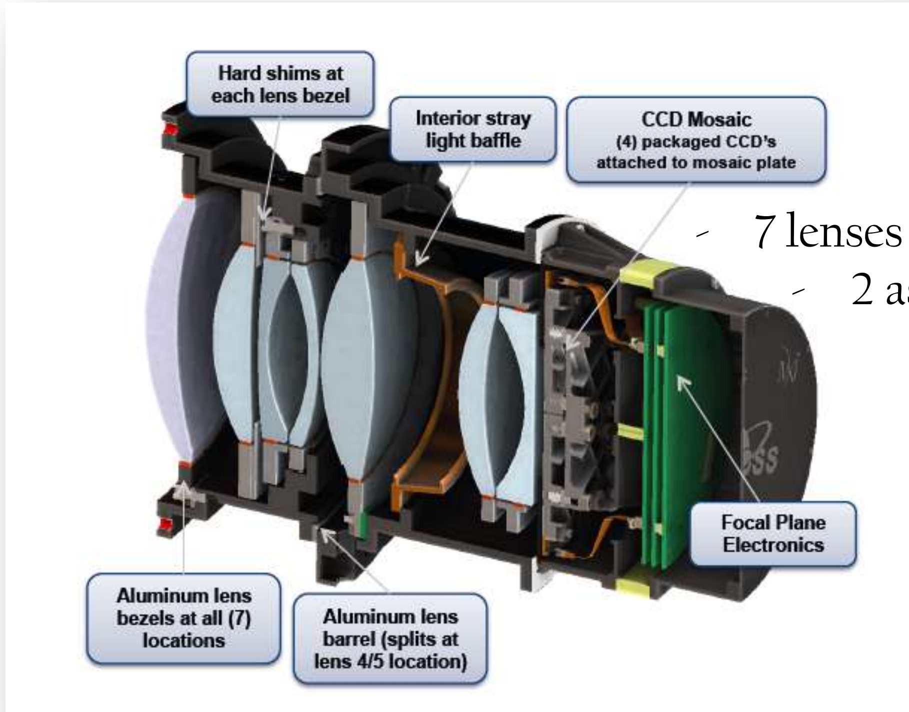
- **Platform**: ~1m^3, ~ 250 kg class.
  - adapted from commercial small platforms
  - 3-axes stabilised, APE < 4 arcsec (rms)
  - roll around Line of Sight, radiators pointed to cold space
- **Orbit:** Sun-synchronous, dawn-dusk, 650-800 km altitude, 6AM LTAN
- **Launch**: secondary passenger → launch date driven by primary passenger
- Mission lifetime of 3.5 years (goal 5 years)

Credit: K. Isaak



Credit: D. Charbonneau

TESS Instrument



- 7 lenses
- 2 asphere

Ricker et al. 2014

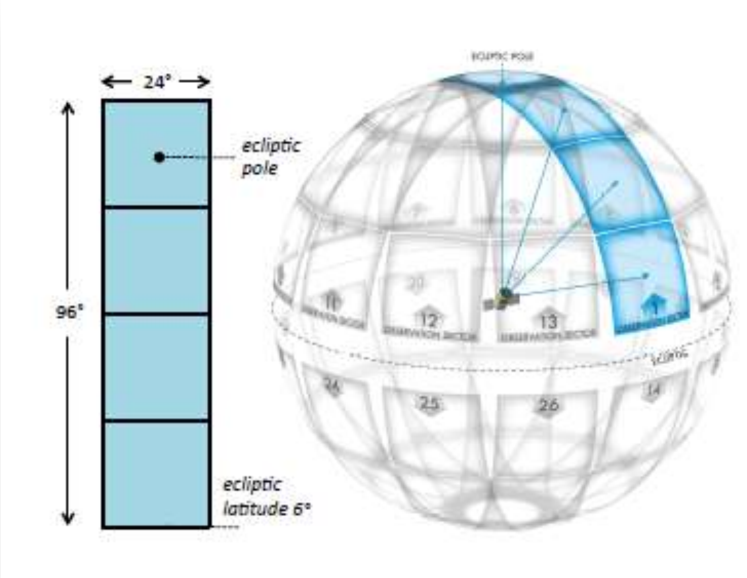
Field of view of each lens	$24° \times 24°$
Combined field of view	$24° \times 96° = 2300$ sq. deg.
Entrance pupil diameter	10.5 cm
Focal ratio ($f/\#$)	$f/1.4$
Wavelength range	600–1000 nm
Ensquared energy	50% within 15×15 μm (one pixel, or 0.35×0.35 arcmin) 90% within 60×60 μm (4×4 pixels, or 1.4×1.4 arcmin)

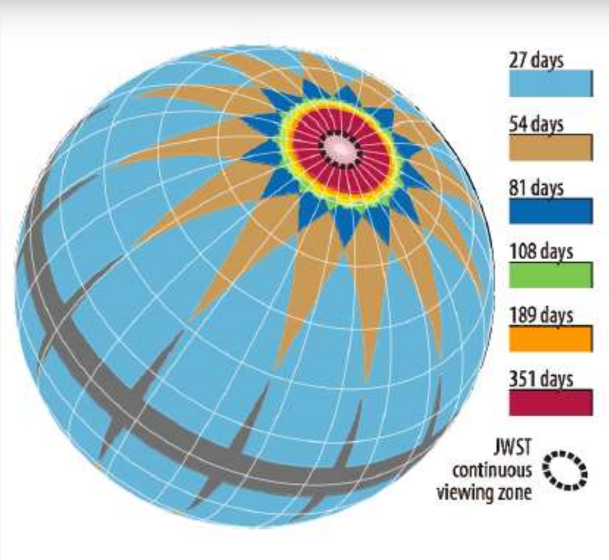
TESS Sky coverage

scan the whole sky, ~1 month/field,
~2% of sky at poles for 1 year

- P_{max} ~ 10 days in general
- P_{max} >40 days surrounding the ecliptic poles

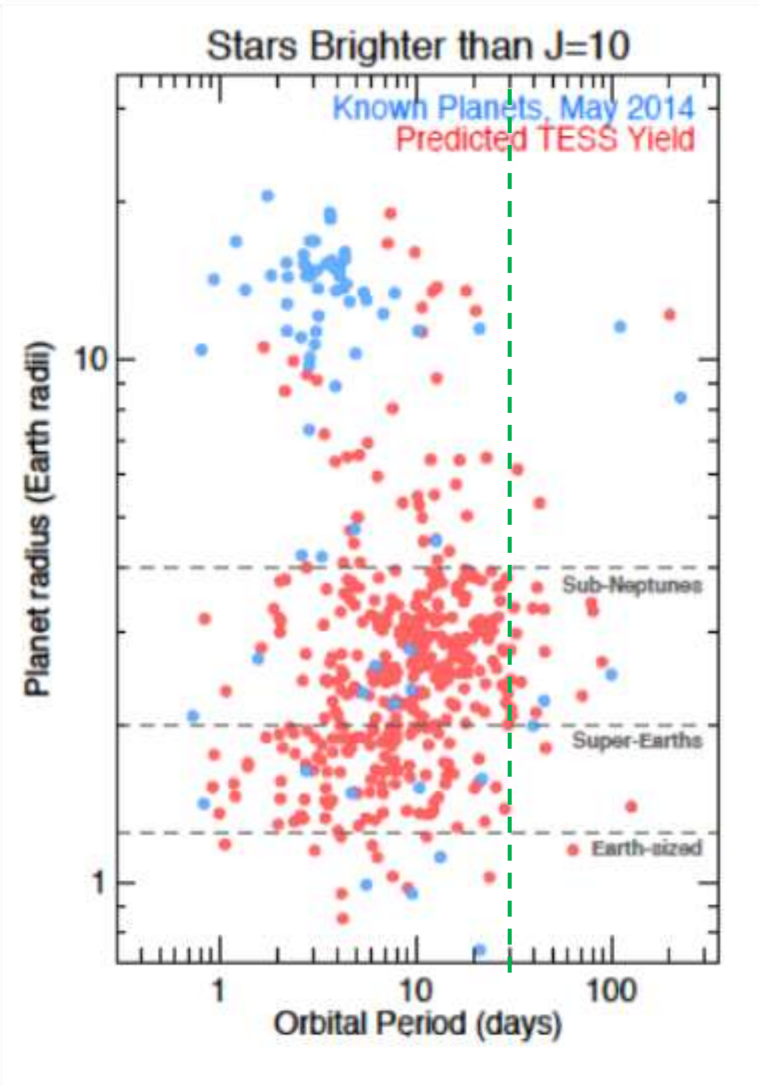
- ~ 30,000 square degrees are observed for at least 27 days
- Close to the ecliptic poles, ~ 2800 square degrees are observed for more than 80 days
- Surrounding the ecliptic poles, ~ 900 square degrees are observed for more than 300 days

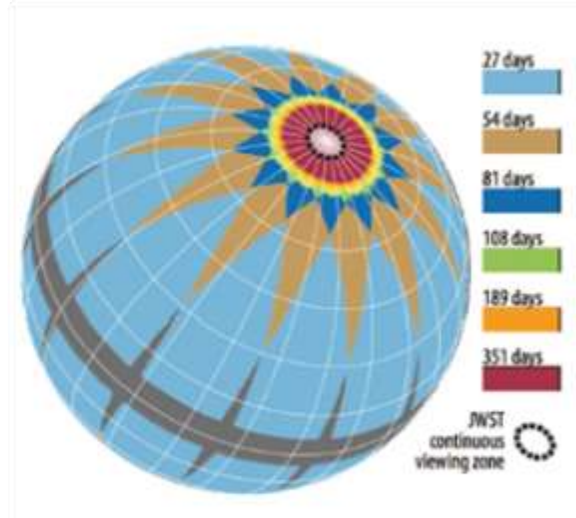




Ricker et al., 2014

TESS planets

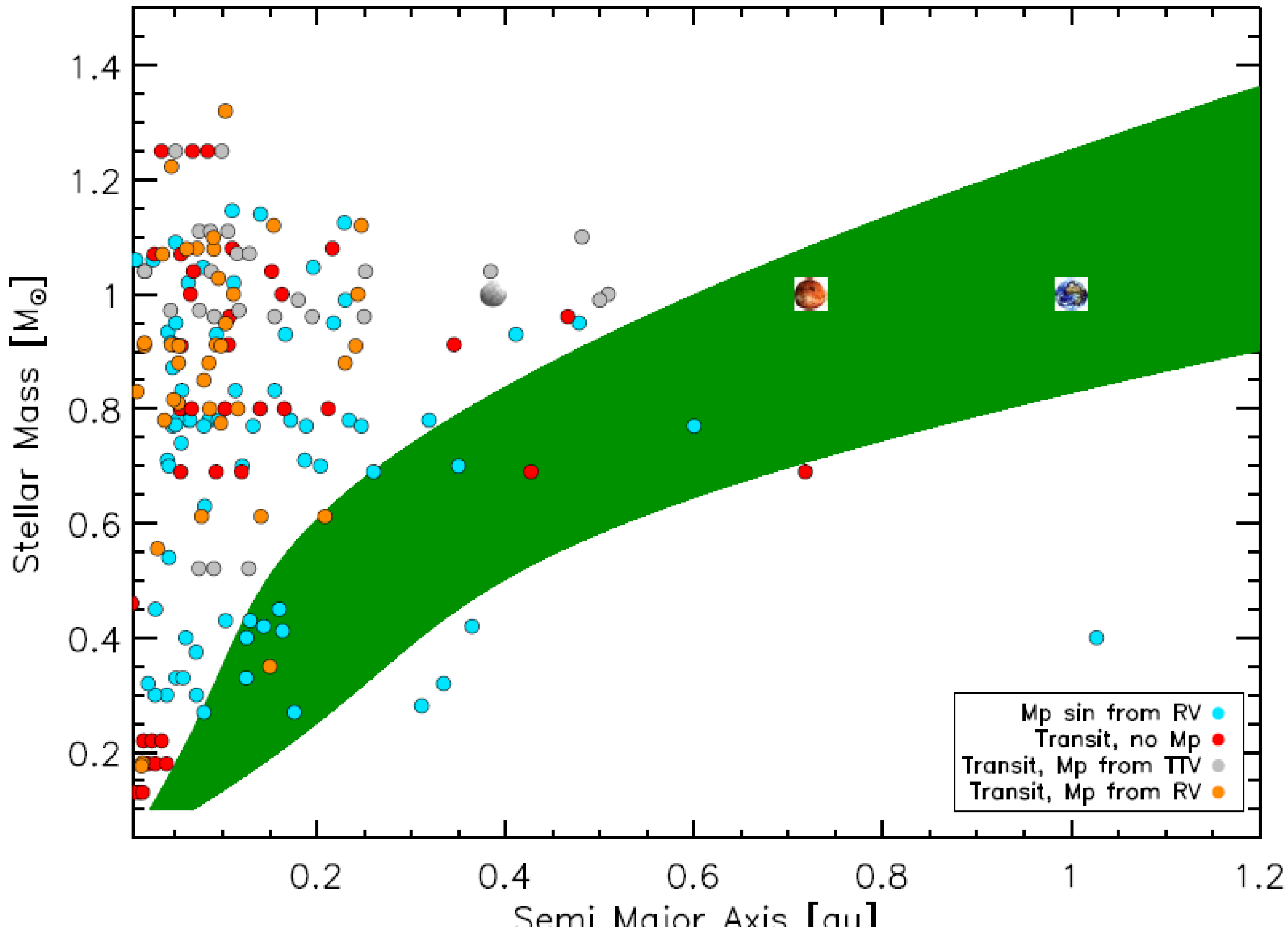




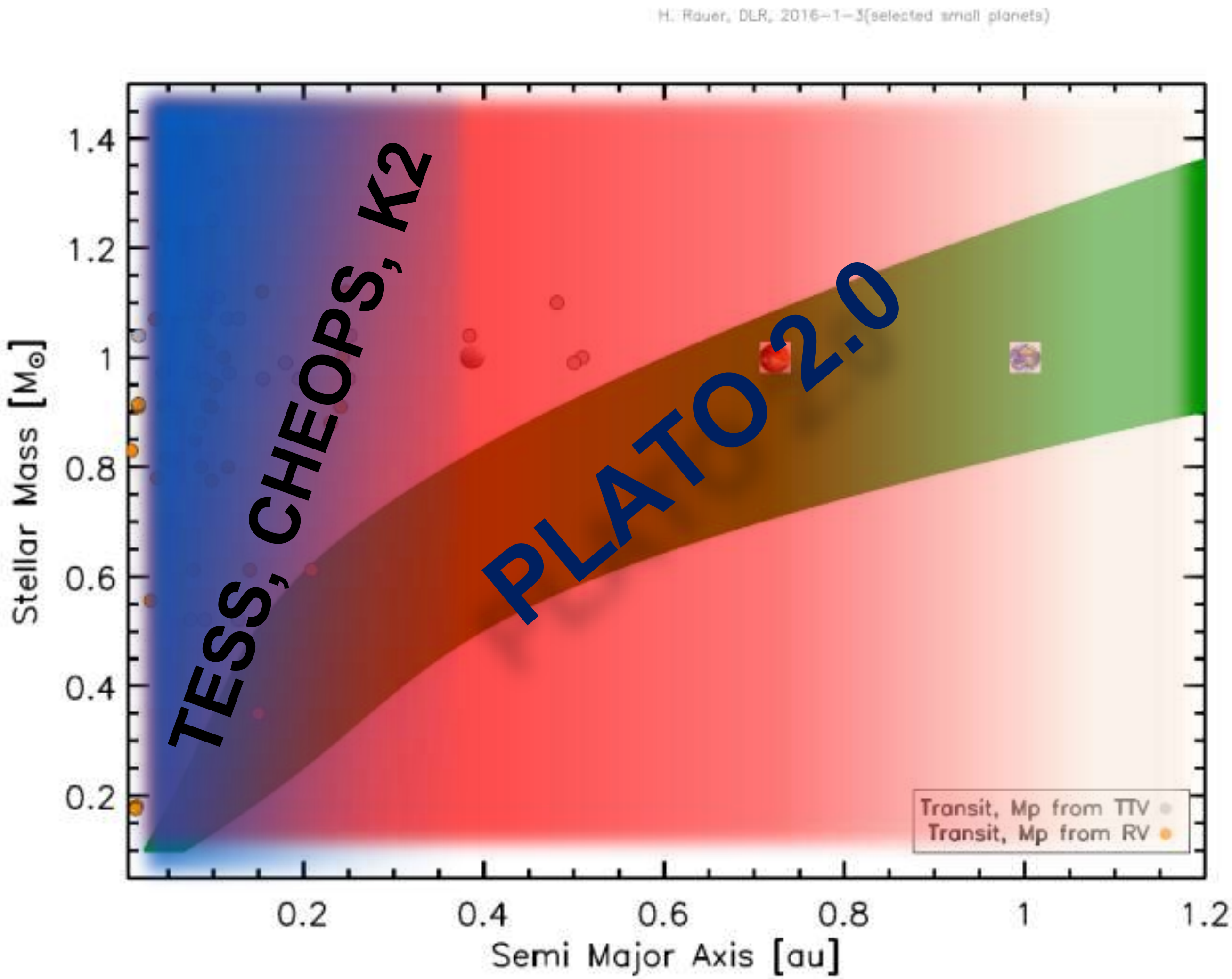
- **thousands of planets smaller than Neptune**
- **hundreds of super-Earths**
- **tens of planets comparable in size to Earth**

G. Ricker et al., 2014, arXiv:1406.0151v2

Bulk characterized super-Earths



Bulk characterized super-Earths



The PLATO 2.0 Mission

- Selected as ESA M3 mission in February 2014
- Now at end of Phase B1
- Mission adoption review in 2016
- Launch end 2024 into orbit around L2 Lagrange point

PLATO 2.0

PLATO 2.0 is a survey mission with the prime goals to:

- **detect planets down to Earth size**
- **characterize the bulk planet parameters**
    - **radius (~3%)**
    - **mass (~10%)**
    - **age (~10%)**

- **for a large sample of planets**
- **for orbital distances up to the habitable zone of solar-like stars**
- **with well-known parameters of host stars**
- **provide input for improved stellar models and to galactic science**

The Methods

Characterize bulk planet parameters:

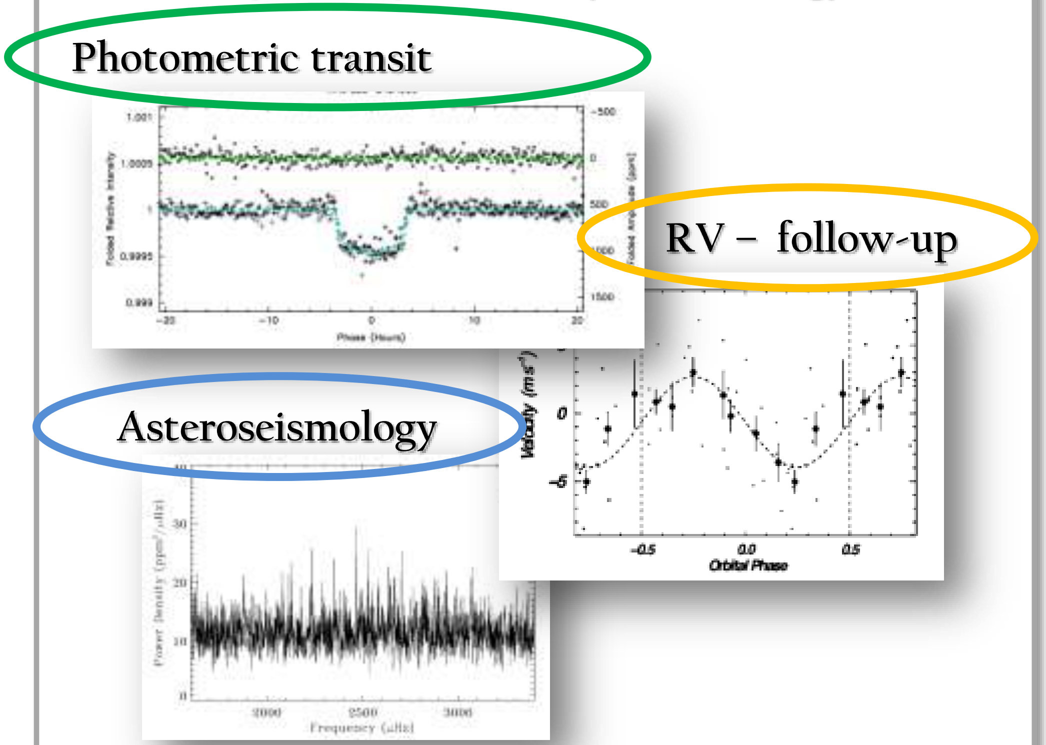
e.g. for an Earth-like planet around a solar-like star of 10mag (goal 11 mag):

- Radius (~3%)
- Mass (~10%)
- Age (~10%)

→ Mean density to ~15%

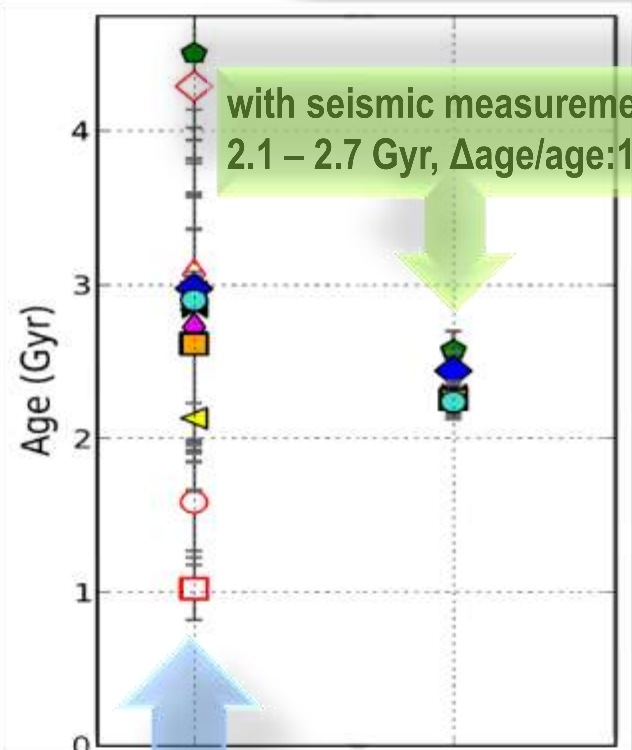
Techniques

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



Asteroseismology

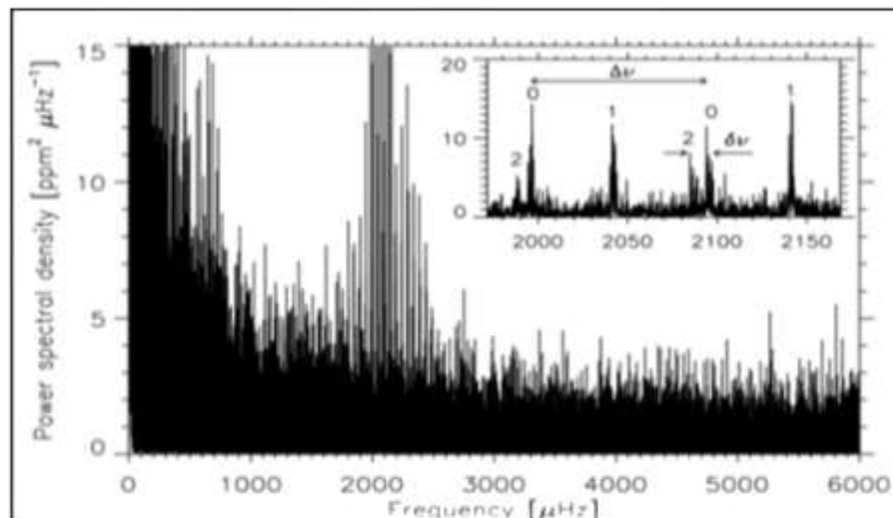
CoRoT and Kepler have demonstrated that the capabilities of asteroseismology



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

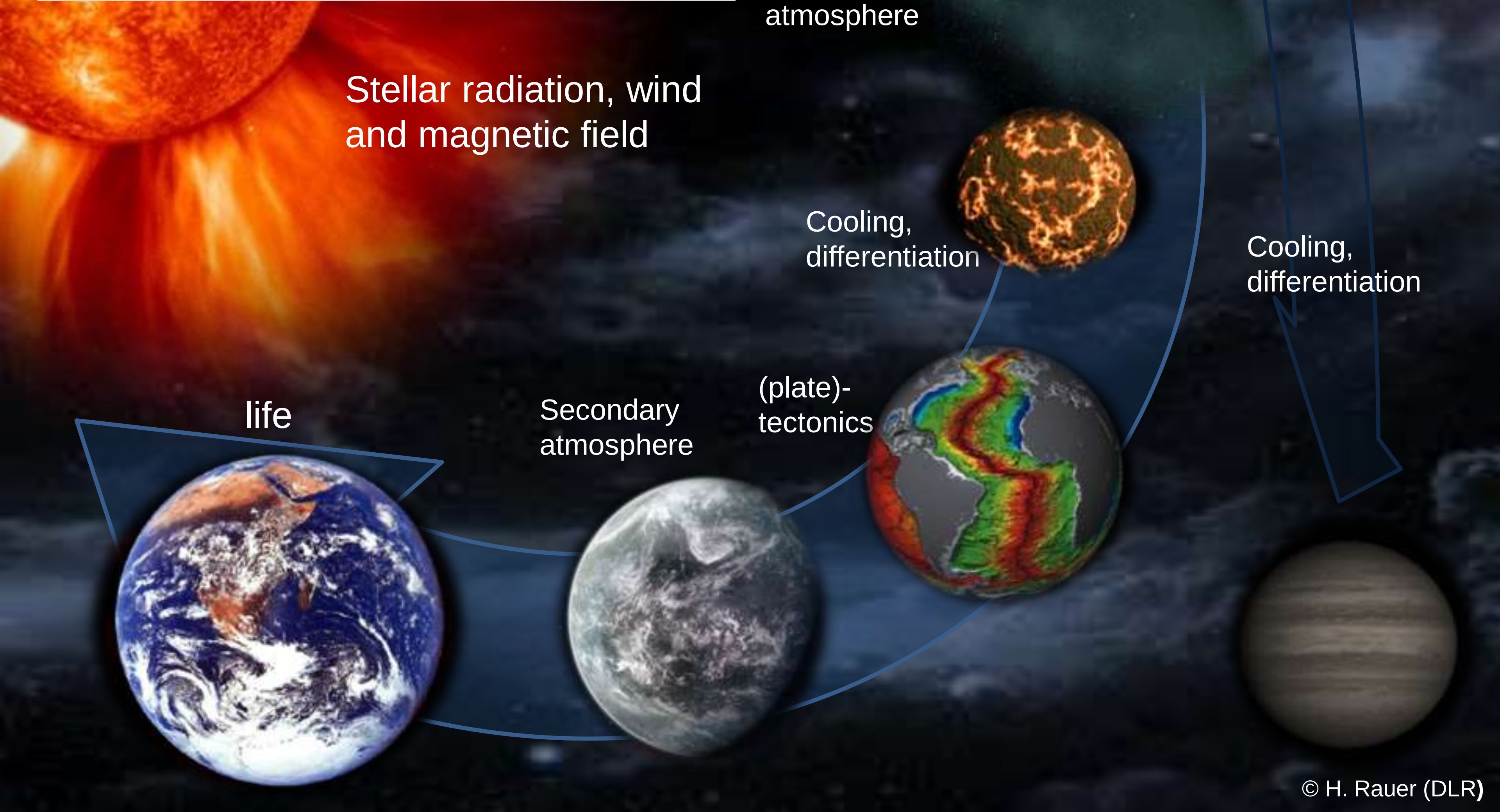


(Gizon et al. 2013)

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

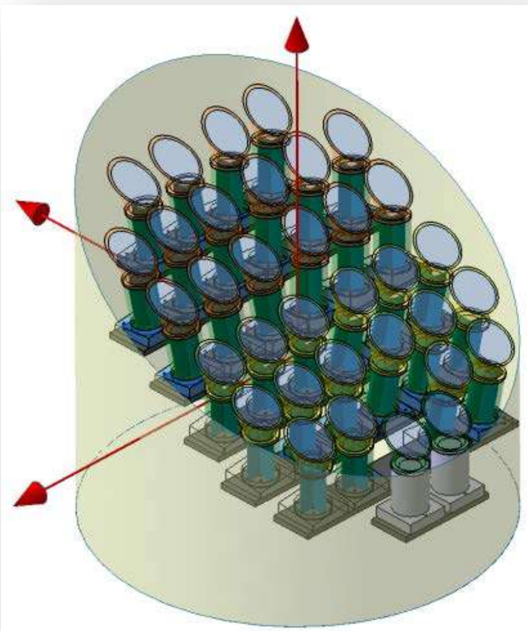
Planets, planetary systems and their host stars evolve

→ Need to derive accurate planetary system age

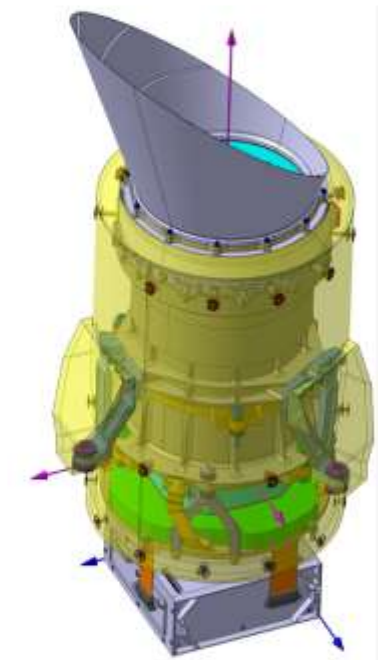


PLATO Instrument

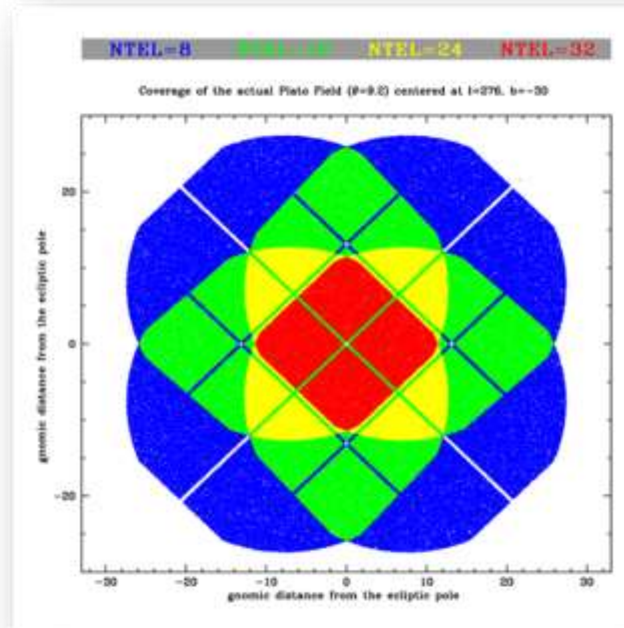
Mounting on optical bench, (final s/c tbd):



Camera



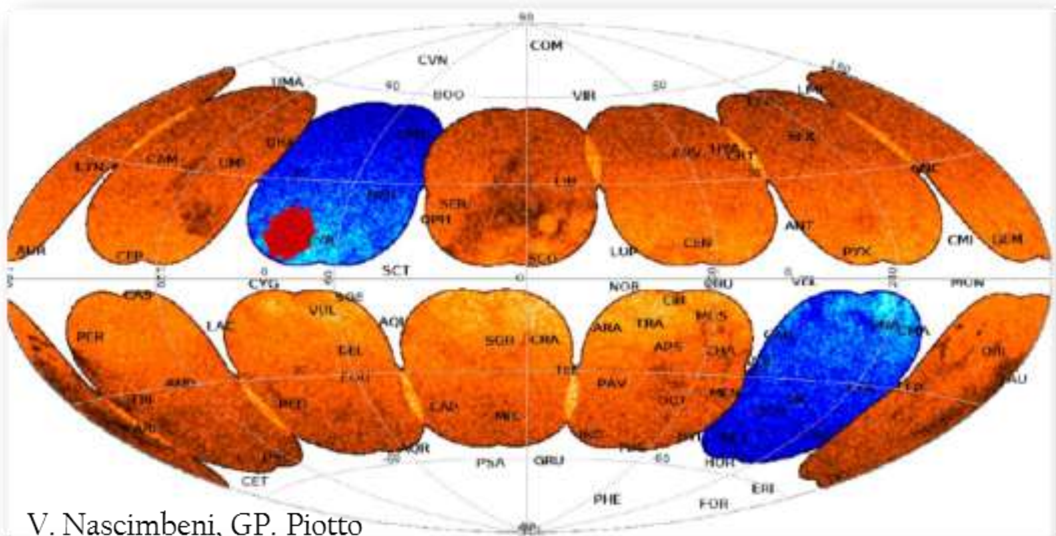
Field-of-view:



- ~49 x 49 FoV, operates in white light
- 12 cm aperture cameras, refractive 6-lens system
- **32 „normal“ cameras** are arranged in 4 groups of 8 cameras each, 4 x CCD, each 4510 4510px per camera,18 µm square pixels, read-out cadence 25 sec
- **2 „fast“ cameras** used for pointing, read-out cadence 2.5 sec, red and blue

PLATO 2.0 Sky

- A baseline observing strategy has been defined for mission design:
  - 6 years nominal science operation:
    - 2 long pointings of 2-3 years
    - step-and-stare phase (2-5 months per pointing)
- The final observing strategy will be fixed 2-3 yrs (tbd) before launch.



- 1,000,000 stellar lightcurves
- >7,000 detected planets around stars <13 mag
- >100 fully characterized planets around bright stars, including terrestrial planets in the HZ of solar-like stars

PLATO Guest observer Science

- The core program focusses on getting accurate parameters of exoplanets and their host stars.

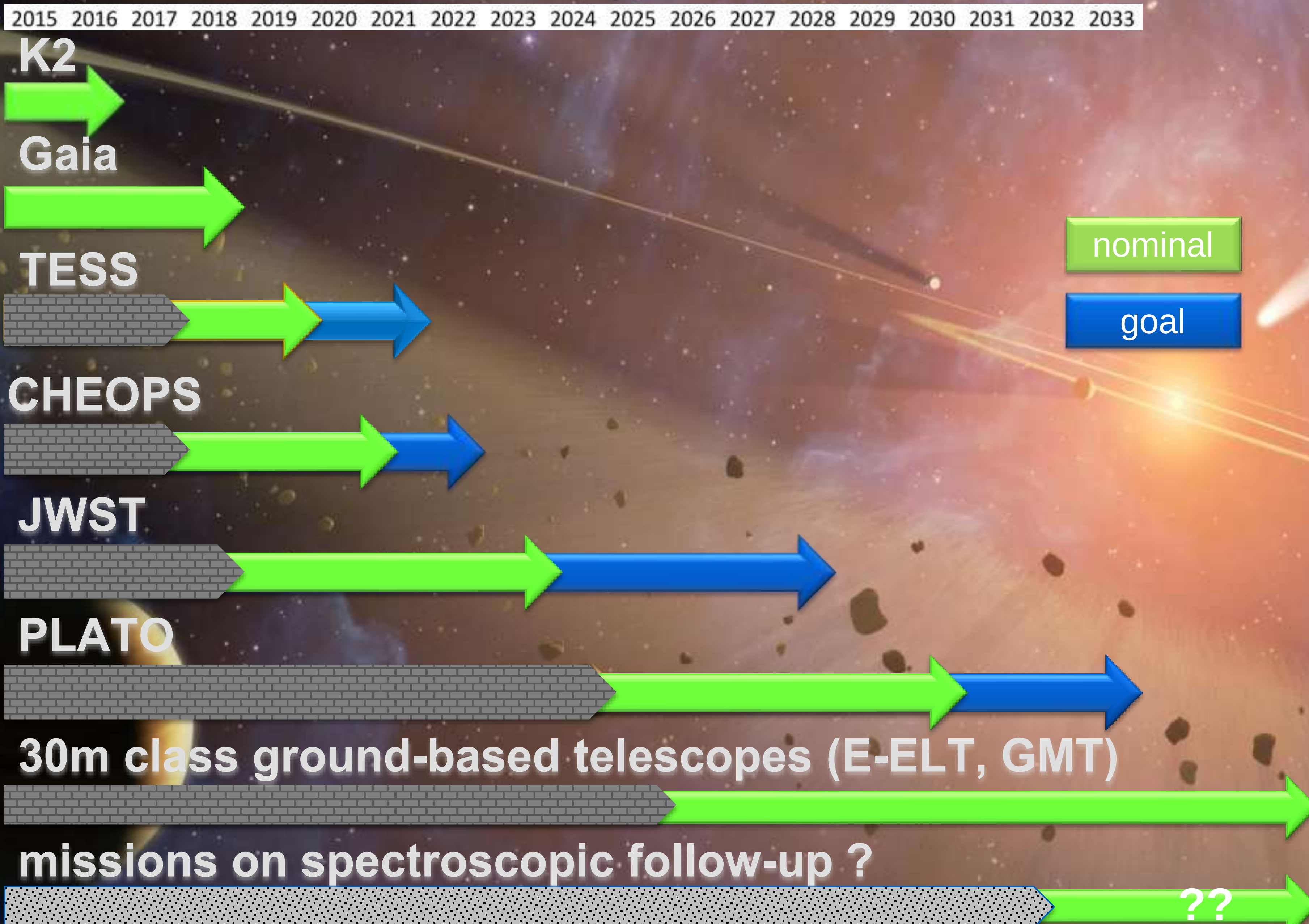
- Complementary Science includes areas such as:
  1) Hot star pulsations
  2) Red giants as tracers of galactic age
  3) CV‘s
  4) …

- There will be regular calls for guest observer targets
  8% of science telemetry is for guest observers

Summary planet transit detection and bulk characterization

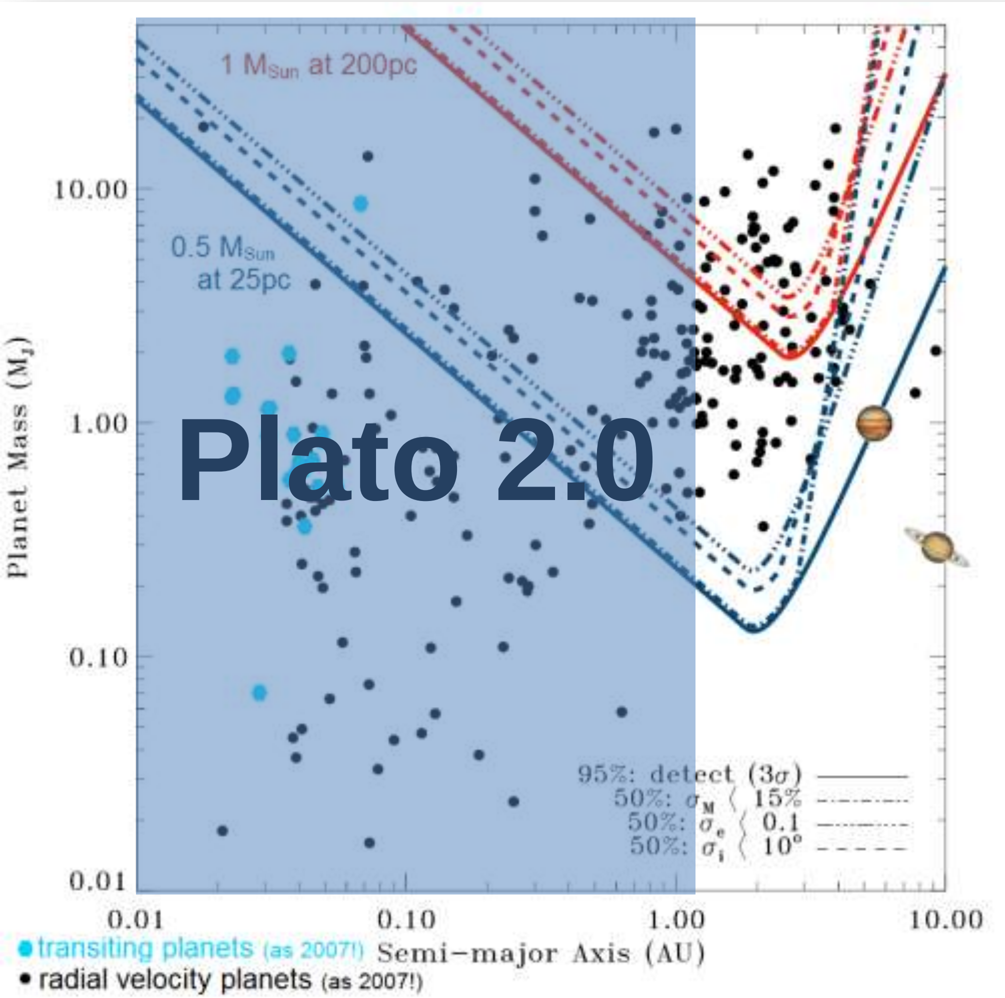
	ground based surveys	M dwarf surveys	K2, TESS, CHEOPS	PLATO 2.0
hot gas giants	YES	YES	YES	YES
hot Neptunes	SOME	YES	YES	YES
hot super-Earths	maybe	YES	YES	YES
warm gas giants	X	SOME	SOME	YES
warm Neptunes	X	SOME	SOME	YES
warm super-Earths & Earths	X	SOME (very cool dwarfs)	SOME (around M dwarfs)	YES

A timeline of exoplanet characterization



NASA/JPL-Caltech

Synergies between PLATO 2.0 and GAIA



from Casertano et al. (2008)

complementary discovery spaces:

GAIA: giant planets in outer orbits

PLATO 2.0: all planet sizes up to the habitable zone of solar-like stars

→ dynamical evolution of systems
→ Planet masses for long-period planets

expected yield of planets by GAIA: synergies with PLATO 2.0

Table 2. Number of giant planets detected and measured by Gaia.

Δd (pc)	$N_\star$	Δa (AU)	ΔM_p (M_J)	N_d	N_m
0–50	~10 000	1.0–4.0	1.0–13.0	~1400	~700
50–100	~51 000	1.0–4.0	1.5–13.0	~2500	~1750
100–150	~114 000	1.5–3.8	2.0–13.0	~2600	~1300
150–200	~295 000	1.4–3.4	3.0–13.0	~2150	~1050

from Casertano et al. (2008)

geometric transit probability ~0.5%

GAIA: ~8500 planets detecte

PLATO 2.0: 430 of them will have transits

- GAIA will constrain the orbital parameters, in particular the orbital inclinations, so we will know which systems to look at
- PLATO 2.0 will further characterize those planets