La missione e le prospettive scientifiche di TNG nell'astrofisica del 2020

Telescopio Nazionale Galileo

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Science of extrasolar Planets

A focused update

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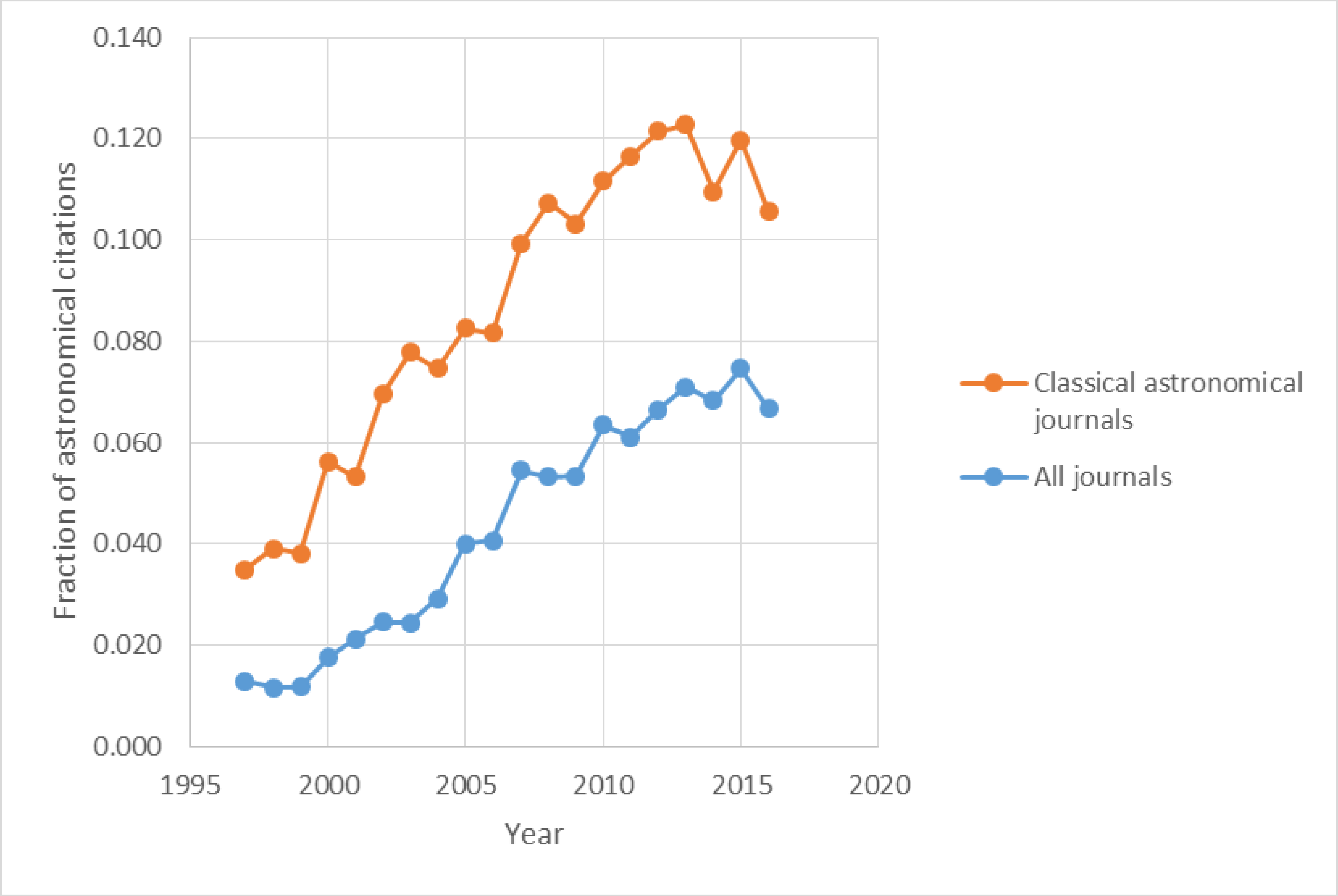
Extrasolar planets: a rapidly growing field of astronomy



Top Tenz: Top 10 most important discoveries in astronomy

http://www.toptenz.net/top-10-most-important-discoveries-in-astronomy.php

1. The movement of the stars and planets
2. The heliocentric model
3. Kepler's laws
4. The moons of Jupiter
5. Herschel's map
6. The theory of relativity
7. The expanding Universe
8. Radio Astronomy
9. Cosmic microwave background radiation
10. Extrasolar planets

ASTRONOMY'S 50 GREAT MYSTERIES

http://www.astronomy.com/magazine/greatest-mysteries

Are we alone?

How many planets surrounds other stars?

Are there other planets like the Earth?

How could we recognize life elsewhere in the Cosmos?

How did the Solar System form?

How many Brown Dwarfs exist?

Main topics in exo-planetary science for the next ten years – my view

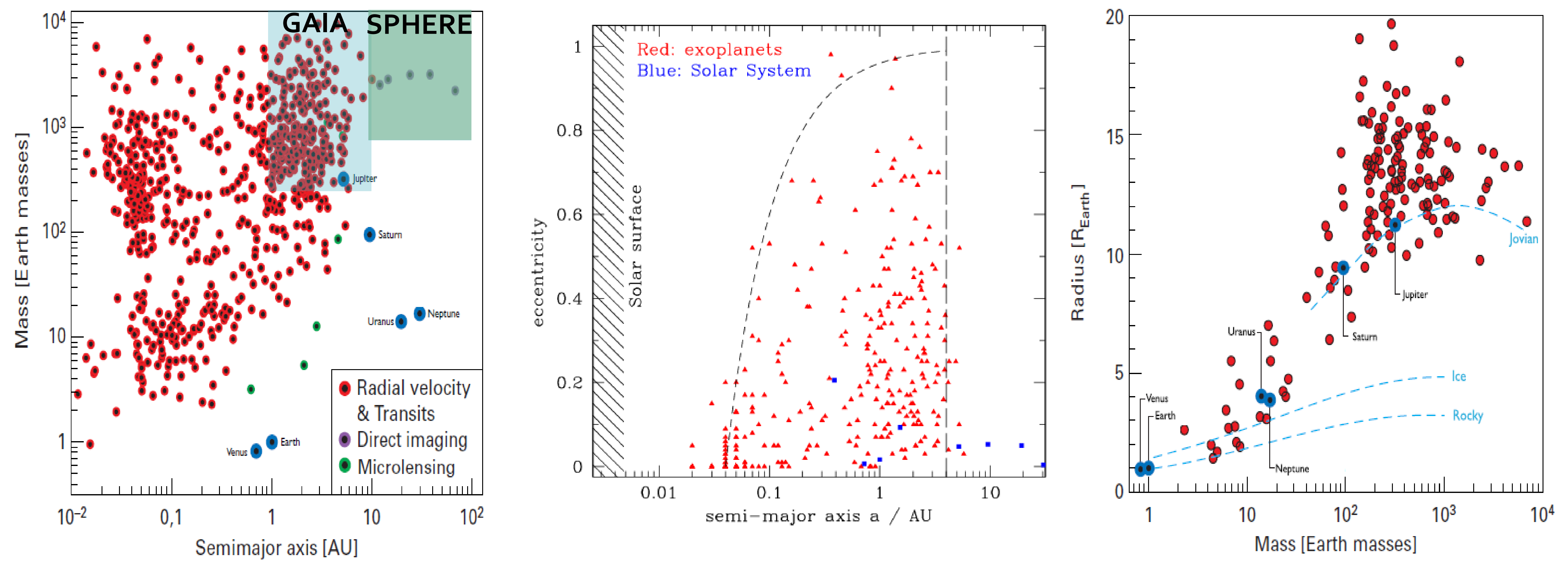
- **Planets formation**
  - How planets form?
  - Why planets have different masses and separation from the stars? What is the impact of disk-planet interactions?
  - What is the impact of the environment?
- **Early evolution**
  - What is the evolution of young planets?
  - How are their atmospheres made and what are their chemical composition?
  - What is the impact of planet-planet interactions?
- **Search and characterization of habitable planets**
  - How common are rocky planets in the habitable zone?
  - What is the structure of small mass planets?
  - What is the composition of their atmospheres?
  - Are/will be we able to detect bio-signatures?

Schematic of methods goals

	Hot planets (P~days)	< snow-line (P~a few years)	> snow-line (P~several years)
Discovery: detection and statistics	**Radial Velocities** Transits	**Radial velocities** Space Astrometry (GAIA) Microlenses ELT/space coro imaging	8m imaging
Dynamical characterization & Structure	**Radial Velocities** + Transits	**Radial velocities** Space Astrometry (GAIA) ELT/space coro imaging	Coupling 8m imaging and GAIA?
Atmospheric characterization & search for biosignatures	Transits - Duration - **Transmission spectroscopy** - **Secondary transit**	ELT/space coro imaging	8m imaging (and) JWST ELT MIR

However, situation may differ for specific target groups (M-stars)!

What do we know about how planets form?



Adapted from Mordasini et al. 2015

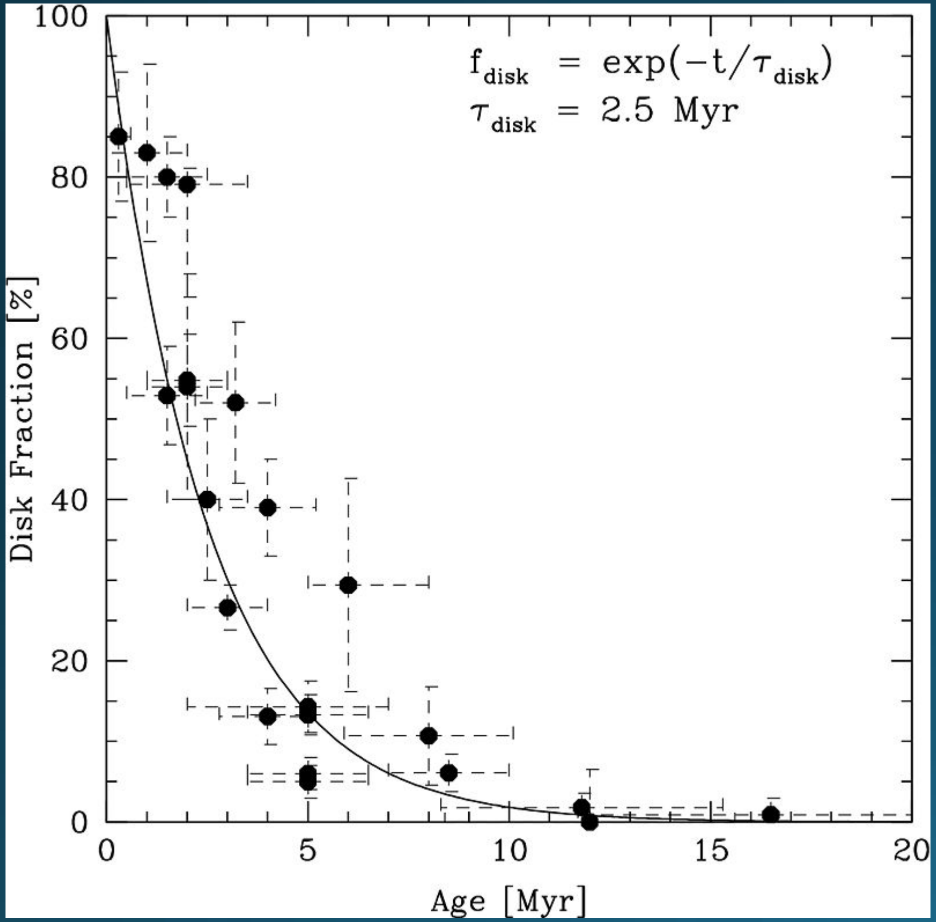
Two mechanisms of planet formation

- Core accretion (Safronov 1972; Mizuno 1980; Pollack et al. 1996; Alibert et al. 2004)
  - Multistage process entailing the buildup of a 10-15 Mearth core followed by rapid accretion of gas from the protoplanetary disk
  - Timescale: a few Myrs
    - Competition with disk dissipation: mechanism too slow for distances larger than ~10 AU (Levison & Stewart 2001)
  - Planets over a wide range of masses (from planetesimals up to gas giants)
  - Bottlenecks:
    - Growth of dust grains up to size large enough for gravitational funneling (uncertain physics)
    - Accretion of gas on seed cores (separation between gas giants and smaller planets)
- Disk Instability (Kuiper 1951; Toomre 1964; Boss 1998)
  - Requires massive (self-gravitating) disks
  - Very short timescale (a few dynamical times)
  - Massive planets at large separations (but perhaps at shorter separations: Nayashkin 2016)

Further complications

- Both mechanisms predict complex interactions between young planets and disk
  - Migration (see Lubow & Ida 2011)
  - Disk features (spiral arms, gaps)
  - Timescale: a few Myrs
- In addition, planet-planet scattering + tidal migration
  - Secular (Kozai) mechanism in multiple planet or binary systems increases eccentricity
  - Interactions between giant planets (Vorbit < Vescape) → scattering of planets → planets in very eccentric orbits
  - After scattering, orbits with small periastron decay into short circular orbits
  - Large range in the timescale, from Myr up to Gyr

A few facts about protoplanetary disks



Mamajek et al. 2009

- Gas is removed by photoionization and radiation pressure in a few Myr
- Small dust grains are removed by radiation pressure and Poynting-Robertson effect on ~10 Myr
- Planet formation also may help dissolving disks
- Disks dissolve after a few Myrs
- There are old (secondary) debris disks

Origin of HJs

- Leading hypothesis is that HJs formed beyond the snow line of their proto-planetary disks (>4 AU for a Sun-like star) before type I-II migrating inwards (Lin+ 1996; Ida & Lin 2008)
- Timescale for this process has yet to be determined observationally and explained theoretically; current ideas is ~10 Myr or less (Mamajek+ 2009)
- However, may be longer if a significant fraction of HJ originates due to planet scattering generating highly eccentric orbits that then circularize at periastron separation due to tidal dissipation (Chetterjee+2008)
- In this case, a significant fraction of HJ with age <100 Myr are on eccentric orbits
- HJ might be more common among young star (age <1 Gyr) if a significant fraction of them spiralize onto the star due to tidal interactions (Matsakos & Konigl 2015; D'Orazi et al 2016)
- Need for statistical sample of young HJs
- Few dedicated transit searches (see e.g. Oelkers+ 2016); no stringent upper limit

Search for habitable planets: the role of M-stars

Distance of habitable planets from the star depends on stellar luminosity

For M-stars the habitable zone corresponds to periods of weeks

For Rocky Planets, the RV signal may be of the order of 10 m/s

Atmospheric composition of transiting planets can be obtained from transit spectroscopy

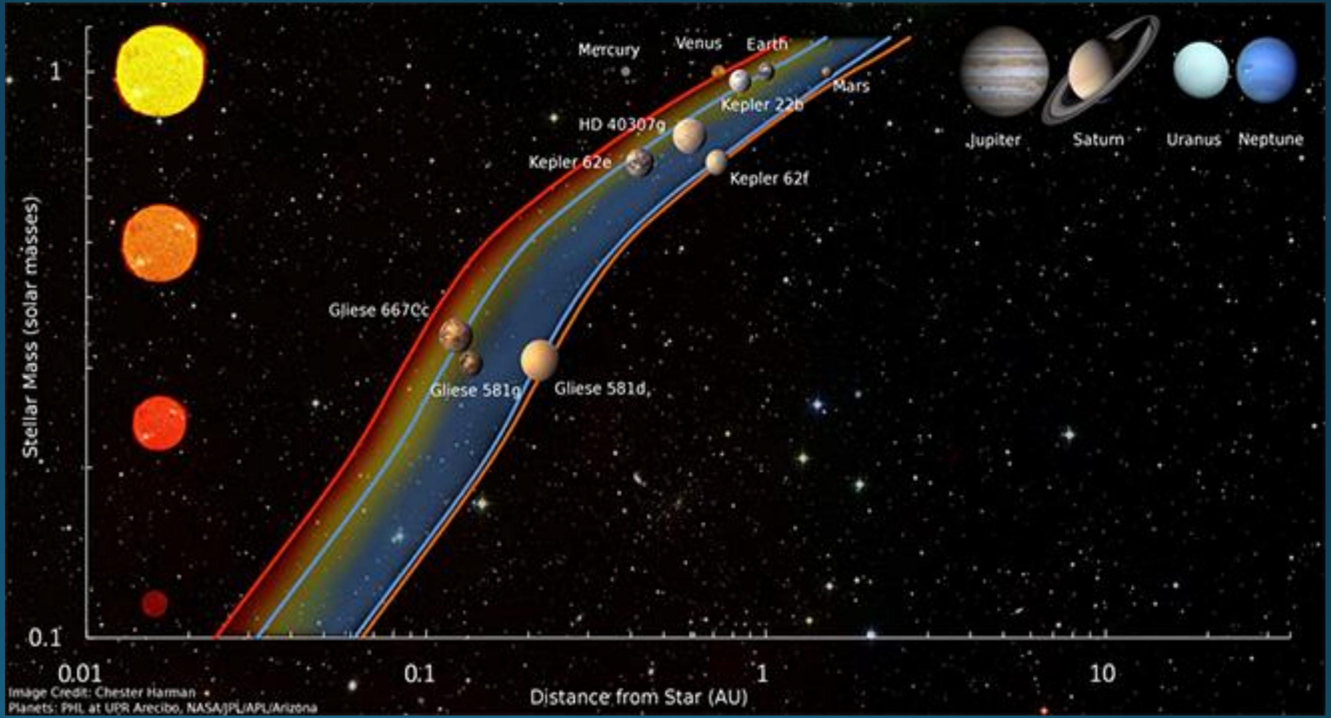
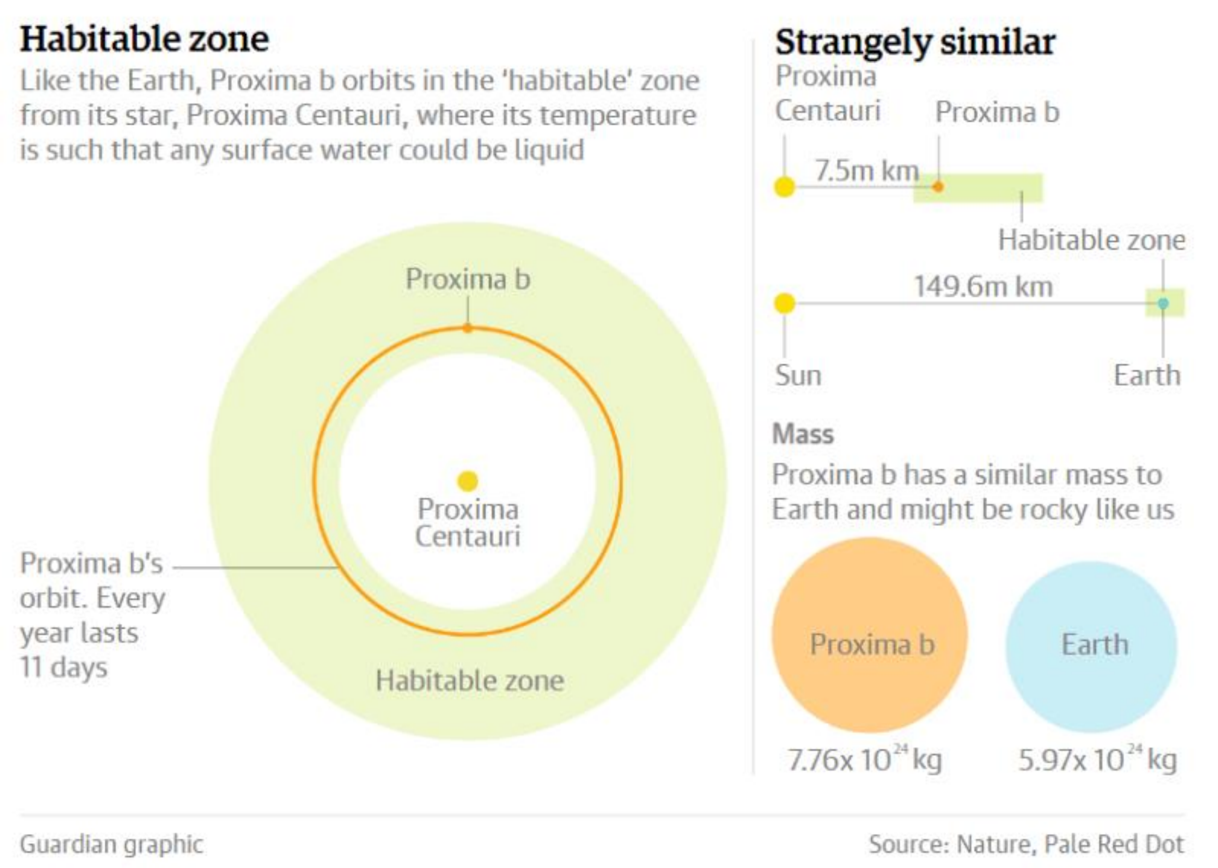


Image Credit: Chester Harman
Planets: PHL at UPR Arecibo, NASA/JPL/APL/Arizona

The case of Proxima b (Anglada-Escude 2016)



Habitable zone

Like the Earth, Proxima b orbits in the 'habitable' zone from its star, Proxima Centauri, where its temperature is such that any surface water could be liquid

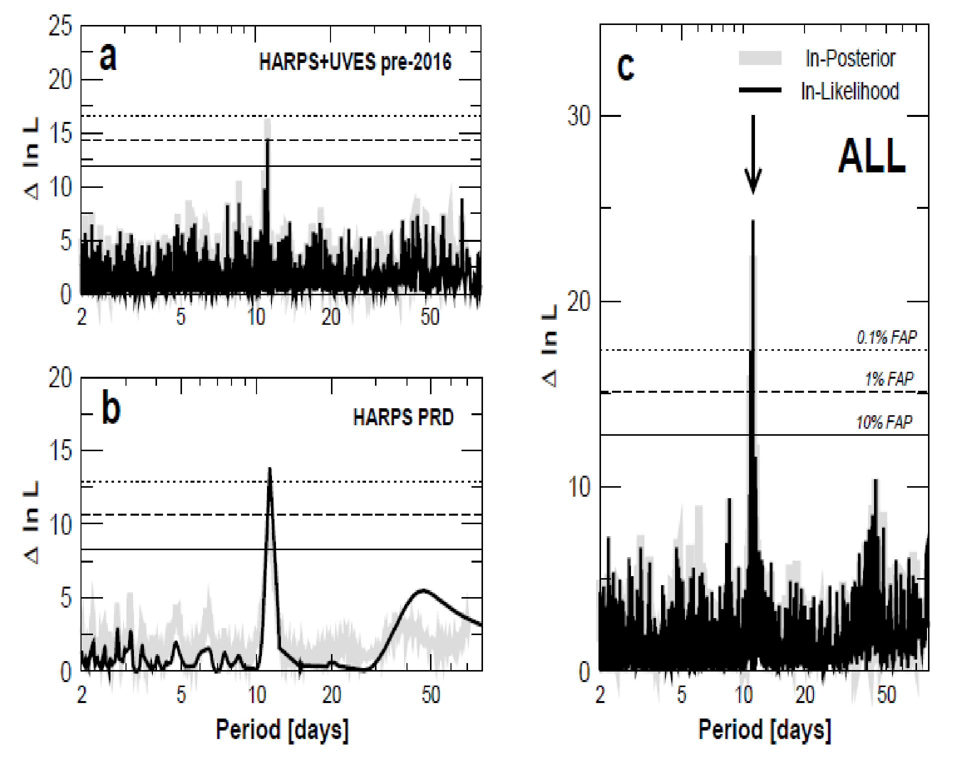
Strangely similar

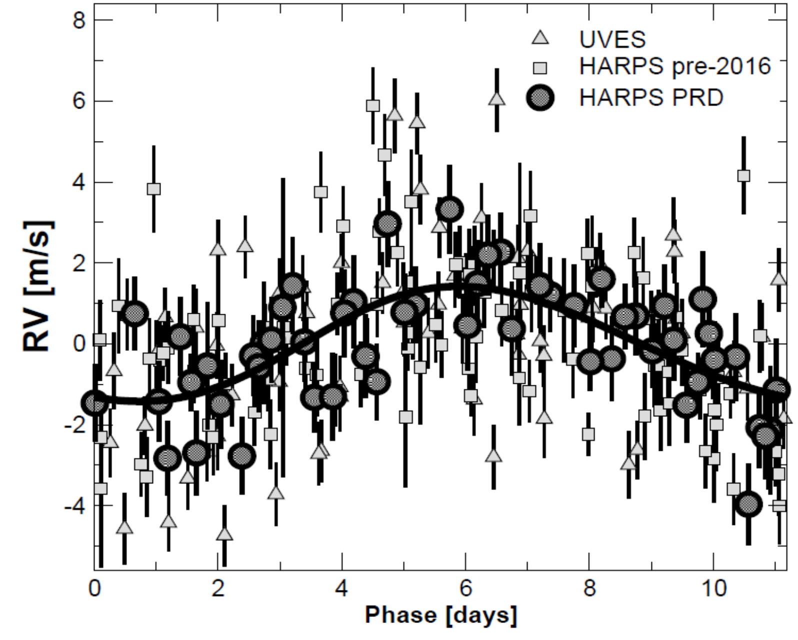
Mass

Proxima b has a similar mass to Earth and might be rocky like us

Guardian graphic

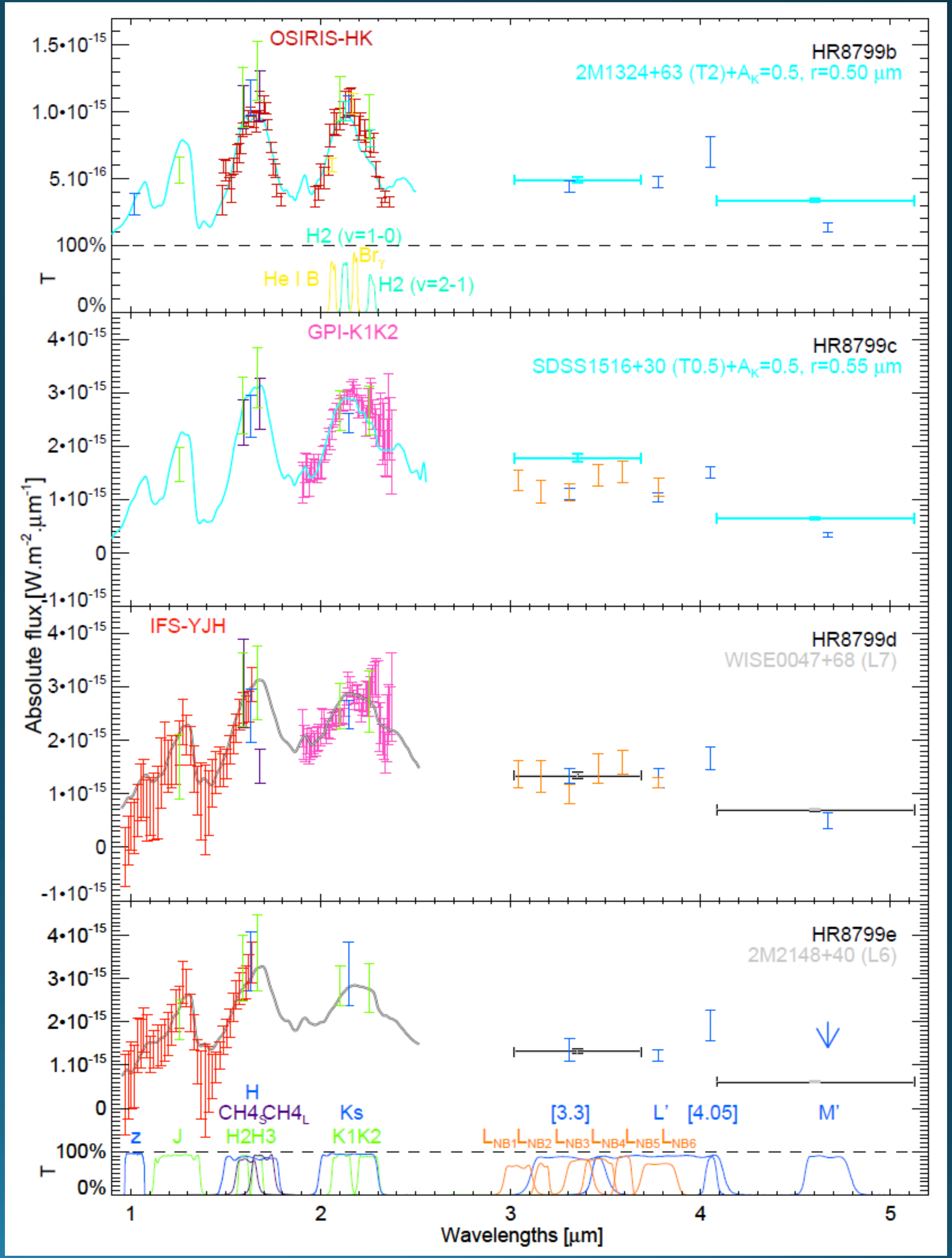
Source: Nature, Pale Red Dot





Spectra of the planets of HR8799

- Combination of:
  - Keck+OSIRIS: Barman et al. 2011; Bowler et al. 2010; Konopacki et al. 2013 (Planets b and c)
  - VLT-NACO (Janson et al. 2010) (Planet c)
  - Gemini+GPI: Ingraham et al. 2014, ApJL, 794, L15 (Planets c and d)
  - VLT+SPHERE: Zurlo et al. 2015 (Planets d and e)



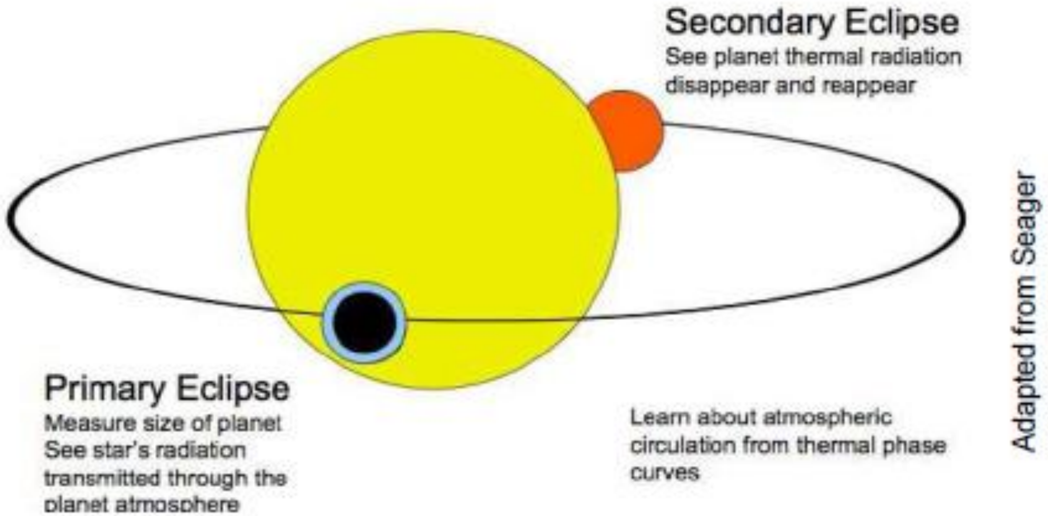
How to detect exoplanetary atmospheres

Spectroscopy of combined light (star+planet) is a powerful tool to probe atomic and molecular species in exoplanetary atmospheres

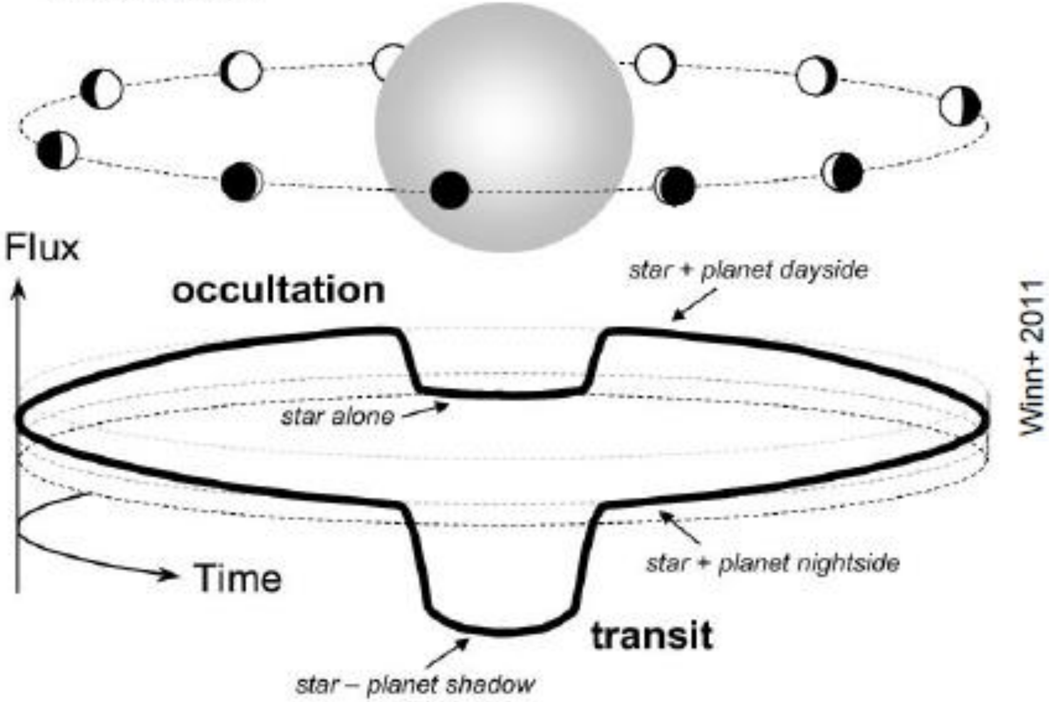
Transmission spectroscopy (TS) during transits is able to probe the terminator region up to several scale heights

Emission spectroscopy (ES) probes the day-side hemisphere of the planet and is more sensitive to the lowest layers. ES does not always require a transiting geometry!

TS and ES are highly **complementary** as they probe different chemical/physical environments and are subject to different biases and limitations. Other complementarities arise from the different spectral range investigated (e.g., IR vs. VIS)



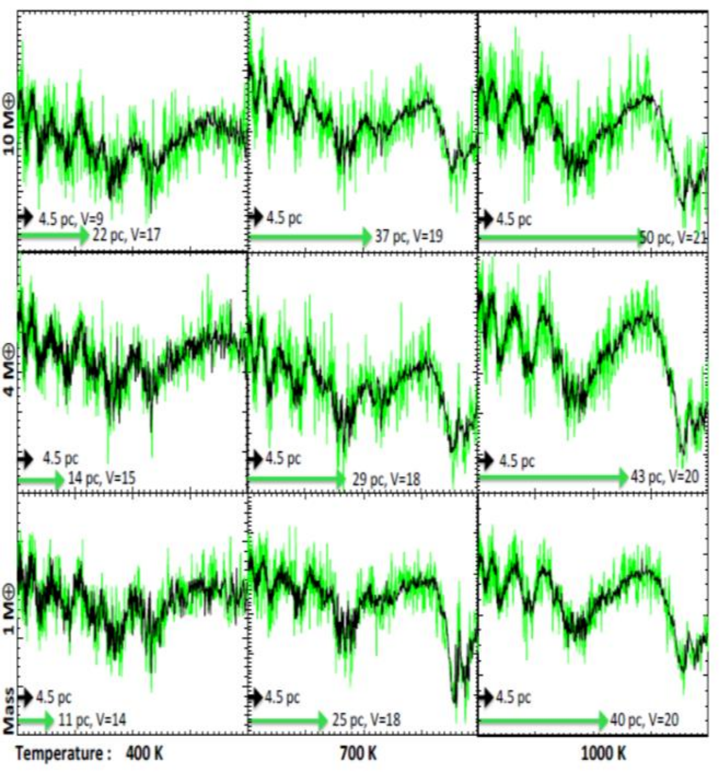
Adapted from Seager



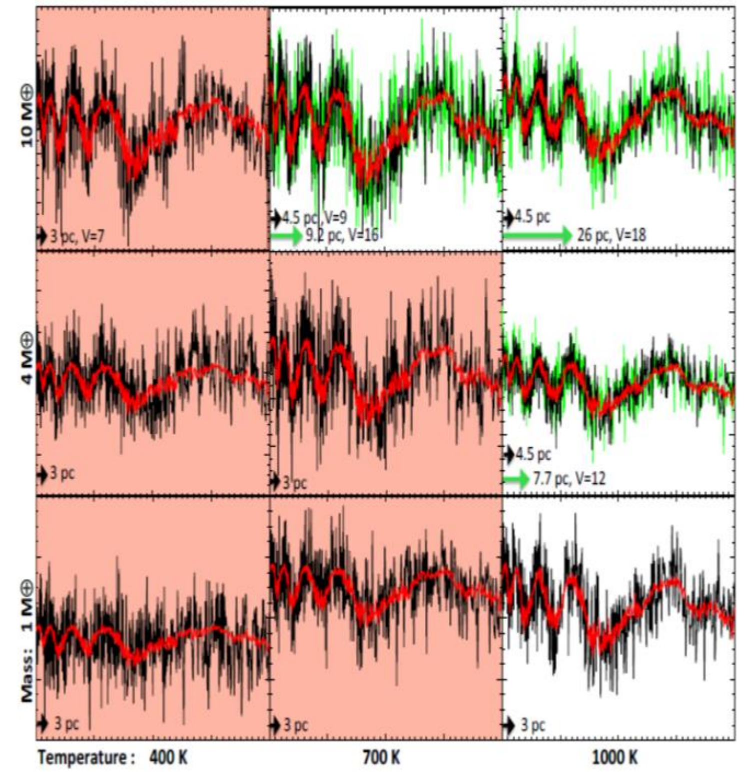
Winn+ 2011

JWST: study of atmospheres of exoplanets

H-rich atmospheres

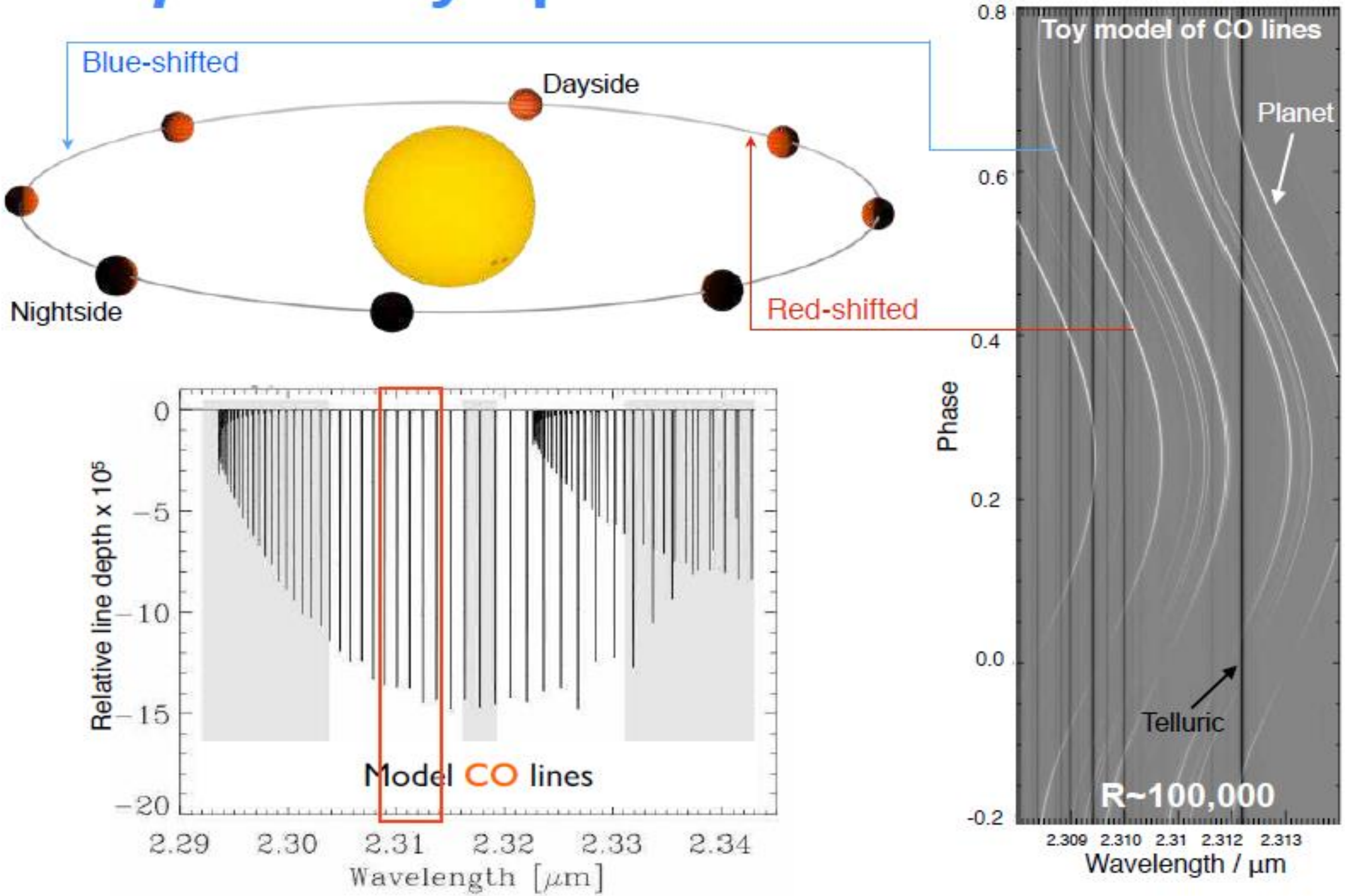


H-poor atmospheres



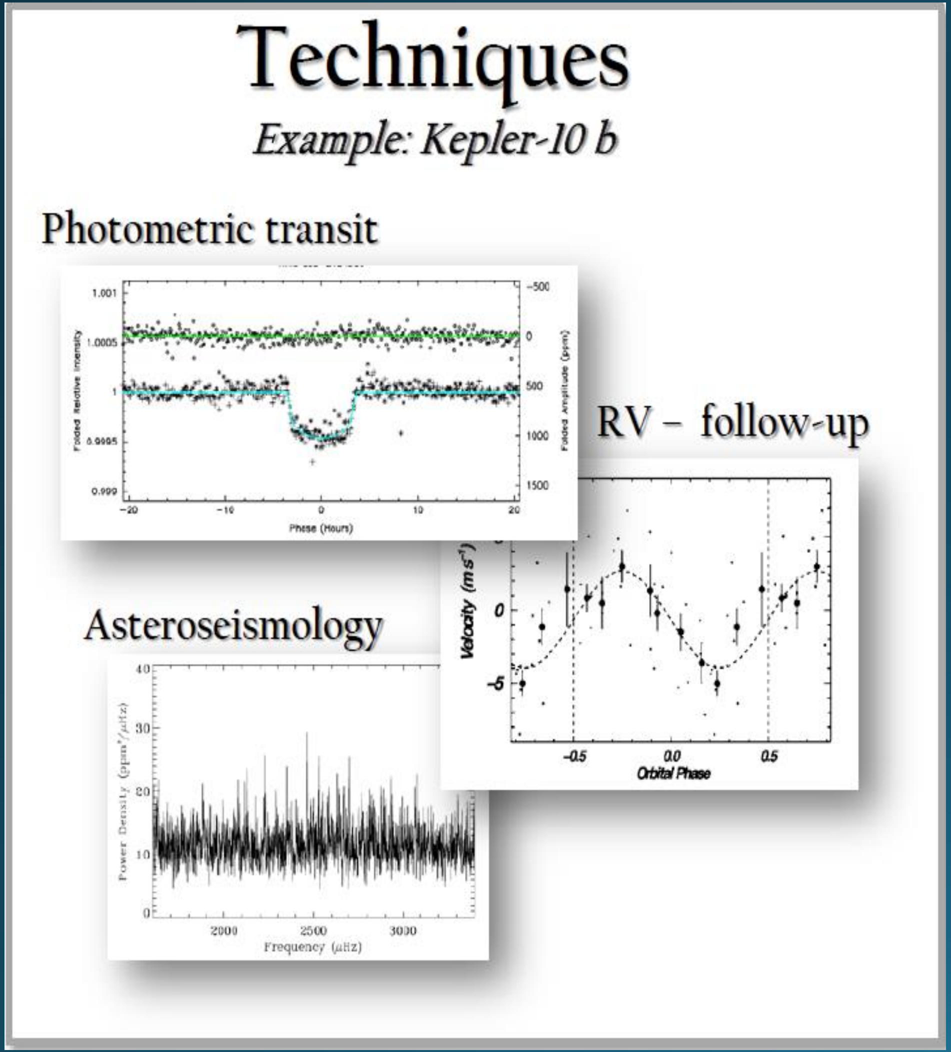
From Batalha et al. 2013

HDS detects the radial velocity shift of the *planetary* spectrum



Snellen+

Kepler (NASA)



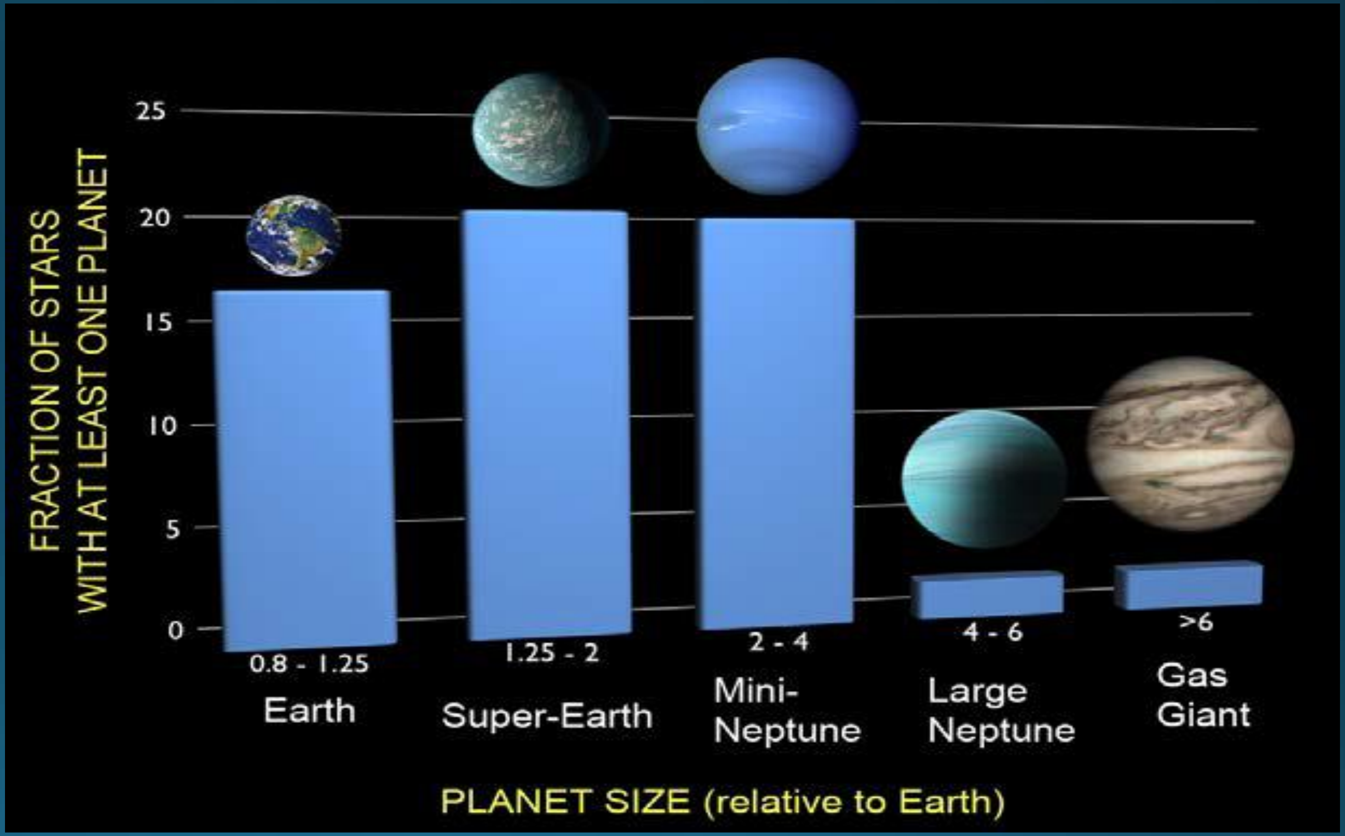
Techniques

Example: Kepler-10 b

Photometric transit

RV – follow-up

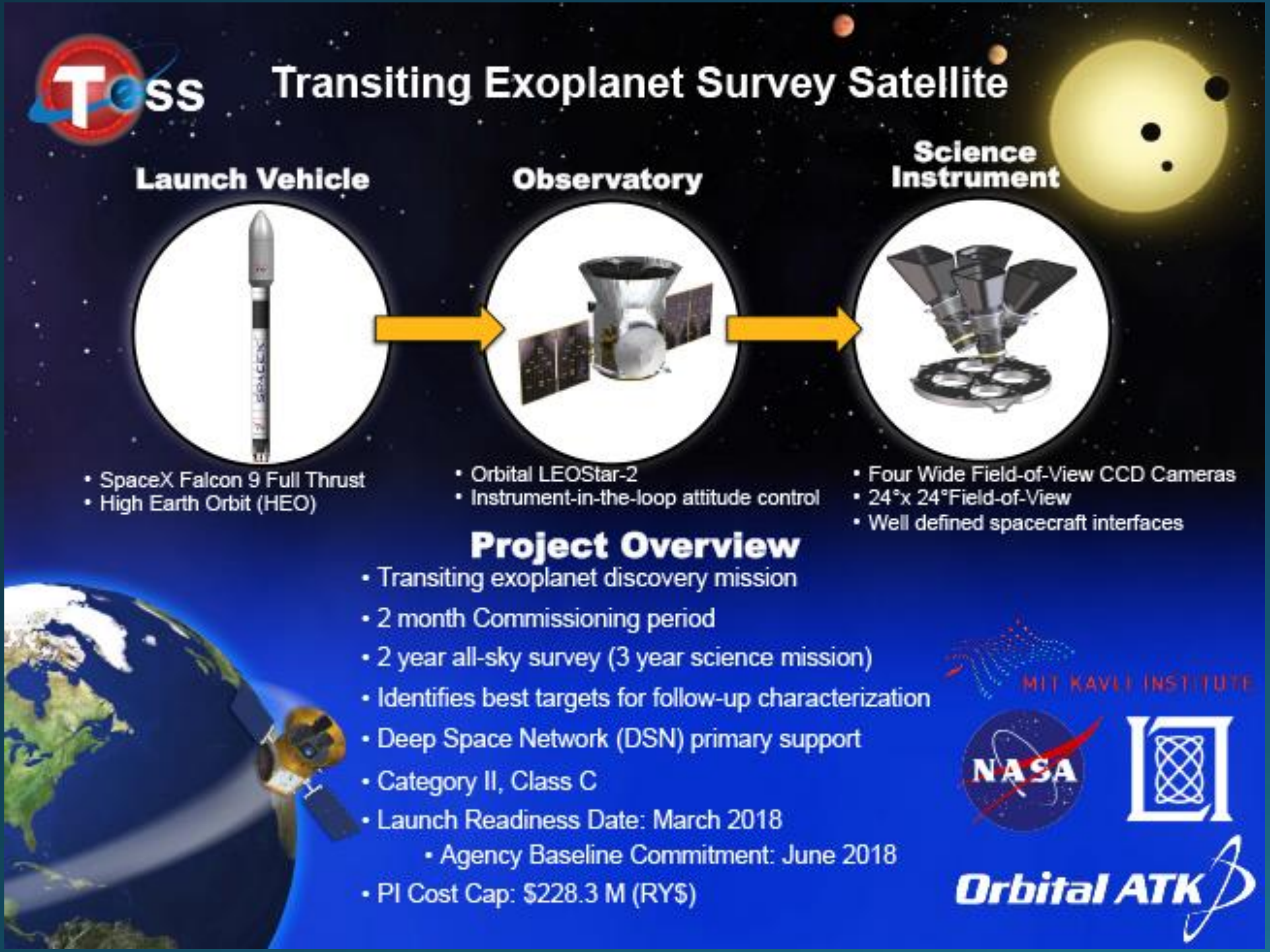
Asteroseismology



CHEOPS (CH-Italy-ESA, S-mission, launch 2018)

- To search for shallow transits on stars already known to host planets obtaining a transit signal-to-noise ratio of 5 for an Earth-size planet with a period of 50 days on G5 dwarf stars with V- magnitude brighter than 9th. This signal-to-noise ratio is sufficient to enable identifying the presence or absence of a significant atmosphere for planets with masses ranging from Neptune to Earth
- To provide precision radii for a number of hot Neptune planets orbiting stars brighter than 12th V magnitude and to search for co-aligned smaller mass planets
- To measure the phase modulation due to the different contribution of the dayside of hot Jupiter planets and in some cases to measure the secondary eclipse. These measurements provide information about the energy flux in the atmosphere of the planet.

TESS (NASA – launch 2018)



TESS

Transiting Exoplanet Survey Satellite

Launch Vehicle
- SpaceX Falcon 9 Full Thrust
- High Earth Orbit (HEO)

Observatory
- Orbital LEOStar-2
- Instrument-in-the-loop attitude control

Science Instrument
- Four Wide Field-of-View CCD Cameras
- 24°x 24°Field-of-View
- Well defined spacecraft interfaces

Project Overview
- Transiting exoplanet discovery mission
- 2 month Commissioning period
- 2 year all-sky survey (3 year science mission)
- Identifies best targets for follow-up characterization
- Deep Space Network (DSN) primary support
- Category II, Class C
- Launch Readiness Date: March 2018
  - Agency Baseline Commitment: June 2018
- PI Cost Cap: $228.3 M (RY$)

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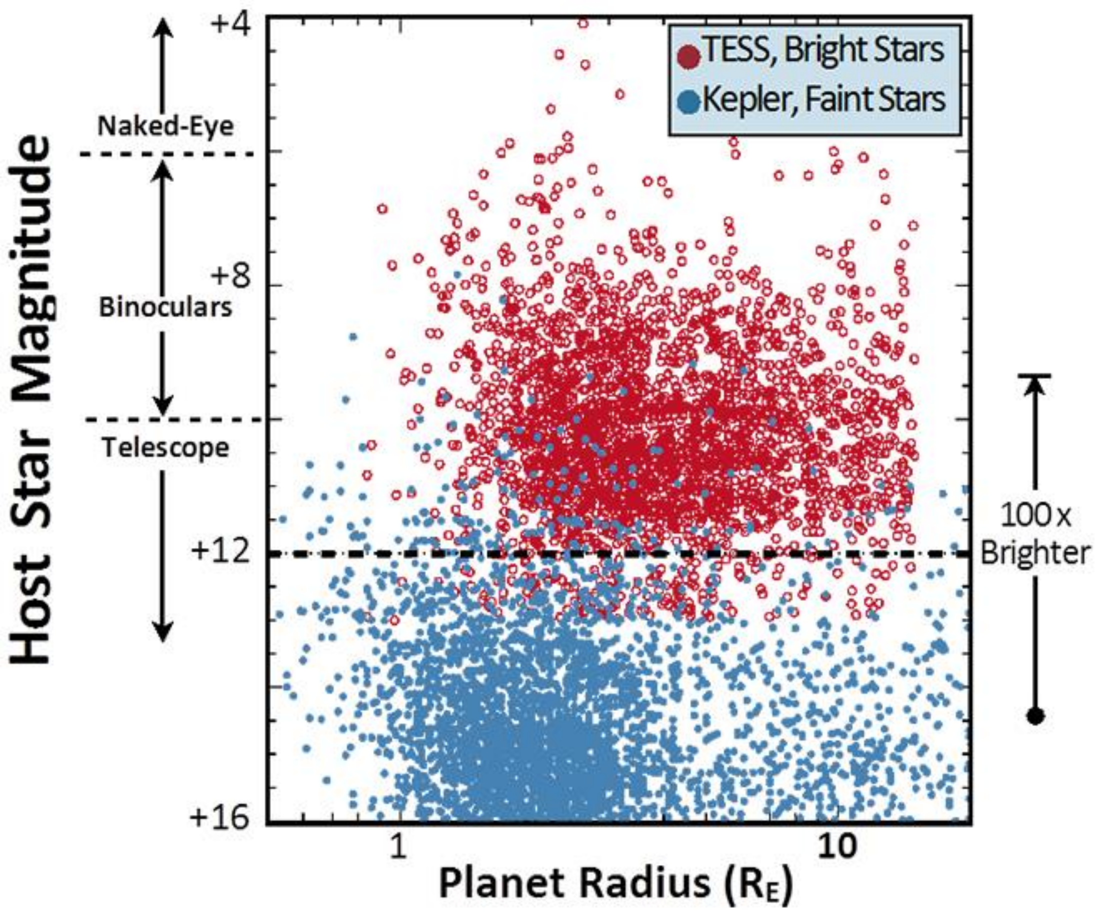
NASA

Orbital ATK



PLATO (ESA, launch 2024)

PLATO will detect Earth-like planets: Small size planets orbiting solar-type stars with about 1 year period.

The exo-planets discovered by PLATO can be fully characterized

✦ The same data that PLATO acquires for the planet search, are used to derive the internal structure of the hosting stars (by means of asteroseismology techniques). This is mandatory to:

★Precisely measure properties of exoplanets: mass, radius, age

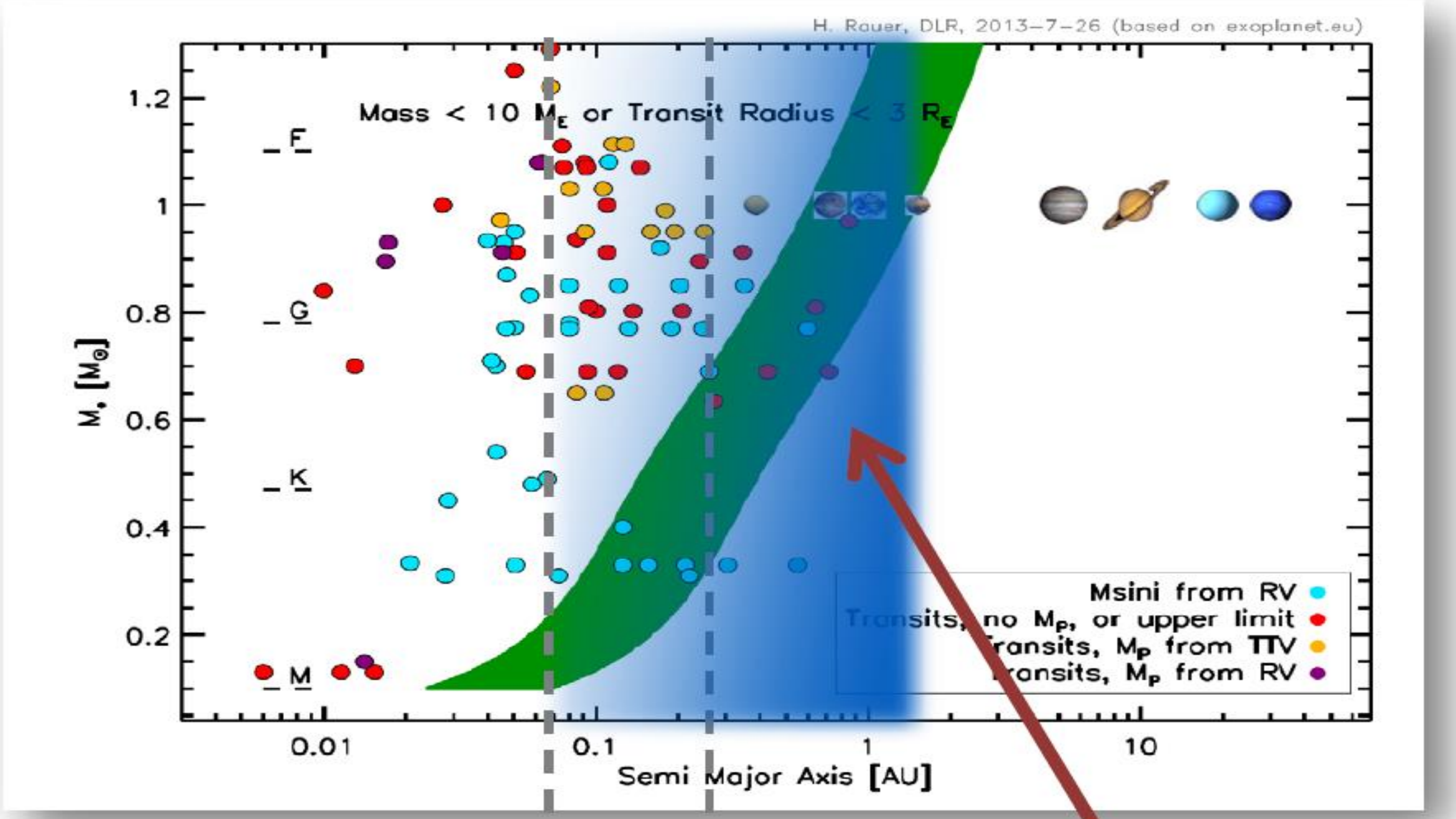
★Comparatively study planetary systems of different ages; e.g., the parameter range of super-Earths to Earth planets is basically unexplored.

★Observe exo-planets in different stages of dynamical evolution and in different stages of physics and chemical evolution

★Correlate the planet and hosting star evolution.

✦ PLATO will search planets orbiting bright stars. After the planet detection, it will therefore be possible to follow up the exo-planetary system with ground based and space telescopes (e.g., E-ELT, JWST, EChO, etc.) in order to obtain a complete characterization of the planet, its atmosphere, and the whole planetary system.

Status super-Earths detection and characterization



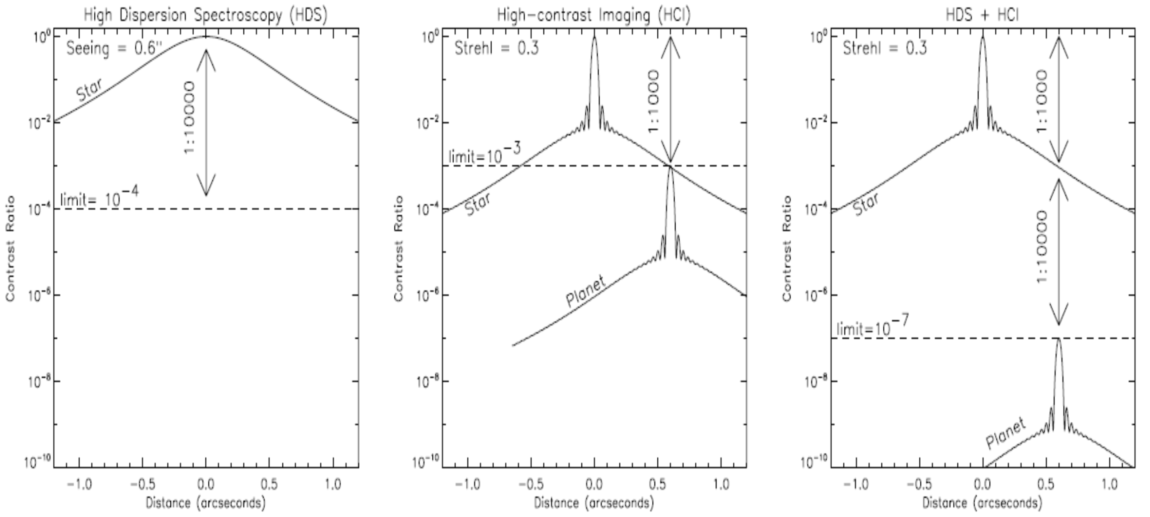
Transits and mass from RV

Mass from TTVs

Main target range for PLATO 2.0 characterization (transit + RV)

E-ELT: coupling high contrast imaging and high dispersion spectroscopy

I. Snellen et al.: HDS+HCI: Probing rocky planets around our nearest neighbours



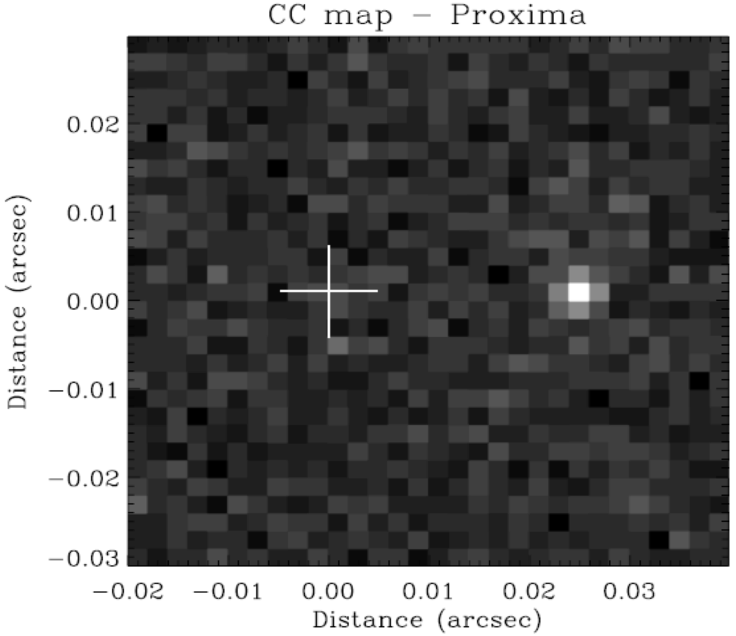
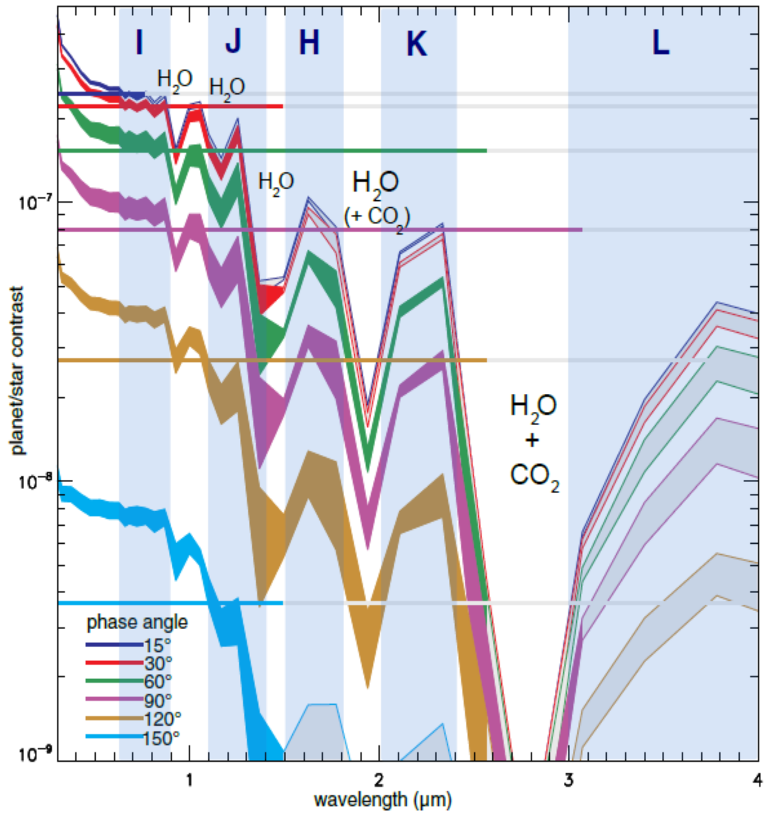


Fig. 6. HDS+HCI cross-correlation map of 10 h of optical observations with the E-ELT using a $R = 100\,000$ IFS and an adaptive optics system producing a Strehl ratio of 0.3. The hypothetical planet with a radius of $R = 1.5\,R_{\mathrm{Earth}}$, albedo of 0.3, and $T_{\mathrm{eq}} = 280$ K such that it is at an orbital radius of 0.032 AU, 25 milliarcsec from the star. The starlight reflected off the planet is detected at an S/N of ∼10.



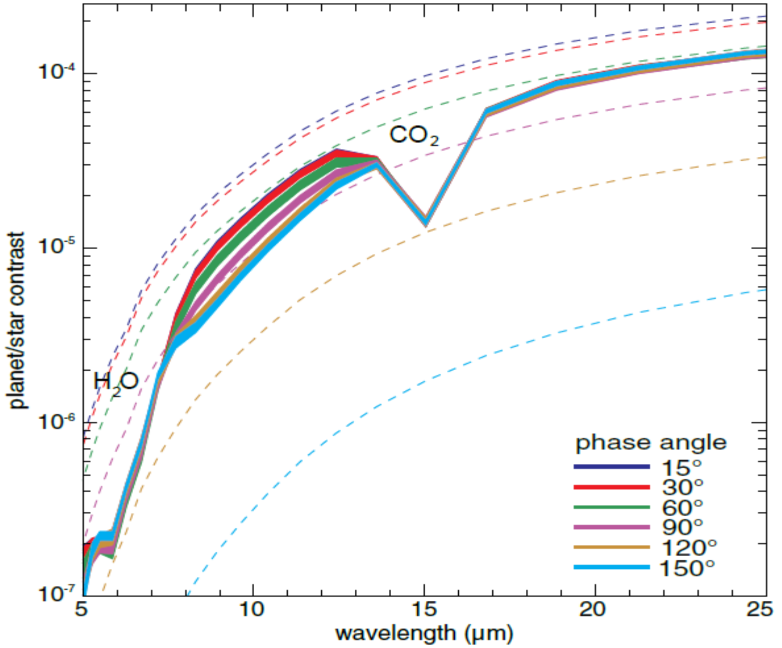


Fig. 12. Emission spectra computed for the synchronous case with an Earth-like atmosphere. Each color corresponds to a phase angle. The thickness of the curves indicate the variability associated with inclination. Dashed lines are calculated for a planet with no atmosphere with a constant surface albedo of 0.2. These plots are obtained with a fixed planetary radius of 1.1 $R_{\oplus}$, whatever the inclination of the orbit.

Science of extrasolar planets boosted enormous technological progresses in the last twenty years

	1995	2015
Photometric precision	10^{-3}	10^{-5}
Astrometric precision	1 mas	0.01 mas
Radial Velocity precision	10 m/s	0.3 m/s
Contrast	10^{-3} at 3 arcsec	3x10^{-7} at 0.4 arcsec

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How TNG may remain competitive?

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How TNG may remain competitive?

TRAPPIST-1 SYSTEM
(Gillon+15, NASA-Spitzer 2017)

Planetary Habitability:

TRAPPIST-1d has the highest Earth Similarity Index (ESI) known (0.90), more than Kepler-438 b (0.88) and Proxima b (0.87) (University of Puerto Rico)

Equilibrium temperature (without greenhouse effect) is 264 K (-9 °C), assuming an albedo similar to the Earth (0.3).

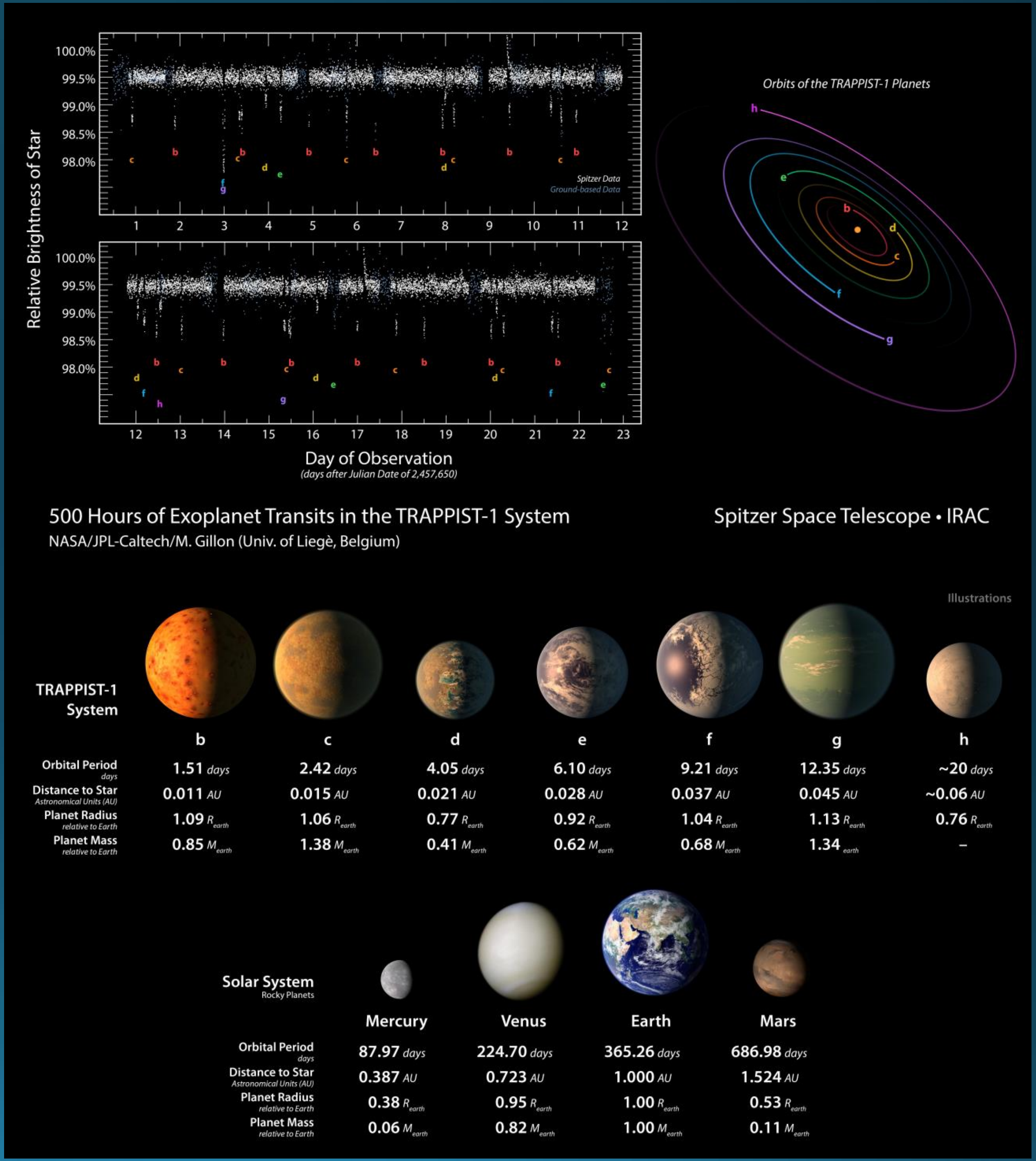
ESI is high also for planet e (0.86), with an equilibrium temperature of 230 K.

How observe TRAPPIST-1 planets?

JWST, CRIRES, perhaps also GIANO-B @TNG (the M8 star is a bit faint: I=14.0, H=10.7)

But why not ~20 TNG nights this late summer?

We can achieve an overall SNR~300…



500 Hours of Exoplanet Transits in the TRAPPIST-1 System

NASA/JPL-Caltech/M. Gillon (Univ. of Liegè, Belgium)

Spitzer Space Telescope • IRAC

TRAPPIST-1 System

	b	c	d	e	f	g	h
Orbital Period *days*	1.51 *days*	2.42 *days*	4.05 *days*	6.10 *days*	9.21 *days*	12.35 *days*	~20 *days*
Distance to Star *Astronomical Units (AU)*	0.011 *AU*	0.015 *AU*	0.021 *AU*	0.028 *AU*	0.037 *AU*	0.045 *AU*	~0.06 *AU*
Planet Radius *relative to Earth*	1.09 R_{earth}	1.06 R_{earth}	0.77 R_{earth}	0.92 R_{earth}	1.04 R_{earth}	1.13 R_{earth}	0.76 R_{earth}
Planet Mass *relative to Earth*	0.85 M_{earth}	1.38 M_{earth}	0.41 M_{earth}	0.62 M_{earth}	0.68 M_{earth}	1.34 $_{earth}$	–

Solar System
Rocky Planets

	Mercury	Venus	Earth	Mars
Orbital Period *days*	87.97 *days*	224.70 *days*	365.26 *days*	686.98 *days*
Distance to Star *Astronomical Units (AU)*	0.387 *AU*	0.723 *AU*	1.000 *AU*	1.524 *AU*
Planet Radius *relative to Earth*	0.38 R_{earth}	0.95 R_{earth}	1.00 R_{earth}	0.53 R_{earth}
Planet Mass *relative to Earth*	0.06 M_{earth}	0.82 M_{earth}	1.00 M_{earth}	0.11 M_{earth}