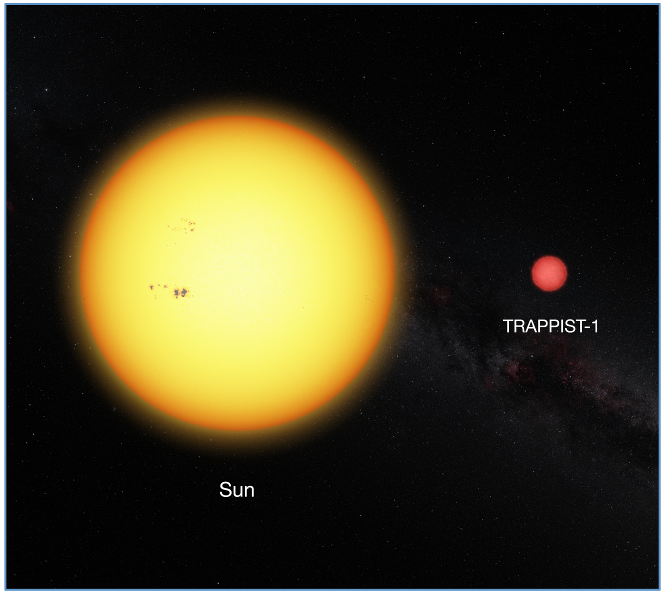
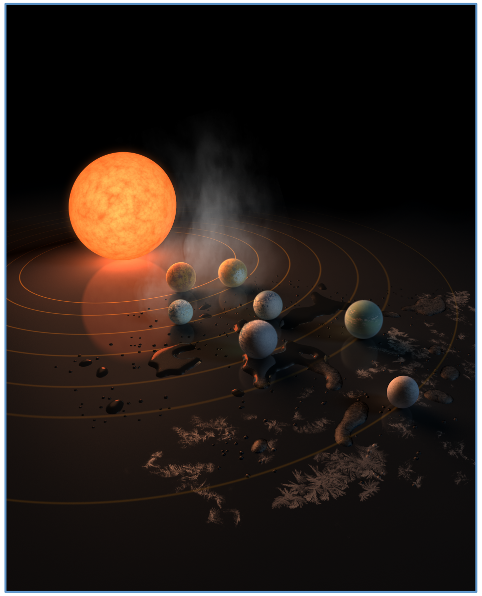
TRAPPIST-1 & SPECULOOS planets

A chance to detect chemical traces of life beyond our solar system





Michaël Gillon (Liège)

University of Liège, Belgium

LIÈGE université · UNIVERSITY OF CAMBRIDGE · MARRAKECH جامعة القاضي عياض UNIVERSITÉ CADI AYYAD · erc European Research Council · SIMONS FOUNDATION · fnrs LA LIBERTÉ DE CHERCHER

SPECULOOS

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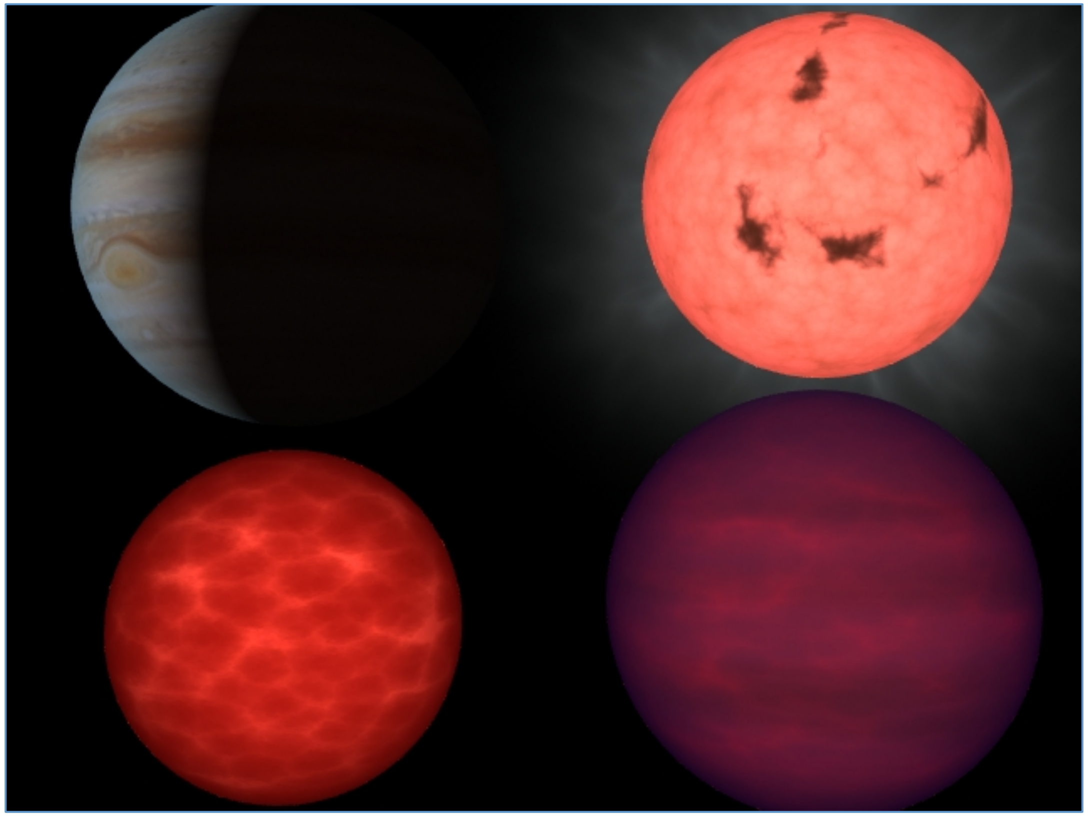
Search for habitable Planets EClipsing ULtra-cOOl Stars

What are « ultra-cool stars »?

Ultracool dwarfs: T_{eff} < 2700K, spectral type later than M6

(Kirckpatrick et al. 1995).

Mix of stars + brown dwarfs



http://www.stsci.edu/~inr/ldwarf3.html

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Search for habitable Planets EClipsing ULtra-cOOl Stars

What are « ultra-cool stars »?

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(Kirckpatrick er al. 1995).

Mix of **stars** + brown dwarfs

Ultracool (dwarf) stars

Spectral type: M7V to L2.5V
(Dieterich et al. 2014)

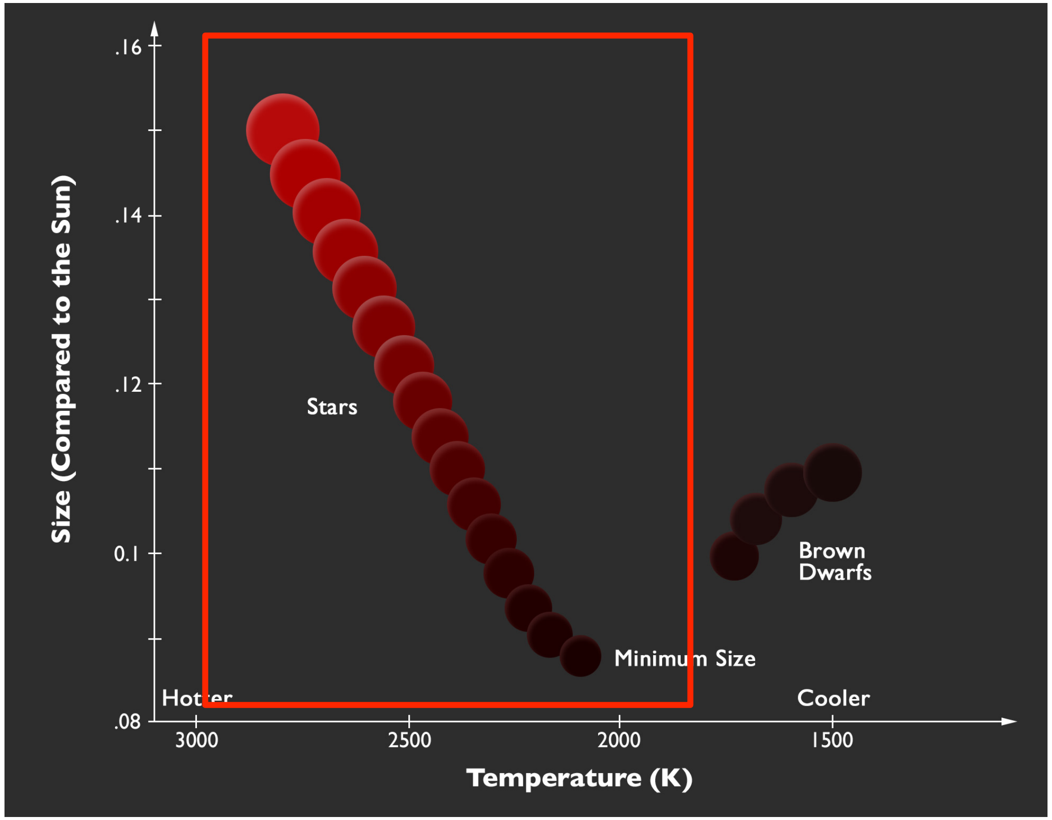
Mass: 0.075 to 0.1 $M_\odot$

Size: 0.08 to 0.15 $R_\odot$

Luminosity: 0.01 to 0.1% $L_\odot$

Main-sequence lifetime:

>1000 Gyrs



Dieterich et al. (2014)

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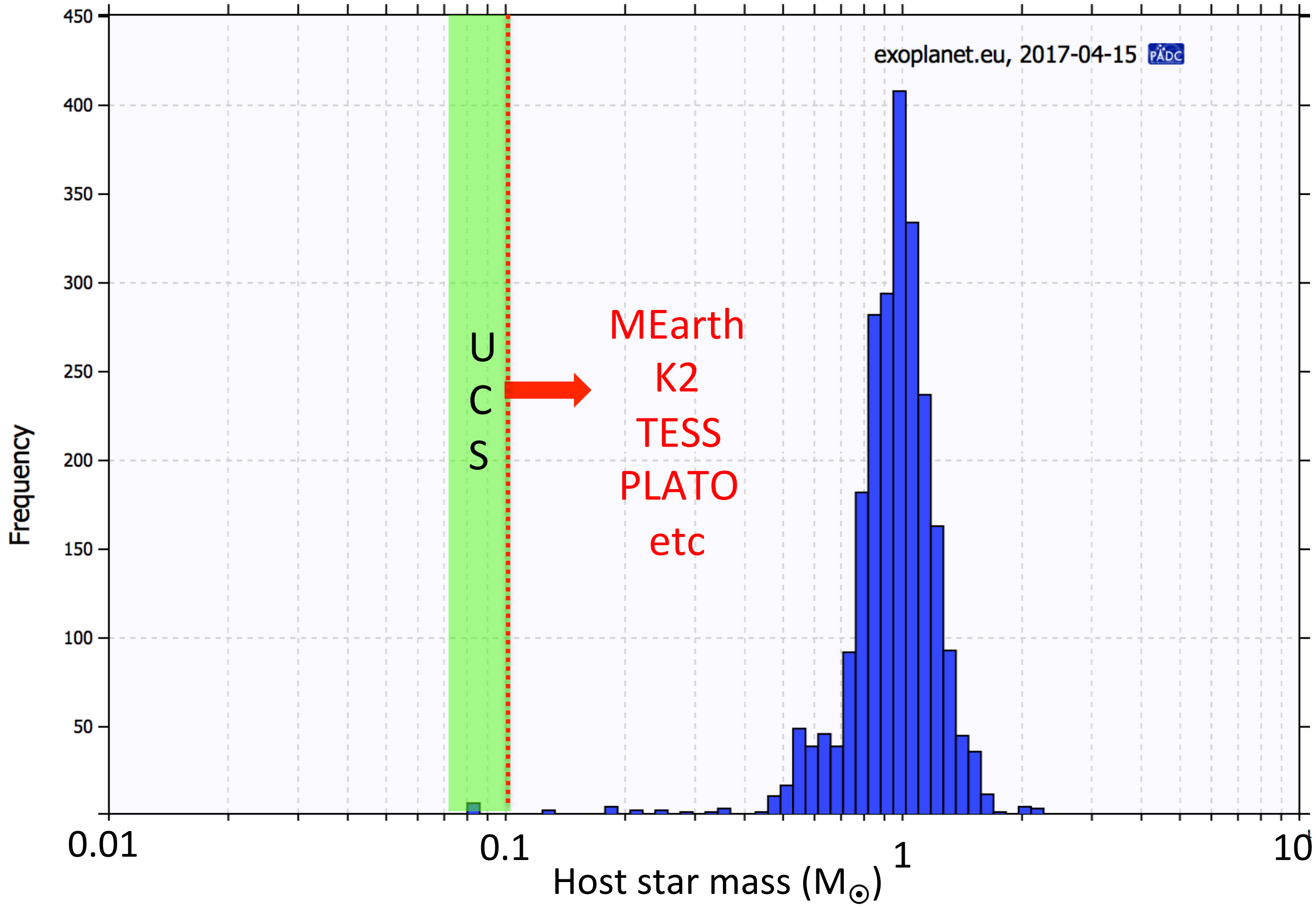
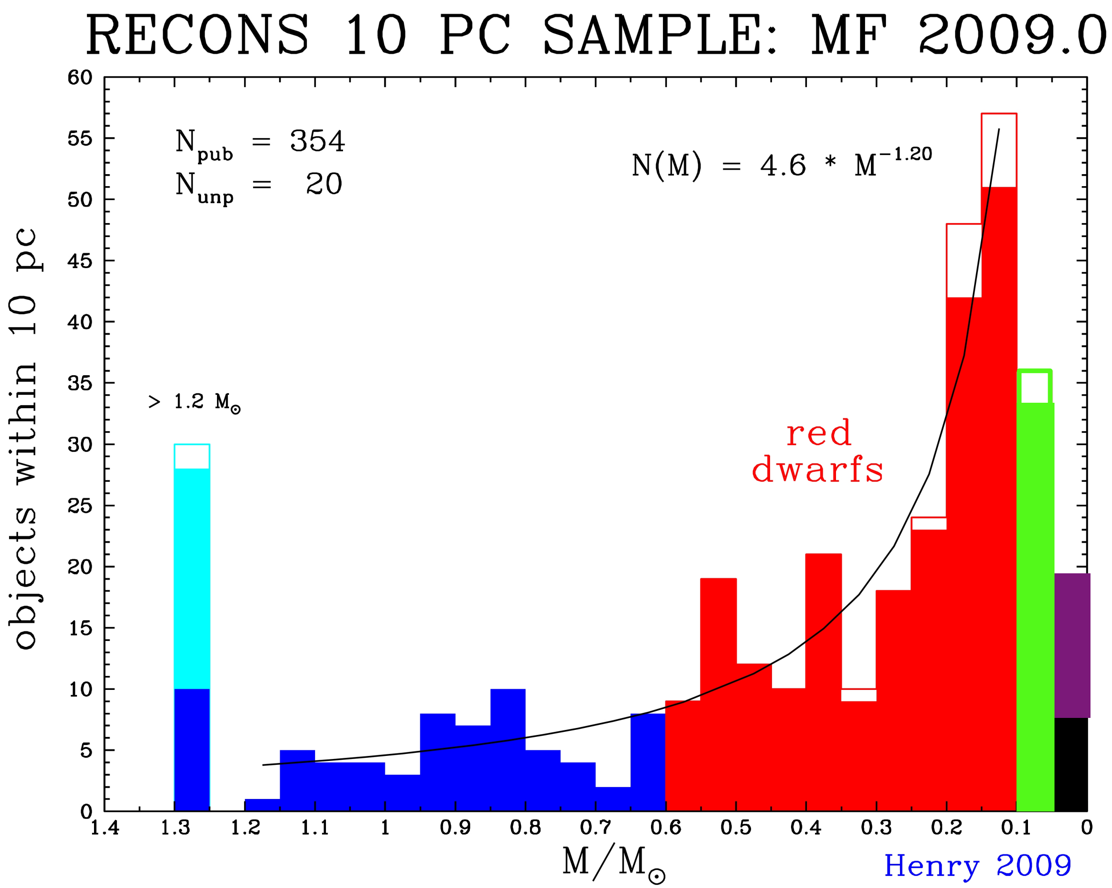
Why a transit survey targeting ultra-cool stars?

1. Uncharted territory



Why a transit survey targeting ultra-cool stars?

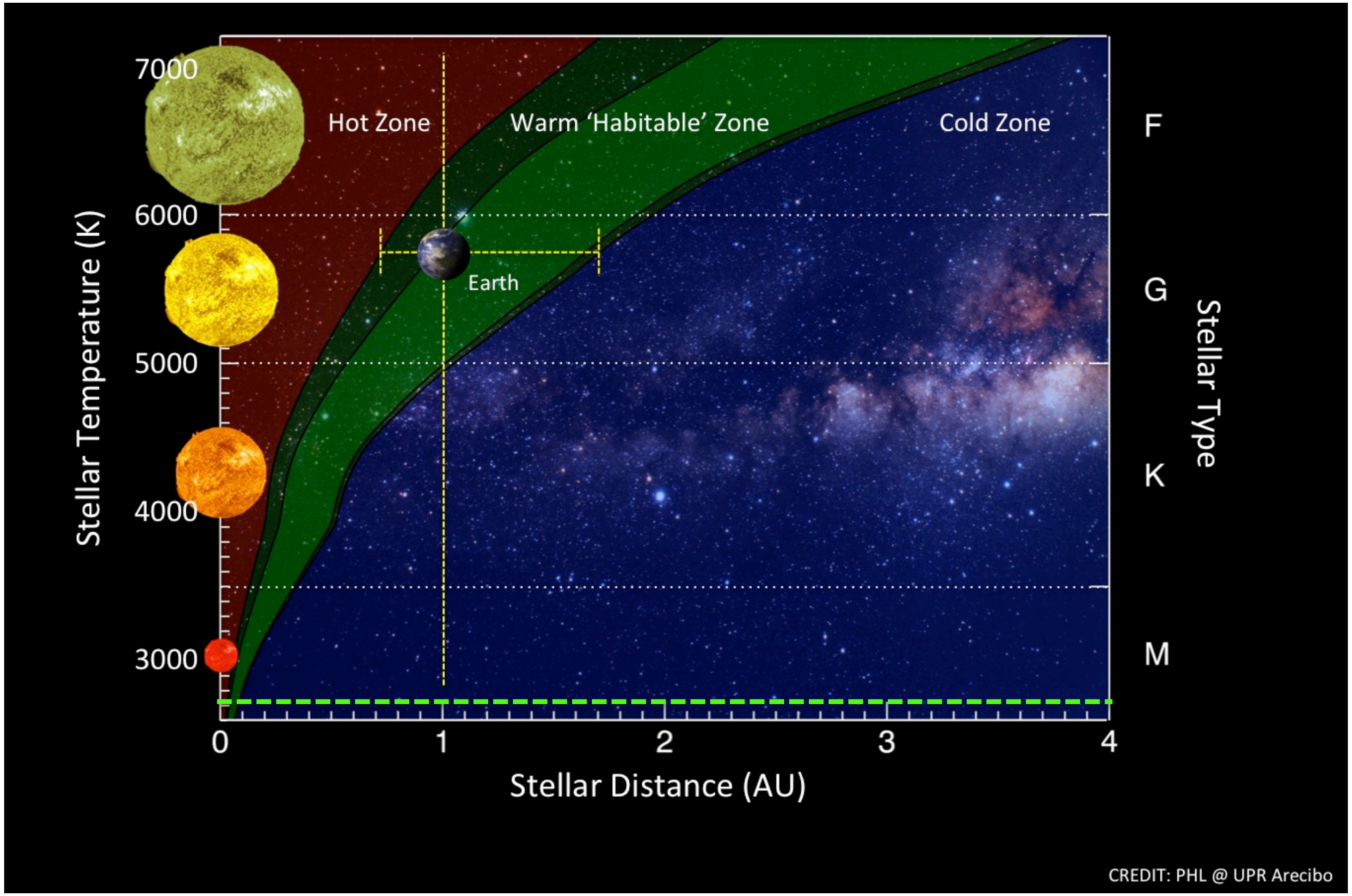
2. Significant fraction of the galactic population



10-15% of stars in solar neighborhood

Why a transit survey targeting ultra-cool stars?

3. Habitable zone is VERY close to the star



Orbital period of a few days
+
Transit probability of a few %

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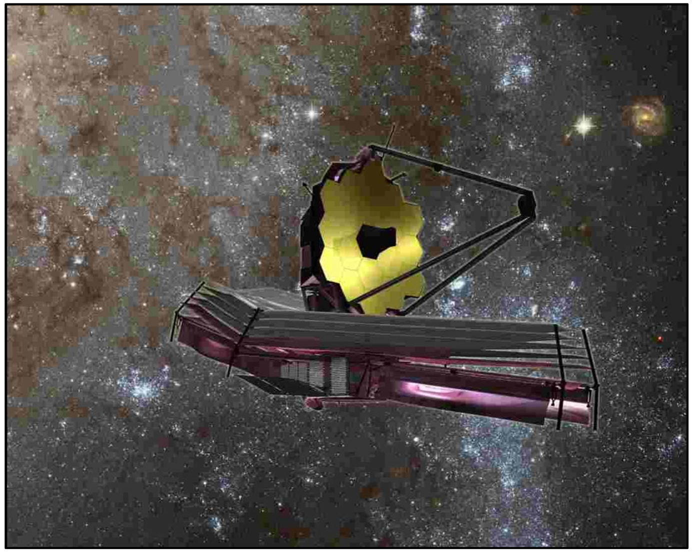
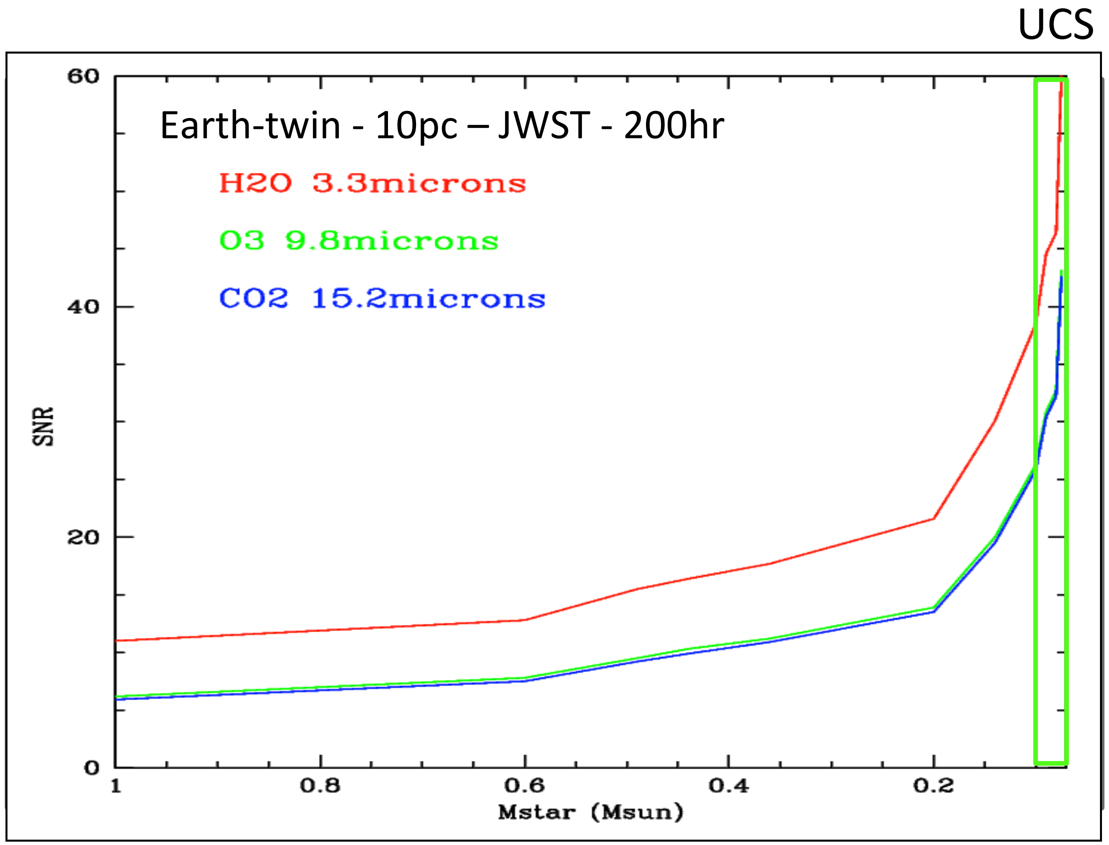
Why a transit survey targeting ultra-cool stars?

4. Atmospheric characterization of HZ Earth-sized planets possible





From Kaltenegger & Traub (2009)

Best targets for JWST : ~1000 ultra-cool stars with Jmag < 14

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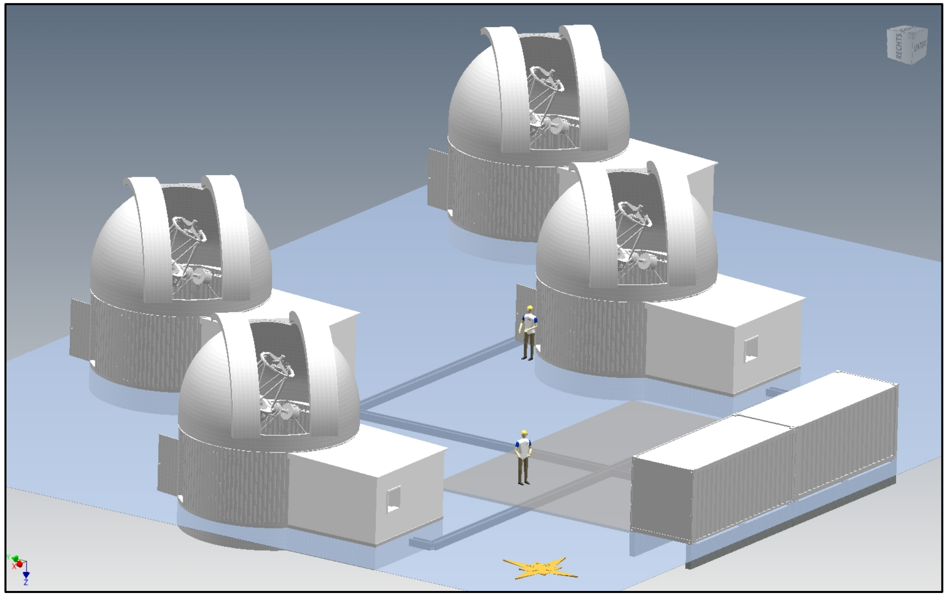
Search for habitable Planets EClipsing ULtra-cOOl Stars

SPECULOOS: basic concept

Targets: 1000 ultra-cool dwarfs of J<14, including 800 stars and 200 brown dwarfs. → Targeted survey

Short transits: down to 10 min → Continuous monitoring

Telescope sizes: detection of the unique transit of an Earth-sized planet, assuming a deep-depletion CCD camera →
Jmag < 12: 60cm
Jmag < 13: 1m
Jmag < 14: 2m



Observatories of 4 x 1m telescopes
1 in the South + 1 in the North

Survey completed after 5 yr (J<13)
after 10 yr (J<14)

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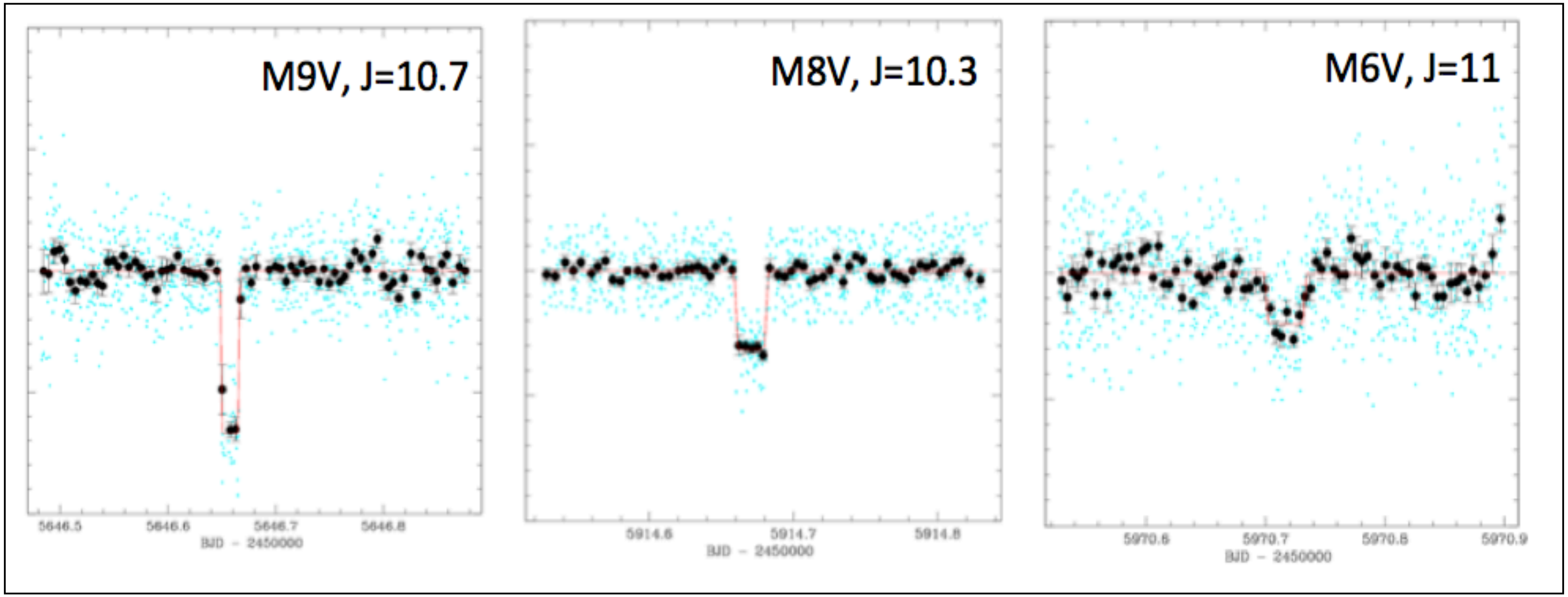
Search for habitable Planets EClipsing ULtra-cOOl Stars

First step: prototype survey

- Since 2011, prototype survey with TRAPPIST 60cm robotic telescope at ESO La Silla
- Targets: 50 brightest southern ultra-cool dwarfs + 30 M6-type stars (e.g. Proxima)



Detection limits from 0.6 to 1.1 R_{earth}

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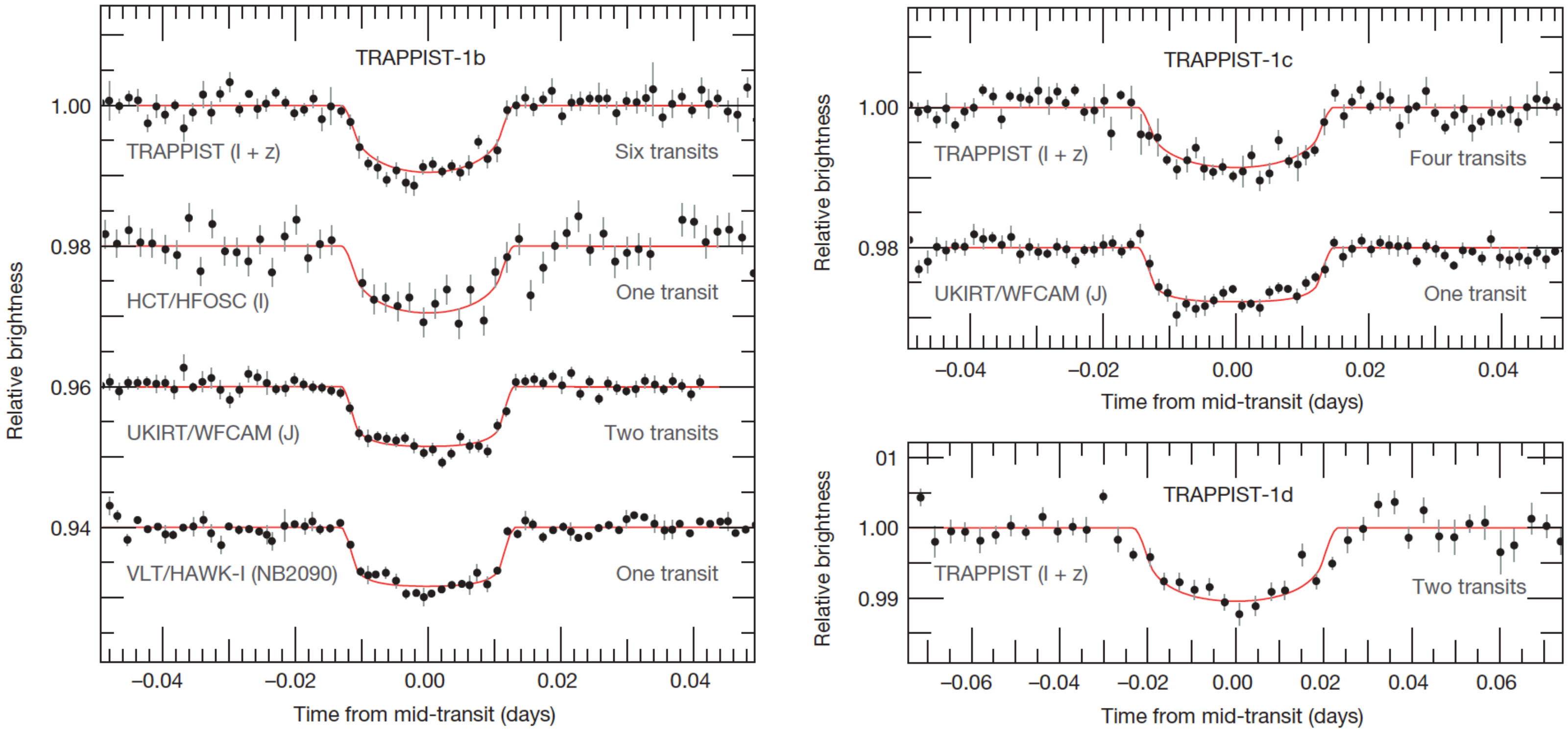
End 2015: TRAPPIST-1

Ultra-cool stars do host compact systems of Earth-sized planets!

3 Earth-sized planets with P=1.5, 2.4 and ~18d transiting a M8V star at 12 parsec



Gillon et al. (2016)

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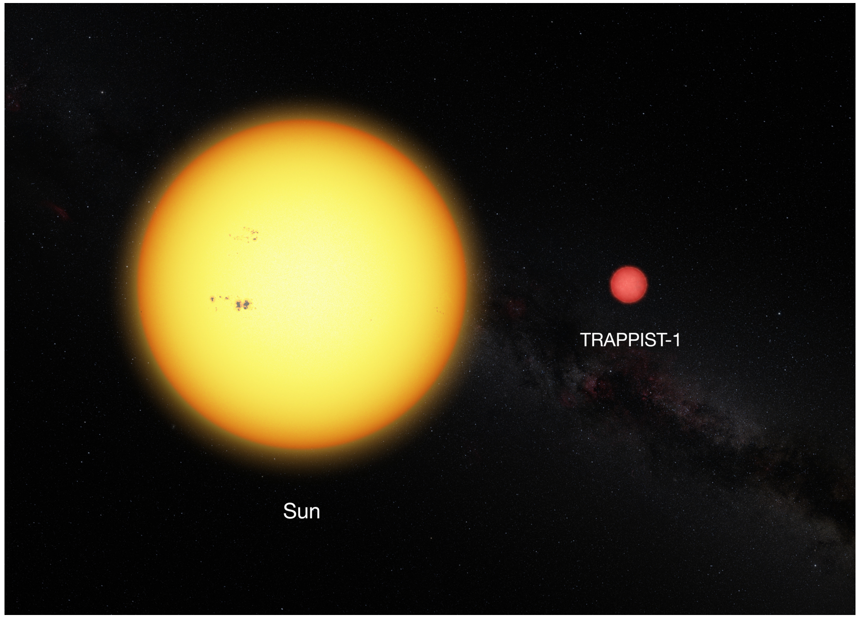
Search for habitable Planets EClipsing ULtra-cOOl Stars

The host star TRAPPIST-1A

Discovered in 2000 by *Gizis et al*. V=18.8, I=14.0, J=11.3, 12.1±0.4 pc

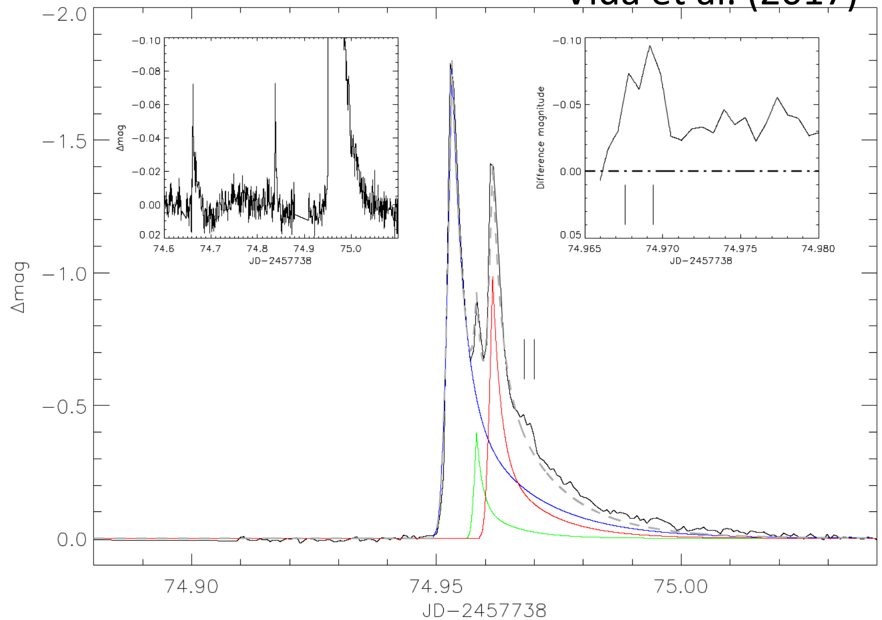
0.080±0.007 $M_{\odot}$, T_{eff} = 2560±55 K, [Fe/H] = +0.04±0.08 (Gillon et al. 2016, 2017)

Rotation period of 3.3d, age of 3-8 Gyr (Luger et al. 2017)



0.117±0.004 $R_{\odot}$, 0.00052±0.00003 $L_{\odot}$

Vida et al. (2017)



~0.4 flare per day

~0.3 superflare every month

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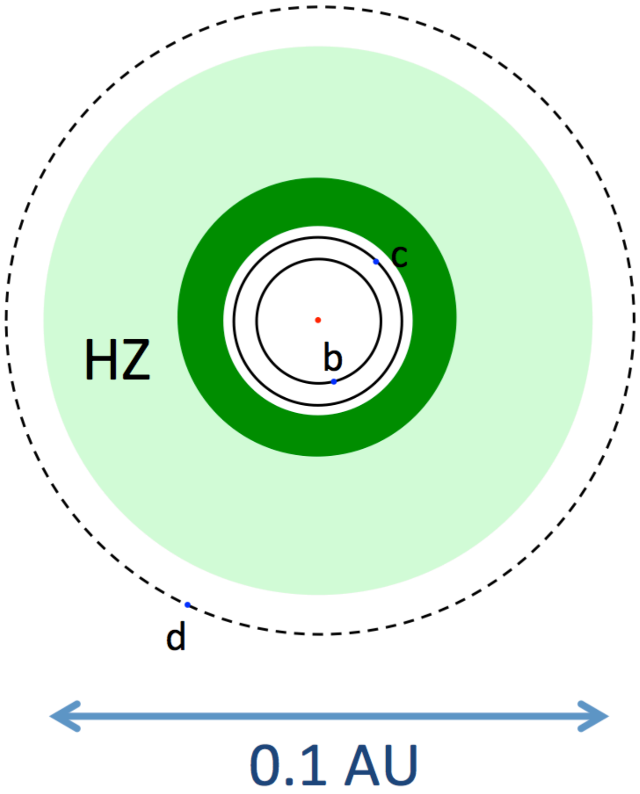
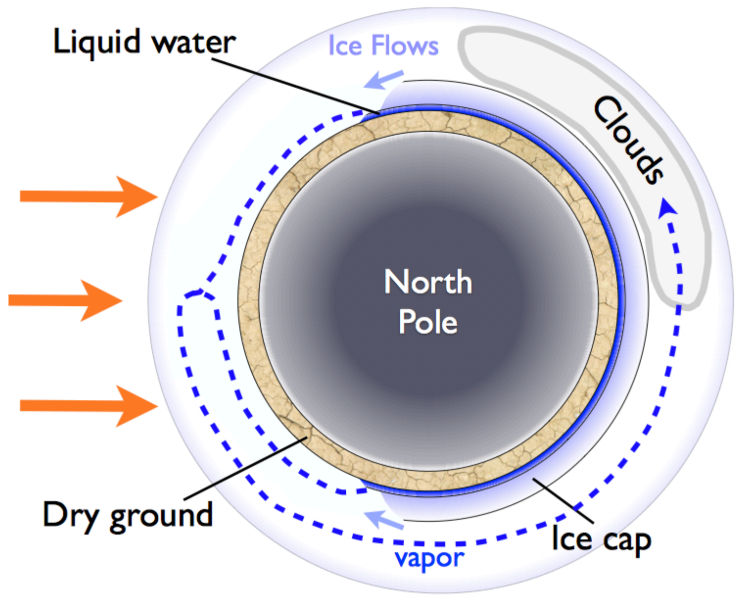
Search for habitable Planets EClipsing ULtra-cOOl Stars

TRAPPIST-1: three temperate Earth-sized planets



Kopparapu et al. (2013) Yang, Cowan & Abbot et al. (2013)



Leconte et al. (2013)

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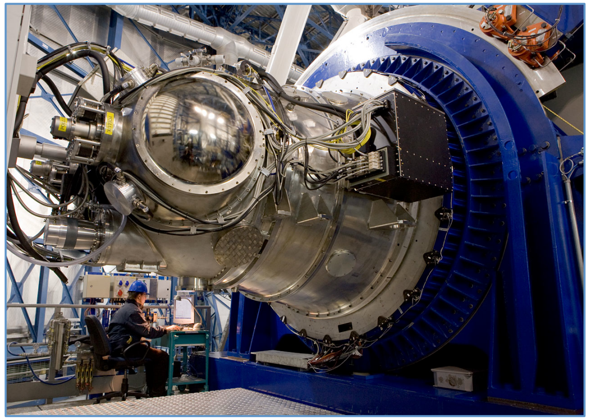
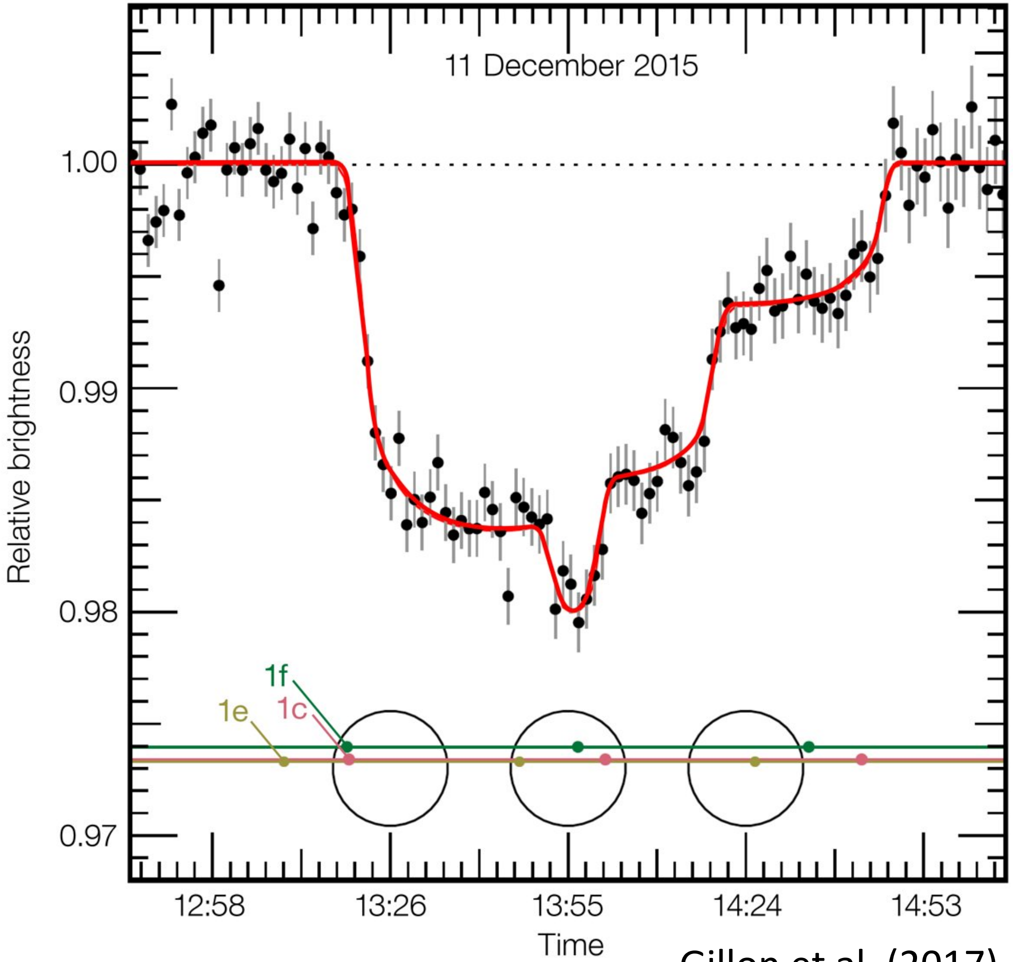
2016: the TRAPPIST-1d mystery…





Gillon et al. (2017)

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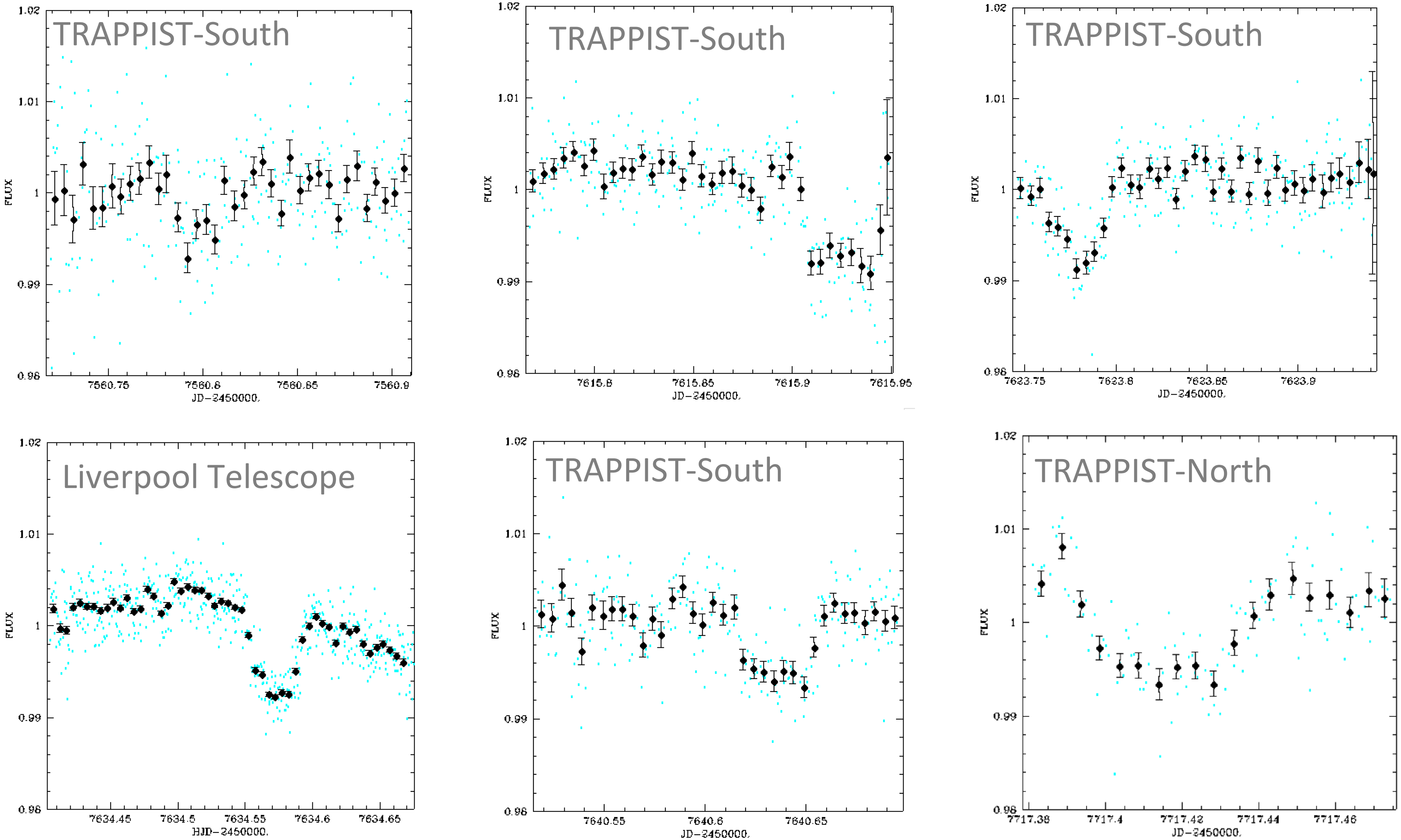
2016: intensive photometric follow-up from the ground



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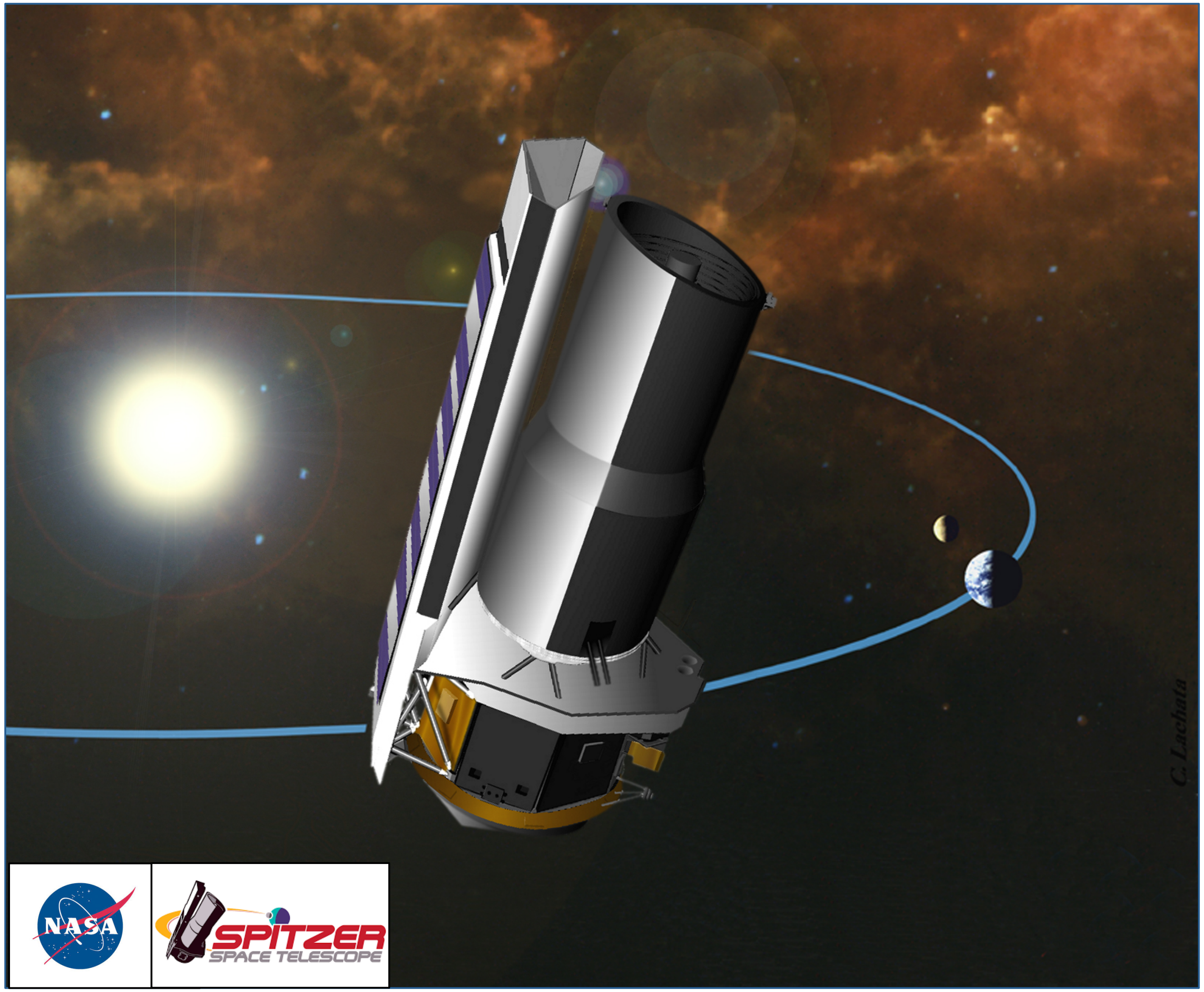
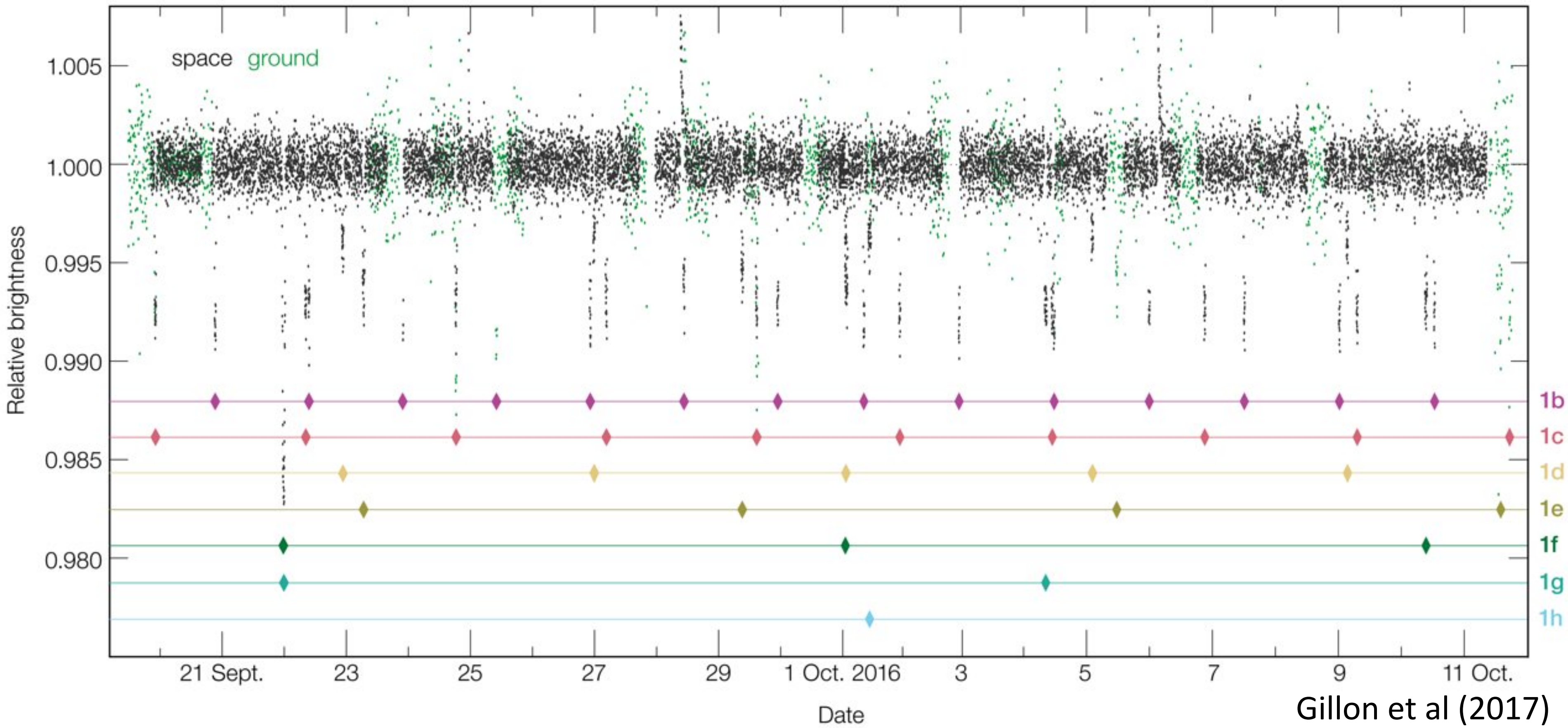
The perfect telescope for the job



Fall 2016: Spitzer cracks the system!



Gillon et al (2017)

20 days of nearly continuous observation… and 34 transits!

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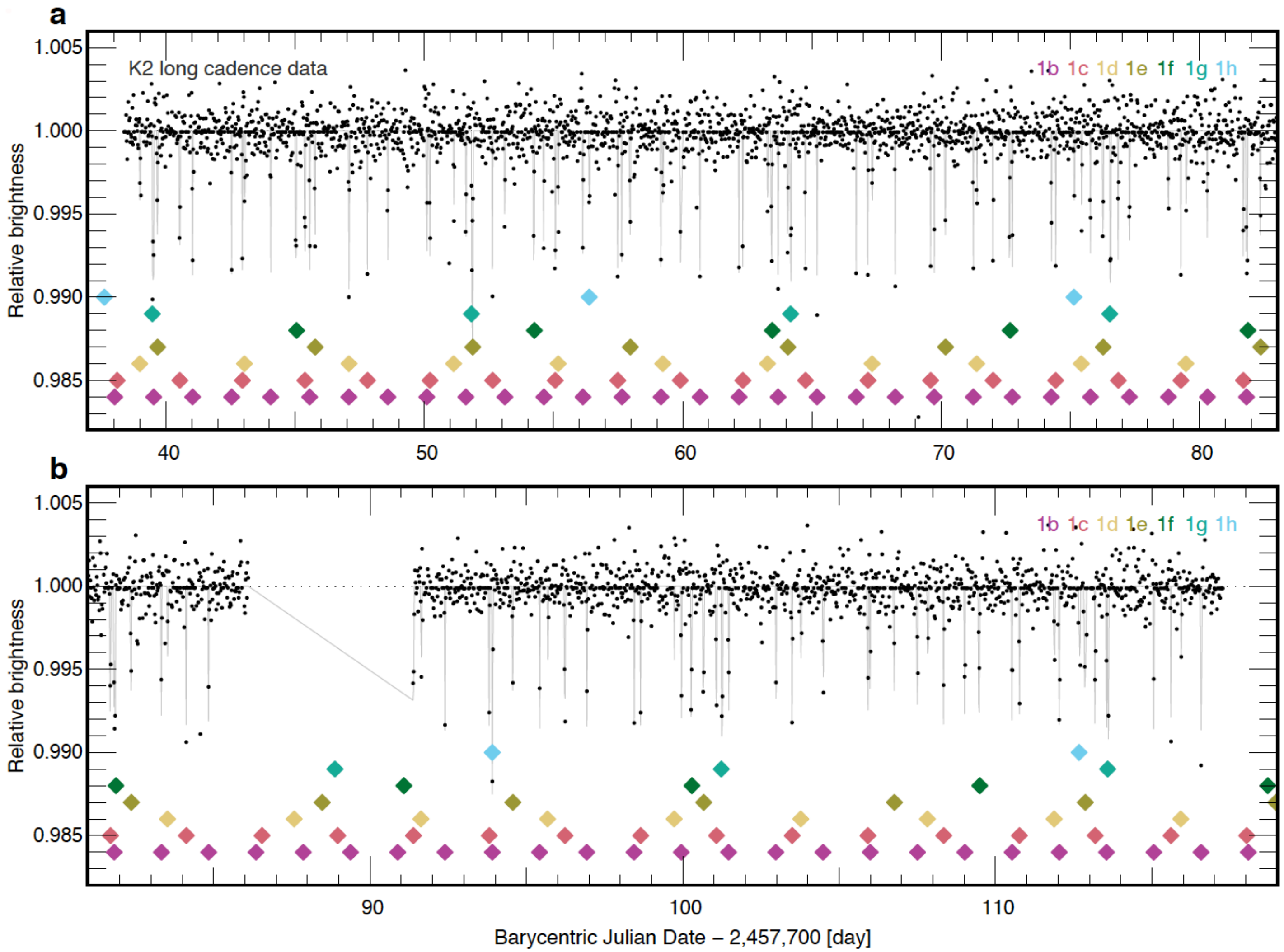
Kepler K2 campaign #12: TRAPPIST-1



Luger et al (2017)

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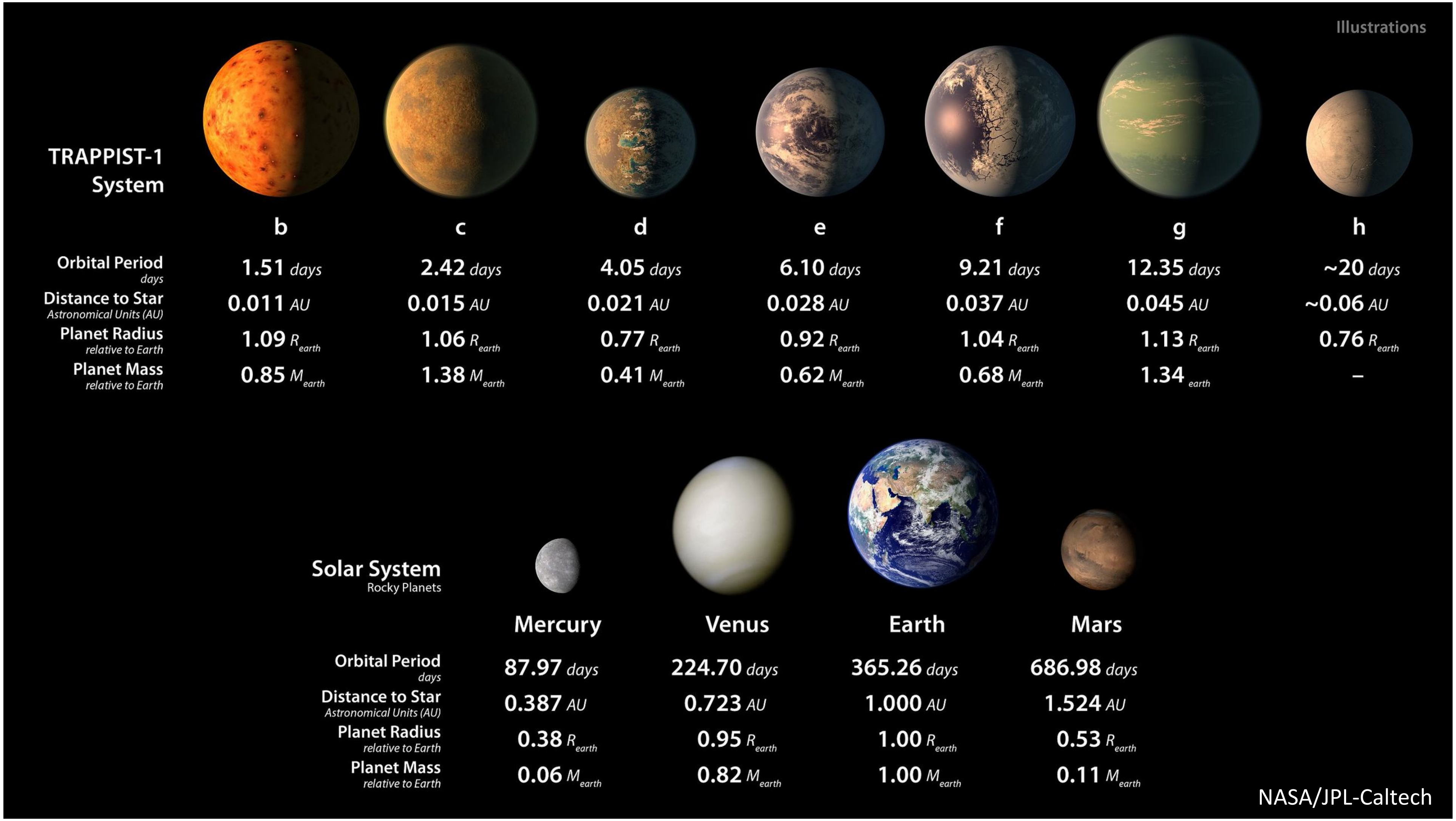
The amazing TRAPPIST-1 system



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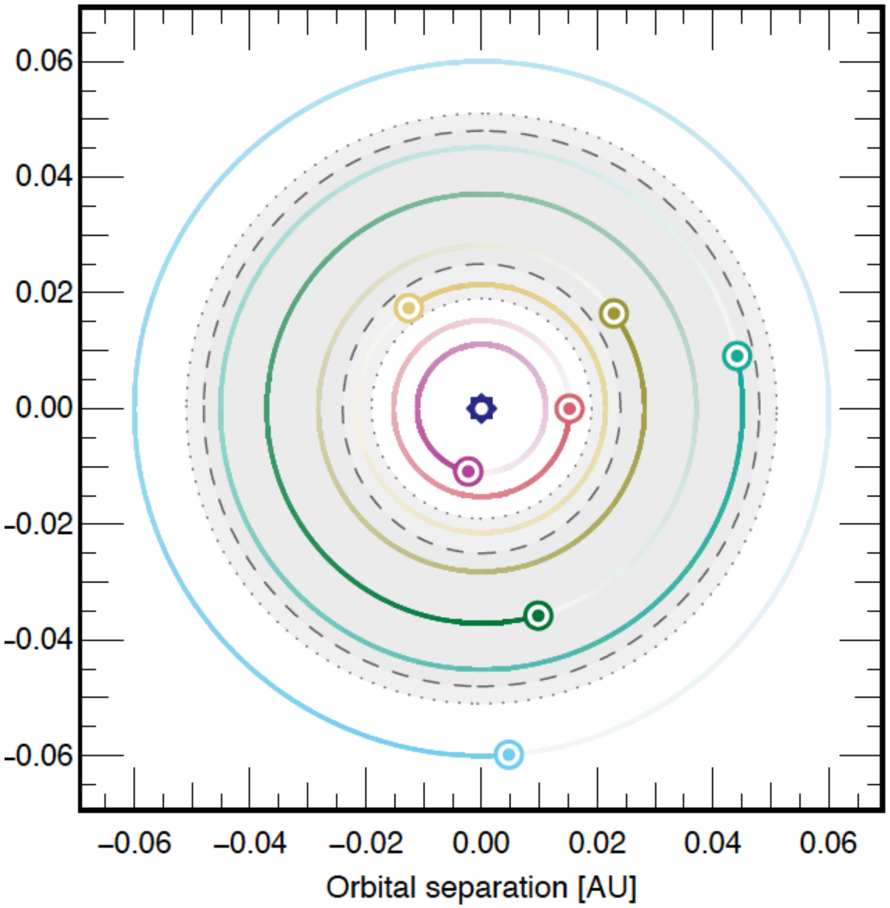
The amazing TRAPPIST-1 system



Luger et al (2017)

3-4 planets in the habitable zone

The seven planets form a near-resonant chain: all sets of 3 adjacent planets are in 3-body (Laplace) resonances

Structure strongly suggests type I migration

Significant transit timing variations enable measuring the planets' masses

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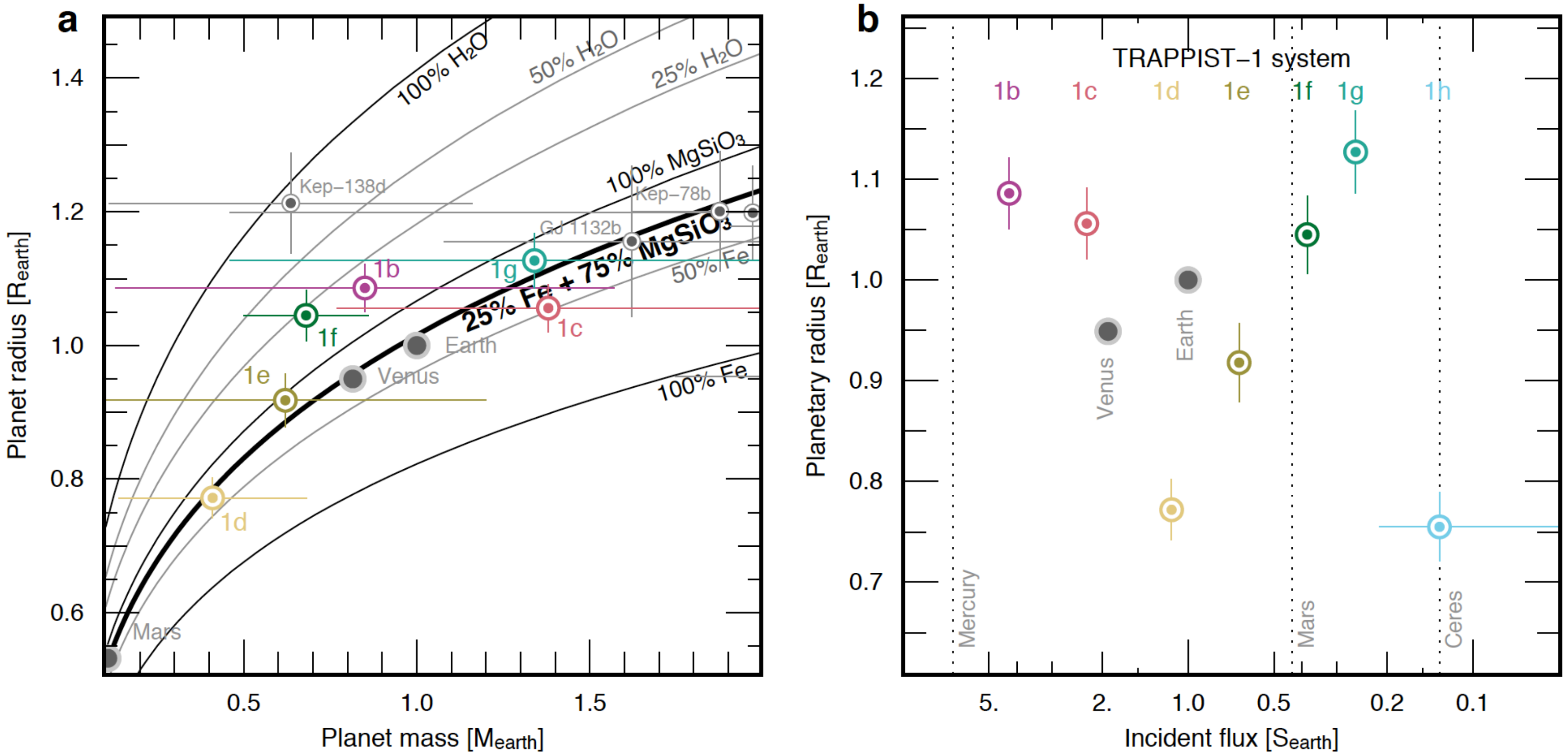
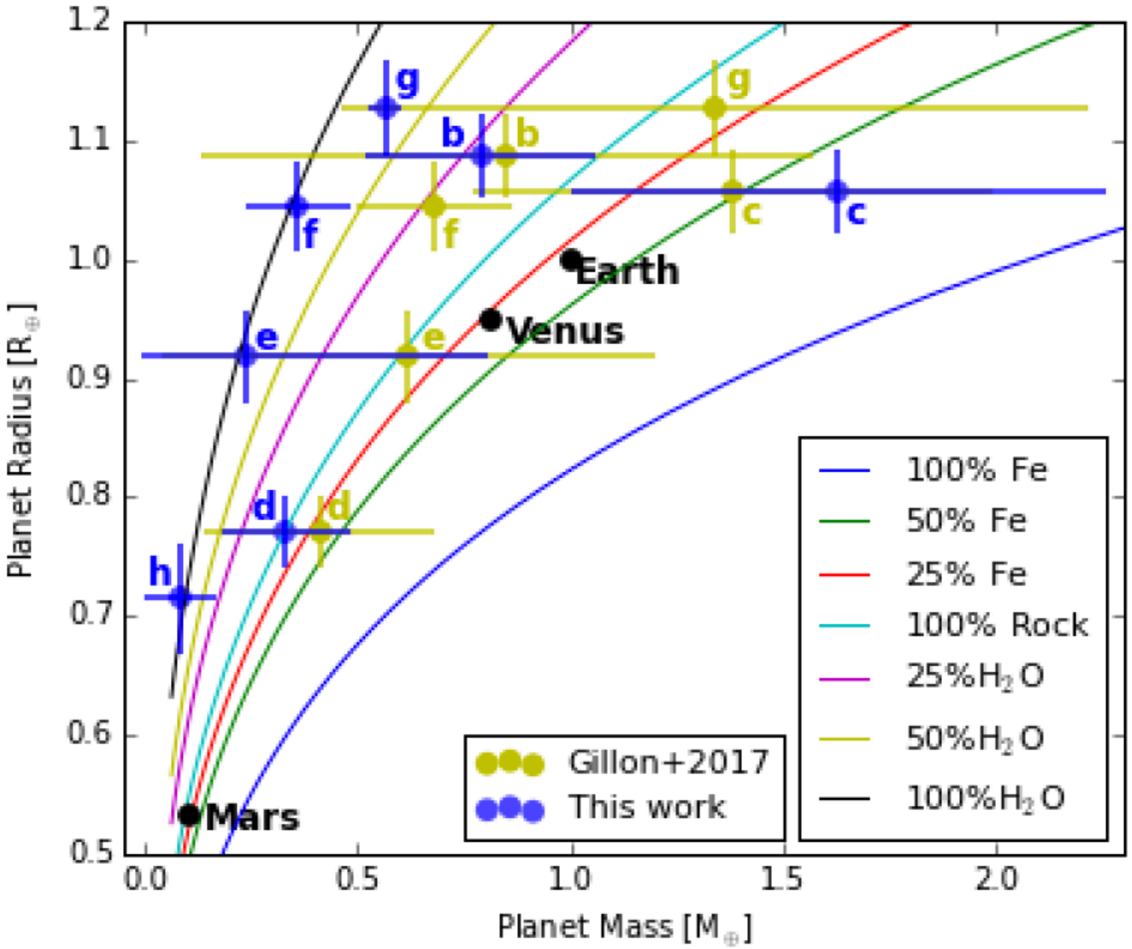
The composition and irradiation of the TRAPPIST-1 planets



Gillon et al (2017)

The updated composition of the TRAPPIST-1 planets



Wang et al (2017)

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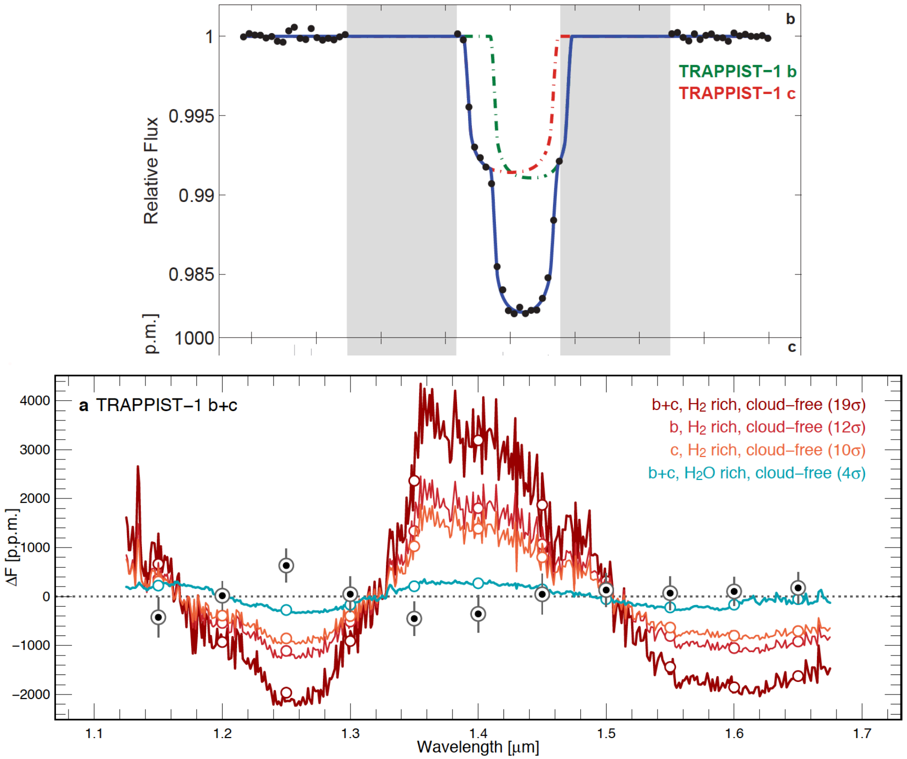
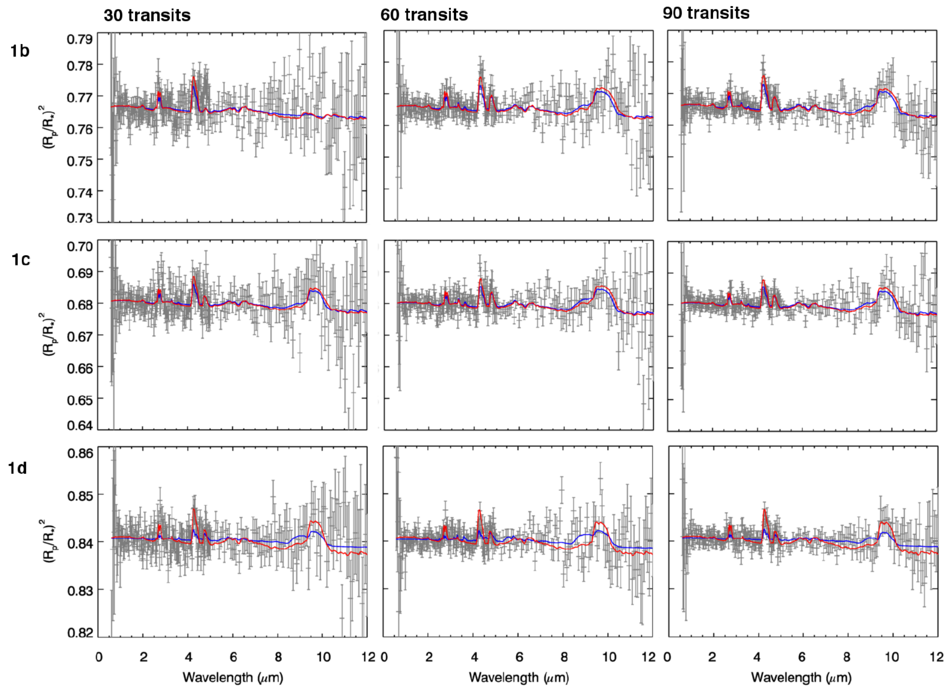
TRAPPIST-1: seven opportunities to study the atmospheric composition of temperate Earth-sized planets

First with HST



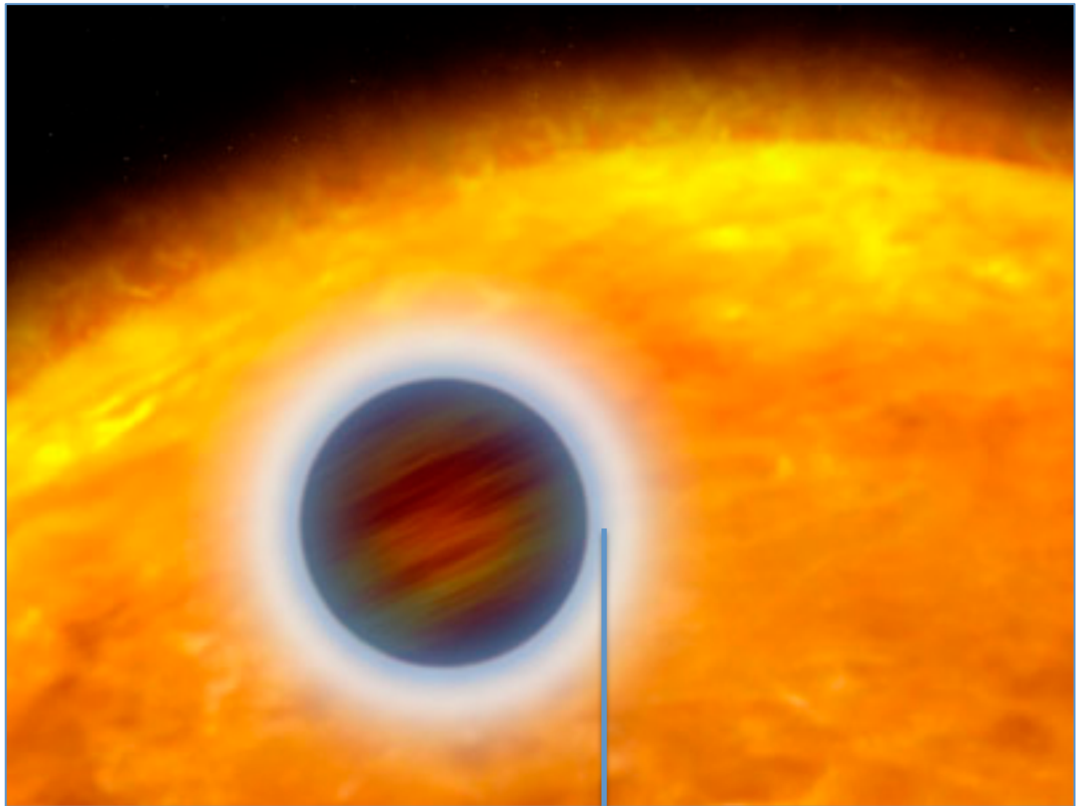
de Wit at al. (2016)

…and then with JWST



Barstow & Irwin (2016)

Infrared transit transmission spectroscopy



Amplitude of the signal?

(e.g. Winn 2010)

M_p = planet mass

R_p = planet radius

μ_p = atmo. mean molecular mass (amu)

= 29 for Earth-like composition,

a_p = planet semi-major axis

$A_{B,p}$ = planet Bond albedo

$T_{eff,*}$ = star effective temperature

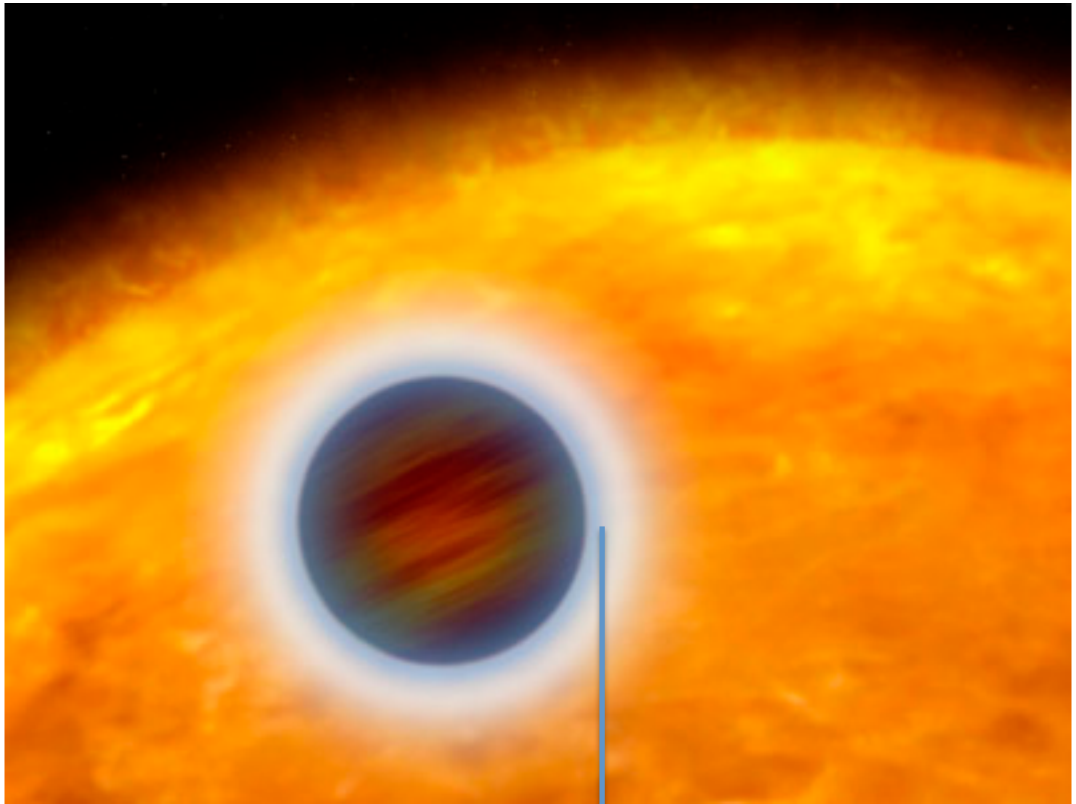
R_* = star radius

k_b = Boltzmann constat

G = Newton constant

$$\Delta\delta = 2\sqrt{2} \times \frac{k_b}{G} \times \frac{R_p^3(1 - A_{B,p})^{1/4}}{\sqrt{a_p}\mu_p M_p} \times \frac{T_{eff,*}}{R_*^{3/2}}$$

Infrared transit transmission spectroscopy



SNR for one transit?

C = constant

K_* = star K-band magnitude

W_{tr} = transit duration

$$SNR_{tr} = C \times \Delta\delta \times \sqrt{10^{-K_*/2.5}} \times \sqrt{W_{tr}}$$

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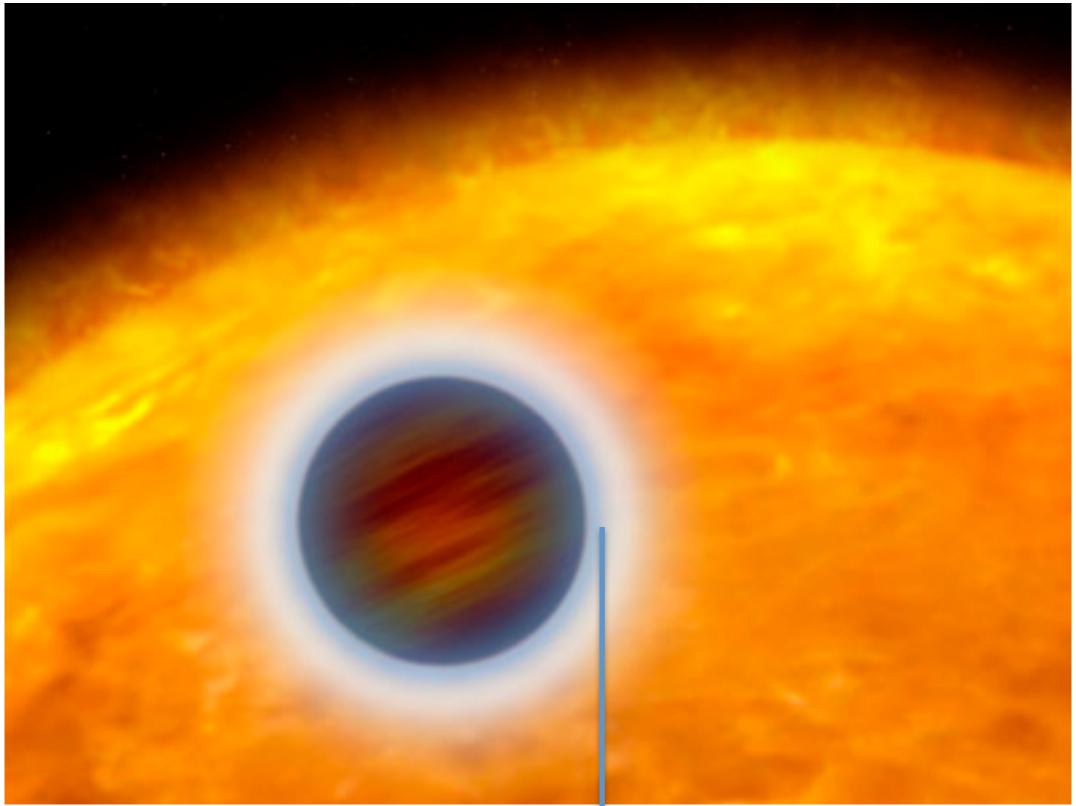
Infrared transit transmission spectroscopy



SNR after N_{yr} years of JWST?

Assumption: all observable transits are observed

Vis = visibility by JWST in days/year
P_p = planet orbital period

$$SNR = SNR_{tr} \times \sqrt{Vis/P_p} \times \sqrt{N_{yr}}$$

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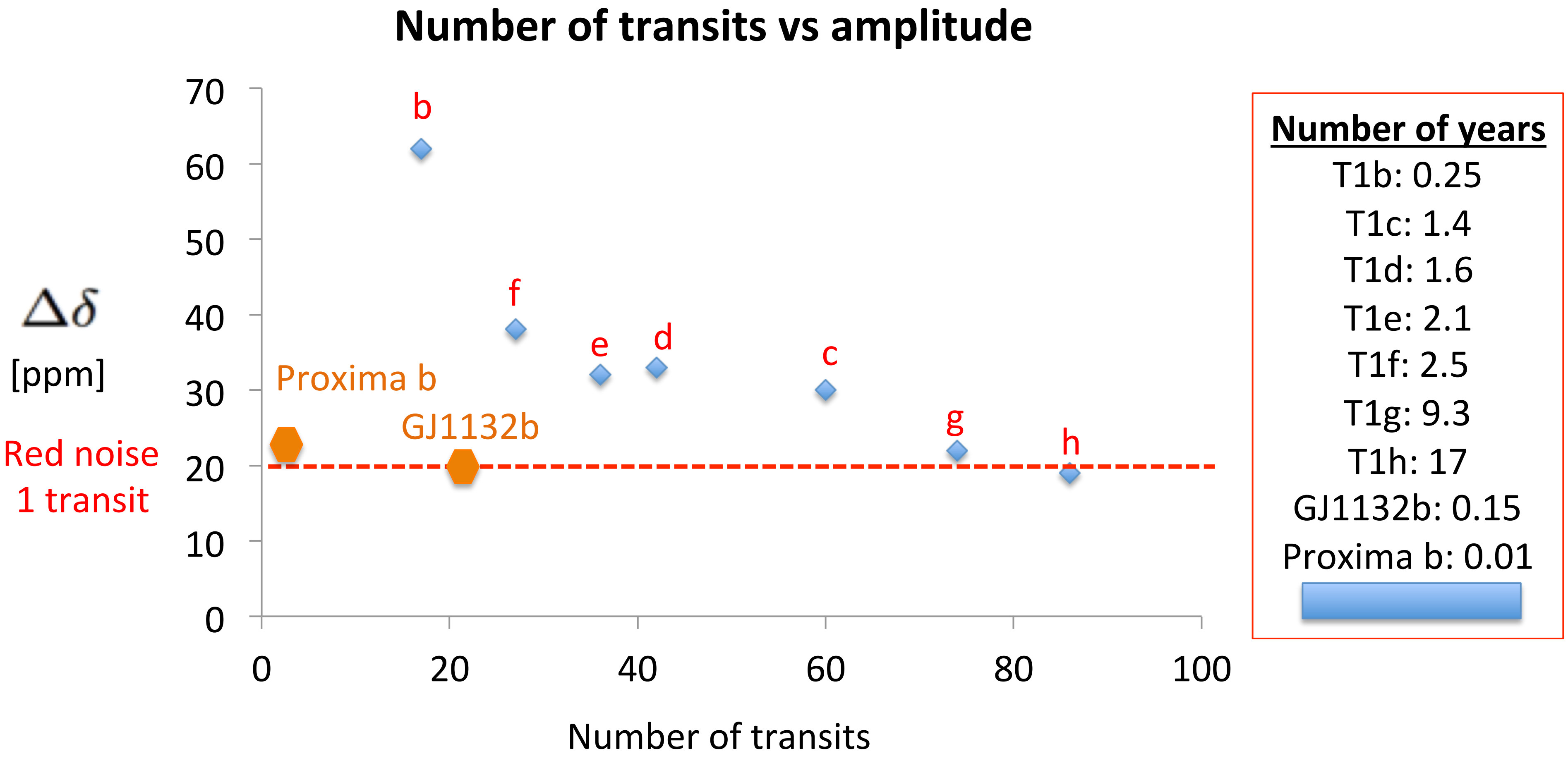
Estimation of the required JWST time

Barstow & Irwin (2016): 30 transits with NIRSPEC and 30 with MIRI for TRAPPIST-1c



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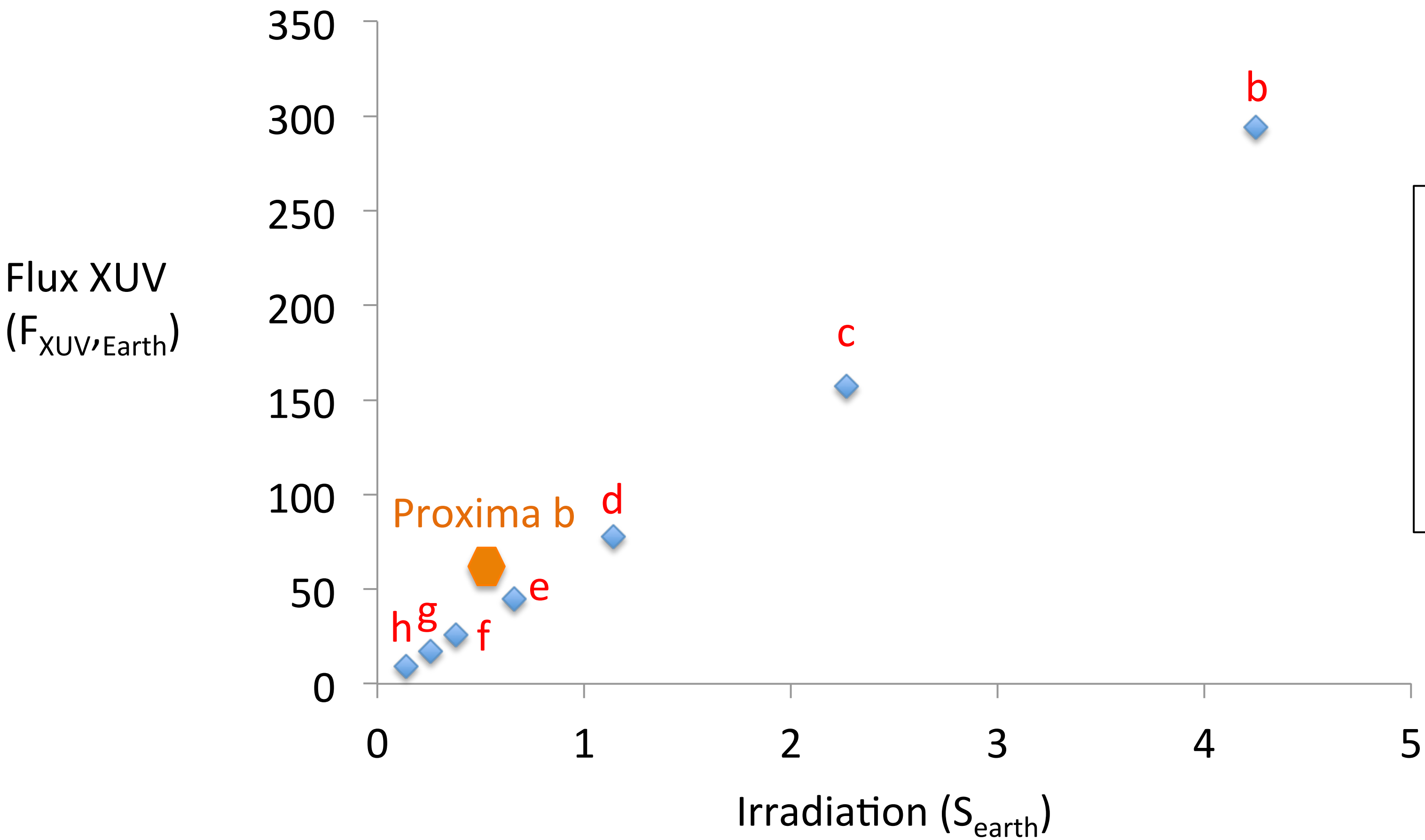
The high-energy irradation of the TRAPPIST-1 planets

X and UV flux on the planets estimated from XMM-Newton (Wheatley et al. 2016) and HST/STIS (Bourier et al. 2017) measurements ➔ **dozens times larger than Earth for e,f,g**



+ stellar winds more frequent & much more powerful than on Earth
(Vida et al. 2017)

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Could the HZ TRAPPIST-1 planets be habitable?

Proxima Centauri b has a larger XUV irradiation than TRAPPIST-1 e, f and g.
Proxima Centauri: ~7 flares/day; TRAPPIST-1: ~0.4 flares/day

The habitability of Proxima Centauri b

I. Irradiation, rotation and volatile inventory from formation to the present

Ignasi Ribas[1], Emeline Bolmont[2], Franck Selsis[3], Ansgar Reiners[4], Jérémy Leconte[3], Sean N. Raymond[3], Scott G. Engle[5], Edward F. Guinan[5], Julien Morin[6], Martin Turbet[7], François Forget[7], and Guillem Anglada-Escudé[8]

ABSTRACT

Proxima b is a planet with a minimum mass of 1.3 $M_\oplus$ orbiting within the habitable zone (HZ) of Proxima Centauri, a very low-mass, active star and the Sun's closest neighbor. Here we investigate a number of factors related to the potential habitability of Proxima b and its ability to maintain liquid water on its surface. We set the stage by estimating the current high-energy irradiance of the planet and show that the planet currently receives 30 times more EUV radiation than Earth and 250 times more X-rays. We compute the time evolution of the star's spectrum, which is essential for modeling the flux received over Proxima b's lifetime. We also show that Proxima b's obliquity is likely null and its spin is either synchronous or in a 3:2 spin-orbit resonance, depending on the planet's eccentricity and level of triaxiality. Next we consider the evolution of Proxima b's water inventory. We use our spectral energy distribution to compute the hydrogen loss from the planet with an improved energy-limited escape formalism. Despite the high level of stellar activity we find that Proxima b is likely to have lost less than an Earth ocean's worth of hydrogen (EO_H) before it reached the HZ 100–200 Myr after its formation. The largest uncertainty in our work is the initial water budget, which is not constrained by planet formation models. We conclude that Proxima b is a viable candidate habitable planet.

The SPECULOOS Southern Observatory at Cerro Paranal (Chile)

Europa in test operation;
Io, Ganymede and Callisto installed in June, Sep and Nov

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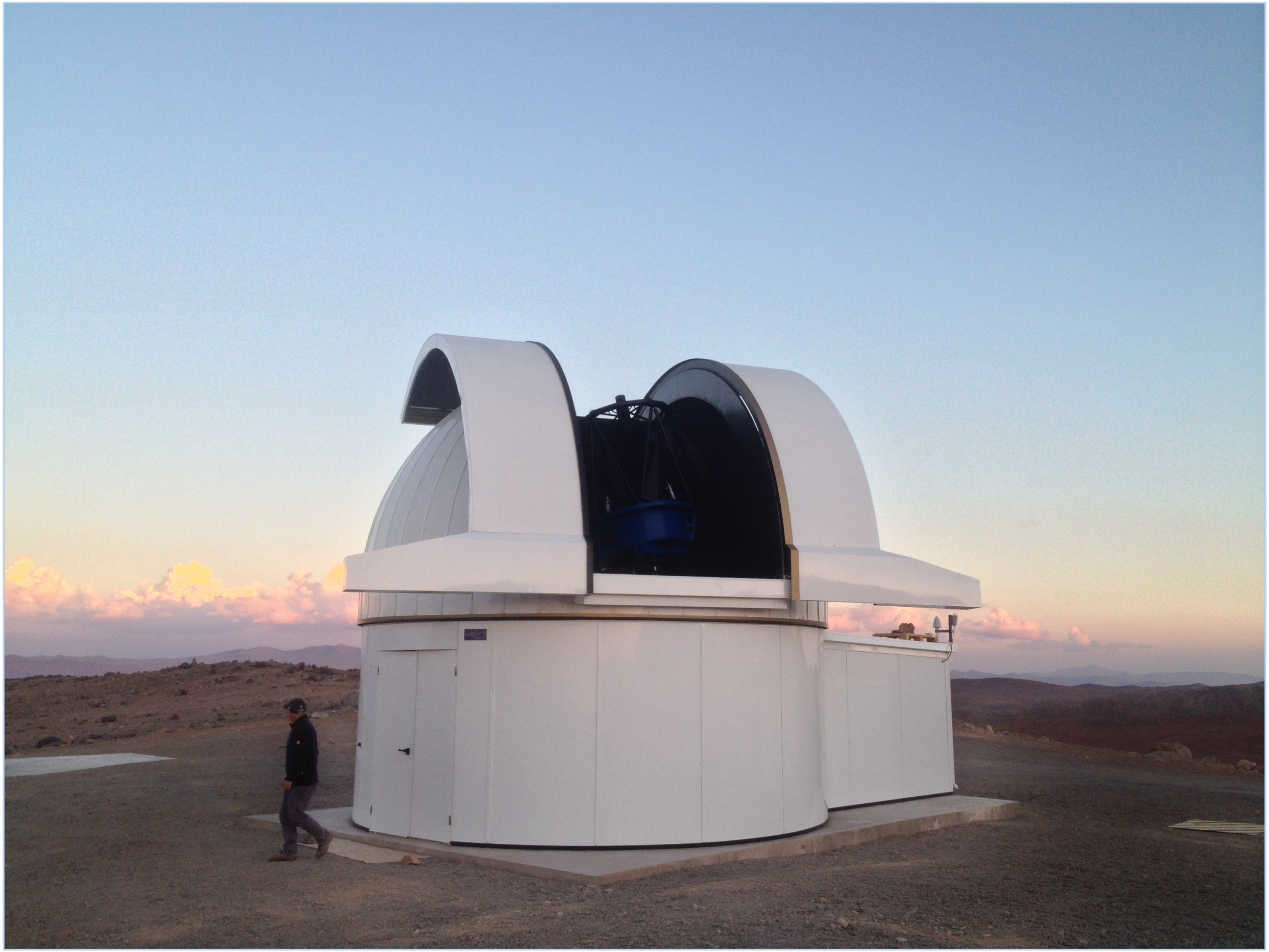
The SPECULOOS Southern Observatory at Cerro Paranal (Chile)



1m Ritchey-Chretien telescope, equatorial mount, deep-depletion 2kx2k CCD camera

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The SPECULOOS Northern Observatory

1. San Pedro Martyr (Mexico): 1m telescope to be installed in 2018
   Univ. Of Berne, PI B.-O. Demory
   50% time on SPECULOOS

2. San Pedro Martyr or La Palma: 1m telescope funded 50-50% by Liège & MIT.
   To be installed in 2018 or 2019.

3. Two to three more 1m telescopes needed, in search of funding

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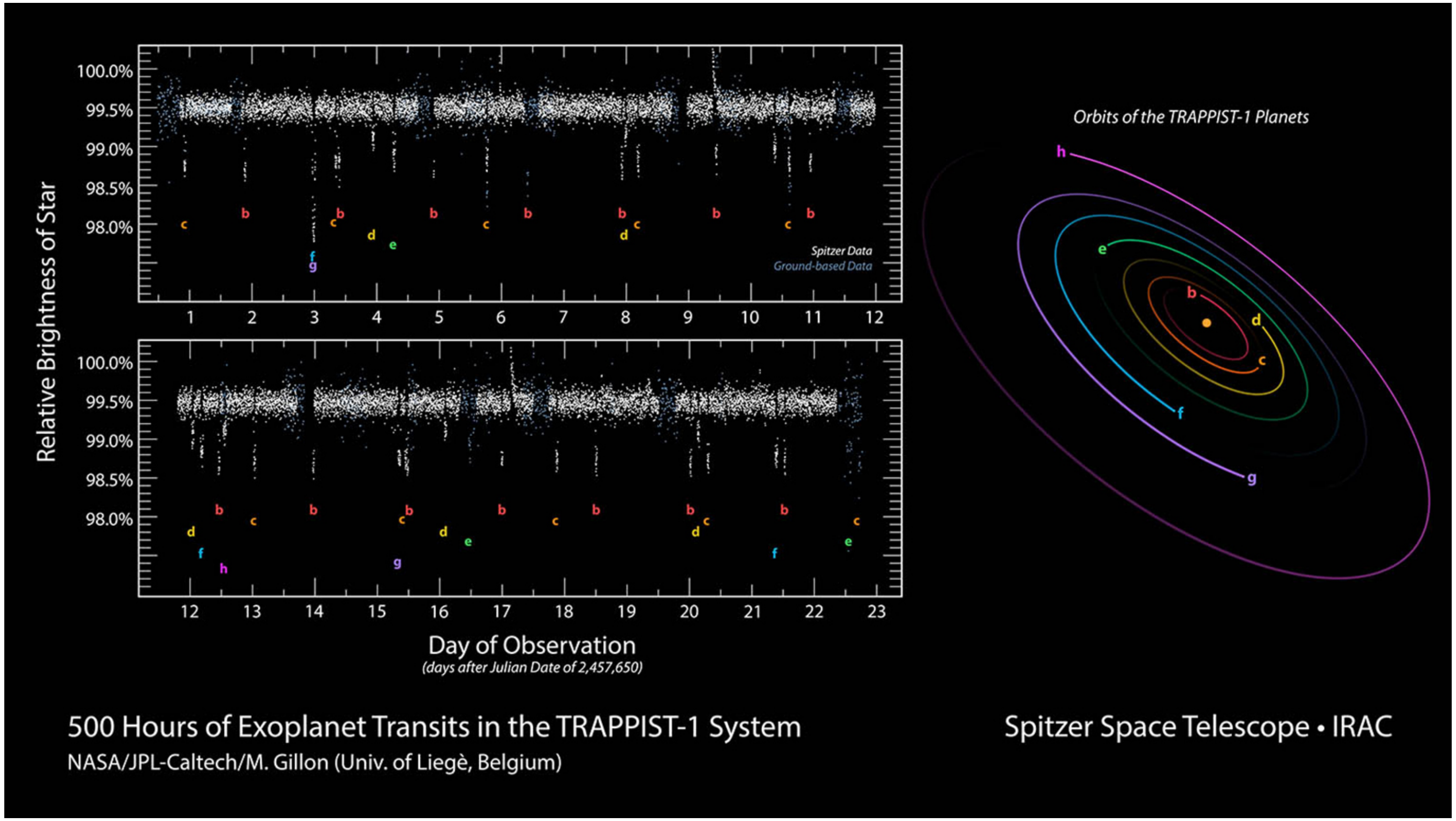
Lesson learned from the TRAPPIST-1 case: the importance of Spitzer

Only facility able to provide long (weeks) high-precision infrared time-series photometry. Operation cost: 9M$/yr



Follow-up of SPECULOOS and TESS candidates – Search for transits on nearest BDs