LIÈGE université Astrobiology
exotic SPECULOOS

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Global results of the Spitzer Exploration Science Program red worlds

Introduction

Context: With more than 1000 hours of observation, the Spitzer Exploration Program *red worlds* (ID: 13067) targeted exclusively TRAPPIST-1, a nearby ultracool dwarf star orbited by seven transiting Earth-sized planets. The program's main goals were (1) to explore the system for new transiting planets, (2) to monitor intensively the planets' transits to bring the strongest possible constraints on their masses, sizes, compositions, and dynamics, and (3) to assess the infrared variability of the host star.
This poster is associated to a paper (in prep.) in which we present the global results of the program. We analysed 71 new transits and combine them with 100 previously analysed transits, for a total of 171 transits observed at 3.6 μm or 4.5 μm.

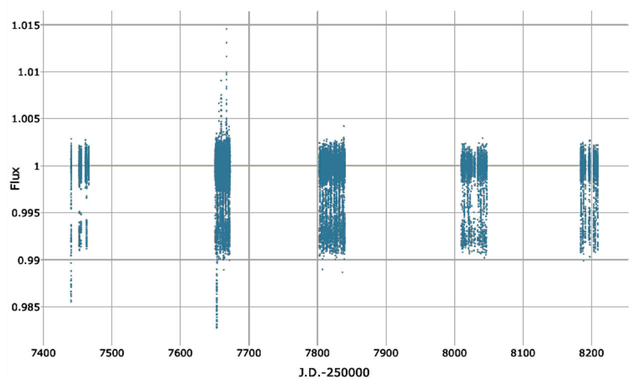
Red Worlds exploration program

More than 1000 hours of observations ! Notably 480 hours of continuous monitoring

Observations were already presented in [1] and [2]

Here 71 new transits in IRAC 1 and 2 + global analyses of the **entire dataset**

Planet	Well isolated transits	Blended transits	Total
TRAPPIST-1b	51	11	62
TRAPPIST-1d	35	8	43
TRAPPIST-1d	20	3	23
TRAPPIST-1e	14	2	16
TRAPPIST-1f	10	2	12
TRAPPIST-1g	6	3	9
TRAPPIST-1h	6	0	6

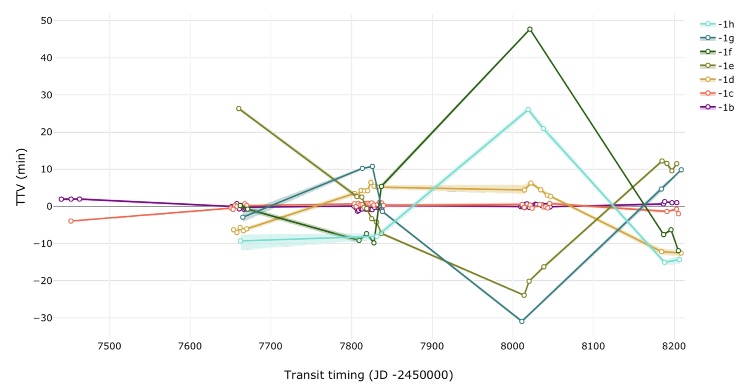


Data analysis

We carried out series of analyses:

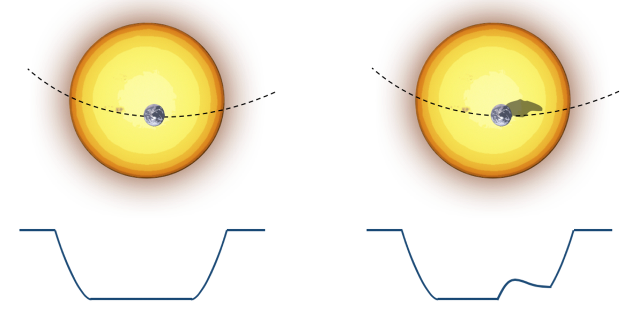
- A global analysis of all transits to refine the planets parameters given in [2]
- Individual analysis of each light curve to seek for transit depth anomalies and orphan structures
- Global analyses of all transit associated to a planet to get the best precision of the depth and to report the transit timing variations (TTV)

Figure 1. evolution of the TTV variations through the SPITZER observations



Stellar variability from photometry

One possible way to gain insight on the host star of a planetary system is to use transits as a scan of the stellar photosphere. By comparing the transits depths at different epoch we can identify unusual events that are invisible outside of transit.



Results

- For all planets the depths are consistent from a transit to another, with no discrepancy larger than 3σ (see Figure 2)
- Measurements obtained in/out-of-transit do not reveal any transit shape asymmetry that could be related to the crossing of spot/faculae.

Besides, the study of flares is essential to get insights on the planetary evolution and the potential presence of life on extrasolar planets.

- We identified the five highest energy flares in the Spitzer dataset and compare them to the minimum flare rate and energy required to trigger prebiotic chemistry

→ TRAPPIST-1e planet currently do not receive enough high-energy flare to sustain abiogenesis

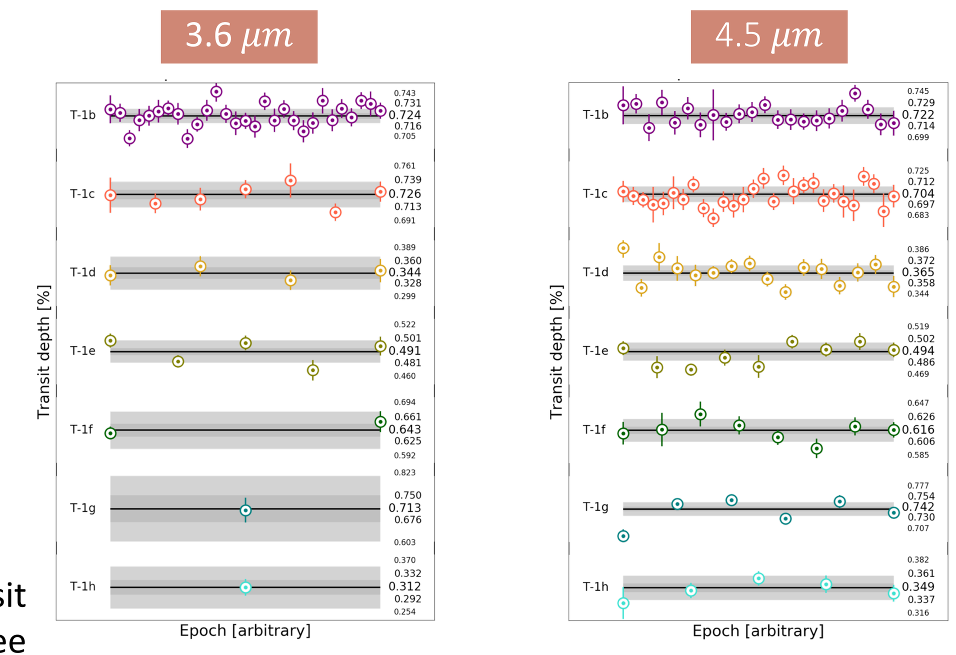


Figure 2. Time dependent variations of the transit depth from individual analysis for planet b to h, black line is the median from global analysis, 1σ and 2σ significance in shades grey

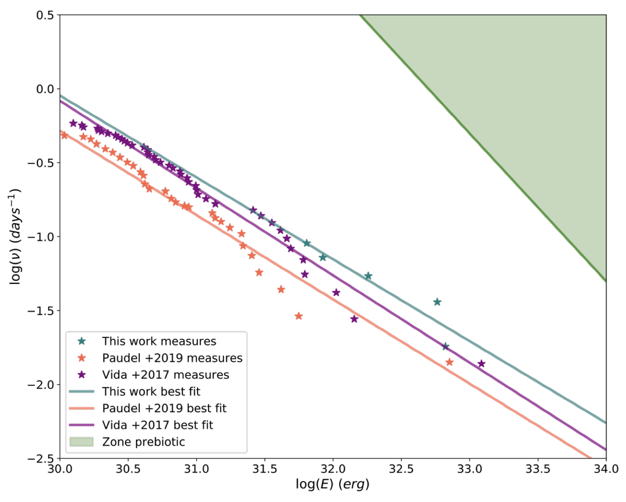
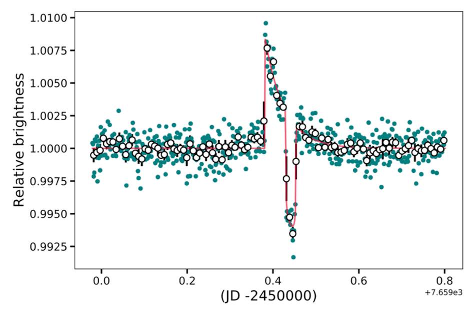


Figure 4. Flare frequency distribution for TRAPPIST-1e. Data from this work are in blue and others are in orange [3] and purple [4], the green area denotes the minimum flare rate and energy required to trigger prebiotic chemistry on a potential exoplanet

Figure 3. Example of one of the high energy flares reported, there is a transit of TRAPPIST-1b is the decay of the flare



Orphan transits & planet occultations

Orphan transits

Event	Depth (%)	Timing (JD-2450000)	Duration (days)	Impact parameter
# 1	0.57 ± 0.13	7658.4609 ± 0.0012	0.0362 ± 0.0047	0.956 ± 0.031
# 2	0.59 ± 0.16	7671.4522 ± 0.0012	0.0329 ± 0.0035	0.975 ± 0.023

We seek for orphan structures:

- We found four orphan events that we could not correct with any baseline or known transit
- Two of them are particularly convincing
- They look similar to each other, if same object the period should be ~12.9 days
- Planet g having a period of 12.35 days, common origin is unlikely
- Could be two distinct transiting objects

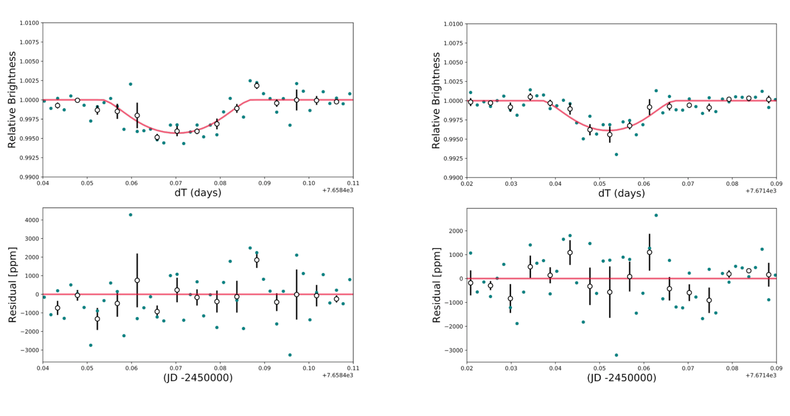


Figure 5. *Top:* Output from the MCMC, transit parameters for the two orphans structures. *Bottom:* Plot of the MCMC fit of the two orphans events.

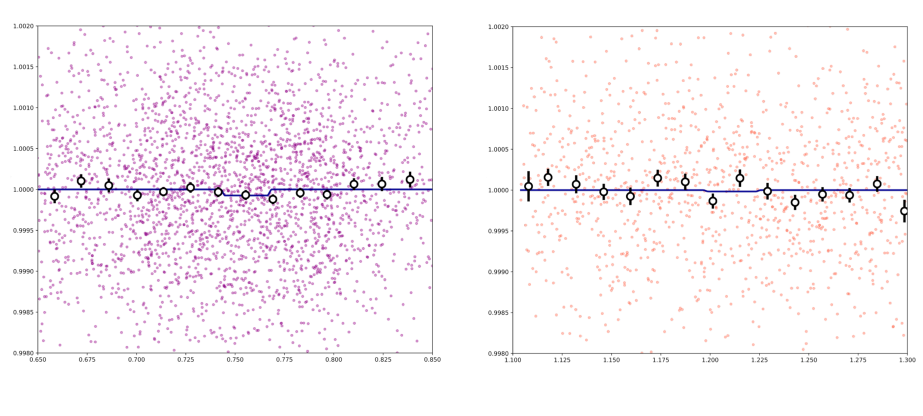


Figure 6. *Left:* 28 phased - folded occultations photometric measurements of TRAPPIST-1b obtained by Spitzer at 4.5 µm. Best occultation model in dark lines *Right:* Similar but for 9 occultations of TRAPPIST-1c

Occultation signals

We do not detect occultation signals for planets b and c with the NASA Spitzer Space Telescope

- We can still use our non-detection to derive an upper limit for the brightness temperature of b and c

→ $T_{p,b,brightness,upper\ limit} = 662\ K$

→ $T_{p,c,brightness,upper\ limit} = 686K$

Broadband transmission spectra

The TRAPPIST-1 planetary system is an exceptional opportunity for the atmospheric characterization of temperate terrestrial exoplanets with the upcoming James Webb Space Telescope (JWST). To prepare those observations we use an extensive follow up from ground and space to construct broadband transmission spectra of the 7 planets:

- On Figure 7. we show the spectra of b and e for observations carried out with K2, Liverpool Telescope, SPECULOOS, AAT, UKIRT, VLT, and SPITZER
- Our analyses reveal chromatic variations at the order of 200 – 300 ppm
- When comparing with theoretical model from [5] we observe that currently our observations can not constraints any scenario, we must wait for JWST
- Nevertheless, we must emphasize that stellar contamination can prevent this retrieval. Indeed, photospheric heterogeneity on the host star impact on the transmission spectra through the Transit Light Source effect [6] and can mimic atmospheric features in the spectra.

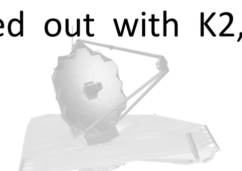
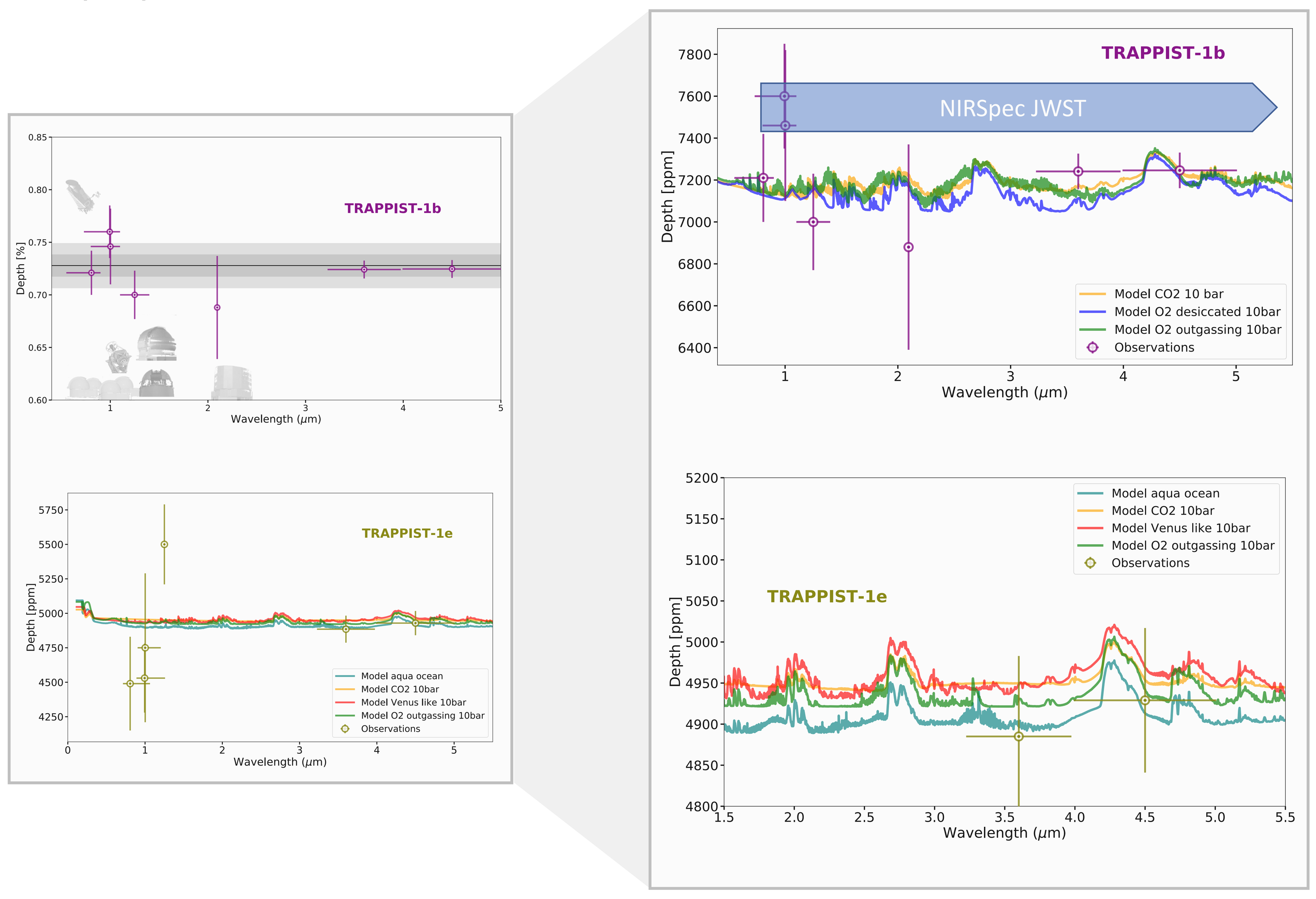


Figure 7. *Top Left:* Broadband transmission spectra of planet b, coloured dots are observation and black line is the weighted mean depth with its 1σ and 2σ confidence in shades grey. *Top Right:* Same as Top left superimposed with 10 bar model spectra from Lincowski et al. 2018. *Bottom Left:* Same as Top Right but for TRAPPIST-1e and different models. *Bottom Right:* Zoom of the plot presented on the Bottom left around SPITZER channels.



References:
[1] Gillon, M., Triaud, A. H. M. J., Demory, B.-O., et al. 2017, Natur, 542, 456
[2] Delrez, L., Gillon, M., Triaud, A. H. M. J., et al. 2018, MNRAS, 24, 1.
[3] Rishi R. Paudel, John E. Gizis, D. J. Mullan, Sarah J. Schmidt, Adam J. Burgasser, Peter K. G. Williams, Allison Youngblood
[4] Vida K., K}ovari Z., Pal A., Olah K., Kriskovics L., 2017, ApJ, 841, 124
[5] Lincowski, A. P., Meadows, V. S., Crisp, D., et al. 2018, ApJ, 867, 76
[6] Rackham, B. V., Apai, D., & Giampapa, M. S. 2018, ApJ, 853, 122