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Proxima Cen and TRAPPIST-1 exoplanetary systems: possible climates and observational constraints

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1. Introduction

The years 2016-2017 have been extremely fruitful in discoveries of interesting nearby Earth-size exoplanets. Radial velocity monitoring with HARPS has found the signature of a M sin i = 1.3 M⊕ planet located within the Habitable Zone of Proxima Centauri, the closest star from the Sun [1]. Meanwhile, 7 transiting temperate Earth-size (at ± 30%) planets have been detected around the ultra-cool star TRAPPIST-1 [2-4]. The detections of Proxima Cen b and TRAPPIST-1 planets are major discoveries mostly because these – very likely rocky – planets are (and will stay) the best candidates for future atmospheric characterization by transit spectroscopy, direct imaging, or thermal phase curve with the forthcoming astronomical ground (e.g. E-ELT) or space-based (e.g. JWST) observatories [2,3,5-9]. These two systems are thus invaluable probes for planetary science outside our Solar System, and possibly habitability.

We explore here the possible climates of these planets, and produce observational constraints that should be used to discriminate between all the possible atmospheric states of the planets.

2. Environment / orbital evolution

Proxima Centauri and TRAPPIST-1 are very active stars, compared to our Sun. Recent work [10,11] have shown that the planets orbiting around them are exposed to X/UV irradiation 10^1-10^3 times larger than received on Earth. Moreover, during the 100My following their formation when TRAPPIST-1 and Proxima Cen were pre-main-sequence stars and their luminosity significantly higher than today, each of the planets could have faced a runaway phase where the most condensable volatiles (e.g. water) would have been vaporized, and exposed to atmospheric escape. As much as several Earth ocean hydrogen content could have been lost in the process [10,12]. Note however that despite this hostile environment, density measurements – through TTV analysis [3,13] - of the TRAPPIST-1 system suggest that most of the planets could still be volatile-rich.
Eventually, Proxima Cen b and all the 7 TRAPPIST-1 planets should be today in slow rotation (and very likely, in synchronous rotation) as expected for such planets influenced by gravitational tides [9,10].

3. Possible climates

We use here the 3D LMD Generic Global Climate Model (GCM) to simulate the atmosphere(s) of Proxima Cen b (and TRAPPIST-1efgh planets), for their two most likely rotation modes, and for various volatile (H_2O, CO_2, CH_4, N_2, ...) contents.

We find that a broad range of atmospheric compositions allow surface liquid water for Proxima Cen b and TRAPPIST-1e. In particular, we find that *if Proxima Cen b or TRAPPIST-1e are 1) in synchronous rotation and 2) water-rich, then the planets should always have a patch of liquid water at least at their substellar point, whatever their atmosphere (as thick or thin as wanted)* [5,9]. All their possible climates are summarized in Fig 1.

Although a few bars of CO_2 [9] would suffice to sustain habitability on planets slightly less irradiated (e.g. TRAPPIST-1fg), these planets could likely be trapped in permanent snowball state, because it should be difficult for them to accumulate enough greenhouse gases like CO_2 or CH_4. CO_2 would easily collapse in the nightside, forming CO_2 ice deposits that should be gravitationally unstable and get buried beneath the water ice shell in geologically short timescales [9,14,15]. Given TRAPPIST-1 planets large EUV flux (at least $\sim 10^3 \times$ Titan's flux), CH_4 and NH_3 should be photodissociated rapidly and thus be hard to accumulate in the atmosphere. This, and the radiative cooling effect of photochemical hazes/stratospheric methane, would make it difficult for TRAPPIST-1fgh to sustain surface habitability.

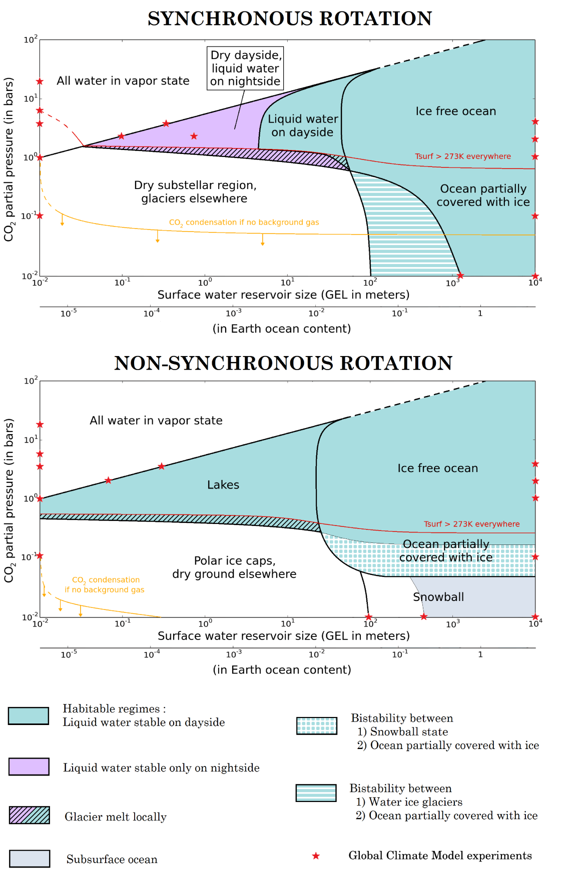

Figure 1: Schematic diagrams of the possible climate regimes reached by Proxima Cen b (and TRAPPIST-1e, by extension) as function of the available CO_2 and H_2O contents. More details can be found in [5].

4. Observational constraints

For each of the climate regimes obtained in our analysis, we produce synthetic observables that can be used to prepare future observations of the planets by either JWST or ELT-class telescopes. In the case of Proxima Cen b, we produced reflection and emission spectra, and phase curves for the simulated climates. We find that atmospheric characterization of the planet will be possible via direct imaging with forthcoming large telescopes. The angular separation of 7λ/D at 1 μm (with the E-ELT) and a contrast of $\sim 10^{-7}$ will enable high-resolution spectroscopy and the search for molecular signatures, including H_2O, O_2, CO_2 ...The observation of thermal phase curves (see Fig 2) can be attempted with JWST, thanks to a contrast of 2×10^{-5} at 10 μm.

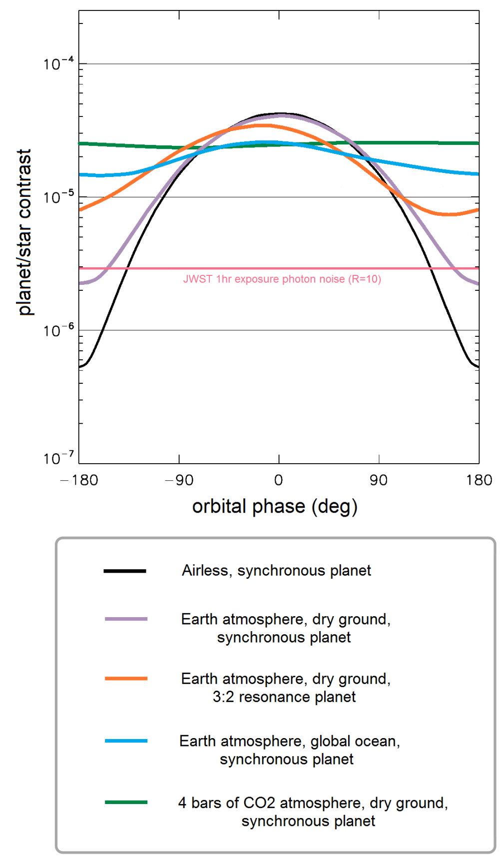

Figure 2: Thermal phase curves (~ 11.4μm) for several configurations : airless planet, Earth-like planet with oceans, planet with a thick atmosphere ... The red curve roughly depicts the relative amplitude of the expected detection limit of JWST for an exposure of ~1h.

More results on Proxima Cen / TRAPPIST-1 systems will be discussed at the EPSC-2017 conference.

References

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