HABITABILITY OF PLANETS ORBITING IN THE HABITABLE ZONE OF LOW MASS STARS

The case of Proxima Cen b and TRAPPIST-1e

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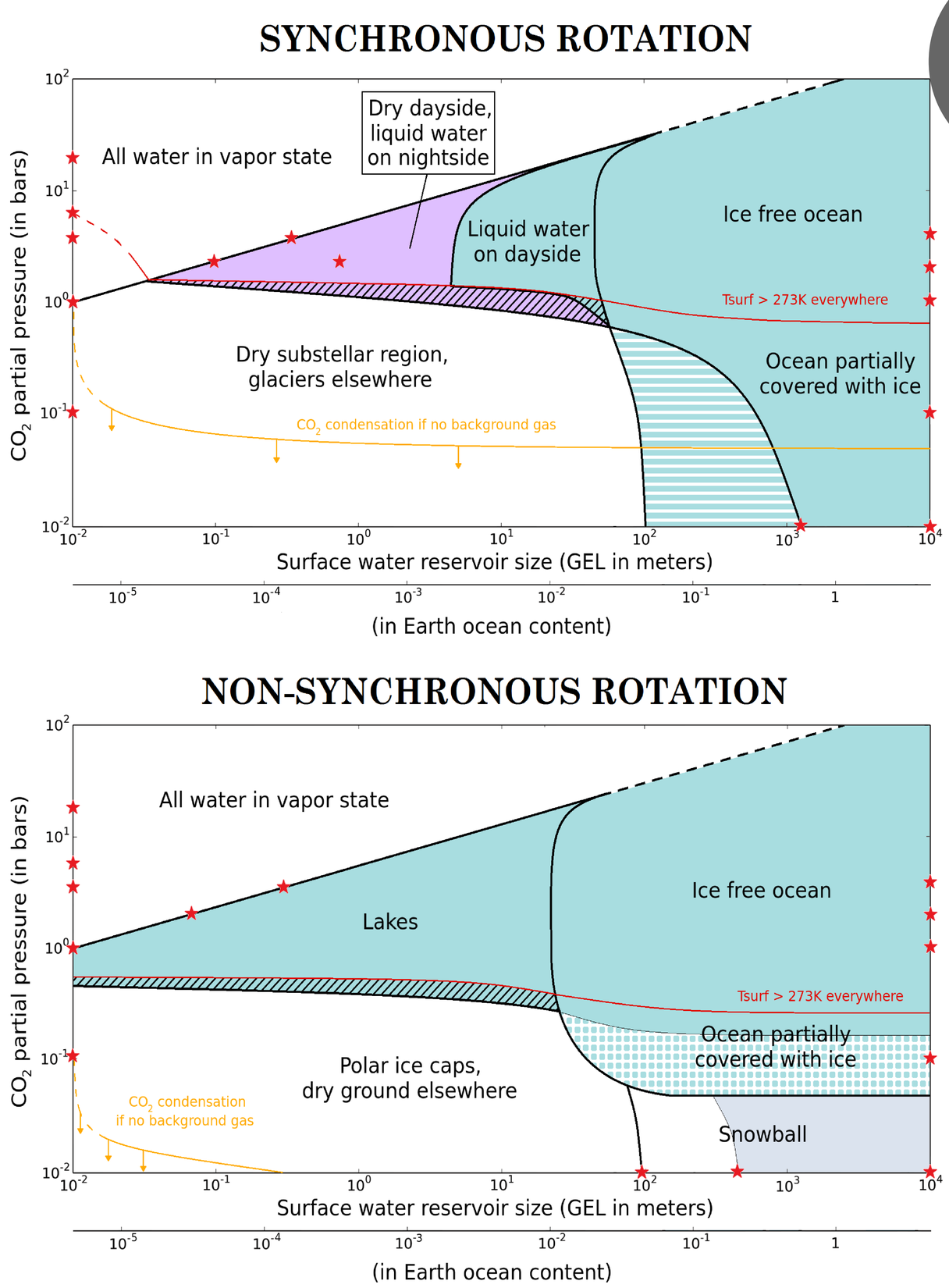
Abstract

Despite a hotter past and an active host star, planets that orbit in the Habitable Zone (HZ) of very low mass stars could have retained enough volatiles to sustain surface habitability. We use here the 3-D LMD Generic Global Climate Model to explore the possible climate regimes of Proxima Cen b and TRAPPIST-1e, depending on their total reservoir of water and greenhouse gases, and depending on their spin state (1:1 and 3:2 spin-orbit resonance). Any low-obliquity, low-eccentricity planet within the HZ of its star should be in one of the climate regimes discussed here.



Habitable regimes : Liquid water stable on dayside

Liquid water stable only on nightside

Glacier melt locally

Subsurface ocean

Bistability between 1) Snowball state 2) Ocean partially covered with ice

Bistability between 1) Water ice glaciers 2) Ocean partially covered with ice

Global Climate Model experiments

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, for a synchronous rotation (upper figure) and a 3:2 spin-orbit resonance (lower figure). More details can be found in Turbet et al. 2016, A&A.

Results

Based on 3-D Global Climate Model simulations of the atmosphere and water cycle of Proxima b and TRAPPIST-1e, we attempt (see Figure 1) to quantify their possible climates for the two most likely spin states (1:1 and 3:2 spin-orbit resonance), while varying the unconstrained surface water inventory and atmospheric greenhouse effect. Our model is designed to simulate the fate of water and other volatiles, and the possible cold trapping. Possible climates range from (1) planets that have all their water in the atmosphere, (2) planets that have all their water (and possibly other volatile species likes CO_2) trapped at their cold points (nightside or poles, depending on the spin-state), (3) planets· that are covered by water ice (e.g. Snowball planets), but for the non-synchronous rotation only, (4) planets that have glaciers (located in the cold traps) melting locally, (5) planets that have sporadic lakes or seas of liquid water and (6) planets that have a global ocean (from partially to totally deglaciated).

We find that a broad range of atmospheric compositions allow surface liquid water. Remarkably, provided a sufficient H_2O reservoir is present, Proxima Centauri b and TRAPPIST-1e should always sustain surface liquid water, at least in the substellar region (see Figure 2). This stems from the synchronous rotation coupled to an ideal insolation. This result is independent of the atmospheric background content (from no atmosphere at all, to a thick atmosphere of hundreds of bars). The H_2O reservoir should be large enough to avoid trapping on the nightside. Thick atmospheres increase the greenhouse effect and tend to warm efficiently and globally the surface, and thus favor surface habitability. Thin atmospheres decrease the atmospheric heat transport, which tends to disconnect the substellar region from the rest of the planet. As a consequence, the substellar region is warmed efficiently and surface liquid water remains stable there.

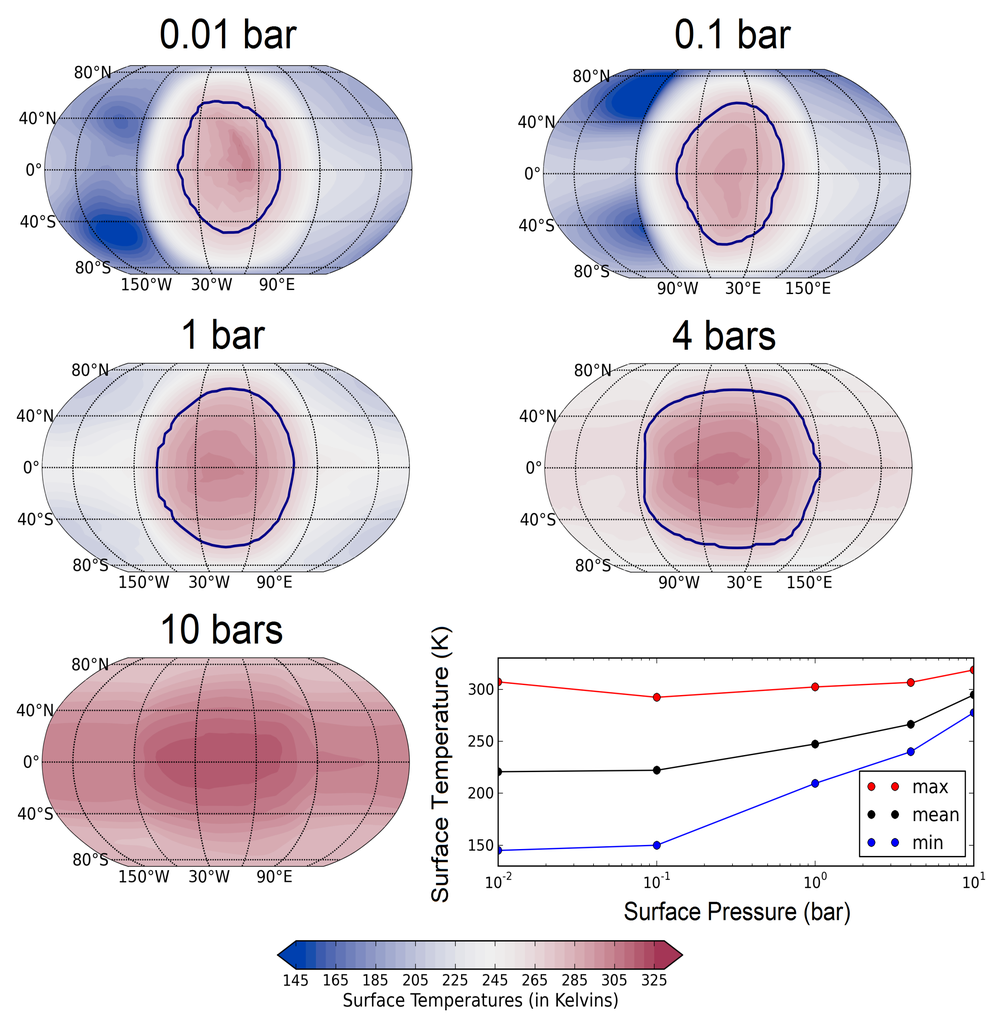


Figure 2: 4-years average surface temperature maps of TRAPPIST-1e endowed with atmospheres made of N_2 and 376 ppm of CO_2 , and for various atmospheric pressures (10 mbar, 0.1 bar, 1 bar, 4 bars and 10 bars). Solid line contours correspond to the delimitation between surface liquid water and sea water ice. The Figure in the bottom right panel indicates in blue, black and red the minimum, mean, and maximum surface temperatures, respectively. Note that the planets were assumed to be initially cold (T = 210 K everywhere) and completely covered by water ice. More details can be found in Turbet et al. 2017, submitted to A&A.

Take home message

We find that a broad range of atmospheric compositions allow surface liquid water on Proxima Cen b and TRAPPIST-1e. We also find that these two planets should always sustain surface liquid water, whatever their atmosphere, and assuming that (1) they are in synchronous rotation and (2) they retained enough water (enough that water cannot be fully trapped on their nightside). In contrast to previous studies that emphasized the fragility of habitability within the Habitable Zone, our work shows that surface liquid water can be robust to climatic variations.

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