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Climate and radiative properties of a tidally-locked planet around Proxima Centauri

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Abstract

Red dwarf stars are the most common type of stars in our Galaxy and the most long-lived ones. For this reason, the search for habitable exoplanets is generally focused on such stars, though the exposure to high XUV fluxes can be responsible for a planetary atmospheric loss rate of heavy elements, e.g. oxygen and nitrogen. We present a study about the climate of a tidally locked Earth-like planet, with preindustrial CO_2 atmospheric concentration, circular orbit and null axial tilt in the Proxima Centauri System, based on the 3-D intermediate complexity atmospheric general circulation model *PlaSim* and the 1-D radiative transfer model *uvspec*. The thermal emission of the planet-host star system, is calculated in the mid-infrared region of the spectrum, in order to evaluate the planet/star contrast variability, in function of the system inclination with respect to a distant observer.

Planetary and orbital parameters[1]

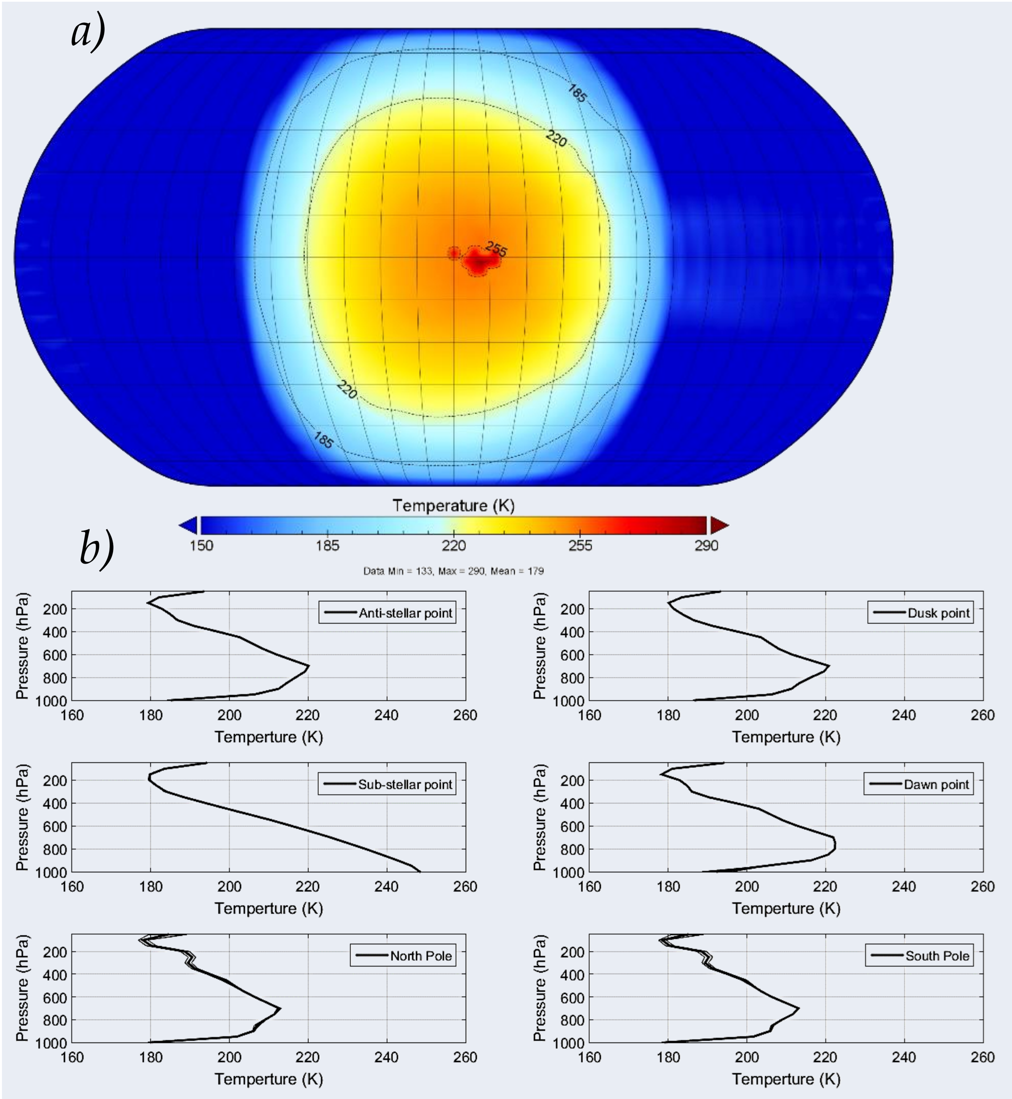
Proxima Centauri b: detected and derived quantities	
Parameters	**Values**
Irradiance compared to Earth's	65% (884.65 Wm^{-2})
Orbital period	11.186 Earth days
Orbital semi-major axis a	0.0485 AU
Eccentricity e	< 0.35
Minimum planet mass $m_p \sin(i)$	1.27 $M_\oplus$
Eq. black body temperature	234 K

Table 1. Parameters used in the simulations of Proxima Centauri b, taken from Anglada-Escudé et al., 2016

Proxima Centauri b: extrapolated quantities	
Parameters	**Values**
Mean density $\rho = \rho_\oplus$	5514.0 $kg\ m^{-3}$
Mean minimum radius r_p	1.08 $R_\oplus$
Gravitational acceleration at the surface g^*	10.6 $m\ s^{-2}$
Inclination of the orbit i	0.0 deg
Rotation rate ω	$6.5 \times 10^{-6}\ \frac{rad}{s}$

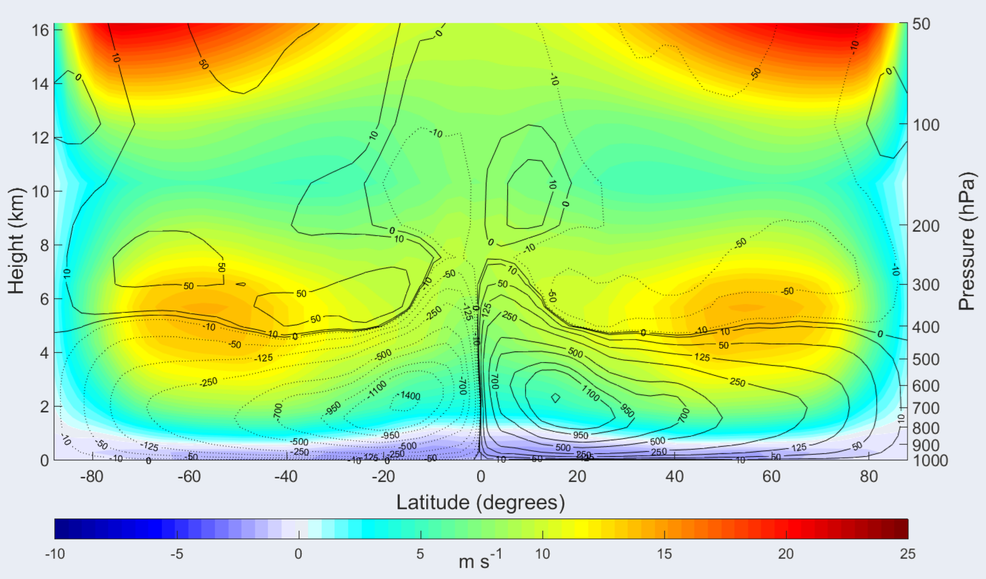
Table 2. Extrapolated physical parameters used in the simulations of Proxima Centauri b, guessing the same mean planetary density of the Earth.

The simulation ran for a 100 years period. The planet is entirely covered by a thermodynamic slab ocean of 50 meters depth, where the horizontal and vertical mixing are neglected. We set the substellar point above the equator at 180°E. The model outputs are gridded on a 128×64 longitude-latitude grid (T42 truncation) with 10 terrain-following vertical levels, subdivided by the postprocessing in 20 pressure-levels, from 1000 hPa to 50 hPa. We set an Earth-like atmosphere with a concentration of 360 ppm of CO_2 and with an ozone profile similar to the Earth's one.



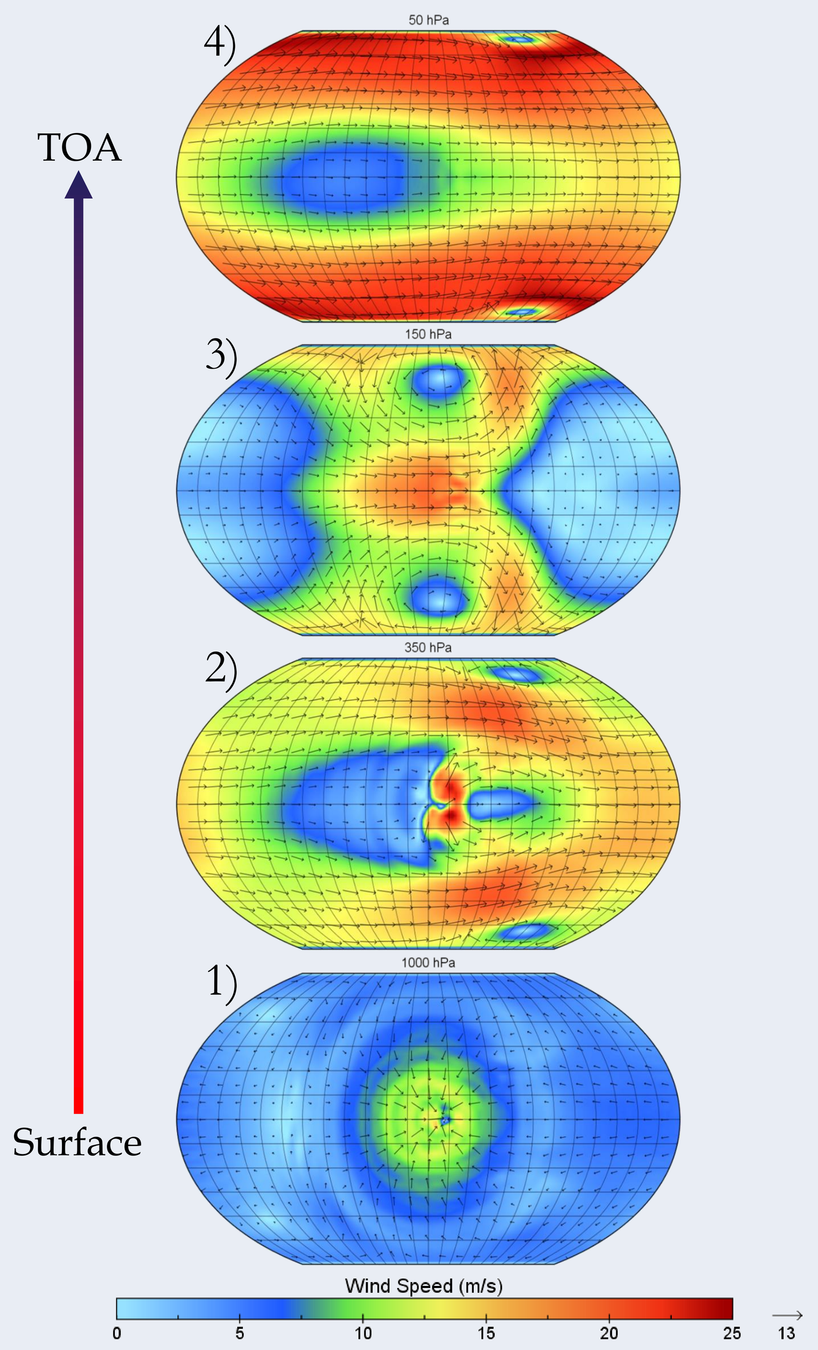
Mean surface temperature and vertical profiles.

The surface temperatures are almost everywhere below the freezing point of water, except in a small region in the proximity of the substellar point (*a*). Vertical profiles of the air temperature with relative standard deviation (shaded gray area beneath the black curves) in different regions of the planet (*b*)



$$\psi = \frac{2\pi r_p}{g^*}\int_0^p \bar{u}\cos\phi\, dp' \quad (2)$$

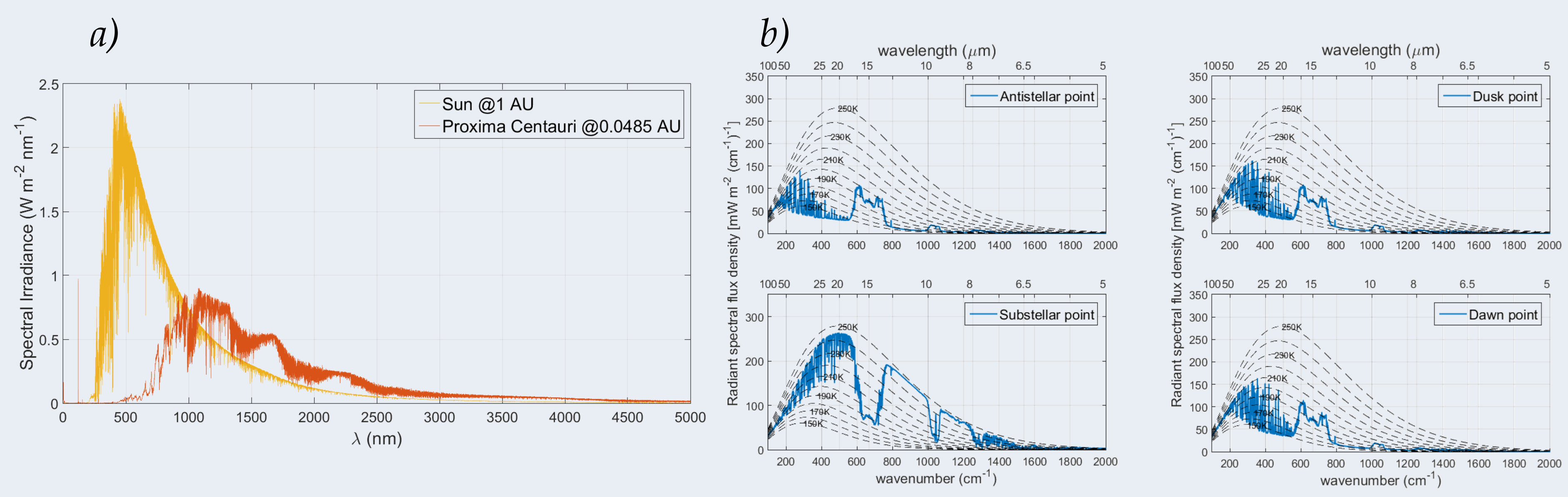
Zonal mean zonal wind and mass stream function. Hadley cell-like structure driven by insolation contrast. Colors: zonal mean zonal wind. Black lines: mass stream function ψ. Numbers upon the lines are the values of ψ in 10^6 kg s^{-1}



Wind horizontal sections on isobaric surfaces.

From bottom to up:

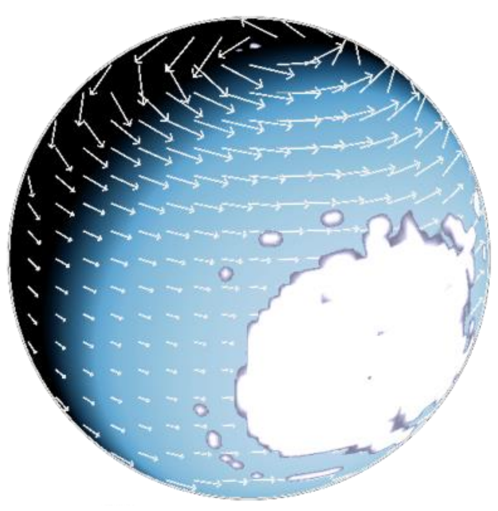
1) surface (1000 hPa): wind convergence at the substellar point with consequent uplift;
2) upper troposphere (350 hPa): high speed winds diverge from the substellar point forming the two low altitude jets. Three "polar" vortices appear.
3) tropopause (150 hPa): the northern and southern polar vortices migrate equatorward.
4) lower stratosphere (50 hPa): high speed wind jets blow in both hemispheres, surrounding the entire planet.



Star spectral irradiance and planet emission spectra.

a) Sun (yellow curve) and Proxima Centaury (red curve) power spectra[3] comparison at the top of the atmosphere of Earth and planet b, respectively. Proxima Centauri is a M6Ve (red dwarf), with a mass $\sim 0.1221\ M_\odot$ and a radius $\sim 0.1542\ R_\odot$. Despite the proximity to the host star, the planet b dayside hemisphere, receives almost 500 $W\ m^{-2}$ less than the Earth.

b) Thermal emission of the planet, estimated with *uvspec*.



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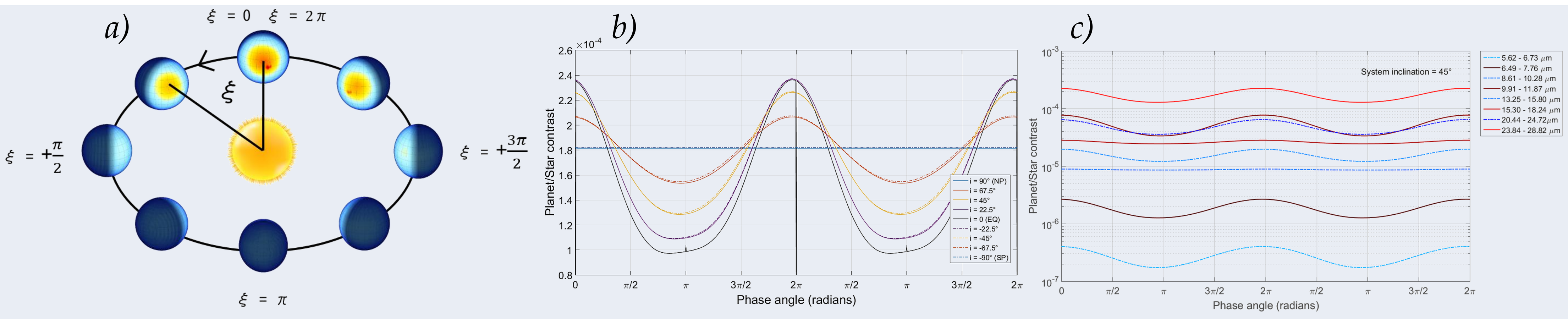

Phase curves. *a)* Planet b orbit and phase angle. *b)* Planet/Star contrast for different system inclinations, as seen from an Earth observer, during two complete orbits, in the spectral band 23.84 - 28.82 μm, available on the MRS[4] - MIRI instrument, on board of the James Webb Space Telescope. *c)* A sample of other MRS available bands with the relative estimated contrasts.

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