Three-Dimensional Ozone Distributions on Tidally Locked Earth-Like Planets Simulated with a Climate-Chemistry Model (Luo et al., 2019, submitted)

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Introduction

- **Ozone has a strong absorption band near 9.6 μm. Detection of this absorption band of transiting terrestrial exoplanets may help us confirm the presence of ozone and oxygen in the atmosphere. In this study, we use a three-dimensional (3D) coupled atmospheric circulation-chemistry model to simulate the spatial distributions of ozone on 1:1 tidally locked Earth-like planets. The observational significance of ozone layers and surface UV habitability are also analyzed.**

Summary of Findings

- **On planets orbiting UV-active M stars, the ozone abundance is similar to the Earth's, and more ozone is distributed on the nightside. As long as the atmospheric oxygen abundance is higher than ~1% of the present atmospheric level, the surface UV environment is safe for terrestrial life. Detecting such an ozone layer requires a photometric precision that is two orders of magnitude higher than the required precision for detecting an Earth-sized planet during transits. By contrast, on planets around UV-inactive M stars, ozone abundance is less than Earth's by three orders of magnitude. Such trace amount of ozone leaves the surface unprotected, and its spectral features are not detectable.**

Model Setup

- Simulated with WACCM 4.0, a 3D coupled general circulation-photochemistry model.
- Same background atmospheric composition as the pre-industrial Earth (78% N_2 and 21% O_2, no halogens from CFC).
- Stellar spectra: UV-active M stars AD Leo and Proxima Centauri, UV-inactive M star TRAPPIST-1.
- The rotation period of the planets is 30 days.

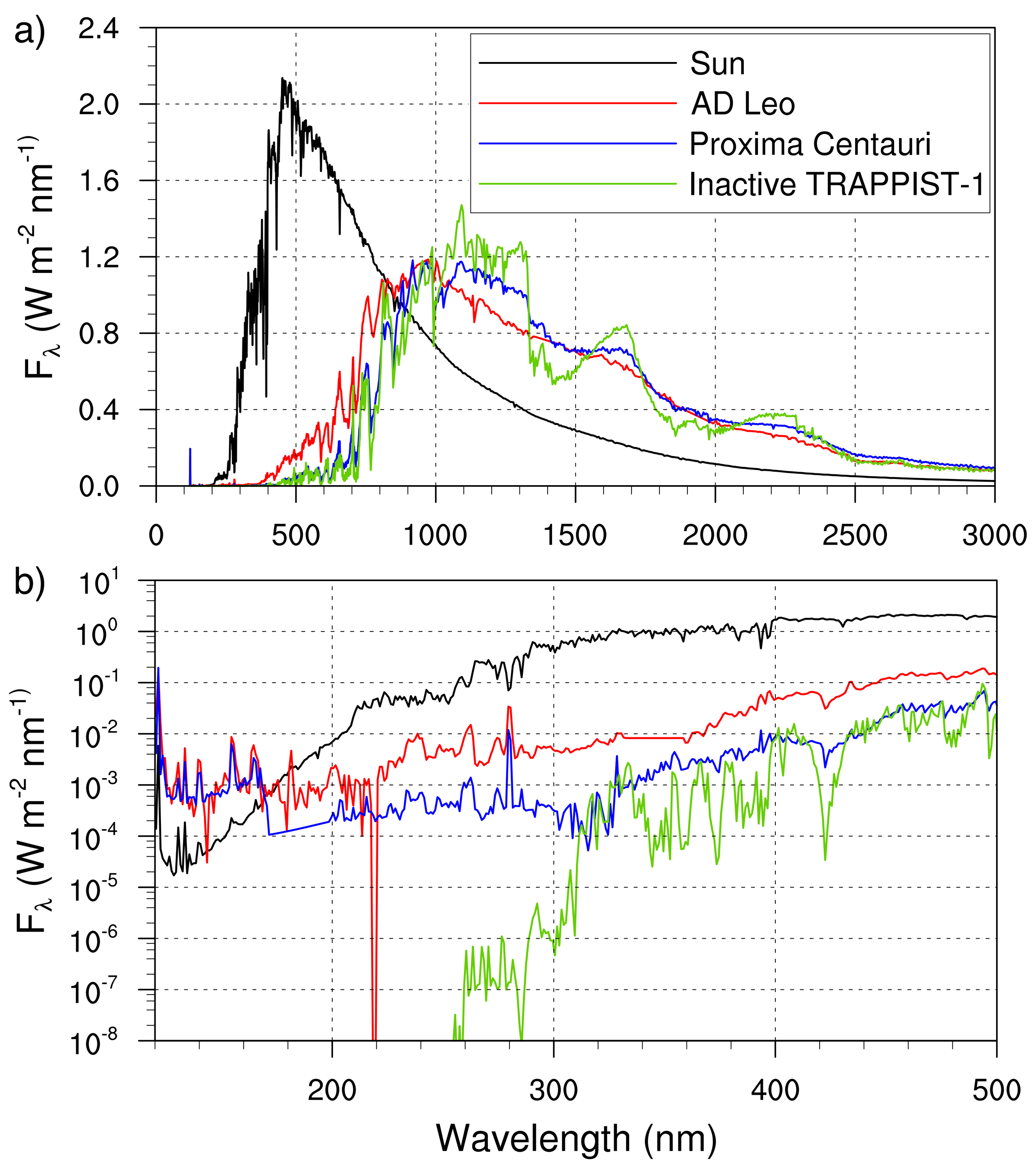

Fig. 1. a) Complete spectra, and b) UV spectra at top of the atmosphere. Incoming UV radiation in the O_2 and O_3 photolysis bands from the UV-active M stars are one or two orders of magnitude less than that from the Sun. The incoming UV radiation from the UV-inactive M star is more than six orders of magnitude less than that of the Sun.

Results

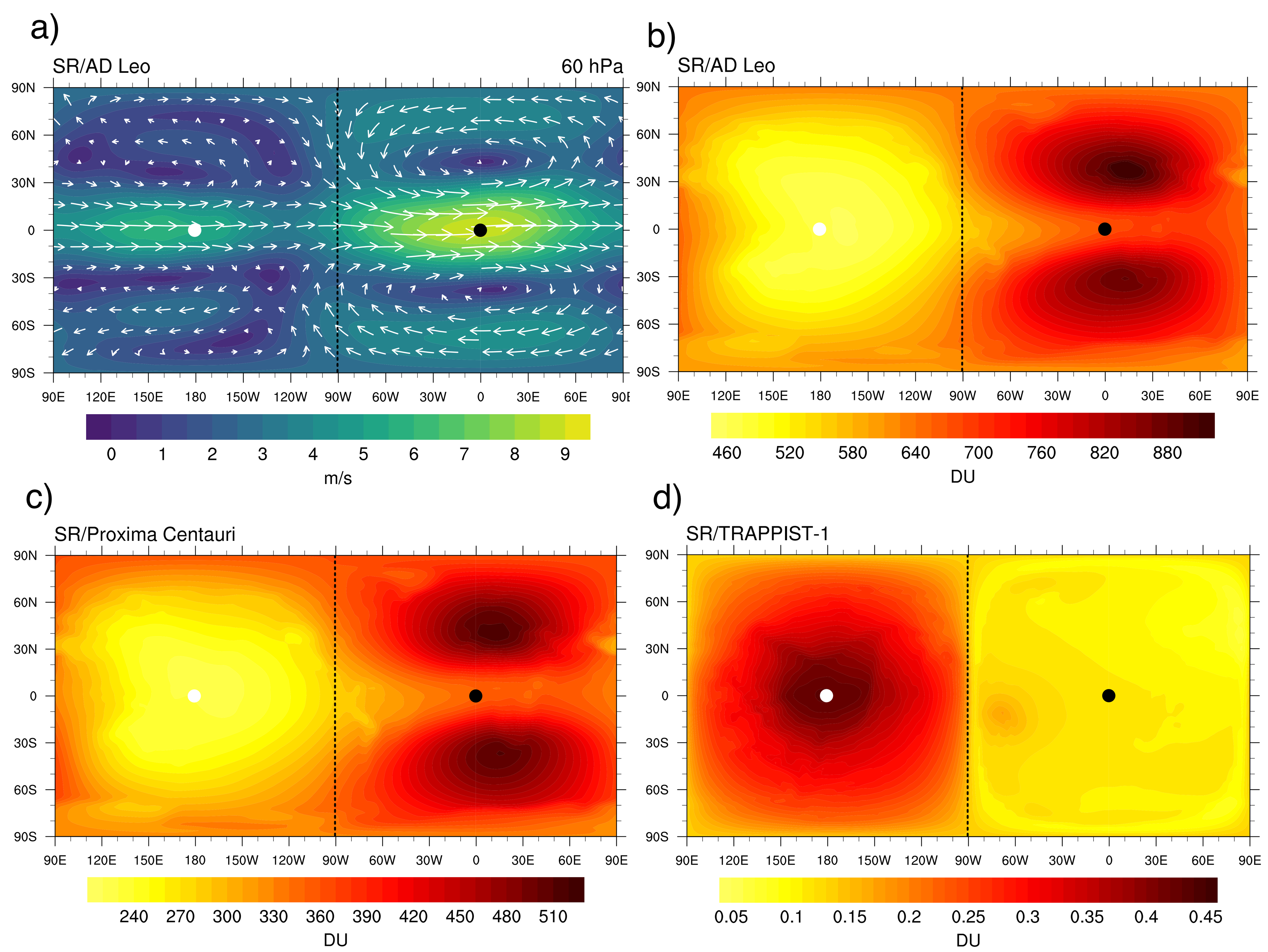

Fig. 2. a) Atmospheric circulations in the lower stratosphere of the tidally-locked planets. b) Ozone column density on the exoplanets around UV-active M star AD Leo, c) Proxima Centauri, and d) UV-inactive TRAPPIST-1. The dayside is on the left side of each plot. On planets around UV-active M stars, the ozone abundance is similar to the Earth's. Tropical westerlies transport ozone from the substellar area to the nightside and then ozone accumulates in the nightside cyclones. By contrast, on planets around UV-inactive M stars, slow oxygen photolysis and accumulation of NO_x in the atmosphere result in a very low ozone abundance. The presence of ozone relies on photochemical production, therefore ozone is confined in the substellar area.

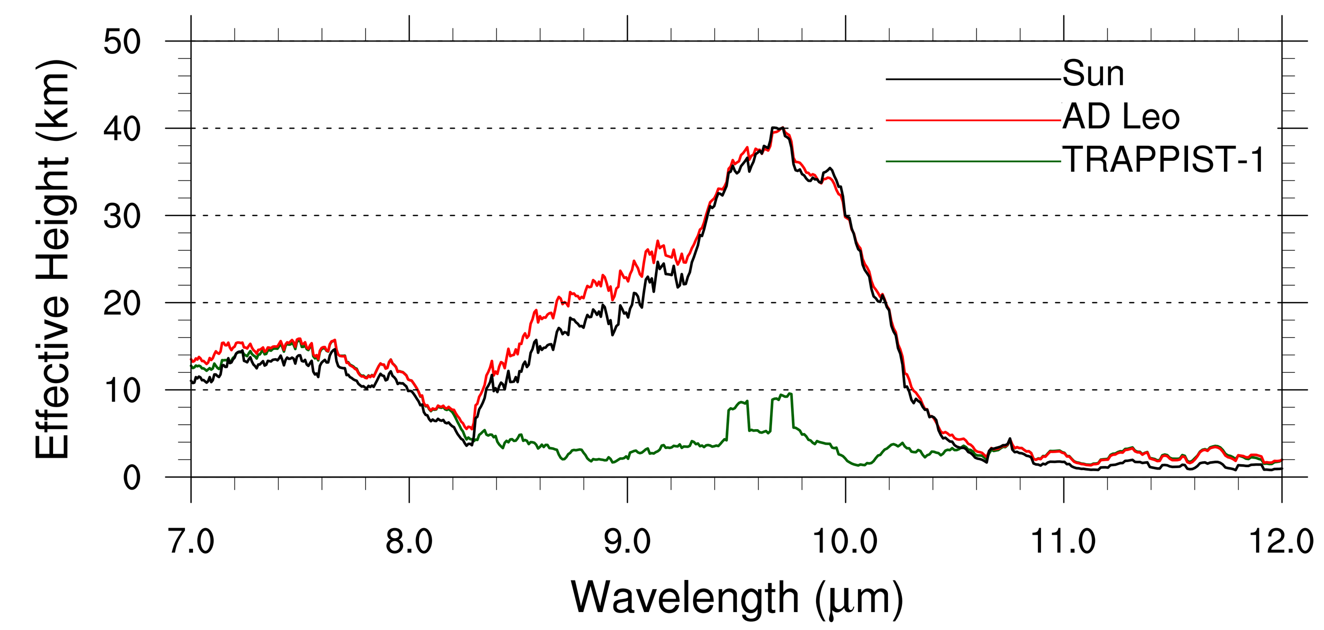

Fig. 3. The effective height of the atmosphere at the 9.6 μm ozone absorption band during a transit. On planets orbiting UV-active M stars, the presence of an ozone layer can increase the radius of the planetary disk by 40 km, which is potentially detectable.

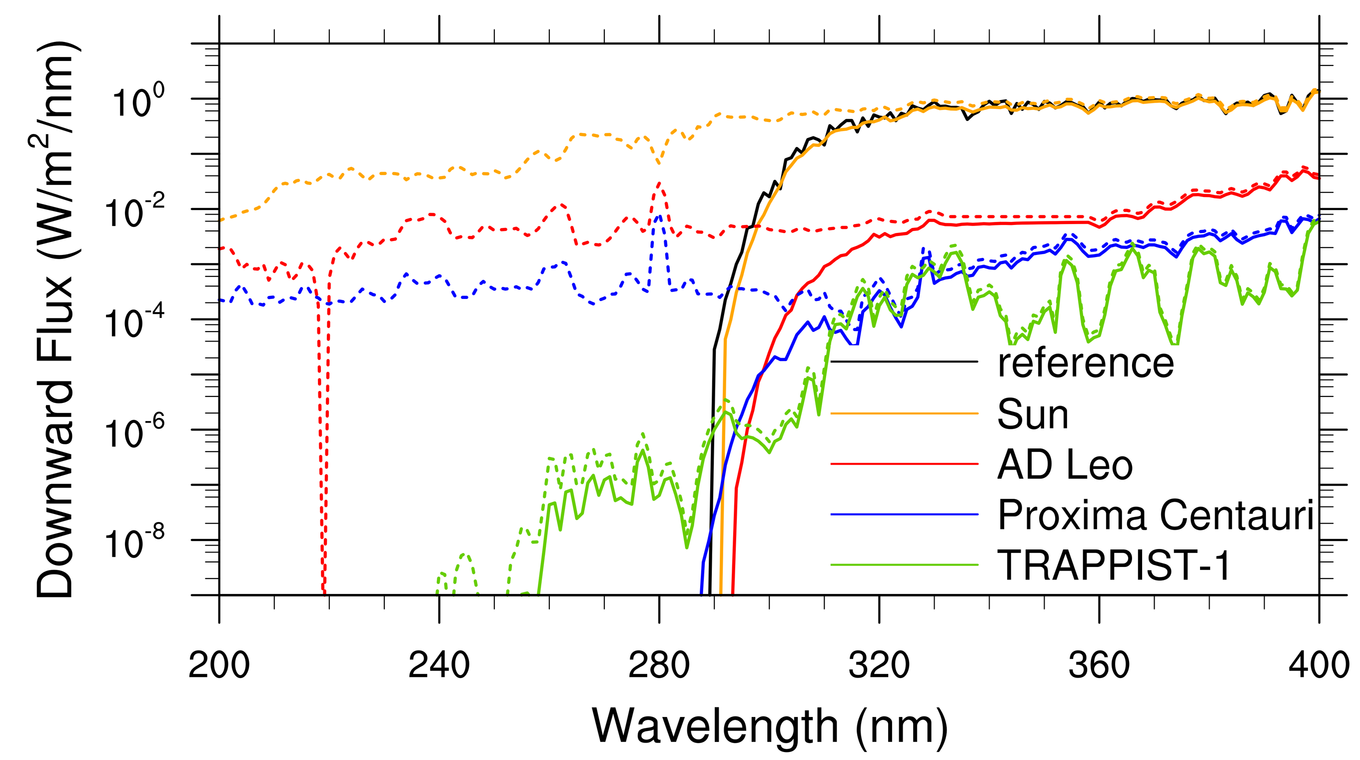

Fig. 4. UV fluxes at the top of the atmosphere (dotted curves) and at the surface (solid curves). Terrestrial life on planets around G stars and UV-active M stars are well protected by the ozone layer. On the contrary, the surface of planets around UV-inactive M stars is exposed to a potentially harmful UVC flux.