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O_2-Dominated Atmospheres for Potentially Habitable Environments on TRAPPIST-1 Planets

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Small exoplanets of nearby red dwarf stars present the possibility to find and characterize habitable worlds within the next decade. TRAPPIST-1, an ultracool red dwarf star, was recently found to have seven Earth-sized planets of predominantly rocky composition. The planets e, f, and g can have a liquid water ocean on their surface given appropriate atmospheres of N_2 and CO_2. Particularly, climate models have shown that the planets e and f can sustain a global liquid water ocean, for $\geq$0.2 bar CO_2 plus 1 bar N_2, and $\geq$2 bars CO_2, respectively. These atmospheres are irradiated by ultraviolet emission from the star's moderately active chromosphere. Using an atmospheric photochemistry model, we investigate how the irradiation drives chemical reactions in the atmospheres of TRAPPIST-1 e and f, where we assume habitable compositions predicted from the climate models and include the effects of lightning and oxidation of the crust. Our models show that chemical reactions driven by the irradiation in the atmosphere produce and maintain more than 1 bar of O_2 and 0.1 bar of CO if the CO_2 is $\geq$0.1 bar. Because of this O_2 runaway, the habitable environments on the TRAPPIST-1 planets entail an O_2-dominated atmosphere, with co-existing CO, CO_2, and N_2. The sole process that would prevent the O_2 runaway is a direct recombination of O_2 and CO in the ocean, a reaction not operating on Earth but might be facilitated biologically. Our results indicate that O_2 and CO should be considered together with CO_2 as the primary molecules in the search for atmospheric signatures from potentially habitable planets of TRAPPIST-1 and other red dwarf stars.