Detectability of biosignatures in warm, water-rich atmospheres

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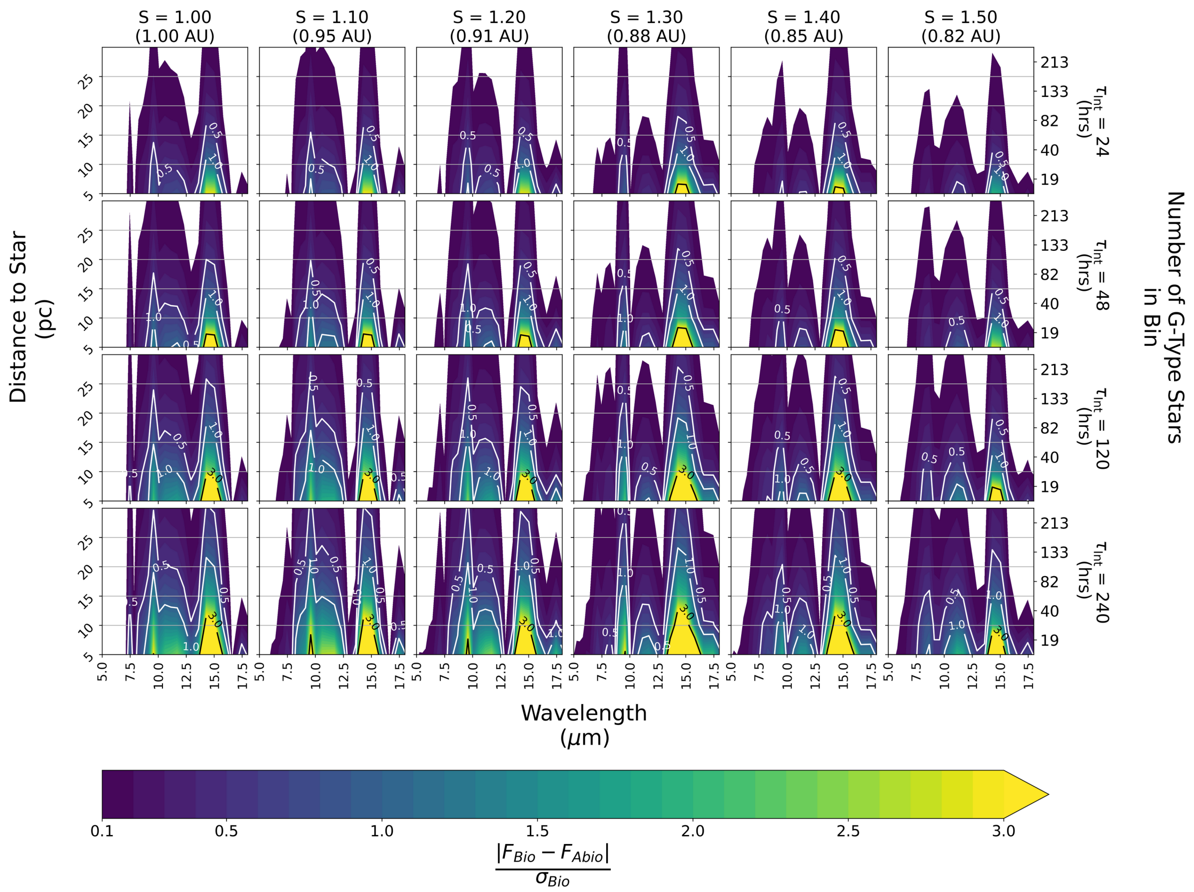
Introduction

Warm rocky exoplanets with instellations varying between those of Earth and Venus are key emerging objects of interest for current and future missions. They are favoured targets which will likely be found and characterized before their cooler, more Earth-like counterparts. Theory indicates these planets could be wet at formation and remain habitable long enough for life to develop. However, it is currently unclear for how long and to what extent an early ocean on such worlds could persist and influence climate and photochemical evolution, including the response of potential atmospheric biosignatures. In this work we test the climate-chemistry response, maintenance, and detectability of biosignatures in warm, water-rich atmospheres with Earth biomass fluxes within the framework of the planned LIFE mission.



Methodology

We use the global-mean, stationary, coupled climate-chemistry column model, 1D-TERRA to simulate the climate and chemistry of planetary atmospheres at different distances from the Sun, assuming Earth's planetary parameters and evolution. We run six biotic scenarios: starting with the modern Earth we increase the incoming instellation by up to fifty percent in steps of 10 percent. This corresponds to rocky exoplanets orbiting from 1.00 to 0.82 AU, approximately half the distance from Earth to Venus. To asses the effect of Earth's biomass fluxes, we repeat the six biotic scenarios without Earthlike biomass and fluxes. For all twelve simulations, we then calculate theoretical emission spectra using the GARLIC model based on the resulting atmospheric temperature and composition profiles. In addition, we use LIFEsim to add noise to and simulate observations of these spectra to assess how biotic and abiotic atmospheres of Earth-like planets can be distinguished.

Results

Our models show moderate ocean evaporation with increasing instellation (S), which results in water-rich atmospheres of roughly 0.01 bar (modern Earth instellation, S=1) up to 0.6 bar (S=1.5). Ozone, a key atmospheric biosignature, survives in the middle atmosphere in all scenarios as hydrogen oxide abundances remain stable since they react with nitrogen oxides instead. Methane is strongly removed for instellations that are 20% bigger than that of the Earth as rising water abundances increase hydroxyl (OH) via UV photolysis. Nitrous oxide (N_2O) generally survives, mainly due to trade-off effects where enhanced photolytic loss in the upper layers due to higher instellation is counterbalanced by the stronger absorption of photons in the lower layers due to increased water abundance. Using LIFEsim, we find that O_3 signatures at 9.6 μm only reliably point to Earth-like biosphere surface fluxes of O_2 for systems within 15 parsecs for integration times of 10 days. However, the differences in atmospheric temperature structures due to differing H_2O profiles enable observations at 15.0 μm to reliably identify planets with a CH_4 surface flux equal to that of Earth's biosphere.