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The Habitability and Atmosphere of the Exoplanet TOI-700 e

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Abstract. The search for habitable exoplanets is fundamental to understanding the diversity of planetary environments and the possibility of extraterrestrial life. In this context, the exoplanet TOI-700 e, located in the habitable zone of the red dwarf star TOI-700, stands out due to its Earth-like characteristics. To study its atmosphere and estimate the UV radiation flux, we used the ATMOS code coupled with the 1D Photochemical Model, which models atmospheres similar to the Archean and Modern Earth, based on observationally validated physical-chemical parameters. To collect data from the exoplanet, we developed a Python program to visualize and analyze the obtained data. The results showed that while the Archean atmosphere offers greater overall absorption of UV radiation due to high CO_2 concentration, the Modern atmosphere provides more efficient protection against UV-C rays thanks to the ozone layer. We used the extremophile bacterium *D. radiodurans* as a bioindicator of habitability due to its proven resistance to extreme conditions, making it an ideal model to assess survival in exoplanetary environments with high radiation. For the exoplanet TOI-700 e, the assessment was carried out using bacterial action spectra and species generation times, which showed survival rates up to 20 times higher than those of *E. coli* under an Archean atmosphere. Therefore, this study contributes to the understanding of the habitability of exoplanets in red dwarf star orbits, highlighting the importance of atmospheric protection against radiation. Simulating atmospheres from different periods of Earth offers insights into planetary evolution and possible biosignatures.

Resumo. A busca por exoplanetas habitáveis é fundamental para compreender a diversidade de ambientes planetários e a possibilidade de vida extraterreste. Nesse contexto, o exoplaneta TOI-700 e, localizado na zona habitável da estrela anã vermelha TOI-700, destaca-se por suas características semelhantes às da Terra. Para estudar sua atmosfera e estimar o fluxo de radiação UV, utilizamos o código ATMOS acoplado ao 1D Photochemical Model, que modela atmosferas semelhantes à Terra Arqueana e Moderna, com base em parâmetros físico-químicos validados observacionalmente. Para coletar os dados do exoplaneta, desenvolvemos uma programação em Python para conseguirmos visualizar e analisar os dados obtidos. Os resultados mostraram que enquanto a atmosfera Arqueana oferece maior absorção geral de radiação UV devido à alta concentração de CO_2, a atmosfera Moderna apresenta proteção mais eficiente contra os raios UV-C graças à camada de ozônio. Utilizamos a bactéria extremófila *D. radiodurans* como bioindicador de habitabilidade por sua resistência comprovada a condições extremas tornando-a um modelo ideal para avaliar a sobrevivência em ambientes exoplanetários com alta radiação. Para o exoplaneta TOI-700 e, a avaliação foi realizada com base nos espectros de ação bacteriana e nos tempos de geração das espécies, que apresentaram taxas de sobrevivência até 20 vezes superiores às de *E. coli* sob uma atmosfera Arqueana. Portanto, o estudo contribuiu para a compreensão da habitabilidade de exoplanetas em órbitas de estrelas anãs vermelhas, destacando a importância da proteção atmosférica contra radiação. A simulação de atmosferas de diferentes épocas da Terra oferece insights sobre a evolução planetária e possíveis bioassinaturas.

Keywords. Planets and satellites: atmospheres – Astrobiology – Ultraviolet: stars

1. Introdução

Exoplanets, which are planets that orbit stars outside the Solar System, have become a focus of intense scientific interest due to their potential for habitability and the possibility of hosting life. The presence of a planet in the habitable zone is one of the main criteria for this analysis, as it allows for the existence of liquid water on its surface (Galante et al. 2016). Furthermore, the diversity of these worlds, with different masses, sizes, and atmospheric conditions, expands the possibilities for study in astrobiology.

In this context, the TOI-700 system (Gilbert et al. 2020), discovered by the TESS satellite (Ricker et al. 2015), stands out for hosting four planets around an M-type red dwarf star (Figure 1). This star exhibits low activity, which favors the atmospheric stability of nearby planets (Gilbert et al. 2020). Among them, the exoplanet TOI-700 e stands out for having a radius similar to Earth's and for being located in the system's habitable zone, with an orbital period of approximately 28 days (Gilbert et al. 2023). Sumida et al. (2025) studied TOI-700 d and found that the UV protection efficiency of Archean-like (haze-dominated) versus modern Earth-like (ozone-dominated) atmospheres varies significantly with stellar UV flux, and the survival of resistant microorganisms such as *Deinococcus radiodurans* can serve as a robust bioindicator of surface habitability.

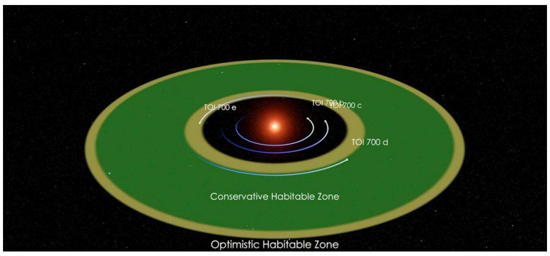

Figure 1. Representation of the TOI-700 system and its four planets. Two of them (TOI-700 d and TOI-700 e) are located in the habitable zone (HZ), shown in green and yellow (optimistic HZ).

Similarly, this study investigates the habitability potential of TOI-700 e through the analysis of atmospheres analogous to Archean and Modern Earth (Jardim 2001; Hayes 2020; Lane 2017). The objectives of the study are: (i) to investigate the habitability potential of TOI-700 e based on its orbital position and the incident stellar flux; (ii) to compare atmospheres analogous to the Archean and Modern Earth, considering chemical and climatic differences (Catling & Zahnle 2020); (iii) to evaluate the amount of ultraviolet radiation that reaches the planet's surface (Cnossen et al. 2007); and (iv) to estimate the survival rate of *Escherichia coli* and *Deinococcus radiodurans* under different atmospheric scenarios, following the methodology of Estrela et al. (2020).

2. Methodology

For the atmospheric simulation, the ATMOS (Arney et al. 2016) code was used, which models planetary atmospheres by considering photochemical reactions, vertical transport, and radiation (Meadows et al. 2018). The Archean Earth model includes 405 chemical reactions involving 77 species, while the Modern Earth model comprises 310 reactions.

The incident stellar flux at the top of the atmosphere was calculated using the physical parameters of the star TOI-700 and the orbital distance, following a methodology similar to that presented by Cnossen et al. (2007). The attenuation of UV radiation was calculated using Beer's Law, considering the absorption cross-sections of molecules such as CO_2, H_2O, SO_2, O_3, and O_2, whose experimental data are described in Cnossen et al. (2007).

To assess the biological impact of ultraviolet radiation reaching the planet's surface, two microorganisms were considered: *Deinococcus radiodurans*, a bacterium resistant to high doses of UV radiation, and *Escherichia coli*, a widely studied common bacterium. The survival rate values corresponding to 37% and 10% of the bacterial populations as a function of the received UV radiation are given by Gascon et al. (1995). These values are 338 and 553 J m^{-2}, respectively, for *D. radiodurans*, and 17.3 and 22.6 J m^{-2} for *E. coli*. The UV wavelength range considered for the calculations is 230 to 320 nm for *D. radiodurans* and 224 to 300 nm for *E. coli*. These intervals are determined by the bacteria's action spectra and by the absorption cross-sections of the molecules considered.

3. Results and Discussion

3.1. Temperature and Pressure Profiles

The results showed clear differences between the Archean and Modern scenarios. The modern profile exhibits smooth curves and greater thermal stability, consistent with oxygenated atmospheres whose dynamics are moderated by gases with strong infrared (IR) absorption capacity, such as water vapor and ozone (Segura et al. 2003). In contrast, the Archean scenario shows instabilities and steeper gradients, consistent with atmospheres rich in methane and sulfur (Catling & Zahnle 2020). The profiles are shown in Figure 2.

3.2. Atmospheric Composition

The atmospheric composition showed significant differences between the Archean and Modern scenarios, especially regarding key gases such as carbon dioxide, methane, and oxygen. In the Archean scenario, high concentrations of methane and CO_2 are observed, associated with a reducing environment and low oxygen levels, which favors greater chemical instability and reduced protection against ultraviolet radiation. In contrast, the Modern scenario presents higher oxygen concentrations, enabling the formation of ozone and, consequently, greater protection against UV radiation, as well as lower methane levels due to its oxidation. These differences are directly reflected in the atmospheric dynamics and the planet's potential habitability.

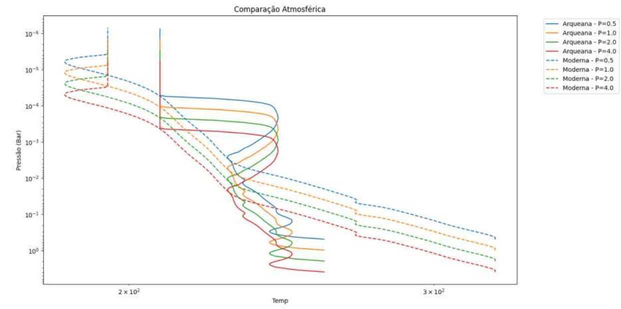

Figure 2. Temperature and pressure profiles for four pressures (0.5, 1.0, 2.0, and 4.0 atm) for Archean (solid lines) and Modern (dashed lines) atmospheric models.

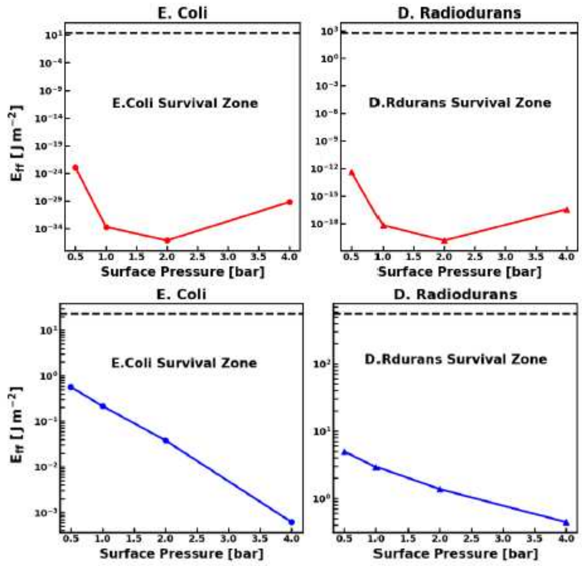

Figure 3. Biological effect on *E. coli* and *D. radiodurans* at different pressures under Archean (red) and Modern (blue) atmospheres. The dashed horizontal line denotes the threshold for 10% survival, above which 90% of the bacteria would not survive.

3.3. Energy Flux and UV Radiation

The results show that the Archean atmosphere allows greater transmission of ultraviolet radiation in the 200–300 nm range, a critical band for DNA damage (Cnossen et al. 2007). In contrast, the modern scenario exhibits strong absorption by O_3 and O_2, blocking a large portion of the radiation.

3.4. Biological Analysis

The analysis of UV radiation impact showed that, in the Archean scenario, the values remained well below the known lethal doses—22 J m^{-2} for *E. coli* and 533 J m^{-2} for *D. radiodurans*—suggesting bacterial survival even under low-oxygen conditions. In the Modern scenario, the values were higher but still below the lethal thresholds, indicating that the presence of O_2 and O_3 provides greater protection against UV radiation. From a biological perspective, the model suggests that, under both Archean and Modern scenarios, the planet's surface could support both organisms within the atmospheric pressures considered (see Figure 3).

4. Conclusion

The analyses showed that TOI-700 presents potentially habitable conditions in both the Archean and Modern scenarios. The Archean scenario, despite its instability and lower UV protection, could still allow environments suitable for resistant microbial life (such as *D. radiodurans*). In contrast, the Modern scenario closely resembles present-day Earth conditions, with the presence of O_2, O_3, and water vapor, creating an environment favorable for less resistant bacteria such as *E. coli*.

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