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# Modelling the atmosphere of potential habitable planets

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**Abstract.** The list of planets discovered in the habitable zone of its star is continuously growing. We present a simple one-dimension radiative transfer model in order to better infer on the habitability of such systems. Particular focus is on the TRAPPIST-1 planets (Gillon *et al.* 2017), particularly on planets b, c, d, e and f.

**Keywords.** planets and satellites: general

## 1. Introduction

We are modelling several terrestrial planets discovered around the habitable zone of TRAPPIST-1. This system is composed of at least seven Earth-sized planets (from 0.77 to 1.15 $R_\oplus$, Grimm *et al.* 2018) orbiting a dwarf M8 star. Their orbital periods range from 1.5 to 9.2 days, receiving from 35% to 4 times the average flux received by Earth from the Sun. Morley *et al.* (2017) and Lincowski *et al.* (2018) presented one-dimension models of the TRAPPIST-1 planets, including thermal structure and planetary spectra with assumptions on their composition. Turbet *et al.* (2018) presented climate modelling of the TRAPPIST-1 planets.

The main stellar, orbital and planetary parameters are summarised in Table 1.

## 2. Model

*Radiative-convective model*

We use the one-dimension radiative-convective model from (Marcq *et al.* 2017). It has been developed for applications to magma ocean planets, with atmospheric mixures of $H_2O$, $CO_2$ and $N_2$. This model solves the longwave radiative transfer using k-correlated calculations. The k-correlated coefficient is computed by KSPECTRUM (Eymet *et al.* 2016) and the radiative transfer is solved using DISORT (Stamnes *et al.* 1988). See Marcq *et al.* (2017) for further details.

The shortwave radiation is not taken into account. Instead, the incoming stellar radiation is parameterised by $(1 - A)S_\star$, where $A$ takes into account $A_{\rm clear}$ and $A_{\rm cloud}$ (both free parameters). The top of the atmosphere temperature can be either calculated or set as a free parameter. The calculation of this temperature, in the absence of consistent heating calculation gives unrealistic results. As a consequence, we treated it as a free parameter.

In order to compare our results to Morley *et al.* (2017), we also compute for each planet an Earth-like composition as well as a Venus-like composition (see Table 2 for the model parameters we used).

**Table 1.** Summary of the planetary system parameters.

| | Parameters | TRAPPIST-1 | | | | | References |
|---|---|---|---|---|---|---|---|
| | | b | c | d | e | f | |
| **Star** | Type | M8 | | | | | [a] |
| | $T_{\rm eff}$ [K] | 2560 | | | | | [b] |
| | $R$ [$R_\odot$] | 0.0117 | | | | | [c] |
| **Orbit** | P [Days] | 1.51 | 2.42 | 4.05 | 6.10 | 9,21 | [b] |
| | a [AU] | 0.0115 | 0.0158 | 0.0223 | 0.0293 | 0.0385 | [d] |
| | $S$ [$S_\odot$][1] | 4 | 2.1 | 1.1 | 0.6 | 0.35 | Calculated |
| **Planet** | $M$ [$M_\oplus$] | 1.02 | 1.16 | 0.30 | 0.77 | 0.93 | [d] |
| | $R$ [$R_\oplus$] | 1.12 | 1.10 | 0.77 | 0.91 | 1.04 | [d] |
| | $\rho$ [$\rho_\oplus$] | 0.73 | 0.88 | 0.62 | 1.02 | 0.82 | [d] |
| | $g$ [$g_\oplus$] | 0.81 | 0.97 | 0.48 | 0.93 | 0.85 | [d] |
| | $T_{\rm eq}$ [K][2] | 400 | 342 | 288 | 251 | 219 | [b] |

*Notes:*
[1] $S$: Stellar constant in units of the Solar constant at 1 AU.
[2] Assuming a zero albedo.
[a] Liebert & Gizis (2006)
[b] Gillon *et al.* (2017)
[c] Gillon *et al.* (2016)
[d] Grimm *et al.* (2018)

**Table 2.** Summary of the simulation parameters.

| **Parameters** | Earth case | Venus case |
|---|---|---|
| $P_{\rm surf}$[*bar*] | 1 | 100 |
| $N_2$ | 78% | 3.4% |
| $CO_2$ | 0.035% | 96% |
| $H_2O$ | 1% | 0.3% |

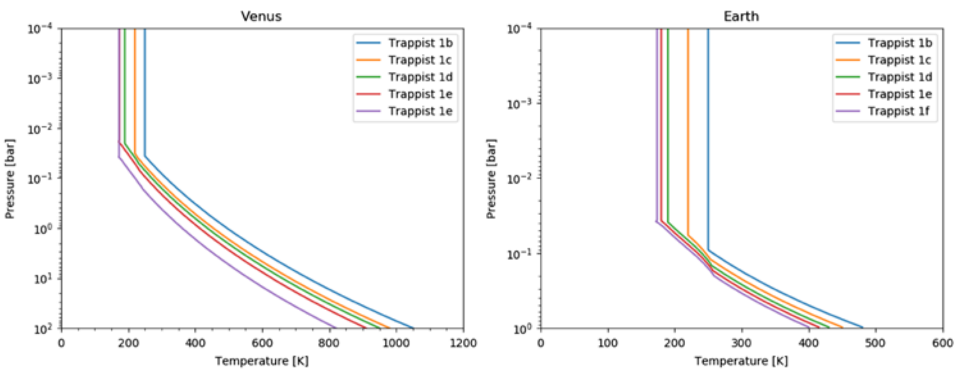


**Figure 1.** Thermal profiles of the Trappist 1 modelled planets in the Venus (*Left*) and Earth (*Right*) atmosphere setups.

## 3. Results

*Thermal profiles*

Figure 1 can be compared with Figure 4 of Morley *et al.* (2017) for the Venus case. They are overall similar. One difference however is that Morley *et al.* (2017) fixed the radiative zone upper boundary to $P = 0.1$ bar and iterated $T_{\rm surf}$ until $T_{\rm eff} = T_{\rm eq}$. Here we do not fix the boundary between troposphere and mesosphere (see Section 2) but have one more free parameter ($T_{\rm top}$ and $T_{\rm surf}$). So we fixed the top of atmosphere temperature

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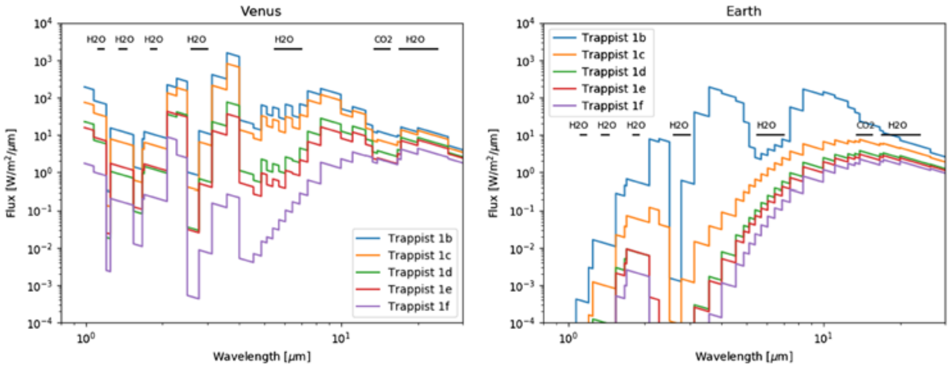


**Figure 2.** Planetary spectra.

to match Morley *et al.* (2017) and iterated $T_{\rm surf}$ until $T_{\rm eff} = T_{\rm eq}$. The fact that the radiative/convective boundary layer is here allowed to vary makes our surface temperatures less spread.

Considering the difference of irradiation between TRAPPIST-1e and TRAPPIST-1f, the very similar temperature profile makes us wonder if the radiative transfer is valid for low temperatures.

*Spectra*

Figure 2 can be compared with Figure 11 of Morley *et al.* (2017) for the Earth case. With a lower resolution in our case, they are qualitatively similar. One can recognize the surface temperature blackbody with some $H_2O$ and $CO_2$ absorption bands. As expected, in the Venus case, the atmosphere is thick enough that the emission spectrum is totally different than a blackbody at the surface temperature, especially at wavelengths shorter than 4 $\mu$m.

## 4. Conclusion

We used a one-dimension radiative transfer code in order to model TRAPPIST planets. This allowed us to calculate thermal profiles as well as thermal emission spectra for these planets. The code is relatively light which will allow us in the future to integrate in e.g. 3D general circulation model. However, the shortwave radiation is yet to be implemented in a consistent way, which is under way (E. Marcq, private comm). The next step would be to couple this radiation code with our General Circulation Model (Plasim), which has been recently applied (with its original radiation scheme) to the planet Proxima Centauri b (Galuzo *et al.* 2019).

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## Discussion

Trimble: Do any of your 3D models yield 3 Hadley cells per hemisphere?

Iro: One equator to pole in each hemisphere is typical in the case of slow rotating planets. If we increase the rotation rate the Hadley cell would break but this is not the case here.

Trimble: And that is because of phase-locking?

Iro: Yes, the phase locked configuration leads to slow rotation of the planet.

Guenther: Temperature of TRAPPIST-1: on the transparency it is 5560K. I guess 2560K.

Iro: Yes, it was obviously a typo!

Anonymous: Have you done any improvements to the traditional model?

Iro: The models we compared to were different ones. We are still in the process of understanding the differences in the 3D models, radiation, composition and cloud parameterization could explain the discrepancies.

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