Exploring hot mini-Neptune atmospheres

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Aims

How does the chemistry as well as the temperature - and therefore detectable features - change for a planet, if it is closer or further away from its host star? We build a grid of mini-Neptune atmospheres models (planets of 10 Earth masses with a solar composition atmosphere), to explore those questions. We also explore hotter and colder stars, where the different energy distribution will influence the chemistry in the upper atmosphere [1].

Methods

✦**Thermal structure**: we adopt a gray atmosphere in hydrostatic equilibrium. The absorption of stellar irradiation (shortwave) and the subsequent reradiation (longwave) are treated separately [2].

✦**Chemistry**: our 1D model takes into account the effect of photochemistry induced by stellar irradiation, considering equilibrium and disequilibrium chemistry [3].

Results

✦When a planet orbits further away from its star, it cools and therefore the major chemical reactions taking place and the atmospheric composition change, while different spectral types imply different fluxes (specially UV) that affect the photochemistry.

✦The stellar spectral energy distribution (shown in Fig.1) influences how much of the star's light gets reflected and absorbed. For cool stars (M, Teff=3600 K), most of the energy received at a planet's orbit gets absorbed, therefore the planet is hotter than the same planet receiving the same radiation from a hotter (F, Teff=7000K) star.

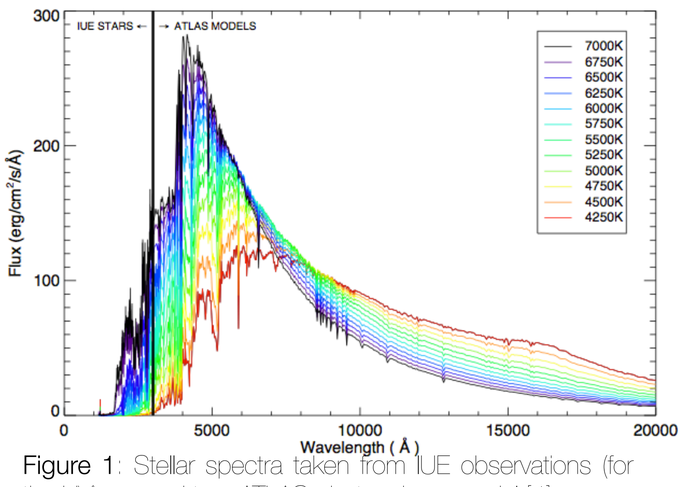

Figure 1: Stellar spectra taken from IUE observations (for the UV) merged to a ATLAS photosphere model [4].

✦CH_4 is more stable at lower T, therefore its abundance increases when going from hot to cool planets. Its abundance also increases with decreasing stellar UV.
✦At low pressures, the incident UV photons dominate the photochemistry.
✦Large concentrations of H and OH are produced from H_2O photolysis, followed by a destruction of H_2 due to its reaction with the produced OH.
✦CO abundance is set by thermochemical equilibrium, except high in the atmosphere where it combines with OH, forming CO_2.
✦CO_2 decreases its abundance above this level due to its dissociation, which is higher for planets around stars with higher emission of UV flux.

Temperature and Pressure structure of the atmospheres

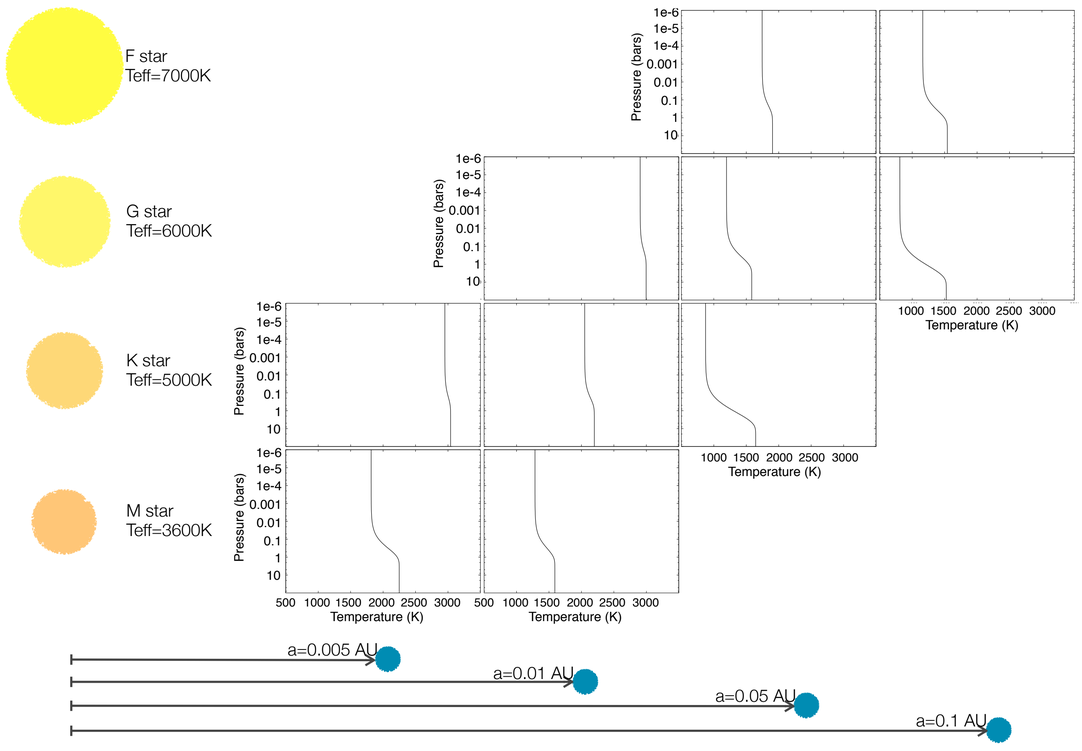

Figure 2: Temperature and pressure profiles for the planets in our grid. First column: planets located at 0.005 AU from its parent star. Columns 2, 3 and 4 correspond to 0.01, 0.05 and 0.1AU, respect. Planets around F, G, K and M stars are shown in rows 1, 2, 3 and 4, as indicated.

Photochemical mixing ratios of the atmospheres

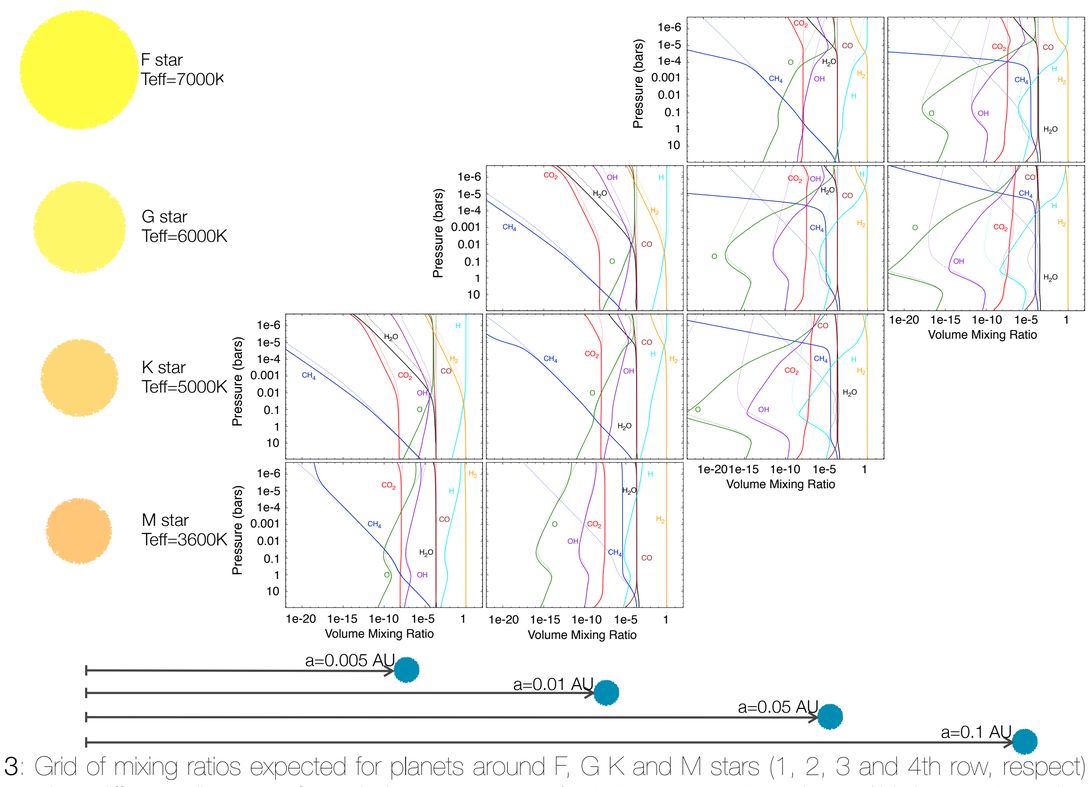

Figure 3: Grid of mixing ratios expected for planets around F, G K and M stars (1, 2, 3 and 4th row, respect) and located at different distances from their parents stars (0.005, 0.01,0.05 and 0.1 AU the 1,2,3 and 4 column, respect.). Dotted lines show chemical equilibrium values, while solid lines are the photochemical results.

Conclusions

✦Fig. 2 and Fig. 3 show how planetary atmospheres change with different distance to their star and for different host stars (F-M).
✦In our models, the atmospheres of the hottest planets in the grid are dominated by H, H_2, O, H_2O and CO (see Fig. 3).
✦For cool planets in our grid, CH_4 is a major constituent in atmospheres of planets orbiting K and M stars.
✦H replace H_2 as the major gas in the high atmosphere for high UV flux - shown in the atmosphere of planets around stars with high emission of UV flux and when going to smaller semimajor axis (see Fig. 3).

References

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[4] Rugheimer, S. et al., 2013, Astrobiology, 13, 251

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