Time-Dependent Stellar Activity Impact on Close-in Exoplanets

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Aims

Stars are dynamic objects and so is their interaction with close-in exoplanet atmospheres. In this work we model star-planet interactions, using synthetic stellar flares [1], to investigate how the atmospheric chemistry and observations change over time, also considering the atmospheric-escape effect of hydrogen. Creating a detailed description of the chemistry and dynamics of evolving atmospheres is a useful tool for the selection of targets and interpretation of data coming from missions like JWST and Ariel.

Methods

We made use of the 1D-chemical kinetics code, VULCAN [2], that includes photo-chemistry and thermal atmospheric escape (i.e. diffusion-limited escape) to simulate the atmosphere of GJ 581c. We also included a time-dependent stellar-spectra routine to simulate stellar flares over a short period of time. The Quiescent stellar spectrum has been obtained from the (mega-)MUSCLES collaboration [3,4,5], and the flare spectra using a fiducial flare program [1]. The emission and transmission spectra are then retrieved using the radiative transfer code petitRADTrans [6,7].

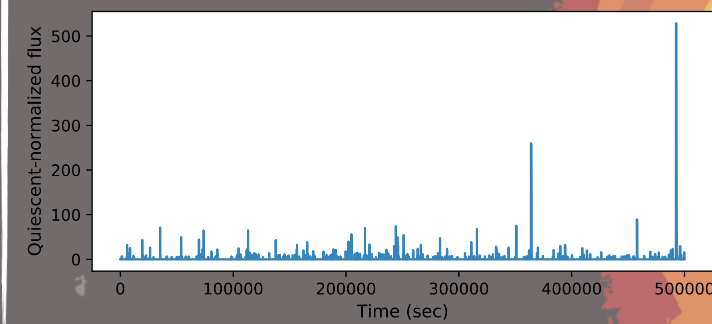

Figure 1. Fiducial lightcurve from a M3V star calculated using [1].

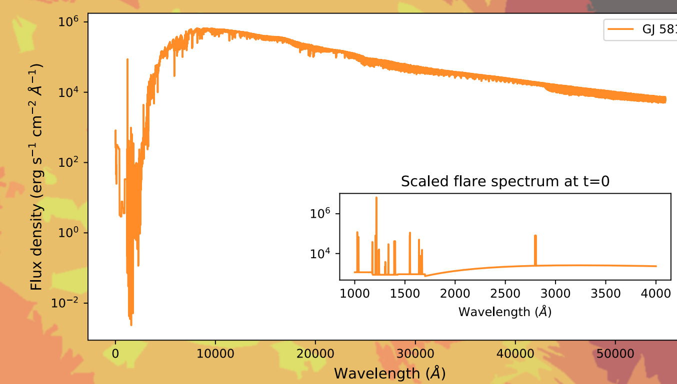

Figure 2. Quiescent spectrum of GJ 581 from the (mega-)MUSCLES survey [3,4,5], as scaled to the surface flux of GJ 581 c. The box-figure represents the stellar spectra just before the flare event stars, in the UV-regime (100-400 nm), created with [1].

Results

- The mixing ratios for H, CH_4, H_2O, and OH change significantly in the upper atmosphere when including fiducial flares and diffusion-limited escape, over a period of ~5.7 days (Fig. 3).
- OH and H also show changes deeper in the atmosphere at ~1-10 bars.
- The normalised emission and transmission spectra (Figures 4 & 5) show some variations over time, however these changes remain small.
- The biggest variations in the emission and transmission spectra are mostly due to the extreme abundance change in CH_4 and NH_3 for the longer wavelength (> 2 microns) and H_2O for the short-wavelength range (< 2 microns).

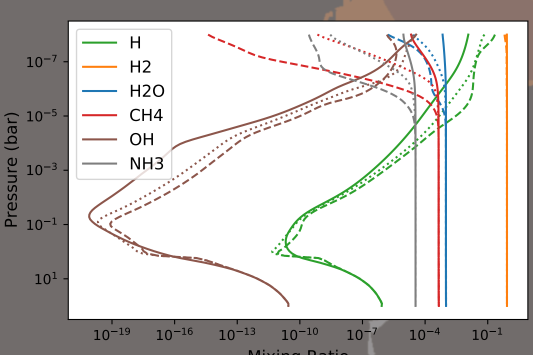

Figure 3. Mixing ratios at different timesteps. The solid lines represent the initial ratios before the flare events, the dotted lines represent the ratios after ~2.3 days, and the striped lines represent the mixing ratios after ~5.7 days.

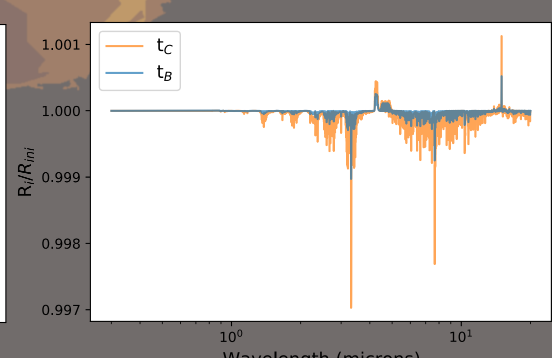

Figure 4. Transmission spectra at two different time steps (blue: t_B = 2.3 days; orange: t_C = 5.7 days) normalized by the initial transmission spectrum at t = 0.

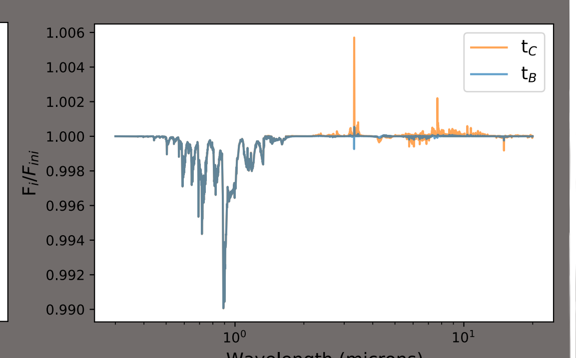

Figure 5. Emission spectra at two different time steps (blue: t_B = 2.3 days; orange: t_C = 5.7 days) normalised by the initial emission spectrum at t = 0.

Conclusions

- The chemistry in the atmosphere of GJ 581c has been simulated using the 1D-chemical kinetics code, VULCAN [2].
  - Simulating the atmosphere for ~5.7 days when including fiducial flares shows some significant changes in mixing ratios for photochemical-sensitive species.
- Using the radiative transfer code petitRADTrans [6,7], the emission and transmission spectra were obtained at different points in the simulation.
  - The emission and transmission spectra show little to no change over time

References

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