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Understanding the influence of magma oceans on the observability of atmospheres of rocky exoplanets.

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Introduction

The last few years have revealed many rocky planets which orbit their host star in less than a day. These ultra-short periods can lead to tidal locking and to surface temperatures of over 2000K on the permanently irradiated day side, hot enough to melt the surface and create magma oceans. These magma oceans act as a key interface between a planet's interior and the atmosphere, influencing atmospheric composition and evolution. One way these reservoirs interact is through the exchange of volatiles. From simulations of an Earth like magma ocean, we know that partitioning of hydrogen into the melt and the outgassing of carbon in the form of CO_2[1] leads to an atmosphere dominated by CO_2, H_2O, SO_2 and silicate vapors. These higher molecular weight atmospheres are much more stable to atmospheric escape. This means that over long periods of time (Gyrs), the atmosphere of a magma ocean planet would lose mass very slowly. The James Webb Space Telescope (JWST) has opened a new window in studying planetary composition through the search for these silicate vapours. One such planet is K2-141b, a super-Earth orbiting a K-type host star every 0.28 days[2]. In this work, we investigate the composition and spectral features of the atmospheres of ultra short period planets like K2-141b.

Method

To achieve this, we couple the chemical equilibrium vaporisation model LavAtmos[3] with the radiative convective model AGNI[4] to create synthetic emission spectra. We generate a range of possible temperature-pressure profiles and atmospheric SiO to SiO_2 ratios (Our atmosphere also includes small amounts of Si,O and O_2). The dayside surface temperature was calculated assuming radiative equilibrium for weak day to night heat redistribution. We assume that the magma ocean temperature is equal to the surface temperature and that the total outgassed pressure of the magma ocean determines the surface pressure.

Using these profiles we then create synthetic emission spectra to explore the parameter space. We compare the resulting emission spectra with recent JWST MIRI LRS observations (PI: Dang, PID:2347[5]) to determine the influence of atmospheric silicate vapour on the spectra of K2-141b

We can study the dynamics of an exoplanet atmosphere using phase curves. Using the global circulation model ISCA[6] we investigate this for the ultra-short period planet TOI-561b which has a very low density but high equilibrium temperature suggesting the possibility of an atmosphere. Initial emission spectra modelling shows that the dayside emission is too low to be explained by a bare rock and thus a global atmosphere is needed to redistribute heat from the day to the night side. We plan to conduct phase curve modelling to investigate different ratios of shortwave to longwave opacities to investigate how much absorption takes place within the atmosphere of TOI-561b and compare these to recent JWST observations (PI: Teske, PID:3860).

Results

Using a reduced chi-squared test we highlight the best fits in Figure 1.

Figure 1: The best-fit results of our emission model using a reduced chi-squared test. The figure on the left shows the AGNI emission spectra interpolated onto the JWST wavelength grid. The figure on the righare the corresponding TP profiles.

Our results show that a silicate vapour atmosphere with a TP profile featuring a strong upper atmosphere inversion is a good fit to the observational data. The TP profiles successfully capture the captures the 7–8-micron SiO_2 emission feature. There is a second emission feature at around 10 microns, but our best-case models only produce flat lines in this region.

Figure 2 shows a selection of the possible TP profiles to see how they compare. We select three families of profiles: an adiabatic profile extending to the top of the atmosphere, a fully inverted profile, and a mixed profiles, as described in Equation 1. We can see that the mixed case does the best job of fitting the observational data, with the adiabatic fluxes being too low and the inverted fluxes too high. For the 7-8 micron feature, an SiO2-dominated atmosphere and an equally mixed atmosphere provide the best fits. However, none of the compositional types can capture the behaviour around 10 microns. This suggests that our simple three-species-model is not capturing the full behaviour of the atmosphere.

Figure 2: The emission spectra created by the three families of possible TP profiles and SiO/SiO_2 ratio.

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