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Photochemical hazes in sub-Neptunian atmospheres with focus on GJ 1214 b

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Abstract

We study the properties of photochemical hazes in super-Earth/mini-Neptune atmospheres with particular focus on GJ 1214 b. We evaluate photochemical haze properties at different metallicities between solar and 10000×solar. Within the four orders of magnitude change in metallicity, we find that the haze precursor mass fluxes change only by a factor of ∼3. This small diversity occurs with a non-monotonic manner among the different metallicity cases, reflecting the interaction of the main atmospheric gases with the radiation field. Comparison with relative haze yields at different metallicities from lab experiments reveals a qualitative similarity with our theoretical calculations and highlights the contributions of different gas precursors. Our simulated haze properties suggest that a high metallicity is required to explain the transit observations of GJ 1214 b.

1. Context

Super-Earth and mini-Neptune size planets constitute a large fraction of the observed exoplanet population, therefore are the subject of intense investigation. Transit observations of such planets reveal a diversity in the depth of spectral features anticipated at near IR wavelengths from molecular absorption, which is attributed to the presence of suspended particulate matter in their atmospheres [1]. The most well studied example of such an atmosphere is the case of exoplanet GJ 1214 b, for which the most accurate constraints at visible from ground based observations with the Large Binocular Telescope [2], in combination with the high-precision Hubble Space Telescope (HST) observations between 1.1 and 1.7 μm [3], and the Spitzer measurements at 3.6 and 4.5 μm [4] reveal a quasi-flat spectrum, that restricts the characterisation of the atmospheric composition. We use detailed models of atmospheric chemistry and haze microphysics to evaluate the production rates and resulting transit signatures of photochemical hazes under different assumptions of atmospheric metallicity (1× - 10000× solar).

2. Results

Our simulated haze production rates demonstrate that although the metallicity conditions change by 4 orders of magnitude the difference in the haze mass fluxes is only a factor of ∼3 between the two extreme cases of solar and 10000×solar metallicity (Fig. 1). This is a clear demonstration of the fact that photochemical products are dominantly photon limited, as long as, the abundance of precursors is not critically affected by their photolysis. Nevertheless, metallicity changes can impose chemical composition changes with a secondary impact on the particle composition. The relative contributions of H, C, and N in the photolysis

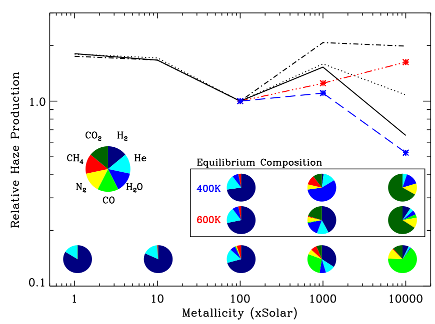

Figure 1: Relative haze production from simulations (lines) and laboratory experiments (asterisks) at different metallicities. The black line corresponds to the nominal haze precursors (CH_4 & N_2 photochemical products), while the dotted and dash-dotted lines present additional contributions from the photolysis of CO and CO_2, respectively.

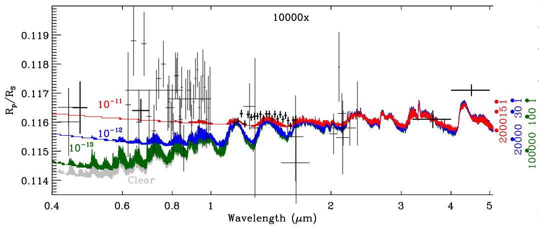

Figure 2: Observed (black crosses) and simulated (color lines) transit depth of GJ 1214 b for the 10000×solar metallicity case. Each color line is a variation on the assumed haze mass flux (in $gcm^{-2}s^{-1}$). The points and associated numbers on the right of each panel present the pressure (in μbar) probed at each wavelength.

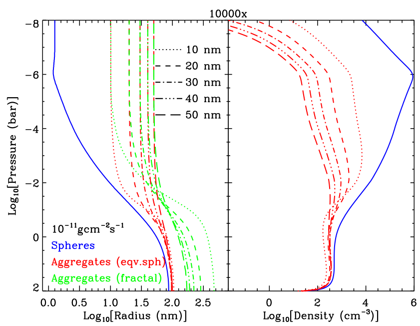

Figure 3: Comparison of spherical (blue) and aggregate (red & green) growth of haze particles at 10000×solar metallicity. Each broken line corresponds to a different primary particle radius. For aggregates the red lines correspond to the average radius of the equivalent mass spherical particle and the green lines to the fractal structure average radius. The corresponding average particle density is shown on the right panels (it is independent of the radius-type averaging).

of precursors demonstrate this dependence on the assumed metallicity. Comparison of our relative haze production rates with laboratory experiments [5] reveals a qualitatively consistent picture.

Our haze simulations demonstrate that higher metallicity results into smaller average particle sizes. Metallicities at and above 100×solar with haze formation yields of ∼10% provide enough haze opacity to satisfy transit observation at visible wavelengths and obscure sufficiently the H_2O molecular absorption features between 1.1 μm and 1.7 μm. However, only the highest metallicity case considered (10000×solar) brings the simulated spectra into closer agreement with transit depths at 3.6 μm and 4.5 μm indicating a high contribution of CO/CO_2 in GJ1214b's atmosphere. We also evaluate the impact of aggregate growth in our simulations, in contrast to spherical growth (Fig. 3), and find that the two growth modes provide similar transit signatures (for D_f=2), but with different particle size distributions. Finally, we conclude that the simulated haze particles should have major implications for the atmospheric thermal structure and for the properties of condensation clouds.

Acknowledgements

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