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Aerosols and clouds in the atmosphere of HD 189733 b

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Abstract

In the last two decades our view and understanding of planetary atmospheres has significantly expanded as a result of the detection and characterization of numerous exoplanets and of their atmospheres. Apart from the exotic chemical inventories observed in these objects, recent studies suggest that subsequent products of chemical evolution such as hazes (in the form of aerosols or/and clouds) can also exist in these atmospheres. Hazes can strongly influence the thermal structure of the atmosphere, the dynamics, and the photochemistry, as their equivalents in the solar system atmospheres have promptly demonstrated. Our goal is to investigate the processes leading to the formation of aerosols and clouds in exoplanet atmospheres with the use of detailed models of aerosol and cloud formation and evolution coupled with photochemical models of the atmosphere. We apply these models to the case of exoplanet HD 189733 b for which observations indicate the presence of heterogeneous opacities. Our results demonstrate that photochemical haze can have important implications for the interpretation of the available observations.

Methods

We perform our studies using detailed models of atmospheric thermochemistry/photochemistry for the evaluation of the atmospheric composition under different temperature conditions in the atmosphere of HD 189733 b [1]. Based on the composition results we apply models for the simulation of the photochemical aerosols and clouds, which are based on previous studies of relevant processes in Titan's atmosphere [2, 3]. We estimate the production rate of photochemical aerosols from the photolysis rates of major compounds in the upper atmosphere of HD 189733 b, assuming an efficiency for aerosol formation based on previous studies in the solar system and particularly the atmospheres of Titan, Saturn and Jupiter. For the simulation of clouds we consider the formation of silicate condensates, which provide the largest mass flux of condensable species under the assumed temperature conditions. For the latter we evaluate our model results for temperature profiles derived by GCM simulations [4] or the inversion of secondary eclipse observations [5].

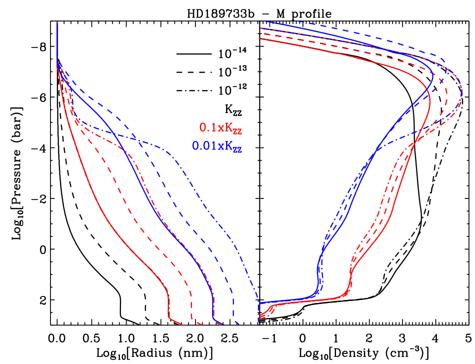

Figure 1: Model results for the average particle size and corresponding density under different assumptions of aerosol mass flux and atmospheric mixing.

Results

Our results suggest that significant mass fluxes of photochemical aerosols can be produced in the upper atmosphere of HD 189733 b (above $\sim$10μbar). However, the resulting aerosol size and population depend strongly on the assumed atmospheric mixing efficiency (Fig. 1). High mixing values limit the growth of the aerosol particles because particles are transported to the lower atmosphere before having the opportunity to collide with each other and coagulate. However, reduced eddies allow for the formation of large enough particles that reach up to 10 to 100 nm depending on the assumed mass flux and eddy mixing. Using

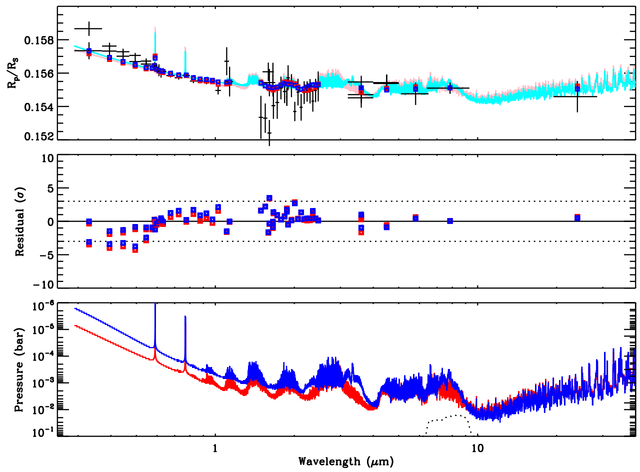

Figure 2: Planetary transit radius for an aerosol mass flux of 5×10^{-13} g cm^{-2}s^{-1} (upper panel). The pink and cyan lines correspond to different temperature profiles, respectively. The red and blue squares present the model mapped on the resolution of the observations. The latter are taken from the compilation of [6]. The simulated spectra are within 3σ of the observations in the whole spectrum (middle panel), although they appear systematically lower than the observed planetary size at UV wavelengths. The two temperature profiles provide a similar transit spectrum, although the reference pressure at the 8μm Spitzer/IRAC band are different (lower panel).

these distributions for the evaluation of the planet radius over transit, we find that mass fluxes of the order to 10^{-13} g cm^{-2}s^{-1} provide a good fit to the observations (Fig. 2), while such mass fluxes are supported by the photochemistry simulations. Our results indicate that in order to match the observed planet size at short wavelengths particles need to be present at pressures lower than 0.1 mbar. Attempting to perform the same fit but assuming only the presence of silicate clouds is a challenge due to the high altitude extend of the cloud layer required. Our simulations indicate that high eddies are required in this case in order to expand the cloud layer to high altitudes, and even in this case the resulting spectral signature is not consistent with the available observations. Thus, our results demonstrate the photochemical hazes are a more likely candidate for the interpretation of the heterogeneous opacity in the atmosphere of HD 189733 b.

Acknowledgements

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