ÖAW — AUSTRIAN ACADEMY OF SCIENCES

Mineral Snowflakes on Exoplanet and Brown Dwarf Atmospheres

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INTRODUCTION

Cloud particle-particle collisions can significantly alter the cloud particle porosity, size and number density distributions within an atmosphere. Recently, microphysical cloud models have included coagulation for exoplanet atmospheres (e.g. Ohno et al. (2018), Gao & Benneke (2018)). Here introduce a hybrid microphysical cloud mode, combining a representative size method for particle-particle collisions with the moment method. This produces a fast model, with mixed condensate cloud particles, which allows us to investigate the importance of collisions in affecting cloud particle distribution and size in exoplanet and brown dwarf atmospheres (Samra et al. (Submitted).

METHODS

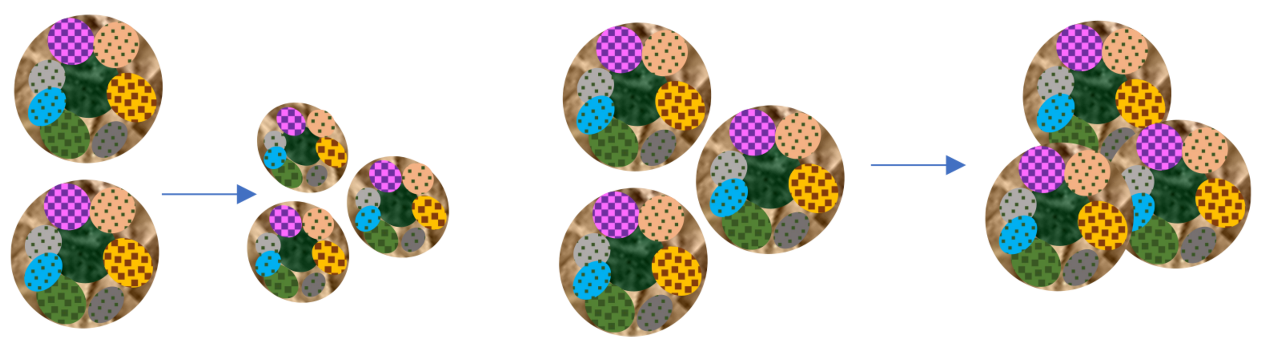
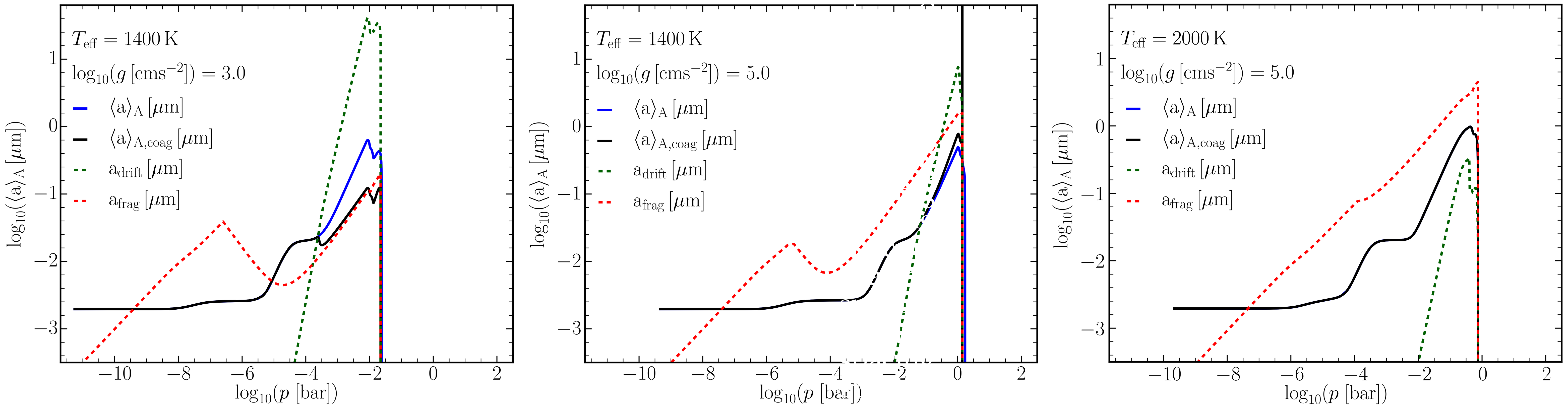


Illustration of simplified collisional outcomes **Left:** destructive collisions ('fragmentation') and **Right:** constructive collisions, ('coagulation').

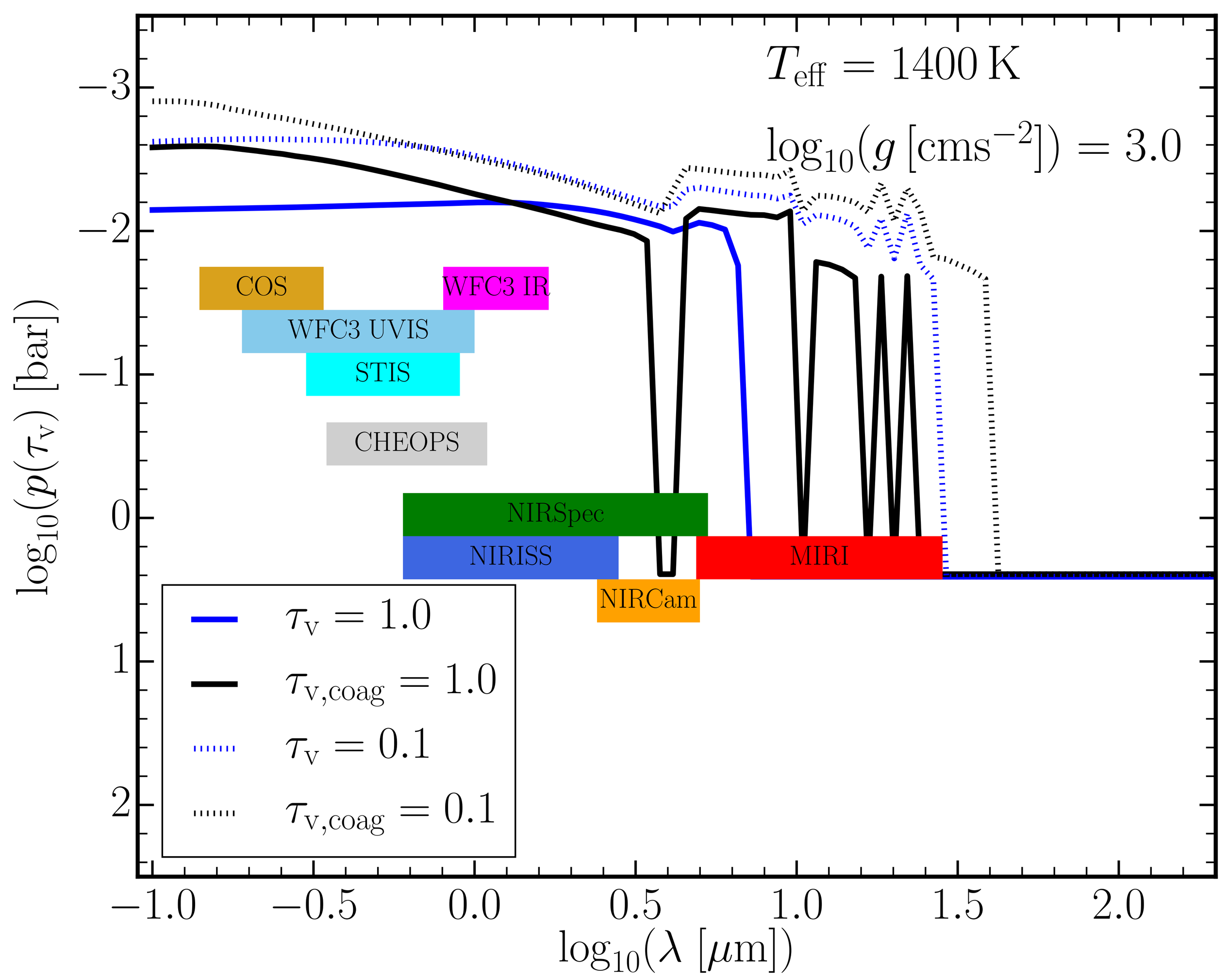
Nucleation, bulk growth/evaporation and settling of cloud particles is modelled by our kinetic, non-equilibrium cloud formation model. We extend this to consistently include cloud particle-partilce collisions using a representative size collisional model inspired by the TWO-POPPY model developed for protoplanetary discs (Birnstiel et al. 2012). Collisions between cloud particles are induced by gravitational settling, Brownian motion and turbulence. The affect of collisions is governed by the collisional timescale and by two limiting effects: fragmentation for cloud particles larger than $a_{\rm frag}$ and settling of cloud particles out of the atmospheric layer without signifcant collisions if larger than $a_{\rm drift}$. The optical depth of cloudsis calculated using Mie theory, with effective medium theory for the mixed material composition of the cloud particles. This is applied to a grid of 1D pressure-temperature DRIFT-PHOENIX profiles for $T_{\rm eff} = 1400, 1600, 1800, 2000, 2400$, K and $\log_{10}(g[{\rm cms}^{-2}]) = 3.0, 5.0$ to see where collisions are impacting the cloud particle size and number density.

RESULTS



Left: Fragmentation Dominated: Exoplanets, e.g. WASP-43b, **Middle:** Coagulation Dominated: Cool Brown Dwarfs, **Right:** Condensation Dominated: Hot Brown Dwarfs

Cloud particle collisions prove to be only efficient at the cloud base: otherwise $\langle a\rangle_{\rm A}$ is greater than the drift limit and cloud particles fall out of an atmospheric layer before they have time to collide. At the cloud base turbulence is the dominant collisional driver. Collisions produce one of three general outcomes: fragmentation dominating less dense atmospheres ($\log_{10}(g) = 3.0$), coagulation for cool compact atmospheres ($T_{\rm eff} \leq 1800$ K, $\log_{10}(g) = 5.0$) , and growth dominating hot compact atmospheres ($T_{\rm eff} > 1800$ K, $\log_{10}(g) = 5.0$).



Pressure level at which vertical optical depth $\tau_{\rm v} = 1$ (solid) and $\tau_{\rm v} = 1$ (dashed) for $T_{\rm eff} \leq 1400$ K, $\log_{10}(g) = 3.0$ atmosphere.

The effect of fragmentation for the cool exoplanet profile ($T_{\rm eff} \leq 1400$ K, $\log_{10}(g) = 3.0$) produces significantly smaller cloud particles than the non-collisional case. This also increases the number density of cloud particles at the cloud base due to conservation of mass. For this profile we compute the optical depth of the clouds and find that in the optical regime the clouds are more optically thick, such affects could impact inferences of cloud properties for HST and CHEOPS. In the mid-infrared silicate features are enhanced, making the clouds optically thick in the features, whilst remaining optically thin to the bottom of the atmosphere outside of the features.

Conclusion

- Turbulence driven collisions between cloud particles for gas-giant atmospheres ($\log_{10}(g) = 3.0$) fragments cloud particles
- For Brown Dwarf atmospheres ($\log_{10}(g) = 3.0$) coagulation does occur, but not dramatic
- Optical depth of clouds for gas-giants at optical wavelengths (e.g. CHEOPS) are enhanced by collisions fragmenting cloud particles, as are the silicate features. These changes may complicate inferences of cloud particle properties, such as material composition, from observations.

References

Birnstiel, T., et al. (2012)
Gao, P., Benneke, B., (2018)
Ohno, K., et al. (2017)
Samra, D., et al. (2020)
Samra , D., et al., (Submitted)

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