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Characterization of Cloud-Haze Interactions in Cool Exoplanets Atmospheres

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1. Abstract

Clouds and hazes are important components of cool exoplanets with equilibrium temperatures less than 1000 K. Models have been developed separately to describe cloud condensation and haze aggregation in exoplanet atmospheres, but the amount of data on cloud-haze interactions are insufficient to develop a model that incorporates both clouds and hazes. We measure the surface energies of the exoplanet haze analogs we produced in laboratory experiments and make predictions on interactions between the haze and cloud particles.

2. Introduction

Over 3000 exoplanets have been detected, the most abundant types being super-Earths (Rp∼1.25-2 R_{Earth}) and mini-Neptunes (Rp∼2-4 R_{Earth}) [1]. Since there is no analog planetary body to super-Earths or mini-Neptunes in our solar system, we must develop a comprehensive understanding of this new diverse class of objects. Observations have shown that clouds and hazes are significant components of exoplanet atmospheres, especially for cool exoplanets with equilibrium temperatures less than 1000 K.

The aerosol particles in exoplanet atmospheres could significantly alter the atmospheric transmission spectrum by diminishing the amplitudes of spectral features, impeding our ability to probe the atmospheric composition and possible biosignatures (e.g., [2, 3]). Thus, modeling of exoplanet clouds and hazes is essential in interpreting the measured spectra and understanding the potential habitability of exoplanets. Several cloud and aerosol microphysics models have been developed for super-Earths and hot-Jupiters (e.g., [4, 5]). Current microphysics models focus on either cloud condensation or haze aggregation. A model that can accommodate both processes, which does not currently exist, could more realistically simulate exoplanet atmospheres. However, there are large uncertainties on how the cloud and haze particles interact with each other, and material properties such as surface energy of the haze particles are largely unknown due to the lack of laboratory experiments.

Laboratory experimental studies have been conducted recently to produce haze in cool exoplanets with a variety of solar metallicities and atmospheric temperature [6]. The production rate and the particle size distribution of the haze analog materials have been measured [6, 7] We further characterize the surface energies of these haze analog materials, which governs microphysical processes such as coagulation, heterogenous nucleation, and cloud formation, and thus could serve as important input parameters in exoplanet microphysics models.

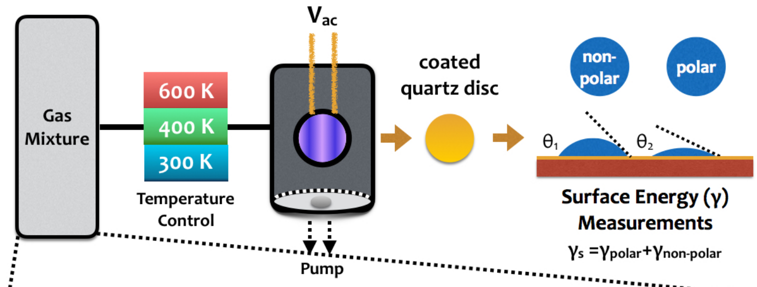
3. Methods

We produce a grid of exoplanet aerosol analogs using the Planetary HAZE Research (PHAZER) experimental system at Johns Hopkins University. The exoplanet atmospheric temperatures and the corresponding gas compositions are summarized in Figure 1. The produced aerosol particles are deposited on smooth quartz discs.

We measure the surface energy of the produced exoplanet haze films using contact angle analysis with a set of polar and non-polar liquids with distinct surface tensions, such as diiodomethane (non-polar, surface tension γ=50.8 mN/m) and water (polar, γ=72.8 mN/m). We deposit a polar (water) and a non-polar liquid (diiodomethane) on the flat coated film. We use a Ramé-Hart goniometer to image the droplet shape and extract the contact angle between the liquid and the surface with ImageJ using the contact angle plugin.

4. Preliminary Results

We measure the surface energy of the Titan aerosol analogs (so-called "tholin") to validate our methodology. The contact angle between water and the tholin film is measured to be 22 $\pm$ 5°, and it is 50 $\pm$ 5° be-



Solar Metallicity	100×	1000×	10000×
600 K	18.3% He, 72.0% H_2, 6.3% H_2O, 3.4% CH_4	13.3% He, 42.0% H_2, 20.0% CO_2, 5.1% N_2, 1.9% CO, 1.7% CH_4	4.1% He, 66.0% CO_2, 8.6% H_2, 5.9% H_2O, 12.0% N_2, 3.4% CO
400 K	17.2% He, 70.0% H_2, 8.3% H_2O, 4.5% CH_4	14.7% He, 56.0% H_2O, 11.0% CH_4, 10.0% CO_2, 6.4% N_2, 1.9% H_2	5.0% He, 67.0% CO_2, 13.0% N_2, 15.0% H_2O
300 K	17.3% He, 68.6% H_2, 8.4% H_2O, 4.5% CH_4, 1.2% NH_3	16.0% He, 66.0% H_2O, 6.6% CH_4, 4.9% CO_2, 6.5% N_2	4.1% He, 67.3% CO_2, 13.0% N_2, 15.6% H_2O

Figure 1: Exoplanet aerosol analog production flow in PHAZER. Gas mixtures for 9 different exoplanet atmospheric compositions are listed in the table. To reach the desired temperature (300–600 K), the gas mixtures will be flowing through a heating coil before they enter the reaction chamber and get exposed to a cold plasma. After 72 hrs of reaction, solid aerosol particles will be deposited on blank quartz discs and the surface energy of the aerosols will be determined through contact angle analysis.

tween diiodomethane and the tholin film. We calculate the surface energy of tholin (γ_s) using the Owens-Wendt-Rabel-Kaelble (OWRK) method [8], which yields $70.9^{+4.6}_{-4.8}$ mN/m. The dispersion component (γ_s^d) is $34.3^{+2.7}_{-2.9}$ mN/m and the polar component (γ_s^p) is $36.6^{+3.7}_{-3.8}$ mN/m [9]. Tholin has a relatively high surface energy with a significant contribution from the polar component, indicating its polar structure.

Further estimation of the contact angle between tholin and relevant liquids on Titan shows that most liquids on Titan (methane and ethane) would wet the tholin surface completely (contact angle θ <20°). This is because most liquids on Titan are simple non-polar hydrocarbons and have low surface tension (<30 mN/m) under low temperature (94 K). For super-Earths and mini-Neptunes, we would expect a higher atmospheric temperature and thus different cloud composition, thus we would expect more complex interactions between the cloud and haze particles in those exoplanet atmospheres.

Acknowledgements

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