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A New View of Haze Formation and Energy Balance in Triton's Cold and Hazy Atmosphere

Xi Zhang (1), Kazumasa Ohno (2), Darrell Strobel (3), Ryo Tazaki (4), and Satoshi Okuzumi (2)
(1) University of California Santa Cruz, Santa Cruz, USA (xiz@ucsc.edu), (2) Tokyo Institute of Technology, Tokyo, Japan, (3) Johns Hopkins University, Baltimore, USA, (4) Tohoku University, Sendai, Japan

Abstract

This research on Neptune's moon Triton consists of two parts. To start we built the first microphysical model of Triton haze formation including fractal aggregation of monomers and condensation of supersaturated hydrocarbons and nitriles. Our model can explain the UV occultation and visible scattering observations from Voyager 2 spacecraft during the Neptune flyby. With our model we find that haze particles play a dominant role in the energy balance in the lower atmosphere of Triton, which was neglected in previous studies. Future ice giant missions with a Triton lander should be able to measure the infrared fluxes from the near-surface haze layers and validate our hypothesis.

1. Introduction

The surface pressure of Triton's atmosphere is about ~1 Pa with a temperature of 30-40 K. Voyager 2 observations show that Triton's lower atmosphere is globally covered by haze layers and partially by discrete bright clouds (Pollack et al. 1990; Rages & Pollack 1992). Because of the cold atmospheric temperature, condensation of hydrocarbons plays an important role in the haze formation (Strobel et al. 1990). The near-surface discrete clouds are likely formed by condensation of nitrogen vapor via local processes, such as convection and plumes. To date there has not been a microphysical model for Triton's haze and cloud formation. On the other hand, Triton's upper atmosphere is relatively warm (~100 K) as a result of heating by energetic particles from Neptune's magnetosphere (Stevens et al. 1992; Strobel & Zhu 2017). A strong heat flux is conducted downward and dissipated in the lower atmosphere at around 50 km, below which the temperature remains roughly isothermal. However, previous studies found that the radiative cooling by carbon monoxide in the lower atmosphere is not sufficient to dissipate the downward heat flux (Elliot et al. 2000). A strong missing coolant is needed to understand the energy balance in Triton's lower atmosphere.

2. Methods

We have built the first bin-scheme microphysical model for Triton's haze and cloud formation. Our model simulates the evolution of size distributions in a one-dimensional framework with sedimentation, coagulation, condensation and vertical eddy mixing. We consider that the haze particles are initially composed of fractal aggregates—non-spherical particles comprised of many many spherical monomers—similar in previous studies on Titan and Pluto (e.g., Cabane et al. 1993; Lavvas et al. 2010; Gao et al. 2017), but we are also tracking the time evolution of fractal dimension of the aggregates. As the surfaces of the particles are coated with hydrocarbon and nitrogen ices, it is also probable that the particles become initially compact spheres. The major processes are illustrated in Figure 1.

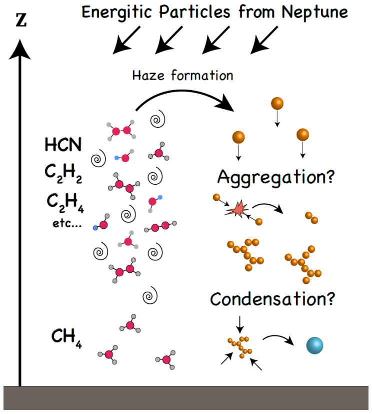

Figure 1: Microphysical processes in haze and cloud formation in Triton's cold atmosphere.

Triton's atmosphere is expected to be in radiative-conductive equilibrium. We adopted the temperature model for Pluto's atmosphere (Zhang et al. 2017) to calculate Triton's energy balance and thermal structure. The gas radiative heating and cooling rates follow Strobel and Zhu (2017) but we include the radiative effect from haze particles. The haze particles and gas molecules are found to be in thermodynamic equilibrium with each other in the lower atmosphere due to frequent collisions.

3. Results and Summary

The simulation results of Triton's haze formation are shown in Figure 2 assuming compact spheres and fractal aggregates. In general, sizes of haze particles increase with decreasing altitude for both cases. The hazes are composed of aggregates and eventually grow into much larger sizes than initial compact spheres (cf. Fig. 2). This process is driven by the fact that haze settling velocities are smaller in the lower atmosphere where the density is higher, leading to efficient growth of the particles. Our simulations match both the imaging (Smith et al. 1989; Pollack et al. 1990; Hillier et al. 1990, 1991; Rages & Pollack 1992; Hillier & Veverka 1994) and UV solar occultation observations (Herbert & Sandel 1991; Krasnopolsky et al. 1992) by the Voyager 2 spacecraft.

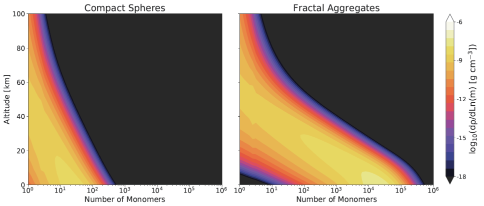

Figure 2. Vertical size distributions of hazes in Triton's atmosphere. The left and right panels show the distributions for compact sphere and fractal aggregate cases, respectively.

In the energy balance calculations, we find that in general the haze particles could have larger solar heating rates than the non-LTE methane heating, and larger cooling rates than the radiative cooling by rotational lines from carbon monoxide and Hydrogen cyanide. Thus Triton's atmospheric energy balance is similar to that on Pluto where the haze particles dominate the energy balance over gases. Detailed calculation will be presented in the meeting. As a result, the haze layers near Triton's surface should emit infrared fluxes capable of detection by future ice giant missions.

Acknowledgements

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