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Global Retrieval of Pluto's Haze

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Abstract

One of the most amazing features seen in Pluto's atmosphere during New Horizons' historic close approach was its multi-layered haze. The haze was directly imaged at visible and near infrared wavelengths by the Long Range Reconnaissance Imager (LORRI), the Multispectral Visible Imaging Camera (MVIC), and the Linear Etalon Imaging Spectral Array (LEISA), and investigated in the ultraviolet by the Alice spectrograph using solar occultations. Using simplified models, neither spherical nor 2-dimensional fractal aggregate particles could satisfy the set of observations [1]. In this work, we present a joint global retrieval of haze particle properties using observations of Pluto's haze from all four instruments and an aggregate scattering model [2], under the assumption that Pluto's haze particles are analogues of those on Titan, as their atmospheric chemistries are similar. Preliminary analysis shows that the fractal dimension of the haze particles may change considerably near the temperature maximum in Pluto's atmosphere at ~25km; the size of the monomers may be smaller than previous thought [1,3]; and the bulk aggregate size may be as large as 1μm. We map out the haze particles' phase functions by simultaneously considering forward scattering and extinction across multiple wavelengths, allowing for the size and shape of the haze particles to be constrained.

1. Introduction

The flyby of the New Horizons spacecraft in July 2015 confirmed the existence of haze in Pluto's atmosphere [4,5]. Originating from photolysis of methane and larger organic molecules in Pluto's upper atmosphere, macromolecular haze particles grow through coagulation of smaller particles as they sediment downwards [3]. Observations of the haze made by New Horizons at optical wavelengths indicate a bluish color from Rayleigh scattering and also strong forward scattering up to ~200km above the surface [1,5]. This suggests that the haze particles are fractal aggregates, highly porous and randomly shaped ~μm particles consisting of small ~10 nm spheres, similar to haze in Titan's atmosphere [6]. On the other hand, 0.5 μm spherical particles show better agreement with observations near Pluto's surface [1]. Thus, a transition from fractal aggregates to spheres may exist in the lowest 50 km of Pluto's atmosphere, where a strong temperature inversion exists [5,7]. However, although Pluto's haze was detected by multiple instruments onboard New Horizons at different wavelengths and phase angles, no unique solution for particle size, number density, and shape has been found that can explain all available spacecraft data [1]. As a result, the nature of Pluto's haze, especially near the surface, is uncertain, and therefore so are its effects on Pluto's atmosphere, e.g. on the temperature structure [8].

2. Methodology and Results

We use Alice, LORRI and LEISA data from published works [1,9,10] for our retrieval. MVIC data is still being processed, so the results presented here are preliminary and based on the observations from the first three instruments. The forward model includes four parameters describing fractal aggregates: fractal dimension D_f, monomer radius r_m, number of monomers per aggregate N_m, and haze particle number density n_a, with the first three parameters related by $N_m=(R_a/r_m)^{Df}$, where R_a is the aggregate radius. The refractive indices of the haze particles are assumed to be those of tholins [6], similar to Titan's hazes, as they are both organic macromolecular products of photochemistry in a nitrogen-dominated and reducing atmosphere. We use a mean field approximation light scattering model [2,11] to compute the optical properties of the aggregates, and a Markov-chain Monte Carlo (MCMC) procedure [12] to search parameter space.

Preliminary results (Figure 1) show that, in the lower 50km of Pluto's atmosphere, haze particles have a fractal dimension ~2; monomer radius ~3nm; and aggregate radius ~1μm. Sedimenting from 50km to the temperature maximum near 25km above Pluto's surface, haze particles become fluffier (decreasing fractal dimension) and their monomers become larger, which may be related to temperature changes. Below 25km, haze particles enter a region with a steep, negative temperature gradient, which may break up monomers in the aggregate so that the monomer size decreases while monomer number in each aggregate increases. The possibly temperature-related processes that lead to the considerable particle morphology changes we have found should be further investigated.

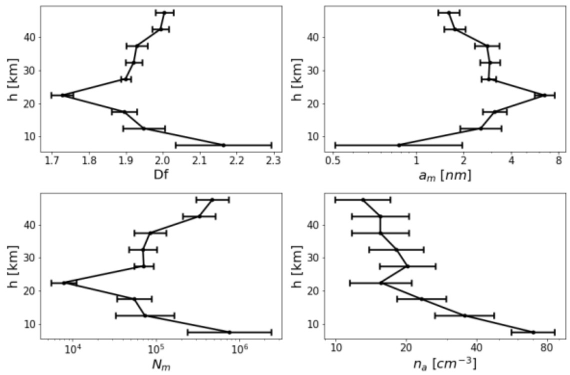

Figure 1. Preliminary retrieval results of vertical profiles of haze particle properties, assuming fractal aggregates.

3. Summary and Conclusions

We present a joint retrieval of Pluto’s haze using observations from multiple instruments onboard New Horizons. Preliminary analysis shows that haze particles are similar to fractal aggregates with monomer size ~3nm and aggregate size ~1μm in the lower 50km. Near the temperature maximum at 25 km above the surface, processes that were not previously considered may result in dramatic morphological changes to haze particles.

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