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Photochemical aerosols on Titan and the giant planets

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Abstract

Our ideas about the nature of photochemical aerosols on Titan and the giant planets is evolving thanks to new data coming in from the Cassini spacecraft, ground-based and space-based telescopes, and theory and modeling. Aerosol formation begins at altitudes around 1000 km on Titan and around 800 km above the 1-bar pressure level in the polar thermospheres of Jupiter and Saturn where auroral energy is available to form ions and radicals. We have evidence that hydrocarbon chemistry is important in aerosol formation for all of these bodies and we believe that hydrazine on Jupiter and phosphine on Saturn may lead to aerosol production. Aerosols have a fractal aggregate structure on Titan and in the polar regions of Jupiter and Saturn. Their vertical and horizontal distributions reflect a balance between local production and horizontal and vertical transport governed by eddies and jets. They are important for radiative energy balance in ways that have only recently come to light.

1. Introduction

Photochemical aerosols play an important role in the energy budgets of the stratospheres of Titan, Jupiter and Saturn. As data accumulate from ground-based and space-based telescopes and instruments we are learning about the optical, physical, and chemical properties of these particles and their spatial distributions. With these data and with recent developments from theory and modeling we are also learning about the processes responsible for their formation and life cycles. The following paragraphs briefly summarize the background and recent developments.

2. Jupiter and Saturn

Photochemical models of Jupiter's stratosphere [6], predict aerosol formation based on nitrogen and hydrocarbon chemistry initiated by photolysis of NH_3 and CH_4. For Saturn replace NH_3 with PH_3. Models specific to the auroral regions [3],[15] predict hydrocarbon chemistry leading to the formation of polycyclic aeromatic hydrocarbons (PAHs). There is some observational evidence for benzene [2]. So far there is no evidence for hydrazine or (for Saturn) diphosphene.

Two aerosol regimes are apparent from observations [1]. Jupiter appears to have polar caps in images in strong methane absorption bands. At near-UV wavelengths the polar regions are dark. Both of these can be explained by a polar stratospheric aerosol that is optically thick at the slant viewing angles observed from earth. The distribution of aerosols is asymmetric, with the north polar aerosol extending to lower latitudes (~45°) in the north versus -67° in the south. These differences most probably reflect the asymmetry in the auroral footprint, although confinement by zonal jets also plays a role. The boundaries of these regions for Jupiter are marked by Rossby waves [9].

Polar aerosols in Jupiter's and Saturn's stratospheres are both highly polarizing and forward scattering at visible and near-IR wavelengths. These combined properties can only be understood if the aerosols are composed of aggregates of small (~40 nm radius) monomers [12]. The altitude and latitude distributions of these aerosols and their optical properties play a pivotal role in the radiative energy balance of the stratosphere.

An unusual feature has been seen only twice and only in near-UV images of Jupiter. It was first seen as a dark oval with the same size and shape as Jupiter's Great Red Spot at high northern latitude in a images from the Hubble Space Telescope obtained in 1997 [13]. It was seen again in 2000 in near-UV images obtained by the Cassini Imaging Science Subsystem where it was observed to evolve over several weeks [7].

Saturn has a feature known as the polar hexagon near latitude 75° N., close to the latitude where auroral energy is deposited. Polarization images and UV images show that the hexagon is a boundary that dynamically confines the aurorally-generated fractal-aggregate haze, much as the terrestrial winter polar vortex confines ozone [10].

3. Titan

Photochemistry converts methane and nitrogen in Titan's atmosphere to photochemical products whose composition is some form of $H_xC_yN_z$. This still leaves considerable uncertainty in the proportionality of H, C, and N, and it is likely that their proportionality changes with altitude as the reaction rates and mixing ratios of the gaseous photochemical products depend on altitude.

Titan haze particles are composed of fractal aggregates [12]. The DISR experiment on the Huygens probe provided data inside the atmosphere to refine our understanding of these particles (average particles have ~4000 monomers with average radius 40 nm) [14]. At altitudes higher than where the DISR sampled the aerosol is thought to be in the form of small monomers. The Cassini INMS and CAPS instruments showed that aerosol formation begins at very high altitudes (~1000 km).

An unusual feature of the haze is a gap in the vertical profile that makes it appear as a 'detached' haze layer. This layer moved in altitude from 500 km when Cassini first arrived in 2004 to about 300 km in 2012, with most rapid change near equinox. Several ideas have been put forth to explain this [8], [5], [4]. See [11],[14] for more detail on these and other observational, theoretical/modeling and laboratory studies of the Titan haze.

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