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The Interaction of Titan's Aerosols with Hydrocarbons Seas

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Abstract

Titan, the enigmatic large moon of Saturn, is the unique satellite of the solar system surrounded by a dense atmosphere. Thick layers of photochemical organic aerosols shroud the surface, and sediment to the ground. In polar regions, large lakes and seas of liquid hydrocarbons have been discovered by *Cassini/Huygens* mission. Aerosols sedimenting above the lakes run into a liquid surface where new interactions take place. In this wrok, we address the question of the first contact between the aerosols and the lakes: will the aerosols particles float or rapidely sink into lakes? And, we investigate the possibility of the existence of a slick formed by this organic material.

1. Introduction

Titan, the main satellite of Saturn, is the only satellite of the solar system possessing a dense atmosphere, which ground pressure is comparable to that of the Earth. However, the most striking feature of Titan is perhaps the presence, in its atmosphere, of a thick layer of haze. The *Voyager* and *Cassini/Huygens* missions have inspired many works focused on aerosols distribution and properties, and now a vast literature is available on this topic (for a review, see for instance: West et al., 2014).

Beside this, the Cassini orbiter instruments have revealed a collection of dark features dotting the polar regions of Titan (Stofan et al., 2007; Turtle et al., 2009). These geomorphological characteristics are interpreted as lakes or seas (depending on their size) of liquid hydrocarbons. These structures were found at both poles and involve diameters up to more than thousand kilometers. Since organic material produced in the atmosphere should be the subject of sedimentation to surface, and could form large depositions (Lorenz et al., 2008), the question of the interactions between the haze particles, also called "aerosols" in this paper, and the liquid hydrocarbon surface, emerges naturally. To understand the fate of the aerosols at the surface of Titan's lakes, a first parameter to be investigated is their floatability.

2. Presence of Aerosols on Titan's Seas Surface

Observations show the presence of a more or less uniform layer of haze over the entire Titan's globe. This haze has its origin in the photochemistry initiated by solar radiations. The end-products of these processes are recognized to be aggregates of organic material (Lavvas et al., 2010). Each haze particles is built by aggregation of small entities called "monomers", which, if considered to be spherical, have a radius around 50 nm (Rannou et al., 2006; Tomasko et al., 2009). One aggregate, containing several thousand monomers, has a fractal structure (Lavvas et al., 2010). Due to their fluffy structure, haze particles are coupled with the atmospheric gas, but Global Circulation Models (GCM) predict the sedimentation of dry aerosols, corresponding of about 3.3×10^{-7} m per Titan year, uniformly distributed over Titan's surface. In the case of dry aerosols, the sedimentation rate changes with latitude, reaching maxima of $\sim 10^{-5}$ m within a few degrees from poles. In addition to these particles, formed at high altitude, other "exotic snows" may be produced in the troposphere. Indeed, many organic simple species are formed by stratosphere, for instance HCN, C_2H_2, C_4H_{10}, C_6H_6, ... (Krasnopolsky, 2014) and may form crystals that could aggregate in the form of "snow grains" when falling in the troposphere. Of course, the existence of this second class of aerosols is speculated and has never been observed.

All these arguments plead for the possible presence of an aerosols deposit, at least transient, at the surface of Titan's lakes/seas.

3. The Floatability of Titan's Aerosols

Two distinct effects may be invoked when the flotability of an object is questioned: (1) the Archimedes' buoyancy, (2) the effect of surface tension. The first mentioned effect requires estimations for both aerosol monomers and Titan's seas liquid densities. The second one demands some acknowledge about the monomers density and also data concerning the values of surface tension. For a long time, the monomers are recognized to be formed by molecules harboring a large number of carbon atoms (Nna-Mvondo et al., 2013). A few articles report density measurements on Titan's aerosols laboratory analogs, the tholins. produced during laboratory experiments The bulk mass density of these analogues is around $1.3 - 1.4$ g cm^{-3}, so more than thousand kg m^{-3} (Trainer et al., 2006; Imanaka et al., 2012; Hörst & Tolbert, 2013; Brouet et al., 2016). Whatever the scenario considered for Titan's lakes composition, the density of their liquid remains around $0.5 - 0.8$ g cm^{-3}, values that impede Archimedes' buoyancy.

It is well known that small bodies heavier than the supporting liquid, including small objects made of iron, can float under the influence of the so-called capillary force. Even some animals, bugs of the familly of the *Gerridae* (water striders) take advantage of this kind of force to survive at the surface of water (Gao & Jiang, 2004). We now discuss a possible Titan's aerosols flotability driven by cryogenic liquid surface tension. We were able to determine the maximum thickness e of the aerosols layers that can be hold by sea surface

$$e \sim \frac{3\,\gamma}{r\,g_{\rm Tit}\,\rho_{\rm mono}} \tag{1}$$

where γ is the surface tension of the liquid, r the radius of monomers, $g_{\rm Tit}$ the Titan's ground gravity and $\rho_{\rm mono}$ the density of monomers. Surprinsingly, this result does not depend on the "porosity" of the aerosols. A numerical estimate can be obtained for e, assuming typical values for involved physical quantities. Namely, we fixed the surface tension γ to 2×10^{-2} N m^{-1}, the real value depends on the precise chemical composition of the liquid, but should be around the nitrogen value. For the density of monomer material we choose 800 kg m^{-3}, value between the density of liquid methane and that of liquid water. The Titan's surface gravity is well known and equals 1.352 m s^{-2}. All this yields to $e \sim 10^3$ m, such an extremely large value, compared to the size of a monomer or even of an aerosol particle, means that the physical process, limiting the thickness of a possible aerosols slick, is not included in this crude estimation.

4. Summary

In this presentation, we will discuss the influence of factors that could limit the thickness of the organic slick, which could accumulate at the surface of Titan's sea. Perhaps more importantly, we will also investigate the physical consequences of the presence, of such a floating layer, on the properties of the sea surface.

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