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Velocity Distributions in Planetary Exospheres: Implications for Titan and Pluto

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Abstract

We apply a Monte Carlo code, designed to model planetary exospheres, to compute particle densities and velocities in Titan's and Pluto's exospheres. For Titan's exosphere, we investigate the thermalized hydrogen, nitrogen and methane population and compare our results to observation data from the Hydrogen Deuterium Absorption Cell (HDAC) instrument on board the Cassini spacecraft. For Pluto's exosphere, we model the thermalized nitrogen, methane and carbon monoxide.

1. Introduction

At and below the exobase, the particles' velocity and density distributions are well understood, since the physical processes determining these properties are well known and collisions are sufficient to thermalize energy input, e.g. from photon absorption. Above the exobase, where the particles move on ballistic and hyperbolic trajectories, gravitational filtering and photo-ionization influence the velocity and density distributions.

2. Model

For each exospheric particle component, our Monte Carlo model follows 100'000 particles on their ballistic trajectories. At each altitude step, we compute the component's density distribution and the particles' tangential & radial velocity distributions. Each particle is only considered as long as it is neither ionized nor dissociated and resides inside the considered altitude domain. If a particle is dissociated, then the newly generated fragments are considered further on.

3. Titan

Our Monte Carlo code computes that about 45% of the hydrogen atoms escape from the exosphere. Figures 1 and 2 depict the tangential and radial velocity profiles of the thermalized nitrogen and methane in Titan's exosphere. The plots show that almost all nitrogen molecules have vanished at an altitude of 300 km above the exobase and that almost all methane molecules have vanished at an altitude of 500 km above the exobase.

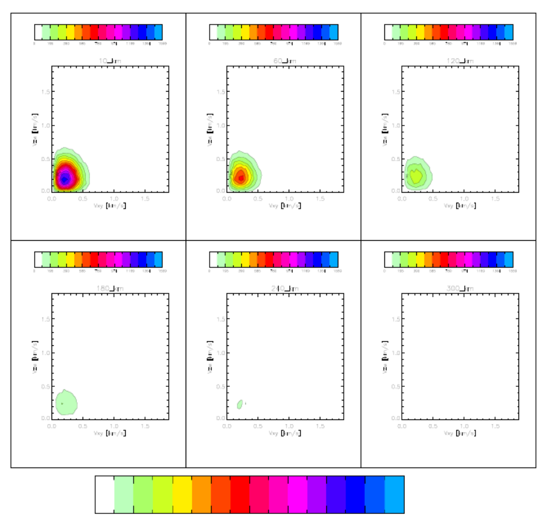

Figure 1: Titan's nitrogen velocity histograms.
(Vxy = tangential velocity, Vzw = radial velocity)

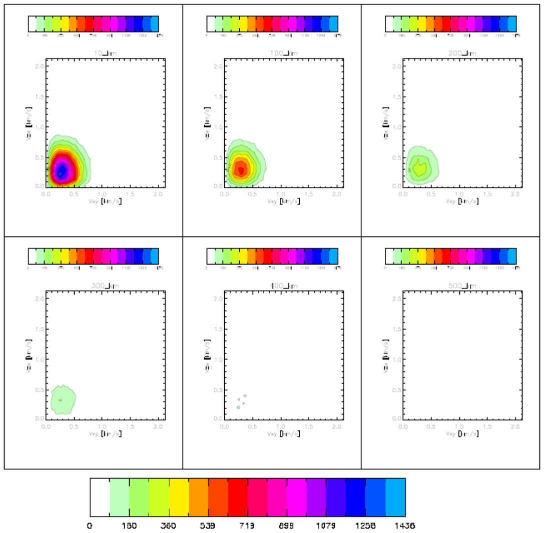

Figure 2: Titan's methane velocity histograms.
(Vxy = tangential velocity, Vzw = radial velocity)

The average radial velocity does not exceed ~ 260 m/s in the case of nitrogen, and ~ 345 m/s in the case of methane. These values are almost an order of magnitude lower than the escape velocity of ~ 2 km/s. None of the modeled nitrogen and methane particle is therefore fast enough to escape Titan's exosphere.

Figure 3 shows that above ~ 2000 km the collisions of nitrogen and methane with ambient atoms and molecules become negligible. Hydrodynamic outflow of these heavy constituents is therefore not possible when factoring in energy considerations.

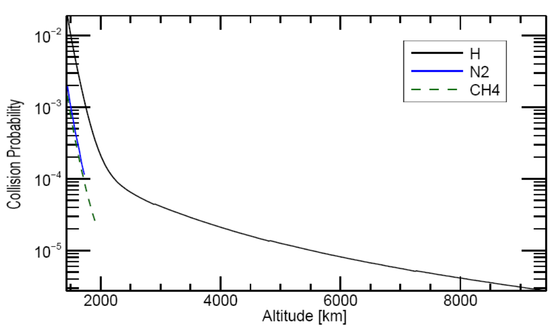

Figure 3: collision probabilities for hydrogen, nitrogen and methane in Titan's exosphere.

Hedelt et al. compare two different models for simulating the hydrogen component in Titan's exosphere and compare their results to the HDAC observational data. One model is the Chamberlain model and the other is our Monte Carlo model. Their results show that the classical Chamberlain model produces a too low exobase density whereas the Monte Carlo density profile is comparable to the density value presented by De La Haye et al. [2].

Our results are therefore in good agreement with the HDAC observational data but disagree with recent hydrodynamic outflow hypotheses.

4. Pluto

Because there are various past studies which suggested that Pluto's upper atmosphere experiences hydrodynamic outflow and even blow-off of its main atmospheric species [3-5] , we apply our code and investigate if hydrodynamic conditions are justified or not. We present velocity and density distributions for the nitrogen, methane and carbon monoxide components in Pluto's exosphere for different mixing ratios and different distances to the sun and compare our results to existing models. As for Titan, we will also be presenting for Pluto collision probabilities for the three main components with the ambient atoms and molecules.

References

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