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Transient exospheres and atmospheres in dwarf planets: SPH treatment with composite gas-dust plumes

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1. Introduction

The presence of a stable atmosphere is a characteristic in most of the planets of our Solar System. First, obviously, the four Giant Planets, including the Saturn main satellite Titan. But also the terrestrial planets, with the exception of Mercury, too close to the Sun, present an atmospheric envelope. At the same time, we have different classes of objects, Dwarf Planets, some of the largest asteroids, and the main satellites of the Giant Planets, that can produce thin transient atmospheres or exospheres [1], depending on the production rate of volatiles and on the ratio of the molecular mean free path to the dimension of the envelope. The process can be triggered by impacts with asteroids or large meteorites, or by tectonic activity [3], and also by solar wind events [4]. The lifetime of the envelope itself grows with the ratio of the escape velocity over the mean thermal velocity, and with the extension of the Hill Lobe, i.e. the region where the gravity of the body prevails on that of the Sun or that of the central planet. So, massive, outer and cold bodies are favoured. Another constraint is the stability of the volatiles, and this is verified if the saturation pressure is less then the vapor pressure. For this reason a privileged status is that of the Main Belt, where Ceres [5], Vesta and Pallas should permit the existence of water vapor with reasonable values of production rate. The same is for Pluto [6], where water can exist only as ice, but N_2 CH_4 and NH_3 can have phase transitions. Jupiter and Saturn satellites, on the contrary, and with the exception of Titan, Enceladus and perhaps Europa are penalized, being cold and close to their central planet, by their relatively small Hill radii and by the stability of icy water.

2. Numerical Model

Due to the large range of variation of the main physical parameters of a dusty plume, we have utilized the SPH approach [2] for the study of the hydrodynamical evolution of the plume, and have used some of the basic SPH paradygms in order to study the dynamics of the dusty particles. Vapor escape, when local thermodynamical equilibrium is not possible, due to low density values, has been studied by implementing a Montecarlo algorithm, that calculates the rate of escape of single molecules that experience a reasonable number of collisions ($<$50) before crossing the Hill limit. For the dust, a pseudo-smoothing scale length, similar to the analogous of the SPH model, was introduced in order to have values of the group velocity and viscous drag. The mutual viscous forces between gas and dust have been normalized, to satisfy global momentum conservation. Recondensation of water vapor and sublimation of ice have been also included. The thermal structure of the gas envelope was considered by adding to the transport equation of the thermal energy, an approximate treatment of the radiative diffusion equation. Besides, the balance between sublimation and recombination, and the deposition of dust and icy particles on cold regions of Ceres surface have been also taken into account. Last, the model evaluates the emission from the subsurface, possibly discovered and described in some detail by the Herschel mission in 2014 [5]. This process is simulated by injecting a time dependent flux of SPH pseudoparticles and dust particles [8, 7].

3. Conclusions

In the talk are examined the main parameters of these processes, as loss timescale of a plume, its dependence on the main physical constraint, and the structure of a nearly stationary plume generated by an hot spot on the surface of Ceres.

References

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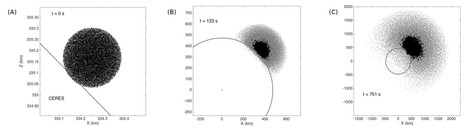

Figure 1: Initial time evolution of a plume generated near the Ceres surface. Here, grey dots represent H_2O vapor SPH pseudoparticles, while the black dots show the dust distribution. Panel (A) corresponds to the initial time, while panels (B) and (C) show different evolutive steps. In panel (C), the velocity of expansion is largely supersonic. The total mass of the plume is 10^{10} kg, the mass fraction of the dust is 10^{-1}. The ensemble is composed by 3×10^4 + 3×10^4 particles.

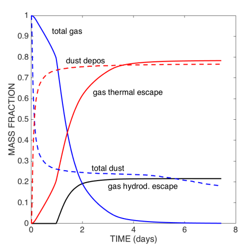

Figure 2: Time evolution of the total mass of the plume inside the Hill Lobe both for H_2O vapor and dust. In the Figure are also indicated the fractions of gas lost both as single non LTE molecules and as LTE gas crossing the Hill boundary. Besides, is also plotted the fraction of dust deposited on the surface of Ceres, at the first time due to the sudden expansion of the plume, and then by gravitational ballistic or orbital infall.

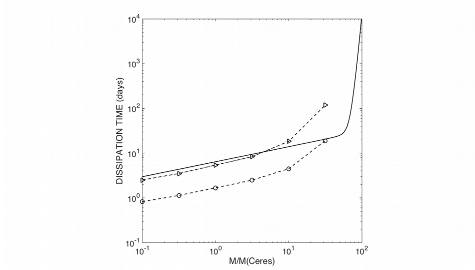

Figure 3: Dissipation timescales of a plume expanding on Ceres or pseudoCeres dwarf planets. These bodies are at the Ceres distance and temperature mean conditions, but with different masses, from 0.1 to 100 times its value. The solid line refers to a nearly-Jeans thermal escape timescale, $t_J = Me/4\pi R_H^2 \rho(R_H) c_s$, where M_e is the mass of the plume, $\rho(R_H)$ is the density at the Hill boundary with radius R_H, and c_s is the sound velocity ar $r = R_H$. The dashed curve with circles represents the effective depletion time up to a fraction 1/e of the initial value, and the upper curve with triangles refers to a depletion factor of 10^{-2}. The mass of the plume is 10^{10} kg.

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