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A Simulation of exosphere of Ceres

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Abstract

After Vesta, the NASA Dawn spacecraft will visit the largest asteroid Ceres, to carry out in-depth observations of its surface morphology and mineralogical composition. We examine different source mechanisms of a possible surface-bounded exosphere composed of water molecules and other species. Our preliminary assessment is that solar wind interaction and meteoroid impact are not adequate because of the large injection speed of the gas at production relative to the surface escape velocity of Ceres. One potential source is a low-level outgassing effect from its subsurface due to thermal sublimation. In this work, the scenario of building up a tenuous exosphere by ballistic transport and the eventual recycling of the water molecules to the polar cold trap is described. It turns out that a large fraction of the sublimated water might be transferred to the polar cap area as originally envisaged for the lunar polar ice storage.

Introduction

The recent impact experiment of the LCROSS mission at the Cabeus crater on the Lunar South pole showed the presence of water ice with a relative abundance of about 5.9% by mass (Colaprete et al., 2010). This important result validated the theoretical estimates by Watson et al. (1961) and Arnold (1979) that the polar craters in permanent shadow could serve as a cold trap of water ice and other volatiles. Later works by Hodges (1991) and Butler (1997) examined the process of global transport of water molecules to the storage zones. There are a number of potential sources according to these authors, namely, cometary impact, interplanetary dust bombardment, chemical sputtering of solar wind hydrogen, and outgassing.

Thermal Model Calculation

For the purpose of tracing the ballistic trajectories of water molecules on Ceres' surface, we have to produce a surface temperature map by omitting the topographic variations and the presence of impact craters. Our model solves the heat conduction equation by taking account of the energy balance condition at the surface boundary and the lower boundary condition (with dT/dz=0) into account. In between the heat diffusion equation is solved by using the Crank-Nicolson finite difference routine

$$
\begin{aligned}
&S_0(1-A)\hat{S}\cdot\hat{n} = \sigma T^4 + k\left.\frac{dT}{dz}\right|_{z=0} && \text{, upper boundary condition} \\
&k\frac{\partial^2 T}{\partial z^2} = \rho c_p \frac{\partial T}{\partial t} && \text{, heat diffusion equation} \\
&\left.\frac{\partial T}{\partial z}\right|_{z=-2} = 0 && \text{, lower boundary condition}
\end{aligned}
\qquad (1)
$$

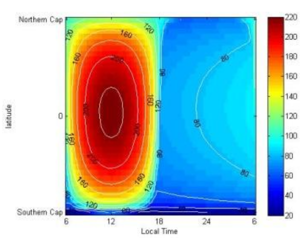

Figure 1 is an example of the temperature map during the summer solstice. Because of the 3 degrees-obliquity, the minimum temperature at the northern pole is T_{min}~ 60 K vs. T_{min}~ 20 K at the southern pole. It is because of this temperature difference, a certain kind of seasonal variation of the polar caps on Ceres might exist.

Monte Carlo Model of Ballistic Transport

As a first approximation, a sample (10,000 in total) of test particles are emitted randomly and isotropically at the surface of Ceres. In future we will improve the model calculation by considering the spatial distribution of the source regions. The returning water molecules will be partially thermalized at hitting the asteroidal surface. They will be re-emitted isotropically from the positions of surface collision. In our calculation, the thermalization process is approximated by using an accommodation coefficient α with the incoming speed given as V_{in}, the outgoing speed given as V_{out} and the surface temperature designated as $V_{surface}$.

$$v_{out} = \alpha \cdot v_{surface} + (1 - \alpha) v_{in} \qquad (2)$$

In mid-flight, the water molecules will be subject to a number of loss processes, predominantly by photodissociation (H_2O + hv → H + OH) with a destruction time scale of $\tau_D \sim 10^6$ sec (Huebner et al.,1979). To simulate such effect, we assign a weighting factor to each test particle at initial surface emission which is given as: $W = \exp(-t/\tau_D)$ where t is the running time of the test particle in sunlight. The trajectory computation is stopped when $W < 0.1$. Following the treatment of Arnold (1979) in which the crater floors in permanent shadow would be the cold traps of water ice, we assume that once reaching latitude of higher than 80° the water molecules would have a 5% chance of falling into the cold traps and be removed from the exosphere. On the other hand, it is also assumed that water molecules hitting places with surface temperature below 100K will be absorbed (say, on the nightside) and only be released again when the temperature rises above 100K because of the diurnal thermal cycle. If not, the molecules will be permanently deposited in this region.

Table 1 summarizes the relative fractions of the test particles being lost via photodissociation or condensation at the northern/southern poles. In the extreme situation, about 80% of the water molecules emitted via subsurface sublimation would be captured at one pole with about 20% escaped.

Final State	Percentage
Southern Trap	84.87%
Northern Trap	10.85%
photodissociate	4.29%

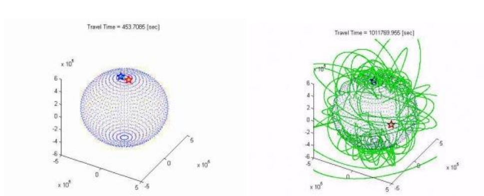

Figure 2 compares the trajectories of two test particles, one with very short lifetime (~453 sec) and the other with a long lifetime (~10^6 sec).

Summary and Conclusions

From our preliminary study, it is shown that water molecules produced by subsurface outgassing process could be efficiently transported to the cold traps on the polar cap of Ceres. The tilting of its rotation axis would open the possibility of formation of transient frost layers near the poles with seasonal variability. In future work, we will examine the contributions from other additional source regions which have been omitted in the present work. The existence of the exospheric gas such as CO_2, O_2, Ne and Ar will also be evaluated.

Acknowledgements

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