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DSMC Simulation of Europa's Gas Plume

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Abstract

The evidence of the water vapor plume at Europa has been found by [1]. We adopt a DSMC (Direct Simulation Monte Carlo) method with the gravitational effect to investigate the gas expansion form the collisional region close to the Europa's surface to the free flow region. It allows us to study the deposition of different size of icy dust grains on the surface. In addition, we also extend the model of gas ejection from Europa to the Jovian system. We will show the gas torus around the orbit of Europa.

1. Introduction

The one of the target of JUICE mission, the Jovian icy moon, Europa, with a radius of 1560 km and a bulk density of 3.03 g cm^{-3} covered by an icy crust has an albedo 0.64, one of the highest of Galilean moons. The vapor plume activity has been detected on Europa by the ultraviolet emissions of Hubble Space Telescope observations in November and December, 2012. It was suggested that two 200 km high plumes of water vapor with line-of-sight column densities of about 10^{20} m^{-2}. The two sources are located at the southern hemisphere. [2] and [3] presented a new transit observation of Europa that show a second event of plumes raising the possibility of a consistently active source of erupting material on Europa. [4] showed the evidence of plume on Europa by using the in-situ observations of the Plasma Wave Spectrometer on the Galileo spacecraft. The water vapor plume might be related to the existence of the subsurface ocean [5] which has the potential to harbor life. In this work, we will show the motion of dust grains in the gas plume and the gas transfer to the Jovian system.

2. Method

2.1 DSMC Method

The DSMC method is proposed by [6] for solving the Boltzmann equation using direct simulation of particle collision kinetics, which can capture the non-equilibrium phenomena automatically and without any convergence problem. This method can applied to all the rarefication regions of gas flow form the collisional region to the free flow region. The ideal of DSMC method is to decouple the movement and collision phase by assuming a time step which is smaller than the mean collision time. By simulating a large mount of particles and taking average of steady flow samples, the gas flow distribution can be calculated. A 3D DSMC code, called PDSC++ [7], has been developed by using unstructured grid, variable time step scheme, and being parallelized for the cluster computing [8] [9].

2.2 Motion of Dust Grains

The motion of dust grains in the gas flow is by the gravity force and the drag force which can be written as:

$$m\frac{d\boldsymbol{v}}{dt} = \frac{1}{2}C_d\sigma_d(\boldsymbol{v}_{gas} - \boldsymbol{v}_{dust})|\boldsymbol{v}_{gas} - \boldsymbol{v}_{dust}|\rho_{gas} + \frac{GMm}{r^2}\hat{r}$$

where m and M are the mass of dust grain and Europa, σ_d is the cross section of dust grains, C_d is the drag coefficient, v_{gas} is the velocity of the local gas flow, v_{dust} is the velocity of dust grains, and ρ_{gas} is the mass density of the local gas flow.

2.3 The Three-body Problem

To apply the DSMC method to the gravitational field of Europa and Jupiter system. The equations of motion on a rotating coordinate system can be written as:

$$\ddot{x} = 2y + x - \frac{(1-\mu)(x-x_1)}{r_1^3} - \frac{\mu}{r_2^3}(x-x_2)$$
$$\ddot{y} = -2\dot{x} + y - \frac{(1-\mu)y}{r_1^3} - \frac{\mu}{r_2^3}y$$
$$\ddot{z} = -\left(\frac{(1-\mu)}{r_1^3} + \frac{\mu}{r_2^3}\right)z$$

where

$$\mu = m_s/(m_s + m_p)$$
$$x_1 = \mu, x_2 = 1 - \mu$$
$$r_1 = [(x-x_1)^2 + y^2 + z^2]^{1/2}$$
$$r_2 = [(x-x_2)^2 + y^2 + z^2]^{1/2}$$

m_p and m_s are the mass of Jupiter and Europa. The unit of time is 2π/Ts and Ts is the orbit period of Europa (Ts = 85 hr). The unit of length is normalized to the distance between Jupiter and Europa.

3. Result

Figure 1 shows an example of DSMC result of gas plume form Europa. Due to the gravitational effect, the gas stream line shows most of gas can't escape from the gravity of Europa. We assume a gas production rate of 500 kg/s with an initial velocity of 1 km/s and a temperature of 150 K. For the next step, we will tracking the trajectories of dust grains in the gas flow. The deposition of dust also will be modeled. In addition, we will also investigate the gas transfer for Europa to its gas torus by extending the DSMC model.

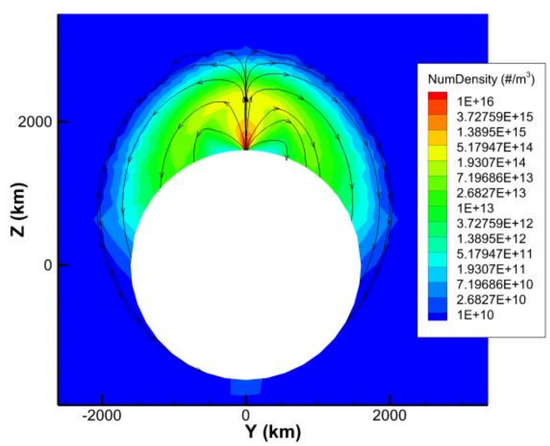

Figure 1 DSMC result of a gas plume on Europa.

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