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Cometary shape and spin-axis evolution due to long term solar driven outgassing

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Abstract

In this work we investigate the role of long term sublimation effects on reshaping the cometary nucleii using 3D shapes coupled with realistic spin-orbit evolution. We try to classify the typical morphological changes that can result from solar driven outgassing starting from various initial conditions. Our model includes different 3D shapes accounting for shadowing and self-heating, orbital elements, orientation parameters and CO sublimation driven cometary activity. These results will provide constraints on the limits pure sublimation activity can provide in terms of nucleus shape and large scale morphology changes during long term evolution of a small icy body in the Kuiper Belt. These simulations provide evidence that certain shape structures (such as observed on the 67P/CG) cannot be produced due to sublimation alone, indicating that other shape defining processes at work (e.g. Jutzi et al, 2017). Similarly, we investigate evolution of spin rates and axis orientations for different nuclei shapes.

1. Introduction & problem

One of the key findings of the Roseta's mission to the Jupiter family comet 67P/Churyumov-Gerasimenko was its peculiar bilobed shape along with the apparent north/south dichotomy in large scale morphology. This has re-ignited scientific discussion on topic of origin, evolution and age of the nucleus. In this work we setup a numerical investigation on the role of long-term solar driven activity on the overall shape, spin-axis, and orbit evolution for objects during their ``storage" phase in the Kuiper belt. We consider five classes of three-dimensional (3D) objects for various initial condition of spin-axis and orbital parameters, propagating them for $\sim 10^9$ years at heliocentric distances corresponding to the Kuiper belt. Analysing the results we hope to learn what are the typical patterns of shape change due to sublimation alone, a task which has not yet been adequately addressed.

2. Modeling

2.1 Shapes

In this work, the Delaunay triangulation method is applied to achieve surface triangulation of different 3D nuclei shapes. As shown in Fig.1, we will investigate the evolution of nuclei with five different shapes: 1) An spherical shape will demonstrate the anisotropic mass loss on a spherical surface and the consequent modification of this idealized shape; 2) An bi-lobed body rotating around its major momentum axis is regarded to be an empirical shape model for solar system small bodies; 3) An elongated shape might be evolved from 1) and 2) (Vovilov et al, 2018) and the precursor of the nucleus shape such as 103P/Hartley 2 and 19P/Borrelly; 4) A concave shape which might be formed by impact induced mass loss of a primordial body; 5) A bi-lobed shape shows the configuration of a contact binary such like Ultima Thule observed by the New Horizon mission. Shadowing and self-heating effects are taken into consideration in our simulations.

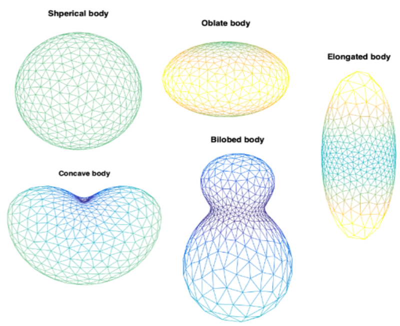

Figure 1: Five different shape models in our simulation, color indicates the surface height. Sphere at upper left has a radius of 10 km, axes length of oblate at upper middle are a=b=16 km, elongated shape on the right has a=16 km, b=c=10 km, the shape with a concave structure on its polar area at the lower left is of dimension about 10 km, and the bi-lobed shape at lower middle is composed by two parts with dimension about 4 km and 8 km, respectively.

2.2 Orbit

We follow the simulation and results demonstrated by Duncan et al (1995) and Levsion et al (1997) and use the N-body code, the Mercury package (Chambers, 1999), to make Monte-Carlo simulations of 10 000 massless test points in order to find how are the nucleus dynamically evolved during their pre JFC stage. Orbital parameters of those JFC presecurs in the distinct Kuiper belt is employed in our work to investigate how orbit affect the sublimation cometary activities and hence have a influence on modification of nucleus morphology.

2.3 Rotation

Sublimation induced orientation and rotation rate change could be evaluated for an irregularly shaped body (Sidorenko et al., 2008; Keller et al., 2015). Combined with the CO sublimation model, we calculate the net torque for each rotational/orbital states in order to investigate the spin state change due to long term cometary activities in distant regions.

2.4 Sublimation

In this work, the sublimation pressure of CO at a given temperature is obtained from Fray & Schmitt (2009) with a fit to the experimental data.

3. Results

Our simulation results show that 1) shape, orbital elements and orientation all have influence on surface mass loss distribution, among which the obliquity may lead to significant north-south dichotomy. 2) Mass loss distribution on tri-axial surface shows only latitudinal differential due to rotation, therefore, a 'neck' region cannot develop arbitrarily displaced from the rotational axis due to sublimation alone. 3) A bi-lobed shape, such as 67P/CG and 19P/Borrelly could not be created due to sublimation solely from a homogenous tri-axial body.

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