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Forming a Churyumov-Gerasimenko–like comet by sublimation

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Abstract

The Rosetta spacecraft, which was sent to the comet 67P/Churyumov-Gerasimenko, collected data of the nucleus revealing its peculiar bi-lobed shape. A discussion about whether the shape is primordial or a result of some processes occurred with the comet such as collisions and sublimation still goes on. One hypothesis suggests that two separately formed components of 67P were brought together at low speed making such a dumbbell-like nucleus [1]. Another idea based on the fact that collisions with other bodies change the comet shape and can lead to transforming it into a bi-lobed one [2]. However, over than a half of comets, which have been imaged with high resolution, have bi-lobed shapes [3] and the precise mechanism of making such objects is still unknown. Here we illustrate that sublimation of matter from the nucleus surface makes a comet more elongated and, in some cases, transforms an originally convex cometary nucleus into a bi-lobed one.

1. Introduction

Sublimation is a physical phenomenon that transits a solid matter directly to the gas phase without passing through the intermediate liquid phase. This process occurs on the surface of a cometary nucleus due to the Sun radiation and, hence, modifies the shape of the nucleus.

2. Differential equation

To investigate how the nucleus shape transforms with time by sublimation we considered the following model.

- The initial shape of a comet is axially symmetrical.
- The comet spins rapidly, so we can average the shape changes over one spin period.
- The spin axis of the comet is perpendicular to the orbital plane.

Since the spin rate is high and the spin axis perpendicular to the orbital plane, the comet shape remains axially symmetrical. That is why we consider a slice of the comet's nucleus in a plane, which contains the spin axis, as a function $y(x)$, where the y-axis counterdirected with the direction of sun rays and the x-axis coincides with the spin axis. $y(x)$ gives us the curve that determines the comet shape and the change of the curve determines the change of the comet shape.

The differential equation, which describes the shape transformations, is the following:

$$\frac{\partial y}{\partial t}(x,t) = -\frac{Z}{\cos\Theta}, \qquad (1)$$

where Z is the sublimation rate at point x and Θ is the angle between the normal to the curve and the direction of sun rays, measured from the normal counterclockwise. The function Z depends on the intensity of Sun rays, therefore it can be considered as a function of heliocentric distance, r, and $\cos\Theta$.

2.1. Sublimation function and initial structure

A sublimation rate from a unit area perpendicular to the sun rays over unit time is a sublimation function. In this work we considered two well-known sublimation functions.

1. r^{-2}
2. $g(r) = \alpha \left(\frac{2.808}{r}\right)^m \left(1 + \left[\frac{r}{2.808}\right]^n\right)^k$

The first function implies that sublimation rate is proportional to the sun radiation intensity. The second one is a standard sublimation function of ice derived by Marsden et al. [4], where $\alpha = 0.111262$, $m = 2.15$, $n = 5.093$, $k = -4.6142$.

Also in the work we considered two cases of initial nucleus structure.

1. Homogeneous spherical nucleus with a uniform density and composition

2. Inhomogeneous spherically symmetric nucleus, the gradient of sublimation rate of which is positive towards the center of the nucleus.

The positive gradient can be explained by the decrease of matter density towards the center as well as the increase of porosity and lighter elements (for example CO or CO_2). In the case of inhomogeneous nucleus we multiply the right hand part of equation (1) by some function $\Gamma(R)$, which is a function of the distance to the center of the comet.

3. Results

The differential equation for a homogeneous initial structure was solved analytically with **any** sublimation functions. For the second initial structure with sublimation function r^{-2} we also found the analytically solution, however, with the sublimation function $g(r)$ we found only a numerical solution.

A homogeneous nucleus remains being convex with both sublimation functions. In the inhomogeneous case after some time the comet shape can become bi-lobed. Here we present pictures of a nucleus after some time for the sublimation function $g(r)$ and as a function of $\Gamma(R)$ we considered e^{-R}. The orbit of the comet was a circle with the radius equals to 4 au.

4. Summary and Conclusions

To sum up we considered how a spherical comet shape changes by sublimation. We got able to solve this problem analytically for **any** sublimation function for a homogeneous nucleus as well as for inhomogeneous spherically symmetric nucleus for sublimation function r^{-2}. For inhomogeneous spherically symmetric nucleus with sublimation function $g(r)$ we found only a numerical solution. It was found that a homogeneous nucleus remains being convex, but an inhomogeneous nucleus could become bi-lobed.

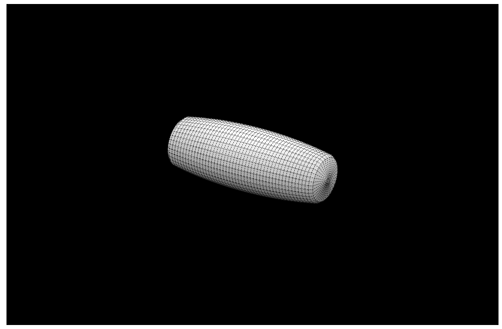

Figure 1: A homogeneous nucleus after some time for sublimation function $g(r)$.

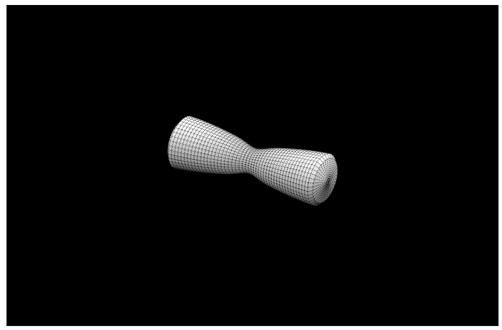

Figure 2: An inhomogeneous nucleus after some time for sublimation function $g(r)$.

Acknowledgements

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