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Comet 67P/Churyumov-Gerasimenko: Activity and Non-Gravitational Forces

H. U. Keller (1,2), S. Mottola (1), Y. Skorov (3), B. Davidsson (4), P. J. Gutiérrez (5), L. Jorda (6), L. Maquet (7), and the OSIRIS Team
(1) Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Planetenforschung, Asteroiden und Kometen, Rutherfordstraße 2, 12489 Berlin, Germany, (2) Institut für Geophysik und extraterrestrische Physik, TU Braunschweig, 38106, Braunschweig, Germany, (3) Max-Planck-Institut für Sonnensystemforschung, Justus-von-Liebig-Weg, 3, 37077, Göttingen, Germany, (4) Department of Physics and Astronomy, Uppsala University, 75120 Uppsala, Sweden, (5) Instituto de Astrofísica de Andalucía (CSIC), c/ Glorieta de la Astronomía s/n, 18008 Granada, Spain, (6) Aix Marseille Université, CNRS, LAM (Laboratoire d'Astrophysique de Marseille) UMR 7326, 13388, Marseille, France, (7) Scientific Support Office, European Space Astronomy Centre/ESA, P.O. Box 78, 28691 Villanueva de la Canada, Madrid, Spain

Abstract

The long term observations during the Rosetta rendezvous and a resulting detailed shape model enable us to calculate the reaction forces caused by sublimation in detail. We use a shape model with > 10^5 facets to simulate the distributed forces and calculate their exerted torques. These torques influence the angular momentum and hence the spin rate of the nucleus. The model can also be applied to calculate the non-gravitational forces influencing the orbital motion.

1. Introduction

Comet 67P/Churyumov-Gerasimenko has been investigated during the rendezvous with ESA's Rosetta spacecraft. Unprecedented, detailed, observations over many months revealed details of the nucleus and its activity starting at a heliocentric distance of 3.7 AU while the comet approached its perihelion in August 2015. Early observations revealed that the rotation period had changed from its last perihelion passage in 2009 [7]. Detailed shape models derived from observation by the OSIRIS cameras [3] along with thermal modeling make it possible to calculate the diurnal activity of the facets [4] while the comet flies along its orbit. [5] determined the torques on the nucleus, exerted by the facets depending of the geometric position, orientation and characteristics of their activity.

2. Model

In order to study the effect of sublimation-induced reaction on the comet's motion, we model the sublimation process as reported in [4]. Basically, 67P is described as a polyhedron with triangular facets, for which we adopted the SHAP4 shape model by Preusker et al (2015), down sampled to approximately 108,000 facets. We assume that sublimation is driven by solar energy input (direct, reflected and re-emitted), and that, due to the low thermal inertia of the cometary material [2], local thermal equilibrium is reached very rapidly with respect to the typical times of changes in illumination. Under those assumptions, the equilibrium temperature of the surface, or of a sublimating sub-surface layer, depends only on the instantaneous solar energy input, and not on the insolation history. For the purpose of this study we use a 2-layer thermal model [8], where a porous, refractory dust layer is superposed to a sublimating water ice/dust layer [4]. The properties of the body are assumed to be constant across the surface, and a net torque arises as a consequence of varying illumination over an irregular body. The net torque due to sublimation can be written as

$$\boldsymbol{T_i} = -\sum_i \frac{dm_i}{dt} \boldsymbol{r}_i \times \boldsymbol{v}_i$$

where v_i is a vector describing the gas ejection velocity, with orientation parallel to the facet's normal, r_i is the vector from the center of mass to the center of the facet and the index *i* runs over all facets. The term dm_i/dt is the mass sublimation rate, whereas $-v_i\, dm_i/dt$ is the reaction force for facet *i*.

2.1 Changes of the Angular Momentum

The net torque will cause a change in the angular momentum $\boldsymbol{L}$ according to

$$\boldsymbol{T} = \frac{d\boldsymbol{L}}{dt}$$

Often, the resulting motion will be an excited rotation with precession of the spin axis. The full rotation can be modelled by integrating the Euler equations of motion. As a first step [5] considered the rotation axis to be stable and adopted a simplified approach and considered only the z component of the torque, which mainly contributes to the change in the spin rate, according to

$$T_z = \frac{dL_z}{dt} = I\,\frac{d\omega}{dt}$$

with I being the largest moment of inertia and ω the spin rate. The inertia axes and moments, body volume and mass are computed by using the method by [1]. We will report about the recent evolution of the rotation period.

2.2 Changes of the Orbital Motion

Rather than considering the effects of the torques on the rotation we can calculate the forces acting on the motion of the nucleus. We will compare our results with the traditional approach to calculate the non-gravitational forces based on the well known empirical formula [6].

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