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Dynamics and Redistribution of Large Particles in the Coma of Active Comets

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Abstract

Ejection and redistribution of matter are important evolutionary processes on comets [1][2]. Large particles can be ejected from the surface of a comet, at which point they can impact the surface or escape from the system, after some time. This work presents the use of orbit-averaged equations of motion for particles in an asymmetric coma for predicting the impact location or escape of material. This will be done assuming the nucleus is spherical and that particles are ejected normal to the surface in a body-fixed frame.

1. Introduction

The lofting and redistribution of material from the surface of comets is a driver of the evolution of a comet and thus must be studied to place the comets of today in the context of the primordial Solar System. Current models for the redistribution of dust on cometary nuclei [3] are case dependent and, while well suited for specific cases, do not give general insights. This analysis will leverage orbit-averaged equations of motion for the Keplerian orbital elements to predict the trajectory of particles lofted at each location on the nucleus varying the initial velocity and area to mass ratio of the particles. This will result in distribution maps that predict particle escape, impact, or prolonged orbit. Predicted impact locations will also be tracked. This will provide insights into the redistribution of particles and the nature of objects that remain near the comet for long periods of time, which is interesting not only scientifically, but also for the operation of spacecraft at comets.

2. Models

The coma will be modeled using the skewed coma model [4] [5] which builds on a free-radial outflow model by accounting for more gas being produced in the sunward direction. First we define the comet frame, a comet-centered frame whose first axis points from the comet to the sun and whose third axis points along the comet's rotational pole, thus constraining the comet's obliquity to 0° or 180° for the rotational pole to be perpendicular to the comet-sun line over an orbit. The second axis completes the right-handed triad. The obliquity of a body is the angle between its orbital and rotational angular momentum vectors. For real comets this is not usually the case; however, for arbitrary obliquity the rotational pole can be constrained to the x-z plane by taking only the component of the rotational angular momentum vector perpendicular to the comet-sun line for a reasonable approximation. The azimuth angle, θ, is defined in the x-y plane relative to the comet-sun line in the right handed sense and is related to the local solar time. The elevation angle, δ, is defined to be positive in the $+z$ direction.The *skewed coma model* is defined as:

$$\rho(\vec{r}) = \frac{\rho_{0,sym} + \rho_{0,skew}\frac{1+\cos(\theta)}{2}\cos(\delta)}{r^2} \quad (1)$$

$$\vec{V}_{flow}(\vec{r}) = V_{flow}\hat{r} \quad (2)$$

where $\vec{r}$ is the vector from the comet center of mass to the spacecraft whose norm is r and whose direction is $\hat{r}$, $\rho_{0,sym}$ is the density of the symmetric component of the coma at unit distance, and $\rho_{0,skew}$ is the density of the skewed component at unit distance along the comet-sun line or, equivalently, above the sub-solar point.

The drag force acting on large particles is modeled using:

$$\vec{F}_{drag,sphere} = \frac{1}{2}\rho C_d s_{sphere} V_{rel}^2 \hat{V}_{rel} \quad (3)$$

$$\vec{V}_{rel} = \vec{V}_{flow} - \vec{V}_{sphere} \quad (4)$$

where C_d is the drag coefficient of the sphere, s_{sphere} is the cross-sectional area of the sphere and $\vec{V}_{sphere}$ is the velocity of the particle.

For simplicity, other perturbations are neglected and point-mass gravity is assumed. These assumptions will be relaxed in future work.

Numerically integrating the equations of motion for a large particle in orbit about an active comet to obtain the osculating orbital elements yields consistent results with the orbit-averaged differential equations equations for the orbital elements, as shown in Figure 1.

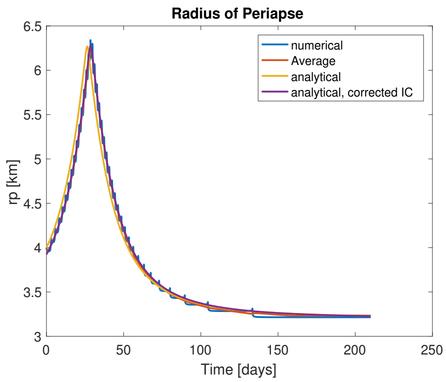

Figure 1: Time evolution of radius of periapse, numerical average of osculating orbital elements compared with integrating the orbit-averaged differential equations for the orbital elements.

This validation shows that integrating the orbit-averaged orbital elements directly provides a good representation of the true evolution of the orbital elements. The evolution of radius of periapse in Figure 1 shows that there are orbits for which the radius of periapse will increase and decrease. This result is important as it implies that there are initial conditions for which a particle lofted from the surface can raise its periapse and enter orbit. It also demonstrates that there are mechanisms for lowering the orbit of periapse, which could result in the particle returning to the surface. Under these dynamics, the growth or decay of the radius of periapse is entirely determined by the argument of periapse.

3. Expected Results

This research will provide a simple, general, model for the motion of dust and large particles in the coma of active comets. Information about which particles are most likely to escape, remain in orbit, or land will be gained. This will provide insights into the loss and redistribution of material on comets and give clues as to the size of material likely to remain around a comet, which is important for the safety of *in situ* spacecraft. Additionally, this analysis will also provide the time a particle remains in orbit. The longer a particle is in orbit the less likely it is to return volatiles to the surface, whereas a particle in orbit for a short time could retain its volatiles and redistribute them on the surface.

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References

[1] M. S. Kelley, D. J. Lindler, D. Bodewits, M. F. A'Hearn, C. M. Lisse, L. Kolokolova, J. Kissel, and B. Hermalyn, "A distribution of large particles in the coma of Comet 103P/Hartley 2," *Icarus*, Vol. 222, No. 2, 2013, pp. 634 – 652. Stardust/EPOXI, https://doi.org/10.1016/j.icarus.2012.09.037.

[2] J. Agarwal, M. F. A'Hearn, J.-B. Vincent, C. Güttler, S. Höfner, H. Sierks, *et al.*, "Acceleration of Individual, Decimetre-sized Aggregates in the Lower Coma of Comet 67P/Churyumov-Gerasimenko," *MNRAS*, 2016.

[3] I.-L. Lai, W.-H. Ip, C.-C. Su, J.-S. Wu, J.-C. Lee, Z.-Y. Lin, Y. Liao, N. Thomas, H. Sierks, C. Barbieri, P. Lamy, R. Rodrigo, D. Koschny, H. Rickman, H. U. Keller, J. Agarwal, M. F. A'Hearn, M. A. Barucci, J.-L. Bertaux, I. Bertini, S. Boudreault, G. Cremonese, V. Da Deppo, B. Davidsson, S. Debei, M. De Cecco, *et al.*, "Gas outflow and dust transport of comet 67P/Churyumov–Gerasimenko," *Monthly Notices of the Royal Astronomical Society*, Vol. 462, 02 2017, pp. S533–S546, 10.1093/mnras/stx332.

[4] M. Moretto and J. McMahon, "On the Evolution of Orbits About Active Comets," *AAS/AIAA Astrodynamics Specialist Conference, Snowbird, UT*, No. 18-389, 2018, pp. 1–20.

[5] M. Moretto and J. McMahon, "Attitude Dependent Evolution of Orbits About Active Comets," *29th AAS/AIAA Space Flight Mechanics Meeting, Ka'anapali, HI*, No. 19-375, 2019, pp. 1–18.