IMPLICATIONS OF OUTGASSING JETS FOR THE COMET DYNAMICAL ENVIRONMENT.

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Background: Due to the similarity in shape and size, the comet dynamical environment yields a set of dynamical problems common to that of asteroids, but it is their outgassing fields that make the dynamical environment of comets unique. This study considers the description of the outgassing jets and their dynamical implications. We define and explore a simple model for an outgassing jet from the surface of a comet while considering its implications, define a methodology for the in-situ estimation of jet structures, and investigate particle and rotational dynamics of comet 81/P Wild2 using the measured jet structure from the Stardust flyby [1].

There exist many theories about the structure of a comet's outgassing fields. These range from isolated jet structures to larger regions of continuous outgassing [1,2]. In this study we adopt the model developed in [1] for the comet 81P/Wild 2 based on images taken by the Stardust spacecraft. This model consists of 20 jets on the surface of comet 81P/Wild2 oriented in specific directions from the surface. Our general model has a full three dimensional geometry and will incorporate multiple jets of varying strengths.

Outgassing Jet Model: We assume that the comet is located significantly far from any other major celestial body so that a particle's motion about the comet follows the two-body orbital equations with the mass of the particle assumed to be significantly smaller than that of the comet.

Comet Assumptions. The comet body is assumed be an ellipsoid of uniform mass density with principle half lengths which represents the best fit to images taken in respect to size and shape. Scheeres [3] describes the gravitational field for an ellipsoid used for a spacecraft in orbit about the comet. This, however, is only an approximation to the true comet body and the model has the potential to use a more complicated shape for the body. The rotation state of the comet can be modeled as a uniform or complex rotation, and the obliquity of the rotational angular momentum vector can be specified.

Outgassing Jet. The simulated model includes multiple discrete jets of varying strength located at the surface of the comet body. Each jet is assumed to be fixed on the surface with it's active region assumed to have a circular cross section. The size and shape of the jet is defined by a constant half angle and surface radius. These two parameters along with the jet orientation define the location of the virtual center of the jet. It is assumed that the gas travels at a constant velocity, V_{og}, in the direction of the jet's orientation. We note that this assumption may not hold close to the comet surface where complex gas dynamics and interactions are occurring

Since a circular cross section is assumed, the outgassing jet is modeled as a solid cone where the outer surface is defined by the half angle from the centerline as well as the time since ejection in the comet body fixed frame. This outgassing will generate a pressure field which is a function of the mass ejection rate per unit area of the jet at the surface of the comet and the velocity of the material being ejected, V_{og} [4]. The strength of the jet is also dependent on the angle it makes with the Sun at the time of ejection such that a jet provides a stronger pressure when it is illuminated by the Sun and a weaker (possibly zero) pressure when it is not. The pressure magnitude felt by an orbiting spacecraft is assumed to be inversely proportional to the distance from the virtual center of the jet. Therefore, since each jet is oriented in an arbitrary direction relative to a comet body fixed frame, its strength is assumed to diminish as $1/r_{cj}^2$, where r_{cj} is the spacecraft's position vector relative to the virtual center of the jet (a position which may not actually reside within the comet body).

Wild 2 Model. The model as described is dependent on real values for the outgassing jet velocity and half angle as well as the size, shape, and mass of the comet for a simulation. Through analysis of images taken of comet 81/P Wild2, the locations and orientations of 20 jets have been made by Sekanina, et al [1]. The simulated model will use the principle half lengths defined by the PDS-SBN values of 2750 m, 2000 m, and 1650 m. Jet outgassing velocities have been estimated to range from 350 m/s at a few tens of meters above the surface and expand adiabatically to ~700 m/s by a few times the nucleus radius (Crifo et al. [2], Combi et al. [5]). In general, the jet half angle has received less attention but analysis of Hale-Bopp has indicated discrete jets with estimated half angles of up to 10 degrees [5] and spherical squares with side lengths up to 50 degrees have been used by Crifo, et al [2] to describe larger active regions. The rotation of the comet is assumed to be about the maximum moment of inertia in the comet body fixed frame which is inclined to the comet's orbital plane with a rotation period of 12 hours [1]. A simulation of this idealized Wild2 with the 20 active jets can be seen in the following figures.

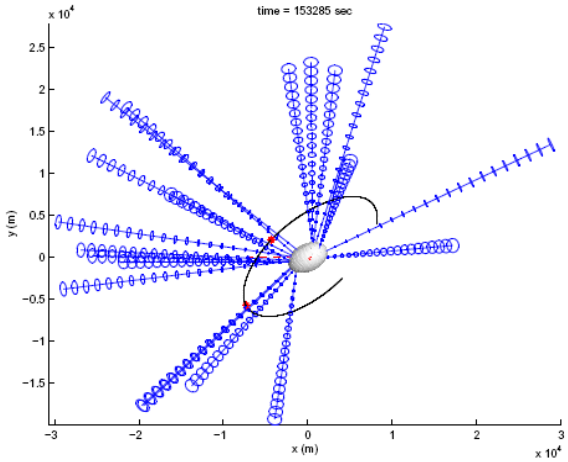

Figure 1: Spacecraft Trajectory in Inertial Frame Interaction with Outgassing Jets with a Half Angle of 1.5 degrees and V_{og} of 0.5 km/s on the Idealized 81P/Wild2.

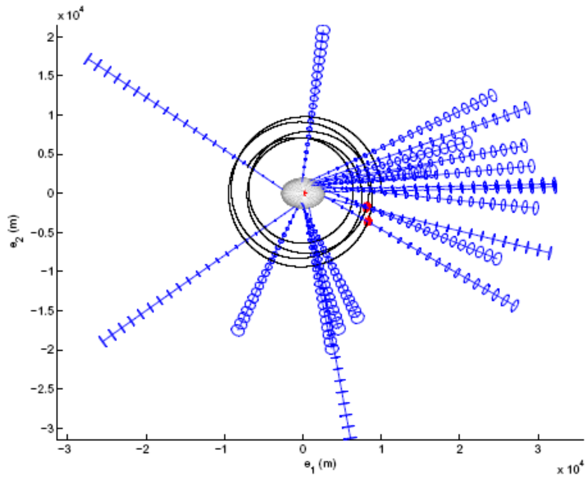

Figure 2: Spacecraft Trajectory in Comet Body Fixed Frame Interaction with Outgassing Jets with a Half Angle of 1.5 degrees and V_{og} of 0.5 km/s on the Idealized 81P/Wild2.

Model Applications: This dynamical simulation has several space mission and science applications. These are listed below and will be discussed in detail in the presentation.

Jet Estimation. The model can be used to estimate the location and strength of outgassing jets on the surface of the comet, given spacecraft tracking data or mass flux measurements. Current work is investigating this application by correlating spacecraft attitude events and dust particle hits detected by the Stardust spacecraft during its flyby of Wild2 to the jets described in Sekanina, et al. [1].

Spacecraft Navigation. Mission planning is a major application of this outgassing model, using it to predict what a spacecraft's trajectory as it flies through a jet's field. First, we note that for large distances from the comet, the radial component of the outgassing is dominant and therefore the outgassing due to a jet passage is considered to be a positive radial impulse. Through analysis of the Lagrange planetary equations, it can be shown that the semimajor axis and the eccentricity will increase while the spacecraft's radial velocity is positive as a result of the true anomaly term. Therefore if the spacecraft has a positive radial velocity component, such as when it is traveling from periapsis to apoapsis, the outgassing jet will tend to make the orbit more eccentric and increase the semimajor axis. Also, it can be shown that a decrease in radius of periapsis occurs when the spacecraft has a positive radial velocity component during a jet passage. This trajectory information can be used as a passive control scheme for the spacecraft's navigation allowing future missions to target jet fields for scientific information.

Rotational Dynamics. This outgassing model allows for the prediction of the rotational state dynamical evolution of the comet. As described above, the strength of the jet is a function of the angle it makes with the sun at time of ejection, the comet's heliocentric distance, as well as the size of the jet and its outgassing velocity. The pressure ejected from the jet produces a reaction moment on the comet body changing its rotational state. Coupled with efficient integration routines, the rotation state evolution of the comet can be modeled over long time spans.

Large Dust Grain Dynamics. The modeling of the outgassing jets can give insight into the dynamics of large dust grains which may have been ejected with the gas from a jet but are too massive to escape the gravitational field of the comet. This model can be used to simulate the trajectory of such types of dust grains and where they may settle back on the comet surface.

References: [1] Sekanina Z., Brownlee D. E., Economou T. E., Tuzzolina A. J., and Green S. F. (2004) *Science, 304,* 1769-1774. [2] Crifo J. F., Itkin A. L., and Rodionov A. V. (1995) *ICARUS, 116,* 77-112. [3] Scheeres D. J (1994) *ICARUS, 110,* 225-238. [4] Neishtadt A. I., Scheeres D. J., Sidorenko V. V., and Vasiliev A. A. (2002) *ICARUS, 157,* 205-218. [5] Combi M. R., Kabin K., DeZeeuw D. L., and Gombosi T. I. (1997) *Earth, Moon, and Planets, 79,* 275-306. [6] Marsden B. G., Sekanina Z., and Yeomans D. K, *Astronomical Journal, 78,* 173, 211-225. [7] Miller J. K., Weeks C. J., and Wood L. J. (1990) *JGCD, 13,* 775-784. [8] Scheeres D. J., Marzari F., Tomasella L., and Vanzani V. (1998) *Planet. Space Sci., 46,* 649-671.