HARTLEY 2: LANDING SITES OF PARTICLES EJECTED FROM THE NUCLEUS T. Hirabayashi[1], J. Steckloff[1], K. Graves[1], [1]Purdue University, West Lafayette, IN 47907-2051, USA. (thirabayashi@purdue.edu)

Abstract: This preliminary work presents particle dynamics around the Jupiter-family comet 103P/Hartley 2 to explore where particles land after ejected from the nucleus. Particles initially rest on the tip of the nucleus's small lobe and then are ejected with speed less than the escape velocity. Assuming the nucleus to be rotating with a spin period of 18 hours and its bulk density to be 500 kg/m^3, we obtain that the landing sites are not concentrated in the waist region, but widely distributed over the nucleus surface. The equipotential plot shows that landed particles may stay because low potential area also spread out on the large lobe. This result implies that while deposition of ejected particles would partially contribute to the formation of the smooth waist, another mechanism is necessary to complete it.

Introduction: On November 4, 2010, as a part of an extended mission called EPOXI (Extrasolar Planet Observation and Deep Impact Extended Investigation), the Deep Impact flyby spacecraft conducted the closest approach to 103P/Hartley 2 [1].

Unique features include the surface morphology, especially a smooth region at the waist of the nucleus. This smooth region is approximately equipotential (see Figure 1) and is considered to result from either flows or deposition [1]. It is distinguished from the knobby terrain on the small lobe [1]. Also, while no water ice is detected, water vapor is recognized above the smooth waist region and is possibly arising from there [1].

These facts lead to a hypothesis of the formation that the smooth waist region has been created due to deposition of mixed particles that consists of dirty grains, fluffy, icy aggregates that have not sublimated yet [1]. Here, we investigate this hypothesis.

Meshod: We use a shape model for the nucleus of 103P/Hartley 2 developed based on images taken by EPOXI [3]. This shape model consists of 1031 vertices and 2058 triangular facets. The shape of the nucleus is bilobate; the volume ratio between the small and large lobes is ~ 0.32. We fix the bulk density at 500 kg/m^3, an approximately mean value of the values estimated by EPOXI, ranging between 220 kg/m^3 and 880 kg/m^3 [1].

We conduct orbital simulations of particles with different locations and ejection velocities. Initially, a test particle rests on an arbitrary vertex of the tip of the small lobe, a primary source of ejected particles [7, 4], and is ejected with a low ejection velocity less than its escape velocity, which is 0.25 m/s. The simulation continues until the particle either hits the surface or is no longer bound by the gravity of the nucleus. This simulation process repeats until the simulation cases cover possible ranges of ejection velocity and locations.

We only take the effects of gravity and rotation into account. Solar radiation pressure may also be an important driver that could perturb the motion of particles because it is reported that the particle size is widely distributed, and the shape is heterogeneous [4]. However, since the orbital motion of particles is always near the surface and ends shortly in our simulations, we consider that such an effect is minor. We also ignore the effect of sublimation pressure on particle dynamics. To compute gravity forces, we use a technique by Werner and Scheeres [5]. We define the minimum, intermediate and maximum moment of inertia axes as the x, y and z axes, respectively.

To simplify the rotation state of the nucleus, we assume that the nucleus is uniformly rotating with a spin period of 18 hours along the maximum moment of inertia axis. We note that Belton et al. [6] reported that the instantaneous spin period at close encounter was 14.1 hours, and the roll around the minimum moment of inertia axis is 26.72 hours. The averaged spin period along the angular moment vector is 18.40 hours and is inclined to the minimum moment of inertia axis by 81.2°. However, since the 18-hour rotation period is slow enough to neglect the rotational effect, we consider that the precession and the roll along the minimum moment of inertia axis plays a minor role in our results.

Results: We first show the surface potential in the rotating frame in Figure 1. High potential regions appear around the tip of the small lobe. The surface of the waist and the larger lobe are almost equipotential, but low potential areas spread out over these regions.

The zero-velocity curve on the equatorial plane, i.e., the $x - y$ plane, determines allowable areas in which particles can enter (Figure 2). At a spin period of 18 hours, since the equilibrium points do not yet touch the nucleus surface, the allowable region still opens around the nucleus widely. Because of this orbital energy condition, particles ejected with low velocities less than the escape velocity can move over the surface.

Figures 3 to 5 show the cases for ejection velocities of 0.1 m/s, 0.15 m/s and 0.2 m/s, respectively. In each simulation, the ejection velocities are constant, while the ejection direction varies. The red dots show the ejection locations while the green dots describe the landing sites. As the ejection velocity increases, the landing sites are widely distributed. It is hardly seen that this distribution is consistent with the surface morphology of the smooth waist region. The surface potential (Figure 1) also suggests that particles landing on the large lobe rarely move to the waist as the potential there is as low as the waist surface. This result may imply difficulty in explaining the formation of the smooth area only by deposition of ejected particles. In the presentation, we will show the results for various cases. Further investigation is necessary to understand the role of ejected particles in the surface morphology of the nucleus.

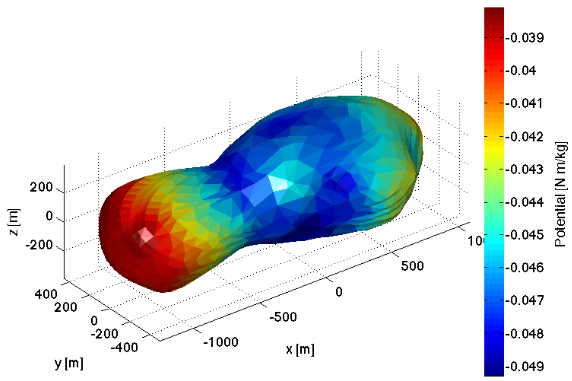

Figure 1: Surface potential map at a spin period of 18 hours. The potential is defined in the rotating frame.

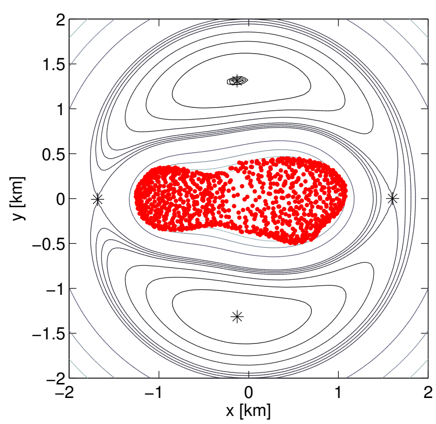

Figure 2: Zero velocity curve on the $x - y$ plane at a spin period of 18 hours. Each contour curve indicates a different energy level in the rotating frame. The stars are the equilibrium points. The red dots indicate a schematic plot of the shape. Larger envelopes are surrounding the body, which implies that if the initial energy level is less than one of the envelopes, a test particle stays moving inside it.

References: [1] M. F. A'Hearn, et al. (2011) *Science* 332(6036):1396. [2] P. Hartogh, et al. (2011) *Nature* 478(7368):218. [3] T. Farnham, et al. EPOXI derived shape model of 103p/hartley 2 `http://pdssbn.astro.umd.edu/holdings/dif-c-hriv_mri-5-hartley2-shape-v1.0/dataset.html`. [4] B. Hermalyn, et al. (2013) *Icarus* 222(2):625. [5] R. A. Werner, et al. (1996) *Celestial Mechanics and Dynamical Astronomy* 65(3):313. [6] M. J. Belton, et al. (2013) *Icarus* 222(2):595. [7] M. S. Kelley, et al. (2013) *Icarus* 222(2):634.

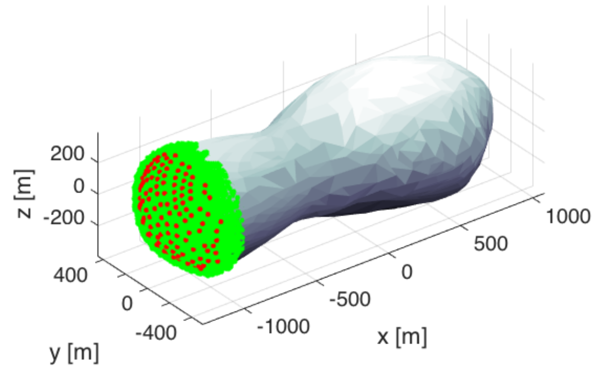

Figure 3: Landing sites of the particle ejected from the tips. The red dots show the ejection points while the green dots are the landing sides. The ejection velocity is 0.1 m/s.

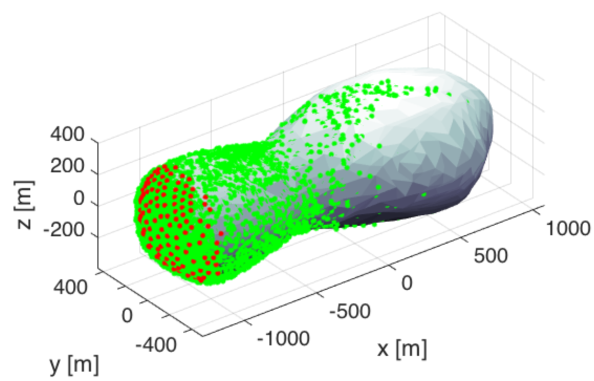

Figure 4: Landing sites of the particle ejected from the tips. The ejection velocity is 0.15 m/s.

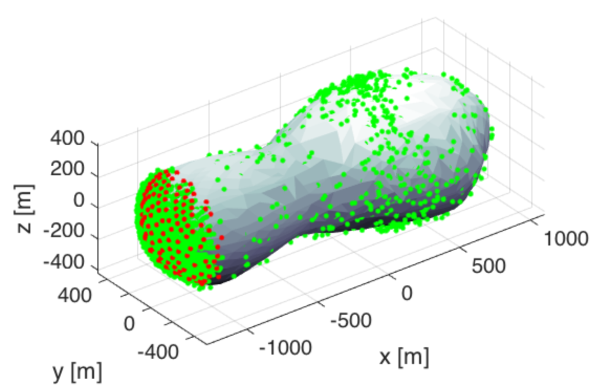

Figure 5: Landing sites of the particle ejected from the tips. The ejection velocity is 0.20 m/s.