COMPUTING THE DIURNAL YARKOVSKY DRIFT RATE FOR A SHAPE MODEL.

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Introduction: The diurnal Yarkovsky force on a body can be calculated analytically according to the following equation: $F = \sum_{i=1}^{n} \frac{2}{3} \frac{\varepsilon_i \sigma T_i^4}{c} \hat{n}_i A_i$, where ε, T, n, and A are the emissivity, temperature, normal direction, and area of each surface element. The Yarkovsky force on a 1 meter sphere can thus be calculated after several approximations are used to obtain the sphere's steady state temperature profile. Peterson 1976 and Spitale & Greenberg 2001 follow this approach to the Yarkovsky problem [1, 2]. While this approach may be useful for simple shapes such as a sphere, we believe the various approximations used lead to an unrealistic temperature distribution for the 1-m sphere presented in these two papers. Additionally, the formula above does not take into account the force of sunlight scattering or indirect infrared rays, which, in most analytical solutions are overlooked due to the complexity and assumed minuteness of their effect. Our generalized approach can be applied to any body to refine ephemerides and assess the effects of non-gravitational forces on the evolution of small solar system bodies.

Methods: We examine the effects of non-gravitational forces by tracking photon momentum through a three dimensional ray-tracing thermal model [3]. The ray-tracing model accounts for the momentum transfer associated with absorption, shadowing, rescattering and emission of solar and infrared photons. The thermal model keeps track of photon energy flux from direct sunlight as well as the indirect bounces off of the body's surface. The model is given a digital elevation model composed of many triangular facets and through an iterative process each facet collects incoming energy and updates its temperature. After several bounces for which rays reflected or emitted are sent to other triangles in its line of sight, a stable temperature profile is achieved. The ray tracing code keeps track of the momentum of each solar and infrared photon and separately tracks the net momentum vector for each triangle.

The momentum vectors on each triangle are converted into forces, which are tracked throughout one rotation period. We average each of the radiation force components over these 100 steps to get the net x and y forces in body centered coordinates. The Yarkovsky forces were converted into accelerations by dividing by the mass of the body. We then apply this Yarkovsky acceleration over a circular orbit to find da/dt, the semi-major axis drift. Orbital stability was achieved for our timestep dt of 0.1 seconds. The radial Yarkovsky force component did not influence the semi-major axis of our orbit, as expected. Only the along-track acceleration component changes the semi-major axis.

We reproduced the Yarkovsky drift figure for a 1 meter diameter sphere presented in the previous studies by mapping their temperature profile onto a level 6 sphere composed of 81,920 triangular facets. We then tested our ray-tracing methods on the same level 6 sphere and obtained a significantly lower drift rate.

To highlight the capabilities of our model, we also found the Yarkovsky effect for R. Gaskell's shape model of the asteroid Itokawa obtained from Hyabusa data. Itokawa's non-symmetric shape provided opportunities to analyze the effects of indirect photon momentum and shadowing. We scaled the Itokawa shape model down to the mass and surface area of the 1-m sphere and found the momentum vectors and forces on each of the 49,152 triangular facets.

Results: We were able to accurately reproduce figure 4 of Spitale and Greenberg within their reported error margin for the analytical case involving the temperature profile of a 1 meter sphere with parameters: albedo=0, emissivity=absorptivity=1, density=2500 kg/m^3, k=1.5 W m^{-1} K^{-1}, and cp=1000 J kg^{-1} K^{-1}. However, using our three dimensional ray-tracing thermal model we obtained a narrower range of surface temperatures for the same level 6 sphere leading to a Yarkovsky drift rate of less than one third of that of the analytical model. This is seen by comparing the orange and blue lines in Figure 1.

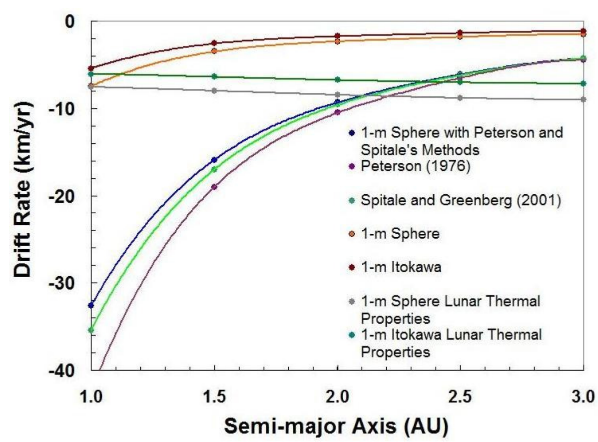

Fig 1. The decay rate of the semi-major axis is plotted for several starting locations of the test sphere and Itokawa shape model.

The force most responsible for the Yarkovsky drift is the thermal recoil force in the along-track direction. However, in the z direction, there is a non-zero indirect infrared force and blackbody force, which can definitely influence motion. This will be investigated further. As expected, when the thermal conductivity was lowered to that of lunar soil, the drift rate of Itokawa increased. However, the drift rate for the low conductivity case increases with distance from the sun, a unique result that will be investigated further. Additionally, we will both examine the effect of simplifying the shape model systematically and analyze the effect of adding sub-gridscale texture.

References: [1] Spitale J. and Greenberg R. (2001) *Icarus, 149,* 222–234. [2] Peterson C. (1976) *Icarus, 29,* 91-111. [3] Paige D. et al. (2010) *Science,* 330, 479-482.

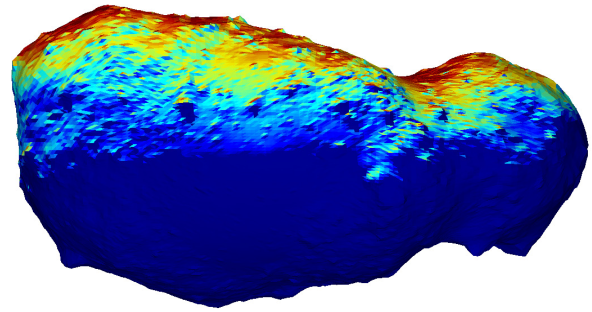

Fig 2. Snapshot of Itokawa model direct solar flux absorbed at step 80. Minimum (blue) 0.0 W/m^2 , Maximum (red) 1370.0 W/m^2.