THE FATE OF IMPACT EJECTA IN THE 1999 KW4 BINARY ASTEROID SYSTEM: A DETAILED MODELING INVESTIGATION. J. E. Richardson[1] and P. A. Taylor[1], [1]Arecibo Observatory, HC 3 Box 53995, Arecibo, PR 00612, richardson@naic.edu.

Introduction: 1999 KW4 is one of the best observed and characterized Near-Earth binary asteroid systems to date. Observations of this system conducted in 2001-2002 using the JPL Goldstone and Arecibo Observatory planetary radars resulted in detailed shape models for both primary (Alpha) and secondary (Beta), as well as their masses and mutual orbital parameters [1-3]. In this study, we utilize these data products to investigate the disposition of impact ejecta resulting from a small impact on either the Alpha or Beta member of this system; that is, we explore what mass fraction of the impact ejecta ends up either lost to space, landed on the opposite body, redeposited on the originating body, or temporarily placed into orbit within the system. This study uses a numerical computer model that generates an impact ejecta plume, represented by an organized swarm of tracer particles, and then integrates the trajectory of these tracers over time until all tracers have either been lost or redeposited upon one of the two bodies.

Impact Ejecta Plume Model: Our ejecta plume model was originally developed for the Deep Impact mission [4,5] and further improved in [6]. This model was designed specifically with impacts on small bodies in mind, wherein both small target strengths and gravities significantly affect the cratering outcome. We selected a 'standard' impact for this study, consisting of a 0.15 m diameter impactor striking the surface at a speed of 15 km/s, and producing a crater of ~22 m diameter with an excavated mass of ~$1x10^6$ kg. We chose an extremely weak target surface strength of 1 kPa, which results in an excavated mass retention (within the system) of ~60% when applied to a non-rotating Alpha, with enough low-speed ejecta to statistically explore the various disposition possibilities. Increasing the strength by a factor of ten (still quite weak) reduces the retained mass to < 20%. This excavated mass is discretized into 1800 individual tracer particles, each representing a unique combination of speed, mass, and ejected direction (Figs. 1 & 2). The effects of being ejected from a rotating, moving body within the system COM frame are also included.

Orbital Dynamics Model: The trajectory of each ejecta tracer particle is computed numerically using a Bulirsh-Stoer ODE integrator (Richardson extrapolation) taken from [7], while the rotation and orbital translation of both Alpha and Beta are computed analytically using the parameters listed in Tables 1 & 2 of [1] and a third-order expansion of Kepler's Equation [8].

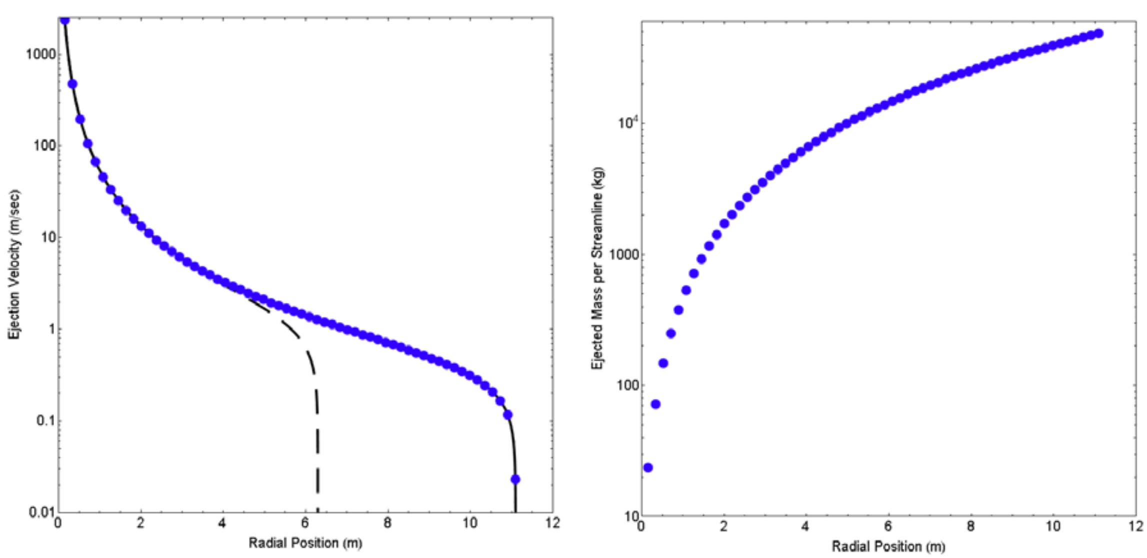

Figure 1: The velocity (*left*) and mass (*right*) distribution produced by a 0.15 m diameter impactor striking the surface of 1999 KW4 Alpha at 15 km/s, and producing a crater ~22 m in diameter. The excavation flow field is discretized into 60 radially spaced streamlines (blue dots),which are then divided into 30 individual tracer particles, each representing the mass ejected over 12^o of arc within its respective streamline, for a total of 1800 tracers. The solid curve on the left shows the velocity distribution resulting from a 1 kPa assumed target strength, while the dashed line shows the effect of increasing that strength to 10 kPa.

The gravitational force from Alpha and Beta on each tracer, at each major and minor time-step, is computed using the polygon surface integration technique of [9]. Major time-steps are variable, limiting the motion of fast tracers to < 100 m per step, permitting collision detection with either Alpha or Beta. Minor time-steps are automatically selected by the integrator to maintain motion accuracy. Integrations proceed until either all particles have either landed, exited the gravitational sphere of influence of the system, or 10,000 time-steps (~27 model-days) have elapsed.

Early Results: For impacts on the equator of Alpha without the presence of Beta, the quantity of ejecta placed into temporary orbit is ~2%, dropping to 0% as one moves toward the poles. Alpha's rapid rotation (2.76 hr period) also reduces the amount of retained ejecta to 45% for impacts near the equator, moving back to 60% for impacts near the poles. The addition of Beta to the system has two noticeable effects. First, the amount of excavated mass placed into temporary orbit (usually 1-16 days) about Alpha increases to 10% for impacts near the Alpha equator, again dropping to 0% as one approaches the poles. Secondly, the fraction of excavated mass expelled from the system increases significantly, with the retained mass from impacts at the Alpha equator reduced to 33%, again moving to 60% as one approaches the poles. The amount of excavated mass landing on Beta ranges from 2% for impacts near the Alpha equator to 0.1% for those near the poles, making it highly unlikely that Beta could have been formed via impact ejecta from Alpha, although some small transport does occur by this process.

Conversely, impacts on Beta usually result in only 23% excavated mass retention on Beta, 7% landed on Alpha, and 70% lost to space, again indicating a general erosion to space via impacts, and a small amount of transport to the other system body.

References: [1] Ostro, S.J., et al. (2006), *Science*, **314**. [2] Scheeres, D.J., et al. (2006), *Science*, **314**. [3] Fahnestock, E.J. and Scheeres, D.J. (2008), *Icarus*, **194**. [4] Richardson, J.E. et al. (2007), *Icarus*, **190**. [5] Richardson,.J.E. and Melosh, H.J. (2013), *Icarus*, **222**. [6] Richardson J.E. (2011), *JGR-Planets*, **116-E15**. [7] Press, W H. et al. (1993), *Numerical Recipes*, Cambridge Univ. Press. [8] Murison, M.A. (2006) *Practical Solution to Kepler's Eq.*, U.S. Naval Obs. [9] Werner, R.A. (1994), *Celest. Mech. Dynam. Astron.*, **59**.

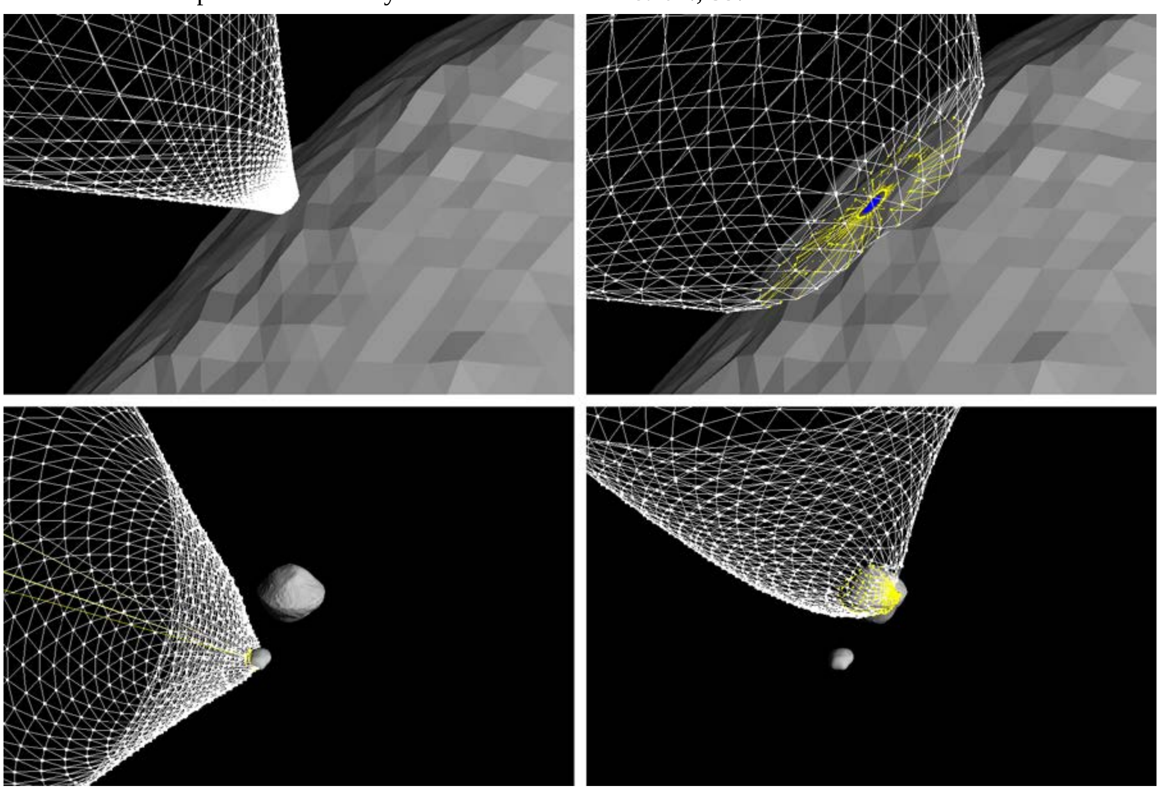

Figure 2: (*upper panels*) The discretized ejecta plume produced by a 0.15 m diameter impactor on the non-rotating surface of 1999 KW4 Alpha**,** shown after 30 sec (*left*) and 4 min (*right*), with tracer particles in flight shown in white, landed tracers shown in yellow, and the crater area marked in blue. (*lower panels*) The same impact on the trailing edge of 1999 KW4 Beta (*left*) and 20^{o} latitude on KW4 Alpha (*right*), each shown 1.5 hrs after the impact. These (*lower*) simulations include both body rotation and orbital motion about the system center-of-mass (COM).