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**LIKELIHOOD FOR RUBBLE-PILE NEAR-EARTH ASTEROIDS TO BE 1<sup>ST</sup> OR N<sup>TH</sup> GENERATION: FOCUS ON BENNU AND RYUGU.** K. J. Walsh<sup>1</sup>, R-L. Ballouz<sup>2</sup>, W. F. Bottke<sup>1</sup>, C. Avdellidou<sup>3</sup>, H. C. Connolly Jr.<sup>4,5,6</sup>, M. Delbo<sup>3</sup>, D. N. DellaGiustina<sup>5</sup>, E. R. Jawin<sup>6</sup>, T. McCoy<sup>7</sup>, P. Michel<sup>3</sup>, T. Morota<sup>8</sup>, M. C. Nolan<sup>5</sup>, S. R. Schwartz<sup>9</sup>, S. Sugita<sup>6</sup>, D. S. Lauretta<sup>5</sup>, <sup>1</sup>Southwest Research Institute, Boulder, CO (kwalsh@boulder.swri.edu), <sup>2</sup>Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, <sup>3</sup>Laboratoire Lagrange, Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Nice, France <sup>4</sup>Dept. of Geology, Rowan University, Glassboro, NJ, USA, <sup>5</sup>Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, <sup>6</sup>American Museum of Natural History, New York, NY, USA, <sup>7</sup>Smithsonian Institution National Air and Space Museum, Washington, DC, <sup>8</sup>Smithsonian Institution National Museum of Natural History, Washington, DC, USA, <sup>9</sup>University of Tokyo, Tokyo, Japan, <sup>10</sup>Planetary Science Institute, Tucson, AZ, USA

**Introduction:** Previous works have provided links between a few well-studied near-Earth asteroids (NEAs; specifically, Bennu and Ryugu), and potential source asteroid families in the inner Main Belt [1-3]. A challenging finding is that the surfaces of both NEAs have very young crater retention ages relative to the estimated ages of their source families [4,5,6]. Here we aim to determine the likelihood that they are direct products of a large asteroid family (1<sup>st</sup> generation), or are products from intermediate size remnants that have subsequently disrupted (2<sup>nd</sup> generation or, “N<sup>th</sup> generation”).

**Origins of near-Earth asteroids:** NEAs are dynamically transient bodies that mostly originate in the Main Asteroid Belt [7]. In the Main Belt km-sized objects aren't expected to survive for timescales as long as the age of the solar system, but a way to refresh this population is through catastrophic collisions [8]. Asteroid families formed by the disruption of a ~100-km body could produce thousands of small, sub-km-sized rubble-piles [9]. Such events also produce a smaller number of intermediate-sized 1<sup>st</sup> generation rubble piles, 5- 10 km in diameter, that themselves are also subject to the collisional environment of the Main Belt and can later be disrupted to produce more, smaller, N<sup>th</sup> generation rubble piles.

The probability of observing a 1<sup>st</sup> generation remnant from an asteroid family can be estimated by modeling an asteroid family created in a collision and following its members subsequent collisional evolution as its smallest members drift towards dynamical escape hatches by the size-dependent Yarkovsky effect. There is a competition between the very large number of first generation sub-km-sized members racing to reach an escape route before being destroyed in a collision and the 5- or 10-km rubble piles, moving more slowly, but more resistant to disruption and capable of producing a new generation of bodies if disrupted.

**Modeling family formation and evolution:** Here, we take advantage of some previously proposed linkages between known NEAs and their source asteroid families [1,2,3]. We built a Monte-Carlo-style model of the Eulalia and New Polana families, with generated starting population of members with a specific size

frequency distribution. These objects drift through the inner Main Belt with rates determined by their sizes and obliquity randomly assigned. If an object experiences a disruptive collision (tested probabilistically at each timestep) then a new family of smaller remnants is generated with its own size distribution. This new generation is also tracked and collisionally evolved.

Objects are removed when they cross the 3:1 resonance with Jupiter at 2.5 au, the  $v_6$  resonance at 2.15 au. Sub-km objects have a 1/3 chance of removal when they cross the overlapping Jupiter 7:2 and Mars 5:9 resonances (at 2.255 au) [3].

**Results:** We find that for scenarios in the inner Main Belt the total number of escaping bodies is dominated by 1<sup>st</sup> generation rubble piles for the first ~1-2 collisional lifetimes of the target body of interest. For older families, with ages 2-3 times the collisional lifetime, the rubble piles reaching escape routes can be equal contributions of 1<sup>st</sup> and N<sup>th</sup> generation objects, and beyond that they are dominated by N<sup>th</sup> generation remnants.

Two possible families for both Bennu and Ryugu, Eulalia and New Polana, are old enough (~800 and 1400 Myr, respectively [3]) that N<sup>th</sup> generation rubble piles are likely to be dominating the sub-km objects they are currently delivering to near-Earth orbits.

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