COMPARING THE PROPERTIES OF OBSERVED MAIN-BELT ASTEROID BINARIES AND MODELED ESCAPING EJECTA BINARIES (EEBs) FROM NUMERICAL SIMULATIONS. D. D. Durda[1], B. L. Enke[1], W. J. Merline[1], D. C. Richardson[2], E. Asphaug[3], and W. F. Bottke, Jr.[1]. [1]Southwest Research Institute, 1050 Walnut Street Suite 300 Boulder CO 80302 durda@boulder.swri.edu, [2]University of Maryland, College Park MD 20742, [3]University of California Santa Cruz, Santa Cruz CA 95064.

Introduction: The recent discovery of a new main-belt binary asteroid system [1] with widely separated and similar-size, low-mass components adds to the number of known systems that match the characteristics of the so-called Escaping Ejecta Binaries (EEBs) produced in numerical models of asteroid satellite formation [2]. The range of parameters of the modeled systems can be compared with observed asteroid pairs to provide clues to better understand the details of origin and evolution of these systems.

Numerical Simulations: Analytic and numerical studies [2-6] have confirmed that bound satellite systems can be formed in small body populations as a result of disruptive impact events. The more sophisticated numerical simulations [e.g., 2,6] explicitly calculate the impact phase of a disruption event via smoothed particle hydrodynamics (SPH) codes and then follow the gravitational reaccumulation and initial mutual orbital interaction of the fragments with the fast N-body code `pkdgrav`. Catastrophic and large-scale cratering collisions create numerous fragments whose trajectories can be changed by particle-particle interactions and by the reaccretion of material onto the remaining target body. Some impact debris can enter into orbit around the remaining target body, which is a gravitationally reaccreted rubble pile, to form a SMAshed Target Satellite (SMATS). Numerous smaller fragments escaping the largest remnant may have similar trajectories such that many become bound to one another, forming Escaping Ejecta Binaries (EEBs).

We have modeled hundreds of impacts to examine the dependence of the rate of satellite formation and the properties of the resulting satellite systems on the parameters of the impacts (e.g., impactor-to-target mass ratios, impact speeds, impact angles). From any single impact event as many as thousands of EEB systems can be formed. Here, as an example, we examine the range of EEB system properties resulting from one such collision simulation: the impact of a 34-km diameter impactor into a 100-km diameter target asteroid, at a speed of 5 km/s with an impact angle of 45°. The large impactor was chosen to produce a catastrophic impact resulting in a large number of SMATS fragments and EEB systems for statisitical analysis and the relative speed and impact angle match the statistically most likely impact parameters for collisions in the main belt [7,8].

This impact produced 62 SMATS and 1125 EEBs after four simulated days. Figure 1 shows the distribution of modeled EEB mutual orbital semimajor axis relative to the radius of the primary component. Figure 2 shows the distribution of secondary-to-primary mass ratio.

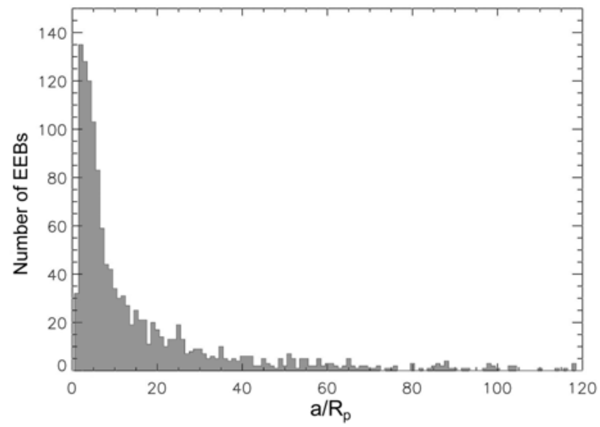

Figure 1. Distribution of mutual orbital semimajor axis (normalized by the radius of the primary component) for the EEBs formed in the case of a 34-km diameter impactor striking a 100-km diameter asteroid at 5 km/s at an impact angle of 45°.

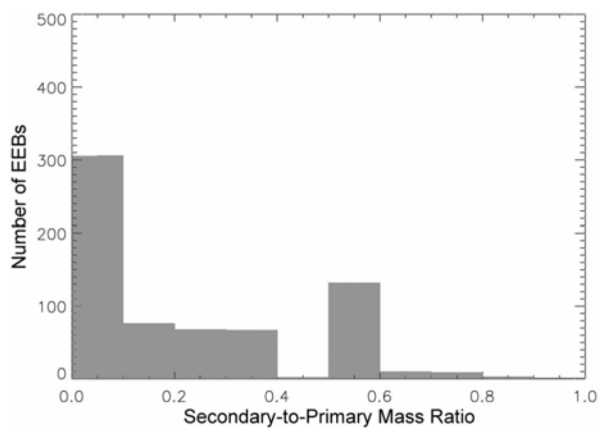

Figure 2. Distribution of secondary-to-primary mass ratio for the EEBs formed in the case of a 34-km diameter impactor striking a 100-km diameter asteroid at 5 km/s at an impact angle of 45°.

Not plotted in Fig. 2 are 700 EEBs with secondary-to-primary mass ratio equal to 1. The majority of those systems contain primary and secondary components composed of individual SPH/N-body particles orbiting other individual particles at the resolution limit of the simulation. However, 13 of those systems are composed of primaries and secondaries that are gravitational aggregates (9 with 2 particles per component, 3 with 4 particles per component, and 1 with 5 particles per component).

Observed Main Belt EEBs: Table 1 lists the mutual orbital and system component properties of the half dozen satellite systems in the main asteroid belt that are likely candidates for origin by the mutual gravitational binding of fragments resulting from the catastrophic disruption of a larger parent asteroid.

Object	D_p (km)	D_s (km)	D_p/D_s	a (km)	a/R_p
317	18.7	5.3	3.5	257	27
1509	12	4	3.0	140	23
3749	7	1.5	4.7	350	100
4674	8	3.5	2.3	250	63
17246	4.5	1	4.5	228	101
22899	4.5	1	4.5	182	81

Table 1. Properties of main-belt asteroid systems that are candidates for formation via the EEB mechanism. All of these systems were discovered by Merline et al. (see refs within [1]). These values come from further refinements to the orbits of these systems by that group.

Note that the components in these systems have separations a/R_p typically in the range 25-100 or more and primary-to-secondary diameter ratios less than about 5. Another group of main belt satellites shows larger primaries and much smaller a/R_p, as discussed below, suggesting formation via the SMATS process.

Comparison of Observed Main-Belt Systems with Modeled EEBs: In Fig. 3 we have plotted the primary-to-secondary diameter ratio versus relative component separation for the presently known main-belt binary asteroid systems for which at least reasonable estimates of mutual orbital and system component properties are available. The six binary systems listed in Table 1 are seen to cluster in a vertical strip along the y-axis. Another major cluster of systems is scattered along the x-axis with small relative separations and a range of primary-to-secondary diameter ratios, including systems composed of comparatively large primaries orbited by very small satellites.

On the same plot we have superimposed the 1125 EEB systems generated in the single numerical simulation described above. It is apparent that the six binary systems in Table 1 all have properties consistent with the EEB systems produced in the numerical simulation. These systems are formed from numerous smaller fragments ejected from the impactor and largest remnant on escape trajectories with similar initial velocities, such that many become mutually gravitationally bound to one another.

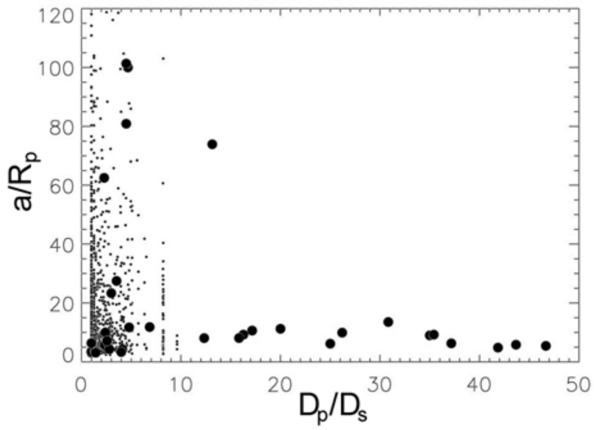

Figure 3. Primary-to-secondary diameter ratio versus relative component separation for the presently known main-belt binary asteroid systems (large dots) compared with modeled EEB systems (small dots) from a single numerical simulation of the catastrophic disruption of a large parent asteroid.

The modeled systems plotted in the bottom left-most corner of Fig. 3, representing EEBs with like-size components and compact orbits, overlap the low-a/Rp space occupied by the span of SMATS binaries (those along the x-axis). In this region, either SMATS or EEBs could be produced, but from these model/observational parameters alone, they cannot be distinguished. Indeed, there is likely to be an actual continuum between the EEB- and SMAT-formation processes here, where the distinction between the two processes is not so clear-cut. Similarly, our models also produce satellites around the other large remnants (second-largest, third-largest, etc.) that are themselves reaccumlated bodies, also leading us to conclude that the formation of SMATs and EEBs may be considered more continuous in this region. Further, in this corner lie other types of systems, such as the double asteroid Antiope and other close (lightcurve) binaries that may be produced in other ways (e.g., YORP).

References: [1] Merline W.J. et al. (2009) IAU Circular No. 9099. [2] Durda D. D. et al. (2004) *Icarus* 170, 243-257. [3] Hartmann W.K. (1979) in *Asteroids*, pp. 466-479. [4] Durda D.D. (1996) *Icarus* **120**, 212–219. [5] Dorissoundiram A. et al. (1997) *Planet. Space. Sci.* **45**, 757–770. [6] Michel P. et al. (2001) *Science* **294**, 1696–1700. [7] Bottke W. F. Jr. et al. (1994) *Icarus* **107**, 255–268. [8] Shoemaker E. M. (1962) In *Physics and Astronomy of the Moon* pp. 283-359.