Binary Asteroid Formation via Tidal Disruption

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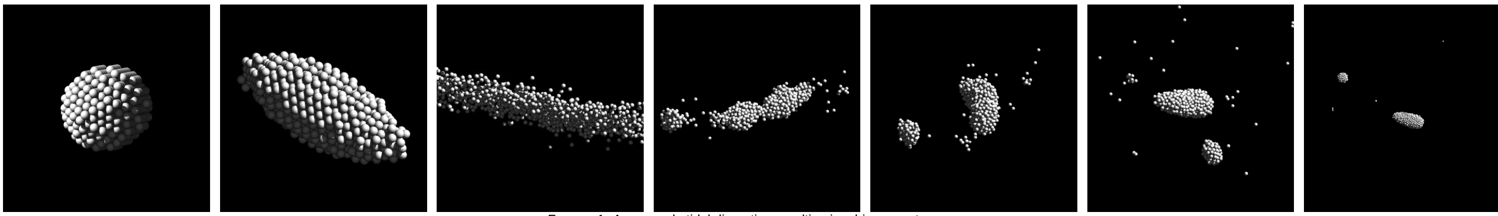

FIGURE 1: An example tidal disruption resulting in a binary system.

NEA binaries

- There are 25 suspected/confirmed NEA binaries detected via lightcurves and radar measurements.
- As many as $\sim$15% of all NEAs are binaries as determined by lightcurve, radar and numerical studies (Merline *et al.* 2002).
- Primary Properties:
  - Nearly all are fast-spinning, 2.2–3.6 hr period
  - Spheroidal, long/short axis ratio < 1.2
  - All primaries have a diameter < 5.0 km
- Secondary Properties:
  - Typically have size ratio between 0.2–0.6 R_{sec}/R_{pri}.
  - Separations are all below 10 R_{pri}
  - Eccentricities constrained below 0.1
  - Large range in spin rates.

Tidal disruption as a formation mechanism

- Tidal disruption is a candidate for forming many NEA binaries.
  1. Fast spinning primaries and small separations suggest similar formation mechanism for most NEA binaries.
  2. NEAs are expected to have multiple close encounters ($\sim$3.0 $R_\oplus$) during their $\sim$ 10 Myr lifetime.
  3. Past simulations suggest tidal disruption could account for $\sim$15% of NEAs being binaries (Richardson *et al.* 1998).

Planetesimal Model

- Asteroids modeled as "rubble piles", or gravitational aggregates.
  - Identical 150 m diameter particles
  - Simulations model gravity and collisions
  - Body bulk density of $\sim$ 2.2 g cm^{-3}
- Body parameters:
  - Elongation (long/short axis) = 2.0, 1.75, 1.5, 1.25 and 1.0
  - Spin period = 3, 4, 6 and 12 h
- Hyperbolic encounters:
  - Velocity at infinity (v_∞) = 8, 12, 16, 20 and 24 km s^{-1}
  - Close approach (q) = 1.2 – 4.5 $R_\oplus$
- For each set of parameters 100 different spin axis orientations were used.

Results – Orbital Properties

- High eccentricities, 90% $>$ 0.1 .
- Range of semi-major axis lengths, peaked around 3–10 R_{pri}.
- Inclination affected by both encounter orbit and progenitor spin.
- Binaries with retrograde motion created.

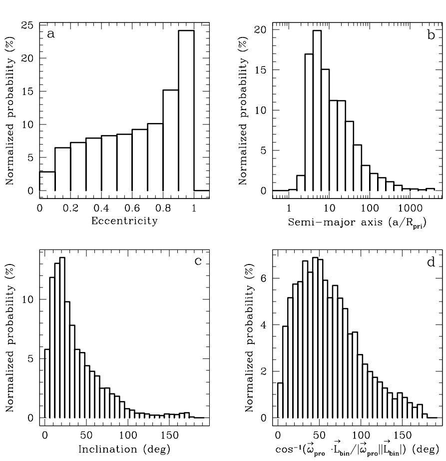

FIGURE 2: Normalized probability of binaries produced as a function of the orbital properties: (a) eccentricity (b) semi-major axis in units of R_{pri} (c) inclination of the binary's orbit relative to the encounter's orbit (d) inclination of the binary's orbit relative to the spin axis of the progenitor.

Results – Physical Properties

- Size ratio tightly peaked at 0.1–0.2.
- Primary spin bracketed between 3.5–6.0 hr period.
- Secondary spin rate smoothly distributed over much larger range, out past 20 hr period.
- Primary spin axis aligned closely with binary plane, 95 % within 20° of binaries orbit.
- Secondary spin axis has nearly random orientation.

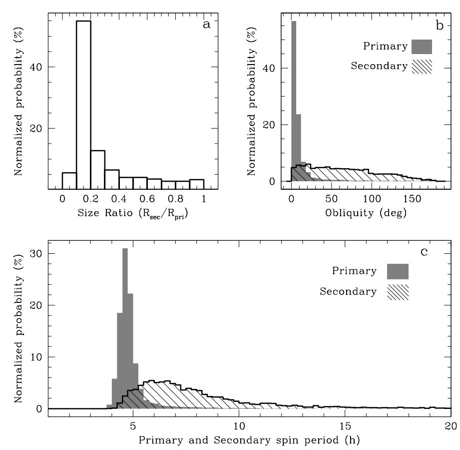

FIGURE 3: Normalized probability of binaries formed as a function of: (a) size ratio (R_{sec}/R_{pri}) (b) spin period (h) for primary (shaded) and secondary (cross hatch) (c) obliquity of spin axis relative to binary plane for primary (shaded) and secondary (cross hatch).

Results – Comparison with observations

- Basic stability limits eliminate binaries with 2.0 > a/R_{pri} > 130 (R_{Hill}).
- Lightcurve observations have a limiting size ratio, R_{sec}/R_{pri} > 0.18 (Pravec *et al.* 2005).
- Probability of mutual events needed for detection decrease with increasing orbital period (Pravec *et al.* 2005).

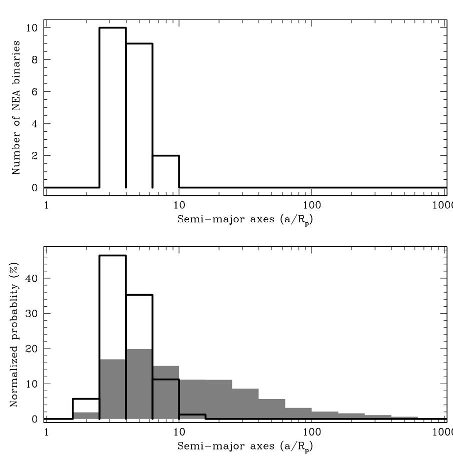

FIGURE 4: (Top) Observed NEA binaries as a function of the systems a/R_{pri}), (Bottom) The shaded histogram shows the raw distribution of semi-major axes for the simulations. The outline shows the distribution after adjusting it for lightcurve discovery capabilities and probabilities.

Results – Evolutionary effects

- Tidal effects will damp eccentricity in most cases, for close spearations very quickly, on order of 1 Myr.
- Encounters with a planet can drastically change or separate a binary.
- NEA population is constantly refreshed from the MBA, and could inherit a significant binary population.
- Thermal effects, such as YORP, may evolve binaries much faster than simple tidal forces.

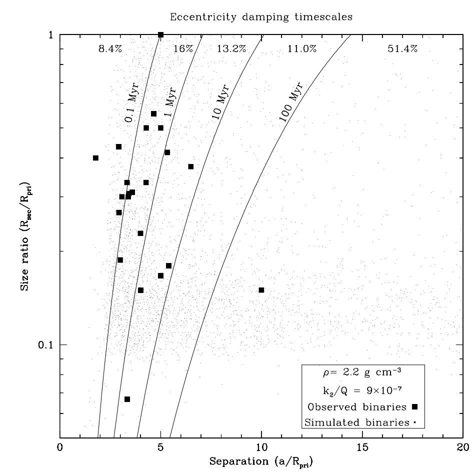

FIGURE 5: Observed binaries and simulated binaries are plotted for size ratio (R_{sec}/R_{pri}) as a function of separation a/R_{pri}, with estimated tidal eccentricity damping times overlaid.

Conclusions

- Tidal disruption of rubble piles produces binaries with qualitative similarities to observed NEA binaries:
  - Consistently fast-spinning primaries
  - Small size ratios
  - Small separations
  - Large range of secondary spin rate
- When weighted by likelihood of discovery via lightcurve observations, simulated separation matches observations very well.
- Most observed binaries have eccentricity damping timescales below 1 Myr, suggesting the simulation results could evolve in time to match observations.

Future Work

- Long-term stability of created asteroids and binary evolution via tidal and thermal effects to estimate steady-state population.
- Better shape and spin statistics of NEA source bodies, i.e., small MBAs, will improve the steady-state model.
- Experimentation with complex tidal disruption schemes including
  - Size distribution of particles
  - Density distribution of particles
  - Complex particle shape
  - Simulation with varying resolution

References

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Acknowledgments

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