FISSION AND STABILITY OF ELLIPSOIDAL CONTACT BINARY ASTEROIDS. D.J. Scheeres, *U. Colorado, Boulder (scheeres@colorado.edu)*, S.A. Jacobson, *U. Colorado, Boulder*.

We find that when a contact binary asteroid composed of two non-spherical components is spun to fission, its initial relative equilibrium state is always unstable. This implies that all fissioned binary asteroid systems should have an initial period of strongly unstable orbital and rotational evolution. The implication is that application of classical tidal evolution results may not be correct during the initial evolutionary phase of a binary asteroid system.

Introduction The YORP effect is a leading candidate for formation mechanisms for binary asteroids. It works by increasing the spin rate of an asteroid till it reaches a "fission limit" and splits into a binary asteroid. How this fission process operates on realistic asteroid models is a fundamental question we are researching and is a direct function of how the asteroid is modeled. If an asteroid is modeled as a collection of gravitationally bound gravel, its fission process would resemble that of a fluidic body, albeit with friction (Holsapple *Icarus* 187: 500-509). However, high resolution imagery of asteroids has shown that their constituents have significant distributions of size scales ranging from sub-centimeter gravels through boulders with sizes ranging up to tens of meters and larger. The asteroid Itokawa is a case in point, and appears to be two rubble piles resting on each other, suggesting a model where collections of boulders are resting on collections of boulders (Fujiwara et al. *Science* 312: 1344-1347). This motivates our use of an ellipsoid-ellipsoid contact binary model.

There are three phases of evolution for such a collection as its spin rate increases: transitions that occur for a rubble pile as different energy thresholds are passed, when the asteroid approaches and passes the fission spin rate, and once the body has fissioned into two or more pieces orbiting each other. The important questions and responses of this system are strikingly different for each of these phases, and involve different issues of mechanics and dynamics at each stage. Basic results for how such systems respond to this environment using simple models of asteroid shapes has been investigated in the past (Scheeres, *Icarus* 189: 370-385, 2007, *Planetary & Space Science*, in press). This abstract reports refined calculations for such systems when both bodies are non-spherical, or when they are spherical but may be distorted slightly by tides.

Minimum energy resting configurations As a contact binary asteroid's rotation rate increases (or decreases) its stable configuration is defined by its minimum energy static configuration at a fixed angular momentum. If we model the system as a collection of rigid bodies resting on each other we can express the total energy and angular momentum of the system as the sum of the rotational kinetic energy of each object, relative to the system center of mass, and the sum of the potential energies between every body. As the angular momentum of the body changes the minimum energy configuration of the collection can change, placing the system into an unstable configuration.

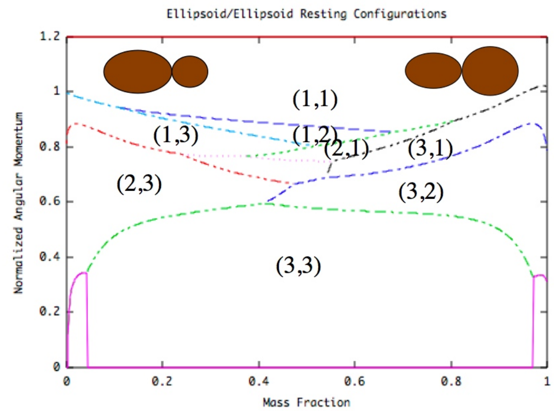

Figure 1: Minimum energy configurations of an contact binary system as a function of mass fraction and total angular momentum. The shape ratios are chosen according to the asteroid Itokawa (which has a mass fraction of ~ 0.25). The numbers indicate the semi-axes of the ellipsoids that rest on each other, the system rotates about its maximum moment of inertia for all combinations.

Once such a transition occurs, the system is "perched" and is susceptible to undergoing a landslide given a small disturbance. The aftermath of such an asteroid landslide may be minimal, some gravel rolling downhill, or may be major and involve large numbers of boulders rolling across each other.

The computation of these stability transitions for ellipsoidal bodies resting on each other has been carried out. In Fig. 1 the stability transition phase diagram for an ellipsoid-ellipsoid system with the same shape parameters as Itokawa's head and body are shown (Demura et al. *Science* 312: 1347-1349). The mass fraction between the components is allowed to vary between 0 (body dominates) to 1 (head dominates). Fission occurs for the (1,1) configuration when the normalized angular momentum equals 1. We note that this configuration is usually the minimum energy configuration at fission.

Fission Conditions As the body spin rate continues to increase two portions of the body will eventually achieve orbital rates relative to each other. When dealing with collections of rigid bodies, these orbital rotation rates occur much earlier than the usual "surface disruption rate". A specific example is the fission rate of two spheres of equal density resting on each other. If one of the spheres is small relative to the other, the system will fission at the surface disruption rate. If, instead, the two spheres have an equal radius fission will occur at half that spin rate. For collections of rigid bodies resting on each other a similar decrease in fission rate occurs, the minimum fission rate of the system being dictated by the two collections whose centers of mass are most distant from each other. For Itokawa, the separation between the "head" and "body" of that asteroid controls this minimum fission rate, and occurs for rotation periods on the order of 6 hours (Scheeres et al., *Icarus* 188: 425-429, 2007).

Stability of proto-binary asteroids Once fission of the system occurs the evolution and ultimate fate of this "proto-binary" depends on the mass distributions of each component. Our calculations show that a fissioned ellipsoid-ellipsoid system will initially always lie in an unstable relative equilibrium state. For a binary asteroid system there is only one stable relative equilibrium for a given system angular momentum, which exists at a lower energy than the fission energy and with the bodies further separated from each other.

There are three different dynamical outcomes that can occur if we assume that the shape, energy and angular momentum are constant. First, it is always possible for the two bodies to re-impact each other, although without loss of angular momentum the system must undergo fission again. Second, if the free energy of the system, defined as the total energy of the system minus the self-potential energy of each component, is positive then the system can escape and would appear as two separate asteroids in very similar heliocentric orbits, such as have been recently discovered (Vokrouhlický and Nesvorný *AJ* 136: 280-290). Third, if the free energy is negative, then the system can evolve ad-infinitum – unable to settle into a stable state unless energy dissipation is allowed.

For these proto-binary systems, there is strong coupling between the rotational and translational motion, meaning that the relative spin rates and orientations of the bodies will vary as they separate. The timescales for these motions are very fast, with the bodies generally entering into a chaotic dynamical evolution. Once such a period of chaotic evolution starts, energy dissipation should occur, and potentially angular momentum loss may occur through the ejection of smaller particles. Energy dissipation will occur due to tidal stresses and occurs within the bodies themselves, leading to loss of energy through reshaping the system into a lower self-potential energy or in the dissipation of excess rotational kinetic energy through creation and radiation of heat. In the presence of such dissipation we expect the system to be preferentially trapped either in an exterior orbit, with the system starting a migration towards the stable relative equilibrium that exists for a given value of angular momentum, or in an internal resting configuration. For a resting configuration we find a dichotomy, however, as the angular momentum of the system has been increased to the point where, in its minimum energy resting configuration, the system had too much angular momentum to remain in contact. Thus either the system must shed angular momentum or change its mass distribution appropriately to remain in that configuration. The detailed modeling and analysis of this pathway has yet to be performed. For a system that becomes trapped into an orbital configuration, the possible evolution of that system is more definite. First, if the free energy of the system remains positive, it may still mutually disrupt, as discussed above. If it does not undergo a disruption, the system will be able to dissipate energy until it reaches the final, stable relative equilibrium state for its level of angular momentum.

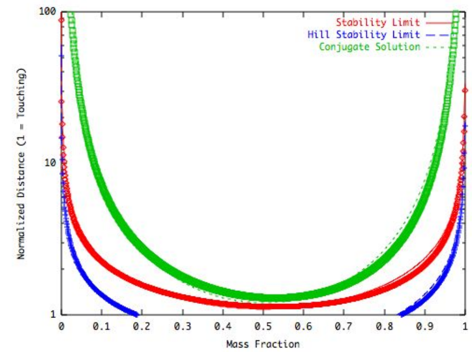

Figure 2: Stability plot for relative equilibrium of an ellipsoid-ellipsoid system. Every point on this diagram can be a relative equilibrium. For every mass fraction between the two bodies the unity distance is the distance at which the bodies rest on each other. The stability limit denotes the minimum separation at which the relative equilibrium becomes stable. The Hill stability limit denotes the minimum separation at which the free energy becomes negative. The conjugate stability limit denotes the relative equilibrium separation for an angular momentum equal to the fission angular momentum (at unity distance). This plot overlays the Itokawa ellipsoid-ellipsoid model with an ideal sphere-sphere model. The qualitative similarity between these curves for such different systems are noted.

This is not necessarily the state the system will evolve to, however, as exogenous forces and alternate evolutionary pathways may lead it into a different configuration. The possible pathways that such a system can evolve into is a topic which we are currently studying. Possible final states must include the system entering a configuration where the primary continues to spin at a rapid rate but the secondary is trapped into a 1:1 spin-orbit resonance. Whether such an outcome is possible under energy dissipation alone or if it requires exogenous forces and torques is a question of interest.

Stability of a sphere-sphere system If we assume that coupling between the bodies occurs through small tidal deformations, we can use the results from our ellipsoid-ellipsoid analysis to identify minimum energy configurations and stability for a sphere-sphere system. This leads to the interesting conclusion that, for a given angular momentum, a Keplerian circular orbit between two bodies can be unstable, if we take rotational energy and angular momentum into account. This result is not relevant for massive planetary bodies, as their tidal forces in close proximity exceed their material strength. It does apply to asteroid-size bodies in close proximity, however, and indicates that even an ideal Keplerian binary asteroid system in relative equilibrium can be unstable and evolve under energy dissipation.