The spin fission of small asteroid into binaries

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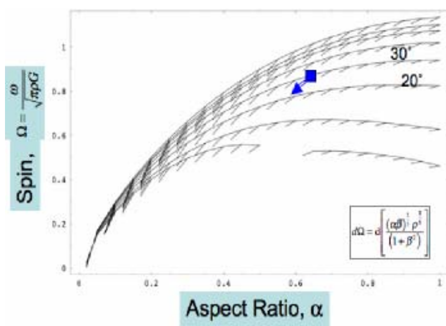
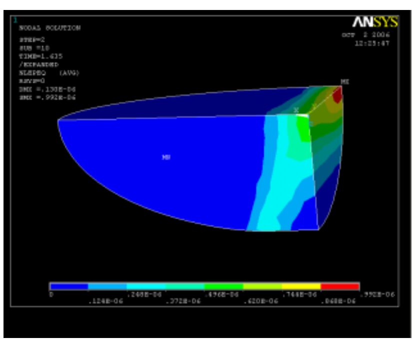
Mechanisms suggested for the formation of binary asteroids include reaccumulation from a tidal encounter or an impact, and, more recently, the spin fission of a body due to spin-up by Yorp or other means (Richardson and Walsh 2006). Spin fission requires that a continuum body have its spin increased to a value where the internal stresses are larger than some failure criterion in a region across the body. An analysis of the internal stresses and failure criteria are required to determine those spin limits, and to determine the failure deformations. Then a final state with a separation of the two parts to give a configuration that is a distinct binary requires sufficient energy for the orbit mechanics of a bound pair. An analysis of spin fission into binaries then has three distinct parts: the spin limits, the deformation mechanics of the disruption, and the energy budget for the subsequent binary dynamics.



I shall first review the spin limits for continuum ellipsoidal bodies with solid strength (Holsapple 2007). Those fall into two regimes: a gravity regime for all bodies with a diameter greater than 10km, and a strength regime for bodies with cohesion and a diameter less than 10km. Then the nature of the failure when the limits are exceeded will be discussed. For the larger, gravity dominated bodies with D>10-20 km or so, the failure mode is a uniform lengthening of the body: that increases its rotational inertia and, via angular momentum conservation, slows the body to a new spin state that is within the new spin limits for its new shape. Curves of spin limits and the path in this spin-shape space are depicted in the figure to the left. Thus, these bodies are generally stable to global disruption due to spin-up, and unlikely candidates for binary formation. This result for continuum bodies is analogous to the loss of mass from the extremities in spin-up seen by the analyses using the strengthless n-body codes (Walsh and Richardson 2006).



So it is the bodies in the strength regime, with a diameter of 10-20 km and smaller, that are candidates for spin fission. With spin-up, these bodies do not fail uniformly and globally, but instead the failure region initiates at the equator and grows to encompass a conical region across its center. The beginnings of such a failure is shown in the cut body figure to the left as the red and light blue regions.

Then what would happen to the two pieces indicated by the failure analysis? They must have enough kinetic energy to overcome the mutual binding energy if they are to separate. However, it they have too much, they will simply fly apart to become two distinct unbound bodies. That limits the spins for disruption to form binaries to distinct limits. I have determined those energy states using a numerical method to get the mutual gravitational potentials of such separated bodies. I find that for a binary outcome the body must have some cohesive strength, but not too much. A spin fission of a very strong and small body will just produce two distinct bodies, at the other limit a spin fission of a very weak body will not be able to separate into two distinct pieces, but will remain in contact.

So, in summary, the analysis of spin limits for solid bodies and the consequences of exceeding those limits suggests that spin fission will not create binary bodies unless the original body is less than about 10 km in diameter. In those cases, and when the cohesive strength is important, the body will tend to split into two pieces of roughly equal size. And, if the spin is not too fast (not too strong) the bodies can remain relatively close, creating a binary outcome with a slightly smaller spin. But if the strength is too large then the spin limit is larger, and the two pieces will just fly apart and escape each other's mutual influences. This suggests binaries formed by spin fission should be spinning near the gravity limit, and with 0.1-10 km diameter.

References: Richardson, D. C., Walsh, K. J. 2006 Annu. Rev. Earth Planet. Sci. 34:47–81. Holsapple, K. A. 2007. Spin limits of Solar System bodies: From the small fast-rotators to 2003 EL61. Icarus 187, 500-509. Walsh, K. J., Richardson, D. C. 2006. Steady-state populationof the NEA binaries and Yorp spinup models. DPS Meeting 38, #38.08.