THE STORY OF 2008 EV5 – EVIDENCE OF FISSION. S. Tardivel[1], P. Sánchez[2], D. J. Scheeres[2], [1]Jet Propulsion Laboratory, California Institute of Technology (simon.tardivel@jpl.nasa.gov), [2]Department of Aerospace Engineering Sciences, University of Colorado Boulder (diego.sanchez-lana@colorado.edu, scheeres@colorado.edu).

A small world severed.
EV5's concavity,
Telltale of its past.

Introduction: Asteroids and comets are more than mere leftovers of the accretion of planets and moons of the solar system and they are definitely not monolithic. For more than a decade now, they have been identified as self-gravitating aggregates (granular asteroids) that form, deform and disrupt due to impacts, gravitational tides and solar radiation pressure induced rapid rotation (YORP). Fission leading to complete disruption has been directly observed in active asteroid P/2013 R3[1,2]. And minor fission has been proposed as a mechanism for the formation of binaries [3].

This paper examines the possibility that the Near-Earth Asteroid (341843) 2008 EV5, approximately 225m radius, underwent a minor fission. Evidence of this event lies in the presence of a 20m deep concavity along its equator [4]. Filling up this concavity results in a dynamical environment favorable to the fissioning of this additional mass for tensile strengths below 1 Pa.

The ridge line: Recent works [5] analyzed the topology of the effective gravity field (gravity plus centrifugal potential) of a mass distribution. Several sets were identified: the z* set, the h* set, the boundary of potential and the ridge line. The *z** set is defined as the set where the effective acceleration cancels on the vertical *z* axis defined as the pole of the small body. The *h** set is defined as the set where the effective acceleration cancels along the planar radius *h* (polar coordinates). When the body spins slowly enough, the intersection of the *z** set and the *h** set is composed of two distinct structures: one outside the body, the other within the body and ultimately uninteresting. The structure outside the body is a curve diffeomorphic to a circle, that we call the ridge line (of potential). This ridge line contains all the equilibrium points exterior to the mass distribution. Beyond the ridge line, the acceleration pulls outwards; within the ridge line, the acceleration pulls inwards, towards the body. When the spin rate ω is increased (or conversely when density ρ is decreased), the ridge line comes closer to the surface.

For the purpose of this paper, the ridge line is especially relevant when it intersects the surface of the body. There is a value of spin rate, ω_0, for which the ridge line touches the surface. For a homogeneous sphere, at this ω_0, there is exactly no radial acceleration on a whole disk extending from the center to the sphere equator. But for arbitrary shapes there is in general no degeneracy and the ridge line survives entry and dives into the surface. Any cohesionless material located beyond the ridge line would be lofted from the surface. Interestingly, the ridge line identifies regions – often a single one, sometimes two diametraly opposed – that exhibit clear outward acceleration.

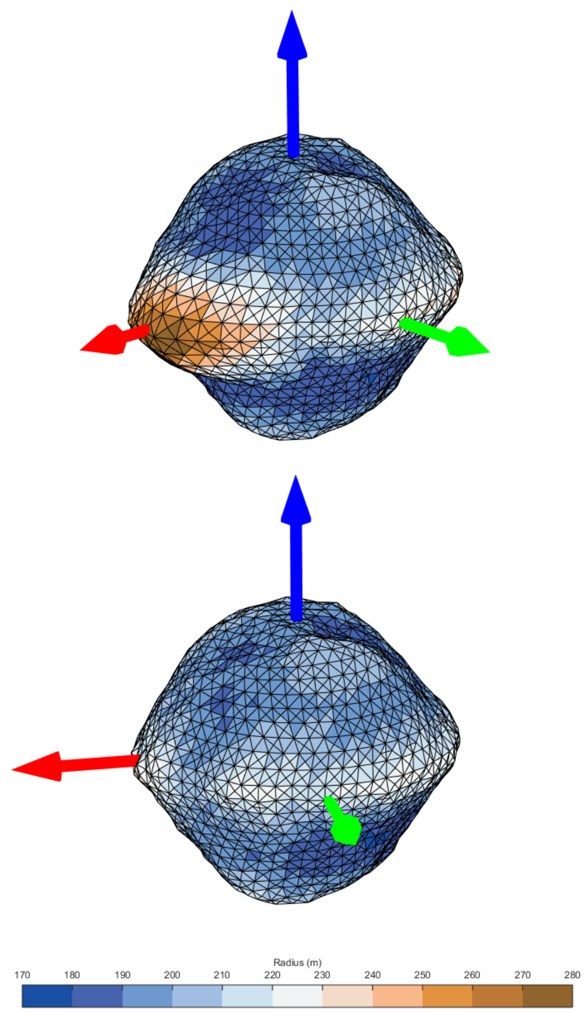

Figure 1. Shape model of EV5: top, altered with 80m protrusion; bottom, original shape model. Arrows indicate the principal axes of inertia (red-green-blue are from lowest to highest inertia).

Altered shape model of 2008 EV5: We examined what effect a protrusion, located where there is now a cavity, would have on the evolution of the ridge line for 2008 EV5. Notice that this analysis considers that the asteroid does not deform, either plasticly or elasticly, prior to fission, which is consistent with the asteroid having a strong core and a weak shell [6, 7]. We use several different protrusion sizes, ranging from 20 - 100 m at their highest point above the cavity level (see Table 1. and Fig. 1). The protrusion affects the shape between longitudes -10° and 80°, and latitudes ±30°. The protrusions have the same homogeneous density (ρ = 1.3 g/cm^3) as the rest of the asteroid. We then used a simplified 1280 facets polyhedron model based on these finer shapes for all computations (polyhedral gravity and relative altitude). The mass of the protrusion ranges from about 1% to 7% of the mass of the actual 2008 EV5, which is the mass ratio range of many asteroid secondaries. Note that the protrusion could be a large single boulder, as those seen on Eros.

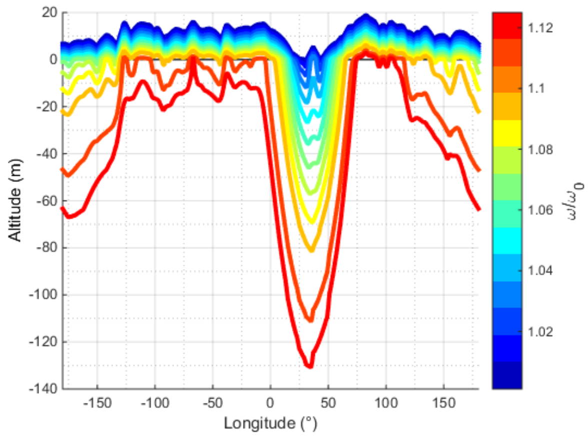

Figure 2. Altitude of the ridge line for a 40m protrusion shape as the spin is increased.

Computations: With this setup, the ridge line is computed for different spin rates. We identify the critical spin rate ω_0, and period T_0, for which the ridge line first enters the body. Because of the shape, the ridge line always enters first in the region of the protrusion, even when the protrusion is at 20m height that corresponds simply to filling up the concavity. As soon as a part of the ridge line enters the surface, it sinks much faster than in any other area (see Fig. 2).

As ω is increased above ω_0 we identify, by projection on the *xy* plane, the largest area within the body that extends beyond the ridge line. Identifying this area to an ellipse of similar dimensions, we consider that the volume extends in the 3rd dimension similarly to a prolate ellipsoid $a > b$ = c, with a, b and c respectively along the equatorial, radial and vertical directions. We then compute the effective acceleration felt by this ellipsoid and divide it by half its total surface. This is an estimate of the tensile strength σ necessary to hold the piece bound to the asteroid. Finally we register for which ω_f, T_f, the mass of the piece is equal to the mass of the protrusion. At the tensile strength σ, the piece would fission from the asteroid, revealing a cavity that would resurface quickly, recreating today's 2008 EV5.

Implications: These results show that even if we consider that granular asteroids have homogeneous interiors, irregularities in their shapes introduce heterogeneities in their stress fields. This also implies that asteroids are more likely to fail locally rather than globally as long as their core is intact [7]. Additionally, if this fission scenario proves to be true, it would constitute evidence of a formation mechanism in which the secondary is formed entirely during one fission event without need for re-accreation [8]. This and other implications will be further explored during the meeting.

Table 1. Stress σ and associated period T_f, critical period T_0, and mass ratios for different protrusion heights.

Protrusion (m)	20	40	60	80	100
Mass ratio (%)	1.4	2.5	3.9	5.1	6.7
Period T_0(h)	3.22	3.42	3.50	3.62	3.76
Period T_f (h)	3.08	3.13	3.17	3.20	3.23
Stress σ (Pa)	0.12	0.38	0.65	0.93	1.29

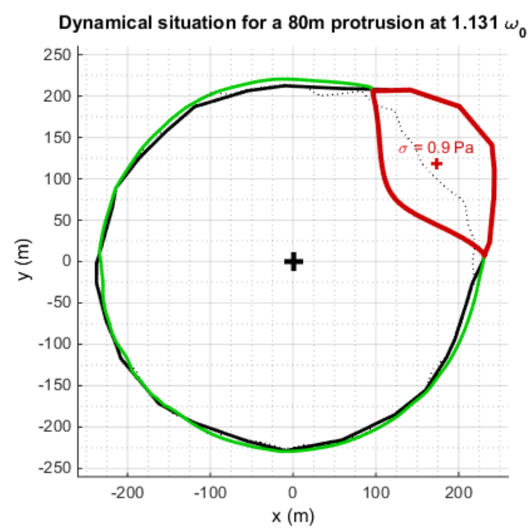

Figure 3. Planar cut of the dynamical situation. The red outline circumscribes the region feeling an outward pull. In green, the ridge line; in black solid, the altered asteroid shape; in black dotted, the actual asteroid shape.

References: [1] Jewitt D. et al. (2014) *ApJ Letters, 784*. [2] Hirabayashi M. et al. (2014) *ApJ, 789*. [3] Jacobson S. and Scheeres D. J. (2011) *Icarus, 214*. [4] Busch, M.W. et al. (2011) *Icarus, 212*. [5] Tardivel S. (2014) *Thesis Univ. of Colorado*. [6] Hirabayashi M. et al. (2015) *ApJ, 808.* [7] Sánchez P. and Scheeres D. J. (2014) *Meteoritics & Planet. Sci.* [8] Sánchez P. and Scheeres D. J. (2014) *ACM 2014.*