# *Asteroid rotation excitation by subcatastrophic impacts*

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# *tumblers*

- most asteroids in a basic rotation state (rotate around the principal axis with the largest moment of inertia) – mostly derived from their lightcurves
- some asteroids in an excited state of rotation (free precession) – they are called tumblers (Harris 1994)
- in precessing body the energy of rotation is dissipated over time and the rotation is gradually damped

*Q* what caused their excited rotation?

# *excitation processes*

- torque related to YORP (Yarkovsky–O'Keefe–Radzievskii–Paddack) effect – Vokrouhlický et al. 2007
- collisions proposed by several authors (Burns & Safronov 1973, Paolicchi et al. 2002, Pravec et al. 2005)
- motivated by the presence of huge impact craters on the surface of many small bodies (asteroids, planetary moons)
- our research: the physical plausibility of excitation by subcatastrophic collisions = cratering impacts that do not disrupt or seriously shatter the asteroid

## *subcatastrophic collision model*

system of two colliding bodies

- the larger one (target) is triaxial ellipsoid, the smaller one is a sphere (impactor, projectile), both are homogeneous (in some simulations we assumed some macroporosity as well)
- before the impact the target is rotating in a basic state
- hypervelocity impact forms an impact crater on the target's surface – its dimensions are calculated by scaling laws (Holsapple & Housen 1993, Holsapple 2003)

## *subcatastrophic collision model*

- linear and angular momentum (AM) exchange between the bodies during the collision
- part of the momentum and AM carried away by ejecta – we calculate the momentum and AM transfer efficiency according to Yanagisawa et al. 1996 and Yanagisawa & Hasegawa 2000
- we calculate the inertia tensor of the ellipsoidal target body with the crater

$\Rightarrow$ we know the rotation of the asteroid after the collision and we can calculate its lightcurve

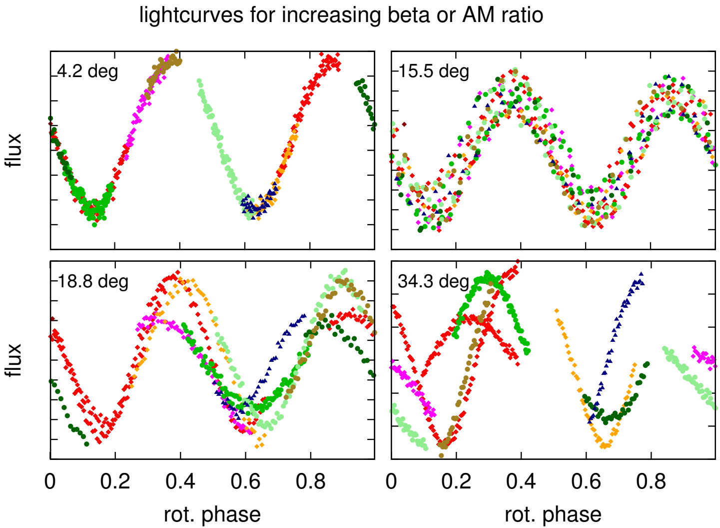
# *lightcurve calculation*

- for every impacted body we calculated its lightcurve (Kaasalainen 2001; Ďurech 2011, pers. comm.)

*Q* is tumbling detectable in the lightcurve by the distant photometry?

- if yes, how large was the excitation of asteroid rotation for specific input parameters?
- as a measure of the excited rotation we took the angle $\beta$ between the target shortest principal axis and its rotational AM vector

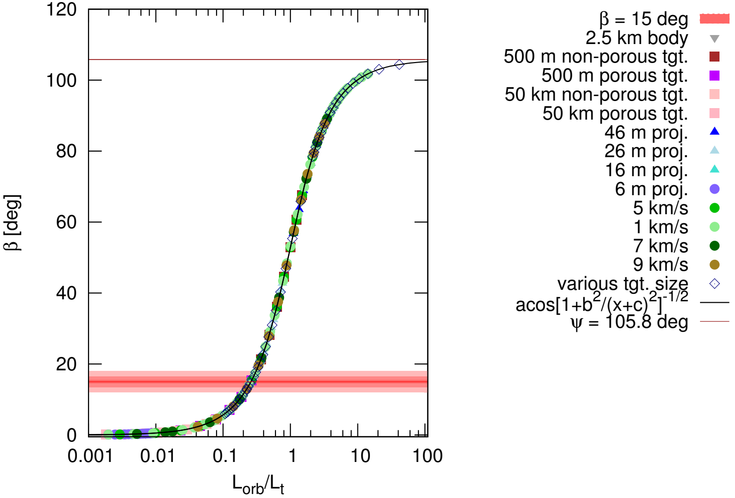
# *sample lightcurves*



## *$\beta$ – the angle between the target shortest principal axis and its rotational AM vector*

- after the collision, this angle is close to the amplitude of the nutation angle
- we tested the sensitivity of the outcome on several input parameters (target size, projectile size, initial rotation period of the target, its material strength, changing shape of the target)
- the determining parameter of the collision is the AM ratio (total orbital AM to the target's rotational AM) and there is a simple relation of $\beta$ to this ratio

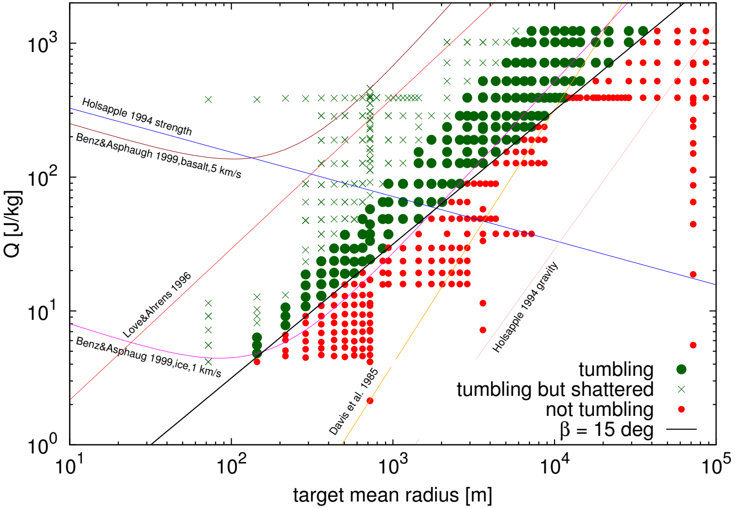
# $\beta = f(L_{orb}/L_t), \beta_{tumbling} \sim 15\,\mathrm{deg}$



## *threshold energy*

- the projectile kinetic energy in every collision was compared to the threshold specific impact energy
- it is the energy which is necessary to seriously shatter the body
- in our calculations we used 1/4 of the shattering energy value according to Housen 2009 and Stewart & Leinhardt 2012

# *specific impact energy vs. target size*



## *conclusions*

- subcatastrophic collisions are physically plausible mechanism for asteroid rotation excitation
- for $\beta \sim 15\,\mathrm{deg}$ the tumbling can be detected by distant photometry
- the determining parameter of the collision is the ratio of orbital AM to target's rotational AM
- we find the relation between this AM ratio and $\beta$
- slowly rotating asteroids of $\sim 100\,\mathrm{m}$ and larger can be excited by collision without being shattered
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# *model weaknesses*

- momentum and AM transfer efficiency can be different (can be greater than 1 and possibly far greater than 1 – Walker et al. 2012, Holsapple & Housen 2012)
- scaling laws work for small to moderate incidence angles and for halfspace, we used it for finite curved surface
- there are other crater formation scenarios, especially compaction mechanism for porous materials proposed by Housen et al. 1999

# *further work*

- improve porosity description
- extend the collisional model for irregular bodies
- run randomized simulations to find the average coll. excitation in a specific asteroid population
- evolutionary model (incl. YORP effect and excited rotation damping) to test the hypothesis of coll. origin of tumbling
- advertisement: SPH or SPH+N-body simulation validation of our results

# *references*


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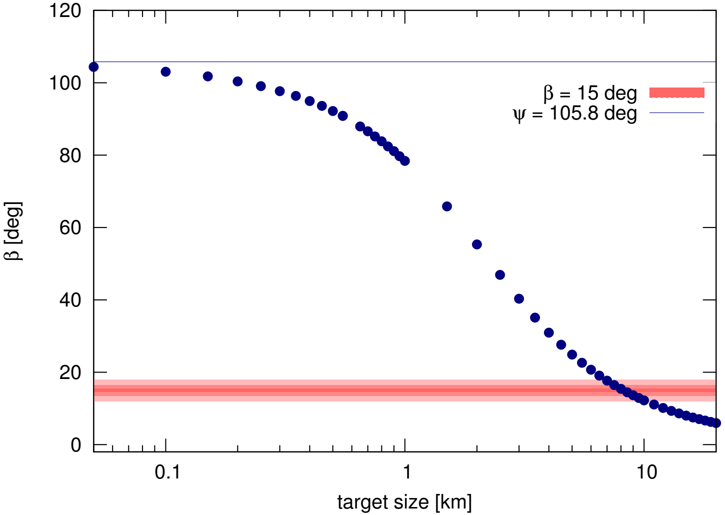
$$\cos\beta = \pm\left[1 + \frac{\sin^2\psi}{(L_{\mathrm{t}}/L_{\mathrm{orb}} + \cos\psi)^2}\right]^{-1/2}$$

$+$ sign: $L_{\mathrm{t}} \geq -L_{\mathrm{orb}}\cos\psi$
$-$ sign: $L_{\mathrm{t}} < -L_{\mathrm{orb}}\cos\psi$
$\psi$: the angle between the two angular mometum vectors before the collision

# *compaction mechanism*

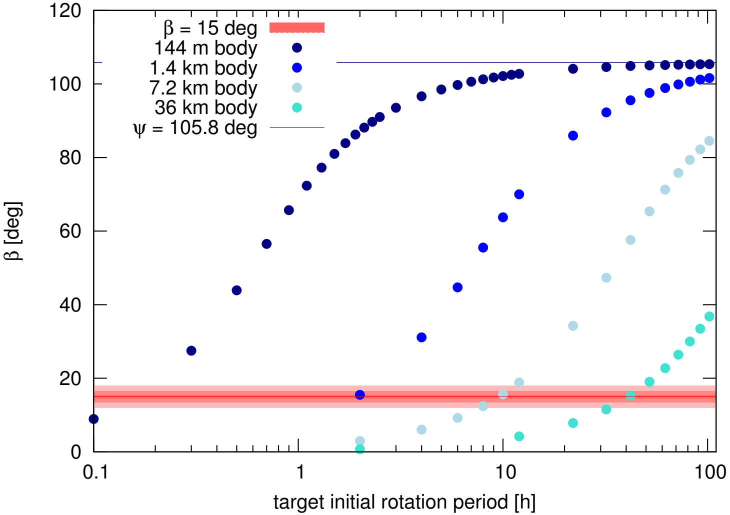
- craters on 253 Mathilde (tumbler) are very large, close to each other and lack larger ejecta
- Housen et al. 1999 proposed the compaction mechanism of cratering on Mathilde
- the projectile compresses the porous material, large portion of its kinetic energy is consumed

*target size*

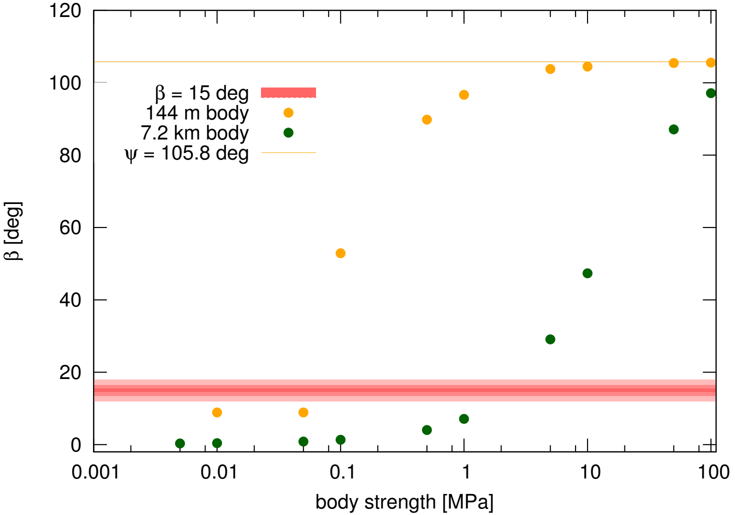


120
100
80
60
40
20
0
β [deg]
0.1
1
10
target size [km]
β = 15 deg
ψ = 105.8 deg

# *target's initial rotation period*



# *target's material strength*



*projectile size*