Centrifugal Shedding of Regolith

Yarkovsky-O'Keefe-Radzievskii-Paddack (YORP) effects

Regolith

Shedding of Regolith by Spinning Rigid Asteroids

John Hornstein

ASTR-630

Dec 2014

YORP Effects

Yarkovsky-O'Keefe-Radzievskii-Paddack

Radiatively asymmetrical bodies

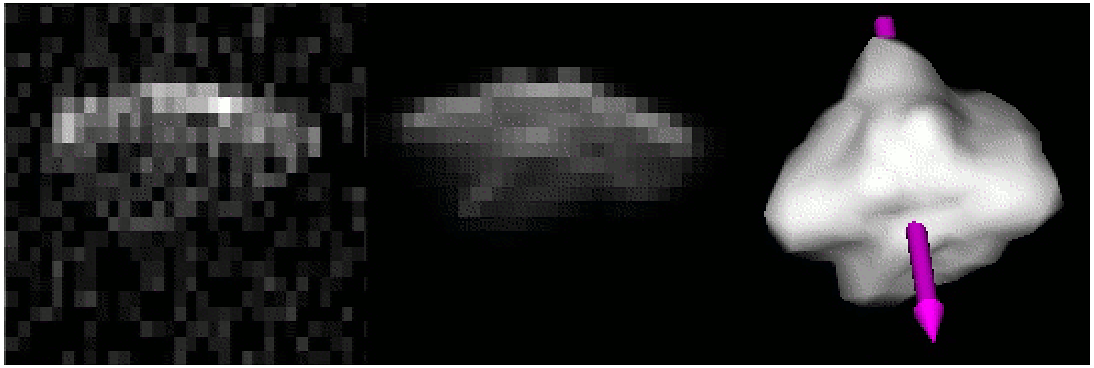
Asymmetrical reflection of incident light

Asymmetrical emission of thermal radiation

Torques
    vector => spin rate and spin axis (obliquity)

Orbital drift

Diameters affected: fraction of km to tens of km



1862 Apollo

YORP Spin Rates and Time Scales

Asteroid	*Spin Period*	*Diameter*	*Spin changes*	*Orbital changes*
Bacchus	**14.9 hr**	**0.64 km**	**0.12 Myr**	
Castalia	**4.095 hr**	**1.08 km**	**1.3 Myr**	
Eros	**5.2702 hr**	**16.84 km**	**1 Gyr**	
1950 DA	**2.1216 hr**	**1.3 km**		**-44.1 Myr**
Itokawa	**12.13237 hr**	**0.32 km**	**0.14 Myr**	

Some of these are rubble piles (based on density), but the calculations below will be for rigid asteroids

Refs: ***Scheeres (2007)*, *Rozitis et al (2014)***

Regolith

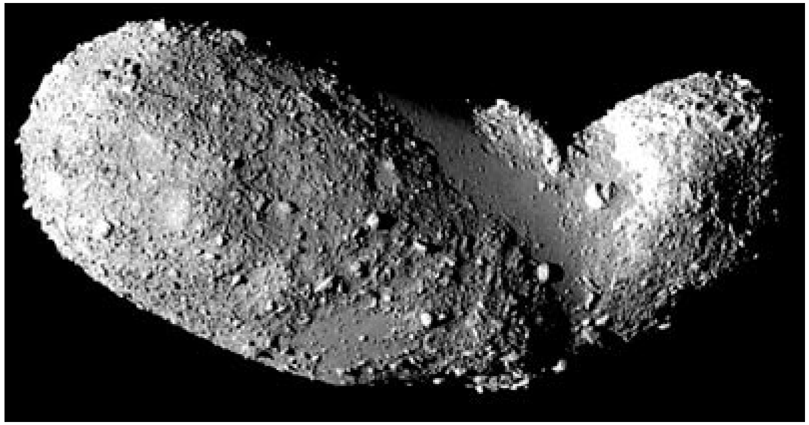
Photo by Buzz Aldrin, Apollo 11

Unconsolidated material that overlies solid rock (based on Merriam-Webster)

Dust, soil, broken rock

Lunar soil "had the cohesive property that wet sand would have" (Buzz Aldrin)
(Quoted in Perko et al. (2001)

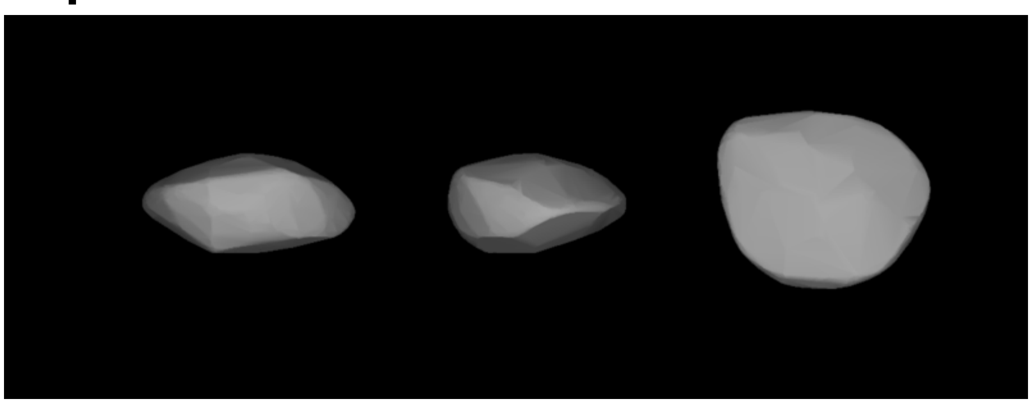
Shedding of Regolith by Spinning Asteroids



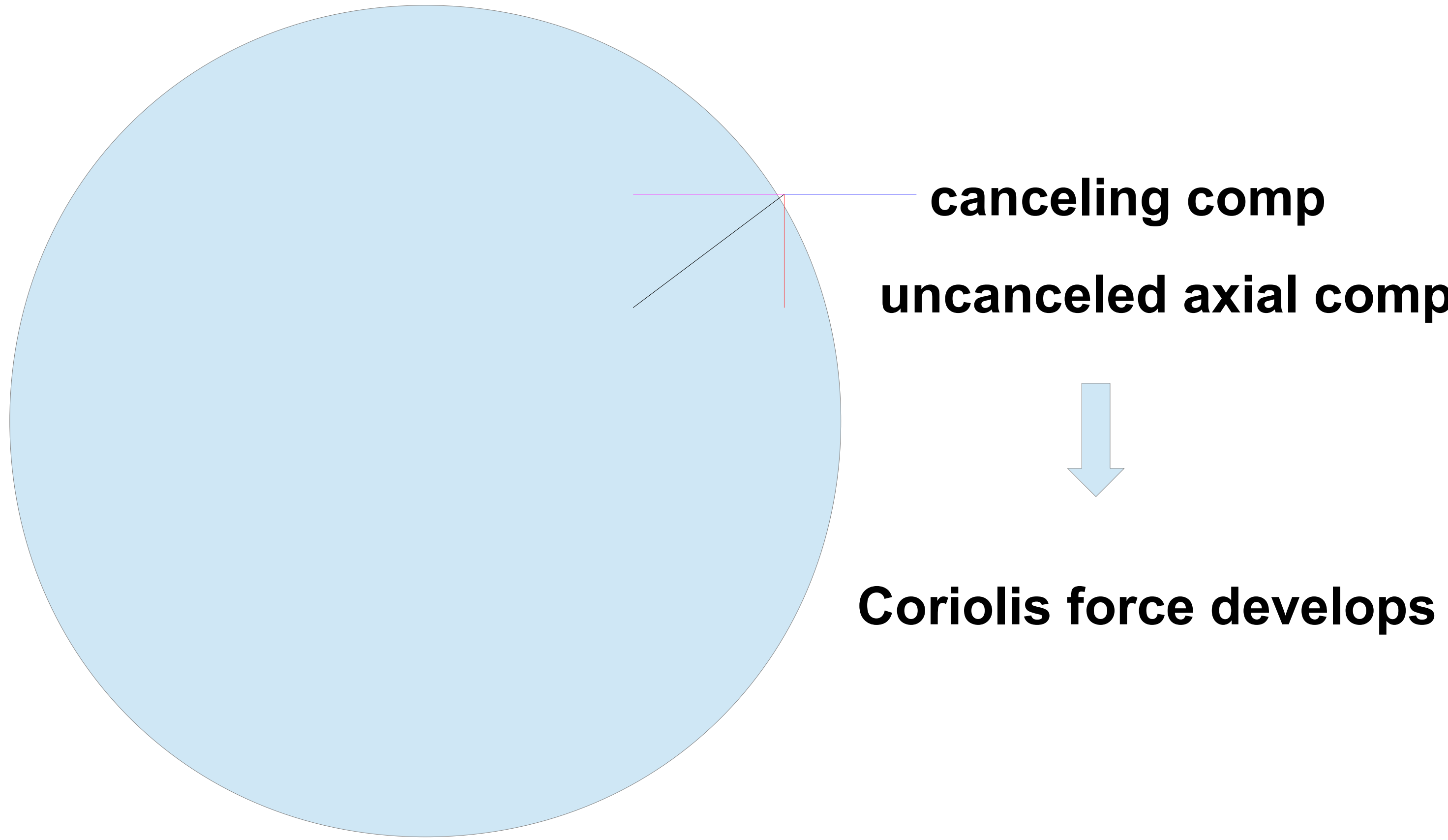
Itokawa

Spin => centrifugal forces => shedding of particles not close to the spin axis.
Tumbling might shed previously safe regolith

Meteoroids produced directly by collisions vrs spun off
Released at a discrete point along an orbit
vrs
Released all along each of a large number of orbits
The sporadic streams of meteoroids?

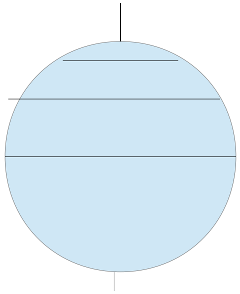


54509 YORP



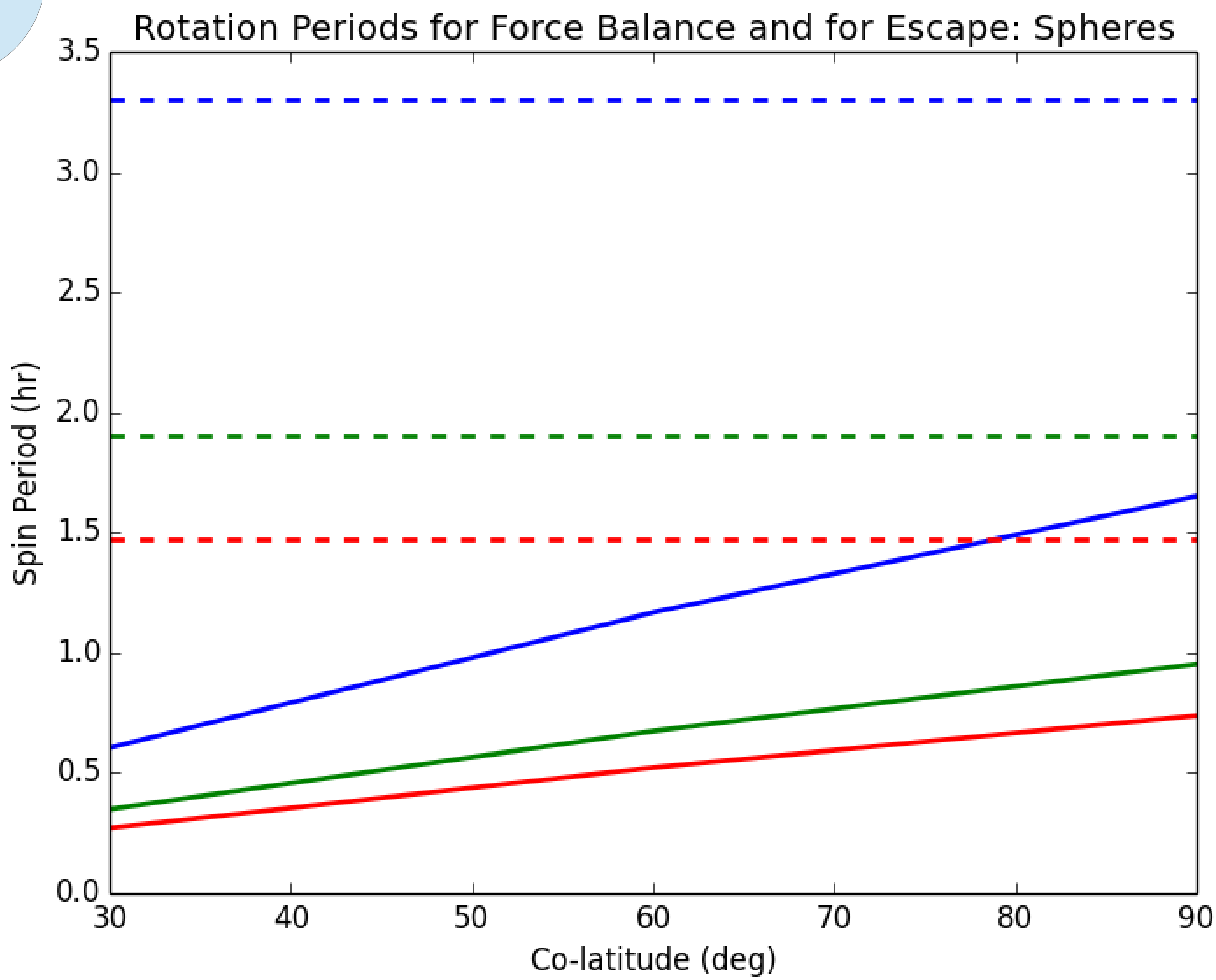
Canceling the force perpendicular to the axis does not suffice for escape, even from the equator.

KE must enable escape from the gravitational potential well.



R = 10 m, 100m, 1 km, 10 km

Dashed: force partially canceled; Solid: Escape

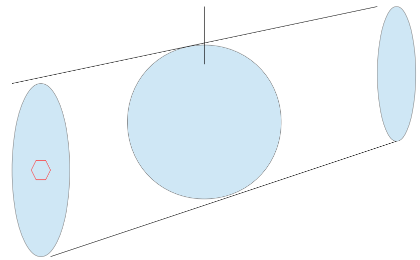


1g/cm^3

3 g/cm^3

5 g/cm^3

A tool for inferring spin histories in favorable cases.



Ratio of the critical spin periods (cylinder to sphere, independent of density):

When length of cylinder = diameter of sphere,
about the same spin period is needed for both.

ratio of periods for partial force balance = 0.934
ratio of periods for escape = 1.180

When length of cylinder = 10 x diameter of sphere,
the cylinder's longer arm more than compensates for the increased gravity at its end-face,
hence produces the same effect at a slower spin.

ratio of periods for partial force balance = 2.61
ratio of periods for escape = 7.98

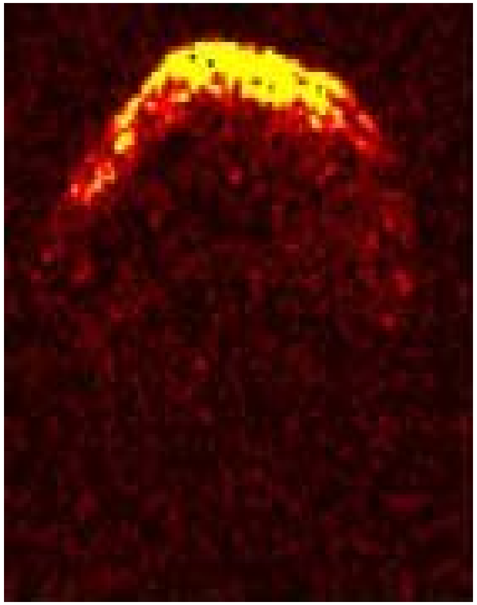
Another tool for inferring spin histories in favorable cases.

van der Waals Forces

Weak attractive forces due to correlations between electric dipoles (permanent or fluctuating) in neighboring atoms or molecules.

Additional energy needed for escape: (Hamaker constant/144) (rgrain/min sep) = 3.3e-7 erg

=> $\Delta t_{spin}/t_{spin}$ = - 5e-7 for the lowest density, smallest sphere



1950 DA (radar image)

Perko et al. (2001), Scheeres et al. (2010), Hartzell and Scheeres (2011), Rozitis et al. (2014)

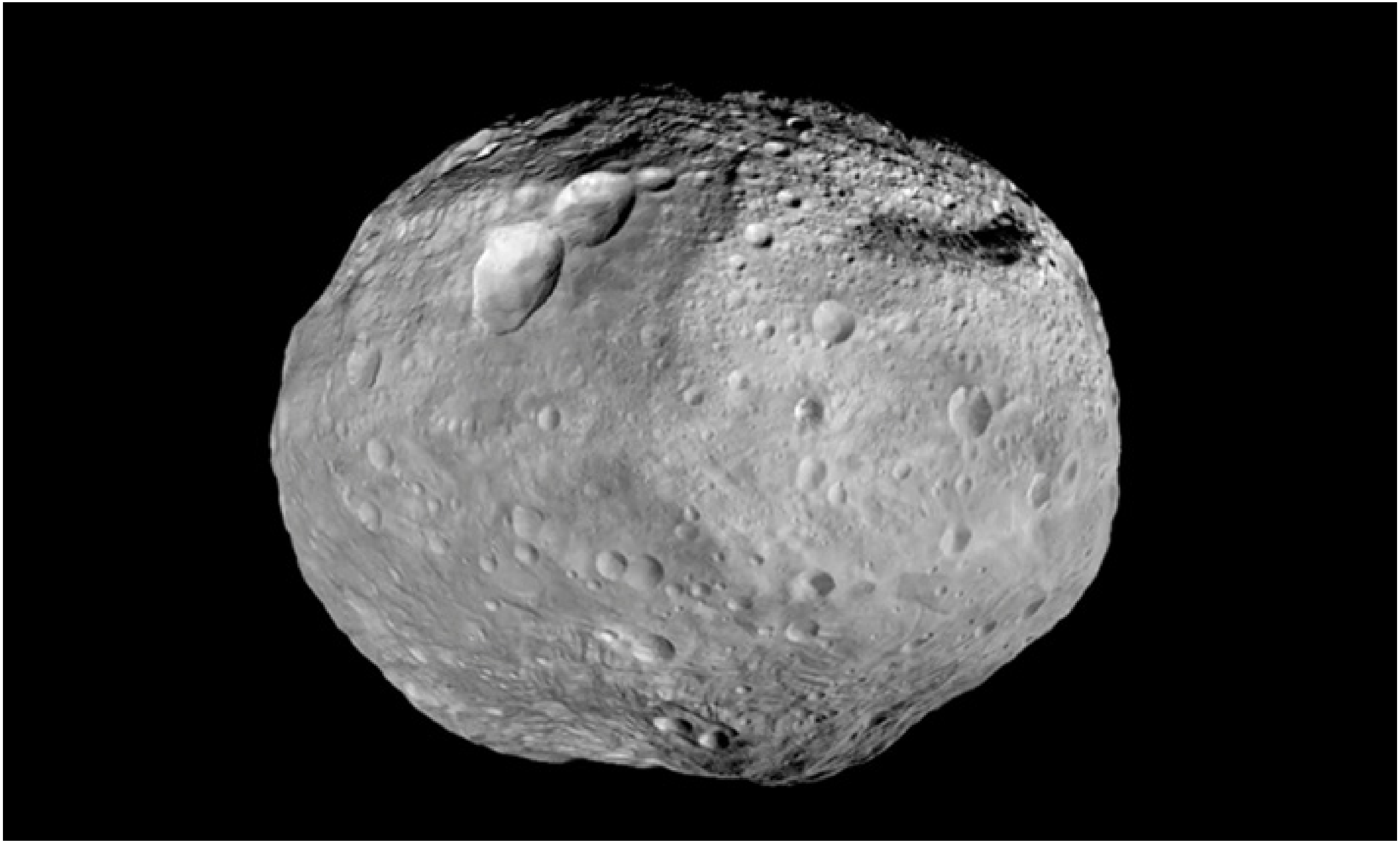
Supplemental Slides

Howard A. Perko, John D. Nelson, Willy Z. Zadeh, “Surface Cleanliness Effect on Lunar Soil Shear Strength”, *Jl. of Geotechnical and Geoenvironmental Engineering*, 127: 371-383 (April 2001).

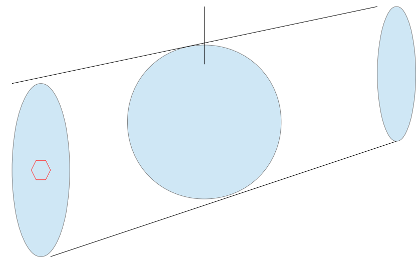
Christine M. Hartzell and Daniel J. Scheeres, “The role of cohesive forces in particle launching on the Moon and asteroids”, *Planetary and Space Science*, 59: 1758-1768 (2011)

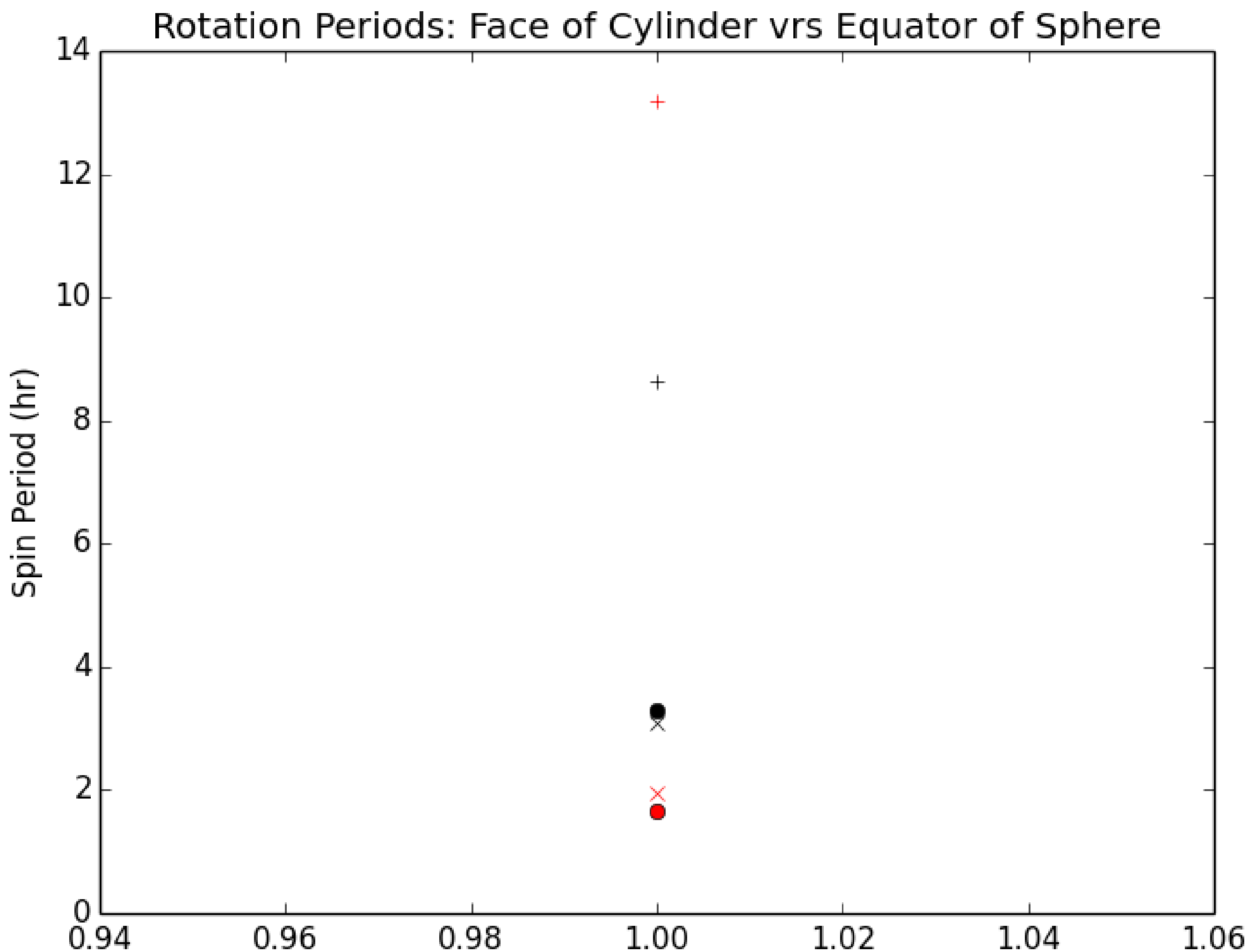
D.J. Scheeres, C.M. Hartzell, P. Sánchez, M. Swift, “Scaling forces to asteroid surfaces: The role of cohesion”, *Icarus*, 210: 968-984 (2010).

Ben Rozitis, Eric MacLennan, Joshua Perry, “Cohesive forces prevent the rotational breakup of rubble-pile asteroid (29075) 1950 DA”, *Nature*, 512:174-176 + 8 pages of online material (14 August 2014).



Vesta





Rotation Periods: Face of Cylinder vrs Equator of Sphere
Spin Period (hr)
0
2
4
6
8
10
12
14
0.94
0.96
0.98
1.00
1.02
1.04
1.06