The YORP Effect on Rubble Piles

How Centrifugal Reshaping of Small Aggregates Kills the YORP Cycle

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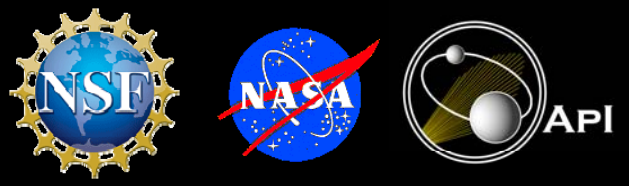

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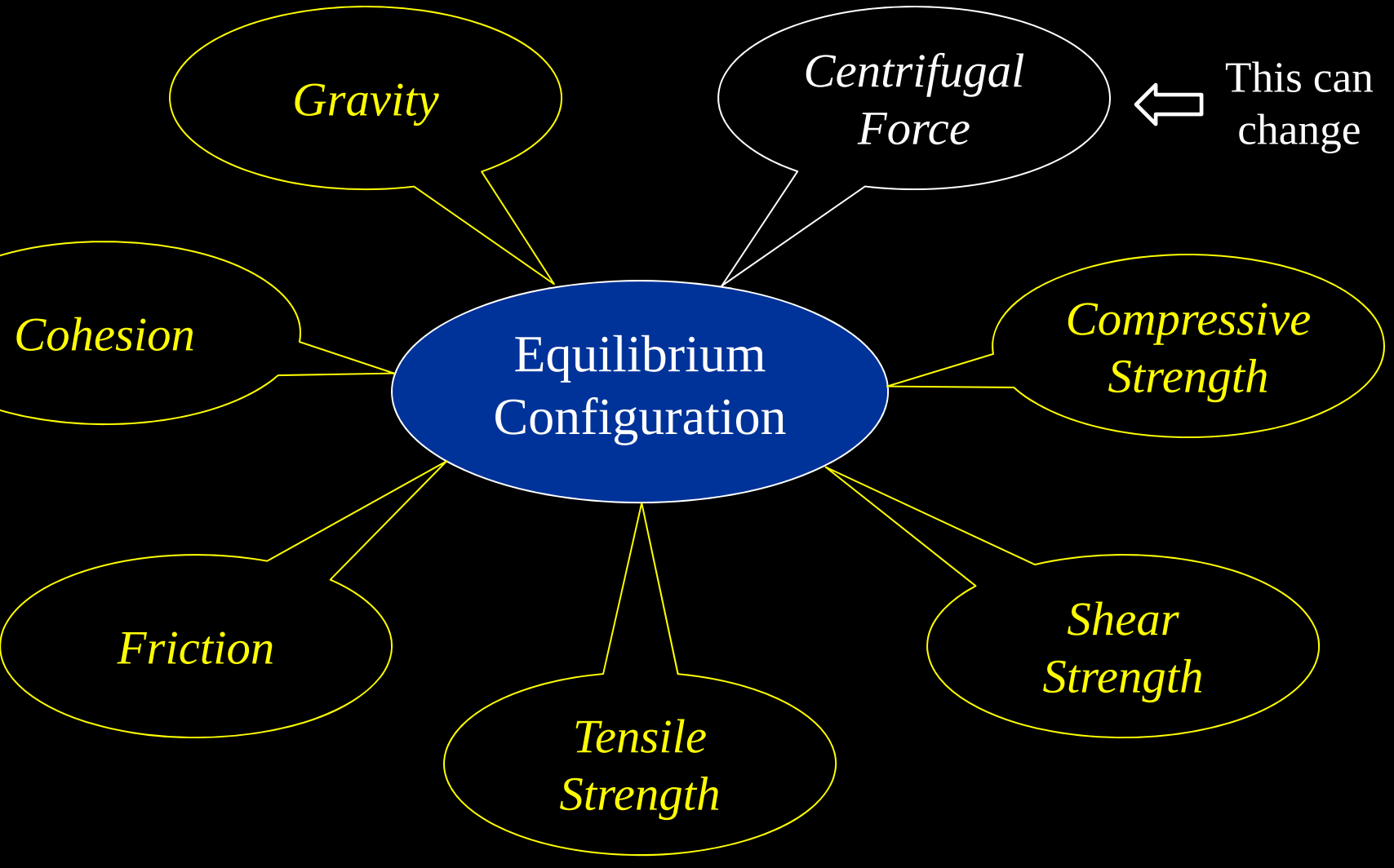
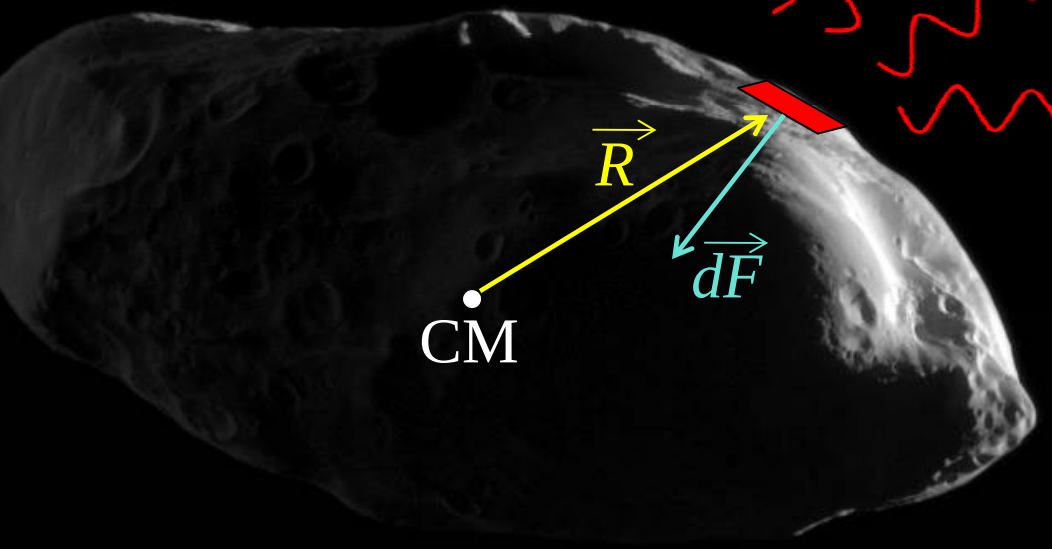
eroid Physical Characterization: Equilibrium Shapes



liation Recoil Torque

$\overrightarrow{(\text{torque})} = \vec{R} \times d\vec{F}$

ancels identically for any
flection-symmetric object
hen summed over surface,
veraged over spin & orbit.



Doesn't cancel for asymmetric objects. Net residual torque is the **YORP Effect**.

y Should We Care about YORP?

YORP timescale is roughly (Diameter in meters)^2 years.

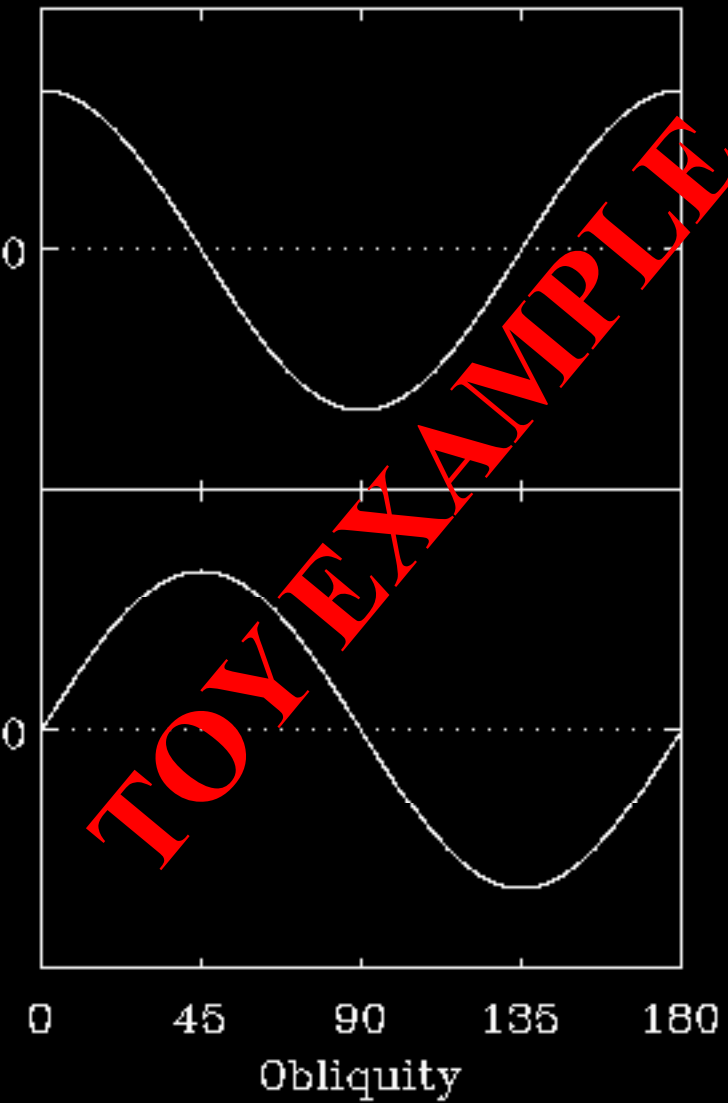
- Millions of years for km-sized objects
- Decades for few-meter-sized objects

Orbit evolution is driven by radiation recoil forces (Yarkovsy ffect) that depend on spin rate and obliquity. Both are altered y YORP.

YORP-driven spin-up *MAY* be responsible for mass shedding, inary formation, and "top" shapes like 1999 KW_4, 1999 RQ_{36}.

Spin characterization is a potentially powerful diagnostic of naterial properties, complementary to spectroscopic haracterization.

RP Evolution of Rigid Asteroids

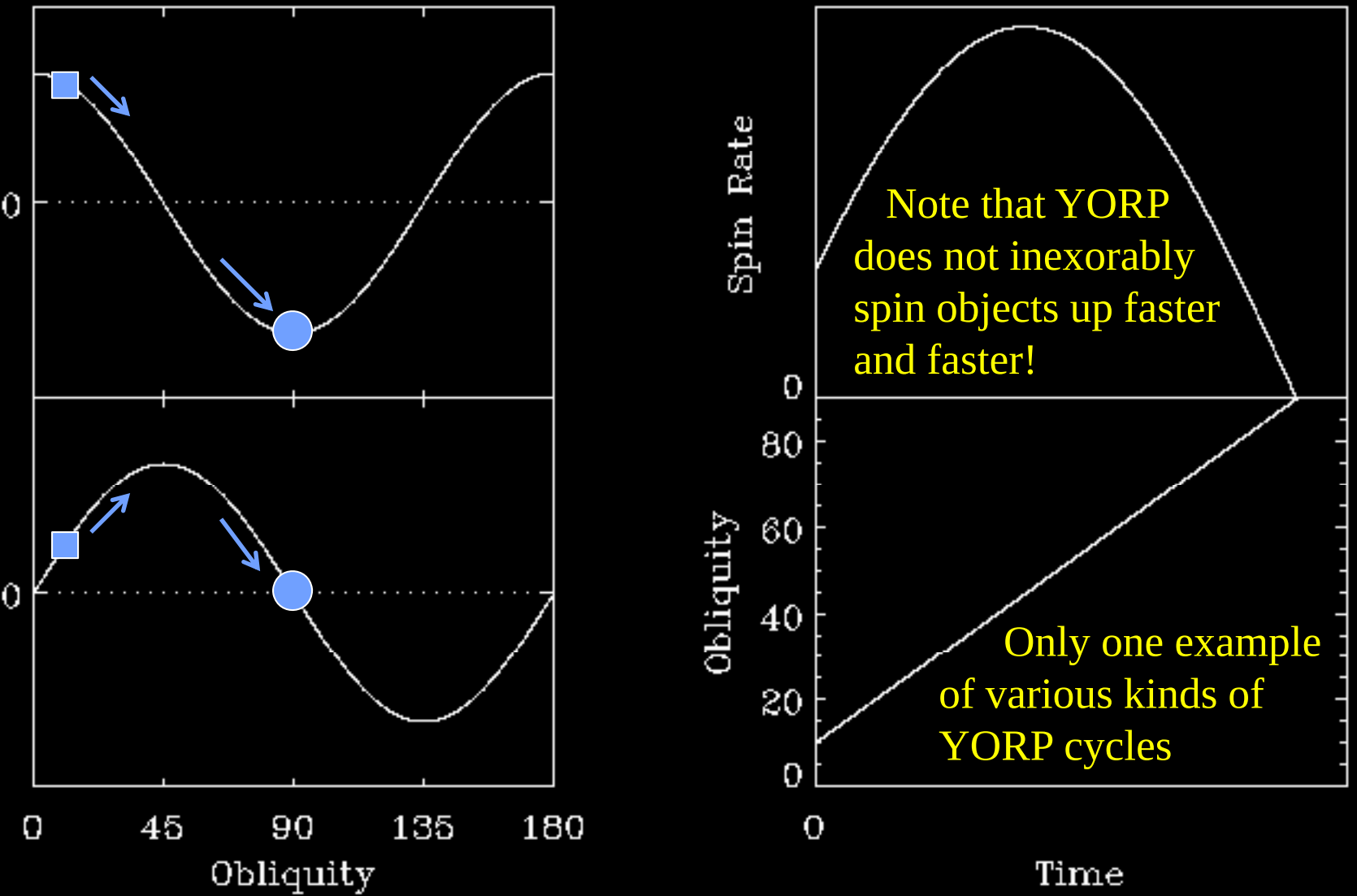


"YORP curves" give averaged torque components at various obliquities.

Exact curves are a characteristic of asteroid shape & surface thermal properties.

Rigid-body shape is constant; hence objects evolve along deterministic "**YORP cycle**".

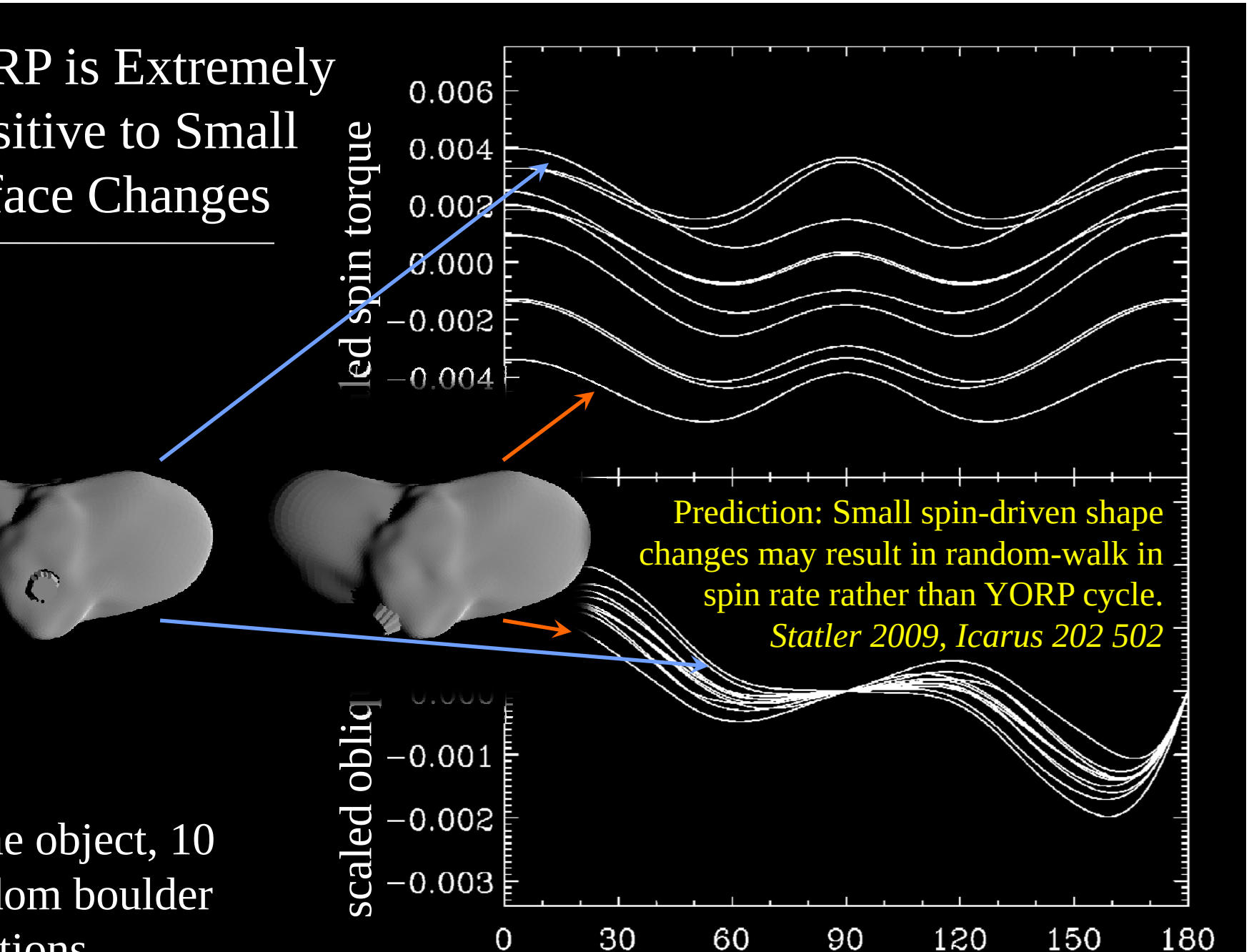
RP Evolution of Rigid Asteroids



Note that YORP does not inexorably spin objects up faster and faster!

Only one example of various kinds of YORP cycles

RP is Extremely
sitive to Small
face Changes



e object, 10
lom boulder
tions

ORP Evolution of Aggregate Asteroids

RST direct simulation of self-consistent spin evolution under the fluence of YORP *and* spin-driven shape change.

YORP changes spin
Spin changes shape
Shape changes YORP

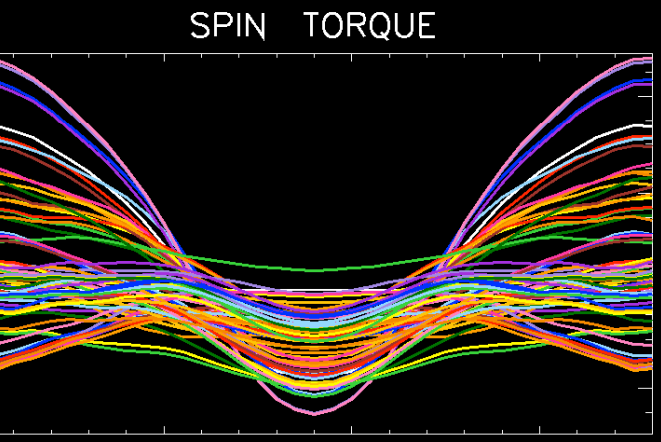
ombine pkdgrav N-body and TACO thermophysical codes.

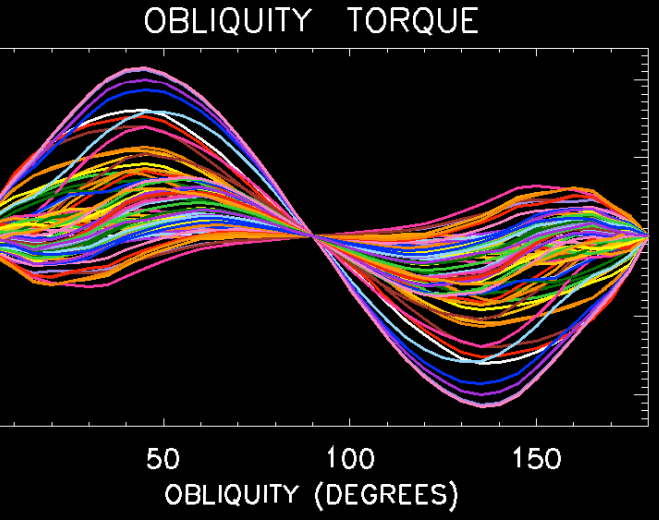
st objects: idealized aggregates of identical gravitating spheres random packing in rotating equilibrium (Tanga et al. 2009 ApJL 6, L197).

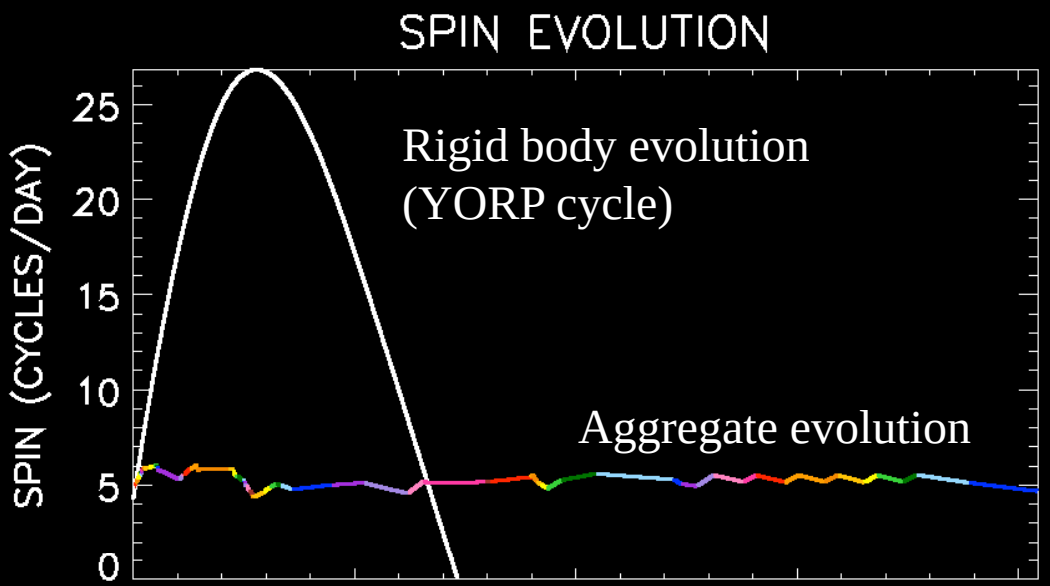
ravity-dominated regime: diameters of a few km, time scales of a w Myr.

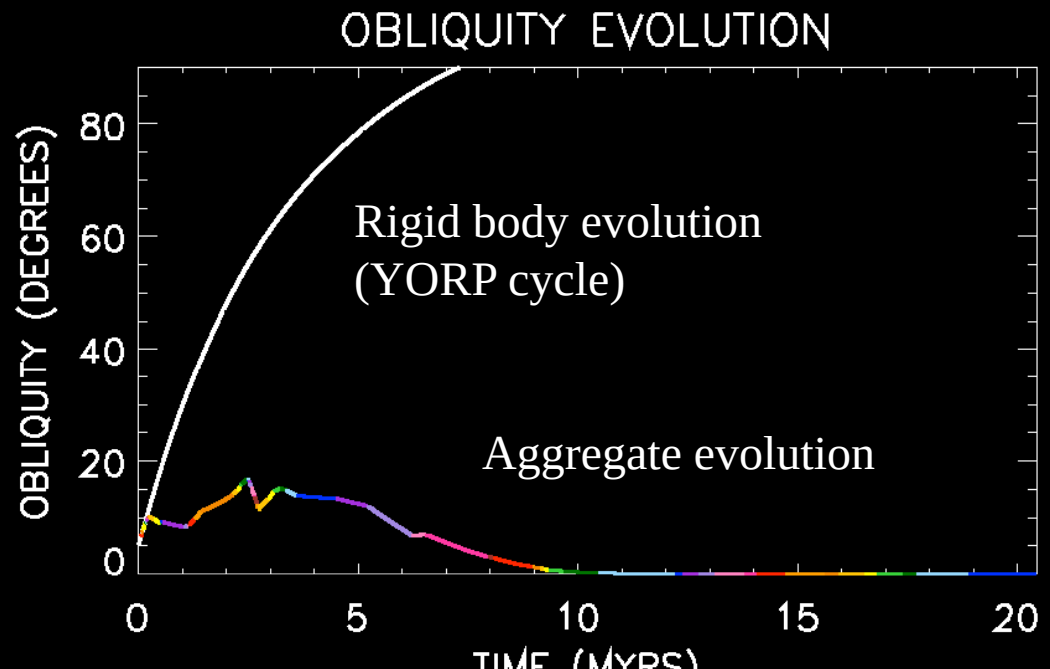
naller, cohesive models to come later.

regate Evolution:
Limiting YORP



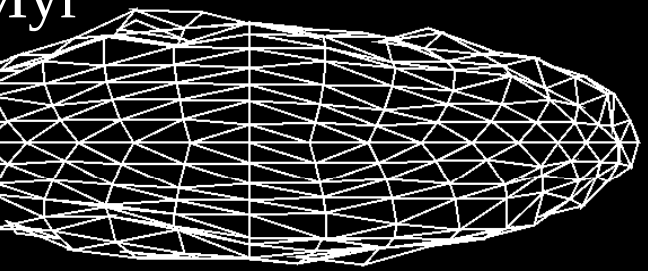




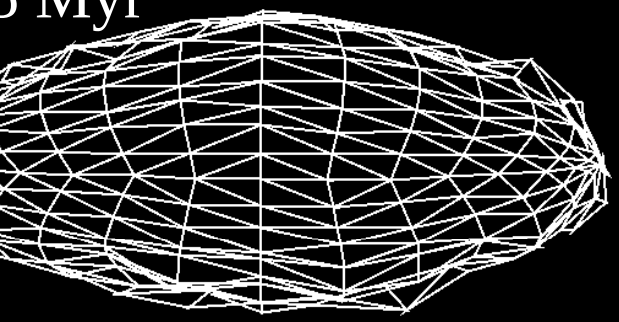


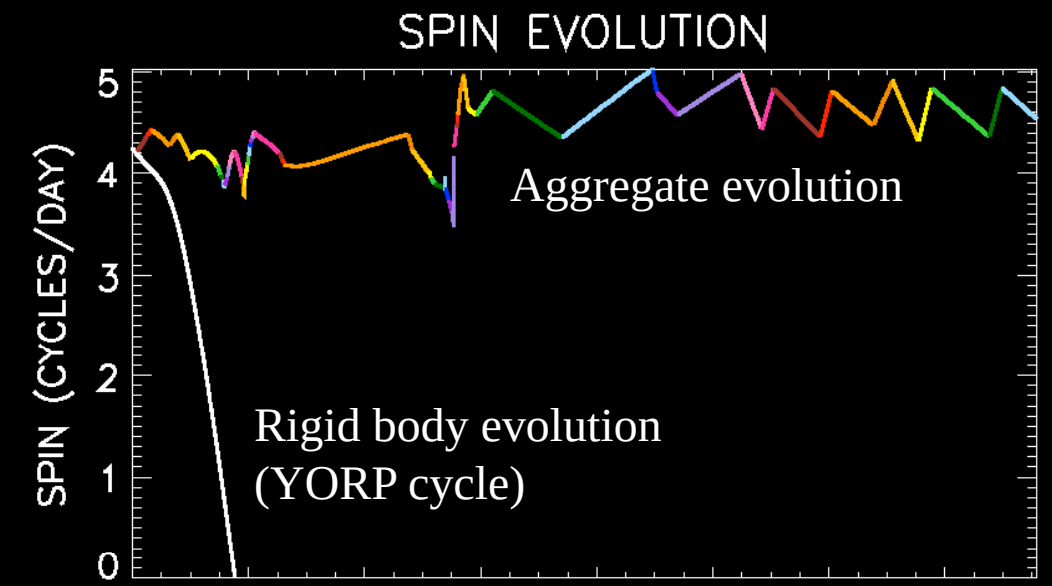
regate Evolution: Self-
ting/Stochastic YORP

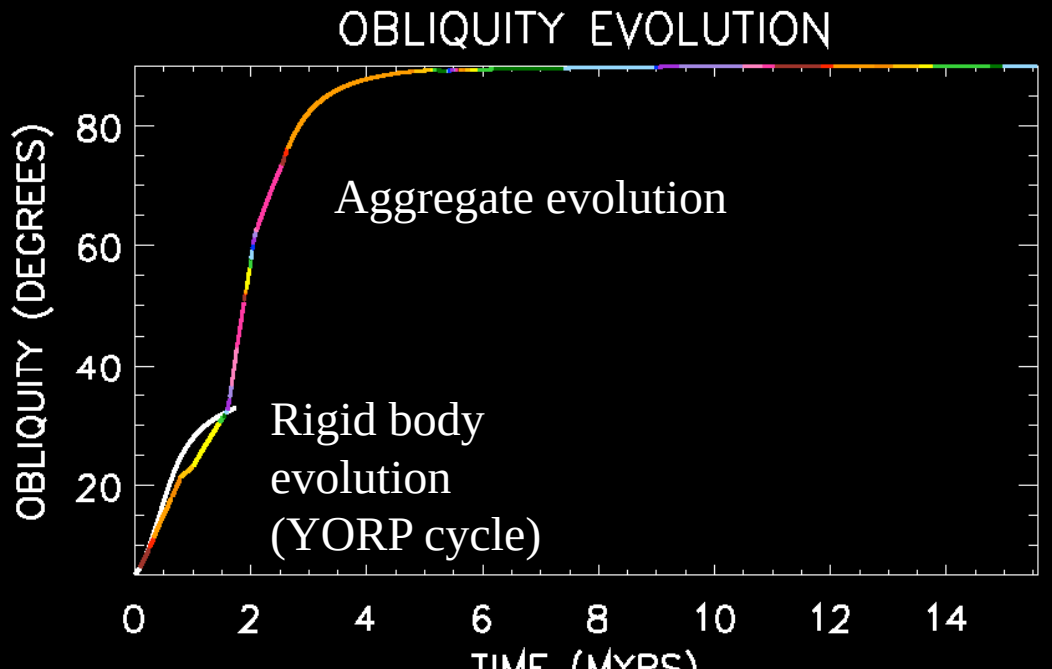
Myr



5 Myr

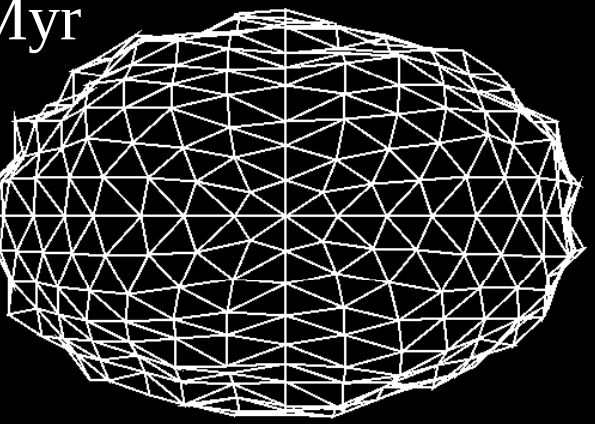




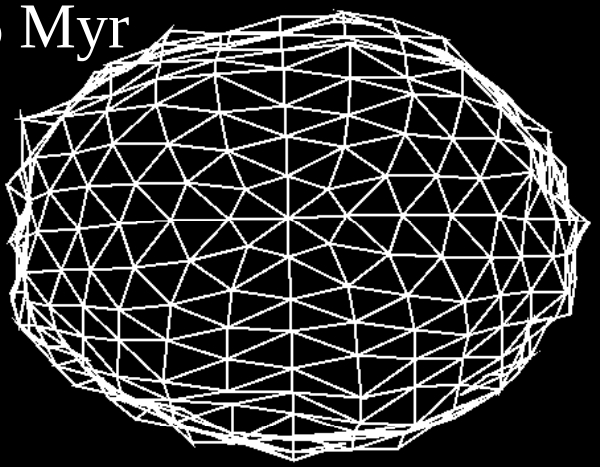


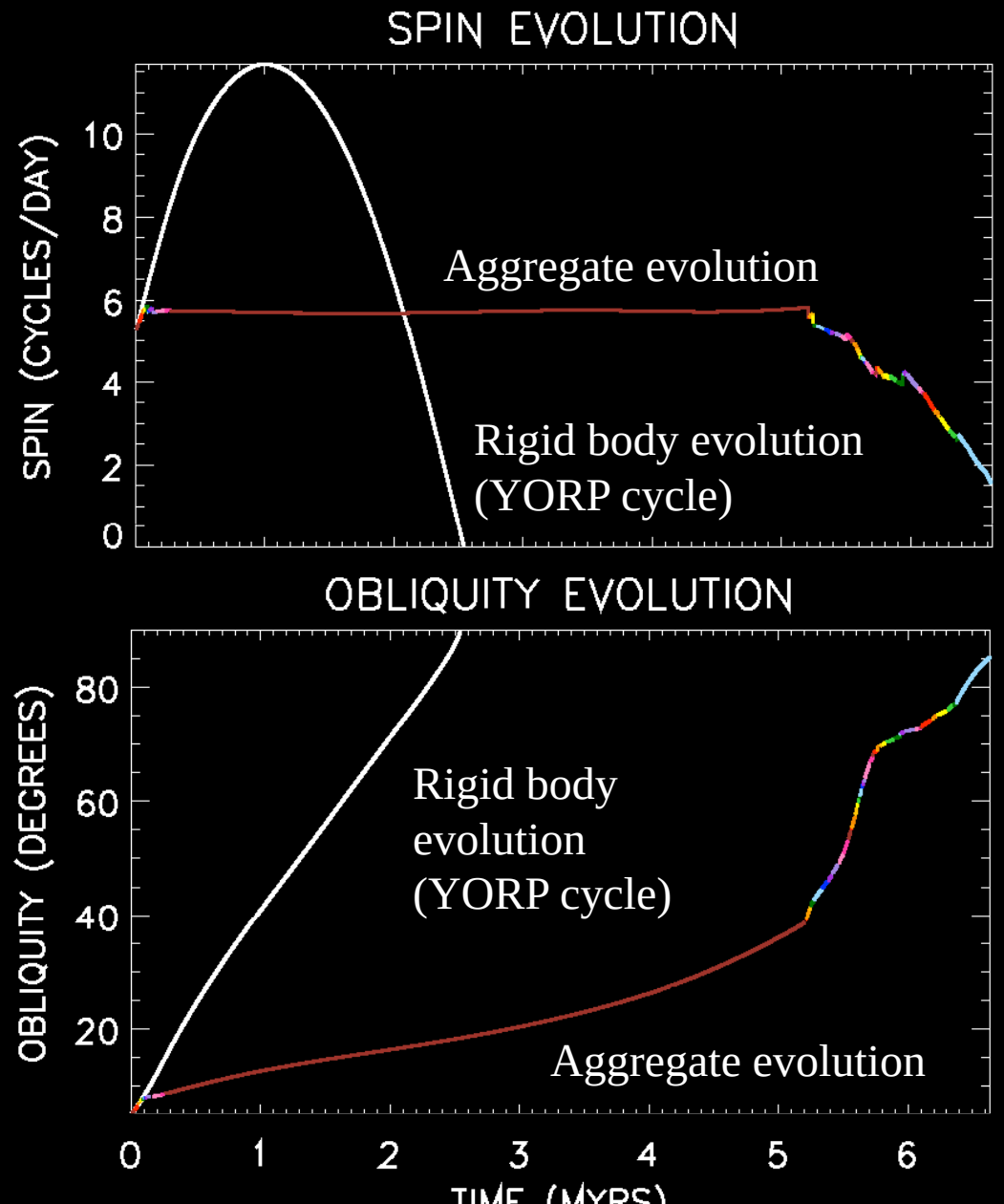
regate Evolution:
nastic YORP

Myr



Myr





onsequences and Implications

Monoliths and rubble piles behave completely differently in their ORP-driven spin evolution.

Detailed spin characterization of asteroid families may therefore ovide a statistical indicator of material properties and structure.

- Example: Yarkovsky-driven orbit spreading of collisional families differs for YORP cycle vs. random walk.
- Bill Bottke/OSIRIS-REx team's preliminary results exciting!

Simple scenario for YORP-driven binary formation needs to be assessed. (Stay tuned!)

Understanding spin evolution of sub-km-sized aggregates will quire more sophisticated simulations that include

- Cohesion
- Friction
- etc.