Radiation Recoil Effects on the Dynamical Evolution of Asteroids.

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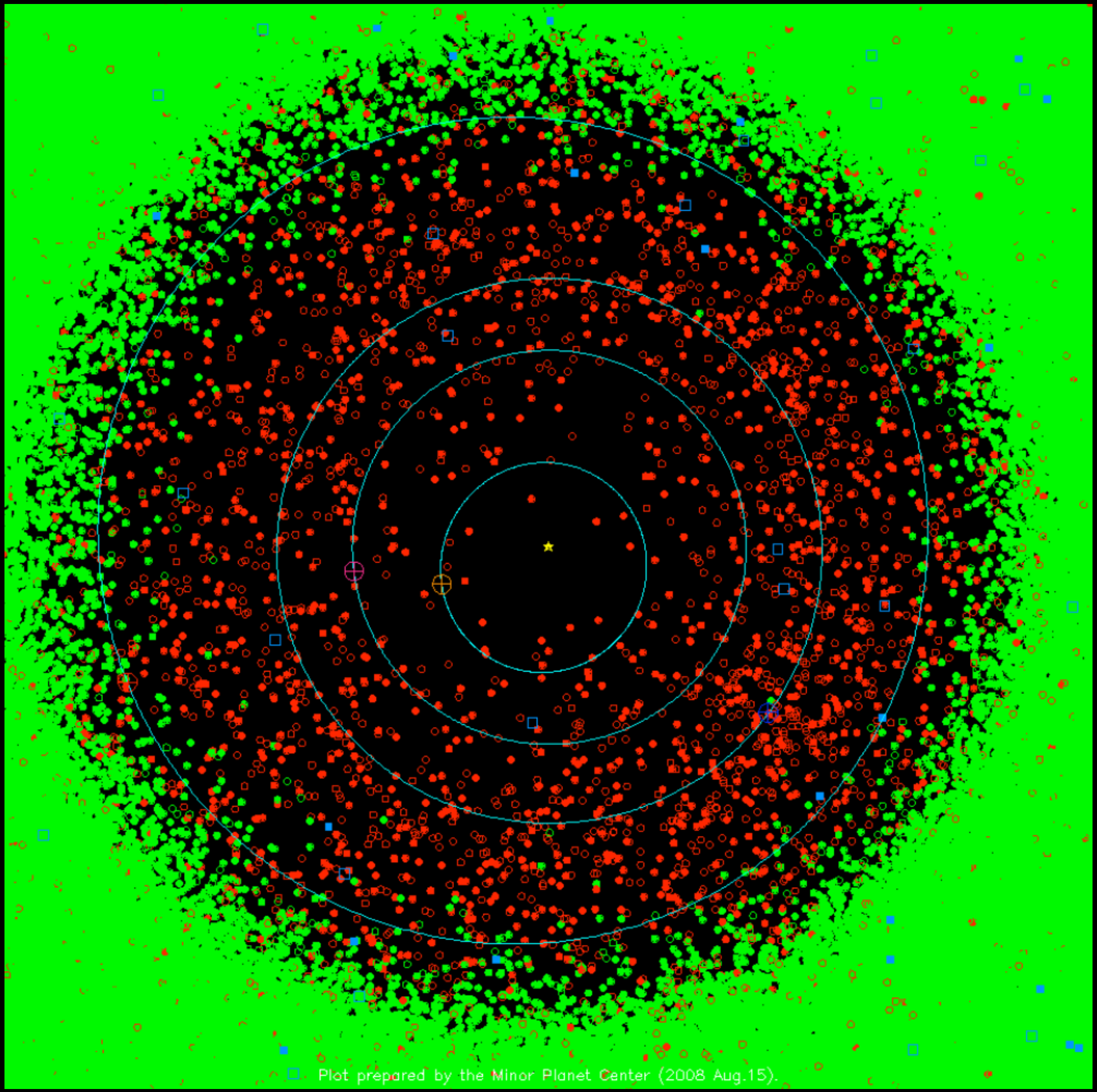
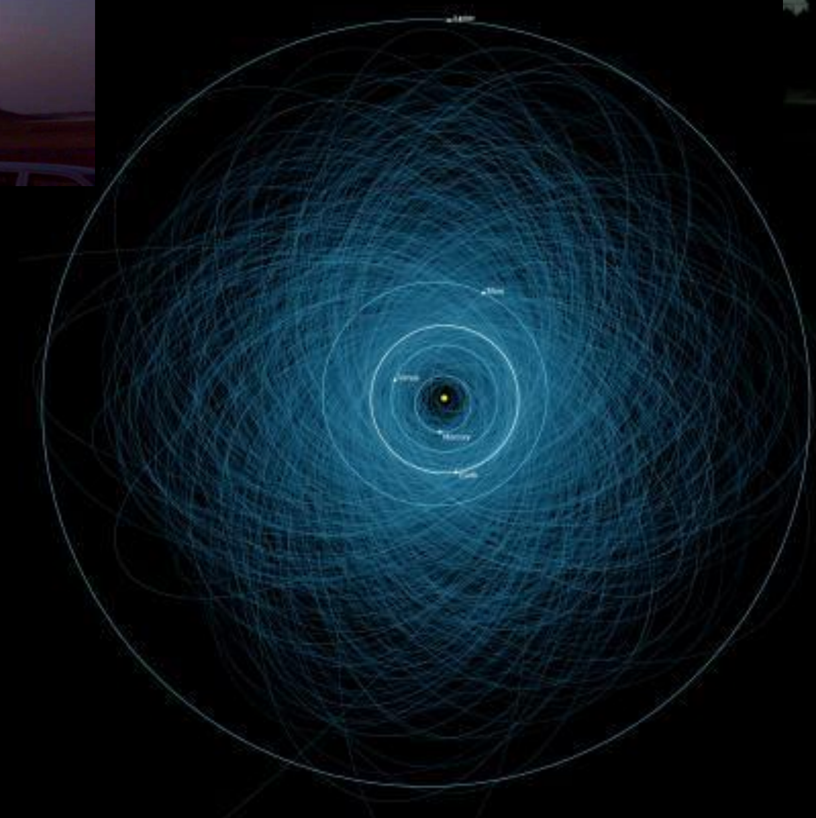
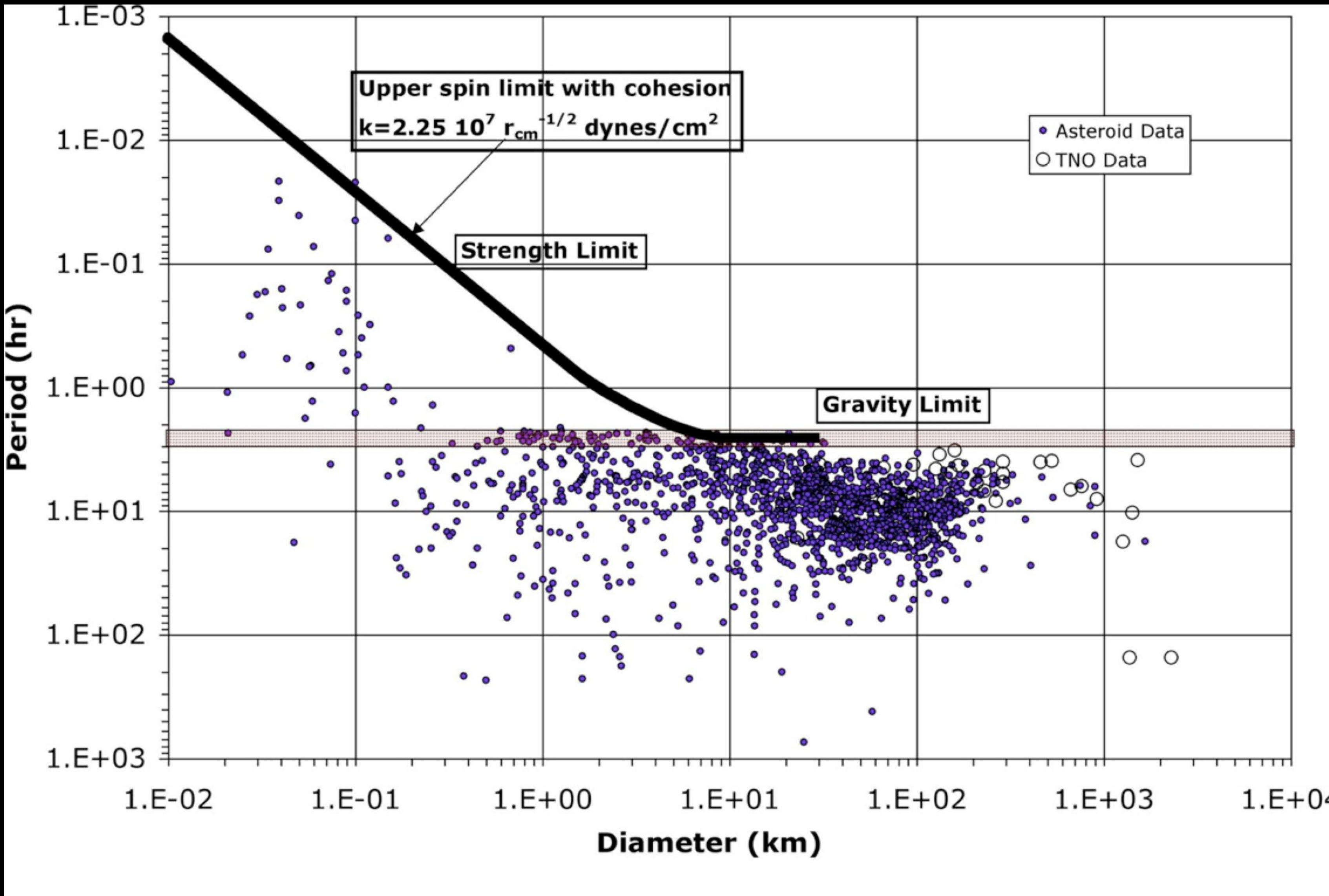
Near-Earth Asteroids (NEAs)



Potentially Hazardous Asteroids

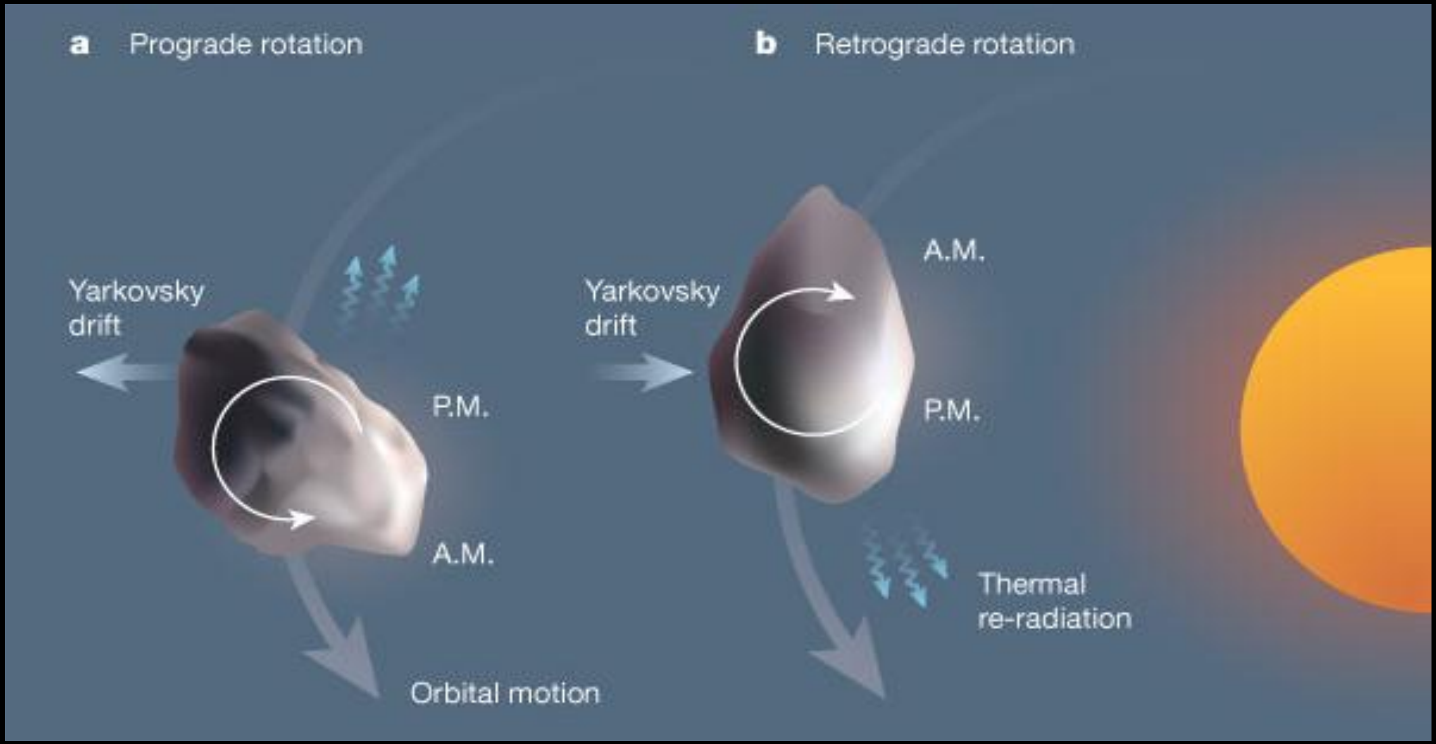


Aggregate Asteroids



Holsapple and Michel (2008)

Yarkovsky Effect

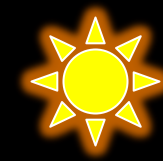


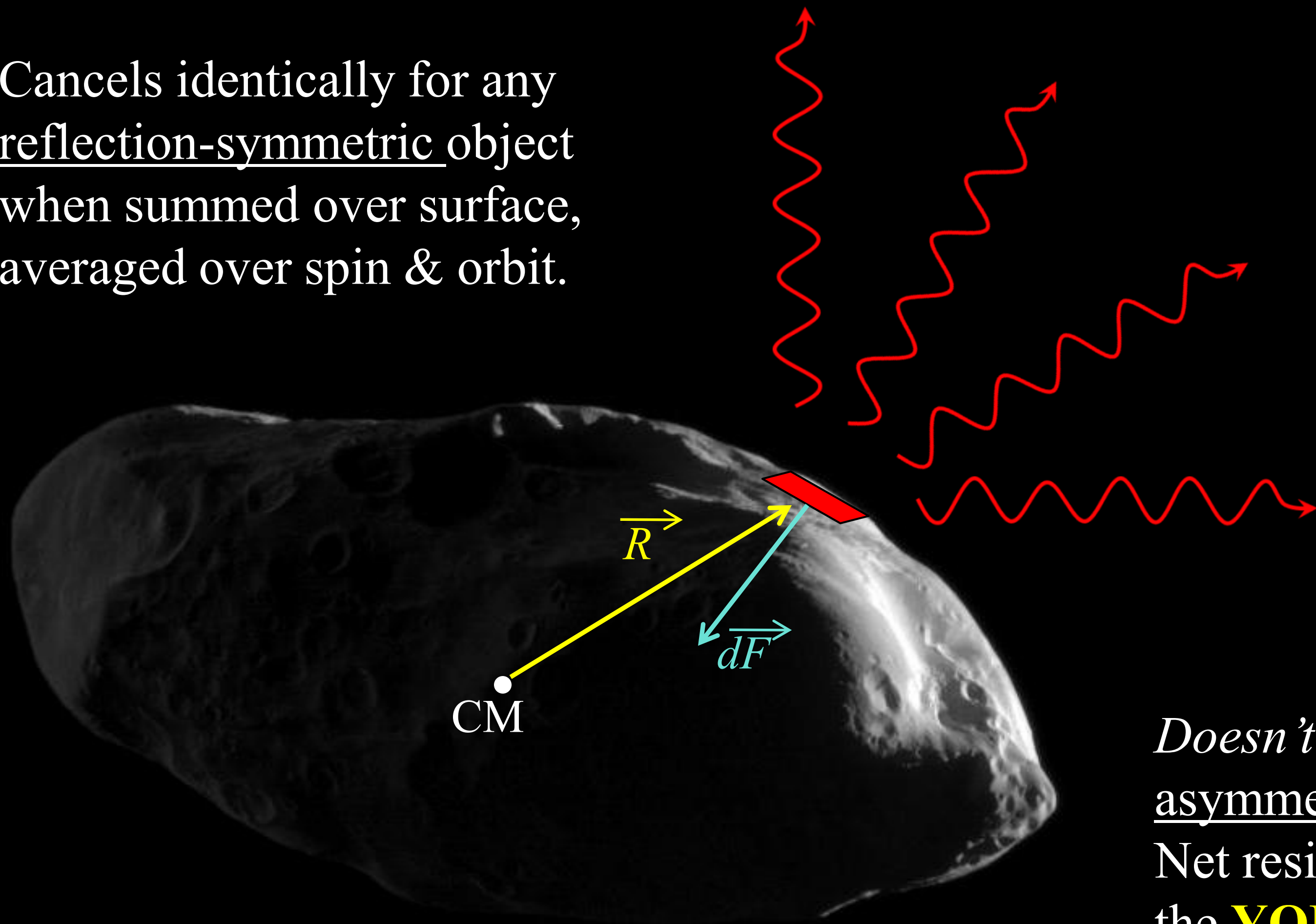
Binzel 2003

Radiation Recoil Torque

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

Cancels identically for any reflection-symmetric object when summed over surface, averaged over spin & orbit.

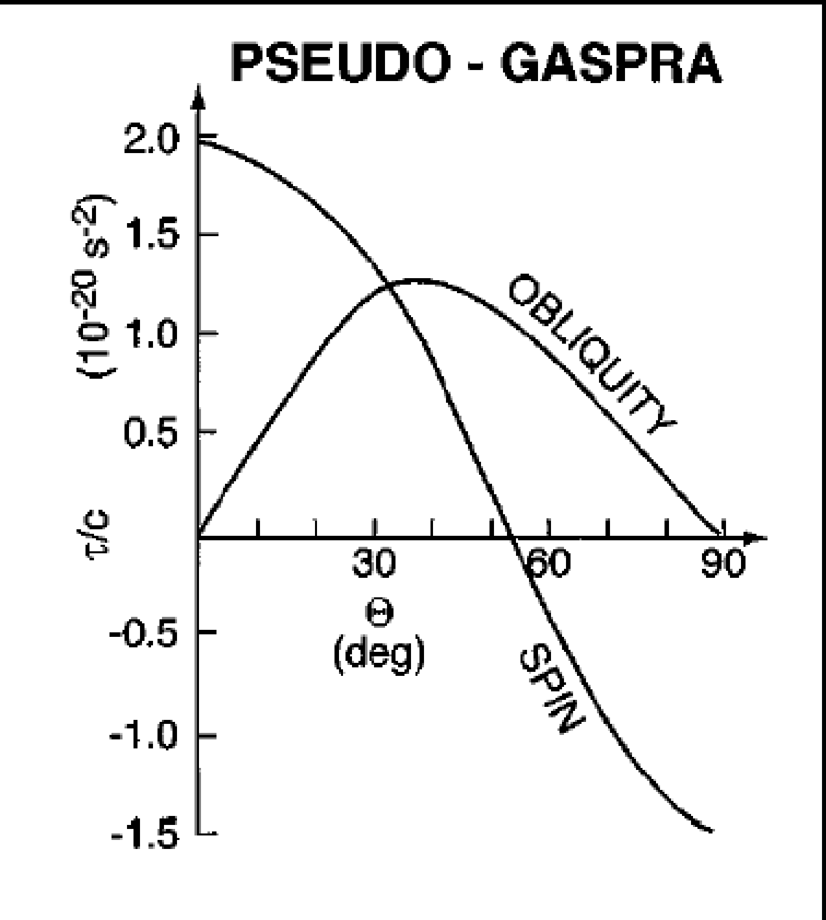


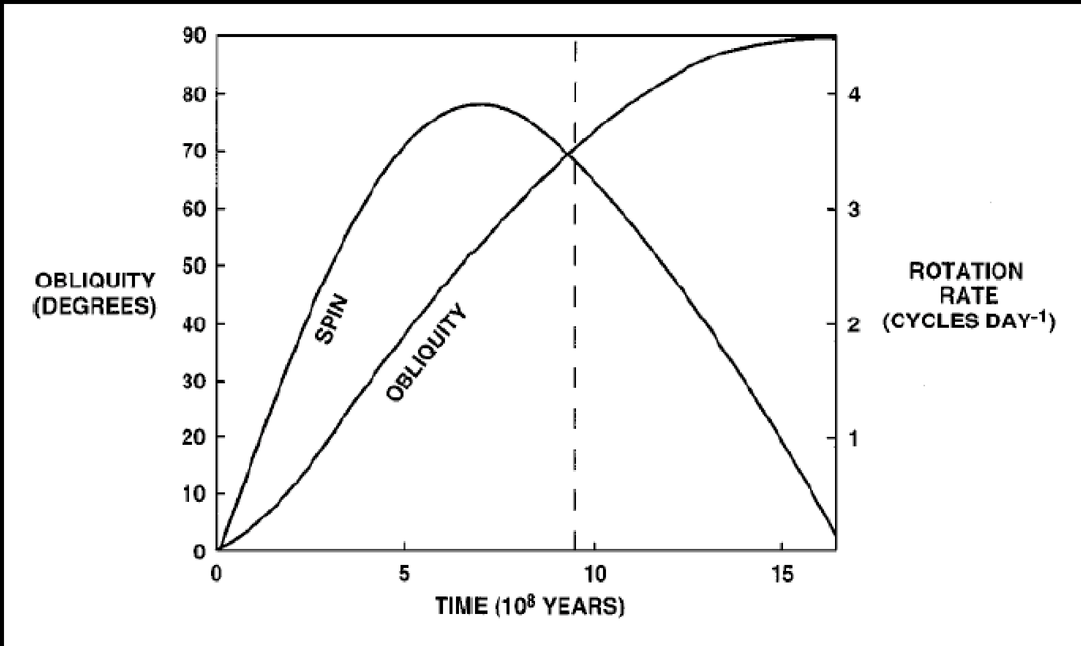


Doesn't cancel for asymmetric objects. Net residual torque is the **YORP Effect**.

T. Statler PDC 2013

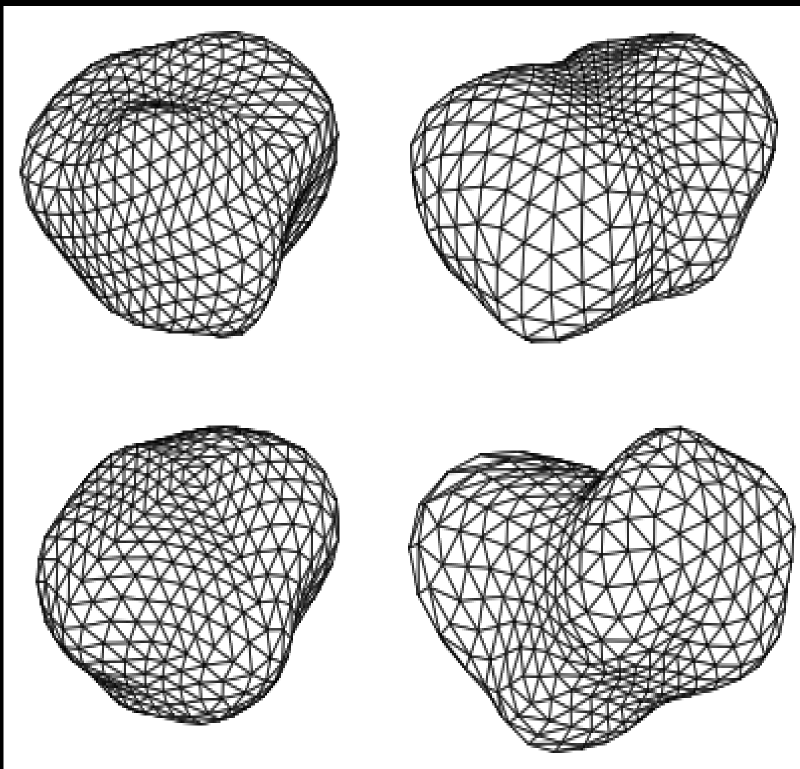
YORP Cycle

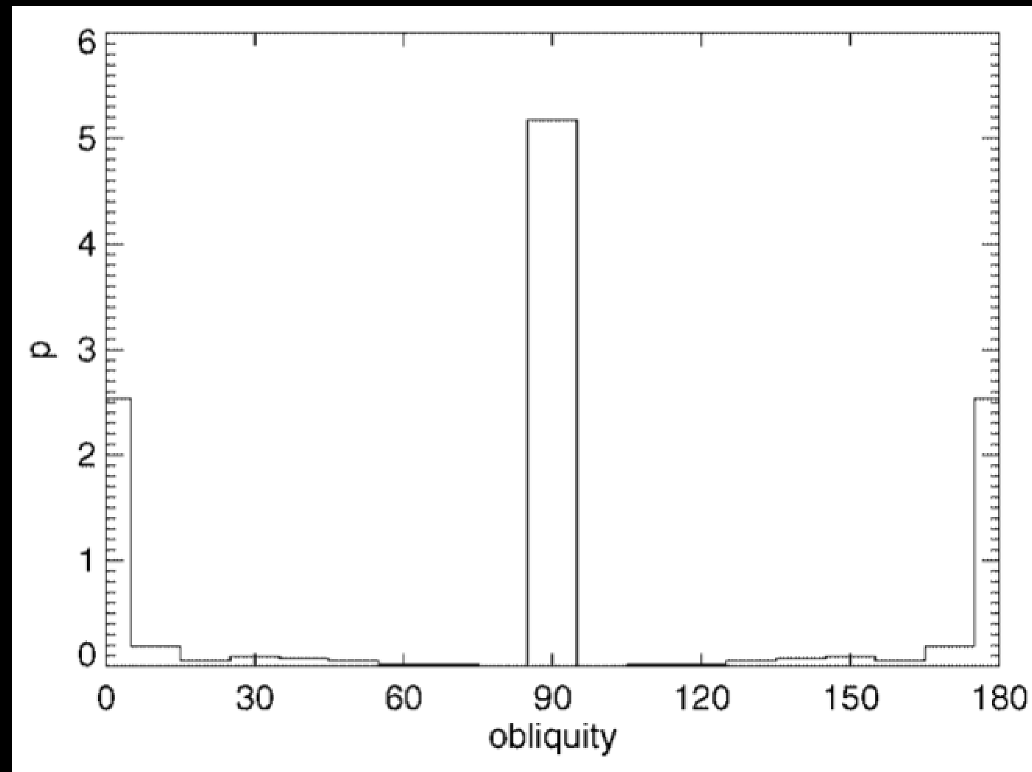




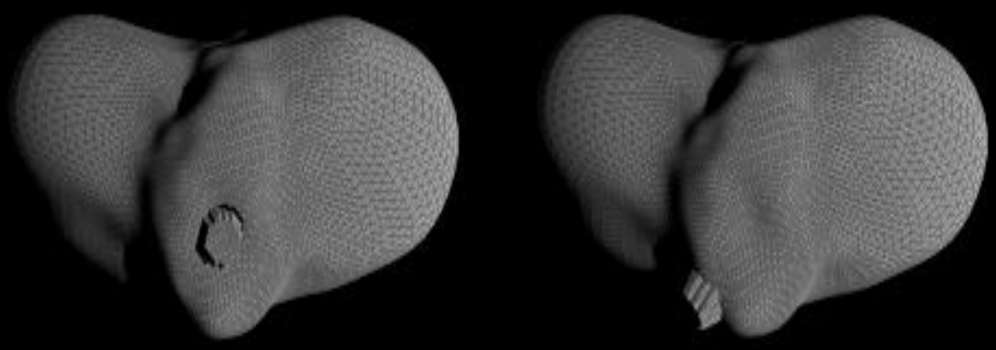
Rubincam (2000)

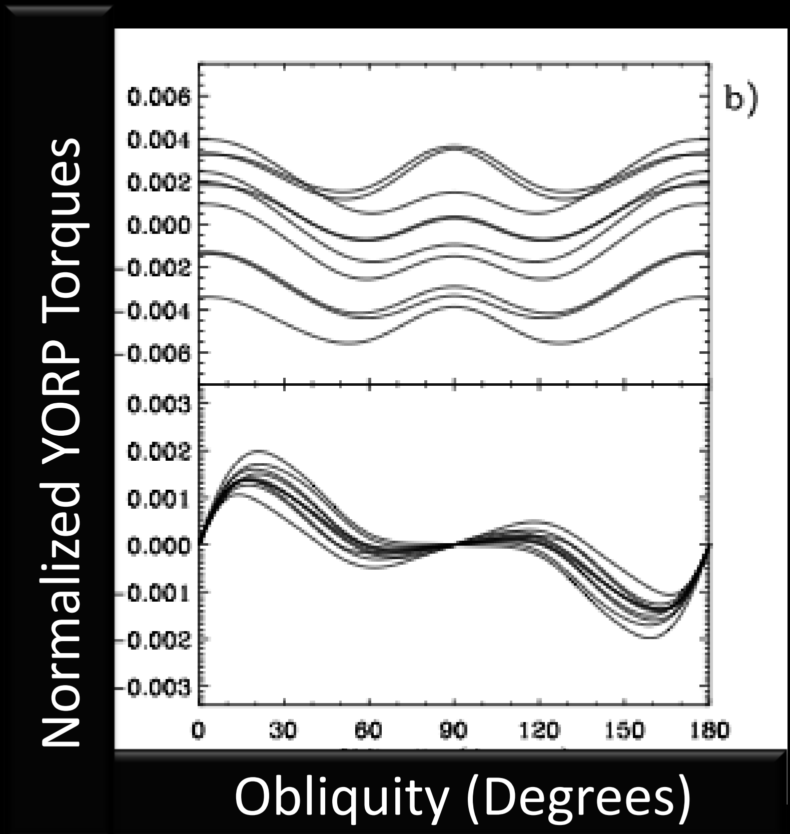
Predicted Obliquity Distribution





Vokrouhlicky and Capek (2002)





❖ The YORP effect has an extreme sensitivity to the topography of asteroids.

Statler (2009)

Open Question

- For rigid bodies, YORP Cycle makes prediction of an obliquity distribution that peaks at 0, 90 and 180 degrees. Therefore, motivation to obtain obliquity distribution.
- You can estimate the obliquity distribution from the Yarkovsky effect.
- Previous studies and a preliminary obliquity distribution obtained in this work using Bayesian inference suggest that the majority of NEAs come through retrograde rotation, which is consistent with delivery models.
- BUT…
- If YORP is a dominant mechanism and the YORP timescales are short (YORP Cycle), the initial spin state should have been forgotten.

Open Question

• YORP spin up may make binaries and top shapes.

• Previous simulations have assumed a constant YORP torque that continuously spin up the object past the point where mass shedding occur.

Walsh et al. 2008

•BUT…

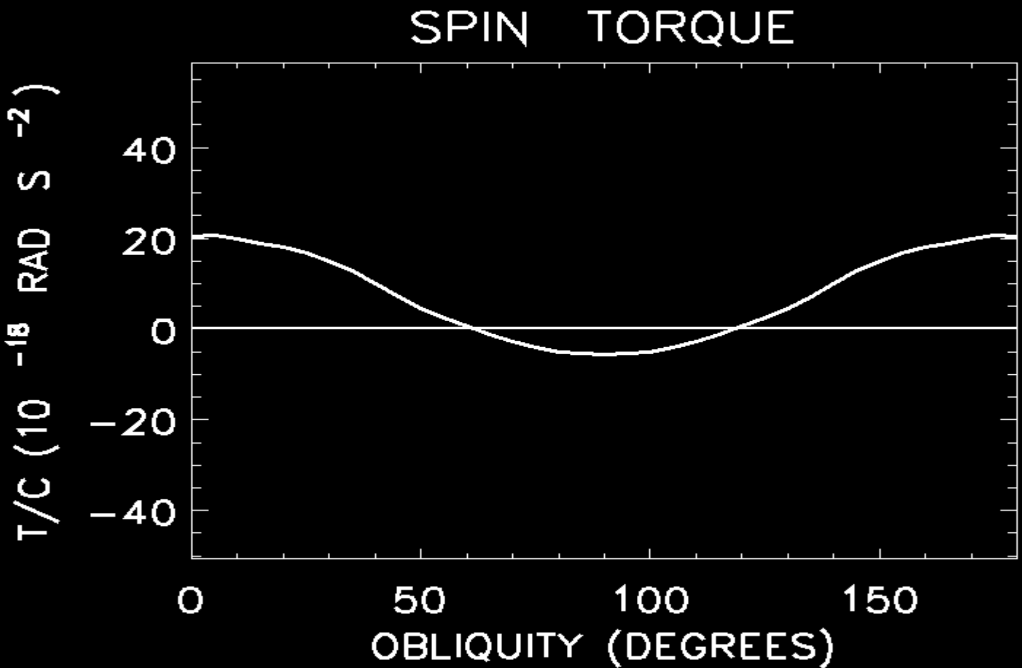
- The time scales over which mass reconfigurations occur are much shorter than the YORP time scales.

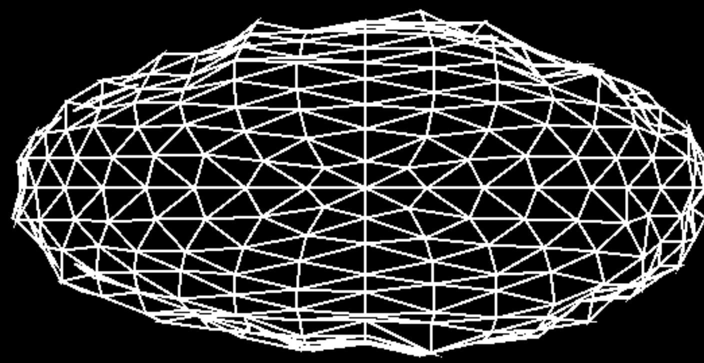
- YORP has an extreme sensitivity to the topography of the asteroids (Statler 2009).

Simulations

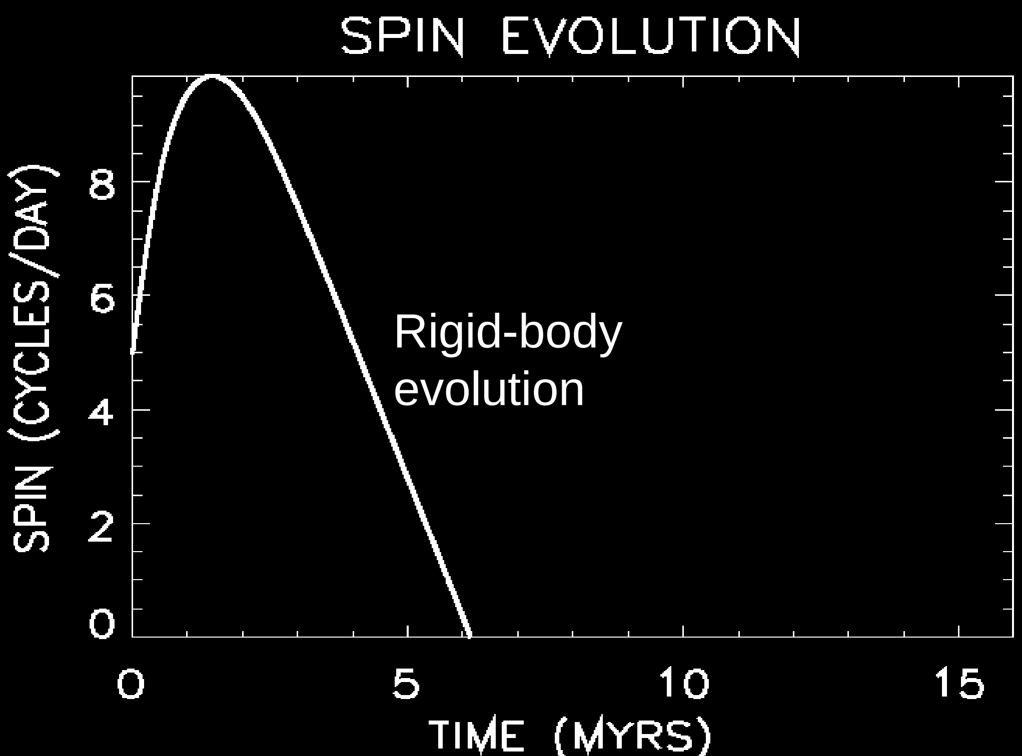
- First simulations that self-consistently model the YORP effect on the spin states of dynamically evolving aggregates.

- We follow the evolution of aggregate objects computing the sequence of spin states and YORP torques through which they evolve as the changing spin alters their shape, which subsequently changes the YORP torques.

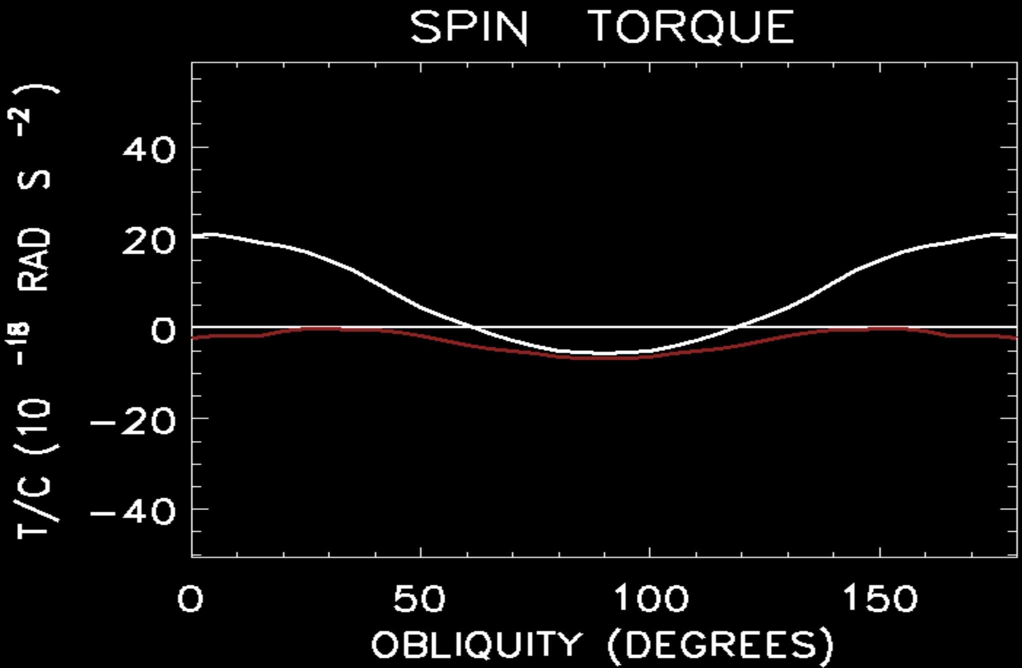


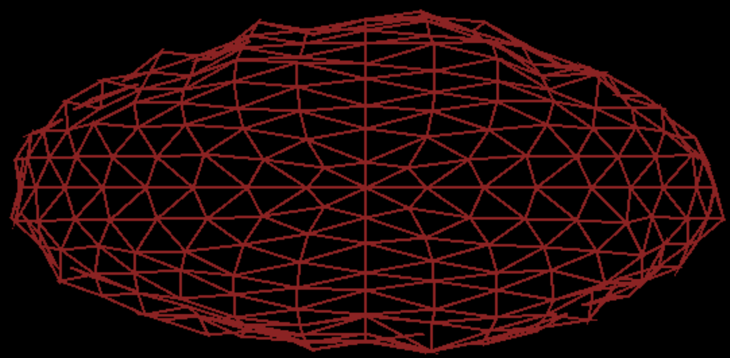


T=0.0 Myrs

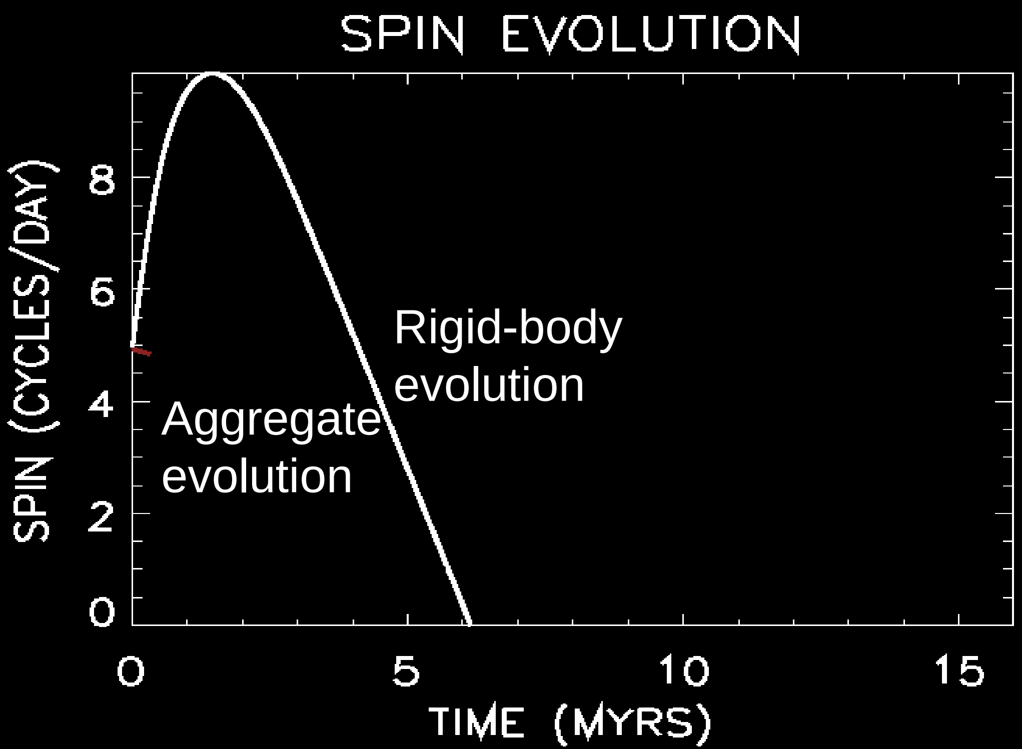


- Initial Object

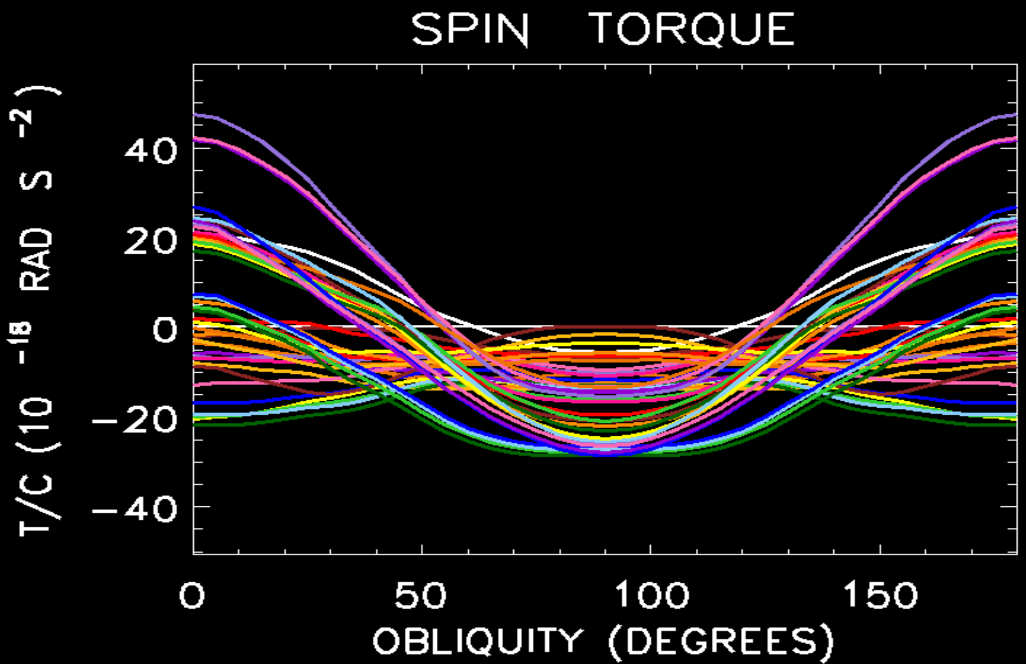


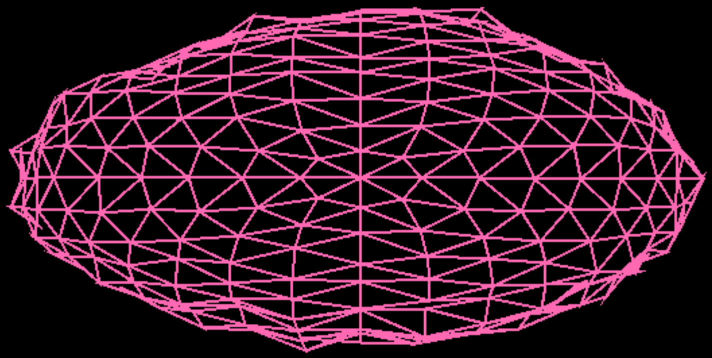


T=0.4 Myrs

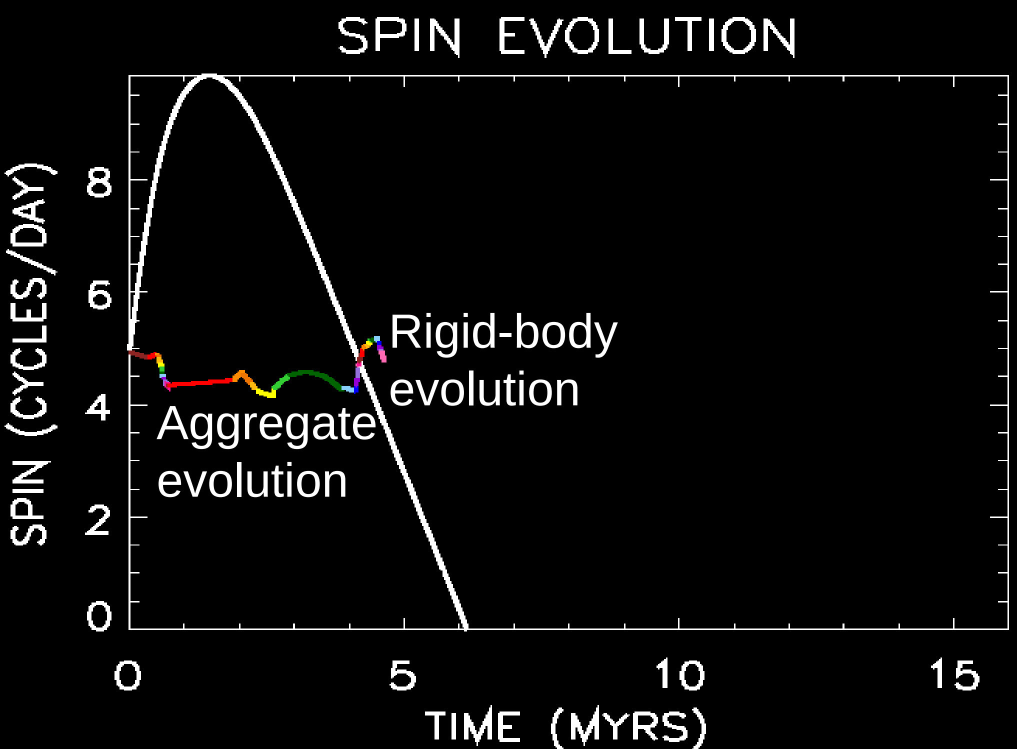


- YORP changes spin
  Spin changes shape
  Shape changes YORP



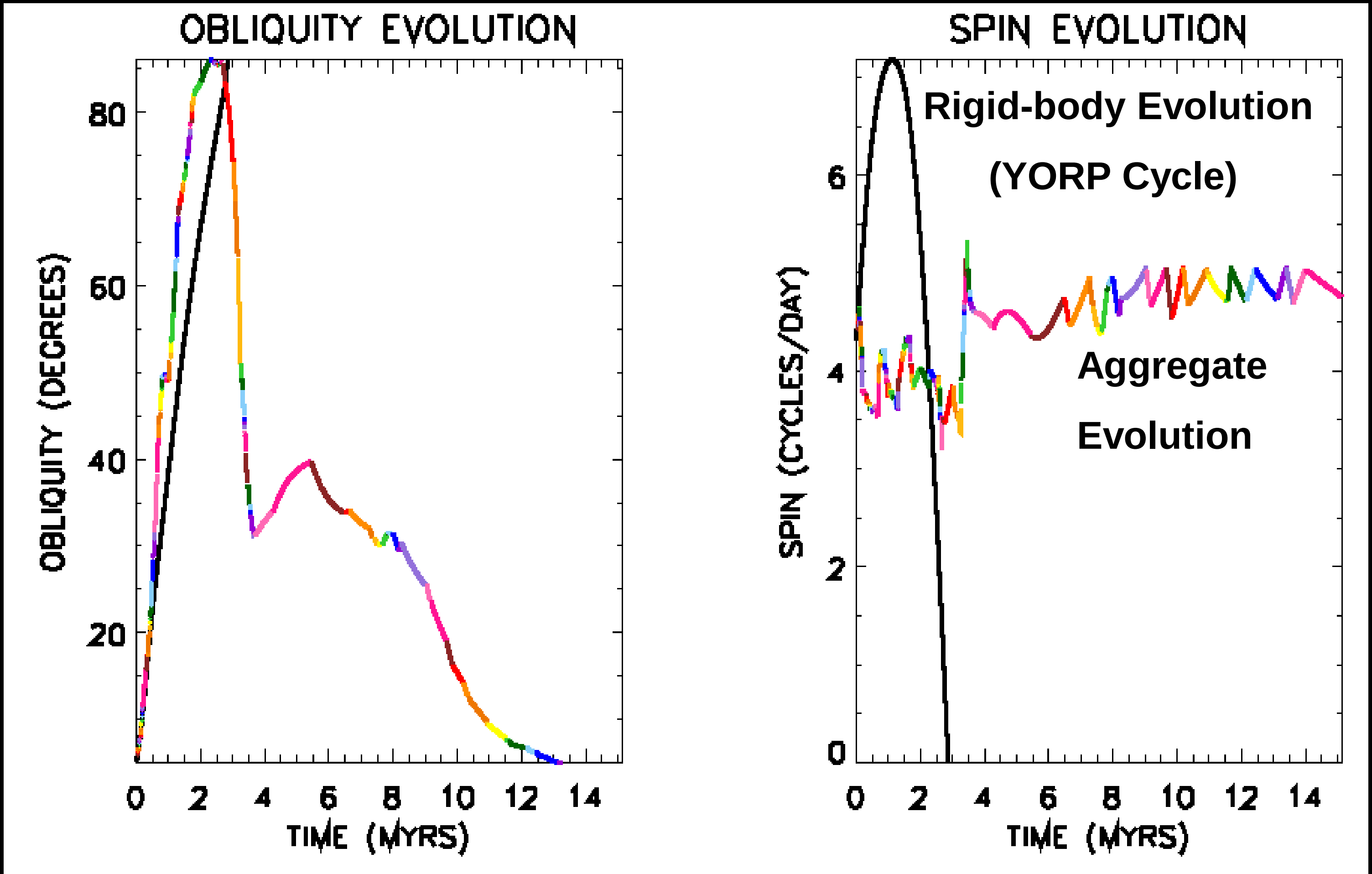


T=4.5 Myrs



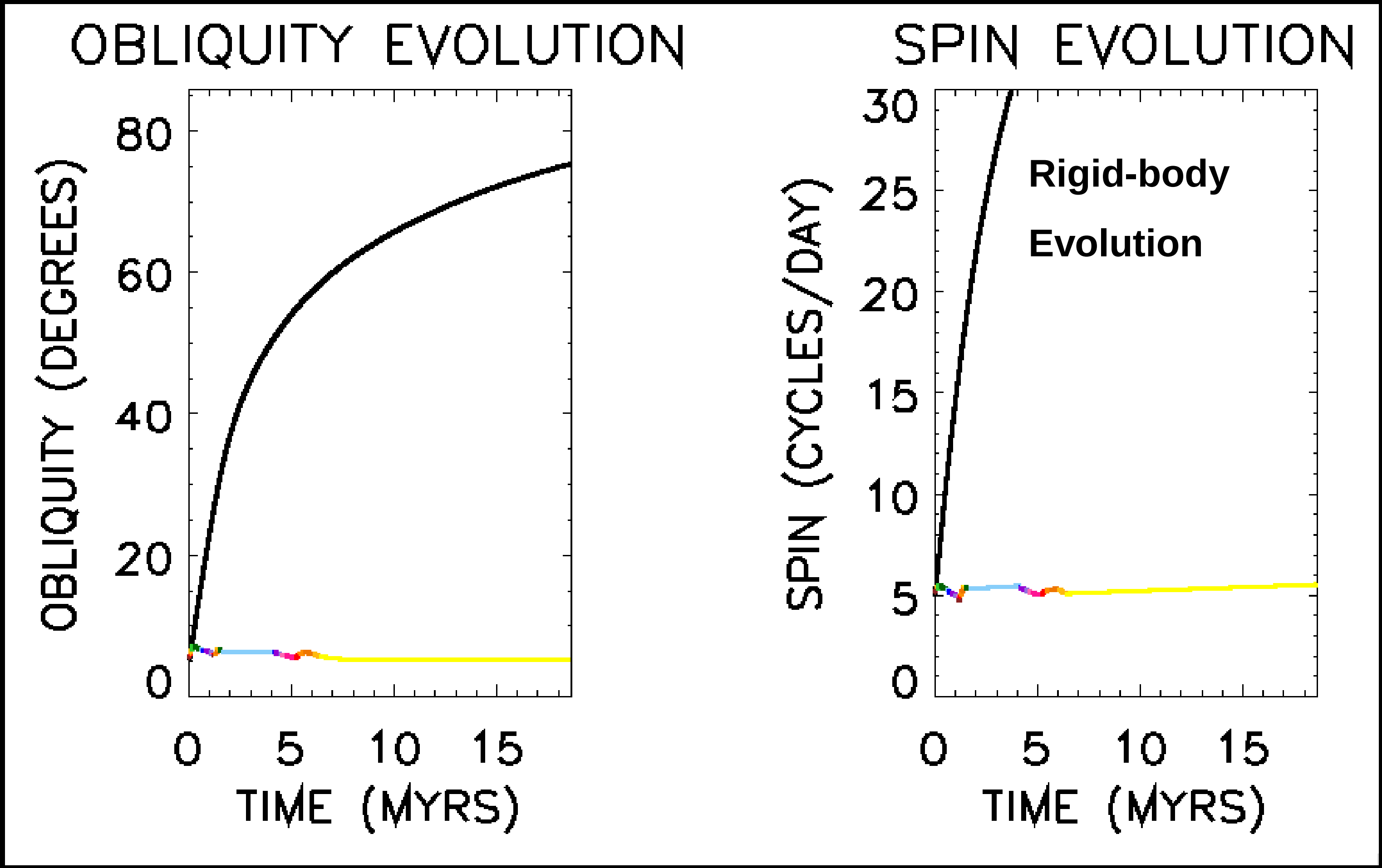
- YORP changes spin
  Spin changes shape
  Shape changes YORP

Self-Limiting YORP



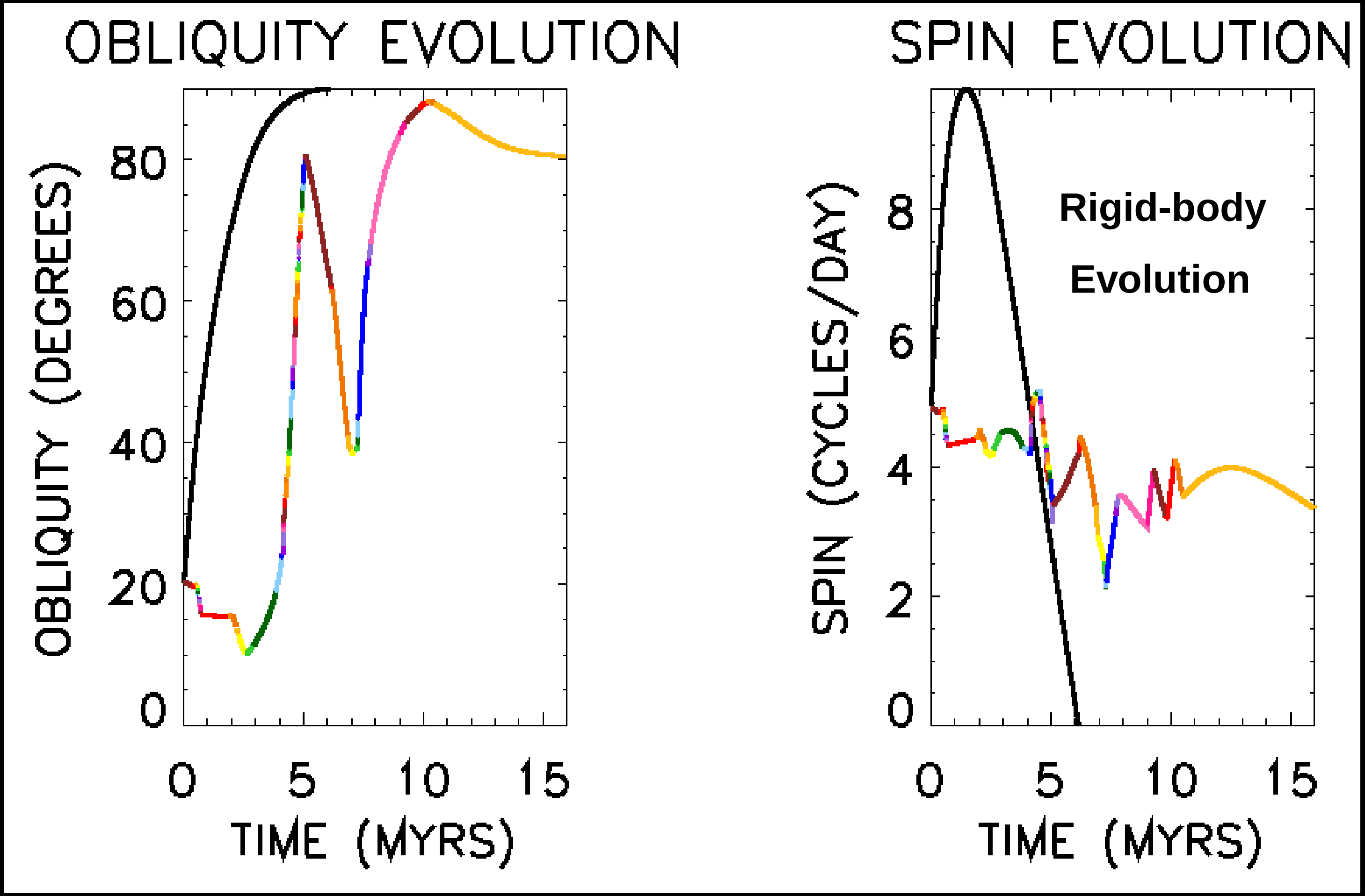
❖ Aggregates don’t follow the YORP cycle

Self-Limiting YORP



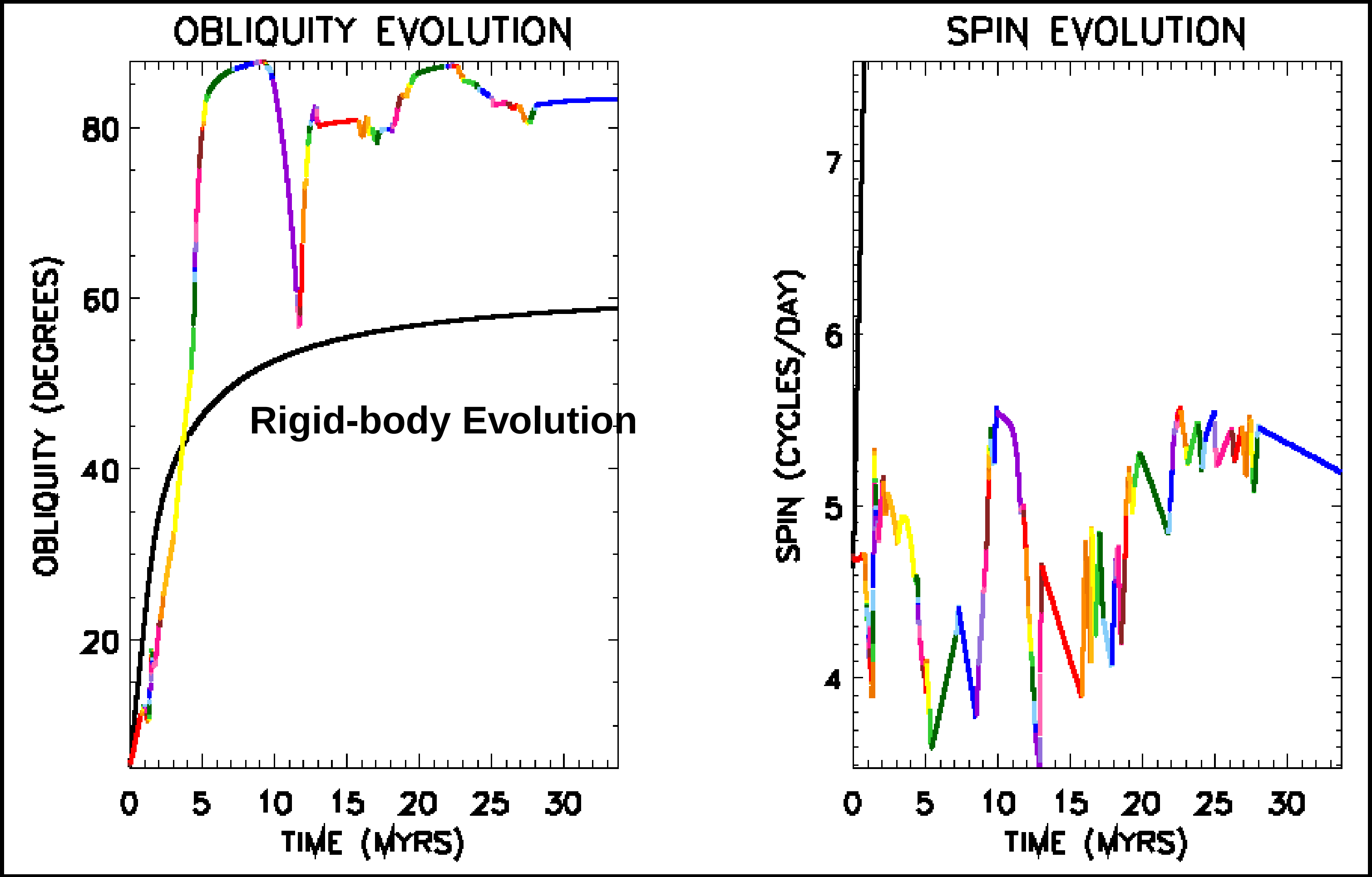
❖ Aggregates don’t follow the YORP cycle

Stochastic YORP



❖ Aggregates don’t follow the YORP cycle

Self-Limiting and Stochastic YORP



❖Aggregates don’t follow the YORP cycle

	Rigid-Body End State			Aggregate End State		
Simulation	Obliquity (deg)	Spin	YORP Cycle (Myrs)	Obliquity (deg)	Spin	N YORP Cycles or Time
1	90	Down	3.59	90	Wander	0.88
2	90	Down	4.25	90	Wander	0.44
3	90	Down	1.64	Wander	Down	2.12
4	90	Down	6.78	Wander	Wander	2.21
5	90	Down	3.67	90	Down	0.45
6	90	Down	7.33	0	Wander	2.79
7	90	Down	1.12	90	Wander	2.19
8	90	Down	16.01	Wander	Down	0.16
9	90	Down	9.30	Wander	Down	0.36
10	90	Down	5.76	0	Wander	7.00
11	90	Down	6.85	Wander	Wander	4.38
12	14	Down	56.09	90	Down	0.34
13	81	Down	49.51	Wander	Down	0.15
14	90	Down	3.62	Wander	Wander	4.17
15	90	Down	2.54	90	Down	2.76
16	90	Up	Infinite	Wander	Wander	18.64 Myrs
17	90	Down	36.39	0	Wander	1.25
18	90	Up	Infinite	Wander	Wander	31.16 Myrs
19	86	Down	2.97	90	Down	0.42
20	90	Down	12.92	0	Wander	2.05
21	64	Up	Infinite	Wander	Wander	33.73 Myrs
22	90	Down	2.86	Wander	Wander	5.28
23	43.5	Down	0.82	90	Wander	14.14
24	32.9	Down	1.77	90	Wander	9.00
25	90	Down	6.15	Wander	Wander	2.60
26	0	Up	Infinite	90	Wander	13.92 Myrs
27	14.9	Up	Infinite	90	Down	6.38
28	90	Down	9.45	90	Down	0.62

23/28 Rigid Bodies spin down to zero.

10/28 Aggregates spin down to zero.

❖Self-limiting and Stochastic YORP prevent the objects from forgetting their initial spin state.

Conclusions

- The most probable value of the fraction of retrograde rotators estimated is 70.0%, which suggest that the whole population of NEAs remember their initial spin state.

- Aggregates DON’T follow the YORP cycle. Instead follow a Self-limiting YORP, a Stochastic YORP or a combination of both.

- Self-limiting YORP and to a lesser degree a stochastic YORP provide a viable means to explain why the NEA population seems to remember their initial spin states.