Coupled spin and shape evolution of small rubble-pile asteroids and self-limitation of the YORP effect

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We present the results of the first simulations that self-consistently model the YORP effect on the spin states of dynamically evolving aggregates. Extensive analyses of the basic behavior of the YORP effect have been previously conducted leading to the idea of the classical "YORP cycle". These studies are based on the assumption that the objects are rigid bodies, but evidence from lightcurve observations strongly suggests that most asteroids are aggregates. The timescales over which mass reconfiguration occur are much shorter than the timescales over which YORP changes the spin states and Statler [2009] has shown that the YORP effect has an extreme sensitivity to the topography of the asteroids (Icarus 202, 501–513). As the YORP effect changes the spin, the change in spin results in a change of the shape, which subsequently changes the YORP torques. The continuous changes in the shape of an aggregate result in a different evolution of the YORP torques and therefore aggregates do not evolve through the YORP cycle as a rigid body would. Instead of having a spin evolution ruled by long periods of rotational acceleration and deceleration as predicted by the YORP cycle, the YORP effect is self-limiting on aggregate asteroids exhibiting a stochastic behavior and/or a self-governed behavior. We provide a description of the stochastic and self-governed behaviors of the YORP effect along with the results of shape evolution including the types, magnitudes, and frequencies of movement and shedding of material. Although rotational acceleration for long periods of time is not achieved, a fraction of objects do present mass-shedding episodes at lower spin rates than the critical spin limit for aggregate asteroids. We also provide the bulk properties of the obtained distribution of changes in the spin rates, which are necessary in order to model correctly the coupled Yarkovsky/YORP evolution.

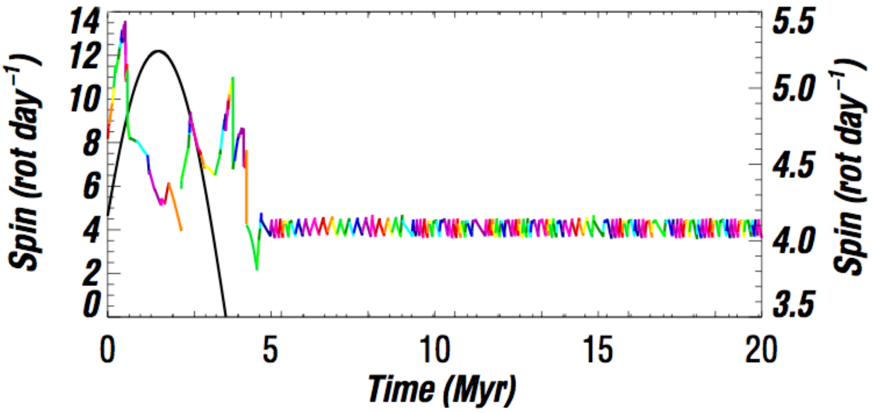

Figure: Self-limitation of the YORP effect. The expected spin evolution of one of the aggregate objects if it was a rigid-body is shown as a black line (left Y-axis) while the actual spin evolution of the aggregate object is shown in a color sequence (right Y-axis). Each different color represents a new shape with a corresponding torque. The spin evolution is stochastic and self-governed. The evolution consist of unpredictably long segments similar to a classical YORP-cycle evolution (stochastic) and of consecutive rapid reversals of the YORP torques (self-governed) as well.