

EVOLUTION OF ASTEROIDS UNDER NON-GRAVITATIONAL TORQUES. O. Golubov^{1,2,3} and D. J. Scheeres¹, ¹Department of Aerospace Engineering Sciences, University of Colorado at Boulder (429 UCB, Boulder, CO, 80309, USA), ²School of Physics and Technology, V. N. Karazin Kharkiv National University (4 Svobody Sq., Kharkiv, 61022, Ukraine, oleksiy.golubov@karazin.ua), ³Institute of Astronomy of V. N. Karazin Kharkiv National University (35 Sumska Str., Kharkiv, 61022, Ukraine).

Introduction: In the talk, we give a review on evolution of an asteroid under joint action of different non-gravitational torques. In the first section, we introduce our three main characters, and then bring them together and make them to act in the following sections.

Non-gravitational torques: There are three main non-gravitational torques exerted on an asteroid by the recoil pressure force of the emitted and scattered light [1].

NYORP, or the normal YORP, is produced by the global asymmetry of the shape of the asteroid [2]. In Figure 1, we illustrate NYORP with the so-called “Rubincam propeller”, the simplest example of an asteroid experiencing NYORP. In general, NYORP can have two components: the axial component, which changes the rotation rate, and the obliquity component, which changes the obliquity of the asteroid’s equatorial plane to the orbital plane. Under the assumption of zero thermal inertia of the soil, NYORP of most asteroids can be quite accurately described by zeroth and first order Fourier harmonics of the obliquity, with a very tight correlation between the coefficients of the decomposition [3,4]. These are the so-called type I/II asteroids according to the classification by Vokrouhlický and Čapek [5]. Still, when the thermal inertia is included, the tight correlation between the coefficients of the Fourier decomposition breaks down. Moreover, for 20-30% of asteroids the fit by zeroth and first order Fourier harmonics fails, and the dependence of NYORP on obliquity becomes much more complicated (type III/IV asteroids). An acceleration, which can be attributed to NYORP, has already been observed for several asteroids [1].

TYORP, or the tangential YORP, is produced by the asymmetric emission of light by individual boulders on the surface of an asteroid [6]. The overall shape of the asteroid and the boulders can be symmetric, but each boulder still tends to emit slightly more light westwards than eastwards, thus accelerating rotation of the asteroid. TYORP is illustrated in Figure 1 with asymmetrically heated boulders on a symmetric asteroid. TYORP has been computed for different geometries of boulders [6,7,8] and different obliquities of asteroids [9]. An analytic approximation has been derived for TYORP and used to integrate it over boulders of different sizes [10]. This results into an approximate analytic expression for TYORP as a function of obliquity, rotation rate, and properties of boulders on the asteroid [3]. TYORP

has not been confirmed by observations, although in some cases discrepancies between the observed acceleration of an asteroid and the predicted NYORP could be attributed to TYORP [7].

BYORP, or the binary YORP, acts upon asymmetric binary asteroids due to their global shape asymmetry [11]. An example of such a system is shown in the lower panel of Figure 1. No observational detections of BYORP have yet been reported.

These three effects are hard to isolate from each other, and often they appear in concert: single asteroids are subject to NYORP and TYORP, while binary asteroids experience all the three effects simultaneously.

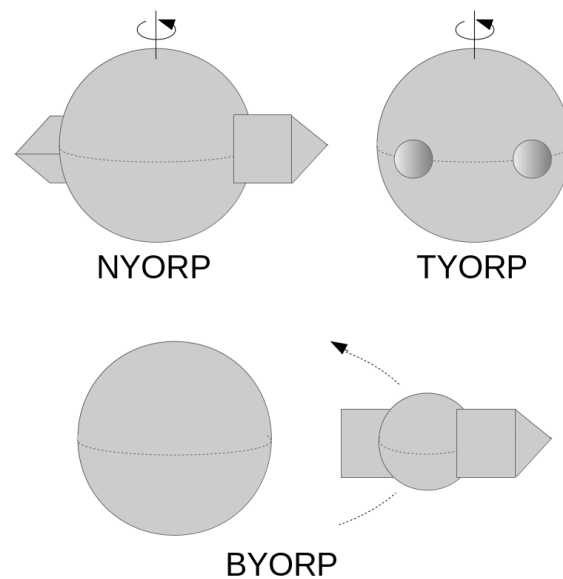


Figure 1. Sketch of the three non-gravitational torques under consideration: NYORP, TYORP, and BYORP.

Evolution under YORP: Non-gravitational torques can accelerate asteroid’s rotation up to the disruption limit. Then the centrifugal forces can cause particles to leave the asteroid, and a satellite can form from the shredded material. The subsequent evolution of the satellite is determined by BYORP, tides and gravitational perturbation exerted by the Sun. These effects can lead to the satellite being lost, and the asteroid starting its evolution anew with a decreased angular momentum. Such periodic accelerations and decelerations of an asteroid are called YORP cycles.

Type I/II asteroids undergo NYORP acceleration in a consistent manner [3]. They can start their evolution at a slow rotation state, accelerate, reach the critical obliquity about 55° , at which the axial component of NYORP changes sign, and then start decelerating. Depending on the initial conditions, such asteroids either reach the disruption limit and form a binary, or return back to slow rotation state, and after some chaotic tumbling, exit it and start a new YORP cycle.

Still, the evolution can be much more complicated if thermal inertia of the asteroid or TYORP are taken into account, or if the asteroid belongs to type III/IV. Under some circumstances, interplay of different non-gravitational torques can lead asteroids to stable rotation states, which can serve as breakers of their YORP cycles.

YORP equilibria: Several types of such equilibria have been studied.

NT-equilibrium can occur for asteroids with small negative NYORP torques. As the angular acceleration produced by NYORP does not depend on the rotation rate, while TYORP changes with the rotation rate, at some particular rotation rate NYORP and TYORP can cancel [3].

NB-equilibrium is possible for doubly synchronous binary systems. As NYORP does not depend on the distance between the asteroids, and BYORP increases with the distance, at the right distance the two effects can compensate each other, creating a stable equilibrium state [12].

NTBt-equilibrium can exist in singly synchronous binary systems. In this case, the primary gets the angular momentum from the combined NYORP-TYORP torque, the secondary loses the angular momentum to BYORP, and tides re-distribute the torque within the binary [13].

The probabilities of these equilibria are estimated to be of the order of a few per cent.

Conclusions: Non-gravitational torques are crucially important for simulation of asteroid populations [14]. We must get a better understanding of values of NYORP, TYORP, and BYORP, of their dependence on the relevant parameters, and the interplay between them, of the role of YORP cycles and YORP equilibria, and this would give us a firm basis to tackle such more general problems as overall evolution of asteroids. Such additional factors as collisions, energy dissipation during tumbling, landslides and mass shredding, must be combined with NYORP, TYORP, and BYORP, as essential ingredients of the grand picture of asteroids' evolution.

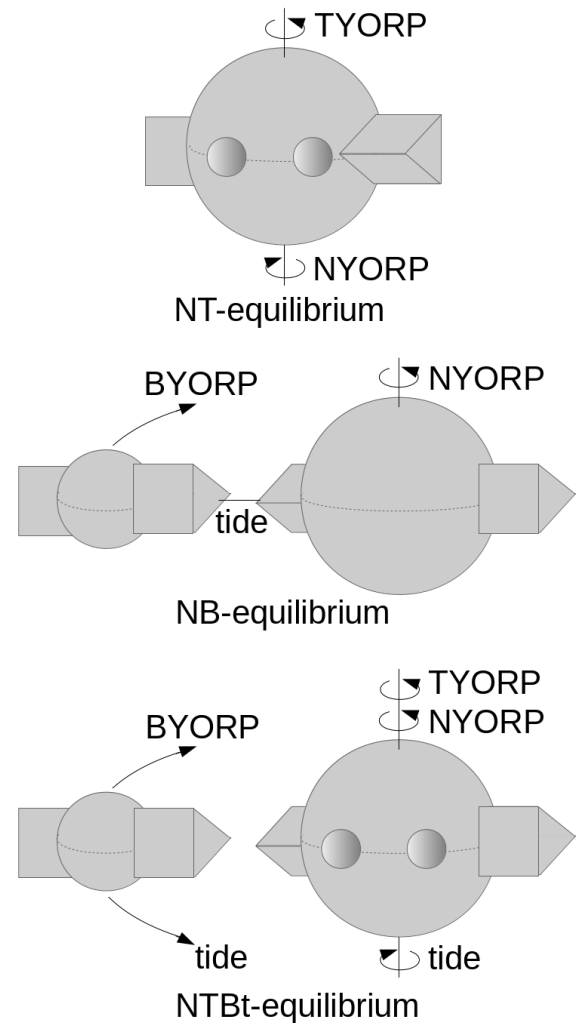


Figure 2. Sketches of three types of equilibria between different non-gravitational torques.

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