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Modelling of the YORP effect

O. Golubov (1,2)
(1) V. N. Karazin Kharkiv National University, Kharkiv, Ukraine, (2) Institute of Astronomy of V. N. Karazin Kharkiv National University, Kharkiv, Ukraine (olexiy.golubov@gmail.com)

Abstract

In the talk I will review the recent advances in the theoretical understanding of the YORP effect. I describe the standard mathematical formalism used for the YORP effect, with the special focus on the limitations of the standard theory and its possible genaralizations. I discuss the sensitivity of the YORP effect to small-scale structures and the novel concept of the tangential YORP, a torque that alters even the rotation of symmetric asteroids due to uneven heat conductivity in small stones composing the surface. Finally, I consider the overall evolution of an asteroid experiencing the YORP effect.

1. Introduction

The Yarkovsky–O'Keefe–Radzievskii–Paddack (or YORP) effect was first proposed by Rubincam in 2000 as recoil torque produced by light emitted or scattered by an asteroid [6]. Since then it established itself as a primary driving force causing evolution of rotation states of small asteroids, acquired many observational confirmations and a sophisticated theoretical description[9].

2. Normal YORP effect

The YORP effect of a convex asteroid with no thermal inertia can be expressed as a surface integral of a function depending on the properly averaged illumination [8].

Equations from [8] deduced for convex asteroids appear to provide a descent approximation for moderately concave shapes. This approach can also be generalized for the case of non-zero thermal inertia [4]. The genaralization is significant only for the obliquity component of the effect, while the axial component of YORP under very broad conditions does not depend on the thermal model. Considering elliptical orbits and scattering laws other then Lambert's present additional amendments of the YORP theory [4].

3. Sensitivity of YORP to small scale structure

Most approachas to the normal YORP rely on local flatness of the surface. But the YORP effect is sensitive to roughness of the surface on the small scale [7]. Asteroid (25143) Itokawa is an especially interesting case, as a high resolution shape model is available for it, but still theoretical predictions for the magnitude of the YORP acceleration differ greatly not only from the observed acceleration, but even with each other [3]. Decomposing the shape of the asteroid into spherical harmonics allows to estimate the error in the YORP acceleration (see the talk by U. Pyrohova).

4. Tangential YORP

Tangential YORP (or TYORP) presents another alteration of the notion of YORP originating from non-flatness of the surface. TYORP appears due to uncompensated heat fluxes through small stones on the surface of an asteroid, causing preferrential emission of infrared radiation eastward rather than westward, and a recoil pressure spinning up the asteroid. TYORP always acts in concert with the normal YORP (or NYORP), and although TYORP force is about two orders of magnitude less than NYORP force, the two torques can be comparable, as NYORP torques of different parts of the surface tend to subtract, while TYORP torques tend to add up. The effect was initially simulated in one-dimentional model [2], then with three-dimentional spherical stones [3], but simulations in more realistic models are still necessary.

5. Overal evolution of rotation state

Distribution of small asteroids over rotation rates and obliquities is formed predominantly by the YORP torques, which continiously alter the angular momentum of the asteroid [5].

If in the course of this alteration an asteroid acquires too big angular momentum, centrifugal forces acting on the surface can make the shape of the asteroid unstable. Then landslides will start changing the shape, which will also influence the YORP acceleration and possibli stop the further increase in the rotation rate. If it does not happen, the asteroid can increase its rotation so much, that matter starts escaping its surface. The escaping matter can form a satellite, which will eventually leave the primary asteroid, carying a substantial fraction of the angular momentum.

6. Unanswered questions

Still, many important questions remain unanswered.

1. *Global evolution of rotation state.* The question of how the YORP torques translate into global evolution of rotation state has been addressed only in a simplified one-dimensional model with no consideration of the obliquity change [5], while the coupled evolution of obliquity could substancially change the results.

2. *Sensitivity to small-scale structure.* YORP is known to be sensitive to small-scale structure of the surface [7], but a more elaborate error estimate for real shape models of asteroids is necessary. Moreover, Itokawa paradox still persists [3].

3. *Disruption of fast rotators.* For fast rotators, the mechanics of landslides, disruption, and satellite formation are still poorly understood.

4. *Tumbling.* For slow rotators, there is still no self-consistent description of tumbling, including the YORP torque and inelastic energy dissipation.

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