Modeling of the Yarkovsky and YORP effects

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The Yarkovsky and YORP effects are now widely regarded to be fundamental mechanisms, in addition to collisions and gravitational forces, which drive the dynamical and physical evolution of small asteroids in the Solar System [1]. They are caused by the net force and torque resulting from the asymmetric reflection and thermal re-radiation of sunlight from an asteroid's surface. The net force (Yarkovsky effect) causes the asteroid's orbit to drift outwards or inwards depending on whether the asteroid is a prograde or retrograde rotator. The first direct measurement of Yarkovsky orbital drift was achieved by sensitive radar-ranging on the near-Earth asteroid (NEA) (6489) Golevka in 2003 [2]. The net torque (YORP effect) changes the asteroid's rotation rate and the direction of its spin axis. It can cause an asteroid to spin faster or slower depending on the shape asymmetry, and the first direct measurement of the YORP rotational acceleration was achieved by lightcurve observations on NEA (54509) YORP in 2007 [3]. Since these first direct detections, the Yarkovsky orbital drift has been detected in several tens of NEAs [4,5], and the YORP rotational acceleration has been detected in four more NEAs [6–9]. Indirect evidence of the action of these two effects has also been seen in the populations of NEAs [10], small main-belt asteroids [11], and asteroid families [12]. Modeling of these effects allows further insights into the properties of detected asteroids to be gained, such as the bulk density, obliquity, and surface thermal properties. Recently, high-precision astrometric observations of the Yarkovsky orbital drift of PHA (101955) Bennu were combined with suitable models informed by thermal-infrared observations to derive a bulk density with an uncertainty comparable to that of in-situ spacecraft investigations [13]. Also, the recent YORP effect detection in (25143) Itokawa was combined with a model utilizing the highly detailed Hayabusa–derived shape model to infer an inhomogeneous internal bulk density distribution [9]. Prediction and interpretation of these two effects are therefore critically dependent on accurate models that describe how asteroids reflect and thermally re-radiate sunlight.

Yarkovsky and YORP effect models must take into account an asteroid's size and shape, mass and moment of inertia, surface thermal/reflection/emission properties, rotation state, and its orbit about the Sun. A variety of analytical, numerical, and semi-analytical models have been developed over the past decade to study these effects with different levels of detail. The Yarkovsky effect is driven by a morning-afternoon temperature asymmetry during a rotation (diurnal effect) or orbit (seasonal effect) that arises on asteroids with non-zero thermal inertias. Models show that this temperature asymmetry can be enhanced by surface roughness through thermal-infrared beaming effects [14]. YORP rotation rate changes are driven by shape irregularities where photon torques induced on opposite sides of the body do not cancel out. These rotation rate changes have been shown to be independent of thermal inertia for asteroids larger than the thermal skin depth [15]. The YORP effect has also been shown to be highly sensitive to small-scale shape variations [16], surface roughness [14], and the shape model resolution [17] such that the uncertainty in any prediction could be very large. However, recent work has shown that this sensitivity could be less than previously thought when both shadowing and global self-heating effects are included [18], and/or when the induced YORP rotation rate change is relatively large [19]. Recently, a new model has been developed that can simultaneously interpret thermal-infrared observations and predict the Yarkovsky/YORP effects for the derived properties, and has been verified against observations for NEA (1862) Apollo [20]. Also, a "tangential-YORP" model has been proposed to explain why only YORP rotational acceleration has been observed when YORP rotational deceleration should also be observed in equal numbers [21].

In the talk, the latest Yarkovsky and YORP modeling techniques and methods will be reviewed, and the future directions of such modeling efforts will be discussed.

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