THE YORP EFFECT AND THE SPIN OF SMALL ASTEROIDS. D. P. Rubincam[1] and W. F. Bottke[2]. [1]Geodynamics Branch, Code 921, Laboratory for Terrestrial Physics, NASA's Goddard Space Flight Center, Greenbelt, MD 20771. email:rubincam@denali.gsfc.nasa.gov. [2]Center for Radiophysics and Space Research, Cornell University, Ithaca, NY 14853.

The YORP effect can spin up or down small asteroids and alter their obliquities. YORP stands for Yarkovsky-O'Keefe-Radzievskii-Paddack [1]-[4]. The YORP effect is due to sunlight shining on a body freely floating in space. A dark asteroid absorbs the energy in the sunlight and re-emits it in the infrared. The infrared photons carry momentum according to the relation p = E/c, where p is the momentum of the photon, E is its energy, and c is the speed of light. By action-reaction, the asteroid will suffer recoil as the infrared photons leave its surface. The photon kicks will not cancel out if the asteroid has a suitable "windmill" shape and will experience a net torque. This torque is independent of the sense of rotation of the asteroid and can spin it up or down. The torque can also change the asteroid's obliquity (obliquity = tilt between the asteroid's equator and its orbital plane).

The YORP effect has been investigated for 5 hypothetical asteroids, called here pseudo-asteroids, whose properties are based on the following real objects: 243 Ida, 433 Eros, and 951 Gaspra, and Phobos and Deimos. Each pseudo-asteroid is assumed to be a black body and in principal axis rotation. Each is assumed to orbit the Sun at the same distance as their real counterparts, except in the case of Pseudo-phobos and Pseudo-deimos, which orbit the Sun at 3 AU, in order to place them in the main belt. All have the same density as their real counterparts except for Pseudo-gaspra, whose density is taken to be 3 g per cubic centimeter (the density of the real Gaspra is unknown). Their sizes are allowed to vary, but their shapes remain the same. The shape of each is a smoothed, spherical harmonic expansion of the shape of the real body, truncated at degree and order 12 for all pseudo-asteroids except Pseudo-deimos; its shape is truncated at degree and order 6, since degrees 7 through 12 do not contribute much to the YORP effect.

It turns out that 4 out of the 5 objects are suitably shaped for the YORP effect; only Pseudo-phobos is too symmetrical for be affected by YORP very much. Though these statistics are small, they may indicate that many small objects may be susceptible to YORP.

All the pseudo-asteroids show similar YORP torques: the torque which speeds up rotation is maximal when the Sun lies in the equator and decreases to zero at obliquities near 50 to 60 degrees; for higher obliquities it goes negative. Between zero to 90 degrees the obliquity torque is always positive, so that zero obliquity is an unstable state.

This lead to the concept of the YORP cycle, wherein a slowly rotating asteroid starting with a small obliquity increases its rotation rate while tipping over more and more; eventually the asteroid tips over so far that it starts slowing down its spin. At some point it will reverse either its spin or spin so slowly it will tumble; with tumbling YORP shuts off until the object re-establishes principal axis rotation. In either case the cycle begins all over again. Integrating 951 Gaspra's present spin and obliquity forwards and backwards gives a YORP cycle of about 1.5 bilion years from slow rotation to speed up to slow rotation again, assuming it has Pseudo-gaspra's shape. The YORP timescale for the actual asteroid may be as much as twice as fast because its density may be lower than assumed , and because the smoothed shape appears to underestimate YORP. The timescales for Pseudo-deimos and a 6 km Pseudo-ida have timescales comparable to Gaspra. 433 Eros has a YORP cycle of about 500 million years. With its present high obliquity, Eros should be spinning down.

Smaller objects spin up even faster due to the (radius) squared dependence of the YORP timescale, so that a 1 km radius Pseudo-gaspra has a YORP cycle of 40 million years, while for a 1 km Pseudo-eros it is 14 million years. YORP should be competitive with collisions and tidal encounters as a way of altering spin states for kilometer-sized asteroids.

Meteoroids can change their spin states on a timescale faster than their cosmic ray exposure ages. This would have implications for the delivery of meteoroids to the resonances via the Yarkovsky effect.

References [1] O'Keefe J. A. (1976) *Tektites and Their Origin*, Elsevier, New York. [2] Paddack S. J. (1969) *J. Geophys. Res. 74*, 4379. [3] Radzievskii V. V. (1954) *Dokl. Akad. Nauk SSSR, 97*, 49. [4] Sazanov V. V. (1994) *Solar System Res., 28*, 152.