Spin control for asteroids

Richard P. Binzel

Random collisions between asteroids would seem to cause their spin axes to be tilted in all directions. Surprisingly, the gentle recoil force of thermal re-radiation may bring their spin axes into alignment.

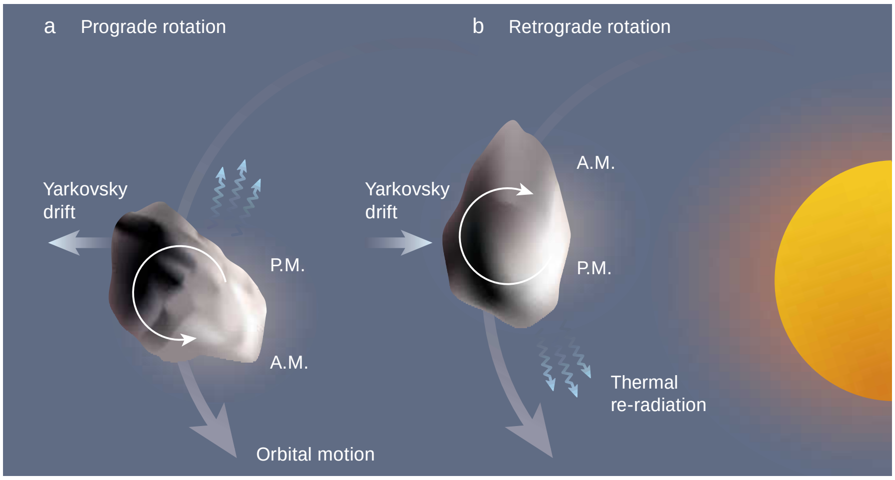

Figure 1 **The Yarkovsky effect. An asteroid is warmed by sunlight, its afternoon side becoming hottest. As a result, that face of the asteroid re-radiates most thermal radiation, creating a recoil force on the asteroid and causing it to drift a little. The direction of the radiation depends on whether the asteroid is rotating in a prograde (anticlockwise) manner (**a**) or in a retrograde (clockwise) manner (**b**).**

Influencing the public perception of a political story might seem like small potatoes compared with controlling the spin of the mountain-sized rocks in space that we call asteroids. These leftover building blocks from the era of planetary formation have undergone random and relentless collisions that have sculpted their shapes over the past 4.5 billion years. These bumps in the night should result in random orientations of the asteroids' spin axes, yet observations have revealed unexpected spin alignments[1]. On page 147 of this issue, Vokrouhlický *et al.*[2] show how the slow but steady recoil force of thermal re-radiation can win out over the heavy hand of collisions in controlling the direction of asteroid spins.

Planetary bodies such as asteroids maintain an equilibrium temperature by re-radiating (at thermal infrared wavelengths) the same amount of energy that they absorb from sunlight. In about 1900, I. O. Yarkovsky[3,4], a Russian engineer, wrote about the effect that this recoil could have on the motion of a planetary body (Fig. 1). The 'Yarkovsky effect' relies on the same principle that drives more swimmers to the beach in the afternoon than in the morning — the afternoon side of a rotating planet is hotter as a consequence of having absorbed a full day's worth of sunshine. Being hottest, the afternoon side therefore produces the greatest amount of thermal re-radiation. Yarkovsky reasoned that the recoil from this one-sided thermal re-radiation could preferentially slow down or speed up the orbital velocity of an asteroid, depending on whether the tilt of its spin axis meant that its afternoon side faced forwards or backwards. The resulting 'Yarkovsky drift' is most effective for small asteroids and might be a key component in the delivery of meteorite samples from the asteroid belt to the Earth[5].

Thermal re-radiation was also recognized to have some effect on the spin rate and orientation of an asteroid, dubbed the 'YORP effect' after the names of researchers who detailed the mechanics involved[6] (Yarkovsky, O'Keefe, Radzievskii and Paddick). The YORP effect, acting over millions of years, might have asteroids dancing the 'hokey-cokey' (also known as the 'hokey-pokey') — spinning them up, spinning them down and turning their spin axes around — but there was no reason to think that any particular rotation state would be preferred. Besides, random collisions would shake them all about and start the dance all over again.

Theory often drives observations, but this time observations led the way. Groups of asteroids called 'families' have similar orbits resulting from the collisional disruption of a larger parent body. An early study[7] of asteroids in the Koronis family, which are nearly three times as far as Earth from the Sun, revealed unusual rotation characteristics. Measurements revealing how Koronis family asteroids reflect sunlight over the course of a rotational cycle (called a 'light curve') showed a greater average variation in brightness than for asteroids in other families or similar-sized non-family asteroids. Two hypotheses were offered[7]: either the formation of the Koronis family resulted in more elongated shapes (and therefore greater variability in brightness) or the spin axes of Koronis family members were preferentially aligned nearly perpendicular to their orbit plane — an orientation that would always display a nearly equatorial view of the asteroid (and hence maximum variability of brightness) to Earth-based observers.

Although early follow-up studies[8] were consistent with a preferential alignment, a decisive test of this hypothesis was a gargantuan task. From Earth, an asteroid's spin vector can be divined only by measuring its light curve from many different viewing angles. For a Koronis family asteroid, an observation opportunity comes only once every 15 months, and five or more sets of observations, all at different angles, might be

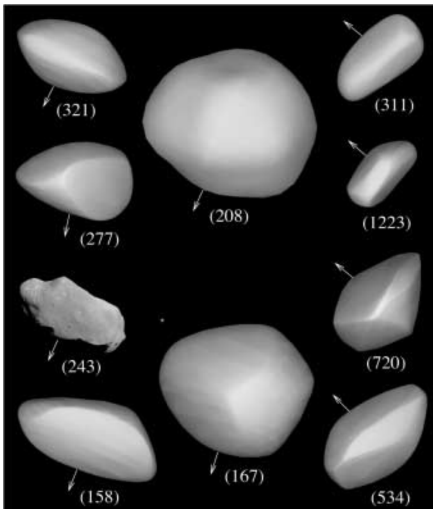

Figure 2 **Spin up, spin down. The spin axes of the Koronis family of asteroids are very closely aligned[1,10], pointing in one of two directions depending on whether the asteroid spins clockwise (downward arrows) or anticlockwise (upward arrows). Vokrouhlický *et al.*[2] show that these 20–40-km-diameter asteroids could have been nudged into these aligned states by a featherweight recoil force created by thermal re-radiation from the hot afternoon side of each asteroid, acting over a period of 2–3 billion years. (Reproduced with permission from ref. 10.)**

required. At each viewing opportunity, many dozens of meticulous measurements are needed over the typical eight-hour rotation period of the asteroid to define its light curve; light curves must be measured repeatedly over several weeks to determine the asteroid's spin period precisely. Now multiply this effort for one asteroid by at least ten, to get a reasonable statistical sample, and… you get the idea.

But someone was up to the challenge. Using the Wallace Astrophysical Observatory's 0.6-m telescope for nearly a decade, postgraduate student Stephen Slivan and a cadre of undergraduate students amassed thousands of measurements for ten Koronis family asteroids[9,10]. Decidedly nonrandom spin vectors were found[1]. Four prograde (anticlockwise) rotators have nearly aligned rotation axes with very similar spin periods of about eight hours, and the remaining six retrograde (clockwise) rotators are also nearly co-aligned together (but on a different heading) with a dispersion of spin periods between 3 and 30 hours (Fig. 2). The alignments almost defied belief — how could a collisionally dominated family have aligned spin vectors? But this *tour de force* data set[1] (confirmed by an independent analysis of spin vectors by Mikko Kaasalainen[10,11]) called out for explanation.

Vokrouhlický *et al.*[2] have responded to the call, with a model that invokes the YORP effect and the influence of Solar System planets. For the 20–40-km-diameter members of the Koronis asteroid family (the same size range and location as the Slivan sample), they find that prograde rotators should have their spins slowed and their spin axes cast into a slow precession like a top. When the precession rate matches the rate at which the plane of Saturn's orbit undergoes a slow twist, the asteroid becomes caught in an equilibrium state that Vokrouhlický *et al.* call a 'Slivan state'. The spin vector and spin rate become fixed, and their calculated values closely match those for the observed sample. Retrograde rotators don't seem to be influenced by Saturn's twist or to land in an equilibrium state, but thermal torques (turning forces) turn their spin vectors upside down with rotation rates diverging towards either fast or slow values — again just as is observed. According to Vokrouhlický and colleagues' model, it takes typically 2–3 billion years for the Koronis family asteroids to evolve to their end states, with smaller and more irregularly shaped objects proceeding more quickly.

How well this YORP-based model[2] holds up can be tested through further observations. Most asteroids smaller than 40 km in diameter should be influenced by the effect, with those in the outer asteroid belt being most likely to land in observable Slivan states. Measuring an abundance of upside-down spin vectors for fast or slowly rotating asteroids would be another tell-tale fingerprint of the YORP effect. If it can be shown to dominate asteroid spins, the implication is that geologically frequent collisions are highly inefficient in transferring rotational angular momentum. Collisions that fracture but do not destroy asteroids might leave them so weak that a hard push has little effect. In contrast to what has been long thought, a light touch might be the best way to influence asteroid spins. ■

Richard P. Binzel is in the Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA.
e-mail: rpb@mit.edu

1. Slivan, S. M. *Nature* **419,** 49–51 (2002).
2. Vokrouhlický, D., Nesvorný, D. & Bottke, W. F. *Nature* **425,** 147–151 (2003).
3. Öpik, E. J. *Proc. R. Irish Acad.* **54,** 165–199 (1951).
4. Hartmann, W. J. *et al. Meteoritics Planet. Sci.* **34,** 161–167 (1999).
5. Bottke, W. F., Vokrouhlický, D., Rubincam, D. P. & Broz, M. in *Asteroids III* (eds Bottke, W. F. *et al.*) 395–408 (Univ. Arizona Press, Tucson, 2002).
6. Rubincam, D. P. *Icarus* **148,** 2–11 (2000).
7. Binzel, R. P. *Icarus* **73,** 303–313 (1988).
8. Binzel, R. P. in *Asteroids, Comets, Meteors III* (eds Lagerkvist, C. I. *et al.*) 15–18 (Uppsala Universitet, 1990).
9. Slivan, S. M. & Binzel, R. P. *Icarus* **124,** 452–470 (1996).
10. Slivan, S. M. *et al. Icarus* **162,** 285–307 (2003).
11. Kaasalainen, M., Mottola, S. & Fulchignoni, M. in *Asteroids III* (eds Bottke, W. F. *et al.*) 139–150 (Univ. Arizona Press, Tucson, 2002).

Ageing

A toast to long life

Toren Finkel

Reducing food intake increases lifespan in many species. A small molecule that occurs naturally in plants seems to mimic the beneficial effects of caloric restriction and extend longevity in yeast.

BETTMANN/CORBIS

Figure 1 **A quest for longevity. Five hundred years ago, the Spanish explorer Ponce de León drank his way around the Florida coast during his expedition to find the legendary fountain of youth.**

In the spring of 1512, three wooden vessels commanded by the Spanish explorer Ponce de León left the warm Caribbean waters off Puerto Rico in search of the fountain of youth. Fuelled by his desire for immortality, Ponce de León was convinced that drinking from this legendary spring would confer a state of eternal youth. Local legend suggested that the fountain could be found in the lands to the north and that it was surrounded by magnificent flowering plants. Over the next few months, the explorers travelled from island to island, tasting rivers and lakes (Fig. 1) until short supplies and hostile natives forced them to abandon their quest.

Today, the once desolate shores of Florida — the 'land to the north' that Ponce de León discovered inadvertently on his voyage — are crowded with ageing retirees who yearn just as passionately for the magical elixir of youth. Although the past two decades have seen an explosion in our understanding of the molecular regulation of ageing, a simple potion or chemical that could slow the ageing process seems as elusive today as it was 500 years ago. But on page 191 in this issue, Howitz *et al.*[1] present a study of longevity in yeast that could represent the first step towards creating such a hypothetical elixir.

It is well established that reducing food intake (caloric restriction) extends lifespan in a wide range of species[2]. But given the current epidemic of obesity in industrialized