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The Thermal Response of Asteroid Surfaces: Results from ESO Large Programme

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Abstract

The (YORP) effect [1] is a torque due to incident solar radiation and the subsequent recoil effect from the anisotropic emission of thermal photons on small bodies in the Solar System. The YORP effect can: change rotation rates and spin-axis orientations over relatively short time-scales; modify orbits (semi-major axis drift from the related Yarkovsky effect depends on the obliquity) and thus plays a key role in replenishment of the near-Earth asteroid (NEA) population; cause regolith mobility and resurfacing as spin rates increase, form binary asteroids through equatorial mass loss and re-aggregation and cause catastrophic disruption. When we began our systematic monitoring programme in 2010, the YORP effect had only been detected for three asteroids [2-4] with a marginal detection following in 2012 [5]. That has now increased to six [6-7]. All detections so far are in the spin-up sense, and theoretical studies are making progress in explaining this observation [8]. However, a much larger statistical sample is required to robustly test this theory. We are conducting an observational programme of a sample of NEAs to detect YORP-induced rotational accelerations. For this we use optical photometry from a range of small to medium size telescopes. This is supplemented by thermal-IR observations and thermophysical modelling to ascertain expected YORP strengths for comparison with observations. For selected objects, we use radar data to determine shape models. We will present our latest results from this programme.

1. Observational Campaign:

Optical photometry and the detection of YORP: Detection of rotational acceleration requires measurement of phase shifts in rotational lightcurves at a minimum of three apparitions. Our observational programme focuses on ~km-sized NEAs with short spin periods to allow suitable lightcurves to be obtained at multiple apparitions with short runs on a range of moderate-sized telescopes. We have acquired a considerable dataset on our target NEAs, mainly through our ESO 3.6m NTT Large Programme (185.C-1033), but also supporting observations from the 2.5m Isaac Newton Telescope and the 2m Liverpool Telescope (La Palma, Spain), and the 5m Hale Telescope at Palomar Observatory (USA), among many others. Lightcurve data from the programme will also be linked to previous published data where available. We use an established light curve inversion code, e.g. [9], modified to include YORP-induced sidereal rotation period changes, to derive shape and spin state models and identify the YORP effect (See Fig. 1).

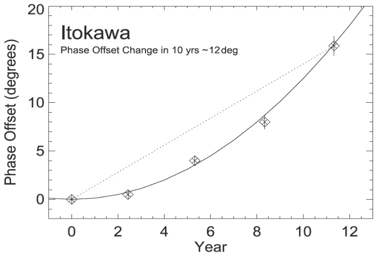

Figure 1. Rotational-phase changes (φ) in Itokawa observed from 2001-2013 [6]. The strong quadratic variation of φ is consistent with YORP-induced rotational acceleration. This is the characteristic signature of YORP that we are searching for with our NEA targets and modelling methods.

Thermal-IR observations and thermophysical modelling: Mid-IR observations provide valuable constraints on size, albedo and surface roughness, required to model the YORP effect, as well as thermophysical properties. We have a parallel programme to obtain mid-IR photometry for all targets that are sufficiently bright for detection with the VISIR instrument on ESO’s 8.2m VLT (185.C-1034, 190.C-0357, 197.C-0816) as well as a

Spitzer/IRAC programme (#11097), augmented by archival data from WISE [10]. YORP effect predictions are made using the Advanced Thermophysical model (ATPM), e.g. [11], with shape models from our lightcurve analysis or derived from radar data (see Fig. 2).

Planetary radar programme: For selected objects, we have radar data available. Radar observations can greatly improve the spin-state analysis by providing a fully independent shape model, thus greatly reducing the range of potential solutions for YORP. The ability of radar to detect surface concavities is an important advantage as many asteroids are reported to have bi-lobed or contact-binary configurations [12]. Radar data can also be merged with optical lightcurve data to provide tighter constraints on rotational pole positions and shape and spin-states. Such detailed shape models also allow for more rigorous modelling of the YORP and Yarkovsky effects [13]. The radar observations used in this programme were obtained using the Arecibo Planetary Radar (Puerto Rico, PID: R2959, R3036) and Goldstone (USA) facilities.

2. Latest Results

We have already detected YORP and inferred density heterogeneity in (25143) Itokawa (Fig. 1) [6]. We will present our latest results and progress on YORP detections/upper limits for a subset of NEAs from our programme, which include: (1917) Cuyo (Fig. 2), (8567) 1996 HW1, (85990) 1999 JV6, 6053, and 1950 DA. Our analysis of observations also yields several additional important results in relation to the physical properties of several of these NEAs. For example, the shape of Cuyo resembles the oblate spheroid or 'spinning top' shape first observed on NEA 1999 KW4 [14]. This shape is due in part to radiative torques. While we do not see a strong YORP signature in the data, this asteroid has likely experienced YORP-induced shape modifications. Furthermore, thermophysical analysis, utilizing our thermal observations and the shape model, reveal that material near the equatorial ridge may be leaving the surface (See Fig. 2). Cuyo has a low thermal inertia of 24 J m^{-2} K^{-1} s$^{-1/2}$, indicating a surface significantly reduced in surface boulders. Our analysis of combined radar and optical photometry of 1999 JV6 reveal a distinctive bi-furcated shape, similar to 1996 HW1 [15] and Itokawa [16]. This asteroid is likely to be the result of a collapsed binary system. We also detect a transverse non-gravitational acceleration (NGA) of (-1.6 ± 0.2) × 10^{-12} m s^{-2} in the orbital motion of this object, based on our radar astrometry. Thermophysical analysis of Spitzer data, combined with the shape model can attribute this NGA detection to the Yarkovsky effect, and also yields a low bulk density measurement of $\leq$ 830 g cm^{-3}. Asteroid 1999 JV6 may therefore be of cometary origin. These results will be discussed in detail at the meeting, along with the full range of latest results from this on-going programme.

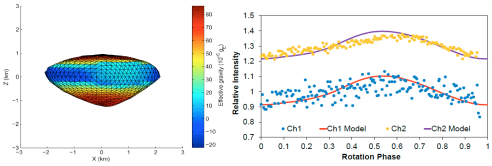

Figure 2. (1917) Cuyo shape model indicating negative effective gravity near the equator (left), used to fit Spitzer/IRAC light-curves (right).

Acknowledgements

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