Icarus 197 (2008) 497–504

Contents lists available at ScienceDirect

Icarus

www.elsevier.com/locate/icarus

Spin rate distribution of small asteroids

P. Pravec [a,*], A.W. Harris [b], D. Vokrouhlický [c], B.D. Warner [d], P. Kušnirák [a], K. Hornoch [a], D.P. Pray [e], D. Higgins [f], J. Oey [g], A. Galád [h,a], Š. Gajdoš [h], L. Kornoš [h], J. Világi [h], M. Husárik [i], Yu.N. Krugly [j], V. Shevchenko [j], V. Chiorny [j], N. Gaftonyuk [k], W.R. Cooney Jr. [l], J. Gross [l], D. Terrell [l,m], R.D. Stephens [n], R. Dyvig [o], V. Reddy [p], J.G. Ries [q], F. Colas [r], J. Lecacheux [s], R. Durkee [t], G. Masi [u,v], R.A. Koff [w], R. Goncalves [x]

[a] *Astronomical Institute, Academy of Sciences of the Czech Republic, Fričova 1, CZ-25165 Ondřejov, Czech Republic*
[b] *Space Science Institute, 4603 Orange Knoll Ave., La Canada, CA 91011, USA*
[c] *Institute of Astronomy, Charles University, V Holešovičkách 2, CZ-18000 Prague 8, Czech Republic*
[d] *Palmer Divide Observatory, 17995 Bakers Farm Rd., Colorado Springs, CO 80908, USA*
[e] *Carbuncle Hill Observatory, P.O. Box 946, Coventry, RI 02816, USA*
[f] *Hunters Hill Observatory, Ngunnawal, Canberra, Australia*
[g] *Leura Observatory, Leura, N.S.W., Australia*
[h] *Modra Observatory, Department of Astronomy, Physics of the Earth, and Meteorology, FMFI UK, Bratislava SK-84248, Slovakia*
[i] *Astronomical Institute of the Slovak Academy of Sciences, SK-05960 Tatranská Lomnica, Slovak Republic*
[j] *Institute of Astronomy of Kharkiv National University, Sumska Str. 35, Kharkiv 61022, Ukraine*
[k] *Crimean Astrophysical Observatory, Simeiz, Crimea, Ukraine*
[l] *Sonoita Research Observatory, 77 Paint Trail, Sonoita, AZ 85637, USA*
[m] *Southwest Research Institute, 1050 Walnut St., Suite 300, Boulder, CO 80302, USA*
[n] *Goat Mountain Astronomical Research Station, Riverside Astronomical Society, 8300 Utica Avenue, Suite 105, Rancho Cucamonga, CA 91730, USA*
[o] *Badlands Observatory, 12 Ash Street, P.O. Box 37, Quinn, SD 57775, USA*
[p] *Department of Earth System Science and Policy, University of North Dakota, Grand Forks, ND 58202, USA*
[q] *The University of Texas at Austin, Astronomy Department/McDonald Observatory, 1 University Station C1400, Austin, TX 78712-0259, USA*
[r] *IMCCE-CNRS-Observatoire de Paris, 77 avenue Denfert Rochereau, 75014 Paris, France*
[s] *LESIA-Observatoire de Meudon, Place Jules Janssen, 92195 Meudon, France*
[t] *Shed of Science Observatory, 5213 Washburn Ave. S, Minneapolis, MN 55410, USA*
[u] *Bellatrix Astronomical Observatory, Via Madonna de Loco 47, I-03023 Ceccano, Italy*
[v] *Campo Catino Observatory, I-03016 Guarcino, Italy*
[w] *Antelope Hills Observatory, 980 Antelope Drive West, Bennett, CO 80102, USA*
[x] *Obs. Ast. de Linhaceira, Escola Superior de Tecnologia de Tomar, Instituto Politecnico de Tomar, 2300-313 Tomar, Portugal*

ARTICLE INFO

Article history:
Received 8 January 2008
Revised 2 May 2008
Available online 4 June 2008

Keywords:
Asteroids, rotation
Photometry
Near-Earth objects
Satellites of asteroids

ABSTRACT

The spin rate distribution of main belt/Mars crossing (MB/MC) asteroids with diameters 3–15 km is uniform in the range from $f = 1$ to 9.5 d^{-1}, and there is an excess of slow rotators with $f < 1$ d^{-1}. The observed distribution appears to be controlled by the Yarkovsky–O'Keefe–Radzievskii–Paddack (YORP) effect. The magnitude of the excess of slow rotators is related to the residence time of slowed down asteroids in the excess and the rate of spin rate change outside the excess. We estimated a median YORP spin rate change of $\approx$0.022 d^{-1}/Myr for asteroids in our sample (i.e., a median time in which the spin rate changes by 1 d^{-1} is $\approx$45 Myr), thus the residence time of slowed down asteroids in the excess is $\approx$110 Myr. The spin rate distribution of near-Earth asteroids (NEAs) with sizes in the range 0.2–3 km ($\sim$5 times smaller in median diameter than the MB/MC asteroids sample) shows a similar excess of slow rotators, but there is also a concentration of NEAs at fast spin rates with $f = 9$–10 d^{-1}. The concentration at fast spin rates is correlated with a narrower distribution of spin rates of primaries of binary systems among NEAs; the difference may be due to the apparently more evolved population of binaries among MB/MC asteroids.

1. Introduction

Rotations of asteroids have been set and altered by several processes during their formation and evolution. Large asteroids (with diameter $D > 40$ km) show a Maxwellian distribution of their normalized spin rates, which is consistent with a relaxed distribution

---

[*] Corresponding author. Fax: +420 323 620263.
E-mail address: ppravec@asu.cas.cz (P. Pravec).

0019-1035/$ – see front matter
doi:10.1016/j.icarus.2008.05.012

due to collisional evolution. Asteroids smaller than $D = 40$ km have spin rate distributions different from Maxwellian, with excesses of both slow and fast rotators (Pravec and Harris, 2000; Pravec et al., 2002). Until recently, data on rotations of small asteroids have been rather limited; below $D \sim 15$ km, there was good and consistent data for near-Earth asteroids only (see the summary in Pravec et al., 2007). Data on spin rates of small main belt asteroids were sparse, as there was no systematic program to obtain them in sufficient number and quality until recently.

In 2004, two dedicated projects of photometric studies of small main belt asteroids were started. Brian Warner began his project of lightcurve observations of Hungaria asteroids. Hungarias are a group of bright (geometric albedos mostly in the range 0.2–0.4) asteroids just outside the orbit of Mars; they are the smallest non-planet crossing asteroids that can be studied with small photometric telescopes. Warner has obtained data on spin rates for more than 80 Hungarias (Warner and Harris, 2007). Their preliminary analysis of the sample showed that the Hungaria spin rate distribution is not fundamentally different from the spin rate distribution of near-Earth asteroids. The subset of Brian Warner's sample of Hungarias that satisfies the quality criteria of the BinAstPhotSurvey has been included in the current study. There were 50 such Hungarias.

Since December 2004, we have run the project *Photometric Survey for Asynchronous Binary Asteroids* (BinAstPhotSurvey; Pravec and Harris, 2007, and references therein) that involves a collaboration of a number of asteroid photometrists around the world. Though the main aim of the project has been to detect and describe binary systems among small asteroids, it has also, as a by-product, obtained data on spin rates for nearly 300 main belt and Mars crossing (MB/MC) asteroids with sizes <15 km. Observations within the BinAstPhotSurvey project have been carried out in a way that largely suppressed selection effects of the photometric technique. In this paper, we present the BinAstPhotSurvey sample of spin rates of small MB/MC asteroids, analyze their distribution, and discuss relationships with theories of evolution of spins of small asteroids and formation of binary systems among them.

2. Data set

In the BinAstPhotSurvey, asteroids with heliocentric semi-major axes <2.5 AU and absolute magnitudes $H > 12$, corresponding to $D < 12.5^{+5.1}_{-2.3}$ km for geometric albedo $p_V = 0.18 \pm 0.09$ assumed for asteroids in the inner main belt,[1] and with favorable observing conditions were selected as observational targets. Lightcurve observations with photometric errors $\leqslant 0.03$ mag were taken and a sufficient amount of telescope time was allocated for most asteroids so that their periods were uniquely established. The spin rate estimates have been very accurate (relative uncertainties typically on an order of 10^{-4}) for asteroids with periods <10 h. Noticeable uncertainties or ambiguities occurred only in some cases of longer periods where we could not allocate an excessive amount of telescope time. Nonetheless, the presence of lower quality data for some slow rotators did not cause any significant uncertainty in our analyses; a possible mutual contamination between the two slowest bins, $f = 0$–1 d^{-1} and 1–2 d^{-1} in histograms presented below was three objects, but likely only 1–2, i.e., below statistical uncertainties. The fact that we have paid great attention to obtain good period estimates even for low amplitude asteroids (by giving a large amount of observing time to tough cases) was a key to the success of the project which has provided good period estimates even for asteroids with amplitudes as low as 0.08 mag. For a small fraction (5%) of targeted asteroids with amplitudes <0.08 mag, we were unable to obtain good period estimates, and they have not been included in the analysis. Since they are so few in number, they could not significantly affect our analyses of spin rate distributions, even in the unlikely case that they might have a non-uniform distribution in f.

In the analyses presented below, we have used data for 268 main belt/Mars crossing asteroids with estimated diameters $D =$ 3–15 km. The median diameter of asteroids in the sample is 6.5 km. Only 16% have $D < 4.4$ km and another 16% have $D > 9.8$ km, so 68% of the asteroids in the sample are within a factor of 1.5 of the median diameter. The dataset is available on http://www.asu.cas.cz/~asteroid/binastphotsurv_mbmc_d3_15_071104.txt. References for the data in the summary file can be found in the Lightcurve Database compiled by Harris et al., http://www.psi.edu/pds/resource/lc.html and, for data on primaries of binary systems in our sample, in the Binary Asteroid Parameters dataset (see Pravec and Harris, 2007).

3. Spin rates of small asteroids

3.1. MB/MC asteroids with D = 3 to 15 km

Figs. 1 and 2 show a distribution of spin rates of main belt/Mars crossing asteroids with diameters from 3 to 15 km. The distribution is consistent with a uniform distribution between $f = 1$ and 9.5 d^{-1}, with an excess of slow rotators at $f < 1$ d^{-1}. The excess of slow rotators among small asteroids has been found already in previous studies (Pravec and Harris, 2000; Pravec et al., 2002) using smaller datasets.

A possible explanation for the uniform distribution of spin rates of small MB/MC asteroids between $f = 1$ and 9.5 d^{-1} is provided from the theory of the YORP effect (see, e.g., Čapek and Vokrouhlický, 2004). The theory predicts that the rate of change of spin frequency ($\dot{f}$) produced by YORP is independent of f, as long as it is in a range of frequencies where damping timescales of excited rotation are short in comparison with YORP spin up/spin down timescales.[2] Any concentration in an original distribution of spin rates is therefore dispersed by the YORP effect, producing a distribution more uniform than the original one. As there is no dependence of $\dot{f}$ on f, the evolution of spin rates by the YORP effect does not produce any new concentration in the spin rate distribution. The resulting spin rate distribution is flattened, i.e., it is more uniform than the original distribution.

A simple model showing how a mechanism evolving asteroidal spin rates with $\dot{f} = \text{const}$ for each individual asteroid produces a uniform distribution from an original non-uniform one is shown in Appendix A. A characteristic timescale τ of the model corresponds to the YORP doubling/halting time t_{d} of an asteroid rotating with angular frequency ω near the middle of the range of spin rates. The doubling/halting time is given by

$$t_{\mathrm{d}} = \frac{\omega}{|\langle\dot{\omega}\rangle|} = \frac{I_c\,\omega}{|\langle T_\omega\rangle|}, \tag{1}$$

---

[1] For most asteroids in our sample, direct size estimates were not available. We have estimated their diameters from measured absolute magnitudes (H) and assumed geometric albedos (p_V) using the relation given in Pravec and Harris (2007). Assumed geometric albedos have been taken from Wisniewski et al. (1997): $p_V = 0.18$ for S, A, and unclassified asteroids, and 0.40 for V and E types. For Hungarias without known taxonomic class, we assumed $p_V = 0.30$ that is about the mean of albedos of S and E types that are present among Hungarias in approximately equal fractions.

[2] A basic YORP theory assumes that asteroid is in its basic rotation state around principal axis, i.e., any excitation of rotation produced by the YORP effect is damped down rapidly by inelastic dissipation of energy inside the body. See also comments on coupling between evolution of spin rate and evolution of obliquity in the first paragraph and footnote in Appendix A.