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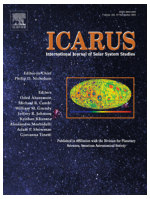

Lightcurves of the Karin family asteroids

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ABSTRACT

The Karin family is a young asteroid family formed by an asteroid breakup 5.8 Myr ago. Since the members of this family probably have not experienced significant orbital or collisional evolution yet, it is possible that they still preserve properties of the original family-forming event in terms of their spin state. We carried out a series of photometric observations of the Karin family asteroids, and here we report on the analysis of the lightcurves including the rotation period of eleven members. The mean rotation rate of the Karin family members turned out to be much lower than those of near-Earth asteroids or small main belt asteroids (diameter $D < 12$ km), and even lower than that of large main belt asteroids ($D > 130$ km). We investigated a correlation between the peak-to-trough variation and the rotation period of the eleven Karin family asteroids, and found a possible trend that elongated members have lower spin rates, and less elongated members have higher spin rates. However, this trend has to be confirmed by another series of future observations.

1. Introduction

Asteroid families are remnants of catastrophic disruption and reaccumulation events between small bodies in the Solar System (e.g. Michel et al., 2003). Each member of an asteroid family has the potential to provide us with clues about the family-formation events that created them. However, since asteroid families are generally old (~Gyr), it is quite likely that the family members have undergone significant orbital, collisional, and spin-state evolution that masks properties of the original family-forming events.

A sophisticated numerical technique devised by Nesvorný et al. (2002) changed the above situation. Using their method, they detected three young asteroid families in the main belt: the Karin family (~5.8 Myr old), the Iannini family (~5 Myr old), and the Veritas family (~8 Myr old). These families are remarkably younger than previously known asteroid families, and more and more younger asteroid clusters have been recognized since then (e.g. Nesvorný and Vokrouhlický, 2006; Vokrouhlický and Nesvorný, 2008; 2009). With these discoveries in hand, we find many aspects of the study of young asteroid families interesting: their spin period distribution, their shape distribution, and possible detection of non-principal axis rotation.

We expect that the young family members preserve some properties of the original family-forming event in their spin period distribution. Although there are several laboratory experimental studies on the spin period distribution of collisional fragments (e.g. Fujiwara et al., 1989; Nakamura and Fujiwara, 1991; Kadono et al., 2009), it is hard to directly apply their results to real collisions between Small Solar System Bodies (SSSBs) in the gravity-dominant regime. Thus, observations of spin rates of the young asteroid family members can be unique opportunities to collect information on large-scale collisions.

As for the asteroid spin rate distribution, it is now widely known that the Yarkovsky–O'Keefe–Radzievskii–Paddack (YORP) effect may spin up or spin down 10-km-sized asteroids on a 10^8 yr timescale, and smaller asteroids could spin up/down even faster (e.g. Rubincam, 2000; Bottke et al., 2006). However, as the ages

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of the young asteroid families are substantially shorter than the timescale of the YORP effect, each family member perhaps statistically retains its initial spin status just after the family-formation event. In old asteroid families, such as the Koronis family, the YORP effect has changed the initial spin rate since the family-formation events (e.g. Slivan, 2002; Slivan et al., 2003; Vokrouhlický and Čapek, 2002; Vokrouhlický et al., 2003). Comparisons between the spin rate distribution of old and young asteroid families can serve as a help in the timescale estimate of the YORP effect. Actually the YORP effect is very sensitive to small-scale topography of asteroids (e.g. Statler, 2009). However, with the current observational data that we have in hand, we have not reached a detailed quantitative estimate of how seriously the YORP effect has influenced the dynamics of the Karin family members. Gaining a deeper understanding of these dynamics remains an aim of future inquiry.

In addition to the spin rate statistics, the shape distribution of the young asteroid family members is important for understanding the fragmentation and reaccumulation process of SSSBs in comparison with laboratory collisional experiments. It may help us understand the dynamical process of fragmentation and reaccumulation of asteroids, such as how angular momentum is distributed to each of the remnants. Also, it is possible to get an estimate of the satellite/binary forming efficiency at asteroid disruption events.

The young asteroid families also draw our attention in terms of possible detection of non-principal axis rotation (sometimes called "tumbling motion"). The study of a celestial body's non-principal axis rotation gives us important insights into energy dissipation and excitation processes, as well as internal structure of the body. Non-principal axis rotation could be excited by collisions of small projectiles, but it will be damped quickly unless the excitation continues. This is the main reason why the non-principal axis rotation of SSSBs has been confirmed only for a few tens of lightcurves (e.g. Harris, 1994; Pravec and Harris, 2000; Paolicchi et al., 2002; Mueller et al., 2002; Warner et al., 2009; Oey et al., 2012; Pravec et al., 2014). However, the age of the young family asteroids is quite young, and we may be able to observe their non-principal axis rotation before it has totally decayed.

Based on the motivations mentioned above, we began a series of photometric observations of the young asteroid families in November 2002. In this paper we focus on the current result of our lightcurve observation of the Karin family asteroids through the *R*-band imaging that we had carried out until May 2004, and summarize the result for eleven Karin family members whose rotation period we determined. Note that throughout the present paper we assume that the lightcurve variations are due to shapes of asteroids, not due to albedo features.

2. Observations

During the period from November 2002 to May 2004, we observed and determined the rotational periods of eleven Karin family members, including the largest member, (832) Karin. Table 1 shows the list of the observatories, the telescopes, and field of views of the instruments that we used for our observations.

We used the *R*-filter for our lightcurve observations because it is widely known that brightness of the reflected light in optical wavelengths from most asteroids becomes the highest in the *R*-band among the Johnson–Cousins *UBVRI* filters. In our observations all the telescopes were driven at the sidereal tracking rate, and the exposure time was limited by the moving rate of asteroids as well as by seeing during the observing nights. As typical main belt asteroids (MBAs) having the semimajor axis $a = 2.8$ AU move at the speed of $\sim 0.55''$/min at its opposition, and as the typical seeing size at the observatories was from $1.0''$ to $3.0''$, we chose a single exposure time of two to eight minutes so that an asteroid has an appearance of a point source. Generally, we continued the *R*-band imaging for a particular asteroid throughout a night except when we took images of standard stars: an "asteroid per night" strategy.

Table 1
Observatories and instruments. E is the elevation of the observatory (m), D_t is the diameter of the telescope mirror that we used (m), and FOV denotes the field of view of the imaging system that we used for our purpose. The full observatory names and the telescope names are as follows: Steward: the 2.3 m telescope ("Bok") at the Steward Observatory (Kitt Peak, Arizona, USA). Vatican: the 1.8 m telescope ("VATT") at the Vatican Observatory (Mt. Graham, Arizona, USA). Maidanak: the 1.5 m telescope ("AZT") at Maidanak Observatory (Uzbekistan). Lulin: the 1 m telescope at the Lulin Observatory (Taiwan). Kiso: the 1 m telescope at the Kiso Observatory (Nagano, Japan). Fukuoka: the 0.4 m telescope at the Fukuoka University of Education (Fukuoka, Japan).

Name	Longitude	Latitude	E	D_t	FOV
Steward	111°36′01.6″W	31°57′46.5″N	2071	2.29	4.5′ × 4.5′
Vatican	109°53′31.25″W	32°42′04.69″N	3191	1.8	6.8′ × 6.8′
Maidanak	66°53′47.08″E	38°40′23.95″N	2593	1.5	8.5′ × 3.5′
Lulin	120°52′25″E	23°28′07″N	2862	1.0	11.5′ × 11.2′
Kiso	137°37′42.2″E	35°47′38.7″N	1130	1.05	50′ × 50′
Fukuoka	130°35′44.7″E	33°48′45.3″N	70	0.40	5.75′ × 4.36′

We used the Landolt standard stars (Landolt, 1992) for the purpose of calibration. Before and/or after each of the observing nights, we took dome flats or twilight sky flats for flat-fielding. After the observation, we applied a standard data reduction procedure against the data: bias subtraction and flat division. Table 2 is the summary of our observational details.

3. Analysis and results

To construct composite lightcurves of asteroids from the observational data, we followed a sequence proposed by Harris and Lupishko (1989). The actual procedure is described in our previous publications (Dermawan et al., 2002; 2011; Yoshida et al., 2004). Principally, it is an iterative repetition of frequency analysis and fitting to Fourier series. We employed two different algorithms to examine periodicities in the lightcurve data: Lomb's Spectral Analysis (LSA, Lomb, 1976) and the WindowCLEAN Analysis (WCA, Roberts et al., 1987). WCA incorporates a discrete Fourier transform as well as the CLEAN algorithm (Högbom, 1974), and (Mueller et al., 2002) adopted WCA when they detected multiple rotational periodicities of asteroid (4179) Toutatis. When the frequency analysis is done, we fit the lightcurve with a Fourier series. We have to be particularly careful when we combine lightcurves derived from several observing runs because they generally have different lightcurve-mean magnitudes. See Section 3.1 for details of how we combined the lightcurves obtained from multiple observing runs.

Once we have obtained the lightcurve of an asteroid, we estimate the peak-to-trough variation of its lightcurve. To compare the amplitudes (A) of the lightcurves of the Karin family members taken at different solar phase angles (α) with each other as well as with other solar system bodies, we used the empirical relationship by Zappalà et al. (1990) that normalizes the amplitudes to a solar phase angle of 0 degree. Zappalà et al. (1990) gives $A(\alpha) = A(0)(1 + m\alpha)$, and it empirically determines the parameter $m = 0.030$ for S-type asteroids, which the Karin family members are classified as. However, we have to note that these amplitudes can be only used in a statistical sense, because, except for (832) Karin, these asteroids' spin obliquities are not known.

3.1. Procedure for combining lightcurves

In this subsection we describe how we dealt with the standard stars in our observation and how we combined lightcurves of asteroids obtained from different observing nights, making a single lightcurve for each asteroid.