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Surface Color Variation of (832) Karin

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Abstract. An S-type asteroid (832) Karin is the largest member of a newborn asteroid cluster, the Karin family. This asteroid is likely a big fragment of a disruption event in the main asteroid belt about 5.8 million years ago. We have obtained multi-color photometric observations of this asteroid since 2003. Here we report an interesting surface color variation of this asteroid that indicates the existence of both mature and fresh surfaces on this asteroid. As of September 2004, this asteroid apparently does not show a strong surface color difference, which gives us some insight into its spin axis orientation and shape. We will need more and longer-term color observation of this asteroid to confirm this interesting surface character.

1. Introduction

The Karin family was recognized quite recently, with the estimated age of only about 5.8 million years (Nesvorný et al. 2002). This family consists of about 70 asteroids with sizes ranging from about 1.5 km to 20 km in diameter (Nesvorný & Bottke 2004). Most asteroid families are very old, and they have undergone significant collisional and dynamical evolution since their formation that likely masks the properties of the original collisions. But the remarkably young Karin family asteroids possibly preserve some signatures of the original collisional event that formed the family.

Since the Karin family is far younger than many other asteroid families, it offers us several significant opportunities for asteroid research, such as the potential detection of tumbling motion of each family member, distributions of rotation period, and shape of newly-created asteroid fragments. Pushed by these motivations, we have begun a program to observe the lightcurves of all the Karin family members since November 2002. A part of our preliminary result is summarized in Yoshida et al. (2004; hereafter we call Paper I). In the present manuscript, we focus on the observing result of surface color of the largest member of this family, (832) Karin. Since (832) Karin is the largest fragment of a recent disruption event, it is possible that this asteroid has both young and old surfaces together: a young surface that was exposed from the interior of the parent body by the family-forming disruption, and an old surface that used to be the parent body surface exposed to space radiation over a long time. If the mixture of these two surfaces is detected by our multicolor observations, it could imply a lot to the research of the evolution of the asteroid surface.

In Section 2, we describe our first observation of (832) Karin in 2003. Method and results of our multicolor observations are summarized in this section. We mention the results of our second multicolor observation on this asteroid in 2004 in Section 3, which is somewhat controversial against our first result. Section 4 includes some discussion.

Table 1. Major parameters during our multicolor observations of (832) Karin. From left, UT referring to the mid-time of each observing night, R.A. and Dec. of the asteroid at the time of the UT, distances between the asteroid and the Sun (r) and the Earth (Δ), the ecliptic longitude (λ) and latitude (β), and the solar phase angle (α) of this asteroid.

Date (UT)	R.A.	DEC.	r	Δ	λ	β	α
2003–09–26.19	21 46 09.10	−11 53 00.2	2.666	1.803	324.8	1.5	13.36
2003–09–27.19	21 45 49.21	−11 55 05.7	2.666	1.811	324.7	1.5	13.68
2003–09–28.17	21 45 30.91	−11 57 03.3	2.665	1.819	324.6	1.5	13.99
2003–09–29.17	21 45 13.56	−11 58 56.7	2.665	1.827	334.5	1.5	14.30
2004–09–22.44	05 40 32.40	+23 34 17.7	2.706	2.442	63.8	0.2	21.71
2004–09–23.44	05 41 22.18	+23 34 28.7	2.707	2.429	64.1	0.2	21.68
2004–09–24.45	05 42 10.76	+23 34 38.1	2.707	2.417	64.3	0.2	21.64

2. Multicolor observation of (832) Karin I. September 2003

2.1. Observing procedure and result

We use the 2k × 2k CCD of the 1.8-m Vatican Advanced Technology Telescope (VATT) on Mt. Graham, Arizona, USA, for our multicolor observation of (832) Karin. We first observed at the end of September, 2003. Some of the major parameters of our observations are listed in the upper four lines of Table 1.

We used B, V, R, and I filters whose wavelengths are centered at 4359.32Å, 5394.84Å, 6338.14Å, and 8104.87Å. For photometric calibration, we observe several Landolt standard stars (Landolt 1992) to determine the extinction coefficients for B, V, R, and I bands. Photometric reduction and aperture photometry are performed using APPHOT/IRAF package. The magnitude of the asteroid at different air masses is corrected by the extinction coefficient at each band. In order to remove the effect of magnitude variation due to asteroid's rotation that affects the asteroid color, we always take R band images before and after we use other filters. Hence our observing sequence is something like RR–BB–RR–II–RR–VV–$RR\ldots$. Each of the R magnitudes is interpolated (or extrapolated) to the value of the same UT when we use other filters. Every night we observed this asteroid for 4–5 hours.

We divided our color data into seven rotational phases, and examined the values of B–V, V–R, and V–I at each phase. The resulting time variation of the colors of (832) Karin in our 2003 observation is summarized in Fig. 1(b). For reference, in Fig. 1(a) we showed the lightcurve of this asteroid during the summer to autumn of 2003 obtained from three telescopes: the 1.0 m Schmidt telescope at the Kiso Observatory in Japan, the 0.4 m telescope at the Fukuoka University of Education in Japan, and VATT. Consult Paper I for more detail about Fig. 1(a). As in Fig. 1(b), we obtained the color data of this asteroid over more than 80% of its rotational period.

Looking at Fig. 1(b), the V–R value is almost constant throughout the rotation. The change of B–V is slight at first, then gradually becomes larger. What is the most interesting is the obvious anomaly in V–I value at phase ~ 0.2. To inspect this anomaly in more detail, we calculated the wavelength dependence of the relative reflectance of this asteroid by subtracting the solar colors of B–V=0.665, V–R=0.367, and V–I=0.705 (Rabinowitz 1998) from our original color data. The relative reflectance is normalized at a wavelength of the V filter, 5394.84Å. As a result, we found that the relative reflectance of this asteroid in long wavelength (i.e. in I band) is much bigger at the rotation phase ~ 0.2 than at other phases, as shown in Fig. 1(c). The steep slope of the relative reflectance in Fig. 1(c) should be called "red", as often seen in regular S-type asteroids (cf. Clark et al. 2002).

2.2. Interpretation of the surface color difference

The surface color variation of (832) Karin described in the previous section suggests that this asteroid possesses an inhomogeneous surface. Since this asteroid is the largest fragment of a recent disruption event, this asteroid likely has both fresh and mature surfaces: a fresh surface that was newly exposed by the family-forming disruption, and a mature ("red") surface that used to be the parent body surface and had been exposed to space radiation or particle bombardment over a long time.

The existence of the color variations found in our 2003 observation is supported by near-infrared spectroscopy of this asteroid (Sasaki et al. 2004). They used the Cooled Infrared Spectrograph and Camera for OHS (CISCO) at the 8.2-m Subaru Telescope on MaunaKea, Hawaii, and observed (832) Karin in near-infrared wavelengths on September 14, 2003, which is close to our 2003 observation. As a result, Sasaki et al. (2004) obtained the spectra of this asteroid at three different rotational phases; 0.30–0.33, 0.34–0.38 and 0.45–0.51 in our Fig. 1(a). They found a significant difference in the slopes between the spectrum obtained at phase = 0.30–0.33 and the others. The former is similar to the spectra of ordinary S-type asteroids (i.e. "red" spectrum), while the latter two match well with the spectra of ordinary chondrites, possibly coming from the fresh inside of parent bodies. This trend of color variation is quite similar to what we have obtained in our 2003 observation (Fig. 1(b) and (c)). Sasaki et al. (2004) interpreted the spectrum difference of this asteroid as being due to the mixed distribution of matured and fresh surfaces on this asteroid.

A small inconsistency between our and Sasaki's observations is the difference of the rotation phase where the "red" spectrum was observed: In our 2003 result the surface of (832) Karin seemed mature when the rotation phase ~ 0.2, while Sasaki et al. (2004)'s result claims that the mature surface appeared when phase ~ 0.3. We think this mismatch was caused by an uncertainty in rotational period determination, and does not have a significant influence on our discussion that this asteroid has old, mature or red surface at the rotation phase of 0.2–0.3 when seen in September 2003.

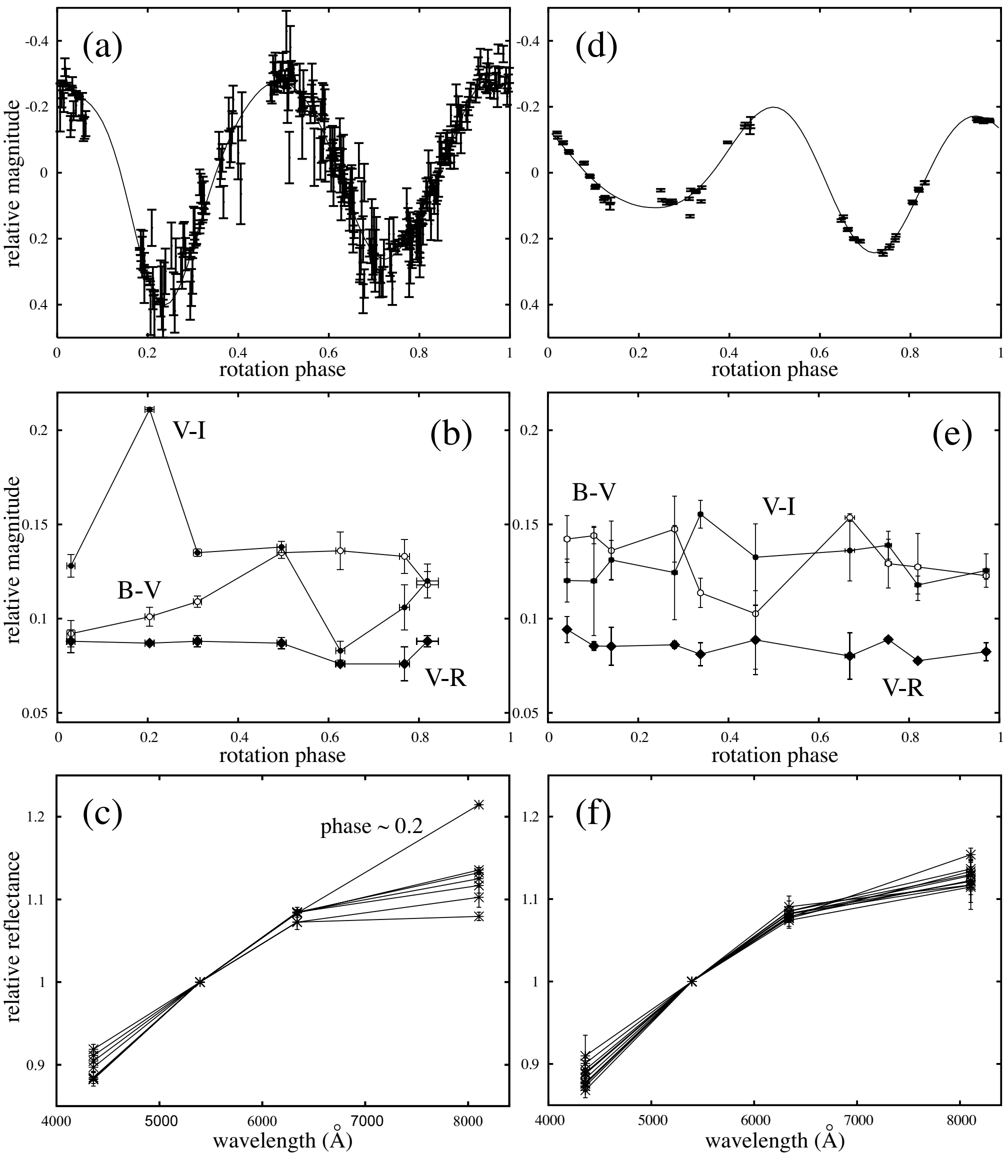

Figure 1. Lightcurve, relative magnitude, and wavelength dependence of relative reflectance of (832) Karin during our two observing runs at VATT in September 2003 and September 2004. Left three panels (a)(b)(c) are for the 2003 observation, and right three panels (d)(e)(f) are for the 2004 observation. (a) and (d): Lightcurve. Note that in (a) we have included the data not only from VATT in September 2003 but the data from two other small telescopes. (b) and (e): Relative magnitude of B–V, V–I, and V–R. (c) and (f): Wavelength dependence of relative reflectance in B, V, R, and I band normalized at the V band wavelength, 5394.84Å.

3. Multicolor observation of (832) Karin II. September 2004

Since the surface color variation of (832) Karin was detected by only two observations by us (Paper I) and Sasaki et al. (2004) in September 2003, we observed this asteroid at multicolor wavelengths in September 2004 at VATT (see the bottom three lines of Table 1 for major observing parameters for this observation). The purpose of these observations was to reconfirm and enforce our discussion that this asteroid keeps both fresh and mature surfaces on it, and hopefully to determine the phase of the mature (red) surface more accurately, solving the inconsistency between our previous observation and Sasaki et al. (2004)'s result. The method and procedure of observing/analysis is almost the same as our previous observation, just a year before.

The major result of this 2004 observing run is shown in Fig. 1(d)(e)(f). Since the relative orbital configuration of (832) Karin and the Earth is different from our 2003 observation, lightcurve of this asteroid (Fig. 1(d)) itself looks different from what we saw a year before (Fig. 1(a)). A remarkable fact obtained from these observations is that we do not see a particularly "red" surface on this asteroid any more; time variation of relative magnitudes of B–V, V–I, and V–R in Fig. 1(e) does not show any definite anomaly as seen in Fig. 1(b) of September 2003. The wavelength dependence of the relative reflectance of this asteroid in Fig. 1(f) is much more like that of phase $\neq 0.2$ in Fig. 1(b) of September 2003 than that of phase ~ 0.2 in Fig. 1(b). In other words, (832) Karin did not show a mature (red) surface in September 2004, exhibiting only a fresh (young) surface with low relative reflectance at longer wavelengths.

So far we do not have a very good explanation for this unexpected mismatch between the 2003 and 2004 observing runs. A key to solving this problem might lie in the difference of the amplitude of two lightcurves in Fig. 1(a) and (d): The lightcurve in September 2003 has a bigger amplitude than that in September 2004. In general, when we look at an asteroid from its pole direction, especially at around opposition, the brightness of the asteroid can be nearly constant. Considering the relative orbital configuration between (832) Karin and the Earth, we have drawn a very rough schematic figure for deducing why we did not see a red surface on this asteroid in our 2004 observation (Fig. 2). As conjectured in Sasaki et al. (2004), (832) Karin might be a cone-shaped asteroid fragment with a small portion of mature surface that used to be a part of parent body's surface. If the rotation axis of this fragment is highly inclined and nearly parallel to its orbital plane as in Fig. 2, it might account for the fact that we see its red surface occasionally as it rotates at the position of September 2003. If the orbital configuration, the spin axis orientation, and the location of the red surface are as in Fig. 2, it might also be possible that we can not see any red surface on this asteroid in September 2004 when we are supposed to look at this asteroid from nearly the pole direction. This geometric configuration could explain why the lightcurve amplitude is smaller in our 2004 observation than in the 2003 observation, depending on the shape of this asteroid.

4. Discussion

The surface color variation of (832) Karin could have a significant impact on the research of evolution of asteroid surface, especially in terms of comparison between the asteroid and the meteorite spectrum. The well-known mismatch of the reflectance spectra between common S-type asteroids and ordinary chondrites has been regarded as a paradox in the past (cf. Sasaki et al. 2001; Clark

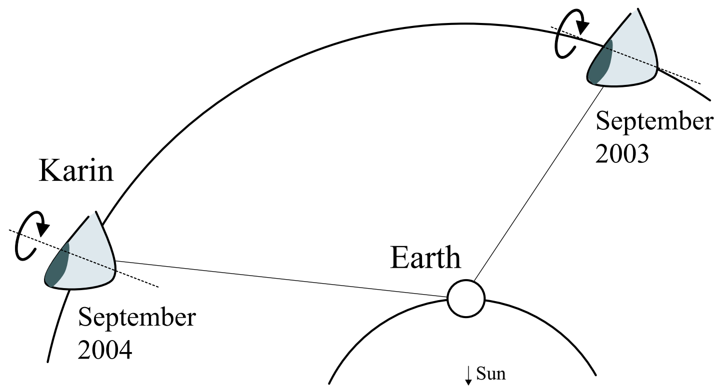

Figure 2. A rough schematic illustration of the orbital configuration of (832) Karin and the Earth in September 2003 and September 2004. Relative location of the two bodies are determined by the solar phase angle in Table 1. The Earth was roughly at the same position at our 2003 and 2004 observing runs. We assume that rotation axis of this (maybe) cone-shaped asteroid is almost parallel to its orbital plane, and it has a small portion of red surface (dark gray area).

et al. 2002). If the surface color variation of (832) Karin is real, this paradox is no longer paradox, and could be explained as a natural consequence of space weathering. We will keep observing this asteroid to figure out the detailed configuration of its spin axis and shape that sometimes shows us red surface and sometimes not. We anticipate that the observation at opposition in March 2006, when we are supposed to look at this asteroid from the back of what we faced in September 2003, will reveal the real surface character of this intriguing asteroid.

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