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A newborn asteroid 832 Karin with old and new surfaces – SUBARU spectroscopy

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Abstract

The mismatch between reflectance spectra of most common asteroids (S-type asteroids) and most common meteorites (ordinary chondrites) is thought to be caused by space weathering. Recent study of celestial mechanics has led to the discovery of a young group of S-type asteroids, “Karin cluster group”, which is thought to be remnants of a collisional breakup only 5.8 million years ago. We performed near-infrared spectroscopy of the brightest asteroid 832 Karin among this cluster group. For different rotational phases of Karin, we derived different spectra such as reddened spectrum like that of S-type asteroid and unreddened spectrum like that of ordinary chondrites. These findings indicate that a part of Karin may retain spectrally mature surface of its parent body. Although Karin might have formed from gravitational accumulation from catastrophic collision of its parent body, there would be some color heterogeneity on its surface if Karin collected materials which derived the weathered surface of the parent body.

Keywords: S-type asteroid; Space weathering: Karin cluster group; Impact disruption; Surface heterogeneity; Spectral mismatch

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1. Introduction

Spectral studies have been clarified “the connection” between asteroid-types and meteorite-classes. However, there is well-known spectral mismatch between S-type asteroids and ordinary chondrites. Although S-type asteroids comprise the most prevalent type of asteroids in the inner part of the main asteroid belt, their reddened visible/NIR reflectance spectra and derived mineralogies are different from those of ordinary chondrites, which are the most common meteorites. Space weathering is thought to be able to explain this spectral mismatch (Chapman, 1996).

In fact, a large number of small near-Earth asteroids show intermediate reflectance spectra between S-type asteroids and ordinary chondrites (Binzel et al., 1996; Burbine and Binzel, 2002). Recently, Galileo and NEAR spacecraft observations have confirmed that interior of S-type bodies Ida and Eros have ordinary chondrite-like composition, despite their surface reddened spectra (Chapman, 1996; McFadden et al., 2001; Bell et al., 2002). On the other hand, the detailed mechanisms involved in space weathering have been clarified recently. Hapke’s hypothesis, which the formation of iron nanoparticles may be responsible for the space weathering (Hapke et al., 1975), was confirmed

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by pulse laser irradiation experiments simulating the heating by high velocity dust impacts. Reflection spectra of laser-irradiated silicate minerals match the typical spectra of S-type asteroids (Yamada et al., 1999; Hiroi and Sasaki, 2001). Additional evidence includes the finding of iron nanoparticles in the laser-irradiated sample (Sasaki et al., 2001, 2002, 2003). As in lunar soils (Keller and McKay, 1993), iron nanoparticles were found in some meteorite recently (Noble et al., 2004).

The degree of space weathering has been used as a tool to estimate the ages of asteroid surfaces (Sasaki et al., 2001), and the relationship between the color and age of S-type asteroid groups has been suggested through the SDSS project (Jedicke et al., 2004). And now, we have a newborn group of asteroids named Karin cluster group, which is thought to have been derived from a breakup that occurred approximately 5.8 million years ago (as indicated by numerical integration of asteroids' orbits (Nesvorn'y et al., 2002) and by numerical simulations of catastrophic disruption which succeeded in reproducing the formation of this cluster (Michel et al., 2003). In this work, we propose that the brightest asteroids 832 Karin in this group is one of excellent targets to examine the effect of space weathering.

2. Observations

Using 8 m Subaru telescope on Mauna Kea, we obtained near-infrared spectra of 832 Karin on September 14th, 2003 (UT). To perform wide-range near-infrared observation, we used CISCO (Cooled Infrared Spectrograph and Camera for OHS) with grisms zJ (0.88–1.40 μm), JH (1.06–1.82), and wK (1.85–2.51). Spectral region between 1.06 and 1.40 μm was observed both by zJ and JH bands. As for Karin observation, integration time is 800 s for each band, i.e., 2400 s for each set of observation. Reference stars (A0 star SAO165395 and A2 star SAO165274) were observed during the Karin observation and a reference star (G2V star HIP3990) was observed after the Karin observation. Detailed observation method is described in Sasaki et al. (2004). During the same night after the Karin observation, we observed comet C/2002 T7 (Kawakita et al., 2004).

We obtained three sets of reflectance spectra of Karin: 7:57–8:40UT, 8:46–9:29UT and 10:45–11:50UT. From lightcurve observations, the rotational period of Karin was estimated to be 18.348 h (Yoshida et al., 2004). According to the lightcurve, rotational phases of our observation sequences are 0.30–0.34 for the first observation set, 0.35–0.38 for the second set and 0.45–0.50 for the last set (Fig. 1).

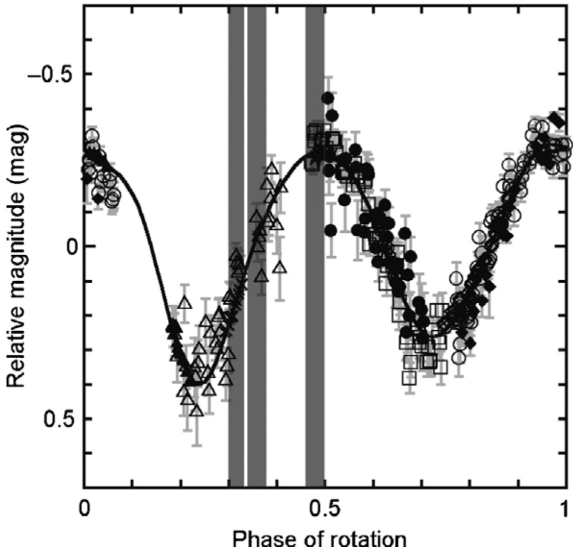

Fig. 1. Lightcurve of 832 Karin (Yoshida et al., 2004). Observations were done by 1.8 m VATT at Vatican observatory at Mt. Graham, Arizona, by 1 m Schmidt telescope at Kiso observatory, Japan, and by 40 cm telescope at Fukuoka University of Education, Japan. Lightcurve observations were done through 9 nights from August to September 2003. Rotational period of Karin is 18.348 h. Rotational phase is zero at 2004 July 31, 0:00 UT. Amplitude of the lightcurve is 0.7 mag at zero solar-phase-angle. Assuming that Karin is an elongated ellipsoid with poles being on the short axis and that observed direction is vertical to the pole direction, the axis ratio of Karin ellipsoid (long to short) is about 2. Three sets of our observations correspond to the rotational phases denoted by gray zones.

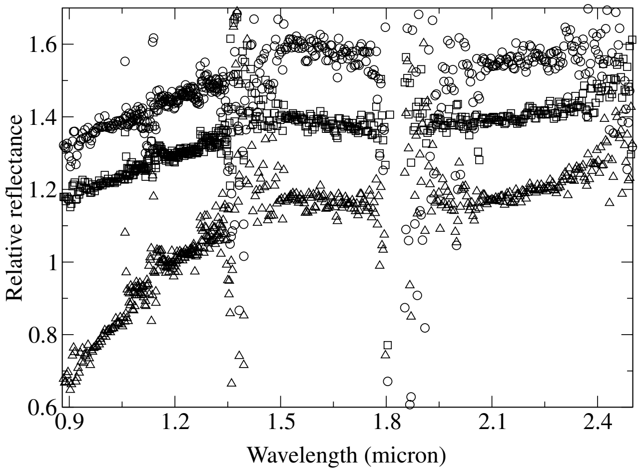

Fig. 2. Relative spectra of 832 Karin. Bottom one is the spectrum relative to the first set, middle one is that relative to the second set, and top one is that relative to the last set. Spectra are smoothed by running average of 5 data points. The top and the bottom spectra are vertically shifted by +0.2 and by −0.2, respectively.

3. Results

Fig. 2 shows the relative reflectance spectra of Karin for these three observation sets. The three spectra in Fig. 2 are that relative to the first, the second, and the last observational sets. There is an obvious difference between the top two and bottom spectra, which we interpret as indicative of Karin's surface being heterogeneous in each rotational phase. We confirmed that spectra of the standard star SAO165395 were not changed before the first set and after the second set of Karin observations (Fig. 3). The observed spectral change of Karin (Fig. 2) was not caused by an instrumental, atmospheric, or hour angle effects.

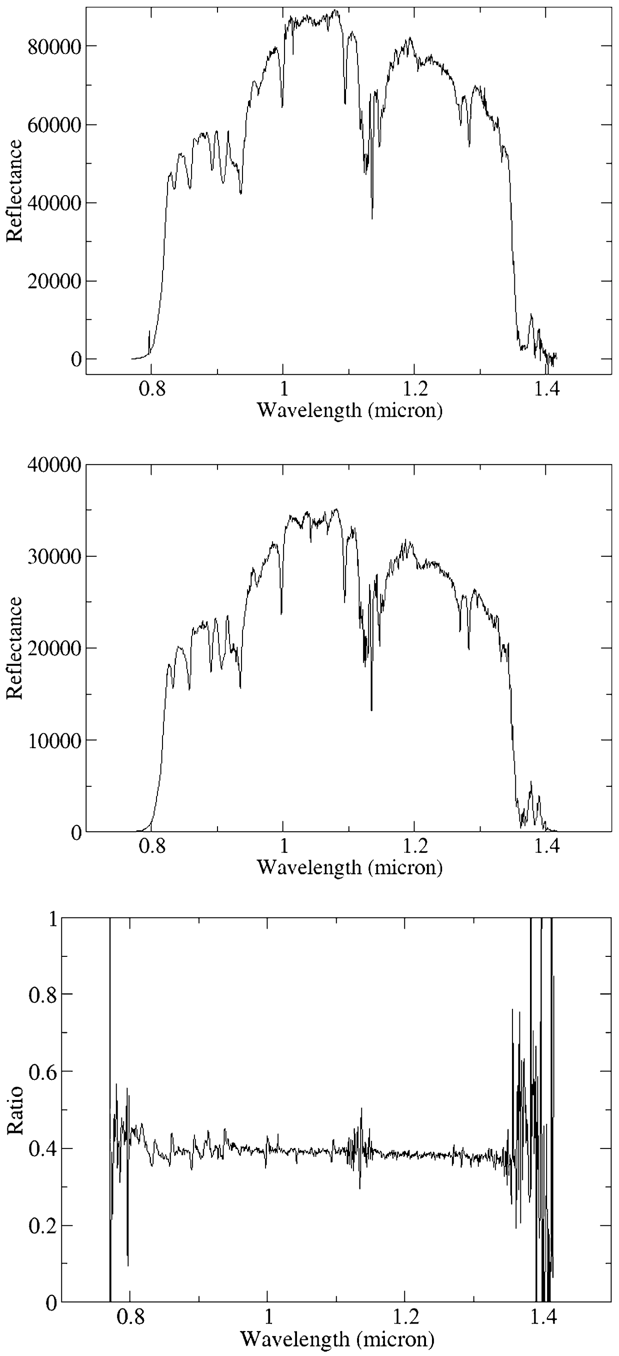

Fig. 3. Relative spectra of SAO165395 (zJ) that were observed before the 1st set (above) and after the 2nd set (middle) of Karin observation, and the ratio of these two spectra (bottom). The difference of absolute value between these spectra reflects the difference of airmass and the difference of integration time.

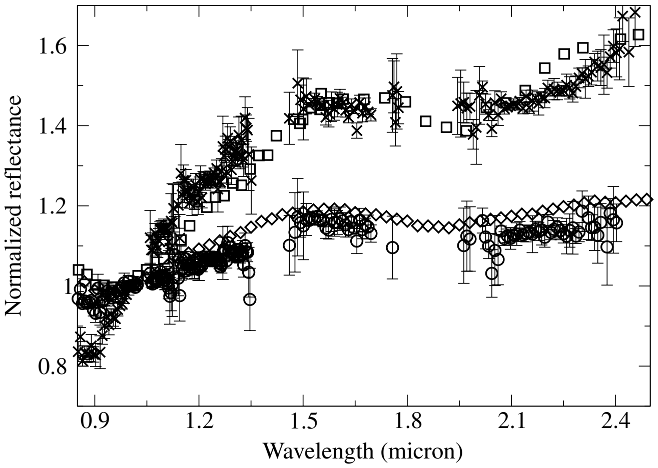

Fig. 4. Reflectance spectra of Karin (the first set by crosses and the last set by circles) along with the previous observations of S(IV)-type asteroid 584 Semiramis (denoted by squares) and L6 ordinary chondrite Paranaiba (denoted by diamonds) normalized to the unity at 1.0 μm. The mean values for every 10 data points are plotted with their error bars of standard deviation. From Fig. 2, we removed data in the wavelength range where the telluric absorptions were strong and the error bars are large. Note that the range between 1.1 and 1.4 μm were observed both by zJ and JH band and their data were overlapped. The change of redness in this region was observed both by zJ and JH bands.

The shape of the first set's spectrum in 0.8–2.5 μm is consistent with that of an S-type object. The spectrum is compared with S-subclass classification where S-type asteroids are divided into 7 subclasses on the basis of the area ratio between the 2 μm/1 μm band, the central position of these two bands, the depth and slope of the 1 μm absorption (Cloutis et al., 1986; Gaffey et al., 1993). The first set's spectrum of Karin belongs to S(IV) class. Fig. 4 shows the normalized reflectance spectra of Karin (first set and last set) along with the previous observations of S(IV) asteroid 584 Semiramis and L6 ordinary chondrite Paranaiba. Whereas, the first set's spectrum of Karin matches that of the S(IV) asteroid, the last set's spectrum of Karin matches a typical normalized spectrum of L6 ordinary chondrite with relatively gentle slope at the wavelength shorter than 1.6 μm. Laboratory simulations of space weathering predict that relatively intense reddening should occur at wavelength shorter than 1.6 μm (Yamada et al., 1999; Sasaki et al., 2001), which suggests that the first set could be the redden spectrum of the last set by space weathering.

4. Discussions

We observed a rapid change of the asteroid NIR spectrum around the rotational phase 0.35, i.e., between the first and the second sets of our observation. From the lightcurve as shown in Fig. 1, this change from the (mature) reddened spectrum to the (fresh) reddened spectrum corresponds to the stage during which observing cross section of Karin increased. During a different night of the same season, Yoshida et al. (2004) performed multi-color visible observation using 1.8 m VATT at the Vatican observatory. They found that *V–I* magnitude is high (V being dark) at rotational phase 0.2 (just earlier than our first set), which we propose can may also be the result of space weathering. Although we cannot rule out the possibility that Karin was a fragment of compositionally differentiated parent body, the above-mentioned spectral similarity between the first set of our observation and S type asteroid suggests that

Karin is more likely to be an impact fragment which keeps the weathered surface. Probably, more reddened reflectance slope should be observed at a phase earlier than 0.3, out first set's spectrum would be some average of more reddened spectrum in earlier phase and unreddened fresh spectrum in later phase.

Let us discuss our results with impact fragmentation processes that formed asteroid groups. The spectral change according to the rotational phase could be explained if Karin is a cone-shaped fragment from a low-velocity impact forming Karin group. Experimental studies of impact disruption suggest that an impact target is disrupted into cone-shaped fragments under a low-velocity (<1 km/s) impact (Fig. 5) (Fujiwara et al., 1989). Cone base is composed of original weathered surface. If the cone base is not replenished by impact ejecta, the cone should have heterogeneous surface, i.e., old cone base and fresh cone sides. In the case of Karin, the cone base (with relatively smaller cross section) should be observed at a rotational phase of 0.2. This would also explain that Karin is a little darker at 0.2 than at 0.7 in the lightcurve (Fig. 1). However, according to the cone fragments model, other bodies similar to Karin's size should have been produced. Currently, Karin is the only large fragment in the Karin group, which is not consistent with the cone fragment model.

The size of Karin (~20 km) is much larger than the transition size (a few 100 m) from "strength-regime" to "gravity-regime" for catastrophic disruption (Asphaug et al., 2002). The interior strength of Karin against disruption is basically controlled by gravitational attraction rather than material strength. The disruption of a parent body (which should be as large as or larger than Karin) should be controlled by gravity rather than strength. Probably the simple cone-shaped disruption model requiring the "strength-regime" would only be applicable to sub-km bodies.

Another possibility is that "Karin" is a heterogeneous rubble pile, i.e., a gravitationally accumulated aggregate (Fig. 5). In this case, impact disruption of the parent body of the Karin group would be core fragmentation or more intensive fragmentation according to high velocity collision. Numerical simulation of asteroid collision simulating asteroid groups suggested fragmentations would be prevalent throughout a parent body. After the fragmentation, some of bodies should have formed by gravitational accumulation (Michel et al., 2003). Thus, if one body collected materials which derived from the surface region of the weathered parent body, there would be some color heterogeneity on its surface. Gravitational accumulation forming a rubble pile would have

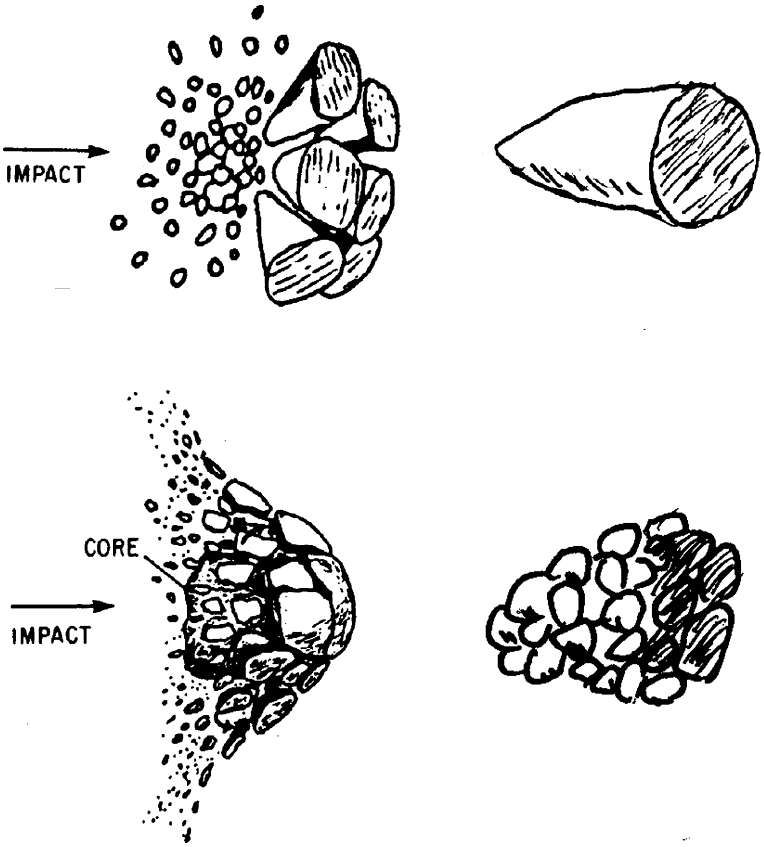

Fig. 5. Impact fragmentation of a parent body of asteroids and two models of Karin with heterogeneous surface. (Left-above) Cone fragmentation under low-impact velocity (<1 km/s). (Left-below) Core fragmentation under high impact velocity. (Right-above) Cone fragment model of Karin. (Right-below) Rubble pile model of Karin. Left-hand side figures were modified from Fujiwara et al. (1989).

also collected finer regolith-forming materials, which might cover and replenish the rubble pile surface. But if those fine materials have some ejecta velocity, they should have escaped before the gravitational aggregate forming Karin was produced.

The other idea is based on non-catastrophic formation of Karin cluster group. Assuming that a body much smaller than Karin should have impacted on proto-Karin with weathered surface at relatively low velocity. Although Karin was not destroyed, impact cratering should have exposed fresher surface. An alternative is that impact-induced shaking would have mixed the surface, which would have replenished the very surface regolith of Karin. Nevertheless, because the Karin group would be comprised of more than 20 bodies, the impact event forming the group should have been catastrophic, even if the impact speed would be low (<1 km/s).

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