

# Mature and fresh surfaces on new-born asteroid 832 Karin

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## 1. Introduction

Although S-type asteroids are the most common among the inner-part main belt asteroids as well as near-Earth asteroids, reddened reflectance spectra and derived mineralogy of S-type asteroids are different from those of ordinary chondrites, the most common meteorites. Space weathering is thought to be able to explain these spectral mismatches between asteroid types and meteorite classes. Recent asteroid surveys suggest a strong link between S-type asteroids and ordinary chondrites. Multispectral observation of Ida by Galileo spacecraft showed that relatively fresh surface such as crater interiors and ejecta have reflectance like ordinary chondrites. Moreover NEAR-Shoemaker mission revealed, thanks to X-ray and near-infrared spectrometer measurements, an ordinary chondrite composition of 433 Eros despite a reddened S-type spectrum, suggesting once again that the space weathering has altered the surface optical properties. The detailed mechanism of space weathering has been remained to be unsolved until recently, when the laboratory experiments using high-energy pulse laser irradiation showed that the reflectance change forming S-type spectra is caused by formation of nanophase iron particles within vapour-

deposited rim around regolith particles<sup>1</sup>. It was suggested that the degree of space weathering, i.e., redness of spectral slope, can be used to discuss the age of asteroids<sup>1</sup>. And recently relation between the color and age of S asteroid groups are found through Sloan Digital Sky Survey project<sup>2</sup>. Here we have an excellent target. Using numerical integration of asteroid orbits, Nesvorny *et al.* recently revealed a new-born group of asteroids named Karin cluster group<sup>3</sup>, which is thought to be remnants of a recent breakup of only 5.8 million years ago<sup>3</sup>. In the present study, we observed the brightest asteroids 832 Karin in this group in order to investigate whether the new asteroid really has fresh and unreddened surface.

## 2. Observation and Data Reduction

A near-infrared spectroscopic observation of Karin was performed by the 8-m Subaru telescope with Cooled Infrared Spectrograph and Camera for OHS (CISCO) on 2003 September 14 (UT). In order to obtain wide range spectrum in the near-infrared region, the grisms named zJ (0.88-1.40  $\mu\text{m}$ ), JH (1.06-1.82  $\mu\text{m}$ ), and wK (1.85-2.51  $\mu\text{m}$ ) were used. The slit size was 108 arcsec  $\times$  0.8 arcsec in our observation, and the typical seeing size at the observation was

about 0.3 arcsec in K band. The integration time for Karin was 800 s for each grism, i.e., 2400 s for each setting (zJ + JH + wK). We obtained 3 sets of spectra, so total integration time was 7200 s. We put the asteroid on the slit at two different positions (A and B) to subtract sky background emissions by the (A-B) operation. Nodding angle was 20 arcsec for the observations. For the cancel of telluric absorption features, a reference star (G2V star HIP3990) was observed just after Karin observation. The reference stars were also observed at the A and B positions.

We used NOAO IRAF astronomical software package to reduce the near-infrared spectra obtained by CISCO. First of all, dark-subtraction and flat-fielding were applied for all frames. Then the OH sky emission lines were used for the wavelength calibration. The Karin's raw spectra were divided by spectra of the reference star to derive the relative reflectance of Karin. Thus we can get a near-infrared reflectance spectrum of Karin. Finally relative magnitudes were computed using aperture photometry. We used an aperture radius of about twice the FWHM, and sky subtraction was performed using a 5-10 pixels wide annulus around the asteroid or reference stars. We scaled our observational relative spectra to be consistent with each other by this photometry.

### 3. Results

We observed Karin at 7:57-8:40 (UT), 8:46-9:29 (UT), and 10:45-11:50 (UT). The synodic rotational period of Karin is 18.348 hours, which was derived from the light-curve obtained by supporting observations<sup>4</sup>. In comparison with the light curve, rotational phases of

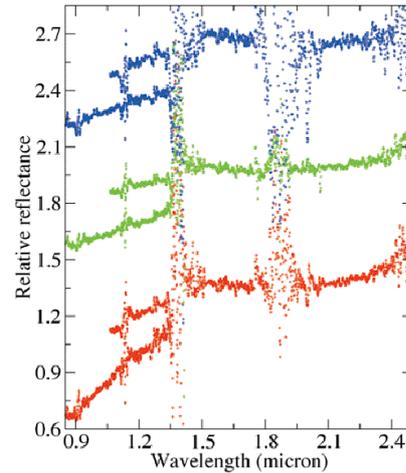


Figure 1 Relative spectra of (832)Karin: Bottom one is the spectrum relative to the first set of the night, middle one is that relative to the second set, and top one is that relative to the last set. Spectral data are smoothed by running average of 5 pixels, and top and bottom spectra are vertically shifted by 0.2 for clarity.

Karin in our observation are 0.30-0.34 (the first set), 0.35-0.38 (the second set), and 0.45-0.50 (the last set). Figure 1 shows the relative reflectance spectra of Karin for these three observation sets. The difference in the airmass at the observations of the asteroid and the reference star was smaller than 0.1 for first set and second set. Since the range between 1.06 and 1.40micron was observed both by zJ and JH bands, we separated the spectra zJ and JH in Fig.1 for each set of observation. Actually we have 6 sets of spectra in this region. There is obvious difference between the top two and bottom spectra sets. Near infrared (0.9-1.4 $\mu$ m) reflectance slope of the bottom spectra is twice as steep as that of the top spectra. In general, major color changes with rotation are very rarely observed on asteroids, e.g. only a little difference in gradients of spectra between different rotational phases observed in Vesta. The color change of Karin would be the biggest color change with rotational phases ever observed. The range, where the most significant spectral change was detected, was

observed both by zJ and JH bands. We confirmed that the spectral change was detected in both bands. And gradual change of the spectral slope is also confirmed through zJ (1st) – JH (1st) – zH (2nd) – JH (2nd) data. In the same season but at different nights (26-29 August, 2003), Yoshida *et al.* performed multispectral (B, V, R, and I bands) Karin observation using Mt. Graham 1.8m telescope at the Vatican observatory<sup>4</sup>. Their result also indicated spectral variation between phase 0.2-0.5.

The shape of 0.88-2.5  $\mu\text{m}$  in the first set's spectrum with the steep slope at shorter wavelength is consistent with an S-type object. We analyzed the data in order to identify which S subclass of the classification scheme can best describe the Karin spectrum. In this classification, the S class is divided into 7 subclasses. Since the first set's spectrum of Karin has the peak position of 1  $\mu\text{m}$  band shorter than 1.0  $\mu\text{m}$  and has apparent 2  $\mu\text{m}$  band, it is placed among the range of S(III), S(IV), and S(V) classes on the basis of this analysis. Fig.2 shows the normalized reflectance spectra of Karin (first set and last set) along with those of S(IV)-type asteroid 584 Semiramis and L6 ordinary chondrite Paranaiba. All spectra are normalized to the unity at 1.0  $\mu\text{m}$ . The first set's spectrum of Karin matches well the spectrum of S(IV) class asteroid. In contrast, the last set's spectrum (blue) of Karin, which has a relatively gentle slope at the wavelength shorter than 1.6 micron, matches (within the noise of our spectrum) the typical normalized spectrum of L6 ordinary chondrite. It is also close to normalized spectra of some Q asteroids. The last set's spectrum seems to be de-reddened spectrum of first one. In other words, the first set could be the reddened spectrum of the last set by space weathering. Laboratory simulation of space weathering also showed

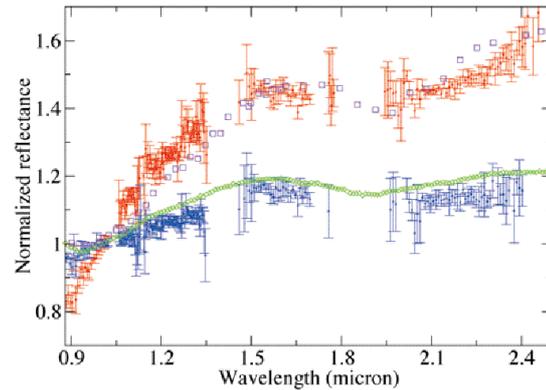


Figure 2 Reflectance spectra of Karin (first set: upper points, last set: lower points) along with the spectra of S(IV)-type asteroid 584 Semiramis (squares) and L6 ordinary chondrite Paranaiba (diamonds) normalized to the unity at 1.0  $\mu\text{m}$ . The data points corresponding to the mean values for every 10 pixels are plotted with their error-bars of standard deviation. The data are removed in the wavelength range where the telluric absorptions were strong and the error-bars are large.

relatively intense reddening at wavelength shorter than 1.6 micron<sup>1</sup>.

#### 4. Discussions

Our result indicates that Karin's surface is inhomogeneous for each rotational phase, which reflects the differences of surface compositions or the degrees of space weathering between the first set and other sets. In the former case, Karin's parent body was partially differentiated, while in the latter case, Karin has fresh and mature surfaces and we have observed these two faces in one night. However, the above-discussed spectral similarity between the first set's spectrum of Karin and S-type asteroid is in favour of the latter space weathering idea. And it is difficult to produce the reddened spectra without space weathering. Hence, we may conclude the differences of Karin's spectra would reflect the difference of the degree of space weathering. At the impact fragmentation forming Karin cluster

group, Karin, which was one of large fragments, could keep the weathered original surface of the parent body, although we cannot eliminate the possibility that Karin would be the fragment of differentiated parent body and then have variable surface compositions.

The mature and fresh surfaces' spectra in one body strongly stand up for the idea that space weathering is responsible for the mismatches between asteroid types and meteorite classes. Our result supports the idea that S-type asteroids are parent bodies of ordinary chondrites. The presence of fresh surface on Karin is the evidence that the space weathering should not proceed in a duration as short as 6 million year. Karin (with other group members) would be basically Q-type asteroid in the main belt.

Let us reflect the spectral change of Karin according to the rotational phase. At rotational phase of 0.35, which is the boundary between the first set and the second set, rapid shift in the degree of space weathering is observed. As cross section area of Karin increases (Karin being brighter), matured redder surface is replaced by immature fresh surface. If Karin could be approximated by an ellipsoid, one end of the long axis (phase 0.2) would be weathered and darkened and the other end would be fresh, although shape difference might be more responsible for this peak height difference. This implies that much more reddened spectra could be observed around 0.2 than 0.3 we observed, and the spectrum of the first set of Karin could be an averaged data of unreddened spectrum and much more reddened spectrum. Indeed, visible observations of Karin indicated that the surface at rotational phase of 0.2 is weathered and the surfaces after phase of 0.3, especially after phase

of 0.5, are not weathered<sup>4</sup>. Their results are consistent with our observation.

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