832 Karin: Absence of rotational spectral variations

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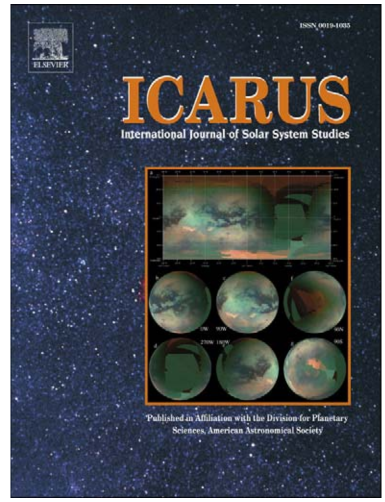

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832 Karin: Absence of rotational spectral variations

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Abstract

832 Karin is the largest member of the young Karin cluster that formed 5.75 ± 0.05 Myr ago in the outer main belt. Surprisingly, recent near-IR spectroscopy measurements (Sasaki et al. 2004) revealed that Karin's surface shows different colors as a function of rotational phase. It was interpreted that 832 Karin shows us the reddish space-weathered exterior surface of the parent body as well as an interior face, which has not had time to become space-weathered.

This result is at odds with recent results including seismic and geomorphic modeling, modeling of the Karin cluster formation and measurements of the space weathering rate. Consequently, we aimed to confirm/infirm this surprising result by sampling Karin's spectrum well throughout its rotation.

Here, we present new visible (0.45-0.95 μm) and near-infrared (0.7-2.5 μm) spectroscopic observations of 832 Karin obtained in January and April 2006, covering most of Karin's longitudes. In the visible range, we find that Karin shows no rotational spectral variations. Similarly, we find that Karin exhibits very little (to none) spectral variations with rotation in the near-IR range. Our results imply that 832 Karin has a homogeneous surface, in terms of composition and surface age. Our results also imply that the impact that generated the family refreshed entirely Karin's surface, and probably the surfaces of all members.

Keywords: Asteroids, rotation; Spectroscopy; Surfaces, asteroids, Regoliths

1. Introduction

Nesvorný & Bottke (2004) have integrated backward in time the known 90 members of the Karin family, a well-defined cluster of asteroids in the proper elements space, formed by a collisional breakup, and embedded within the larger Koronis family. The orbital elements of the Karin family members converge toward a single parent-body orbit, at 5.75 ± 0.05 Myr ago. The discovery of the Karin family offers an excellent opportunity for physical studies of a young family whose members have apparently suffered limited dynamical and collisional erosion. Indeed, this family has been the subject of several studies (Nesvorný et al. 2002, 2005, 2006; Michel et al. 2003, 2004; Sasaki et al. 2004; Yoshida et al. 2004; Brunetto et al. 2006, Vernazza et al. 2006b}.

Michel et al. (2003, 2004) and Nesvorný et al. (2006) modeled the collision of the parent body of this family. Michel et al. (2003, 2004) originally proposed that the parent body of the Karin cluster was a fractured/rubble pile asteroid. They took into account the second largest fragment (4507) which was later on found to be an interloper (Nesvorný & Bottke (2004); see also Vernazza et al. 2006b). Later on Nesvorný et al. (2006) performed a similar analysis (excluding the interloper 4507) and proposed that the Karin cluster may have been produced by a disruption of a monolithic (or perhaps only lightly fractured) parent body. Moreover, they refined the parent body's size (~ 33 km).

Through laboratory research, Brunetto et al. (2006) estimated the rate at which the surface of asteroid 832 Karin should become weathered through the ion implantation process. They obtain a weathering timescale comparable (or slightly shorter) to the 5.8 Myr age of the family.

Vernazza et al. (2006b) characterized the physical properties of the family. They observed 24 Karin cluster members in the visible and 6 family members in the near-IR. Their results suggest global homogeneity of the parent body and none of the investigated objects seems to be an interloper. These results are consistent with the dynamical hypothesis of a common origin. Comparing the spectral slope of the Karin members with the slope domain of ordinary chondrites, Vernazza et al. (2006b) found that the Karin members are slightly redder than OCs. Vernazza et al.

(2006b) interpret this result as an indication of a low degree of spatial alteration for the surfaces of these objects, which is in agreement with the young age of the Karin family (5.8 Myr).

The most studied object of the Karin cluster is 832 Karin (the biggest fragment), an S-type asteroid with a 16-20 km diameter. Yoshida et al. (2004) performed photometric observations of Karin from July to September 2003. The rotational synodic period of Karin was determined to be 18.35 ± 0.02hr. Moreover, the lightcurve amplitude was found to be quite high during that period (peak to peak variation of ~0.61±0.02 mag).

Recently, Sasaki et al. (2004) obtained three near-IR (0.8-2.5 μm) spectra of 832 Karin at three different rotational phases (0.30-0.34, 0.35-0.38, and 0.45-0.50). They found that Karin shows very different colors as a function of rotational phase. It was argued that 832 Karin shows the reddish space-weathered exterior surface of the parent body as well as an interior face, which had no time to become space-weathered. In other words, the Sasaki et al. (2004) results 1) support the idea that 832 Karin could have preserved a surface 'older' than the age of the family 2) indicate that space weathering processes should not be effective in a time span as short as 5.8 million years.

These conclusions are at odds with recent results including seismic and geomorphic modeling (Richardson et al. 2004), modeling of the Karin cluster formation (Nesvorný et al. 2006) and measurements of the space weathering rate (Strazzulla et al. 2005; Brunetto et al. 2006; Vernazza et al. 2006a):

1) It is not clear how 832 Karin could have preserved a surface 'older' than the age of the family. According to recent results of Richardson et al. (2004), impact-induced seismic shaking can produce considerably regolith movements. This should have been quite important for the impact that formed the family, and presumably affected the entire Karin surface. Moreover, Nesvorný et al. (2002, 2006) state that it is likely that the largest cluster members (i.e. 832 Karin) accumulated small fragments. These secondary impacts would have erased any trace of previous space weathering (keep in mind that space weathering affects a very thin upper layer of the surface), both by direct mixing of the regolith layer and through seismic shaking mentioned before. In these

conditions, it seems hard that Karin could have retained an old surface. We would expect that after the major collision that created the family, all the parent body's surface was rejuvenated.

2) Nesvorný et al. (2006)'s simulations predict that surfaces of the final fragments (i.e. Karin's surface for example) represent a complex mixture of interior and near-surface rocks of the original object instead of two very different faces (i) one face mainly composed from the exterior surface of the parent body ii) and the other face mainly composed from the rock that was excavated from the interior of the parent body).

3) Finally, the measurements of the space weathering rate (Strazzulla et al. 2005, Brunetto et al. 2006, Vernazza et al. 2006a) suggest that space weathering processes operate on shorter timescales (≤ 5.8 My) to modify the Q-type spectrum into the S-type spectrum (i.e., produce a steeper spectral slope, suppress 1 and 2 µm absorption bands). Indeed, Brunetto et al. (2006) and Vernazza et al. (2006b) found that Karin and its family members are not quite as red as typical S-types, but are on average redder than OCs.

Here we report multiple spectroscopic observations of 832 Karin in the visible and near-IR at different rotational phases. The derived results should help in understanding the nature of the collisional event that generated the family. The detection of 'young' and 'old' surfaces would confirm previous results (Sasaki et al. 2004) while an absence of rotational spectral variations would rather imply that the disruptive event erased any trace of previous surface alteration.

2. Observations and data reduction

We observed 832 Karin at two apparitions (January 2006, April 2006). The observing circumstances are reported in Table 1, which lists the date and time (UT) for each observation, the associated rotational phase (Φ_w), the wavelength range, airmass (a.m.), V magnitude, the solar phase angle (α_s), the heliocentric distance (R) and the topocentric distance (Δ). The January 2006 observations covered Karin's entire rotation. In April 2006, the coverage was relatively sparse compared to January 2006.

Table 1

The observations presented here were performed in the visible at the European Southern Observatory (La Silla, Chile) with the 3.58 m New Technology Telescope (NTT) and in the near-IR with the 3m NASA Infrared Telescope Facility (IRTF) on Mauna Kea.

During each night we recorded bias, flat-field, calibration lamp and several solar analog stars spectra at different intervals. Spectra were taken through a slit oriented along the parallactic angle in order to avoid flux loss due to the atmospheric differential refraction.

2.1 Visible (NTT)

We used the grism 1 (150 gr/mm) in the RILD arm of EMMI to cover the 0.4-1.0 μm wavelength range with a slit width of 1.5". We obtained 30 spectra over 4 nights covering almost all rotational longitudes (Fig. 1) with an exposure time for each Karin spectrum of 500 seconds. During the first three nights, the seeing was in the 0.6-1.0 arcsec range. The seeing became worse during the last night but remained below 1.2 arcsec.

Standard techniques for visible spectroscopy reduction have been used in order to obtain the reflectance. We used the software MIDAS for the data reduction, applying the general procedures described in the following steps. An average bias was created for each night and was subtracted to all our images. These images were divided by a normalized flatfield to remove pixel to pixel sensitivity variation on the CCD. At this point the two-dimensional spectra were collapsed to one-dimension and then calibrated in wavelength. In order to perform a good correction for atmospheric extinction and to ensure the slope for each acquired spectrum, we collected spectra for the same solar analog star (Landolt 102-1081) at different airmass during each night. We computed the ratio of these solar analog spectra to estimate the variation induced by the change of airmass and/or a possible variation of the atmospheric condition during the night. The ratios normalized to unity were found to be almost flat with a maximum deviation of 1-2 % from 0.55 µm to 0.95 µm. Finally, the reflectivity of Karin was obtained by dividing each Karin spectrum by a Landolt 102-1081 spectrum. Spectra were finally smoothed with a median filter technique, using a box of 10 pixels in the spectral direction for each point of the spectrum. The threshold was set to 0.1, meaning that the original value was replaced by the median value if the median value differs by more than 10 % from the original one.

2.2 Near-Infrared (IRTF)

The run was remotely conducted from the Observatory of Paris-Meudon, France (Birlan et al. 2004; Vernazza et al. 2005; Vernazza et al. 2006b). The spectrograph SpeX (Rayner et al. 2003), combined with the 0.8 x 15 arcsec slit (resolving power R=100) was used in prism mode for acquisition of the spectra in the 0.7-2.5 µm wavelength range. During these nights, the seeing was in the 0.8-1.2 arcsec range. We obtained 3 spectra (Table 1, Fig. 2).

The data reduction was performed using the software Spextool 3.2 (Cushing et al. 2004), dedicated to reduce data obtained with Spex. In the near-IR, the technique for the data reduction is nearly identical to the one performed in the visible. The difference comes from the high luminosity and variability of the sky in the near-IR. As a solution, the telescope was moved along the slit during the acquisition of the data in order to obtain a sequence of spectra located at two different positions (A and B) on the array. These paired observations provided near-simultaneous sky and bias measurements. A first step of the reduction process was to create bias and sky-subtracted images A-B and B-A. The other steps included division by the flat-field image, extraction from two-dimensional images to one-dimensional arrays and the wavelength calibration of the spectra.

During each night, we observed the same star (HD 95364: G2V) just before and after every 832 Karin observation, with the star being in the same field (angular separation: 18.6°; difference in airmass with Karin: less than 0.03) as the asteroid. The explanation for this 'same star' choice (during each night) is that different stars within the same class, show little variation in their spectra. Since we were looking for possible spectral variation, we wanted to avoid such ‘problems’.

We computed the ratio of the two HD 95364 spectra (i.e. acquired before and after every 832 Karin observations) to estimate the variation induced by a possible variation of the atmospheric condition during the night (the variation of the airmass being negligible: ≤0.03). The three ratios (i.e. for each night) are shown in Fig. 2. For the first two nights, the divisions produce an almost flat spectrum (less than 3% variation). For the first night, we clearly see that the depth of the water vapour absorption bands (1.3-1.4 µm & 1.8-2.0 µm) varies between the two spectra. This indicates a difference in the degree of humidity. However, this variation of the degree of humidity doesn't change the slope of the star spectra (i.e. see ratio). For the second night, we don't see any trace of water vapour absorption bands residuals in the ratio, which tends to show that the degree of humidity remained relatively constant. For the third night, the ratio is almost flat in the 0.7-1.8 µm range and shows a 5-10% variation in the 1.8-2.45 µm range. We also see some water vapour absorption bands residuals in the ratio, indicative of a small variation of the degree of humidity. Finally, Karin's reflectance was obtained by dividing each Karin's raw spectrum by the average of the two HD 95364 spectra.

3. Results

3.1 Visible data

We obtained 30 spectra over 4 nights. The spectra have been normalized to unity at 0.55 µm. Fig. 1 shows the averaged spectrum for the 4 different nights.

Figure 1

With the knowledge of Karin's rotational period (18.35 hr), we could place our observations along Karin's period and attribute to each spectrum ‘its rotational phase’. Our observations being too far (in time) from Karin's lightcurve data (Yoshida et al. 2004), we could not place our spectra along Karin's lightcurve. We consider the first obtained spectrum as rotational phase 0.0 (Fig. 1).

Our observations covered most of Karin's rotational longitudes (see Table 1). First, we made an analysis of each spectrum in terms of the position of the maximum. In this wavelength range, the position of the maximum of the spectra is the only characteristic that allows us to investigate a possible variation of the surface composition. Longward of the maximum, all the Karin spectra exhibit the beginning of an absorption feature which appears clearly in the near-IR range (Fig. 2). We find that the position of the maximum is the same (0.747±0.007 μm) for all spectra.

In Fig. 1, we show the difference between the 4 daily average spectra with respect to the mean spectrum. We observe a maximum variation of 2 % which is found to be more relevant after 0.75 μm. The 0.75-0.95 μm range corresponds to the wavelength range were the grism 1 shows a second order contamination. This may explain the little spectral variation observed in this range. Moreover, this little variation is within the error bar of the data reduction (i.e. the ratios of the Landolt 102-1081 star show a 1-2 % variation).

A concise way to quantify how the different spectra behave w.r.t the average can be given by a norm defined as:

$$\sum_{i=1}^{N} \left| \frac{\text{spectrum\_data(i) - average\_spectrum(i)}}{\sigma} \right| / N$$

where spectrum_data(i) represent each data point of each spectrum, average_spectrum(i) is the average spectrum at a given wavelength, σ is the standard deviation of the 30 NTT spectra and N is the number of data points in each spectrum. If all the spectra were equal to the average spectrum all the points (i.e the norm) should be equal to 0. Most of them are between 0.5 and 1σ which is 'normal' and a few are above 1σ. This calculation is certainly partly affected by the numerous telluric peaks mentioned previously. Nonetheless, the fact that most of the points lie in a band between about 0.5 and 0.9 reflects again the very little deviation of each spectrum with respect to the average one. Note that the upper limit obtained with this norm is about 1.25, reached at the beginning of day 3 observations and at the end of day 4.

To sum up the situation, the position of the maximum remains constant with the rotation while the slope variation is less than 2 % (in the 0.72-0.95 μm range). Whatever the cause of this very little (i.e. negligible) slope variation, our visible data implies that 832 Karin, in its January 2006 pole configuration, is homogenous (i.e. same surface composition and same surface age). This result is in agreement with Chapman et al. (2006). Chapman et al. (2006) observed Karin on the IRTF during the same period (UT 7-14 January 2006) sampling its spectrum well throughout its rotation. As in our case, they find that Karin exhibits minimal spectral variations with rotation, certainly nothing of the magnitude reported by Sasaki et al. (2004).

3.1 Near-IR data

We obtained 3 spectra over 3 nights. Our observations covered the following rotational phases: 0-0.04, 0.31-0.35 and 0.62-0.69. Note: these rotational phases do not refer to those defined for the January 2006 (i.e. visible) observations. The spectra have been normalized to unity at 0.8 μm and are shown in Fig. 2. The spectra have been brought to lower resolution by Gaussian smoothing. The Gaussian width used was 4 points. As in the visible range, the 3 near-IR spectra look very similar. The three spectra show no variation in the 0.7-1.3 μm range. Band I minimum is the same for the three spectra (0.915 ± 0.01 μm). In the 1.4-2.45 μm range, the precise calculation of Band II center is quite difficult due to the presence of the water vapour absorption band in the 1.8-2.0 μm region. However, we find similar values for the three spectra (phase 0-0.04: 1.99 ± 0.025 μm; phase 0.31-0.35: 1.99 ± 0.025 μm; phase 0.62-0.69: 2.00 ± 0.03 μm). Since both parameters (Band I minimum and Band II center) are representative of the mineralogical composition, these similar values for the three spectra suggest an absence of compositional variation at our rotational longitudes.

Figure 2

However, we notice a little slope variation in the 1.4-2.45 μm range. In particular, the spectrum obtained at rotational phase 0.62-0.69 ("blue" spectrum) is bluer than the two other spectra (0.05 reflectance unit less than the Φ_w = 0.31-0.35 spectrum). This variation may be due to the division by the star. As mentioned before, the ratio of the HD95364 star (i.e. third night) is not completely flat (0.1 reflectance unit deviation above unity). Thus, the little variation we observe is again (i.e. as in the visible) within the error bar of the 'data reduction process'. Also, some problems with Spex can not be excluded (see Appendix A in Hardersen et al. (2006)). This variation is nothing of the magnitude reported by Sasaki et al. (2004). In the near-IR, we obtain the same result as in the visible: Karin's spectrum shows no "real" rotational spectral variations. Finally, we do not show a complete Karin spectrum over the 0.4-2.5 µm range since it has already been done in Vernazza et al. (2006b). Indeed, we do not see any difference between the Vernazza et al. (2006b)'s complete spectrum obtained at different observing dates and the present Visible-NIR spectrum.

4. Discussion

The spectral study of this peculiar asteroid over its rotational period is of primary importance. One major question raised by a major collision is whether it erases any previous trace of spatial alteration on top of the reaccumulated fragments or if some previously altered regolith can be found with a heterogeneous repartition on top (i.e. surface) of these fragments. Our 'observational experiment' which consisted to measure the spectrum of a "product of the collision" (i.e. Karin) well throughout its rotation allows to bring an answer to such question.

In contrast to the results of Sasaki et al. (2004), our observations (and those of Chapman et al. (2006)) indicate that Karin's surface is homogeneous throughout its rotation. We do not see any spectral variation reflecting a variation of the surface composition and/or a variation of the surface age (i.e. space weathering degree). Indeed, our near-IR data resemble Sasaki's 'blue' and 'green' sets. Two possible explanations exist for the difference between our results and those obtained by Sasaki et al. (2004) based on a much redder spectrum:

1) Their 'red' spectrum is 'spurious'. In this case, the reported color change by Sasaki et al. (2004) would be wrong, as well as all the implications mentioned by Sasaki et al. (2004).

2) Their 'red' spectrum is correct. In this case, the results difference must be due to a significant difference in the pole position between our January & April 2006 runs and their 2003 observational campaign.

Unfortunately, we don't have enough lightcurve data, which would allow us to determine Karin's pole position for a given period. However, the ignorance of Karin's pole orientation doesn't necessarily imply that we cannot bring an answer concerning the presence/absence of Karin's rotational spectral variations.

If Karin was pole-on during both runs (January & April 2006), we would not expect a spectral variation with the rotation. Thus, our obtained result would be normal (banal) and the reported color change (Sasaki et al. 2004) could be right. Sasaki et al. (2004) showed that they observed Karin (from the lightcurve plot in their Fig. 1) in a configuration that was not pole-on.

In our case, if Karin's axis of rotation was perpendicular (or nearly so) to the orbital plane, then Karin could not be pole-on during both runs (the inclination of Karin's orbit to the ecliptic plane is ~1°). The only possibility for us to have observed Karin pole-on, is the case where Karin's axis of rotation would be significantly inclined with respect to the orbital plane (i.e., obliquity close to 90°). In that case, since the rotational axis should be nearly fixed in inertial space, there would be a period during which we would observe the South Pole, one during which we would observe the North Pole and in between we would observe the middle latitudes. From Karin's orbital diagram (see neo.jpl.nasa.gov/orbits), we can see that we (both us and Chapman et al. (2006)) observed Karin half heliocentric orbit apart from the Sasaki et al. observations. Therefore, since Sasaki et al. (2004) did not observe pole-on, we did not too, because the portions of the orbit in which Karin would show us one of the poles are those 90° (in true anomaly) either before or after our observations.

In order to establish a clear picture of the situation, we computed Karin's aspect (i.e. sub-Earth latitude) for January and April 2006 assuming that Karin was in nearly edge-on geometry in September 2003 (i.e. 2003's sub-Earth latitude in the [-15°: +15°] range). The sub-observer coordinates have been computed following the method described in Taylor (1979) and Montenbruck et al. (2002). Indeed, the very high amplitude (peak to peak variation of ~0.61±0.02mag) of the September 2003 lightcurve obtained by Yoshida et al. (2004) implies that Karin was close to an equatorial aspect.

Table 2

Figure 3

The January & April 2006 sub-Earth latitudes are plotted as histograms (Fig. 3) versus their frequency. We note that the range of sub-Earth latitudes is larger in January 2006 (± 45°) than in April 2006 (± 30°). Indeed, there is a slim chance (Table 2, Fig. 3) that we observed some regions farther from those observed by Sasaki et al. (2004). For example, the pole solution (220,-13) will produce a sub-Earth latitude of +15° in September 2003 and -43° in January 2006, while the pole solution (80, 13) will produce a sub-Earth latitude of -15° in September 2003 and +43° in January 2006. However, it appears clearly from Figure 3 that there is no way that we could observe Karin in a pole-on configuration. Indeed, if the lack of spectral variation in 2006 is due to a pole-on aspect, then we found for 2003 a similar pole-on configuration which is in contradiction with the observed lightcurve amplitude at that moment. Finally, ≥89% of Karin's possible aspect angles (Table 2 and Fig. 3) suggest that we observed the asteroid in a 'more or less' equatorial aspect in January & April 2006 (sub-Earth latitudes values in the [-30°:+30°] range). This implies that we can't have missed the 'red' region (if it exists) reported by Sasaki et al. (2004).

Therefore, while it is true that determining Karin's pole position would help us to better constrain the results, the difference between our results and those of Sasaki et al. (2004) can't be due to a dramatically different viewing geometry. This implies that it is highly probable that Sasaki et al. (2004)'s ‘red’ spectrum is ‘spurious’ and that the reported color change is wrong. On the basis of our observations, we rather suggest that 832 Karin is very homogeneous throughout its rotation which is in agreement with Nesvorný et al. (2006)'s simulations.

5. Conclusions

We observed the asteroid 832 Karin at two apparitions (January & April 2006). In January 2006, we obtained 30 visible spectra over 4 nights covering almost all rotational longitudes. In April 2006, we obtained 3 spectra in the near-IR.

Our results imply that 832 Karin has a homogeneous surface, in terms of composition and surface age. The difference between our results and those from Sasaki et al. (2004) can't be due to a dramatically different viewing geometry. Indeed, our observations and those from Sasaki et al. (2004) have monitored almost the same portion of the Karin surface. Thus, our results suggest that Sasaki et al. (2004)'s reported color change is wrong.

This implies that the collision which formed the family certainly erased any previous traces of alteration on the surface of the parent body, and that Karin, and probably all the family members, have been completely resurfaced. This result will serve as an important input for the hydrocodes simulations carried out to study the nature of the family originating events.

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Table 1. Observational circumstances for 832 Karin with the associated rotational phase range (Φ_w), heliocentric distance (AU), topocentric distance (AU) and phase angle (α_s) with respect to the observation date.

Day	UT	Φ_w	λ (µm)	a.m.	V. mag	α_s	R(AU)	Δ(AU)
NTT								
29jan06	05:12-09:05	0-0.21	0.45-0.95	1.15-1.48	16.2	13.5	3.06	2.29
30jan06	05:29-09:09	0.32-0.52	0.45-0.95	1.15-1.39	16.2	13.5	3.06	2.29
31jan06	05:07-08:55	0.61-0.82	0.45-0.95	1.15-1.47	16.2	13.5	3.06	2.29
01feb06	05:14-07:48	0.93-0.07	0.45-0.95	1.15-1.41	16.2	13.5	3.06	2.29
IRTF								
17apr06	06:31-07:20	0-0.04	0.7-2.5	1.05	16.2	13	3.09	2.3
18apr06	06:34-07:26	0.31-0.35	0.7-2.5	1.04	16.2	13	3.09	2.3
19apr06	06:32-07:48	0.62-0.69	0.7-2.5	1.04	16.2	13	3.09	2.3

Table 2. Domains of sub-Earth latitudes of Karin (Fig. 9) and their corresponding likelihood for January and April 2006.

Sub-Earth lat.	[-10°:10°]	[-20°:20°]	[-30°:30°]
Jan 2006	0.48	0.73	0.89
Apr 2006	0.63	0.88	0.98

FIGURE CAPTIONS

Figure 1. Upper part: Daily average spectra (NTT). The spectra are normalized to unity at 0.55 μm. The peak around 0.76 μm is a telluric feature that the division by the standard star did not remove. Lower part: Difference between daily average spectra and the mean spectrum.

Figure 2. Upper part: Karin spectra obtained during three consecutive nights with SpeX (IRTF). The spectra are normalized to unity at 0.8 μm. The spectra have been brought to lower resolution by Gaussian smoothing. The Gaussian width used was 4 points. We report the error bar of the blue (noisiest) spectrum. The 1.8-2.0 micron region being strongly affected by the atmospheric water vapour is removed from the plot. Lower part: Ratios of the two HD 95364 (solar analog) spectra obtained before and after every Karin observation (each night). The ratios are normalized to unity at 0.8 μm and vertically displaced for clarity.

Figure 3. Karin's sub-Earth latitudes in January and April 2006 versus their frequency (% from all the pole solution considering a near-equatorial aspect in Sept 2003). It appears that there is a quite high probability (Table 2) that we saw Karin close to an equatorial aspect during both runs. We also report the sub-Earth latitude range for September 2003, assuming a near-equatorial aspect for this epoch (Yoshida et al. 2004).

Figure 1, Vernazza et al., 832 Karin shows no rotational spectral variations

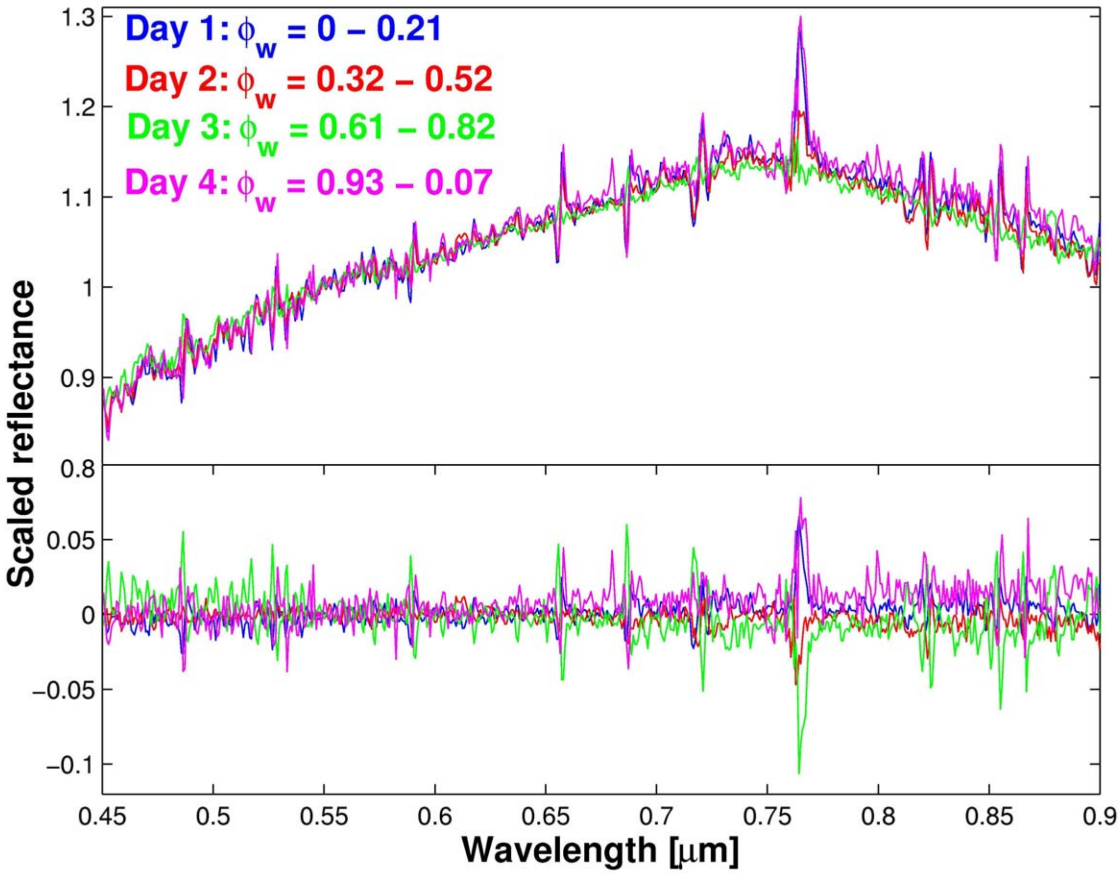

Figure 2, Vernazza et al., 832 Karin shows no rotational spectral variations

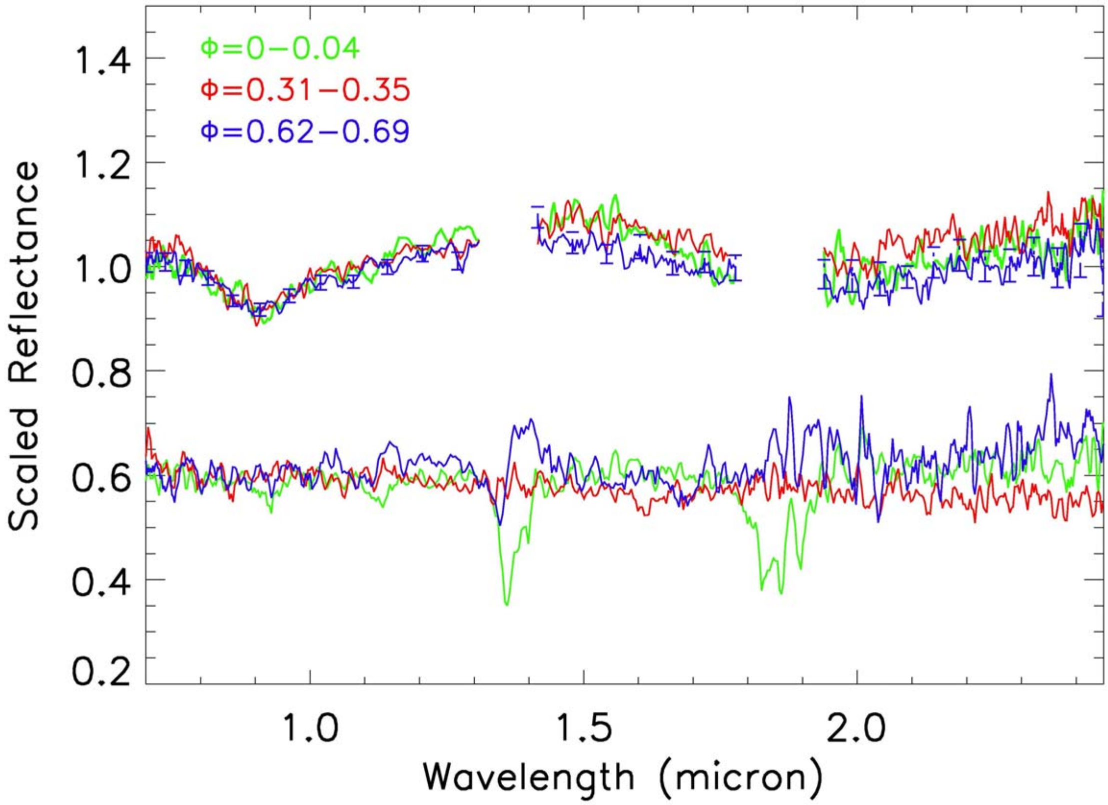

Figure 3, Vernazza et al., 832 Karin shows no rotational spectral variation