COLLISIONS HISTORY IN THE MAIN-BELT BY SPECTROSCOPIC METHODS

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ABSTRACT

New results concerning binary or multiple asteroids (Marchis et al (2005), Michałowski et al (2004), Margot et al (2002), Behrend et al (2006)) as well as those concerning the young families (Nesvorný & Bottke (2004)) bring forth the history of the main-belt on which mutual collisions play the major role.

Investigating the nature of the surface of fragments by spectroscopic methods is necessary for refining several aspects, namely: mineralogical homogeneity of the whole surface of object, degree of space weathering, homogeneity of the parent body, mineralogy of family members, and the balance between the space weathering and the astrophysical timescale for a given object. The spectroscopic results in the 0.8-2.5 μm spectral range for 809 Lundia and 832 Karin will be presented, and some generalizations will be pointed out.

Key words: asteroids, spectroscopy, mineralogy.

1. INTRODUCTION

The last decade was marked by several discoveries of complexes of bodies among asteroids of the main belt as well as to near-earth ones. The binary or multiple structures of asteroids, hypothesized around 1980 (Zappala et al (1980), Leone et al (1984)), were accessible for observing later thanks to the large aperture telescopes and innovative techniques (adaptive optics, correlated observations photometry/radar, ...).

When the components of a double object have comparable sizes, the generic term of *binary object* is commonly used. Particular geometries of the system will allow observations from the ground where the components will be mutually occulted. Recording these events by photometric techniques will allow the obtention of the lightcurve, and further, modeling several physical and dynamical parameters such as dimensions, shape, bulk density and dynamical parameters of binary system.

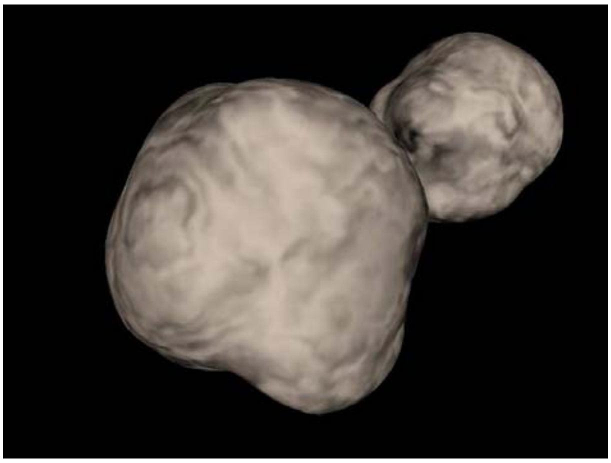

Figure 1. Example of synthetic binary object and the beginning of the mutual event

The occultation of a component by its pair in a binary asteroid (Figure 1) represent an important event which allows to investigate its mineralogical structure and to discriminate between the homogeneity/heterogeneity of components, thus tracing a most probable history of the system. The low-resolution spectroscopy in the visible and the near-infrared regions will be involved in this kind of studies. The correspondent lightcurve has particular behaviors, exhibiting several profiles and depths in magnitude decreasing, associated to mutual event.

Spectroscopic techniques might be also used in studying the young families of asteroids in the main-belt. The asteroids are considered a population dynamically relaxed, characterized by rare mutual collisions. Recent work (Nesvorný et al (2003); Nesvorný & Bottke (2004); Farley et al (2006)) reveal young families of asteroids resulted from relative recent breakups and re-accretion of fragments of the parent bodies (in the order of tenths of millions of years). Some of them (e.g. Karin, Veritas families) could be related to the solar system dust bands or dust showers. The study of young families allows to refine our knowledge concerning the spreading mechanisms of orbital elements of families members by small, but long term effects such is the Yarkovsky effect (Nesvorný & Bottke (2004)).

Sophisticated numerical codes have been also used also recently (Michel et al (2002, 2004)) in order to study the formation of asteroid families by both fragmentation and gravitational re-accumulation. The post-collision phase reveal a re-accumulation of fragments in aggregates commonly named *rubble piles*, held together by small gravitation filed, by little (or zero) tensile strength. This implies a structure of the surface very unstable on the external conditions (planetary perturbations, gravitations instabilities,...). This scenario favours the fresh surface of rubble pile asteroids, less affected by the *space weathering* effects.

Since the discovery of its young family, the asteroid 832 Karin was the subject of a systematic campaigns of observations using both photometric and spectroscopic techniques. Near-IR spectroscopy (Sasaki et al (2004)) revealed spectra with quite distinct trends, corresponding to different surfaces of the asteroid. The authors conclusion is that 832 Karin presents surface variations corresponding to different ages of minerals (i.e. experiencing several degrees of space weathering).

The enlargement of the available observing timescale to do spectroscopy in the solar system has increased the sample of asteroids with well defined spectral characteristics, also widening the asteroid period coverage having spectra taken at different rotation phases. If any difference is to be find, discriminating the real, intrinsic variation from more spurious instrumental induced artifacts (Gaffey et al (2002)) is a necessary step before advancing a surface inhomogeneity explanation

Laboratory studies are also emphasized in order to combine both spectra obtained through astronomical observations with spectra of irradiated minerals, in order to simulate the space weathering. One important aspect of this promising work is the establishment/correlation of the surface status (astrophysical age) with the amount of irradiation experienced by this surface.

The asteroid 809 Lundia was reported as a V type asteroid by Florczak et al (2002) based on the spectroscopic observations in the visible region. As long as its orbital elements are far enough from Vesta family, the authors suggested 809 Lundia to be a V-type non-member of Vesta family. Carruba et al (2005) have investigated also the possibility of 809 Lundia as a member of Vesta family to whom the orbital elements drifted mainly by non-gravitational effects, and the object being captured by the ζ_2 resonance. Last but not least, photometric observations of this asteroid allow (Kryszczynska et al (2005)) to conclude that 809 Lundia is a binary system spinning with a period roughly estimated of 15.4 hours.

The main purpose of this article is to present the results of observational campaigns in near-IR of two asteroids: the binary asteroid 809 Lundia and the asteroid 832 Karin. The article describes the observing technique, data reduction procedures, and the main aspects wich occur in discrimination between various sources of noise and the intrinsic signal obtained from the asteroid.

Both asteroids may be related to catastrophic disruptions occured at different moments in the history of the main belt. The variation in mineralogy of these bodies could be evidence of the degree of melting of chemical elements and the degree of segregation experienced by the parent body. Also, the variation in mineralogy can be correlate with the freshness of various parts on the surface of them.

2. OBSERVATIONS

Both objects were observed in the 0.8-2.5 μm spectral region. The observations were carried out using the SpeX instrument mounted on the IRTF, located on Mauna Kea, Hawaii. Remote observing technique was used from CODAM -Paris Observatory (Birlan et al (2004)), 12,000 km away from the telescope. The time lag between Paris and Hawaii allows day light remote observations. A versatile schedule together with the remote observing facilities of IRTF allow short, punctual observations which could not be predicted long time in advance. This is the case of the asteroid 809 Lundia, who was announced as a binary object in October 2005, and for which it is important do have coordinated photometric and spectroscopic observations in order predict with accuracy the moment of mutual events of the system.

The asteroids 809 Lundia and 832 Karin were observed in circonstances described in Table 1. In the case of 809 Lundia, the observation time was limited for two time intervals of one hour each, during the technical time of the telescope, for two distinct configurations of the binary system. The lighcurves of the asteroid 809 Lundia, obtained just before the run allowed observations to be planned around the time corresponding to one of the minima of the lightcurve and the plateau, respectively.

SpeX was used in Low resolution Prism mode, with a 0.8 x 15 arcsec slit oriented North-South. Spectra of the asteroids and solar analogs were obtained alternatively on two distinct location on the slit (referred to as A and B beam).

832 Karin was observed as close as possible to the zenith, while 809 Lundia was observed at different airmasses, function of the desired configuration. The solar analogs were chosen as close as possible to the asteroids.

3. RESULTS AND DISCUSSION

Data reduction was carried out by means of standard procedures for near-IR spectral range. The median flat-field for each night was constructed. The A-B pairs of images were subtracted in order to eliminate the sky influence. The result was the adition of these images. The final images were flat-fielded, and collpsed to a two dimensional pixel-flux matrix. Finally, the callibration in wavelength, using the Argon lamp lines was performed.

The same steps were performed for solar analogs. This paper presents the spectral reflectances of the asteroids with respect to the solar analogs, normalized to 1.25 μm (value of the maximum in J filter).

As long as accurate results are required, a cautious analysis has to be carried out. We can identify several sources of errors who can hide the intrinsic properties of the asteroid. Several sources of errors could be identified, namely: 1) the atmospheric influence, 2) the spectral variations of solar analog, 3) the intrinsic anomalies in instrument recording.

The atmospheric influence is presented mainly by the amount of water vapours in the atmosphere column, which could exibit variations between the time interval of the asteroid integration and those of the standard star. Its influence could be minimized by the atmospheric modelling during the procedure of data reduction. Another manifestation of atmospheric influence could be the different extinction coefficient depending upon the azimuthal angle of observations (Gaffey et al (2002)). This error could be minimized if the solar analog is chosen as closely as possible to the asteroid target.

The spectral analog variations in time must also be taken into account as a possible element which could impeade the results. Thus, the solution must be the choice of reliable solar analogs, (i.e. stars with the same spectral class, well studied in the near-IR spectral region). These analogs could be observed several times during the night.

By the intrinsic anomalies in instrument recording we define all the functionality of the instrument

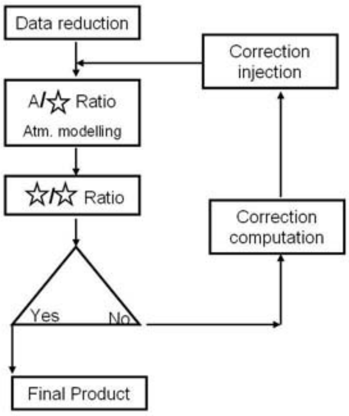

Figure 2. Diagram explaining the data reduction procedure applied for obtaining spectra of the asteroid 832 Karin.

(spectrograph) which may change the signatures of the asteroid final spectrum. In our case, the observations were performed in two consecutive nights. Tests concerning the signal analysis for the standard stars must be done to study possible exchanges in the spectral trend of the standard star spectrum between the nights.

For the high quality spectra of the asteroids, not only the high S/N ratio, but also the error-bars in the flux and their propgation in the final product must be taken into account. Furthermore, these spectra will be the input for particular studies linked to the mineralogy of the surface.

In our case, we experiment several steps, iteratively. The data reduction procedure is shynthetized in Figure 2. The diagram provides good results in a few steps.

3.1. 832 Karin

The data reduction process is described in Figure 2. A pipeline Image Reduction and Analysis Facility (IRAF) was used at several stages, the data reduction steps being largely described by Rivkin et al (2004), Rivkin et al (2005), and Binzel et al (2006), which act like a wrapper over the real IRAF set of instructions. Based on some assumptions on the file names, the script groups together the flat fields, calibration, and science images having the advantage that the reduction procedure should be run only once for the entire data gathered in one night of observations. At the first step the pipeline extracts from the entire frame the region containing the spectrum. Then, a bad pixels map and a master flat frame to apply the corrections is computed. Images in A and B positions of the slit are then paired and substracted

Table 1. Observational circonstances occured during the observations of 809 Lundia and 832 Karin. Date, exposure time, airmass, seeing and humidity are presented for both asteroids and solar analogs.

Date (UT)	Object	Texp	Itime (s)	Cycles	Airmass	Seeing (")	Humidity (%)
Nov, 4, 2003, 6h 16m	832 Karin	32 min	120	8	1.21	1.0	28
Nov, 4, 2003, 5h 18m	SA 113-276	4 min	40	3	1.06	1.0	28
Nov, 5, 2003, 5h 35m	832 Karin	24 min	120	6	1.17	0.7	23
Nov, 5, 2003, 6h 35m	SA 113-276	128 s	8	8	1.14	0.7	23
Dec, 21, 2005, 7h 16m	809 Lundia	16 min	120	4	1.04	0.6	18
Dec, 21, 2005, 7h 30m	HD 16018	11.0	25.0	12	1.05	0.6	18
Dec, 22, 2005, 9h 26m	809 Lundia	20 min	120	5	1.52	0.56	14
Dec, 22, 2005, 10h 04m	HD 16018	2s	0.5	2	1.53	0.56	14

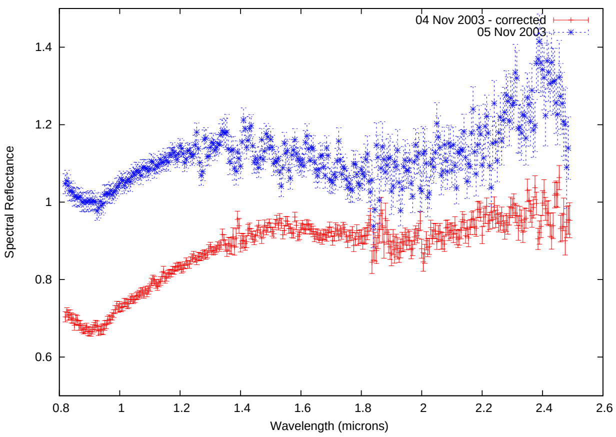

Figure 3. Spectra of 832 Karin obtained in November 4 and November 5, 2003, obtainded with respect to the standard star SA 113-276. These spectra are corrected by the star influence in the region 0.8-1.3 and the error-bars are also estimated. The spectra presents similar trends, but they are clearly distinct, outside the error-bars. This may support the hypothesis of surfaces which have been experienced different degrees of space weathering.

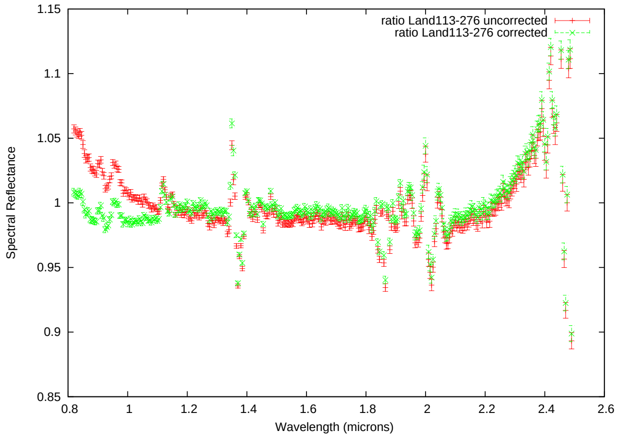

Figure 4. The standard star SA 113-276 spectrum of November 4 was divided by the one of November 5, 2003 (red color). The region 0.8-1.3 μm presents a negative slope which was modeled and corrected (green color) in order to erase this spectral influence in the final spectra of 832 Karin. The error-bars are also represented in the figure

to minimize the sky background and the telescope influence. One-dimensional spectra are extracted from the newly obtained images containing both a negative and a positive spectrum , and wavelength calibration using an Argon lamp spectrum is done.

After comparing wavelength scales for A and B beams and computing the average shift between the two, the images are trimmed, so only the positive half of them is retained and scaled to achieve peak data value. User defined groups of asteroids and reference stars taken at similar airmasses are combined, then single one-dimensional spectra are extracted for each of the groups. Applying the wavelength calibration to all groups spectra concludes the first step of the reduction procedure.

The second step of the reduction rely on IDL procedures making use of the ATRAN model (Lord (1992)) to correct for telluric absorbtion. Final spectra obtained for each group in the previous step are paired with values of zenith angles, each asteroid spectrum being divided by each reference star spectrum to obtain the final normalized reflectance spectrum.

Additionally cross division of the reference stars spectra should be checked for any important slope variation in the normalized reflectance spectrum that could artificially induce spectral variation in asteroid spectra taken in different times. As it can be seen in Figure 3 the comparison between two different series of the solar analog SA 113-276 obtained in two different nights exhibits a non-neutral trend in the wavelength region 0.8-1.3 μm. This affectes the mineralogic interpretation of Karins' spectra, the region being the subject of major signature of minerals typically associated with silicates. A correction factor was introduced for this spectral region, then the data reduction was performed in order to verify the quality of this correction. While the correction has given stisfatory results (i.e. constant values for the ratio of two series for the solar analog) it was injected into the asteroid spectra.

The final results are presented in Figure 4. The correction applied decreases the difference between the spectra, however the spectra remain distinct, the errorbars of reflectances at the same wavelength cannot be superimposed. The global trend of both spectra are similar, with absorption bands around 1 μm and a shallow absorption band around 2 μm, which corresponds to silicate minerals. The difference in spectra could be associated to material which have experienced different irradiation (space weathering).

The spectra data of 832 Karin were correlated with its corresponding surface, by taking into account the lightcurve deduced by Yoshida et al (2004). The spectrum obtained in December 4, corresponds to a rotational phase of 0.95, quite close to one of maxima, while the that of December 5 was obtained to a rotational phase of 0.21. The distinct trend in the spectra, corroborated with the information deduced from the composite lightcurve in the hypothesis of a $pole-on$ geometry of the asteroid may conclude to a spectral variation of two distinct parts of its surface.

At this stage, the science concerning the asteroid 832 Karin will be oriented toward a precise/qualitative analysis of its mineralogy, by taking into account both the visible and the near-IR spectral intervals. The possibility of heterogeneous regions of the asteroid surface will be also taken into consideration. Finaly, the approach with reflection spectra obtained in the laboratory from terrestrial minerals and meteoritic material will be investigated.

3.2. 809 Lundia

The asteroid data reduction was performed using the Spextool package (Cushing et al (2004)). 809 Lundia analysis was performed with respect to the HD 16018 solar analog. The spectra of the asteroid, normalized to 1.25 μm and presented in Figure 5 are the first obtained in peculiar conditions of a spectroscopic study of a binary system in coordination with photometrical observations. The planning of observations was made in order to observe spectroscopically at least a minima of the lightcurve. This occured in December 22, 2005, at 11h50m UT when one of component was occultated by the other. The blue color spectrum in Figure 5 corresponds to a moment very close to this minimum. As the magnitude 809 Lundia drops with more than an unit, this effect could be observed also in terms of error bars of the spectrum comparing with the one obtained in December 21, 2005 in the conditions of similars integration time and a minor difference in atmospheric extinction.

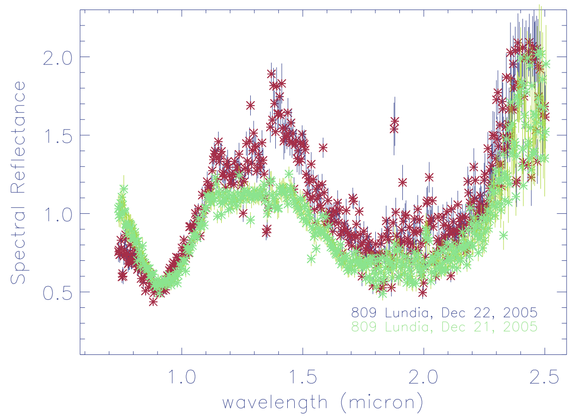

Figure 5. Spectra of 809 Lundia obtained in December 21 and 22, 2005, obtainded with respect to the standard star HD 16018. The spectrum of December 22 correspons to a position in the lightcurve on which one component is occulted by the other one, while the spectrum of December 21 corresponds to the plateau of the lightcurve (contribution of both components).

In December 21, 2005, the spectrum cooresponded almost to the plateau of the lightcurve (i.e. the collected flux is the contribution of both components, in almost equal proportions).

The eye-made preliminary analysis conclude for 809 Lundia a typical V-type spectrum in the near-IR region, with large absorption bands around 1 and 2 μm for both spectra. Our data support the classification proposed by Florczak et al (2002). The visible part of the spectrum, combined with the present one can be easily designed, allowing to obtain the entire absorption band with the mimimum one around 1 μm.

The differences between spectra are included in the error-bar, which may conclude to a binary system with homogeneous components in terms of mineralogy of theirs surfaces. The dichotomy between spectra are mainly in the region 1.2-1.45 μm. As weel as this region contains telluric bands, a deep and carefully analysis will be done (i.e. atmospheric modelling).

In the case of a binary system, in order to have the highest contrast between spectra components, the ideal geometry of observations would be to record two consecutive mutual events (central, if possible) for which the contribution in the flux belongs to each component. Future opportunities for observing such configurations will be analyzed.

4. CONCLUSIONS

The space weathering has been proposed for long time as one of the principal mechanisms who partially explain the paradox asteroids-meteorites. Near-IR spectroscopy could be used as a tracer of this alteration for some objects of the main-belt, namely objects issued for relatively recent collisions, and complex ones.

In the case of the asteroid 832 Karin, we can conclude a relative diference between spectra which could be explained by regions on the asteroid surface experiencing different degree of maturity.

For the binary object 809 Lundia, the spectra obtained in two distinct geometries exhibit similar features, however more studies are under work in order to confirm a possible/probable homogeneity of this complex.

ACKNOWLEDGMENTS

The work of Alin Nedelcu was supported by the ESA grant RES-H/3006. This article is based on IRTF/SpeX observations performed in remote observing mode from CODAM - Paris Observatory.

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