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Near infra-red spectroscopy of the asteroid 21 Lutetia

I. New results of long-term campaign

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ABSTRACT

Aims. Investigation of the physical nature of the asteroid 21 Lutetia, target of Rosetta mission, is required for the completion of its ground-based science and in the frame of its future fly-by. Monitoring this object is essential in preparing the future encounter with the spacecraft.
Methods. The asteroid was observed with SpeX/IRTF in the spectral region 0.9−4.0 μm, in remote observing mode from Meudon, in March 2003 and August 2004.
Results. The new spectrum in the range 0.9−2.5 μm confirms the previous results (Birlan et al. 2004), for a neutral trend with a large shallow band around 1 μm. The spectral region around 3 μm is usually considered as a tracer of aqueous alteration of the surface. The 3 μm band in Lutetias' spectrum is shallower than those of hydrated asteroids, and the 2.9 vs. 3.2 ratio reveals a value close to the CV−CO meteorites. The band around 3.1 μm, if it exists in the spectrum of 21 Lutetia, is different from the one present in the spectrum of 1 Ceres, and is lower than 0.5%.

Key words. minor planets, asteroids – techniques: spectroscopic – methods: observational

1. Introduction

The asteroid 21 Lutetia was chosen as one of the two targets for a future fly-by by the Rosetta mission, successfully launched on March 2nd, 2004. This asteroid is located in the inner part (a = 2.43489811 ua, e = 0.16380387, i = 3°.064298) of the main belt, with low eccentricity and inclination. The encounter of the spacecraft with the asteroid is scheduled for July 2010.

Physical parameters of the asteroid are still subject of study. Partial and composite lightcurves of the asteroid were reported by several authors (Zappala et al. 1984; Dotto et al. 1992; Lagerkvist et al. 1995). Colors were reported by several large surveys (Zellner et al. 1985), articles (Rivkin et al. 2000), and spectrophotometry (Bell et al. 1988). Visible and near-IR spectroscopy data were also published in surveys (Bus & Binzel 2002) and some new articles (Barucci et al. 2005; Lazzarin et al. 2004; Birlan et al. 2004). These new articles are motivated by refining the knowledge of this object before the encounter with Rosetta spacecraft.

Using the standard thermal model (STM), its diameter was estimated to be 95.5 ± 4.1 km for an albedo of 0.221 ± 0.02 (Tedesco & Veeder 1992). Studies concerning the thermal albedo (Mueller et al. 2005) as well as the albedo deduced by radio echoes (Magri et al. 1999; Shepard et al. 2005) were also published.

Spectroscopy is a powerful tool allowing the investigation of the mineralogy of solids in general, the surface of asteroids in this case. Minerals exhibits complex structures of absorption in the visible and near-IR region. Large absorption bands in this spectral range, may serve not only to determine the mineralogical composition (minerals or mixture of minerals), but also to model the surface in terms of space weathering alteration.

This article deals with near-IR spectra of 21 Lutetia, obtained in the framework of groundbased science preparing for the Rosetta encounter. The comparison of these spectra with those of minerals obtained in laboratory as well as the analysis of particular features such as the presence of the water band around 3 μm are also discussed.

2. Observations and data reduction

The asteroid was observed two times using the 3-m aperture telescope IRTF located on Mauna Kea. Near-IR spectroscopy investigations were carried out by means of the spectrograph SpeX.

The geometries of the asteroid are presented in Fig. 1 while the physical parameters are described in Table 1.

The asteroid was modeled using the semimajor axis already determined by lightcurve inversion and the pole solution of de Angelis (1995), combined with the first maximum of the

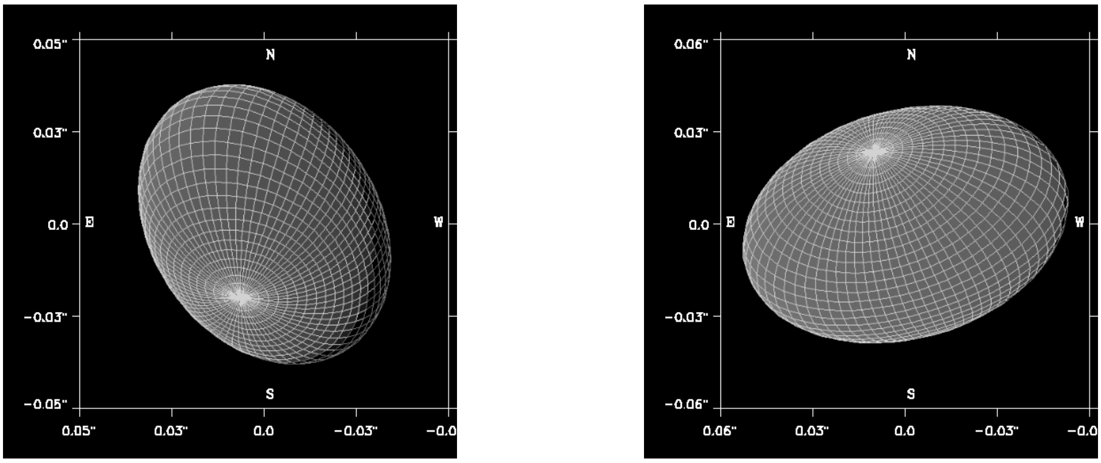

Fig. 1. Aspect of 21 Lutetia at 14 August 2004 14h18m56s UT (*left side*), and 31 March 2003, 7h15m12m UT (*right side*). The asteroid was considered ellipsoidal and the Minnaert scattering law with a coefficient of 0.5, typical for dark asteroids, was used for these figures.

Table 1. Physical ephemeris of the asteroid 21 Lutetia. Date, universal time for the middle of the exposure interval, as well as geometrical parameters of 21 Lutetia are presented.

Date	UT	SSP (λ, β) [deg]	SEP (ω, δ)[deg]	North Pole (deg)
12 August 2004	14h 18m 56s	178.45 –38.65	141.04 –44.54	341.78
31 March 2003	7h 15m 12s	98.38 +45.37	78.26 +44.18	23.30

Table 2. Observational circumstances for the asteroid 21 Lutetia. Date, universal time for the middle of the exposure interval, instrumental mode, time of exposure (in seconds), time of individual exposure, number of coadds and cycles, and the airmass for the middle of exposure are presented.

Date	UT	Mode	$T_{\rm exp}$ (s)	Itime (s)	Coadds	Cycles	Airmass
12 August 2004	14h 18m 56s	SpeX/Prism mode	600	15	2	10	1.068
31 March 2003	7h 15m 12s	SpeX/LXD mode	2400	40	4	14	1.227

provisional lightcurve proposed by Raoul Behrend (`http://obswww.unige.ch/~behrend/page1cou.html`) and the synodic period proposed by Zappala et al. (1984), and the Minnaert scattering law with an assumed limb-darkening parameter of 0.5, typical of dark atmosphereless body.

The observations were performed in remote observing mode from Centre d'Observation à Distance en Astronomie de Meudon (CODAM). Low resolution Prism mode of the spectrograph was used in the 0.8−2.5 μm spectral interval, and simultaneous LXD mode in the 1.9−4.2 μm spectral range. In order to perform the data reduction, the package Spextool (Cushing et al. 2004) and personal procedures performed in IDL have been used.

For the spectral measurements with SpeX (a wide description of instrument design and operating modes described in Rayner et al. 2003) we used a 0.8×15 arcsec slit oriented North-South. The spectra of the asteroid and the solar analogs were obtained alternatively on two distinct location on the slit (referred to as A and B beam). Observational circumstances are presented in Table 2.

In order to minimize the atmospheric and telescope influence, we subtracted the B position spectrum from the A position spectrum for each pair of exposures, in the assumption of quasi-homogeneous sky background during A plus B exposure pairs. The result of the subtraction was flat fielded. For each object, we median combined the result of all cycles in each observing series. This technique produces one positive and one negative spectrum on the same image. Next step was the construction of an accurate spatial profile for the extraction of the spectra, and the collapse of two-dimensional spectra to one-dimensional (intensity-pixel) spectrum. Finally, the wavelength calibration was carried out.

2.1. Prism mode

The spectral interval 0.8−2.5 μm was observed during August 12, 2004. We used SpeX instrument in Prism mode (R = 100). The seeing was 0.75 arcsec and the humidity was 34%.

The solar analog HD 19061 was chosen and observed just before 21 Lutetia. The asteroid was observed as close as possible to the zenith (airmass of 1.075) and the solar analog was chosen as close as possible to the asteroid (airmass of 1.131). The spectrum of 21 Lutetia was obtained in 600 s of exposure time, while the spectrum of the solar analog was obtained in 270 s.

The ratio between the spectrum of 21 Lutetia and the solar analog, normalized at λ = 1.25 μm[1] is presented in Fig. 2.

2.2. LXD mode

The spectrum covering the 1.9−4.3 μm spectral range was obtained on March, 31, 2003. The seeing varied between 0.9−1.8 arcsec, while the humidity was in the 50−75% range. The LXD mode of SpeX allows simultaneous coverage of the whole interval with the overlap of spectra at the edges of two consecutive orders. Thus, the spectrum can be calibrated for the whole interval, despite the atmospheric opacity in the 2.5−2.9 μm spectral interval. The disadvantage of this mode is the saturation of the CCD detector in the 4.1−4.3 μm spectral

[1] This wavelength usually corresponds to the maximum in the J filter.

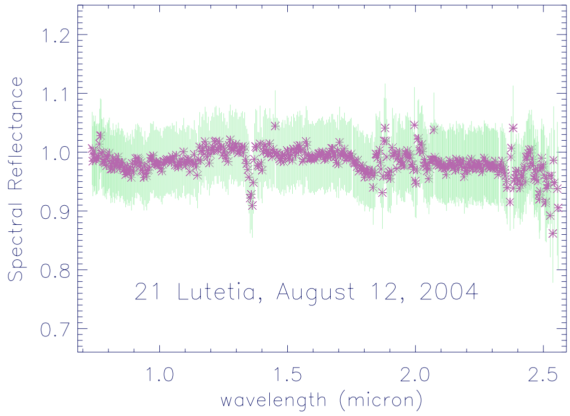

Fig. 2. Spectrum of 21 Lutetia with respect to the solar analog HD 19061. Each reflectance channel is represented with its own errorbar obtained by flux measurements and error propagation.

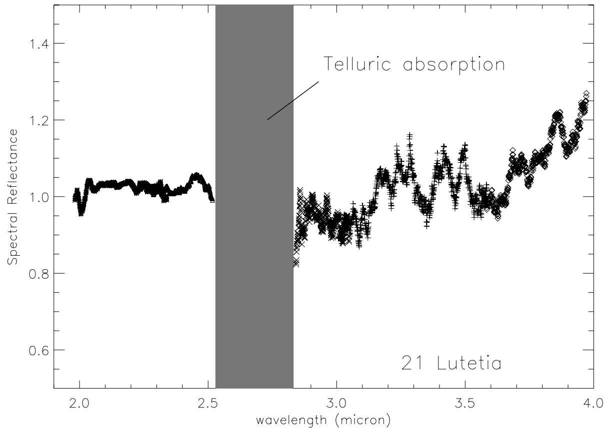

Fig. 3. Spectrum of 21 Lutetia with respect to the standard star TYC 4966-1029-1. Thermal influence was removed for the spectrum taking into account the STM and the IRAS albedo of the asteroid. The spectrum was normalized at $\lambda = 2.2\,\mu$m (this wavelength usually corresponds to the maximum of K filter).

interval which is typically due to the brightness of the sky. In our case, the useful spectral information covers only the 1.9–4.0 μm range.

The spectrum of 21 Lutetia was obtained at an average airmass of 1.220. The standard star TYC 4966-1029-1 was used as reference and observed just before the asteroid (airmass of 1.09). The Standard Thermal Model was applied taking into account the albedo value estimated by IRAS, in order to obtain the final spectrum presented in Fig. 3. The spectrum was smoothed to a lower resolution ($R = 50$) in order to enhance the signal-to-noise ratio and to allow us to detect the presence of large spectral features such as the absorption band around 3 μm, associated with the water of hydration of minerals.

3. Discussion

Our first approach in analyzing the spectra of 21 Lutetia was to find the best correspondence between them and those from libraries of minerals and meteorites. We must underline the importance of such studies and especially the limitations of this technique, mainly due to the difference in scale (reflectance spectra of km sized bodies versus reflectance spectra of thin micron sized samples of minerals/meteorites).

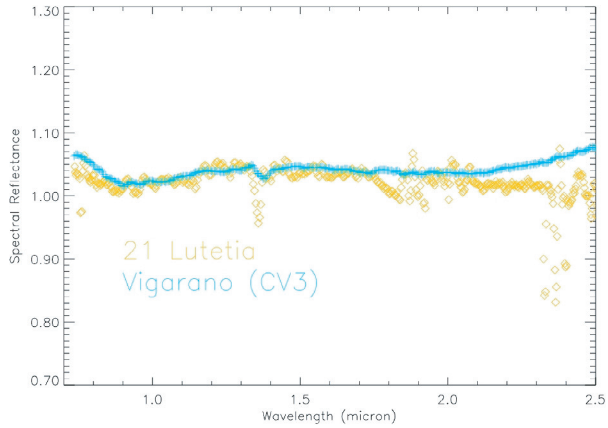

Fig. 4. Spectrum of 21 Lutetia superimposed with the reflectance spectrum of Vigarano meteorite (CV3 type).

In the region 0.8–2.5 μm, the spectrum is almost neutral and flat, in good agreement with those published by Birlan et al. (2004), and also shows a shallow absorption band around 0.95 μm. The obtained spectrum is in good agreement with the laboratory spectrum obtained using a powder sample of the Vigarano meteorite, classified as CV3 type, belonging to the category of carbonaceous chondrite meteorites (Fig. 4). The agreement diminishes after 2 μm and this fact could be explained by differences in the mineralogical composition (asteroid minerals versus meteorite ones).

The CV class of meteorites contains two subclasses, namely oxidized and reduced, defined on the basis of the ratio of metal versus magnetite (Fe_3O_4), and the nickel atoms contained in the sulphides (McSween 1977). CV meteorites are poor in carbon or water, the black aspect is mainly due to the relatively high content of oxidized iron in the form of magnetite. In their structure it is also important to mention the presence of irregular inclusions, rich in calcium and aluminum (CAIs). Laboratory studies concerning the porosity of this class reveal two distinct groups: "high porosity" meteorites spanning the range of 19–24% in porosity, and "low porosity" ones (range of 1–10% in porosity). Preliminary analyses exhibit a direct correlation between the "high porosity" group and the "oxidized" subclass, while the "low porosity" group belongs mostly to the "reduced" subclass (Britt & Consolmagno 2003).

Vigarano belongs to the "reduced" subgroup of CV meteorites. Its texture and mineralogy is mainly composed by chondrules (from 30% to 50% of the total matter in CV type), CAIs, chondrite fragments, metal and sulfide grains (Lee et al. 1996). Vigarano contains both magnetite and metallic iron, around 2.73% of the total mass (Hyman & Rowe 1986). Its average porosity was estimated to be of 0.3% and the bulk density of 3.25 ± 0.06 g cm^{-3} (Britt & Consolmagno 2003) or less than 3% for a bulk density of 3.3 ± 0.1 g cm^{-3} (Britt & Consolmagno 2000). Laboratory studies of small samples of the meteorite (Lee et al. 1996; Kojima et al. 1993; Komatsu et al. 2001) bring forth the conclusion of low H_2O/rock ratio during the parent body processing of Vigarano, as well as the relatively low temperature required for the formation of its matrix. The lack of severe volatile depletions is evidence that the chondrules were formed from previously condensed solids (Grossman & Wasson 1983).

By means of the microscopic considerations on Vigarano, under the hypothesis that an asteroid such as 21 Lutetia is covered by minerals similar to CV3 types, we may expect a shallow

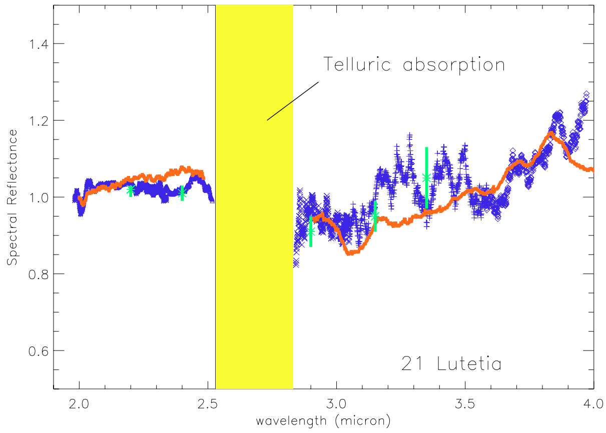

Fig. 5. The spectrum of 21 Lutetia (in blue) was superimposed with the reflectance spectrum of the asteroid 1 Ceres (in red), and the photometry of 21 Lutetia obtained by Rivkin et al. (2000) on September, 29, 1996 (light green points with error-bars). The data in the spectral region of 2.55−2.9 μm were omitted from the figure because of telluric absorption. The good concordance between the photometric results and our spectrum may be noteworthy. The spectral region around 3 μm of 21 Lutetia is very different than that presented in the spectrum of 1 Ceres.

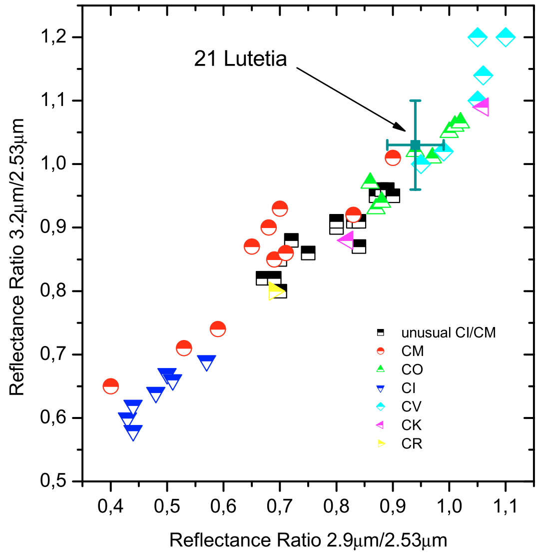

Fig. 6. The continuum defined at 2.53 μm is used in analyzing the correlation between reflectances at 2.9 μm and 3.2 μm The value computed for the asteroid 21 Lutetia was overplotted in a representative statistics containing dark meteorites. The value of Lutetia is close to those of CV and CO meteorites.

and even a lack of absorption feature at 3 μm, characteristic of water hydration.

A large 3 μm water band is the result of the vibrational fundamentals of OH radicals as well as the first overtone of H_2O molecules (Rivkin et al. 2003). Spectra around 3.1 μm for some asteroids (e.g. 1 Ceres) exhibit another absorption band, attributed, to water ice frost (Lebofsky et al. 1981), ammoniated phylosillicates (King et al. 1992), or water ice-asphaltite mixtures (Vernazza et al. 2005).

In Fig. 5, the spectrum of 21 Lutetia in the 2.0−4.0 μm interval was superposed with the spectrum of the asteroid 1 Ceres, obtained with the same instrument in the same observing mode, and presented by Vernazza et al. (2005), and photometric data obtained by Rivkin et al. (2000) on September, 29, 1996.

The spectrum of 21 Lutetia exhibits a shallow absorption feature in the 3 μm water band. Visual comparison of the spectra shows no evidence of the absorption feature around 3.1 μm, however noting the spectrum of 21 Lutetia is much noisier than the one of 1 Ceres. We can define an upper limit of our detection, by considering a mean value of the reflectance in the 2.90−2.99 μm region and comparing it with the mean reflectance obtained in the 3.01−3.10 μm region. We conclude that if this small band is present on 21 Lutetia, it could not be greater than 0.5% of the continuum of our spectrum.

The 3.2−3.4 μm region of the spectrum is difficult to explain and we consider it to be the combination of reflected IR radiation of the asteroid and the telluric contribution (mainly the carbon compounds of the atmosphere).

Qualitative analysis of the spectrum presented in Fig. 5 was made using the approach of Miyamoto & Zolensky (1994); Sato et al. (1997); Rivkin et al. (2003).

C-type meteorites are characterized by the ratio of reflectances at 2.9 μm and 3.2 μm taking into account a continuum defined by the value of the reflectance at 2.53 μm (Fig. 6). In order to compute the same ratio for 21 Lutetia, as long as the reflectance at 2.53 μm is not relevant in our spectrum, the reflectance at 2.5 μm was used as reference value. Consequently, an error two times greater than the estimated one was taken into account for this reflectance.

The plot of the value obtained for 21 Lutetia is located on the upper left part of Fig. 6, a region essentially populated by the values of CV and CO meteorites. This may reinforce the link between the mineralogy of the surface of 21 Lutetia and the Vigarano type meteorite.

We must mention that this mineralogical solution is not unique, but the simplest/plausible one. Actually, mixtures of different minerals, combined with laws simulating the space weathering could be responsible in order to obtain a similar spectral profile.

IRAS albedo and new radiometric measurements (Mueller et al. 2005) exhibit very large values compared to the C-type asteroids, contrasting with polarimetric measurements of albedo (Belskaya & Lagerkvist 1996; Zellner et al. 1977). Radar echoes (Shepard et al. 2005) could partially confirm minerals with high concentration of metals in the asteroid composition.

However, our article must be considered as a starting point for more refined studies concerning the mineralogy of 21 Lutetia. Different mineralogies are usually associated with several scenarios of formation and evolution of asteroids. Mixtures of "pure" minerals must be also investigated in order to solve the ambiguity of a non-unique solution for 21 Lutetia.

In the spectral interval covered by our data, the spectra of Lutetia looks similar to that of the Vigarano meteorite, which suggests similar surface compositions.

4. Conclusions

The observations of 21 Lutetia, obtained during two periods (31 March 2003 and 12 August 2004), cover the 0.8−4.0 μm spectral region. 21 Lutetias' spectrum exhibits a shallow absorption band around 0.95 μm, with an overall neutral slope. This is consistent with the spectrum of the CV3 meteorite Vigarano.

The analysis of the spectral region around 3 μm reveals a shallow absorption band compared with other C-type meteorites. By measuring the reflectances ratios $R_{2.9\,\mu m}/R_{2.5\,\mu m}$ and $R_{3.2\,\mu m}/R_{2.5\,\mu m}$ of 21 Lutetia we obtain a value close to those representative of CV and CO meteorites.

Our study also allows us to define an upper limit of 0.5% (in depth) concerning a possible absorption band around 3.1 μm.

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