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Physical characterization of asteroid targets of space missions

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Abstract. Physical characterization of minor bodies of the solar system which are targets of space missions is a fundamental task to properly plan the observing procedure and strategy from the spacecrafts. In the last years we have been involved in a detailed study of surface properties of asteroid targets of Rosetta and Dawn space missions. Herein we present and discuss some preliminary results obtained for 4 Vesta and 21 Lutetia, as well as our research activity dedicated to the identification of the best suitable target for a next generation space mission devoted to a sample return from a Near Earth Object.

Key words. Techniques: photometric – Techniques: spectroscopic – Minor planets, asteroids

1. Introduction

The knowledge of physical properties of asteroid targets of space missions is of fundamental importance to optimize the observing procedure during the rendez-vous or fly-bys, and to plan specific observations of the most interesting regions of the target surface. Furthermore, the comparison of the results obtained from ground-based observations and those obtained "in situ" will provide the ground truth for observations of the asteroids which will be never encountered by a spacecraft. The INAF-Osservatorio Astronomico di Roma (INAF-OAR) Planetary Science Group is involved by several years in the physical characterization of space missions' asteroid targets. Herein we report on near-infrared (NIR) observations of 4 Vesta (target of NASA-Dawn mission) and 21 Lutetia (target of ESA-Rosetta mission) we carried out with the NACO instrument of the ESO VLT/UT4. Moreover, we have been involved in mid-infrared (MIR) observations of Lutetia carried out with the Infrared Spectrograph (IRS) of the Spitzer Space Telescope. Finally we report on our research activity devoted to the selection of the best target for a sample return space mission to a Near Earth Object (NEO), presenting some preliminary results we obtained from MIR Spitzer observations, as well as from visible and NIR ground-based data.

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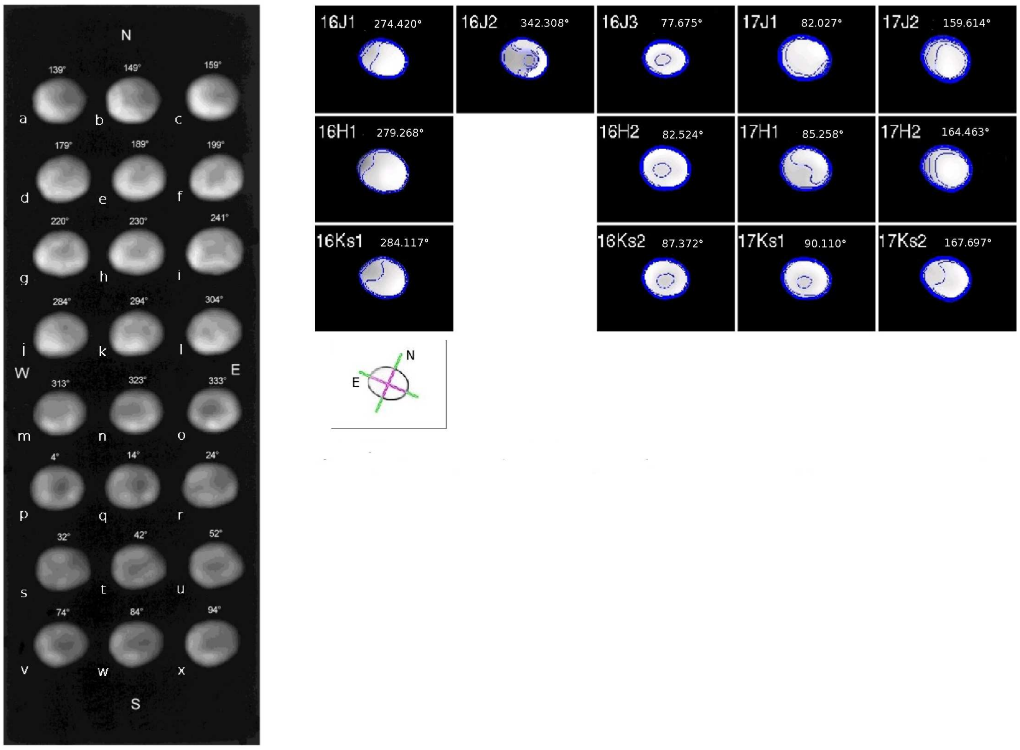

Fig. 1. (left): HST-WFPC2 images of Vesta (Zellner et al. 1997) compared to (right): Our VLT-NACO observations. Above each image the longitude of the centre of the body is reported.

2. Asteroid targets of space missions

2.1. (4) Vesta

4 Vesta is the largest main belt object showing a basaltic crust. Its surface composition is very similar to that of Eucrite, Diogenite, and Howardite (HED) basaltic achondrite meteorites. The identification of a Vesta dynamical family whose members present spectra similar to those of Vesta and HED meteorites, and the detection of a large impact crater on Vesta, allowed to hypothesize a link between Vesta and HEDs, via basaltic fragments that reach the Earth through complex dynamical processes (see Binzel et al. 2004 and references therein). Vesta will be visited by the NASA Dawn space mission from September 2011 to April 2012. Therefore it is of straightforward importance to perform detailed ground-based studies of this asteroid, to better plan and organize its ”in situ” analysis.

In order to improve our knowledge of the surface properties of Vesta, in January 2006 we performed ESO VLT-NACO observations, obtaining NIR high resolution imaging and spectroscopy of the asteroid. Some preliminary results are shown hereafter.

2.1.1. Imaging

CCD images (J, H, Ks filters) were firstly pre-reduced with standard procedure and then deconvolved using the MISTRAL package (Mugnier et al. 2004). The comparison of our results with images obtained with the WFPC2 instrument of the Hubble Space Telescope (HST), published by Zellner et al. 1997 (see also: Binzel et al. 1997; Thomas et al. 1997), is shown in Fig. 1. A general good match be-

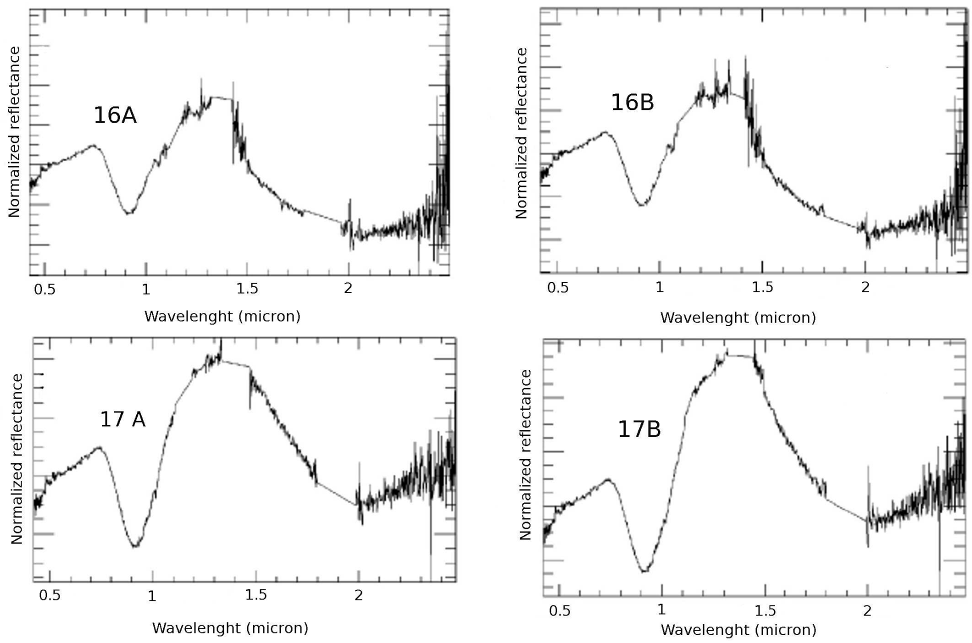

Fig. 2. NIR spectra of Vesta (acquired with VLT-NACO on 2006 Jan. 16-17), together with visible data from SMASS. All the spectra are normalized at 7000 Å.

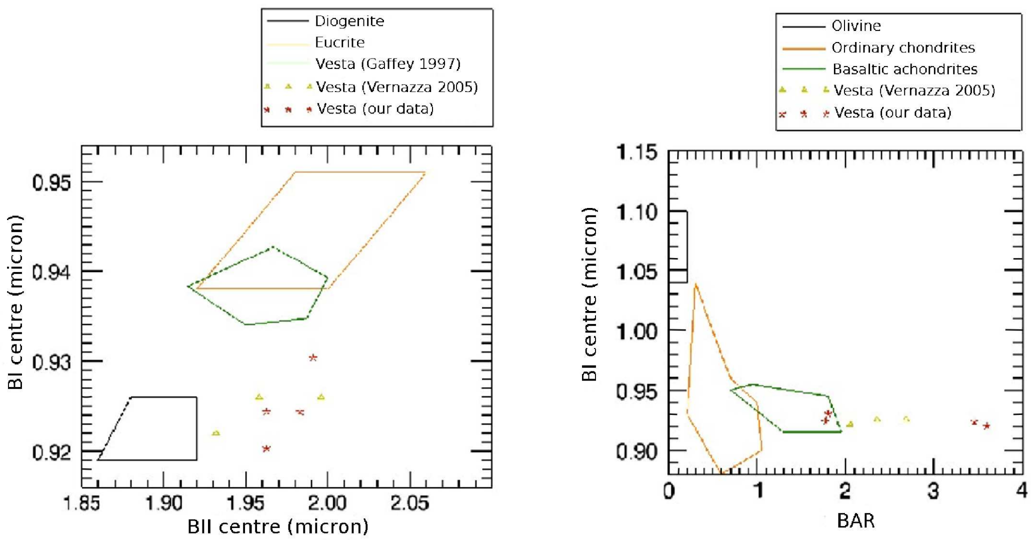

Fig. 3. (left): BI centre vs. BII centre positions. In the plot the centre positions published by Vernazza et al. (2005) are shown together with the results by Gaffey (1997) and the typical regions where eucrite and diogenite meteorites lie. (right): Position of the BI centre vs. BAR. In the plot the results published by Vernazza et al. (2005) are shown together with the typical regions where olivines, ordinary chondrites and basaltic achondrites lie.

tween our images and those obtained by HST is evident. The same surface characteristics are detected in images acquired at similar longitudes (using the reference system proposed by Thomas et al. 1997), even if with different filters. In particular the *Olbers Regio*, a low albedo region with diameter ∼ 200 km located at the origin of the coordinate system, can be clearly seen both in our dataset (image 16J2) and in the HST-WFPC2 one (images o, p). The diameter of this region, computed in our images taking into account the scale of the used camera and the distance between Earth and Vesta at the moment of the observation, is consistent with those available in the literature. A smaller (diameter ∼ 80 km) low albedo zone is also visible in both datasets (images 16J3, 16H2, 17H1, 17Ks1 and v, w, x).

2.1.2. Spectroscopy

Fig. 2 shows four of our J+HK spectra of Vesta linked with visible data from the *Small Main-Belt Asteroid Spectroscopic Survey* (SMASS, http://smass.mit.edu). These NIR spectra have been acquired with NACO, in the northern hemisphere of the asteroid, at different rotational phases. Following the method by Gaffey et al. (2002), we measured area and position of the 1 μm and 2 μm absorption bands (hereafter we will refer to these bands as BI and BII), to investigate the composition of the different surface regions we observed. We found a pyroxene composition with orthopyroxenes (Ca-poor pyroxenes) dominant respect to clinopyroxenes (Ca-rich pyroxenes). As shown in Fig. 3 (left) the positions of BI centre vs. BII centre in the Vesta spectra lie in the transition region between the Eucrite and Diogenite meteorites. Our results are in good agreement with those published by Vernazza et al. (2005). Fig. 3 (right) shows the values of the position of BI plotted against the ratio of BII area to BI area (BAR, Band Area Ratio). Since the BAR value is directly related to the ratio of pyroxene to olivine abundances (Gaffey et al. 2002), our results show a dichotomy of Vesta surface: for what concerns the two spectra taken in the western hemisphere (rightmost points), the content of olivine is almost null, while the two spectra taken in the eastern regions suggest a small but relevant content of olivine. This result is in agreement with lithological and geological maps of Vesta published by Gaffey (1997) and Binzel et al. (1997), which prompt the presence of several craters in the eastern hemisphere, where olivine has probably been brought to the surface by impacts.

2.2. (21) Lutetia

ESA Rosetta mission will fly-by Lutetia on July 2010. Although several observations are available since a couple of decades, the nature of this asteroid is still controversial. Because of its high IRAS albedo (0.22), this object was firstly classified as a M-type asteroid (Barucci et al. 1987; Tholen 1989) and supposed to be a parent body of iron meteorites. Nevertheless, further spectroscopic (Howell et al. 1994; Burbine & Binzel 2002) and polarimetric (Belskaya & Lagerkvist 1996) observations suggested that Lutetia is characterized by a primitive composition, with a spectrum similar to those of carbonaceous chondrites (Birlan et al. 2004; Barucci et al. 2005). Due to this atypical behavior, ground-based observations are fundamental to improve our knowledge of the physics of Lutetia before the visit of Rosetta.

On June 6th, 2007 we performed VLT-NACO observations of Lutetia at different rotational phases and we obtained 18 low resolution J, K, and L spectra (Fig. 4) of different portions of the asteroid surface. We covered about 7.3 of the 8.17 hours of the rotational period. Our aim was to map the surface of the asteroid, investigating its composition and checking if some inhomogeneities are present. From our spectra no clear evidence of variations with rotational phase arised. Following Torppa et al. (2003)'s best pole solution, the aspect angle of Lutetia during our observations was of about 148 degrees, i.e. the northern asteroid hemisphere was observable from the Earth. Hence, no substantial compositional differences seem to be present in these regions.

Fig. 5 shows our KL spectra. A shallow absorption band around 3 μm suggests the presence of water hydration on the analysed por-

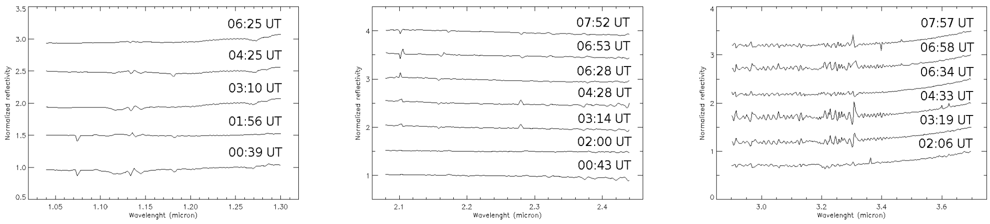

Fig. 4. J (left), K (centre), L (right) spectra of Lutetia obtained with VLT-NACO on June 6th, 2007.

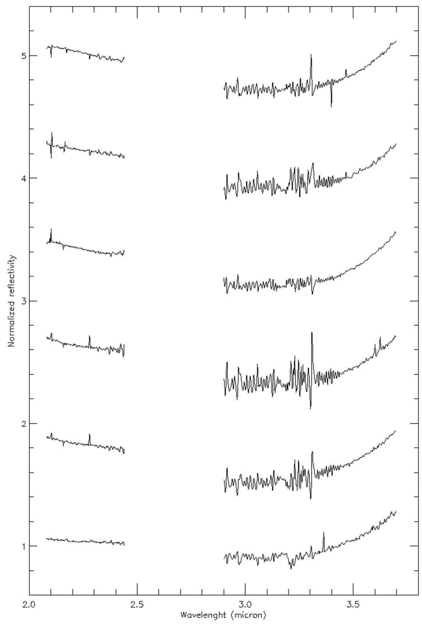

Fig. 5. Time linked KL spectra of Lutetia.

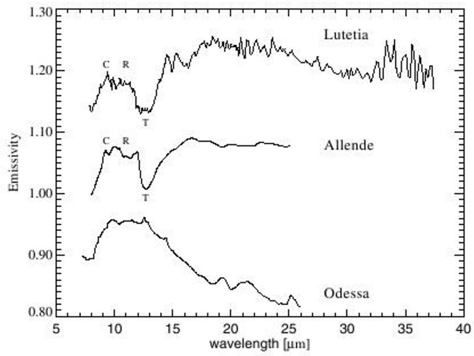

Fig. 6. The emissivity of Lutetia (average of 14 individual spectra) compared with the emissivity of the Allende meteorite and of the Odessa meteorite. The Christiansen, Reststrahlen and Transparency features are indicated as C, R, T (figure from Barucci et al. 2008).

tion of the Lutetia surface. No evidence of the 3.1 μm band has been found. Since this spectral feature is usually attributed to water ice frost, ammoniates phyllosilicates, or water ice-asphaltite mixtures, we can exclude the presence of these compounds on the surface of our target. These results are in good agreement with those published by Birlan et al. (2006), who found a shallow absorption band in the 3 μm region and the lack of the 3.1 μm absorption feature.

Barucci et al. (2008) presented also mid-infrared observations of Lutetia, obtained with the IRS instrument of the Spitzer Space Telecope. Also these data did not show any difference in the emissivity of Lutetia during its rotation. As shown in Fig. 6, the analysis of the Christiansen, Reststrahlen and Transparency features, which are the most diagnostic spectral characteristics at mid-infrared wavelengths (Salisbury 1993), suggests a very good spectral match with the emissivity spectrum of the Allende meteorite, a CV carbonaceous chondrite. On the contrary, the emissivity spectrum of the iron meteorite Odessa is completely different from the one of Lutetia, and hence the possible metallic nature for this asteroid can be ruled out.

3. Target selection for a sample return space mission to a NEO

In the last years ESA proposed a preparation initiative for a sample return mission to a NEO, inserting direct laboratory analysis of these samples among the major topics to be investigated in the Cosmic Vision 2015-2025 timeframe. In this context the proposal of the European-Japanese space mission ”Marco Polo” passed in September 2007 the first evaluation process.

The target selection is a fundamental task in the assessment study of a space mission, since it must be able to guarantee both technical feasibility and high scientific return. During the target selection we must take into account both the scientific interest of the investigated candidates and their ”accessibility” for the spacecraft. The classical definition of accessibility of a celestial body is given in terms of the velocity changing (delta–V) needed to realize a rendez-vous mission. Starting from this definition, it is possible to show that NEOs can be more accessible than the Moon or as difficult to reach as Jupiter and beyond.

In the past years our team has been deeply involved in an international observational programme devoted to the identification of the best target for ”Marco Polo”. Considering that the NASA NEAR-Shoemaker and the Japanese Hayabusa missions already reached evolved S-type asteroids Eros and Itokawa, it is of great importance that ”Marco Polo” will visit a primitive C, P, or D-type object.

In order to select the best target to be visited by ”Marco Polo” we analysed a wide sample of NEOs easily accessible for a spacecraft. So far, we have obtained visible (V) and NIR photometric and spectroscopic data (with Subaru, TNG, ESO-NTT, ESO-VLT and NASA-IRTF telescopes), as well as MIR spectra with Spitzer Space Telescope, of 39 low delta–V NEOs (10 observed in V, 12 NIR, 5 V+NIR, 1 V+MIR, and 11 MIR). The data of 21 objects have been reduced and analysed right now. The other obtained results are still under analysis and interpretation. For all the analysed bodies we performed the taxonomic classification, and we compared the observed

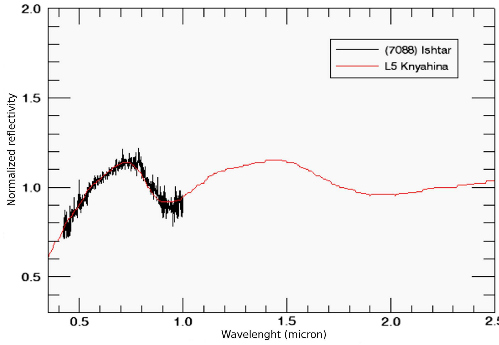

Fig. 7. Visible spectrum of 7088 Ishtar (ESO-NTT), compared with laboratory spectrum of Knyahina ordinary chondrite.

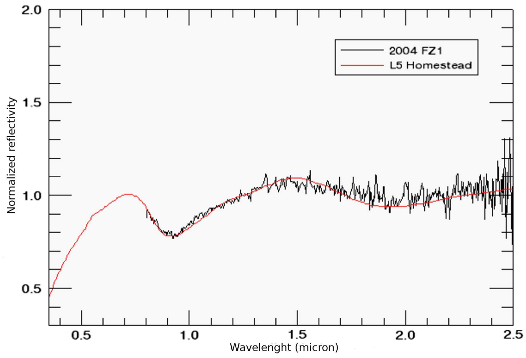

Fig. 8. Near-infrared spectrum of 2004 FZ1 (NASA-IRTF), compared to laboratory spectrum of Homestead ordinary chondrite.

spectra with laboratory spectra of minerals and meteorites searching for possible analogies.

As examples, Fig. 7 and Fig. 8 show the spectra we obtained for 7088 Ishtar and 2004 FZ1, with superimposed the best meteoritic analogs we found (ordinary chondrites Knyahina and Homestead, respectively). On the basis of our observations, 7088 Ishtar and 2004 FZ1 have been classified as S-type asteroids.

We modeled the thermal continuum of the NEOs we observed with Spitzer, by applying the Standard Thermal Model (STM, Lebofsky et al. 1986) and/or the NEA Thermal Model (NEATM, Harris 1998). For all the observed objects we computed albedo and diameter (Dotto et al. 2008). As an example, Fig. 9 shows the MIR spectrum we have obtained for 68359 2001 OZ13. The thermal contin-

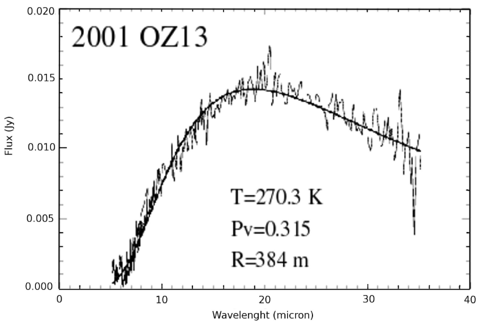

Fig. 9. The spectrum of 68359 2001 OZ13 obtained with the Spitzer Space Telescope. The continuous line represents the best fitting NEATM continuum.

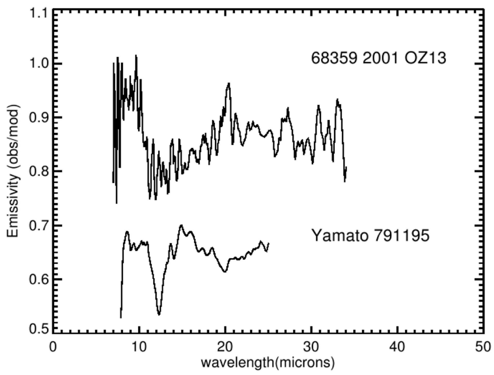

Fig. 10. The emissivity of 2001 OZ13 compared with the laboratory emissivity of Yamato 791195 eucrite meteorite. The good match suggests that 2001 OZ13 is a quite evolved V-type asteroid.

uum of this object has been modeled using the NEATM with beaming parameter η=2.3, which suggests that the asteroid has a high thermal inertia or irregular surface facets. We estimated a diameter of 0.7 km and an albedo of 0.31. In order to investigate the nature of this object, we compared its emissivity with laboratory emissivities of minerals and meteorites and we found a quite good match with the eucrite meteorite Yamato 791195, an achondrite usually related to V-type asteroids (Fig. 10). These results suggest that 2001 OZ13 is a quite evolved asteroid.

4. Conclusions

In the last years we started an observational programme devoted to the physical characterization of asteroids which are suitable targets of space missions. We performed V+NIR ground-based and MIR Spitzer observations. Herein we presented some preliminary results we obtained from NIR observations of the asteroids 4 Vesta (target of the Dawn space mission) and 21 Lutetia (target of the Rosetta space mission), as well as V, NIR and MIR data on suitable targets of a space mission to a NEO.

On the basis of our preliminary results we confirm the presence of some inhomogeneities on the surface of Vesta, as suggested by HST data. In particular, we argue a dichotomy of the surface, with relevant abundance of olivine only in the eastern hemisphere. This result is in agreement with the lithological and geological maps of Vesta available in the literature.

Our infrared spectra of Lutetia did not show any variation with rotational phase. Hence, no important inhomogeneities should be present on the surface of Lutetia, at least in the northern hemisphere. Water hydration could be present in the analysed regions, since the spectra have shown a shallow absorption band at about 3 μm.

In the framework of an international observational programme devoted to the identification of the best target for a sample return space mission to a NEO, we collected V, NIR and MIR data of 39 low delta–V NEOs. To date we have reduced and analysed data on 21 of them, and further analysis are presently ongoing. For all of the analysed NEOs we performed the taxonomic classification and we searched for meteoritic analogs. Diameter and albedo have been computed for a sample of 12 objects observed with Spitzer Space Telescope. The large majority of the NEOs we observed has been classified as belonging to evolved taxonomic classes (mainly S-types). Considering that the main objective of the European space mission to a NEO ”Marco Polo” is to reach a primitive C- P- or D-type object, the obtained preliminary results did not allow us to find out any interesting target.

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