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SINEO: Spectroscopic Investigation of Near Earth Objects

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Abstract. In this paper we present the results obtained until now from our long term spectroscopic survey in the visible and Near Infrared Region (NIR) of Near Earth Objects (NEO), named SINEO, started some years ago. Up to now we have obtained a data set of 107 spectra of which 98 in the visible range (0.40-0.95 μm) and 63 in the Near Infrared region (0.40-2.5 μm). The observations have been performed with the NTT of ESO (Chile) and the Telescopio Nazionale Galileo (TNG) at the Canary Islands. We present the results of a taxonomic classification of the objects, their linkage with meteorites and the influence of space weathering.

Key words. Asteroids: spectroscopy – Near Earth Objects: mineralogy – Near Earth Objects: taxonomy

1. Introduction

Near-Earth Objects (NEOs) represent an heterogeneous population which comprises asteroids and extinct comet nuclei in orbits with perihelion distances q <1.3 which periodically approach or intersect the orbit of the Earth. Given their vicinity to the Earth, NEOs are believed to be a source for most meteorites which arrive on Earth. The importance of studying NEOs has been recognized worldwide, and a great deal of resources are being used for this task, both for ground-based facilities and space missions.

Even if it is accepted that most NEOs come from Main Belt (MB) and only a small fraction are dead or dormant comets (Harris & Bailey 1998; Weissman et al. 2002), their proportions are not well defined yet. The detailed comprehension of the sources and mechanisms of the resupply of the NEO population is one of the principal aims of NEO investigations. Although a global picture of NEOs origin is now widely accepted, a detailed knowledge of their physical properties has been obtained only for less then 10% of them. The different nature of these bodies is particularly evident from their taxonomy. In fact almost all taxonomic classes identified among MB asteroids have been also found among NEOs, including the C, P and D classes that are typical of outer MB asteroids. The most common taxonomic class among NEOs is however the S-type. Besides a possible selection effect (being this class dominated by high albedo objects), this could indicate that asteroidal NEOs derive mostly by the inner MB, via the ν_6 resonance, where S-types are the most common asteroids. However, other sources have been pro-

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Send offprint requests to: M. Lazzarin posed like the the 3:1 resonance (see for example Morbidelli et al. (2002)), which is surrounded by C- and S-type asteroids in almost equal quantity.

Another possible source of NEOs is represented by dead or dormant comets that is devolatilised cometary nuclei and/or comets whose icy surface is covered by a subtle non volatile crust which inhibits possible gas emissions. The spectra of these objects show a behaviour typical of cometary nuclei (featureless and flat to reddish spectrum).

Finally, another interesting issue is the now evident relationship between NEOs and meteorites: understanding the sources of NEOs means also to understand the origin locations for most meteorites.

Spectroscopic investigation of NEOs is fundamental to investigate most of the issues indicated above (mineralogy, taxonomic classification, origin, relationships with comets, MB asteroids and meteorites) and in this paper we present the results obtained so far from our spectroscopic investigation.

2. Observations and data reduction

The observations, both in the visible and in the near infrared spectral range, have been performed with the ESO-NTT in Chile (4 runs) and the Telescopio Nazionale Galileo (TNG) at the Canary Islands (3 runs).

2.1. TNG

37 spectra have been recorded with the TNG in the course of three runs performed in December 2002, July 2003 and May 2004 for a total of 9 nights, 4 in the visible and 5 in the NIR.

In the visible we used the Low Resolution Spectrograph (LRS) with the LR-R Grism which provides a resolving power of about 300, in the 0.5-0.95 μm range. We used a slit aperture of 5″ in order to minimize effects due to atmosphere differential refraction. For the same reason for all objects the slit was oriented along the parallactic angle.

In the near-infrared (NIR) we used NICS (Near Infrared Camera Spectrometer) equipped with the AMICI prism, which provides a resolving power of about 50 almost constant through out the range 0.8-2.5 μm. In the NIR we used a 2″ slit width. As the influence of the differential refraction is less relevant in the NIR, we oriented the slit along the direction of the motion of every asteroid and along the parallactic angle for solar analogues.

For both visible and NIR, to minimize the possibility of losing objects, we decided to check the position of each moving target on the slit every 15-20 minutes, depending on the velocity of the asteroid. Longer exposures, needed on fainter objects, have been split in shorter ones, repeated as many times as needed to reach the required S/N ratio.

2.2. NTT

70 spectra have been recorded with the ESO-NTT during four runs in October 2000, November 2001, May 2003 and December 2004, for a total of 16 nights, 6 in the visible and 10 in the NIR.

For the visible observations the NTT was equipped with EMMI (ESO Multi–Mode Instrument) in low resolution spectroscopy mode. The disperser element was the Grism #1 which gives a dispersion of 0.59 nm/pix, and the spectra obtained are in the range 0.38–1.0 μm with a resolution of 270 (for a slit of 1″). As for TNG+LRS we used a slit aperture of 5″. We oriented the slit along the parallactic angle for all objects.

In the NIR we used NTT equipped with SOFI (Son OF Isaac) in the low resolution mode with two different dispersers: the Grism Blue that in the range 0.95–1.64 μm gives a resolution of 1000 with a slit of 0.6″; the Grism Red for the range 1.53–2.52 μm, with the same resolution. As for TNG+NICS we used a 2″ slit width for all objects. We oriented the slit along the direction of the motion for every asteroid observed and along the parallactic angle for solar analogues.

The reduction was carried out with usual reduction techniques, and for details we refer, for instance, to Lazzarin et al. (2004) and Licandro et al. (2002). To obtain the relative reflectance, several Landolt G stars (Landolt

1973) and Hyades 64 were observed during the nights at different airmasses. All these stars showed negligible differences. They were also observed in previous runs together with the solar analogue star P330E (Colina & Bohlin 2000) and they present similar spectra in the infrared region, so we used them as solar analogues for both visible and NIR.

3. Data analysis

In this section we describe the analysis we have performed with the main aim to obtain the taxonomic types and to study the link between the observed NEOs and meteorites. We recall that our work, based mainly on statistical analysis, is in progress, being a long term observational program.

3.1. Taxonomic classification

One of the principal aims of this spectroscopic investigation is the taxonomic classification of the observed NEOs. This has been obtained by performing a best fit between our data and the mean spectra of each spectral class proposed by Bus (1999) on SMASSII data. Since Bus taxonomy was restricted to visible data, we applied this analysis only to NEOs for which visible measurements were available (the range considered was 0.52-0.92 μm). The "best" solution of the fitting was chosen as the "right" taxonomic class.

Afterwards, we applied the Principal Component Analysis (PCA) technique to the data. Fig. 1 shows a plot of the first two components (*slope* and *PC2′*), in the 0.52–0.92 μm range, computed on a set that includes all the SMASSII main belt data, all TNG NEOs and all the ESO-NTT NEOs visible spectra obtained so far. The Bus' mean types locate in different zones on the $(slope, PC2')$ plot. It clearly results that we can distinguish between the C-,X- complexes and the S-complex. Moreover all S subclasses are well separated. As a result, we found an excellent compatibility between the taxonomic classification obtained by the best fitting with Bus' mean types described above and the location of the NEOs in the $(slope, PC2')$ plane, as obtained by the PCA.

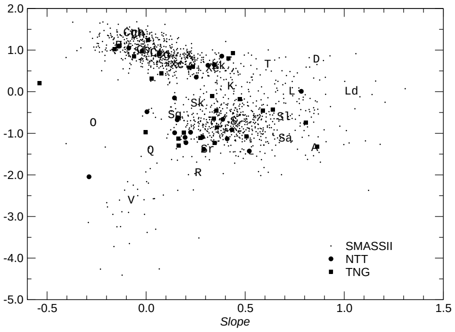

Fig. 1. PCA of SMASSII main belt asteroids spectra and NEOs spectra obtained in SINEO project.

For some NEOs we did not have visible measurements, and for this reason they were excluded from the previous analysis. However, the "taxonomic" information contained in a NIR spectra are so important that we attempted a rough classification by visual inspection. For this purpose we restricted the analysis only to distinguish among the three (S-, C-, X-) main complexes.

Some of the investigated NEOs were previously classified. We find small differences compared with our classification, and in general the complexes are the same. These differences could be due to surface inhomogeneities.

So, the distribution among the several taxonomic complexes obtained so far can be summarised as in the following: 62% belongs to S-complex, 20% to X-complex, 12% to C-complex and 6% to other classes.

3.2. Link with meteorites

The investigation of NEOs can give important information on the origin of meteorites, NEOs being the bodies closest to the Earth.

We compared the visible plus near infrared spectra of our NEOs with those of meteorites. For this task, we developed a code which is able to automatically perform a least square fit between our NEOs spectra and the vast meteorite spectral database available on RELAB (http://www.planetary.brown.edu/relab/). We used all the public spectra cataloged as 'XT' (namely extraterrestrial), for a total of 847 spectra. For each NEO of which we had NIR measurements we selected 20 meteorites in order of descending fit quality. The best fitting was chosen through visual inspection, to avoid possible mistakes, especially in the case of too noisy NEOs spectra, and to check if there were a real acceptable solution or not: in some cases we did not find a good meteorite analog in the database. NEOs with only the visible part of the spectrum have not been considered as the fit in this interval does not tell much of their relationships with meteorites (see also Lazzarin et al. (2004)). In Fig. 2 we report some NEOs for which a good fitting has been achieved.

In most cases we obtained a good match providing also new information about the relationships between ordinary chondrites meteorites, aubrites and carbonaceous chondrites with NEOs.

For several NEOs the fit, even if not completely bad, was not satisfactory. Typically, the shape and/or the band positions are slightly different. Several processes could be invoked to explain the differences observed, like slight compositional variations and/or grain size effects, just to mention some.

3.3. Space weathering effects

For part of the S-type objects the fit was really bad, indicating that for these objects we are dealing either with big compositional differences having no analogues among meteorites, or we are in presence of big alteration processes. We think the latter is more likely, because if such large compositional differences were so common among S-types we would expect to find some similar meteorite samples. While their overall composition should not greatly differ from that of OCs (all basically made of olivine and pyroxene as witnessed by the presence of typical olivine/pyroxene bands), the spectra of these NEOs are moderate to much redder than typical OCs. Such red slopes can be achieved by increasing the

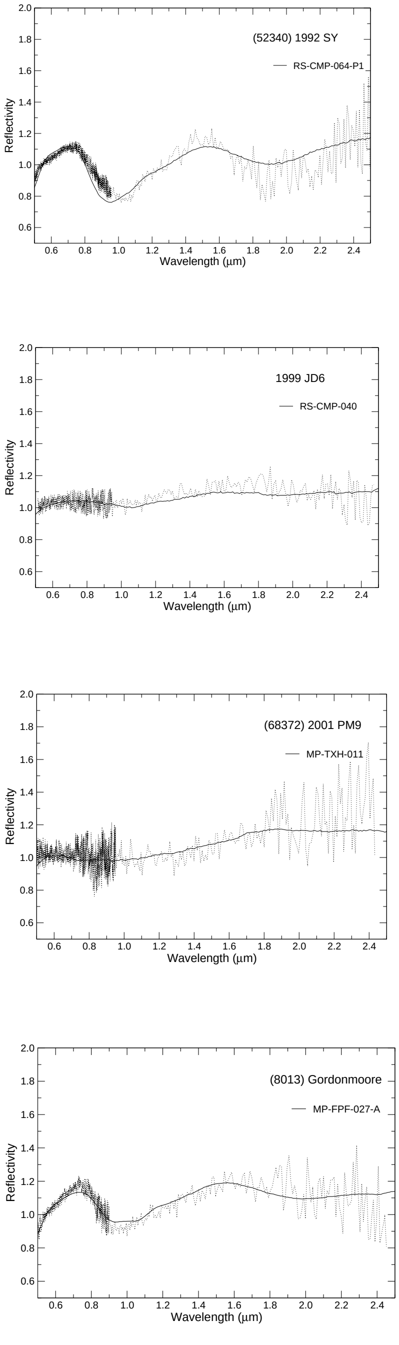

Fig. 2. Some examples of NEOs spectra with the "best fitting" meteorites. The spectra are normalized at 1 around 0.55 μm. Meteorites names refer to the RELAB Catalogue nomenclature.

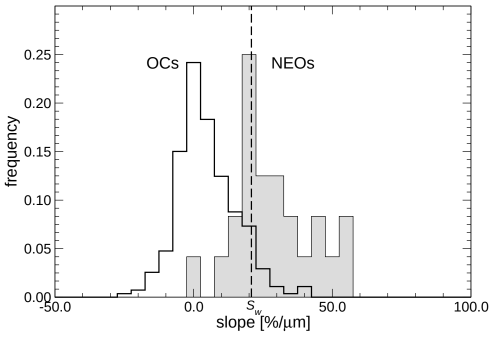

Fig. 3. In this plot we report the distributions of OCs slopes and S-type NEOs slopes (shaded area). The vertical dashed line represents the limit of 95% between non-weathered and weathered objects, as determined from the OCs slope distribution. The corresponding slope value is 20.8 %/μm. Both distributions have been normalized to unity area (see text for further details).

content of metal (Fe-Ni) with respect to that of silicates. The origin of this metal is not easily determined by remote analysis, and it could be both primordial or due to some alteration process, like the so-called space weathering. In fact, as described in Pieters et al. (2000), silicate grains under the flux of micrometeorites and solar wind sputtering develop nanophase iron rims, which alter the optical properties of silicates. In order to quantify this mismatch we determined the spectral slopes of all S-type NEOs and a large sample (about 300) of OCs in the range 0.52-2.4 μm. The results are reported in Fig. 3.

As expected, the vast majority of OCs has small slopes, although some OCs exhibit a red spectrum. 95% of OCs are below a slope of 20.8 %/μm. So, in this analysis we assumed this value of slope (S_w) as indicator for the space weathering process. The striking feature is that in comparison with OCs, many NEOs are redder than S_w. On the basis of these considerations, NEOs having a slope greater than S_w have been considered to be space weathered.

However it is not yet possible to say whether we are in presence of space weathering or not and a final discernment between these two different possibilities can only be obtained with the help of more data of NEOs, and also of their albedoes.

4. Discussion and conclusion

In this work we presented the observational program of a long term survey of NEOs started some years ago by our group and named SINEO. In particular we discussed the spectral properties of 107 NEOs observed so far with the NTT Telescope of ESO-La Silla and the TNG telescope at La Palma. From the analysis of the spectra we have obtained indications about the surface composition of these objects. Moreover, all the visible spectra have been also parametrized in terms of Bus' taxonomy (Bus 1999). From this analysis, it has been possible to taxonomically classify the observed NEOs, obtaining 62% of S-complex, 20% X-complex, 12% C-complex and 6% other classes.

The NIR part of the spectrum indicated that in some cases the classification performed using only the visible part could be sometimes uncertain.

We observed also two NEOs in cometary orbits and both present featureless spectra in the 0.5-2.5 μm range.

By comparing the NEOs observed in the full spectral range and a large set of meteorites (847 spectra), we obtain a good match in many cases providing also information about the relationships between chondrites meteorites and NEOs.

Finally, for 15 S-type objects, no fit with meteorites has been achieved and this could be due to space weathering.

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