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Minor bodies of the Solar System: ISO and ESO–VLT infrared spectroscopic data

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Abstract. Over the last decade our knowledge and understanding of the physical properties of small bodies in the Solar System have been widely improved, due to the results obtained by near– mid– and far–infrared spectroscopy. We observed several main belt asteroids with the Infrared Space Observatory (ISO), obtaining the first asteroid spectrum up to 45 μm. Moreover, we started a systematic study of the physical properties of the population of Trans–Neptunians Objects (TNOs). The physical and dynamical characteristics of these bodies, as their origin and evolution, are far to be understood. We carried out near–infrared spectroscopic observations at ESO–VLT of several of these objects, obtaining useful information about their surface composition.

Key words. Asteroids – Centaurs – TNOs – infrared – spectroscopy – ISO – VLT

1. Introduction

It is widely believed that minor bodies of the Solar System are remnants of the early phases of the planetary formation. Being the less thermally evolved bodies in our planetary system, they can provide information about the primordial processes that governed the evolution of the protonebula and operated at different solar distances.

The analysis of near– mid– and far–infrared spectra of these bodies is particularly important as these wavelength regions contain several diagnostic spectral features from minerals, ices, and organic compounds. In spite of their importance these spectral ranges are not widely explored. For this reason in the last years we devoted a strong effort to the observation and the analysis of infrared spectra of minor bodies in the inner and outer Solar System, in order to assess their surface composition and to infer some information about their thermal and dynamical history.

2. ISO observations of Asteroids

We observed sixteen asteroids with the Infrared Space Observatory (ISO), using three different instruments (Barucci et al. 1997; Dotto et al. 1999). We obtained pho-

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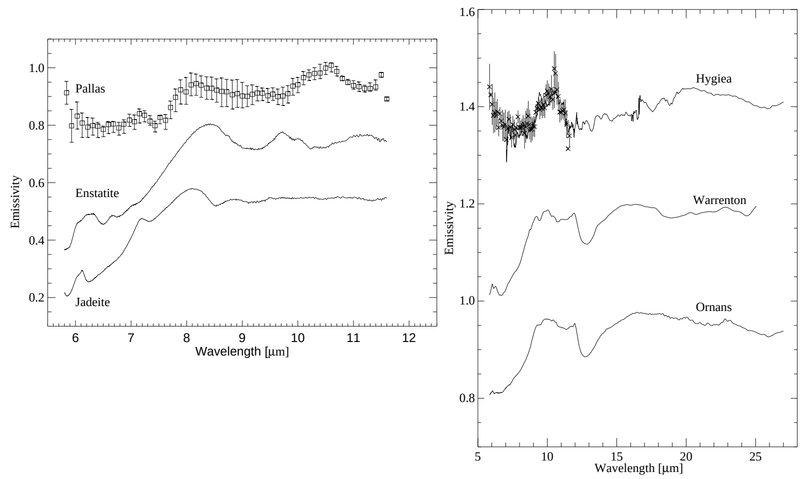

Fig. 1. Left panel: PHT-S emissivity of 2 Pallas compared with the emissivity of two pyroxenes (enstatite and jadeite) (Dotto et al. 2000). Right panel: comparison between PHT–S and SWS emissivity of 10 Hygiea and the emissivity of the CO3 carbonaceous chondrite meteorites Ornans and Warrenton (Barucci et al. 2002). The spectra are vertically offset for clarity.

tometric observations in several filters up to 60 μm, low resolution spectra up to 11.6 μm and high resolution spectra between 5.3 and 45 μm. For all the observed asteroids sub–solar temperatures, diameters and albedoes have been computed applying the standard thermal model by Lebofsky & Spencer (1989): the obtained results are in agreement with the IRAS results (Dotto et al. 1999, 2000; Barucci et al. 1997, 2002). The standard thermal model and an advanced thermophysical model (Lagerros 1998), have been applied also to model the thermal continuum. The emissivity spectra of the observed asteroids have been computed as the ratio between the ISO spectra and the computed expected fluxes at the time of the ISO observations. The interpretation of the spectral features above the thermal continuum is still a difficult task, as asteroid surfaces are composed by mixtures of different minerals whose spectral properties are combined following non-linear paths. Moreover, asteroid spectra are affected by several unknown physical parameters, such as density, mineralogy, particle size and packing. In order to interpret the obtained spectral behaviors and to infer the surface composition of the objects observed by ISO, we considered all the available data bases of laboratory spectra of minerals and meteorites (Salisbury et al. (1991a,b), ASTER spectral library on http://speclib.jpl.nasa.gov). Moreover, selected samples of mineral and meteorite particulates at different grain sizes have been chosen and laboratory experiments have been performed at the Capodimonte Observatory (Dotto et al. 2000; Barucci et al. 2002). As an example Fig. 1 (left panel) shows the emissivity of 2 Pallas obtained by the ISO spectrophotomer PHT-S. In the mid–infrared wavelength range the most important spectral structures are the Christiansen, reststrahlen, and transparency features. The Christiansen peak is directly related to the mineralogy and the grain size, and occurs at wavelength that for silicates is just below the Si–O stretching vibration bands. The reststrahlen bands are due to vibrational modes of molecular complexes. The transparency features usually occur at 11–13 μm between main reststrahlen bands. In the spectrum of Pallas the feature at about 8 μm is the Christiansen peak which occurs at a shorter wavelength than in most mineral and meteorite spectra. The only meteorite with similar position of this emission peak is the aubrite which is essentially composed of enstatite. The behavior of the obtained spectrum of Pallas beyond 7.6 μm suggests the presence on the surface of this object of a mixture of pyroxenes. The narrow feature at about 10.5 μm may be related to the presence of water ice on the surface. If confirmed, this is surprising and suggests the existence of renewal mechanisms.

Our observations with ISO provided also the spectrum of 10 Hygiea obtained by the Short Wavelength Spectrometer (SWS) up to 45 μm, the first high resolution spectrum of an asteroid at these wavelengths. To interpret this spectrum several minerals have been selected as possible candidates to be present on the surface of this C-type asteroid. None of the analysed mineral spectra matched the Hygiea spectrum. Many attempts have been made by combining different components while maintaining consistency with the hypothesized composition, and the quality of the numerous matches has been always very poor (Barucci et al. 2002). We obtained the most consistent analogy with spectra of the carbonaceous chondrite meteorites. As shown in Fig. 1 (right panel), CO3–type carbonaceous chondrite meteorites Ornans and Warrenton represent the best similarity with the spectral behavior of Hygiea up to about 27 μm: the analogy is supported by the comparison of the Christiansen peak at about 9.2 μm and by the transparency features around 13 μm and at 26 μm (Barucci et al. 2002). The similarity of 10 Hygiea with CO3 carbonaceous chondrite meteorites would imply that this is a "primitive" asteroid which may have started some metamorphism.

3. ESO–VLT observations of Centaurs and Trans–Neptunian Objects

Observational evidences have shown, beyond the orbit of Neptune, a region densely populated by small bodies, named Trans–Neptunians Objects (TNOs). This region, named Edgeworth–Kuiper Belt (EKB), is supposed to be the source of short-period comets and Centaurs (whose orbits are between Jupiter and Neptune). EKB objects are believed to be remnants of the early phases of the planetary formation at these solar distances and to contain the most primordial material that we can observe today. Up to now more than 600 TNOs and about 40 Centaurs are known: their physical and dynamical properties show a wide diversity. This implies that, although they all have the same origin, they have experienced different dynamical and physical evolution over the age of the Solar System. We carried out systematic near–infrared spectroscopic observations at ESO–VLT to look for spectral features which are diagnostic of ices and other mineral compounds as silicates and/or organics, in order to retrieve the surface composition of these objects and to investigate their history and thermal evolution. The stony ingredients of the original EKB objects should be primarily of silicate nature. Even if their detection is extremely difficult, since they may be covered by ice and/or organic mantles, some signature seen in the Centaur Pholus between 0.6 and 1.6 micron is attributed to silicates (Cruikshank et al. 1998). Water ice absorption bands at 1.5 and 2 μm have been identified in the reflectance TNO 1996 TO66 (Brown et al. 1999). Fig. 2 shows the result obtained for the Centaur 8405 Asbolus. Barucci et al. (2000) found a rather featureless spectral behavior with no detection of water ice. On the basis of this observation and using a radiative transfer model they argued that, to reproduce the observed spectral features, no more than few percents of the surface of this Centaur can be covered by water ice. This is sur-

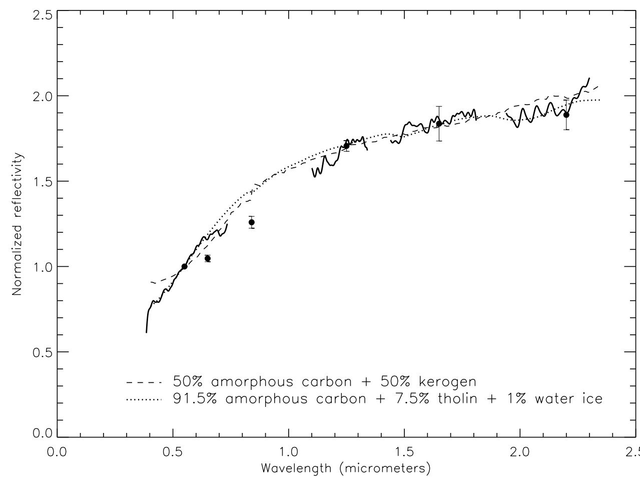

Fig. 2. Visible and near–IR spectrum of 8405 Asbolus (Barucci et al. 2000). The surface has been modeled as a mixture of amorphous carbon and kerogen (dotted line) and as a mixture of amorphous carbon, tholin and a few percent of water ice (dashed line).

prising since objects at that solar distance and at temperature of about 30 K have to contain some type of ices. Some other mechanisms, as collisions and space weathering, are under investigation in order to explain the different compositions of TNO and Centaur surfaces.

4. Conclusions

Near– mid– and far–infrared observations are a powerful tool to infer information about the surface composition of small bodies of the Solar System and to set constraints about their thermal history. Although the obtained results in infrared wavelength range seem to be very promising for the investigation of the physical properties of main belt asteroids, TNOs and Centaurs, the available data sample is not enough to have a complete scenario of the formation and evolution of these bodies. The main obstacle for a comprehensive study is the lack of measurements. For this reason there is a strong need of high–quality observational data, and we are widely involved to carry out infrared observations of a large, statistically significant sample of small bodies of the Solar System.

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