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Study for potential candidates for a Sample Return Spase Mission to a Near Earth Object

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Abstract. Near-Earth Objects (NEOs), namely asteroids and comets orbiting close to the Earth, are widely believed to be the remnants - or fragments - of planetesimals that accreted into the planets. Since they are supposed to come from different regions of the Solar System, they represent an optimal sample to investigate the thermal and physical processes that took place during the first evolutionary phases of the Solar System, and to investigate the initial structure of the Solar Nebula. Moreover, they are one of the principal sources of meteorites, and represent a threat for human being. Due to their scientific interest and their dynamical properties, NEOs are interesting and accessible targets for space missions. Because of that, in the last years, several national and international Space Agencies have promoted assessment studies of a mission to a NEO, and a sample return mission to a primitive object has been promoted by ESA in the framework of the *Cosmic Vision* programme.

Key words. Minor planets, Near Earth Objects – Space mission

1. Introduction

The Near-Earth Object (NEO) population includes the small bodies of the Solar System with perihelion distances q<1.3 AU and orbits that approach or intersect the orbit of the Earth.

Numerical simulations have shown that NEOs can live only $10^6 \div 10^7$ years before colliding with the Sun or a planet, or being expelled from the Solar System (Bottke et al. 2000). In spite of such a short lifetime, the NEO population is still observable and it is estimated in a number greater than 10^3 objects with a diameter larger than 1 km and about 10^5 larger than 100 m (Stuart 2001). It is therefore evident that this population must be continuosly replenished by objects coming from other regions of the Solar System.

Presently, only 4500 NEOs of all sizes have been discovered, and information on the physical nature is available for a percentage

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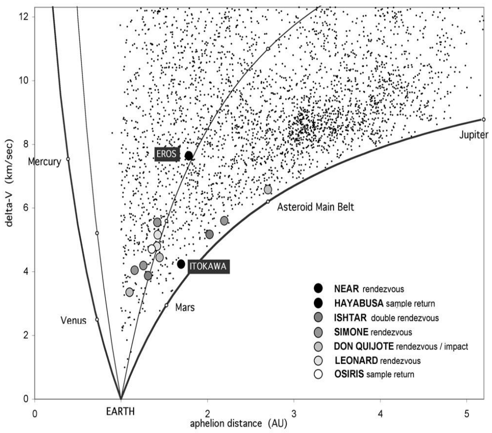

Fig. 1. An “H-plot” diagram. The dots represent known NEOs. Circles represent targets of the past (*black*) and future (*grey*) space missions to NEOs

of about 10%. The main characteristics of the NEO population is the extreme heterogeneity, with objects of different structures, dimensions, shapes and surface compositions. Dynamical and physical studies have shown that the asteroid main belt contributes to the NEO population for about 80%, while the other 20% has probably a cometary origin.

Moreover, NEOs are responsible for most of meteorite falls and of the occurrence of occasional major catastrophic events. Since NEOs constitute a potential hazard to human beings and more in general to life on our planet, their physical characterization is essential to define successful mitigation strategies in case of a possible impact. In fact, whatever the scenario, it is clear that the technology needed to set up a realistic mitigation strategy depends upon the knowledge of the physical properties of the impacting object.

2. Space missions to a NEO

For both scientific and technological interests, in the last years national and international Space Agencies have promoted space missions to NEOs. In particular, the NASA mission NEAR-Shoemaker performed in 2001 the complete survey of 433 Eros, and in 2005 the Japanese Hayabusa studied 25143 Itokawa, experimenting the first sample return (probably not successful). In 2007, the European Space Agency (ESA) has promoted a study for a sample return space mission to a primitive NEO, in a framework of the *Cosmic Vision* programme.

2.1. Target selection

The target selection is a crucial item in the assessment study of a space mission, since it must be able to guarantee both technical feasibility and high scientific return. It is therefore fundamental to organize international observational campaigns to observe all the objects in cluded in the list of potential candidates, in order to identify the basic characteristics of the potential targets, to optimize the observing procedure during the encounter and maximize the scientific return of the mission.

Starting from the classical definition of “accessibility” of a celestial body in terms of the velocity changing (delta–V) needed to realize a rendez-vous mission, it is possible to show that NEOs can be more accessible than the Moon or as difficult to reach as Jupiter and beyond. The accessibility from Earth of a potential target of a space mission is studied by novel applications of classical orbital transfer algorithms: i.e. the Hohmann transfer formulation which gives the minimum energy transfer trajectory between two orbits in space. Using this algorithm it is possible to estimate the delta–V of each potential target. The accessibility of NEOs is illustrated in Fig.1. The two V-shaped curves mark the classical Hohmann apocentre raising (thick line) and circularization (thin line) delta–V requirements at any given heliocentric distance, corresponding respectively to minimum-energy flyby and rendezvous missions. Missions to NEOs with perihelia at 1 AU and increasingly large aphelion distances (at zero inclination) are therefore located along the thick line: any displacement is measure of the additional delta–V required to match the actual semimajor axis, the eccentricity and the inclination of the target orbit. The upper delta–V limiting value equals to the Solar System escape velocity (12.3 km/s).

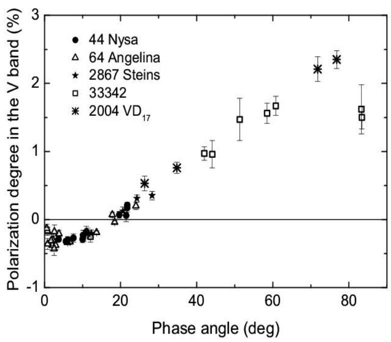

Fig. 2. 144898 2004 VD17 polarimentric data compared with other E-type main belt asteroids and NEOs (De Luise et al. 2007).

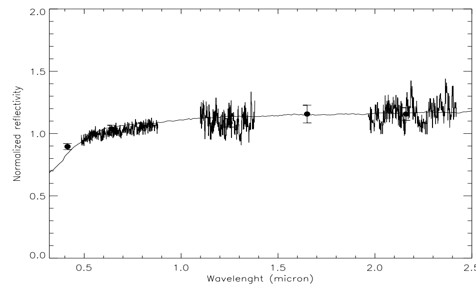

Fig. 3. 144898 2004 VD17 V+NIR spectrum; superimposed the Maya Belwa meteorite spectrum (De Luise et al. 2007).

Once obtained a list of NEOs that, due to their dynamical properties, are potential good candidates to be visited by a space mission, ground-based observations are needed to characterize their physical properties and nature, and therefore allow the selection of the most interesting target.

Our team is deeply involved in an international observational programme devoted to the selection of the best target for an European space mission to a NEO. One of the problems in characterizing the NEO population by means of telescopic observations is the large number of objects involved. Therefore, for the selection of our observation targets we take into account both scientific interest and mission design considerations (Perozzi et al. 2001). In particular, we give priority for observations to the objects that are more likely to be visited by spacecraft at the present/near future technological level. We therefore perform visible and near-infrared spectroscopy and photometry of objects having delta–V lower than about 9 km/s in the H-plot. Our investigation is performed by ground-based (ESO, ENO, IRTF) and space (Spitzer) telescopes.

2.2. The case of 144898 2004 VD17

An example of investigation that can be carried out to improve the knowledge of a possible candidate for its final selection as target of a dedicated space mission, is the survey we carried out for 144898 2004 VD17 in the year 2006 (De Luise et al. 2007).

144898 2004 VD17 was discovered in November 2004 by the LINEAR asteroid survey, and classified as an Apollo type. It has a delta–V value of 8.22 km/s, and it is in the Potentially Hazardous Asteroid list, which includes all the objects having a diameter larger than 150 m and coming close to the Earth less than 0.05 UA. 2004 VD17 will have a close approach with our planet in 2102.

In spite of the good knowledge of its dynamical properties, on March 2006 its nature was completely unknown. We therefore performed visible and near-infrared spectroscopic and photometric observations, as well as polarimetric measurements at the European Southern Observatory (ESO) telescopes. The aim of our observational campaign was *i)* to investigate the rotational status of 2004 VD17, by analysing the periodicity, shape and amplitude of its lightcurve; *ii)* to investigate its surface composition, looking for spectral evidence of minerals and mixtures present on its surface; *iii)* to determine its albedo and hence to constrain its size and taxonomic classification.

The project was awarded in April-May 2006 with three nights at ESO–NTT (La Silla), and six nights at ESO–VLT (Paranal). The behaviour of the polarization degree in the V band at different phase angles, resulted for 2004 VD17 was analogous to that one of several E-type main belt asteroids and NEOs (Fig.

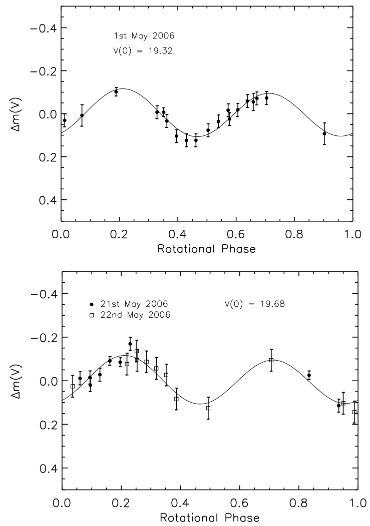

Fig. 4. V lightcurves of 2004 VD17. The zero point is at 0 UT of 12th May (De Luise et al. 2007).

2). On the basis of the polarimetric slope it has been possible to compute the albedo of 2004 VD17 which resulted $p_v = 0.45 \pm 0.10$, typical of an E-type object. The obtained visible and near-infrared spectra (Fig. 3) are flat and featureless, confirming the E-type classification. A good agreement was found with the spectrum of aubrite meteorites. In particular, Fig. 3 shows the comparison with the spectrum of the *Mayo Belwa* meteorite that, being mainly composed by enstatite, confirms the enstatitic nature of our target.

The Fourier analysis (Harris et al. 1989) of the photometric data, allowed the determination of the rotational period, P_{syn}=1.99±0.02 hours. The lightcurve amplitude (Fig. 4) of 0.21±0.02 mag, gives a lower limit of the semimajor axes ratio a/b >1.21±0.02. The measured V magnitudes give an absolute magnitude H = 18.9, that with the computed albedo, allowed to estimate a diameter of about 320 m.

On the basis of the obtained results, 2004 VD17 is a small and fast rotating object close to the break-up limit fixed by Pravec and Harris (2000) for a typical "rubble pile" structure. A more robust structure is then expected, and 2004 VD17 seems to be a monolith, maybe partially fractured, even if the lack of any information about its porosity does not make possible to constrain its nature.

3. Conclusions

The nature of the NEO population is still largely unknown and an observational bias seems to strongly affect the population of small-dark objects (De Luise et al. 2007). Therefore it is of fundamental importance to carry out systematic ground-based observations to improve our knowledge of the nature of NEOs, mainly the smaller ones.

On the other hand, due to the wide variety of the orbital characteristics of NEOs, the selection of the target of a space mission is a crucial point in the space assessment studies, since the object selected to be studied "in situ" must be able to guarantee the technical feasibility and to maximize the scientific return of the mission.

Our team is widely involved in the assessment study of a space mission to a NEO and in the last years we have carried out several observational campaigns from the major telescopes available from ground (ESO, ENO, IRTF) and space (Spitzer) to contribute to the choice of the best target to be analysed "in situ". The study carried out for 2004 VD17 and here presented is only an example of the results that can be obtained by ground-based observational campaigns. Once a suitable target of a space mission to a NEO is selected on the basis of its dynamical properties, a complete and detailed survey must be performed, in order to have a complete investigation of its physical properties, and therefore to check if the object fully satisfies the mission design and maximizes the scientific return of the mission.

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