NEOShield-2

Science and Technology for Near-Earth Object Impact Prevention

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1 Introduction

1.1 Scope

In this document we report about our activity to organise, coordinate, and prioritise the NEOShield-2 astronomical observations of NEOs.

We stress that our target asteroids are selected based on the tools developed by DMS to prioritize the observations for the physical characterization of NEOs (NEOShield-2 task 10.5).

Section 2 deals with the negotiations and ongoing activities for Guaranteed Time Observations at the 3.6-meter ESO-NTT.

Section 3 reports about a proposal for a Large Programme submitted to use the 8.2-meter ESO-VLT for NEOShield-2 observations.

Section 4 details the ongoing and future plans to acquire further data about the physical properties of NEOs by the different WP10 partners.

1.2 List of Abbreviations

AD	Applicable Document
EPIC	Ecliptic Plane Input Catalog
ESO	European Southern Observatory
FOV	Field of View
GA	Grant Agreement
GTC	Gran Telescopio CANARIAS
GTO	Guaranteed Time Observations
LBT	Large Binocular Telescope
LP	Large Programme
NEO	Near Earth Object
NIR	Near InfraRed
NTT	New Technology Telescope
OHP	Observatoire de Haute Provence
OPC	Observing Programme Committee
PDM	Pic du Midi
PHA	Potentially Hazardous Asteroid
PI	Principal Investigator
RD	Reference Document
S/C	Spacecraft
SSO	Solar System Object
TNG	Telescopio Nazionale Galileo
VLT	Very Large Telescope
WP	Work Package

1.3 Applicable Documents

[AD1] NEOShield-2: “Science and Technology for Near-Earth Object Impact Prevention”, Grant Agreement no. 640351, 28.10.2014.

[AD2] “Agreement concerning the granting of observing time at the New Technology Telescope (NTT) at the La Silla Site of the La Silla Paranal Observatory in Chile”, between the European Organisation for Astronomical Research in the Southern Hemisphere (ESO) and the Observatoire de Paris in the name of the Laboratoire d’Etudes Spatiales et d’Instrumentation en Astrophysique (LESIA), 01.03.2015.

1.4 Reference Documents

[RD1] Pal, A., Szabo, R., Szabo, G. M., Kiss, L. L., Molnar, L., Sarneczky, K., & Kiss, C. 2015, The Astrophysical Journal Letters, 804, L45

[RD2] Szabo, R. et al. 2015, The Astronomical Journal, 149, 112

[RD3] Bottke, W.F., et al. 2000, Science, 288, 2190

2 Purchased Guaranteed Time Observations at ESO-NTT

Negotiations with the European Southern Observatory (ESO) for the purchase of Guaranteed Time Observations (GTO) at the 3.6-meter NTT were conducted by OBSPM-LESIA during and after the Grant Agreement preparation phase of NEOShield-2. After the positive recommendation by the ESO Observing Programme Committee (OPC) on our proposal "Characterizing the small near-Earth asteroid population in the framework of the NEOShield-2 EC project" in November 2014, and the following negotiations on the monetary compensation, schedule and conditions for the use of the NTT, an agreement has been finally signed on 1/3/2015. It is agreed that 30 NTT observing nights are allocated to our GTO proposal (ESO programme 095.C-0087, PI: D. Perna) during the timespan April 2015 – June 2017, in about 12-15 observing runs split into 2-3 nights roughly every 1.5 months. All NEOShield-2 observations will be handled according to the standard ESO policies for GTOs. LESIA – Observatoire de Paris will pay to ESO € 3300 for each night executed at the NTT, and will be charged for travel, accommodation and lodging services according to general ESO rules and prices. This GTO programme is mainly devoted to spectroscopic observations, but some time slots could be reserved also for photometric observations, e.g. if no spectroscopic targets are available in specific moments of the observing night.

The first 7 observing nights have been already executed on 13-15 April, 7-8 June, and 18-19 July 2015. Unfortunately a very bad weather affected the April run, and only few low-quality data could be acquired. Some time has been lost due to bad weather conditions also on July 19. A total of 43 small NEOs have been investigated up to now (cf. Table 2-1), using the EFOSC2 spectrograph combined with grism #1 to get visible spectra in the wavelength range 318.5-1094 nm. All of the acquired data are currently under reduction.

Our runs for the next ESO observational semester are already scheduled for 4-6 November 2015 (3 nights), 13-14 December 2015 (2 nights), 29-31 March 2016 (3 nights). The target list for each run is prepared a few days before of the observations, in order to consider all of the small NEOs that are discovered near their close approaches with the Earth.

Table 2-1: Summary of GTO observations at the ESO-NTT (first out of four semesters).

Date	Observed Targets	Notes
13 April 2015	2011KD11 2015 EE7 2014 WP365 2014 TF17 2001 HY7	Poor weather conditions
14 April 2015	2014 TF17	Most of the night lost because of bad weather conditions
15 April 2015	No data	Whole night lost because of bad weather conditions
7 June 2015	2015 KU121 2015 JY1 2013 BO73 2011 AM24 2015 HP43 2015 HB117 Asclepius 2011 OL5 2007 RQ17 2015 GF	Good weather conditions

Date	Observed Targets	Notes
	2010 LN14 2015 BY310	
8 June 2015	2015 HA1 2011 KD11 2015 FD134 2003 KZ18 2015 HP43 2015 KS121 2015 LH 2014 YS34 2001 XP88 2000 EW 2009 XO	Good weather conditions
18 July 2015	2015 LH14 2010 NY65 2000 YJ11 2014 QK362 2015 MN44 2002 RB 2012 PG6 2001 XP88 2015 JJ2 2015 LN21	Thin clouds, but overall good weather conditions
19 July 2015	2012 RS16 2007 WU3 2012 NP 2015 AY245 2014 OE338 2008 JV19 2015 LU24 2015 HM10	Thin clouds, but overall good weather conditions. Second part of the night affected by strong wind (dome closed 1h before the end of the night)

3 Proposal for a Large Programme at ESO-VLT

In March 2015 we submitted to ESO a proposal for a Large Programme (LP) at ESO-VLT. The proposal preparation was led by OBSPM-LESIA, with contributions from other WP10 partners. We proposed to use the VLT for a total of 240 hours spanning over 1.5 years to obtain visible spectroscopy, visible and thermal photometry of about 200 very small NEAs.

In particular the LP was divided in four sections (led by OBSPM-LESIA, INAF, OBSPM-IMCCE, and CNRS, respectively), to get:

- The visible spectroscopy of about 100 very faint and small NEOs, beyond the capabilities of the NTT, using the FORS2 instrument. These observations were intended to obtain for the first time ever a detailed picture of the composition of a large sample of "ultra-small" NEOs.
- The photometric colors of about 60 targets too faint for spectroscopy even at the VLT, using the FORS2 instrument. These observations would have allowed us to perform the first taxonomic classification of a large number of small objects.
- The light-curves of ~15 selected objects of particular interest for the NEOShield-2 project, too faint to be observable with our small guaranteed-access telescopes, to derive with good precision their shapes and rotational properties (using the FORS2 instrument).
- Thermal infrared observations of about 40 small NEOs, to determine their size and albedo. These targets were selected as all of the NEOs with D<300 m observable (within a reasonable integration time) by the recently-upgraded VISIR instrument.

This large sample of data acquired with the VLT would have allowed us to carry out an in-deep statistical study of the ultra-small NEA population, obtaining complementary information about their size, shape, rotation, composition, regolith properties, albedo, etc., also increasing the database of potential space-mission targets.

Unfortunately in July 2015 the LP has been rejected by the ESO OPC, with the following comment for our proposal:

This large program proposal was extensively discussed in the joined C-panel. Although the importance for mankind was recognized for a better understanding of the NEA population, the direct science yield in relation to the enormous investment in observing time was not regarded positive. In particular since a large amount of observing time is already available to the proposers through the NTT GTO time. The panel was not sure about what the factor two increase in the number of studied objects is going to teach us. It was also found that the justification of the VISIR time was rather weak. The team was also found to be relatively small for such a large undertaking.

4 Further ongoing and future observations

Following the ESO decision and comments about our LP proposal, we decided to not resubmit a LP at the next 6-monthly ESO deadlines for call of proposals. Instead, to fulfill the NEOShield-2 requirements, each WP10 partner will apply for available telescope time around the world (including ESO, of course) with smallest and more focalized proposals. The next deadlines to ask for observational time at most of the middle/large size telescopes lie between the end of September and mid-October 2015, so in early September we will have one or more conference calls to make the status of the astronomical observations and first results of the various groups, and to coordinate the preparation of the proposals to be submitted in the Autumn 2015.

Some more details per WP10 tasks are given in the following sections.

4.1 Spectroscopic observations (led by OBSPM-LESIA)

OBSPM-LESIA is actively working at the best preparation of the next GTO runs at ESO-NTT, at the reduction of the obtained data, and for the coordination of the whole WP10 activity.

As for the next deadlines for observational time, we plan to apply in particular for ESO-VLT, asking for the X-Shooter instrument. Heavily requested for several fields of astrophysical research, X-Shooter offers a unique opportunity to obtain a reliable compositional analysis of asteroid surfaces, as this instrument is capable of acquiring the whole UV-to-NIR wavelength range (0.3-2.2 μm) in a single shot (i.e. under the same observational conditions, like rotational phase, aspect angle, phase angle, airmass, etc.). This offers the best conditions to compare the obtained asteroid spectra with those obtained in the laboratory for minerals and meteorites, hence a very detailed description of the asteroid surface composition.

A few, selected asteroids of particular interest for NEOShield-2 will be identified as targets of our proposal.

4.2 Colours and phase functions (led by INAF)

In April 2015 a proposal led by INAF partners to obtain the photometric colours of 15 small NEOs at the 3.6-meter TNG has been rejected. New proposals will be presented at the next deadlines.

An agreement with LBT-Italia to perform NEO observations with the 8.4-meter Large Binocular Telescope even on short notice has been signed. A recovery of the extremely faint (magnitude V=26.4) 2014 KC46 has been carried out in November 2014, enlightening the capacities of such facility.

Small telescopes at Asiago and Campo Imperatore observatories will be used during the upcoming months to get photometric observations of bright enough targets.

4.3 Light-curves and rotational properties (led by OBSPM-IMCCE)

4.3.1 Ground-based observations

The observatories that are available to the IMCCE for astrometric and photometric observations of NEOs are the Observatoire de Haute Provence (OHP) and Pic du Midi (PDM). While both telescopes are used to generate robust ground based astrometry for fainter sources on a regular basis, only relatively bright NEOs (around apparent visual magnitude 17-18) can be targeted with respect to photometry, if a signal-to-noise-ratio around 50 is aimed for. Pic du Midi is accessible throughout the year. However, the observation program has to be funded through the NEOShield-2 travel and/or IMCCE team budget. Fortunately, observation time at the OHP site could be shared with Gaia-FUN-SSO and GBOT projects. Table 4-1 summarizes the preselected

NEOShield-2 targets compatible with the brightness limits of OHP and PDM which are observable during scheduled observation times in 2015. As pointed out in this table, some targets have already been observed. For 2016, a higher utilization of PDM is foreseen.

Table 4-1: Conducted and scheduled IMCCE observations for NEO astrometry and photometry.

TARGET	TELESCOPE	INSTRUMENT	PROGRAM	TYPE	DATE	STATUS	REMARKS
2000 LF6	OHP	120cm	Gaia FUN-SSO (shared)	Lightcurve; Cousins R	11th-15th June 2015	executed	unsuccessful (bad weather)
2010 EV45	OHP	120cm	Gaia FUN-SSO (shared)	Lightcurve; Cousins R	14th-15th June 2015	executed	successful (bright back-up target, irregular light curve)
1998 AX4	OHP	120cm	Gaia FUN-SSO (shared)	Lightcurve; Cousins R	15th June 2015	executed	successful (bright back-up target, binary asteroid)
2003 NZ6	OHP	120cm	Gaia FUN-SSO (shared)	Astrometry; Cousins R	14th June 2015	executed	successful astrometry follow up, bad weather (no light curve)
2015 JH2	OHP	120cm	Gaia FUN-SSO (shared)	Astrometry; Cousins R	15th June 2015	executed	successful astrometry follow up
2015 KJ7J	OHP	120cm	Gaia FUN-SSO (shared)	Astrometry; Cousins R	15th June 2015	executed	successful astrometry follow up
2015 KL122	OHP	120cm	Gaia FUN-SSO (shared)	Astrometry; Cousins R	15th June 2015	executed	successful astrometry follow up
2006 WP127	OHP	120cm	Gaia FUN-SSO (shared)	Lightcurve; Cousins R	21st and 23rd July 2015	executed	successful
2015 NZ13	OHP	120cm	Gaia FUN-SSO (shared)	Astrometry; Cousins R	20th July 2015	executed	successful
2010 PR66	OHP	120cm	Gaia FUN-SSO (shared)	Lightcurve; Cousins R	10th - 13th August 2015	scheduled	x
2012 NP	OHP	120cm	Gaia FUN-SSO (shared)	Lightcurve; Cousins R	10th - 13th August 2016	scheduled	x
2001 RB12	Pic du Midi	106cm	NEOShield-2	Astrometry; Lightcurve	9th-14 September 2015	scheduled	x
2013 JR22	OHP	120cm	Gaia FUN-SSO (shared)	Astrometry; Lightcurve	12th - 15th October 2015	scheduled	x
1998 NX2	OHP	120cm	Gaia FUN-SSO (shared)	Astrometry; Lightcurve	7th - 12th December 2015	scheduled	x

Since the GBOT[1] astrometric pipeline has become available recently, astrometric data reduction is currently tested on a semi-automated basis. Astrometric results are satisfactory (better than the residuals listed for OHP by the Minor Planet Center for 2015), especially so given the fact that the observation conditions were far from optimal during the observation run (clouds, high humidity, rain). In contrast, a pipeline for differential ensemble photometry is not yet available. Although the current GBOT pipeline does extract photometric data, it has not been designed to provide high precision photometric results. In this respect more work needs to be done. The GBOT photometric pipeline could be improved, or a closer collaboration with NEOShield-2 consortium partners who already have access to a suitable pipeline could be attempted.

4.3.2 Space-based observations

Given the limited number of objects accessible via OHP and PDM, other options for asteroid photometry have been considered. The basic idea was to use photometric data of asteroids acquired by NASA's Kepler spacecraft during the K-2 mission.[2] Kepler is known to produce high accuracy photometry for stars. The possibility of extracting photometry of Solar System Objects (SSOs) passing the FOV of Kepler has been discussed e.g. by [RD1] and [RD2]. During the K-2 mission, the Kepler spacecraft enacts step and stare phases along the ecliptic. However, not all of the SSOs in K-2's FOV have actually been observed due to telemetry constraints. Only small areas around the stars, the so called "boxes" or "imagettes" around the ecliptic plane input catalog (EPIC) target objects, are scanned on a regular basis. In contrast to the previous works, we are using Virtual Observatory tools[3] such as SKYBOT and MIRIADE developed at the IMCCE to scan K-2 FOVs for passing asteroids. As soon as FOV crossing asteroids have been identified, they are checked in more detail with regard to whether they have actually been recorded in the imagettes of EPIC targets. As examples for such events, we present Figures 4-1 and 4-2. Those show the crossing of EPIC image boxes by the main-belt asteroid 484 Pittsburghia and the NEO Chelyabinsk, respectively. The results of this query are directly fed into an image reduction pipeline providing photometric data on those frames which contain the crossing asteroid. From those frames light-curve data can be extracted, such as presented in Figure 4-3.

[1] http://gbot.obspm.fr/
[2] http://keplerscience.arc.nasa.gov/
[3] http://vo.imcce.fr/

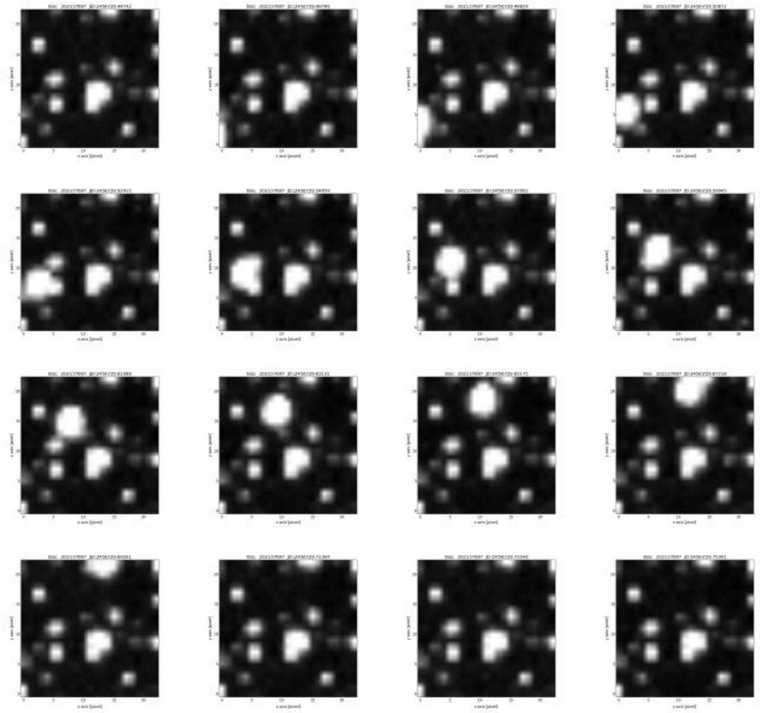

Figure 4-1: Time series of K-2 Campaign 0 images of the target EPICID 202137697. The asteroid 484 Pittsburghia enters the field at the lower left corner and leaves it at the upper right corner. The cadence is 30 minutes. Photometry can be extracted when the asteroid is totally in the field of view.

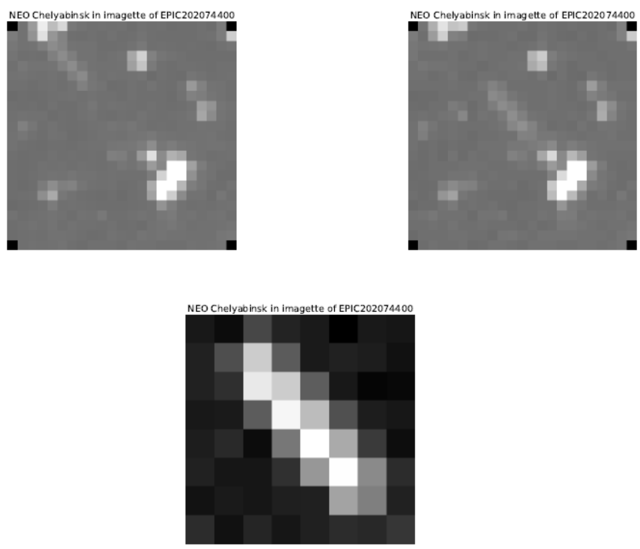

Figure 4-2: Same as 4-1, only for the NEO Chelyabinsk. The asteroid enters at the upper left corner and proceeds very rapidly towards the center of the image. It is considerably fainter than the EPIC target stars.

The quality of the extracted asteroid light-curves strongly depends on the brightness of the EPIC target object in the imagette. If the targets are much brighter than the crossing asteroid and somewhat variable, reliable light curve estimates become difficult to acquire. Since the pointing of the Kepler S/C is already hampered, the variation in the star's position in the imagette can be cause for an passing asteroid's light-curve to be basically unusable. Similarly, the flux of stars near the edges of the imagette becomes variable purely though the pointing issues of the S/C alone. In order to achieve the best possible results our algorithm needs to be steeled against such problems. At the very least, high quality photometric configurations have to be catalogued separately. The SKYBOT query that identifies potential targets in Kepler's FOV is currently only valid for Earth-based observations. As the parallax between the Earth and the Kepler S/C becomes non-negligible over the mission's lifetime, however, FOV crossing predictions for NEOs can be rather inaccurate. This may lead to a loss of possible targets. An update of the SKYBOT service is necessary in order to be able to predict all FOV crossings of NEOs from the viewpoint of the Kepler spacecraft. This update is under development. Another challenge regarding NEOs is the fact that they tend to have fast apparent motions. Thus, their images are rather elongated in the boxes, and the box-permanence time can be short. The NEO Chelyabinsk may serve as example (Fig. 4.2).

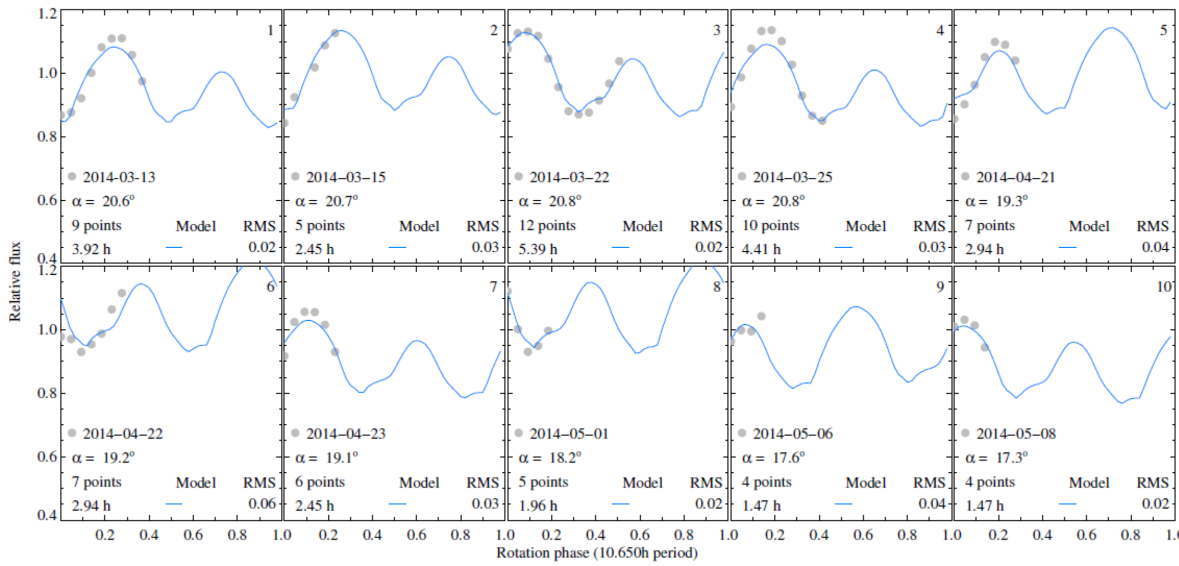

Figure 4-3: Light-curve data extracted from images such as presented in Figure 4-1 for 484 Pittsburghia. The blue curve symbolizes the light-curve prediction based on the current shape model. The grey dots represent the data extracted from K-2 image crossings.

4.4 Thermal infrared observations (led by CNRS)

Team members of the CNRS-Laboratoire Lagrange analysed thermal infrared observations of the potentially hazardous asteroid (99942) Apophis obtained with the CanariCam mid-infrared camera and spectrograph attached to the Gran Telescopio CANARIAS (GTC) at the "Roque de los Muchachos" Observatory, La Palma, Spain. Spectrophotometry using the Si2-8.7, Si6-12.5 and Q1-17.65 filters was obtained, with the aim of deriving the object diameter (D), geometric albedo (p_V) and thermal inertia (Γ). A detailed thermophysical model analysis of the GTC data combined with previously published thermal data obtained using Herschel Space Observatory PACS instrument at 70, 100, and 160 μm was performed. The thermophysical model fit of the data favour low-roughness surface solutions (within a range of roughness slope angles rms between 0.1 and 0.5), and constrain the effective diameter, visible geometric albedo and thermal inertia of Apophis to be D = 380–393 m, p_V = 0.24–0.33 (assuming absolute magnitude H = 19.09±0.19) and Γ = 50–500 $Jm^{-2}\ s^{-0.5}\ K^{-1}$ respectively. A publication on this subject has been submitted to the peer reviewed journal Astronomy and Astrophysics (Canaricam/GTC observations of (99942) Apophis, by J. Licandro, T. Muller, C. Alvarez Cabrera, V. Ali-Lagoa, and M. Delbo).

Moreover, members of the CNRS-Laboratoire Lagrange developed a new version of the near-Earth Object model presented in [RD3], which is calibrated on 40x the original number of observations, uses orbital distributions built by integrating 100x more particles, and takes into account the real distribution of the inclination of asteroids injected into the resonances. In particular, the contribution included an estimation of debased albedo distributions of NEOs. This was achieved by fitting an NEO albedo distribution model to NEOs with known albedos. The latter were obtained from a set of 394 NEOs whose albedos have been measured by the WISE survey.

Furthermore, in the momentary absence of ground based thermal infrared observations of small NEOs, members of the CNRS-Laboratoire Lagrange have developed a suite of algorithms, C and Python codes to search for, identify, download and analyse data of small NEOs from the NASA's Wide Filed Infrared Space Explorer (WISE) and from the Spitzer Space telescope. At the moment these procedures have been applied to main-belt asteroids only, in particular to small B-types. However, we expect application to NEOs very soon.