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The European NEO Coordination Centre

E. Perozzi[1,2,4], B. Borgia[1,3,4], and M. Micheli[1,3,4]

[1] ESA NEO Coordination Centre - ESRIN, Via Galileo Galilei 64, I-00044 Frascati, Roma Italy, e-mail: ettore.perozzi@esa.int
[2] Deimos Space, Strada Bucharesti 75-77, Bucharest, Romania
[3] SpaceDyS, Via Mario Giuntini 63, 56023 Navacchio di Cascina, Pisa, Italy
[4] INAF - IAPS, Via Fosso del Cavaliere 1000, 00133 Rome, Italy

Abstract. An operational approach to NEO (Near-Earth Object) hazard monitoring has been developed at European level within the framework of the Space Situational Awareness Program (SSA) of the European Space Agency (ESA). Through federating European assets and profiting of the expertise developed in European Universities and Research Centers, it has been possible to start the deployment of the so-called SSA NEO Segment. This initiative aims to provide a significant contribution to the worldwide effort to the discovery, follow-up and characterization of the near-Earth object population. A major achievement has been the inauguration in May 2013 of the ESA NEO Coordination Centre located at ESRIN (Frascati, Italy). The goal of the NEOCC Precursor Service operations is twofold: to make available updated information on the NEO population and the associated hazard and to contribute to optimize the NEO observational efforts. This is done by maintaining and improving a Web Portal publicly available at http://neo.ssa.esa.int and by performing follow-up observations through a network of collaborating telescopes and facilities. An overview of the SSA-NEO System and a summary of the first two years of NEOCC operations is presented.

Key words. Asteroids: NEOs – Asteroids: impactors

1. Introduction

The NEO Segment is one of the three major service components of the ESA Space Situational Awareness (SSA) programme, together with the SST (Space Surveillance and Tracking of man-made space objects) and the SWE (Space Weather monitor and forecast) segments. The SSA program aims to raise awareness on the population of space objects, the space environment and the existing threats and risks by timely providing data and services to users, customers and stakeholders, which range from the scientific community to satellite operators, from governmental institutions for risk monitoring to Space Agencies, insurance companies and the public at large.

The SSA NEO Segment, according to its design (Perozzi et al. 2011), is intended to play a leading role in the worldwide efforts on NEO hazard and mitigation, fruitfully interacting with known entities such as the Minor Planet Center (the authoritative source of NEO data on behalf of IAU) and the NASA funded JPL Near Earth Object Program (mainly devoted to NEO impact monitoring). In order to reach this goal it is foreseen the development of a software system for NEO data

Fig. 1. The SSA NEO Web Portal

management and dissemination, the coordination of European-based follow-up astronomical observations and the realization of a network of telescopes for providing a significant contribution to the worldwide efforts for NEO discovery. Federating already existing assets represents the first step to this end. The European worldwide excellence in orbit determination and impact monitoring is witnessed by the long-standing operational experience of the NEODyS system (Chesley & Milani 1999). The Spaceguard Central Node provided an algorithm to prioritize NEO follow-up observations in order to maximally improve their orbits. This is done by ranking NEOs by importance and likelihood of been lost, thus ensuring that the highest possible percentage of these objects, and in particular the newly discovered ones, is properly followed-up and can then be recovered at subsequent apparitions (Boattini et al. 2007). EARN (European Asteroid Research Node) keeps on-line updated lists of the available physical characteristics of known NEOs, which are essential in order to evaluate the consequences of an impact, to prepare mitigation actions and to compute high-accuracy long-term orbital evolutions. NEO observations are in general carried out on a voluntary basis, thus leaving the possibility to optimize their outcome through a coordinated effort. Therefore, SSA-NEO collaborating facilities ready to observe even upon short notice can significantly contribute to the orbit improvement of already known/recently discovered objects. Finally, the contribution of space-based assets, such as the ESA Gaia mission, which foresees the issue of astrometric alerts, is envisaged (Perozzi et al. 2013).

2. The NEO Coordination Centre

So far, the SSA-NEO Segment activities have been successfully initiated and the ESA NEO Coordination Centre, located at ESRIN (Frascati, Italy), was inaugurated on 22 May 2013. It consists of a NEO software system available on-line through a Web Portal at `http://neo.ssa.esa.int`, of on-site personnel carrying out daily operations and of the necessary hardware and software assets needed

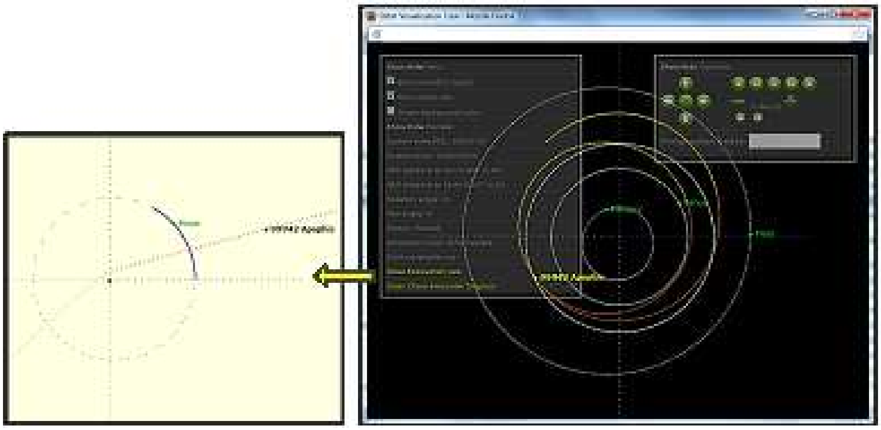

Fig. 2. The NEOCC orbit visualization tool showing the perturbed trajectory of asteroid Apophis before and after its 2029 encounter with the Earth in a heliocentric (right) and geocentric (left) reference frame. Note in the right plot the pop-down control panels, while the plot on the left has been drawn enabling the inverted background option.

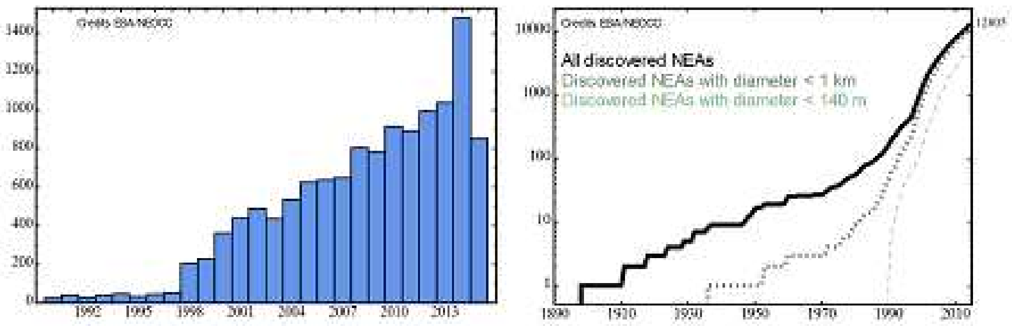

Fig. 3. The NEOCC orbit visualization tool showing the perturbed trajectory of asteroid Apophis before and after its 2029 encounter with the Earth in a heliocentric (right) and geocentric (left) reference frame. Note in the right plot the pop-down control panels, while the plot on the left has been drawn enabling the inverted background option.

to support, maintain and improve the NEO Segment functionalities and services. Routine operations foresee the execution of all tasks needed to keep the system alive (e.g. update the contents of the web pages, prepare and issue news, support system maintenance), issuing alerts to the professional and amateur observers community on objects bearing a specific interest for NEO science and mitigation as well as representing the reference contact point for external users and stakeholders (e.g. collaborating observatories, ESA, the media).

The NEOCC is an is an evolving environment: the services are continuously improved and are designed to ensure complementarity with respect to other NEO systems (e.g. Minor Planet Center, NASA Near-Earth Object Program) while keeping a high degree of completeness. In the following sections a summary of the NEOCC functions and services available in the forthcoming NEO software system release is given.

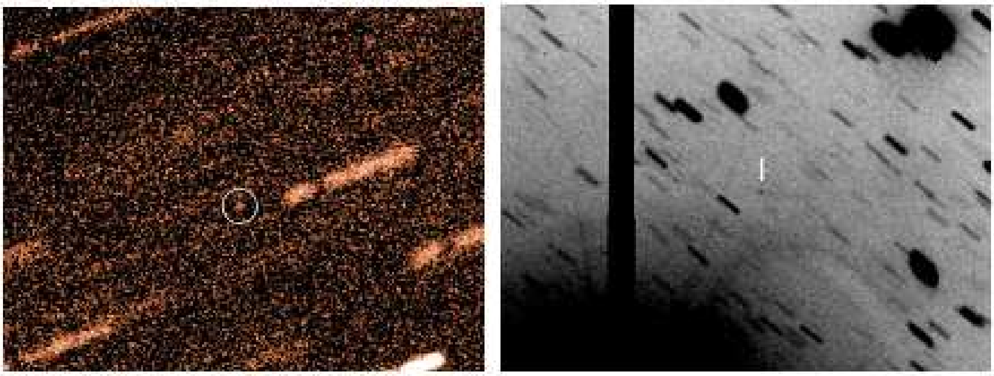

Fig. 4. Challenging recoveries: 2009 FD (left, credit: ESO) and 2014 KC46 (right, credit: LBT)

2.1. Databases and catalogues

The NEO Coordination Centre hosts a large collection of Small Bodies data. The orbital elements of all asteroids (NEOs, Main Belt, TNOs, etc.) for which good quality orbits are available, are regularly provided by NEODyS (`http://newton.dm.unipi.it/neodys/`) and AstDyS (`http://hamilton.dm.unipi.it/astdys/`) and stored in the NEO system. As far as NEO physical properties are concerned, EARN data (`http://earn.dlr.de/nea/`) are integrated into a fully searchable database. Thus, a single web interface allows to display both the dynamical and the physical properties of any given asteroid or to search for objects within certain parameters range for further investigation. In order to extend the NEO Segment services, the availability of other solar system objects relevant to NEO hazard is implemented. No impact monitoring is foreseen for comets but an updated catalogue (as provided by JPL at `http://ssd.jpl.nasa.gov/dat/ELEMENTS.COMET`) is made available. Fireballs are considered a crucial population to be better understood for being just located at the lower range of the mass-size NEO distribution. A fireball database would therefore further complement and extend the NEO Segment services. Due to the widely dispersed data sources maintained by both, scientific and amateur organizations, harmonization of the database content is necessary. To this goal ESA has developed an independent Fireball Information System fully compatible with the NEO system. The NEO Coordination Centre is intended also to receive data from collaborating observatories, to properly archive them and provide users with the necessary tools to retrieve them. Suitable FITS standard have been adopted for the currently available images, at present mostly provided by the La Sagra Sky Survey and by the ESA Optical Ground Station (OGS).

2.2. Visualization tools

Several visualization tools and graphical aids are foreseen for the NEOCC users in order to ease the comprehension of the NEO risk problem. Providing clear and informative material is a key issue in properly disseminating information on the asteroid hazard in order to avoid potentially dangerous misinterpretations of scientifically correct facts and figures, and the availability of visualization tools is a powerful means to this end. Asteroid orbits can be drawn, as a first approximation, using the Keplerian elements of the selected object. The position along the orbit of a given object can be computed at regular time intervals from well-known formulas thus showing an animation of its past and future motion along the orbit. A three-dimensional animated plot of the asteroid

Table 1. VIs removed in one year of activity of the ESA NEO Coordination Centre

Object	Date	PS_0	Telescope	Instrument	Archive
2007 UW1	2013-11-28	-3.4	CFHT	MegaCam	-
2013 XE2	2013-12-10	-4.0	PS1	GPC	PS1
2008 CK70	2013-12-18	-3.1	CFHT	MegaCam	CADC
2013 BP73	2013-12-20	-3.8	SDSS	SDSS	CADC
2013 YC	2014-01-22	-2.9	VLT (UT1)	FORS2	-
2014 BD33	2014-01-29	-4.2	PS1	GPC	PS1
2004 BX159	2014-02-18	-4.5	CFHT	MegaCam	CADC
2014 AF16	2014-03-11	-2.4	VLT (UT1)	FORS2	-
2012 HP13	2014-04-09	-6.6	VLT (UT1)	FORS2	-
2014 DN112	2014-05-01	-3.6	VLT (UT1)	FORS2	-
2014 HM129	2014-05-22	-4.2	VLT (UT1)	FORS2	-
2014 HM187	2014-05-28	-4.5	VLT (UT1)	FORS2	-
2012 VU76	2014-06-09	-6.1	VLT (UT1)	FORS2	-
2013 YD48	2014-06-30	-4.8	VLT (UT1)	FORS2	-
2014 LU27	2014-07-17	-2.4	PS1	GPC	PS1
2014 PB58	2014-08-12	-4.5	PS1	GPC	PS1
2014 QF392	2014-08-14	-8.0	PS1	GPC	PS1
2014 QJ392	2014-08-14	-6.1	PS1	GPC	PS1
2014 RC	2014-09-04	-7.0	PS1	GPC	PS1
2014 KC46	2014-10-30	-4.1	LBT	LBC	-
2014 WV363	2014-12-01	-3.4	PS1	GPC	PS1
2014 XL7	2015-01-15	-3.0	VLT (UT1)	FORS2	-
2003 LN6	2015-01-23	-5.2	VLT (UT1)	FORS2	-
2015 BU92	2015-01-27	-2.9	LCOGT OGG (FTN)	Spectral	-
2014 XM7	2015-02-09	-6.5	PS1	GPC	PS1
2015 DA54	2015-02-26	-5.4	PS1	GPC	PS1
2015 DF198	2015-02-26	-5.4	PS1	GPC	PS1
2014 NG65	2015-03-25	-4.5	PS1	GPC	PS1
2014 WP362	2015-04-10	-4.8	VLT (UT1)	FORS2	-
2008 LG2	2015-06-16	-5.8	VLT (UT1)	FORS2	-
2015 KL157	2015-07-13	-3.9	OGS	SDC	-

trajectory in space is therefore obtained, with the possibility of changing the viewpoint, the zoom factor, the timescale and the direction of motion. This approach was originally used by the NEOCC Orbit Visualization Tool.

Yet, in order to provide orbital plots more closely reflecting the actual dynamical evolution of a NEO, a more refined modelling of the trajectory which includes planetary perturbations is needed. In particular when Earth close encounters occur the availability of enhanced functionalities (e.g. adopting an Earth-centered reference frame, providing a visual evaluation of the orbit uncertainty) is desirable. This involves leaving the simplified 2-body approximation and using pre-computed high accuracy ephemeris instead. An enhanced orbit visualization tool has been therefore developed. In order to fully appreciate the orbital changes due to close encounters, the perturbed trajectory is drawn for a given time span ahead and behind the running position of the asteroid. Switching to the geocentric reference frame, where the orbit of the Moon is also displayed, can be selected during close encounters for better appreciating the geometry of the encounter and the underlying dynamics. An example is shown in Fig. 3 for the 2029 encounter of asteroid (99942) Apophis with the Earth, which raised significantly the aphelion of its orbit. Following the advances of our knowledge on the NEO population is also well suited for graphical display: by using simple statistical representations it is possible to monitor NEO discoveries on a daily basis.

2.3. Other services

An NEA chronology page listing significant past and forthcoming events - previously hosted by the International Astronomical Union - has been migrated into the NEO System and regularly updated. News are published on the NEO web portal when appropriate; the publication of a monthly newsletter summarizing the most important events related to NEO hazard monitoring has begun in April 2015 (to subscribe please write to neocc@ssa.esa.int). Public outreach material is also provided as a collection of images, diagrams and articles.

3. Observation campaigns

Follow-up observations are essential to prevent newly discovered objects from becoming lost as well as to improve the accuracy of the orbit of risky objects (i.e. those possessing impact solutions, referred to as VIs – virtual impactors). While large scale surveys are devoted entirely to the discovery of new objects, and some specific projects are focusing on physical characterizations, up to now there has been a lack of centralized effort to coordinate the follow-up of objects. The NEOCC has as a major goal the coordination of a network of observatories that are being alerted when high-relevance objects need follow-up. At the same time, the Centre is directly performing astrometric observations of high-priority targets, both using its own facilities and large aperture telescopes all over the world (Micheli et al. 2014a). Several observational campaigns have been carried out both developed through cooperating partners and directly managed by the NEOCC. The most accessible resource is the 1.0-meter ESA OGS telescope in Tenerife, which is routinely used to follow-up and recover NEOs, for about 4 nights per month. In addition to the OGS, a very fruitful collaboration has been established with ESO to observe faint VIs, down to magnitude ~ 26, with the 8.2-meter Very Large Telescope on Cerro Paranal. In 2014 over a dozen VIs were observed, most of which were removed from the risk list thanks to our observations, e.g. the recovery of 2009 FD (Fig. 4, left) and the observation of 2008 LG2 at visual magnitude 26.6, the faintest NEO ever detected (Hainaut et al. 2015). A collaboration with INAF - Osservatorio di Roma has allowed us to access the 8.4-meter Large Binocular Telescope located in Arizona and operated by an international consortium. LBT, with its twin wide-field cameras and large aperture, is the ideal instrument to recover large-uncertainty NEOs, as evidenced by the successful detection of 2014 KC46 in October 2014 (Fig. 4, right), at visual magnitude 26.3 (Micheli et al. 2014b).

Archival data have been also used to find precoveries (i.e. serendipitous observations) of virtual impactors: as shown in the last column of Table 1, it is an extremely successful technique. Therefore implementing this functionality in the NEO System, either as an ESA-based archive of astronomical images from collaborating observatories or by complementing already existing assets, is foreseen as a future improvement of the NEOCC services.

4. Collaborating observatories

As far as NEO detection is concerned, there are many collaborations that can be carried out between Gaia-FUN-SSO and the NEO Coordination Centre. The two telescope networks are somehow complementary in terms of performances and locations. Whereas the Gaia-FUN-SSO is geographically well dispersed in longitude, the NEOCC collaborating observatories are more focused on large FoV instruments and large aperture telescopes. Thus the interchange of information when urgent follow-up observations are needed, either triggered by Gaia astrometric alerts or by objects entering the NEOCC risk list, is likely to increase the chances of successful observations. This has been, for example, the case of the 2002 GT campaign, which was organised in 2013 in order to characterise the target selected for the NASA EPOXI (former Deep Impact) mission, at its last apparition before the encounter. Photometry and lightcurves were performed from the 1 m-diameter C2PU telescope at the Observatoire de la Cote d'Azur, which allowed the calculation of the rotation period. Spectra and photometric data were collected from the Asiago Observatory (Padova, Italy) allowing the determination of the asteroid taxonomic type; infrared observations were carried out from the Campo Imperatore Station (INAF - Observatory of Rome, Italy); astrometric measurements were provided by six telescopes belonging to the Gaia-FUN-SSO. A further collaboration involves the possibility of using some of the data displayed on the NEO web portal to test the response of the Gaia follow-up network in a real case scenario. Through properly rearranging the NEOCC priority list, it is possible to select objects which have observational characteristics similar to those expected from Gaia. In this way the NEOCC acts as sort of Gaia simulator. Providing targets which are in principle observable from Gaia in order to check the efficiency of its moving object detection system is also an appealing possibility currently under study.

5. Conclusions

The deployment of the ESA NEO segment precursor services allowed to establish and carry out operations, maintenance, and upgrading of a NEO hazard monitoring system which relies on existing European expertise and assets. The SSA-NEO Coordination Centre, located at ESRIN (Frascati, Italy) represents a focal point for the SSA programme stakeholders and it provides the institutional interface with other entities involved in NEO activities (e.g. the JPL NEO Program, the EC NEOShield-2 project). The experience gained so far setting up, maintaining and upgrading the SSA-NEO SW System as well as in coordinating follow-up observations performed by a network of collaborating telescopes provides the necessary background for future developments. The establishment of an ESA "Wide Survey" focused on discovering small-size objects on a collision course with our planet with sufficient warning time to undertake mitigation actions. represents a major future development of the NEO segment. It will drive the present NEO Coordination Centre to a transition toward a full fledged "Small Bodies Data Centre" by migrating all software and data processing algorithms inside the ESA NEO system. As such it will be recognized as an authoritative NEO data source also for astrometry and orbit determination functions, thus providing the necessary redundancy within the existing scenario.

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