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## The SSA NEO Segment and Gaia: present opportunities and future developments

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### Introduction

One of the major elements of the ESA Space Situational Awareness (SSA) programme is devoted to NEO hazard monitoring through the set-up and the operation of a dedicated data centre [1]. This implies the availability of advanced systems for orbit computation and impact monitoring, the possibility to store and retrieve all relevant data (orbital parameters, physical properties, raw image archives etc) and the coordination of NEO observations for discovery and follow-up. Thus the aim of the SSA NEO Segment is to become a worldwide reference for potential SSA customers and stakeholders such as the scientific community, governmental institutions, insurance companies and the public at large. The NEO Segment is presently in the Precursor Services phase and the deployment of a NEO Data Centre at ESRIN (Frascati, Italy) has been successfully achieved.

Within this framework, there are many opportunities for fruitful collaborations between the Gaia Follow-up Network of Solar System Objects (Gaia-FUN-SSO [2]) and the SSA-NEO Segment. The Gaia scanning law determines a peculiar pattern for observing at low solar elongations and the onset of fast and reliable communication between the respective follow-up networks could greatly contribute to optimize the observation of high-priority targets. In this respect the relatively small wide field telescopes characterizing NEO observations and the large-diameter telescopes available to the Gaia-FUN-SSO address complementary observational requirements. The availability of Gaia NEO spectrophotometric observations can also provide valuable information for risk assessment and mitigation. Finally, the involvement of the NEO Segment into the international coordination efforts for hazard warning and mitigation (e.g. UN Action Team 14) would provide the necessary framework for the NEO-related Gaia data products.

## 1. The NEO Segment

### 2.1 *System Design*

Because of the intrinsic nature of the asteroid hazard, the SSA NEO Segment needs to be considered in an international context. It represents the European contribution to a world-wide effort for assess and mitigate the NEO impact risk, thus entering a scenario where many countries are actively participating in an international coordination devoted to this end. Since 1998 the contribution of NASA is prominent, acting under a specific mandate from the US Congress : as a consequence there is the need for Europe to provide a contribution which is technologically and scientifically competitive. This has been a key design issue of the architectural studies for the SSA-NEO Segment [3]: to support the already existing European expertise in NEO studies, while further expanding its domain of intervention.

The deployment of a NEO Data Centre exploiting the European worldwide excellence in orbit determination and impact monitoring, as provided by the long-standing operational experience offered

by the NEODYs system [4], was recognised as a major design driver of the SSA NEO Segment. The expertise of the European scientific community in asteroid physical characterization and the possibility of an incremental implementation of the NEO Data Centre to become a worldwide authoritative data source on small solar system bodies added further momentum to both the final operational system design and to the Precursor Services scenario.

Federating existing European assets, such as telescopes and radars under NEO Data Centre coordination was also envisaged for follow-up (i.e. tracking) purposes, since this function was (and still largely is) performed by the scientific and amateur communities on a voluntary basis. Dedicated SSA NEO tracking facilities ready to observe even upon short notice could then significantly contribute to the orbit improvement of already known/recently discovered objects leading to a better evaluation of the corresponding impact probabilities. The European expertise in follow-up coordination provided by the Spaceguard Central Node priority list and the availability of European assets such as the La Sagra Sky Survey (LSSS) and the ESA OGS (Optical Ground Station) facility provide the basic observational scenario.

As concerning NEO survey and discovery, the overwhelming US supremacy in the field deserved to be carefully investigated. The efficiency of a European “Wide Survey” scenario aimed at discovering small (10 – 50m in size) NEOs approaching the Earth using innovative “fly-eye” telescope technology was demonstrated by extensive simulations [5]. The aim is to ensure a complete coverage of the whole visible sky at least twice per night with sensors characterized by a large field-of-view (about 45 square deg) and a high sensitivity (reaching down to 21.5 limiting magnitude). A “Wide Survey” as such could guarantee the European competitiveness on a class of small hazardous objects: the US surveys are in fact designed for fulfilling the Government mandate of discovering 90% of NEOs larger than 140m (which is the threshold between a local damage and a global catastrophe).

This choice fulfils at best the SSA NEO Segment users and customers needs because the events that small impactors are likely to produce (fireballs, meteorite falls, small cratering) are less catastrophic and more frequent. Moreover it allows to increase the warning time from discovery to impact, extending also to space the possibility of a mission devoted to early warning especially for objects coming from the direction of the Sun.

Summarizing, the NEO Segment design [3] foresees three major elements:

- *Wide Survey*: a network of optical telescopes performing an all-sky survey focused on the discovery of small size, potentially hazardous objects
- *Small Bodies Data Centre*: in charge of the downstream data processing (astrometric data collection, orbit determination, risk assessment, follow-up coordination) and the provision of NEO-related services (raw image archives, physical properties and fireball databases, precovery etc.)
- *Collaborating Observatories*: for dedicated astrometric and physical follow-up (under Service Level Agreements) as well as for unsolicited and serendipitous observations coordination (e.g. amateurs, space telescopes, etc.)

The set up and the operation of a NEO Data Centre located at ESRIN (Frascati, Italy) during the SSA Preparatory Programme phase (2008-2012), has been the first step in this direction. The funding of the follow-on NEO Segment activities successfully achieved at the recent ESA Ministerial Council (November 2012) has provided the necessary ground for further developments.

## 2.2 *Precursor Services*

In order to guarantee all basic functionalities needed for impact monitoring activities, the NEO Data Centre relies on already existing expertise, software systems and databases. In particular :

- NEODyS - Near Earth Object Dynamic Site – developed at the University of Pisa and currently operated by SpaceDys represents an authoritative source of data for NEO orbit characterization and impact monitoring. Access to its data is essential in order to provide state-of-the-art information on the NEO hazard.
- EARN – Near-Earth Asteroid Research Node - maintained at DLR, aims to gather NEO physical data into one single source site. The availability and the update of these data allows to harmonise NEO orbital and physical information.
- SCN – Spaceguard Central Node - developed at INAF, offers on-line services for optimising follow-up observations of NEOs at risk of being lost. In particular the “Priority List” has shown to be extremely effective to this end and has been integrated into the NEODC during SN-III.
- NEO observations are performed by many European amateur and professional observatories, e.g. the highly successful La Sagra Sky Survey and the ESA OGS station. Their collaboration with the SSA program foresees performing follow-up observations and contributing to the growth of the image database available at the NEO Data Centre.
- AstDyS - Asteroid Dynamic Site: developed at the University of Pisa and currently operated by SpaceDys represents an authoritative source of data for asteroid orbit characterization, observation quality control and proper elements. Although AstDyS is not primarily concerned with NEO data (it addresses other solar system bodies: Main Belt Asteroids, Trojans, TNOs, Centaurs etc) it provides a fundamental service to NEO observers (it is not possible to observe NEOs without observing a much larger number of MBAs).

The NEO Data Centre is organised as a dynamic three-layer structure, including a database, the related services and an interface (Web Portal) allowing interrogations of the database and as placeholder for additional services. The current version provides the necessary tools for searching and visualizing NEO data to external users and applications and other advanced features addressed to more experienced users. The portal is available at the following location: <http://neo.ssa.esa.int/>

The early deployment of the Precursor Services has allowed gaining an understanding of the technical issues involved and of the interfaces needed to establish and carry out operations, maintenance and upgrading of the system. Moreover the web portal has been designed in order to be ready to further expand both, the functionalities and the services. Near Earth Comets are expected to enter the NEO database as well as Fireball data, thus encompassing all celestial objects which are likely to come in the vicinity or actually hit our planet.

Therefore the SSA NEO Data Centre has the potentiality to represent a unique facility in the NEO scenario because it hosts data and services which are at present addressed by different institutions, often being physically and logically separated ( e.g. the share between the Minor Planet Centre and the JPL Near Earth Object program, the former focussed on orbit determination and cataloguing functions, the latter on impact monitoring).

## 2. Space based assets

The contribution of space-based assets to NEO observations has been investigated during the SSA preparatory phase. Present and future space missions, either specifically devoted to observing NEOs or having a different primary target have been checked for their potential benefits to impact monitoring [6]. Results are summarized in Table 1.

**Table 1:** Present and future missions which could perform NEO observations from space (note that the Asteroid Finder mission has been recently cancelled)

	Herschel	BepiColombo	Asteroid Finder	NEOSSat	Venus Express	Rosetta	NGO	Gaia
<b>Primary mission</b>	Infrared observatory	Mercury exploration	NEOs	NEOs	Venus exploration	Comet exploration	Gravity-wave observatory	Star catalogue
<b>Operator</b>	ESA	ESA	DLR	CSA	ESA	ESA	ESA	ESA
<b>Nominal operation dates</b>	2012-2017	2014-2020 cruise 2020-2021 Mercury	2013-2014	2012-2013	2011-2012	2014-2015	?	2013-2017
<b>Instrument type</b>	IR telescope	3x star trackers	Optical telescope	Optical telescope	2x star trackers	Optical/IR telescopes	Laser interferometer	Dual optical telescope
<b>Limiting Magnitude</b>	- ?	5.2-14?	18.5	20	5.5-14.2?	12 (WAC) 16 (NAC)	N/A	20
<b>Observable region</b>	All sky Sun-LoS angles down to 60.3°	All sky from Mercury	All sky Sun-LoS: 30°-60°	All sky Sun-LoS: 45°-55°	All sky from Venus	Depending on allowable manoeuvres	Objects intersecting the trajectory of Sun-Earth L1 point	Celestial Sphere Sun-LoS: down to 45°
<b>Field of view</b>	0.25°	20° (cone)	2x2°	0.85°	16.4°	2°x2° (NAC) 12.1°x12.7° (WAC)	N/A	0.7°x0.7°
<b>Observation strategy</b>	Fine pointing / scan law modes	Close-range passive detection	Sky survey from sun-synchronous orbit	Sky survey from sun-synchronous orbit	Close-range passive detection	Pointing on demand	Close-range passive detection	Optimized for uniform sky coverage
<b>Type of observations</b>	Follow-up Physical observations	Follow-up	Discovery	Discovery Follow-up	Follow-up	Follow-up	Discovery	Discovery; Physical observations
<b>Expected return</b>	Low	Very Low	Very high <b>CANCELED</b>	Very high	Very low	Low	Very Low	High

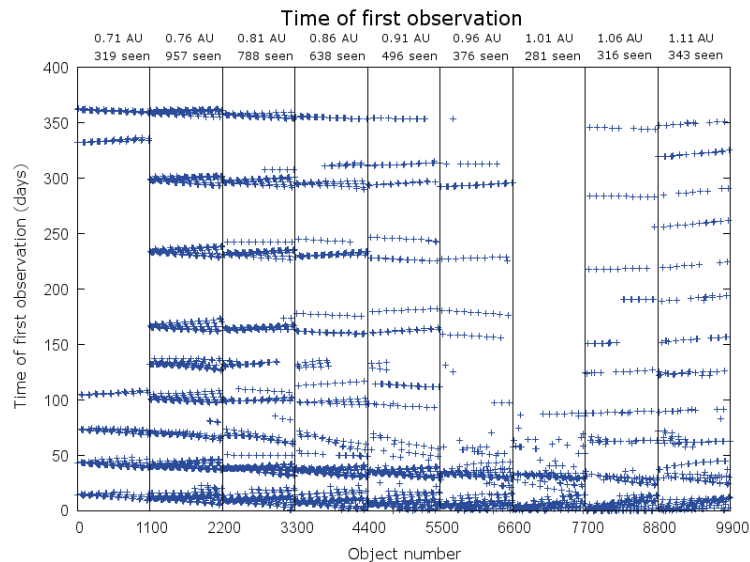
We remark the following:

- Infrared observations from space are very effective for both, NEO detection and follow-up; however, the corresponding missions are expensive because of the specialized payload, and have a more stringent operational lifetime because of the cooling requirements.
- When the primary goal of a mission is not NEO detection, there can be consistent limitations to both perform dedicated observations and access the data processing pipeline.
- Low-earth orbiters devoted to NEO observations represent a cost effective option for space-based observations (both Asteroid Finder and NEOSSat are very small -100 kg- satellites).
- Although the WISE mission was devoted to mapping the infrared sky it has been very successful also in observing NEOs, and much can be learned from it. In particular:
  - many low solar elongation objects could be detected;
  - only the objects which were then tracked from ground-based observatories within a few days of their first detection resulted in having good quality orbits.
  - collaboration with the MPC and with the worldwide NEO observation network played a crucial role.
  - objects in peculiar orbital configurations have been found by post processing the image set released after the end of the mission; challenging ground-based follow-up was then necessary to confirm the discoveries (e.g. WISE 2010TK7 needed the 3.6m Canada-France-Hawaii telescope)
- The exploitation of star trackers and cameras on board interplanetary missions could be attempted provided that they are used in a different way (e.g. Venus Express long exposure strategy) or designed ad hoc (BepiColombo). Searching for NEOs by post processing images taken during primary mission operations is also a viable option (presently under study for Rosetta). Even if these techniques are not expected to produce a large amount of detections, nevertheless they could give a significant contribution in peculiar cases

- Gaia is equipped with two telescopes reaching sufficiently high limiting magnitude and its attitude dynamics allows observations at low solar elongations. This favorable configuration can be exploited for detecting NEOs, even if the scanning law is not optimized to this end.

### 3. Gaia observations simulation

Simulations have been run in order to explore the performances of the Gaia mission when observing small bodies at increasing distances from the Sun [6]. In particular, a fictitious population of low inclination circular orbits with radius between 0.71 and 1.11 AU has been generated; to each object has been given an absolute magnitude of 18.12, which approximately corresponds to an asteroid with albedo 0.1 (C-Type) and 1 km diameter. In this way it was possible to highlight some characteristic patterns of Gaia observing moving solar system objects, which would have been hidden if a more complex (and realistic) NEO population were considered.



**Fig. 2:** Time of first detection from Gaia for objects belonging to the fictitious population described in the text. The simulation time was 1 year; only objects with an apparent magnitude less than 20 were accounted as seen.

From Figure 2 it can be seen that the time of detection of new objects is not randomly distributed but it occurs at intervals of about 31.5 days. This periodicity can be explained by the fact that when the Gaia spin axis crosses the ecliptic (which happens twice during a full 63 day precession cycle) then the LoS sweeps through the ecliptic plane at the lowest solar elongation possible (45 deg) thus allowing the detection of the lowest semiaxis objects.

The lack in Figure 2 of objects with semimajor axis close to that of the Earth is possibly due to their long synodic period when compared to the simulation time (1 year). The consequence is that the objects starting in favorable observing conditions are discovered almost immediately, while those in bad observing geometries will slowly exit the 90° “blind zone” centered on the Earth-Sun direction. As an example a 1.1 year revolution period corresponds to a synodic period of 11 years, which in turns gives an angular speed with respect to Earth of about 35.7%/year. An object from our population which initially enters the blind zone takes 2.53 years to leave it, thus remaining unobservable during the whole simulation timespan.

The number of objects actually detected within every semimajor axis bin, initially filled with the same number of objects (1100), is reported on top of the plot of Figure 2. As expected, the 1.01 bin, where

the largest synodic period objects reside, has the fewest detections. In general the larger the semimajor axis, the less the discoveries, because lower semimajor axis regions are more densely populated. The only exception is the smallest semimajor axis bin, where the long time span in which no objects are detected is due to being at the very edge of the accessible zone for the Gaia instruments.

## Conclusions

The Gaia mission, although not designed specifically for NEO detection, is expected to give a significant contribution to NEO observations, when supported by ground-based follow-up as provided by the Gaia-FUN-SSO. The SSA NEO Segment has the goal of significantly contributing to the worldwide NEO hazard monitoring scenario through becoming an authoritative data source on small solar system bodies, coordinating follow-up observations and deploying an high efficiency all-sky survey. Interaction between the Gaia-FUN-SSO and the NEO Segment is therefore highly desirable for the many benefits that it can bring to both projects. In particular :

- the generally large FOV telescopes used for NEO detection/recovery could efficiently deal with the astrometric accuracy produced by Gaia alerts, while the largest Gaia-FUN-SSO telescopes could allow the NEO Segment an easier access to deep follow-up facilities.
- once operational, the NEO Segment « wide survey » will provide on a daily basis an all-sky transient survey ; this can be used to validate both Gaia astrometric and photometric alerts (e.g. searching for precure observations) ;
- the SSA NEO Data Center is expected to evolve into a full-fledged Small Body Data Center encompassing databases of the dynamical and physical characteristics of all small solar system bodies, and in this respect the Gaia mission can be considered as an European space based asset for small bodies physical data.

A possible cooperation between Gaia-FUN-SSO and the NEO Segment could be realised already in the Precursor Services phase : as a result of routine operations, the NEO Data Centre could provide NEO « astrometric alerts » which can be used test the response of the Gaia follow-up network in real cases.

In the long term, the star catalogue produced at the end of the 5-year Gaia mission will allow to improve significantly the orbit determination accuracy for the whole NEO population.

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