IDENTIFICATION OF SST COMMUNITY SUPPORT TO REDUCE FALSE POSITIVES IN THE IDENTIFICATION OF NEO IMMINENT IMPACTORS

Juan L. Cano[(1,2)], **Noelia Sánchez-Ortiz**[(1)], **Marco Micheli**[(2)], **Jaime Nomen Torres**[(1)]

[(1)] *Deimos Space, Ronda de Poniente 19, 28760, Tres Cantos, Madrid, 28760, Spain,*
juan-luis.cano@deimos-space.com, noelia.sanchez@deimos-space.com, jaime.nomen@deimos-space.com,
[(2)] *ESA NEO Coordination Centre, Largo Galileo Galilei, 1, 00044 Frascati (RM), Italy*
juan-luis.cano@esa.int, marco.micheli@esa.int

ABSTRACT

A large number of near-Earth object (NEO) observers provide observations of moving objects to the Minor Planet Center (MPC) database. Those observations are used by several systems (like NASA's Scout [1] or the European NEOScan [2] systems) for identification and early warning of 'imminent impactors'. These systems use the information on the MPC NEO Confirmation Page (NEOCP) and evaluate all possible orbital solutions compatible with the small amount of available observations.

In the event of an Earth-orbiting object (space debris or satellite, in the domain of space surveillance and tracking, SST) being observed, and due to this unavoidable poor accuracy of the initial estimated orbit solutions, both geocentric and heliocentric orbits are often compatible with the data. In this situation, some of those objects may be considered as potential NEO close approachers or imminent impactors. This case has occurred recently in several occasions, such as with the small artificial objects ZTF00Y5 and ZS0BB63.

In order to avoid the identification of these objects as false imminent impactors, there is a need for NEO observers to quickly identify if their observations map to some known SST object, ideally before sending information to MPC, or at least notify the MPC and the community that some observations are compatible with a known artificial object. The same process should be routinely applied to objects already on the NEOCP but flagged as having a non-zero chance of being in Earth orbit, to make sure no obvious identification with known man-made objects has been missed.

In order to reach this goal, several approaches are possible. A first option can be based on using available SST object catalogues to allow observers to identify these correlations themselves. This option is partially possible, and can be based on public SST catalogues as the American two-line elements (TLE) dataset. However, this approach has several drawbacks, among them the lack of completeness of the public catalogues. In addition, the need of SST-specific knowledge and/or tools may be an obstacle to the use of these tools for some NEO users that are not used to handling data in the SST domain.

The other option may be the development of a service to which observers can provide observations and receive a confirmation whether they correlate to any known SST object. This service could be based on a TLE catalogue, or any other data source, maybe maintained by other SST systems different to the American JSpOc one.

An additional type of support from the SST community can be envisaged in the form of availability of SST sensors in the case a follow-up of some of those objects is needed. Suitability of those sensors is larger than that of the NEO community due to the adaptation to the higher angular velocities [3]. In order to allow this kind of support, several aspects shall be addressed, namely: observation approaches, data formats, data processing pipeline suitability, corrections to be applied, timeliness for tasking response, etc. A benefit of this approach is to acquire a larger number of observations that can be handled by the SST community to update and upgrade the SST knowledge [3].

The benefit for the SST community from this support is to get observations from some objects which are unlikely to be observed and maintained by the SST surveillance systems, as they orbit in regimes at higher altitudes than those systematically monitored. This paper evaluates the current situation, details the needs of the NEO field, and summarises the requirements and interface issues of such kind of services that the SST community can offer to support the NEO community. The particular case of the correlation service offered by ESA's SCOOP system is analysed, in order to identify the suitability for the solution of this problem, and the required upgrades needed to allow its use in the NEO community.

1 EXAMPLE CASES

Among the ever-growing collection of geocentric objects serendipitously discovered by NEO surveys, a few have interesting dynamical properties that provide peculiar challenges and opportunities for orbit computers.

Proc. 1st NEO and Debris Detection Conference, Darmstadt, Germany, 22-24 January 2019, published by the ESA Space Safety Programme Office
Ed. T. Flohrer, R. Jehn, F. Schmitz (http://neo-sst-conference.sdo.esoc.esa.int, January 2019)

In most cases, these issues arise from the limited temporal coverage of the observational arcs provided by NEO surveys. In some cases, these objects are only detected 3-4 times over the arc of about an hour, following the typical observational cadence of asteroid-oriented surveys. Some of them may be successfully recovered by other observers over the subsequent hours or days, but they are rarely followed-up for more than a week or so, and therefore quickly become lost. In some cases, objects on similar orbits are rediscovered months or years later and can be tentatively identified with older discoveries, but successfully linking the observations together is often a significant challenge.

The best studied of such cases was the object known with its observer-assigned designation WT1190F [4], discovered by the Catalina Sky Survey in October 2015, and quickly predicted to impact the Earth about a month after discovery. The peculiarities of this body were not limited to its dramatic ending: the object itself was moving in an extremely high Earth-bound orbit, with a very large (for typical SST objects) orbital period of about a month. Because of its motion, it had been detected by NEO surveys multiple times in the past, going back as far as 2009. The entire set of observations, covering more than 6 years, shows that the object's motion cannot be fit just with pure gravity, but also with the addition of a simply modelled constant radiation pressure force. Modelling the observed motion over the entire arc provides an interesting challenge for the SST community. In this particular case, observations during the final hours before Earth impact were also acquired by sensors normally devoted to SST observations, profiting of a high accuracy in the time-stamp and thus on the location of the object within the orbit.

A similar case is currently being provided by XL8D89E, the only currently known object in geocentric orbit with a period of more than a month. This body has been seen multiple times since 2015, but it is likely identical to 6Q0B44E, an object in a very similar orbit seen more than a decade ago, in 2006-2007. Again, the motion of the object is not modelled well by gravity alone, nor by the addition of a simple radiation pressure force. A more complex model may be capable of fully fitting the available observations of XL8D89E, and ideally link its observed arc with the one for the much older 6Q0B44E, thus ensuring the predictability of the object’s motion for the foreseeable future.

Finally, in the more recent past a few small objects with geocentric orbital periods of a day or two have been found by the Zwicky Transient Facility and by other asteroid surveys. These objects have the unusual characteristic of displaying a very strong non-gravitational signature, compatible with solar radiation pressure if their densities are assumed to be extremely low. Linking together different observed arcs on these objects is therefore an even more extreme challenge, but it is essential to ensure that their positions can be routinely predicted, and they can be easily excluded as candidate new NEOs by asteroid surveys.

2 PROPOSED SERVICE GOALS

The service proposed in this paper is the one associated to providing the observers with a web-based tool to identify whether their observations are compatible with any of the objects contained in a dedicated database of objects in what we call High-Energy Stranded Earth Orbits (HESEO). This would include objects above geostationary orbit (GEO), in Lagrange point orbits and in periodically Earth-bound orbits. To this end, the first step would be the construction of such objects database in high-energy orbits to which the users can perform queries. Next, a web service should be constructed to provide access to external users to the data. This shall include tools to calculate the ephemerides of those objects at any time and compare them with the ones that the user will provide.

Summarising the above considerations the main goals of the proposed service would be the following:

- Goal #1: the Service shall allow that some operators define and maintain a database of high energy Earth-bound objects (periods typically larger than 1 day, and then well above the geostationary disposal orbits).
- Goal #2: the Service shall allow that some external users/observers request whether some collected observations are compatible with any object in the above-mentioned database.
- Goal #3: the Service shall provide some external users/observers with a list of objects to be observed in a given timeframe such that those objects can be kept in the database within a given propagation uncertainty in the future.
- Goal #4: The Service shall provide to some external users/observers a table of ephemeris or orbital elements (e.g. TLEs) of a selected object in a given time interval and at a given time step, from a given observation point on Earth.
- Goal #5: The Service shall monitor the Scout and NEOScan systems and automatically run the process in Goal #2 whenever an object is flagged with a geocentric score above a certain threshold.

3 DEFINITIONS

Following definitions apply through this document:

- Service: whatever part of the web system (frontend and backend) that allows completing a system goal.
- Module: whatever part of the backend that

allows performing a high-level task in support of a service.

- Function: whatever part of the backend that allows performing a low-level task in support of a module.
- HESEO objects: the objects considered within this article are those in Earth bound orbits with orbital periods above the ones for the GEO disposal orbits, or in Lagrange point orbits and in periodically Earth-bound orbits.

4 PROPOSED SERVICE ARCHITECTURE

The HESEO system architecture is provided in Fig. 1 where all the identified goals are covered by independent services either operated by system operators or in conjunction with input from or output to observers, or automatically with input from the NEO impact monitoring services (Scout and NEOScan).

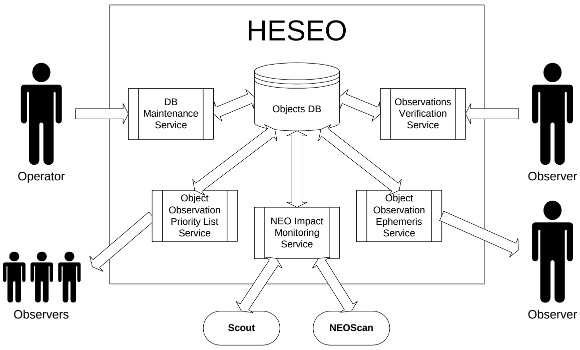

Figure 1. HESEO services architecture diagram

This architecture may also have some external links to other SST databases, in order to maintain the DB information.

5 PROPOSED SERVICE DATABASE

The database of HESEO objects will include the full list of objects known to be orbiting the Earth under the mentioned conditions. A remarkable factor for this service is the goal to include detailed models for the motion of the object in space. This implies that further than the standard propagation models, it is foreseen to use complex models for the solar radiation pressure interaction, possibly linked to rotational information, if available. Due to the uncertainty in the object model, it is considered interesting that this catalogue service considers the concept of having the possibility to host several assumptions on the object model and exerted forces to allow different fits.

In line with the above considerations, the following information will be saved in the database for each object:

- All available measurements. This may come from NEO and/or SST community, and thus, it may have different formats and accuracy [3].
- Object model information

The object information will at least include:

- A list of object identifiers (at least ten fields) to track the multiple denominations that a given object could have
- The initial values of the state vector or the associated orbital elements at a given epoch
- Any parameters characterising its dynamical motion (as SRP parameters)
- The covariance matrix associated to the estimated object and orbit parameters
- Object model, if known, at least dimensions in three main directions
- Any rotation parameters
- The absolute magnitude range

The database will need to be initially constructed form data already available. Initial sources of information for such database are:

- MPC’s Distant Artificial Satellites Observation (DASO) page [5]
- Bill Gray’s Assorted artificial satellite pseudo-MPECs page [6]
- The CelesTrack page [7]
- The Space-track page with TLE data [8]
- Special Perturbations (SP) catalogue, if available. It is not public and only accessible under SSA Data Sharing Agreement with USSTRATCOM, [8]
- Any other catalogue or database maintained by independent systems, as currently there is a number of SST catalogues maintained by public (i.e EU SST) and private institutions. At the time of writing this paper, the contents of none of them are publicly available.

The database will be maintained by means of additional observations of the objects in the database and the addition of newly discovered objects.

6 PROPOSED SERVICE FUNCTIONS

The HESEO Service would need to be provided with the following main basic functions in order to perform the expected goals within the modules to be developed:

- Object orbit propagation function: this shall allow propagating the orbit and covariance of an object with the model parameters available in the database.
- Object orbit determination function: this shall allow fitting the available observations with a minimum residuals orbit and model solution.
- Object ephemeris generation function: this shall allow producing object topocentric

ephemerides at any time, including its uncertainties (with observation coordinates either specified by the user, or taken from the MPC observatory codes list). Ephemeris can be published in orbital data format (i.e. state vectors suitable for computing the telescope pointing, which is the usual approach in the SST observer community) and in RA/DE format (linked to the observer site, and commonly used in the NEO observer community).

The current situation in regards to these services is as follows: object orbit propagation, determination and ephemeris generation is normally done by scientific community in the basis of proprietary tools, and initial state vector of the objects. There is not a dedicated system that allow executing this tasks in a systematic and independent way, allowing any observer to get the initial state vector of these very high altitude (long orbital period) objects.

An example of a system allowing these functions is the ESA SCOOP system. The main objective of the Space COllaborative Observation Platform (SCOOP) is facilitating the organisation of collaborative coordinated observations campaigns among ESA and/or IADC and sensor owners willing to participate voluntarily, in order to allow the observation of interesting events related to the space debris population. It provides three main functionalities (and a number of auxiliary functions); Pass prediction to compute visibility time windows from each sensor, integrating a propagation function; Orbit determination, to compute the orbit which better fits a set of observations; and Correlation, i.e. association of observations provided by the observers to the objects in the SST catalogue (the so-called identification in the NEO field).

Unfortunately, there are some issues that do not allow using SCOOP for the proposed objective of HESEO:

- SCOOP is based on observation campaigns, which are open with a dedicated objective, and require sensor to be registered as participant for each campaign. HESEO would benefit from a running campaign with a more general approach and scope.
- The underlying catalogue for identification/ correlation purposes is currently based on TLE data, and may not include the large orbital period objects which are not maintained in the TLE dataset.
- Propagation Function does not include the propagation of the covariance information, which is of interest to evaluate the capability of sensors to observe an uncertain orbit depending on the Field of View, and thus allowing selecting the most convenient sensor to track the object.

7 PROPOSED SERVICE MODULES

In correspondence to the above identified functions and making use of the database of objects the following modules are proposed:

- *Object Orbit Determination Module* (OODM): this module shall allow an internal operator to perform an accurate orbit determination process on a given object considering any measurements provided by the user. Associated covariance matrix shall also be derived and reported. Object dynamical model shall include typical perturbations plus various types of SRP models (defined by several parameters). This module may incorporate a dedicated function to evaluate the rotation state of the objects in the basis of visual magnitude information.
- *Object Orbit Dispersion Propagation Module* (OODPM): this module shall allow an internal operator to perform an accurate orbit propagation process on a given object considering both state and covariance. Object dynamical model shall include typical perturbations plus various types of SRP models (defined by several parameters). Atmospheric drag would not need to be modelled due to the very high altitude of the expected objects.
- *Population Orbit Determination Module* (PODM): this module shall allow an internal operator to invoke the OODM process over a list of objects and associated observations.
- *Population Orbit Dispersion Propagation Module* (PODPM): this module shall allow an internal operator to invoke the OODPM process over a list of objects, independently on whether there are new observations or not.
- *Object Identification Module* (OIM): this module shall allow an external user to verify whether a set of measurements is compatible with any object in the service database. I can be mentioned that in the SST field, this process is normally denominated ‘correlation’.
- *Object Ephemerides Generation Module* (OEGM): this module shall allow an external user to request observational ephemerides and expected covariance in the plane of the sky from a given observatory or observing point on Earth of an object from the service database and in a given time interval. Ephemeris shall also be provided in orbital state format (TLE or CCSDS OEM format), as this is the usual approach for the SST observers community.
- *NEOCP Identification Module* (NCPIM): this module shall allow an automated processing of the objects appearing in the confirmation pages

of the Scout and NEOScan services in order to identify whether the available measurements are compatible with any of the objects already available in the database. The module shall immediately inform the operators of the result of the process in case the observations are compatible with a database object.

Finally, a number of *Auxiliary modules* (AuxM) shall be developed to allow executing different ancillary tasks. For example, daily download of external data information (as Earth Rotation information, Space Weather data for propagation purposes); registering, updating or removing sensors from the network of observers, etc.

8 SERVICE USERS

The following users are identified for the system:

- Operator: this user is the one executing the Database Maintenance Service (goal #1) and the Object Observation Priority List Service (goal #3), and the one monitoring the automated execution of the NEO Impact Object Verification Service (goal #5)
- Observer: this user is the one requesting the execution of the Observations Verification Service (goal #2) and the Object Observation Ephemerides Service (goal #4)

9 POSSIBLE ADDITIONS

An additional service could be added to the system in order to allow that the residuals after the orbit determination process can be analysed by either internal or external users to try identifying trends justifying the incorporation of additional model parameters. In such case, different fits to the data could be tested to check which one provides smaller residual metric.

10 CONCLUSIONS

We propose in this paper establishing a web-based service to allow observers identify whether their observations are compatible with objects orbiting in high-energy Earth-bound (continuously or periodically) orbits. This service would allow avoiding that such observations are reported to centres, as MPC, that will not process them in their pipeline. Furthermore, those observations, together with refined dynamical model, will be used to keep a sufficiently accurate orbit for those objects. Whenever such accuracy is degraded, the system is foreseen to inform observers to try collecting new measurements that shall allow keeping the orbits within a constrained boundary.

11 REFERENCES

1. Farnocchia, D., Chesley, S.R. & Micheli, M. (2015). Systematic ranging and late warning asteroid impacts. *Icarus* **258**, 18-27.
2. Spoto F. et al. (2018). Short arc orbit determination and imminent impactors in the *Gaia* era. *Astronomy & Astrophysics* **614**, A27.
3. Nomen Torres, J., Sánchez-Ortiz, N., Domínguez-González, R. (2019). From NEO to LEO optical observations and back: Sensors features and observing strategies. In *Proceedings of the 1st ESA NEO and Debris Detection Conference – Exploiting Synergies*, Darmstadt, Germany
4. Micheli, M. et al. (2017). The observing campaign on the deep-space debris WT1190F as a test case for short-warning NEO impacts. *Icarus* **304**, 4-8.
5. Minor Planet Center, *Distant Artificial Satellites Observation Page*: https://minorplanetcenter.net/iau/DASO/DASO.html
6. Gray, B. Assorted artificial satellite pseudo-MPECs: https://www.projectpluto.com/pluto/mpecs/pseudo.htm
7. *CelesTrack Page*, https://celestrak.com/
8. *Space-track.org Page*, https://www.space-track.org/