OBSERVATIONAL ACTIVITIES OF ESA'S NEO TELESCOPE NETWORK ON FAST-MOVING OBJECTS

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ABSTRACT

ESA's Planetary Defence Office operates a network of telescopes with a nearly-global worldwide distribution, with the specific task of responding in near real-time to observing alerts triggered by the discovery of new threatening near-Earth objects.

The network is routinely used to observe very fast-moving targets, such as NEOs during extreme close approaches or imminent impactors. In such cases, the observational circumstances often resemble those of artificial objects in distant Earth orbit, and therefore most of the challenges are also close analogs to those common during SST observations.

Our team has also organized specific campaigns targeting artificial objects in high orbits, and those in unbound orbits during launches or fly-bys. These observations provide us with the ideal testing grounds for our techniques, since they closely replicate the observational peculiarities of a nearby NEO while providing a "ground truth" against which the results can be compared.

In this contribution we will present some of these observational challenges, and how we address them with our observatories and telescopes, with the hope of triggering a fruitful discussion and exchange of strategies between the NEO and the SST communities.

Keywords: NEOs; astrometry; fast moving objects; timing.

1. INTRODUCTION

ESA's Planetary Defence Office is currently organized into three main "pillars" covering the different goals of the Programme. The first such pillar is the *Observational Pillar*, and it manages the various observational assets that the team use to collect observations of NEOs.

Part of the activities focus on the development of new telescopes and observatories (such as the Flyeye telescope). However, in this discussion we mostly focus on the existing network of follow-up facilities that we use to obtain astrometric follow-up observations of high-priority objects, often those known to pose an impact threat to Earth.

2. THE TELESCOPE NETWORK

Discovery survey telescopes, such as those existing today, or the future Flyeye, do not provide follow-up to the targets they discover, unless they happen to reobserve them incidentally.

Over the last decade, the Programme developed a network of observatories dedicated to get follow-up observations, often on the short-notice cadence that is needed for some of these targets.

This need for urgency is essential because nearby objects, often nowadays discovered from the Southwest of the United States (where survey telescopes are located), can often become lost over timescales of less than 12 hours, i.e. the time it takes for the same area of the sky to become visible from continental Europe. It is therefore necessary to have access to telescopes located all over the world, not just in latitude, but also in longitude.

Our network of small quick-reaction telescopes gives us access to such resources, via a variety of forms:

- Direct ESA ownership and control (e.g. ESA's OGS telescope).
- Full control of a telescope made available via contracts (e.g. CAHA Schmidt).
- Rapid response time to external facilities under contract.

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- Institutional agreements (e.g. ESO VLT).
- Scientific collaborations with other teams.
- Traditional science proposals evaluated through the normal time allocation route.
- DDT proposals in case of unforeseen high-profile targets.
- Financial support to external teams operating their observatories.

3. USE OF THE NETWORK

We routinely use the various observational assets provided by our network to obtain various types of observations. The following are some examples of the types of observations and observational challenges our team is currently working on, using the telescopes we have access to.

- Collecting quick-reaction observations for urgent objects (e.g. imminent impactors or fly-bys). Typically, we need to be "on the sky" within minutes to hours.
- Obtaining extended follow-up of faint high-importance objects (e.g. risk list objects, Atiras, Trojans, Interstellar Objects).
- Organizing and/or participating in international campaigns (e.g. IAWN, DART).
- Observing objects in challenging conditions (e.g. low elevation, twilight).
- Experimenting with new observing techniques (e.g. synthetic tracking, non-linear stacking, timing calibration, CMOS sensors).
- Observing artificial objects that might be a source of confusion for NEO follow-up (high Earth orbiting satellites or debris, interplanetary launches or fly-bys).

4. POINTS OF CONTACT WITH SST OBSERVATIONS

Some of the activities and requirements outlined in the previous section present close analogies with challenges that are more typical of SST observations. We outline a few here.

- Fast-moving targets, and therefore trail-fitted astrometry.
- Accuracy of timing and location.
- Need to observe an object from various (and/or specific) regions of the Earth.
- Observing objects that move at fast and variable tracking rates.
- Using techniques that allow production and processing of large datasets.
- Observing under challenging conditions (i.e. twilight and/or low elevation).

In the following subsections of this paper we will briefly discuss some of these observational challenges, and how we address them with our observatories and telescopes.

4.1. Fast movers and trail-fitted astrometry

Some observations, such as the rapid follow-up of imminent impactors, involve very fast moving objects, and result in trailed detections. Extra care must be placed while extracting astrometry, because the detections on the image are often faint and extremely trailed.

In order to be successfully detected, these objects require immediate access to telescopes, and a properly devised observational strategy, often customized for each specific instrument.

Astrometry of the obtained detections is often not trivial, and requires dedicated astrometric techniques involving trail-fitting of an extremely elongated source.

An example of these challenges was given by the imminent impactor 2022 EB5, a small asteroid discovered only a few hours before impact, for which our team worked on the extraction of high-precision trail-fitted astrometry from images obtained by various external observers.

4.2. Astrometry beyond sky coordinates

Obtaining an astrometric measurement does not just mean determining sky coordinates (RA and Dec) of an object.

Two additional factors are extremely important for the case of nearby objects: an accurate timing, and an accurate determination of the observing location.

During the last few years, the NEO astrometry community has realized that timing inaccuracies are often the dominant source of error for high-importance observations of nearby asteroids. Timing accuracies much better than a second, in the past typically reserved to SST observations, are now needed for NEO observations too.

Achieving this timing quality requires a variety of checks: a proper synchronization of the clock is often insufficient, and other technical issues, such as timing the motion of the shutter, or electronic or software delays, need to be identified and accounted for.

The NEO community, under the support of the International Asteroid Warning Network (IAWN), now organizes worldwide observing campaigns dedicated to timing checks [1]. Tools to calibrate the timing, specifically configured for the needs of NEO observers, have also been developed by members of the community (e.g. Bill Gray's tool on the Project Pluto webpage[1]).

At the same time, the Minor Planet Center (MPC) is now thoroughly addressing the long-standing issue of geographical coordinates of observing stations. In the past, entire observatories and mountaintops, often dispersed over kilometers of physical space, were identified by single observatory code, providing insufficient topocentric accuracy for the astrometry of nearby objects. Recently, most professional telescopes have been assigned their own dedicated codes, corresponding to their exact location, and there is now sufficient attention to this issue at all levels of the community.

4.3. Multi-station campaigns for orbit determination

Some observations we perform specifically take advantage of our network of telescopes covering a large longitude span, when coverage is needed over a timespan longer than hours, but shorter than a day. This is especially common with close fly-bys, which only remain easily observable for a few hours.

As an example of this mode of operation, specifically applied on an SST object but with NEO analogies, we carried out a dedicated campaign observing the BepiColombo Earth fly-by in 2020.

The fly-by geometry closely replicated the challenges of an imminent impactor, allowing an ideal test of the capability and accuracy of our network.

The results of this campaign, thoroughly discussed in [2], show that optical observations from multiple stations can provide highly accurate determination of an object's trajectory, fully consistent with ground-based radio tracking.

The campaign also provided us with extremely valuable information and training on how to collect high-precision observations on short notice, with very different telescope facilities.

4.4. Challenging observing conditions

It is unfortunately not unusual that interesting NEO (and SST) targets are only visible when located at low elongation and in bright evening or morning sky. These observations are often challenging for most professional telescopes, with strict altitude constraints.

During the last few years we attempted challenging observations of objects that can only be observed in twilight, such as 2020 XL5, Earth's second known Trojan asteroid. We were able to use various telescope to track it down to an elongation of almost 30 degrees, allowing for an accurate dynamical study of the object [3].

5. CHALLENGES OF ASTROMETRY ON NEARBY OBJECTS

Nearby objects, e.g. high-orbiting satellites, fly-bys of interplanetary hardware, and occasional recaptures of heliocentric objects, provide a critical test for many observational and orbit computing capabilities.

As an example of how to properly observe a challenging nearby object, we performed observations of an object designated as "2020 SO" at the time of discovery, which later turned out to be artificial and identified with the Surveyor 2 Centaur upper stage.

The object, discovered while in Earth orbit after a temporary recapture, had a highly non-linear motion on the sky, caused by parallax effects.

In order to achieve high signal-to-noise ratio detections of such an object, it is necessary to quickly stack hundreds of images, following a curved ephemeris. Modern tools and technologies are essential for this kind of work.

5.1. New technologies

Among these technological advances are two new technologies that are changing the way we obtain astrometry observations today: CMOS sensors and GPUs.

CMOS detectors are imaging sensors with extremely fast download speeds. Thanks to the dramatic reduction of download times, it is now competitive to observe an object with many individual short frames (hundreds to thousands), instead of using longer individual exposures.

At the same time, GPUs, now widespread also on small consumer-level computers, allow us to stack hundreds or thousands of images, such as those produced by CMOS cameras, in a matter of seconds. Furthermore, if the motion of the object is unknown, techniques like synthetic tracking can allow us to test a large parameter space of motion vectors, automatically detecting new objects.

[1] https://projectpluto.com/gps_find.htm

6. CONCLUSIONS

NEO astrometry, when performed on high-priority difficult objects, often presents challenges in common with SST observations. The NEO community is now starting to develop techniques to deal with these issues, often taken from the experience of the SST community: timing and location accuracy are becoming a top priority, challenging geometry of observations are being attempted, and astrometry on trailed objects is becoming more and more common. We are also routinely using SST objects as test targets for our systems, both as timing calibrators and as challenging test cases and ground truths to simulate fly-bys of natural NEOs.

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