Automatic Detection of Asteroids and Meteoroids - A Wide Field Survey

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Abstract. We propose a low-cost robotic optical survey aimed at 1 – 300 m Near Earth Objects (NEO) based on four state-of-the-art telescopes having extremely wide field of view. The small Near-Earth Asteroids (NEA) represent a potential risk but also easily accessible space resources for future robotic or human space in-situ exploration, or commercial activities. The survey system will be optimized for the detection of fast moving - trailed - asteroids, space debris and will provide real-time alert notifications. The expected cost of the system including 1-year development and 2-year operation is 1,000,000 EUR. The successful demonstration of the system will promote cost-effective ADAM-WFS (Automatic Detection of Asteroids and Meteoroids - A Wide Field Survey) systems to be built around the world.

Keywords. Survey, asteroids, meteoroids, space debris

1. Introduction

It has been more than 200 years since the first asteroid, now defined as a dwarf planet, Ceres, was discovered. Progressive development of instrumentation and techniques in astronomy revealed the existence of the asteroid main belt and other dynamically stable and unstable populations of minor bodies throughout the Solar System including NEAs encountering the Earth. In 2013, 10,000th NEO was discovered by the Pan-STARRS survey (Kaiser et al. 2010). Although, the number of NEA has been rising rapidly within the last decade due to the dedicated asteroid surveys such as Spacewatch (Gehrels et al. 1986), LINEAR (Stokes et al. 2000), LONEOS (Koehn & Bowell 1999), NEAT (Pravdo et al. 1999), space-based NEOWISE (Wright et al. 2010) or ongoing next generation surveys such as Catalina Sky Survey (Larson et al. 1998) and Pan-STARRS, there is a large uncertainty in the population count and orbital properties of small NEA within the size range of 1 – 300 m are not understood well. In previous studies (Rabinowitz et al. 1994, Bottke et al. 2002, and Stuart and Binzel 2004) the population count of 10 m size NEA differed more than one order of magnitude. Although, NEOWISE mission supposedly derived accurate diameters of asteroids by the thermal modeling and assumed that there are less small NEAs that it was predicted before (Mainzer et al. 2013), recent studies by Harris (2008) and Brown et al. (2013), based on recent ground-based discoveries and the fall of the Chelyabinsk meteoroid in 2013, suggest a much higher count. Other previous studies also indicated that small NEA population could be enhanced by tidal disruption of rubble-pile asteroids during close approaches to the Earth, such as a theory about the common origin of Příbram and Neuschwanstein meteorites coming from heterogeneous stream of meteoroids (Spurný et al. 2003) when the frequency of rubble-pile asteroids disruption were estimated (Tóth et al. 2011). Similarly in subsequent studies, Schumová et al. 2012, Schumová et al. 2014 analysed the creation mechanisms.
of NEA’s families and showed supporting evidence for mentioned theories. Moreover, the meteoroid streams may contain large particles from break-ups and enriched population of small NEOs (Porubčan et al. (1992), Rudawska et al. (2012), Babadzhanov et al. (2013)).

In the past (Tóth & Kornoš (2002), Tóth & Kornoš (2003), Vereš et al. (2006)), we proposed a simple low-cost survey for discovering population of small asteroids flying-by within one lunar distance from the Earth. In this paper we introduce an advanced and more sophisticated, yet low cost concept that will characterize the population of small NEA that from the large part is undetectable by current telescopic systems.

2. Concept

Automatic Detection of Asteroids and Meteoroids - A Wide Field Survey (ADAM-WFS) will consist of 4 identical wide-field (Terebizh 2011) astrographs (Houghton-Terebizh D=300 mm, f/1.44) on a fast-track mount with high-precision guiding (Fig. 1). Each telescope will be equipped with a large-scale single chip CCD camera (4096x4096 pix) providing a total FOV of almost 100 square degrees. The predicted limiting magnitude with the wide-band optical filter will be +17.5 mag. at S/N=5.0 with 30 sec exposures and a pixel scale of 4.36 arcsec/pix. This configuration is able to survey almost an entire sky visible from a specified location in 3 visits per night (Fig. 2), with the rapid image processing providing moving targets in almost a real-time. We will use the Moving Object Processing System (MOPS, Denneau et al. (2007)) that has been utilized by the Pan-STARRS and ATLAS (Tonry 2011). Stationary transients will be processed during the daytime. We propose to build the system at an existing observatory with a dedicated 60-80 cm follow-up telescope and existing infrastructure.

2.1. Advantages of ADAM-WFS

The survey budget is considered low-cost compared to the existing or planned all-sky surveys that focus on deeper limiting magnitude, or space-based observatories, which are up to two orders of magnitude more expensive. In contrast to existing or planned deep surveys with narrower fields of view, our survey will cover entire visible night sky few times per night. In spite of its lower limiting magnitude, large pixels would decrease the effects of trailing loss for fast moving targets. Thus, ADAM-WFS will detect more fast moving objects than any survey equipped with telescopes of similar size.

Usually, the development of a new survey takes years due to the new hardware and software development and methods to be implemented. Our goal is to avoid reinventing the wheel.
and use existing routines for image processing, moving object processing, hardware, mount and optics to speed-up the delivery of the complete system and cut down the cost. We will also count on a compact team of astronomers and engineers with work and science experience on existing surveys (Pan-STARRS) or surveys under the development (ATLAS), on full-time and sub-contracts.

Significant advantage is the existing infrastructure that will serve the prototype for the development and operation. It will be built on existing observatory – Astronomical and Geophysical Observatory of the Comenius University, Modra, Slovakia (AGO Modra) – that contains workshop, complete infrastructure and nonstop technical support. Future deployment of ADAM-WFS systems is also strongly encouraged on existing observatories (e.g. Canary Islands, South Africa). New generation surveys are often focused on multiple tasks (e.g. Pan-STARRS). Our survey will be optimized towards small NEA detection with byproducts available for additional science.

2.2. Targets of the survey

The main target of the survey is discovery and characterization of small NEA and other close-approaching populations. The survey will search for potential Earth im-
Impactors of small and intermediate diameters (1–100 m) and pre-entry detections of bright bolides. The all-sky coverage and optimization toward high angular rate of motion would make the system a good detector for monitoring, characterization and discovery of space debris. This combination of survey properties will also benefit the detection of telescopic meteors as well. Because the limiting magnitude will not be a competition for multi-meter apertures and space based telescopes, it will serve the photometry of objects that are too bright and saturated for next generation surveys, such as bright main belt asteroids. The extremely low focal ratio and large light gain of the aperture would help discovery of active asteroids (Jewitt 2012), especially at low solar elongations. The important feature of the project will be the accessibility of the data - the database will be available for external scientists to mine additional resources for science byproducts, such as variable stars, novae, supernova, lensing events, gamma-ray bursts.

3. Expected outcomes

We simulated a one-year ADAM-WFS survey based at AGO Modra Observatory, by using MOPS with the realistic pointings, avoiding Moon and using orbits of large MB asteroids, synthetic orbits of asteroids that will approach the Earth within 10 lunar distances based on real asteroids and Earth impacting asteroids (Chesley and Spahr 2004; Denneau et al. 2013). The apparent rate of motion of asteroids at the closest distance and phase effect of asteroids near the Earth are shown in Fig. 3. Figure 4 shows the efficiency of the proposed system in discovering Earth impacting asteroids and close approachers as the function of diameter and the duration of the survey. Depending on the population model, this system will be able to discover 30 – 120 NEAs with $D > 10$ m within 10 lunar distances per year and a comparable number of smaller asteroids with diameter $D < 10$ m. Figure 5 shows the number of known large main belt asteroids that will be discovered within one year survey. Due to the cadence of the survey we will obtain $\sim 650$ light curves of bright main belt asteroids every year, suitable especially for slow rotators detection. We also performed the simulation of space debris detection by using the SPACE-TRACK debris catalog. The simulation detected 350 - 550 space debris particles per night (Fig. 6).
4. Conclusion

The project of ADAM-WFS represents a new way of observation and exploration of the small NEO population in the close vicinity of the Earth. The project will fill up the current gap in our knowledge of small solar system bodies between the bolide-sized objects observed in the atmosphere and the large asteroids and comets observed telescopically. Identical telescopes can be installed all over the world or cooperate with other similar projects like ATLAS to increase the sky coverage and not depend on the daylight cycle to search for small NEOs.

![Figure 5](image1.png)  
**Figure 5.** Survey efficiency of large main belt asteroids.

![Figure 6](image2.png)  
**Figure 6.** Number of detection of space debris per night by ADAM-WFS based on space-track data. The number of detections per particle per night ($N > 0$, at least one detection; $N > 1$, two and more detections; $N > 2$, more than two detections). Variations in the rates are produced by the combination of weather conditions and Earth’s shadow vs. field of view geometry.
Earth impactors and optical transient events like variable stars, novae or supernovae. Data gathered during the operation will provide terabytes of images and database entries for years of research and data mining. Naturally, additional coordinated follow-up observations will be needed to complete the orbital and physical determination of newly found asteroids.

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