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INASAN NEO finder (INF) project

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Abstract. The INF (INASAN Near Earth Objects Finder) project is a dedicated network of robotic telescopes to detect 10 m asteroids coming to the near Earth Space. The main features of the project are a short cadence time (1 h) of all-sky survey, a moderate limiting magnitude (19^m) without filters and a possibility of carrying out the additional scientific program. The INF multiaperture telescope consists of 8 VT-78d telescopes on a fast mount. The VT-78d telescope provides a unique combination of parameters: the aperture (250 mm), the fast focal ratio f/1.58, the field of view (10 deg diameter, 78.5 deg^2) and the D_{80} image quality (5 arcsec). The INF total field of view is 574 deg^2 (298 Mpixels) with a 5.2 arcsec pixel^{-1} scale. According to our estimates the INF will discover about 7330 NEOs of 10 m size in 5 years in the case of everyday operation (8 hour per night).

Key words: Near Earth Objects – Wide field telescopes

1. Introduction

After the Chelyabinsk event it is evident that not only large asteroids but also >10 m size bodies pose a substantial hazard (Shustov et al., 2017; Shugarov et al., 2018). The number of Neart-Earth objects with sizes more than 20-m is estimated at 7.7 million (Emel'yanenko & Naroenkov, 2015).

The current programs of ground-based surveys, such as the Catalina Sky Survey, Pan-STARRS and ZTF, typically focused on 100 m class objects. Up to date it is impossible to make a complete catalogue to predict a collision of decameter size bodies with the Earth in advance. The only way to protect the Earth against such bodies and/or to mitigate is to detect NEOs in the near-Earth Space and to warn about a possible collision.

The Asteroid Terrestrial-Impact Last Alert System (ATLAS) is an example of a successful system designed to detect 30-50 m impactors about one week in advance (Tonry et al., 2018).

INASAN proposes to build a dedicated network of robotic telescopes to detect 10 m class NEOs entering the near-Earth space. Several hours of warning time provided by the INF project is sufficient to decrease risks, the larger warning time implies a dramatically larger cost of the system.

The INF project main features are a short cadence time (1 h) of all-sky survey and a moderate limiting magnitude (19^m) without filters, with the possibility of carrying out the additional scientific program.

The main advantage of INF over other similar projects, such as SuperWASP (Pollacco et al., 2006), ADAM-WFS (Vereš et al., 2014) and GWAC (Claret, 2018), is a better combination of the field of view, sensitivity and the spatial resolution (pixel scale).

Table 1. INF comparison with other similar projects.

Parameter	INF	SuperWASP	ADAM-WFS	GWAC
Telescope aperture, mm	250	200	300	180
Pixel format	6k × 6k	2k × 2k	4k × 4k	4k × 4k
Field of view, deg^2	574	482	100	5000
Field of view of single tube, deg^2	72	60	25	164
Pixel scale, arcsec pixel^{-1}	5.2	13.7	4.36	11.2
All-sky servey	1 h @ 19^m	40 min @ 15^m	2 h @ 17.5^m	2 min @ 16^m

Besides NEOs detection, INF has potential to work on other scientific programs such as gravitational wave events electromagnetic counterparts, variable stars, supernovae, gamma ray bursts and monitoring of space debris.

In this paper we describes the optical parameters of the system and system performance. Data processing software, which is a very important part of such project, is beyond the scope of this article.

2. INF architecture

The INF multiaperture telescope (Fig. 1) consists of eight VT-78d telescopes at one fast-track mount ASA DDM160. INF multiaperture telescope main parameters are presented in Table 1.

Table 2. INF main parameters.

Parameter (8x telescopes)	Value
Telescope aperture	250 mm
Field of view	17.6 × 35.2
	574 deg^2
Pixel format	12k × 24k
Number of pixels	298 Mpixel
Pixel scale	5.2 arcsec pixel^{-1}
Readout time	<1 s
All sky @ 10 s exposure	10 min @ 18.3^m
All sky @ 30 s exposure	20 min @ 18.9^m
All sky @ 100 s exposure	1 h @ 19.4^m

Figure 1. INF multiaperture telescope: 8 x VT-78d's on the ASA DDM160 mount.

For fast repointing INF will be installed in a "shell type" dome. To provide 24 h operation and to detect NEOs coming from 2π sr (night sky), several INF multiaperture telescopes are required to be installed in the northern and southern hemispheres at sites with low sky background.

It is possible to put a filter change mechanism with one specific filter for each telescope. All telescopes can be aligned by a special mechanism to look at one field in order to perform multicolor photometry or improve telescope sensitivity (20.4^m for 100 s exposure).

For specific scientific tasks (Beskin et al., 2010) INF can be used for high time resolution photometry with a frame rate up to 44 Hz.

2.1. VT-78D wide field telescope

VT-78d telescope (Table 3) is a new generation (Terebizh, 2016) wide field telescope designed by V. Terebizh (INASAN patent 162010 (RU)). VT-78d optics consists of simple optical elements with all spherical surfaces and simple types of glasses.

The telescope provides a unique combination of aperture (250 mm), field of view (10 deg) and D_{80} image quality (5 arcsec).

The optical quality throughout the field of view allows us to use a 6k $\times$ 6k detector with small pixel instead of a 4k $\times$ 4k one, which are commonly used for similar projects. The typical FWHM is expected at the level of one pixel over the whole field of view of 10 deg. The other benefit of the 6k $\times$ 6k detector is improvement in the pixel background noise, which is the main limitation factor for such a wide field system with a long (up to 100 s) exposure time.

Table 3. VT-78d main optical parameters.

Parameter	Value
Entrance pupil diameter	250 mm
Effective diameter	212 mm
Effective focal length	395 mm
F-ratio	F/1.58
Field of view angular diameter	10 deg
Field of view linear diameter	69.5 mm
Scale	1.915 μm arcsec^{-1}
Spectral range	450-850 nm
D_{80} in integral light, center-edge	8-10 μm, 4-5 arcsec
Maximum distortion at 550 nm	0.45 %

The telescope limiting magnitude vs exposure time for a non-moving object is shown in Fig. 2. Calculation was done using the detector with 90 % quantum efficiency, without filters, seeing of 1.5 arcsec and sky background of 20.5^m arcsec^{-2}. The main limitation factor for a long (up to 100 s) exposure time are the sky background and proper motion of the object. For moderate weather conditions and for a fast moving object the limiting magnitude will be lower.

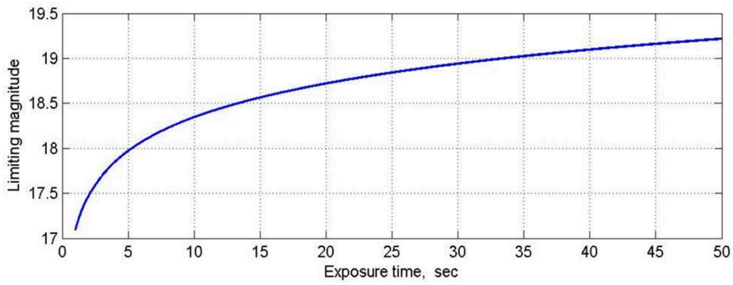

Figure 2. VT-78d limiting magnitude (SNR = 7) vs exposure time.

The telescope was designed to be used with a modern scientific CMOS GSENSE 6060BSI (6k×6k, 61×61 mm) detector. The CMOS has a rolling shutter with global reset architecture, provides up to a 44 Hz frame rate, 4.6 e- rms noise, 14 bit digitization. The back illuminated version has the peak quantum efficiency of 95%.

2.2. INF system performance

The position of INF on a survey merit diagram is shown in Fig. 3. The ideal system capable of detecting 10 m class NEOs should have:

– short cadence time (< 1 h);

– limiting magnitude of 19^m and fainter to detect 10 m NEOs at a reasonable distance;

– reasonable angular resolution of the telescope to prevent contamination.

INF seems to be an efficient instrument to detect 10 m class NEOs. The ATLAS project is optimized for detection of 50 m class NEOs with a cadence time of about 1 day.

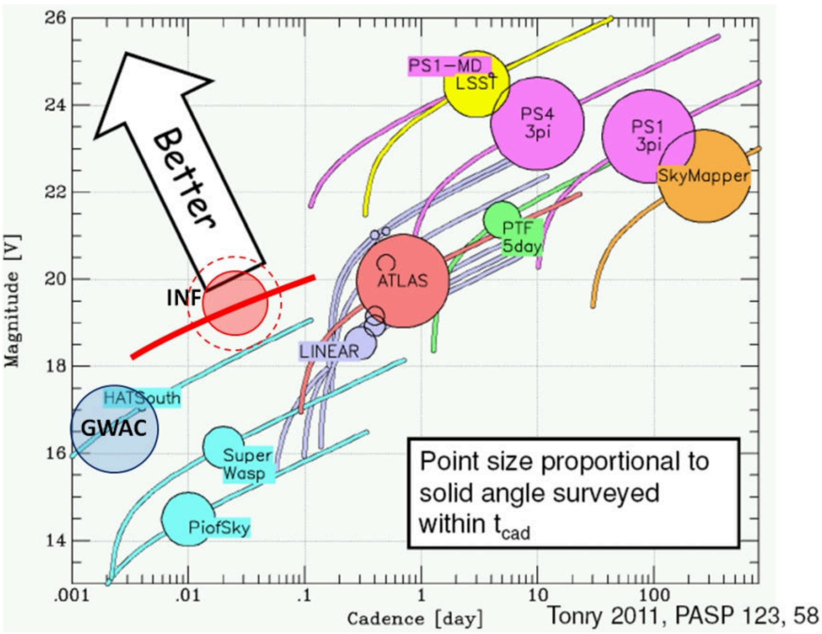

Figure 3. INF on the survey merit diagram (Tonry, 2011).

To calculate visibility zones of a NEO, the following parameters should be taken into account (Shugarov, 2013):

– the size and albedo of the NEO, the phase angle and the distance to the Sun and the observer;

– the main characteristics of a telescope and a detector;

– the background illumination, i.e., zodiacal light and scattered light in the telescope;

– exposure time.

To determine the NEO visibility zone, the criterion of a significant signal to noise ratio (SNR) was used. The significance is determined by a specific task. To perform a reliable detection and to take into account the INF's moderate pixel scale, we suggest to use the criteria SNR > 9.

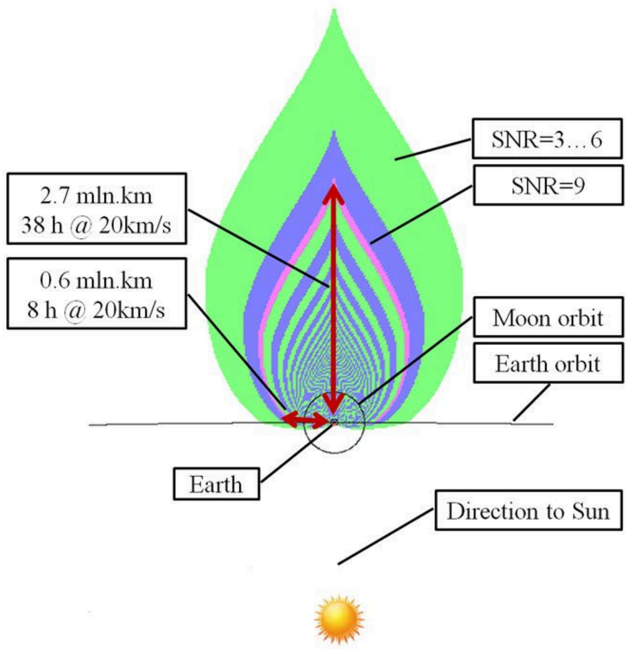

Figure 4. INF visibility zone for 10 m NEOs with 100 s exposure.

In Fig. 4 the visibility zone for a 10 m NEO with 0.15 albedo for 100 s exposure time is shown. Isophote bands of constant SNR are shown with a step of 3 units. A separate pink isophote is given for SNR $= 9$ which corresponds to a reliable detection. The INF is practically unable to operate at the day-time hemisphere because of the phase angle and background light. The sharp peak in the detection distance around the opposite direction to the Sun is due to a micro reflectivity effect that is typical for asteroids.

For 10 m class bodies the INF will provide a visibility zone of 0.6-2.7 million km from the Earth. The world wide network of INF telescopes can provide a warning time of 6-30 h and possibility to detect a good share ($\sim$80%) of 10 m class NEOs coming from the night sky.

The discovery rate for the INF project was estimated using the NEA population model by Granvik, Morbidelli and Bottke. According to our estimates the INF will discover $\sim$7330 NEOs in 5 years in the case of everyday operation

(8 hour per night) with a limiting magnitude of 19.7^m. A model distribution of discovered NEOs on the sky is shown in Fig. 5.

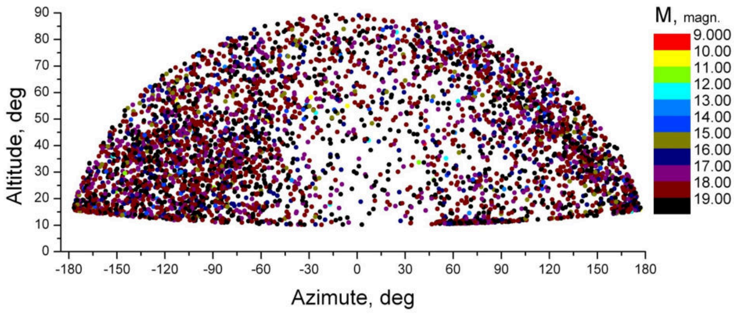

Figure 5. Distribution of possible near Earth asteroids in the (Az-Alt) plane that could be detected by INF.

2.3. INF prototype

INASAN is finishing the construction of a prototype of the INF multiaperture telescope. The prototype consists of 2 identical wide-field telescopes equipped with 4k×4k CCD cameras on the fast-track mount. First light is expected in 2019. The INF prototype consists of:

– 2 VT-78d telescopes, 2 FLI ML16803 CCD cameras;

– 2 FLI Atlas focusers, ASA DDM85PRO mount;

– ScopeDome 3m full robotic dome;

– control computer and equipment;

– observation planning software;

– data processing software.

3. Conclusion

The INF project combines sensitivity and survey efficiency. According to our calculations today it is one of the most efficient projects to detect 10 m class NEOs with a warning time of 6-30 h.

Combination of the survey rate (one sky per hour), limiting magnitude (19^m), possibility of multicolor photometry and fast photometry makes the INF project suitable for many scientific programs. The first light of the INF prototype (2x tubes) is expected in 2019 at the Zvenigorod observatory of INASAN.

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