ISON'S SUB-NETWORK OF SMALL APERTURE TELESCOPES FOR OBSERVATIONS OF NEOS, SPACE DEBRIS AND METEORS

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ABSTRACT

ISON (International Scientific Optical Network) is one of the world-wide largest cooperations of observatories specialized in observations of satellites, space debris and minor bodies of the Solar System. Every year there is a considerable number of bright NEOs. To study this category of NEOs ISON plans to organize a broad sub-network of over 25 telescopes with apertures of 22–25 cm which are primarily used for observations of satellites and space debris. The objective of this endevour is to guarantee observation results during the short flyby period of a NEO. The results of preliminary test observations have shown that these telescopes fully meet the task needs. At the ISON-Castelgrande Observatory a pilot project is in preparation for optical and radio observations of fireballs and meteor showers.

1 INTRODUCTION

ISON (International Scientific Optical Network) is one of the world-wide largest cooperations of observatories specialized in observations of satellites, space debris and minor bodies of the Solar System [1, 2]. Tens of telescopes with different aperture sizes ranging from 10 to 100 cm are successfully involved in ISON (Fig. 1) for appropriate scopes of work. Every year there is a considerable number of bright NEOs (sometimes reaching up to the 12th magnitude). On the basis of our acquired observation experience we propose to use small aperture telescopes to study this category of NEOs, thus broadening their spectrum of observation targets, yielding qualitative and valuable scientific results and increasing the effectiveness and universality of their use through combination of different observation types.

2 SUB-NETWORK

ISON plans to organize a broad sub-network of over 25 telescopes with apertures of 22-25 cm which are primarily used for observations of artificial satellites and space debris in survey and/or tracking mode. A dedicated asteroid analysis center at the Keldysh Institute of Applied Mathematics (KIAM) of Russian Academy of Sciences in Moscow, which coordinates ISON, will (1) regularly select appropriate observation targets out of all discovered NEOs, (2) schedule observations, and (3) deliver observation schedules to the participating observatories. The observatories will (1) conduct observations, (2) do image processing and photometric reduction, and (3) provide obtained data to the collaborating team at the Institute of Astronomy of Kharkiv National University (Ukraine) for deeper analysis and interpretation.

3 SOFTWARE

Custom-built software such as FORTE [3] and KDS will be used for telescope control. Image processing, especially for observations of satellites and space debris, will be done with the software package APEX [3]. In some cases (especially when observation target will be located in a star-crouded field when star subtraction could become crucial in image processing) the MPO Canopus software will be used for the photometry of asteroids.

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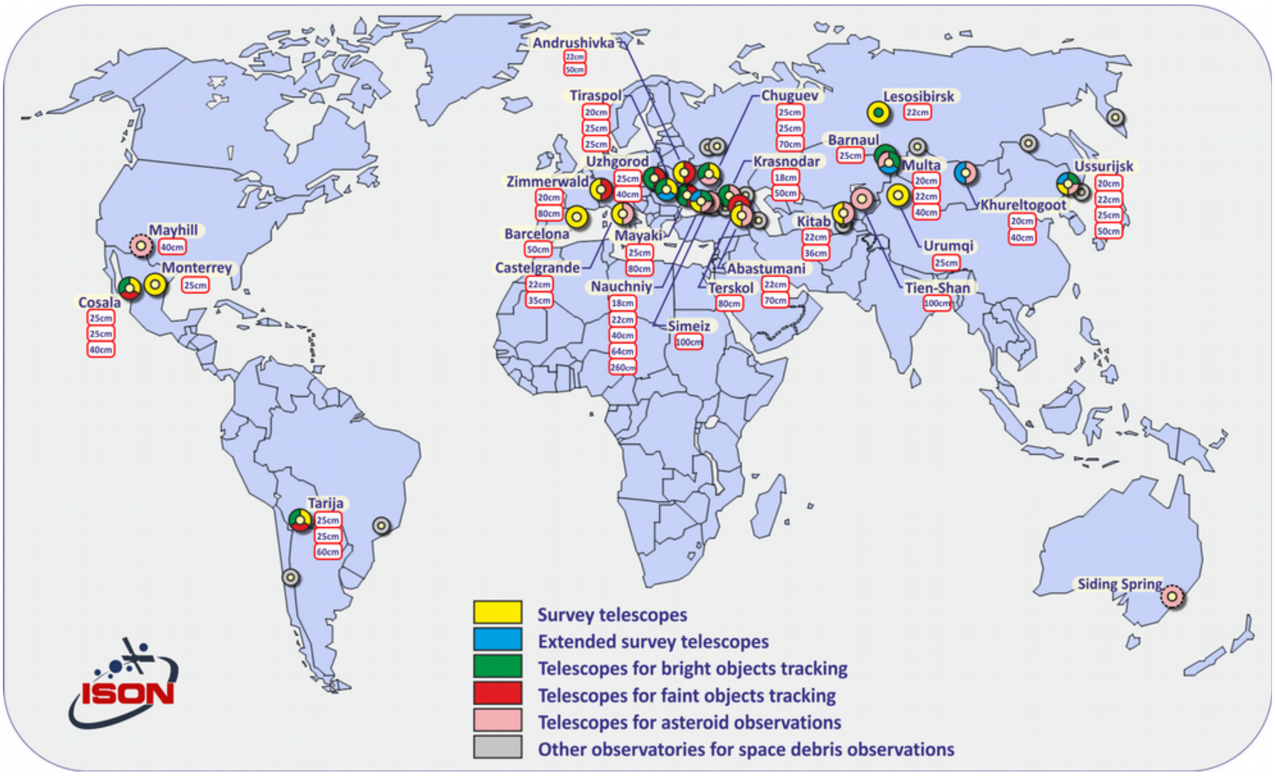

Figure 1. ISON by the end of 2018. Locations of observatories and telescope apertures.

3.1 FORTE

The software package FORTE (Facility for Operating Robotic Telescopes) can be used both in command line mode and through a graphical user interface (GUI) to control all instruments of an observatory. It is mainly written in Python which among other features provides: 1) running own scripts which can use the complete set of FORTE and Python commands, 2) very powerful and flexible modularity allowing to incorporate new own modules and to use third party freeware. Thus, FORTE takes advantage of using well-known software packages such as NumPy, SciPy and AstroPy. Not only common control tasks can be run through FORTE, but also some important routines can be easily accomplished automatically, such as acquisition of sky flats, auto-focusing or telescope alignment. Finally, FORTE offers the possibility to perform fully automated observations on the basis of scripts with a custom format; the observation targets in the script can automatically be sorted in time-slots more appropriate for observation; also, FORTE can monitor any changes in the script during the observation and immediately adjust the running observation schedule; apart from that FORTE has a priority system for observation tasks which gives the user larger flexibility in his observation schedule; these features taken together also make possible automated and unattended alert observations induced by a trigger event (with an option to stop the running observation and to resume it after the alert observation is finished). FORTE will be primarily used on controlling computers with the operating system Linux Ubuntu.

3.2 KDS

To give observatory operators the freedom of choice to use Windows (XP or higher) as the operating system on controlling computers, the KDS software suite written in C# can be used for automated control of robotic observatories. The main window of the KDS GUI gives access to the observatory device management, visual control of current device parameters, and the observation task scheduler. The scheduler works either in an automated linear or in a manual mode (a hybrid system of the automated linear and dynamical modes is currently in development, it will allow rapid response observations triggered by an incoming alert and started within tens of seconds); supported are schedules in the RTML format (compatibility with the APC Scheduler) and the ObjectList format implemented in FORTE; the schedule can be loaded either locally through the GUI or remotely through a cloud service or a socket connection. KDS uses the open ASCOM protocol to control the telescope mount and optical instruments (CCD camera, focuser and filter-wheel); in the case of FLI devices also their native drivers can be used. The built-in automated focusing system with the optional manual fine-tuning can attain the desired focus quality within 40 to 60 seconds which is comparable to the FocusMax software tool. KDS also provides automated telescope alignment assisted by local astrometric image reduction with either PinPoint or Astrometry.NET tools. Finally, to keep the track of the work-flow the operater can get the logging information uploaded to an FTP server or receive specific event messages by email.

3.3 APEX

Acquired observation images are processed with the Python-written software package APEX runnable both in command line and through a GUI, both on Linux and on Windows machines. It is a fully developed and configurable for any observatory setup pipe-line solution which provides all image processing either in separate stages or in an automated sequence, the major of them are: 1) full image calibration, 2) astrometric and photometric reduction using star catalogues with user-defined priorities (supported among others are Tyho-2, UCAC 5, 2MASS, USNO B1.0, XPM and APASS DR9), 3) moving object detection/identification and calculation of object ephemerides using orbit catalogues (given as TLE or in a custom format), 4) quality check of measurement accuracy (residuals), and 5) visualization of data such as light-curve plotting or creation of object centered animations. Image processing can be done either already during the observation with the APEX monitor script, or at any later time. If a moving object in images cannot be detected and measured automatically for any reason, it is also possible to mark it manually and then to process the images. Images with either point-like or trailed star morphology can be successfully reduced by APEX. The package provides scripts specifically dedicated and tweaked for processing of satellite, space debris and asteroid observations. The processing results can be simultaneously output in different report formats which are either human readable or can be easily parsed by other software for further usage, e.g. the astrometry format used at the Minor Planet Center.

4 OBSERVATIONS

Preliminary tests and real-life scientific observations have already been successfully conducted in at least four ISON observatories.

4.1 Barnaul

On October 7th, 2015 a 25-cm telescope TAL-250 at the ISON-Barnaul Observatory (Altai region, Russia) was successfully involved in a multi-telescope campaign of photometric observation of the potentially hazardous near-Earth asteroid 2015 FS332 (Apollo family) when it was brighter than 14 mag, located at the phase angle about 28.0 degrees (almost the minimum phase angle during that flyby) and at the distance of about 0.06 AU from the Earth, just a couple of days after its closest approach to the Earth on October 5th. The telescope was equipped with a CCD camera Apogee Alta U8300, the observation was performed without a filter. A series of 198 obtained images (FOV 41×31 arcmin) with 30 s exposure time covered a long time range from 16:35:34 to 23:09:11 UT, this allowed to get a substantial amount of data to create the light-curve more than twice spanning the rotation period of ~2.4 hours (Fig. 2). [4] Currently, the ISON-Barnaul Observatory is in the process of obtaining the MPC observatory code.

4.2 Uzhgorod

On May 23rd, 2016 a 25-cm telescope BRC-250 at the ISON-Uzhgorod Observatory (MPC observatory code K99; Ukraine) was successfully engaged in a multi-telescope campaign of photometric observations of long-period and low-amplitude asteroids. The observation target was the main-belt asteroid (995) Sternberga while it was 13.8 mag bright. The telescope was equipped with a CCD camera Apogee Alta U9 without a filter-wheel. Obtained images with 40 s exposure time contributed to the finding of the 11.198 ± 0.002 h long rotation period (Fig. 3). [5] From 2016 to 2018 a couple of dozen of other main-belt asteroids were photometrically observed as well. [6]

On July 9th, 2017 the same telescope had successfully taken part in a multi-telescope observation campaign to test a new method of immediate detection of asteroids with near-zero apparent motion. Its observation target was the Amor family near-Earth asteroid (1980) Tezcatlipoca with brightness of 15.8 mag. Exposure time of 30 s was used for the observation. Despite the 99% Moon phase the used setup confirmed the efficiency of the applied method. [7]

4.3 Ussuriysk

In January-February 2015 a 25-cm telescope GAS-250 at the ISON-Ussuriysk Observatory (MPC observatory

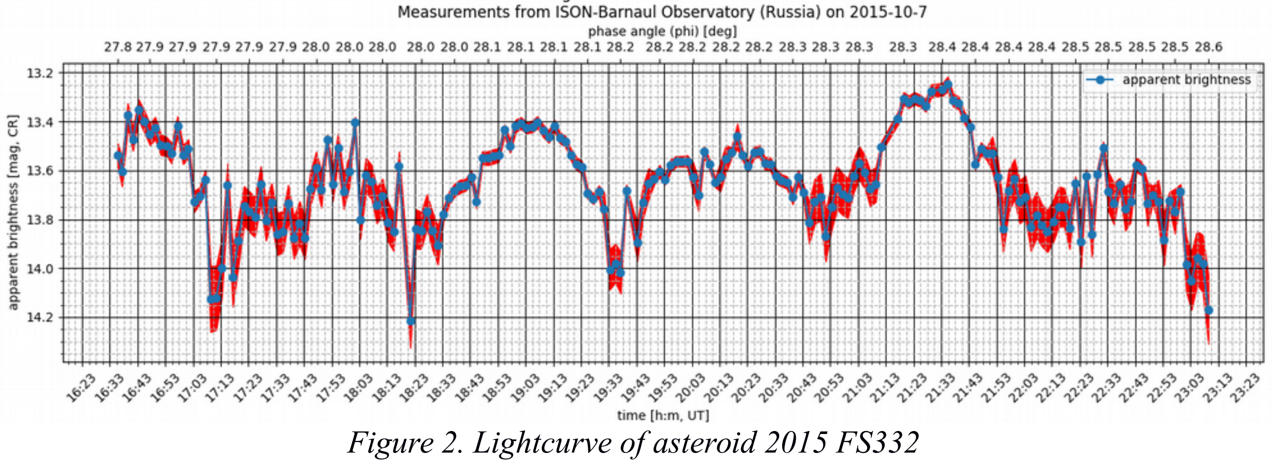

Figure 2. Lightcurve of asteroid 2015 FS332

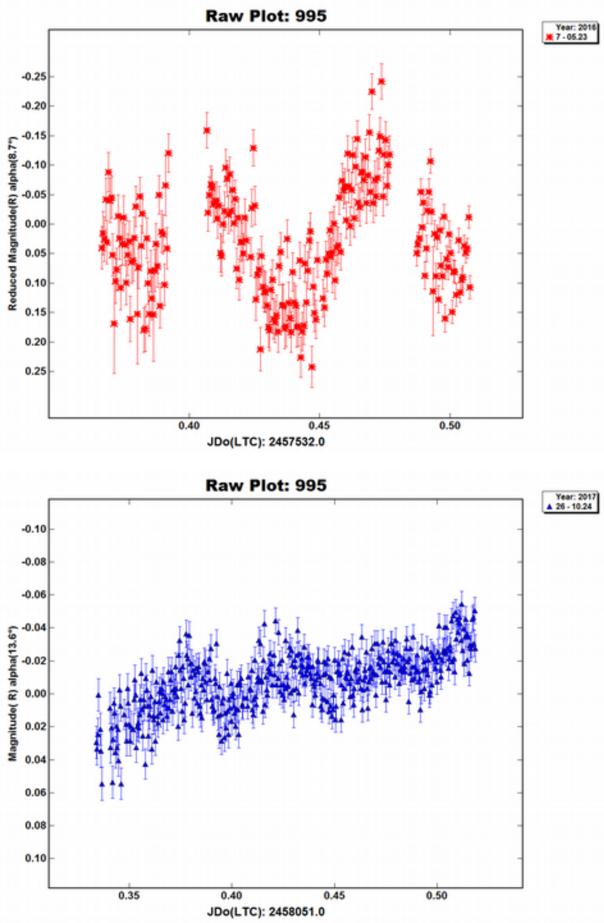

Figure 3. Two lightcurve fragments of asteroid (995) Sternberga.

code C15; Far East region, Russia) had successfully played an important role in a multi-telescope campaign of baseline observations of a near-Earth asteroid (357439) 2004 BL86. [8] Similar observations were carried out for two potentially hazardous near-Earth asteroids – 2014 JO25 from April 18th to 25th, 2017 and (418094) 2007 WV4 from July 1st to 5th, 2017. [9] The results proved the possibility to construct precise orbits

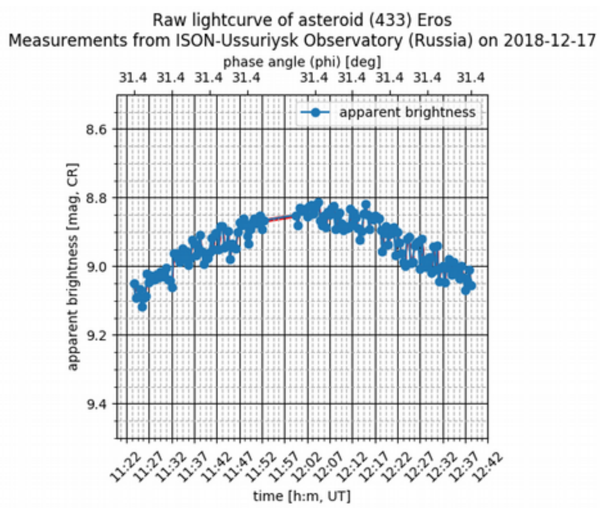

Figure 4. Lightcurve of asteroid (433) Eros.

using short (1-2 hours) observation arches. From October 20th to 31st, 2015 the telescope collaborated in photometric observations of the near-Earth asteroid 2015 TB145. [4]

Also, a 22-cm telescope ORI-22 is in use at the observatory for polarimetric observations of NEOs. Thus, the near-Earth asteroid (3200) Phaethon was observed on December 14th, 16th and 17th, 2017 at large phase angles to study its Umov effect. About 10 potential observation targets are planned for the next two years. [10, 11] Asteroids 2017 VR12, (39) Laetitia, (88) Thisbe and (95) Arethusa were photometrically observed during 2018.

4.4 Castelgrande

A 22-cm telescope ORI-22 at the ISON-Castelgrande Observatory (MPC Observatory code L28; South Italy) started its regular observations of satellites and space debris in October 2017. [12, 13] First attempts to do unfiltered photometry of artificial space objects were undertaken for the failed geostationary satellite Angosat-1 (NORAD 43087) in January 2018, shortly after its launch on December 27th, 2017; immediate results showed the tumbling state of the satellite; observations continued also in April 2018. The quality of the obtained light-curve (Fig. 5) was comparable even in small details to that of a 60-cm Zeiss-600 telescope (Fig. 6) in Arkhyz which happened to observe the same satellite at the same time on one of the nights. Since then, light-curves of more than 30 active and inactive satellites and space debris in GEO or HEO domain have been obtained. In the case of the failed GEO satellite Comets (NORAD 25175) the rotation period of ~600 seconds could be confirmed (Fig. 7).

After receiving the MPC observatory code on June 24th, 2018 the telescope was used since September 2018 for follow-up observations of newly discovered NEAs and comets with brightness down to 17 mag, which are published on the NEOCP and PCCP pages of the Minor Planet Center's website. In total, astrometric observations of L28 have been published in 10 Minor Planet Electronic Circulars (MPEC), two of them for the visually discovered comet C/2018 V1 (Machholz-Fujikawa-Iwamoto); a few of the objects reported on the NEOCP were not confirmed which was promptly messaged to the dedicated NEOCP Followup Reports page of the MPC website. Taking into account the very large field of view of the telescope (4.1×4.1 deg), it is perfect for search of bright yet unconfirmed objects with unprecise orbits.

During the fall of 2018 astrometric observations of Distant Artificial Space Objects (DASO) have been conducted and the measurements have been submitted to the MPC; the observed objects were Spektr-R (NORAD 37755) and Delta 4 R/B (NORAD 36109); at the time of writing of this paper there was no DASO Circular published yet to refer to the measurements; observations of other targets listed on the DASO page of the MPC's website are planned.

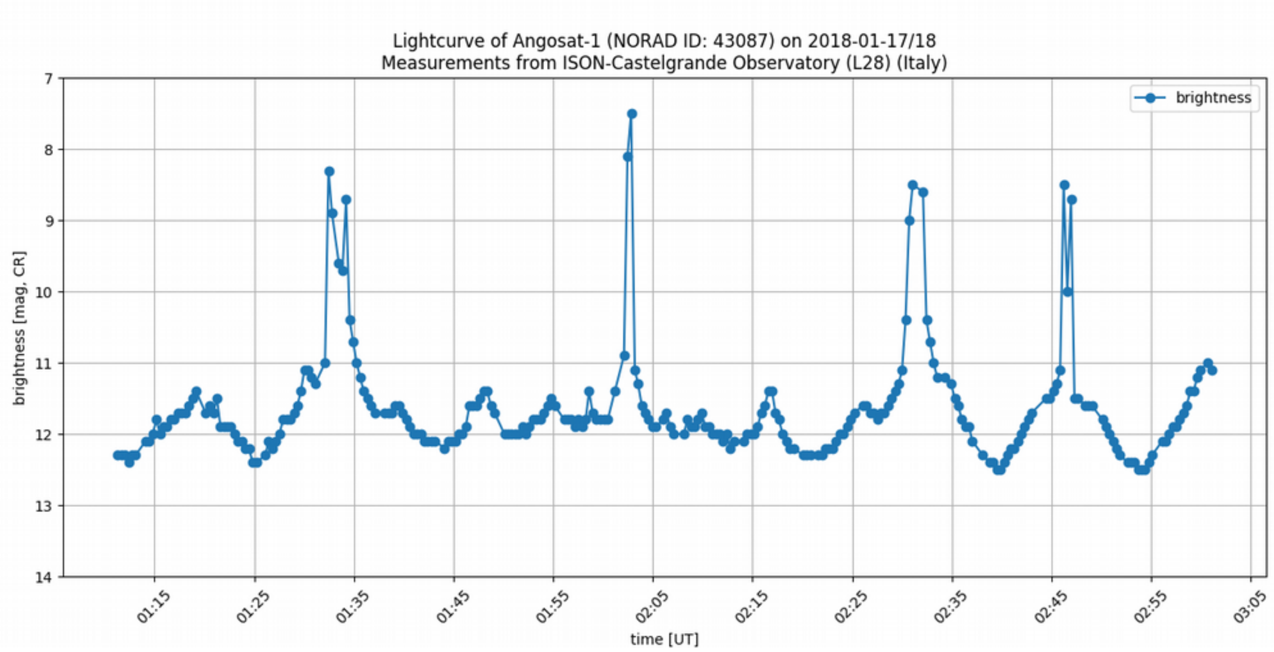

Figure 5. Lightcurve of Angosat-1 from Castelgrande.

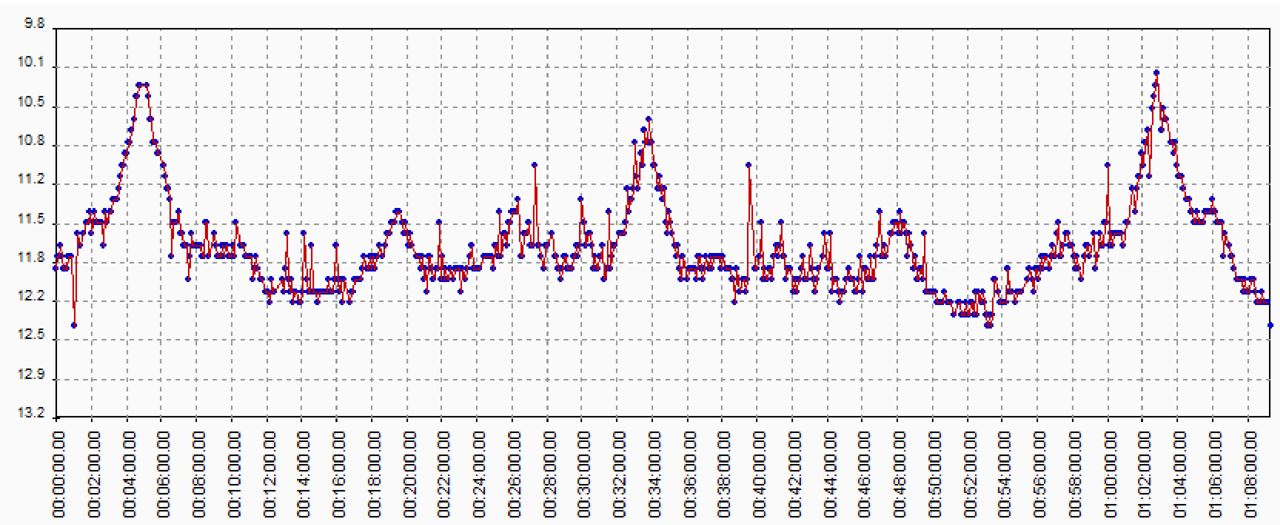

Figure 6. Lightcurve of Angosat-1 from Arkhyz.

First photometric test observation of a near-Earth asteroid was conducted on April 16th, 2018 for the Amor family NEA (194126) 2001 SG276. On September 8th, 2018 we successfully observed the Aten famile NEA 2018 RC, the rotation period of 10 (or possibly 40) min could be determined (Fig. 8). On two occations the light-curve of the Amor family NEA (433) Eros was obtained.

By the course of multiple tests we found that ORI-22 telescope is able to track objects with brightness down to 17 mag by using exposure time up to 120 sec (and up to 60 sec for the 16th magnitude). In terms of photometry for both asteroids and artificial space objects we were able to obtain good quality light-curves for objects with brightness at least down to 15 mag, provided that the rotation period was at least a couple of minutes long and with brightness variation amplitude of at least 0.2 mag; if the expected rotation period is longer than tens of minutes then objects with brightness down to 16 mag can also be taken into consideration.

On March 31st, 2018 a series of images of the decaying Chinese space station Tiangong-1 were obtained (quite possibly, it was the last optical CCD observation available around the globe), while it was at the height of ~150 km above Earth surface shortly before its fall into the Pacific Ocean. That pre-reentry observation as well as the planned installation of an all-sky camera Starlight Xpress Oculus 180 (with FOV of 180°) along with extensive past experience in visual observations of meteor showers have given an impetus to start a pilot

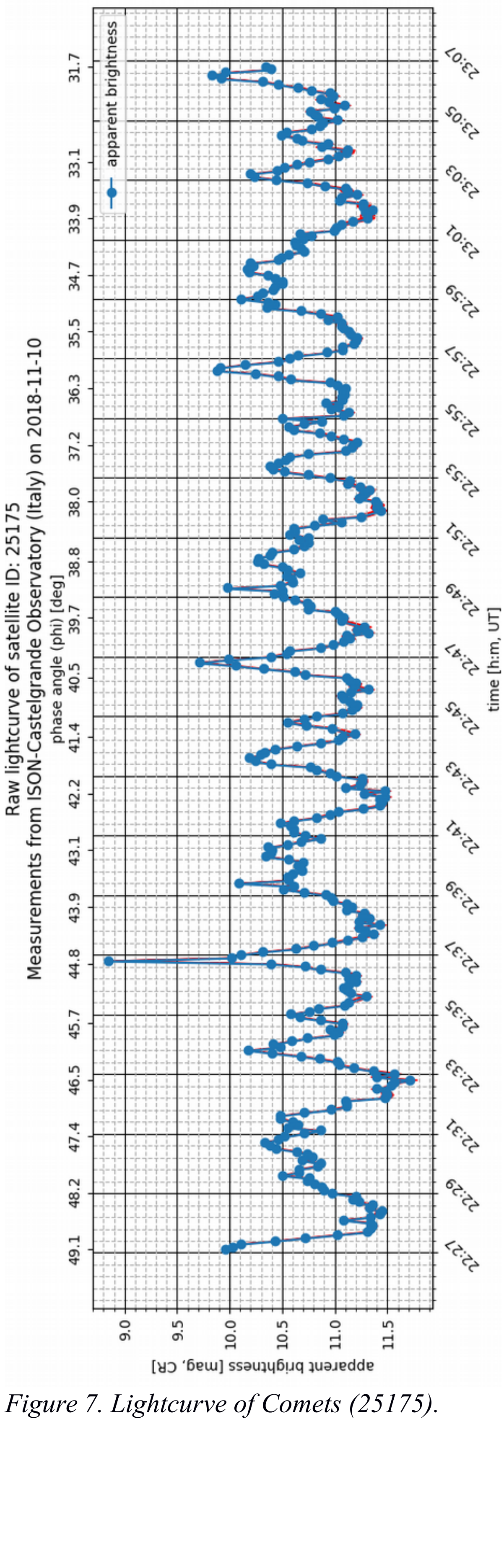

Figure 7. Lightcurve of Comets (25175).

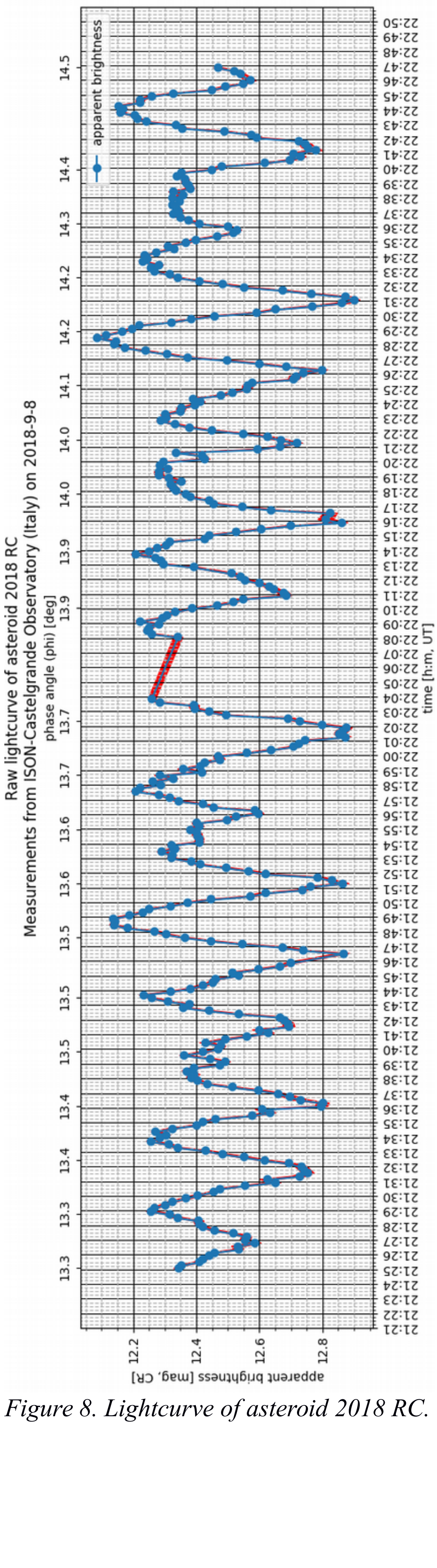

Figure 8. Lightcurve of asteroid 2018 RC.

project for optical and radio observations of fireballs and meteor showers. We will use the Watec 902H2 Ultimate video-camera equipped with the wide-field lense Panasonic WV-LA608 (6 mm, f/0.75), and the computer-controlled ICOM PCR-1500 radio-receiver. Also, telescopic (with large FOV) observations of radiant-close fields, where shower meteors normally have short trails, are planned to investigate the possibility to study the sub-radiant structure of meteor showers with high activity such as Perseids, Geminids or Quadrantids.

4.5 Other observing sites

Many other telescopes with apertures of 22 or 25 cm have been installed by ISON throughout the world, some of them are:

- SRT-220 in Multa (Altai region, Russia)
- ORI-25 in Urumqi (China)
- TAL-250 in Mayaki (Ukraine)
- ORI-25 and TAL-250 in Cosalá (Mexico)
- ORI-25 and TAL-250 in Tiraspol (Moldova)
- ORI-22 in Lesosibirsk (Siberia, Russia)
- ORI-22 in Kitab (Uzbekistan)
- TAL-250 in Chuguev (Ukraine)
- ORI-22 in Abastumani (Georgia)
- ORI-25 in Tarija (Bolivia)
- SRT-220 in Nauchny (Crimea)
- ORI-25 in Monterrey (Mexico)
- ORI-22 in Andrushivka (Ukraine)

In total, at least 20 telescopes of this type at 17 observing sites are already active and their number is supposed to be increased to more than 25. Learning from the observational experience of the above described four observatories, other telescopes will be gradually involved more and more in observations of NEOs.

5 RESULTS & OUTLOOK

The results show that these telescopes fully meet the task needs thus replacing other larger and more expensive telescopes whose observing time should be used for targets rather too faint and inaccessible for small aperture telescopes.

The common brightness distribution of observed targets by this type of telescopes reaches just 15th magnitude, but successful tests with long exposures have proven the possibility to reach the 17th magnitude in tracking mode observations even at relatively high angular velocities of observed targets; the star-trailed images are easily processed by the described software, so that no image stacking is necessary (but is actually also possible). Planned are regular photometric observations for all near-Earth asteroids with brightness down to 16 mag; to select the targets we will use the Observing Target List page and the Close Approaches list of the MPC's website.

The objective of this sub-network is 1) to diversify optical observations with small aperture telescopes engaging them more in scientific field, and 2) to guarantee observation results during the short flyby period of a NEO in the case of unacceptable weather conditions at the one or the other observing site. Also, we plan to develop a photometric database at the KIAM for light-curves of artificial space objects.

An additional goal is to teach and to train observers at international photometry workshops which have been regularly organized by KIAM together with the collaborating Space Research Institute (IKI) of Russian Academy of Sciences (Moscow) already twice in Russia in 2015 and 2018, and once in Kazakhstan in 2016 with assistance of the Fesenkov Astrophysical Insitute (Almaty).

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