ISON SEARCH AND STUDY THE NEAR-EARTH SPACE OBJECTS

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ABSTRACT

International Scientific Optical Network (ISON) is the open international voluntary project on self-financing basis specializing in observation of the near-Earth space objects. Observatories collaborating with ISON provide global coverage and successfully combined the observations of space debris with observations of asteroids. The network works already 14 years and includes more than 50 telescopes of 27 observatories in 17 countries. From one side ISON provides permanent monitoring of the whole GEO region and tracking of objects at GEO, GTO, HEO and LEO. KIAM supervises this space debris research, maintain database of space objects, develops the space debris population model, and provides conjunction analysis for satellites at high orbits. From other side, KIAM and IAKhNU develop the technology of asteroid survey with small telescopes and provide photometry observations of the near-Earth asteroids to investigate YORP effect, to search new binary NEAs, and to support the radar experiments.

1 INTRODUCTION

International Scientific Optical Network (ISON) [1] is the open international voluntary project on self-financing basis specializing in observation of the near-Earth space objects. ISON project is developed to be an independent source of data about space objects for scientific analysis and spacecraft operators and to obtain the scientific results in astronomy. Overall coordination of the ISON project is performed by the Keldysh Institute of Applied Mathematics (KIAM) of the Russian Academy of Sciences. One from goals of the ISON project are supporting the astronomical observatories of Former Soviet Union (FSU) countries and improving the international collaboration between FSU observatories and scientific organization in other countries. Therefore ISON promotes enhancing the international collaboration between observatories in developing countries and scientific organization in industrialized countries in the field of optical observation of natural and man-made celestial objects. Other important goals are developing of instruments and methods of space surveillance. Most types of Russian telescopes [2] used for surveillance the near-Earth space, specialized software for processing CCD frames [3], controlling telescopes [4] and planning observations were developed within the framework of the ISON project. The main types of geostationary orbit (GEO) surveys - complete, extended and local on telescopes with fields of view from 2.5 to 7 degrees - were also worked out. Based on the acquired experience of ISON, KIAM assisted to the creation of the subsystems of Roscosmos specialized facilities [5] and industrial organizations [6], which allowed to KIAM/ISON to be a world leader in field of investigations of space debris at high orbits for a long time. However, after the allocation of these subsystems in independent segments with their own centers of planning and data processing, the

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parameters of the ISON were significantly decreased. In this regard, new directions of development of the ISON network were outlined, as well as the redistribution of the attracted telescopes toward of increasing the astronomical observations.

2 CURRENT ISON NETWORK STRUCTURE

Currently the network includes more than 50 telescopes of different apertures of the 27 observatories in 17 countries. Geographical locations of optical facilities participating in the project are shown at Fig. 1. Various subsystems of telescopes are highlighted in different colours, and also are indicated the apertures of telescopes installed in observatories. These subsystems carry out the 5 different types of observations: (1) standard GEO surveys with telescopes of 20ï 50 cm apertures having field of view (FOV) 3.3ï 4.4 degrees (yellow colour in Fig. 1), (2) extended GEO survey with telescopes of 18ï 19.2 cm apertures having FOV of 7 degrees (blue colour), (3) tracking of bright (brighter than 15.5 magnitudes) GEO and HEO objects with telescopes of 25 cm aperture (green colour in Fig.1), (4) tracking of faint (fainter than 15.5 magnitudes) space debris at GEO and GTO with telescopes of 35ï 80 cm apertures (red colour) and (5) observations of asteroids with telescopes of 35 cm to 2,6 m. At the same time, small telescopes mainly belong to KIAM and KIAM Ballistics-Service and spend all their time on the tasks of the project, while telescopes larger than 70 cm are owned by observatories and spend only part of the time on ISON observations, obtained on the basis of approved scientific applications.

The greatest result on space debris continues to make the global survey and search subsystem, the foundations of which were laid in 2007 [7]. This subsystem, consisting of 15 telescopes with FOV from 3.4 to 5.5 degrees, is still the only one in Russia that covers the entire geostationary orbit with survey observations. At present, the subsystem includes five 22-cm telescope ORI-22 (the optical scheme of the Hamilton-Newton with a focal length of 510 mm, see Fig. 2) in Ussuriysk (far East), Kitab (Uzbekistan), Abastumani (Georgia), Andrushivka (Ukraine), Castelgrande (Italy), five 25-cm telescope ORI-25 (system Hamilton-Newton with a focal length of 625 mm) in Urumqi (China), Chuguev (Ukraine), Monterrey (Mexico), Tarija (Bolivia), Cosala (Mexico), and the 20-cm telescope ASA in Zimmerwald (Switzerland) and 50-cm telescope TFRM in Barcelona (Spain). Every observation night they automatically double-view the entire visible part of the GEO in a wide band of 18 degrees and are guaranteed to detect all space objects (SO) with brightness up to 15.5 magnitudes. The length of the measuring arcs (15-30 minutes) for each space objects minimally required to maintain a good accuracy of the

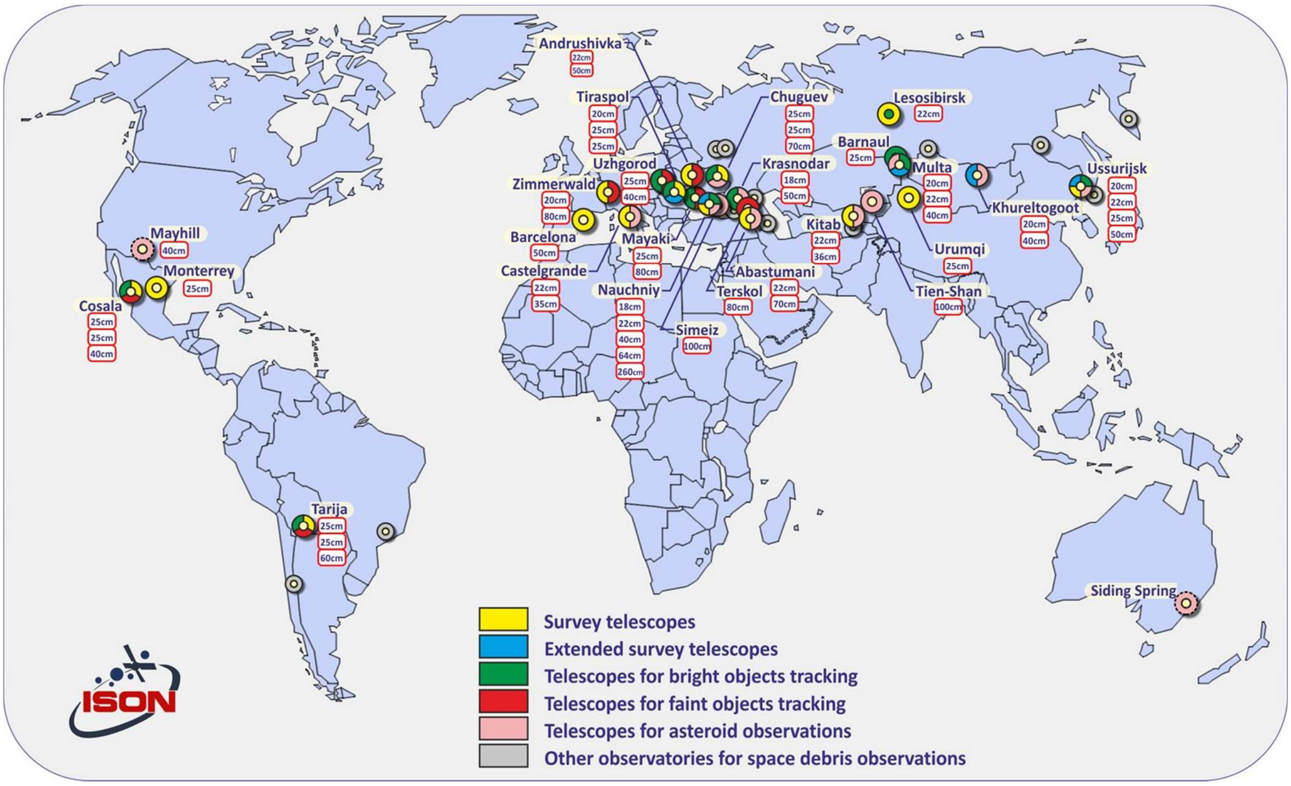

Figure 1. Map of the ISON observatories

orbits in the database, as well as for the detection of new SO, caught in several "adjacent" (spaced at 1 - 2 nights) surveys, were experimentally selected.

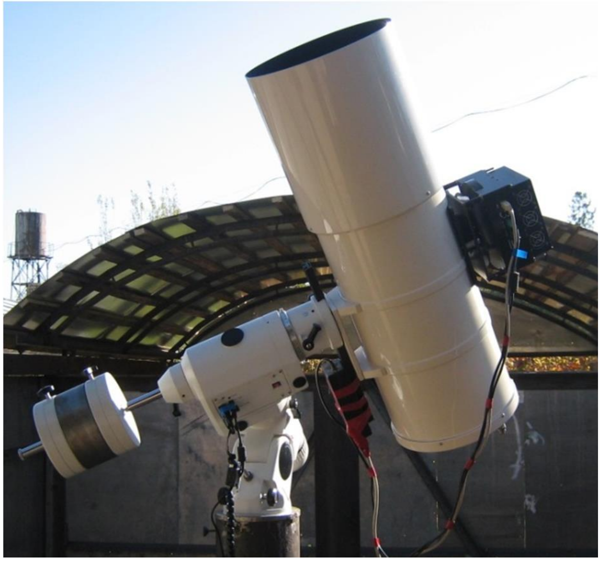

Figure 2. Typical 22-cm telescope ORI-22 with field of view 4x4 degree for standard GEO survey in Kitab (Uzbekistan)

The principle of planning reviews is shown in Fig. 3, where the trajectories of all known geostationary objects are shown, the area at the level of 16 hours along the axis of direct ascent is the Earth's shadow. Rectangles are the fields of view of telescopes, forming barriers, which are viewed by the observation telescope during the night.

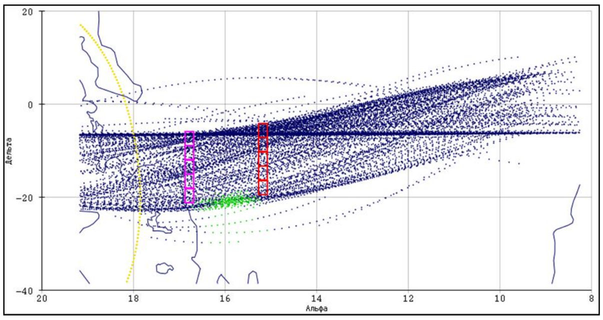

Figure 3. Planning barriers to standard GEO survey observations

During the survey, the telescope must pass all trajectories twice. Barriers to surveys are selected in front and behind the Earth's shadow, in an area where GEO-objects become brighter due to the favourable phase angle. For each such "pass", the telescope makes 10 frames of each area of the survey mosaic. This number of frames is selected, as well, empirically, on the basis of experience and allows you to confidently detect SO even in dense star fields, where part of the frames SO "merge" with the tracks from the background stars. During the full night, each survey telescope receives several thousand astrometry measurements for several hundred GEO-objects, and in total, the survey observations of the subsystem allow monitoring the situation throughout all GEO, including detecting objects of new launches and objects in high-elliptical orbits (HEO) crossing the GEO region.

Extended GEO survey subsystem [8]. consist of four 19.2-cm telescope VT-78a (optical scheme Schmidt-Houghton with a focal length of 296 mm, see Fig. 4) with a field of view 7x7 degree, set in Ussuriysk (Far East), Khureltogoot (Mongolia), Multa (Republic of Altai) and Tiraspol (Pridnestrovian Moldavian Republic).

Figure 4. Typical 19.2-cm telescope VT-78a with field of view 7x7 degree for extended GEO survey in Ussuriysk (Far East)

The technique of the extended GEO surveys (see Fig. 5) significantly increases the number of GEO views per night (from 2 to 10 times) when using telescopes with a large field of view (from 7 degree or more).

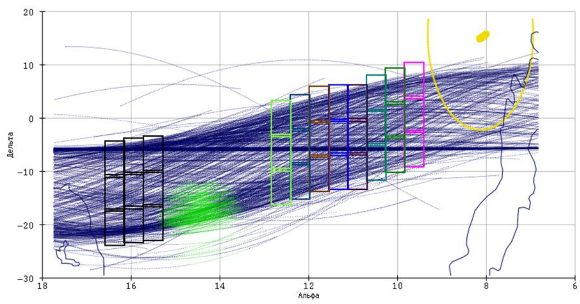

Figure 5. Planning barriers to extended GEO surveys

For a full night, each telescope for extended surveys receives up to 15 thousand astrometry measurements for

500-700 SO with brightness up to 14.5 magnitudes. This significantly increases the accuracy of the orbits of most of the bright GEO-objects (due to the extension of the measuring arcs to 10-12 hours), as well as the possibility of more careful tracking of spacecraft manoeuvres in clusters at the points of standing and increases the probability of detection of HEO-objects.

Subsystems of telescopes for tracking of bright (up to 15.5 magnitudes) and faint (fainter than 15.5 magnitudes) SO by target indications, whose task is to observe SO not included in the surveys, and to improve the orbits of SO participating in dangerous approaches. The subsystem to track the bright SO includes the five 25-cm telescopes - GAS-250 in Ussuriysk (Far East), BRC-250 in Uzhgorod (Ukraine), ORI-25 in Tiraspol (Pridnestrovian Moldavian Republic), and also new telescopes with a small field of view (for obtaining high-precision measurements on approaching SO) TAL-250K in Barnaul (Altai Region) and TAL-250K in Kosala (Mexico).

The subsystem of observations of faint SO includes 7 telescopes ï 80-cm telescope K-800 at Terskol (Kabardino-Balkaria), 64-cm telescope AT-64 and 40-cm telescope of the new series DIN-400 (for high-precision measurements of the approaching faint SO, see Fig. 6) in Nauchny (Crimea), 50-cm telescope ORI-50 Andrushevka (Ukraine). 40-cm telescope CHV-400 in Uzhgorod (Ukraine), 50-cm CDK20 in Zimmerwald (Switzerland) and 50-cm CH-500 in Cosala (Mexico).

Figure 6. First 40-cm telescope DIN-400 with field of view 25x16 angular minutes for high precision measurements in Nauchny (Crimea)

Subsystem for asteroid observations includes 10 telescopes: 5 large class telescopes of observatories on which part of the observation time is obtained by scientific applications ï 2.6-m ZTSh in Nauchny (Crimea), 1-m Zeiss-1000 in Simeiz (Crimea), 1-m Zeiss-1000 in Tien-Shan (Kazakhstan), 70-cm AS-32 in Abastumani (Georgia), 70-cm AZT-8 in Chuguev (Ukraine), and 5 medium class telescopes of the ISON project ï 50-cm ChV-500 in Ussuriysk (Far East), 50-cm RC-500 (Krasnodar), 40-cm ORI-40 in Khureltogoot (Mongolia), 36-cm RC-360 in Kitab (Uzbekistan), and 35-cm RC-350 in Castelgrande (Italy).

Large telescopes participate in periodic ISON observation campaigns on the photometry research of asteroids. Medium class telescope additionally provide follow up of new the near-Earth objects.

In 2018 two test asteroid surveys on 40-cm telescopes SANTEL-400A (see Fig. 7) in New Mexico (USA) and ASA 16ò Deltagraph in Siding Spring (Australia) were stopped.

Figure 7. Old 40-cm telescope SANTEL-400A with field of view 1.65x1.65 degree for asteroid survey that worked in New Mexico (USA) during last 6 year

It is planned that asteroid survey will be resumed with 40-cm telescope SATNEL-400/500 (see Fig. 8) of new series (having field of view in 8 times larger) in Multa (Republic of Altai) in summer-autumn of 2019.

ISON project is interested in finding new places to install these two telescopes (SANTEL-400A and ASA 16ò Deltagraph on ASTRO-PHYSICS 1600GTO mounts). Both telescopes are universal and capable of observing different types of objects. Please send your suggestions for sites with good astroclimate. SANTEL-400A is also equipped with BVRIC filter wheel.

Figure 8. New 40-cm telescope SANTEL-400/500 with field of view 5.5x4 degree for asteroid survey that will be installed in Multa (Republic of Altai) in 2019

3 SPACE DEBRIS OBSERVATIONS

Keldysh Institute of Applied Mathematics (KIAM) supervises the space debris research with ISON for filling measurements the KIAM Space Debris database. KIAM database consists of three main parts - the Centre on collection, processing and analysis of information on space debris (CCPAISD) as a central information node to perform space debris research in RAS and to support the ISON network development and operations, centre on conjunction analysis as of ASPOS OKP system [5], and space debris population model at high orbits [9]. In addition, a part of ingenious scheduling and data analysis software has been adopted in order to operate with other customers including foreign ones and provide supply of raw measurements, orbital data and conjunction analysis (CA) based of the ISON data only.

Key solving tasks of CCPAISD are (i) maintenance of the ISON master database on space objects, related events (launches, fragmentations, re-entries etc.), measurement data and derived products (orbits etc.); (ii) elaboration and implementation of optical observation strategies; (iii) daily scheduling of the ISON sensors for routine and special survey and tasking observations of GEO, HEO and MEO regions of the near-Earth space; (iv) collecting and processing of the ISON and other facilities produced optical measurements on objects in the near-Earth space; (v) tracklets association, determination of parameters of improved orbit and their accuracy estimation for each observed object, new objects cataloguing; (vi) evaluation of physical characteristics of observed objects.

During 2018 CCPAISD collected 28 382 100 measurements (see Fig. 9) , from which 6 775 500 were provided by ISON.

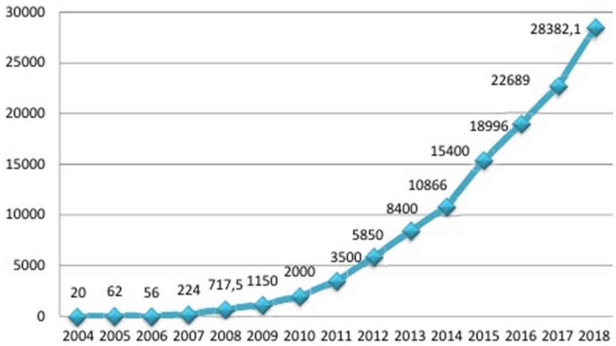

Figure 9. The number of measurements (in thousands) collected by CCPAISD annually for the 2004 ï 2018 period

Created space debris population model is verified with faint debris measurements obtained with 80-cm telescope K-800 at Terskol (Kabardino-Balkaria). There are plan of significant improvement of K-800 by re-aluminizing the main mirrors and enlarging of field of view to 3x3 degrees.

4 SUMMARY OF ASPIN PROJECT

KIAM and Institute of Astronomy Karazin Kharkiv National University (IAKhNU) develop the Asteroid Search and Photometry Initiative (ASPIN) project in that the technology of asteroid survey is adjusting (since 2010) and the regular campaigns of the photometric observations of near-Earth asteroids are carrying out (since 2008).

Main objects and aims of photometry observations are (1) newly discovered and/or closely approaching the Earth NEAs, especially potentially hazardous asteroids (PHA); (2) NEAs, whose orbits and bodies properties suggest the possibility of the YORP effect detection; (3) binary NEAs, with the focus on the BYORP effect determination; (4) search for new binaries; (5) small NEAs with diameters smaller 200-300 m, which can have very fast rotation; (6) NEAs that are radar targets. During 2017 more than 70 NEAs were observed for obtaining lightcurves during more than 250 nights. Among them: 20 newly discovered NEAs; more than 15 closely approaching the Earth PHAs; 5 known binaries and 9 suspected binaries; the triple asteroid 3122 Florence; asteroids 1862 Apollo and 3103 Eger with detected YORP, and about 10 asteroids suitable to investigate the influence of the YORP effect (1864 Daedalus; 1865 Cerberus, 85990 1999 JV6; 138852

2000 WN10 and others); binaries 65803 Didymos, 66391 1999 KW4 and 137170 1999 HF1 for testing BYORP; NEA 496018 2008 NU showed two-periodic lightcurves.

ISON asteroid test survey that was arranged with two 40-cm telescopes (H15 and Q60) was directed on elaboration of concept of ñsecond waveò asteroid survey ï survey with small telescopes that provide full sky coverage during night to detect fast NEAs missed in the dedicated asteroid surveys with large telescopes. Observations with limiting magnitude of 20.5 were carried out remotely via the Internet, the received CCD frames are downloaded to the KIAM in real time and processed in the created center for planning and processing of asteroid surveys. Testing of the own version of the software for the control of the telescope equipment during observations of small bodies of the Solar system has been completed. Usage of the KDS software package allowed increasing productivity by 25%. During this work it was obtained more than 1 230 500 astrometry measurements and discovered 1605 main belt asteroids, 17 near-Earth asteroids, 8 comets, 20 Trojans of Jupiter, 4 objects from the family of Hilda, 4 objects of family Centaur. The asteroid survey will be resumed in 2019 with new 40-cm telescope SANTEL-400/500 that will be installed in Multa (Republic of Altai) in this summer.

To involve ISON observatories in follow up observations of discovered NEAs the special work is arranged on obtaining of MPC codes for ISON observatories (D53, D00, 820, D05, C15, O75, H15, N42, ş99, L96, Q60, L28). The successful tests of telescope subsystem for NEAs follow up were arranged in December 2018.

5 CONCLUSION

Currently, ISON scientific cooperation consists of 53 telescopes at 27 observatories. ISON small survey telescopes cover all GEO orbit and continue to provide the main contribution to the maintenance of the bright objects catalogue and to the conjunction analysis procedure. Observations of the subsystem for tracking of bright and faint SO are ordered also and by foreign customers. 6 775 500 measurements were obtained in 2018.

Created space debris population model is verified with faint debris measurements obtained with 80-cm telescope K-800 at Terskol (Kabardino-Balkaria).

ISON project successfully combines observation of space debris and asteroids. Created KDS software for telescope control will allow carrying out both types (space debris and asteroids) of observations on the same telescopes fully automatically. An important result was obtained in the study of asteroids by photometric observation. Trial asteroid surveys aimed at testing equipment, software and methods have been completed. 1 230 500 astrometry measurements were obtained since 2010. The first ISON regular asteroid survey with new series of 40-cm telescopes (22 square degrees field of view) will start in 2019.

Subsystem for follow up NEOs was arranged and tested in December 2018.

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