



PHYSICAL SCIENCES

Search and study of the space debris and asteroids within ISON project

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Abstract: International Scientific Optical Network (ISON) is an open international voluntary project specializing in observations of the near-Earth space objects. Observatories collaborating with ISON provide the global coverage and successfully combine the observations of the space debris and asteroids. The network includes more than 50 telescopes of 27 observatories in 15 countries and has been working since 2005. ISON monitors the whole GEO region and tracks the objects at GEO, GTO, HEO and LEO. ISON data allowing maintenance of the database of the space objects orbits, validating space debris population model and providing conjunction assessment analysis for satellites at high orbits. ISON develops the technology of asteroid survey with small telescopes and arranges regular photometry observations of near-Earth asteroids (NEA) to investigate the YORP effect, search new binary NEAs, and support radar experiments.

Key words: space debris, near-Earth asteroids, optical telescopes, survey, photometry, binary system.

INTRODUCTION

Development and research of near-Earth outer space (NES) has led to the awareness of the space threats – asteroid hazard and problems of technogenic pollution known as space debris (SD). Tasks of NEA detecting and cataloging, investigating evolution of their orbits, and studying their physical and mineralogical properties are important now. Goals of studying, modeling and preventing man-made threats to the implementation of space activities are more urgent than ever before. Both of these tasks are combined with an approach to their study, thus it requires a scientific tools of geographically

distributed network of optical telescopes covering all longitudes of the globe. Attempt to create such tool was an initiative project of the International Scientific Optical Network (ISON) (Molotov et al. 2008).

ISON project started in 2004 and was one of pioneers in CCD sky surveying in Russia. A lot of equipment and software was elaborated: few series of dedicated telescopes (12.5 cm, 19.2 cm, 22 cm, 25 cm, 40 cm, 50 cm and 65 cm apertures) with large field of view (FOV) from 2.3° to 12.3° (Molotov et al. 2019a), GPS-based time reference system, standard set of software for telescope control and CCD image

processing (Kouprianov & Molotov 2017), for observation scheduling (Elenin et al. 2018) and data analyzing. Cooperation agreements with few former Soviet Union observatories were signed. ISON expeditions visited Argentina, Armenia, Brazil, Bolivia, Bulgaria, Italy, Mexico, Mongolia, Tajikistan, Uzbekistan and Venezuela for investigating possibility to install the ISON telescopes. International cooperation in space monitoring was arranged with team of the Astronomical Institute, Bern University (AIUB) in Switzerland (Zimmerwald observatory (Herzog et al. 2013)), TFRM project in Spain (Barcelona observatory (Fors et al. 2013)), GAUSS team in Italy (Castelgrande observatory (Graziani et al. 2018)), Mexican universities (Autonomous University of Sinaloa and Autonomous University of Nuevo Leon (Mokhnatkin et al. 2018)), Institute of Astronomy and Geophysics (IAG) of Mongolian Academy of Science (Khureltogoot observatory (Tungalag et al. 2015)), National Astronomical Observatories of Chinese Academy of Sciences (Urumqi observatory), National Research Institute of Astronomy and Geophysics in Egypt (Kottamia observatory (Abdel-Aziz et al. 2020)). Training courses were arranged for all teams of the ISON observatories. Also annual workshops are regularly arranged for the common lectures of the ISON group representatives and the exchange of experience between the ISON observatory teams. Thanks to these accomplishments the ISON project to establish new observation points to cover with observations all longitudes.

A global network of the 100 optical telescopes at 42 observatories of 18 countries was created. It had been the most powerful system in the world for a long time. For years the network had provided a leading position in the field of space debris investigation at high orbits and made an important contribution to studying asteroids. However, it was later divided

into several components with its own scheduling center each. Set of the Roscosmos specialized facilities and the telescopes of the industrial organizations (Molotov et al. 2016) separated from the network and parameters of the ISON significantly decreased. Nevertheless the network is still one of the largest and continues to cover with observations all longitudes of the globe.

CURRENT STATUS OF THE ISON NETWORK

Currently the network includes 27 observatories in 15 countries with more than 50 telescopes of different apertures. Geographical locations of optical facilities participating in the project are shown at Fig. 1. ISON is mostly based on telescopes of the Small Innovation Enterprise (SIE) “KIAM Ballistics-Service” (30 telescopes, mainly 20 cm – 40 cm apertures, installed in 18 locations). Nine partner observatories having signed agreements on scientific and technical cooperation with Keldysh Institute of Applied Mathematics of the Russian Academy of Sciences, Research Institute of Astronomy of the Karazin Kharkiv National University or the SIE “KIAM Ballistics-Service”, and added ISON twelve instruments (50 cm – 80 cm apertures). Moreover, ISON observation program implemented with 10 larger telescopes (60 cm to 2.6 m apertures) at 8 observatories, where observation time competitively allocated by annual scientific applications.

All telescopes depending on their technical characteristics are grouped in seven subsets of telescopes: (i) global survey with 20–25 cm aperture telescopes having FOV of 3.5–4.4°, (ii) extended survey with 18–19.2 cm aperture telescopes having FOV of 7°, (iii) local (deep) survey with 40–50 cm aperture telescopes having FOV of 2.2°, (iv) tracking bright (brighter

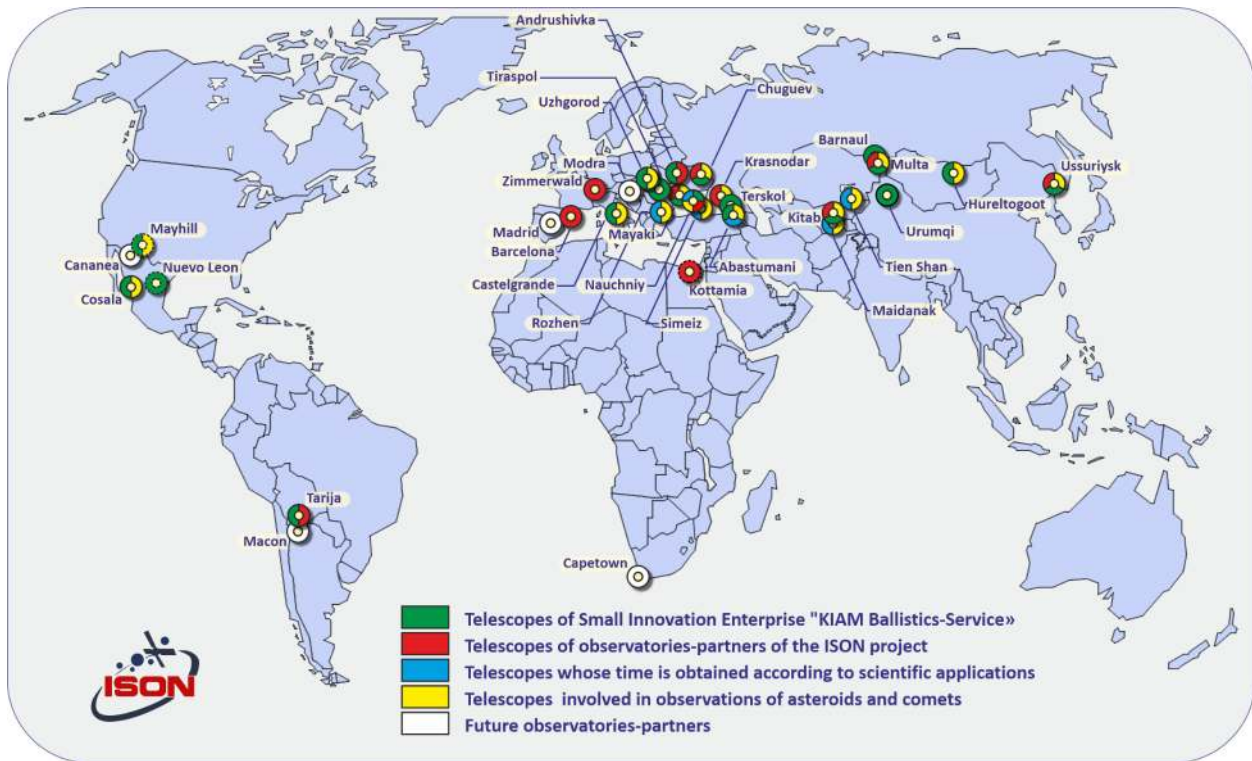


Figure 1. Map of the ISON observatories. Here geographical location and names of observatories are presented. Various colors indicate the status of participation of the observatory in the project.

than 15.5^m) space objects with 25 cm aperture telescopes having FOV of 0.5° – 1.5° , (v) tracking faint (fainter than 15.5^m) space debris at high orbits with 40–80 cm aperture telescopes having FOV of 0.5° – 1° , (vi) asteroid photometry with 0.6–2.6 m aperture telescopes having FOV of 0.2° – 0.5° , (vii) following up NEA with 36–50 cm aperture telescopes having FOV of 0.5° – 1.25° . Additionally, the asteroid surveys performed in period 2010 – 2018 with three 40 cm aperture telescopes having FOV of 1.76° – 2.2° . We plan to resume the surveys in 2021.

SPACE DEBRIS RESEARCH

SD is a unique object of study, because it is at the crossroads of interests of various industries and departments. Data obtained are very important for science (although space debris

population is of technogenic origin, but the laws and trends of its evolution as well as creating SD population model are of natural science interest), space industry (safety of space flight, developing spacecraft protection, prognosis of the dangerous approaches, predicting re-entering in the atmosphere, minimizing causes of spacecraft destruction), diplomacy (development and adoption of measures decreasing pollution of the NES, preventing restrictions on access to space, presentation of claims, development of rules of behavior in space), defense ministries (space situation analysis, identification of threats to the orbital groups). Therefore, efforts to monitor the situation in NES are undertaken by a large list of countries and are partly coordinated through meetings of the Inter-Agency Space Debris Coordination Committee (IADC), and the UN Committee on the Peaceful Uses of Outer Space

(COPUOS). Data on space situation are obtained using optical (ground-based and space-based) and radar systems. Usually, radars are used to monitor space debris in low orbits, and optical telescopes are used for high orbits. ISON optically monitors space objects at geostationary (GEO), highly elliptical (HEO) and medium Earth orbits (MEO) to obtain better understanding of the near Earth environment. Directions of work are: (i) extending the catalogues of “known” space objects toward smaller sizes, (ii) acquiring statistical orbit information on small-size objects in support of statistical environment models, and (iii) characterizing objects to understand their nature and to identify the sources of space debris. Research provides the scientific rationale to devise efficient space debris mitigation and remediation measures enabling sustainable outer space activities. Risk assessment from SD objects for operational satellites at high orbits performs daily using ISON data (Streltsov et al. 2018). Technologies for SD monitoring with optical instruments are regularly improved (Molotov et al. 2018a).

Method of so-called “comprehensive” surveys in the wide strip of 18° along all GEO developed and implemented on the global survey ISON subsystem (Molotov et al. 2018b). It allowed for the first time in Russia to solve the task of detection and tracking all GEO-objects brighter 15.5^m to maintain the catalogue of the orbits. Each observation night these telescopes twice automatically scan the entire visible part of the GEO and are guaranteed to detect all space objects having accessible brightness. The resulting lengths of measuring arcs is 15-30 minutes for each detected object that enough to maintain the orbits in database, as well as to discover new objects that fell into several nearby (spaced for 1-2 nights) surveys. Each survey telescope obtains several thousand astrometric measurements for few hundred GEO objects. In

general, survey observations allow monitoring the situation throughout the GEO, including new launches detection and the HEO objects finding during the GEO intersection.

ISON subsystem for extended surveys significantly increases the number of GEO scans per night (from 2 to 10 times) using telescopes with a larger FOV. Each telescope of extended surveys obtains up to 15 thousand astrometric measurements for 500-700 space objects brighter 14.5^m . The resulting lengths of measuring arcs is 10-12 hours for each detected object allowing significant increasing accuracy of the orbits for most of the bright GEO objects and providing good detection of maneuvers of GEO satellites in clusters and a higher probability of finding HEO objects.

These subsystems continue to make a major contribution to monitoring bright GEO-objects providing full coverage of GEO. Measurements for 90% population of bright GEO objects are regularly obtained, ensuring that accurate orbits are maintained for 98% population which is necessary condition for prognosis of dangerous rapprochements (Molotov et al. 2020). See Fig. 2 where curves of different colors indicate total number of bright (to 15.5^m) objects (green), number of objects measured during current night (blue), and number of objects with accurate orbits (red). Error of 0.1 minute along the object’s orbit was chosen as the criterion for orbit accuracy.

Method for detecting and tracking faint GEO objects (fainter 15.5^m) was developed using ISON subsystems for local (deep) survey and tracking faint space debris. It made possible first time in Russia discovering small fragments of space debris at high orbits and confirming the presence of clouds of fragments at GEO and HEO caused by the destruction of satellites and rocket stages. Independent research confirms the existence of a new class of objects with

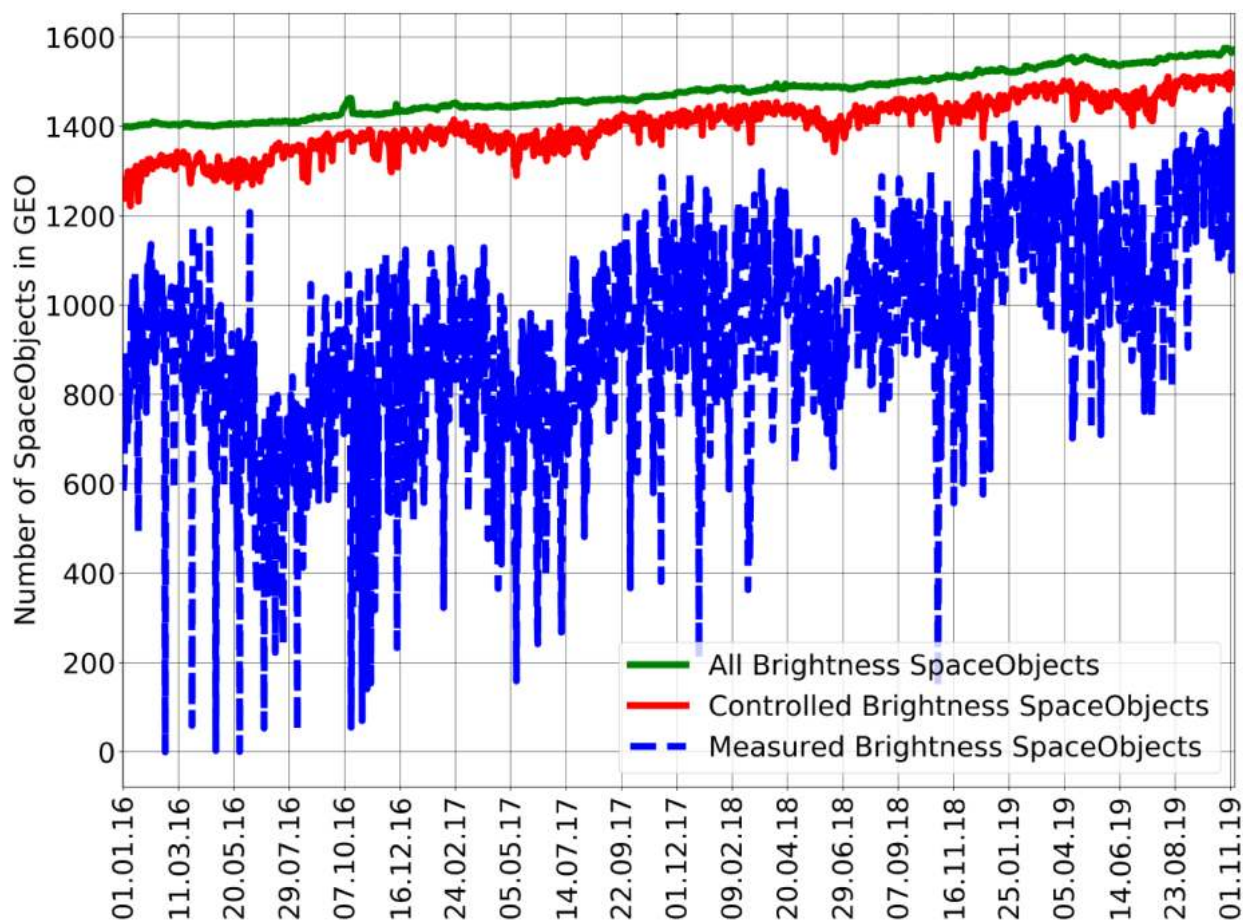


Figure 2. Status of the ISON catalog of bright GEO objects in 2016–2019. Here are shown the parameters of the catalogue of bright GEO objects for the 4 years period. Curves of different color indicate total number of objects brighter 15.5^m (green), number of objects measured during current night (blue), and number of objects with accurate orbits (red). Vertical axis - number of objects, horizontal axis-dates.

high area-to-mass ratio (HAMR) so that light pressure substantially influence on eccentricity and inclination of their orbits (Bazey et al. 2015). For the first time significant volume of data was obtained for HAMR objects over long time intervals, which allowed identifying and analyzing their observational properties and orbital evolution, and determining their origin (Agapov et al. 2020). Among the HAMR-fragments, subclass of objects whose orbits intersect the trajectories of high-elliptical and low-orbital spacecraft was discovered. Several detected HAMR-objects show periodic great increase of their visible brightness up to 10^m ,

making them comparable in brightness to the largest known GEO-spacecraft. Variable light pressure force during unpredictable rotation relative to the center of mass of HAMR-objects leads to large errors in prediction of their orbital position even at short time intervals. Ballistic evolution of HAMR-objects is very critical to the presence of shadow areas, which combined with variable value of the area-to-mass ratio, leads to additional uncertainties in determining their movement. According to our estimates, objects with an area-to-mass ratio greater than $1 \text{ m}^2/\text{kg}$ is about 23.4% of the SD population at GEO and HEO orbits. Fig. 3 shows distribution of the high

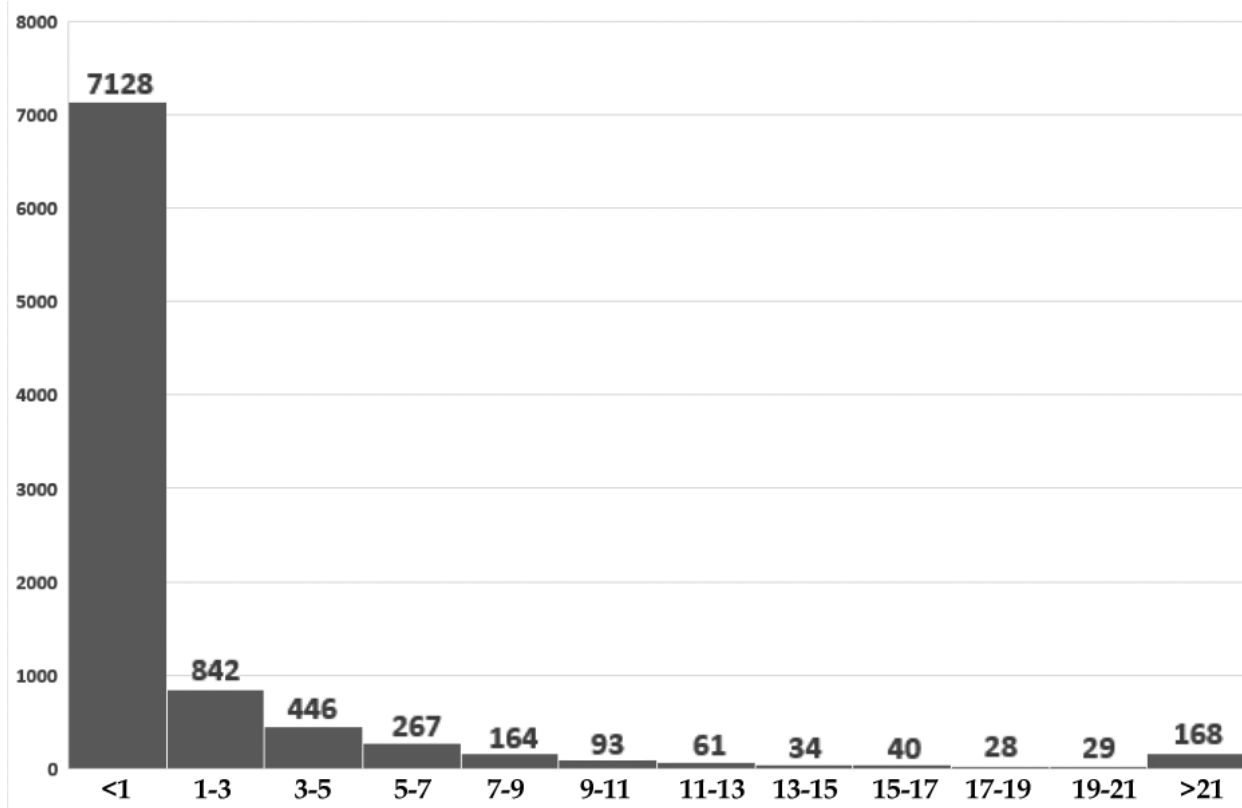


Figure 3. Distribution of the high orbit space objects in the ISON database by the average value of area-to-mass ratio, m^2/kg (vertical axis - number of objects, horizontal - ratio of area to mass).

orbit space objects in ISON database by value of area-to-mass ratio.

Number of such objects turned out to be so large that is necessary to revise the existing mathematical models of the dynamic distribution of space debris in NES and also hazard estimates for operational satellites.

In recent years, the composition of the catalog in part of faint high-orbit objects changed significantly. Fig. 4 shows the number of faint high-orbit objects by type of orbit in the ISON database yearly. Fig. 5 shows that the quantity of faint HEO-objects increased 5 times and now the number of faint HEO-objects is 2 times more than faint GEO-objects. It was detected 4 destructions of the rocket stages (Molotov et al. 2019b) producing more than 2,000 new fragments at HEO.

Fig. 6 shows that such sharp increase in the number of faint HEO-objects leads to significant deterioration of the catalog parameters in part of faint GEO-objects due to forced reallocation of observational resources – see Fig. 6.

Fig. 6 shows that the difference between total number of faint GEO-objects and the objects with accurate orbits (between green and red curves) is very large – only 34.5% of objects meet the selected criterion for acceptable orbit accuracy. It is noticeable that the number of faint GEO-objects with accurate orbits changes strongly about every 4 months, and in the last 2 years it has significantly decreased, which indicates the beginning of catalog degradation for this type of objects. This results from the fact that measurements are regularly obtained only

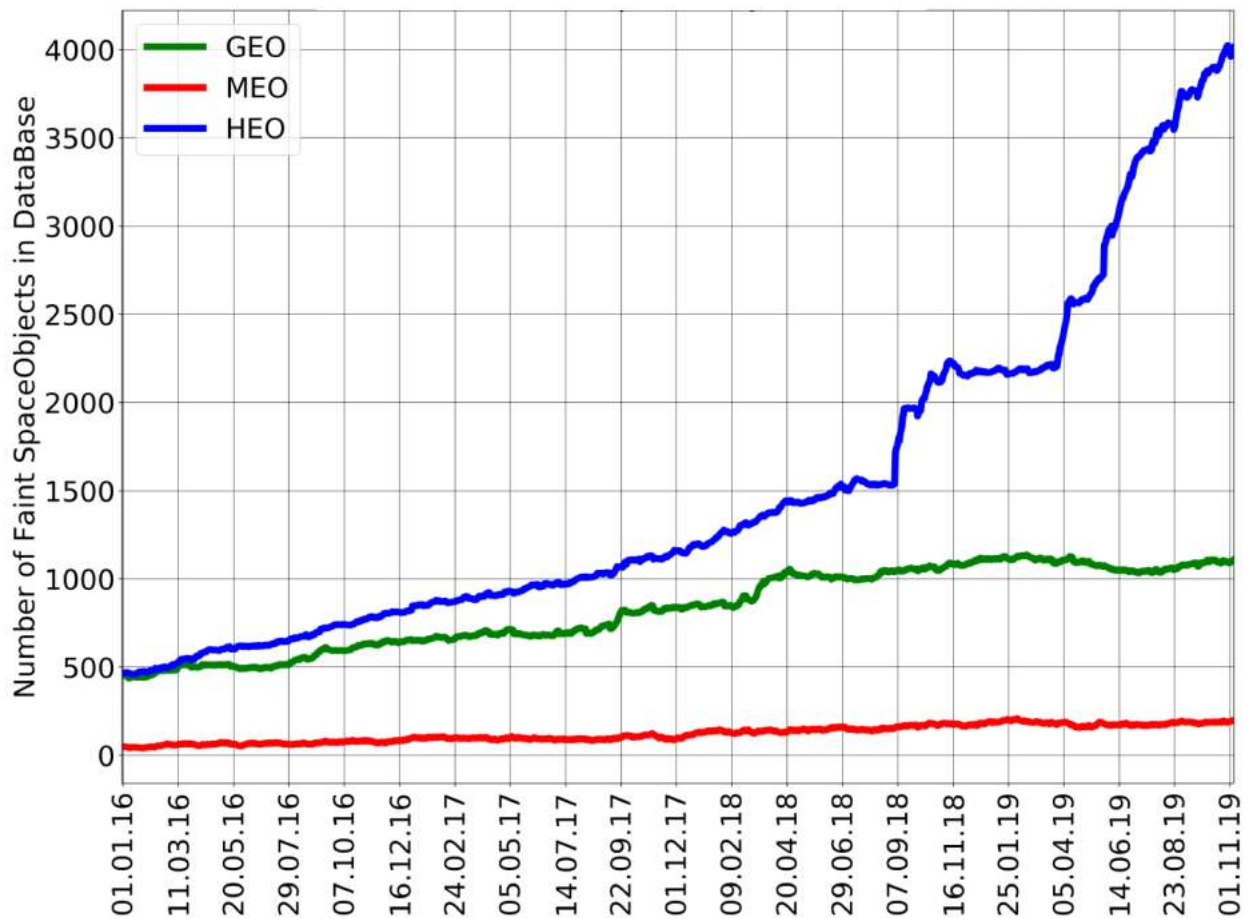


Figure 4. Number of the faint objects at high orbits yearly in the ISON database. This shows how the number of different types of faint objects in the catalog changes over time – GEO (green color), HEO (blue color), MEO (red color). Vertical axis - number of objects, horizontal – dates.

for a very small percentage of faint GEO-objects - 17% (sometimes decreasing to 5-7 %).

The monitoring network needs in further development as well as new observational methods. In general, for 15-year series of the ISON observations of space debris our knowledge about the population of space debris in GEO and HEO reached a fundamentally new level (number of the high orbit objects in the ISON database is 9300 on 19.09.2019). Nevertheless, the SD population at high orbits is still far from being fully studied. Fig. 7 shows the distribution of 8838 objects (95% population) with a reliable estimate of the average reduced brightness in

the ISON database (values of brightness bringing to standard conditions: diffuse-reflecting sphere model, range 40000 km, phase angle 0°).

Brightness 15.5^m approximately corresponds (for GEO) to 1 m size of the object in 1 m, 17^m – 40 cm, 18.5^m – 20 cm, 20^m – 10 cm. The dip between 13^m and 16^m due to the state of the population of space objects while decline beyond 18.5^m due to the insufficient sensitivity of telescopes used. Thus there is area of insufficient control on the right and it is not yet known how many space debris objects can be expected here.

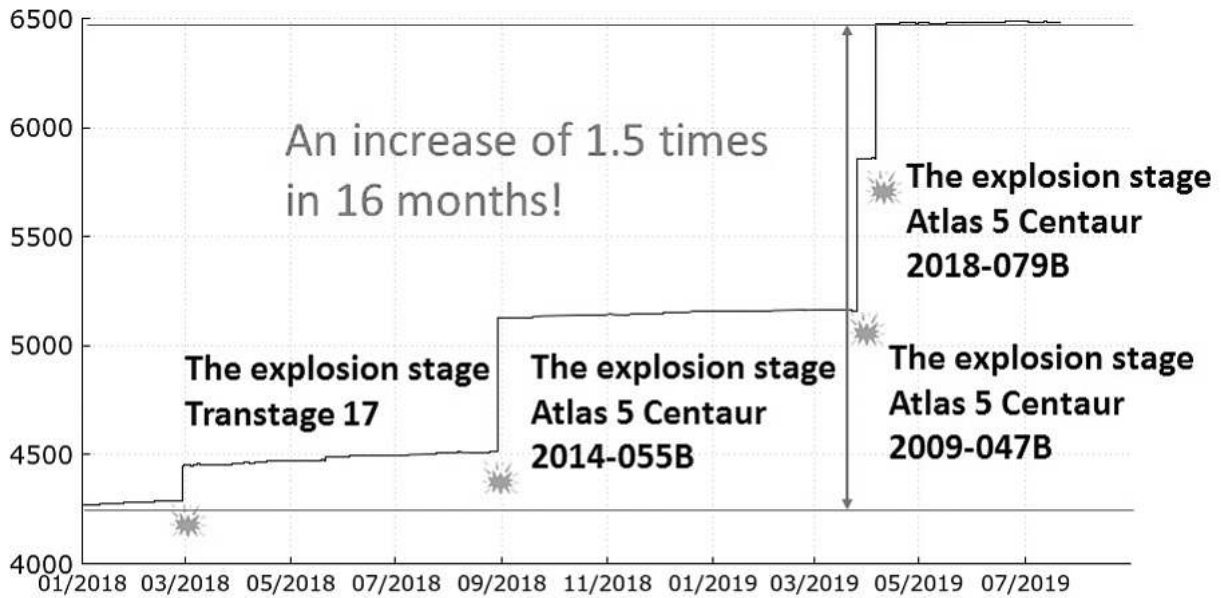


Figure 5. Changes in number of cataloged objects, identified with parent bodies. The figure shows the significant increase in the number of fragments of space debris caused by the detected destructions of rocket stages. Vertical axis - number of objects, horizontal – dates.

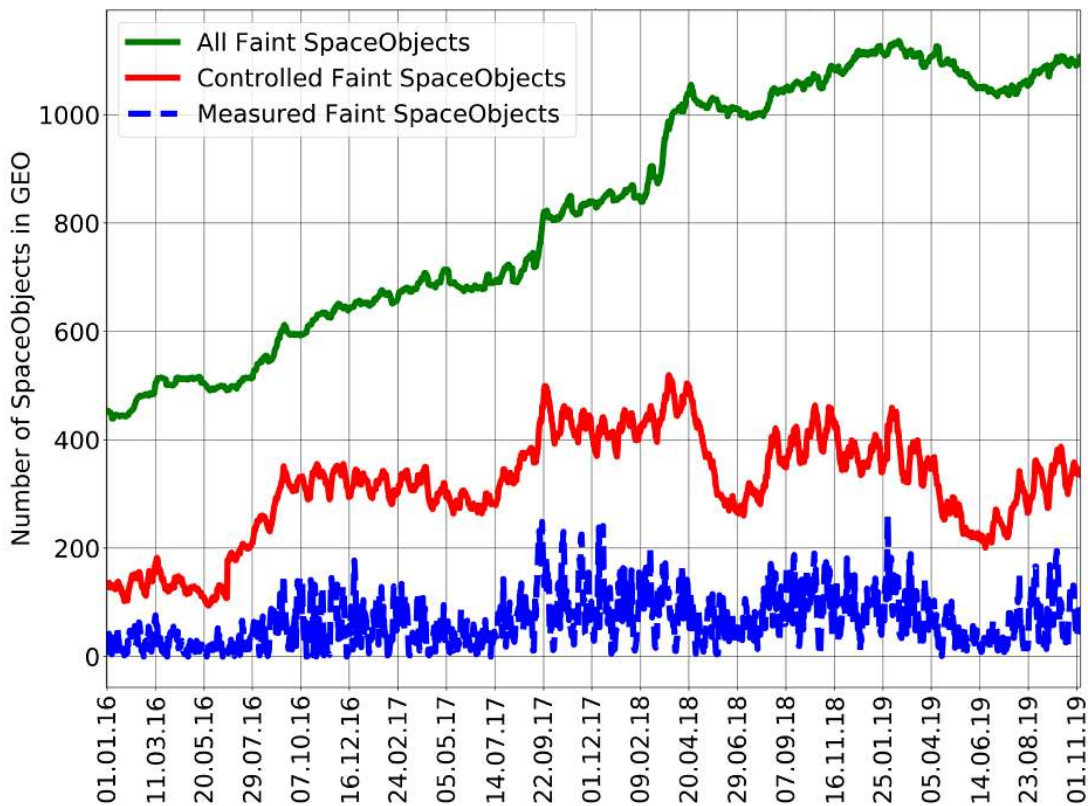


Figure 6. State of the ISON database in part of faint GEO-objects yearly. Here are shown the parameters of the catalogue of faint GEO objects for the 4 years period. Curves of different color indicate total number of objects fainter 15.5^m (green), number of objects measured during current night (blue), and number of objects with accurate orbits (red). Vertical axis - number of objects, horizontal axis-dates.

ASTEROID FOLLOW-UP AND DISCOVERY SURVEYS

ISON project develops the technology of the asteroid surveys, so called a survey of “second wave” (using small telescopes having large FOV) for the purpose of detecting asteroids and comets missed by “deep” asteroid surveys (like Mt. Lemmon (Christensen et al. 2019) and Pan-STARRS (McNeill et al. 2018)).

Among small bodies found in the Solar system scientists distinguish special population of asteroids that approach the Earth – near-Earth asteroids (NEA). From the fundamental science perspective, NEA offer opportunity to study physical and chemical properties of the smallest celestial bodies that are available for observation only due to their close proximity to the Earth. Studying NEAs provides unique scientific information about the origin of asteroids and draw conclusions about the evolution of the Solar system and migration of small bodies in the Solar system. At the same time, these space bodies represent potential hazard to the inhabitants of the Earth in an event of impact, as well as is possible source of extraterrestrial raw materials for the exploration of outer space and also interesting in terms selecting targets for space missions. Therefore scientists of many countries involved in detecting and cataloging objects approaching Earth, studying evolution of their orbits and investigating physical and mineralogical properties of NEA. International Asteroid Warning Network (IAWN) was created under auspices of the United Nations, to track and characterize newly discovered NEAs.

ISON has been conducting the regular search and survey observations of the asteroids since mid-2010. Three main tasks were solved: developing an effective search strategy for NEA (method for effective scheduling of the asteroid surveys), selecting optimal set of

the equipment for survey observations and creating full complex of dedicated software for the robotic observatories. During 2016-2017, surveys were performed using two 40-cm telescopes - in Mayhill, USA (SANTEL-400A having FOV of 1.75°) and Siding spring, Australia (ASA 16” Deltagraph having FOV of 2.2°) on AP-1600GTO automated mounts. Observations with limiting magnitude of 20.5 were carried out remotely via the Internet with downloading of obtained CCD images to Moscow in real time to process at the center created for planning and analyzing asteroid surveys. Such spreading in latitude and longitude, along with favorable weather conditions, allowed conducting almost continuous monitoring and quick follow up of the discovered objects. Both telescopes in the USA and Australia covered the 900 square degrees per night. Testing own version of the KDS software to control the telescope equipment during the observations of small bodies of the Solar system completed. KDS software package allows increasing productivity of the survey by 25%. During this work more than 1 230 500 astrometry measurements were obtained and 1605 main belt asteroids, 17 near-Earth asteroids, 8 comets, 20 Trojans of Jupiter, 4 objects from the family of Hilda, 4 objects of the family of Centaur were discovered (Elenin et al. 2017). It is planned to resume the asteroid survey with new 40-cm telescope SANTEL-400/500 having FOV of 4.7° which will be installed in Multa (Republic of Altai, Russia). Four such telescopes will be able to cover survey the entire sky with limiting magnitude of 20.5 during two or three nights.

Fig. 8 shows the distribution of the ISON discovered asteroids by semi-major axis and eccentricity. Obtained data used to develop a model of the probability of the NEA detection in various parts of the sky (Ipatov & Elenin 2018), which will significantly increase the efficiency of the asteroid survey.

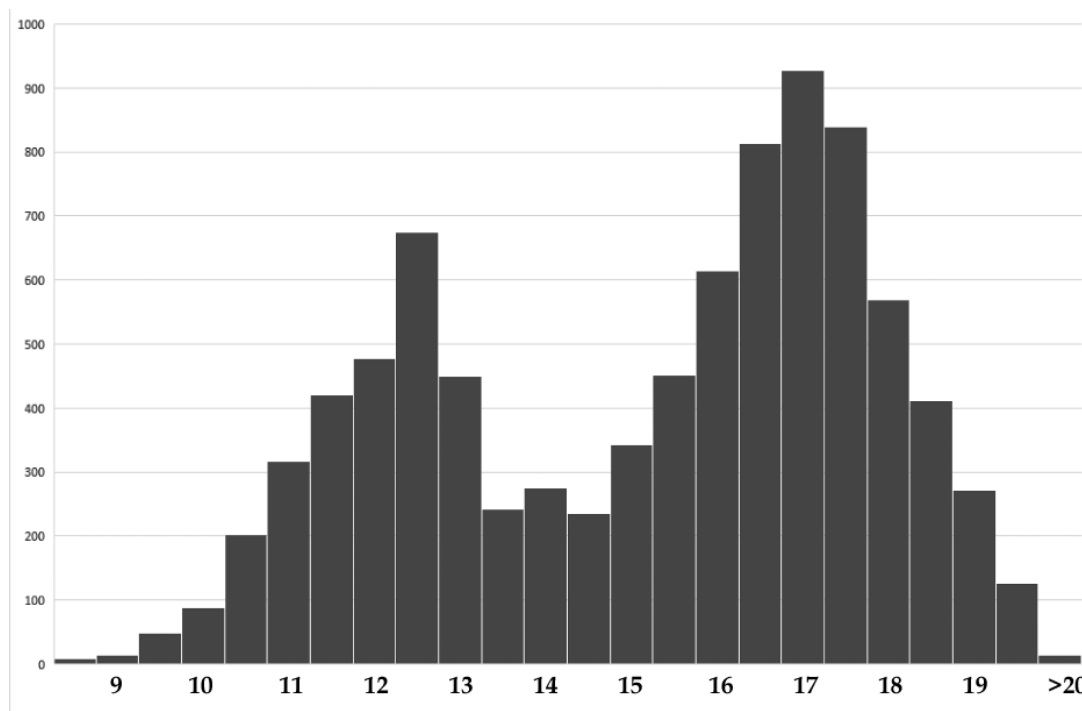


Figure 7. Distribution of objects in the ISON database by the average reduced brightness (vertical axis – number of objects, horizontal – brightness in magnitudes).

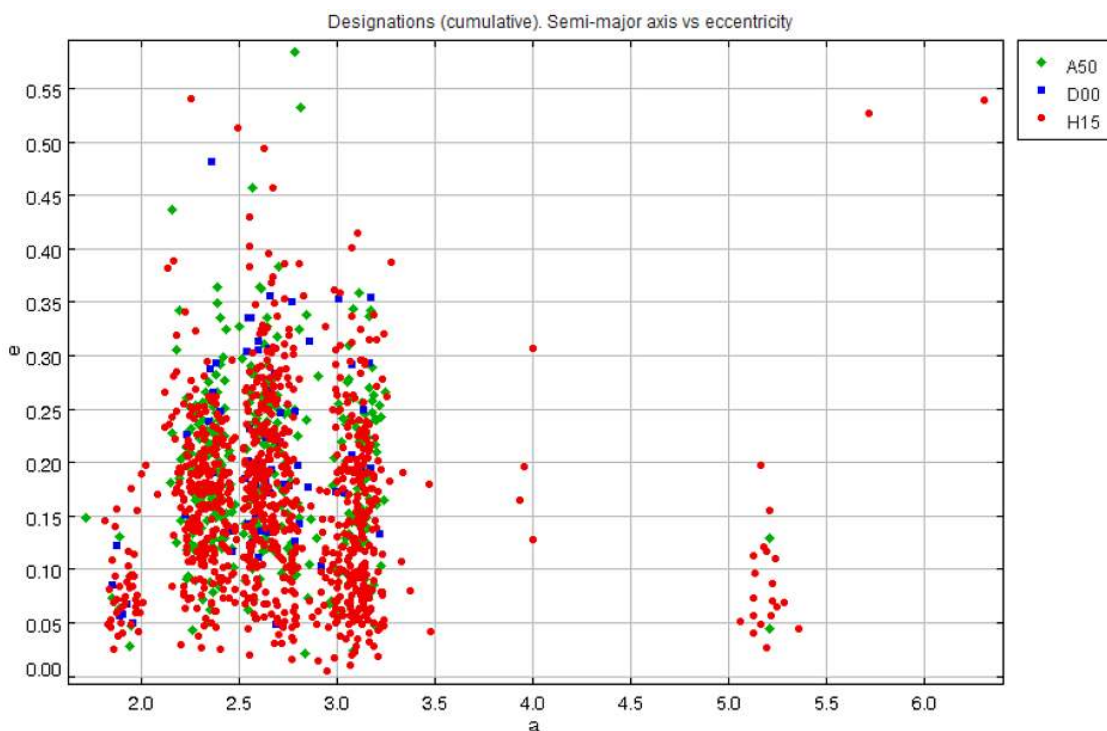


Figure 8. Distribution of asteroids discovered with ISON by orbital elements (semi-major axis/inclination). Discoveries related to different observatories are highlighted in color (MPC code A50 - green, D00 – blue and H15 – red). Vertical axis –values of semi-major axis, horizontal –value of inclination.

ASTEROID PHYSICAL PROPERTIES INVESTIGATION BY PHOTOMETRY

ISON project investigates the physical properties of near-Earth asteroids by regular photometric observations on telescopes of the ISON network. Main purpose of the observations is obtaining NEA characteristics: rotation period, size and shape of the body, surface composition etc. Research aims to study newly discovered and potentially hazardous NEA, binary asteroids, targets of radar observations and space missions, as well as to investigate the influence of the non-gravitational effects (the Yarkovsky–O’Keefe–Radzievskii–Paddack (YORP) and the BYORP effects) on the dynamics of asteroids.

During 11 years, ISON arranges several photometric observation campaigns for asteroids per year involving a significant number of telescopes with apertures from 60 cm to 2.6 m (Krugly et al. 2010). To contribute to this goal, few relatively large telescopes (2.6-m ZTSh and 64-cm AT-64 in Nauchny, 1-m Zeiss-1000 in Simeiz, 70-cm AS-32 in Abastumani, 70-cm AZT-8 in Chuguev, 80-cm RK-800 in Mayaki, 1.5-m AZT-22 and 60-cm Zeiss-600 in Maidanak) were upgraded and/or equipped with the CCD cameras and filter wheels forming the basis of the international cooperation, which was then joined by Rozhen observatory (2-m Zeiss-2000 and 60-cm Zeiss-600) in Bulgaria and Tien-Shan observatory (1-m Zeiss-1000) in Kazakhstan. Observations and their reduction were performed using the original technique for fast moving NEA, developed by the Institute of Astronomy of KhNU (Krugly et al. 2002, Krugly 2004).

ISON extended network is well suitable for studying asteroids that can be observed for long-time intervals to cover few possible rotation periods. The solar-heated surface of asteroid re-emits the thermal photons that

cause reactive forces, which ultimately act on changing both the speed of rotation of asteroid and the position of its axis of rotation. It is a subtle effect called YORP (Bottke et al. 2006, Vokrouhlicky et al. 2015, Golubov et al. 2016). It can increase or decrease the asteroid rotation speed, but its influence becomes noticeable only over secular time interval. The effect depends on the size and shape of an asteroid and its distance from the Sun. In addition, it also depends on the structure and optical properties of the surface. Moreover, YORP can modify the orbital parameters of binary asteroids system, the so called BYORP-effect (Cuk & Burns 2005, Steinberg & Sari 2011). In the case of the available shape model and the surface albedo is possible to calculate the expected influence of the YORP-effect on the period of rotation. The effect can be directly detected for asteroids in real time by measuring the rotation speed variations using lightcurve photometry. If asteroid lightcurves are obtained at sufficiently large intervals of time (several years to several decades), it possible to determine the sidereal period with accuracy greater than the period change caused by the effect during this time (Kaasalainen et al. 2007).

The value of YORP can be estimated by constructing the physical model of the asteroid by the lightcurve inversion method. If the effect is valid, then the observational data are better fitted by the model under assumption of linear change of the sidereal rotation period P in time t . In the terms of the rotation speed $w = 2\pi/P$, it can be expressed as: $w(t) = w(t_0) + v(t-t_0)$, where $v = dw/dt$ is a constant with dimension of $rad\ day^{-2}$, which stands for YORP.

Besides the systematic researching new discovered NEA, ISON observations include the survey of the well-known NEAs, small main-belt asteroids and their clusters to confirm the presence of binarity and to study the influence of YORP-effect on the formation of the binary and

multiple systems (since one of the YORP actions is the unwinding of small asteroids to the limit of their destruction). Also known binary systems are observing for identifying BYORP-effect. On average, about 50 asteroids are observed during 250 nights per year. In general around the 700 lightcurves for 300 NEAs were received.

Fig. 9 shows as asteroids are selected for observational programs, where the ratio of the known binaries and suspected to be binary NEAs is presented for the 2013-2016 period. Among 190 observed NEAs 18 were binaries and 30 NEAs had been suspected to be binary (the signs of binarity for 7 of them were actually found). Fig. 10 shows sample of the obtained results

– determined rotation periods for asteroids in 2015.

Data obtained allowed taking part in a number of the pioneering theoretical and observational studies (Pravec et al. 2012, 2016), in particular the YORP effect was discovered for (1862) Apollo, (1620) Geographos, (3103) Eger, and (1685) Toro. In 2019 the experimental confirmation of the BYORP effect was firstly obtained for the binary asteroids (66391) 1999 KW4 and (88710) 2001 SL9 (Scheirich et al. 2020). On other side, the YORP-effect was not registered for (1865) Cerberus, and (2100) Ra-Shalom (Ďurech et al. 2012) for which the effect was predicted from the shape models.

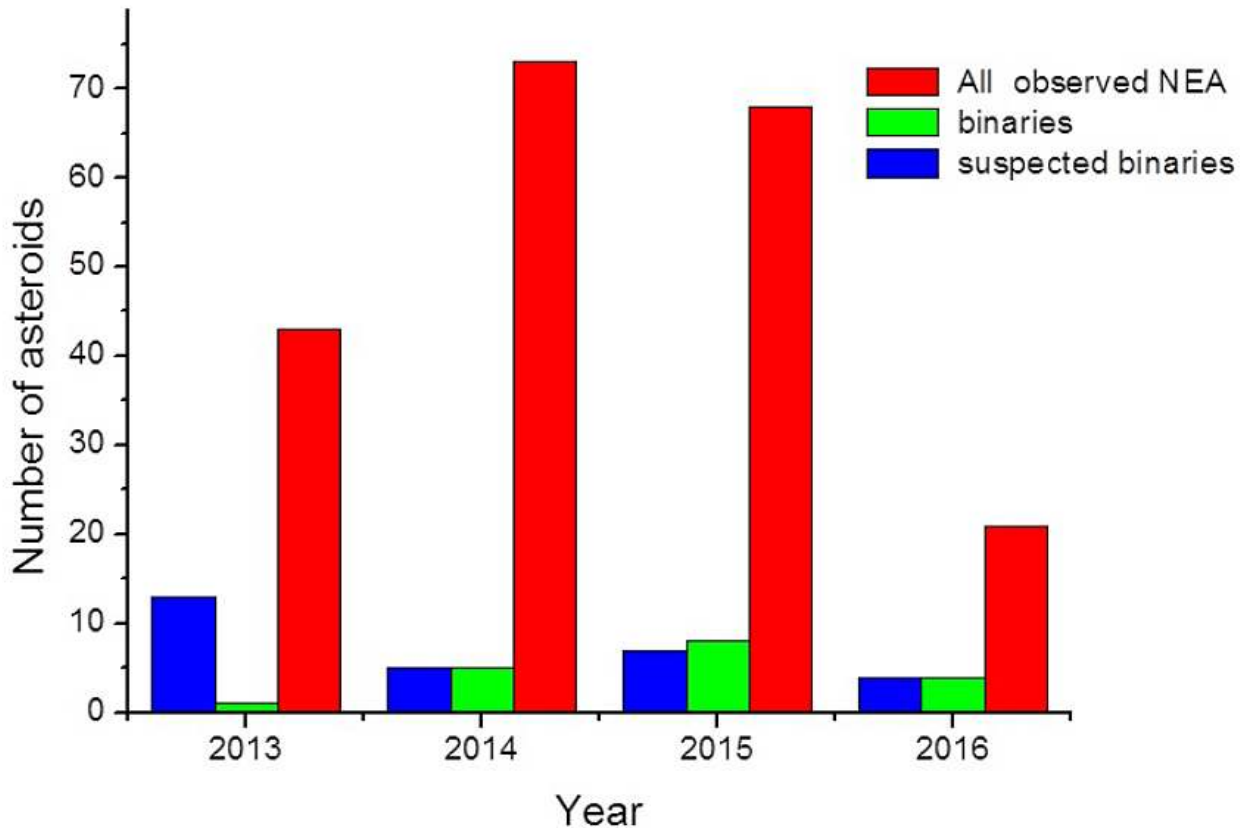


Figure 9. Number of simple, binary and potentially binary NEAs observed in 2013-2016. Statistics of observations over a 4-year period. Vertical axis –numbers of asteroids, horizontal – years.

Fig. 11 shows example of lightcurve obtained in 2016 for asteroid (1685) Toro (this result was later used for obtaining YORP value (Ďurech et al. 2018)).

During 2019 the photometry of 70 NEA was carried out during over 300 nights which allowed accomplishing the following tasks:

- 1) Determination of the rotation period, estimation of the size and elongation of the asteroid body shape: rotation period was found for eight NEA with diameters greater than 0.5 km. In particular for (18172) 2000 QL7; (89959) 2002 NT7; (152754) 1999 GS6; and (162082) 1998 HL1. In addition, rotation periods for five NEA were confirmed.
- 2) Observations of small size NEA: 17 NEA with diameters less than 300-500 m were observed, of which eight are newly discovered asteroids. Rotation periods for 10 of them have been determined or estimated for the first time.
- 3) Binary asteroids search and confirmation: According to the features of binary bodies which include a short rotation period in the range from 2.2 to 4.5 hours and low amplitude of lightcurve, four NEA were selected and observed: (1866) Sisyphus; (68216) 2001 CV26; (152931) 2000 EA107; and (454177) 2013 GJ35. The light curves for (68216) 2001 CV26 indicated that the asteroid brightness deviations from the periodic variations were present, that is, the exhibition of possible occultation phenomena in the binary system, which needs further investigation.
- 4) Observations of well-known binary asteroids: extensive observations were made for four binary NEA (7088) Ishtar; (65803) Didymos; (66391) 1999 KW4, and (137170) 1999 HF1. These observations will be used to refine the dynamics and shape models of these binary systems, to analyze the evolution of the binary asteroids, and to determine the BYORP effect.
- 5) Study of the YORP effect influence on the rotation of the NEA: within the long-term observation program to discover and study the YORP-effect several asteroids have been observed: (1620) Geographos; (1862) Apollo; (1917) Cuyo; (1865) Cerberus; (2100) Ra-Shalom; (5797) Bivoj; (68950) 2002 QF15; and (105140) 2000 NL10. Particular attention was paid to obtaining light curves for the so-called coorbital NEA, whose orbits are very close to the Earth: (441987) 2010 NY65; (511684) 2015 BN509; and (522684) 2016 JP.
- 6) Photometry of asteroids that are targets of space missions: BVRI photometry was done for NEA (3200) Phaethon that is an unusual Apollo-type asteroid identified as possible dormant or extinct cometary nucleus associated with the Geminids meteor stream. The asteroid will be the target of the space mission DESTINY+ of the Japan Space Agency. The binary asteroid (65803) Didymos that is the target of international double-spacecraft collaboration between NASA and ESA for 'Asteroid Impact Deflection Assessment' experiment (DART and Hera missions) was also observed.
- 7) International observation campaign: In May-July 2019, the network actively participated in an international monitoring company organized by the UN IAWN project for the study of the binary NEA (66391) 1999 KW4 which now has a name Moshup. The asteroid was observed during 55 nights using 10 telescopes with diameters from 36 cm to 1 m.

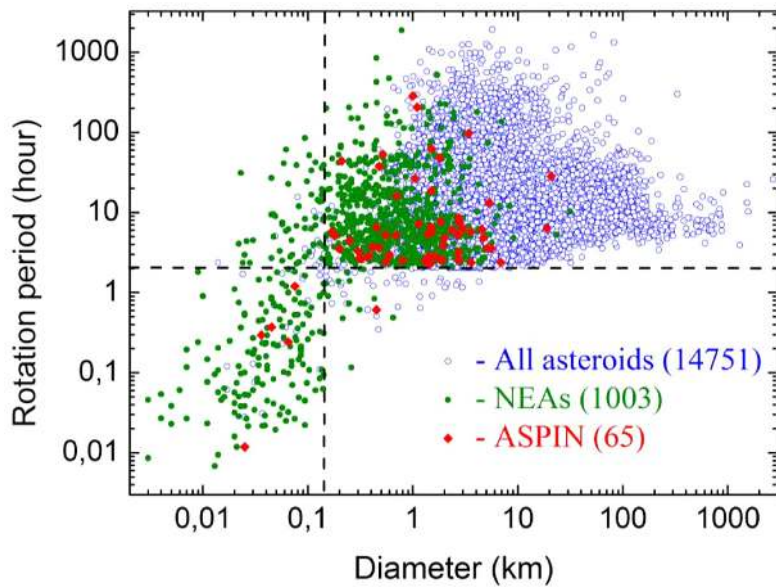


Figure 10. Distribution of asteroids rotation periods and diameters. NEA observed by ISON in 2015 are highlighted in red.

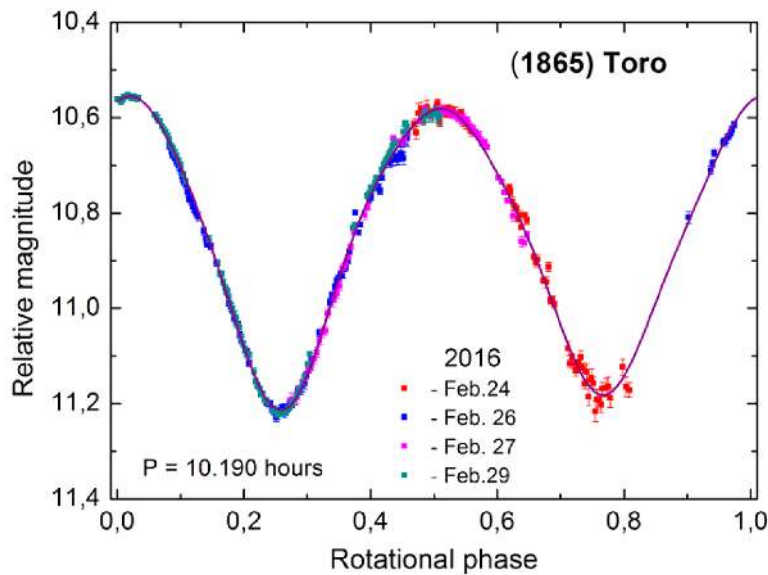


Figure 11. Composite lightcurve of the asteroid (1685) Toro from observations at the 70-cm telescope AS-32 in Abastumani Observatory in February 2016.

CONCLUSIONS

Currently, ISON scientific cooperation consists of 53 telescopes at 27 observatories and carries out the investigations of the space debris and asteroids. ISON small survey telescopes cover all GEO orbit and provide the significant contribution to the maintenance of the catalogue’s accuracy for space objects brighter 15.5^m that is important for the conjunction analysis procedure.

Due to a 15-year series of the observations of space debris by ISON the knowledge about the SD population at the GEO and HEO has reached a fundamentally new level. ISON database contains the orbital information for 9300 objects at high orbits and 23.4% of that have an area-to-mass ratio greater than 1 m²/kg. More than 2,000 new fragments at the HEO were catalogued in last 2 years because of the 4 detected destructions of the rocket stages.

Trial asteroid surveys aimed at testing the equipment and developing the software and methods have been completed. 1 230 500 astrometry measurements were obtained since 2010. 1605 main belt asteroids, 17 near-Earth asteroids, 8 comets, 20 Trojans of Jupiter, 4 objects from the family of Hilda, 4 objects of the family of Centaur were discovered. The obtained data are used to develop a model of the probability of the NEA detection in various parts of the sky. The next ISON regular asteroid survey with new series of 40-cm telescope (22 square degrees field of view) will start in 2021.

For 11 years ISON has been conducting several photometric observation campaigns for asteroids per year. In average, more than 50 asteroids are observed each year during more than 250 nights. In common around 700 lightcurves for 300 NEAs were received. Obtained data allowed taking part in a number of pioneering theoretical and observational studies. Few binary asteroids and asteroids with the YORP-effect and BYORP-effect were detected with an involvement of the ISON data.

The results of the work are based partially on observational data obtained with the 1 m telescope in Simeiz of the center for collective use of INASAN. The work at Abastumani was supported by the Shota Rustaveli National Science Foundation, Grant RF-18-1193. The work is supported by the Targeted Financing Program BR05336383 Aerospace Committee of the Ministry of digital development, innovations and aerospace industry of the Republic of Kazakhstan. Authors thank Igor Kirilenko for carefully reading the text and editing the language.

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