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New status of ISON - an open international project and database for space debris information exchange

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Abstract

International Scientific Optical Network (ISON) was an open international scientific project specializing in observations of the near-Earth space objects. Started in Pulkovo observatory in 2004, ISON project then continued in Keldysh Institute of Applied Mathematics RAS (KIAM RAS), and is currently under dedicated company Small Innovation Enterprise "ISON Ballistics-Service" (SIE ISON-BS). With this goal SIE ISON-BS developed the observation scheduling centre and database. A new direction of project development was the arrangement of an international centre for the exchange of measurement and orbital information on space debris. SIE ISON-BS established an international exchange of data with a number of observatories, universities and scientific institutes. Therefore, although the number of observatories of the project has decreased to 22 (telescopes of SIE ISON-BS are now in 14 observation points and there are 8 partner observatories) the volume of measurements in the ISON database has grown few times. In 2022 ISON database received in average daily 120 thousand measurements and obtained to end of year over 45 mln. measurements in almost 5 mln. tracklets, and maintains the orbits of 10086 space objects (3122 GEO, 5267 HEO and 1697 MEO), from that 3226 are objects with high are to mass ratio (including 901 GEO, 1461 HEO and 864 MEO) on 01.09.2023. ISON carries out the scientific and commercial activities under grants and contracts with foreign organizations.

Keywords: optical telescope, measurements, space debris, orbit, database

1. Introduction

The exploration and investigation of the near-Earth space (NES) has led to the emergence of problems associated with its technogenic pollution by the so-called "space debris" (SD). The number of exhausted satellites, various rocket stages and fragments accompanying each launch has reached the limit when it begins to pose a serious threat not only to manned orbital stations and functioning spacecraft (spacecraft), but also to the ecology of the Earth and the NES. Further exploration of the NES is impossible without knowledge of the current situation, analysis of sources and patterns of evolution of the SD population. Data on the population of the NES by space objects (CO) are necessary to create a model of the SD population, develop the measures to reduce clogging, as well as determine the degree of danger that a particular CO poses to the spacecraft. The main tool for solving these problems is a regularly updated database containing measurement and orbital information about spacecraft and SD objects. One of the important ways to fill it with astrometric measurements are observations using optical telescopes. And within the framework of the International Scientific Optical Network (ISON) initiative project [1,2], a global network of optical monitoring of SO in high Earth orbits is developed since 2004.

In the interests of creating a monitoring network, the current state of observatories in the former Soviet Union countries was investigated, a cooperation of ISON observers was established and grants were received for the purchase of the country's first large-format CCD cameras. In order to re-equip the observatories participating in the project, the production of several types of new optical telescopes with an aperture from 12.5 cm to 65 was arranged [3]. In total, 70 new telescopes were produced, including 21 telescopes commissioned by Roscosmos [4]. Modernization or retrofitting of 15 existing telescopes with an aperture of 50 cm – 2.6 m has been carried out. A standard set of software (software) has been created for controlling telescopes and processing CCD frames [5], a single solution (based on a GPS receiver) has been developed for accurate measurement time reference. At the end of 2016, thanks to these works, a global interdepartmental network of optical monitoring of high Earth orbits was formed [6]. 76 telescopes of 38 observatories of various departmental affiliation (academies of sciences, universities, Roscosmos, commercial companies, as well as privately owned ones) participated in obtaining measurements, which were combined into 6 main subsystems.

At its peak, the global interdepartmental network of observatories included up to 100 telescopes in 33 observatories in 17 countries (Australia, Armenia, Bolivia, Brazil, Georgia, Spain, Italy, China, Mexico, Mongolia, Transnistria, Russia, USA, Uzbekistan, Ukraine, Switzerland, Chile). The multiple increase in the flow of measurements led to the disintegration of the network into departmental components and a drop in interest in the data of the ISON itself and the actual termination of funding for the origin core of the project. An attempt to save the ISON project in the new conditions was made by Small Innovation Enterprise "ISON Ballistics-Service" (SIE ISON-BS).

2. Current status of the ISON network and database

2.1 Small Innovative Enterprise "ISON Ballistics-Service" as new coordinator of the ISON project

Small Innovative Enterprise "Ballistics-Service" was established in 2015 at the Keldysh Institute of Applied Mathematics (KIAM) of the Russian Academy of Sciences, which coordinated the ISON project since 2010, with its equity participation to formalize ownership on the telescopes of the ISON project, as well as the formal commercialization of the results of scientific research. Additionally, it was planned to provide an opportunity to conclude contracts with foreign partners and customers, to organize new job places for the participants of the ISON project to provide the exploitation of the ISON telescopes. In total, 32 ISON telescopes were taken to the balance of SIE "Ballistics-Service".

At the end of 2019 KIAM came out of the co-founders of the SIE "Ballistics-Service". And an attempt to save the ISON project in the new conditions was made by the company SIE "Ballistics-Service". The company changed its name to SIE "ISON Ballistics-Service" and began to look for new customers for observation service, as well as to build a new cooperation of the ISON project. SIE ISON-BS has established its own observation scheduling centre, which operates on a daily basis, and has organized its own database. The development of new software for controlling telescopes and equipment was supported [7]. A building was purchased in which a workshop was organized for the repair of astronomical equipment and small-scale production. In order to increase the degree of automation of ISON telescopes, a series of focusing devices was manufactured, and a shutter design for a CCD camera was developed. The new cooperation of the ISON project was formed on the basis of SIE ISON-BS, with which the agreements with partners and financial contracts with customers are signed. The agreement on collaboration were signed with 3 new observatories and 5 Universities. In terms of the development of the ISON network, small telescopes were installed in Slovakia (20-cm Celestron) and South Africa (22-cm SRT-220), 2 telescopes were repaired in Mongolia (19.2-cm VT-78a and 40-cm ORI-40), one telescope was repaired in Bolivia (60-cm Zeiss-600), the re-start of the 25-cm ORI-25 telescope in Mexico is in preparation. Fig. 1 shows the geographical locations and technical status of SIE ISON-BS telescopes and the partners. The number of observatories of the project has decreased to 22 (telescopes of SIE ISON-BS are now in 14 observation points and there are 8 partner observatories). Therefore, to increase the volume of measurements in the ISON database it was proposed new conception the arrangement of an international centre for the exchange of measurement and orbital information on space debris. SIE ISON-BS established an international exchange of data with a number of observatories, universities and scientific institutes and the volume of measurements in the ISON database has grown few times.

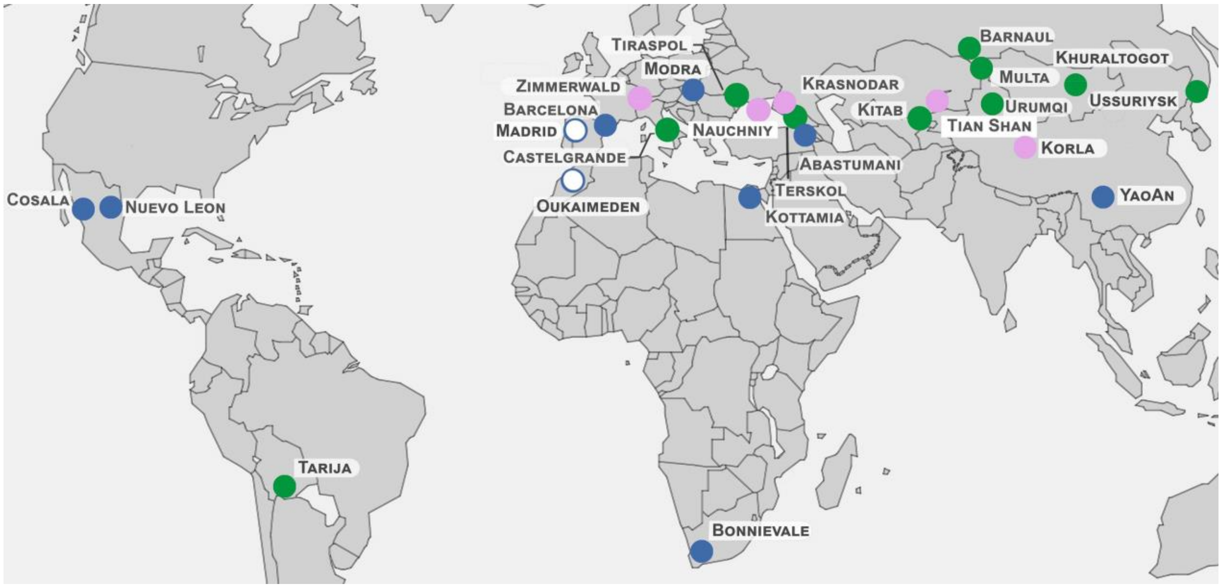

Fig. 1. Map of the ISON observatories: green colour – working telescopes, blue colour – stopped telescopes, rose colour – working telescopes of partners

2.2 New ISON database

The software system of data collection and analysis is based on the free object-relational database management system PostgreSQL, deployed under the Ubuntu 20.04 (LTS) operating system. The main structure of the database is shown on Fig. 2.

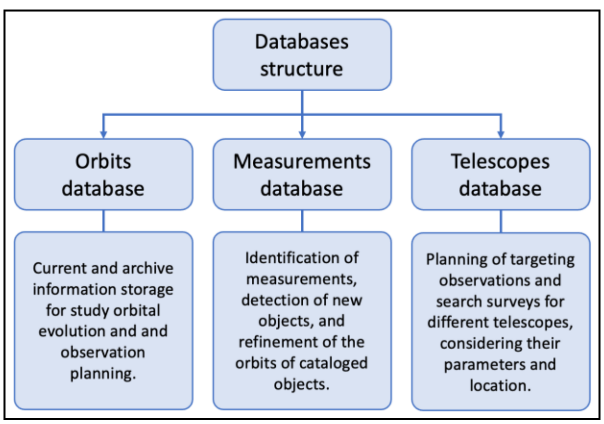

Fig. 2. Main structure of the new ISON database

Data of two types: optical position measurements and orbits list, are received on the server via FTP or SFTP protocols, after which they are validated. Several encodings are supported to work with international partners. The source files can also be uploaded in archives (tar).

After successful validation of the received data and determination of their type, they are delivered to one of the two processing pipelines (measurements and orbits), where they are parsed and written to the database. The system works with two independent tables "meas" and "orbits. If errors are detected during input validation, the source will be informed by the automated system to correct possible formatting problems or other errors. The data on telescopes contains all necessary information about optical telescopes: their coordinates and technical parameters, for the subsystem of automatic planning of observations. Its structure is presented in Fig.3.

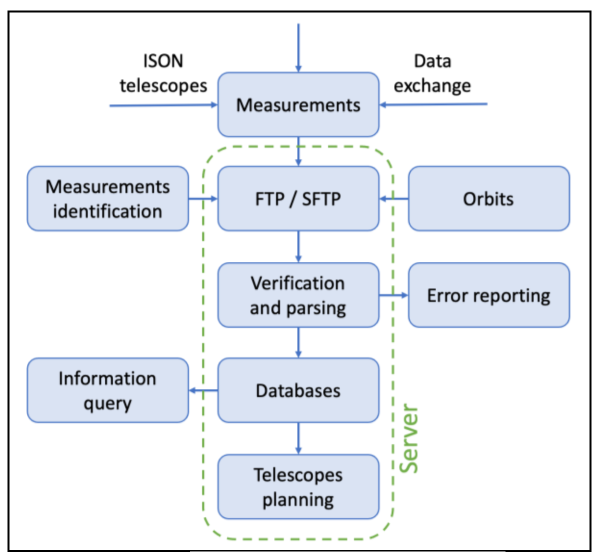

Fig. 3. Overall scheme of the system

The data processing software package was developed using the free cross-platform framework NET Core 6 and can be deployed on different types of x86 operating systems (Linux, Windows, MacOS). The hardware component of the server is based on Intel Xeon E2697 v2 processor (12 cores, 24 threads) and 64

GB of RAM. The total volume of disk storage is 12 TB (RAID 1 array, can be expanded if necessary).

As of September 1, 2023, the total database exceeds 127 million entries and takes up more than 45 Gb of disk space. It contains 96,333,409 measurements, 9,750,341 tracklets and an orbital archive for 10086 SO from which 3122 objects are at Geostationary orbits (GEO), 5267 objects - at highly-elliptical orbits (HEO) and 1697 objects - at Medium Earth orbits (MEO). Distribution in % of 96,333,409 measurements by magnitudes is shown on Fig. 4.

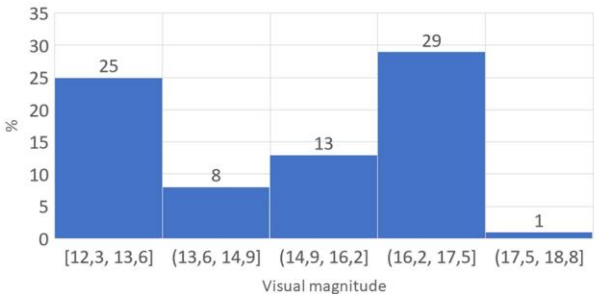

Fig. 4. Visual magnitudes distribution of measurements

In recent years, the composition of the database of high-orbit SO has changed significantly - on Fig. 5 are shown the curves of number of GEO, HEO and MEO objects by year. Parameters of the database of bright GEO-objects are presented on Fig. 6. The curves of different colours indicate total number of bright (15.5^m) objects in database (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. Measurements for 90% population of bright GEO-objects are regularly obtained, ensuring that accurate orbits are updated for 98% population that is necessary condition for conjunction assessment analysis [8]. Distribution in % of 1165 GEO-objects with accurate orbits by longitude is shown on Fig. 7.

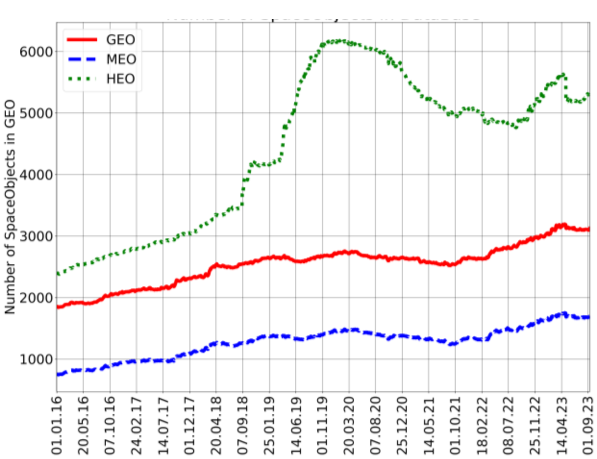

Fig. 5. Changing the number of objects at high orbits

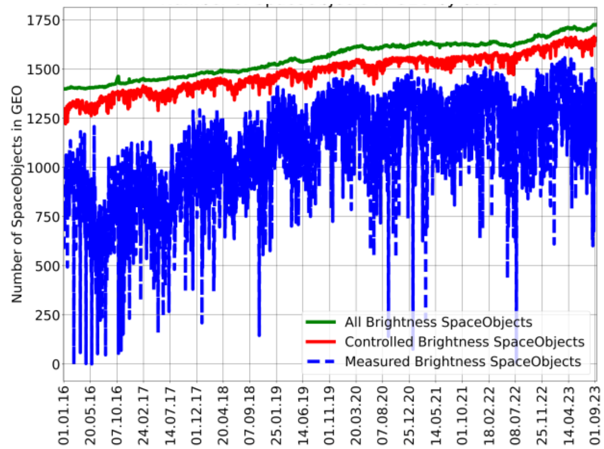

Fig. 6. Parameters of the database of bright GEO objects

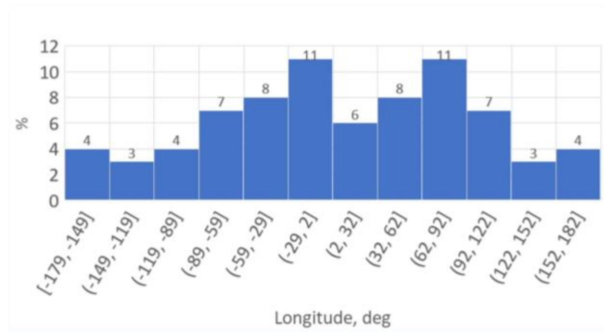

Fig. 7. Distribution of 1165 GEO-objects with accurate orbits in % by longitude

3. Parameters of the SO population at high orbits from the ISON database

On 01.09.2023 database contains the orbital information on 10086 SO from which 739 are the operating satellites. Distribution of the objects in the database by the brightness is shown on Fig. 8. Among these SO there are 3226 objects with high are to mass ratio (HAMR) > 1 m^2/kg (901 GEO, 1461 HEO and 884 MEO) what makes up 34.5% of known debris population. This is in 2 times more than it was in 2021 [3]. Distribution of HAMR-objects in the database by average value of ARM is shown on Fig. 9.

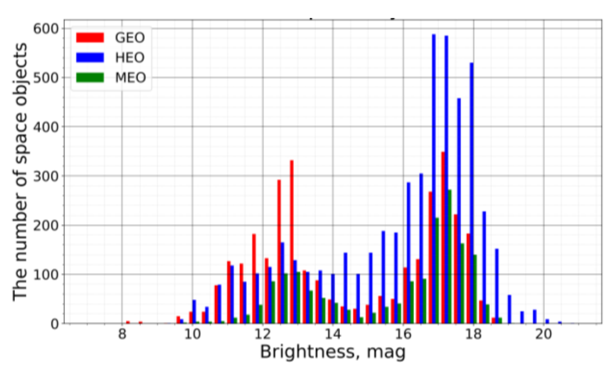

Fig. 8. Distribution of SO at high orbits by brightness

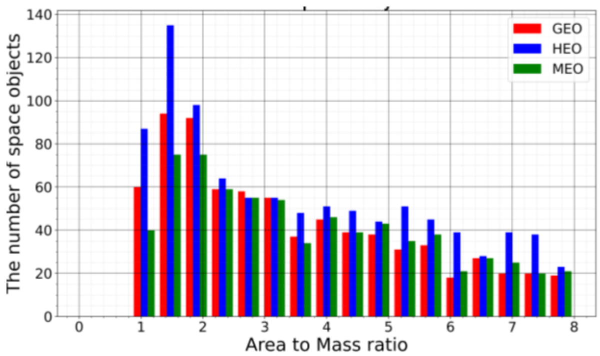

Fig. 9. Distribution of 3226 SO at high orbits by AMR

Twofold increase in the percentage of objects with a large area-to-mass ratio confirms the estimates in [9] that objects with an area-to-mass ratio greater than 1 m^2/kg make up at least half of the population of fragments of space debris in high orbits. Distribution of HAMR-objects by the brightness is shown in Fig. 10, by the inclination of the orbit - in Fig. 11, by the orbital period - in Fig. 12. Fig. 13 demonstrates the changing the number of faint objects (less than 15.5^m) at high orbits (GEO, HEO and MEO) in the ISON database. Comparison of Fig. 5 and Fig. 13 shows that the growth of number of the objects in the database is mainly due to the detection of space debris fragments, and that the main contribution to the change in the shapes of curves is made by faint SO.

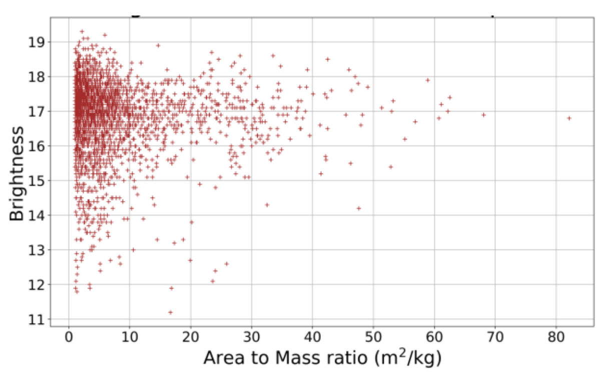

Fig. 10. Distribution of HAMR-objects by brightness

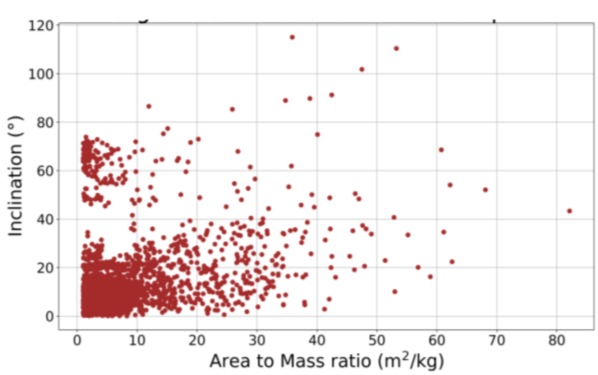

Fig. 11. Distribution of HAMR-objects by inclination

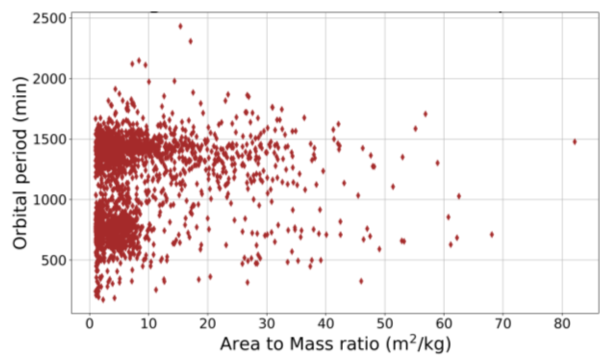

Fig. 12. Distribution of HAMR-objects by orbital period

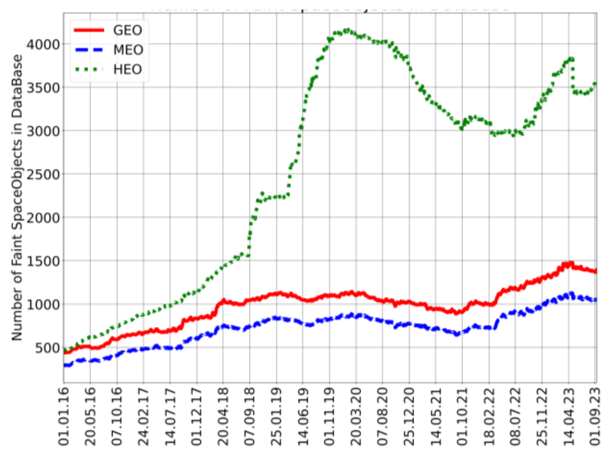

Fig. 13. Changing the number of faint SO at high orbits

Growth of number of the objects in the database occurred mainly due to HEO-fragments. For 6.5 years, their quantity has increased 7 times (!). Due to such a sharp increase in the number of weak objects, of which a significant part are HAMR-objects that are difficult to track, it is almost impossible to ensure their regular observations and reliable maintenance their orbits in the database. For example, Fig. 14 shows the parameters of database for faint GEO-objects.

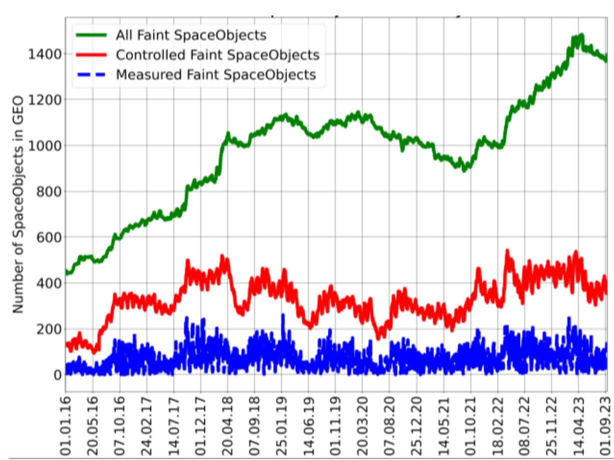

Fig. 14. Parameters of the database of faint GEO-objects

Fig. 14 demonstrates that measurements are regularly obtained only for a small percentage of faint GEO-objects (blue curve) and therefore the gap between their total number (green curve) and number of objects with accurate orbits (red curves) is very large and continues to increase with every year. Therefore, the orbits of most of the faint GEO-objects have an insufficient accuracy to be used in the conjunction assessment analysis.

The gap between 13^m and 16^m on Fig. 8 is reflection of the real state of the SD population, while decline after 18.5^m results due to the insufficient sensitivity of telescopes used. Thus, there is an area of insufficient control on the right and it is not yet known how many space debris objects can be expected here.

4. Conclusions

Since 2019, the ISON project has been implemented by the private company SIE ISON-BS. Thus, ISON has turned into an open international private project. The systemic crisis of the ISON network has been successfully overcome with the support of the grants and contracts with foreign customers [10,11] (although there are still many non–functioning ISON telescopes - see Fig. 1), the project development has resumed again, new telescopes are being put into operation. SIE ISON-BS elaborated the software for observation scheduling and database for collecting and analysis of the measurements and orbital information. There is the experience of conjunction assessment analysis for GEO satellites during half year of operations. Another important feature of the new phase is the strengthening of cooperation with the Chinese Academy of Sciences [12,13]. ISON continues to provide the significant contribution to monitoring the bright GEO-objects providing full coverage of GEO. In addition, the ISON project is gradually turning into an international centre for the exchange of information on space debris, which has allowed to significantly increase the volume of measurements entering the database. All interested parties are invited to cooperate. The exchange of measurements and orbits can take place in a variety of forms - for example, a telescope on a telescope, or obtaining measurements, analysing them and identifying with the reconstruction of orbit (with involving of ISON data), it is also possible to select the measurements from database for objects that are interesting to the partner.

References

[1] I. Molotov, V. Agapov, V. Titenko et al., International scientific optical network for space debris research, Adv. Space Res. 41, 7 (2008) 1022-1028.

[2] I.E. Molotov, Yu.N. Krugly, L.V. Elenin et al., Search and study of the space debris and asteroids within ISON project, An. Acad. Bras. Cienc. 93, 1 (2021) ID: e20200145, 1-17.

[3] I.E. Molotov, Ch. Zhang, L.V. Elenin et al. Development of survey telescopes in the ISON project, IAC-21-A6.1.12, 72nd International Astronautical Congress, Dubai, United Arab Emirates, 2021, 25-29 October.

[4] I. Molotov, V. Agapov, Yu. Makarov et al., EOP-1/EOP-2 mini-observatories for space debris observations: characteristics, tasks and first results of operation, IAC-14-A6.1.4, 65th International Astronautical Congress, Toronto, Canada, 2014, 29 September – 03 October.

[5] V. Kouprianov, I. Molotov, FORTE: ISON robotic telescope control software, id 475, 7th European Conference on Space Debris, Darmstadt, Germany, 2017, 18–21 April.

[6] I. Molotov, T. Schildknecht, F.J. Montojo F.J. et al. Increasing of new GEO/HEO space debris discovery rate with ISON optical network, IAC-16-A6.1.1, 67th International Astronautical Congress, Guadalajara, Mexico, 2016, 26-30 September.

[7] L.V. Elenin, I.E. Molotov, Software for the Automated Control of Robotic Optical Observatories, J. Comput. Syst. Sci. 59, 6 (2020) 894–904.

[8] A.I. Streltsov, M.V. Zakhvatkin, I.E. Molotov et al., Identification of potentially dangerous space objects and conjunctions, Keldysh Inst. Prepr. 3 (2019) 1-30.

[9] V.M. Agapov, I.E. Molotov, G.K. Borovin, A.I. Streltsov, Study of a population of space debris objects with a high area-to-mass ratio in high earth orbits, Eng. J. Sci. Innov. 2 (2020) 1-26.

[10] D. Escobar, F. Ayuga, A. Anton, A. Agueda, I. Molotov, GMV/ISON combined optical campaigns, id 414, 7th European Conference on Space Debris, Darmstadt, Germany, 2017, 18–21 April.

[11] Micheli M., Koschny D., Conversi L. et al., Optical observations of the BepiColombo spacecraft as a proxy for a potential threatening asteroid, Acta Astronaut. 184 (2021) 251-258.

[12] I.E. Molotov, R. Yu Sun, C. Zhang et al., Russian-Chinese observations of fragments of the destruction of the Centaur rocket stage are the first step to the network of BRICS observatories, in L. M. Zelenyi, B. M. Shustov (Eds.), Space Debris: Fundamental and Practical Aspects of the Threat, IKI RAN, Moscow, Russia, 2019, pp. 95-102.

[13] T. Zhu, X. Wang, J. Zhang, Sh. Yu, I. Molotov, Mean-Shift clustering approach to the tracklets association with angular measurements of resident space objects, Astron. Comput. 40 (2022) 100588.