STAGES OF DEVELOPMENT OF THE ISON OPTICAL TELESCOPE GLOBAL NETWORK

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ABSTRACT

ISON project had few stages of new tools and methods development to monitor the space debris. Firstly the obsolete telescopes that remained since the USSR were used. Then the 22-cm telescopes with FOV 4x4 deg. that could survey the entire visible part of the GEO were installed to maintain a catalogue of bright GEO-objects. Then the 19.2-cm telescopes with FOV 7x7 deg. were and the extended surveys were elaborated increases the orbit accuracy orbits for bright GEO-objects by obtained long tracklets. To detect HEO-objects the 2-tube and 4-tube systems were produced for Roscosmos observatories, with FOV 9x7 and 9x14 deg. Separation of Roscosmos and industry organizations segments caused to the refreshed ISON network for scientific and commercial activities under the auspices of Small Innovation Enterprise ñKIAM Ballistics-Serviceò.

1 INTODUCTION

Development and research of near-Earth outer space (NES) has led to the appearance and the awareness of problems of technogenic pollution known as space debris (SD). Goals of studying, modelling and preventing man-made threats to the implementation of space activities are more urgent than ever before. High Earth orbits are of great interest both for applied purposes of communication and navigation systems, and scientiýc researchers as well. Moreover Geostationary orbit (GEO) represents a limited natural resource which requires preservation for future use. There is no natural mechanism of self-cleaning here, similar to the low Earth orbit (LEO) region (decay of space debris fragments in the Earth atmosphere). Most of the GEO objects will live eternally, moving along the orbit. Monitoring of this region is a very topical goal due to the signiýcantly increased number of the catalogued space objects there, including works on providing for the safety of satellites and the development of the proper model of space debris population. This task requires a scientific tool 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) [1].

ISON is started in 2004 as open international voluntary project developed to be an independent open source of data about space objects for scientific analysis and spacecraft operators. ISON has not any special state budget support and is works based on scientific grants and contracts on observations of space objects. Therefore significant part of collaborating observatories participates in the project for scientific or applied

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interests and has possibility to use provided telescopes, equipment and software for solving of own goals. One from goals of the ISON project was supporting the astronomical observatories of former USSR and improving the international collaboration. Other important goals are developing the tools and methods of space surveillance. ISON project was one of pioneers in CCD sky surveying in Russia. Therefore a lot of equipment and software was elaborated and then distributed in tens observatories in Russia and other countries, and also implemented during creation of dedicated optical complexes of Russian agencies. The development of the ISON project took place in several stages, which are described in this paper.

2 START OF THE ISON PTOJECT

The first GEO object observations within this project were carried out in April 2001 at Pulkovo observatory which has a long history of astrometric satellite observations. It was the 10-cm AKD telescope that made the first photographic frame of the "Sputnik" rocket body on October 10, 1957. In next years, Nauchnij, Mayaki and Goloseevo observatories (Ukraine) joined this activity. Then, in 2002-2003, the work on identifying the present condition of all optical observatories of the former USSR and negotiations for possibility of their participation in the project of scientific network was performed. This allowed to elaborate the program of refurbishing and modernization of the telescopes involved, that was accomplished step by step with the support of the grant no. 03-70-567 of the International Association for the Promotion of Co-operation with Scientists from the New Independent States of the former USSR and the grant no. 09.255.52/053 of the Ministry of Education and Science of the Russian Federation during 2004-2006. 9 optical telescopes were equipped with CCD cameras and GPS receivers to arrange the optical network for space debris research: 64-cm AT-64 in Nauchny (Crimea), 32-cm ZA-320 in Pulkovo (near St.-Petersburg), 60-cm Zeiss-600 in Maidanak and 40-cm double Zeiss astrograph in Kitab (Uzbekistan), 40-cm double Zeiss astrograph in Ussuriysk (Far East), 40-cm double Zeiss astrograph in Abastumani (Georgia), 60-cm RC-600 in Mayaki and 70-cm AZT-8 in Chuguev (Ukraine), 23-cm expedition astrograph in Tarija (Bolivia), 70-cm AZT-8 in Gissar (Tajikistan) [1] and one new 25-cm MEAD LXD-75 telescope was installed in Paratunka (Kamchatka). The operational group for planning and scheduling ISON observations and the technical group providing a necessary support for ISON observatories, developing the dedicated software and technical solutions, and arranging the training courses, were created. Apex II [2], a universal software platform for astronomical image processing, being developed at the Pulkovo observatory, was distributed among the observers.

First ISON observations of tens of object at GEO and highly-elliptical orbits (HEO) objects were carried out in support of the radar experiments with Evpatoria RT-70 transmitter [3]. Later, in addition, a sample of GEO objects was regularly observed to verify their presumable explosions predicted using the Pulkovo theory [4]. Since June 2004, the continuous coordinated observation campaign for the GEO region was conducted jointly with Zimmerwald observatory of the Astronomical Institute of the University of Bern (AIUB) and observatories of the PIMS (the UK government asset for the surveillance of space with observatories in the UK, Gibraltar and Cyprus), aimed at searching, detection, and subsequent tracking of unknown GEO objects, determination of their orbital parameters, and orbital evolution estimation [5]. Results of orbital determinations for 60 objects were published in the 7th issue of the European Space Operation Center (ESOC) "Classification of Geosynchronous Objects" [6] and for 103 objects in the 8th issue [7] as unidentified objects in section 4.10.

These works in 2005-2007 allowed firstly in nation history to cover Geostationary orbit in the whole, but after the start of regular research, it became obvious that outdated non-automated telescopes with small fields of view (FOV) and insufficient sensitivity are not suitable.

3 CREATION OF GLOBAL SURVEY SUBSYSTEM

Since arranged telescope network modernization (purchasing the series of modern CCD-cameras) did not cause the expected effect on measurement obtaining rate, a decision was met to develop own dedicated telescopes. Therefore second stage of project in 2008-2011 had the main focus on elaboration of small survey telescopes with large FOV. Modelling and experiments showed that to fully cover the visible part of the GEO in a wide band, it is necessary to have a field of view of the telescope of about 15 square degrees. Therefore, 2 series of 22-cm telescopes, which have a field of view of 4x4 deg. with 36x36 mm CCD chip (and 5.5x5.5 deg. with 50x50 mm CCD chip), were developed - RST-220 (the optical scheme of the Slevogt Richter with a focal length of 507 mm) and ORI-22 (the optical scheme of the Hamilton-Newton with a focal length of 510 mm). For these new telescopes a strategy was developed for complete double surveys of the geostationary region for the night with a strip width of 18 deg. to detect all objects accessible by brightness. The principle of planning reviews is shown in Fig. 1, where the trajectories of all known geostationary objects are indicated, the area at the level of 16 hours along the axis of direct ascent is the Earth's shadow. Rectangles are FOV of telescopes, forming barriers, which are observed by the telescope during the night. Initially, survey telescopes were installed on top of obsolete

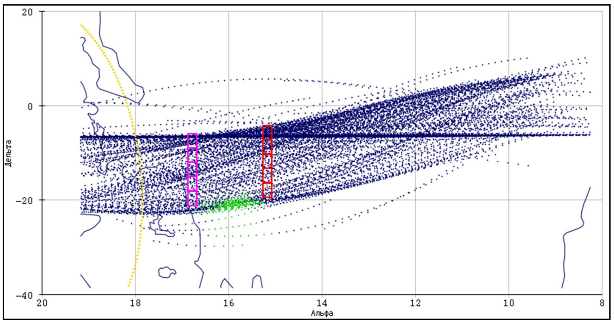

Figure 1. Planning barriers to standard GEO survey observations

telescopes (see example in Fig. 2) - in Pulkovo (on 10-cm AKD telescope), in Kitab (on 40-cm double Zeiss astrograph), in Ussuriysk (on 15-cm Zeiss Coude-refractor) in Abastumani (on 40-cm double Zeiss astrograph), and in Nauchny (on 40-cm Zeiss astrograph).

Then small automated mounts EQ6 Pro of Chinese production appeared on sale and 22-cm telescopes step by step were reinstalled on its, which required the elaboration of mount control software [9].

Also new such telescopes were putted in operations in Tiraspol (Pridnestrovian Moldavian Republic), Paratunka, Blagoveshchensk (Amur region), Lesosibirsk (Siberia), Andrushivka (Ukraine) and Collepardo (Italy). In addition 25-cm ORI-25 telescopes (the optical scheme of the Hamilton-Newton with a focal length of 625 mm) and automated mounts WS-180 were produced. Such sets were installed in Tarija, Cosala and Moterrey (Mexico), Chuguev (Ukraine), Urumqi (China) and Artem (Far East) thus completed the full overlap of the GEO with surveys.

Each 22-25 cm telescope provides per night a few thousands measurements for a few hundreds objects up to 15.5^m and average arcs from 15 to 40 minutes.

Figure 2. 22-cm survey ORI-22 telescope installed on 40-cm double Zeiss astrograph in Kitab (Uzbekistan)

Figure 3. 22-cm survey ORI-22 telescope on automated EQ6-Pro mount in Ussuriysk (Far East, Russia)

This work made it possible to compile and maintain a list of orbits of all bright GEO-objects. This subsystem continues 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 updated for 98% population which is necessary condition for conjunction assessment analysis [10]. Fig. 4 demonstrates the curves of different colors which 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 objectôs orbit was chosen as the criterion for orbit accuracy.

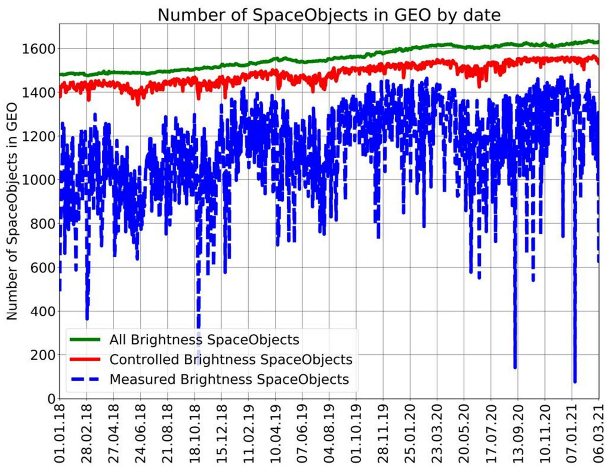

Figure 4. Parameters of the catalogue of GEO objects brighter 15.5^m for the 2018-2021 period

4 SUBSYSTEM FOR EXTENDED SURVEYS AND HEO-OBJECTS OBSERVATIONS

Next step in the ISON project development is connected with involving in the Roscosmos project "Automated

Figure 5. 19.2-cm VT-78a telescope on automated EQ6-Pro mount in Ussuriysk (Far East, Russia)

system for prediction and warning on the hazardous situations in the near-Earth space" (ASPOS OKP) [11]. It was necessary to elaborate new tools and methods to increase the accuracy of orbits of GEO-objects in catalogue. Therefore the 19.2-cm VT-78a telescopes (the optical scheme of the Schmidt-Houghton with a focal length of 296 mm) (see example in Fig. 5) with FOV 7x7 deg. were elaborated and method of extended GEO-survey was proposed.

Such telescope sets were installed in Ussuriysk (Far East), Khureltogoot (Mongolia), Multa (Republic of Altai) and Tiraspol (Pridnestrovian Moldavian Republic).

The technique of the extended GEO surveys (see Fig. 6) 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 deg. or more). 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^m. 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

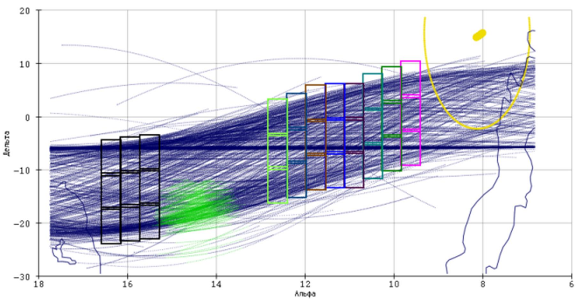

Figure 6. Planning barriers to extended GEO surveys

Figure 7. Four-tube 19.2-cm system of EOP-2 ASPOS OKP observatory in Kislovodsk (Karachay-Cherkessia)

detection of HEO-objects.

To solve the goal to detect more HEO-objects, two-tube and four-tube telescope (see Fig. 7) systems with FOV 9x7 and 9x14 deg. were developed within of elaboration of Roscosmos EOP-1 and EOP-2 observatories [12]. Four two-tube EOP-1 were installed in Kislovodsk (Karachay-Cherkessia), Byurakan (Armenia) and Nauchny (Crimea). Two four-tube EOP-2 were installed in Blagoveshchensk (Amur region) and Kislovodsk (Karachay-Cherkessia).

This work made it possible to greatly increase the quantity of HEO-objects in catalogue. Therefore in recent years, the composition and quality of the catalogue changed significantly (see Fig. 8). Quantity of HEO-objects increased 2 times and their number becomes 2.6 times more than GEO-objects. Such sharp increase in the number of objects leads to significant deterioration of the catalog parameters due to insufficient of observational resources. Since March 2020 quantity of HEO and GEO objects in catalogue for the first time it began to decrease. About 1000 objects were lost.

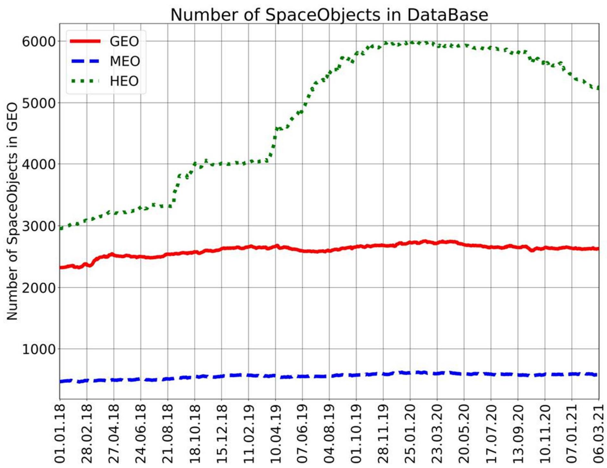

Figure 8. Changing the number of objects at high orbits (GEO, MEO and HEO) in the catalogue in 2018-2021

5 TRANSFORMATIONS OF THE ISON PROJECT

A global network of the 100 optical telescopes at 42 observatories of 18 countries was created. It was 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. 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 [13] 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 (see Fig. 9). Refreshed ISON network for scientific and commercial activities is arranged under the auspices of Small Innovation Enterprise ñKIAM Ballistics-Serviceò Ltd.

Currently, ISON consists of 53 telescopes at 27 observatories that includes own telescopes, telescopes of partners and telescopes observation time of that is received on base of scientific proposals. ISON carries out the investigations of the space debris and asteroids, has own scheduling and data analysing center.

ISON continues to provide the significant contribution to the maintenance of the catalogueôs accuracy that is important for the conjunction analysis procedure.

New ISON carries out the exchanges by measurements with observatories ï partners and provides the observations of the space objects for goals of commercial orders including foreign (supply of raw measurements, orbital data, conjunction assessment analysis). A first foreign customers is GMV [14].

6 CONCLUSION

Using the elaborations the ISON project, a powerful group of optical observation facilities was created, the measurements of which made it possible to maintain an orbital catalogue of about 9000 high-orbit space objects. In general, for 15-year series of the ISON observations the knowledge about the population of space debris in GEO and HEO reached a fundamentally new level. Nevertheless, the SD population at high orbits is still far from being fully studied. Status of catalogue (see Fig. 8) shows that observation network need in further developments. In particular, new methods of GEO monitoring will be developed with the new 40-cm

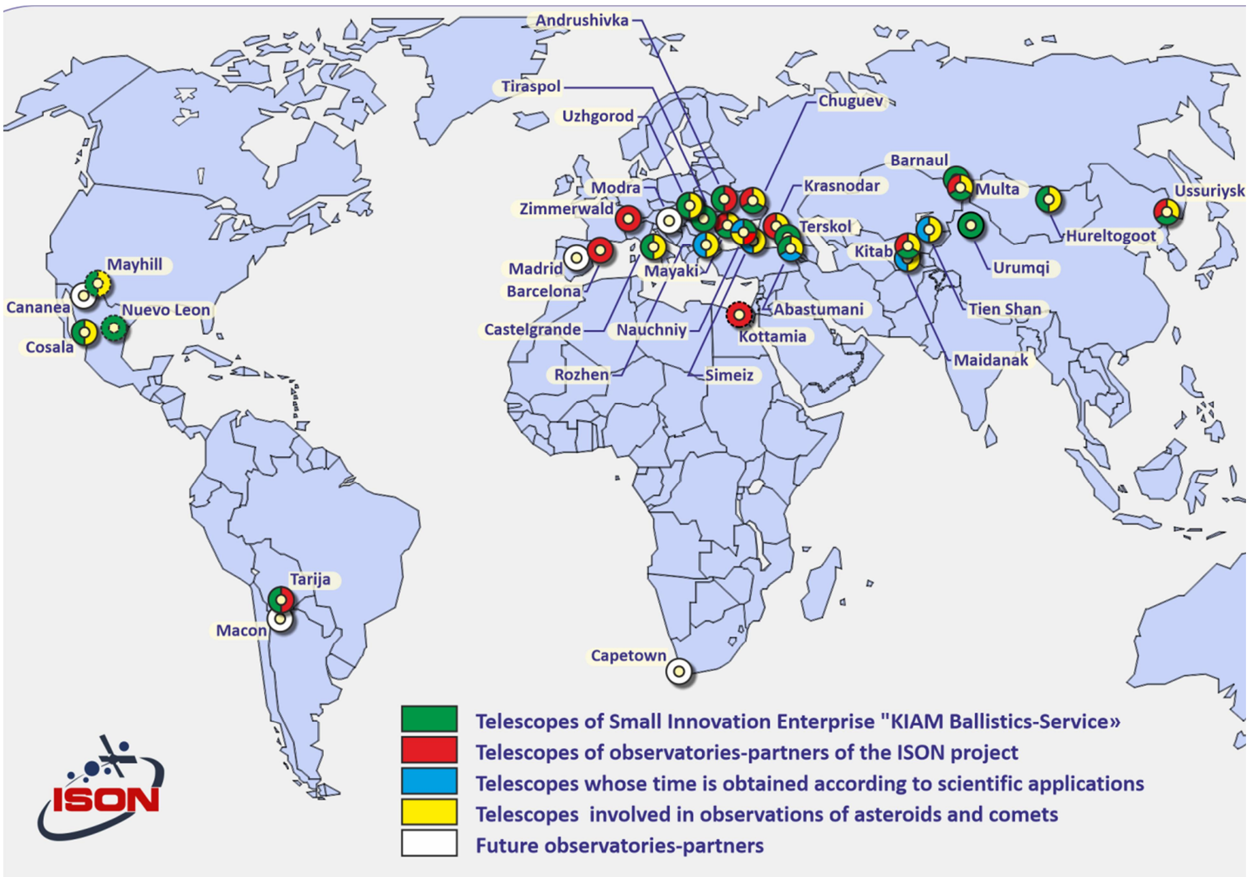

Figure 9. Map of the ISON observatories

SANTEL-400/500 telescope in Multa [15].

The withdrawal of the Roscosmos observatories and the cooperation of industrial organizations from the project did not lead to the collapse of the ISON network. The ISON project is being reassembled under the auspices of Small Innovation Enterprise ñKIAM Ballistics-Serviceò Ltd. Currently, ISON scientific cooperation consists of 53 telescopes at 27 observatories and continues to provide the important contribution to the maintenance of the bright objects catalogue. Now a new step in the development of the project is being carried out. 10 telescopes, including new types will be installed and put into operation. In particular Egyptian observatory in Kottamia [16] joins to ISON.

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8 REFERENCES

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

2. Kouprianov V. Distinguishing features of CCD astrometry of faint GEO objects. *Adv Space Res* **41** (7), 1029-1038.

3. Molotov, I., Konovalenko, A., Agapov, V. et al. (2004). Radar interferometer measurements of space debris using the Evpatoria RT-70 transmitter. *Adv in Space Res* **34** (5), 884-891.

4. Sochilina, A., Kiladze, R., Grigoriev, K., Molotov, I., Vershkov, A. (2004). On the orbital evolution of explosion fragments. *Adv in Space Res* **34** (5), 1198-1202.

5. Agapov, V., Dick, J., Guseva, I. et al. (2005). Joint RAS/PIMS/AIUB GEO survey results. In *Proceedings of the Fourth European Conference on Space Debris*, (Ed. D. Danesy), ESA SR-587, ESA Publication Division, Noordwijk, Netherlands, pp. 119-124.

6. Serraller, I. & Jehn, R. (2005). *Classification of Geosynchronous Objects* **7**. ESA, ESOC, Ground Systems Engineering Department, Mission Analysis Office.

7. Hernandez, C., Jehn, R. (2006). *Classification of Geosynchronous Objects* **8**. ESA, ESOC, Ground Systems Engineering Department, Mission Analysis Office.

8. Molotov, I., Agapov, V., Elenin, L. et al. (2009) Application of the ISON wide field of view optical telescopes for space debris research. In *Proc. 60th Int Astronaut Congr*, Daejeon, Korea, IAC-09.A6.1.8.

9. Kouprianov, V. & Molotov, I. (2017). FORTE: ISON robotic telescope control software. In *Proc. 7th European Conference on Space Debris* (Eds. T. Flohrer & F. Schmitz), published by ESA Space Debris Office, Darmstadt, Germany, id 475.

10. Molotov, I.E., Krugly, Yu.N., Elenin, L.V. et al. (2021). Search and study of the space debris and asteroids within ISON project. *An Acad Bras Ciênc* **93** (Suppl. 1), id e20200145.

11. Shilin, V.D., Lukyanov, A.P., Molotov, I.E., Agapov, V.M., Kolessa, A.E. (2013). Problems of prevention of dangerous situations in near Earth space, plans and opportunities, role of optical observations. *Ecological Bulletin of Research Centers of the Black Sea Economic Cooperation* **4** (2), 171-175.

12. Molotov, I., Agapov, V., Makarov, Yu. et al. (2014). EOP-1/EOP-2 mini-observatories for space debris observations: characteristics, tasks and first results of operation. In *Proc. 65th Int Astronaut Congr*, Toronto, Canada, IAC-14.A6.1.4.

13. Molotov, I., Schildknecht, T., Montojo, F.J. et al. (2016). Increasing of new GEO/HEO space debris discovery rate with ISON optical network. *Proc 67th Int Astronaut Congr, Guadalajara, Mexico,* IAC-16.A6.1.1.

14. Escobar, D., Ayuga, F., Anton, A., Agueda, A., Molotov, I. (2017). GMV/ISON combined optical campaigns. In *Proc. 7th European Conference on Space Debris* (Eds. T. Flohrer & F. Schmitz), published by ESA Space Debris Office, Darmstadt, Germany, id 414.

15. Molotov, I., Krugly, Yu., Elenin, L. et al. (2019). ISON search and study the near-Earth space objects. In *Proc. 1st NEO and Debris Detection Conference*, (Eds. T. Flohrer, R. Jehn, F. Schmitz), published by the ESA Space Safety Programme Office, Darmstadt, Germany, id 409.

16. Abdel-Aziz. Ye., Abdelaziz, A.M., Tealib, S.K., Attia, G., Molotov, I., Schmalz, S. (2020). First Optical Satellite Tracking Station (OSTS) at NRIAG-Egypt. *New Astronomy* **77**, id 101361.