ISON WORLDWIDE SCIENTIFIC OPTICAL NETWORK

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ABSTRACT

The international scientific optical network (ISON) that was developed in the last few years is one from largest system specialized on space debris observations at high orbits and is able to observe whole GEO ring. Now ISON collaborates with 25 observatories in 9 countries. Series of standard telescopes and mounts was produced, and a lot of the modern CCD cameras is purchased to equip the ISON observatories. Standard solution for precise time keeping is installed at each telescope together with standard software packages for CCD frame processing, CCD camera, GPS receiver and mount control. 32 telescopes with aperture in range between 0.2 and 2.6 m are arranged in the three ISON subsets dedicated to different class objects. The ISON observations are coordinated mainly by the Center on collection; processing and analysis of information on space debris (CCPAISD) developed and operated on the basis of the Ballistic Centre at the KIAM, Russian Academy of Sciences. Almost one million measurements about 2000 space objects were received at CCPAISD up to now. More than 700 earlier unknown objects are discovered. It is planned to obtain about two millions measurements per year since 2009. ISON is an open international non-government project and may be considered as a free source of information on space objects for global civil SSA.

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1. INTRODUCTION

International Scientific Optical Network (ISON) is an open international non-government project mainly aimed at being a free source of information on space objects for scientific analysis and other applications. It was initiated in framework of the program of the GEO objects investigations started by the Keldysh Institute of Applied Mathematics (KIAM) of the Russian Academy of Sciences in 2001. Initially ISON was a project supporting the radar experiments [2] with additional tracking data using for determination of orbital parameters precise enough to properly point narrow radar beams of selected objects. Next goal was establishing of regular observations of the GEO region in order to obtain enough data to confirm the theory of evolution of fragment clouds created in explosions of old GEO resident objects [3].

Major cooperation of the ISON project are established in 2004 during first joint attempts with European observatories to track small GEO fragments of space debris firstly detected in Nauchny, Crimea [4]. ISON started routine observations of the GEO objects in 2005 with support of the International Association for the promotion of co-operation with scientists from the New Independent States of the former Soviet Union and the Russian Ministry of education and science grants.

During 2005-2007 main aim of the project was improving of our knowledge about pollution of Geostationary ring (GEO) that is unique region of the near-Earth space from the point of view of solving the various tasks (television and communication services, weather monitoring, data relay, etc.), and, on the other hand, it is a limited natural resource which requires preservation for future use. In 2008 the regular observations of objects at highly-elliptical orbits (HEO) of various classes (GTO, "Molniya" etc.) were started. In 2007, 2008 and 2009 the project was officially presented at the United Nations level at the sessions of the Scientific and Technical Subcommittee of the UN Committee on the Peaceful Use of Outer Space.

2. ISON STRUCTURE AND DEVELOPMENT

ISON observations are carried out using 32 telescopes of the 25 observing facilities in 9 states - Bolivia, Georgia, Moldova (Pridnestrovie), Russia, Spain (ESA), Switzerland, Tajikistan, Ukraine, and Uzbekistan. The geographic positions and names of the observatories where telescopes and CCD-cameras were installed under ISON project are presented at Fig. 1, and the used telescopes are listed in Table 1. ISON activities are arranged with four supporting groups (i) electric and software engineering, (ii) optical and mount engineering, (iii) observation planning and data processing, (iv) network development.

Electric and software engineering group has developed: (i) the time keeping hardware for precise determination of CCD frame capture moment, utilizing the trigger mode of the CCD shutter, (ii) full set of software modules for control of all telescope devices under common platform – GPS receiver (AccuTime module), CCD camera (CameraControl module), telescope mount (CHAOS module), (iii) Apex II software package for astrometric and photometric reduction of the CCD frames [5]. All software components can interact with each other. Apex II provides calibration of CCD frames, detection of space objects, differential astrometry and photometry using stellar catalogs, identification of detected space objects using catalog of orbits, checking of the internal accuracy of measurements. A number of improved versions of all modules are issued each year (current versions are: AccuTime 2.0-4, CameraControl 3.7.2.542 and Apex 2.3.0), based on the constantly improving observational experience. A dedicated web site was established for centralized, downloading of new versions from all ISON observatories (http://apex.lna.gao.len.su authorisation required). About 35 time keeping devices were produced at Pulkovo and installed at all ISON telescopes (ISON standard requires that each telescope has its own time keeping system). Standard software is used already at 25 observatories. Technical support is maintained with each user with help of dedicated board at ISON projects' web site (http://lfvn.astronomer.ru/forum/index.php).

Optical and mount engineering group has developed: (i) a set of dedicated telescopes, (ii) a set of mounts with different weigh capacity, (iii) lots of individual solutions (but utilizing common standards for control and tracking capabilities) for automation of the mounts of legacy telescopes that are working with ISON. In the whole, 20 optical telescopes (ranging apertures from 80-cm to 12.5 cm (one 80-cm in Mayaki, two 60-cm – in Mayaki and Andrushivka, one 50-cm in Ussuriysk,

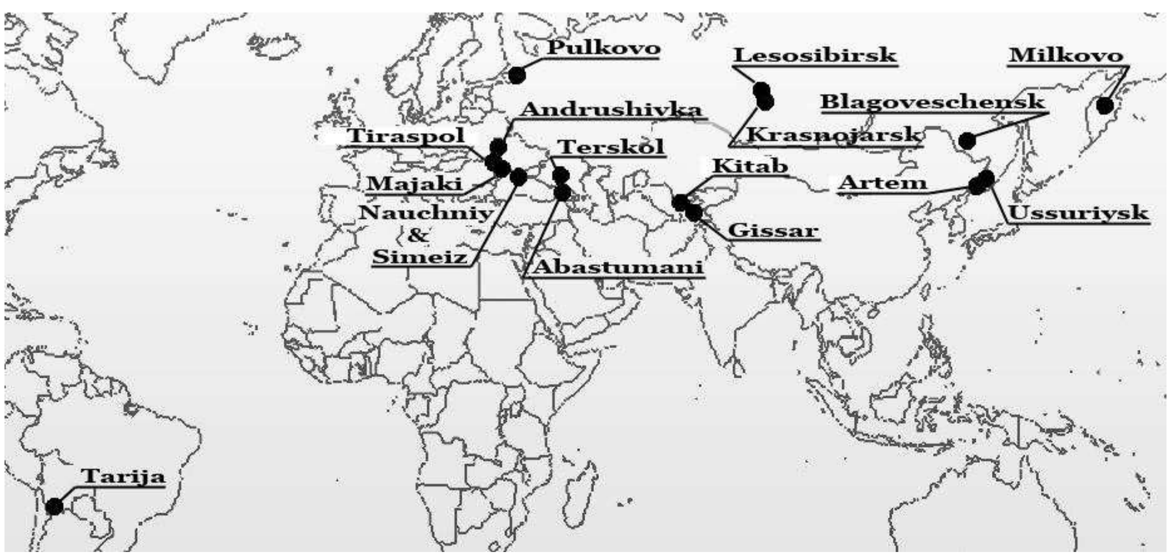

Figure 1. Geographic positions and names of the ISON observatories

Table 1. Observatories and telescopes of the International Scientific Optical Network in March 2009

Observatory	**Telesc. type**	**CCD, pixels**	**FOV**	**Lim. m.**	**Mount type**	**Time**
Unit:	size in cm	microns	degree	^{m} for 5 s		%
Milkovo	ORI-22, 22	3k*3k, 12	4°	15	EQ6Pro	100
Ussuriysk	VT-40/500, 50	3k*3k, 12	1.8°	17.5	WS-300	75
	GAS-250, 25	3k*3k, 12	2.8°	15	partial autom.	75
	ORI-22, 22	2k*2k, 24	5.5°	15	EQ6Pro	100
	VT-15e, 12.5	3k*3k, 12	12.3°	14	EQ6Pro	100
Artem	ORI-22, 22			15	EQ6Pro	100
Blagoveschensk	ORI-22, 22	3k*2k, 9	2.6°	15	EQ6Pro	100
Krasnojarsk	ORI-40, 40	3k*3k, 12	2.3°	16.5	WS-240GT	75
Lesosibirsk	ORI-22, 22	3,3k*2,5k , 5.4	1.5°	15	EQ6Pro	100
Gissar	AZT-8, 70	1k*1k, 24	30’	17.5	partial autom.	75
Kitab	ORI-40, 40				WS-240GT	100
	ORI-22, 22	2k*2k, 24	5.5°	15	partial autom.	100
Abastumani	AS-32, 70	2k*2k, 24	1.5°	18	partial autom.	50
	ORI-22, 22	3k*3k, 12	4°	15	partial autom.	100
Terskol	Zeiss-2000, 200	2k*2k, 24	12’	20	automated	8
	K-800, 80			18	partial autom.	75
Nauchniy-1	ZTSh, 260	1k*1k, 24	8.4’	20	partial autom.	10
	AT-64, 64	4k*4k, 9	1°	17.5	automated	75
	RST-220, 22	3k*3k, 12	4°	15.5	automated	100
Nauchniy-2	RST-220, 22	4k*4k, 9	4°	15	not-automated	75
Simeiz	Zeiss-1000, 100	1k*1k, 24	12.8’	18.5	partial autom.	25
Mayaki	PK-800, 80	3k*3k, 12	25’	18	partial autom.	75
	PK-600, 60	1k*1k, 24	17’	17	partial autom.	75
Pulkovo	RST-220, 22	3k*3k, 12	4°	14	automated	100
Andrushivka	S-600, 60	3k*3k, 12	24°	17	automated	100
Tiraspol	RST-220, 22			14	EQ6Pro	100
	VT-15e, 12.5	3k*3k, 12	12.3°	13.5	WS-240GT	100
Tarija	Astrograph,23	1k*1k, 24	35’	14	not-automated	100
	ORI-25, 25	3k*3k, 12		15.5	EQ6Pro	100

two 40-cm in Krasnojarsk and Kitab, one 25-cm in Ussuriysk, eleven 22 cm in Tiraspol, Pulkovo, Nauchniy-1, Nauchniy-2, Abastumani, Kitab, Lesosibirsk, Blagoveschensk, Artem, Ussuriysk, Milkovo, two 12.5 cm in Tiraspol and Ussurysk) are produced, and six telescopes of 0.6-0.8-m class are refurbishing now. Three new mounts were produced – two WS-240GT mounts with 80 kg weigh capacity for ORI-40 in Krasnojars and K-360 in Tiraspol, and one WS-300 mount with 150 kg weigh capacity for VT-40/500 in Ussuriysk.

Observation planning and data processing group develops standard observation modes for telescopes - survey, search scan, ephemeris tracking etc., and adjusts new observations techniques with each observatory team. Network development group plans the telescope upgrade, production of the new ones, purchasing CCD cameras for each ISON observatory to meet the requirements of observations techniques developed by the observation planning and data processing group.

Network development group plans the telescope upgrade, production of the new ones, purchasing CCD cameras and mounts for ISON observatories to meet the requirements of observations techniques developed by the observation planning and data processing group. Already 30 CCD cameras (3 of 2kx2k, 24µm; 2 of 4kx4k, 9µm; 12 of 3kx3k, 12µm; 8 of 1kx1k, 24µm; 3 of 3kx2k, 9µm; 1 of 1kx1k, 13µm ; 1 of 3.3kx2.5k, 5.4µm) and 8 EQ6Pro automated mounts with 25 kg weigh capacity (for RST-220 in Tiraspol, ORI-22 in Kitab, ORI-22 in Lesosibirsk, ORI-22 in Blagoveschensk, ORI-22 in Artem, ORI-22 and VT-15e in Ussuriysk, ORI-22 in Milkovo) were purchased. Under activities of this group the operations of 5 observatories (Kitab, Gissar, Abastumani, Tarija and

Blagoveschensk) were renewed and 5 new observation points put into operation (Tiraspol, Milkovo, Artem, Krasnojarsk and Lesosibirsk).
Training courses were arranged for all teams of ISON observatories (or members of teams were invited by a more experienced observatory, or ISON observer-instructor visited new observatory to deliver a lecture). 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.

ISON telescopes are grouped in three subsets dedicated to tracking of different classes of the space objects – bright GEO-objects, faint fragments at GEO region, bright objects at highly elliptical (HEO) and low orbits (LEO). The ISON search and survey subsystem for studying of the bright (not fainter than 15.5^m) objects in GEO region consists of the eleven 22-cm telescopes RST-220 and ORI-22 with field of view (FOV) of 4° and 5.5° that are installed at Milkovo, Ussuriysk, Artem, Blagoveschensk, Lesosibirsk, Kitab, Abastumani, Nauchniy-1, Nauchniy-2, Pulkovo, Tiraspol and Tarija [6]. See examples of such telescopes in Fig. 2. The work on full automation of the observations is in progress. It is planned that the telescopes of this subset will implement the GEO survey mode in a zone ±16 with respect to the "true" GEO ring. Now such mode is implemented only for longitudes 31.5°W to 90°E with RST-220 in Nauchniy-1 – up to 7500 measurements in 750 tracklets are obtained per night with good weather conditions. Subsystem for high altitude faint (15.5^m to 18.5^m) space debris fragments detection and tracking consists of the telescopes with aperture from 0.40 to 2.6 m and includes 64-cm AT-64 telescope in Nauchniy-1, 70-cm AZT-8 telescopes in Gissar, 48-cm AZT-14 in Mondy, 60-cm RC-600 telescope in Mayaki, 70-cm AS-32 telescope in Abastumani, 60-cm S-600 telescope in Andrushivka and collaborates with team of the Astronomical Institute of the University of Bern (AIUB) providing the observations with 1-m ZMLAT telescope in Zimmerwald and 1-m ESA Space Debris Zeiss-1000 telescope in Tenerife and 70-cm AZT-8 telescope in Evpatoria. Also the portions of observation time of the four large telescopes - 2.6-m ZTSh in Nauchniy-1, 2-m Zeiss-2000 in Terskol, 1.5-m AZT-33IK in Mondy and 1-m Zeiss-1000 telescope in Simeiz are regularly devoted to the tracking of the very faint (19^m to 21^m) fragments. In addition few more telescopes are in installation or refurbishing – 40-cm ORI-40 in Krasojarsk, 40-cm ORI-40 in Kitab, 50-cm VT-40/500 in Ussuriysk, 80-cm RC-800 in Mayaki, 80-cm K-800 in Terskol, 60-cm Zeiss-600 in Sanglokh, 60-cm Zeiss-600 in Tarija, 60-cm Zeiss-600 in Simeiz. See examples of these telescopes in Fig. 3 and Fig. 4. The negotiations about joining to the ISON project are in progress with few observatories having 0.6 m – 2m telescope class in Bulgaria, Azerbaijan and Ukraine – i.e. the successful observations of faint fragments are carried out with 70-cm AZT-8 telescope in Evpatoria, 70-cm AZT-8 telescope in Lesniki, 65/50-cm Schmidt telescope in Rozhen.

Third subsystem is for studying the objects at HEO and LEO orbits and will be consisting from 125-mm VT-15e lens objectives with FOV up to 15°. The HEO objects will be observed during fast surveys of the sky, while LEO objects will be observed with fixed VT-15 objective - it is expected that each objective can obtain up to few hundred tracklets of LEO objects per nights. First two VT-15e objectives are installed in Ussuriysk and Tiraspol, two more VT-15e are in producing for Kitab and Tarija. In addition ten 25-cm ORI-25 and GAS-250 telescopes will be produced in order to provide follow up tracking of HEO and LEO objects. First GAS-250 is installed in Ussuriysk. See examples of these telescopes in Fig. 5.

Figure 2. Examples of the 22-cm telescopes: RST-200 in Nauchniy-1, ORI-22 in Milkovo and Ussuriysk

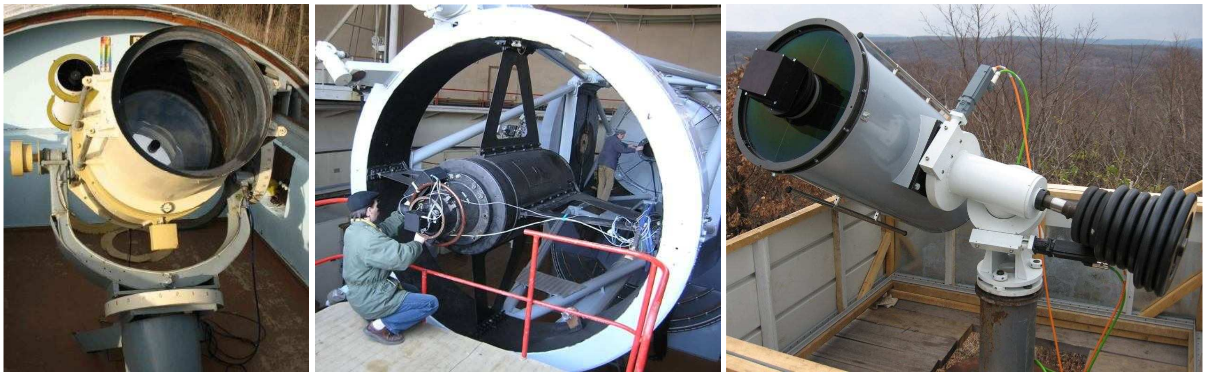

Figure 3. Examples of telescopes for the faint fragment observations: 64-cm AT-64 and 2.6-m ZTSh in Nauchniy-1, new 50-cm VT-40/500 in Ussuriysk.

3. STATUS OF ISON OBSERVATIONS

The ISON observations are coordinated mainly by the Center on collection, processing and analysis of information on space debris (CCPAISD) of the Keldysh Institute of Applied Mathematics (KIAM). CCPAISD is developed and operated on the basis of the Ballistic Centre at the KIAM, Russian Academy of Sciences. Since 2007 the observations are carried out almost each acceptable night – 1042 telescope-nights were in 2007 and 1324 telescope-nights - in 2008. The performances of the ISON are continuously increased – the quantity of measurements for 2007 is in 3.4 times more in comparison with 2006, and for 2008 is in 3.1 times more in comparison with 2007 (in 10 times for last two years) – see summarized statistics of measurements and tracklets per year in Fig. 5. CCPAISD already collected almost 1000000 measurements on about 2000 space objects [7]. ISON is capable to perform the observations of selected objects across the whole GEO belt (the highly accurate measurements at level of 0,4’- 1’ may be obtained for priority list objects), the near GEO belt (± 2°) surveys for the arc 130.3W – 210.6E, wide surveys of the GEO region for the arc 30W – 90E with the goal of discovery of all objects brighter than 16^m, uncatalogued GEO debris search (using different strategies with limiting magnitudes range down to 19^m) and tracking (limiting magnitude 21^m), observations of the GTO and other HEO objects including faint space debris, tracking selected LEO-objects, and photometry of tracked objects.

More than 700 earlier unknown objects are discovered together with AIUB team: 155 bright GEO objects, 140 HEO-objects and nearly 450 faint (fainter than 15^m) GEO and GTO faint fragments, including objects with high area to mass ratio (AMR). Some more than 200 faint fragments are tracked continuously. Thus population of tracked objects in GEO region is increased on 35%. Orbital data on discovered bright GEO objects (brighter than 15^m) are publishing annually in «ESOC Classification of Geosynchronous Objects» (the last one – Issue 11, Feb 2009 [8]). Information on faint objects is publishing monthly by KIAM in High Geocentric Orbit Space Debris Circular. Large amount of observations that is collected on regular basis makes possible an accurate analysis of the peculiarities of controlled motion of the spacecrafts

Figure 4. Examples of telescopes for the faint fragment observations:70-cm AS-32 telescope in Abastumani, new 60-cm RC-600 telescope in Mayaki, new 60-cm S-600 telescope in Andrushivka

Figure 5. Examples of telescopes for observations of the HEO and LEO objects: - 12.5-cm VT-15e and 25-cm GAS-250 in Ussurysk and 12.5-cm VT-15e in Tiraspol

belonging to different owners, but located in the vicinity of the same GEO position, and a prediction of the dangerous approaches of operational satellites with space debris objects.

4. CONCLUSIONS AND OUTLINES

Started in 2005 the ISON project is significantly expanded by the current time and presents now new global optical network - it already joins 25 observatories and observation facilities around the world. Overall work of the ISON is coordinated by the Keldysh Institute of Applied Mathematics of the Russian Academy of Sciences.

The ISON network at present is the only civilian non-governmental one which is capable to produce significant results in area of space surveillance of the higher Earth orbits which can be used for various purposes including scientific research of space debris problem as well as space situation awareness in the interests of commercial and other civilian spacecraft operators. The output produced by the ISON by it's quality and quantity is comparable if not exceeds in some points similar data producing and officially distributing by the most powerful space surveillance system in the world operated by the U.S. Air Force. By now the ISON have discovered more than 700 new

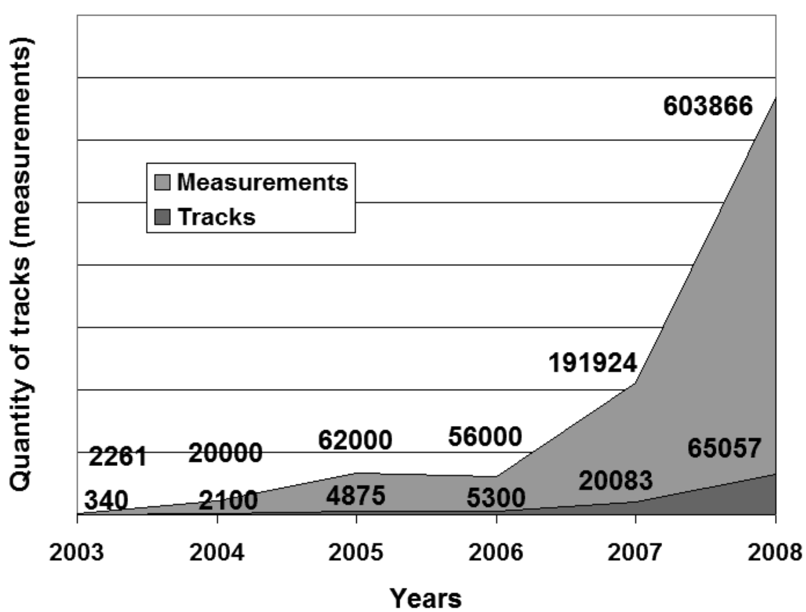

Figure 6. Statistics of the ISON measurements and tracklets from 2003 to 2008 years

objects on high geocentric orbits. The ISON observation system covering whole GEO and capable to search and track objects both on GEO and various classes of HEO orbits (GTO, Molniya etc.). The work of ISON and AIUB significantly improved our knowledge of the real situation in GEO region. Thanks to the conducted research the number of continuously tracked objects in this vital near-Earth region of space increased 35%. Number of newly discovered objects continues to grow.

Another important thing demonstrated by the ISON is possibility of very fruitful and successful cooperation between researchers in many countries within framework of very complex program of the near-Earth orbital population studying. Obtained data are open for scientific analysis; indeed, it was the first example of measurement data exchange between Russian and European observers on an operational basis. Also thank to ISON activity the telescopes in the former Soviet Union countries participate in the dedicated IADC campaigns to study the physical properties of high AMR value objects. ISON news are published on dedicated web sites: www.lfvn.astronomer.ru and www.ISONteam.com.

It is expected that quantity of the ISON telescopes will increase up to 40 in 2009. It will be provided an independent continuous tracking of all objects larger than 1 m in size and about 90% of objects larger than 0.5 m in size along all GEO arc, an improved capability to detect and to track faint GEO and HEO objects with magnitude down to 21^m, monitoring of GTO, Molniya and other types of HEO and continuous tracking of more than 80% HEO objects larger than 1 m in size, capability to carry out regular optical surveys of LEO-objects of the priority list

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