Faint High Orbit Debris Observations with ISON Optical Network

Igor Molotov, Vladimir Agapov
Keldysh Institute of Applied Mathematics, Moscow, Russia
Zakhary Khutorovsky
JSC "Vimpel" International Corporation, Moscow, Russia
Vladimir Titenko
Zverev Krasnogorsky Zavod, Krasnogorsk-7, Russia
Vasily Rumyantsev, Vadim Biryukov
Scientific-research institute"Crimean Astrophysical Observatory", Nauchny, Ukraine
Nasredin Minikulov, Makhmud Gulyamov, Bakhodur Abdulloev
Institute of Astrophysics, Dushanbe, Tadjikistan
Sergei Andrievsky, Svetlana Kashuba, Vladimir Kashuba
Scientific-research institute "Astronomical Observatory", Odessa, Ukraine
Raguli Inasaridze, Teimuraz Phiralishvili, Vova Ayvazian
Georgian National Astrophysics Observatory, Tbilisi, Georgia
Yury Ivashchenko
Andrushivka Astronomical Observatory, Andrushivka, Ukraine
Ivan Korobtsev, Tatyana Tsukker. Vladimir Tergoev
Institute for Solar-Terrestrial Physics, Irkutsk, Russia

ABSTRACT

New cooperation for global monitoring of space objects at high orbits, International Scientific Optical Network (ISON), is appeared under auspices of the Keldysh Institute of Applied Mathematics of the Russian Academy of Sciences. At present, there are more than 30 telescopes of 20 observatories in 8 states which participate in coordinated programs. ISON provides the observations of faint deep space debris in cooperation with team of the Astronomical Institute of the University of Bern since 2004. It is jointly discovered already 556 faint space debris fragments at high orbits and more than 200 of them are continuously tracked with ISON. Presence of space debris clouds created in earlier suspected fragmentations of GEO objects is proved by long deterministic observations of individual members of the clouds. For the first time, a large amount of data on long time intervals is obtained for objects with high area-to-mass ratio. Uncatalogued faint deep debris are discovering mainly with Teide ESA OGS telescope and Crimean observatory in Nauchny, while object tracking is providing by cooperation of 10 telescopes the 0.5-2.6-m class. New strategy of detection and reacquired of uncatalogued fragments is adjusted using uncorrelated one-night tracks obtained by survey telescopes.

1. INTRODUCTION

International Scientific Optical Network (ISON) [1] 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 region investigations started by the Keldysh Institute of Applied Mathematics (KIAM) of the Russian Academy of Sciences in 2001 and in order to support the space debris radar experiments [2] with additional tracking data used for determination of orbital parameters precise enough to properly point narrow radar beams of selected objects.

ISON is now one of the largest observation systems and it is just one of two such systems in the world capable to observe the sky globally from both – Eastern and Western - hemispheres. At present, there are more than 30 telescopes of 20 observatories in 8 states - Bolivia, Georgia, Italy, Moldova, Russia, Tajikistan, Ukraine, Uzbekistan which participate in coordinated observation program under the ISON project (see geographic locations of the ISON observatories and partners at the Fig. 1, and the used telescopes are listed in Table 1).

Fig. 1. Geographic positions and names of the ISON observatories

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) [3]. 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. The obtained data are stored at Center on collection, processing and analysis of information on space debris (CCPAISD) developed and operated on the basis of the KIAM Ballistic Centre, Russian Academy of Sciences.

Goal of the ISON observations of the faint space debris fragments at high orbits was formulated since beginning steps of creation of the ISON in 2004. First experiments arranged with 64 cm telescope AT-64 in Nauchny, Crimea in October 2004 were devoted to adjusting of a method of the fragments discovering [4] and checking of the Pulkovo theory on orbital evolution of the GEO object explosion fragments [5]. These successful attempts (it was discovered 7 uncatalogued fragments and obtained 1240 measurements in 18 tracks) initiated the fruitful cooperation with team of the Astronomical Institute of the University of Bern (AIUB) [6]. The regular coordinated AIUB-ISON observing campaigns were carried out during 2005 [7], the ISON subsystem for the tracking of the faint fragments at GEO region started operations in 2006 [8]. The ISON news is regularly published in a dedicated web site: www.lfvn.astronomer.ru.

2. STATUS OF THE ISON FAINT FRAGMENT OBSERVATIONS

The main goals of the ISON program of observations of faint space debris objects are searching as many as possible faint fragments and continuous tracking the objects detected to analyze their orbital evolution and physical properties, to identify the possible parent object, and to estimate the level of their danger for operational satellites. AT-64 and ZTSh telescopes in Nauchny (see Fig. 2) and Zeiss-1000 in Tenerife were searching fragments using the predetermined strategy in selected search fields; after the detection of an unknown fragment, it was tracked on a one-two hours arc in order to make possible rediscovery of the fragment on the next night. Zimmerwald, Nauchny, Maidanak, Mondy, Arhyz and Mayaki observatories provide the fragment follow up tracking. The fields for fragment search were chosen at the points where the apparent density of catalogued GEO objects in the right ascension - declination space has maximum, or where fragments of presumably exploded objects cross the GEO ring and their parent objects' orbits [6]. In the two-year period, 160 unknown objects of 15-20.5^m were detected, and about 32,000 measurements in 2150 tracks were obtained [9]. The observation statistics is presented in Table 2 and Fig. 3. The research shows that objects having high area-to-mass ratio (AMR) in 300 to 13000 times larger than that for spacecrafts and rocket bodies, firstly discovered by the AIUB team [10], are not exclusion. The existence of

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

Observatory	Telesc. type	CCD, pixels	FOV	Lim. m.	Mount type	Nights in Jan-Aug. 10, 2009
Unit:	size in cm	microns	degree	^{m} for 5 s		
Milkovo	ORI-22, 22	3k*3k, 12	4°	15	EQ6Pro	38
Ussuriysk	VT-40/500, 50	3k*3k, 12	1.8°	17.5	WS-300	2
	GAS-250, 25	3k*3k, 12	2.8°	15	partial autom.	86
	ORI-22, 22	2k*2k, 24	5.5°	15	EQ6Pro	30
	VT-15e, 12.5	3k*3k, 12	12.3°	14	EQ6Pro	in adjusting
Artem	ORI-25, 25	3k*3k, 12	4°	15	EQ6Pro	11
Blagoveschensk	ORI-22, 22	3k*2k, 9	2.6°	15	EQ6Pro	35
Krasnojarsk	ORI-40, 40	3k*3k, 12	2.3°	15.5	WS-240GT	1
Lesosibirsk	ORI-22, 22	3,3k*2,5k , 5.4	1.5°	15	EQ6Pro	in installation
Gissar	AZT-8, 70	1k*1k, 24	30’	17.5	partial autom.	56
Sanglok	Zeiss-600, 60	4k*4k, 9	45’	17	automated	under upgrade
Kitab	ORI-40, 40	3k*3k, 12	2.3°	16.5	WS-240GT	in installation
	ORI-22, 22	2k*2k, 24	5.5°	15	partial autom.	148
	VT-15e, 12.5	3k*3k, 12	12.3°	14	EQ6Pro	in installation
Abastumani	AS-32, 70	2k*2k, 24	1.5°	17.5	partial autom.	51
	ORI-22, 22	3k*3k, 12	4°	15	partial autom.	24
Terskol	K-800, 80	3k*3k, 12	1°	18	partial autom.	under upgrade
Nauchny	ZTSh, 260	1k*1k, 24	8.4’	20	partial autom.	17
	ZTE, 125	1k*1k, 24	7’	19	partial autom.	3
	AT-64, 64	4k*4k, 9	2.3°	17.5	automated	86
	RST-220, 22	3k*3k, 12	4°	15.5	automated	105
	RST-220, 22	4k*4k, 9	4°	15	not-automated	55
Simeiz	Zeiss-600, 60	1k*1k, 24	45’	17.5	partial autom.	under upgrade
Mayaki	PK-800, 80	3k*3k, 12	25’	18	partial autom.	under upgrade
	PK-600, 60	1k*1k, 24	17’	17	partial autom.	86
Pulkovo	RST-220, 22	3k*3k, 12	4°	14	automated	17
Andrushivka	S-600, 60	3k*3k, 12	24°	17	automated	35
Tiraspol	RST-220, 22			14	EQ6Pro	103
	VT-15e, 12.5	3k*3k, 12	12.3°	13.5	WS-240GT	4
Uzhgorod	BRC-250	3,3k*2,5k , 5.4	40’	15	partial autom.	in installation
Collepardo	ORI-22, 22	3k*3k, 12	4°	15		3
Tarija	Astrograph,23	1k*1k, 24	35’	14	not-automated	35
	ORI-25, 25	3k*3k, 12	4°	15.5	EQ6Pro	in production

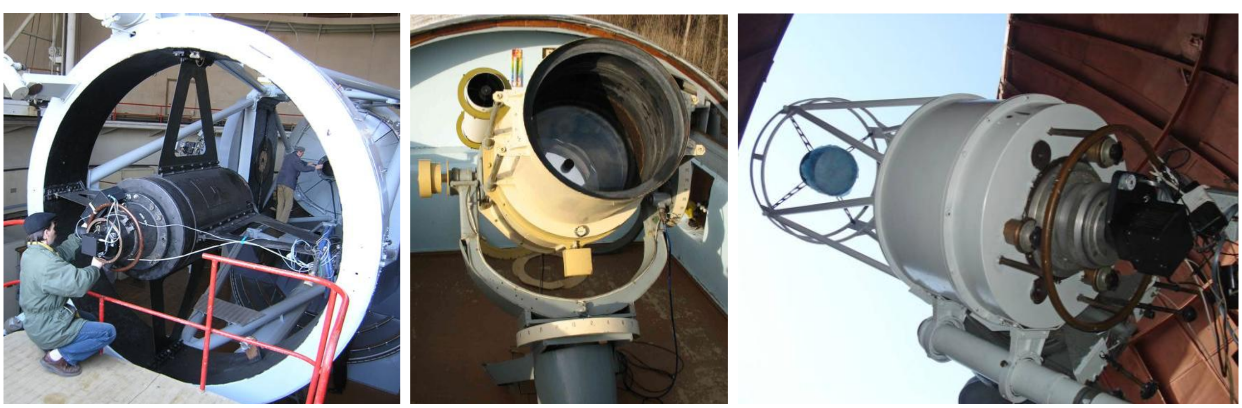

Fig. 2. First ISON telescopes for the faint fragment observations: 2.6-m ZTSh and 64 cm AT-64 in Nauchny, and new 60 cm RC-600 in Mayaki.

Table 2. Observation statistics (by V. Titenko) of the ISON telescopes and partners.

Observatory, telescope, aperture in cm	Tracks						Discovered fragments / single tracks
	2005	2006	2007	2008	2009	Total	
Nauchny, AT-64, 64	71	322	809	1711	860	3791	39 / 63
Nauchny, ZTSh, 260	55	114	150	225	65	609	18 / 76
Nauchny, Zeiss-600, 60	23	71	0	0	0	94	3 / 7
Nauchny PH-1, RST-220, 22	0	4	232	484	692	1412	111 / 5
Nauchny ZTE, 125	0	0	0	0	13	13	1 / 0
Simeiz, Zeiss-1000, 100	0	15	78	55	0	148	1 / 4
Mondy, AZT-33IK , 150	0	0	185	12	16	213	0 / 6
Mondy, Zeiss-600, 60	25	9	0	8	53	95	1 / 2
Maidanak, Zeiss-600, 60	10	186	620	0	0	816	1 / 11
Arkhyz, Zeiss-1000, 100	9	39	10	0	0	58	0 / 0
Arkhyz, Zeiss-600, 60	0	10	6	477	472	965	1 / 0
Mayaki, RC-600, 60	0	34	169	199	357	759	6 / 11
Gissar, AZT-8, 70	0	0	150	1105	669	1924	4 / 4
Abastumani, AS-32, 70	0	0	4	133	222	359	0 / 0
Terskol, Zeiss-2000, 200	0	23	56	25	39	143	1 / 4
Andrushivka, S-600, 60	0	0	0	0	66	66	5 / 0
Kitab, ORI-22, 22	0	0	7	68	39	114	1 / 0
Ussuriysk, ORI-22, 22	0	1	7	32	18	58	3 / 0
Tiraspol, RST-220, 22	0	0	17	52	83	152	0 / 1
Tenerife, Zeiss-1000, 100	79	244	467	375	0	1165	140 / 17
Zimmerwald, ZIMLAT, 100	177	619	1369	820	0	2985	3 / 4
Other telescopes	0	7	27	82	21	137	3 / 0
Total	449	1698	4363	5863	3685	16076	341 / 215

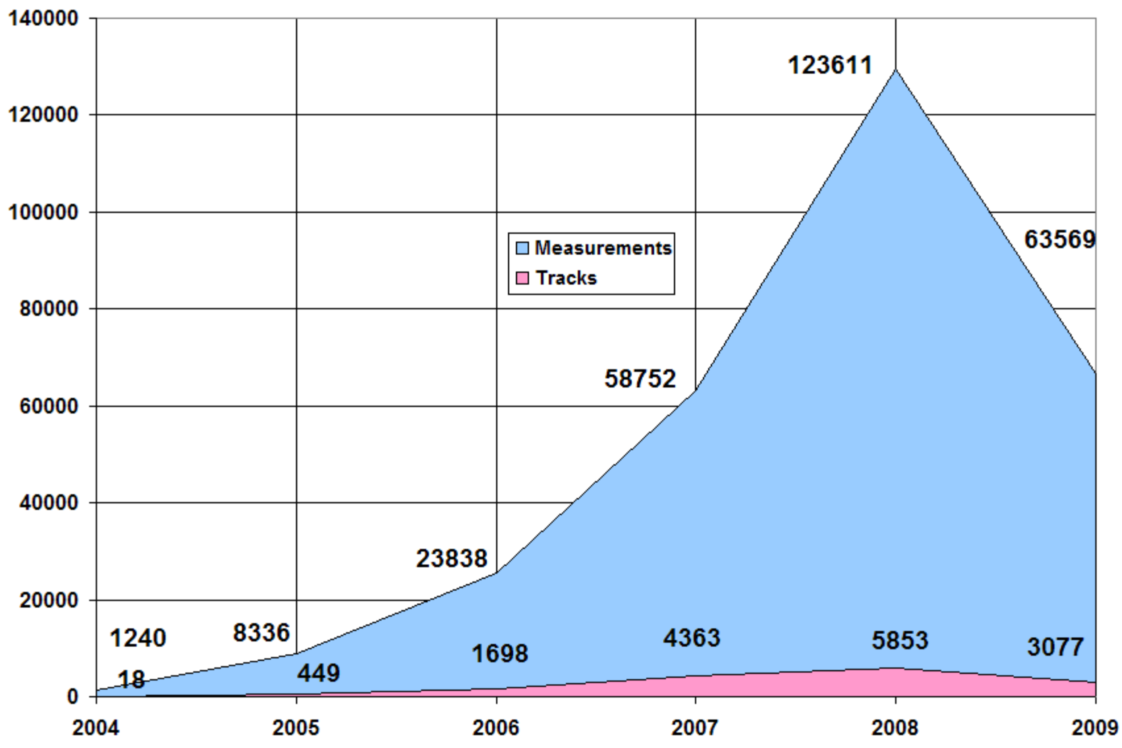

Fig. 3. Statistics of the ISON measurements and tracks for faint fragments from 2004 to 2009 years.

clouds of fragments which were produced by explosions of few Ekran spacecrafts and Transtage rocket bodies was confirmed.

In 2008-2009 the collaboration of ISON with AIUB team was irregular, also it was clear that too big part of very faint fragments discovered with ZTSh was lost (76 from 94). Therefore the strategy of ISON faint fragment observations is reconsidered – both ZTSh and AT-64 stopped the searching of new uncatalogued fragments and concentrated on reacquisition and tracking of the fragments that were discovered earlier and three addition telescopes of 60-70 cm class were involved in regular observations of the fain fragments, AZT-8 in Gissar, Zeiss-600 in Arkhyz and AS-32 (Maxutov) in Abastumani (see Fig. 4). In the same time, new method of fragment discovering and follow up tracking is in adjusting using the survey telescopes of small aperture but large field of view (FOV). It was noticed that many faint fragments with high AMR display extra high brightness variability (up to 7 - 9 magnitudes, see example on Fig. 5) – periodically some such objects are visible even for small telescopes. This phenomenon was confirmed when 22 cm PH-1 (RST-220) telescope (see Fig. 6) with FOV of 4° and limiting magnitude down to 16.5^m in Nauchny, Crimea started regular wide (±16°) surveys of the GEO region for the arc

Fig. 4. Refurbished 70 cm telescopes for faint fragments: AZT-8 in Gissar and AS-32 in Abastumani.

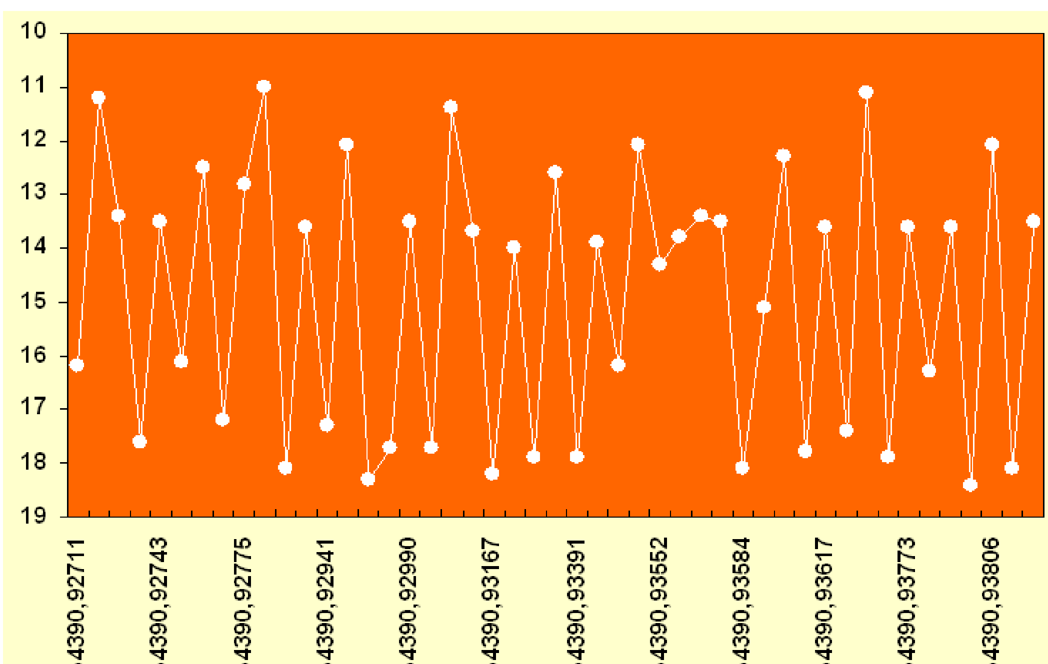

Fig. 5. Light Curve (magnitudes vs. modified Julian dates) of 90022 fragment measured in Gissar.

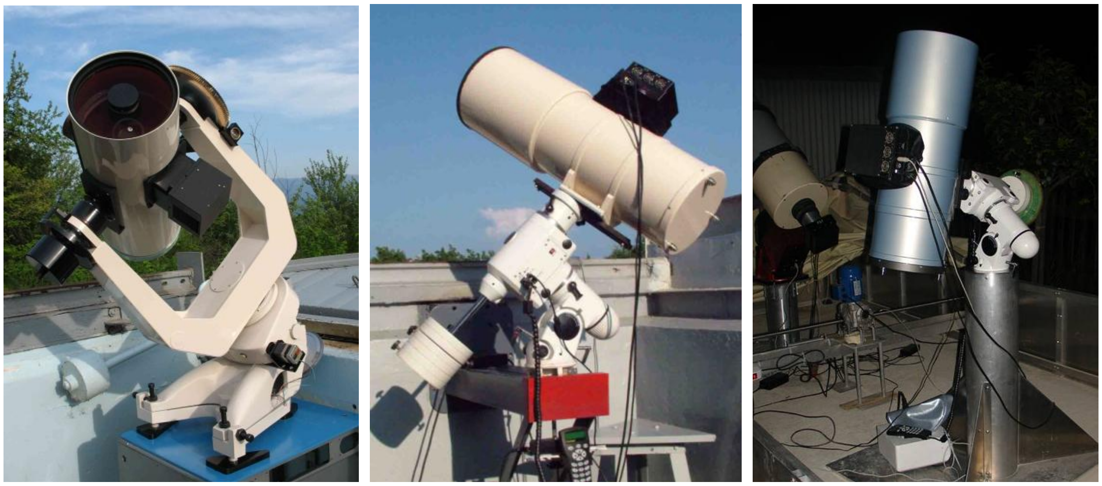

Fig. 6. 22 cm survey telescopes with FOV of 4°: PH-1 in Nauchny, ORI-22 in Ussuriysk, ORI-22 in Collepardo.

30W – 90E. It is elaborated and tested few survey modes and algorithm permitting to find correlation between short arc tracks of non-correlated objects in order to discovery of new objects and to establish their orbits. Faint fragments are regularly detected with PH-1 almost in each survey including catalogued objects and uncorrelated one-night tracks. In 2008 it is detected 47 faint fragments and their orbits are successfully determined using uncorrelated one-night tracks or PH-1 telescope from other night survey or from other telescopes (many uncorrelated tracks are obtained as by product during tracking observations of catalogued objects). In addition the survey mode of observations is adjusted now with new 60 cm S-600 telescope in Andrushivka (starts operations in 2009) and upgraded 48 cm AZT-14 telescope in Mondy (see Fig. 7). Even if new objects are not discovered in specific survey with these two telescopes the obtained uncorrelated one-night tracks are used to find correlation with tracks of PH-1. It is planned that few other 22 cm telescopes – ORI-22 in Ussuriysk, Collepardo, Blagoveschensk and Tiraspol will learn survey mode in 2009. Moreover, four survey telescopes will be putted in operations soon - 50 cm VT-50/400 (FOV is 1.8°) in Ussuriysk, 40 cm ORI-40 (FOV is 2.3°) in Krasnojarsk and Kitab, and 50 cm Santel-500a (FOV is 1.6°in Zvenigorod (see Fig. 8). It is expected that faint fragment discovered statistics and orbit maintenance will be significantly improved since 2010.

Fig. 7. Telescopes adjusting the methodic of GEO region survey: new 60 cm S-600 (FOV is 2°) in Andrushivka and upgraded (FOV enlarged up to 1.3°) 48 cm AZT-14 in Mondy.

3. ISON OBSERVATIONS RESULTS

556 faint (fainter than 15^m) GEO and GTO objects are discovered in GEO region surveys during the last 3 years, including objects with high AMR. Of this number, more than 200 faint fragments are tracked continuously. Presence

Fig. 8. New survey telescopes: 50 cm VT-50/400 (FOV is 1.8°) in Ussuriysk, 40 cm ORI-40 (FOV is 2.3°) in Krasnojarsk (second ORI-40 will be installed in Kitab in 2009) and 50 cm Santel-500a (FOV is 1.6°in Zvenigorod (over VAU camera mount).

of space debris clouds created in earlier suspected fragmentations of GEO objects is proved not only by statistical observation approaches but for the first time – by long deterministic observations of individual members of the clouds. For the first time, a large amount of data on long time intervals is obtained for objects with high AMR. Both observational and orbital peculiarities of these objects are revealed and studied. Fig. 9 to Fig. 13 represents distributions of the objects discovered by the ISON by brightness, AMR value and some orbital parameters. One can see that the most part of 546 fragments included into the brightness plot (Fig. 9) is concentrated around magnitude range of 16^m to 18^m. This picture reflects rather current observation capabilities of the ISON then real distribution of existing population of space debris in GEO region. Fainter objects are much hard to discover and track especially taking into account high brightness variability of many of them. Large aperture sensitive distribution of existing

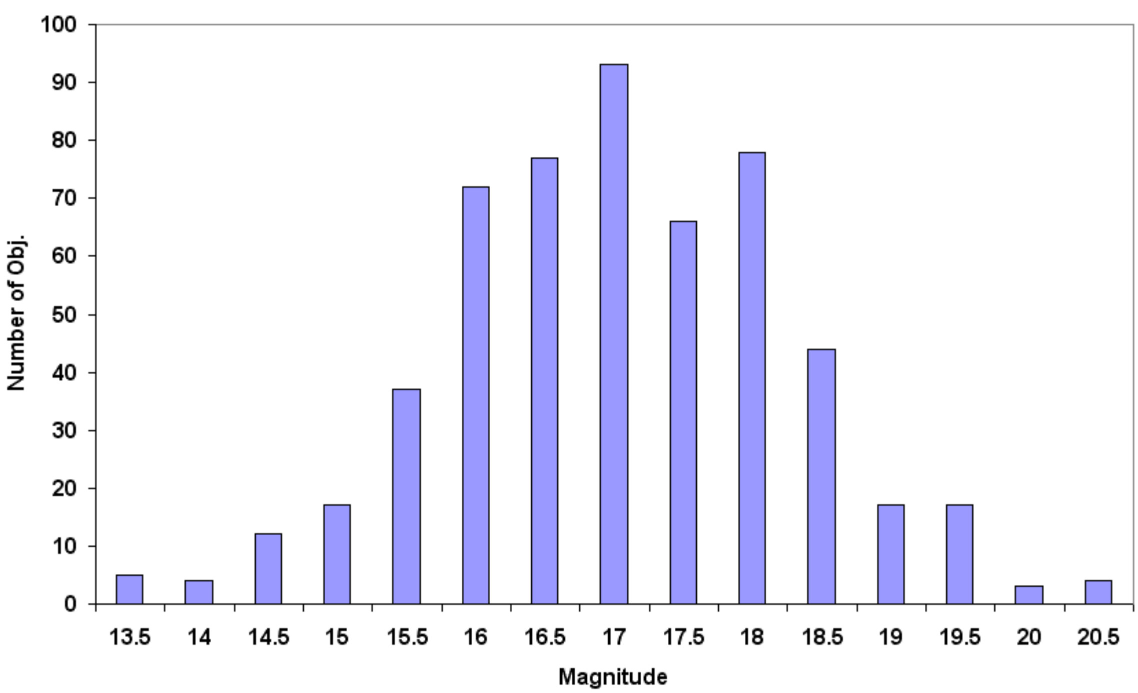

Fig. 9. Distribution of average brightness for 546 fragments
(including 341 object and 205 uncorrelated one-night tracks).

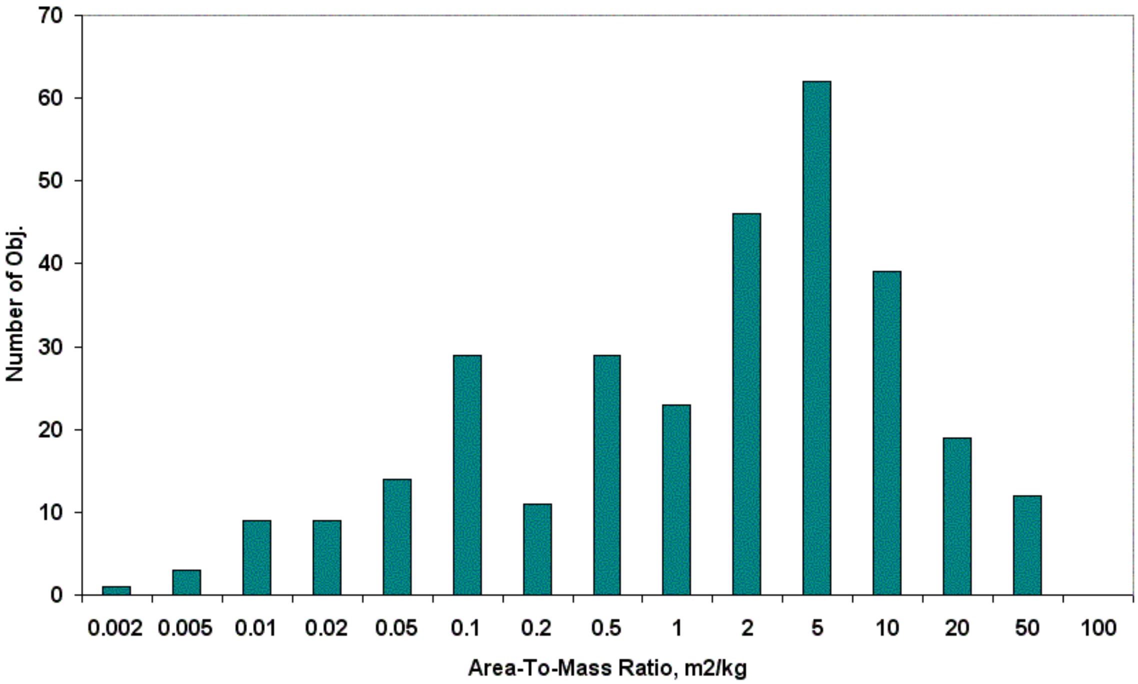

Fig. 10. Distribution of average AMR value for 306 fragments.

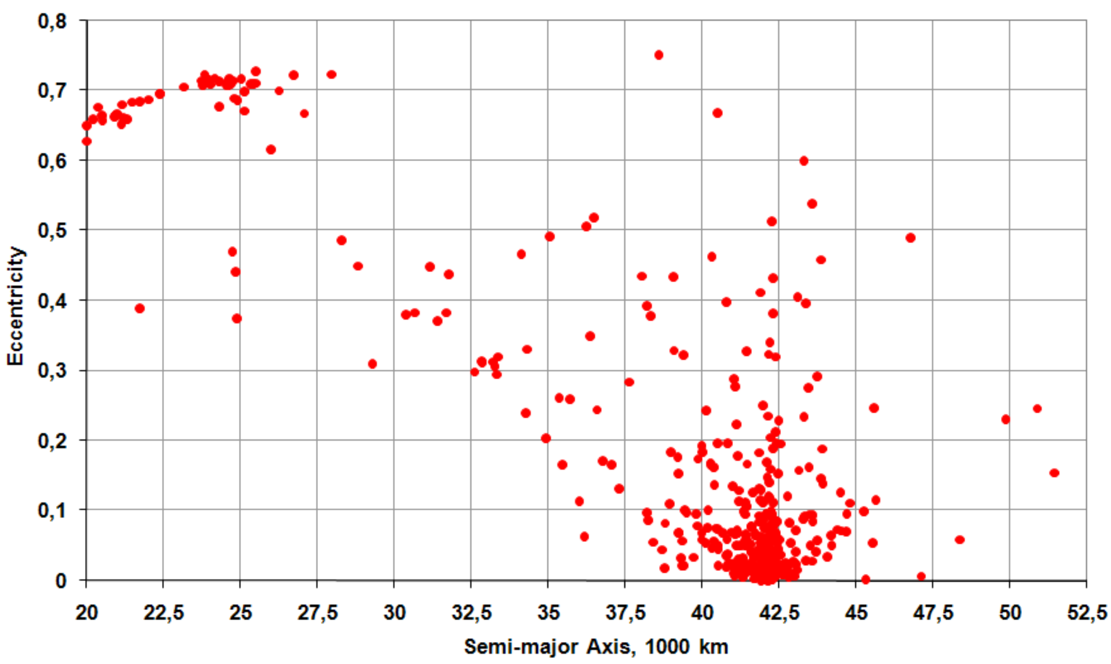

Fig. 11. Distribution of eccentricity and semi-major axis for 439 fragments
(including 341 object and 98 uncorrelated one-night tracks).

.

population of space debris in GEO region. Fainter objects are much hard to discover and track especially taking into account high brightness variability of many of them. Large aperture sensitive instruments are required for this goal. The ISON primary instruments at present are mid-class telescopes (with aperture up to 0.8 m) so one can expect that involvement of additional larger aperture telescopes into the project will significantly change the distribution for fainter objects.

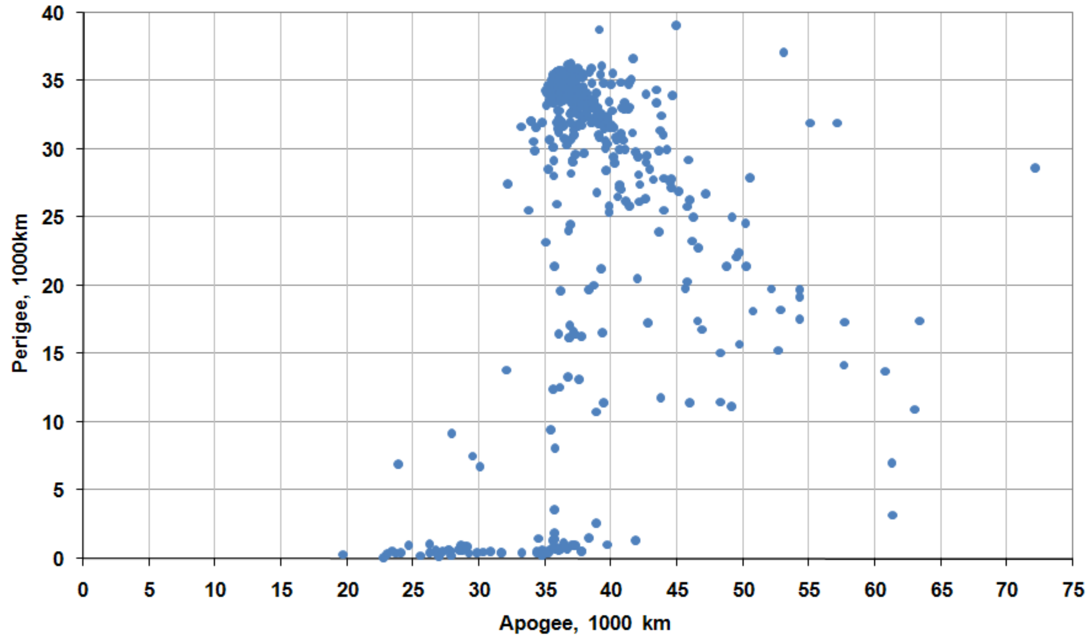

Fig. 12. Distribution of apogee and perigee for 439 fragments
(including 341 object and 98 uncorrelated one-night tracks).

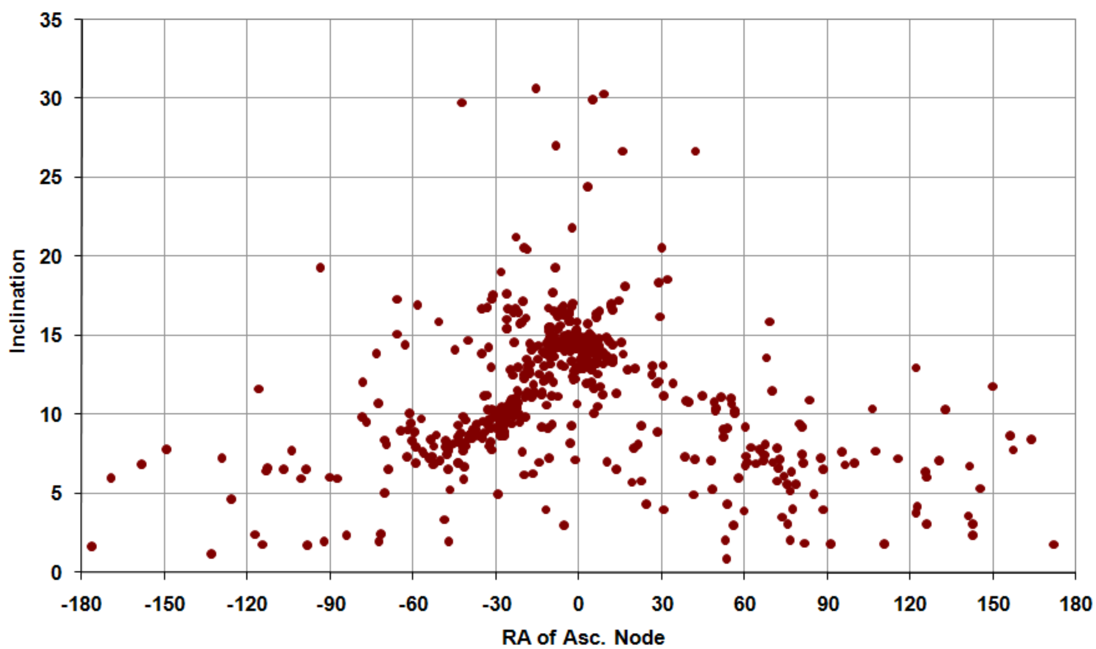

Fig. 13. Distribution of RAAN and Inclination for 544 fragments
(including 341 object and 203 uncorrelated one-night tracks).

Distribution of AMR values for fragments (Fig. 10) is constructed taking into account only those of discovered debris objects for which full 6 orbital parameters vector was obtained and amount of measurements and length of a measurement distribution arc (by time) was enough to estimate the AMR value as an additional parameter. Only 306 of 556 discovered fragments are satisfied these criteria. For other fragments the measurement distribution arc is too short in order to reliably determine AMR value or even full 6 parameters orbit vector. The nature of objects with

AMR larger than 1 m^2/kg is not clear yet. Dominating hypothesis is that objects formed of a multi-layer insulation (MLI) pieces which are separating from a spacecrafts under influence of space environment conditions.

Fig. 11 and Fig. 12 represent distribution of orbital parameters for only those of discovered debris objects for which reliable full 6 orbital parameters vector is obtained even in case when AMR value is not estimated.

Fig. 13 shows distribution in RAAN-Inclination of debris objects. It is interesting that the ISON work resulted in discovery of many objects in GEO region having orbital plane parameters significantly different of those objects for which orbital data are provided officially by the U.S. Space Surveillance Network (SSN).

4. CONCLUSION

ISON represent first in the world civilian global space surveillance system covering whole GEO and capable to search and track objects both on GEO and various classes of HEO orbits (GTO, Molniya etc.). Dedicated ISON subsystem for observations of the faint fragments at high orbits is formed and includes now 14 telescopes with aperture from 0.4 to 2.6 m. Small 22 cm telescopes with large FOV (especially PH-1 in Nauchny) provide addition contribution in fragment discovery rate due to high variability of fragment brightness. So, the regular process of discovering and stable tracking of many high orbit fragments is established (to the date almost 300,000 measurements in 16,000 tracks obtained for 556 fragments). 200 faint fragments are tracked practically continuously, 30 of that are already tracked during three years and 6 – during four years. The level of the faint GEO fragment research has increased significantly. For the first time, a large amount of data on long time intervals is obtained for objects with high AMR. It was found that many of the faint GEO objects have not only the unusual AMR value, but also a strange magnitude pattern. Presence of space debris clouds created in earlier suspected fragmentations of GEO objects is proved not only by statistical observation approaches but for the first time – by long deterministic observations of individual members of the clouds.

The ISON research team participates in the special IADC campaign on studying the physical properties of high AMR value objects in order to understand their nature and possible origin.

It is expected that faint fragment discovered statistics and orbit maintenance will be significantly improved since 2010 thank to involving of new telescopes and adjusting of the observation survey mode.

5. REFERENCES

1. Molotov I. et al., International scientific optical network for space debris research, *Advances in Space Research*, Volume 41, Issue 7, 1022-1028, 2008.
2. Molotov I. et al., Radar interferometer measurements of space debris using the Evpatoria RT-70 transmitter, *Advances in Space Research*, Volume 34, Issue 5, 884-891, 2004.
3. Molotov I. et al., Standard approaches used for the integrated work with ISON network, *Proceedings of 59th International Astronautical Congress*, Glasgow, Scotland, IAC-08-A6.1.09, 2008.
4. Agapov V. et al., Faint GEO objects search and orbital analysis, *Proceedings of the Fourth European Conference on Space Debris*, Darmstadt, Germany, 153-158, 2005.
5. Sochilina A. et al., On the orbital evolution of explosion fragments, *Advances in Space Research*, Volume 34, Issue 5, 1198-1202, 2004.
6. Volvach A. et al., Research of the space debris fragments at geostationary area, *Kosmichna Nauka i Tekhnologiya*, v. 12, no. 5/6, 50-57, 2006. (In Russian).
7. Agapov V. et al., Results of GEO space debris studies in 2004-2005, *57th IAC Final Papers DVD*, Valencia, Spain, IAC-06-B6.1.12, 2006.
8. Agapov, V.M and Molotov, I.E., Worldwide scientific optical network as a global space surveillance data source, *Proceedings of the 3rd IAASS Conference 'Building a Safer Space Together'*, Rome, Italy, 2009
9. Agapov V. et al., Analysis of the results of the 3 years observations of the GEO belt and HEO objects by the ISON Network, *Proceedings of 59th International Astronautical Congress*, Glasgow, Scotland, AC-08-A6.1.02, 2008