Arranging Observations of Faint Debris with ISON Optical Network

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ABSTRACT

New cooperation for global monitoring of space objects at high orbits, International Scientific Optical Network (ISON), appeared under coordination 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 countries which participate in coordinated programs. ISON provides the observations of faint deep space debris in cooperation with the Astronomical Institute of the University of Bern since 2004. It jointly discovered already 556 faint space debris fragments at high orbit and more than 200 of them are continuously tracked with ISON. Space debris cloud created earlier suspected fragmentations of GEO object is proved by deterministic observations of individual members of the clouds. For the first time, a large amount of data is obtained for objects with high area-to-mass ratios. Uncatalogued faint deep debris are discover mainly with the Teide ESA OGS telescope and the Crimean observatory in Nauchny, while object tracking is provided by cooperation of 10 telescopes of the 0.5-2.6-m class. Strategy of detection and tracking of uncatalogued fragments is adjusted using uncorrelated one-night tracks obtained by survey telescopes.

1. INTRODUCTION

The 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 the 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 in order to support the space debris radar experiments [2].

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 countries - Bolivia, Georgia, Italy, Moldova, Russia, Tajikistan, Ukraine, and Uzbekistan, which participate in a coordinated observation program under the ISON project (see geographic locations of the ISON observatories and partners at the Fig. 1, and the 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 GEO region fragments, 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 the 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.

The ISON observations of the faint space debris fragments at high orbits were started since the beginning steps of the creation of the ISON in 2004. First experiments arranged with the 64 cm telescope AT-64 in Nauchny, Crimea in October 2004 were devoted to adjusting a method of discovering the fragments [4] and checking the Pulkovo theory on orbital evolution of the GEO object explosion fragments [5]. These successful attempts (7 uncatalogued fragments were discovered and 1240 measurements in 18 tracks were obtained) initiated the fruitful cooperation with 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 the 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 was 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 are presented in Table 2 and Fig. 3. The research shows objects having high area-to-mass ratio (AMR), 300 to 13000 times larger than that for spacecrafts and rocket bodies, firstly discovered by the AIUB team [10]. The existence of clouds of fragments,

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

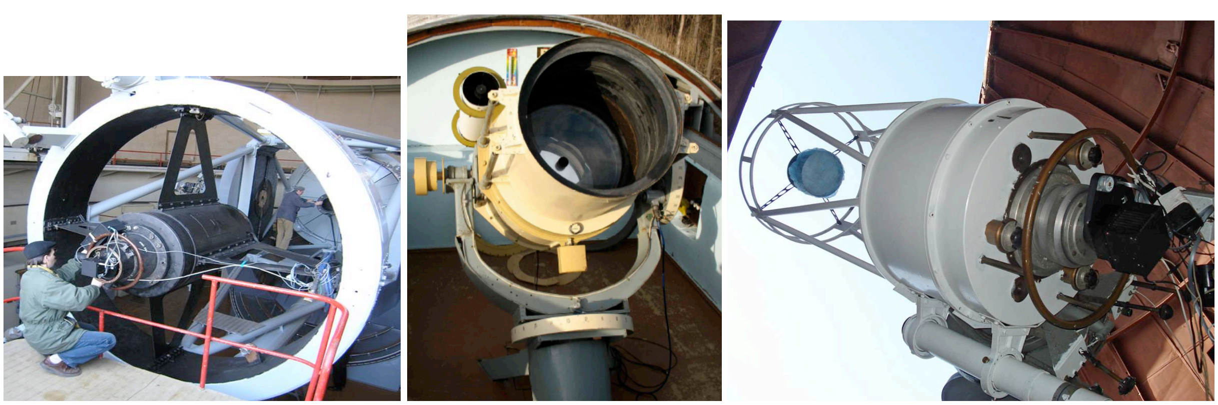

Fig. 2. First ISON telescopes for the faint fragment observations: 2.6-m ZTSh and 64 cm AT-64 in Nauchny, and new 60 cm RC-600 in Mayaki.

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

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

In 2008-2009 the collaboration of ISON with the AIUB team was irregular; also it was clear that too many very faint fragments discovered with ZTSh were lost (76 from 94). Therefore, the strategy of ISON faint fragment observations was 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 faint fragments, AZT-8 in Gissar, Zeiss-600 in Arkhyz and AS-32 (Maxutov) in Abastumani (see Fig. 4). At the same time, a new method of fragment discovering and follow up tracking, using the survey telescopes of small aperture but large field of view (FOV), was implemented. It was noticed that many faint fragments with high AMR display extra high brightness variability (up to 7 - 9 magnitudes, see example in Fig. 5) – periodically some such objects are visible even for small telescopes. This phenomenon was confirmed when the 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 30W – 90E. It elaborated and tested the survey mode and the algorithm permitting to find correlation between short arc tracks of non-correlated objects, in order to discovery new objects and to establish their orbits. Faint fragments are regularly detected with PH-1 including catalogued objects and uncorrelated one-night tracks. In 2008 it detected 47 faint fragments and their orbits were successfully determined using uncorrelated one-night tracks of PH-1 telescope and other telescopes (many uncorrelated tracks are obtained during tracking observations of catalogued objects). In addition the survey mode of observations is adjusted now with the 60 cm S-600 telescope in Andrushivka (starts operations in 2009) and the upgraded 48 cm AZT-14 telescope in Mondy (see Fig. 7). The obtained uncorrelated one-night tracks are used to find correlation with tracks of PH-1. It is planned that the other 22 cm telescopes – ORI-22 in Ussuriysk, Collepardo, Blagoveschensk and Tiraspol will learn the survey mode in 2009. Moreover, four survey telescopes will be put in operation 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 the faint fragment discovered statistics and orbit maintenance will be significantly improved.

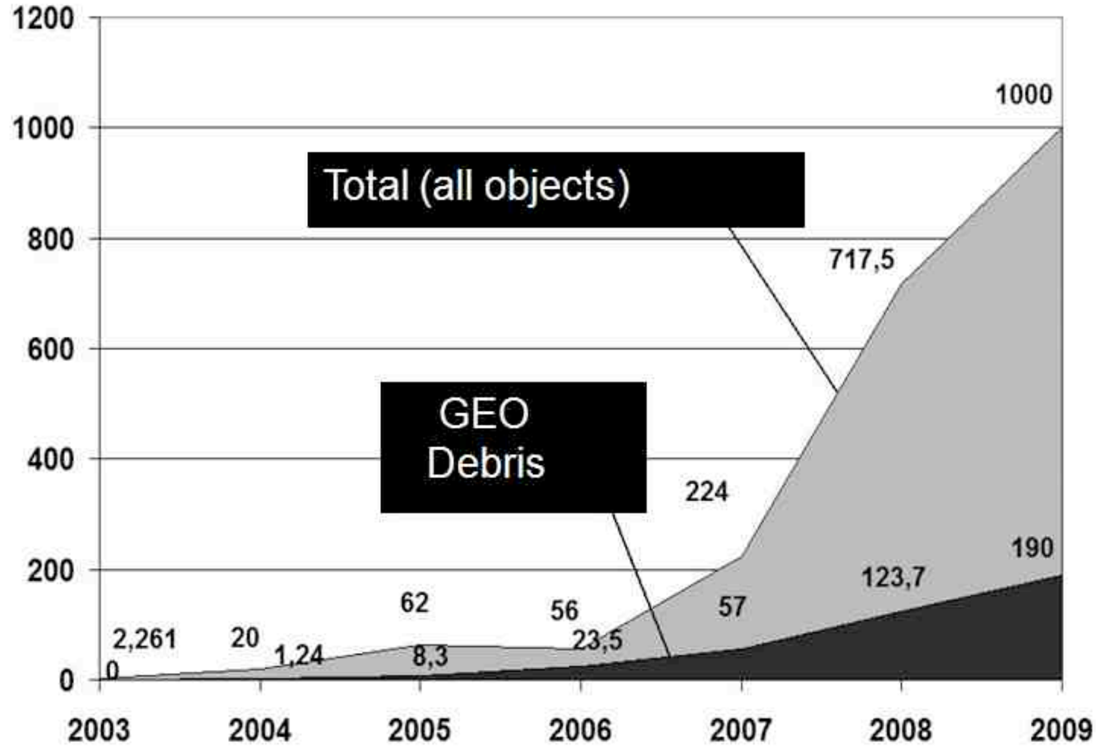

Fig. 3. Statistics of the ISON measurements and tracks for faint fragments from 2004 to 2009 years

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

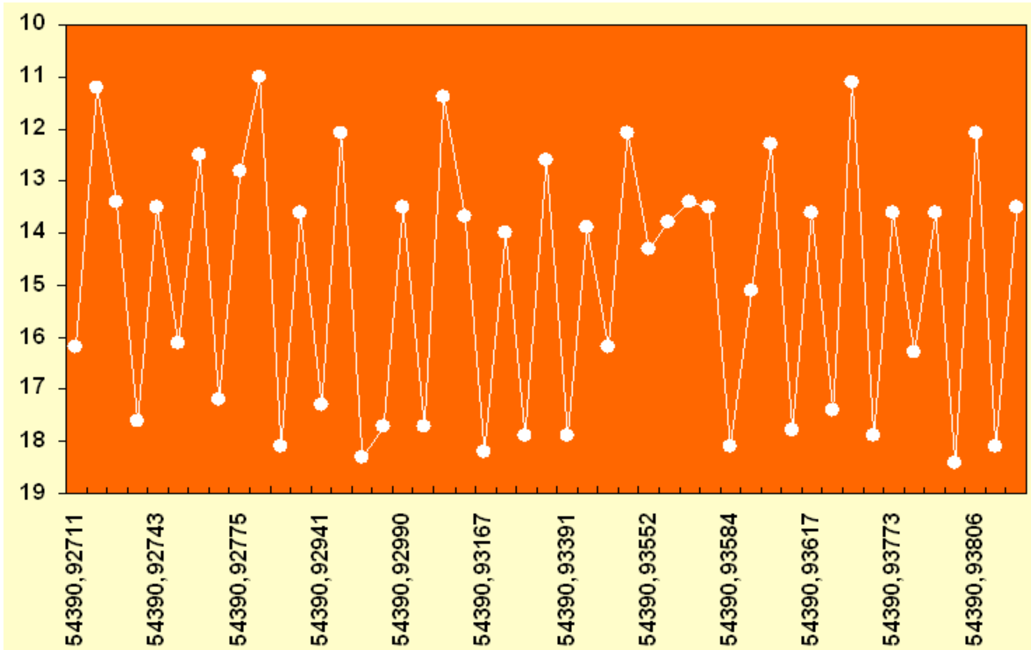

Fig. 5. Light Curve (magnitudes vs. modified Julian dates) of 90022 fragment measured in Gissar.

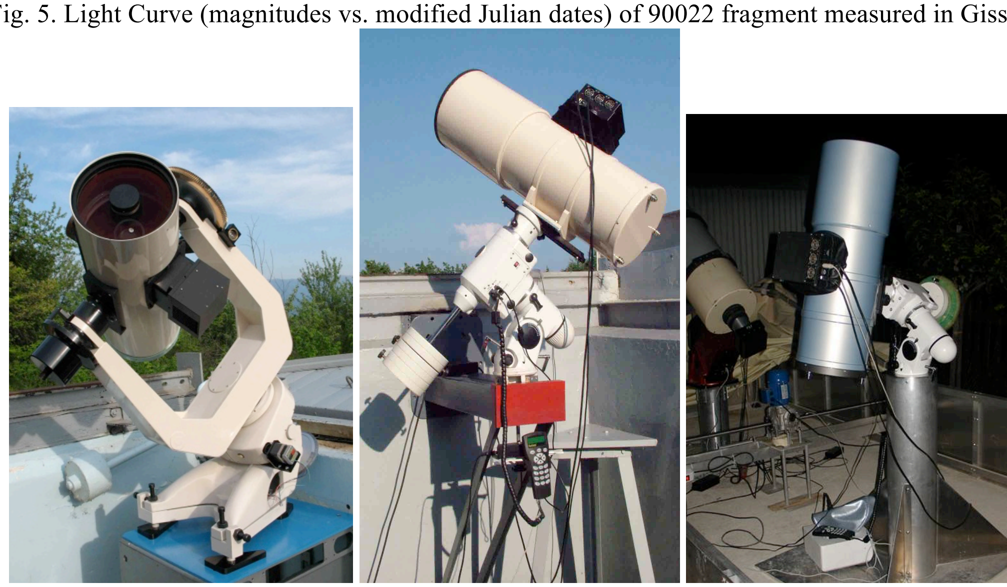

Fig. 6. 22 cm survey telescopes with FOV of 4°: PH-1 in Nauchny, ORI-22 in Ussuriysk, ORI-22 in Collepardo.

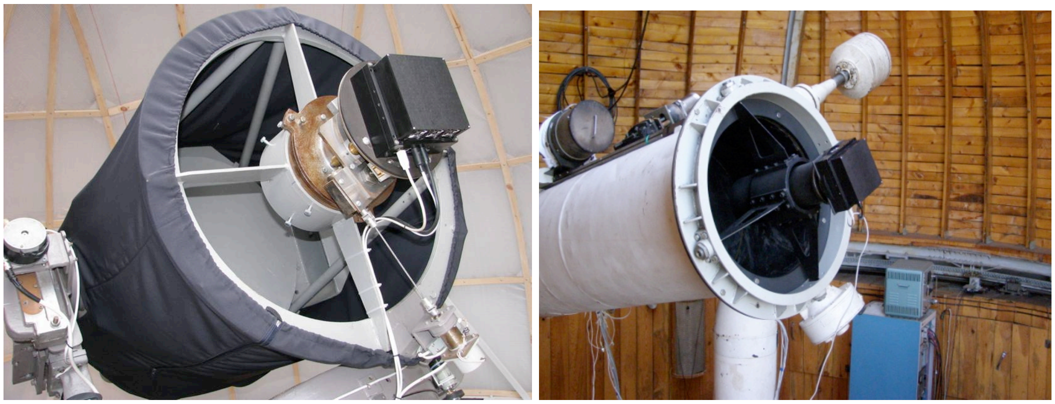

Fig. 7. Telescopes adjusting the method of GEO region survey: new 60 cm S-600 (FOV is 2°) in Andrushivka and upgraded (FOV enlarged up to 1.3°) 48 cm AZT-14 in Mondy.

3. ISON OBSERVATIONS RESULTS

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

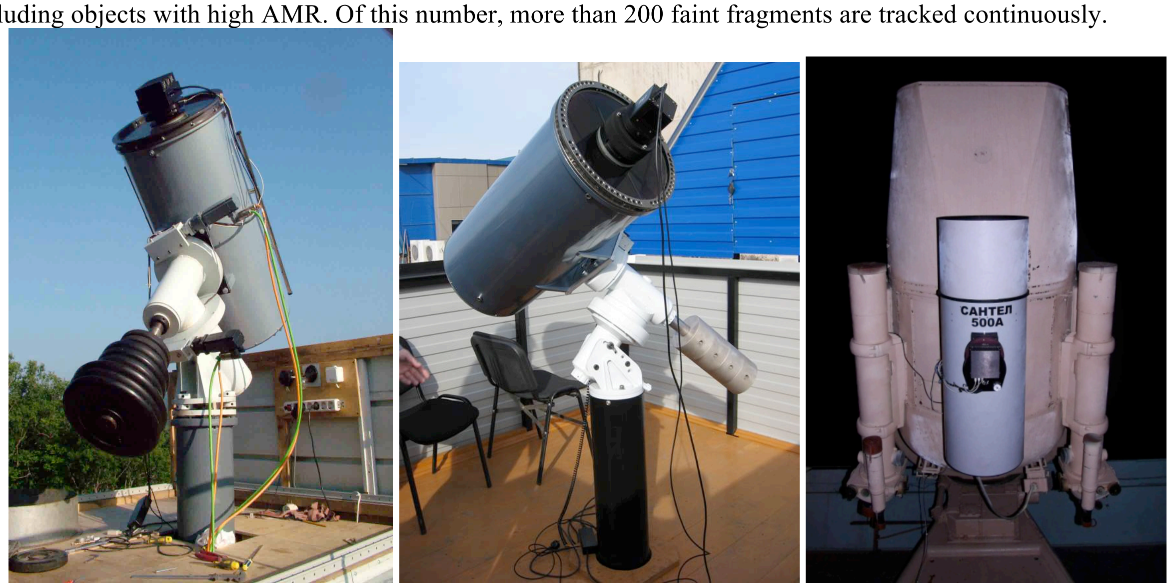

Fig. 8. New survey telescopes: 50 cm VT-50/400 (FOV is 1.8°) in Ussuriysk, 40 cm ORI-40 (FOV is 2.3°) in Krasnojarsk (second ORI-40 will be installed in Kitab in 2009) and 50 cm Santel-500a (FOV is 1.6°in Zvenigorod (over VAU camera mount).

Space debris clouds, created in fragmentations of GEO objects, is proved not only by the statistical observation approach, but for the first time – by long deterministic observations of individual members of the clouds. For the first time, a large amount of data 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 values, and some orbital parameters. One can see that most of the 546 fragments included into the brightness plot (Fig. 9) concentrated around the magnitude range of 16^m to 18^m. This picture reflects more the current observation capabilities of the ISON than the real distribution of the existing population of space debris in GEO region. Fainter objects are much more complicated for discovering and tracking, especially taking into account high brightness variability of many of them.

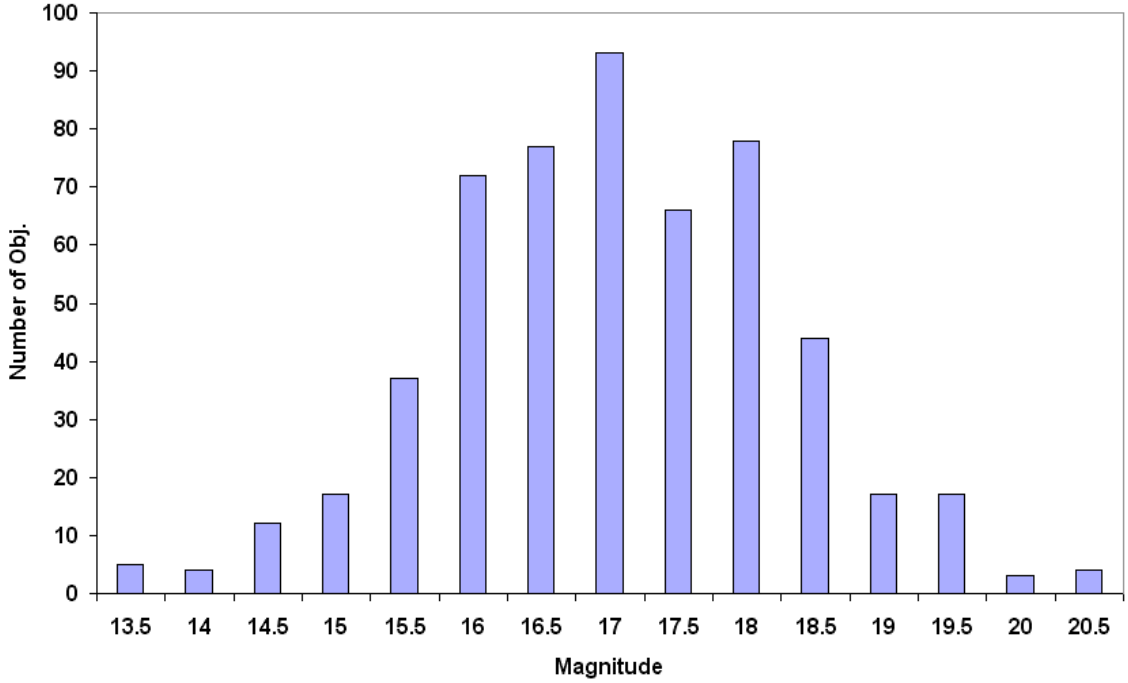

Fig. 9. Distribution of average brightness for 546 fragments
(including 341 object and 205 uncorrelated one-night tracks).

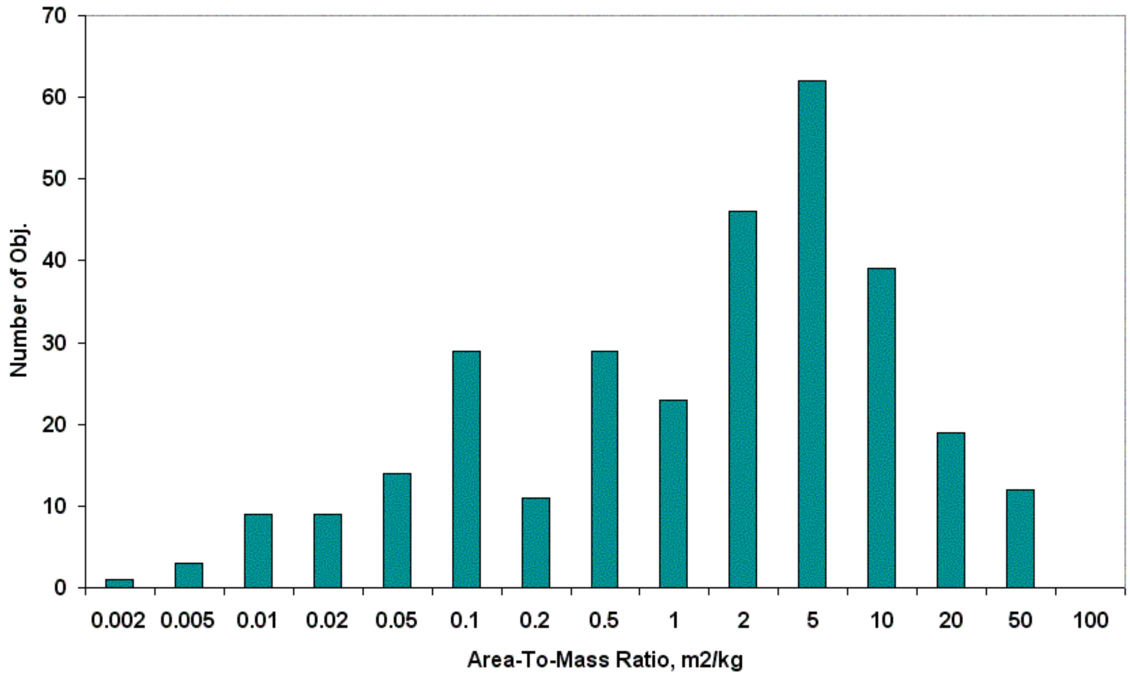

Fig. 10. Distribution of average AMR value for 306 fragments.

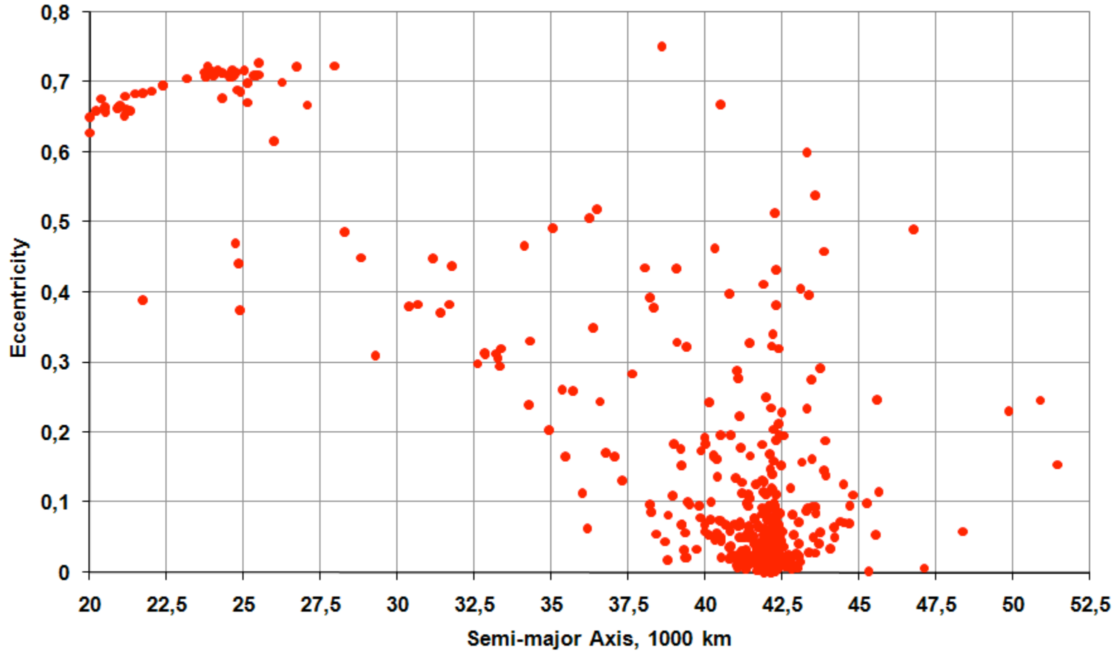

Fig. 11. Distribution of eccentricity and semi-major axis for 439 fragments
(including 341 object and 98 uncorrelated one-night tracks).

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 the involvement of additional larger aperture telescopes into the project will significantly change the distribution for fainter objects.

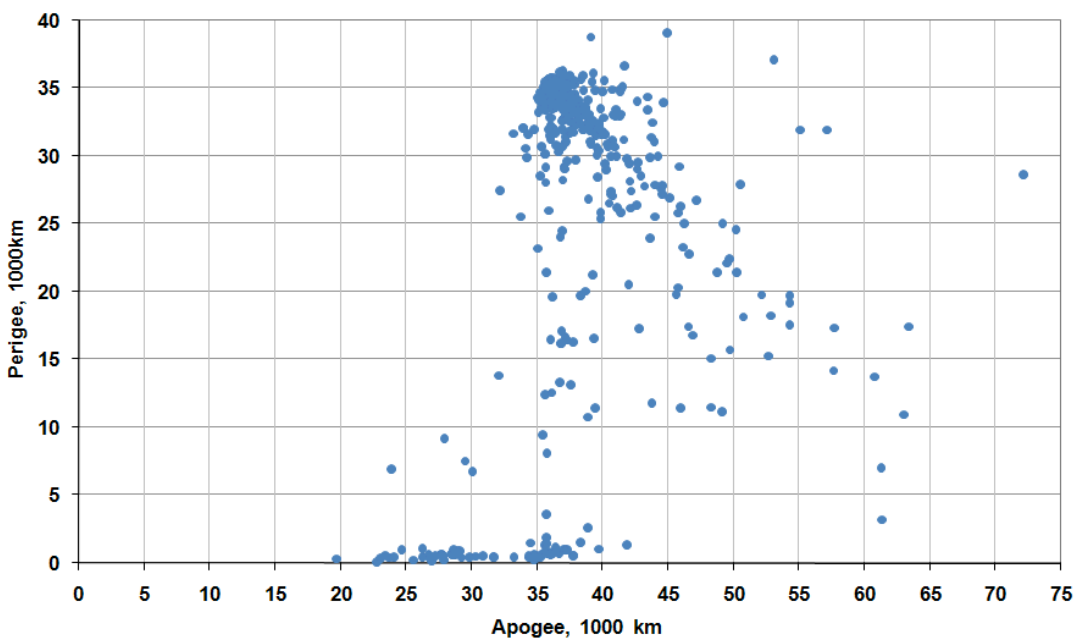

Fig. 12. Distribution of apogee and perigee for 439 fragments
(including 341 object and 98 uncorrelated one-night tracks).

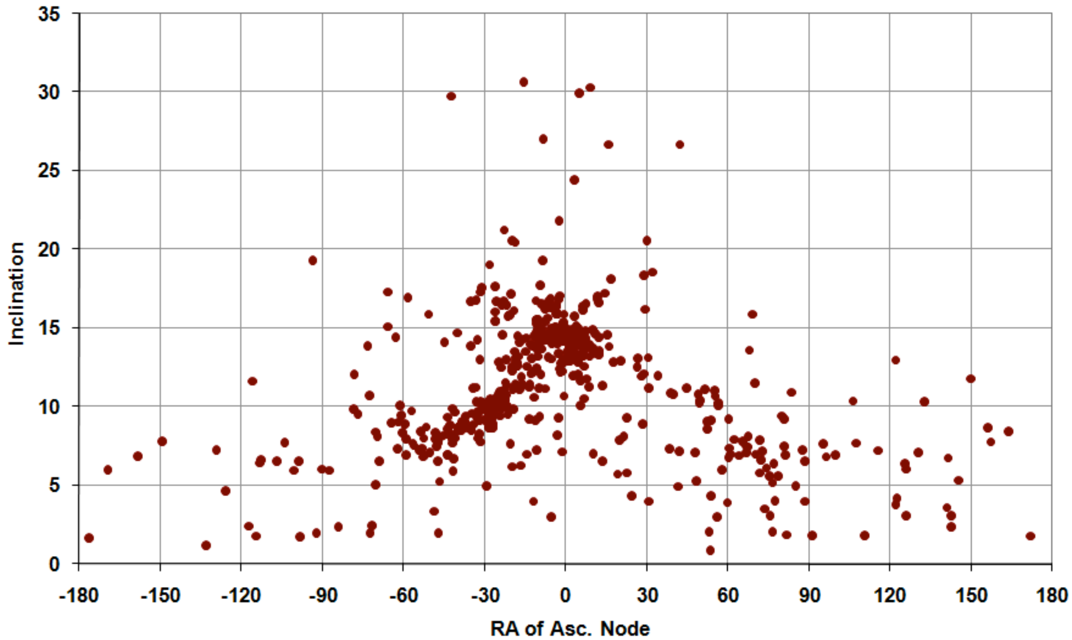

Fig. 13. Distribution of RAAN and Inclination for 544 fragments
(including 341 object and 203 uncorrelated one-night tracks).

Distribution of AMR values for fragments (Fig. 10) is constructed taking into account only those of the discovered debris objects for which the full 6 orbital parameters vector was obtained and the amount of measurements and length of a measurement distribution arc (by time) enough to estimate the AMR value as an additional parameter. Only 306 of 556 discovered fragments satisfied these criteria. For other fragments the measurement distribution arc is too short to reliably determine the AMR value or even the full 6 parameters orbit vector. The nature of objects with AMR larger than 1 m^2/kg is not clear yet. It may be such objects are formed of a multi-layer insulation (MLI) pieces, which are separating from spacecraft under the influence of space environment conditions.

Fig. 11 and Fig. 12 represent distribution of orbital parameters for only those discovered debris objects for which the full 6 orbital parameters vector is obtained, even in the case when the 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 the GEO region having orbital plane parameters significantly different than those objects for which orbital data are provided officially by the U.S. Space Surveillance Network (SSN).

4. CONCLUSION

ISON represents the first in the world civilian global space surveillance system covering the whole GEO and capable to search and track objects both on GEO and various classes of HEO orbits (GTO, Molniya etc.). The ISON subsystem for observations of the faint fragments at high orbits is formed and includes now 14 telescopes with apertures from 0.4 to 2.6 m. Small 22 cm telescopes with large FOV (especially PH-1 in Nauchny) provide addition contributions in the fragment discovery rates due to the high variability of fragment brightness. So, the regular process of discovering and stable tracking of many high orbit fragments is established (to date almost 300,000 measurements in 16,000 tracks obtained for 556 fragments). 200 faint fragments are tracked practically continuously, 30 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 unusual AMR values, but also a strange magnitude pattern. Space debris clouds created in earlier suspected fragmentations of GEO objects is proved by long deterministic observations of individual members of the clouds.

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

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

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