Russian Academy of Sciences
Keldysh Institute of Applied Mathematics

Worldwide Scientific Optical Network As A Global Space Surveillance Data Source

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3rd IAASS Conference
October 21-23, Rome, Italy

The UN General Assembly Resolution 62/117 (1 February 2008)

The General Assembly,

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Considering, that space debris is an issue of concern to all nations,

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28. *Considers* that it is essential that Member States pay more attention to the problem of collisions of space objects, including those with nuclear power sources, with space debris, and other aspects of space debris, **calls** for the continuation of national research on this question, **for the development of improved technology for the monitoring of space debris and for the compilation and dissemination of data on space debris**, also considers that, to the extent possible, information thereon should be provided to the Scientific and Technical Subcommittee, and agrees that international cooperation is needed to expand appropriate and affordable strategies to minimize the impact of space debris on future space missions;

The ISON network – Beginning…

The International Scientific Optical Network (ISON) started with the single small instrument in Pulkovo Observatory and a few people involved into observations and data processing.

First trial observations of GEO – May 2001

Initial tasks for the project:

- support of radar experiments
- obtaining data to confirm the theory of evolution of fragment clouds created in explosions of old GEO resident objects

… and Present

As of the mid of 2008 the ISON network joins:

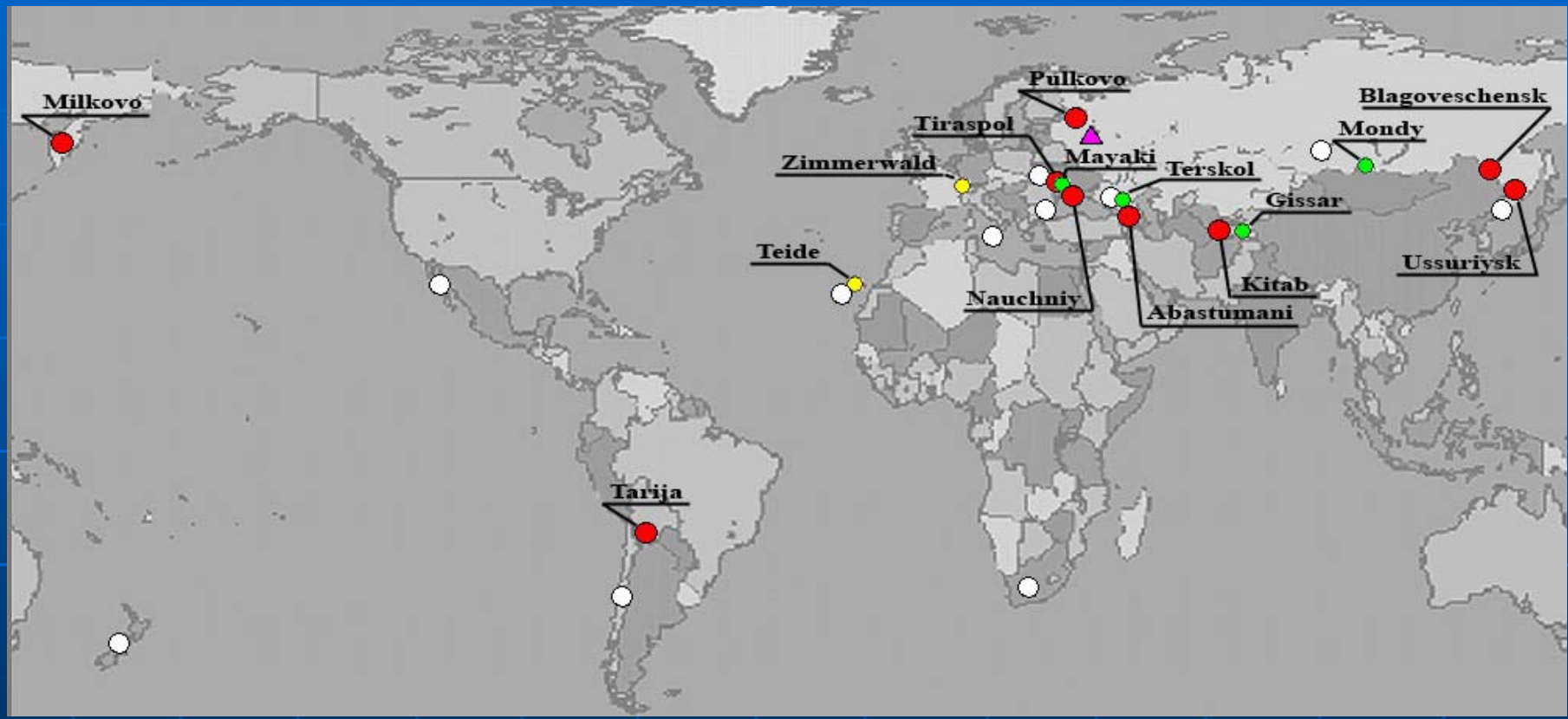
- 18 scientific institutions in 9 states, including partners from ESOC, AIUB, astronomical organizations of Bolivia, Georgia, Moldova, Russia, Tajikistan, Ukraine, Uzbekistan
- 18 observatories and observation facilities
- more than 20 optical instruments
- nearly 60 observers and researchers

Project principal coordinator responsible for the formulation of the solving tasks, observation planning, collecting and analysis of the results is Keldysh Institute of Applied Mathematics of the Russian Academy of Sciences (KIAM RAS).

Current primary tasks:

- regular GEO monitoring, new objects discovering and tracking maintenance as complete GEO objects database as possible
- new objects on GTO and other HEO regimes discovering and individual tracking, special HEO surveys will start soon

I S O N
International scientific optical network



ISON is an open international non-government project for regular collection and processing of information on space objects for various applications

Key works performed

- Renewed the operations of observatories in Kitab, Gissar, Abastumani, Tarija. Two new observation points put into operation in Tiraspol and Milkovo
- 16 new telescopes are produced (one 80-cm, two 60-cm, one 50-cm, one 25-cm, nine 22-cm, two 12.5-cm)
- 27 CCD cameras are purchased and installed (with chip size of 25x25 mm to 50x50 mm)
- 30 GPS-based timing devices are produced on the base of the Trimble Resolution T board
- 3 mounts are produced (two WS-240GT for load up to 80 kg, one WS-300 – up to 150 kg), 7 mounts EQ6Pro (up to 25 kg) are purchased
- standard software APEX-II for CCD frames reduction is elaborated and is implemented now in 20 observatories
- full set of software modules for control of all telescope devices is elaborated
- training courses for staff of 20 observatories are carried out and four annual workshops for lectures and experience exchange were arranged

The ISON structure

- **network of optical facilities:**

  - search and survey subsystem for studying of the bright (not fainter than 16th magnitude) objects in GEO region (initial operations stage)

  - subsystem for high altitude faint space debris detection and tracking (operational)

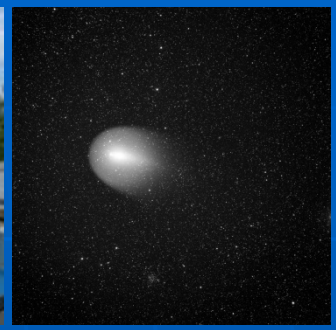
  - search and survey subsystem for studying of the bright (not fainter than 16th magnitude) objects on HEO, MEO and LEO orbits (in development)

- **center for observation planning and data processing including maintenance of the database on space objects**
- **group of technical and programming support including production of telescopes, mounts and special devices**
- **group of the network development**

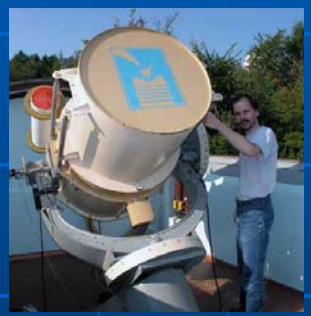
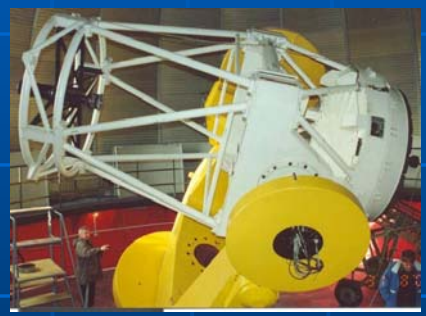
1. Global GEO Search and Survey Subsystem for regular surveying of the GEO and GTO objects down to 15,5^{m} from 10 telescopes of 22-cm with FOV of 4°x4°





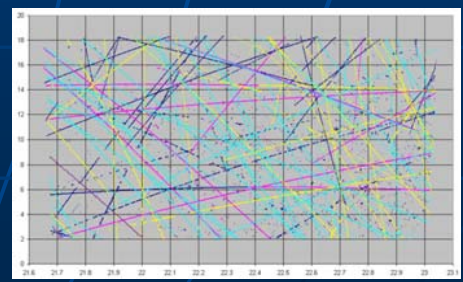



2. Subsystem for high altitude faint (15.5^{m} to 20^{m}) space debris detection and tracking from telescopes of 0.5-m to 2.6-m

3. Subsystem for monitoring of the objects on HEO, MEO and LEO orbits from cameras with FOV of 15°and 25 – 40-cm aperture telescopes on “fast” mounts



Characteristics of the ISON telescopes

Observatory	Telescope	CCD	FOV	m
Nauchnij -1	2.6-m ZTSh	1kx1k, 24	8.4’x8.4’	21,0
Nauchnij -1	64-cm AT-64	4kx4k, 9	1°x1°	18,0
Nauchnij -1	22-cm RS-220	4kx4k, 9	4°x4°	16,0
Nauchnij -2	22-cm RS-220	3kx3k, 12	4°x4°	16,3
Zimmerwald	ZIMLAT-1000	3kx3k, 12	23’x23’	20,0
Tenerife	ESASDT	4kx4k	0.7°x0.7°	21,0
Simeiz	Zeiss-1000	1kx1k, 24	13’x13’	19,0
Pulkovo	22-cm RS-220	3kx3k, 12	4°x4°	14,5
Mayaki	60-cm RC-600	1kx1k, 24	17'x17'	17,0
Tiraspol	22-cm RS-220	3kx3k, 12	4°x4°	15,0
Terskol	Zeiss-2000	512x512	8’x8’	21,0
Abastumani	22-cm ORI-22	3kx3k, 9	4°x4°	15,5
Abastumani	70-cm AS-32	3kx2k, 9	45'30'	18,0
Mondy	1.6-m AZT-33IK	1kx1k, 16	8’x8’	21,0
Kitab	22-cm ORI-22	2kx2k, 24	5.5°x5.5°	15,5
Gissar	70-cm AZT-8	1kx1k, 24	30'x30'	18,0
Blagoveschensk	22-cm ORI-22	1kx1k, 24	2.6°x2.6°	15.5
Ussuriysk	22-cm ORI-22	3kx3k, 12	4°x4°	15,5
Ussuriysk	25-cm GAS-250	3kx2k, 9	1°x2°	15,5
Milkovo	22-cm ORI-22	3kx3k, 12	4°x4°	15,5
Tarija	23-cm astrogr.	1kx1k, 24	35’x35’	14,0

Current capabilities and research directions

As of mid 2008 the ISON is capable to perform:

- Selected objects observation across whole GEO-belt (360°)
- Near GEO-belt (± 2°) surveys for the arc 130.3 W – 210.6 E
- GEO region wide surveys for the arc 30W – 90E with the goal of discovery of all objects brighter than 16^m
- Uncatalogued GEO debris search (using different strategies, limiting magnitude 19^m) and tracking (limiting magnitude 21^m)
- GTO and other HEO objects observations including faint space debris
- Photometry of tracked objects
- High altitude space debris physical properties study
- Measurements, orbits and object properties database maintenance
- Close encounters analysis
- Improvement of the motion model using for data processing in part of non-gravity perturbations

Main results obtained in 2005-2008

OPERATIONAL CAPABILITIES

- Global GEO coverage capability is achieved that is important for continuous studying of the situation in that region
- Since Jun 2007 wide GEO survey mode is implemented for longitudes 31.5W to 90E in a zone ±16° with respect to the “true” GEO ring. Partial GEO survey mode is implemented for other longitudes

DISCOVERIES AND OVERALL AMOUNT OF DATA

- Overall number of obtained measurements exceeded 750000
- Number of continuously tracked objects in GEO and HEO - 1690, including 152 unknown bright GEO objects (brighter than 15^m) and more than 120 unknown bright HEO objects
- 439 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 192 GEO objects are tracked continuously.
- Thus population of tracked objects in GEO region is increased more than 35 per cent. New discoveries continues to happen in every survey.

Main results obtained in 2005-2008 (cont.)

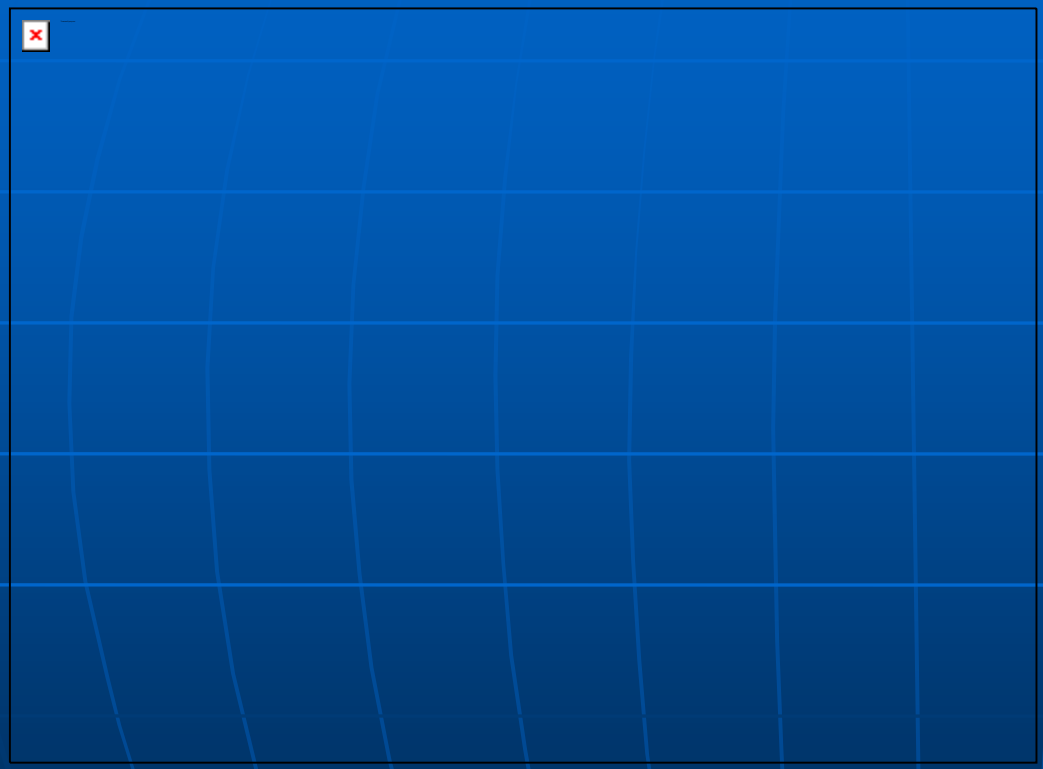
ORBITAL EVENTS ANALYSIS

- Unexpected changes in orbital motion of old GEO objects are revealed. Cause of those changes is not yet understood but in any case they can not be explained by natural forces like gravity or solar radiation pressure
- Large amount of observation is collected that makes possible to perform accurate analysis of the peculiarities of controlled motion of the spacecraft belonging to different owners but located in the vicinity of the same GEO position
- Some of discovered objects are clearly identified with operational fragments (usually not announced by operators) released during initial operations of the spacecrafts – DSP, Fenyung-2D, MSG etc.

DATA PUBLICATION

- orbital data for brighter objects are publishing annually in «*ESOC Classification of Geosynchronous Objects*» (the latest one – Issue 10, Feb 2008)
- results for GEO debris are publishing monthly by KIAM in *High Geocentric Orbit Space Debris Circular* .

Quantity of measurements increased 8 times in 2 years



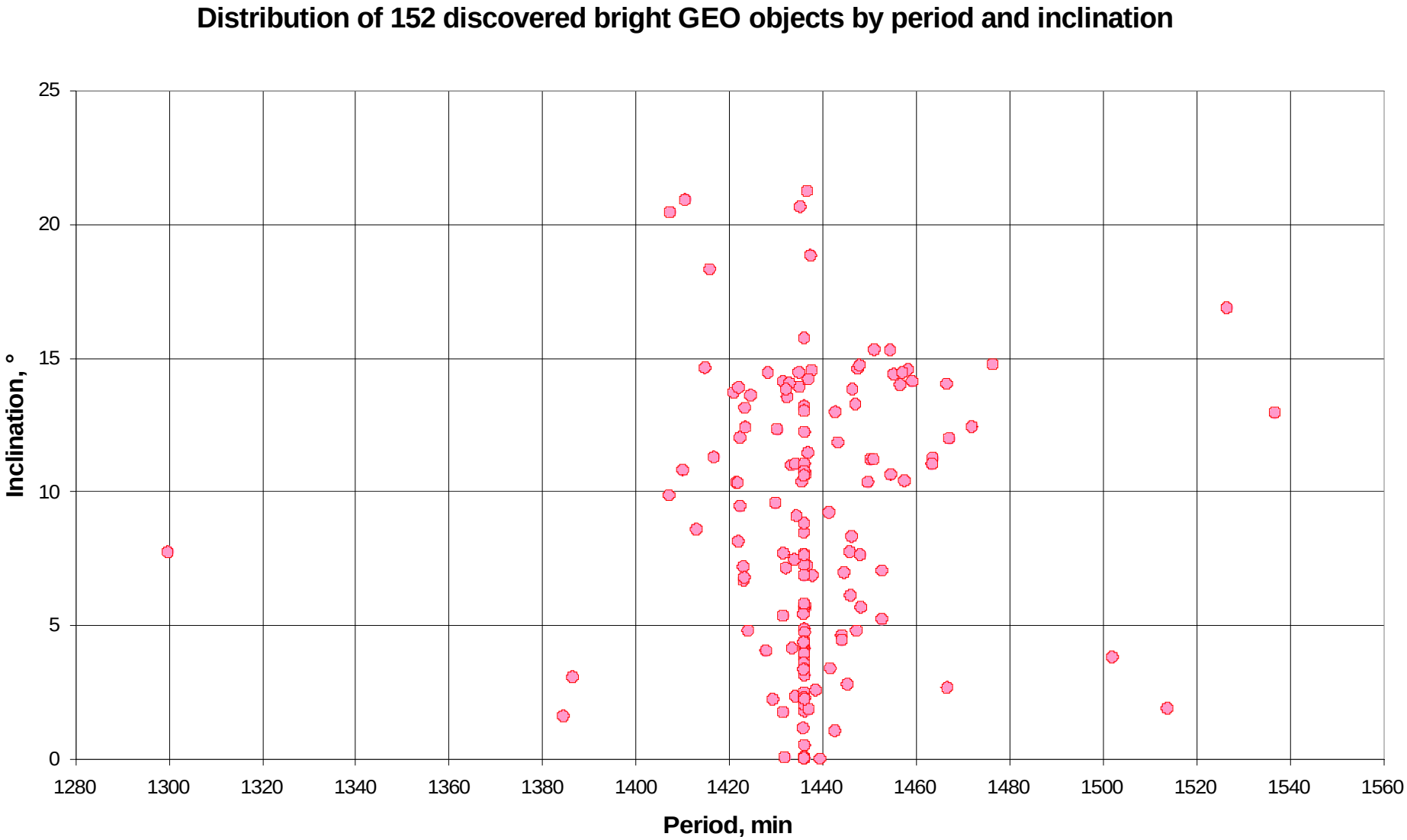
Statistics of the ISON measurements from 2003 to 2008 years for the all measurements (upper line) and measurements for faint fragments only (bottom line).

330000 measurements in 41000 tracks across the whole GEO belt (360°), were obtained by the ISON during Jan.-Aug.2008

ISON statistics for 2008

Parameter	January	February	March	April	May	June	July	August
Observing nights	30	28	31	29	31	30	31	31
Quantity of tracks	7077	5212	4858	4838	4826	5294	3602	4053
Common duration of all tracks (hours)	1627	2402	872	899	925	908	552	899
Average duration of a single track (min)	14	15	11	11	11	10	9	13
Quantity of measurements	49053	39751	34391	42750	48880	55568	35717	38932
Average quantity of measurements in a single track	7	8	8	9	10	11	10	10
Quantity of observed space objects	1200	972	1008	1060	1064	1051	824	961
Covered GEO arc (degree)	330	228	360	360	360	360	360	360

Discovered new bright GEO objects characteristics



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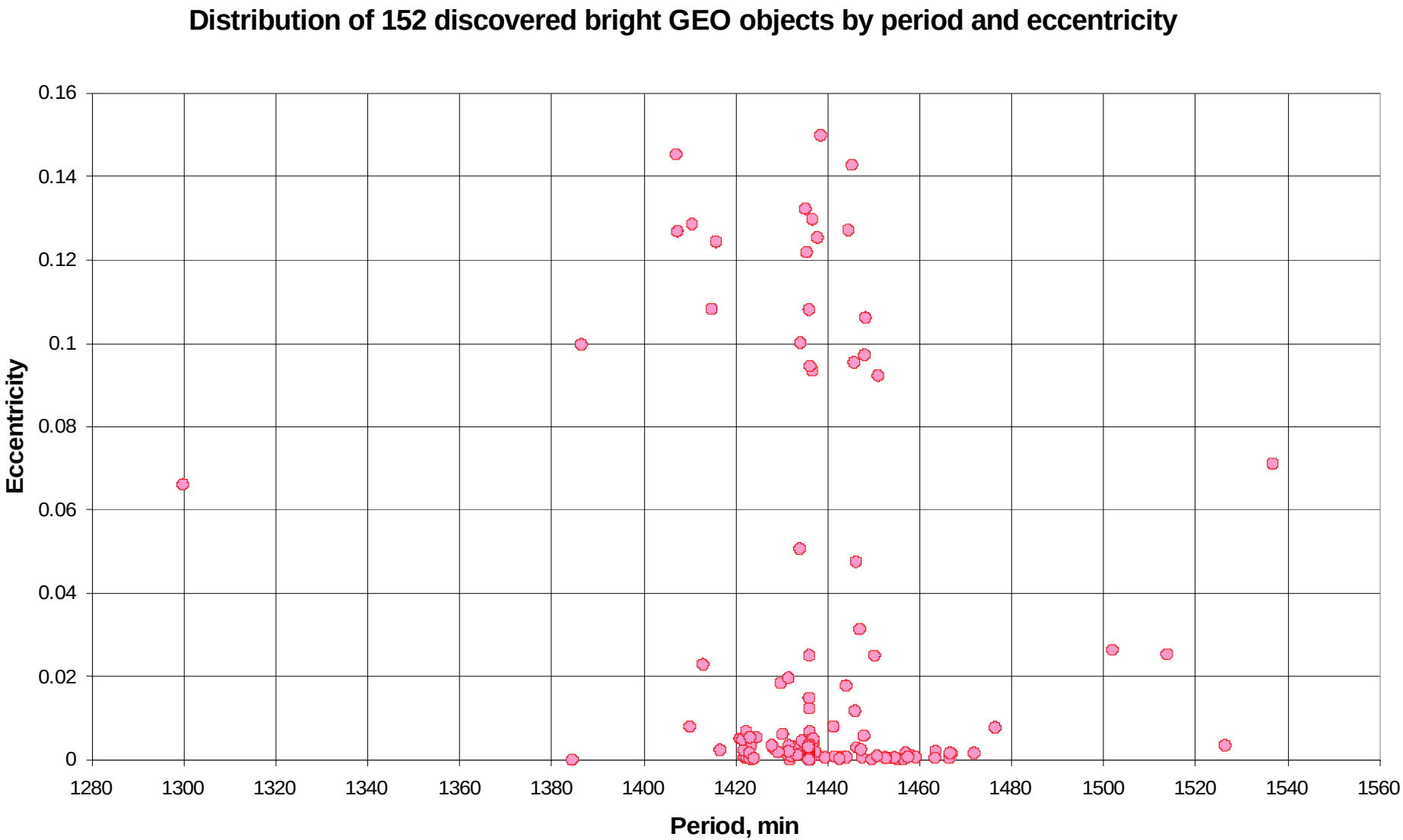
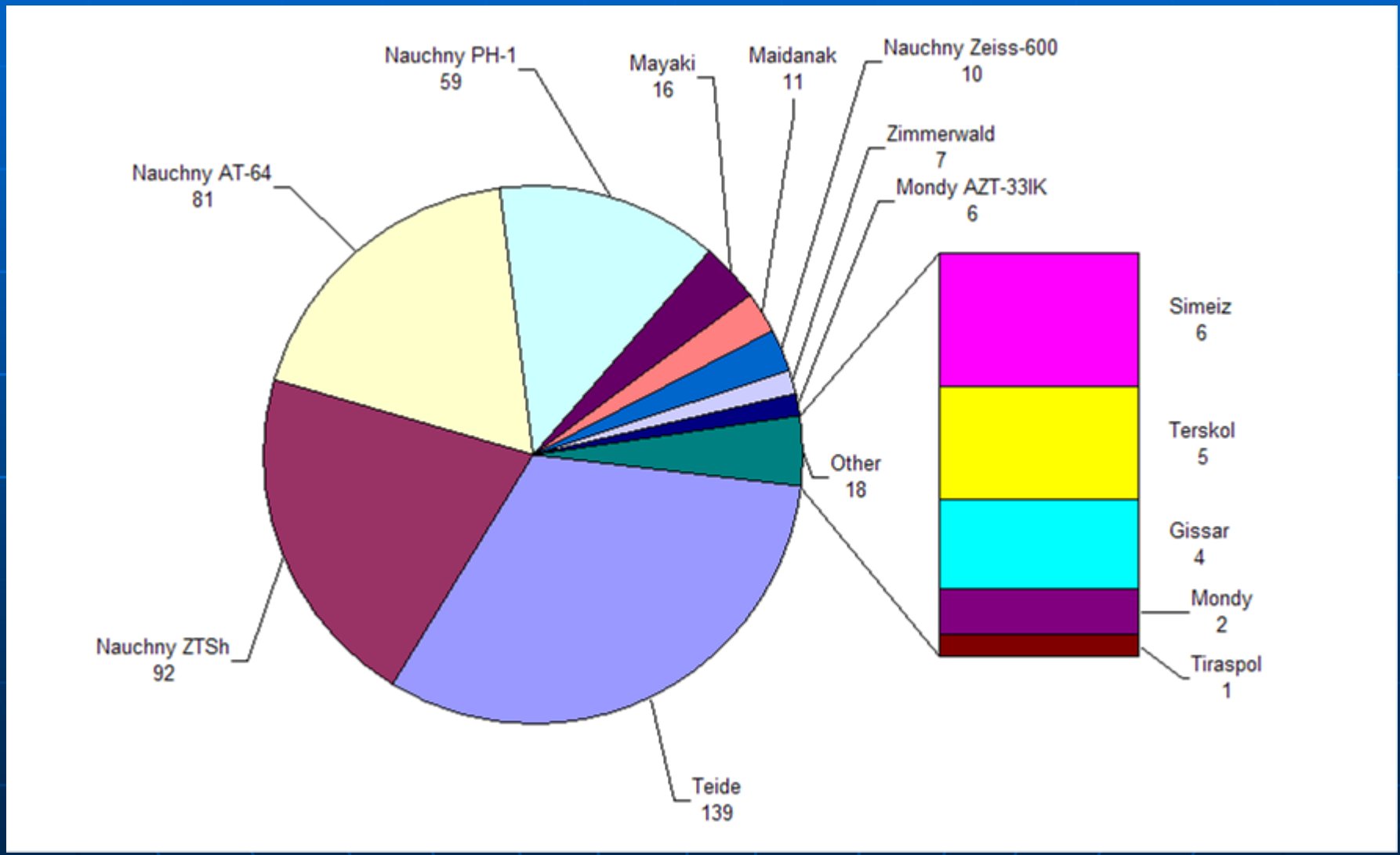
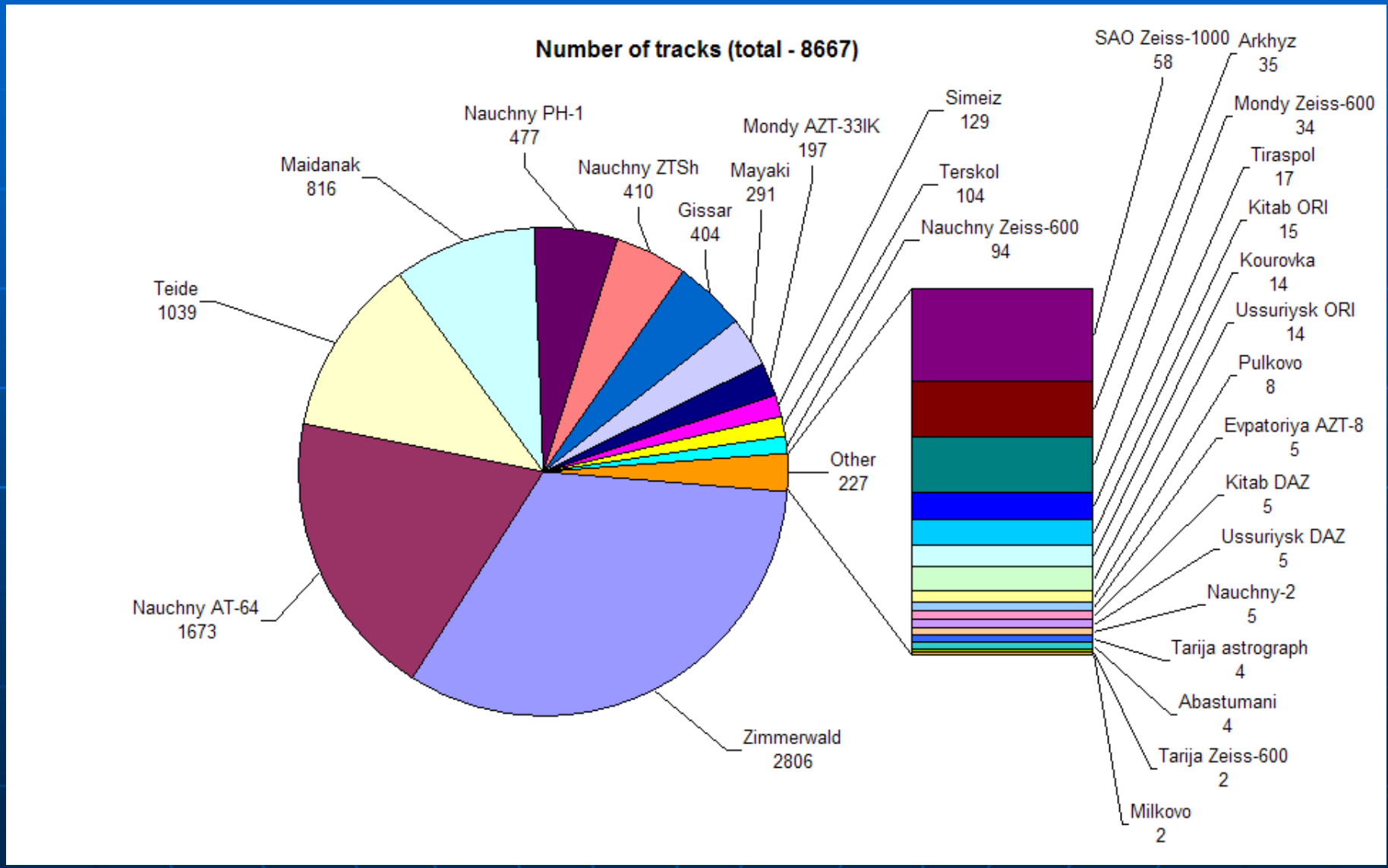


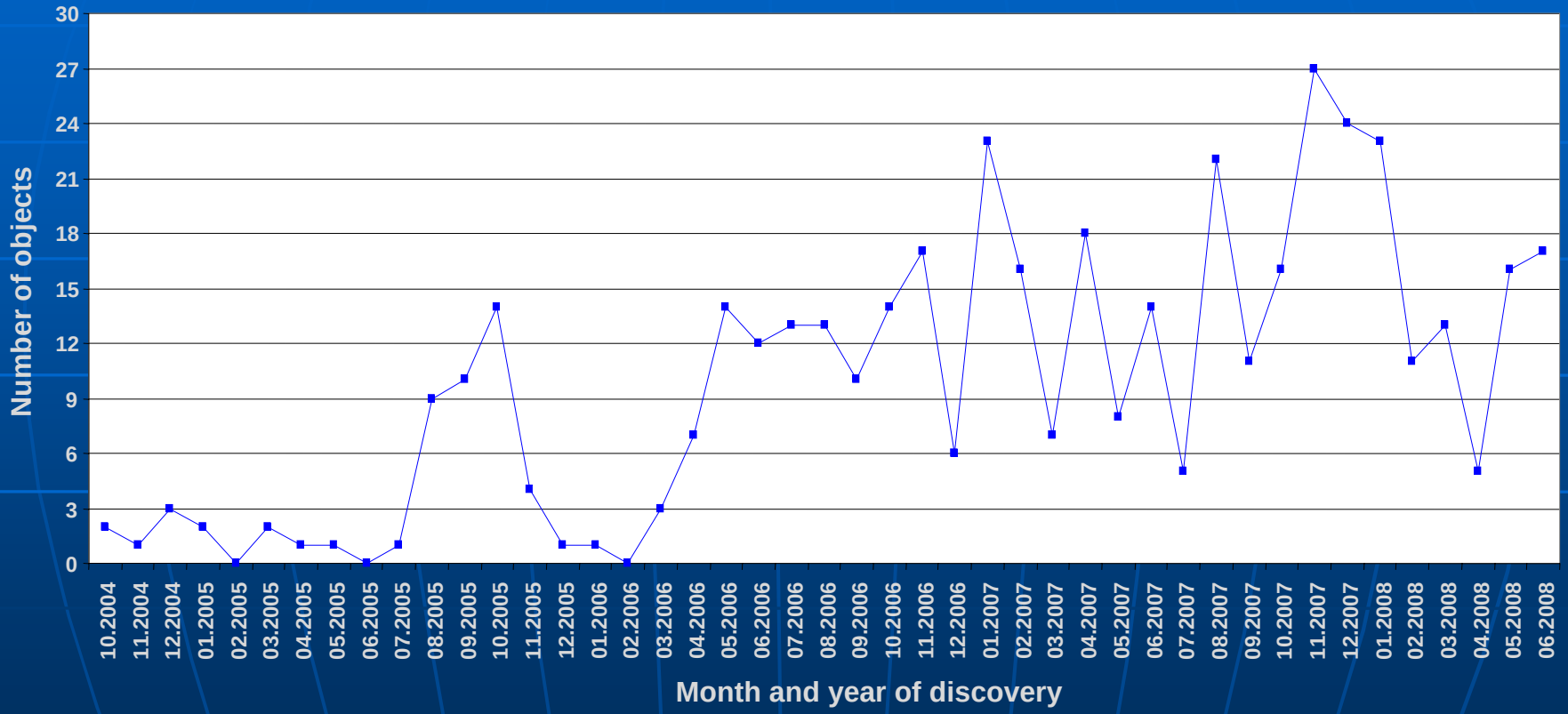
Distribution of 439 discovered fragments by telescopes (2003-2008)



Discovered space debris measurement statistics

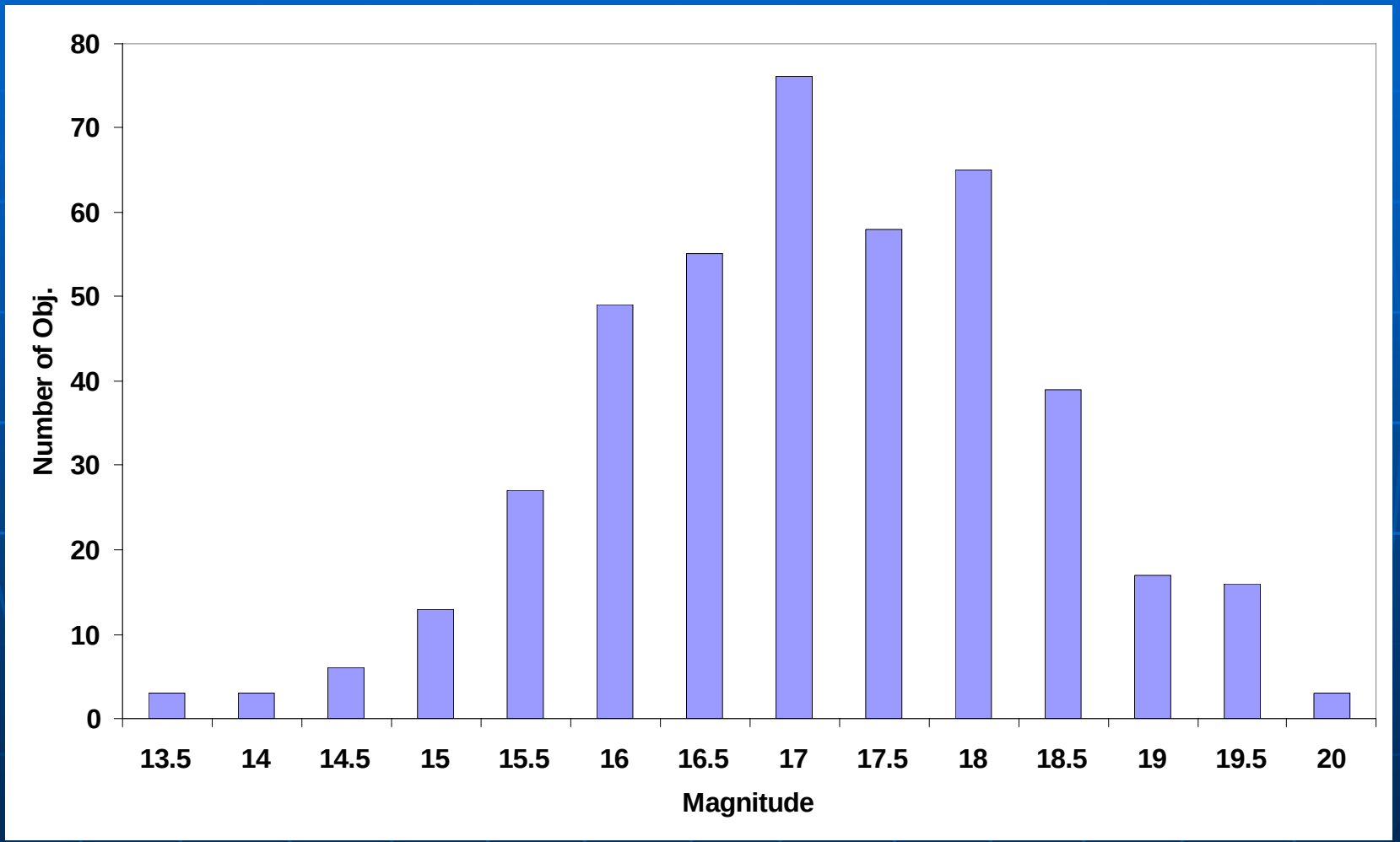


ISON monthly discovery rate of faint fragments



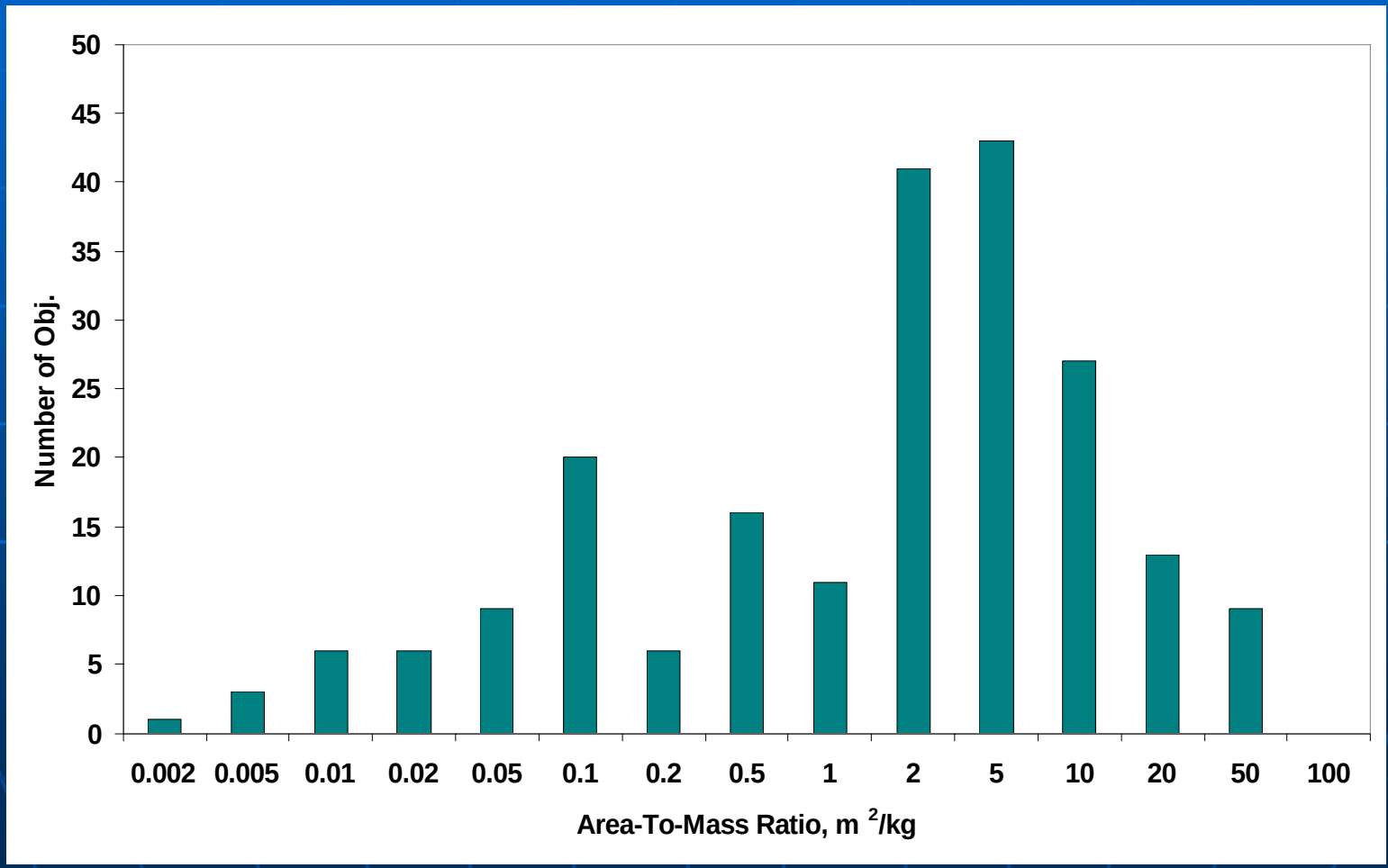
Average discovery rate is 14-15 fragments per month since May 2006

Discovered space debris population characteristics



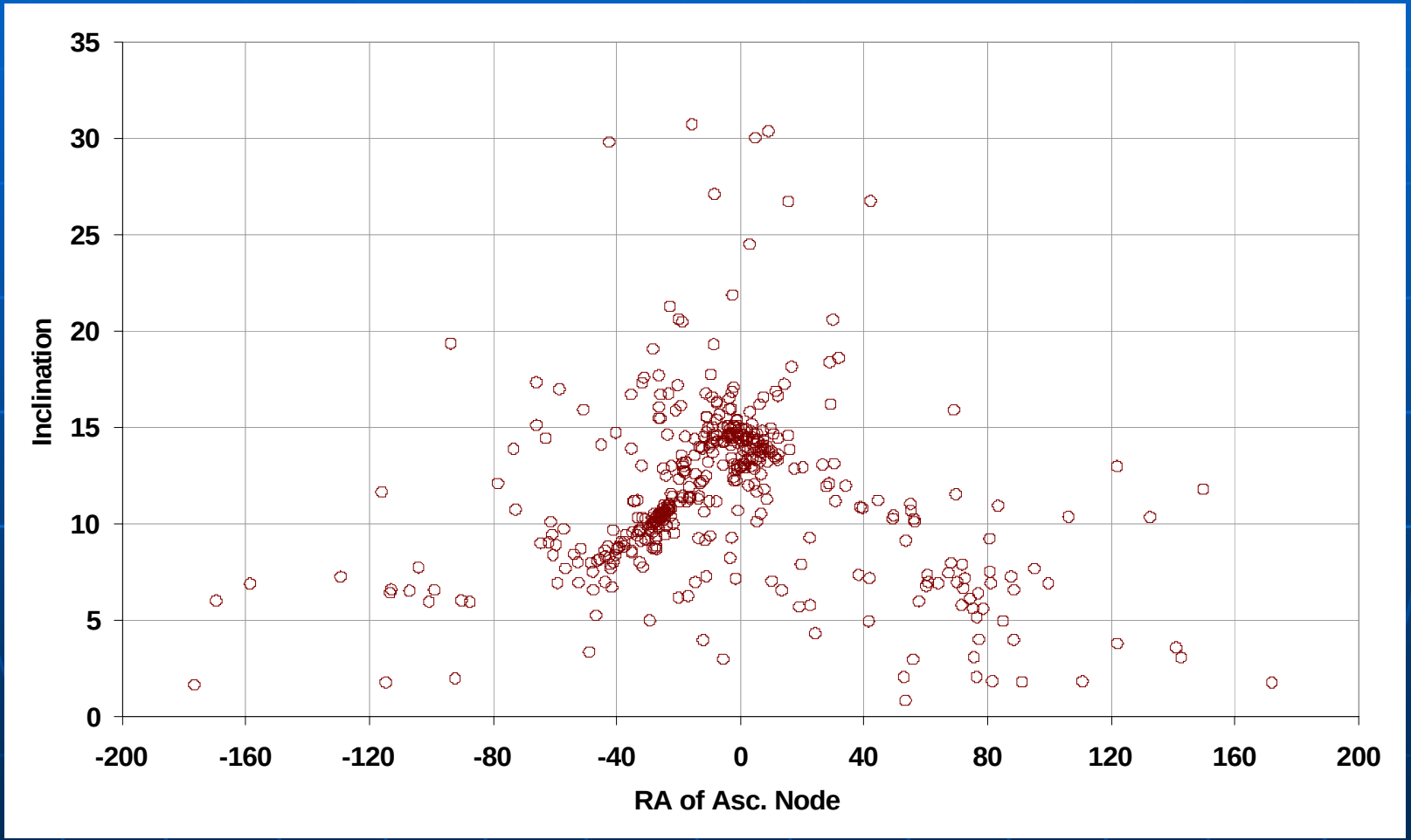
Distribution of average brightness for 434 fragments

Discovered space debris population characteristics



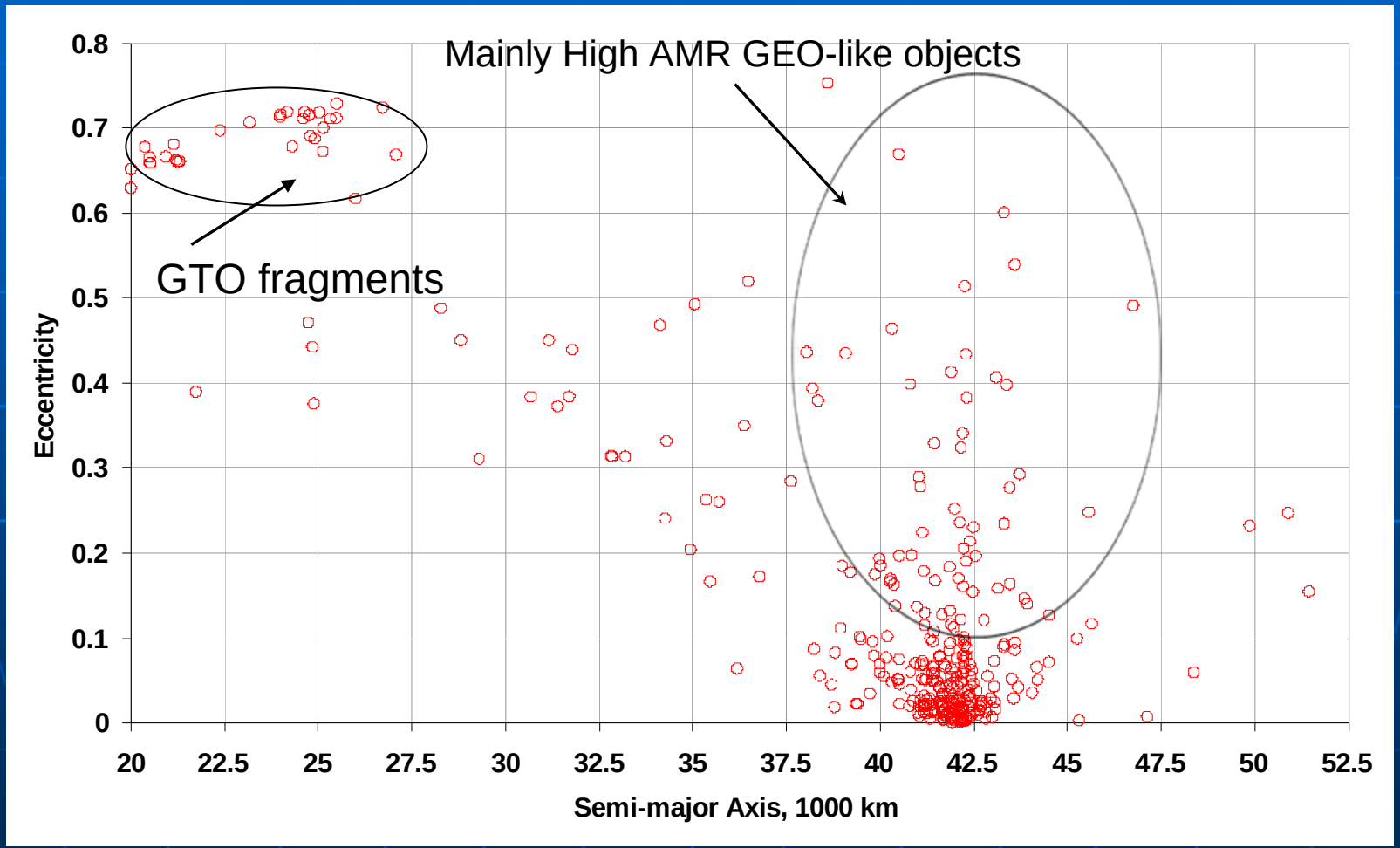
Distribution of average AMR value for 211 fragments

Discovered space debris population characteristics



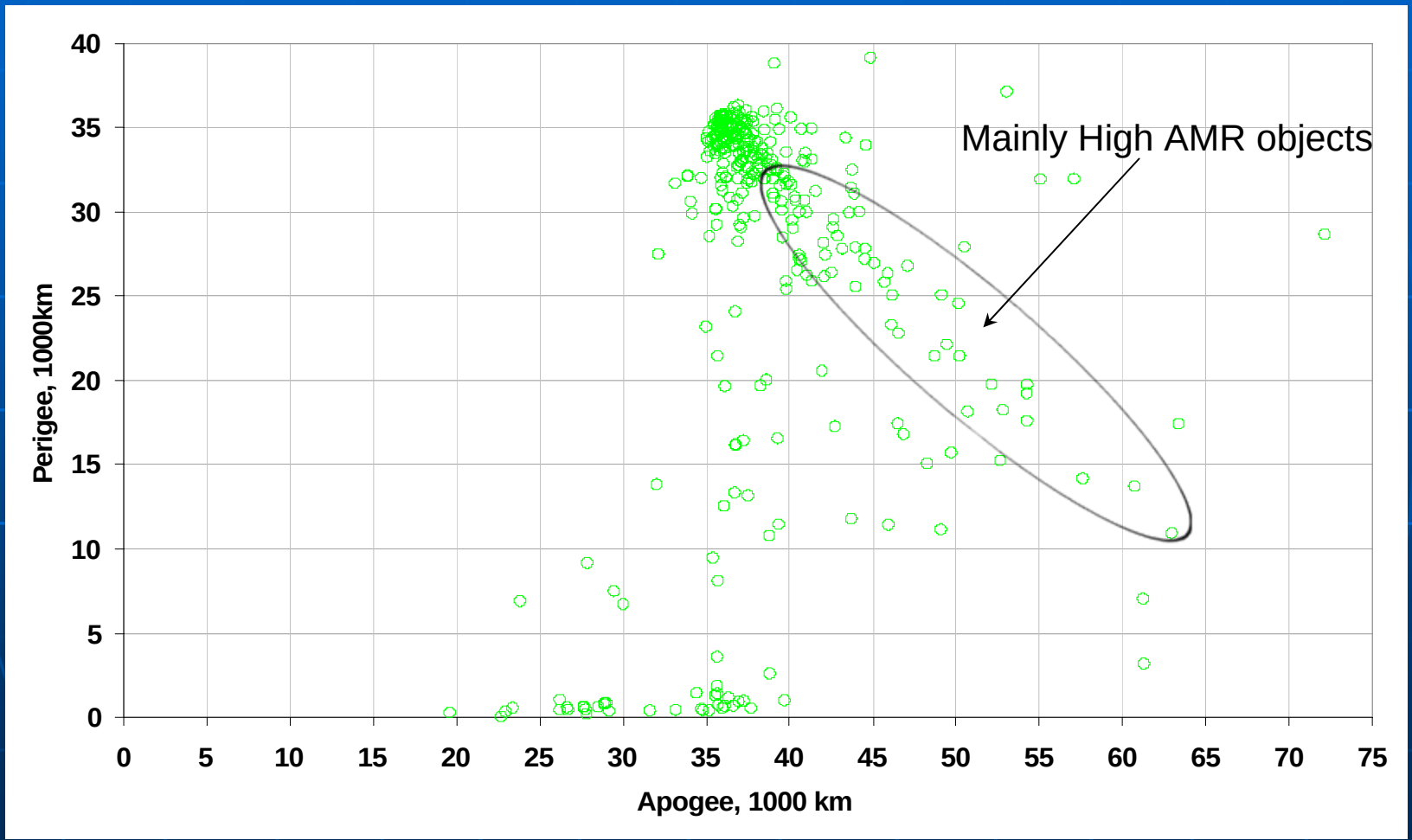
Distribution of inclination and RAAN for 432 fragments

Discovered space debris population characteristics



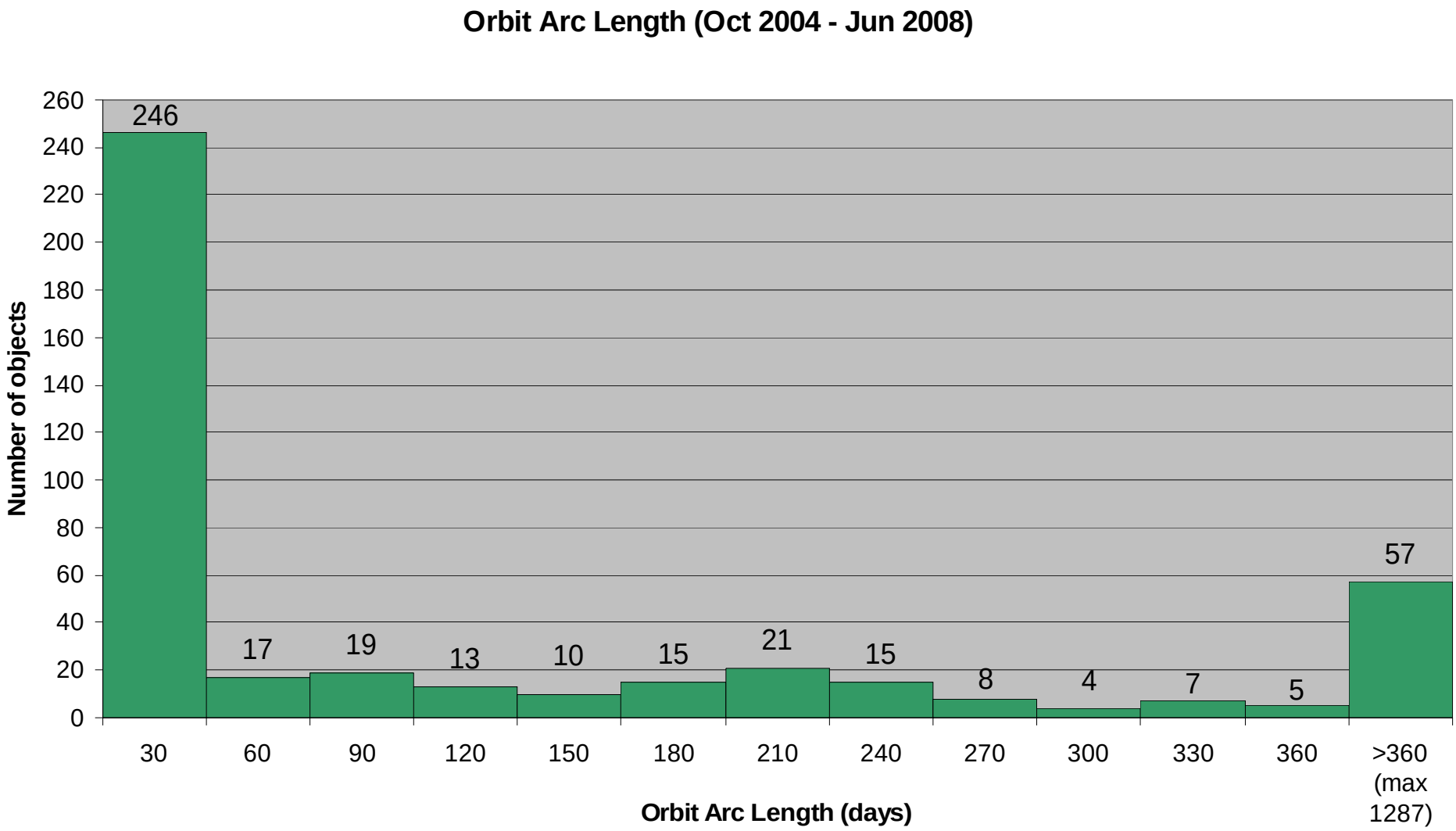
Distribution of eccentricity and semimajor axis for 336 fragments

Discovered space debris population characteristics

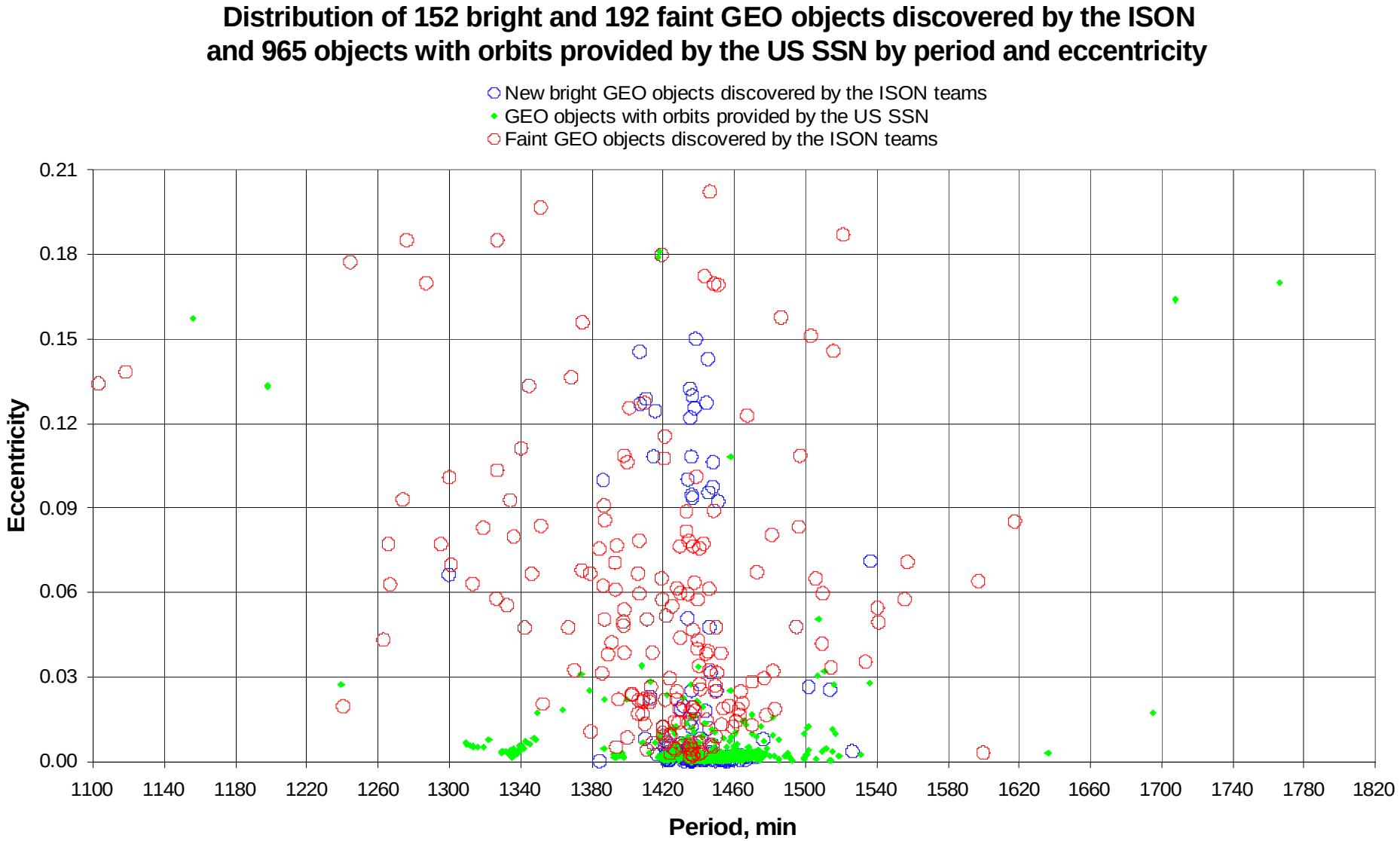


Distribution of perigee and apogee for 336 fragments

Orbital arcs (6+ params orbit)



All known GEO objects population orbital characteristics



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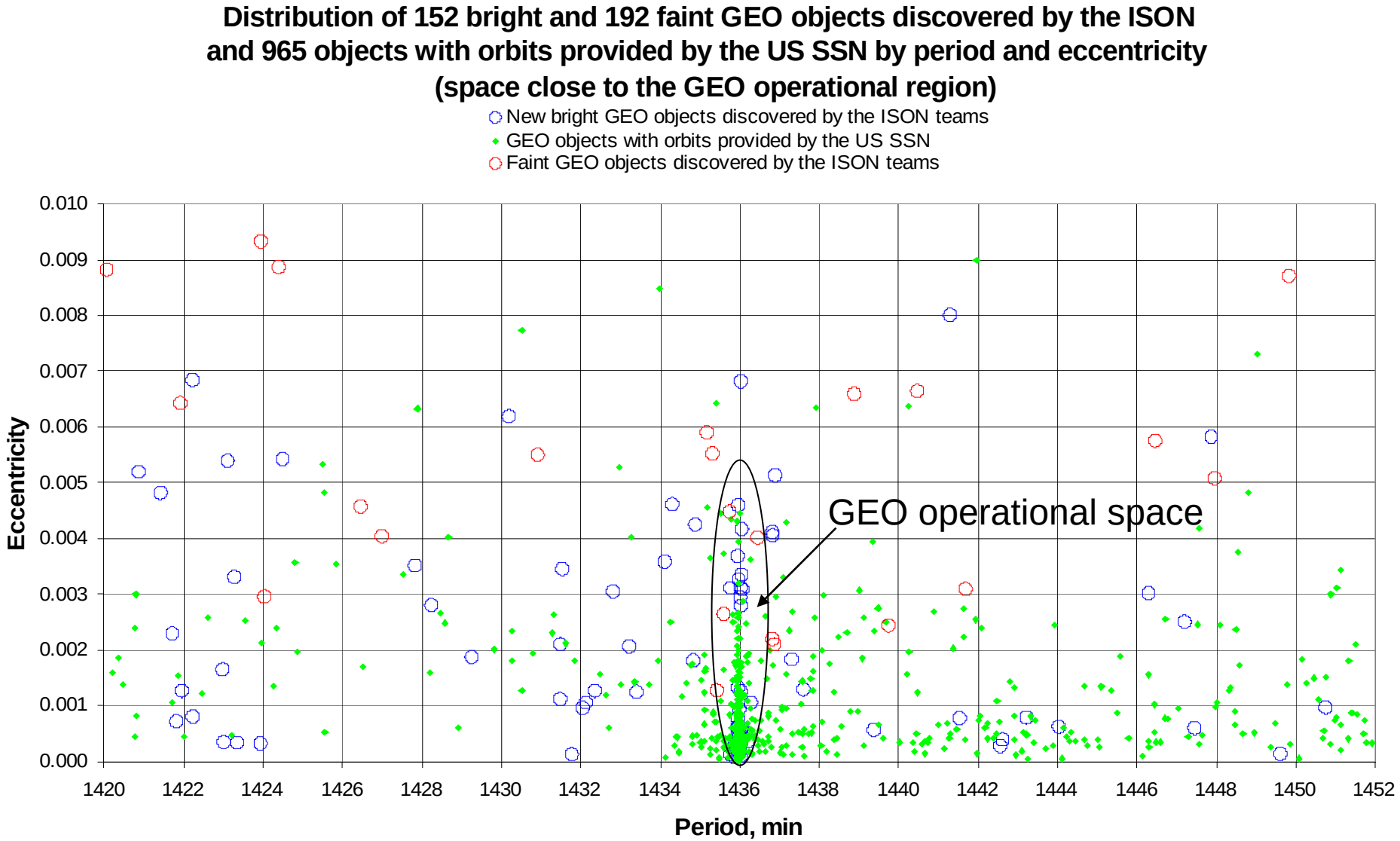

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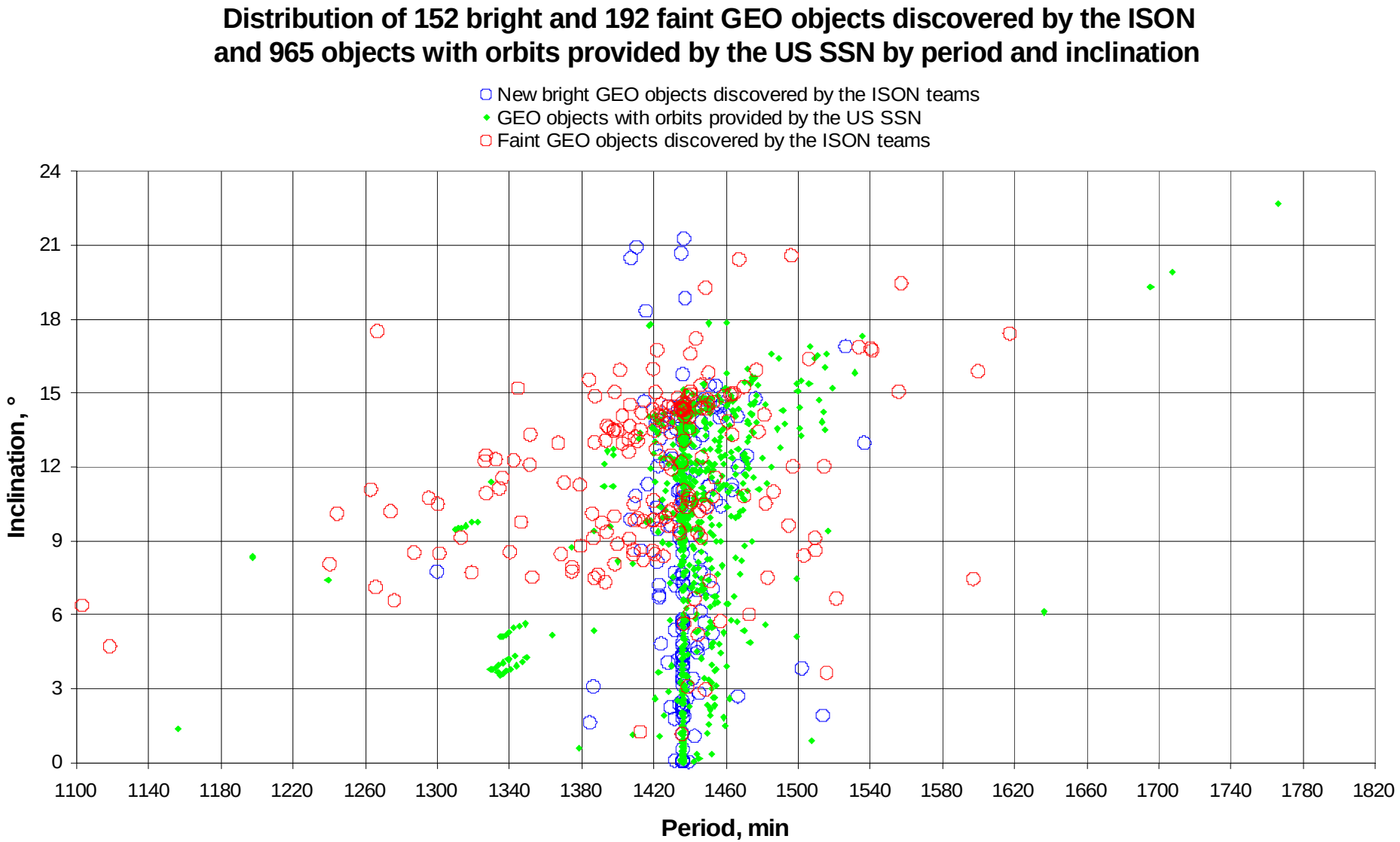

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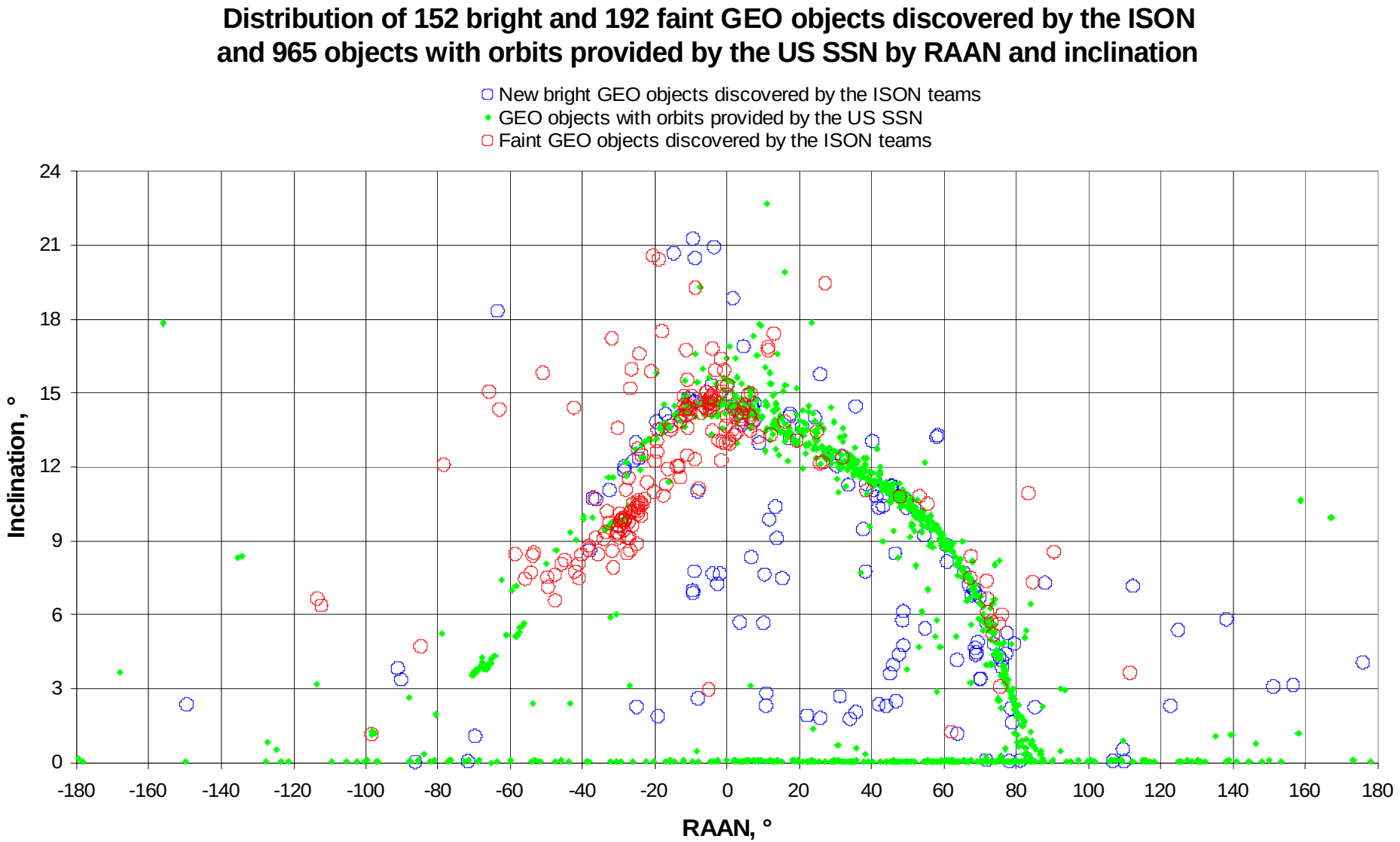


Different mechanisms are involved into GEO debris creation

Fragments in GEO region are discovered on different types of orbits both drifting and librating. That means there are different GEO debris creation processes:

- for debris on libration orbits → separation with small relative velocity from the “parent” object (possible scenario – low velocity collision, deterioration of outer surface under influence of the environment or low velocity operational fragment separation)
- for debris on drifting orbits → high velocity separation from any object in GEO region (possible scenario – fragmentation in explosion) or low velocity separation from objects moved to the graveyard orbit (possible scenario – low velocity collision or deterioration of outer surface under influence of the environment)

Additional studies are required to understand the most probable scenario of GEO fragments creation and to develop recommendations how to avoid (if possible) new fragments generation in the future.

Operational GEO objects orbital motion characterization

New classification of orbits for GEO operational satellites is proposed based on analysis of obtained data.

Following classes of satellites are observed:

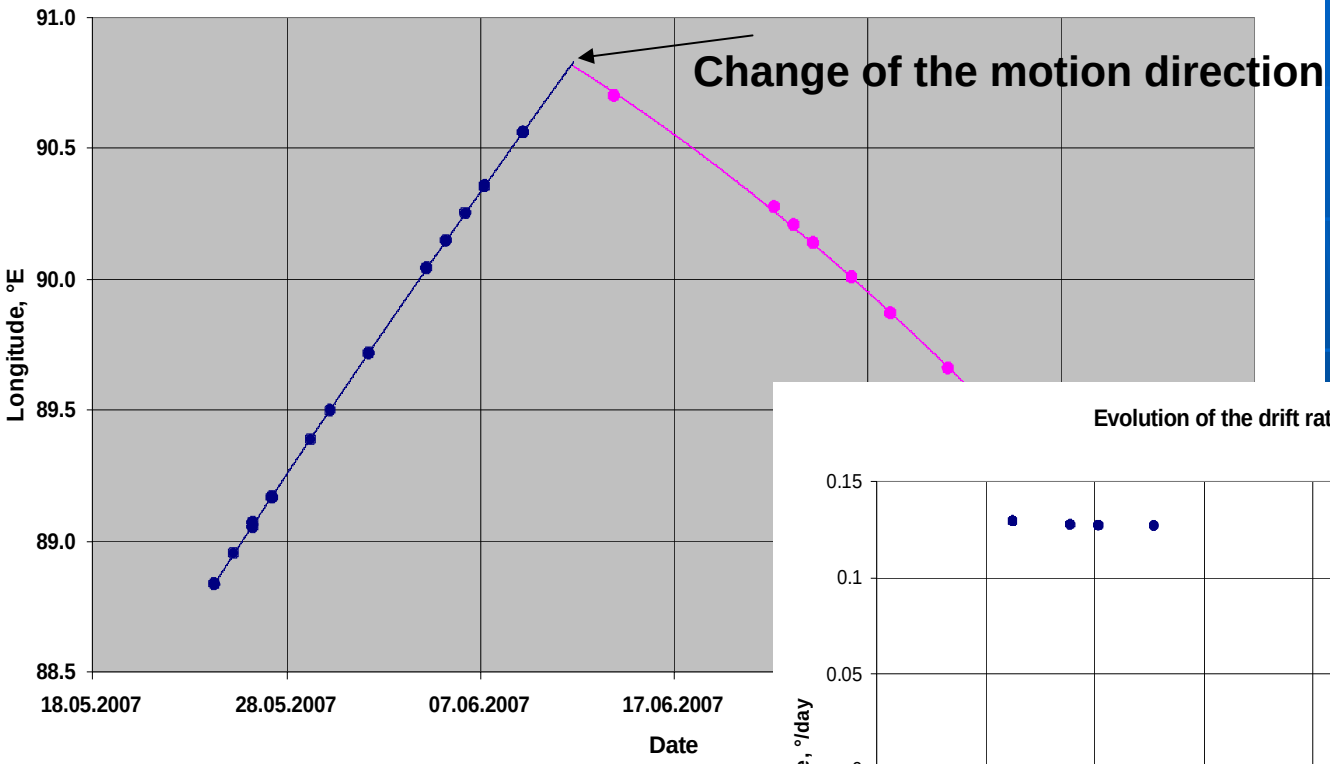
C1 – maintaining longitude and near-zero inclination
C2 – maintaining longitude only
C3 – maintaining longitude and non-zero inclination
C4 – maintaining non 'true GEO' period and near-zero inclination while remaining in GEO protected region
C5 – making manoeuvres on non 'true GEO' period orbit (including graveyard one) while remaining in defined GEO region

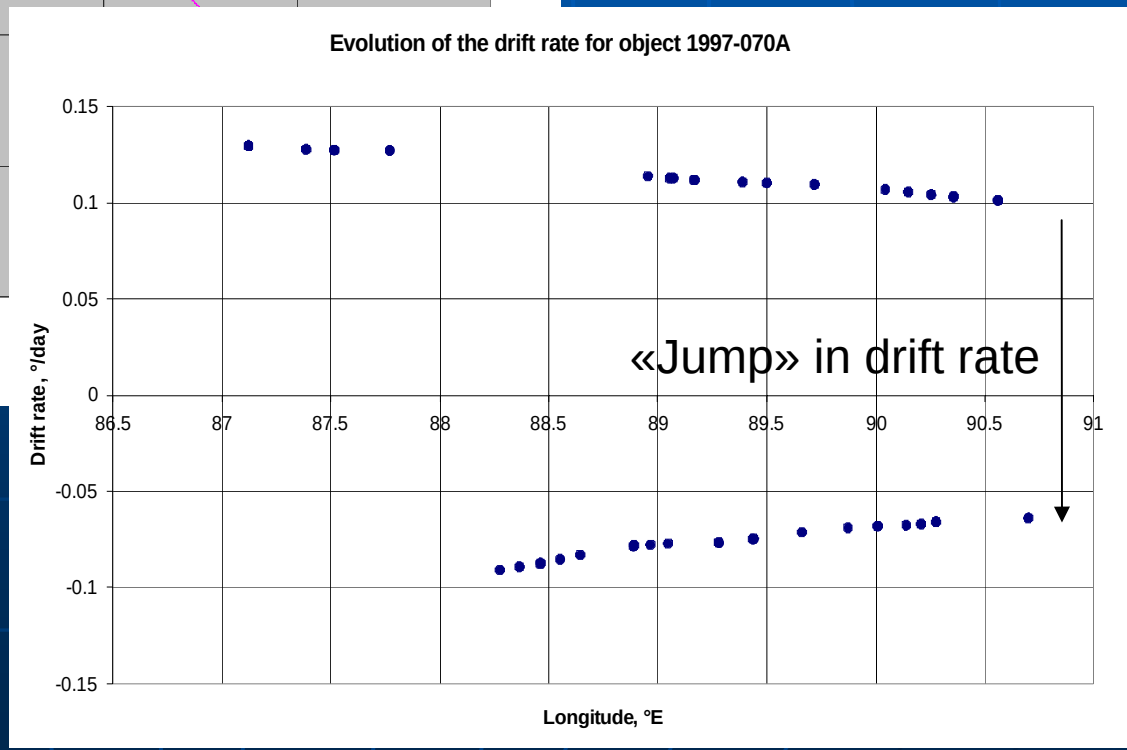
Each class can be divided into two subclasses:
- orbits with eccentricity less than 0.001
- orbits with eccentricity between 0.001 and 0.15

Orbital events characterization for GEO region

- Strange non-evolutionary changes are discovered for several old GEO objects
- Object 1997-070A (old spacecraft «Koupon») unexpectedly changed the direction of the drift on Jun 11, 2007 when it was near 90.82°E (drift rate changed on 0.16 °/day). Surprisingly it remained on libration orbit
- Object 1993-013A (old spacecraft Raduga) showed minor non-evolutionary changes in it's drift rate in Apr and Sep 2007. The reason of the changes is unclear.

Koupon orbit change on Jun 11, 2007

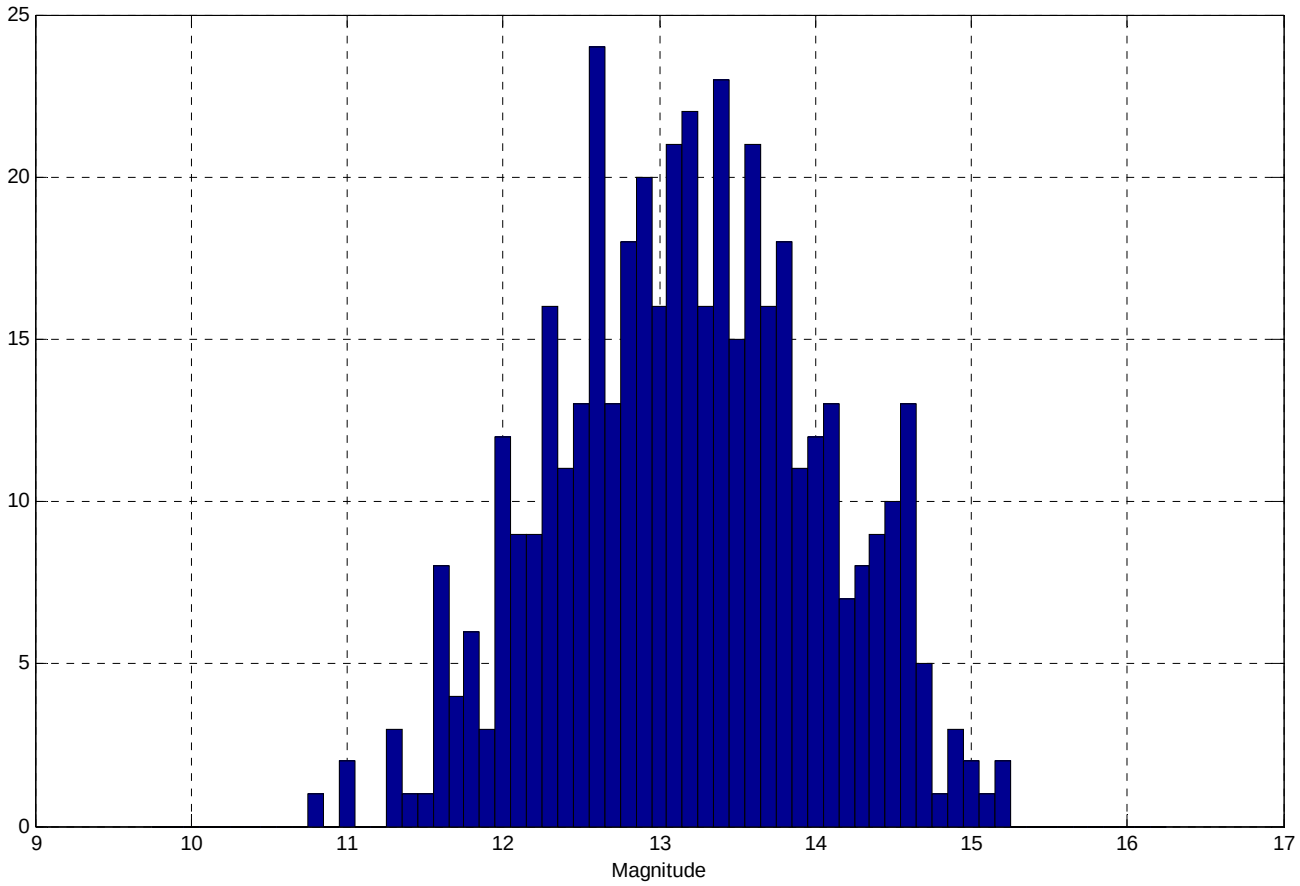




LEO and HEO experimental observation results obtained in 2007-2008

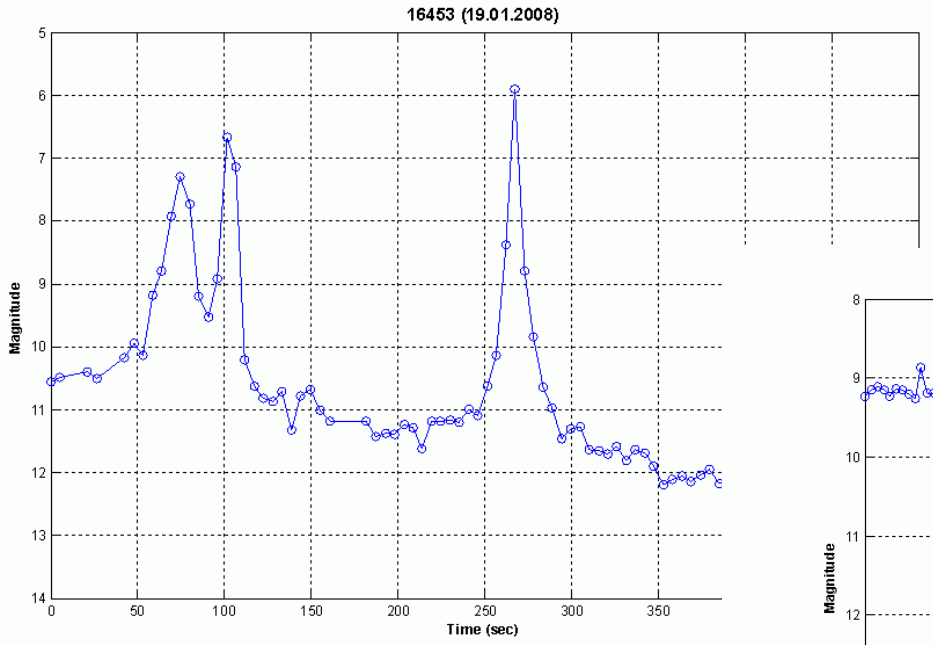
- Successful experiments on independent discovery and tracking of debris created in fragmentations of Briz-M upper stage (object #28944), Block of ullage motor (#25054) and Fengyun 1C (#25730) are carried out. Small aperture (22 cm) optical instrument is used.
- More than 120 earlier unknown bright and more than 150 faint objects are observed on HEO orbits (mostly GTO and Molniya-type). All discovered bright objects are continuously tracking at present.

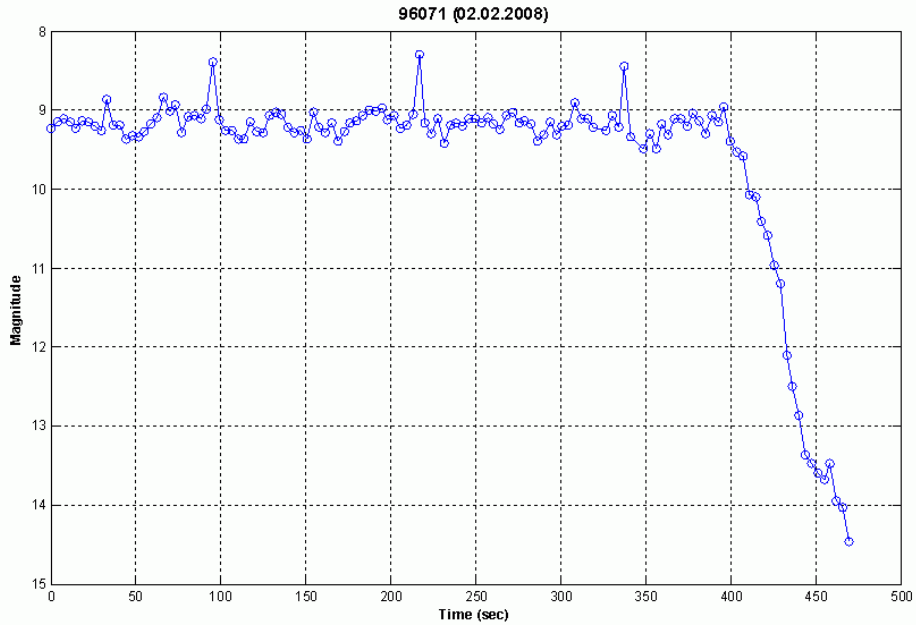
LEO objects observations with small aperture optics



Brightness distribution for object #30457 (average size 26 cm)

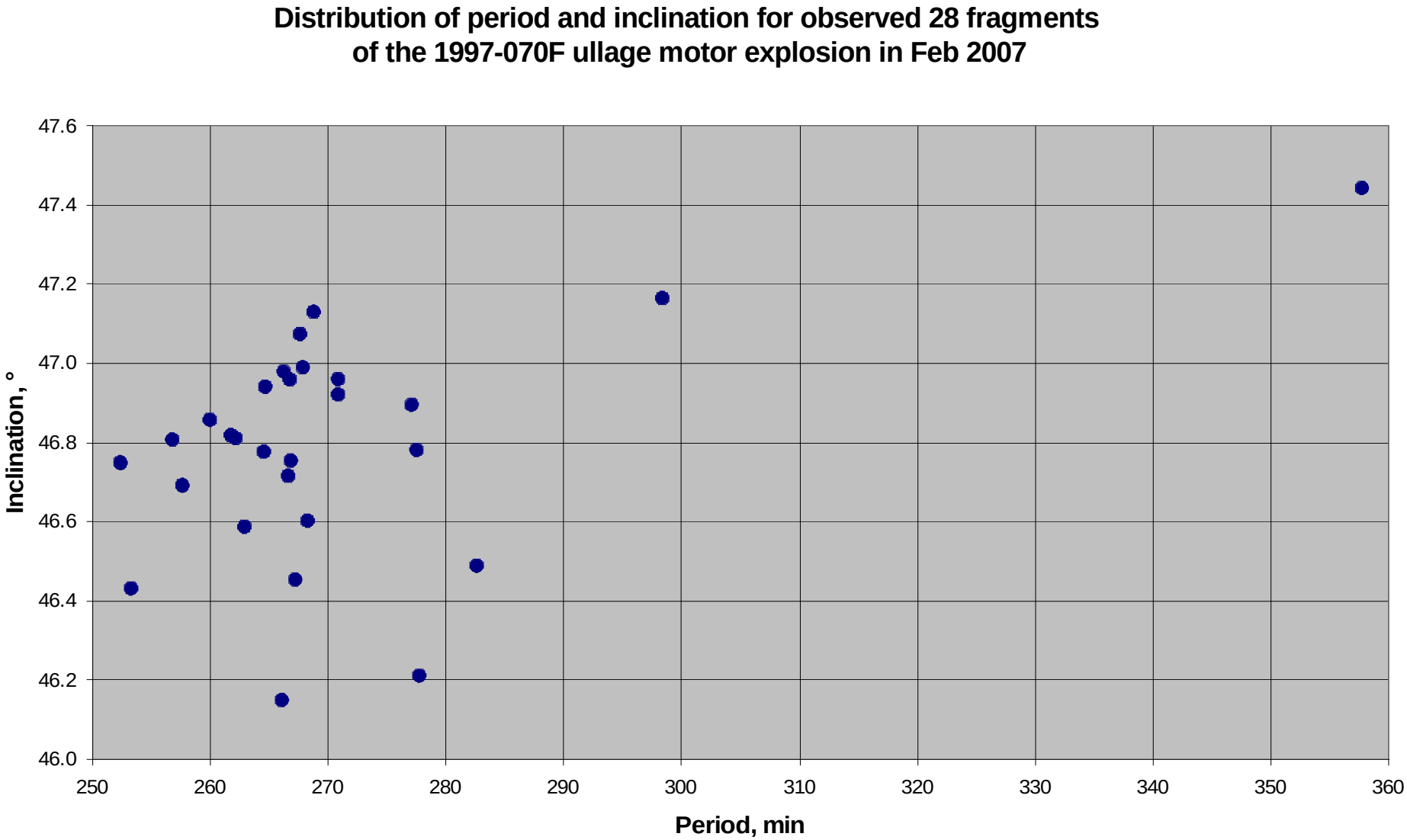
LEO and HEO objects observation



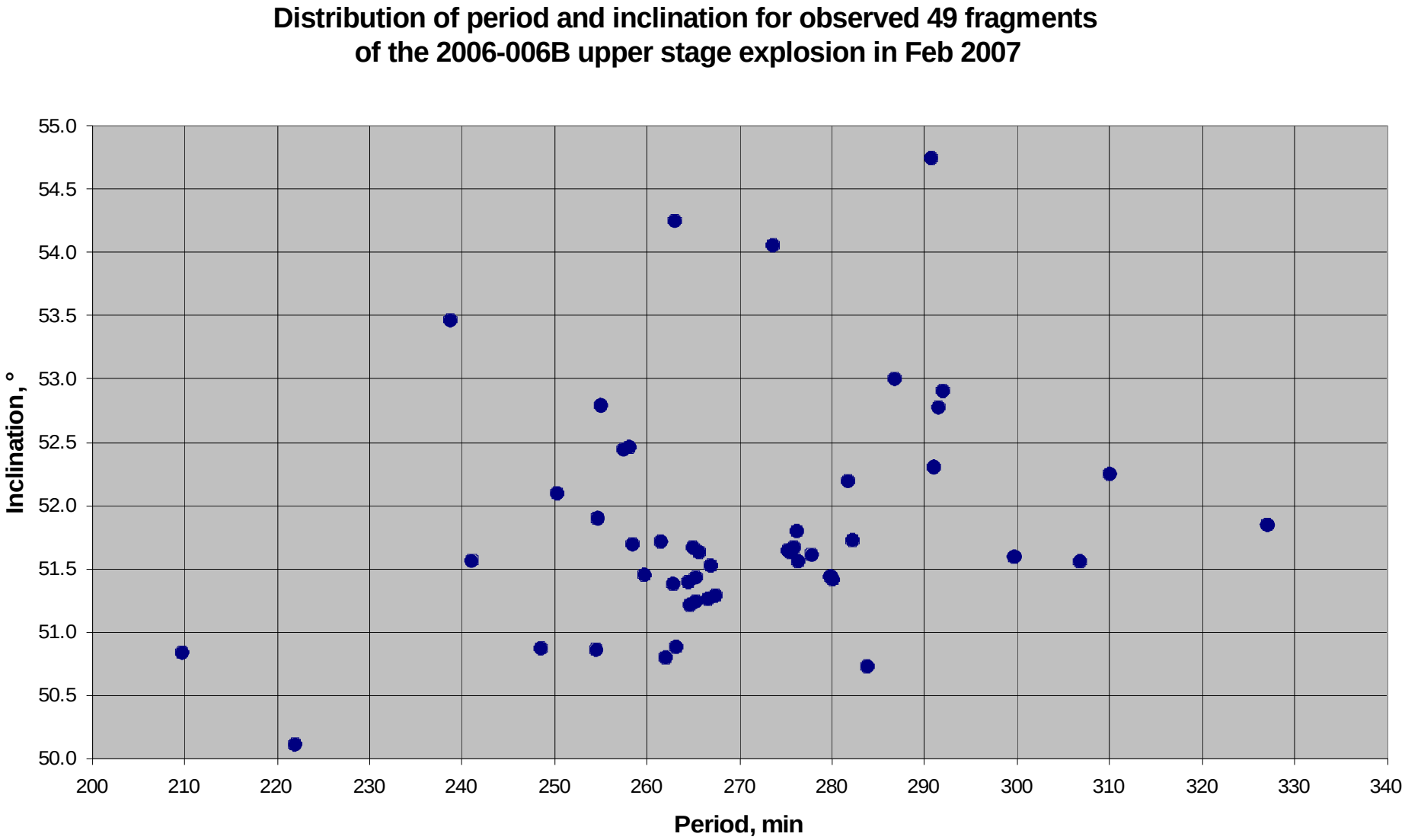


Typical brightness patterns for unknown HEO object 96071 and LEO object #16453

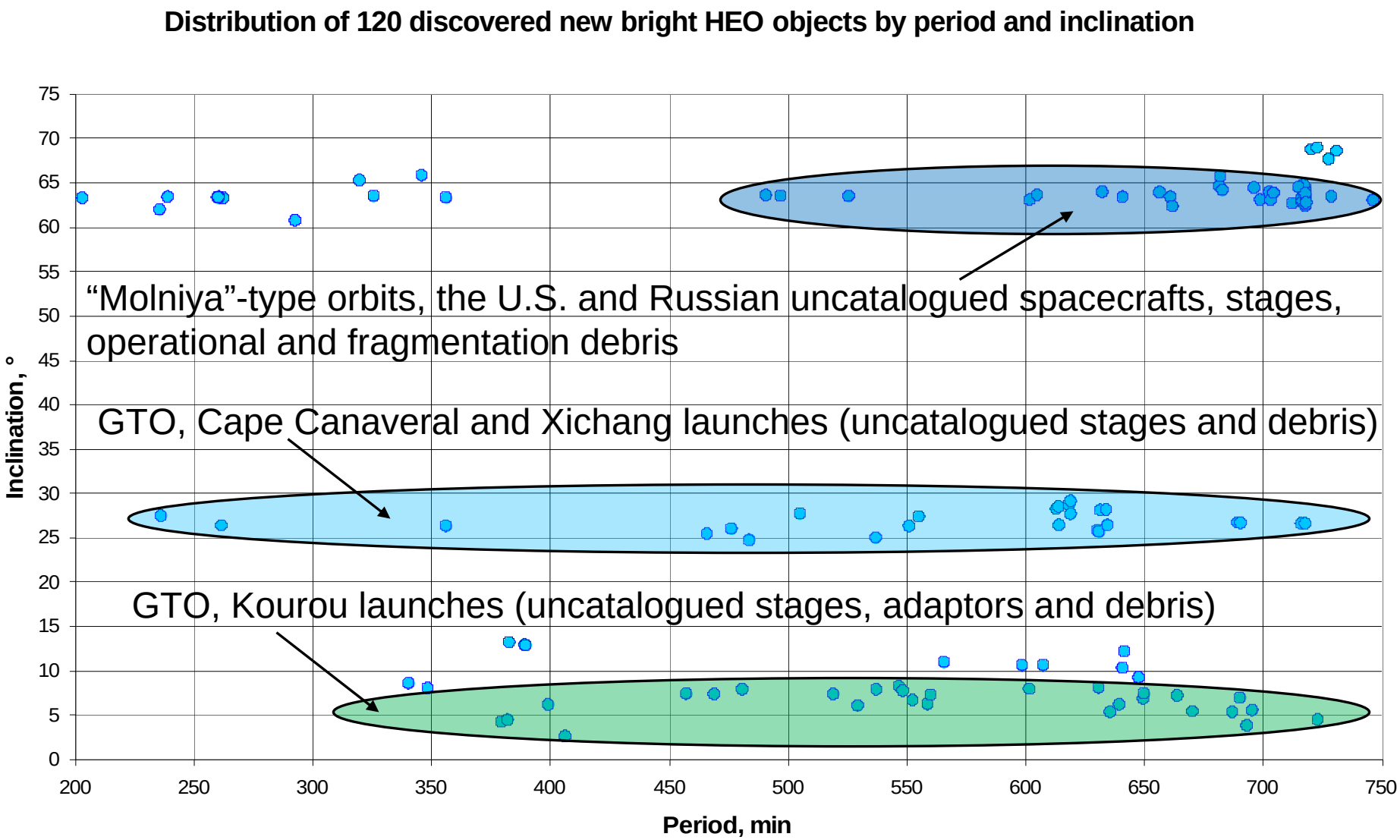
HEO objects observation



HEO objects observation



HEO objects observation



The ISON perspectives for 2009

- > 30 telescopes with aperture from 15 cm to 2,6 m
- Independent continuous tracking of all objects larger than 1 m in size and more than 90% of objects larger than 0.5 m in size along all GEO arc
- 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
- Publication of special information bulletin
- Maintenance of the special public Internet-resource with updated orbital information on all tracked high altitude objects

Conclusions

- New level of quality of GEO region research is achieved: full GEO arc coverage is established, regular wide surveys are carried out, for the first time our knowledge of true GEO population of objects brighter than 15^{m} is complete and presented for public.
- Several hundreds of earlier unknown objects discovered in GEO region and on HEO orbits are presented a clear indication of lack of our knowledge of true high orbits population. Number of discovered new high altitude fragments continues to grow so the research should be expanded in order to obtain as complete information as possible on potentially dangerous objects crossing orbits of operational GEO and HEO spacecrafts.
- Obtained information can be used for spaceflight safety and traffic management tasks on high orbits (GEO, HEO) thanks to more complete set of covered objects (35% more for GEO), much higher accuracy and overall reliability comparing other existing public sources
- The ISON network is developing intensively and will be capable soon to independently track all GEO and HEO objects brighter than 15^{th}-16^{th} magnitude as well as to accurately monitor LEO dangerous objects
- The ISON is an open scientific structure and all are welcome to participate