Keldysh Institute of Applied Mathematics
Russian Academy of Sciences

Results of GEO region artificial objects population research and proposal for organization of cooperative international GEO space debris monitoring

Presentation to the 44th Session of the
Scientific and Technical Subcommittee
Committee on the Peaceful Uses of Outer Space
United Nations

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Outline

- The research work goals and tasks
- Organizational basis
- GEO region research program stages
- Instruments involved into the faint GEO debris research program
- Overview of results
- Unique ‘GEO-like’ objects
- Further steps in GEO population study
- Proposal for organization of international monitoring of faint objects on GEO and other high orbits

The research work goals and tasks

- **Testing and improvement of the different strategies of GEO region survey and search of unknown objects**
- **Search and detection of all unknown bright (brighter than 15.5m) GEO objects and as maximal as possible number of faint GEO objects for providing solid basis for construction o most reliable picture of dynamical distribution of GEO region objects having size more than 15-20 cm**
- **Continuous tracking of detected objects**
- **Determination of trajectory parameters, estimation of area-to-mass ratio (AMR) for all tracked objects**
- **Analysis of orbital elements evolution and possible conjunction events with other objects**

Organizational basis

- Space debris scientific expert commission of the Space Council of the Russian Academy of Sciences is responsible for the tasks definition and high-level coordination
- Center on space debris data collection, processing and analysis of the Keldysh Institute of Applied Mathematics (KIAM) of the Russian Academy of Sciences is organizing and coordinating the particular research projects and maintaining space debris dynamical data archive
- Agreements on scientific collaboration between KIAM and observatories
- Participation in programs tasked by Roscosmos including support of the Russian delegation activity within framework of the IADC

Sources of financial support

- Russian Academy of Sciences
- KIAM contracts with Roscosmos
- Ministry of education and science of Russian Federation
- INTAS international association grants
- Support from the industry partners (ISC Vympel)
- Support from the observatories' host institutions

Developing strategy

- **Use existing classical astronomical instruments (including those involved into asteroid search and tracking programs) and make their appropriate step-by-step upgrade: installation of modern CCD-cameras, time synchronization equipment, CCD images processing software for fast moving objects, mount automation, FOV increasing by means of special optical constructions addition**
- **Develop methods of search and tracking of studied objects, test these methods with help of the most experienced teams of observers**
- **Install new observation instruments specially developed for wide and deep searches of the relatively fast (up to few arcmin per second) moving objects**
- **Involve observation facilities/instruments providing jointly coverage of GEO, GTO and other HEO orbits as global as possible and also providing ability to establish follow-up measurements of faint objects by alert (new discovery, urgent need to update orbit for obtaining precise parameters etc.)**

The research program step-by-step

Early history

- **Early 1970s** – start of observations of bright manmade objects in GEO region by observatories of the Russian Academy of Sciences.
- **1990s** – technology transfer from photo to CCD
- **Early 2000s** – test measurements of faint space debris objects in GEO

Modern history

- **2004** – start of systematical research work on observation of faint objects on GEO and joint work on maintenance of dynamical archive of space objects as complete as possible in part of GEO bright objects. One of main driving force pushed forward this research program is international efforts on space debris studying coordinated by the IADC. Project "Scientific optical cooperative network" started.
- **2005** – start of program of instrument's technical upgrade. First tests of wide field of view instruments. Expansion of the network to the East (Ussuriysk) and to the West (Bolivia). Start of observations of various HEO faint objects
- **2006** – already 16 instruments in 12 observatories from 6 countries have taking part in joint coordinated research program

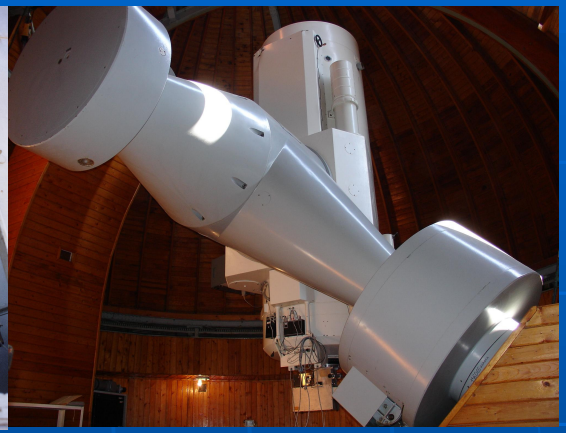
Faint objects observation facilities

Observatory	Location	Observing GEO arc	Instrument	FOV	CCD	Sensitivity
Tarija	21.596 S 64.624 W	135W…1W	Zeiss-600	11.5'x11.5'	1024x1024	18^m
Tenerife	28.301 N 16.512 W	71W…46E	1-m telescope	0.7° x0.7°	4096x4096	21^m
Zimmerwald	46.877 N 7.465 E	56W…70E	ZIMLAT-1000	20'x20'	2048x2048	19^m
Mayaki	46.397 N 30.273 E	39W…95E	RC-600	20'x20'	1024x1024	17.5^m
CrAO/Simeiz	44.403 N 33.997 E	29W…100E	Zeiss-1000	30'x30'	1024x1024	19.5^m
CrAO/Nauchnyi GAISh	44.728 N 34.016 E	25W…100E	ZTSh 2.6 m AT-64 PH-1 (22 cm) Zeiss-600	8.4'x8.4' 53'x34' 2.8° x2.8° 18.2'x18.2'	1024x1024 1024x1024 1024x1024 1024x1024	20^m 18^m 15.5^m 18^m
SAO/Arhyz	43.649 N 41.443 E	20W…95E	Zeiss-1000	15'x7.5'	4000x2000	19.5^m
INASAN/Terskol	42.499 N 43.276 E	10W…80E	Zeiss-2000	8'x8'	1024x1024	20^m
Maidanak	38.673 N 66.896 E	5E…103E	Zeiss-600	11.5'x11.5'	1024x1024	18^m
Mondy	51.617 N 100.919 E	65E…150E	Zeiss-600 AZT-33IK	7.5'x7.5' 3'x3'	1024x1024 1024x1024	18^m 20^m

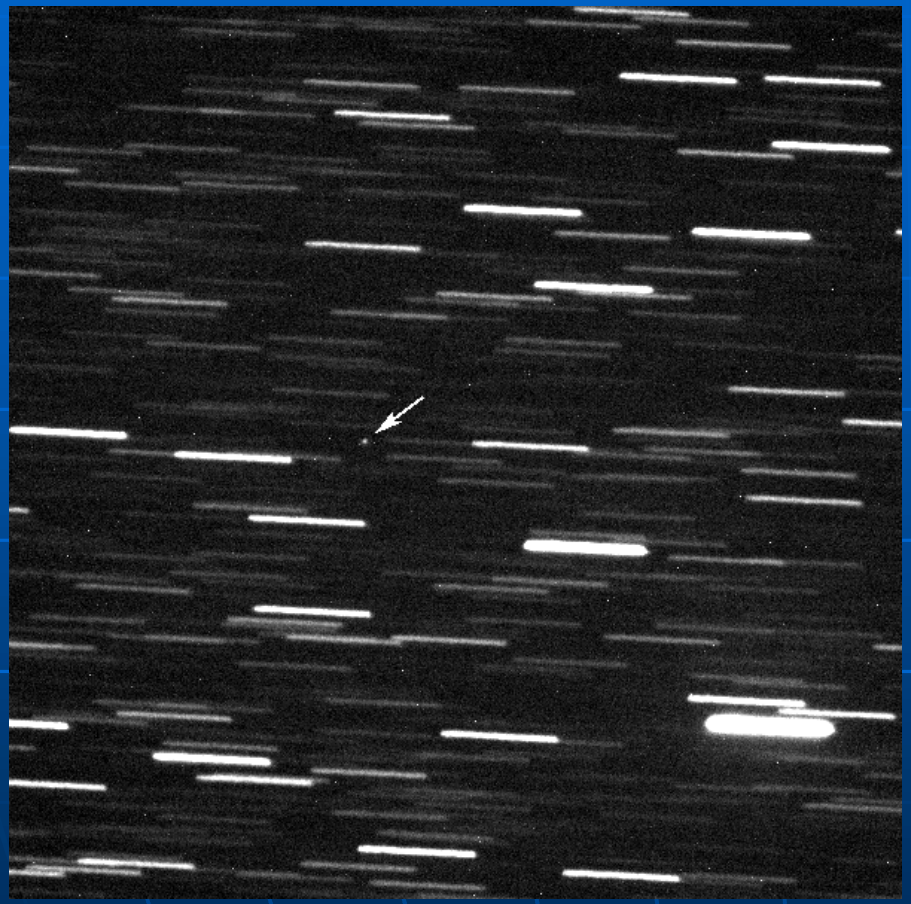
1 participating instrument – aperture 22 cm
8 participating instruments – aperture 60-70 cm
5 participating instruments – aperture 1-1.5 m
2 participating instruments – aperture 2-2.6 m

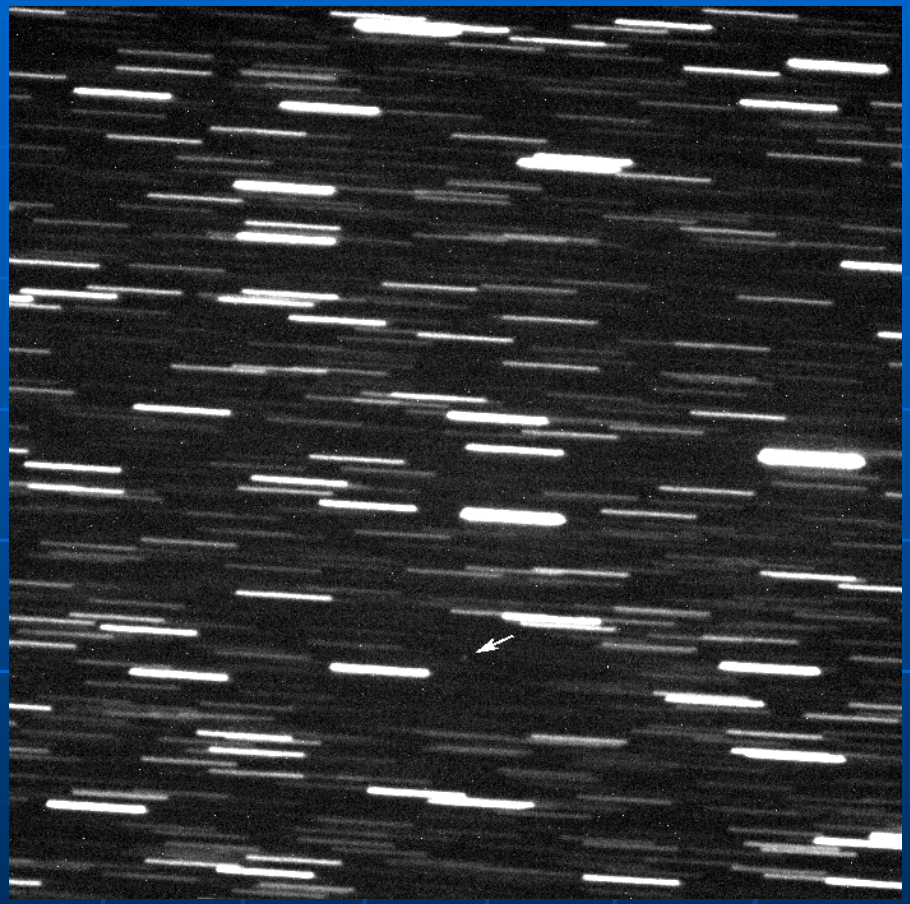
Some of instruments




How they looks like?

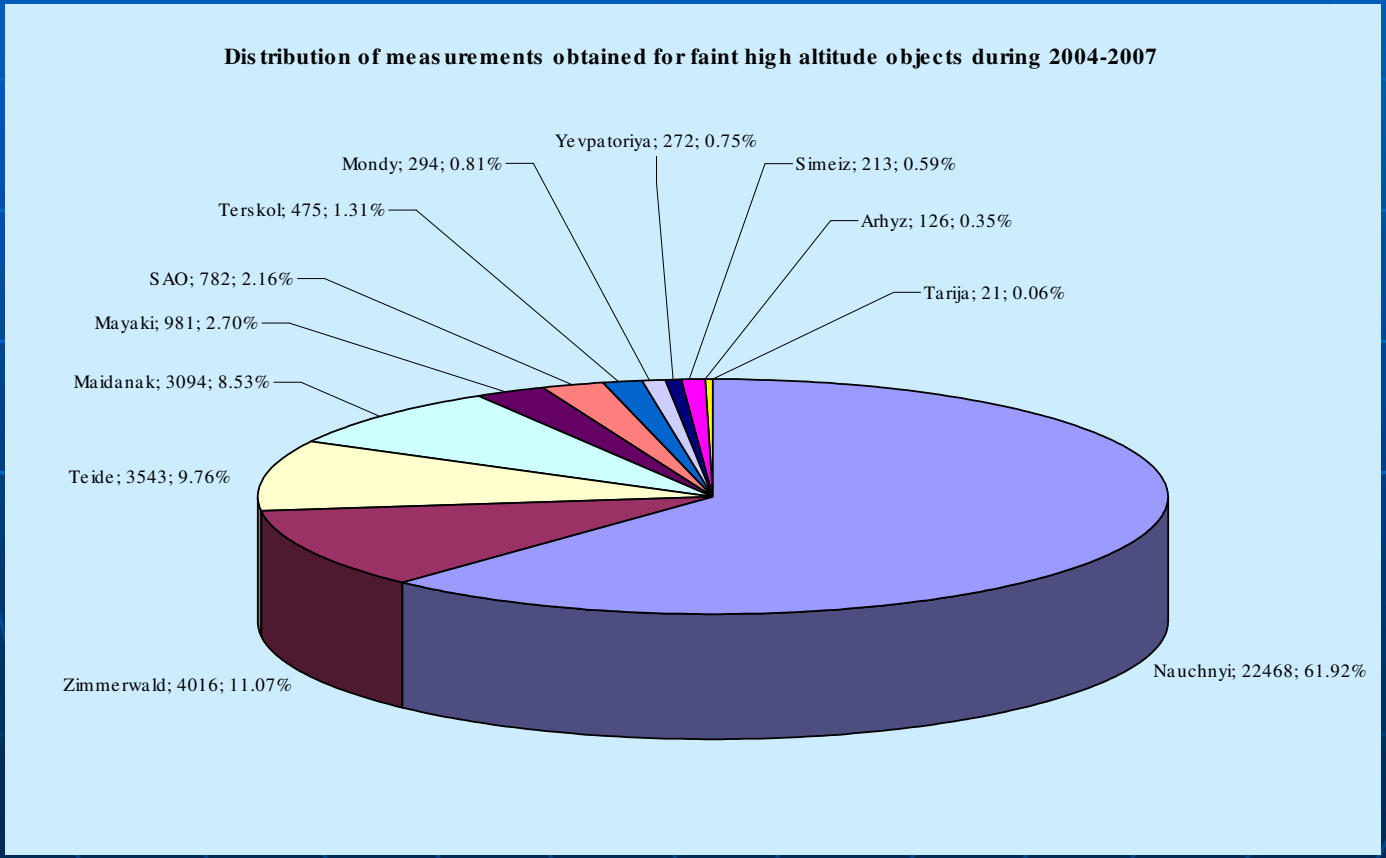




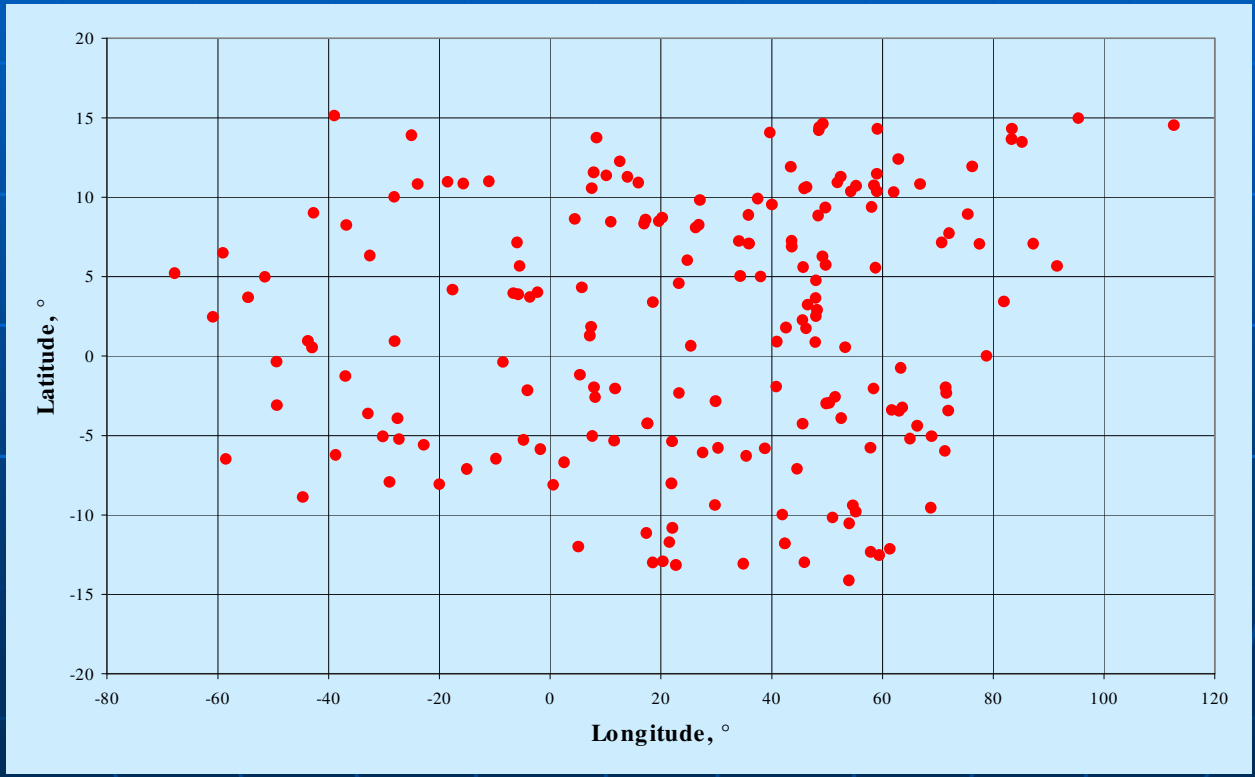
Key Obtained Results 2004-2006

- It is proved that classical astronomical instruments been appropriately upgraded can be effectively used for observations of objects (including faint space debris) on high near-Earth orbits
- GEO belt is covered at present between 130.3W and 210.6E (i.e. 340.9° of whole 360° arc is covered for zero inclination objects) for bright objects and between aprox. 120W and 120E for faint objects
- At about 110000 measurements used for orbit determination are obtained including more than 36000 ones for faint objects
- 138 new GEO region objects brighter than 15^m are discovered and orbital data for them is published in the ESOC Classification of Geosynchronous Objects on a yearly basis. Last update – Issue 9 (February 2007)
- 185 previously unknown faint (fainter than 15^m) high altitude orbit objects are discovered. 80 of them are tracking on more or less regular basis.
- Results obtained with the developed by Pulkovo scientists theory of fragmentations on GEO and KIAM scientists analysis of possible fragmentation events on GEO are confirmed in a separate research by our colleagues from the Astronomical Institute of the University of Bern (AIUB). Accumulated statistical measurements have revealed presence at least 12 space debris clouds in GEO in agreement with the theory predictions.

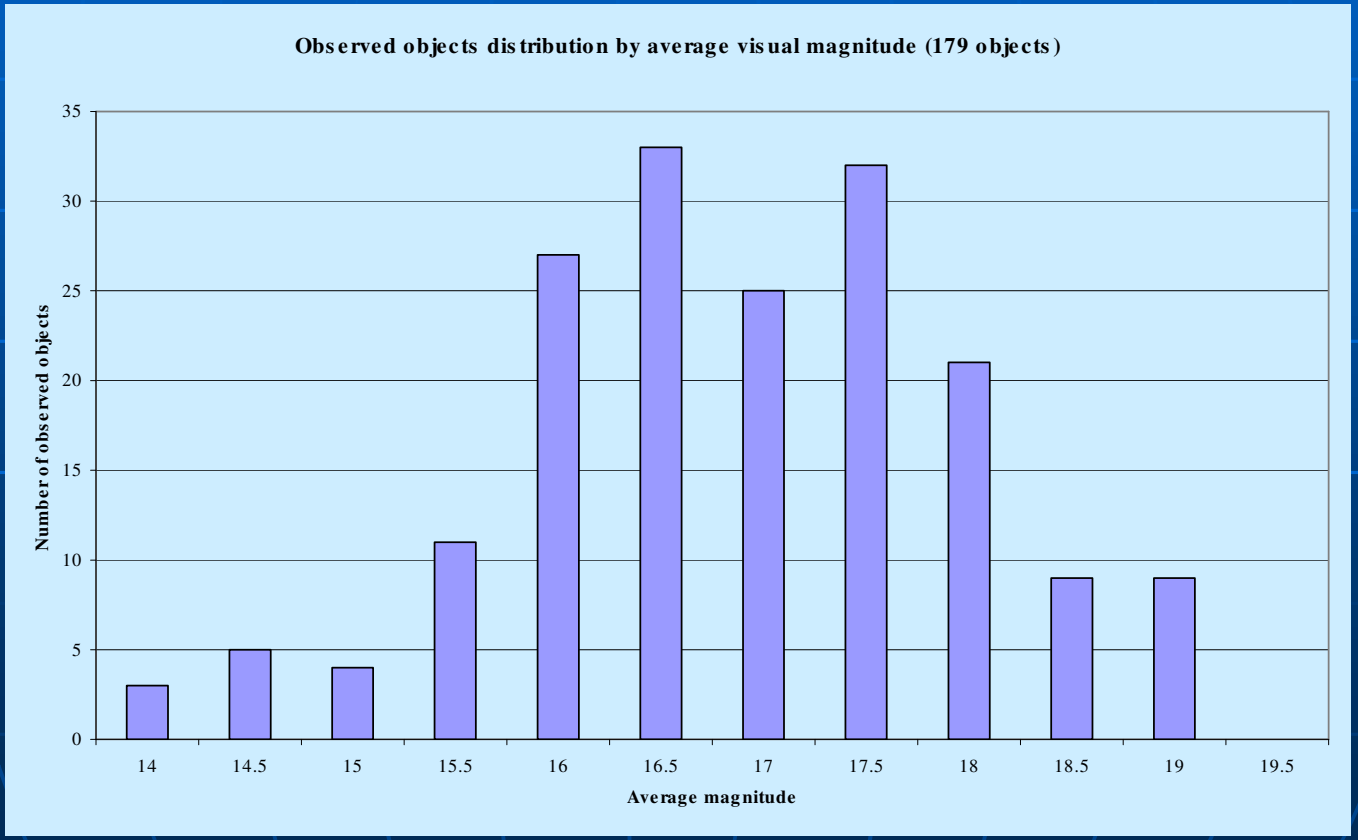
Faint high altitude objects' obtained measurements statistics (as of Jan 25, 2007)



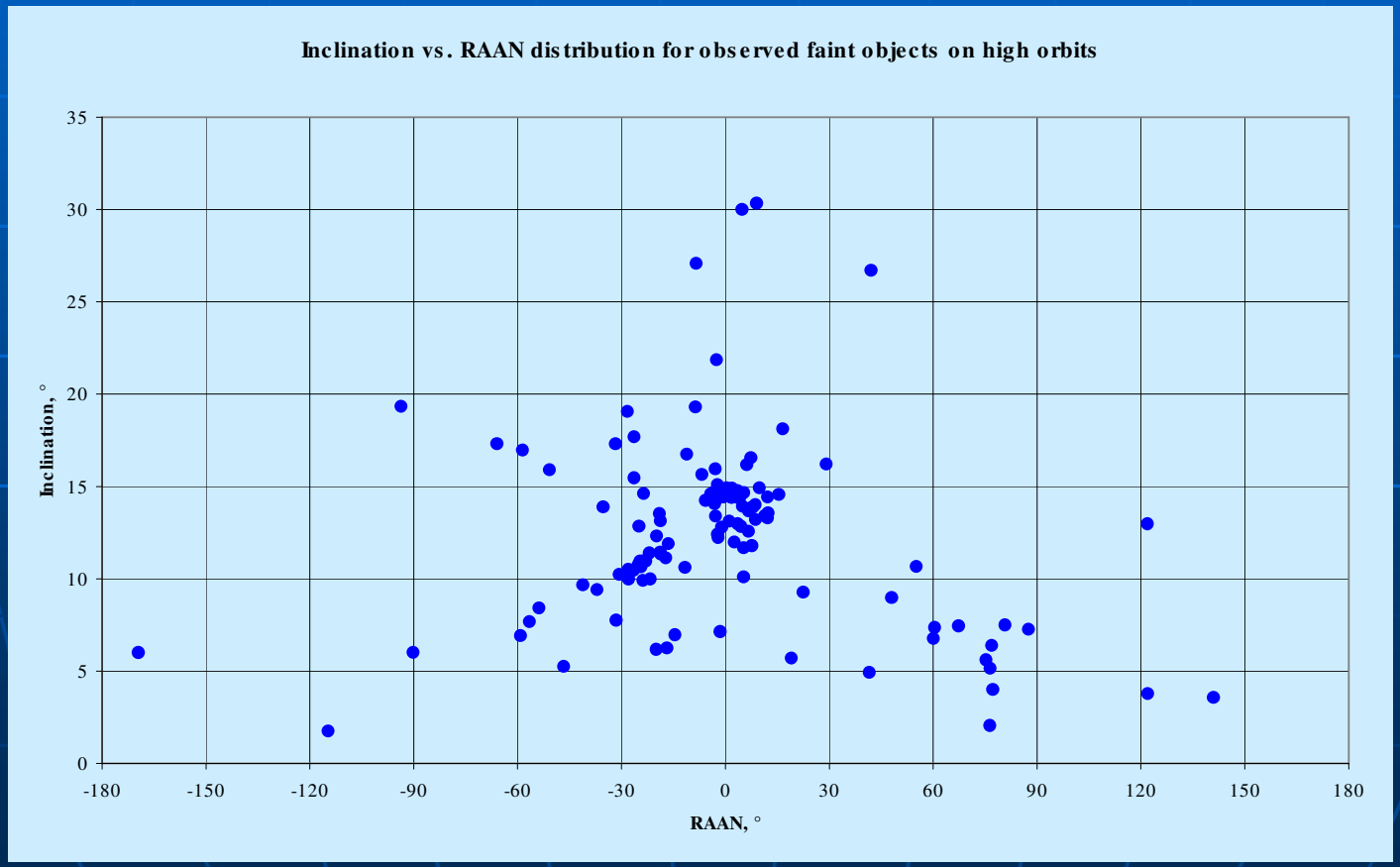
Position of subsatellite point at the moment of each faint object discovery



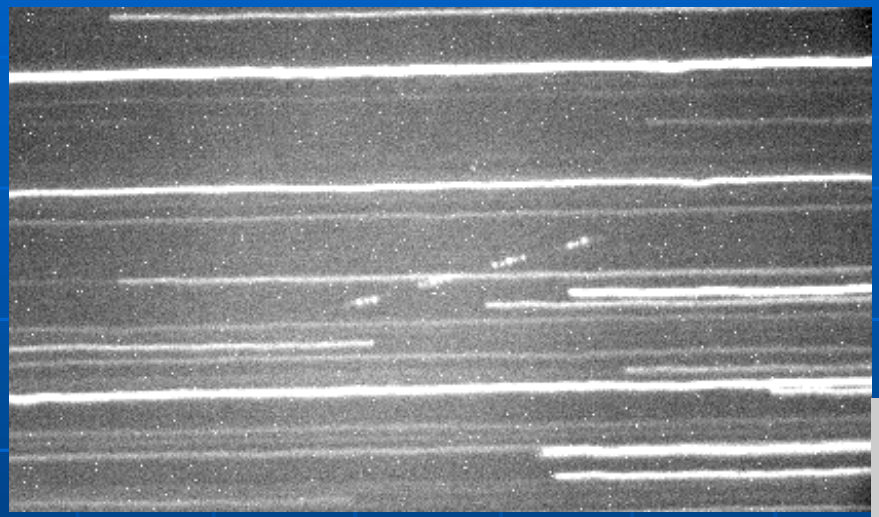
Distribution of objects by the average visual magnitude value at the moment of observation



Distribution of Inclination vs. RAAN for orbits of discovered faint objects



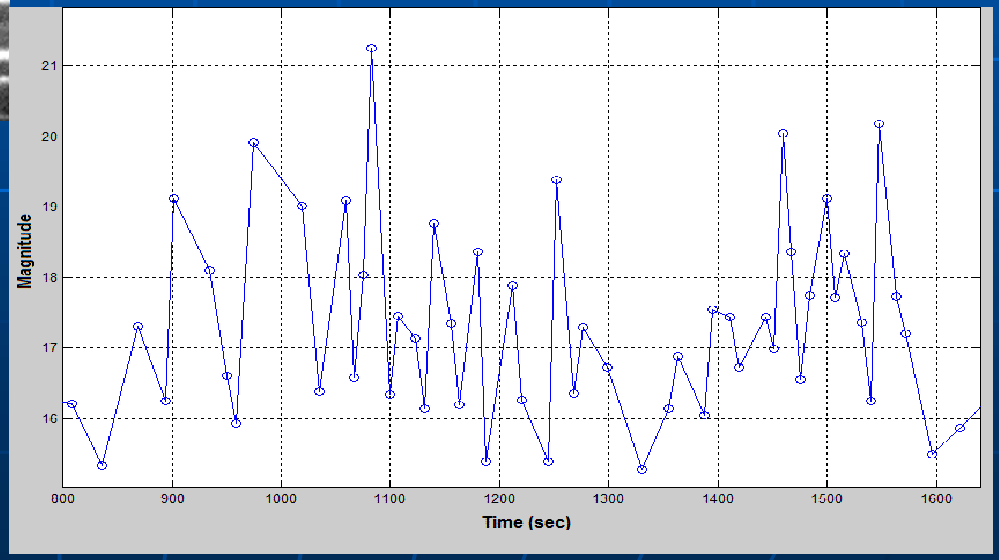
Faint high orbit space debris objects are not easy targets



Most of faint objects have significant brightness variations during short period of time

Object 90053
Observation on Jan 16, 2007

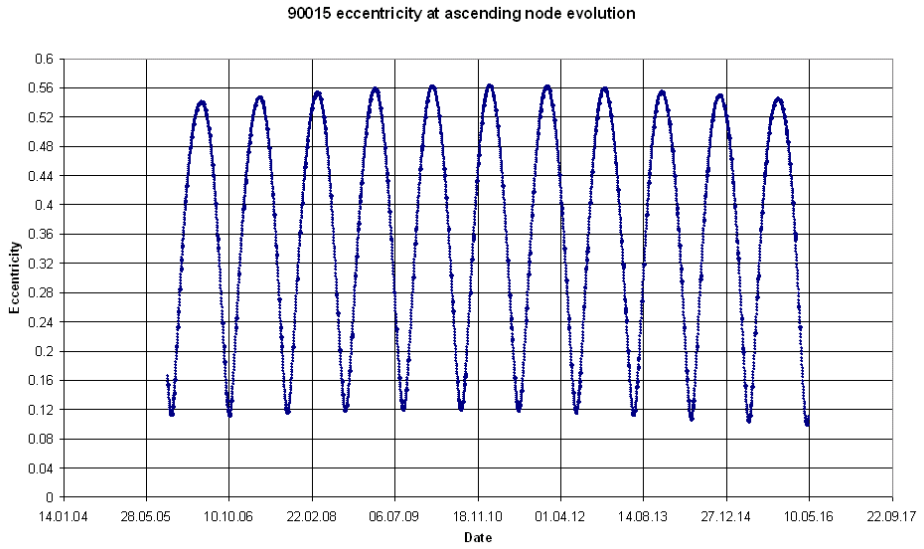
Observing instrument – 2.6 m ZTSh telescope (Crimea)

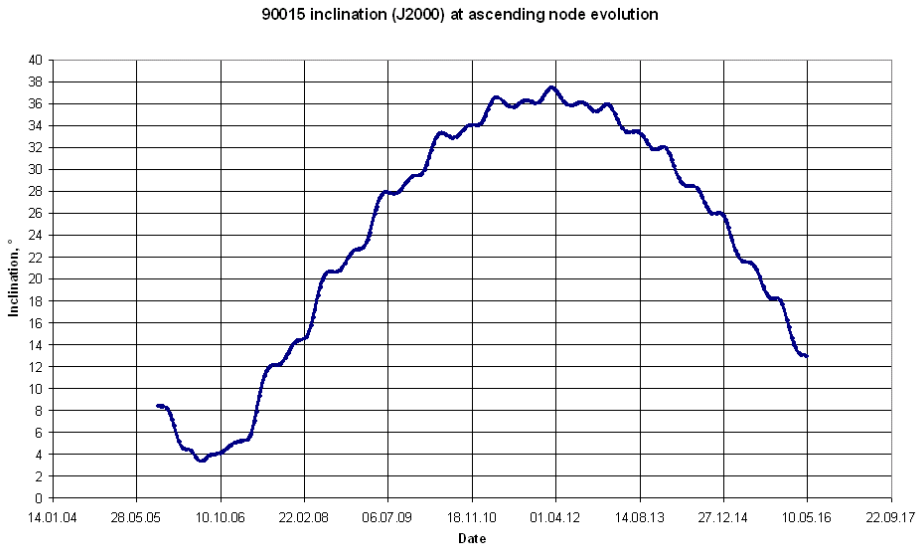


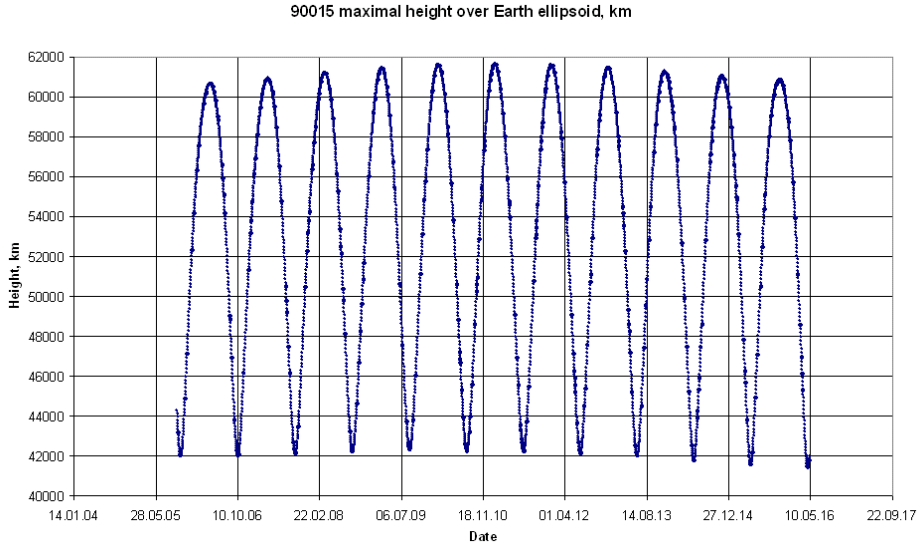
Objects with unique properties

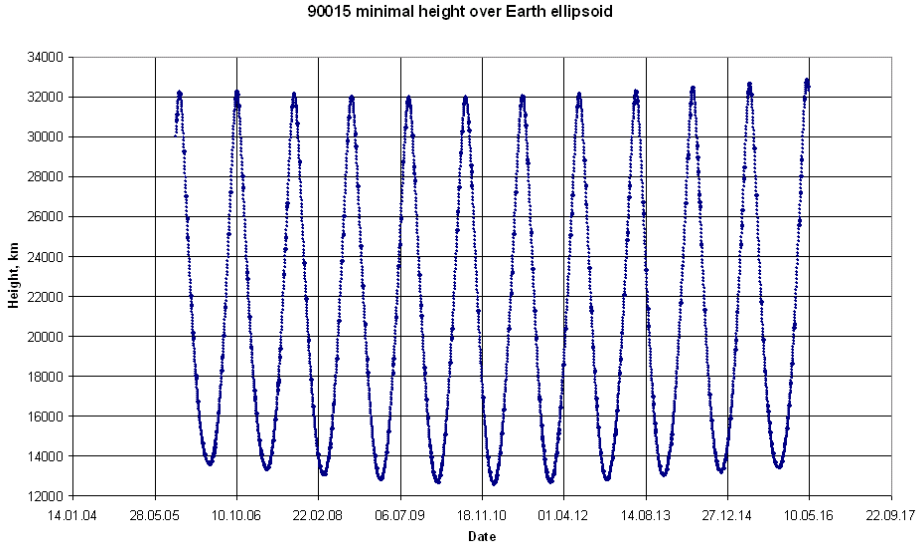
- The research shows that objects with unique properties – having high area-to-mass ratio (300 to 13000 times larger than for ‘normal’ spacecrafts and spent rocket bodies) first discovered by the AIUB team in statistical surveys are not exclusion
- They have orbital energy of the same order as usual representatives of GEO population that is an indicator of their genetic relation with ‘parent’ bodies on GEO
- Due to their such physical properties these objects have very strong orbital evolution that differs from other GEO population evolution. In particular, orbit eccentricity for objects with highest known to the date AMR value can vary between near 0 and 0.7 just in half a year. So these objects are not ‘truly GEO population’ members from classical point of view but they are representing absolutely new class of objects we call ‘GEO-like’
- Unknown attitude motion along with the high AMR value makes accurate motion prediction for this objects impossible for time intervals longer than just few days after the last observation obtained
- All these peculiarities along with high brightness variability makes this class of objects the most hard target from observational point of view

Object 90015

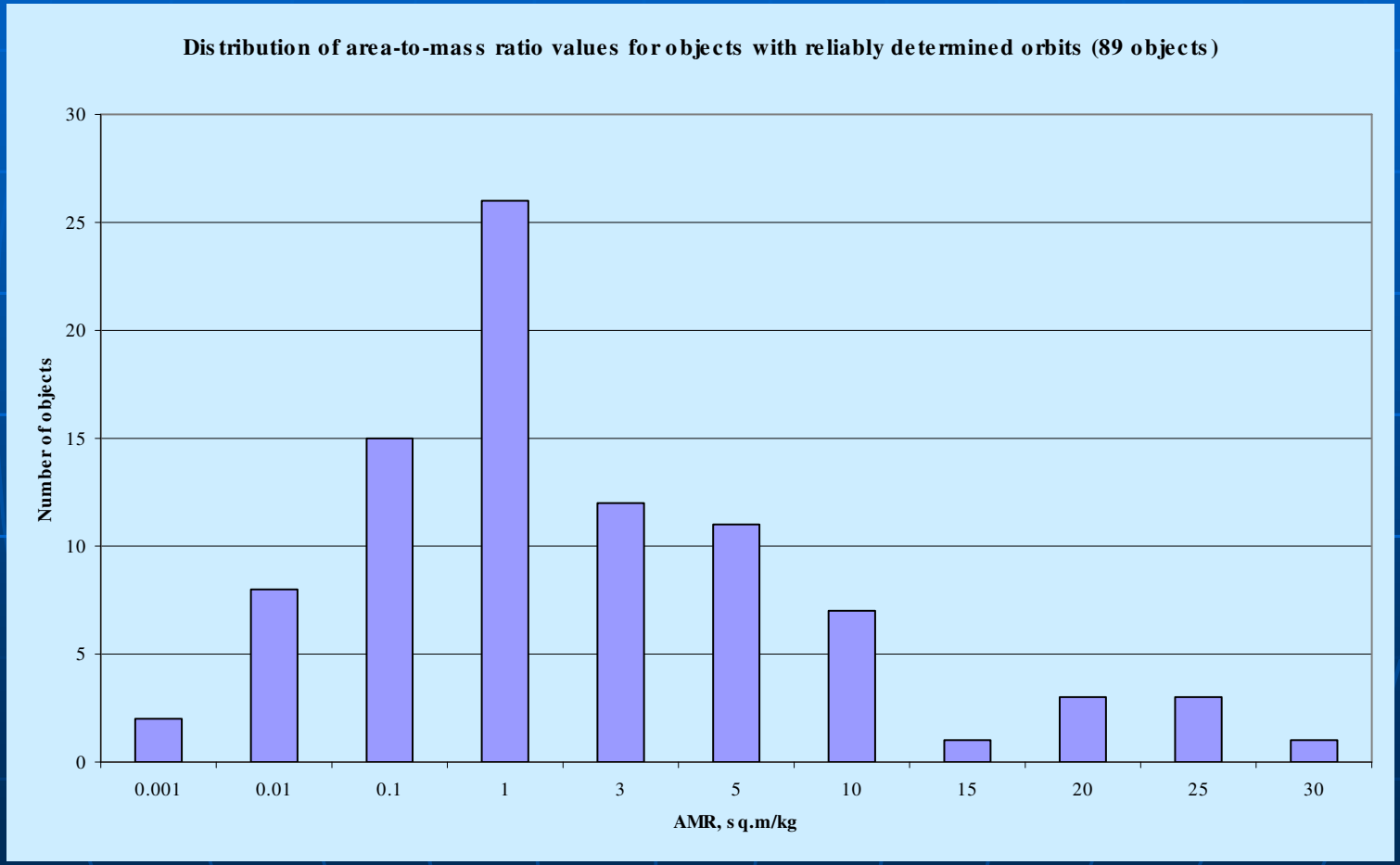








Average area-to-mass ratio value distribution for 89 objects



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Are those faint high orbit objects dangerous for active spacecrafts?

- Long term evolution analysis of large GEO population objects have been conducted based on archive of orbital and measurement information covering last 35 years
- Significant number of relatively small “jumps” in drift rate of many of large non-functional objects in GEO was revealed. Those “jumps” can’t be explained by natural perturbations as gravity or solar radiation. GAO (Pulkovo) team have preliminary concluded that collisions with yet not known pieces of space debris in GEO can serve as one of possible explanations but this theory should be accurately verified by different ways
- Analysis of possible conjunctions of newly discovered and tracked faint debris (GEO and GEO-like) with some GEO operational orbital slots (protected area of space limited in ±0.5° by longitude, ±0.1° by inclination and bounded in height by maximal eccentricity value 0.0005) showed that many of them have crossing protected space from time to time thus being potentially dangerous
- Existence of high AMR value objects in GEO region makes reliable encounters predictions impossible even on relatively short time intervals due to uncertainties in orbital propagation. The problem can be solved only in case of regular observations of such objects.

Further steps in high altitude orbit space debris research program

- Special program of observation instruments modernization as well as new instruments development is carrying out in order to increase of amount of measurements obtained, to shorten periods between consecutive observations of the same object especially having large AMR value, and to increase instrument's sensitivity along with improvement of their search (survey) capability.

- Research team participates in the special IADC campaign on studying of physical properties of the high AMR value objects in order to understand their nature and possible origin source

- Dynamical archive of information on observed objects maintained by the KIAM will be upgraded as well. It is planned that special public resource for scientists and researchers providing access to accumulated information and to observation scheduling and processing service will be opened early 2008

- New ***High Geocentric Orbit Space Debris Circular*** starts from Feb 2007. It will be completely devoted to results of researches similar to described in this presentation. The first issue of the Circular is proposed to your attention at this session.

Faint high orbit near-Earth objects and NEAs – similar tasks and methods

- Tasks of the search and permanent tracking of high near-Earth objects and NEAs are very similar from observational point of view though there are some differences

Similarity	Difference
Both types of objects requires: •wide FOV instruments for search •sensitive instruments for 'deep look' •distributed network of sensors in order to timely provide follow-up measurements •automated instruments for providing larger number of observed objects •ephemeris support •search strategy for one opposition (for NEAs) or one night (for faint GEOs/HEOs) objects •processing software for orbit determination and tracks correlation	*Faint near-Earth objects*: •faster than NEAs so long exposures are not possible •the most faint of them are hard to detect due to angular motion (requires much more sensitive CCDs an optics) in combination with narrow FOV •those having high AMR value should be observed without long gaps even in case initial very accurate orbit is obtained otherwise they become lost immediately

- In general high near-Earth objects search and tracking task, especially in case of high AMR value objects, is more complex in sense of requirements to observation instruments and strategy of observation

Importance of the task

- GEO belt is a limited natural resource and it should be kept usable for future generations and for all nations without any doubts. That means our activity in GEO should not result in pollution of this very important for all of us region.
- Just discovering and tracking of space debris on high orbits and GEO as one of them is not the solution we need. The goal is to provide spacecraft designers and operators with accurate information for close encounters calculations and estimation of real danger posed by space debris on high orbits. We definitely need information for understanding of space debris origin in order to make appropriate changes in spacecraft and upper stages design to prevent creation such debris in the future. And finally we need as complete as possible information to construct reliable space debris population evolutionary models for high orbits.
- Taking into account all specific properties of the high orbit space debris we think that the task formulated here can't be solved by any nation alone.

Proposal for organization of international GEO faint space debris monitoring

- In our opinion, organization of the wide international cooperation on search and regular tracking of faint (of 15^m-20^m) objects on high altitude near-Earth orbits especially in GEO region would provide invaluable help from the point of view of quality and completeness of solving of the task of obtaining and prediction with high reliability of situation caused by space debris pollution in that region

- Our experience of successful usage of classical astronomical instruments for high orbit space debris research and the fact of existence of large number of astronomical instruments (including and especially those involved into NEA search and tracking program) in different countries around the world serves as a good starting point for such cooperation organization.

- Support of designers and operators of GEO and HEO spacecrafts as well as of insurance companies who needs reliable information on risks caused by space debris population on high altitude orbits would be helpful in organization of cooperative international GEO space debris monitoring and creation of the appropriate international informational resource.

- Russian Academy of Sciences and KIAM of the RAS in particular is able and ready to play coordination role in such wide international project which is valuable both in scientific and applied fields.