



Small telescopes and their application in space debris research and SST



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Introduction



Space debris, definition



- “All the man-made objects which are orbiting the Earth and have no further application.”

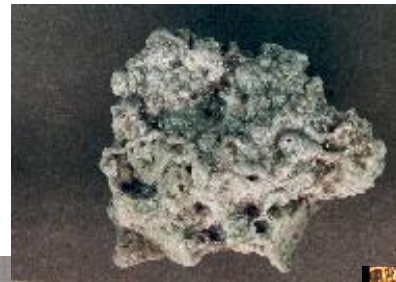
Probe Phobos Grunt



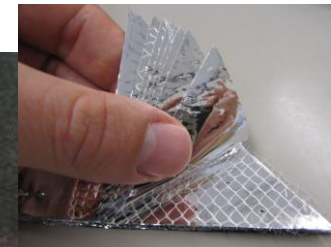
Upper stage Agena D



Al₂O₃



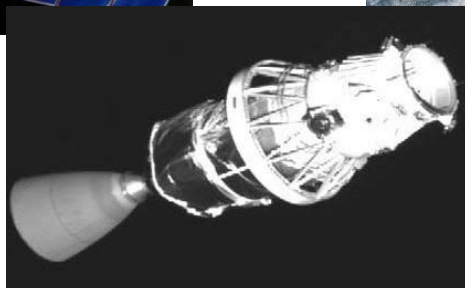
MLI



Humanity Star



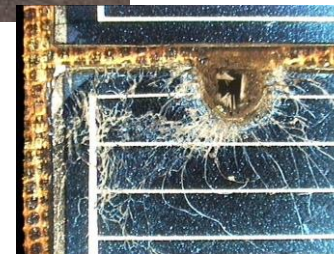
Satellite Astra



Upper stage Delta



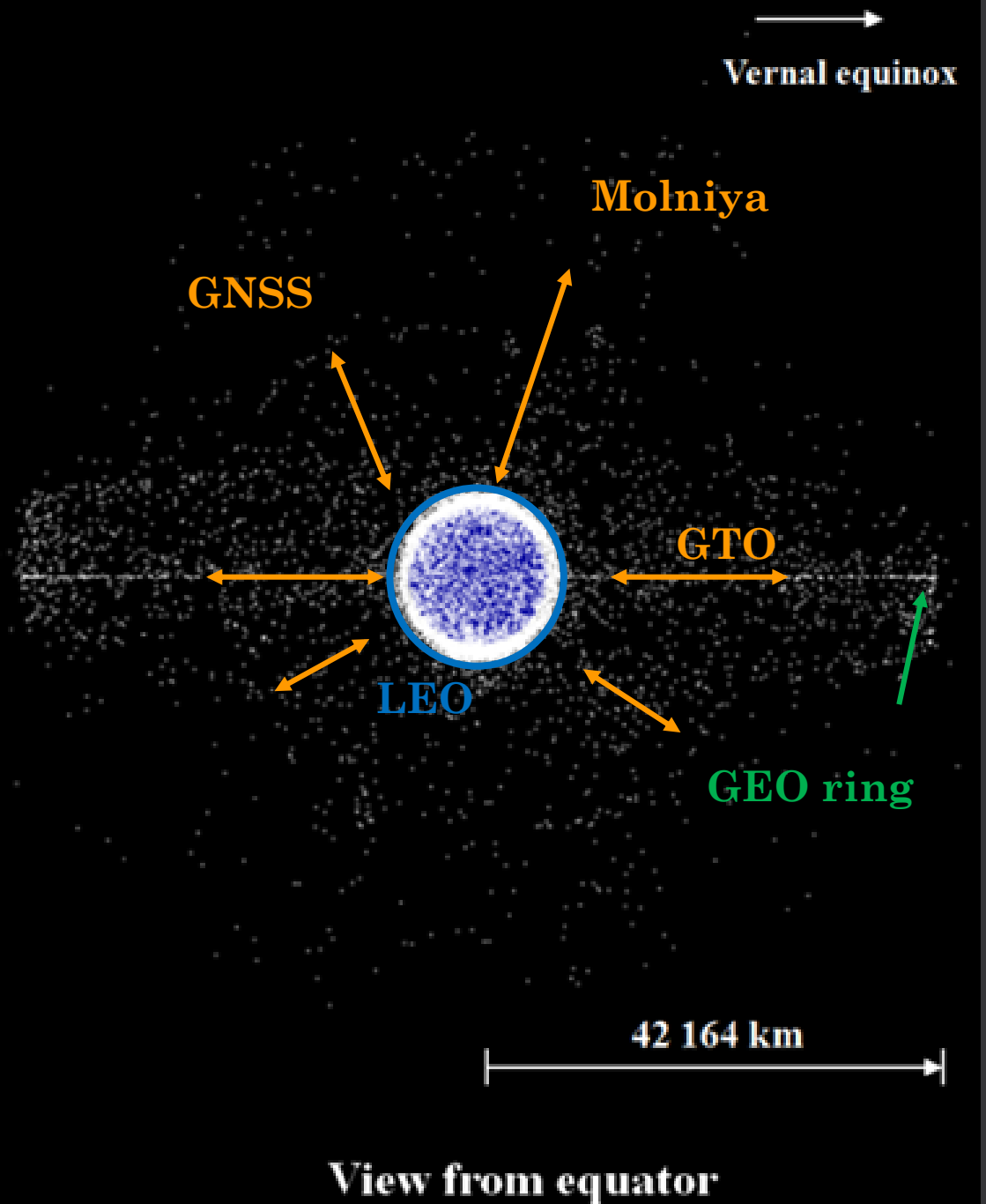
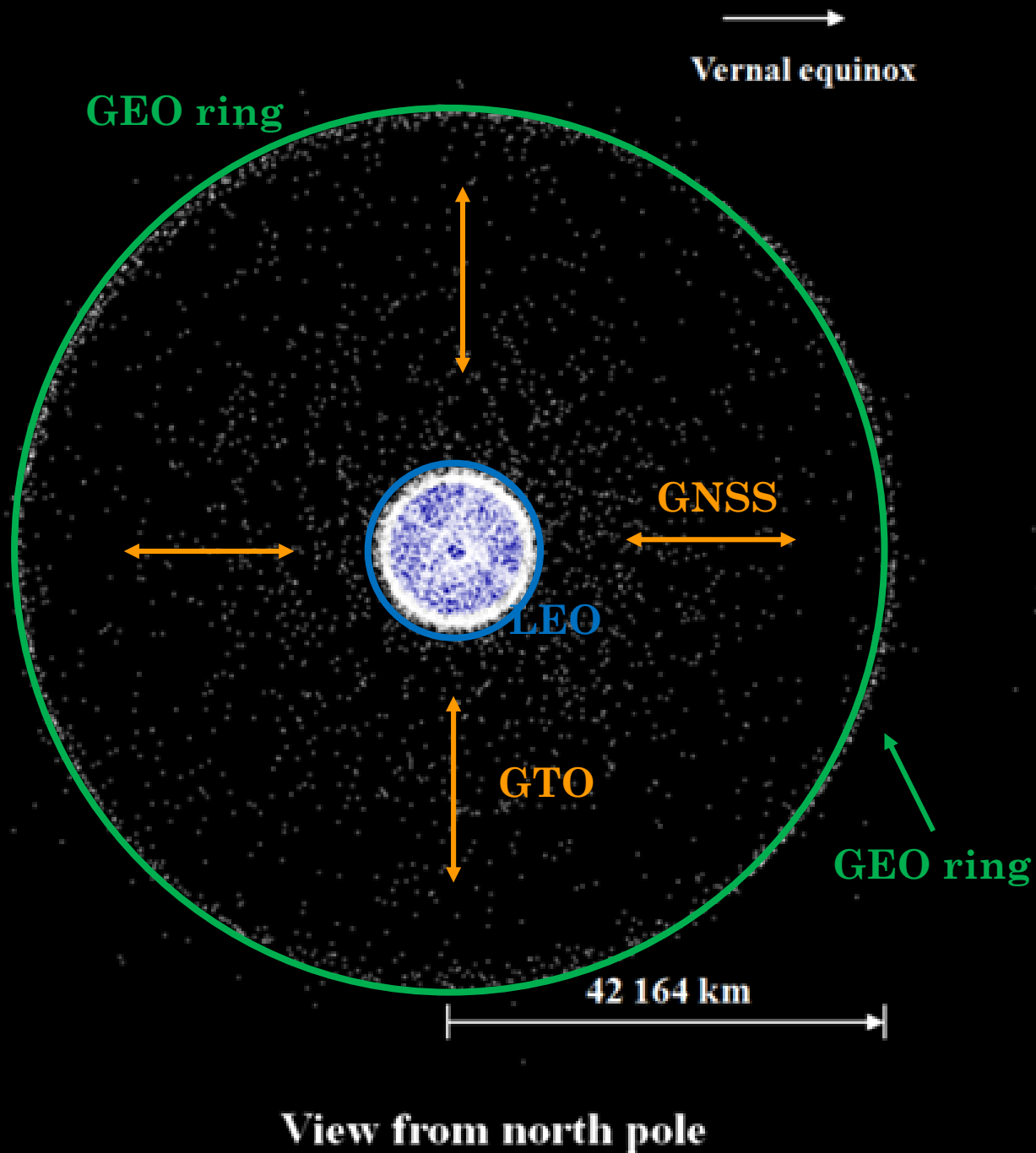
Fragment SOCIT4 37



HST solar panel



Tesla Roadster





Research and SST, goals

- **Where is it?**

- Surveys
- Catalogues
- Models
- Etc.

- **How to protect against it?**

- Collision predictions
- Shielding
- Removal
- Etc.

- **What is it?**

- Material composition
- Origins
- Reflectance properties
- Other physical characteristics
- Etc.

- **How it behaves?**

- Rotation
- Change of rotation
- Etc.



Research and surveillance

- Observations
- Space surveillance and cataloguing
- Orbit determination and prediction
- Attitude determination and prediction
- On-orbit fragmentation modeling
- Debris environment modeling
- Operational collision avoidance
- Re-entry analysis
- Hypervelocity impacts and shielding
- Debris mitigation, active removal



Observations techniques

- **Survey** observations used to discover new objects, to model space debris population (including small particles e.g. <math><1\text{mm}</math>) spatial distribution
- **Tracking** observations used to investigate the physical and dynamical properties of space debris

- **Optical** (ground-, space-based)
 - Optical passive – optical telescopes
 - Satellite Laser Ranging (SLR) (optical active) – debris SLR systems

- **Radar** (ground-, space-based) – tracking and survey radar systems

- **In-situ** (space-based) – in-situ probe, surface



Optical observations

- **Surveys** – to discover new objects for cataloguing and modeling
- **Astrometry** – follow-up (tracking) observations, to obtain the astrometric positions (apparent position of the object on celestial sphere) to be used for orbit determination and improvement
- **Photometry** - to get properties of the sun light reflected from the object toward observer
 - Attitude related information, light curve, rotation axis direction and rotation period size, e.g. ADR application
 - Attitude change over time monitoring, e.g., ADR application, monitoring of the near Earth environment
 - Reconstructed phase function, shape of object, e.g., object identification, type identification
 - Colors, color indices, surface properties, e.g., space-weathering, surface composition, origin identification
- **Reflectance Spectroscopy** – to get solar spectrum reflected from the object's surface, e.g., surface composition → source/origin identification

Optical observations

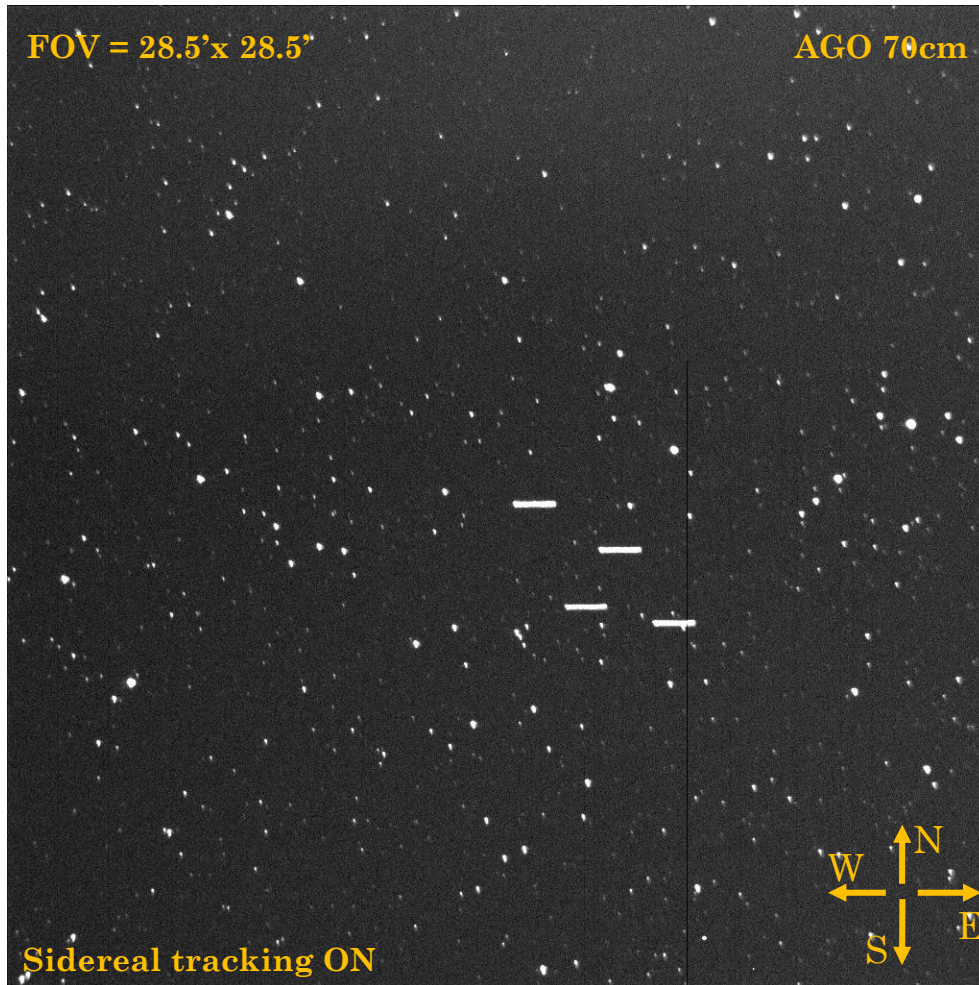


Figure – Astra satellites are tracked. During exposure, the sidereal tracking was ON so the satellites on GEO are displayed as streaks and stars as points. Image acquired by AGO 70-cm telescope. The 5s exposure time was used in both cases.

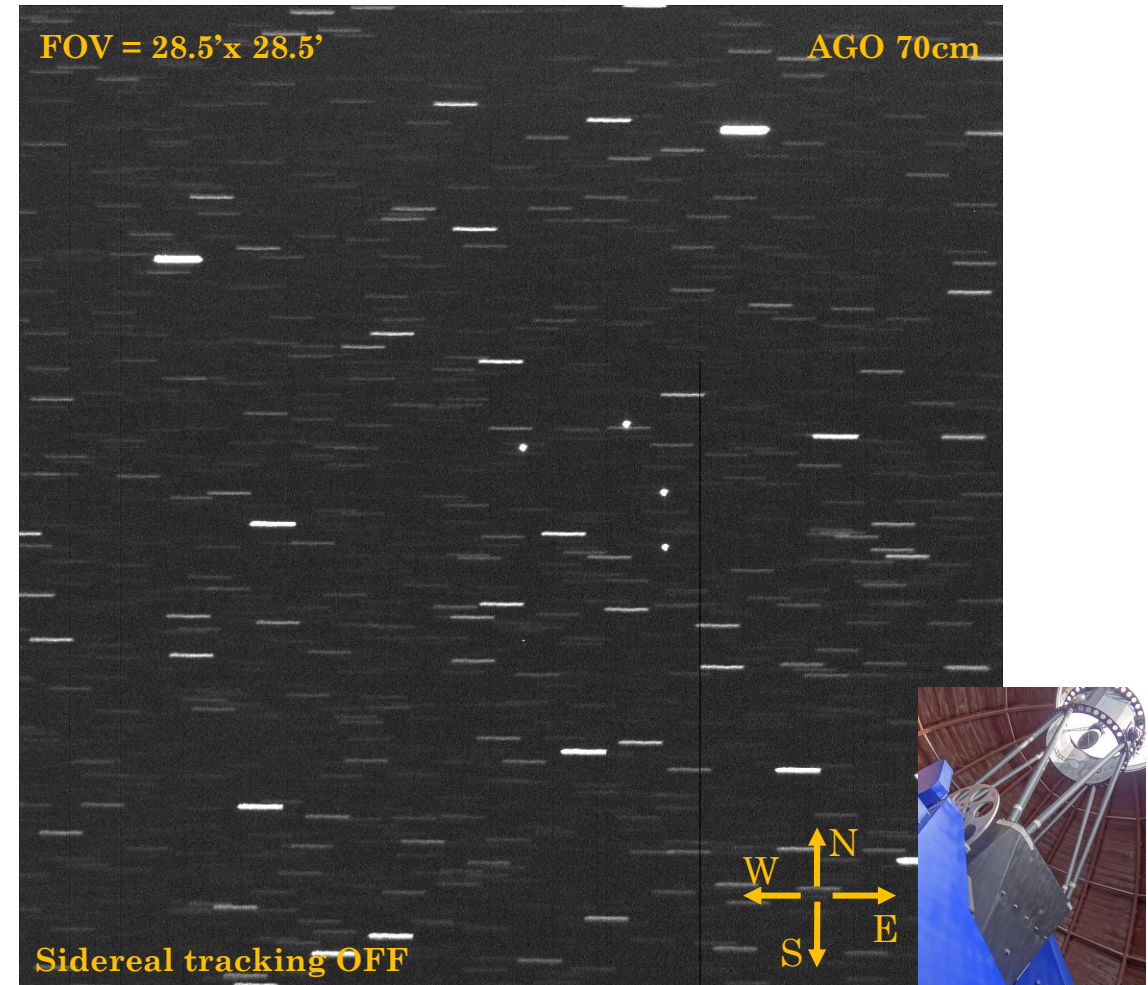


Figure – Astra satellites are tracked. During exposure, the sidereal tracking was OFF (for GEO equivalent to GEO tracking) so the objects appears as point and stars appear as streaks. Image acquired by AGO 70-cm telescope. The 5s exposure time was used in both cases.

Surveillance networks





Surveillance networks

- Sets of sensors with full/large coverage of specific regions, e.g., GEO, LEO, or all regions
- Networks always perform survey and also follow-ups, additional service attached to them, e.g., research, collision avoidance, break-up prediction and monitoring, etc.
- Able to perform orbit determination and improvement, **cataloguing**
- Coordination of sensors, development of interfaces, data quality monitoring, connection to other systems, e.g., radar or SLR

United States Strategic Command

- US governmental network USSTRATCOM
- Consists from 29 optical and radar systems
- Full coverage from LEO to GEO
- More than 16,000 orbits in form of TLEs (Two Lines Elements) available to public and scientific community
- www.space-track.org



Figure – US space surveillance network (Jakhu et al., 2017).



United States Strategic Command

- Limited information about the data, e.g., quality, error estimates, etc.
- No information how the orbit was calculated, what measurements were used, etc.
- In the past not known what reference frame is used...it is TEME (ECI, the True Equator, Mean Equinox) (Vallado et al., 2006)
- Orbital elements available and basic information about the object's origin, e.g., parent body/launcher, country of origin
- No information about physical characteristics, only RCS – small, medium, large

ISON network

- The international scientific optical network ISON
- Operated by the Keldysh institute of applied mathematics, Russian academy of sciences
- 90 telescopes in 16 countries
- Covered all regions from LEO to GEO, also NEA
- Focus on cataloguing and research

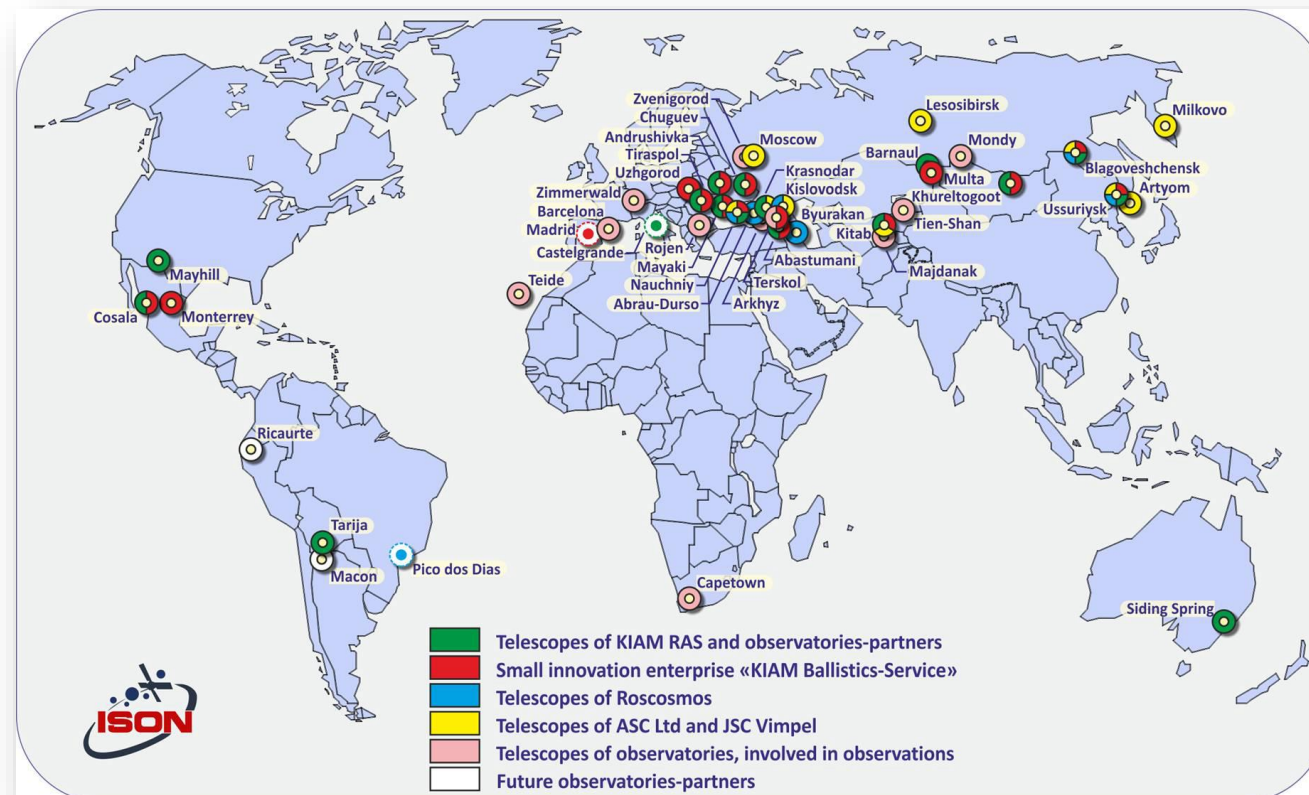


Figure – ISON surveillance network (Mokhnatkin et al., 2017).

ISON network

- Within ISON telescopes with diameter from 0.125 – 2.6 m
- Majority of re-used optical systems
- In 2012 observations to 3500 objects (Molotov et al., 2013)



Figure – 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..

ISON network

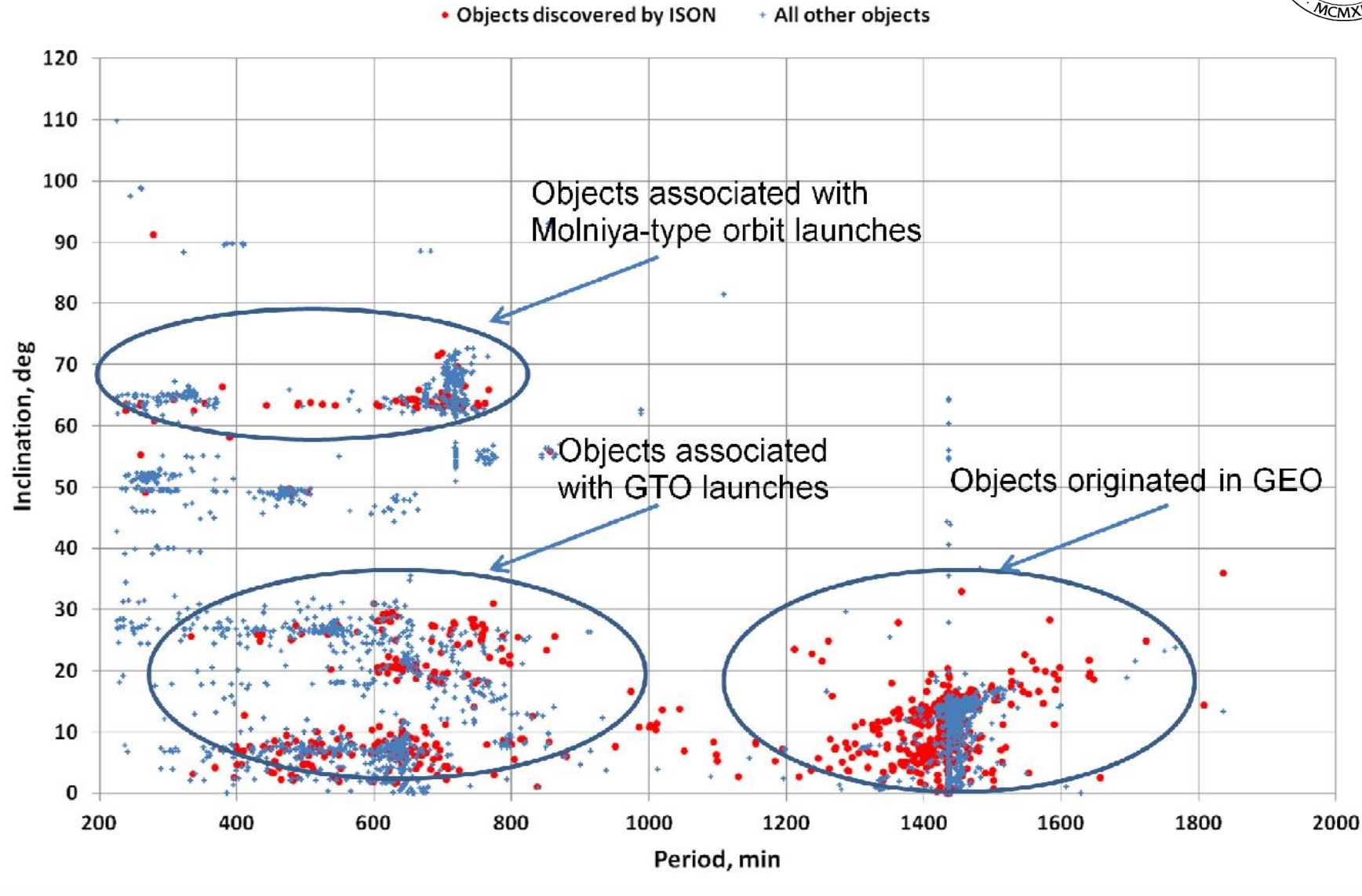


Figure – Orbital parameters of 3200 objects in ISON database including 897 of these objects were newly discovered during 10 years of ISON work (red color points). Data collected between 2002 – 2012. Molotov et al., 2013.

Another networks

- **Korean OWL-Net** – Network of 5 telescopes redistributed around the equator
- LEO tracking of Korean satellites, collision avoidance

Telescope design	Ritchey-Chretien
Mount	Equatorial (English/Yoke)
Camera	CCD
Dimension	4096 x 4096
Primary mirror diameter [m]	0.5
Focal length [mm]; focal ratio	-
FOV [arc-min]	66.0 x 66.0
iFOV [arc-sec/pix]	1.0

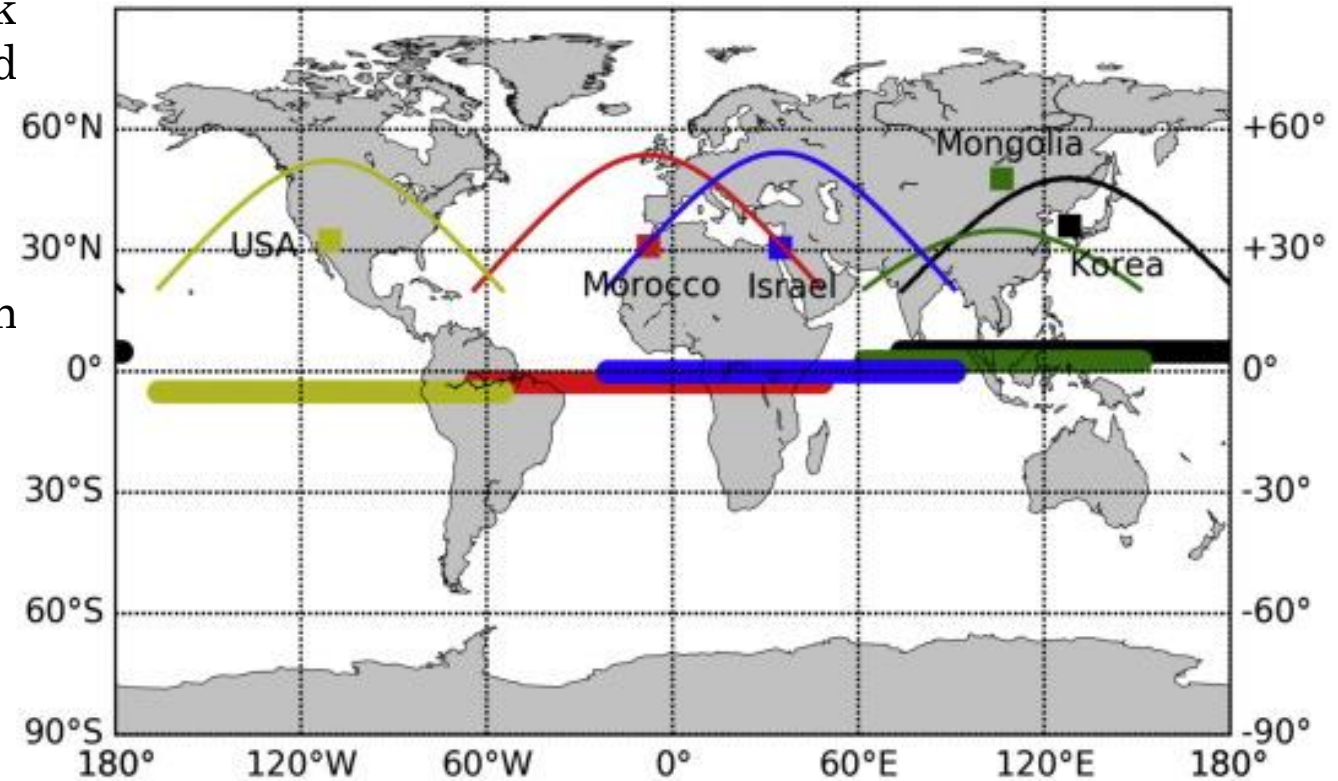


Figure – Site location map (colored squares) of the OWL-Net. GEO belt elevation (colored lines) angle and coverage (centered lines) are also shown when the elevation angle is greater than 20°. The color code is the same as that of the square colors. (Park et al., 2018)



Single research telescopes



Single research telescopes

- Single sensor not able to cover any population completely
- Single sensors used for acquiring statistical information about specific population (e.g. $> 10\text{cm}$) on specific orbital regime, e.g. GEO, GTO, Molniya, GNSS, LEO, etc.
- Support of models, ESA MASTER, NASA ORDEM, Russian Nazarenko, etc.
- Limited cataloguing and support of surveillance through collaboration

ESA OGS ESASDT, MASTER model

- For surveys and FUPs used 1-m Zeiss ESA Space Debris Telescope (ESASDT) situated at Tenerife
- Surveys acquired since 2001 by AIUB on regular basis, started with 14 nights per month, today 3 nights per month
- In the beginning discovered new population of space debris, so-called HAMR (High Area-to-Mass Ratio) objects with unknown origin (Schildknecht et al., 2005)

Telescope design	Ritchey-Chretien
Mount	Equatorial (English/Yoke)
Camera	CCD
Dimension	4096 x 4096
Primary mirror diameter [m]	1.0
Focal length [mm]; focal ratio	4500.0; f/4.5
FOV [arc-min]	42.0 x 42.0
iFOV [arc-sec/pix]	0.62

Table – AGO70 telescope configuration.



Figure – Optical ground station (OGS) (left) and ESA OGS telescope (right).

AGO70 - observation programs - astrometry

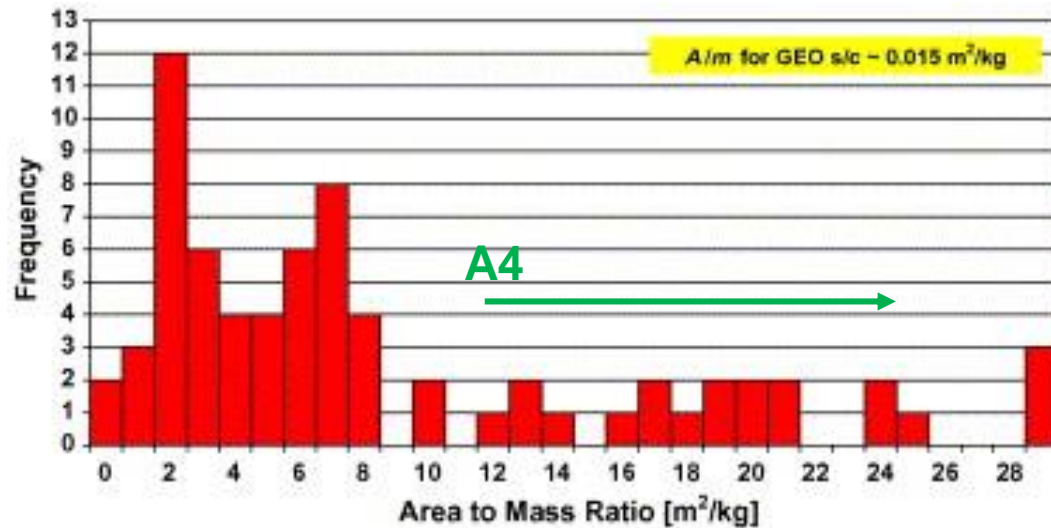


Figure – A/M values as determined for the objects discovered during OGS GEO/GTO surveys.

Taken from Schildknecht et al. (2008)

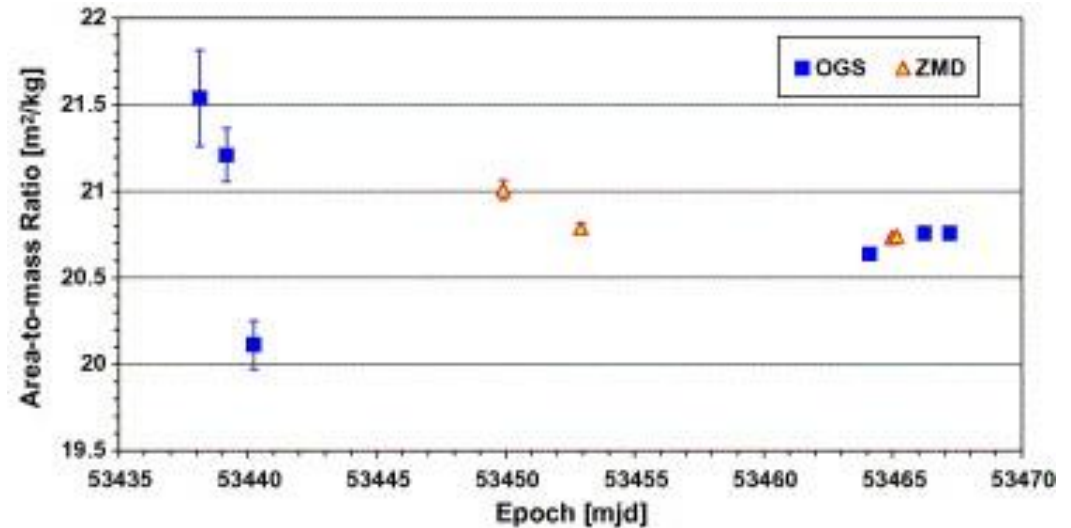


Figure – AMR value calculated for a one specific discovered GEO/GTO object.

AGO70 - observation programs astrometry

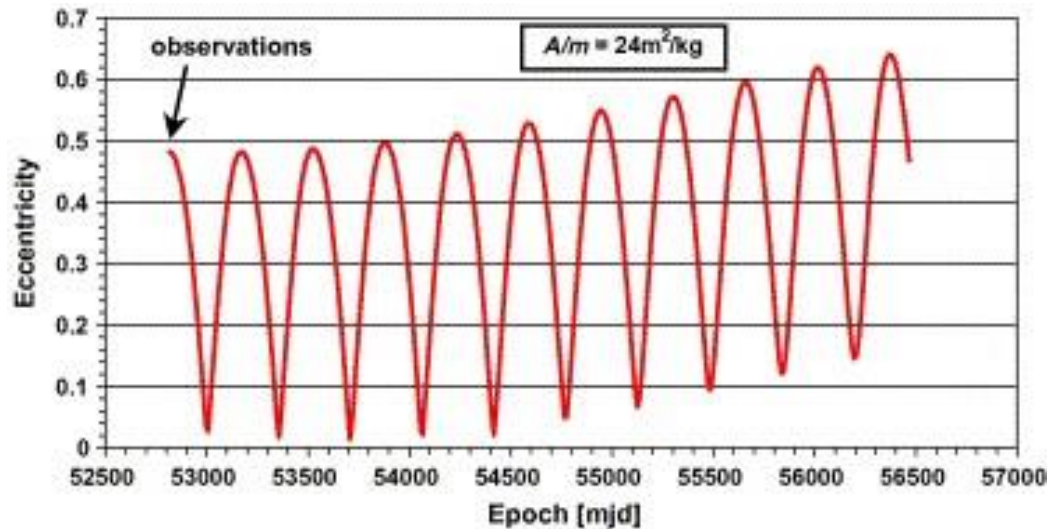


Figure – A/M values as calculated from the orbit numerical integration for an object discovered during OGS GEO survey. Object's AMR = 24m²/kg. Duration of investigated period was 12,3 years.

Taken from Schildknecht et al. (2008)

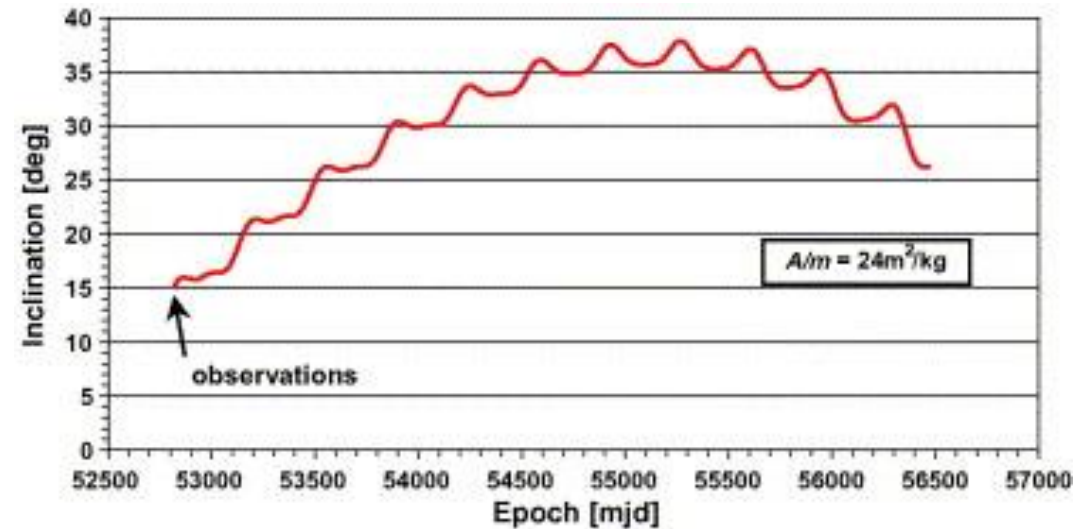


Figure – Inclination values as calculated from the orbit numerical integration for an object discovered during OGS GEO survey. Object's AMR = 24m²/kg. Duration of investigated period was 12,3 years.

ESA OGS, MASTER model

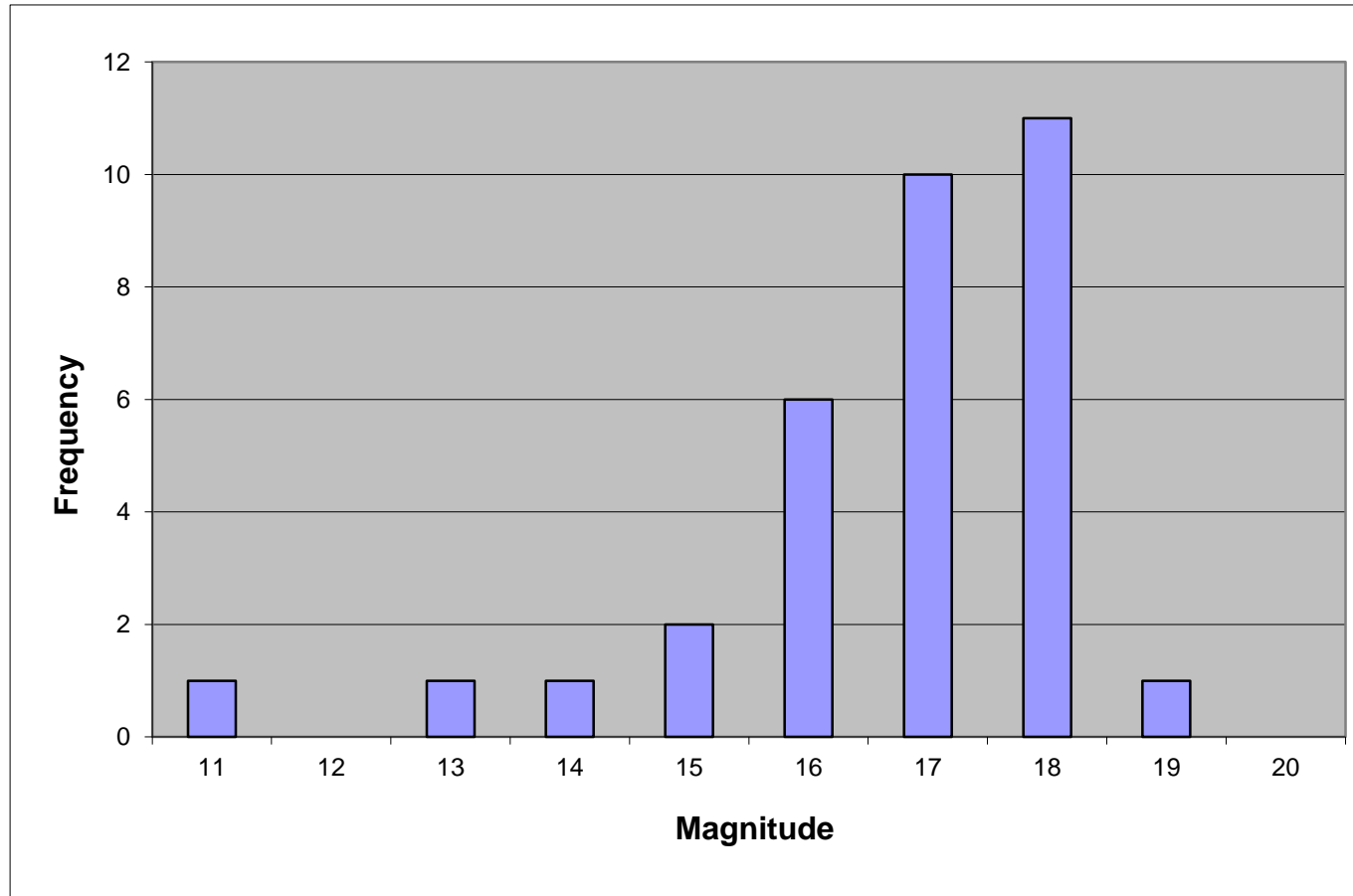


Fig. – Molniya objects apparent brightness in V filter. Values plotted for 41 UCTs discovered in 2013 and 2014. Silha et al. (2017)

ESA OGS, spectroscopy

- Reflectance spectroscopy to study the surface material of debris objects with using optical observations from the ground
- ESA study let by AIUB (Vananti et al., 2017)
- Spectra compared to laboratory spectra of space materials, e.g., MLI, solar panel, etc.
- Along spectroscopic measurements also acquired multiband photometry

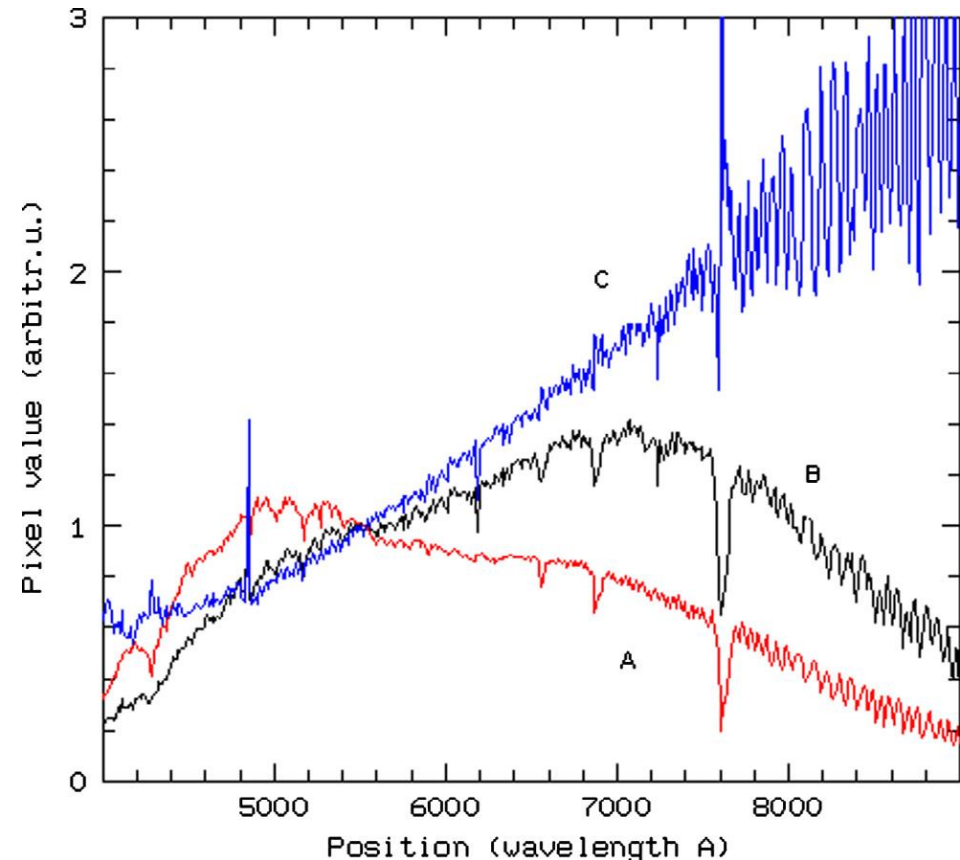


Figure – The observed spectrum of the object (A) is divided by the spectrum of the solar analog (B) to obtain the reflectance spectrum (C). Vananti et al. (2017)

ESA OGS, spectroscopy

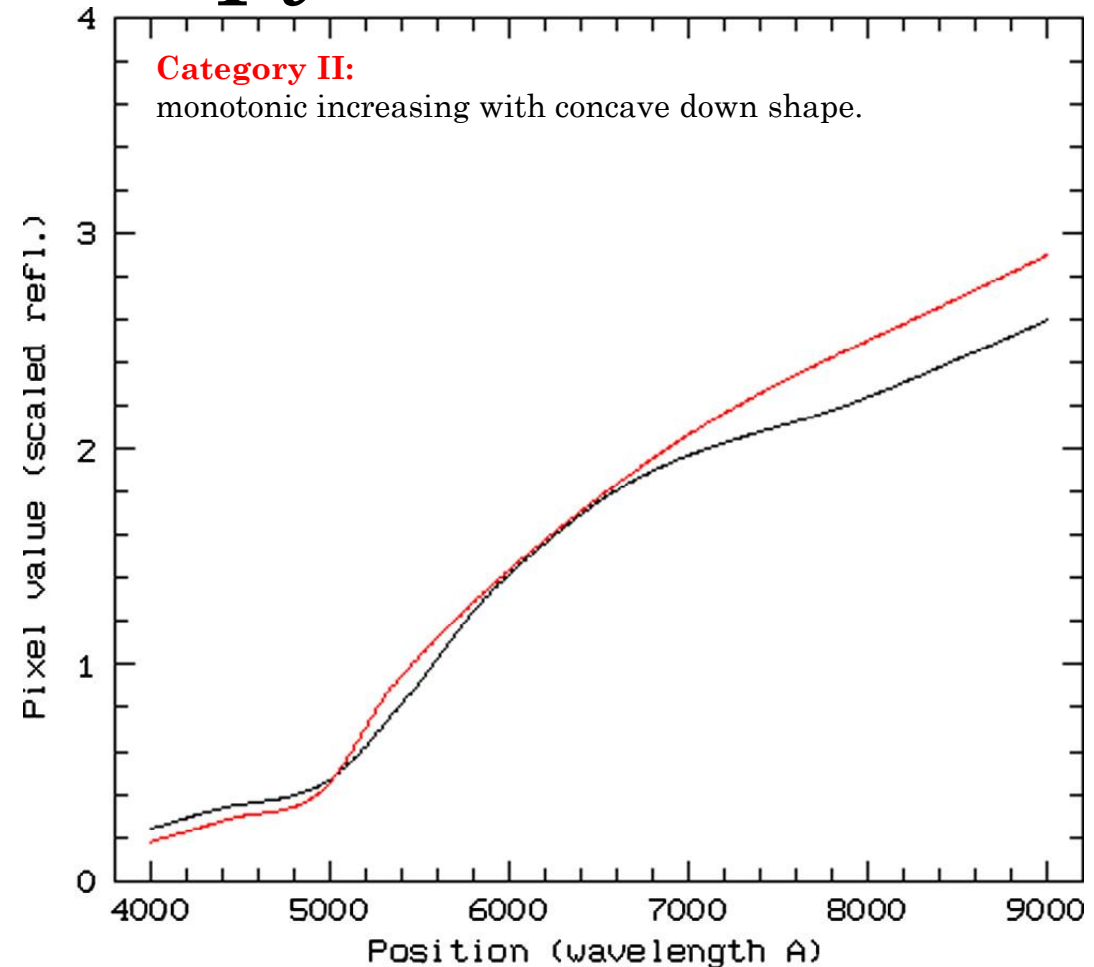
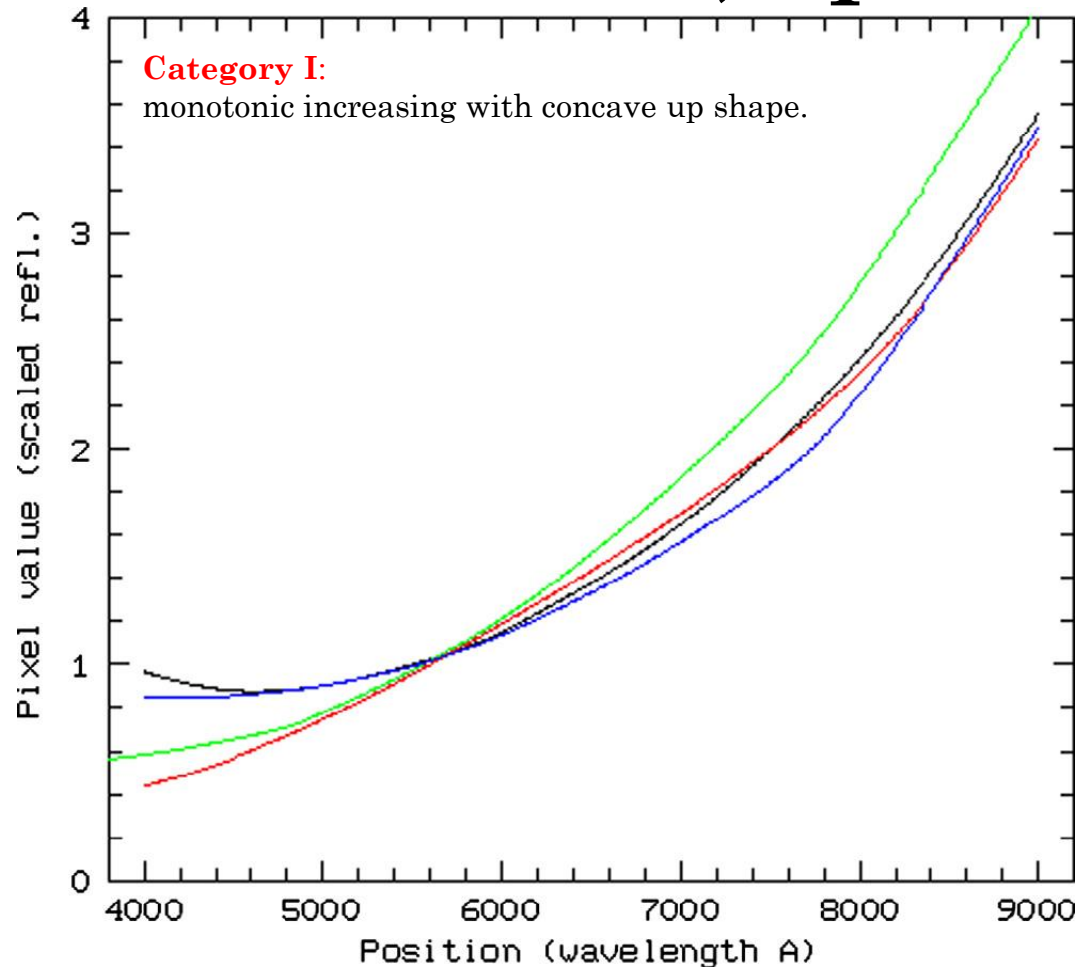


Figure – Spectra of the bright GTO debris object S92005 taken on different nights (mag = 13.4, AMR = 0.02 m²/kg). Errors: $\sigma_{450} = 0.05-0.06$, $\sigma_{800} = 0.12-0.16$. Vananti et al. (2017)

Figure – Spectra of faint ‘elliptic GEO’ debris object 84980 measured on different nights (mag = ~16, AMR = 3.0 m²/kg). Errors: $\sigma_{450} = 0.03$, $\sigma_{800} = 0.12-0.14$. Vananti et al. (2017)

ESA OGS, spectroscopy

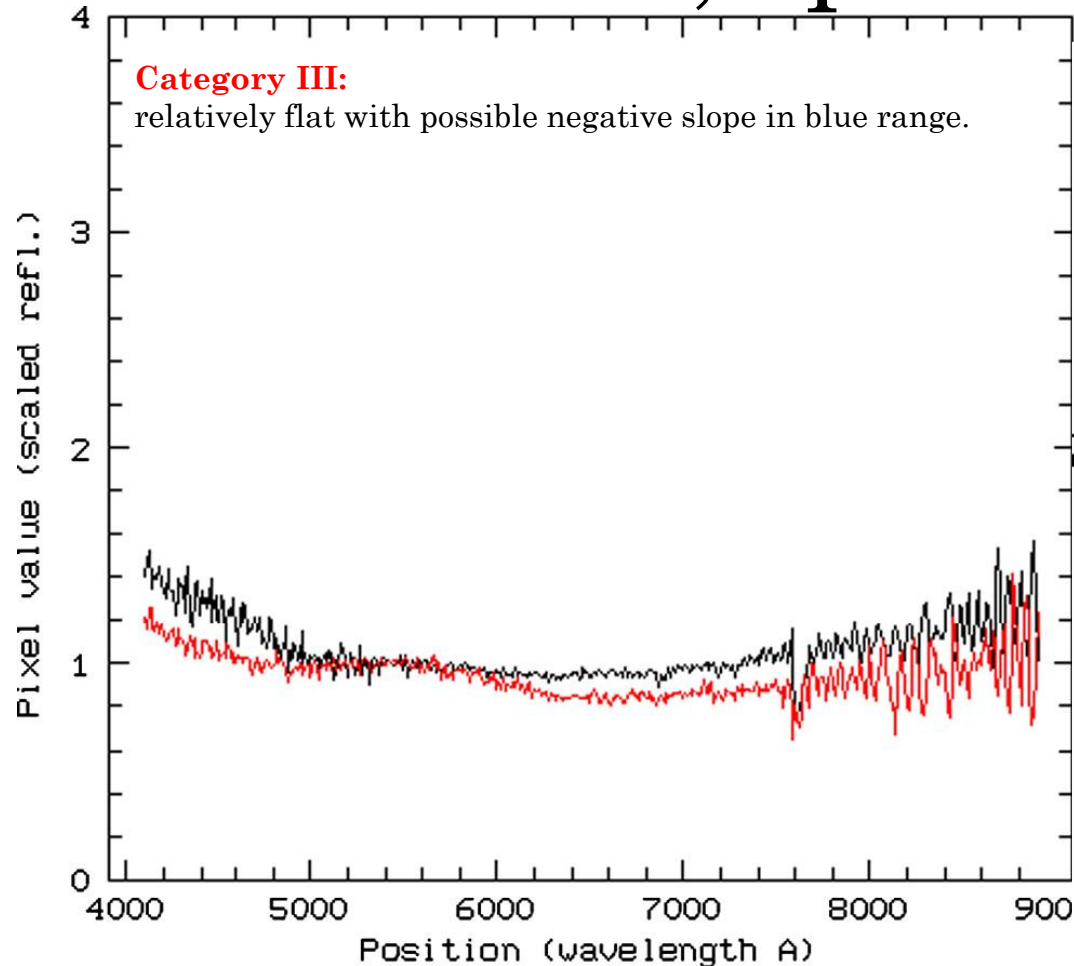


Figure – Spectra of the bright ‘elliptic GEO’ debris object E08152A measured on different nights (mag = 13.1, AMR = 0.02 m²/kg). Errors: $\sigma_{450} = 0.08$, $\sigma_{800} = 0.06$. Vananti et al. (2017)

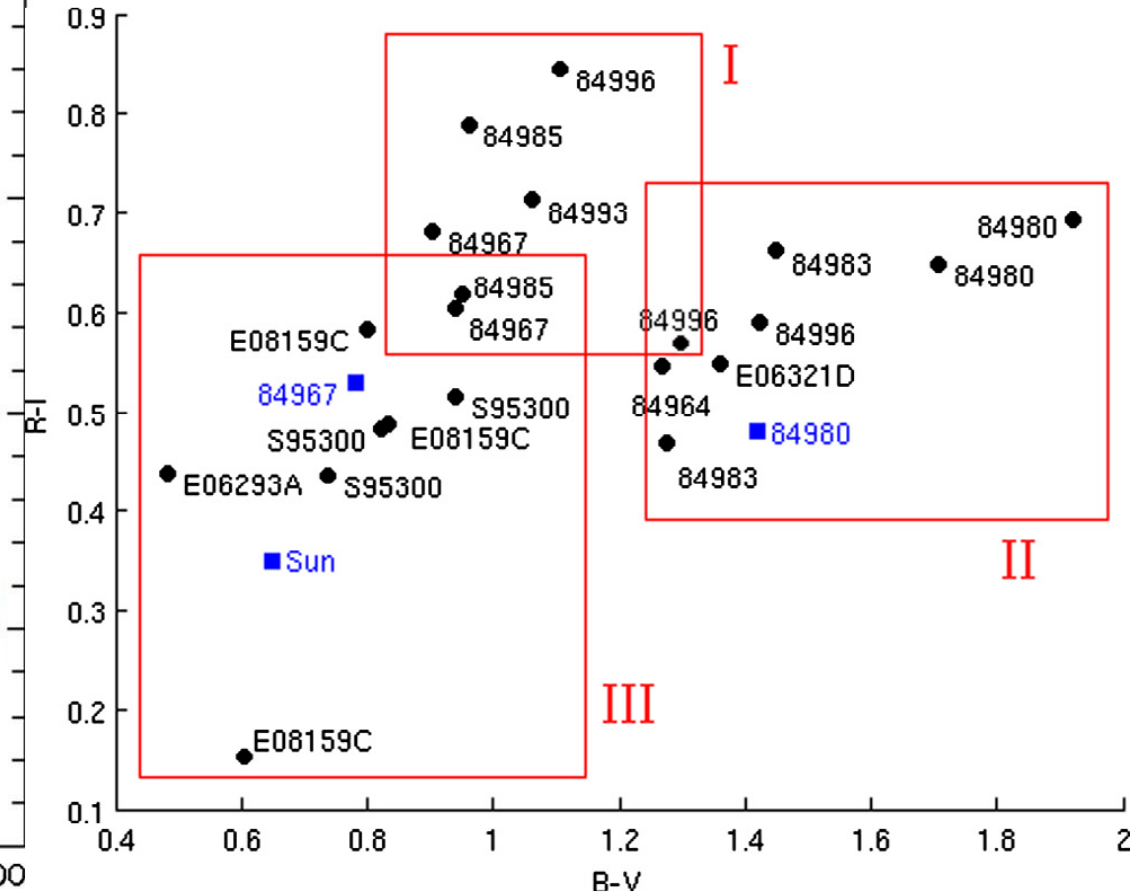


Figure – Diagram B-V vs. R-I of the observed high AMR space debris objects. The red rectangles delimit the object classification: category I (upper side), category II (lower right), category III (lower left). Vananti et al. (2017)

ESA OGS, spectroscopy

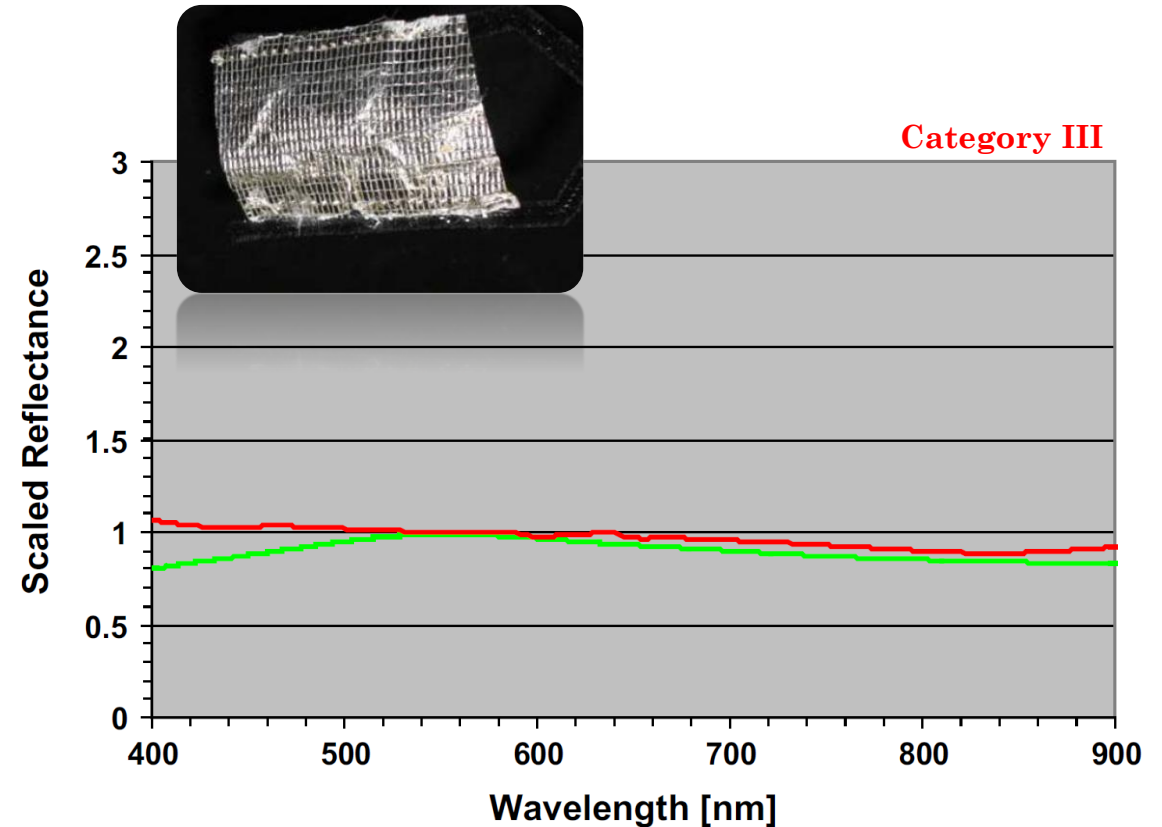
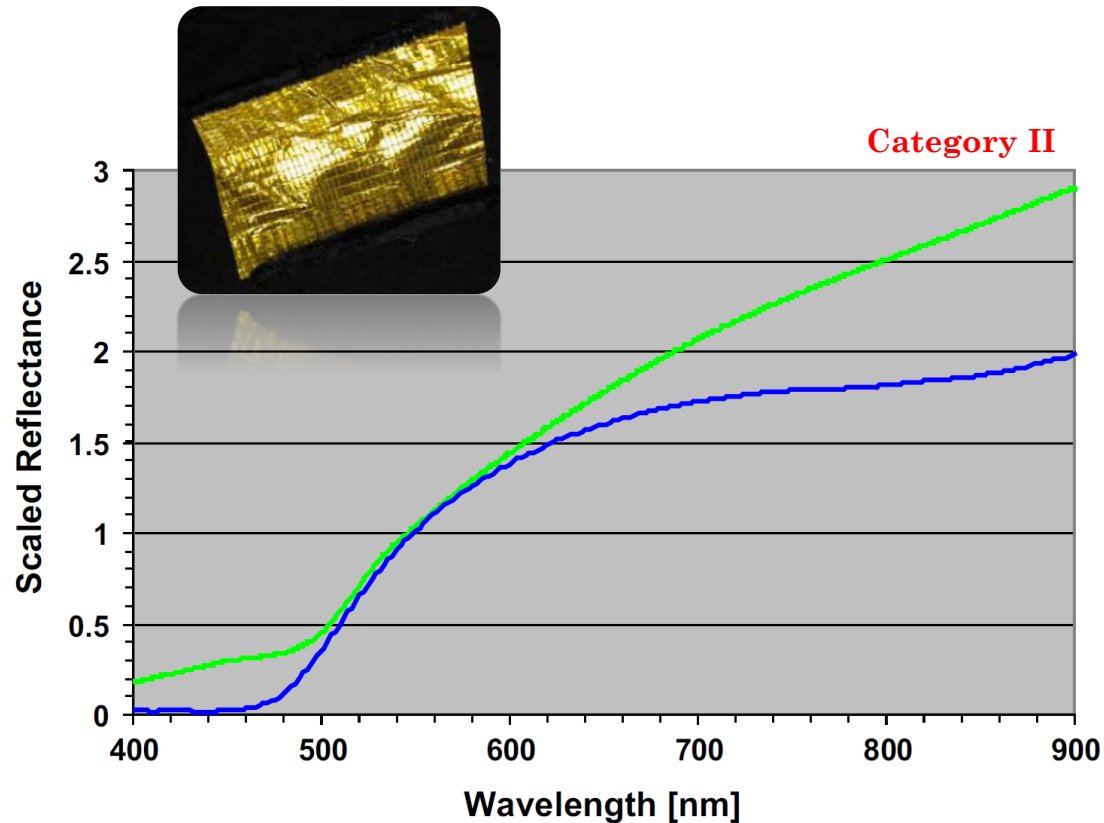
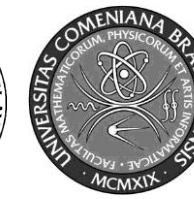


Figure – Spectra of object 84980 (green; see also Fig. 10) and 'gold' MLI (blue). Vananti et al. (2017), Cowardin (2011)

Figure – Spectra of object S95300 (green; see also Fig. 11) and 'silver' MLI (red). Vananti et al. (2017), Cowardin (2011)



NASA MODEST, ORDEM model

- MODEST (Michigan Orbital DEbris Survey Telescope) provided to NASA Orbital Debris Office for research
- University of Michigan's Curtis Schmidt telescope (1950) located at the Cerro Tololo Inter-American Observatory (CTIO) in Chile
- MODEST observations:
 - surveys to GEO, support of ORDEM model (Seitzer et al., 2011)
 - color photometry, monitoring of spaceweathering effects (Seitzer et al., 2009)

Telescope design	Curtis Schmidt
Mount	Equatorial (Cross-axis)
Camera	CCD
Dimension	2048 x 2048
Primary mirror diameter [m]	0.61
Focal length [mm]	2135.0; (f/3.5)
FOV [arc-min]	78 x 78
iFOV [arc-sec/pix]	2.3



Tab. – MODEST telescope configuration.



Figure – CTIO observatory (left) and NASA MODEST (right).



NASA MODEST, ORDEM model

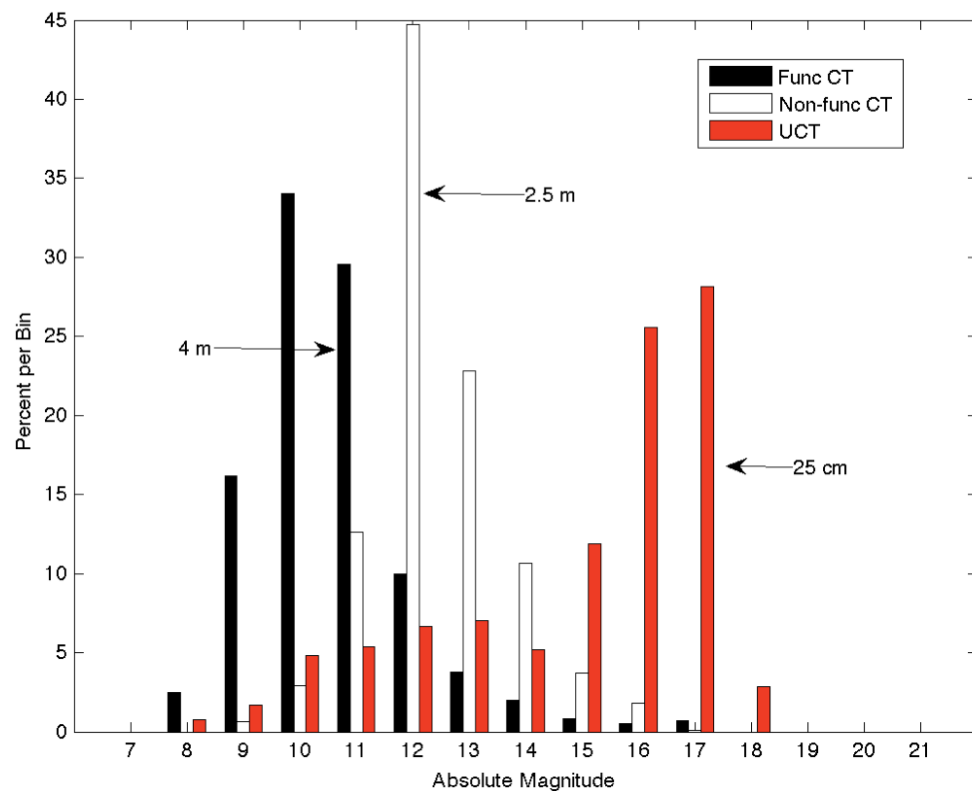


Figure. – Histogram of R magnitudes of GEO objects detected during 2007-2010 with the 0.6-m MODEST. (Seitzer et al., 2011)

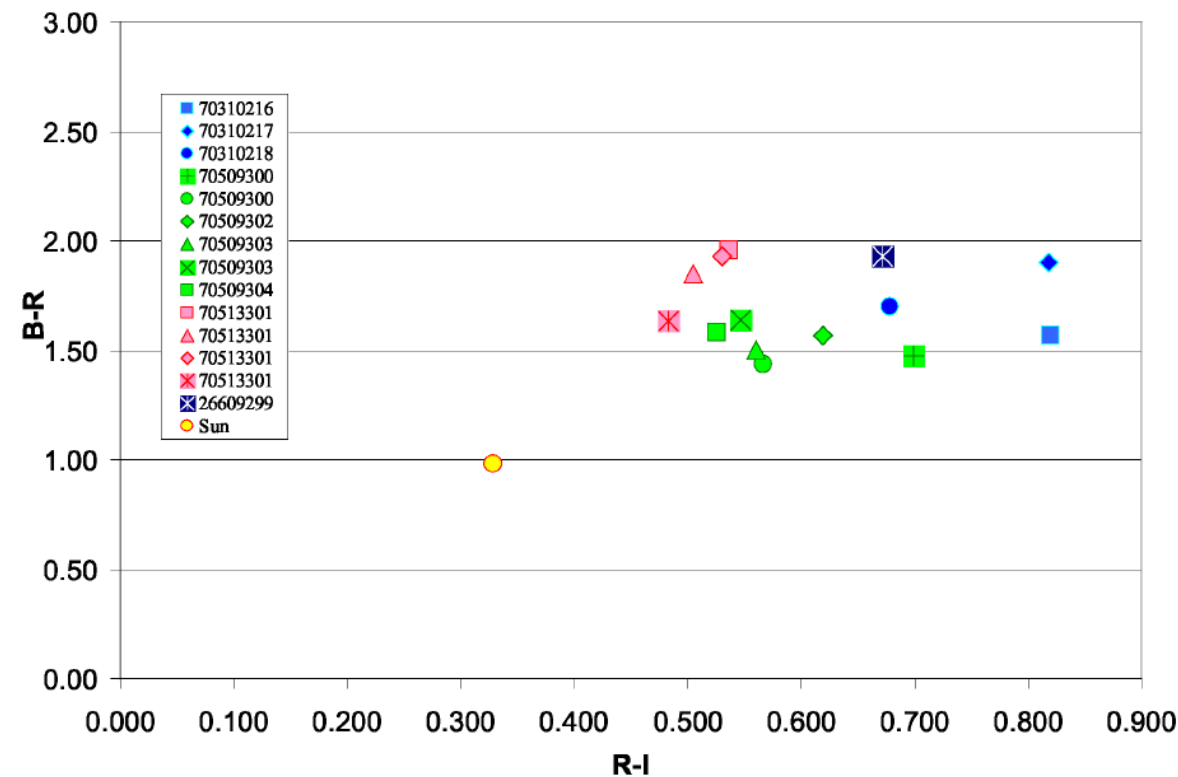


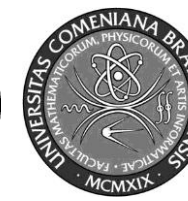
Figure – Color-color plot of a collection of stable objects (magnitude variations smaller than 0.5 magnitudes in all filters..(Seitzer et al., 2009)



Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald

- The Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald, Switzerland (hereafter Zimmerwald observatory) is operated by the Astronomical Institute of the University of Bern (AIUB)
- Several different experimental sensors focusing on space debris tracking and research
- Zimmerwald observatory includes:
 - 1-meter combined Laser and Astrometry Telescope ZIMLAT combined with SLR installation
 - 20cm/30cm automated telescope ZimSMART/ZimSMART-2 (Zimmerwald small aperture robotic telescope) equipped with CCD-camera
 - ZimTWIN telescopes, two identical 0.4-m telescopes on the same mount
 - SMARTNet2 0.8-m telescope on AltAz mount)





Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald

- ZIMLAT (1997) used for SLR, astrometric and photometric measurements, possible mode for SLR simultaneous with photometry
- Support of AIUB/ESA cataloging, internal „Z“ catalogue
- CCD camera FLI SI1100, 2048x2064, 3 different focus lengths, possibility to use sCMOS camera
- FOV during astrometry ~ 25'x25'

Telescope design	Ritchey-Chretien
Mount	Alt-azimuth
Camera	CCD (sCMOS*)
Dimension	2048 x 2064
Primary mirror diameter [m]	1.0
Focal length [mm]	4000, (f/4.0)
FOV [arc-min]	25 x 25
iFOV [arc-sec/pix]	0.7

Table – ZIMLAT telescope configuration.
* configuration with sCMOS not listed.



Figure – 1-m ZIMLAT telescope.

FMPI's AGO70 telescope



FMPI/AGO's 70cm telescope - AGO70



- Manufactured by astronomer amateur at Observatory Gaisberg, Austria
- Purchased by FMPI CU and installed at the Astronomical and geophysical observatory in Modra, Slovakia (AGO) in Sep 2016
- CCD FLI Proline PL1001 Grade 1, 1024 x 1024 pixels
- S/W development ongoing, e.g., LLTC, CSA, etc.



Figure – AGO 70cm telescope.

Telescope design	Newton
Mount	Equatorial (Open fork)
Camera	CCD
Dimension	1024 x 1024
Primary mirror diameter [m]	0.7
Focal length [mm]; focal ratio	2962.0; f/4.2
FOV [arc-min]	28.5 x 28.5
iFOV [arc-sec/pix]	1.67

Table – AGO70 telescope configuration.

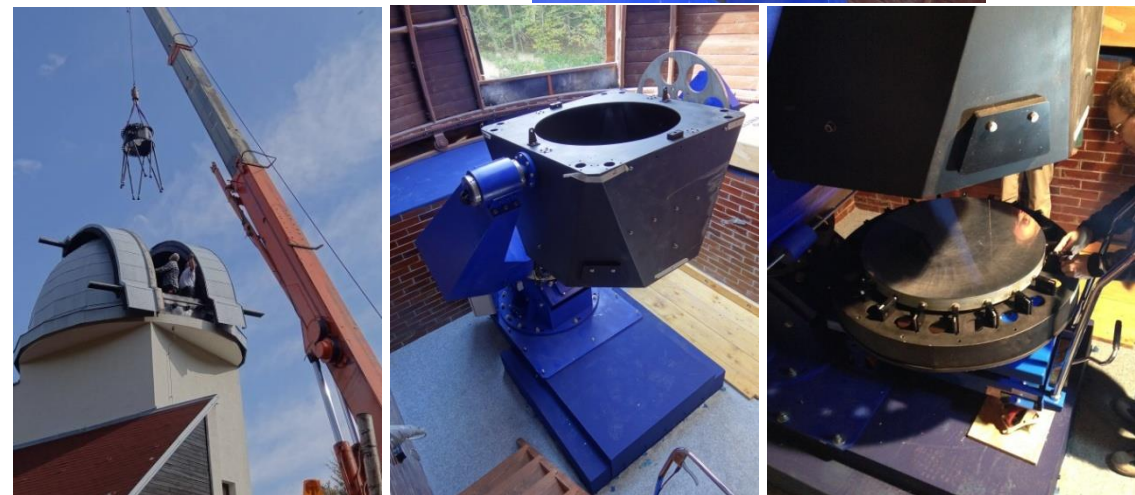


Figure – AGO 70cm telescope installation (left), mount (middle) and 70 cm primary mirror (right).



AGO70, observation programs





AGO70, observation programs

- Three major programs on AGO 70cm:
 - **Astrometry, surveys and tracking** - to maintain the objects catalogue, to discover new objects, cooperation with partners
 - **Instrumental photometry, light curves (LC)** – attitude state characterization, attitude motion determination, attitude evolution monitoring, internal LC catalogue
 - **Absolute photometry, colors and color indices (CI)** – surface properties, space-weathering aging monitoring, internal CI catalogue
- Each program with its own data types, planning and outputs
- Activity to be finished in Nov 2018, all defined goals were achieved



AGO70, observation programs, astrometry



- There were 48 nights of observations in total within ESA PECS activity, 20 nights in 2017 and 28 nights in 2018
- There were 20 nights of GNSS observations processed by AIUB, calculated O-C (Observed - Calculated)
- astrometric accuracy between 0.8-0.9 arc-sec for the best period (May and June 2018) and 10.3 arc-sec for the worst period (April 2018)

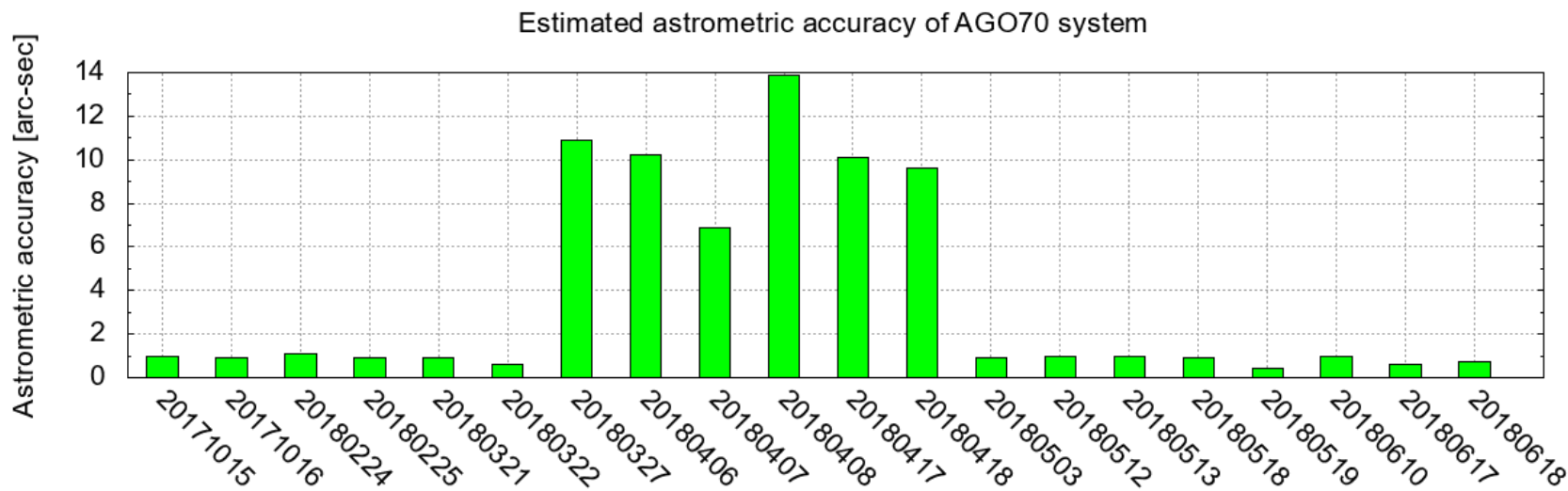
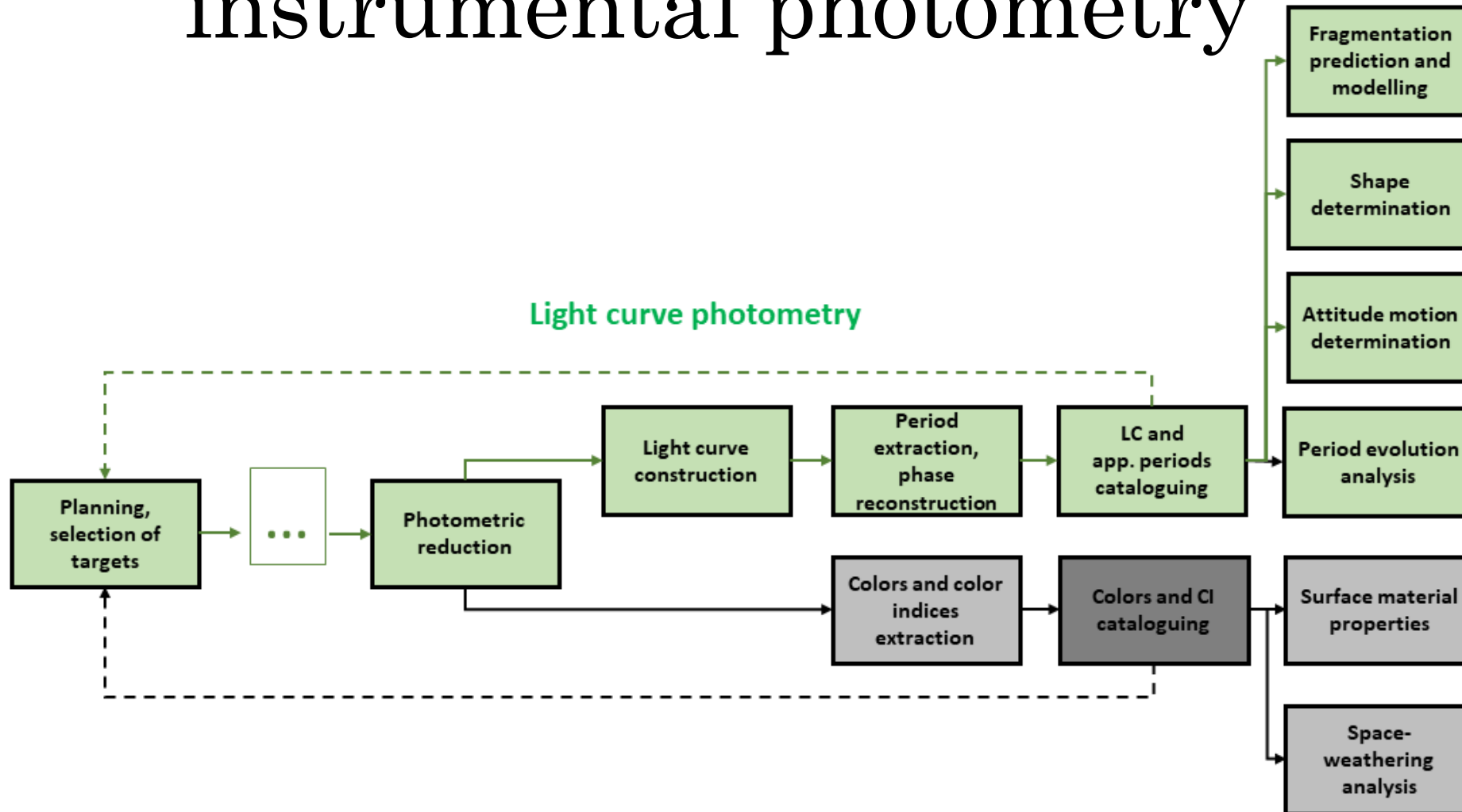


Figure – Estimated astrometric accuracy of AGO70 system. Data obtained from AGO70's GNSS measurements processed by AIUB. (Silha et al., 2018)



AGO70 - observation programs instrumental photometry



V1.1

AGO70 - observation programs – instrumental photometry



- During 48 nights of observation campaign we acquired 339 light curves for 148 individual objects
- Covered orbital regions GTO to GEO
- Majority of objects showed rotating behavior, processing by using PDM (R.F. Stellingwerf, 1978)

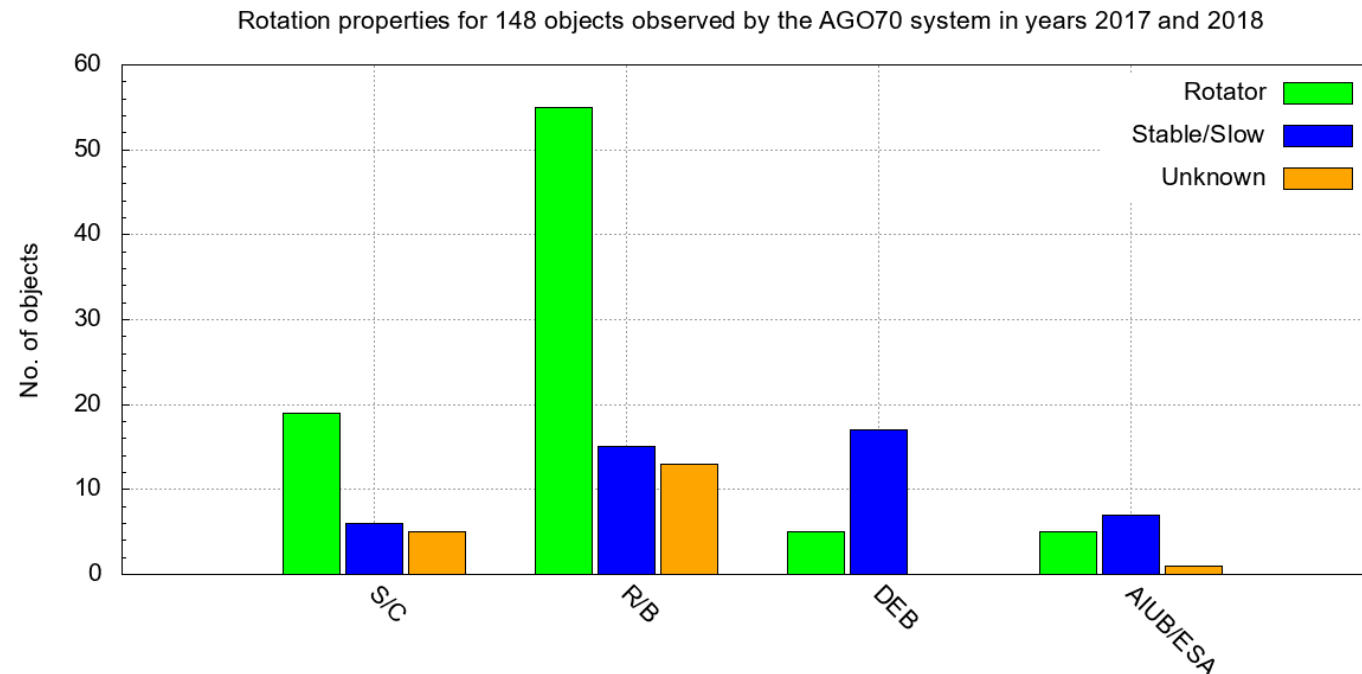


Figure – Distribution of the objects observed by AGO70 system in years 2017 and 2018 according to their rotation properties and type.

AGO70 - observation programs – instrumental photometry



- 2017-063B – Falcon 9 R/B, GTO

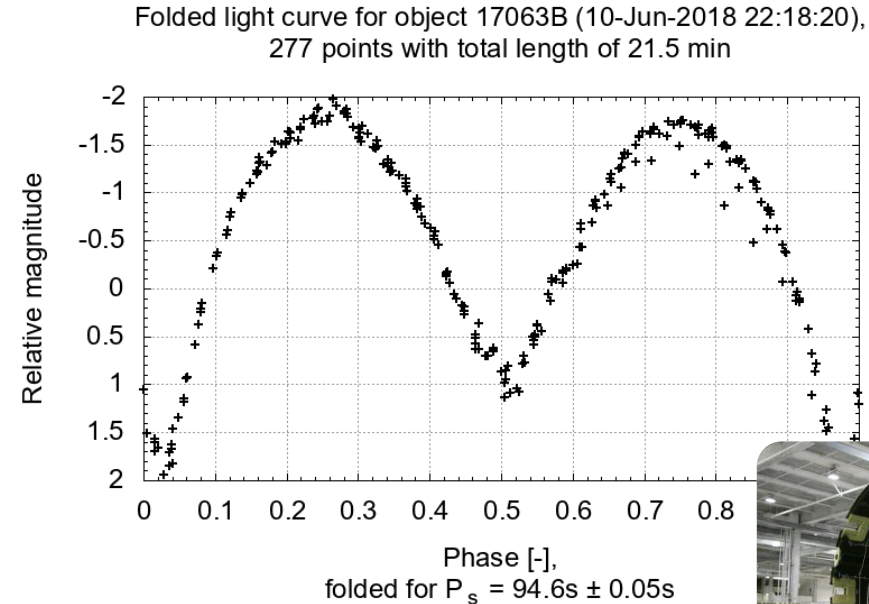
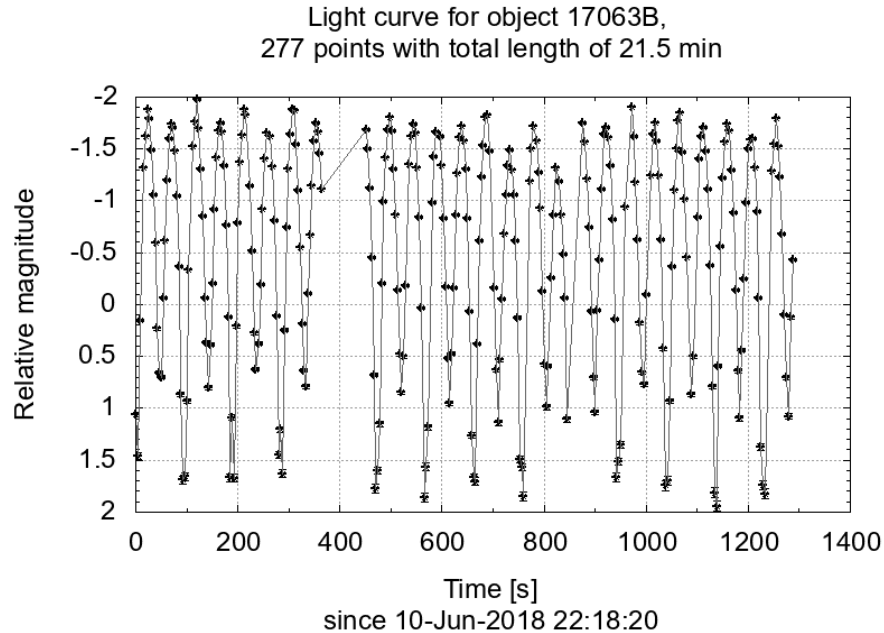


Figure – Light curve (left) and folded light curve (right) acquired by AGO 70cm telescope for object 17063B.

AGO70 - observation programs – instrumental photometry



- 1996-040C – Ariane 44L+3 R/B, GTO

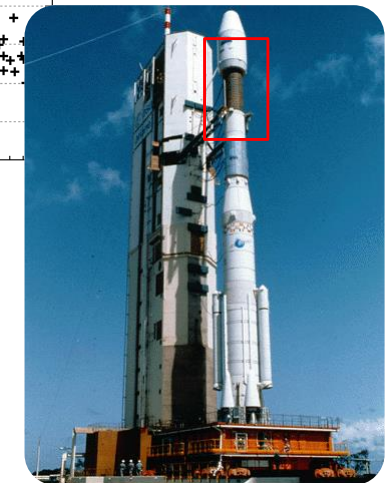
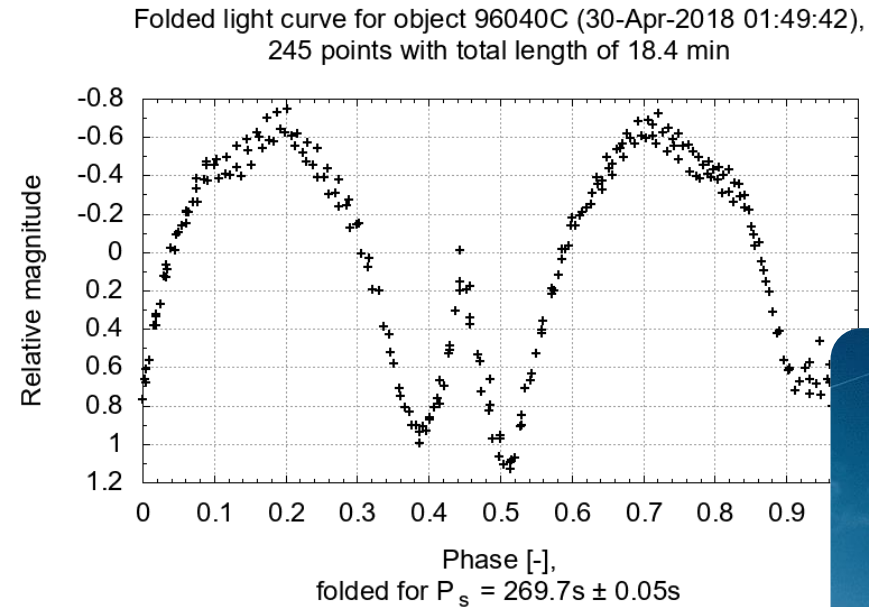
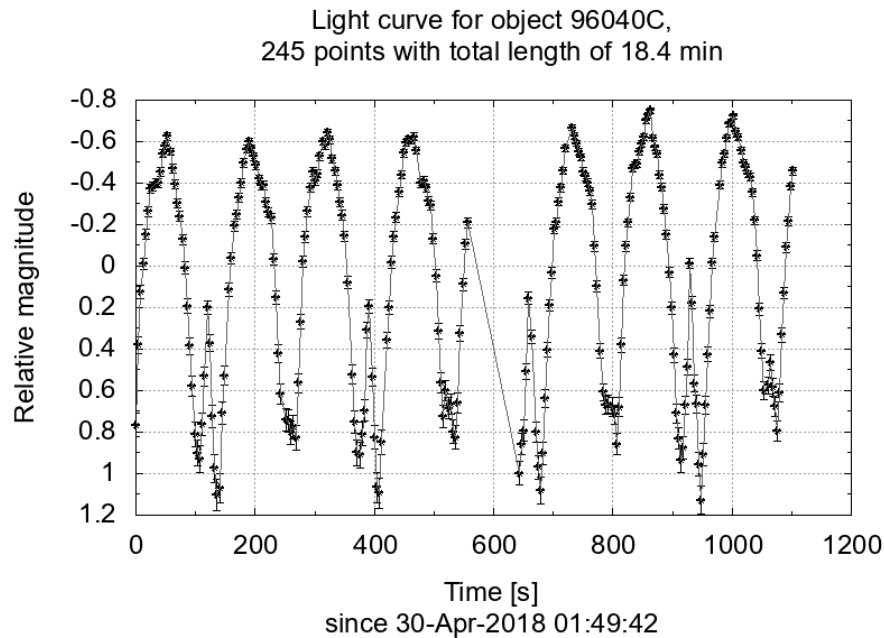
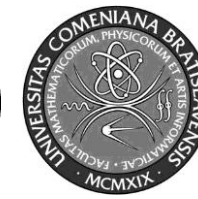


Figure – Light curve (left) and folded light curve (right) acquired by AGO 70cm telescope for object 96040C.

AGO70 - observation programs – instrumental photometry



- 1983-066A – Gorizont 7, GEO

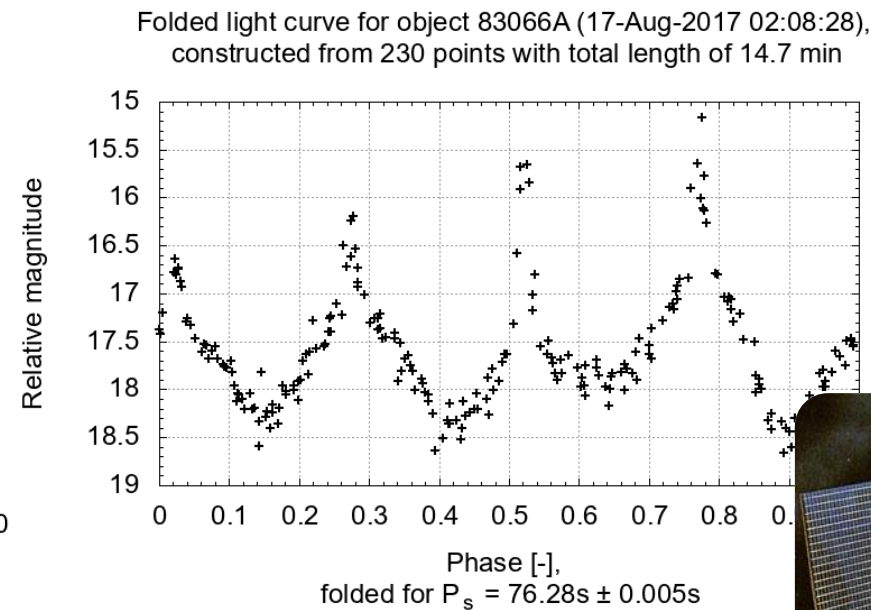
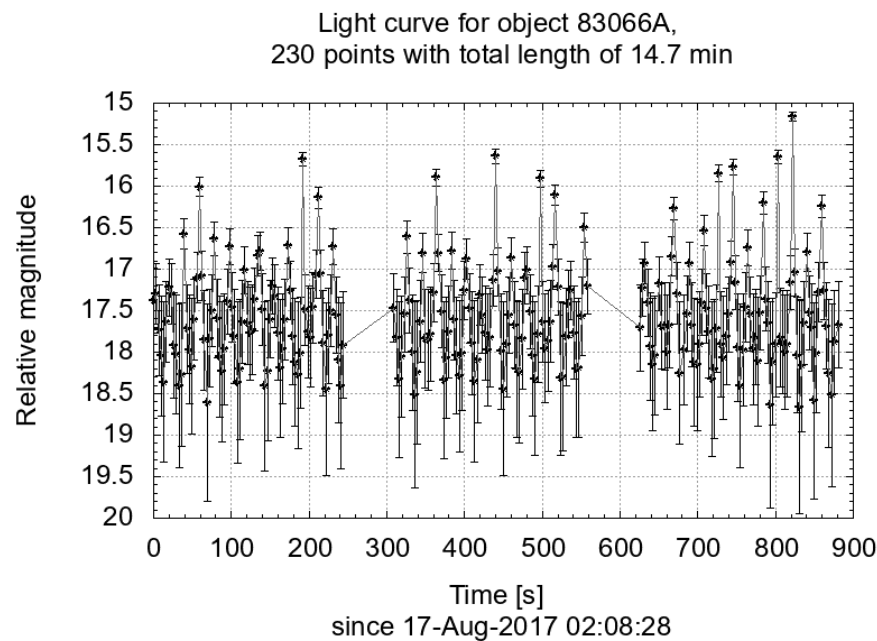


Figure – Light curve (left) and folded light curve (right) acquired by AGO 70cm telescope for object 17063B..



Summary

- Space debris:
 - Research – spatial distribution modeling, photometry, reflectance spectroscopy, etc.
 - SST service – astrometric measurements, surveys, etc.
- Possible to cooperate with international partners, e.g., ISON, AIUB, FMPI CU, ESA/ExpCen*, etc.
- For SST necessary to fulfill strict criteria, data quality, latency, security measures, etc.
- Slovakia possible candidate for contribution to European research and SST thanks to the ESA PECS activity, future follow-up ESA activities
- Currently interest too explore synergies between NEA and space debris communities, “NEO and debris detection conference”, 22. – 24. January, 2019, ESOC Darmstadt, Germany



Thank you for your attention.



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WWW: <https://fmph.uniba.sk/microsites/daa/daa/kozmicke-smetie/>