Space debris and its research in Slovak Republic

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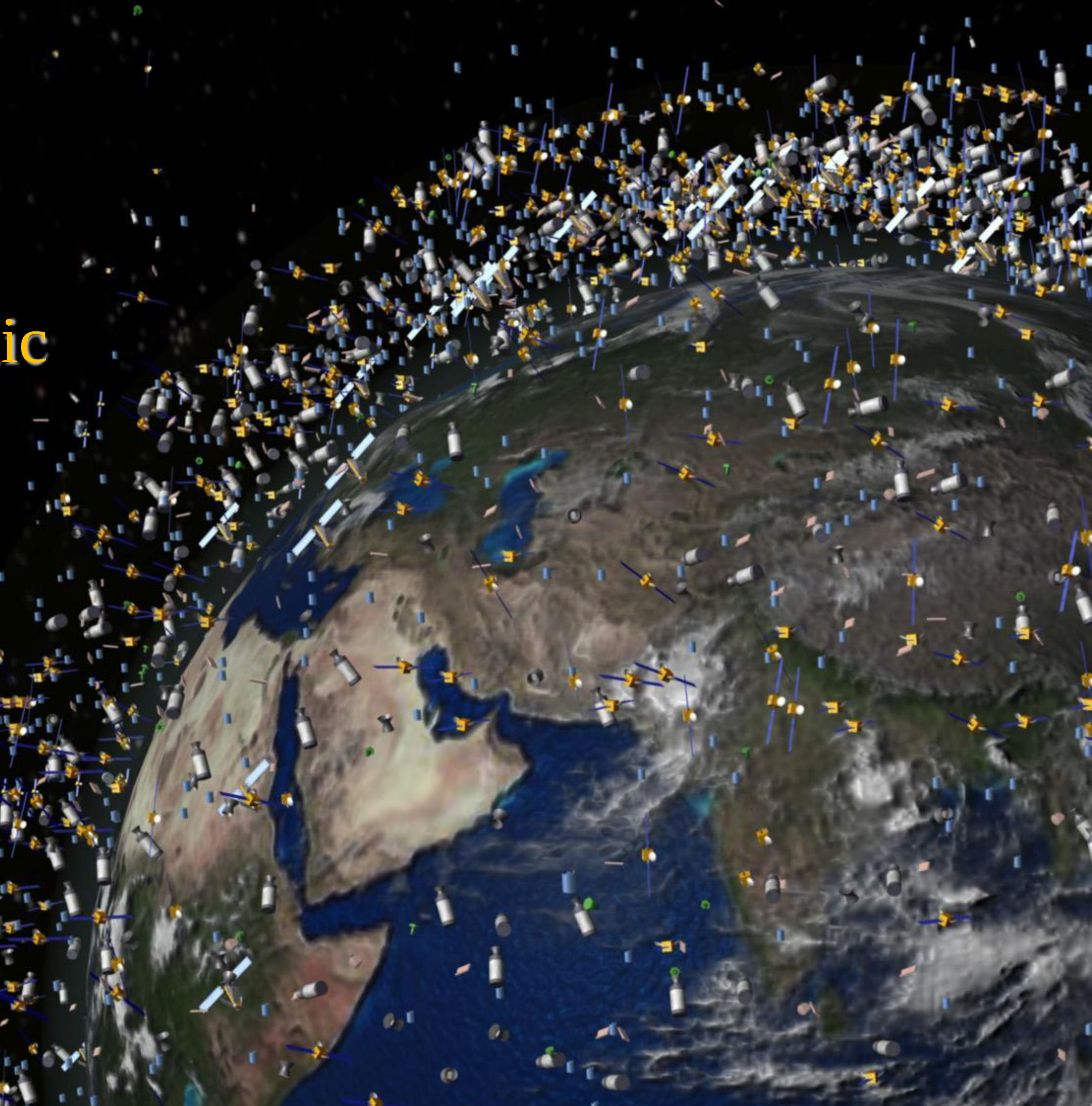

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Space debris, introduction

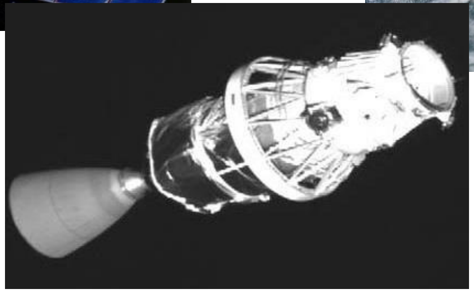
Space debris, definition

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

Probe Phobos Grunt

Satellite Astra

Upper stage Agena D

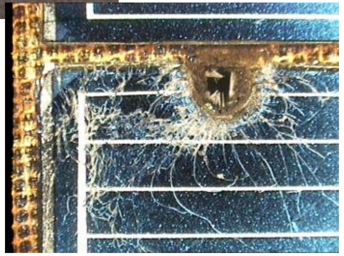


Upper stage Delta

Al_2O_3

Fragment SOCIT4 37

MLI

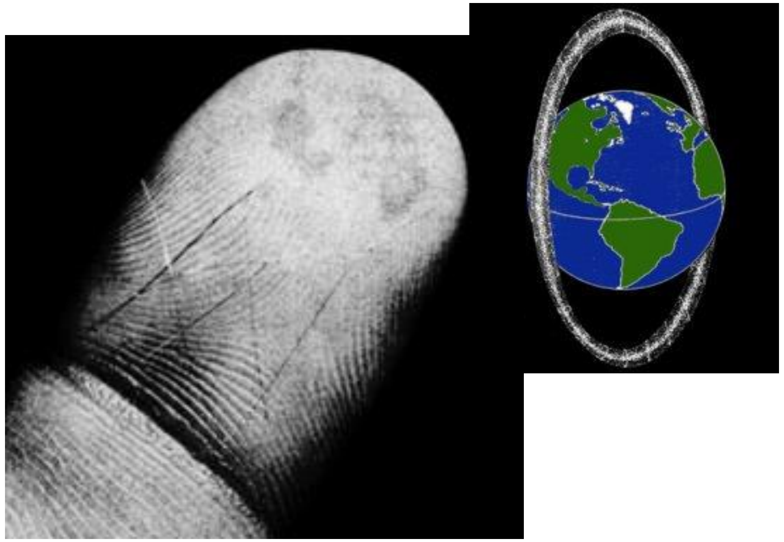


HST solar panel

Humanity Star

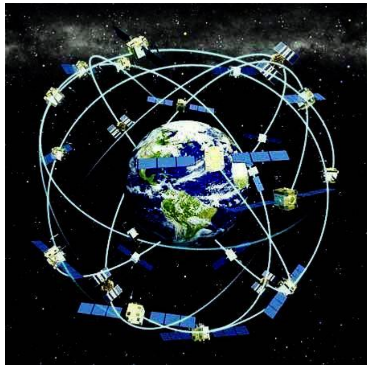
Tesla Roadster

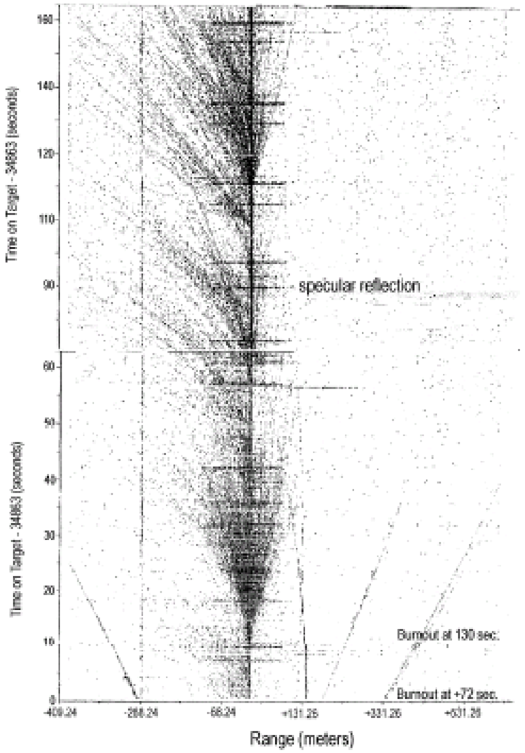
Small debris



West Ford Project (1960s)

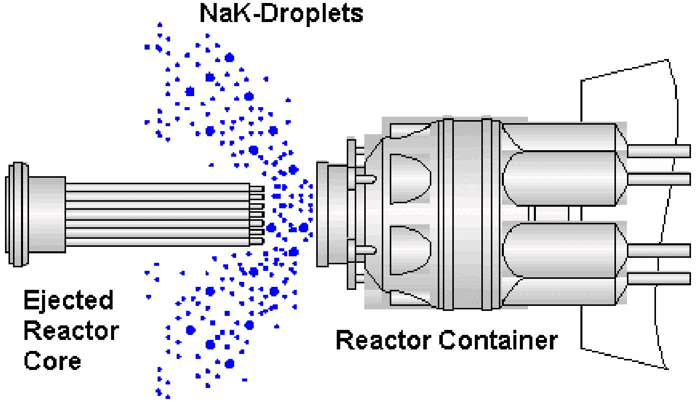
Al_2O_3 (od 1958 till early 2010s, ~50x/year)



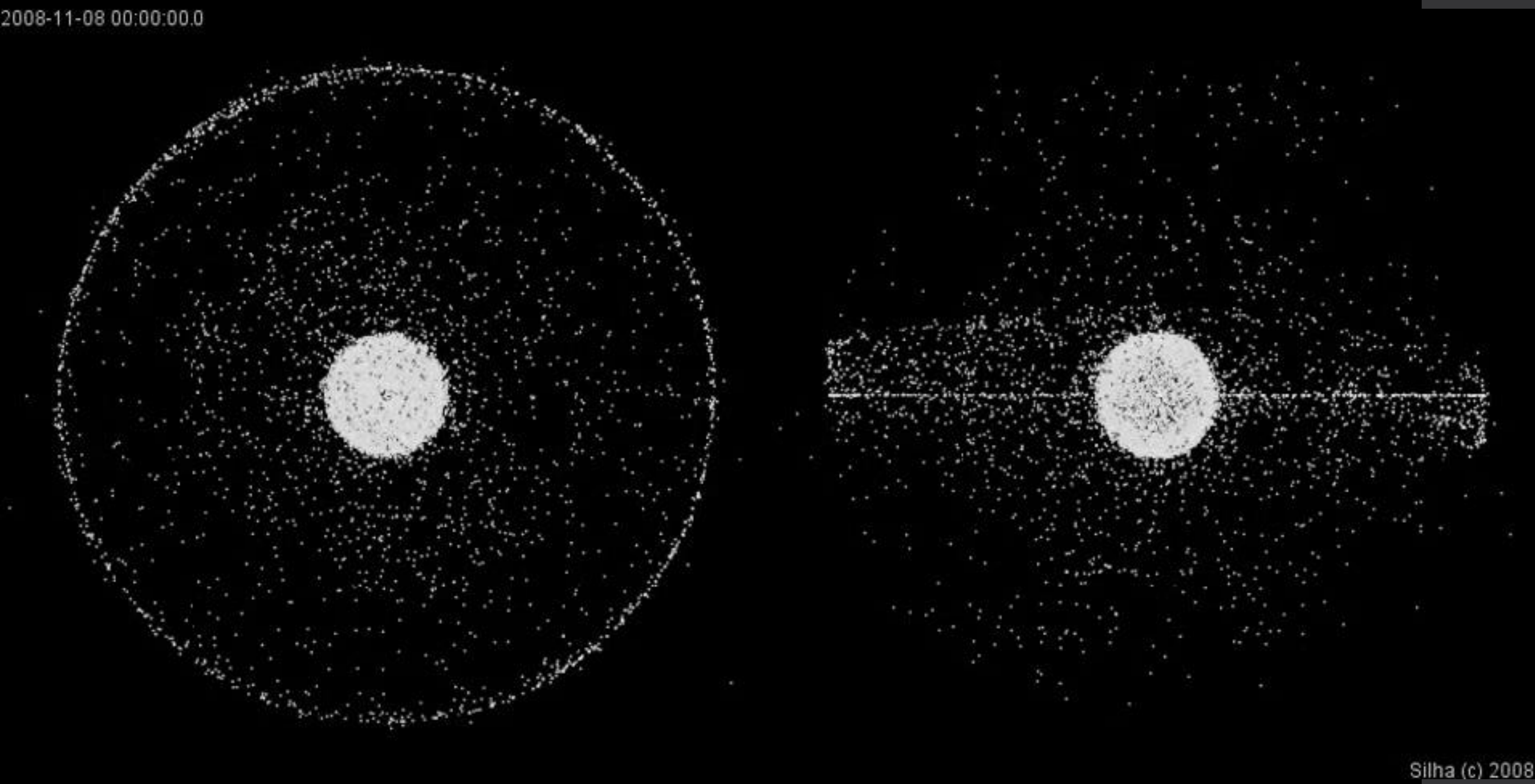


Particles from Ascending Rocket Burn (Haystack Radar)

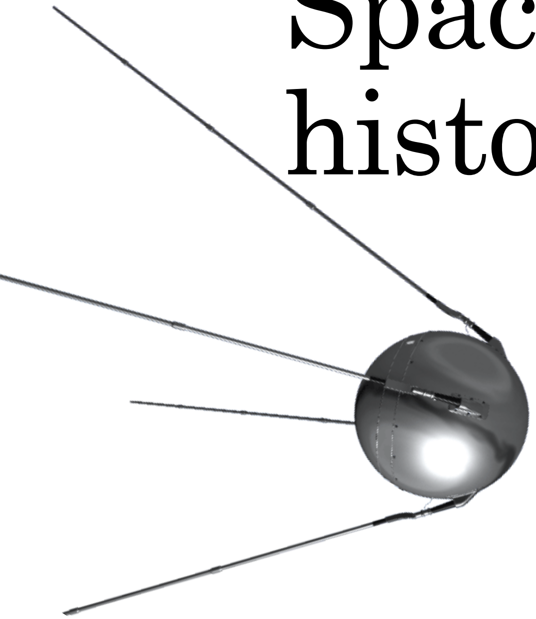
MIT Lincoln Laboratory
Support by NASA Johnson Space Center

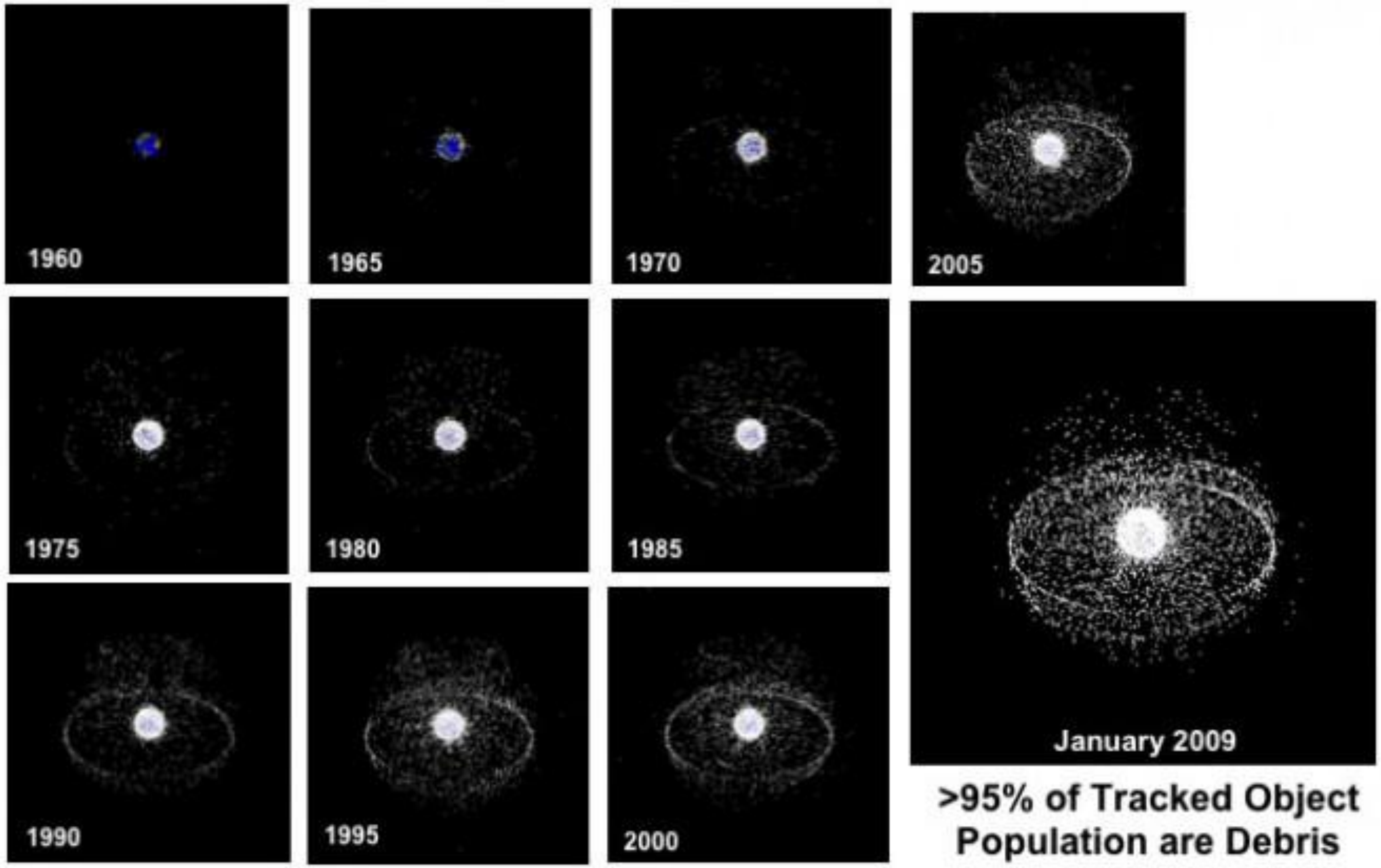


NaK droplets – RORSAT project (16x in 1980s)

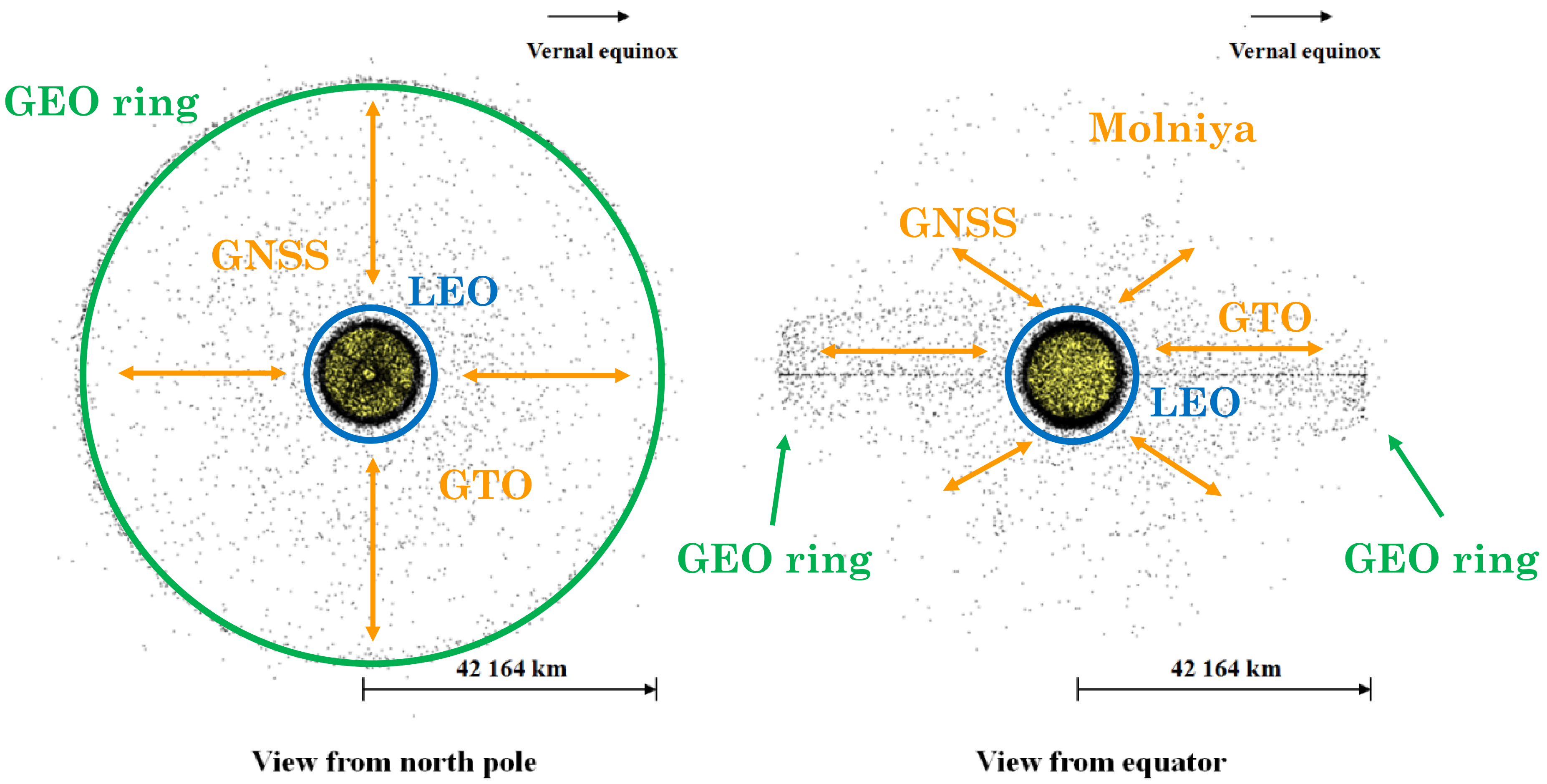

2008-11-08 00:00:00.0
Silha (c) 2008

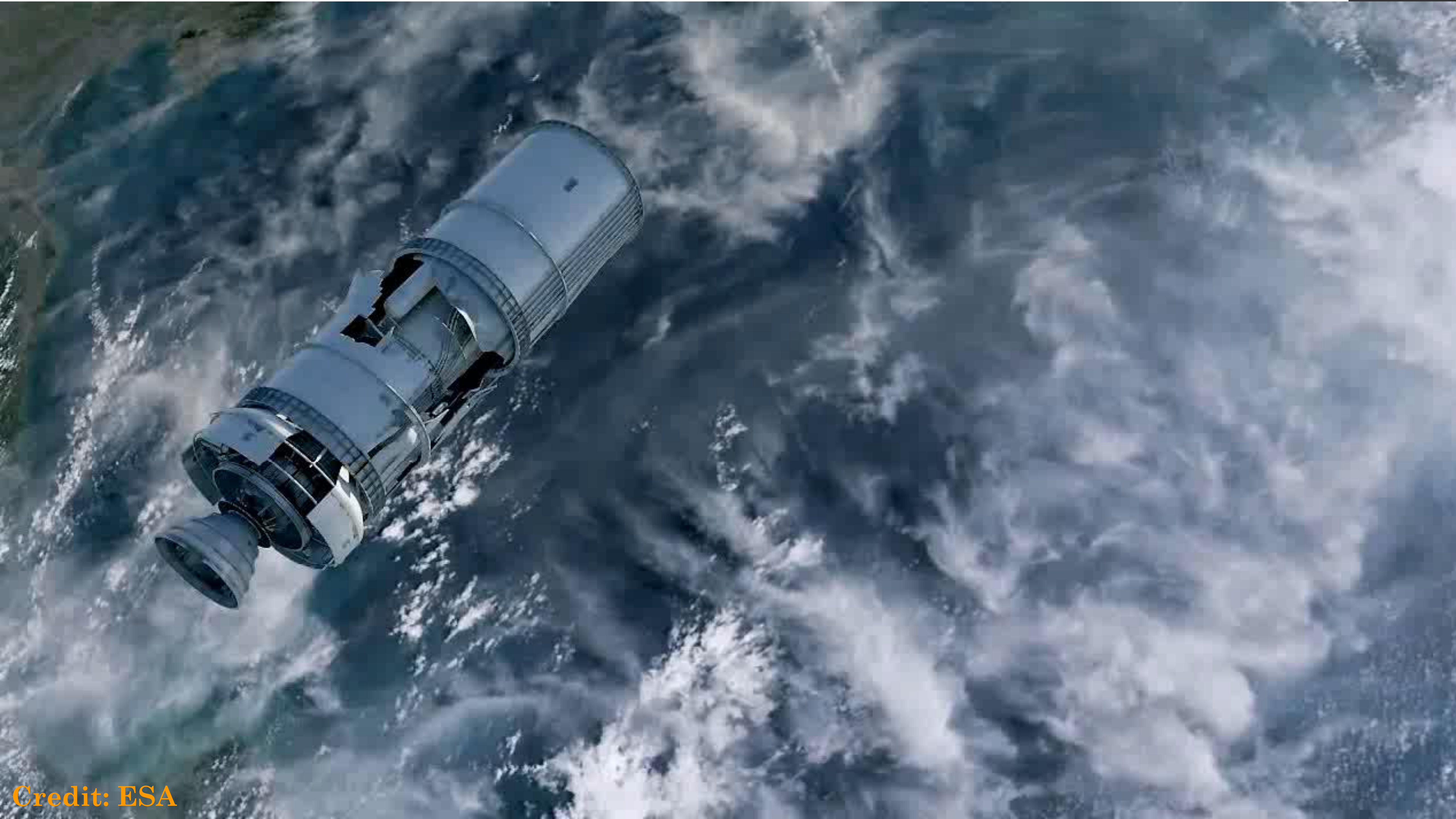
Space debris, history





Space debris, spatial distribution





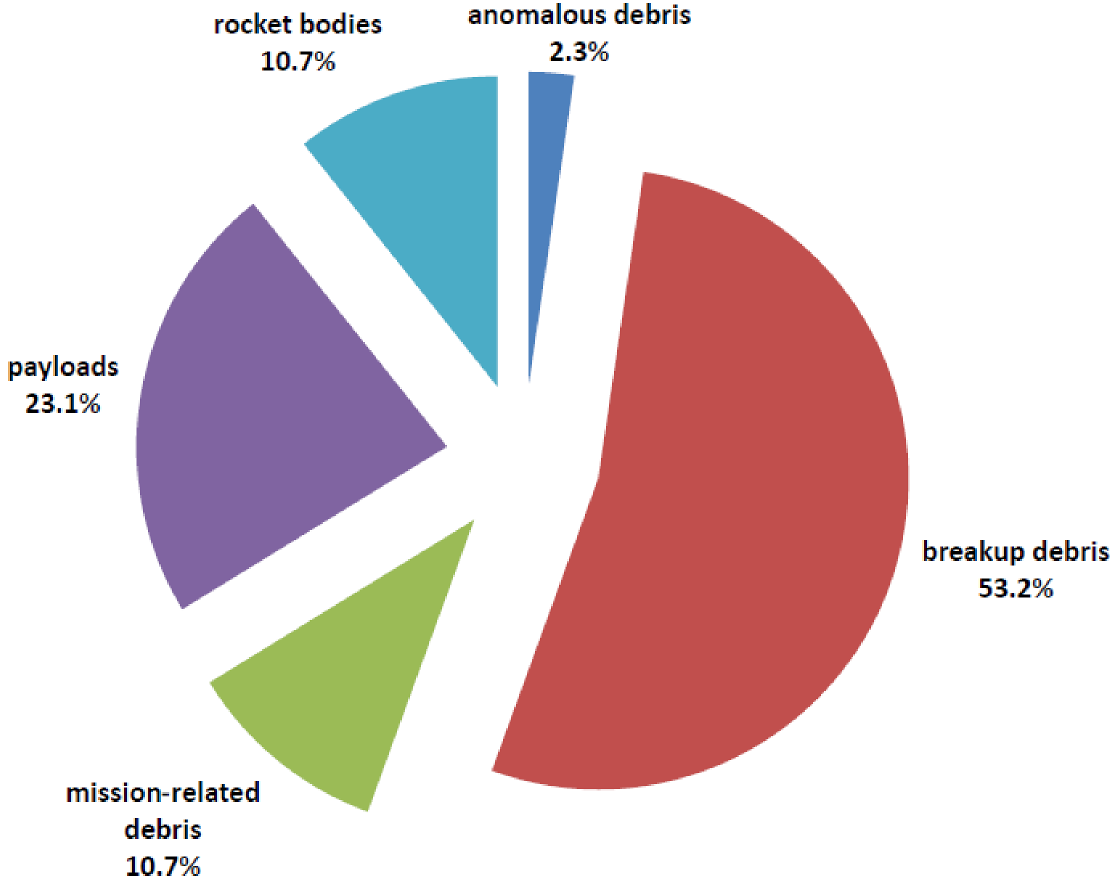
Credit: ESA

Space debris, sources

- at present (2019-11-05)
- catalogue 18291

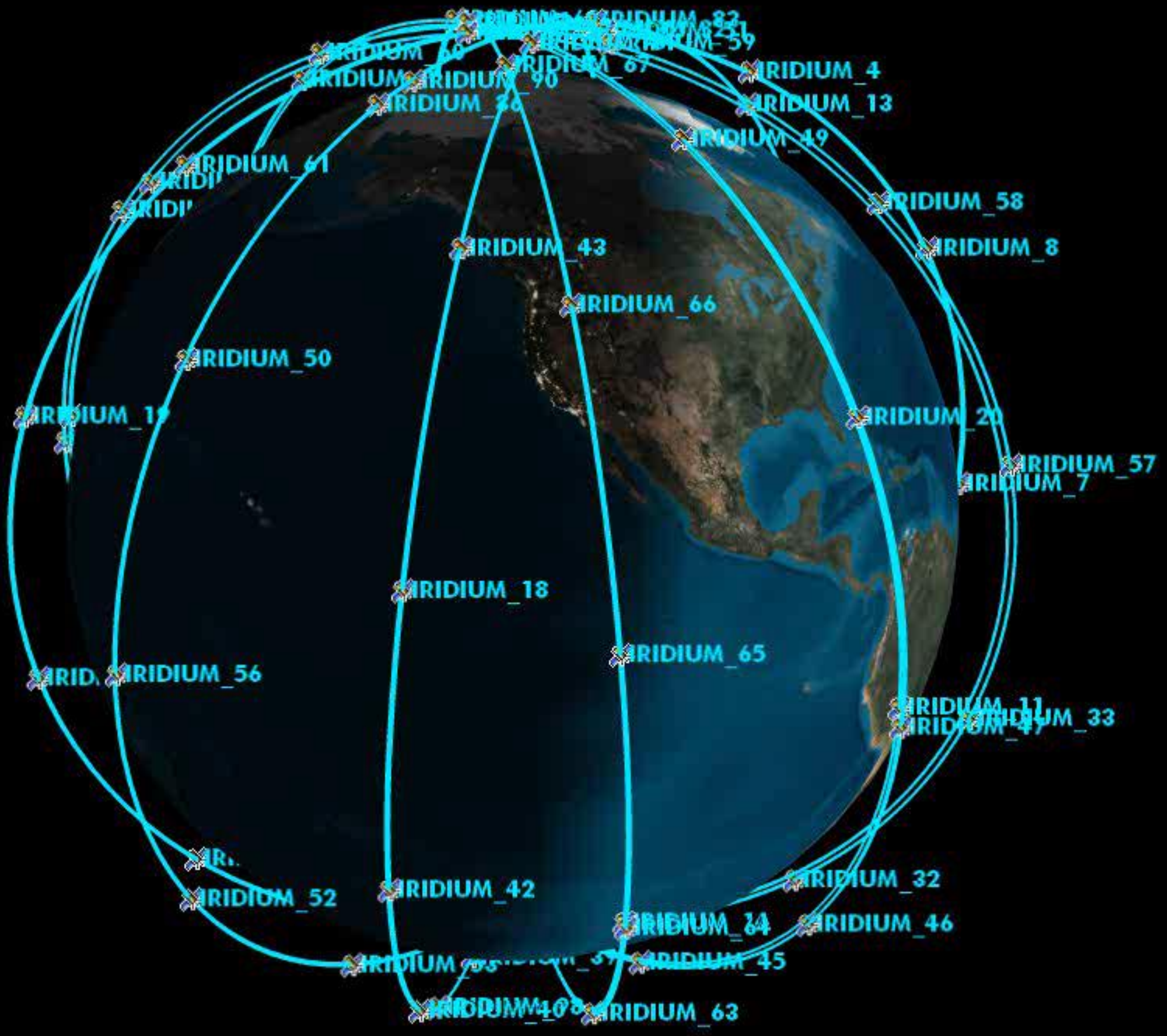
- satellites
  - functional (~1000)
  - non-operational

- space debris (> 5 cm)
  - upper stages
  - fragments
  - mission related debris
  - anomaly debris



Source: Orbital Debris Quarently News, 2017, issue 2

Credit: ESA



IRIDIUM_82
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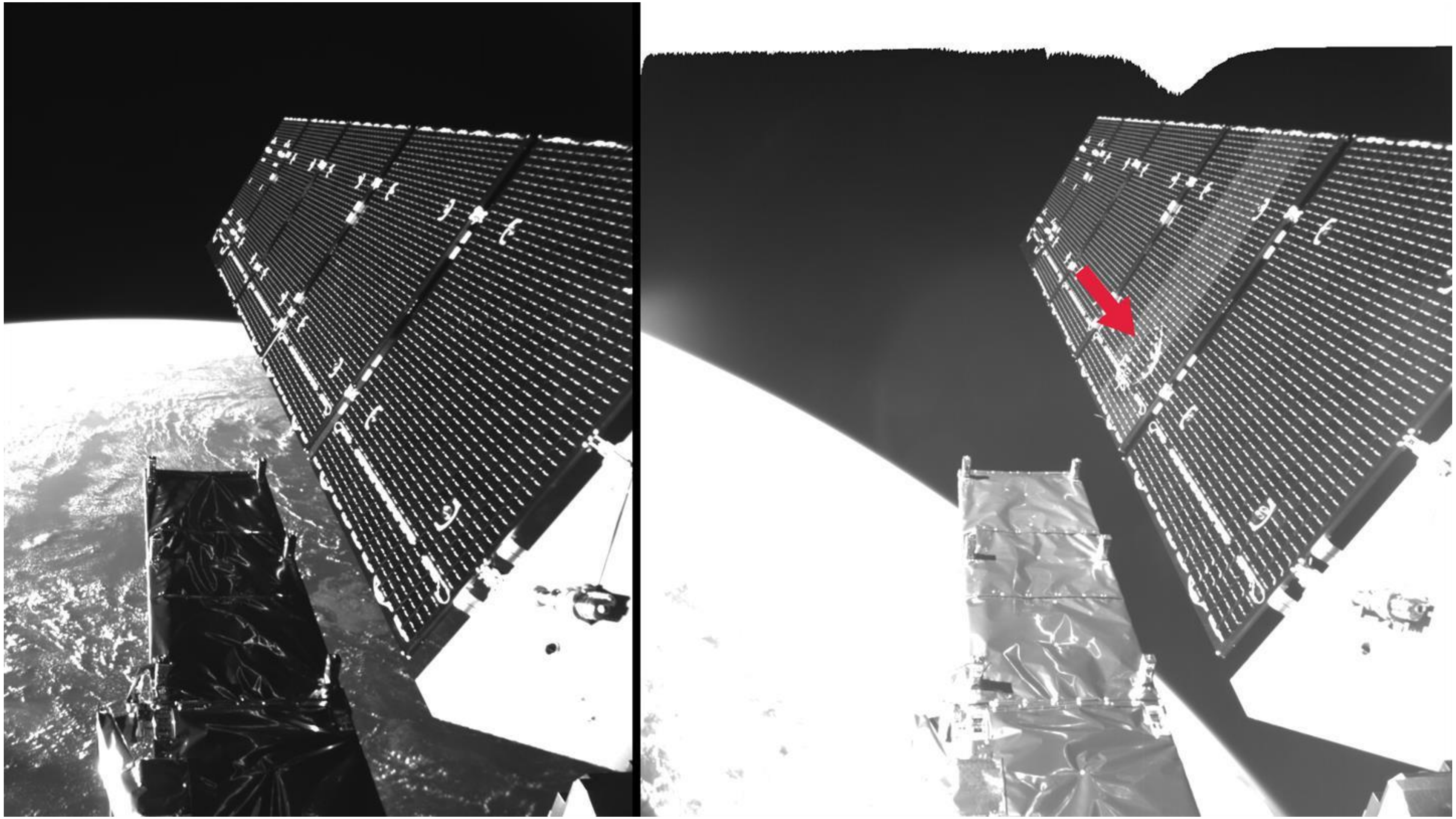
Sentinel 1A event, 23rd of August 2016



Indian ASAT, March 2019

Indian Anti-satellite test performed in 27th of March 2019, ~ 270 fragments reported by US Airforce, candidate Microsat-R satellite.

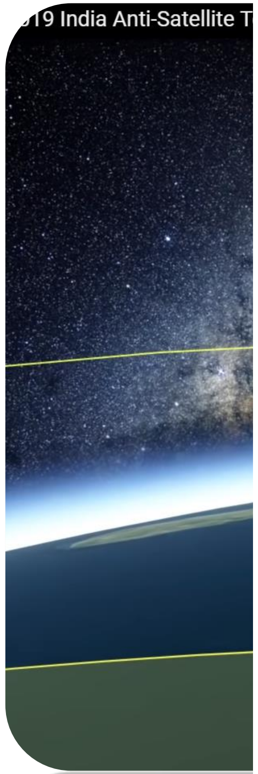
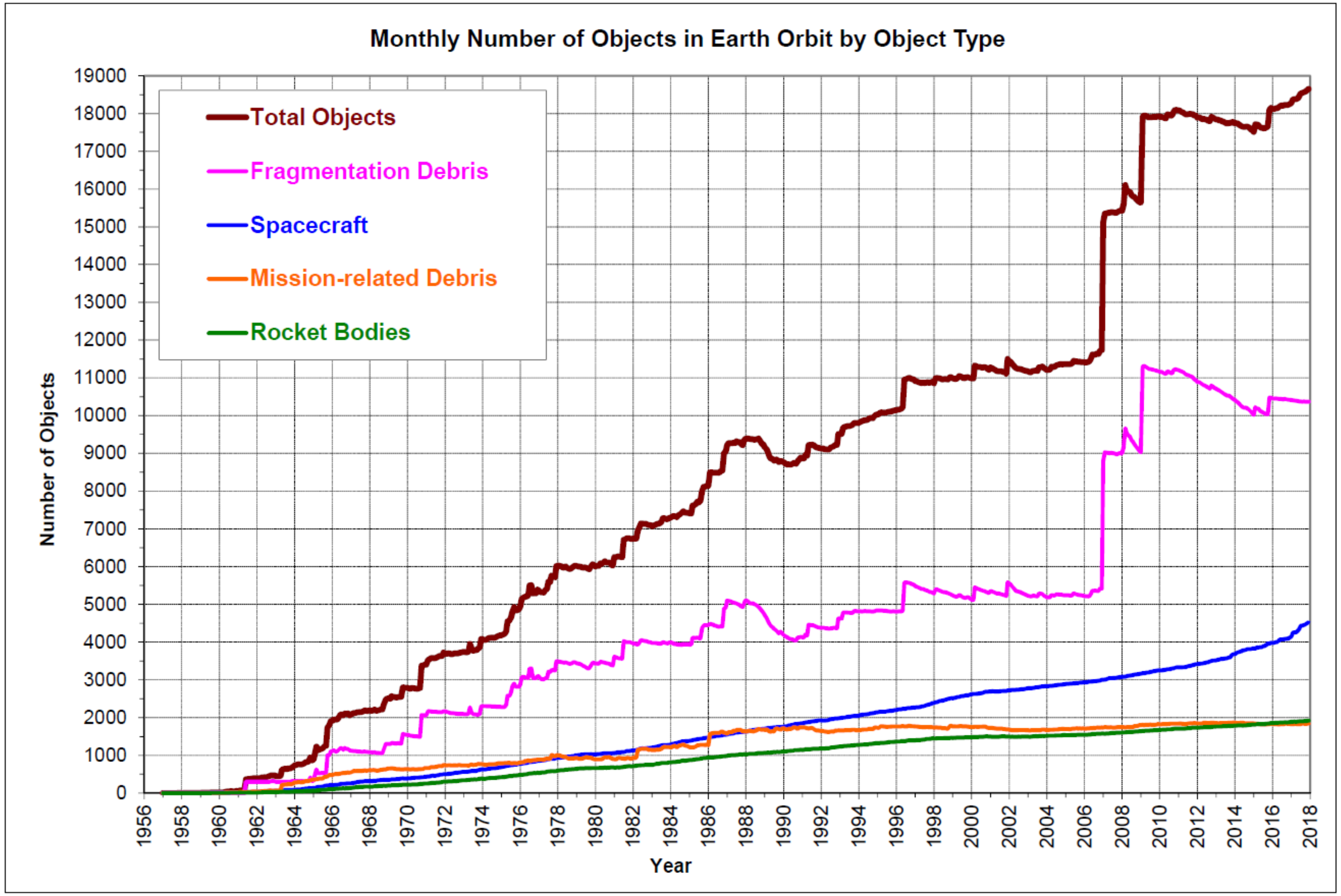


Figure: Indian Anti-satellite test, 2019-03-27
Credit: AGI



Monthly Number of Cataloged Objects in Earth Orbit by Object Type: This chart displays a summary of all objects in Earth orbit officially cataloged by the U.S. Space Surveillance Network. "Fragmentation debris" includes satellite breakup debris and anomalous event debris, while "mission-related debris" includes all objects dispensed, separated, or released as part of the planned mission.

Source: ODQN 22i1

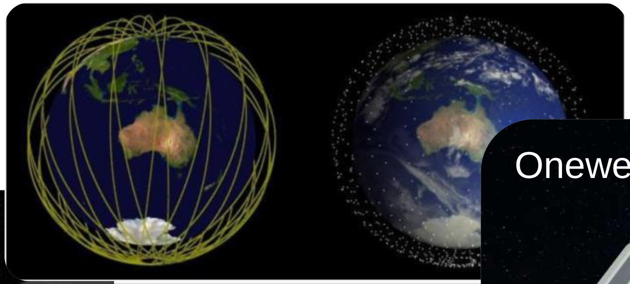
Starlink launch, May 2019

Credit: Lowell Observatory

Credit: SatTrackBlog/Marco Langbroek

Source: NASA Orbital Debris Quarterly News issue 22i1

Starlink launch, May 2019



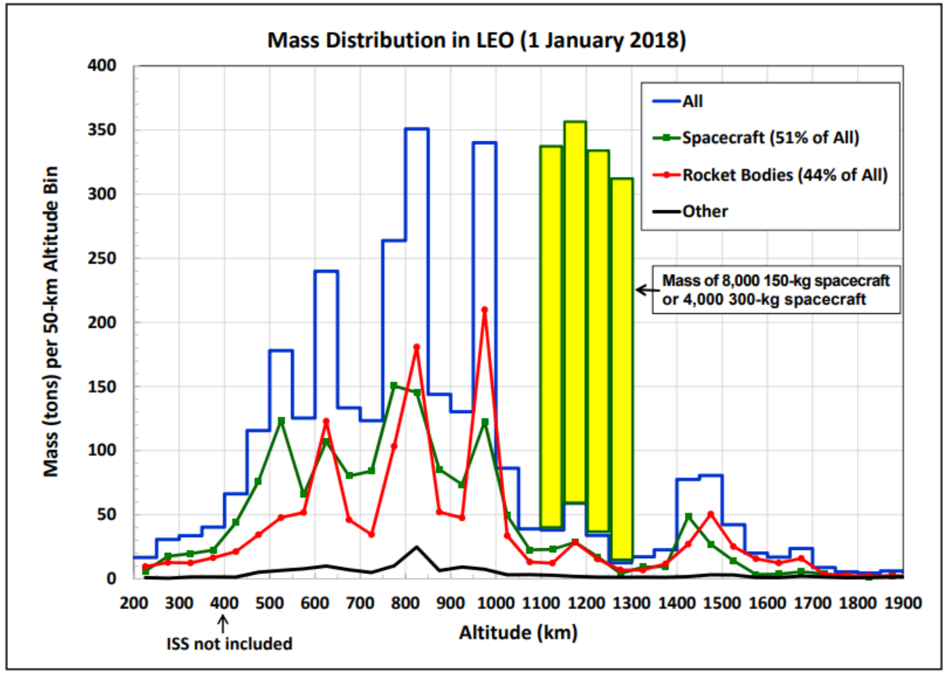


Figure 1. Mass distribution in the current LEO environment. The blue histogram is the total and the population breakdown is shown in red (rocket bodies), green (spacecraft), and black (others). The yellow bars between 1100 km and 1300 km shows the notional mass distribution from 8000 150 kg spacecraft or, equivalently, 4000 300 kg spacecraft.

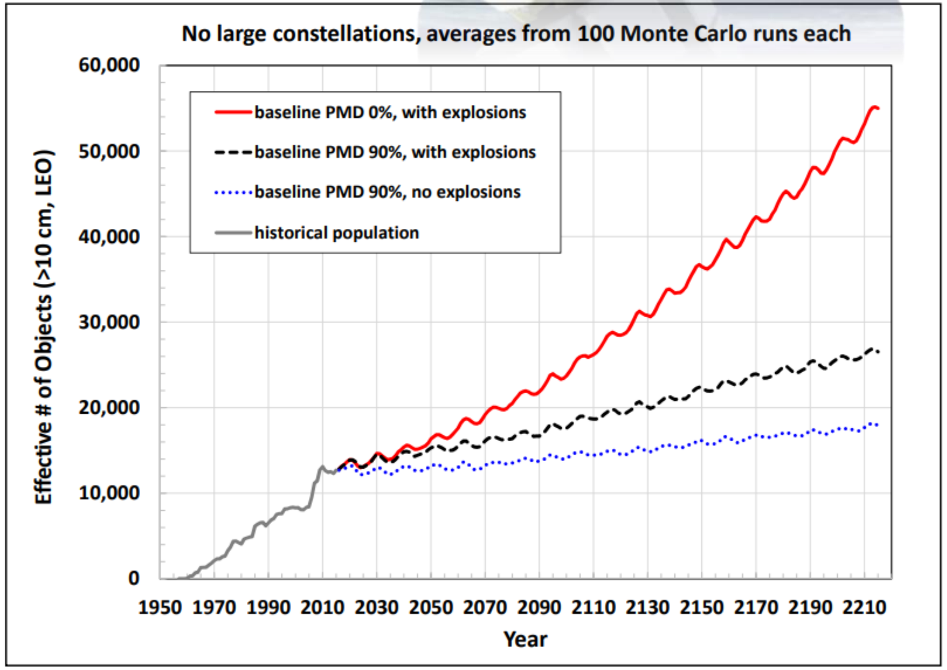


Figure 2. LEGEND-simulated historical LEO environment and results from three different future projection scenarios. Each projection curve is the average of 100 MC runs. The effective number is defined as the fractional time, per orbital period, an object spends between 200 km and 2000 km altitudes.

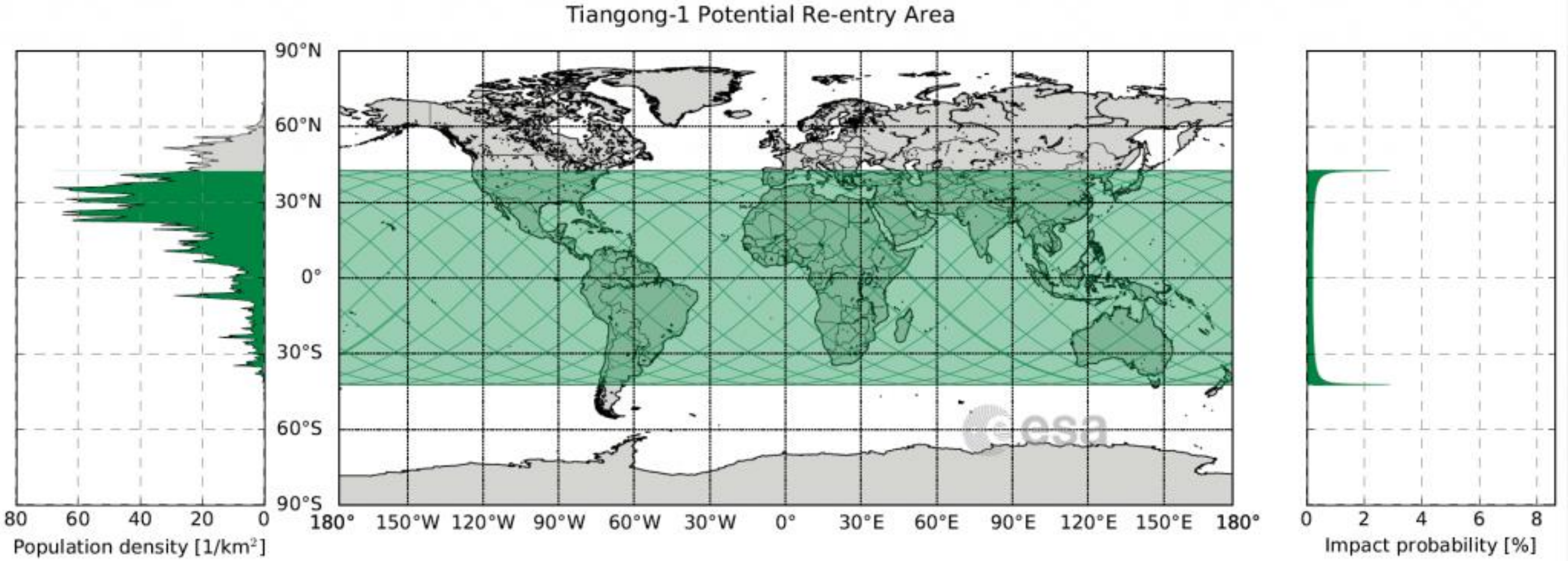
Source: NASA Orbital Debris Quarterly News issue 22i1

Tiangong 1 reentry

- In spring 2018 uncontrolled re-entry of Chinese space station Tiangong 1
- According to space-track.org (ref. date 2018-02-21) reentry expected 2018-04-10, according to ESA the reentry window (ref. date 2018-02-23) is 2018-03-24 – 2018-04-19
- Still large error margin of ± ~2.0 weeks
- Possible period of re-entry **2018-03-24 – 2018-04-19**

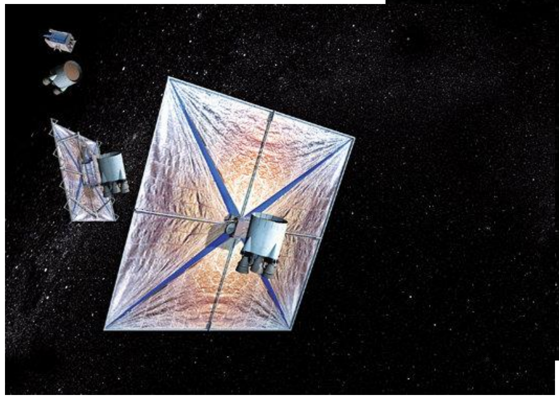
- <u>Reentry 2nd of April 2018</u>

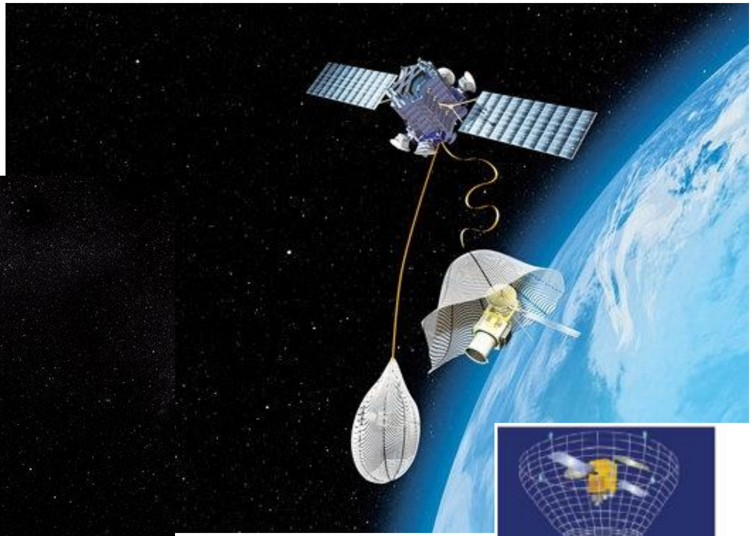
<u>00:15 / 00:16 UTC</u>



Active debris removal

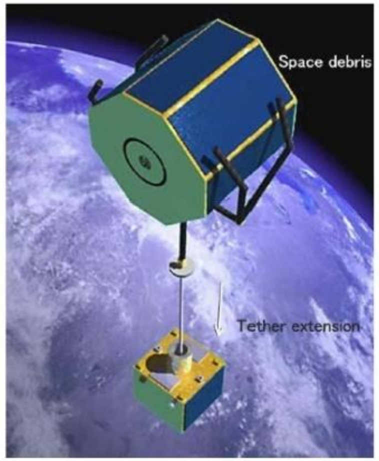
- Active removal of the large compact object by decreasing its mean altitude, decrease lifetime from centuries to 10-20 years
- Most popular concepts:
  - Net
  - Robotic arm
  - Harpoon
  - Solar sail





ROGER net-based capture concept, EADS Astrium.

- Most feasible concept combination with commercialization, e.g., mission service, refueling



Micro Remover tether-extensible gripper with foldable arms, JAXA.

- Currently demonstration on net, harpoon (RemoveDEBRIS)

Space debris, observations

Research & development, main questions

- **Where is it?**
  - Surveys
  - Catalogues
  - Population models
  - Dynamical models
  - ...
- **What is it?**
  - Material composition
  - Origins
  - Reflectance properties
  - Model for acting forces
  - ...
- **How to protect against it?**
  - Collision predictions
  - Shielding
  - Removal
  - ...
- **How it behaves?**
  - Rotation properties
  - Change of rotation
  - Space weathering
  - ...

Observations techniques

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

Figure – AGO70cm telescope.

- ***Optical*** (ground-, space-based)
  - Optical passive – optical telescopes (e.g. AGO 60cm and 70cm telescopes)
  - Satellite Laser Ranging (SLR) (optical active) – debris SLR systems

Figure – ZIMLAT SLR.

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

Figure – TIRA radar.

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

Figure – LDEF experiment.

United States Strategic Command

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

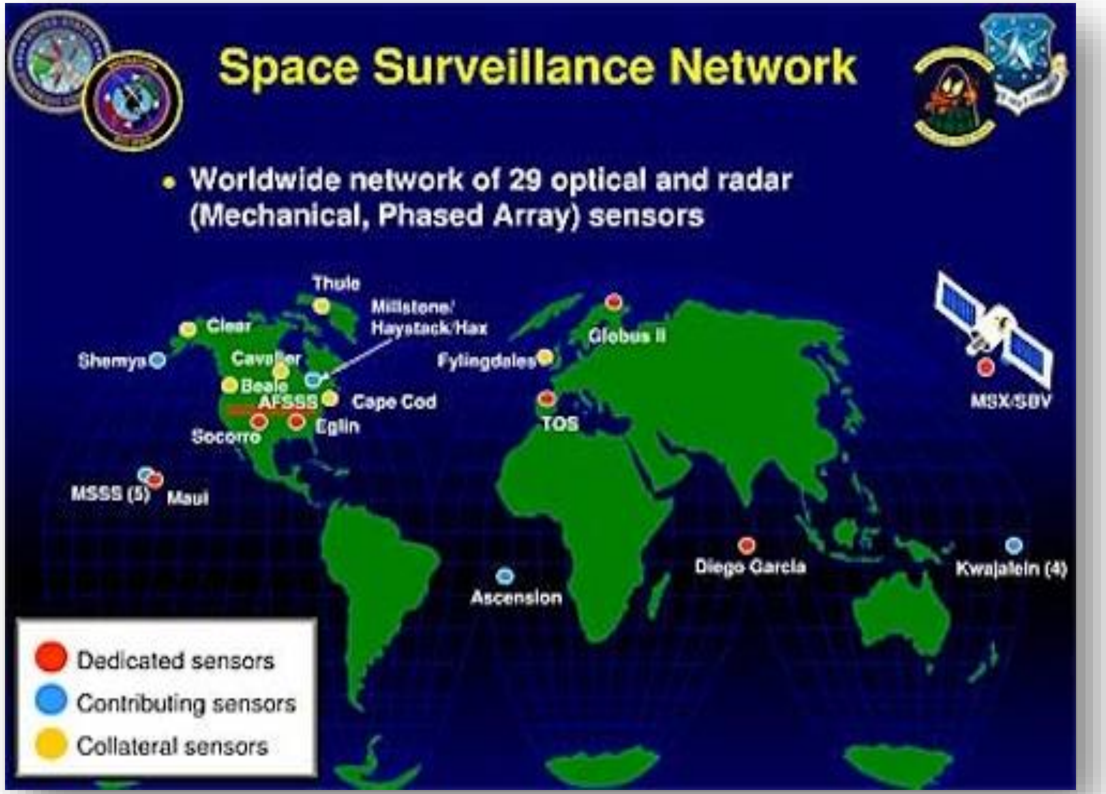


Figure – US space surveillance network (Jakhu et al., 2017).

ISON network

- The former 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

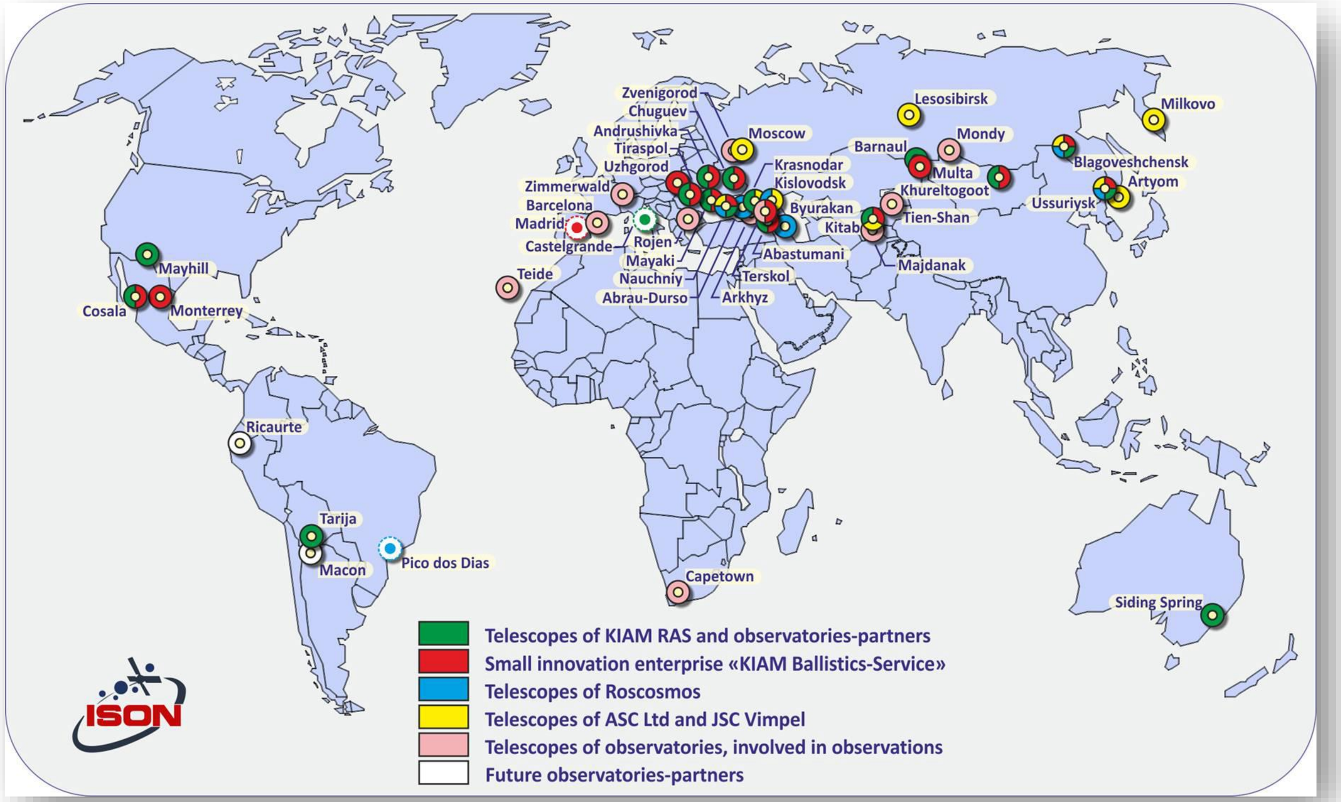


Figure – ISON surveillance network (Mokhnatkin et al., 2017).

Optical (passive) observations

- Space debris not emitting own radiation (!)
- Interested only in the sun (visible) light reflected from the object

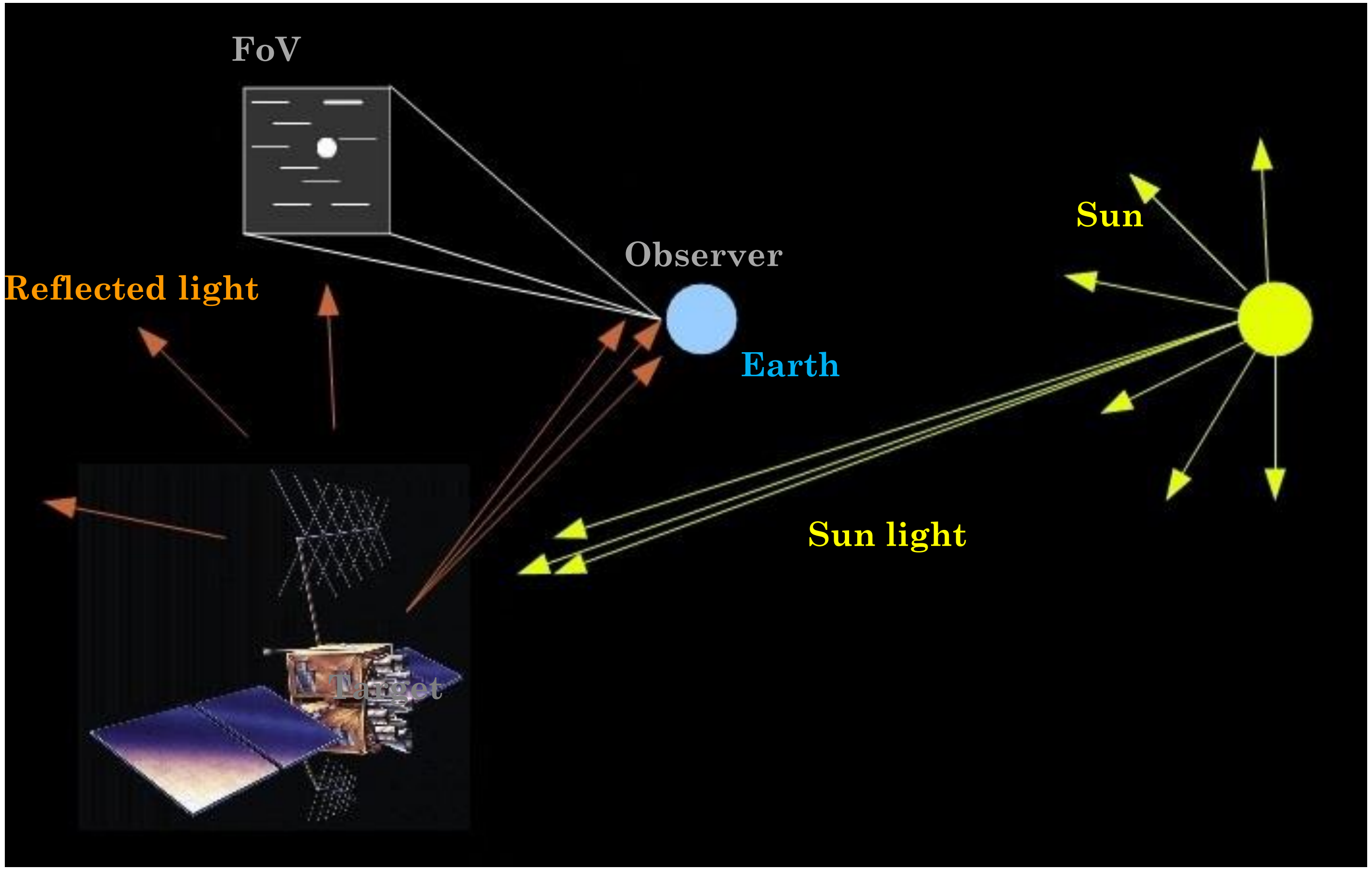


Figure – Schematic demonstrating sun light reflected from the object (satellite) toward observer.

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
- **Spectrocsopy** – to get the spectrum of an object during reentry ➔ fragmentation modeling

Space debris on FMPI and AGO

- **AGO** – FMPI CU Astronomical and geophysical observatory in Modra, Slovakia

Figure – AGO Modra main dome.

Figure – AGO Modra small upper dome.

FMPI/AGO's 70cm telescope

- Main objective:

Perform tracking to space debris in order to support European space debris cataloguing, physical characteristics of debris

- Former ***ESA PECS HAMROptSen*** dedicated to the main objective, cooperation CU (SK, prime) + AIUB (CH)

- Currently ***ESA PECS ImpEuroLEOTrack***, cooperation CU (SK, prime) + AIUB (CH) + IWF (AUT)

- Activities cover all aspects – low-level control, planning S/W improvement, observation planning, data acquisition, data processing, image processing SW improvement, tracklet building, object identification, orbit improvement, cataloguing, data format conversion, 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.

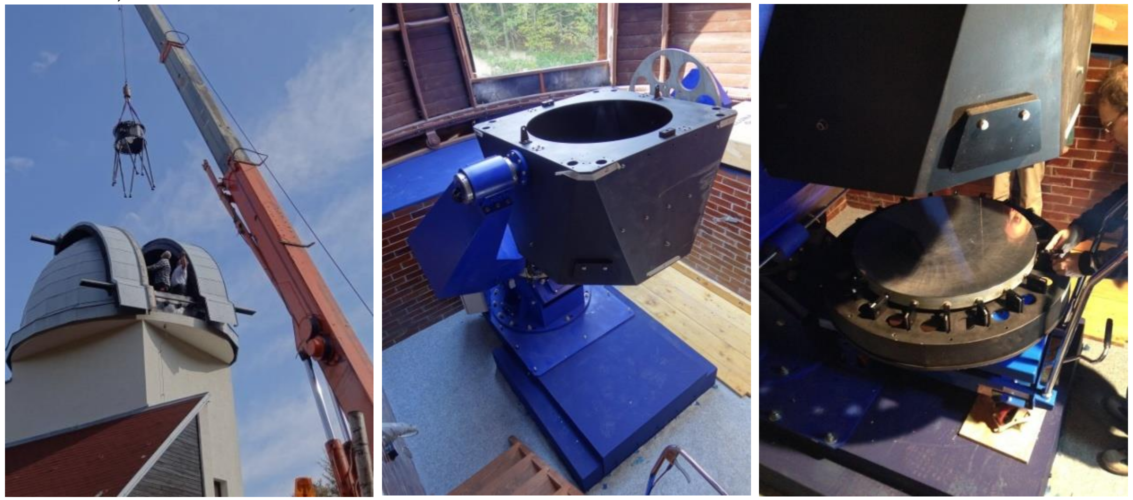


Figure – AGO 70cm telescope installation (left), mount (middle) and 70 cm primary mirror (right).

ESA PECS ImpEuroLEOTrack

AIUB

ÖAW AUSTRIAN ACADEMY OF SCIENCES

Figure – Geographical distribution of sensors to be used during the activity for LEO tracking, namely FMPI's AGO 70cm telescope (Slovakia), AIUB's ZIMLAT telescope and SLR sensor (Switzerland) and IWF's Graz SLR station (Austria). Character (*) indicates optical passive sensor (telescope) and character (') indicates optical active (SLR) sensor.

ESA Plan for European Cooperating States (PECS)

- ***European Space Agency Plan for European Cooperating States - main objective to prepare Slovakia to be become competitive within ESA once full member.***

- Since the beginning of ESA PECS for Slovakia in 2015, 4 ESA PECS calls have already taken place.

- The ministry responsible for the PECS activities is the Slovak Ministry of Education, Science, Research and Sport.

- In Spring 2018 a 3rd call was closed and winners were announced in summer 2018. Fourth call closed in Feb 2019, winners still to be announced.

- Evaluation of results, outputs in the early 2020s, to decide whether SR to join ESA or not.

FMPI/AGO instruments, AMOS cameras

- **AMOS** (All-sky Meteor Orbit System) of Comenius University in Bratislava

- Originally developed optical system for intensified video night sky observation focused on meteors

- Network of 8 AMOS cameras in Slovakia (4), Canary Islands (2), Chile (2), plan to expend the network to USA (HI), Australia and Namibia

- AMOS at AGO, Tenerifa and Chile accompanied by AMOS-Spec cameras

- Currently several different national funding available for improvements

- Properties:
  - Automatic detection S/W
  - Own astrometric reduction S/W, astrometric accuracy around 4'-10’, expected after improvement 1.8’ (→ 0.5km for 1000 km range)
  - Limiting magnitude comparable to the naked eye, ~ 5 mag

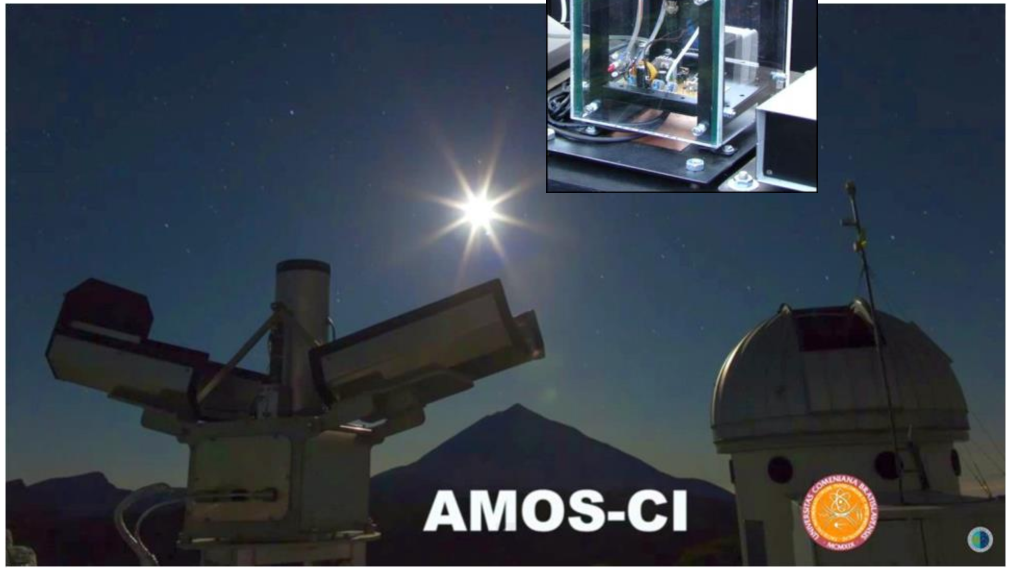
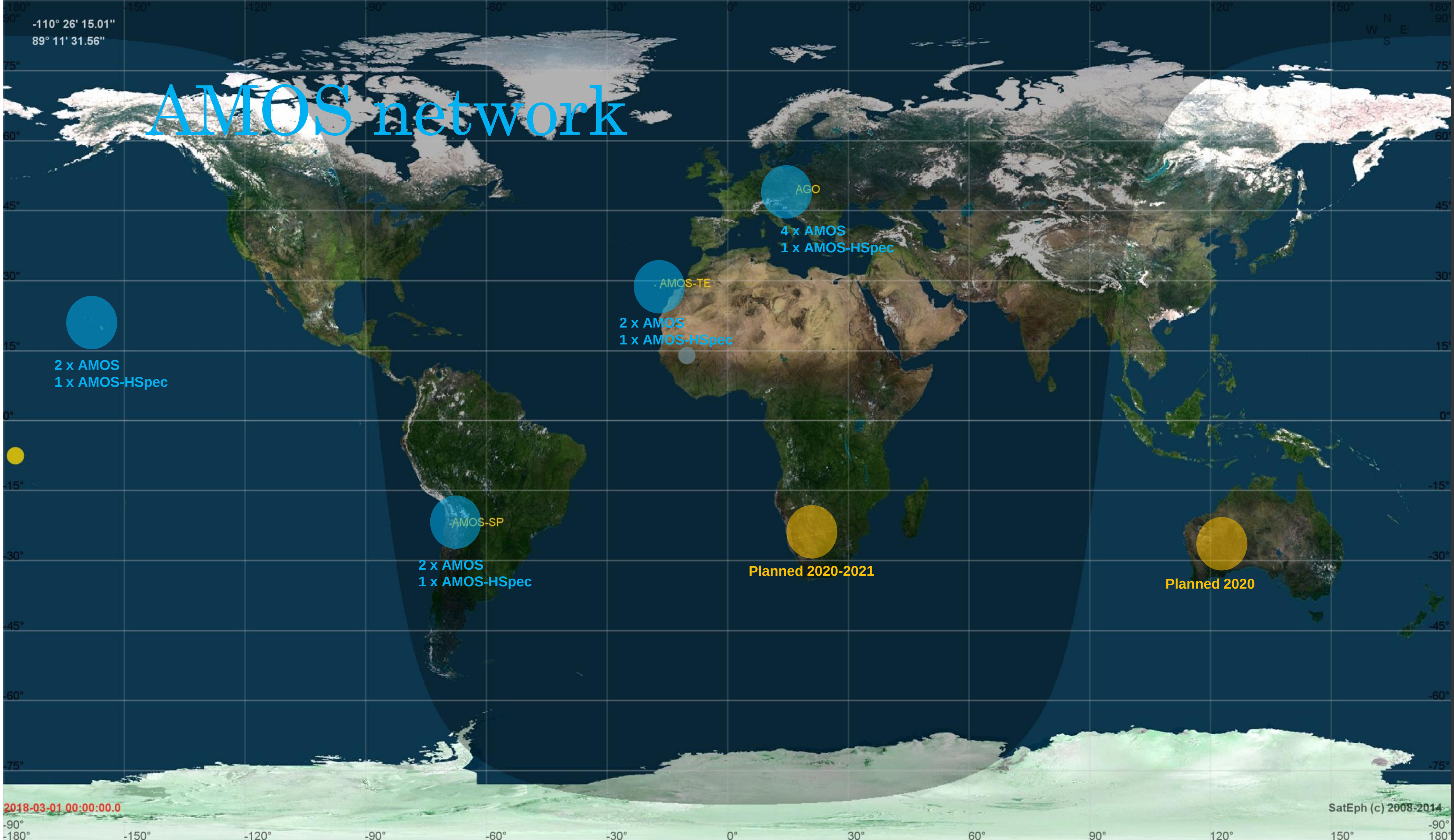
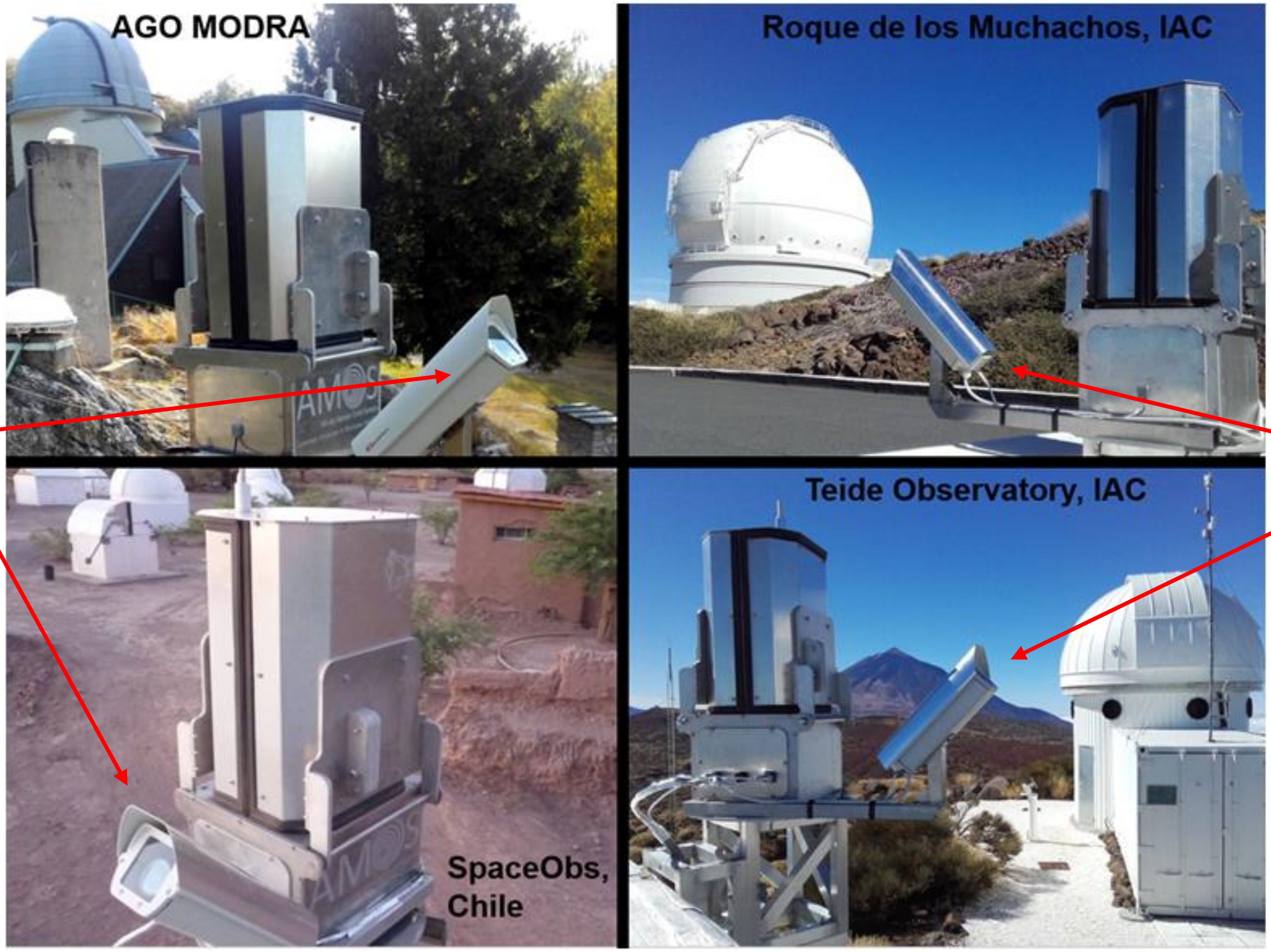


Figure – AMOS in Chile.

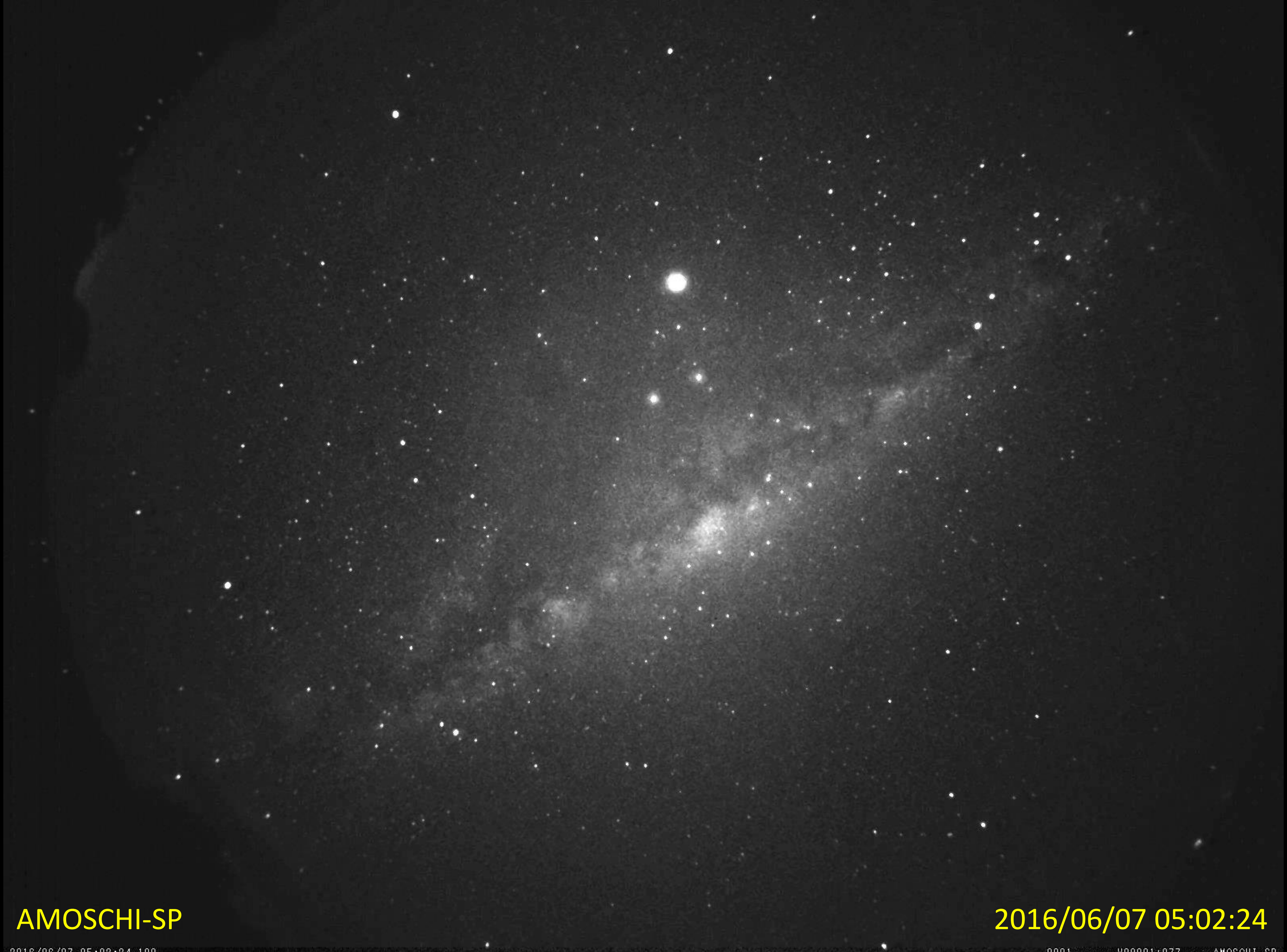

AMOS network
-110° 26' 15.01"
89° 11' 31.56"
AGO
4 x AMOS
1 x AMOS-HSpec
AMOS-TE
2 x AMOS
1 x AMOS-HSpec
2 x AMOS
1 x AMOS-HSpec
AMOS-SP
2 x AMOS
1 x AMOS-HSpec
Planned 2020-2021
Planned 2020
2018-03-01 00:00:00.0
SatEph (c) 2008-2014

FMPI/AGO instruments, AMOS cameras



Amos-Spec

Amos-Spec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Observations planning

Observation planning

- In space debris community used so-called Two-Lines Elements format for geocentric orbital elements
- TLE fully compatible with the Simplified General Perturbation (SGP) model developed by US Department of Defense in 1980s
- Originally Fortran code, now available from Vallado (2013) in JAVA, Python, C++, etc.
- FMPI has two major sources of TLEs:
  - US www.space-track.org
  - ESA/AIUB's internal catalogue
  - Alternatively Russian ISON network or US NASA

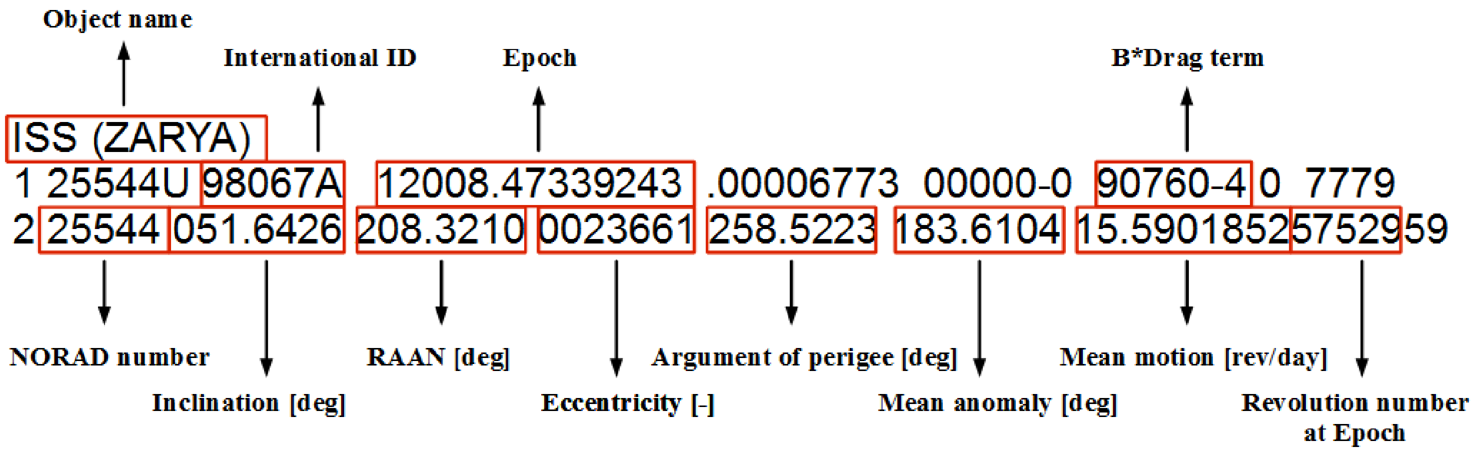


Figure – Example of TLE format for the International Space Station. Reference epoch 12008.47339243, which corresponds to date/time 2012-01-08 11:21:41.11 and MJD = 55934.47339243 days.

Observation planning

- Currently for space debris observations at AGO is used FMPI's JAVA S/W tool SatEph (Satellite Ephemeris)
- SatEph reads TLE and uses SGP to calculate the ephemeris of selected objects for given observer and observation time
- Graphic User Interface (GUI) available
- Program provides several different functionalities and outputs:
  - Topocentric coordinates of the objects, horizontal and equatorial
  - Visualization of the field
  - Output files such as ephemerides file and field emulation image

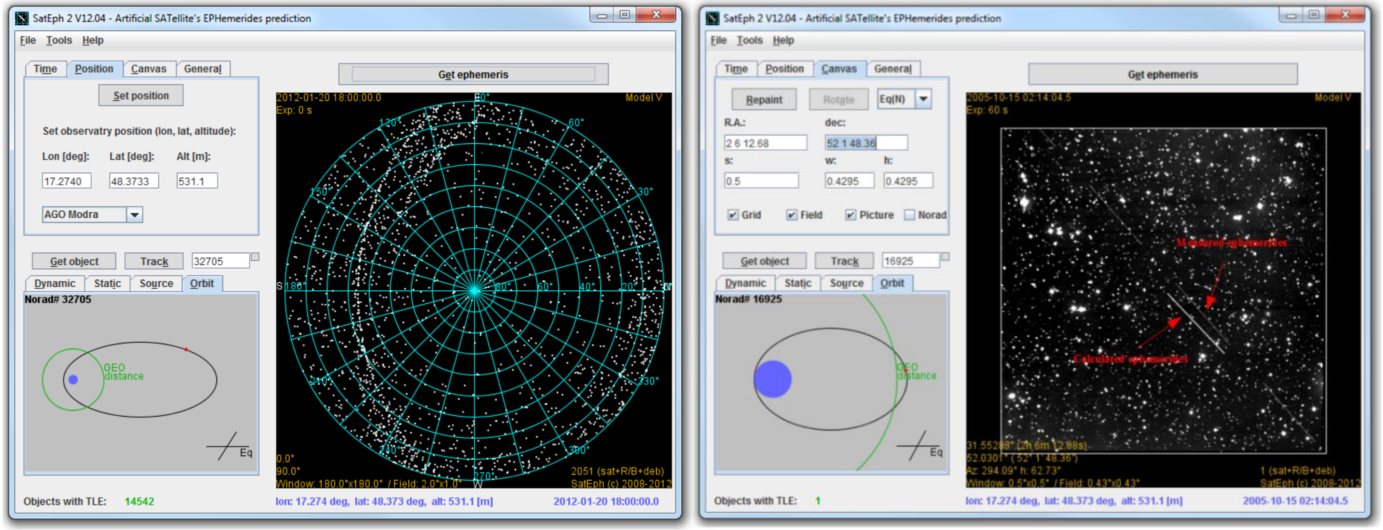


Figure – Example of SatEph's GUI main window. On left are plotted 2051 objects assuming and FOV=180deg in horizontal coordinates. On the right is plotted one object assuming FOV=0.5deg in equatorial coordinates.

Object identification

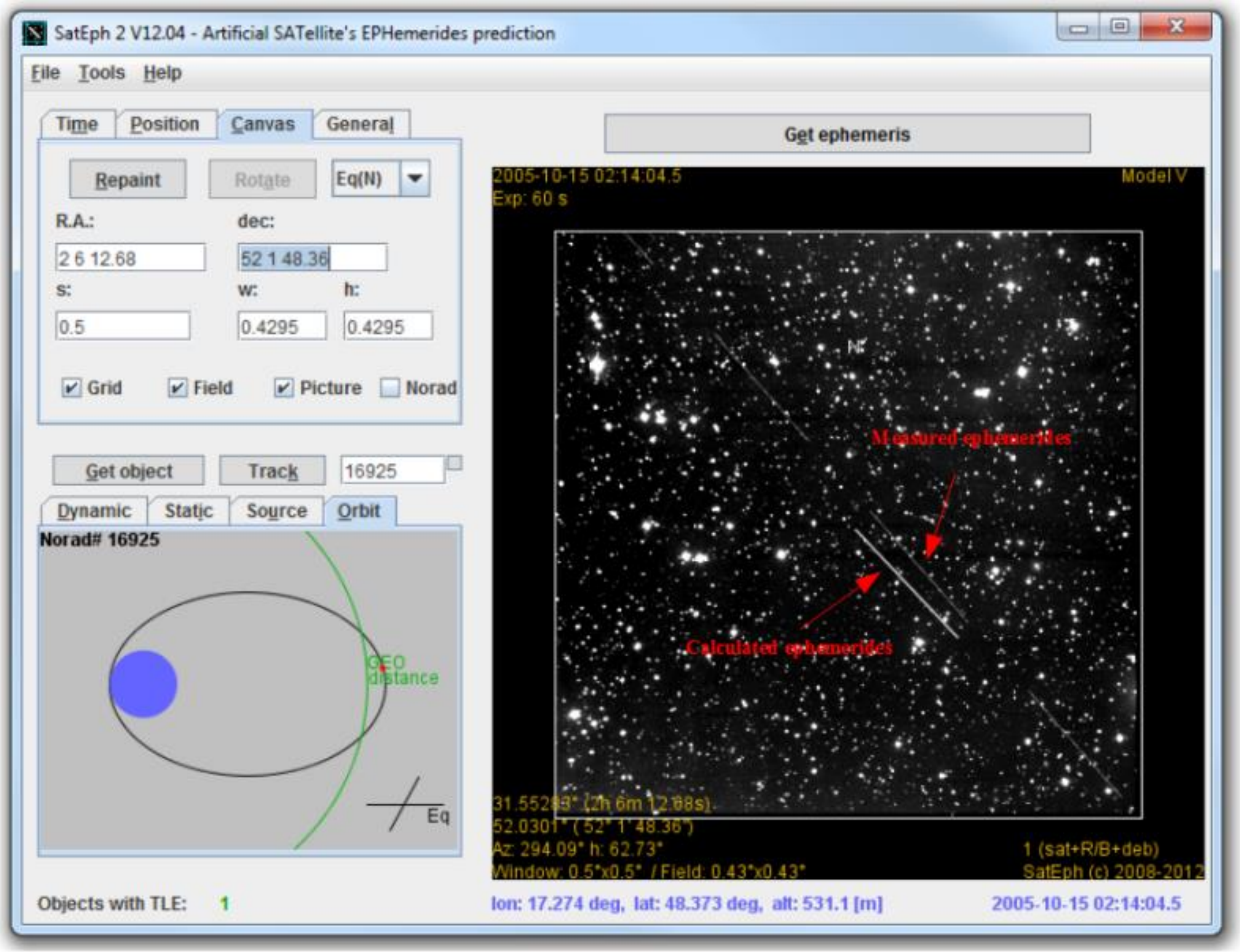
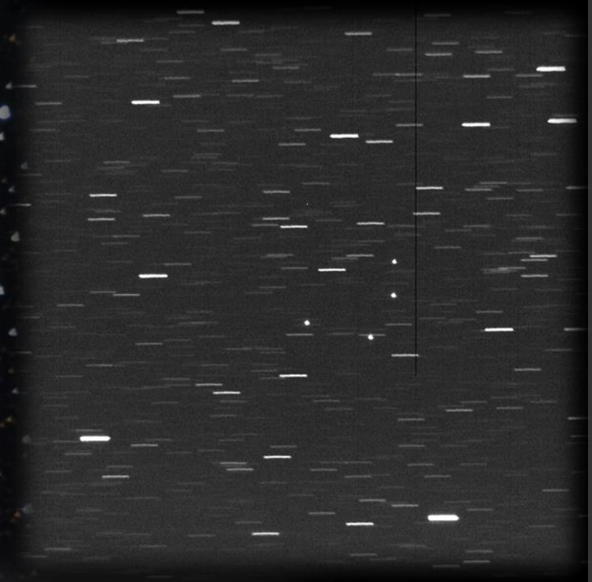
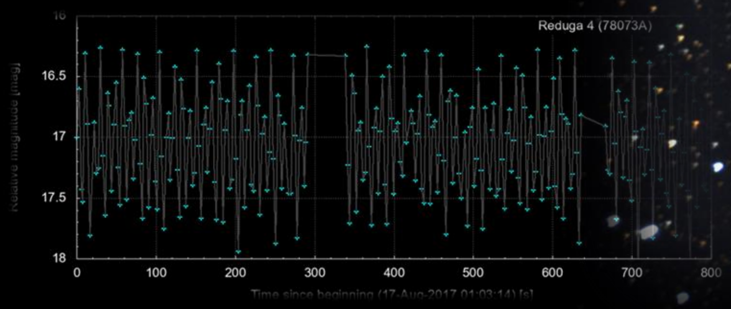


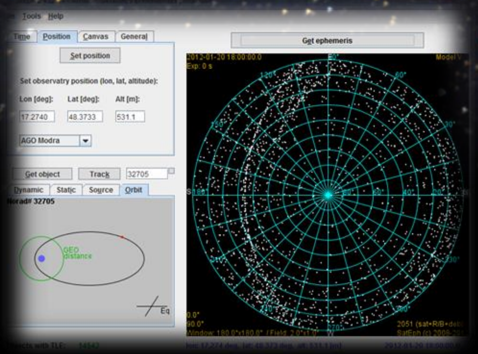
Figure – Visual real time object identification by using SatEph program.

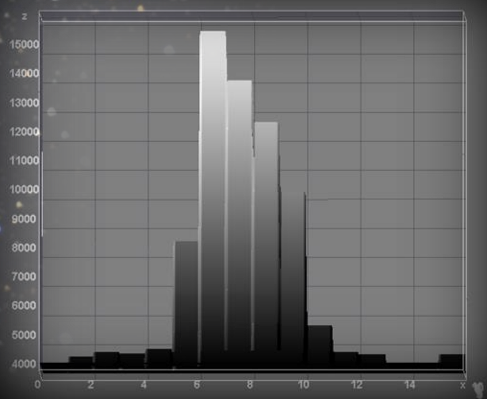
Thank you for your attention.

Break?









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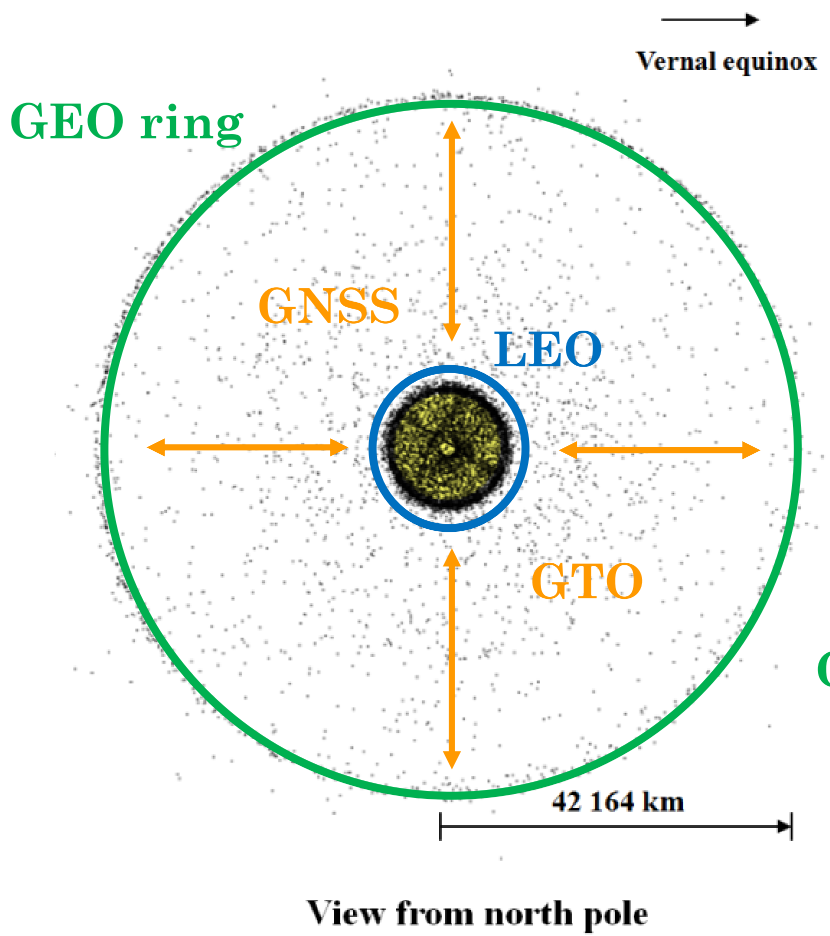
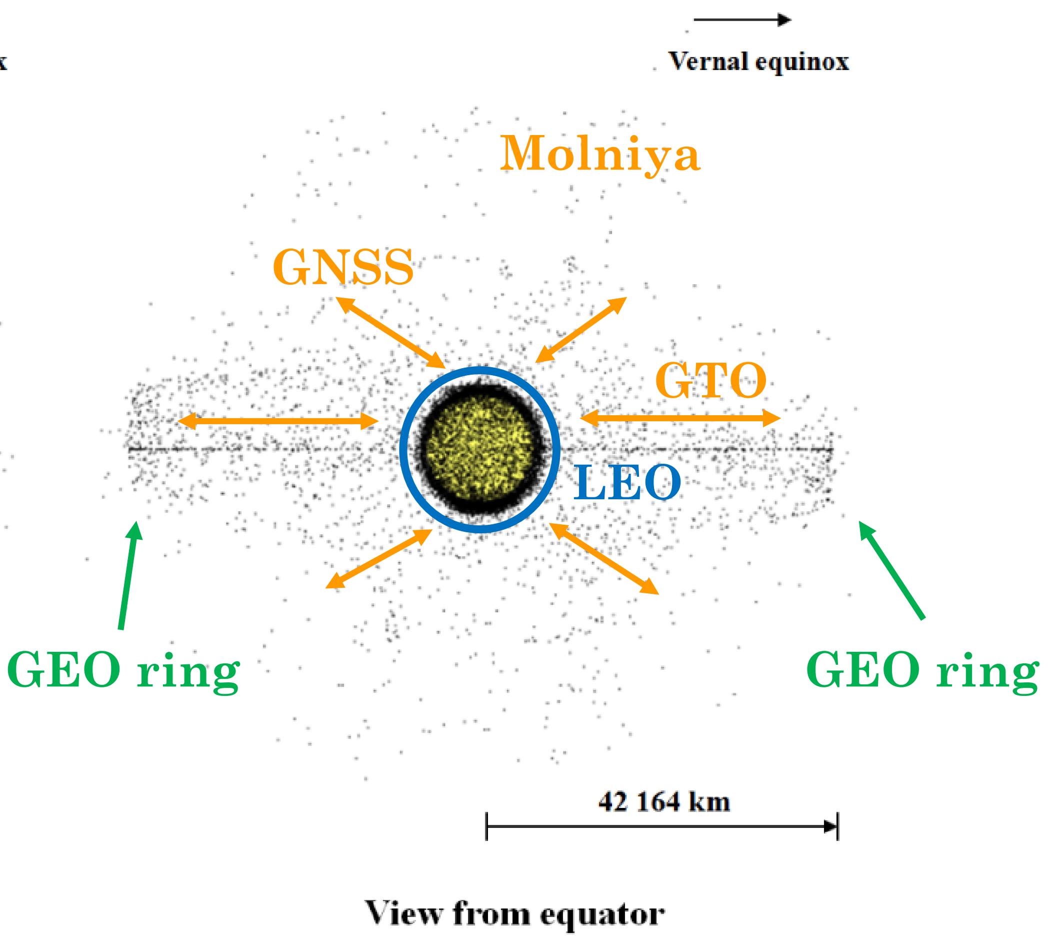
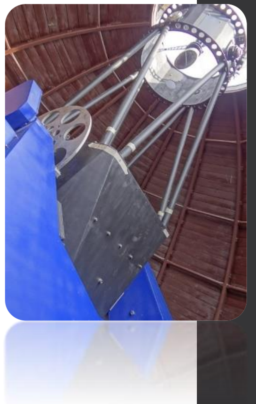
Survey and astrometry

Optical observations with AGO70

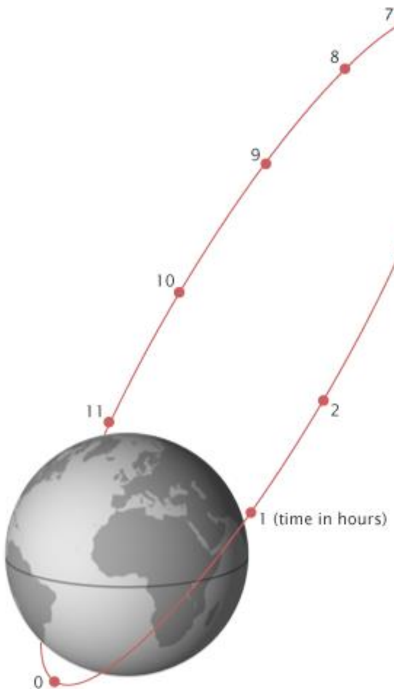




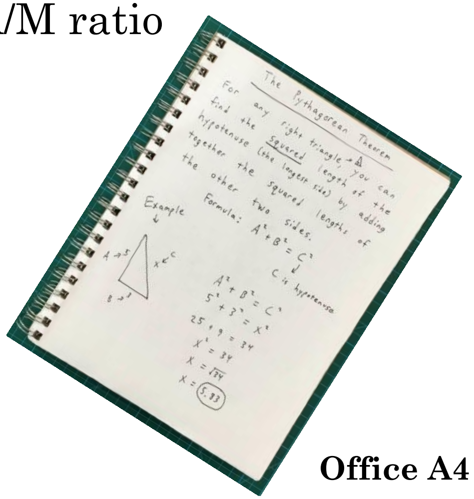


Optical observations, astrometry

- To measure relative position of the object from the observer perspective on the celestial sphere
- Aim is to determine and improve orbit, maintain catalogues, orbit prediction
- Except dynamical parameters (a,e.i, RAAN, AoP, M(t)), also physical parameter A/M ratio



Astra satellite AMR ~ 0.02 m^2/kg



Office A4 sheet of paper AMR ~ 12 m^2/kg

Optical observations, astrometry

Taken from Schildknecht et al. (2008)

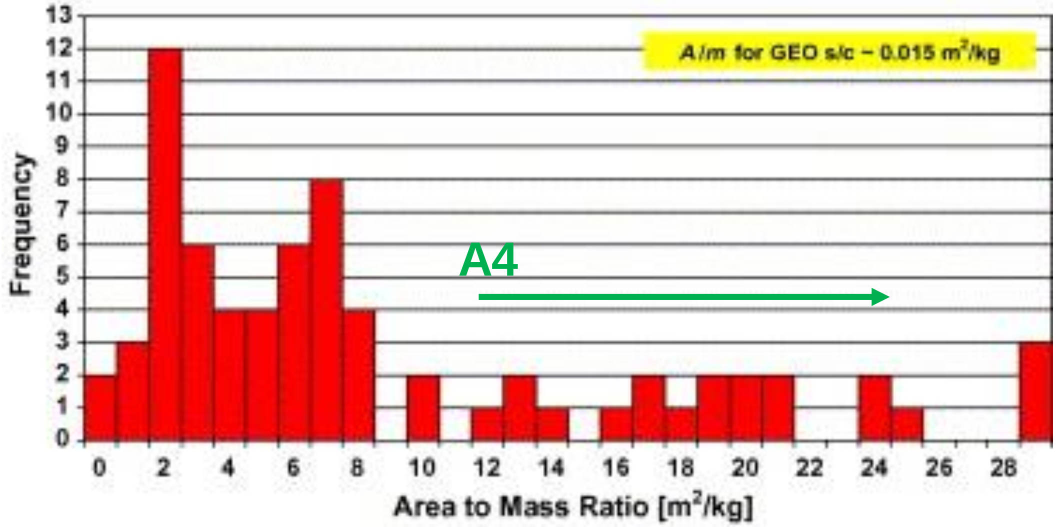


Figure – A/M values as determined for the objects discovered during OGS GEO/GTO surveys.

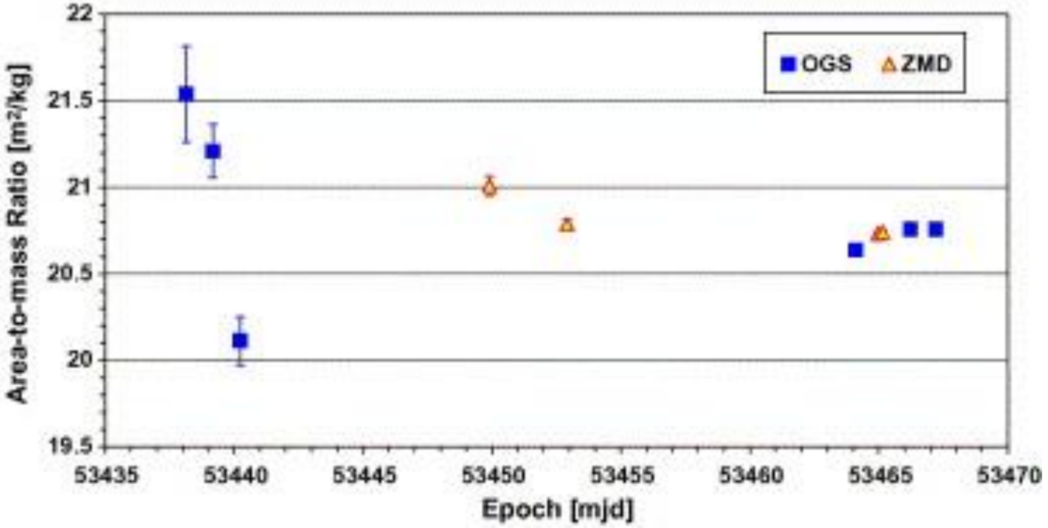
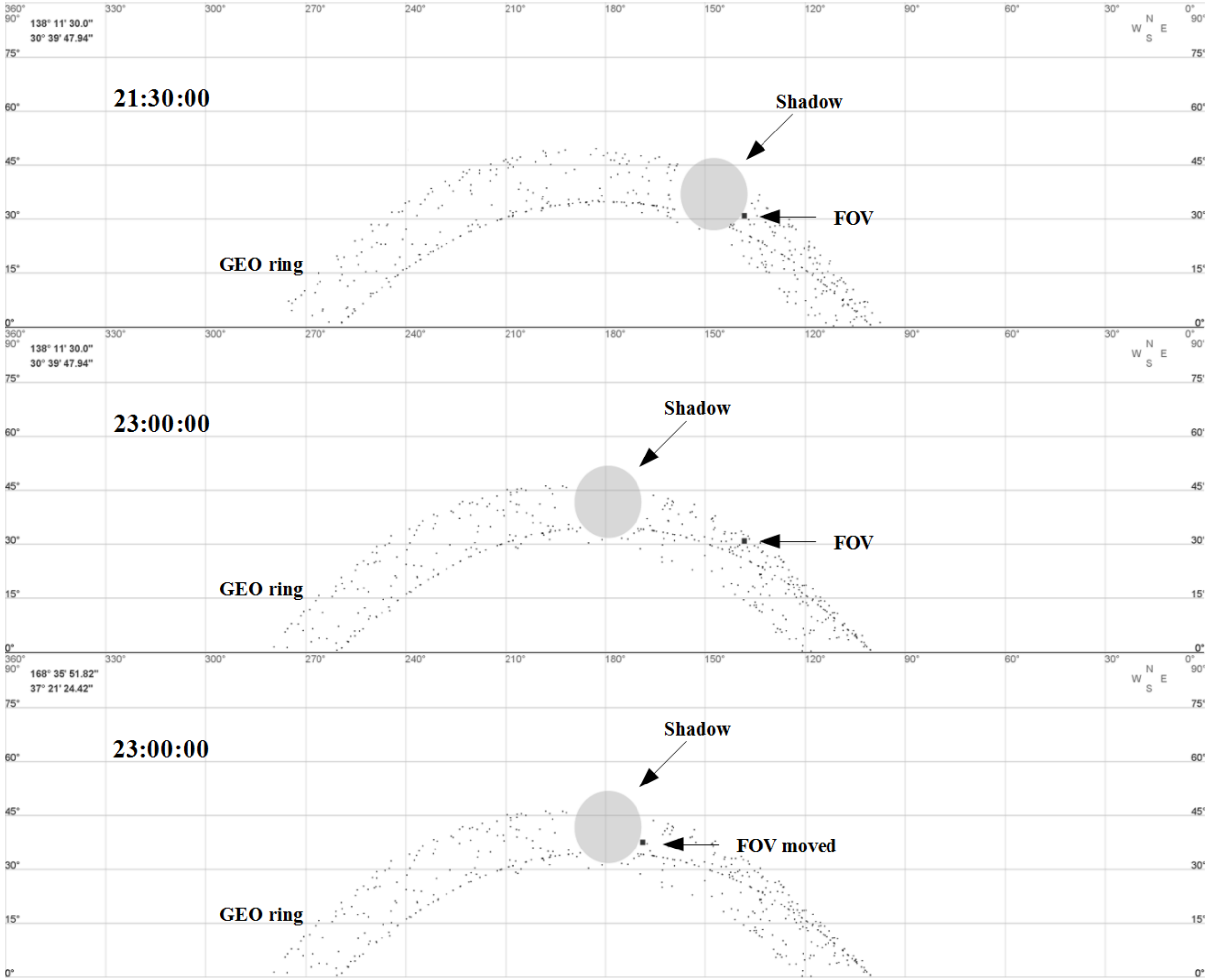


Figure – AMR value calculated for a one specific discovered GEO/GTO object.

Optical observations, survey



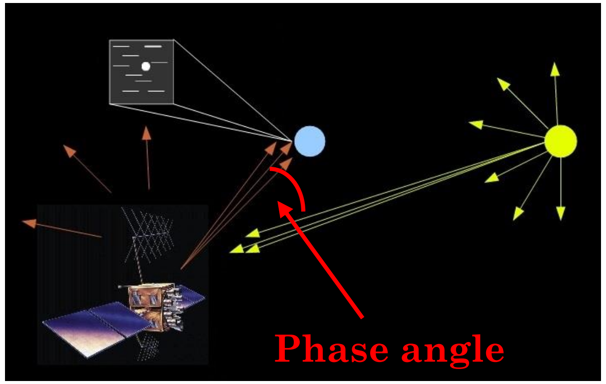


Figure – Demonstration of GEO survey strategy plotted in horizontal coordinates. At first, the field of view (FOV) (black square) is put right behind the Earth's shadow (gray circle) (upper figure). After 1.5 hours of scanning the shadow moved but the FOV didn't (middle figure). Then the telescope's FOV is moved by the observer behind the Earth's shadow to get the maximum phase angle and the scanning starts again (lower figure). Small black dots representing objects on GEO orbit.

AGO70 – astrometry

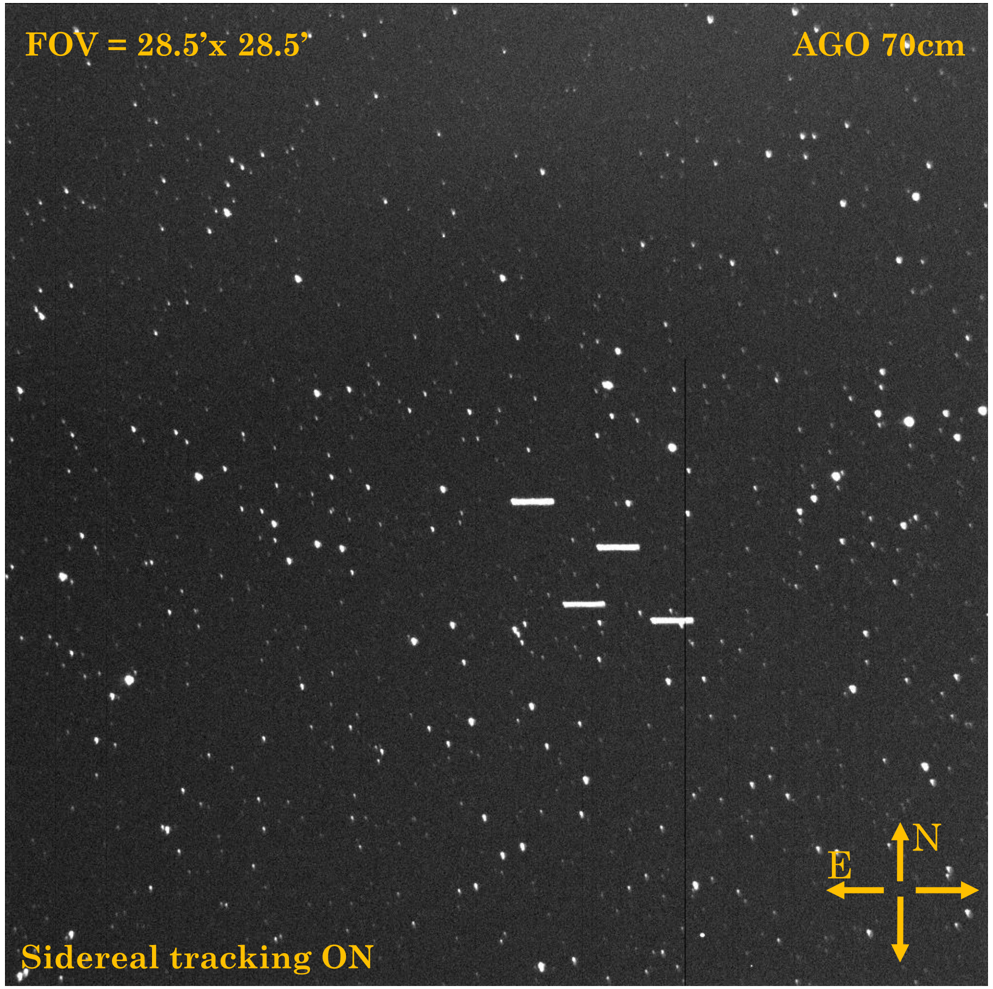
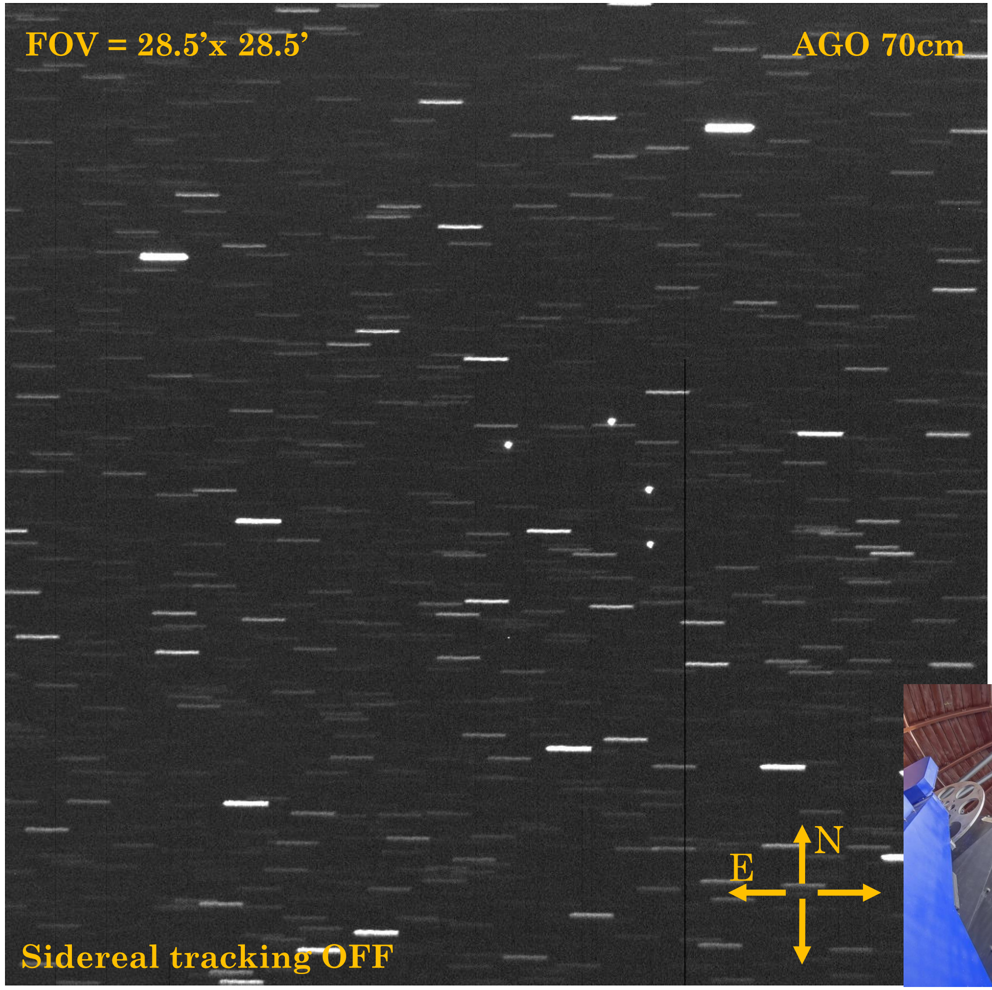


Figure – Astra satellites are tracked. During exposure, the sidereal tracking was ON so the satellites on GEO are displayed as streaks and stars as points. Image acquired by AGO 70-cm telescope. The 5s exposure time was used in both cases.



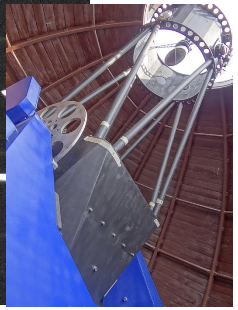


Figure – Astra satellites are tracked. During exposure, the sidereal tracking was OFF (for GEO equivalent to GEO tracking) so the objects appears as point and stars appear as streaks. Image acquired by AGO 70-cm telescope. The 5s exposure time was used in both cases.

AGO70 – astrometry

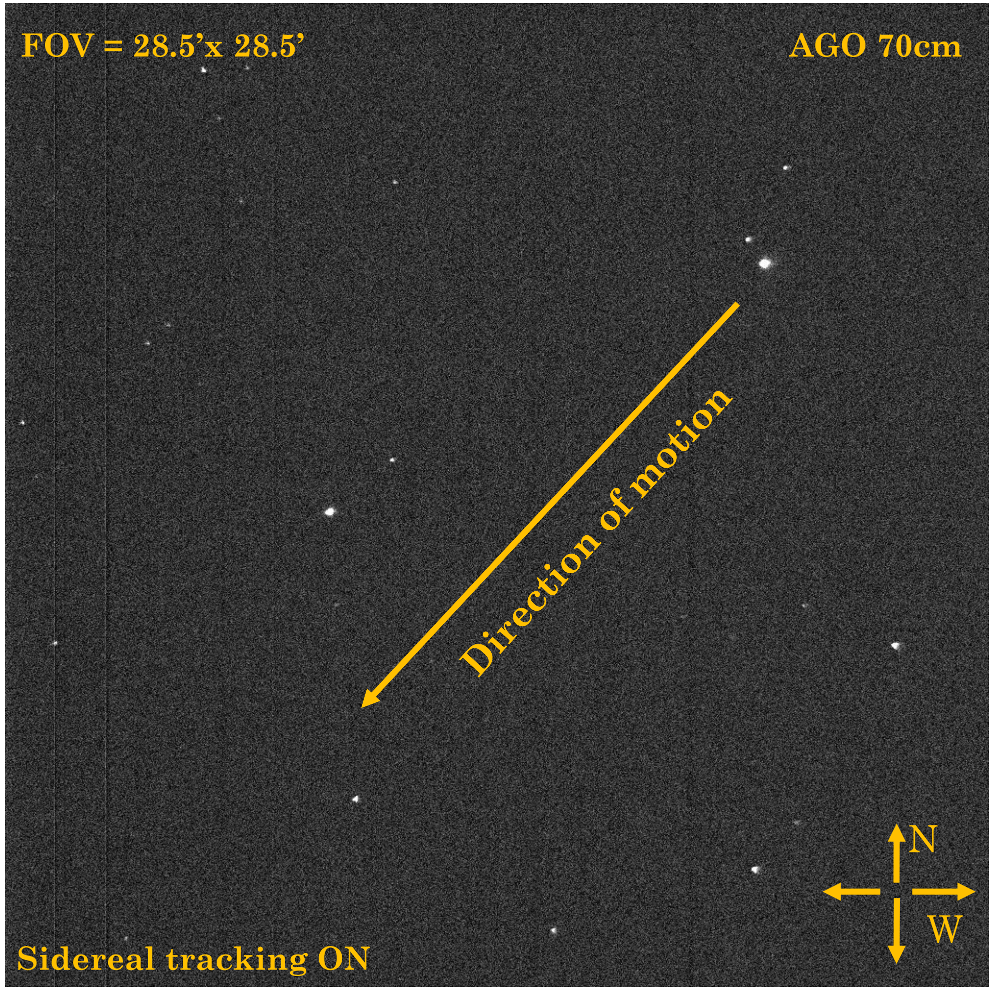


Figure – GPS satellite 15033A tracked during sequence of 8 images. Images acquired by AGO 70-cm telescope with 0.1s exposure and R filter.

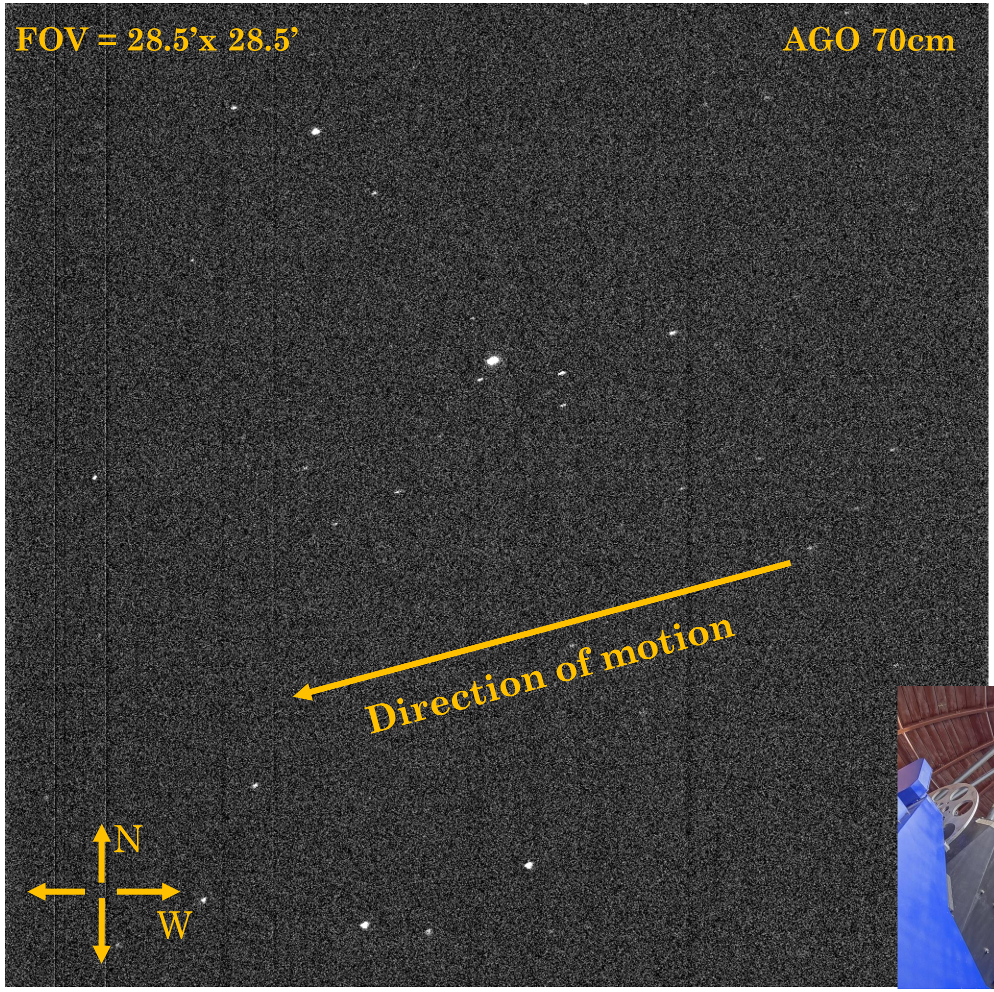


Figure – HAMR GEO object E09233A tracked during sequence of 8 images. Images acquired by AGO 70-cm telescope with 0.2s exposure and R filter.

AGO70 - astrometry, time precision

- 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)

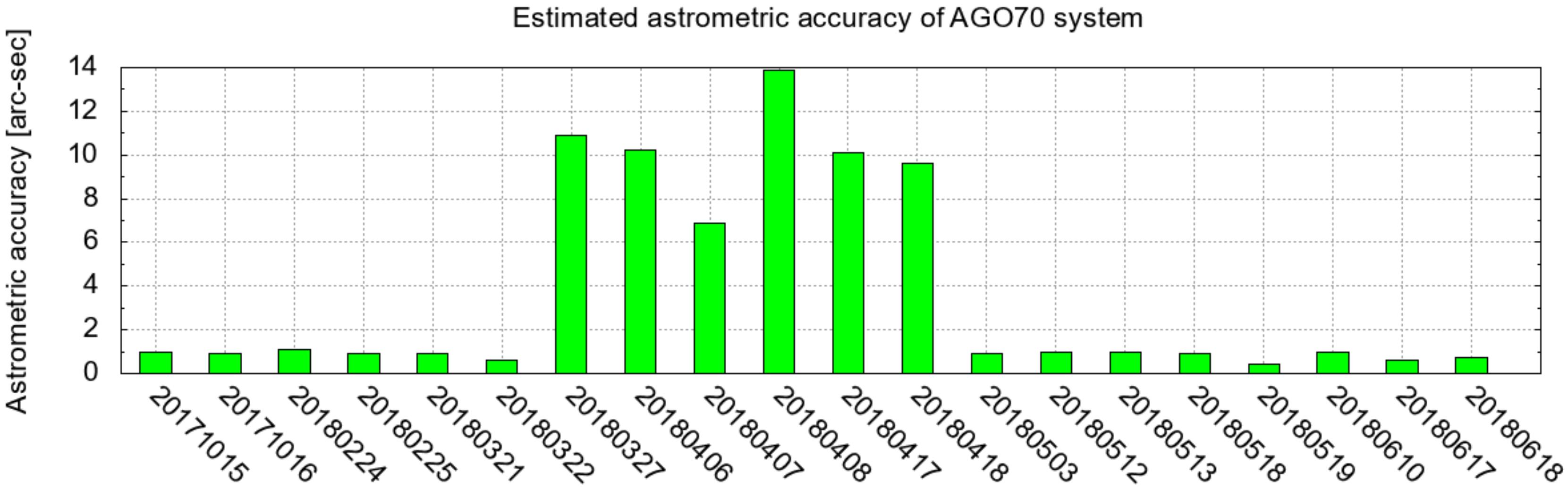


Figure – Estimated astrometric accuracy of AGO70 system. Data obtained from AGO70's GNSS measurements processed by AIUB. (Silha et al., 2018)

AGO70 - astrometry, time precision

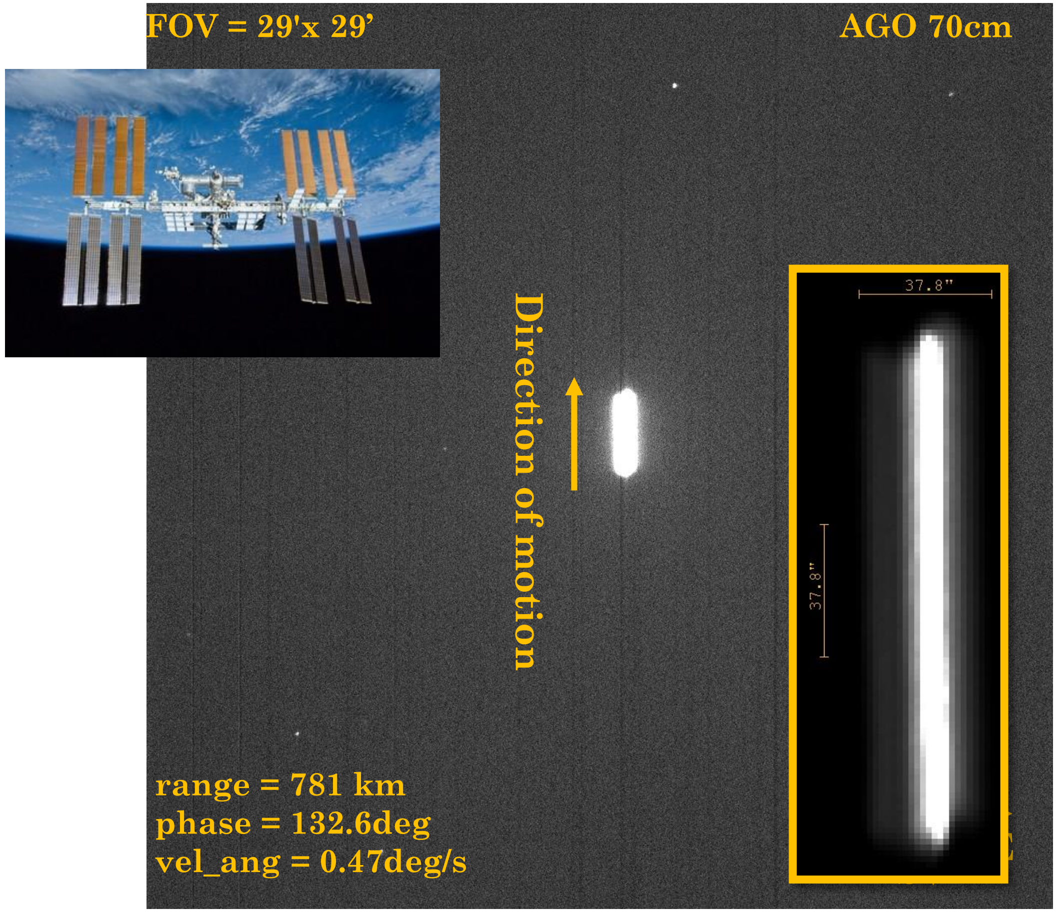


Figure – International Space Station ISS (98067A) acquired by the AGO 70cm telescope. Field RA=07:42:50 and DEC=+46:17:47.6 observed at 2018-05-28T20:40:30.0 with V filter, exp = 0.05s and sidereal tracking ON.

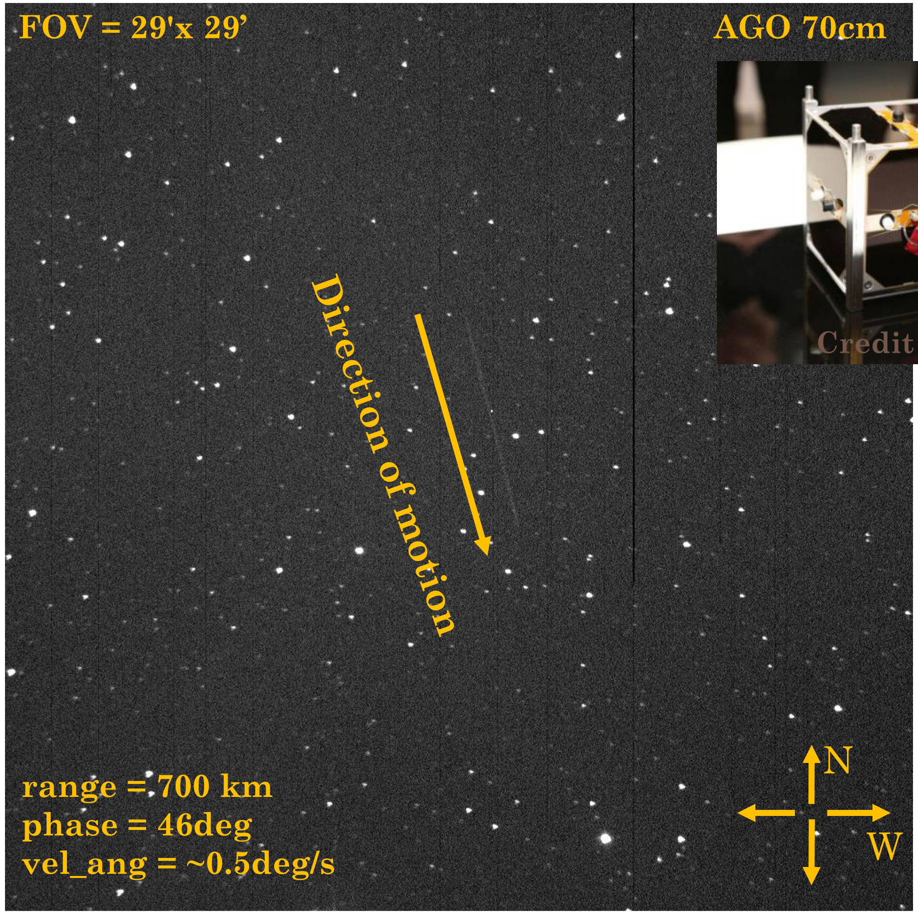
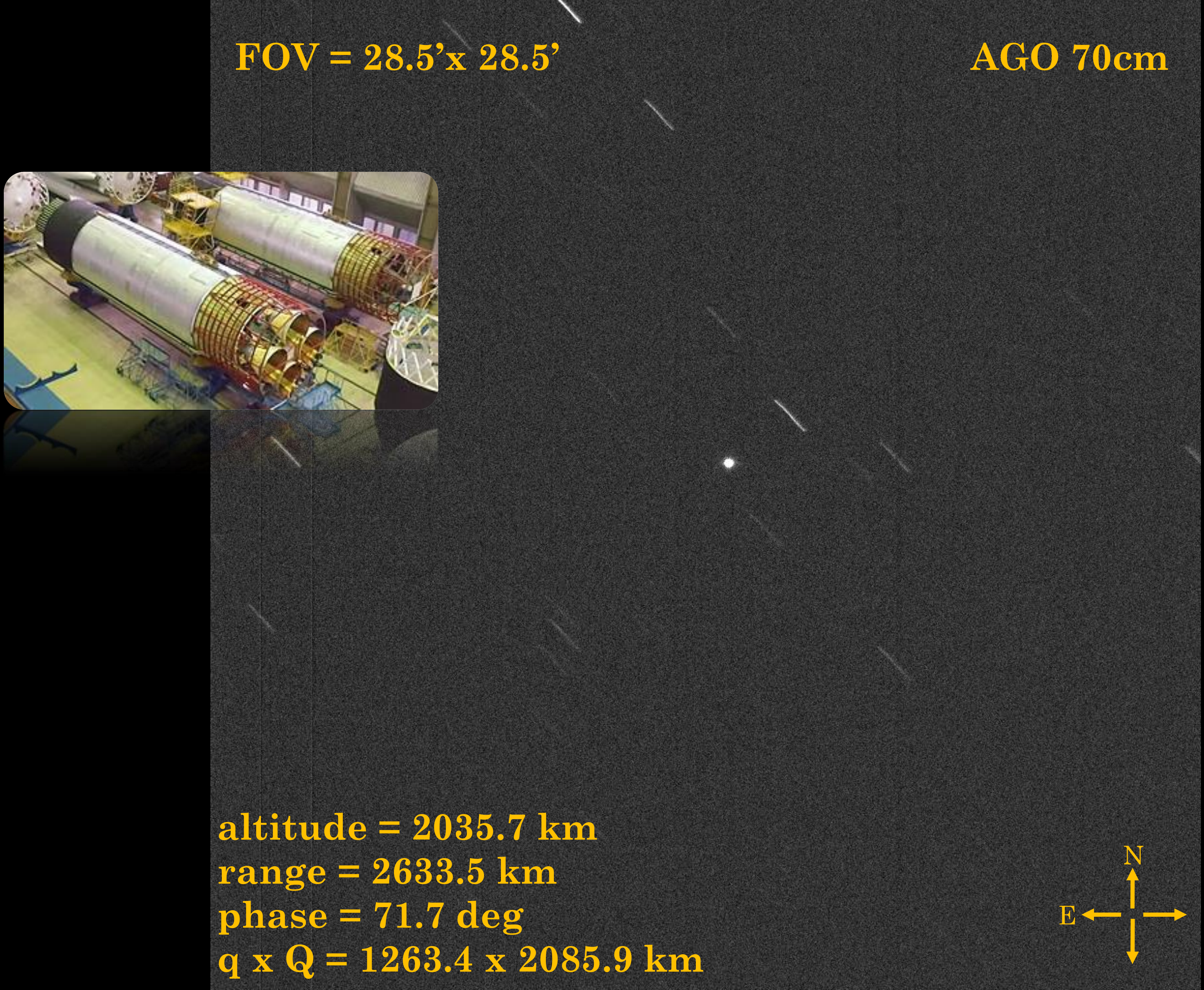


Figure – LEO cubesat SKCube (17036AA) acquired by the AGO 70cm telescope. Field RA=18:0:22.21 and DEC=+02:40:49.3 observed at 2017-08-01T19:49:00 with 'Clear' filter, exp = 0.2s and sidereal tracking ON.


FOV = 28.5’x 28.5’
AGO 70cm
altitude = 2035.7 km
range = 2633.5 km
phase = 71.7 deg
q x Q = 1263.4 x 2085.9 km
N
E

AGO70 - observation programs - astrometry

```
COD 118
OBS J.Silha/J. Vilagi
MEA J.Silha/J. Vilagi
TEL 0.7-m f/3.0 reflector + CCD
ACK MPCReport file updated 2017.07.25 20:01:53
AC2 ago@fmph.uniba.sk
NET Gaia DR1
     13034A    C2017 05 09.85830 15 57 11.433+21 04 28.72          17.0 R      118
     13034A    C2017 05 09.85839 15 57 19.912+21 03 57.01          17.0 R      118
     13034A    C2017 05 09.85847 15 57 28.406+21 03 25.22          17.0 R      118
     13034A    C2017 05 09.85856 15 57 36.897+21 02 53.91          17.0 R      118
     13034A    C2017 05 09.85866 15 57 45.511+21 02 21.01          17.0 R      118
     13034A    C2017 05 09.85875 15 57 53.969+21 01 49.56          17.0 R      118
     13034A    C2017 05 09.85884 15 58 02.500+21 01 17.63          17.0 R      118
     13034A    C2017 05 09.85894 15 58 10.946+21 00 45.36          17.0 R      118
     13034A    C2017 05 09.85903 15 58 19.417+21 00 13.35          17.0 R      118
     13034A    C2017 05 09.85912 15 58 27.850+20 59 42.09          17.0 R      118
     13034A    C2017 05 09.85920 15 58 36.240+20 59 10.56          17.0 R      118
----- end -----
```

Figure – Astrometric measurements of object 13034A in IAU MPC format. Measurements acquired by AGO 70cm. Astrometric reduction performed by Astrometrica.

```
AGO_70           E08219B00                                57968.016460000 21.114925000 -06.53244000 12.91  1 "
AGO_70           E08219B00                                57968.016890000 21.122551000 -06.51159000 12.91  1 "
AGO_70           E08219B00                                57968.023140000 21.210331000 -06.20441000 12.91  1 "
AGO_70           E08219B00                                57968.023390000 21.212507000 -06.19278000 12.91  1 "
AGO_70           E08219B00                                57968.023660000 21.214690000 -06.18101000 12.91  1 "
AGO_70           E08219B00                                57968.024680000 21.231154000 -06.13119000 12.91  1 "
AGO_70           E08219B00                                57968.024940000 21.233345000 -06.11539000 12.91  1 "
AGO_70           E08219B00                                57968.025120000 21.234804000 -06.11023000 12.91  1 "
AGO_70           E08219B00                                57968.025380000 21.240994000 -06.09447000 12.91  1 "
AGO_70           E08219B00                                57968.079310000 22.384178000 -01.52581000 12.91  1 "
AGO_70           E08219B00                                57968.079570000 22.390361000 -01.51454000 12.91  1 "
AGO_70           E08219B00                                57968.079650000 22.391092000 -01.51216000 12.91  1 "
```

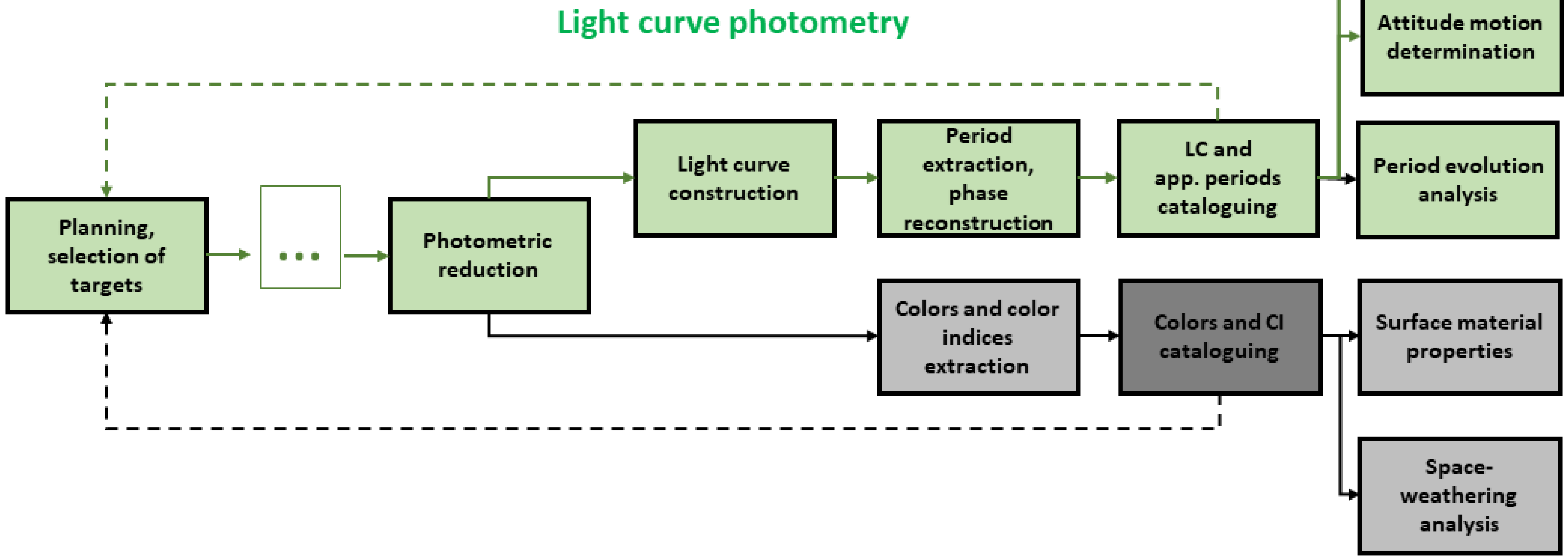
Figure – Astrometric measurements of object E08219B in AIUB OBS format. Measurements acquired by AGO 70cm. Astrometric reduction performed by Astrometrica.

```
CCSDS_TDM_VERS = 2.0

COMMENT TDM example created by yyyyy-nnnA Nav Team (NASA/JPL)
COMMENT StarTrek: one minute of launch angles from DSS-16

CREATION_DATE = 2005-157T18:25:00
ORIGINATOR = NASA
META_START
TIME_SYSTEM = UTC
START_TIME = 2004-216T07:44:00
STOP_TIME =  2004-216T07:45:00
PARTICIPANT_1 = DSS-16
PARTICIPANT_2 = yyyy-nnnA
MODE = SEQUENTIAL
PATH = 2,1
ANGLE_TYPE = XSYE
CORRECTION_ANGLE_1 = -0.09
CORRECTION_ANGLE_2 = 0.18
CORRECTIONS_APPLIED = NO
META_STOP

DATA_START

ANGLE_1 = 2004-216T07:44:00 -23.62012
ANGLE_2 = 2004-216T07:44:00 -73.11035

ANGLE_1 = 2004-216T07:44:10 -23.04004
ANGLE_2 = 2004-216T07:44:10 -72.74316

ANGLE_1 = 2004-216T07:44:20 -22.78125
ANGLE_2 = 2004-216T07:44:20 -72.53027

ANGLE_1 = 2004-216T07:44:30 -22.59180
ANGLE_2 = 2004-216T07:44:30 -72.37598

ANGLE_1 = 2004-216T07:44:40 -22.40527
ANGLE_2 = 2004-216T07:44:40 -72.23730

ANGLE_1 = 2004-216T07:44:50 -22.23047
ANGLE_2 = 2004-216T07:44:50 -72.08887

ANGLE_1 = 2004-216T07:45:00 -22.08984
ANGLE_2 = 2004-216T07:45:00 -71.93750

DATA_STOP
```

Figure – Astrometric measurements of object E08219B in AIUB OBS format. Measurements acquired by AGO 70cm. Astrometric reduction performed by Astrometrica.

Light curves

FMPI/AGO instruments, 70cm telescope



V1.1

FMPI/AGO instruments, 70cm telescope

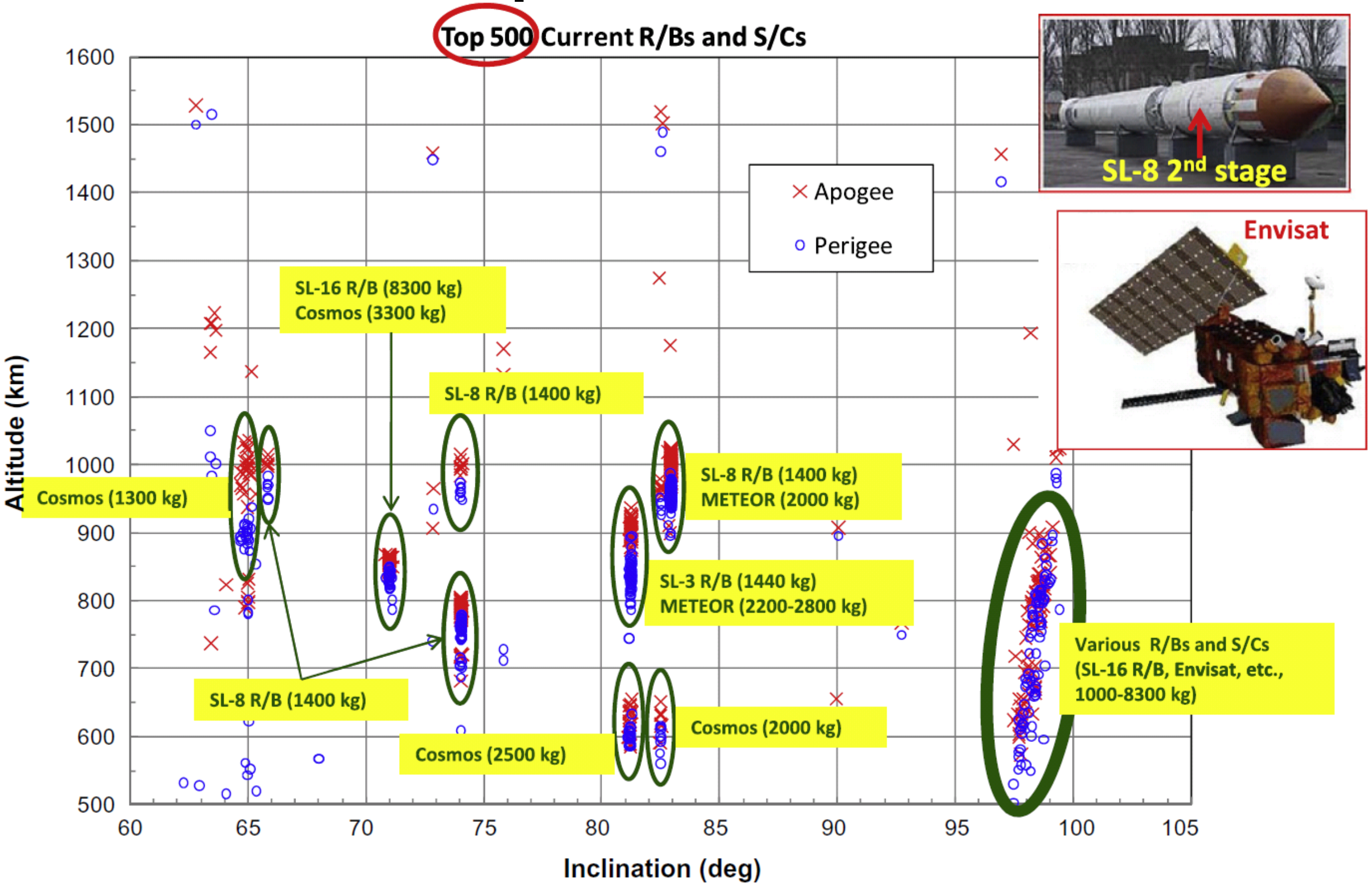
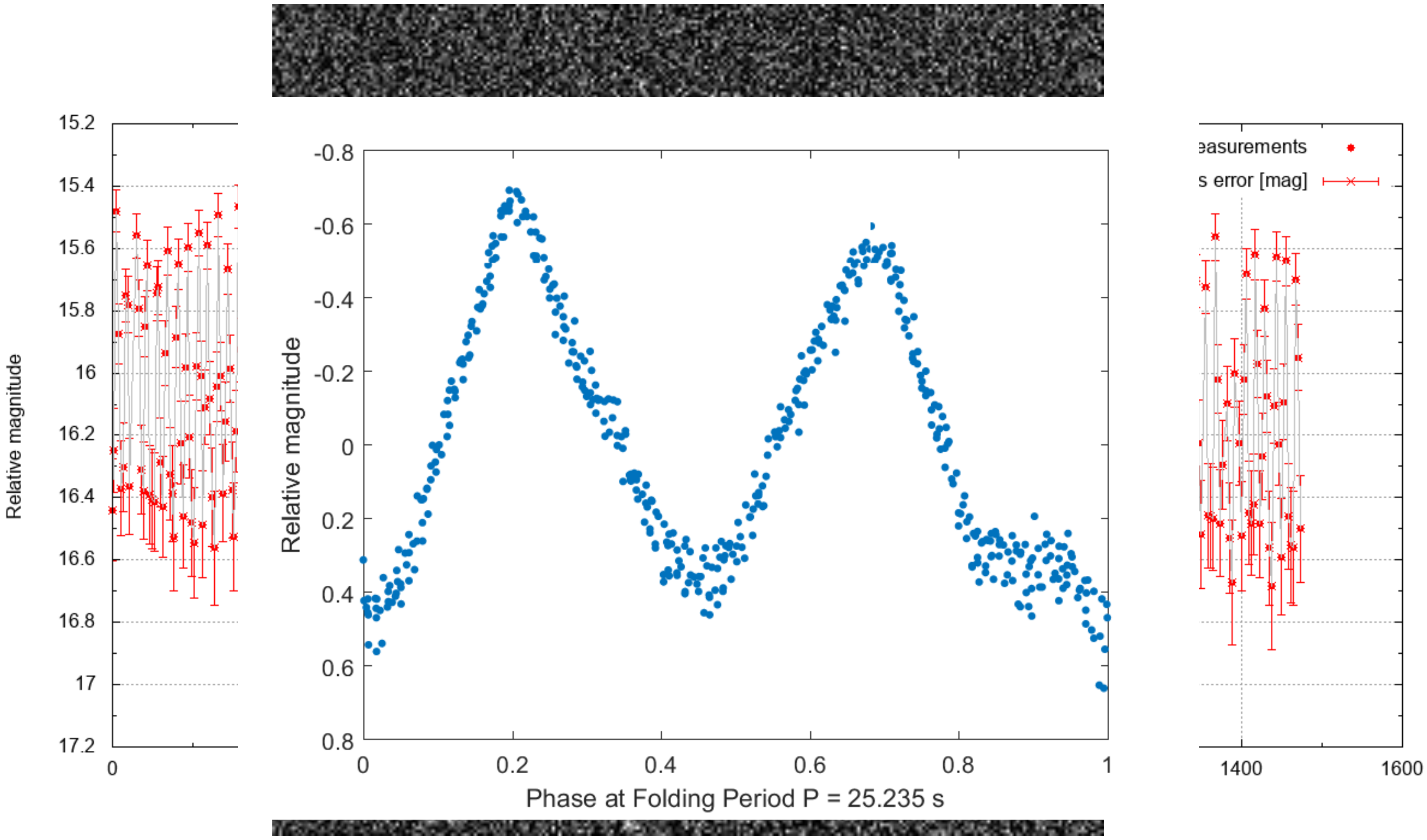


Figure - Apogee altitude (crosses) and perigee altitude (open circles) versus inclination distributions of the existing LEO R/Bs and S/Cs that have the highest mass and collision probability products. Only the top 500 are shown. Taken from (Liou, 2011).

AGO70 - instrumental photometry



ITAN 3C
R/B

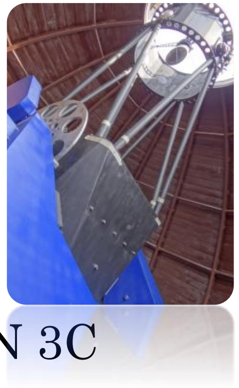
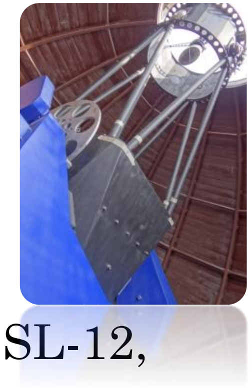


Figure – Photometric measurements acquired by AGO 70cm telescope during night 20181016 (left) and the constructed light curve (middle) and its phase diagram (right) for the object Titan 3C Transtage R/B (74039C).

AGO70 - instrumental photometry



D – SL-12,
/B

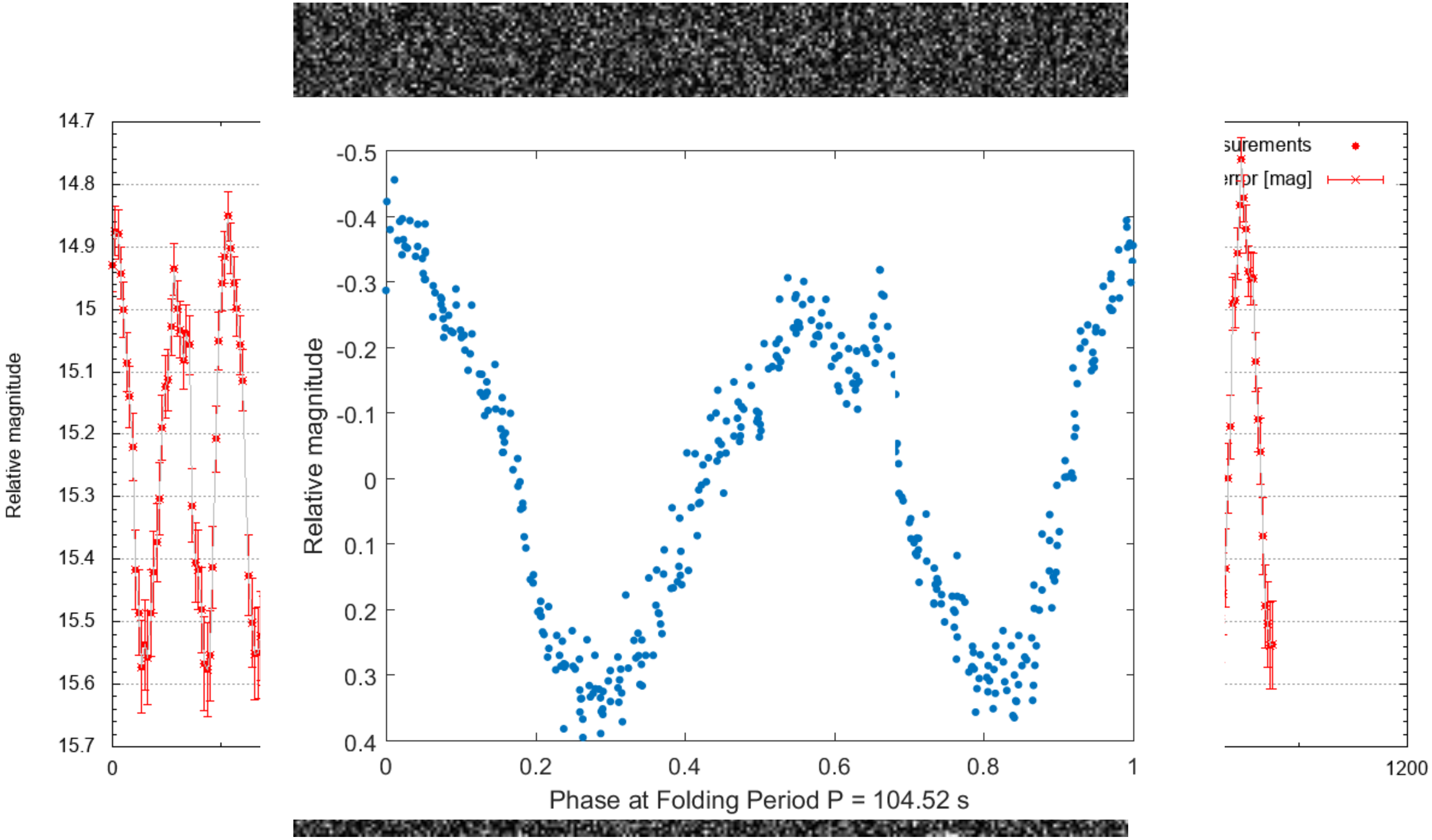


Figure – Photometric measurements acquired by AGO 70cm telescope during night 20181016 (left) and the constructed light curve (middle) and its phase diagram (right) for the object SL-12, Blok-D (97076D).

AGO70 - instrumental photometry

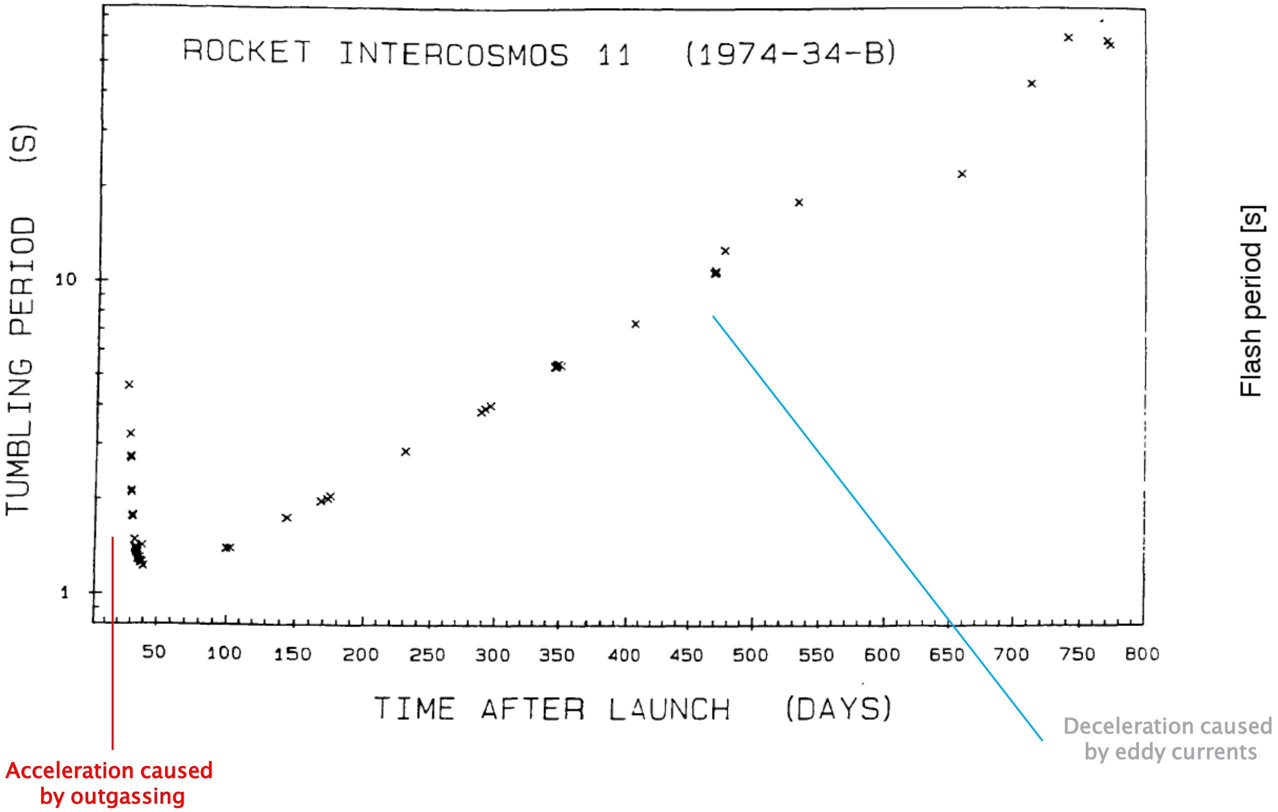


Figure – Overview of the tumbling period development of the Soviet SL-8 R/B 1974-034B from June 1974 to June 1976. Taken from [Boehnhardt et al., 1989].

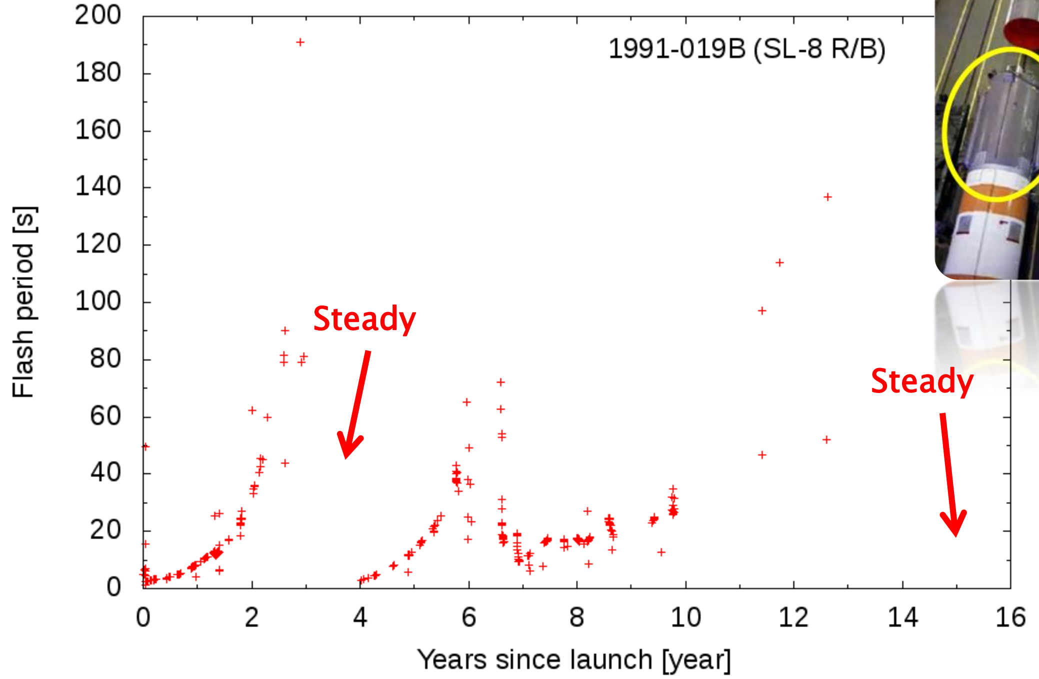
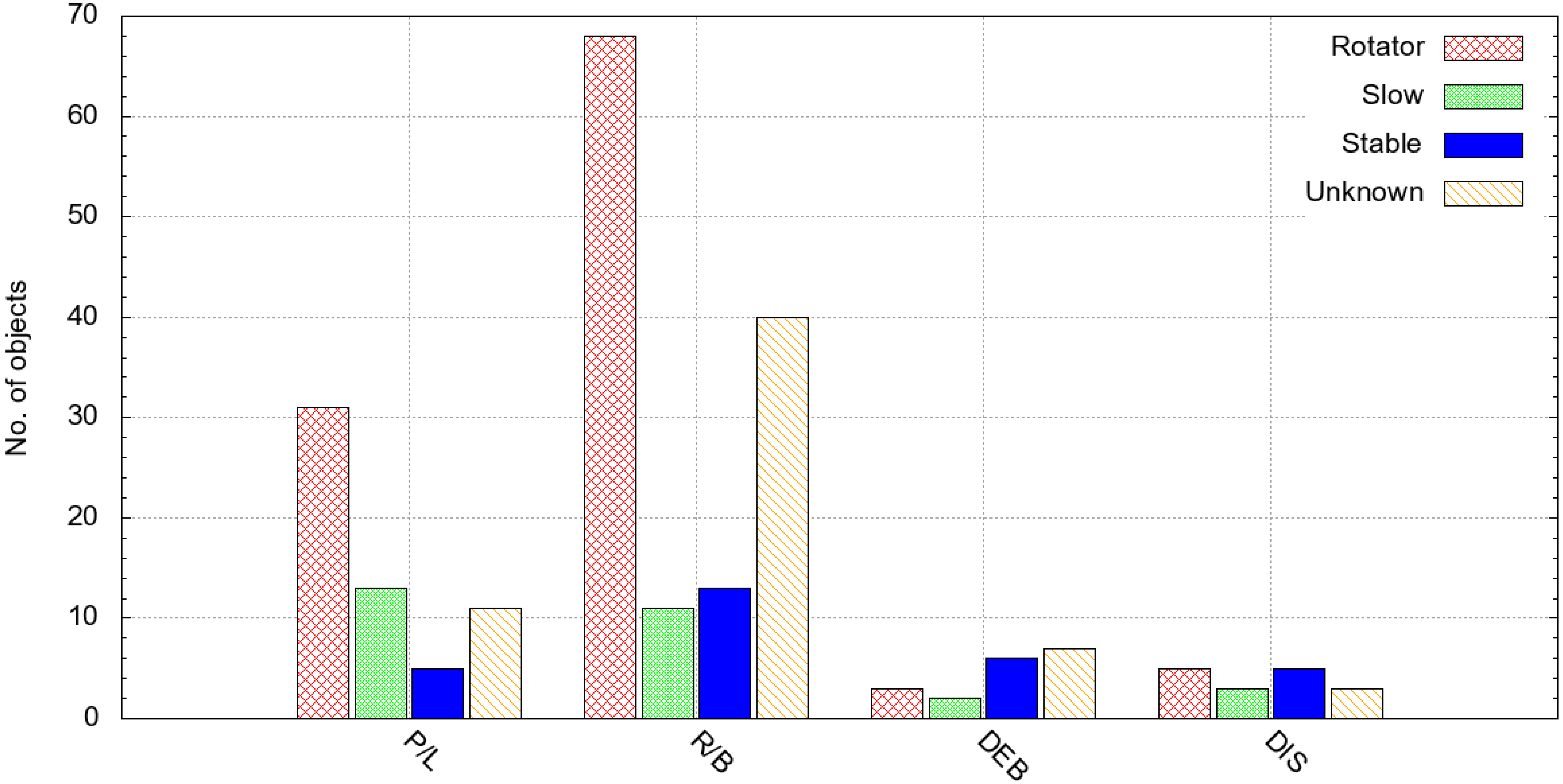


Figure – Flash periods evolution of the R/B SL-8 1991-019B (RUS, ~980 km). Figure generated from PPAS database data.

Results



47.7%

Fig. - Distribution of 226 objects observed by AGO70 system in years 2017 to 2019 according to their rotation properties and type. Plotted are rotators, slow rotators, stable objects and objects for which the light curve could not be processed.
Source: *Šilha et al. (2019)*.

Color photometry

Optical observations, color photometry

- Only light with defined wavelengths will pass trough given filter
- Most popular Johnson-Cousins filters

  (AGO 60cm and 70cm)
- Detected light properties dependent on object's properties (absorption, emission)
- Color indices ➔ B-V, V-R, R-I, V-I, B-R

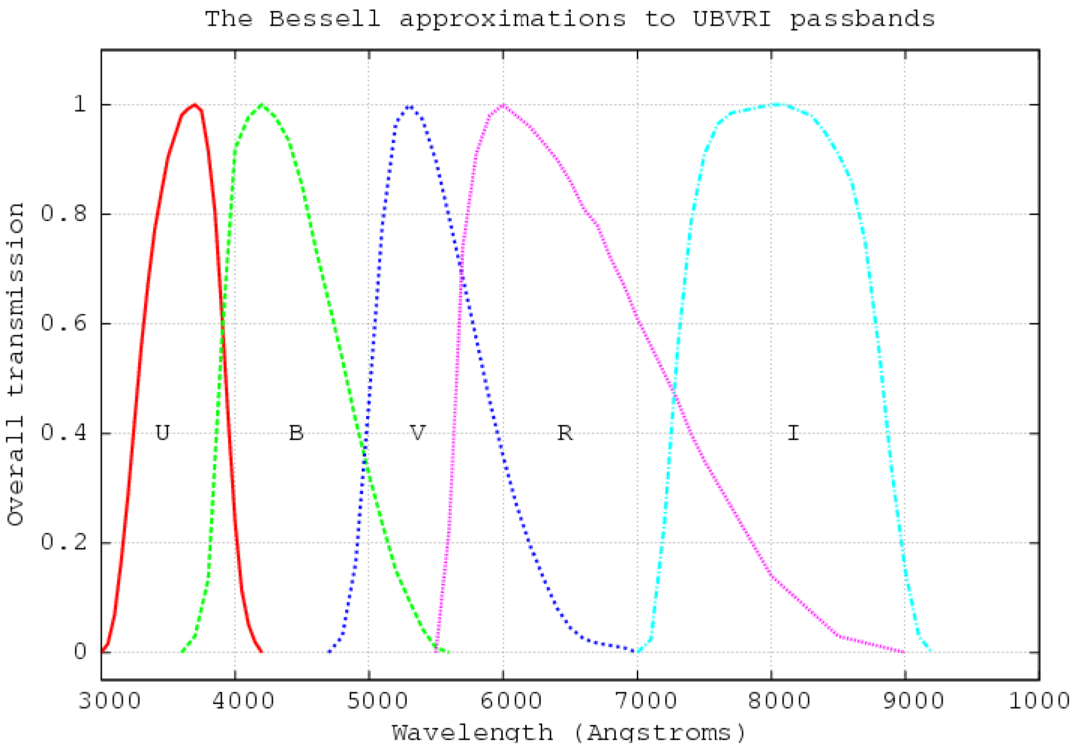
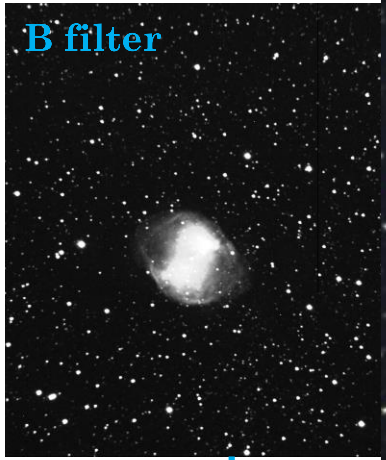
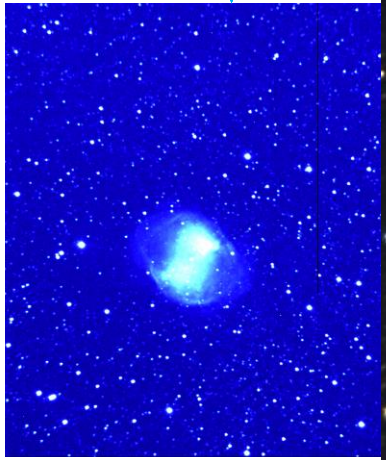


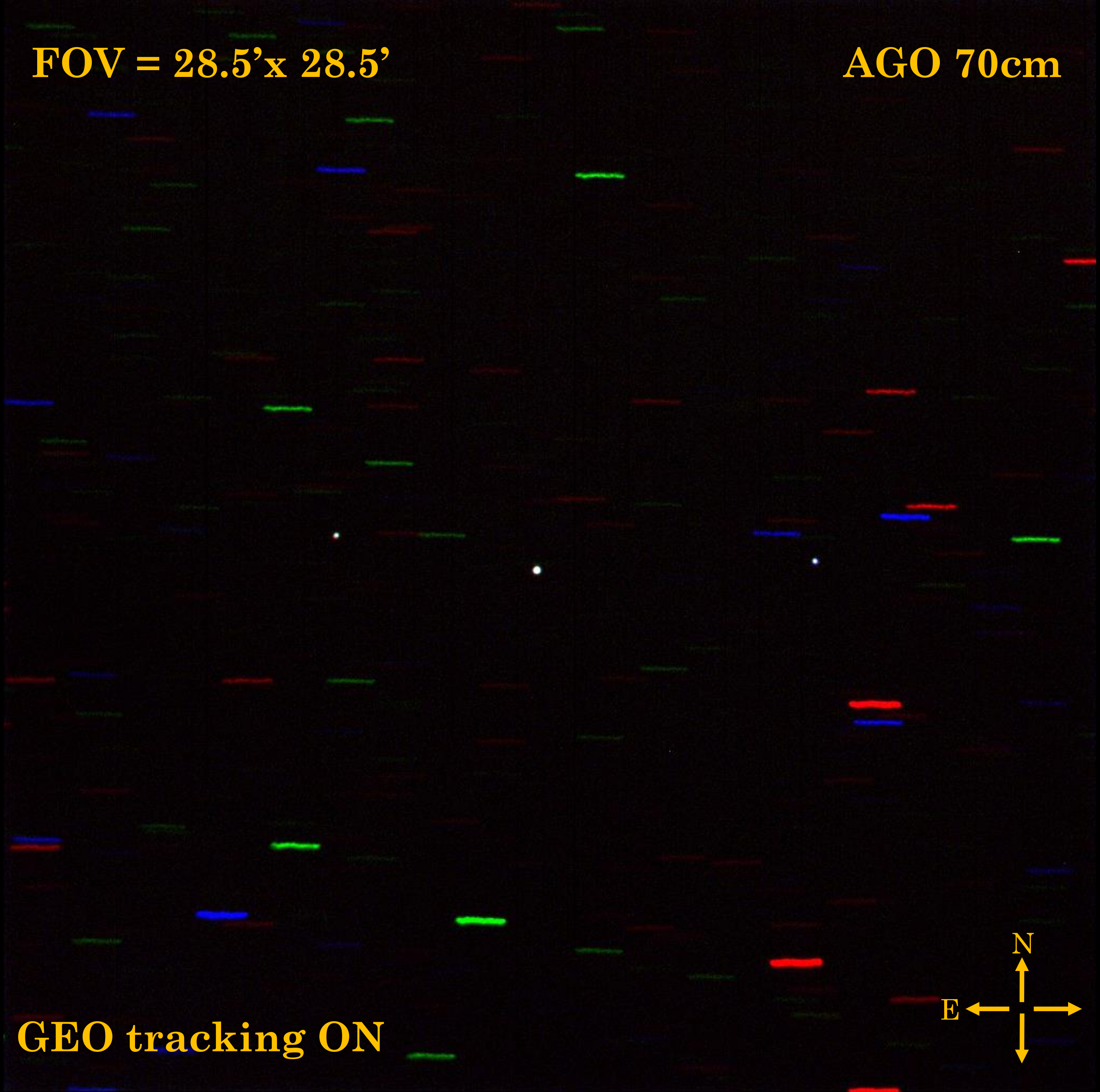
Figure – Schematic passbands of broad-band system Johnson-Cousins. Taken from Bessel (1990).

Opt
colo





Figu
cm tel


FOV = 28.5’x 28.5’
AGO 70cm
GEO tracking ON
N
E

Optical observations, color photometry

Taken from Silha & Hamara et al. (2013)

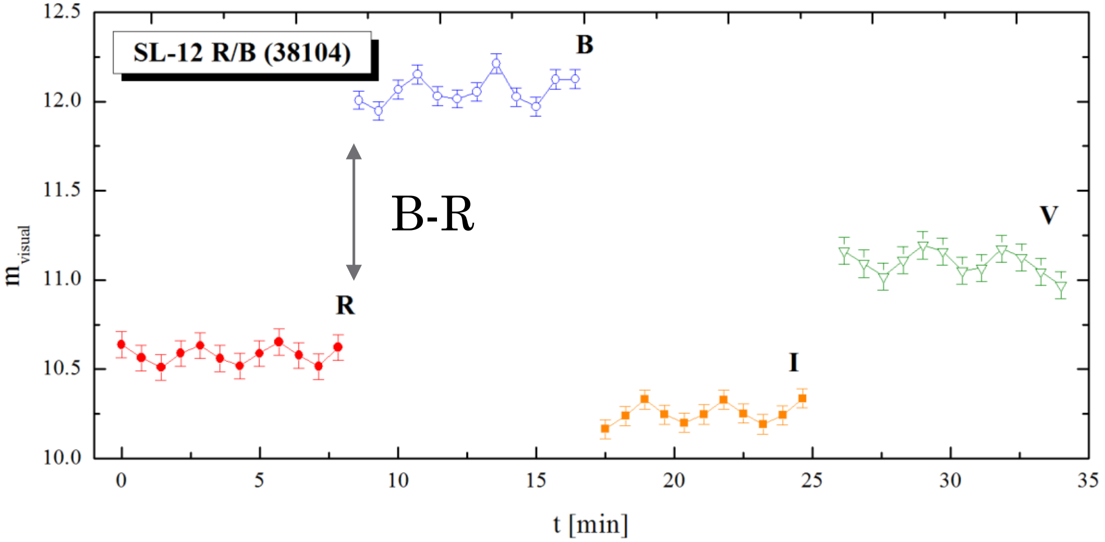


Figure – The magnitudes of the SL-12 R/B for B, V, R, I filter (y axis) as a function of time (x axis) obtained during single telescope observations.

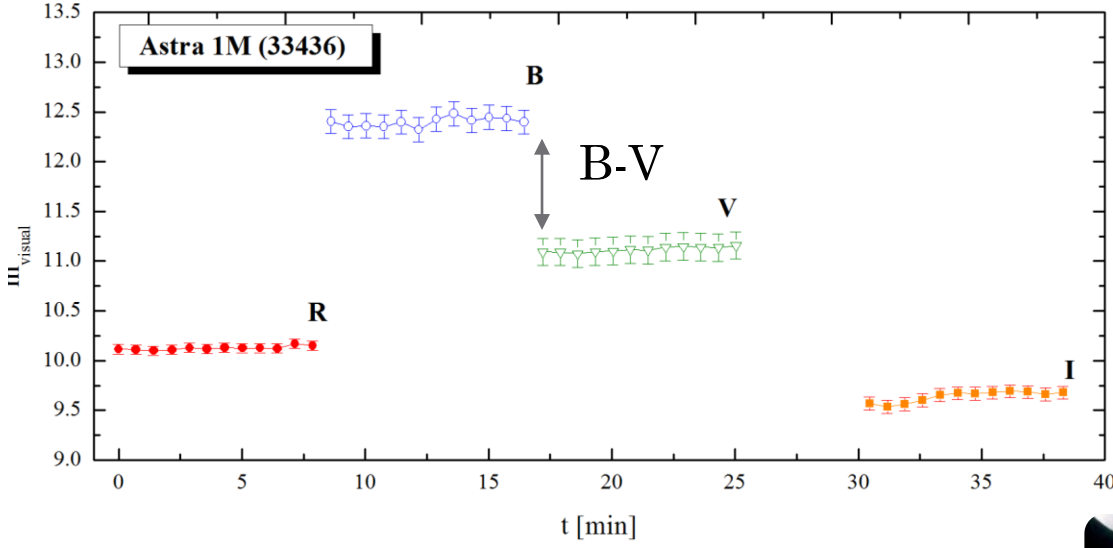


Figure – The magnitudes of the Astra 1M satellite for B, V, R, I filter (y axis) as a function of time (x axis) obtained during single telescope observations..

Results – Attitude-controlled objects

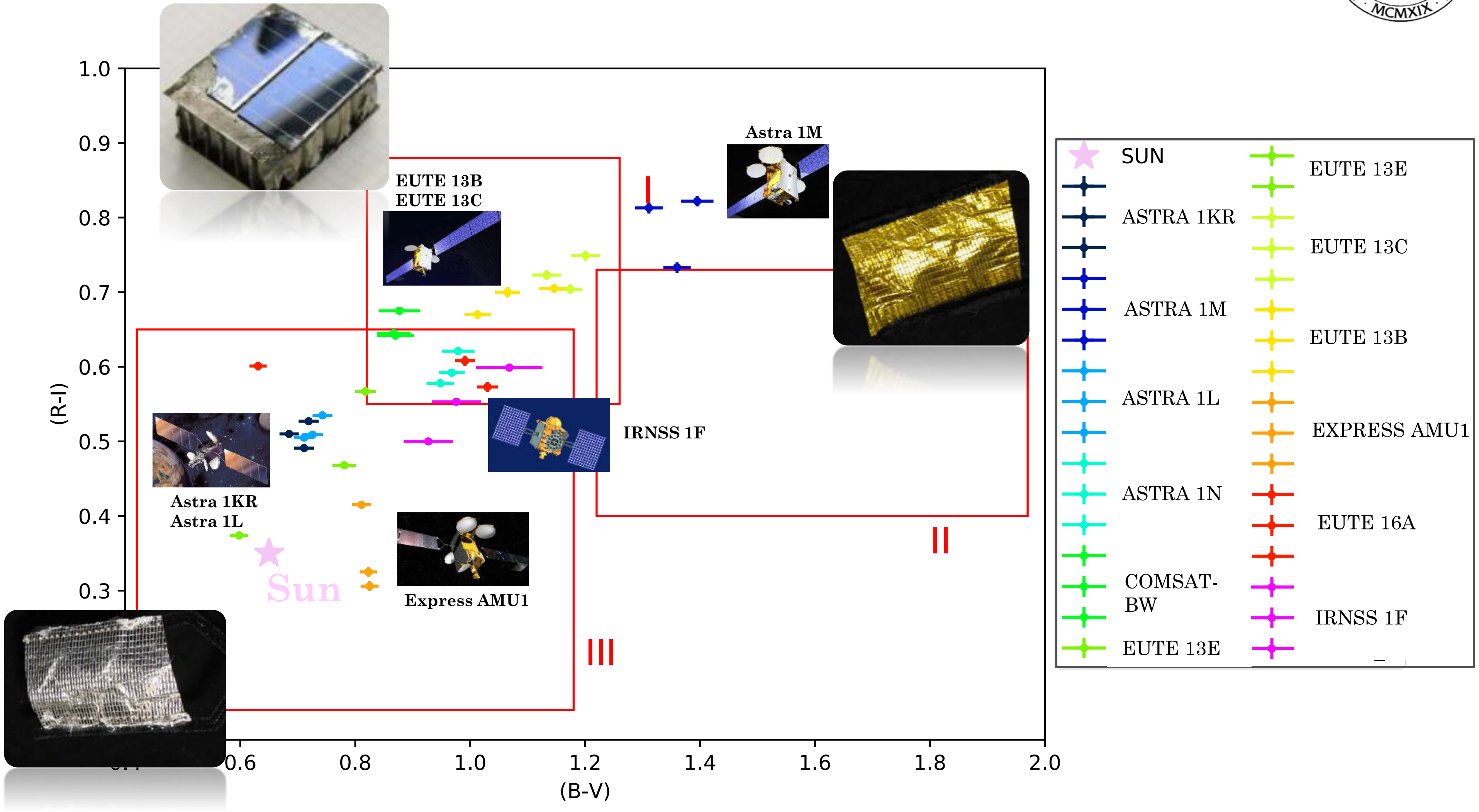
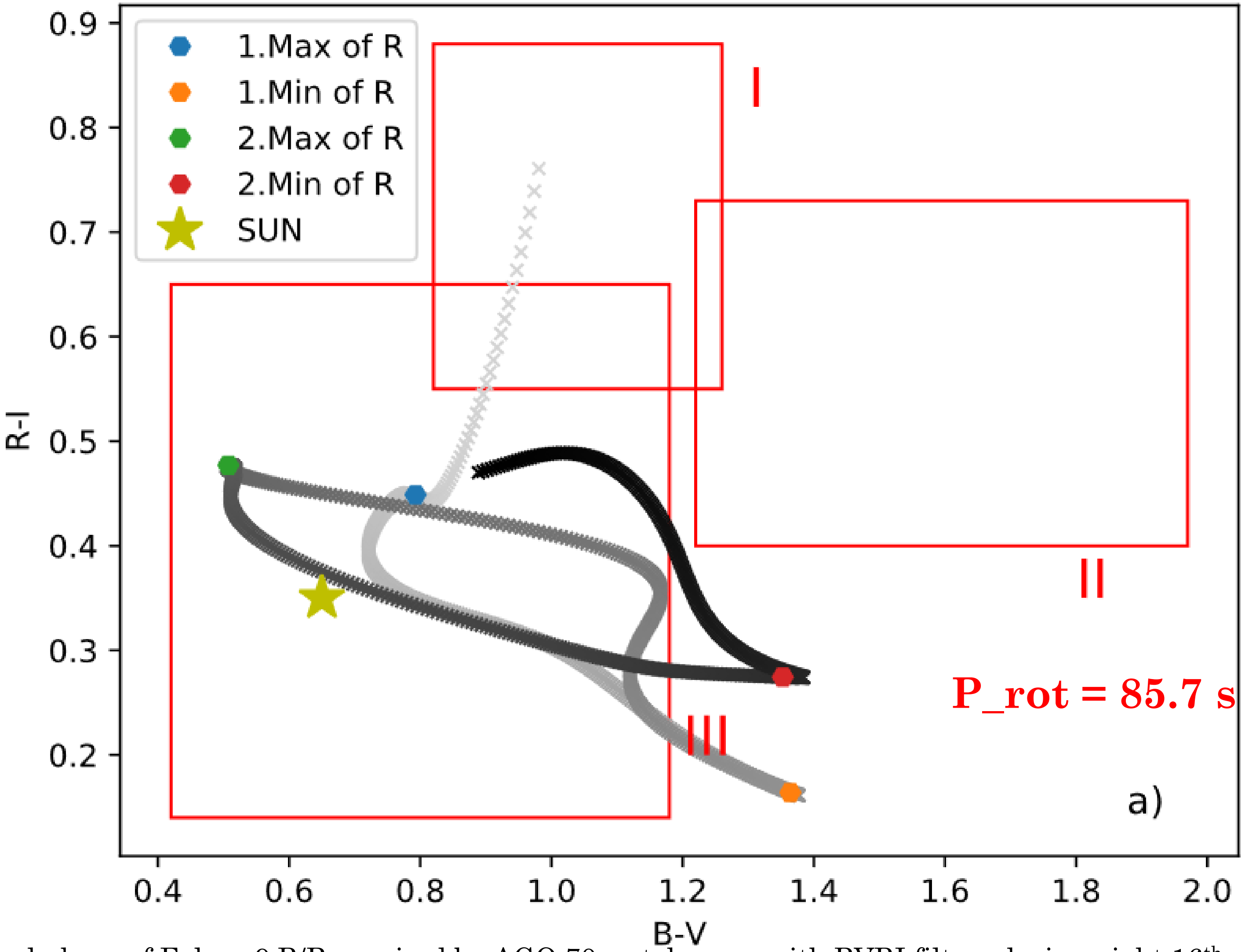


Fig. Results of the observational night from 24th of the July, 2019. On the B-V vs R-I diagram are plotted three position in phase angles of each object. Objects are situated on the Geosynchronous orbits. Source: Zigo et al. (2019)

Results – Rotating objects



φ=15.6 – 13.3 deg

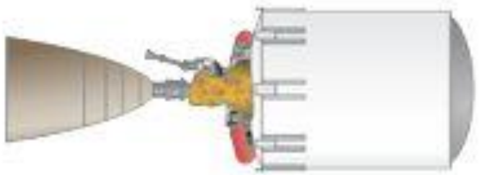
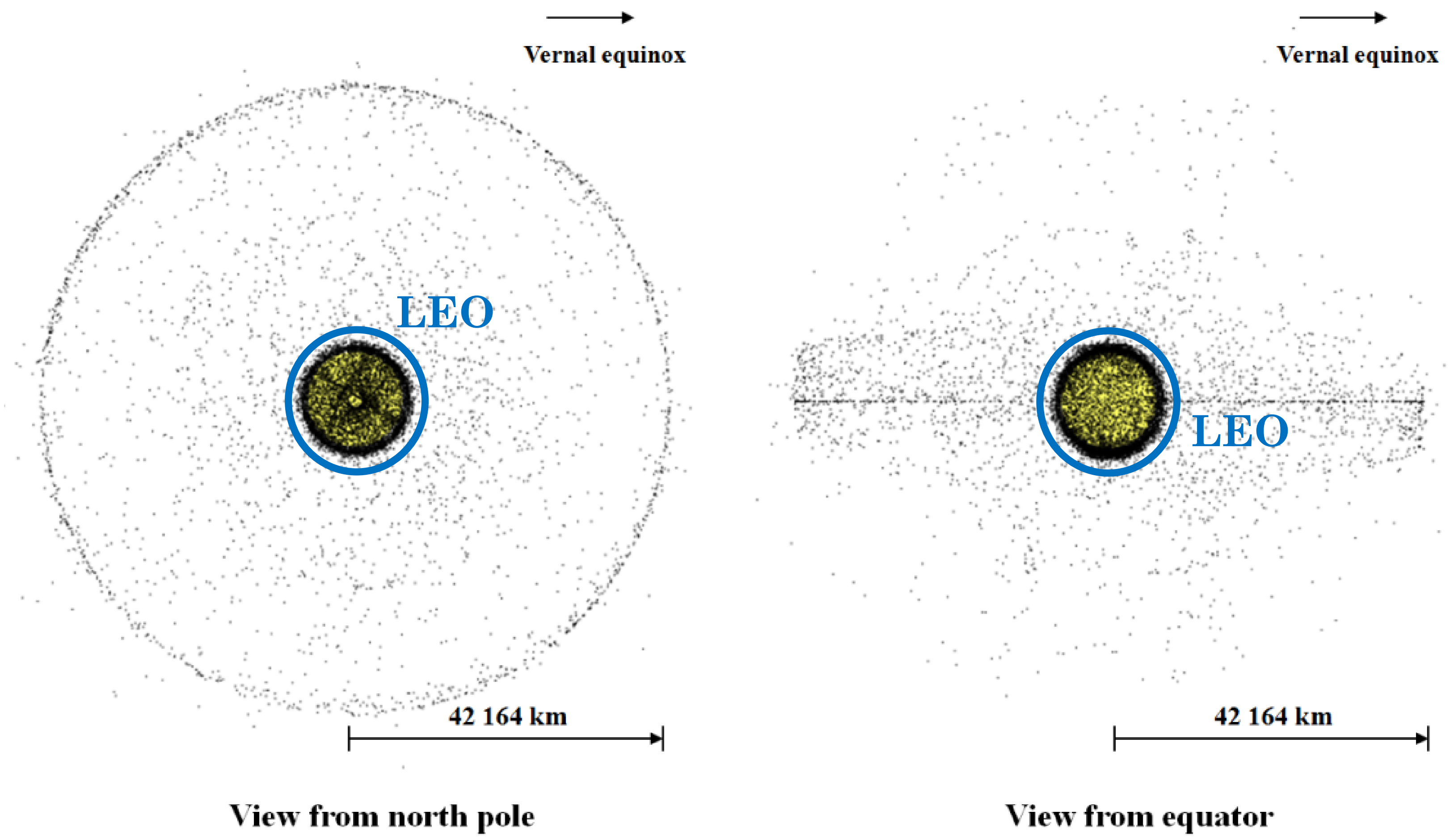


Fig. – Reconstructed phase of Falcon 9 R/B acquired by AGO 70cm telescope with BVRI filters during night 16[th] of November 2018.

Right: Resulting R-I vs B-V diagram of the Falcon's color indices calculated along the phase. The curve in greys color scale represents the path along the phase.

AMOS system, spectroscopy

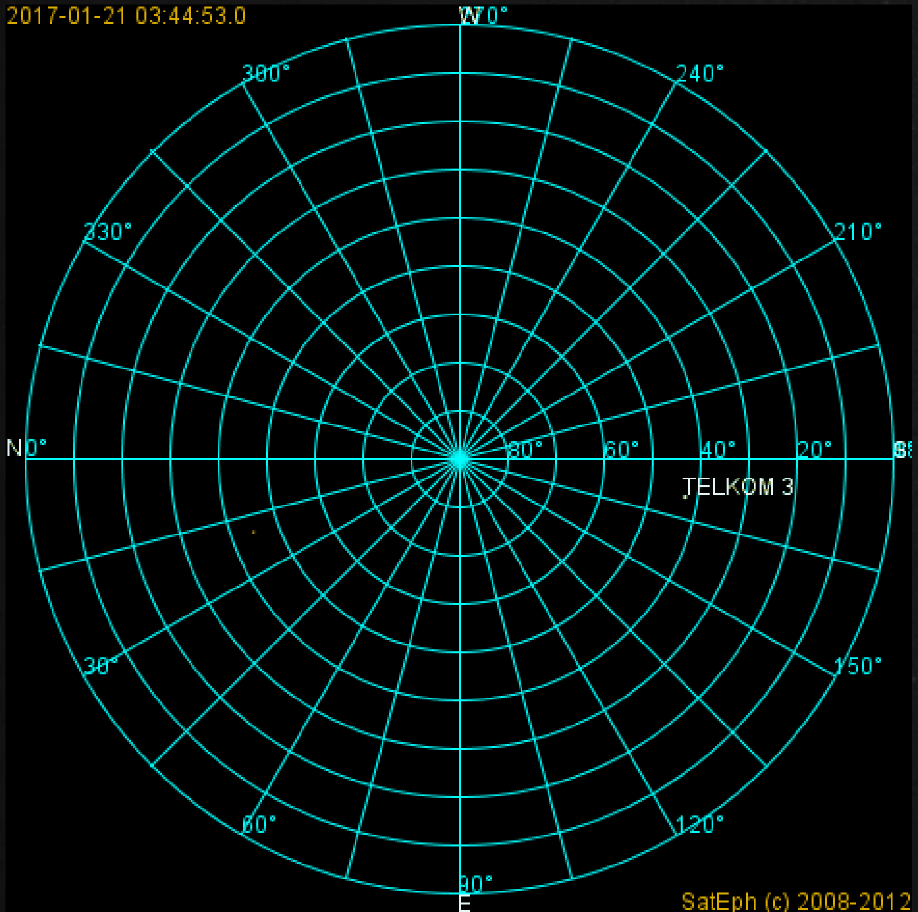
Optical observations with AMOS



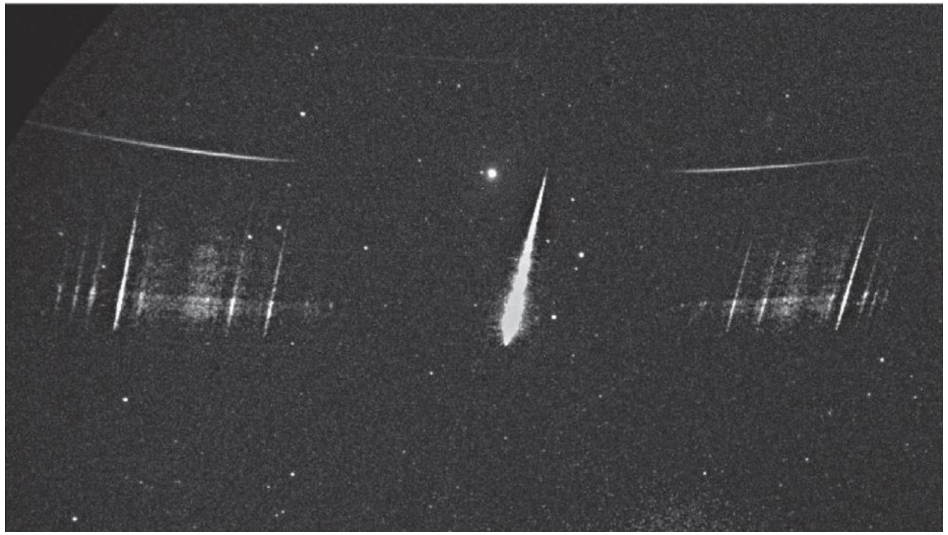
Speed 30x

Telkom 3

Optical observations, survey



Optical observations, spectroscopy



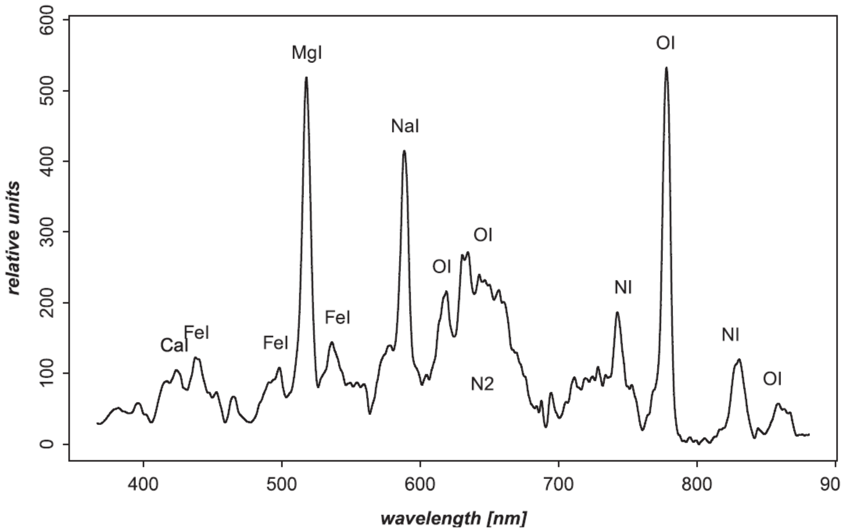


Figure – Example of meteor spectra of σ Hydrids.
Taken from Rudawska et al. (2016).

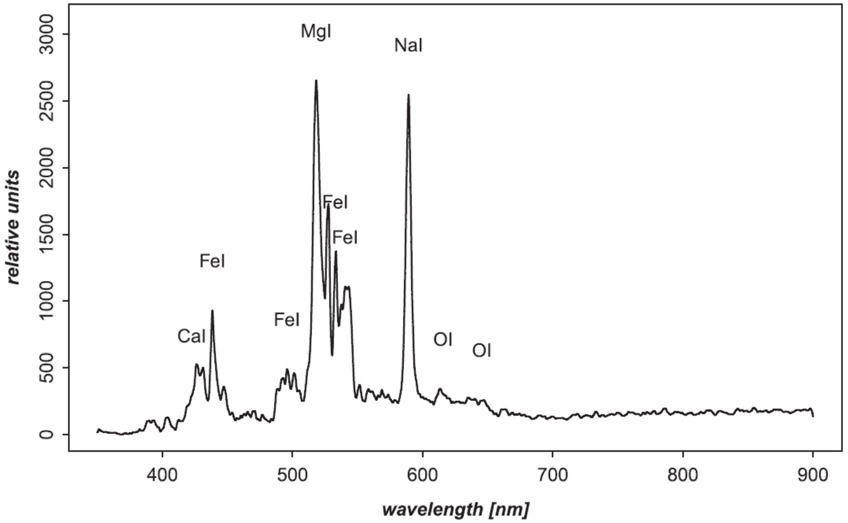
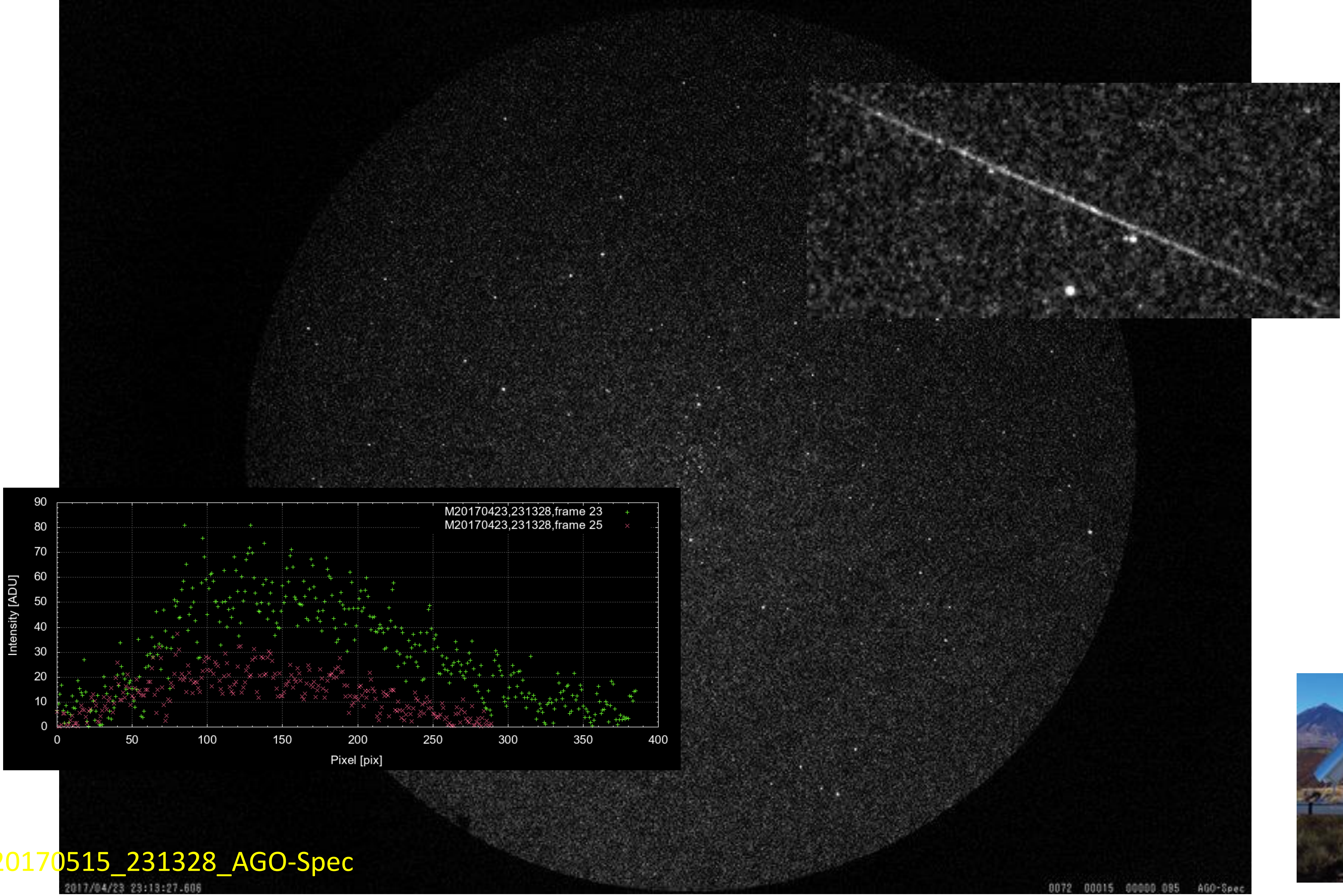


Figure – Example of meteor spectra of sporadic meteor.
Taken from Rudawska et al. (2016).



M20170515_231328_AGO-Spec

Optical observations, spectroscopy

Taken from Taken from Vananti et al. (2017)

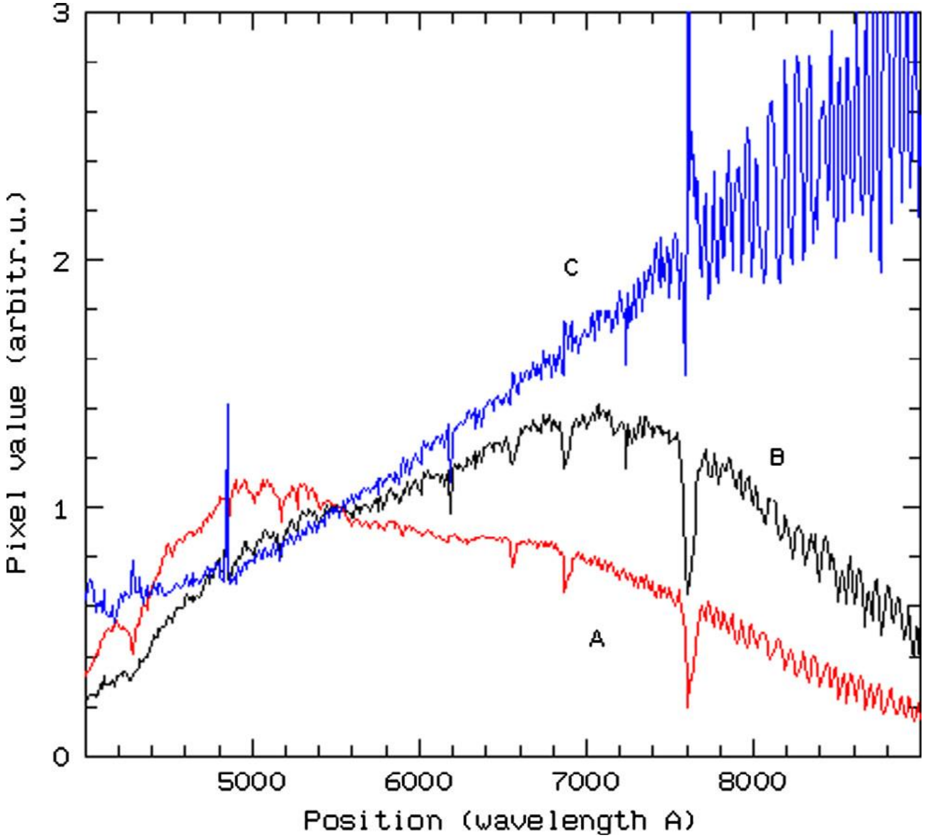


Figure – The observed spectrum of the object (A) is divided by the spectrum of the solar analog (B) to obtain the reflectance spectrum (C). Taken from Vananti et al. (2017).

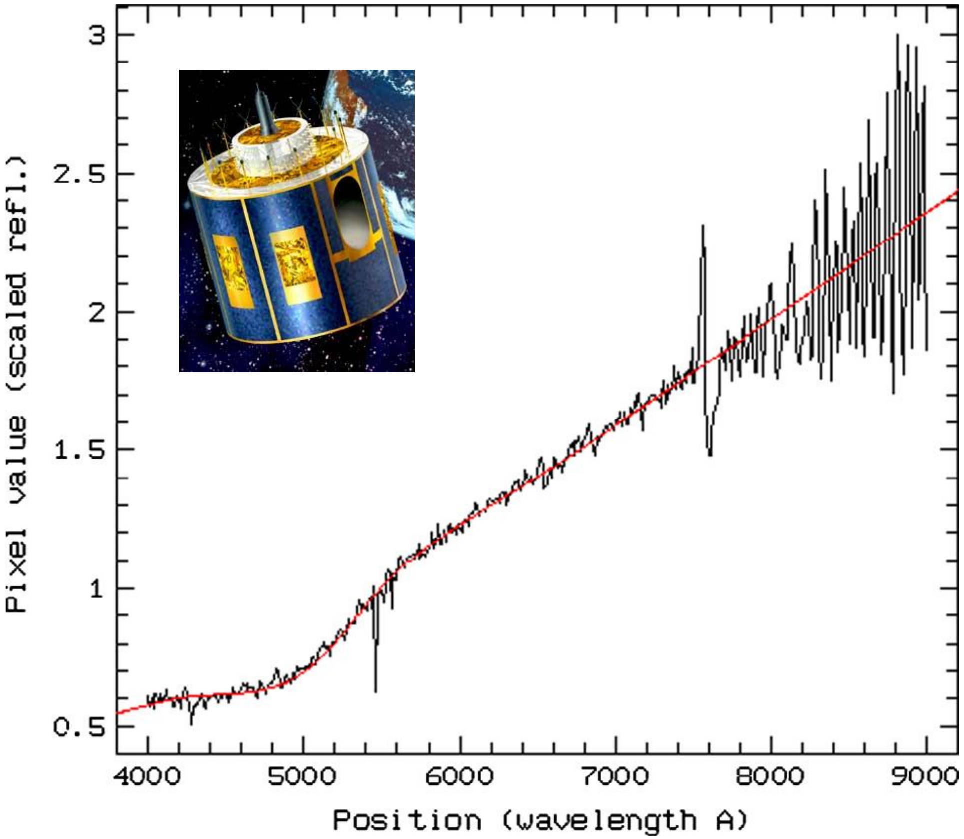


Figure – Reflectance spectrum of Meteosat satellite MSG-1 (02040B). Errors: σ450 = 0.05, σ800 = 0.11. Taken from Vananti et al. (2017).

Optical observations, spectroscopy

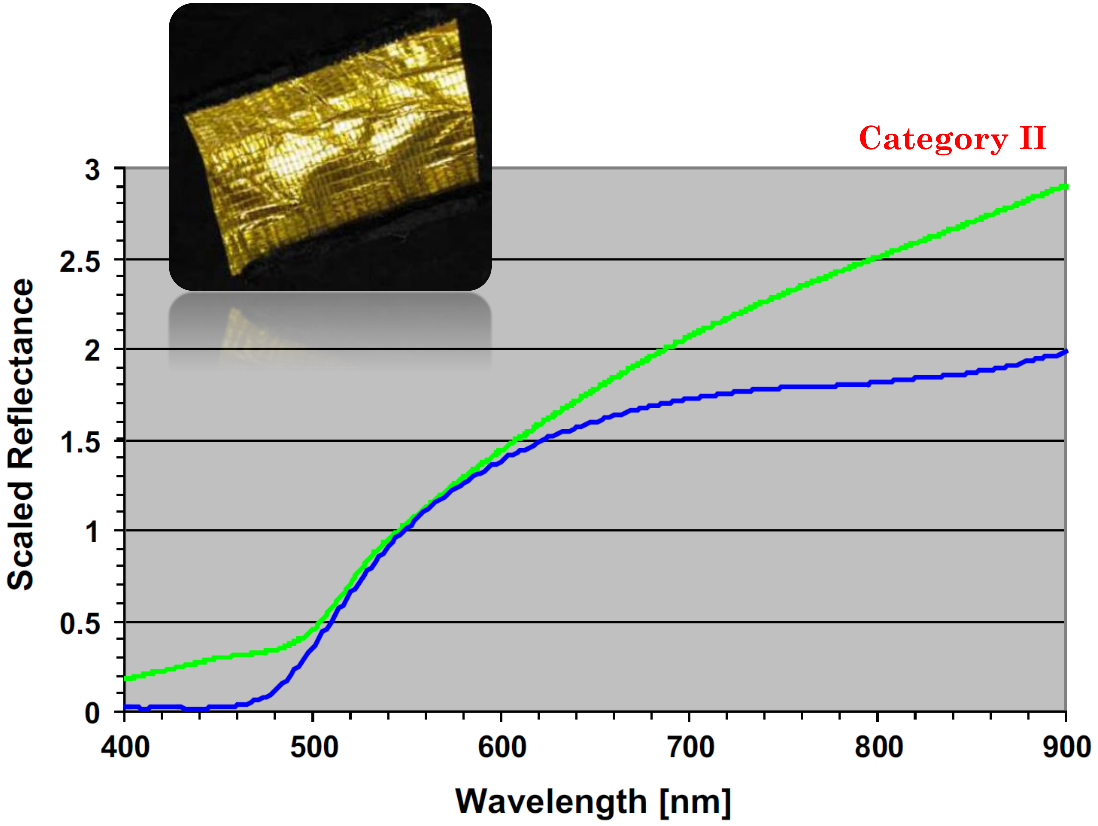


Figure – Spectra of object 84980 (green; see also Fig. 10) and 'gold' MLI (blue). Vananti et al. (2017), Cowardin (2011)

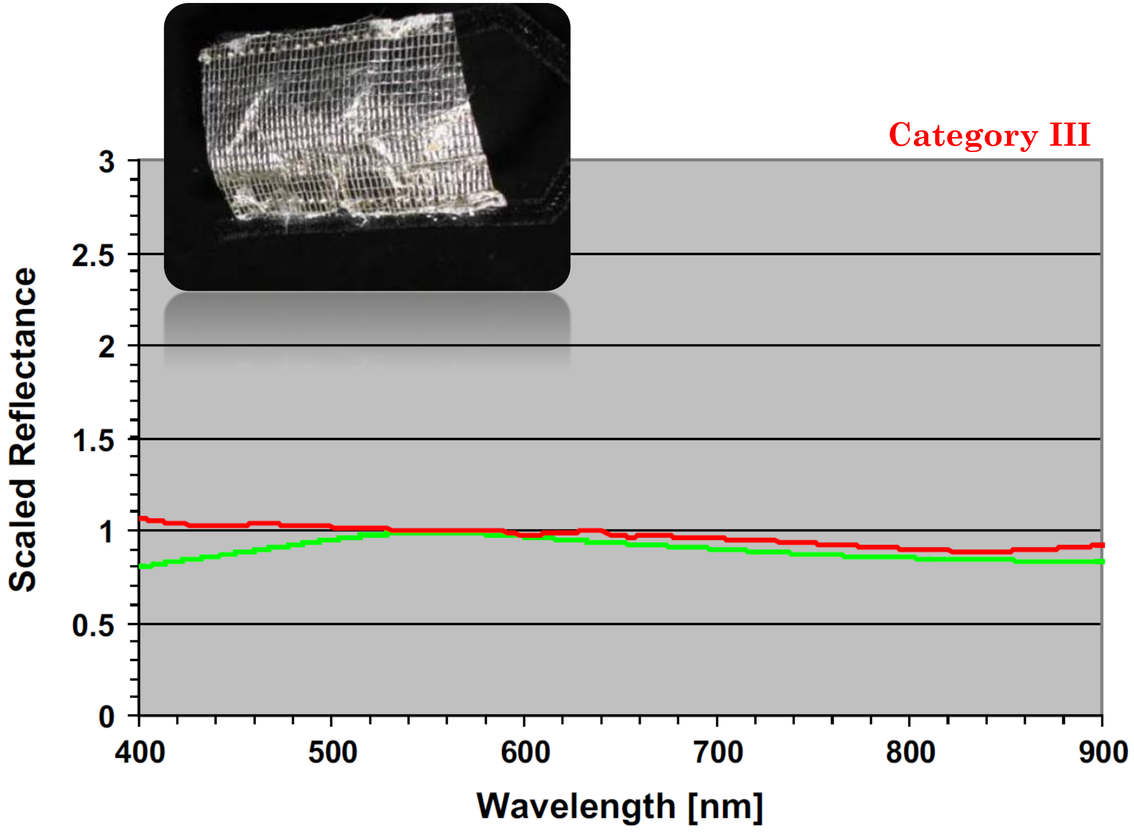
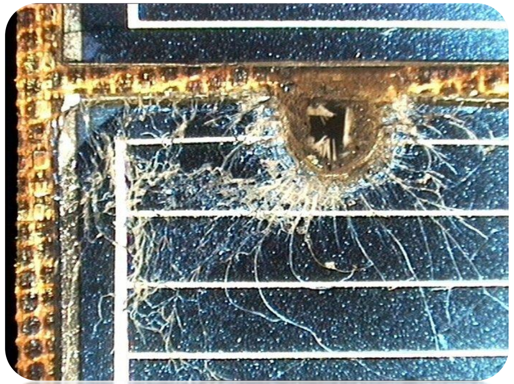


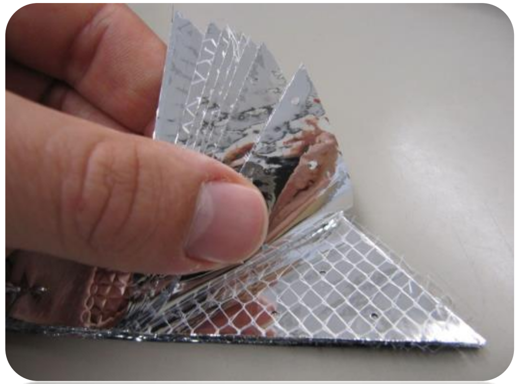
Figure – Spectra of object S95300 (green; see also Fig. 11) and 'silver' MLI (red). Vananti et al. (2017), Cowardin (2011)

Optical observations, spectroscopy

- For AMOS-Spec cameras expected mostly specular “flashes” from compact bright LEO objects (h < 1000 km)

- Specular flashes from highly reflective surfaces such as metal parts, stainless iron (Fe), aluminium alloy (Al), aluminium MLI (Al), copper MLI (Cu), solar panel (Si)



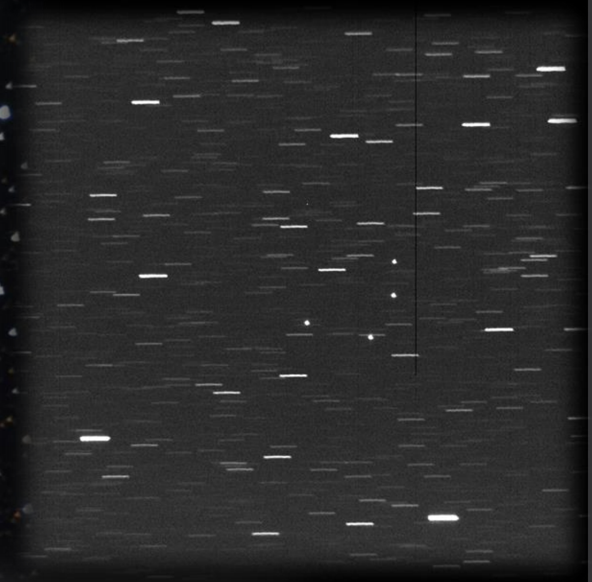


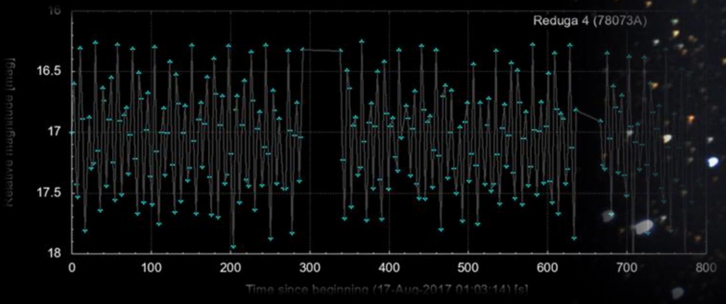
Conclusions and future work

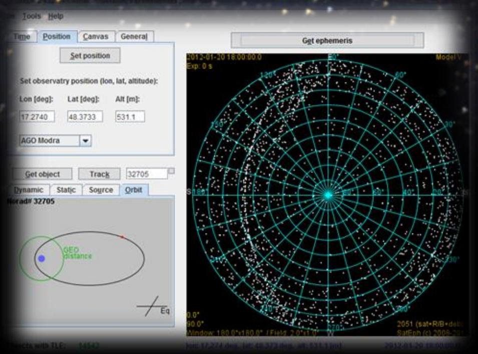
- Space debris research and development mostly on AGO70 system (several ESA PECS and ESA activities)
- Maintainance and extension of light curve catalogue, object's attitude and shape estimation from light curves, fragmentation candidates identification (bachelor project)
- Creation of public color indices catalogue, phase angle dependency analysis, albedo estimation, space-weathering effects monitoring (PhD project)
- Extension of space debris research and methodology to Near Earth Objects (addition to PhD project)
- Analysis of AMOS reflectance spectra of LEO space debris, link to the color photometry from AGO70 (master project)
- S/W development and validation, cooperation with DAI (PhD project of Mr. Stanislav Krajčovič)

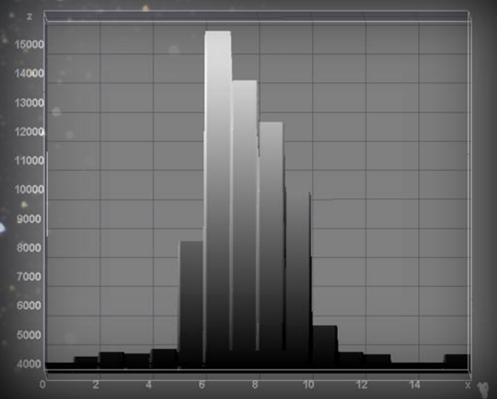
Thank you for your attention.

Questions?









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