GUSDON

Global University Space Debris Observation Network

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7th UNISEC Global Meeting
30 November - 3 December 2019, Tokyo University
Tokyo, Japan

What is a space debris?

- Every man-made object, or part of it, that is orbiting around the Earth and is not functional anymore.
- They consist in: final rocket stages, fragments produced in collisions and explosions in orbit, dust originated from paint erosion, engines expelled material, etc.

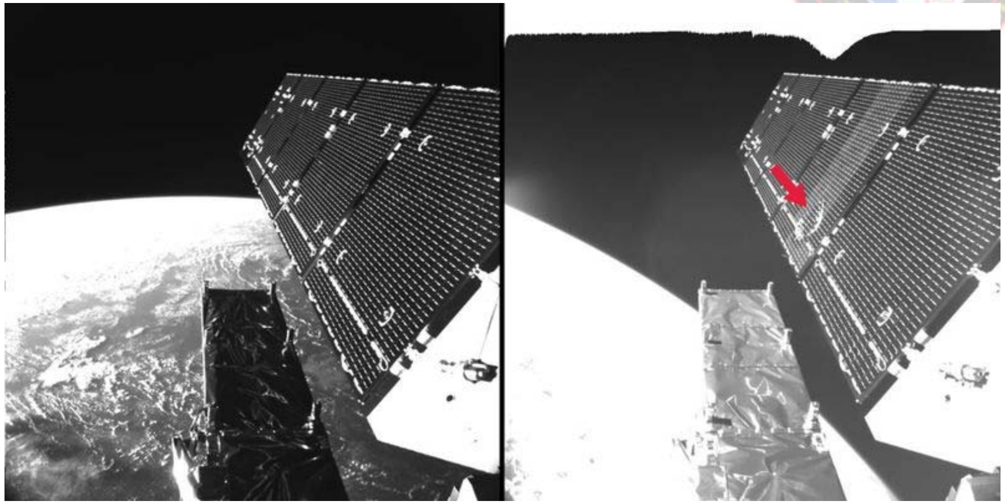
What is their dimension?

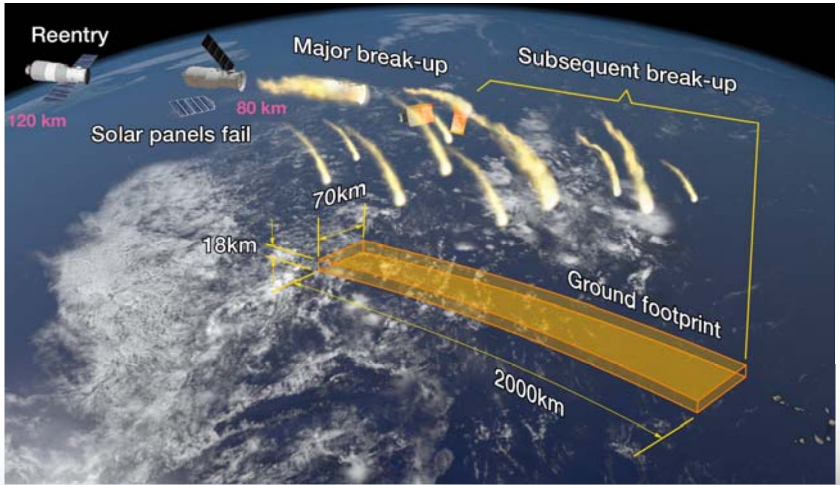
- Estimated 700 000 objects larger than 1cm in diameter. More than 170 000 000 objects larger than 1 mm
- These objects are travelling at extremely high speed, up to 56 000 Km/h

Why are space debris dangerous ? Do collisions happen so frequently?

Small objects in orbit:

On 23 Aug 2017 Sentinel-1A was hit by a small millimeter size debris causing a cm size hole in the solar array. The lack of energy during an operative mission can possibly compromise the entire mission. Just imagine the effect of an impact on the satellite bus. Let’s also imagine the experience of being hit by a debris while prfotming an EVA.



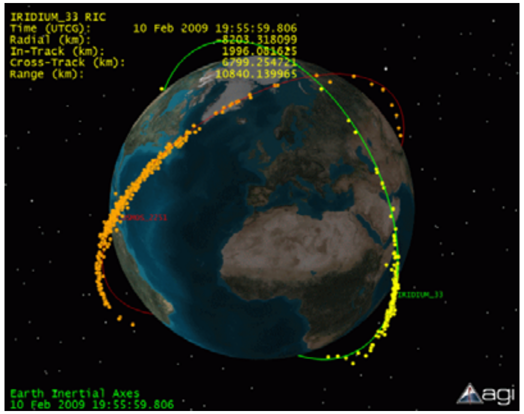


Large objects in orbit:

On 2 Apr 2018 the Tiangong-1 chinese space station re-entered in the atmosphere exploding at an approx 80 km height. Its debris impacted on the Pacific Ocean. The fina trajectory was determined only few hours before the impact involving a huge effort of the national space agencies and the IADC.

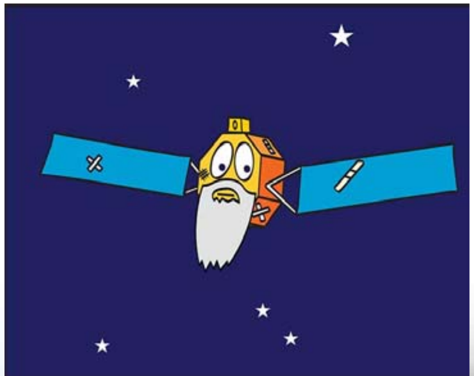
How can we prevent their accumulation?

- Avoiding collisions and unmotivated explosions in orbit.



In 2009, Iridium 33 and Cosmos 2251 collided, originating a debris cloud in LEO. The collision could be avoided by exploiting the satellites Orbit Control sub-system with a collision avoidance maneuver.

- Programming the re-entry of the satellites, while they are still operative, when we lose control of them or when they reached the end of their mission

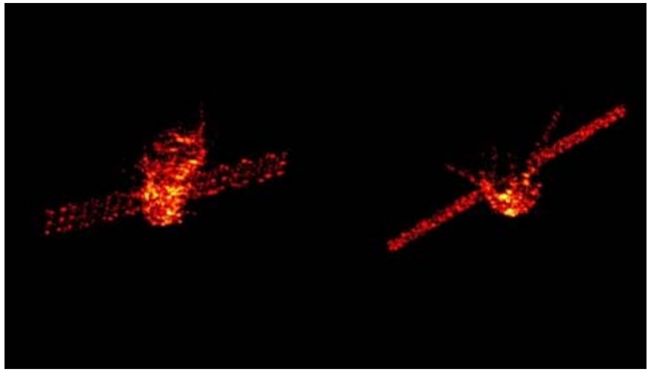


What can we do for the already orbiting objects?

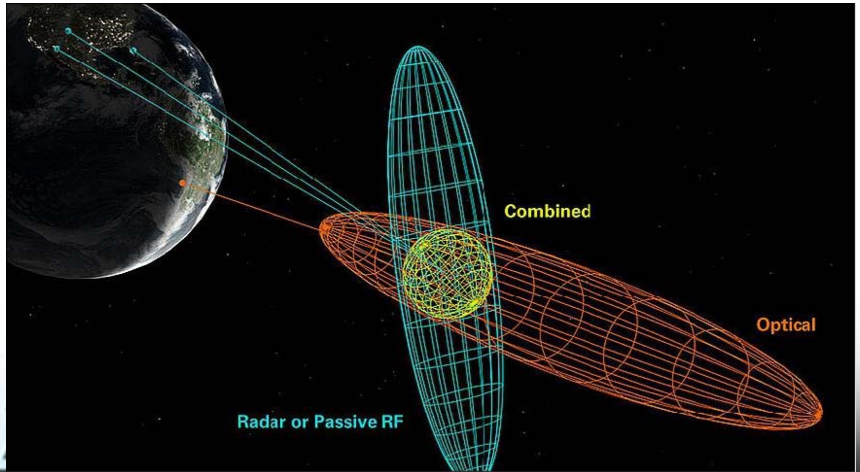
- Monitoring the debris orbit is of fundamental importance in order to command avoiding maneuvers.

How are space debris monitored?

RADAR RANGING



OPTICAL OBSERVATION



Typical Radar Configuration: TIRA Radar

TIRA FACILITIES (TRACKING AND IMAGING RADAR)

- **L-band tracking Radar**
  - High power radar (< 1.5 MW)
  - Detection of a 2 cm target at $1000\ km$
- **Ku-band imaging radar**
  - High resolution imaging of space objects, current resolution $< 25\ cm$
- $\mathbf{34\ m}$ **parabolic** dish in Cassegrain configuration, operational up to $40\ GHz$
- **High angular velocity** ($24°/s$) and acceleration ($6°/s^2$) for target tracking under extreme conditions
- **Very high angular resolution**: $0.6"$ (ca. $3\ m$ at a range of $1000\ km$)
- **Radome** diameter: $47.5\ m$

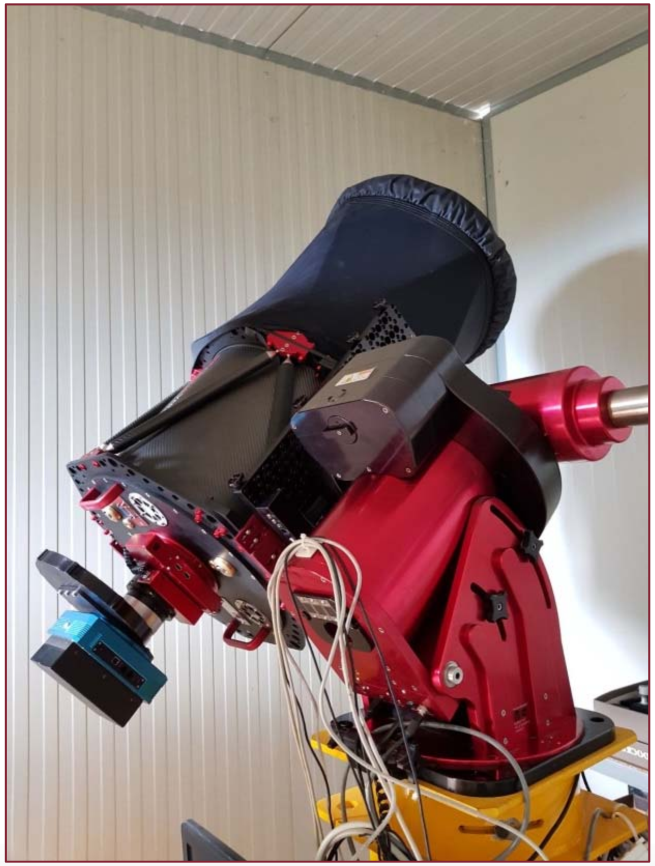
Typical Optical Configuration:

RESDOS (Sapienza University of Rome, Italy)

- **RESDOS**

40 cm optical tube, Field of View: 2 deg x 2 deg

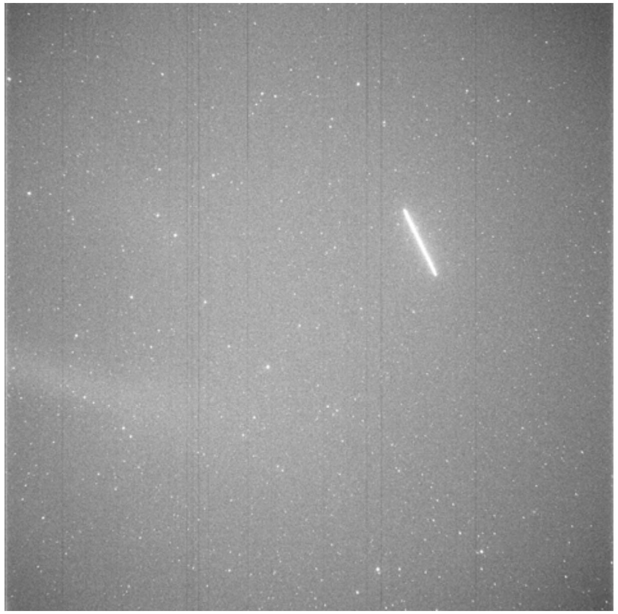
- **Compatible with various CCD models**
- **PC controlled mount**
- **Automatic image acquisition**
- **Observations scheduling software**
- **Shelter**
- **Completely remotely controllable telescope**



Space debris optical observations techniques

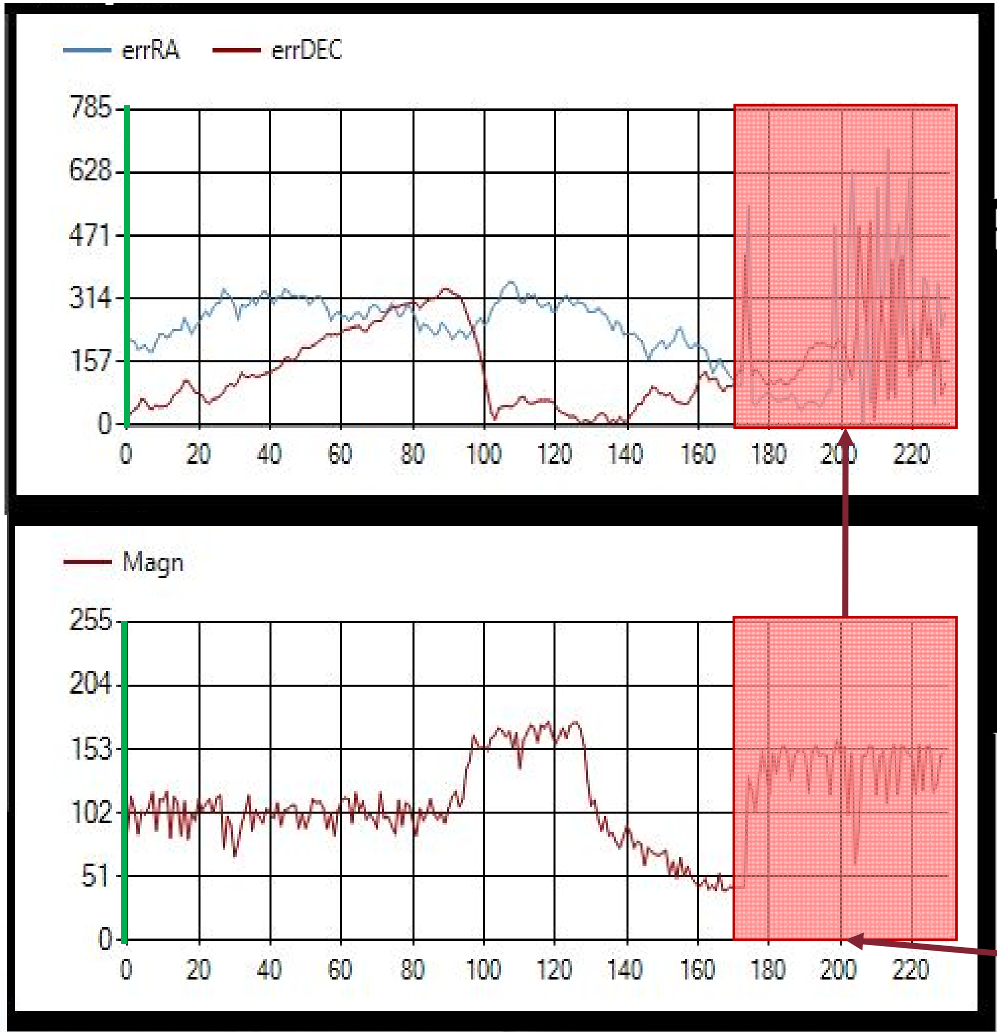
- Sidereal tracking
- Target tracking

SIDEREAL TRACKING: Tiangong1



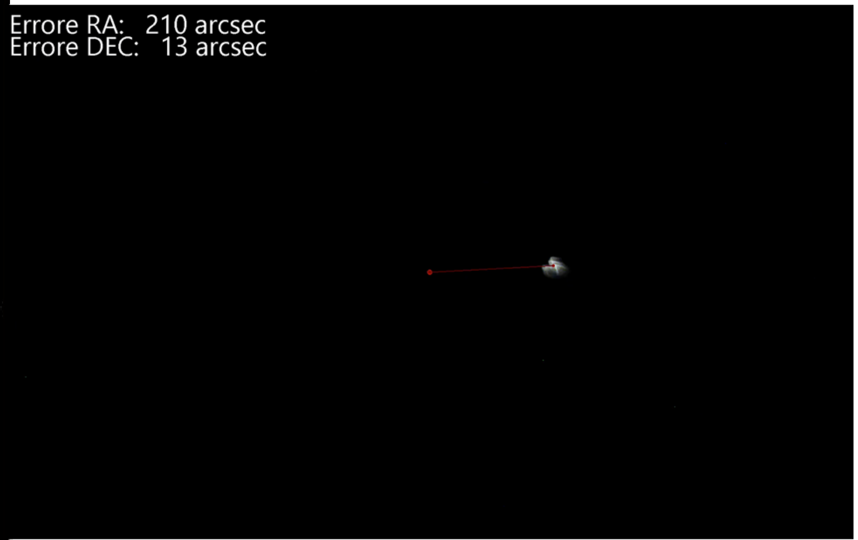
TARGET TRACKING: two GEO satellites

Real time LEO tracking



Real time tracking of COSMOS 1340:

- T_{exp} = 0.2 s
- mag_{sat} = 4.0



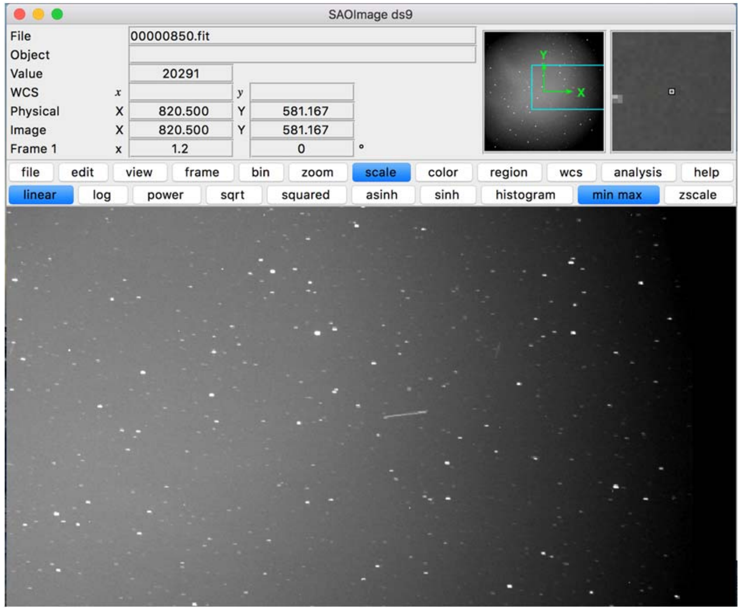
RA error: 230 ± 40 arcseconds

Dec error: 174 ± 21 arcseconds

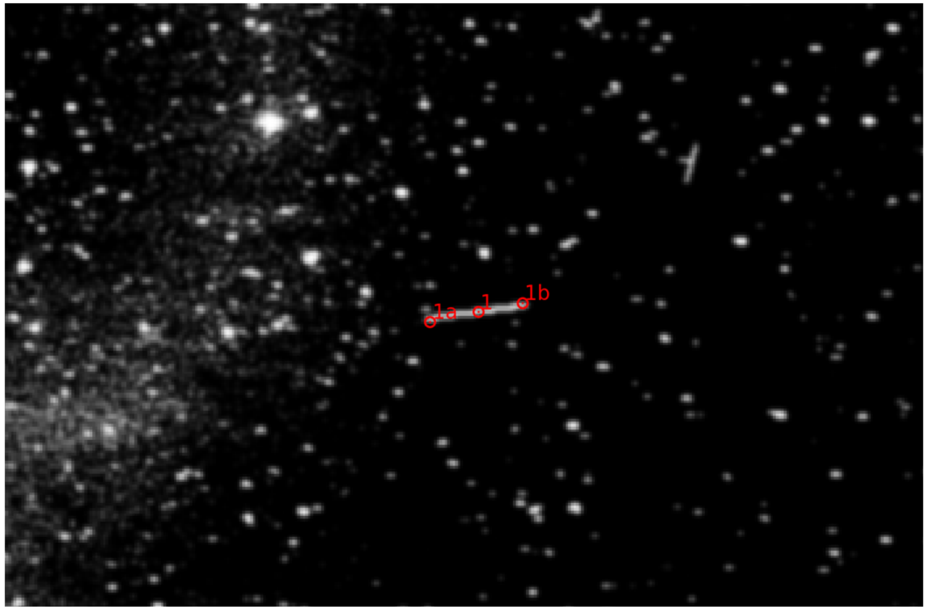
End of passage

Sidereal Tracking - example

RAW IMAGE

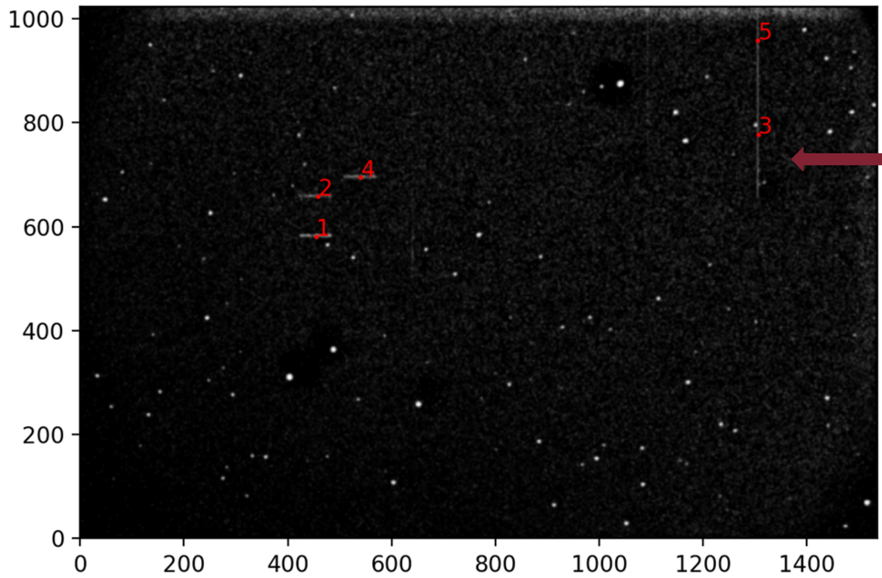


PROCESSED IMAGE: with identified object



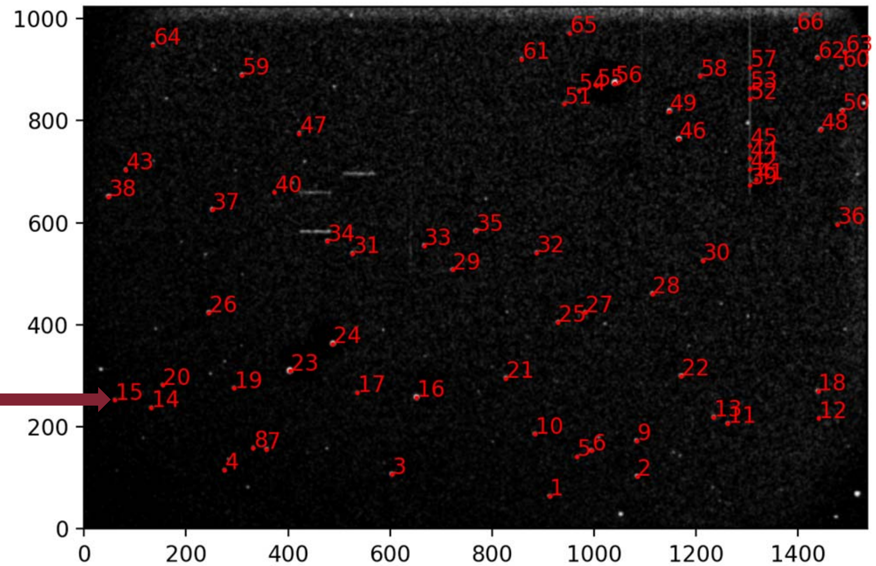
- Once the object has been identified the stellar field can be solved (astrometric solution) and its celestial coordinates can be inferred.

Stellar Background Identification – Celestial Coordinates determination



From the BITMAP image moments of inertia of the found objects are computed and objets are identified ($I > I_{threshold}$) finding the CM of the corresponding pixels

The same procedure is then performed on a BITMAP image, properly thresholded to identify stars, computing the star positions (CM of the star pixels)



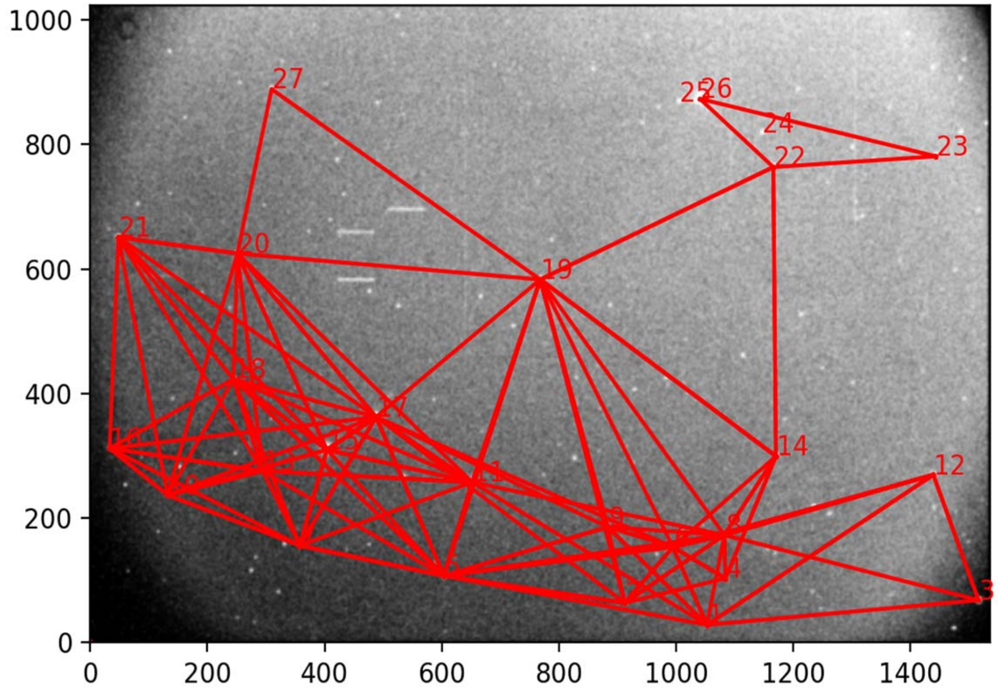
Stellar Background Identification – Celestial Coordinates determination

Once stars and objects are identified in the image the celestial coordinates of the center of the image are extracted from the header file.

An index file reporting the triangles characteristics is then generated from the star catalogue Tycho2

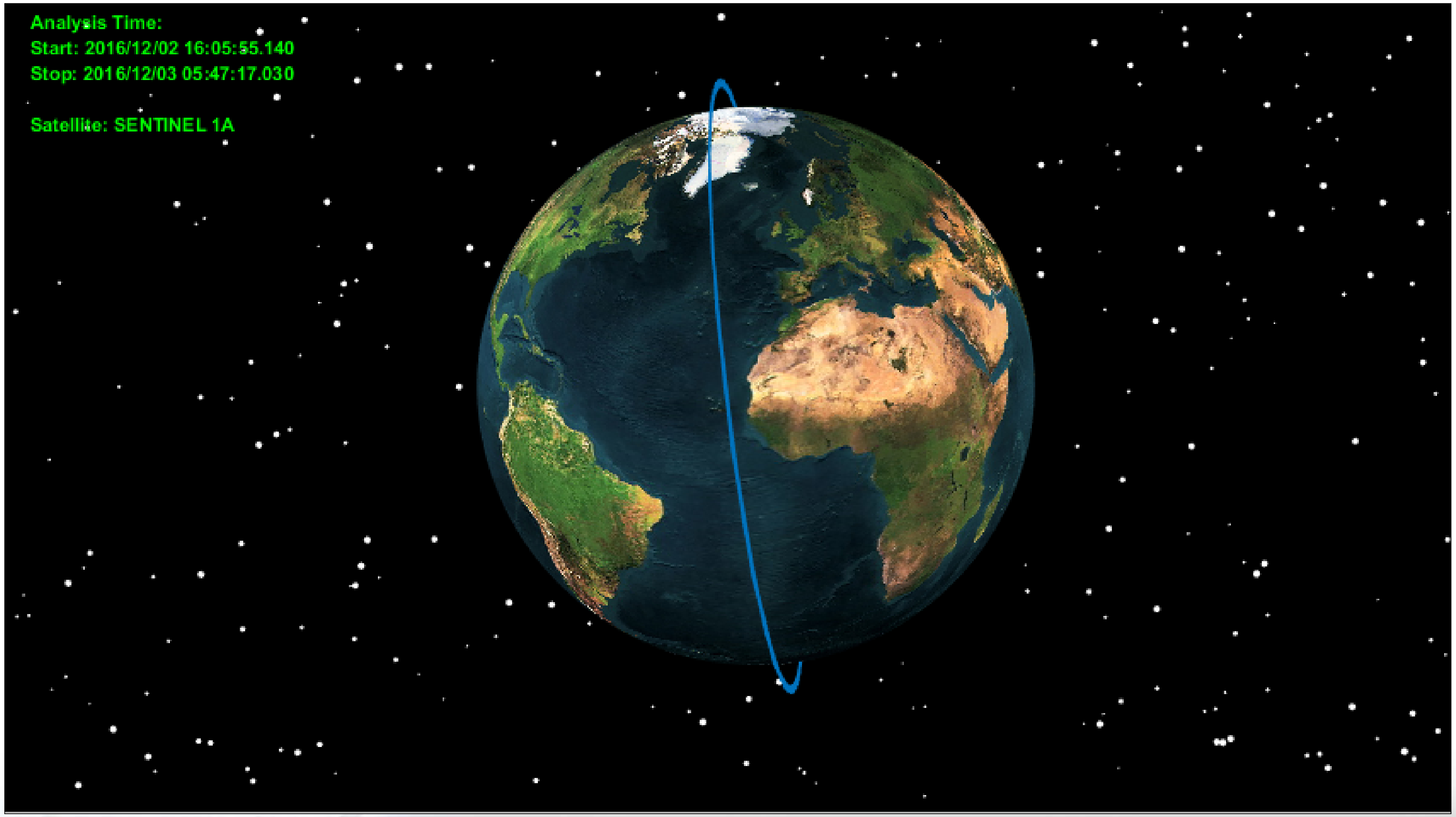
The same file is then generated considering the star positions identified in the image

Image and catalogue index are then scanned looking for matching triangles



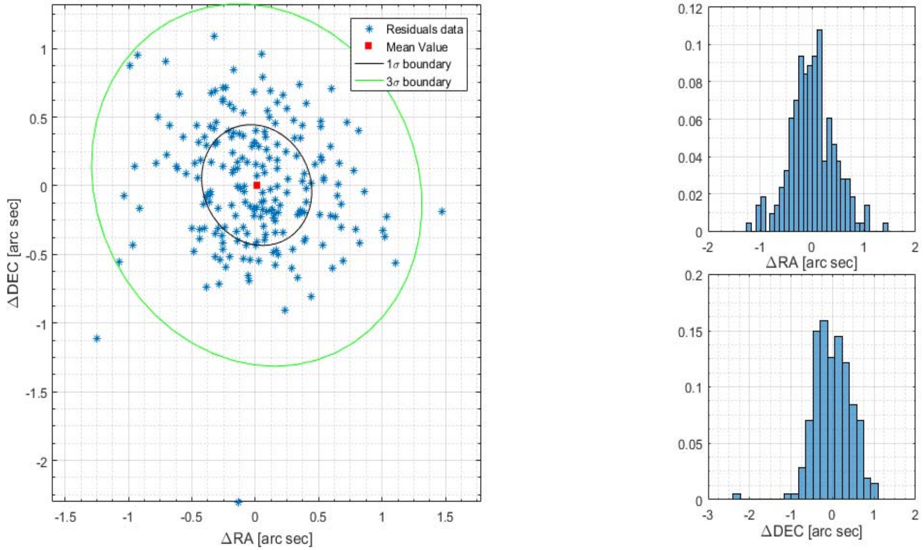
Orbit Determination

All the measures are integrated to evaluate the orbital parameter of the object

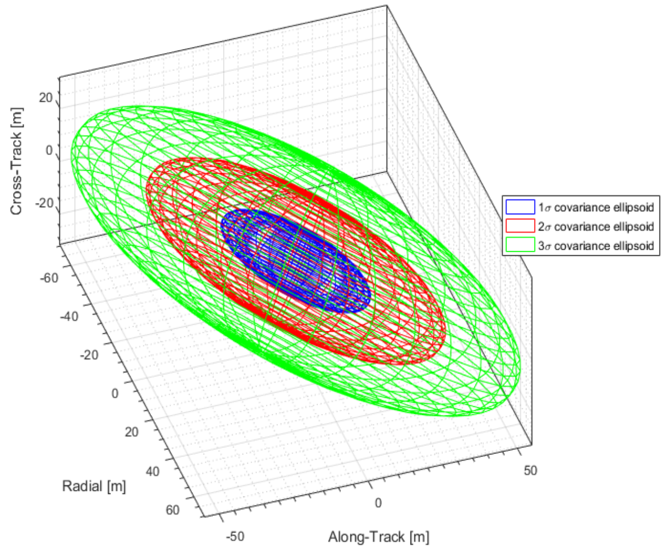


Orbit Determination

Geostationary Satellite Residuals

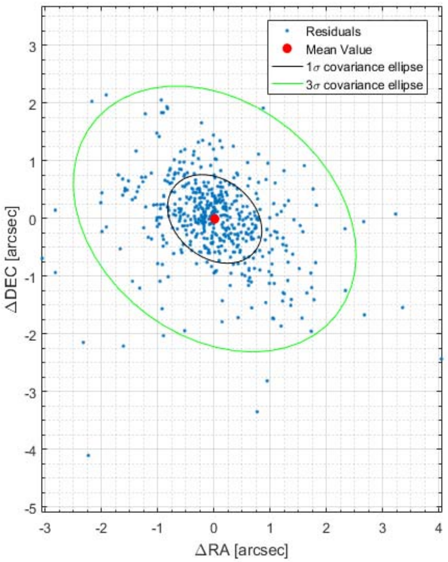


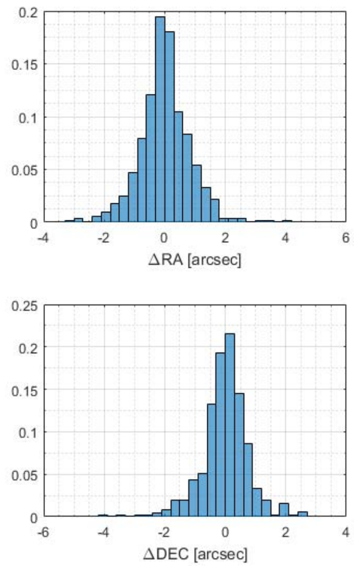
Geostationary Satellite Covariance Ellipsoid



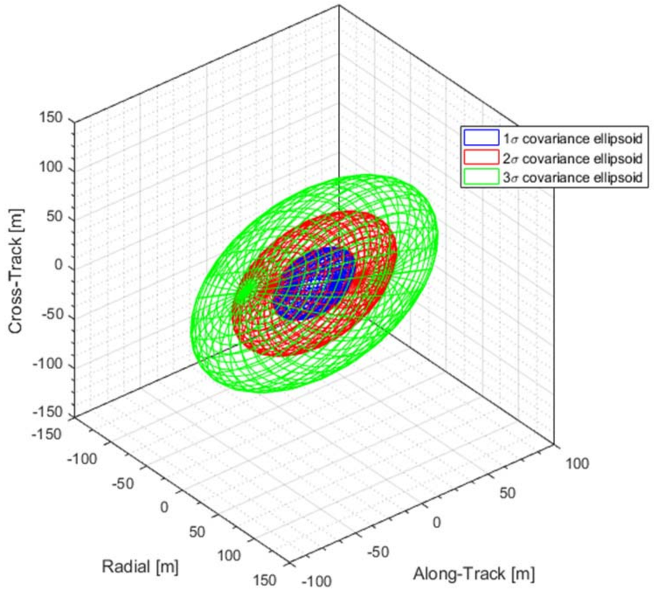
Orbit Determination

GPS Satellite Residuals





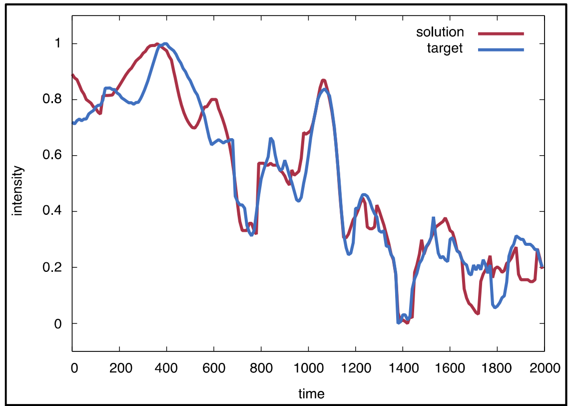
GPS Satellite Covariance Ellipsoid



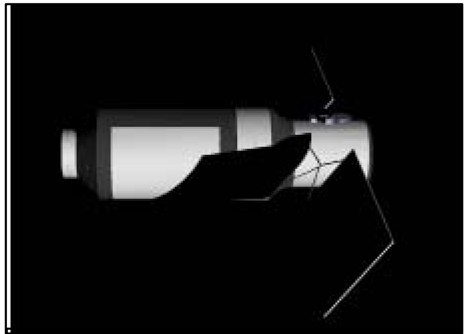
Light-curve analysis

The acquired images can be exploited for analysing the luminosity changes of the identified target. By knowing the observable geometry and materials, it is possible to reconstruct the attitude of the object.

Acquired image



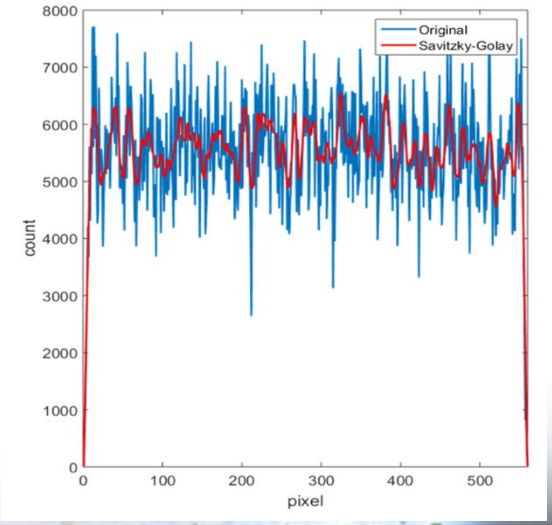
Analysis of the tracklet luminosity



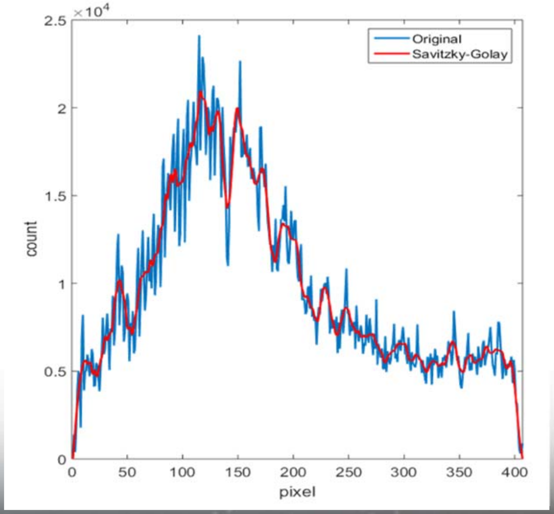
Attitude reconstruction

Light-curves analysis examples

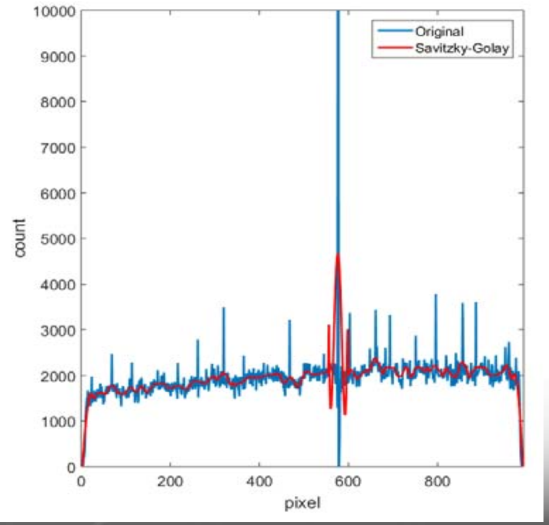
SSN 20491: H-1 R/B



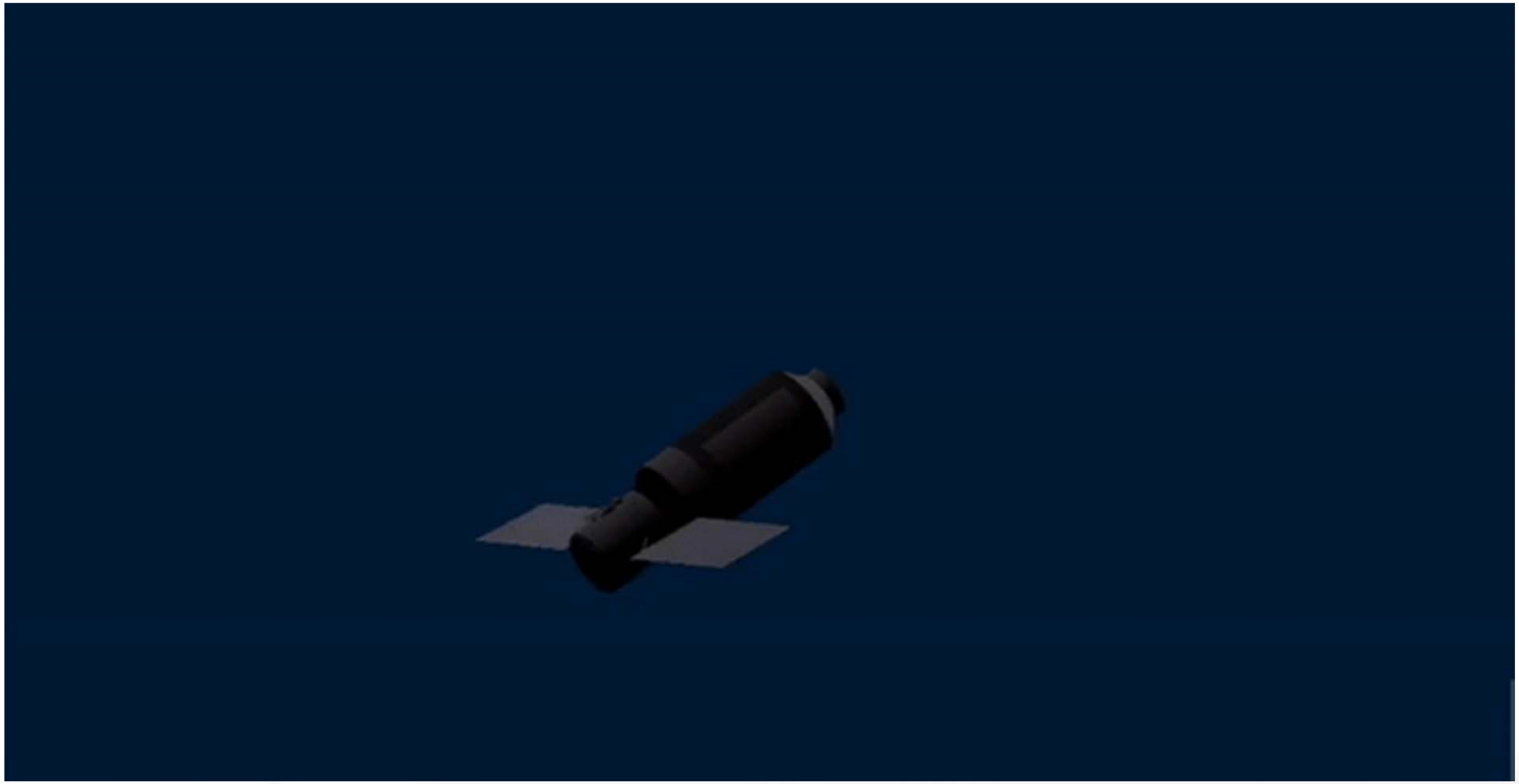
SSN 27386: Envisat



SSN 37820: Tiangong-1

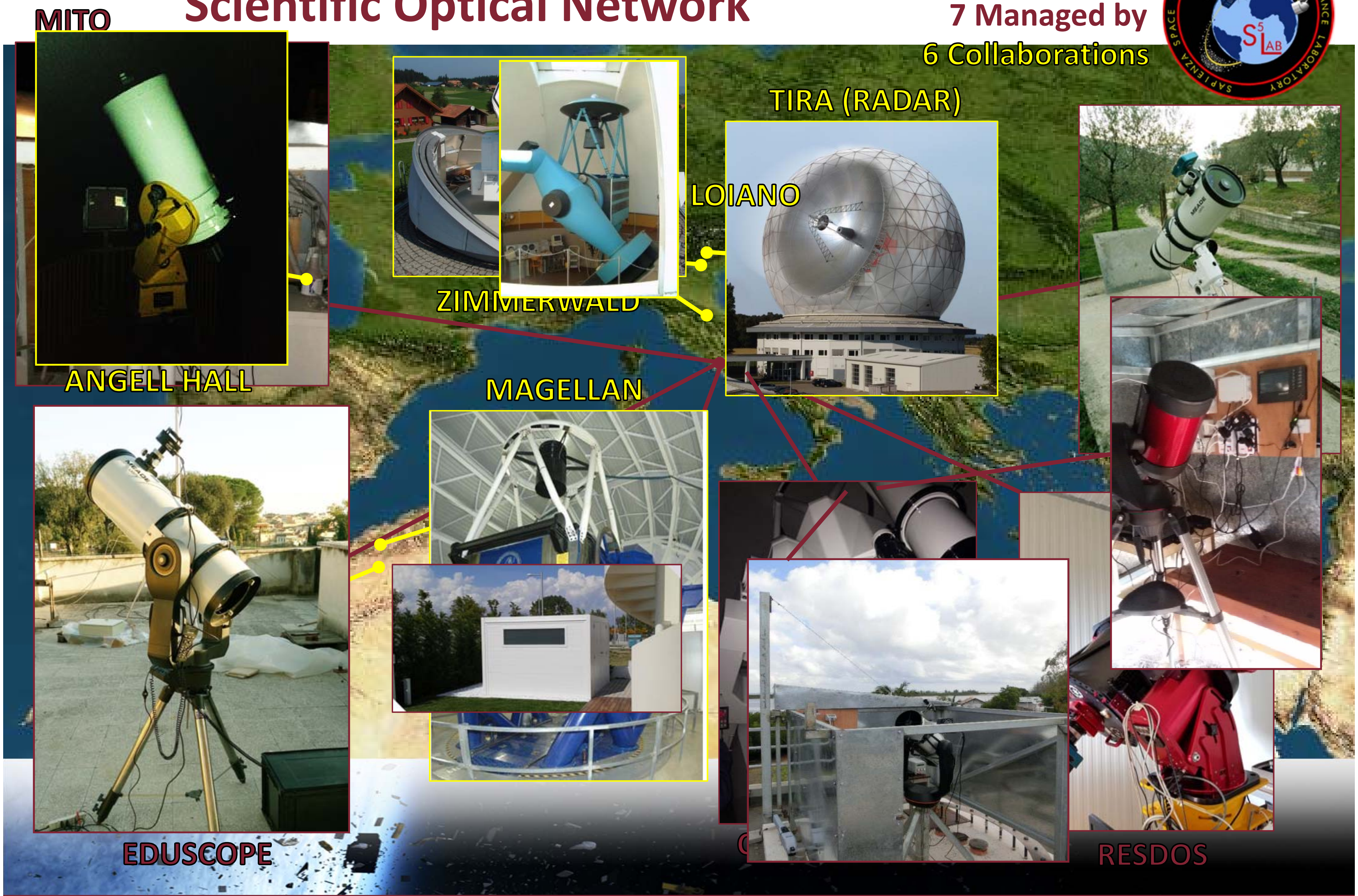


Tiangong-1 reentry analysis



Scientific Optical Network

7 Managed by
6 Collaborations

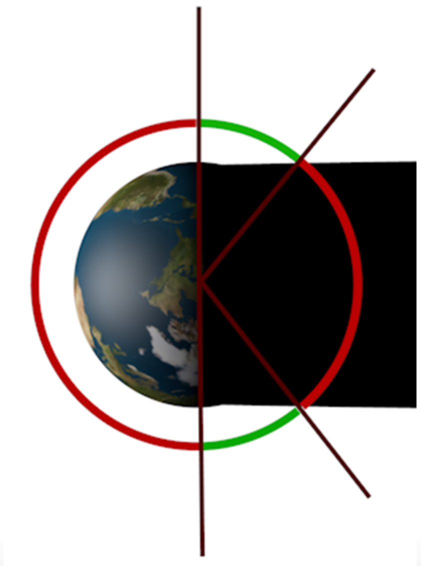


Why more than a single telescope?

- Optical observations are constrained by weather conditions of the observational site;
- The observations can be performed only when the observational site is in darkness and the target is in Sunlight. The suitable angular range is restrained to small regiones at dawn and dusk.

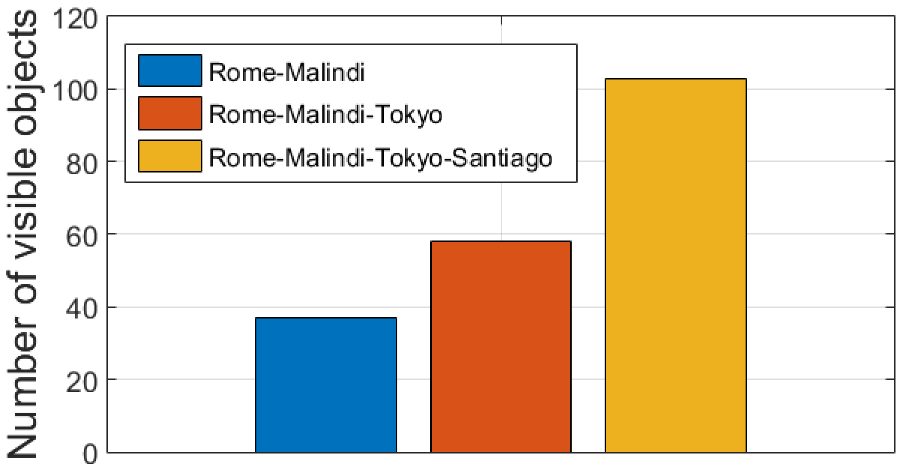
OBSERVATIONAL CONSTRAINTS → Weather

OBSERVATIONAL CONSTRAINTS → Light



Why more than a single telescope?

- With an observational network of observatories dislocated on multiple continents, the coverage over debris visible passages increases exponentially.
- As example, let us compare the visible passages number of example configurations of two/three/four observatories.



The analysis has been performed on the average number of visible passages in a single week of the 100 brightest objects.

Introducing GUSDON

- A Global Observation Network for space debris that involves a great number of institutions in all continents
- An invaluable space debris infrastructure with a great educational return in the field of:
  - ❖ Hardware installation, operations, control
  - ❖ Data analysis of raw images
  - ❖ Data integration for orbit determination
  - ❖ Optimal observational strategies evaluation
  - ❖ Light-curve and spectroscopic analyses

Introducing GUSDON: Hardware

- Institutions interested in establishing an optical observatory can profit from a reliable, modular architecture
- Affordable components can achieve valuable results in debris identification and tracking
- Already existing telescope stations will join by adapting their observatories

Observatory Standard Architecture

The modular architecture for the observing station is composed of:

- A Newtonian telescope with large FoV (approx. 1.5 degrees);
- A PC controllable motorized mount;
- A high resolution VIS CCD;
- Tools for the scheduling of the operations;
- (Optional) Shelter design;

Introducing GUSDON: Data

- As baseline data distribution principle, the entire data set acquired from all the observatories should be made available to all the involved institutions
- The de-localization will help in covering all the visible passages of observations targets
- There is strenght in numbers: the larger is the network, the more accurate will be the results of the orbit determination process
- The contribution of the network may be critical in the case of re-entry observational campaigns, as done by Sapienza for the Tiangong-1 station in early 2018.

Why joining GUSDON?

Space debris research

- An invaluable research tool for identification, monitoring and tracking of space debris
- A potentially critical tool for the observation of re-entering objects

Space debris education

- Students will familiarize early in their University curricula with the space debris issues;
- Students and researchers will be involved in:
  - ❖ Collection of space debris images and observational campaigns;
  - ❖ Angular measurement extraction and raw data analysis;
  - ❖ Advanced space debris determination;
  - ❖ Analyses focused on the space debris attitude determination (photometry, spectroscopy, etc.)