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Global University Space Debris Observation Network (GUSDON)

Fabio Santoni, Fabrizio Piergentili (Sapienza University of Rome)
and Rei Kawashima (UNISEC-Global)

UNISEC is very active in spreading knowledge and making students aware of the space debris global thread, stimulating them to find solutions for a cleaner space.
Several Universities around the world are active in space debris observation using telescopes. Basic, but still significant and useful measurements, can be obtained by using a quite affordable equipment.
Many measurements of the same object are necessary for accurate orbit determination. These can be achieved by single telescopes, but the accuracy of the overall orbit determination process is strongly limited by the relatively short arc of the orbit observable by single sites. If data gathered by a network of many telescopes are available, the global observation time, the number of objects tracked and the accuracy of the orbit determination would be greatly improved.
The Sapienza Space Space Systems and Space Surveillance Laboratory (S5Lab) has a long experience in space debris observation using telescopes. A small network of observatories was established. Students are involved in space debris observation activities very early in their curriculum, familiarizing with activities ranging from collection of single images to angular measurement extraction and advanced orbit determination techniques.
Being part of the UNISEC Consortium, the idea is to share this experience with UNISEC partners, establishing establishment the UNISEC - Global University Space Debris Observation Network (GUSDON).
The paper will describe possible affordable implementation of scientific and education observatories, specifically designed for space debris observation, with
the aim to involve interested universities in building a global network of space debris observatories, sharing a valuable scientific tool, which can mutually beneficial for all the partners.

Biography

Fabio Santoni

Fabio Santoni received PhD in Aerospace Engineering at Sapienza University of Rome. He is presently Associate Professor in Aerospace Systems at the Dipartimento di Ingegneria Astronautica, Elettrica ed Energetica (DIAEE) of University of Rome “La Sapienza”, where he established the Aerospace Systems Laboratory. He is delegate for the Italian Space Agency in the IADC (InterAgency Space debris Committee) and in the UNCOPUOS (United Nations Committee On Peaceful Use of Outer Space). He is point of Contact in Italy for UNISEC (University Space Engineering Consortium). His research activity is mainly devoted to nanospacecraft design, attitude determination and control, space debris observation, mitigation and remediation techniques, including end-of-life disposal and active debris removal.

GUSDON

Global University Space Debris Observation Network

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SAPIENZA UNIVERSITÀ DI ROMA

UNISEC GLOBAL University Space Engineering Consortium

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Contents

- Optical space debris observation for university students
- Experience at Sapienza Space Systems and Space Surveillance Lab - S5Lab
- Proposal for a:

Global University Space Debris Observation Network

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Sapienza Space Systems and Space Surveillance Laboratory (S5Lab)

- Established in 2014
- Research and education in space systems and space surveillance
- Collaboration with space agencies (ASI, ESA) and other institutions (U-M, AIUB-Bern, ISON, UONBI)
- Main project topics:

❖ Space surveillance

- Optical observation systems
- Data analysis
- Orbit determination
- Attitude Determination

❖ Satellite systems

- Design, development, operations of space systems
- Stratospheric balloon payloads
- CubeSats

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Space Engineering hands-on education at S5-Lab

BSc (third year engineering)

- Space Systems Introductory Course (design "on paper", CAD models)
- Participation to international contests (e.g. UNISEc's MIC)
- **Introductory practical activities:**
  - ➢ **mission program development: stratospheric ballon experiments (REXUS-BEXUS)**
  - ➢ ***Optical space debris observation***
  - ➢ **Satellite operations in the ground station**

MSc (fourth-fifth year)

- Satellite design in CEF (Concurrent Engineering Facility)
- **Participation in satellite programs:** **satellite design, project planning, parts procurement, schedule organization, international conferences, interface to launch provider, contracts with hardware and service providers**
- ***Orbit Determination using optical measurements***
- Internship and/or part time job in partner companies

PhD (Three years program)

- Professional research activity
- **Leadership in satellite and *space debris observation* programs**

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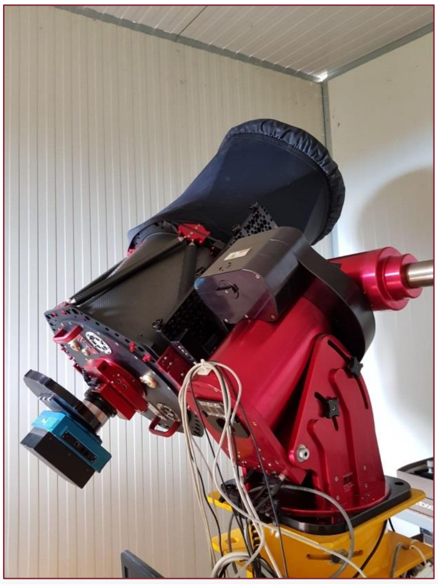
Typical University Observatory Configuration

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**



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 $< 25\ cm$
- **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

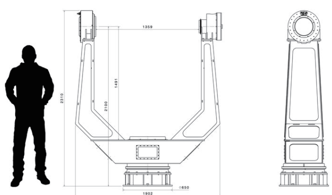
Radar OD Alghorythms

- Investigation of Adaptive IOD algorithms during beam-park experiments (observation time < 10 sec).
- Development of Adapted Tracking Filters for follow-up. A number of different real time filters are going to be used and compared.

Spin-off: Dedicated professional instrumentation

1 m class Alt-Az mount

Maximum telescope weight: 500 kg
Ultimate telescope weight: 1000 kg
Maximum speed: >30° deg/sec (up to 45 deg/sec currently tested)
Angle measurement resolution directly on the axes: 0,01 arcsec



NPC new production concept

SPACE MIND

BSc Student Program on Observatory Activities

- Fundamentals of optical observation
- Observatory hardware installation and functional testing
- Observatory software: available + custom developing assignments
- Active participation in observation campaign

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Sapienza (low cost) Scientific Observatory Network

MITO: 25.0 cm diameter.
Total field of view is about 3.5° x 2.5°

EDUSCOPE: 25.0 cm diameter. FOV 2°x2°

EQUO OS: 15.0 cm diameter. The total field of view is about 0.5° x 0.5° degrees

EQUO OG: 25.0 cm diameter telescope
The total field of view is about 2.2° x 2.2°

FASTSCOPE: 10 cm diameter telescope
The total field of view is about 0.5° x 0.5°

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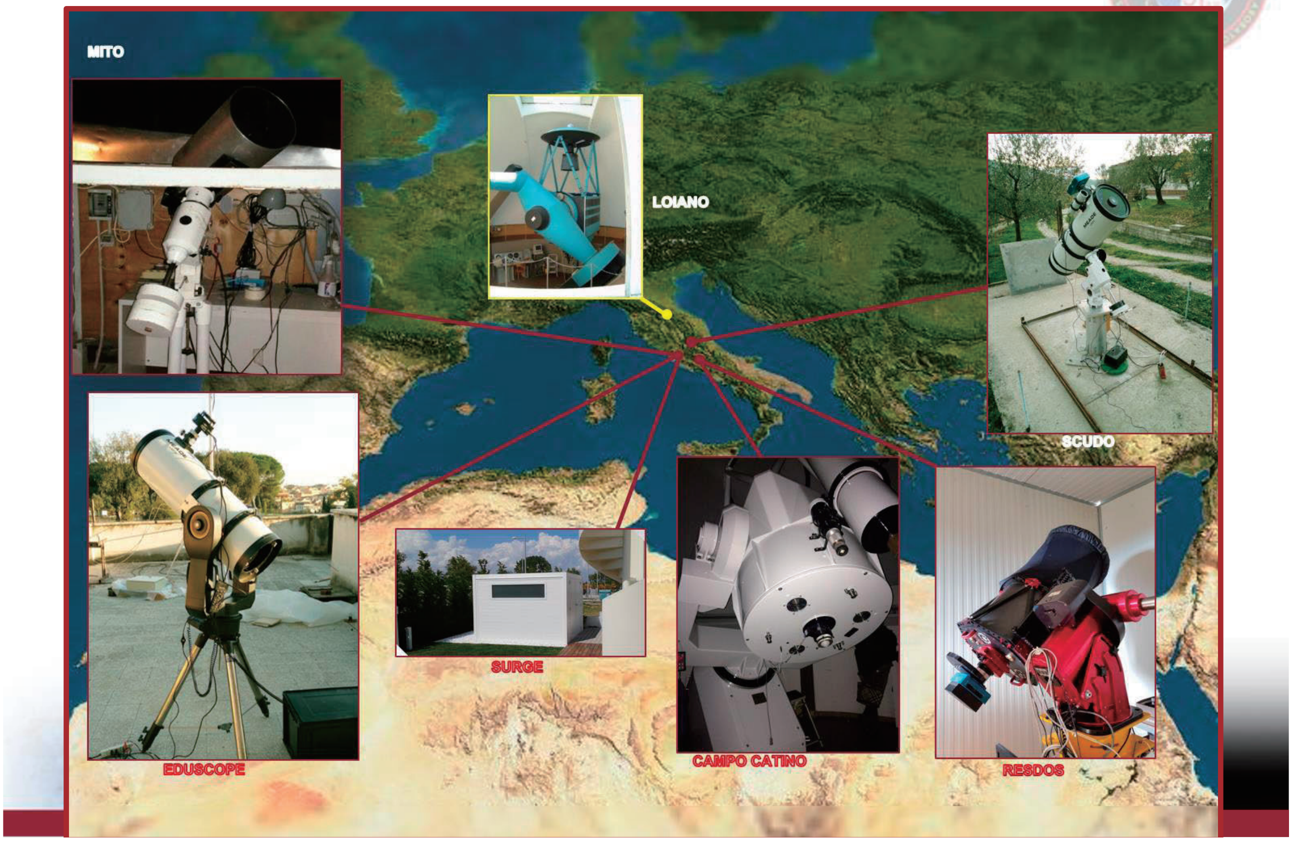
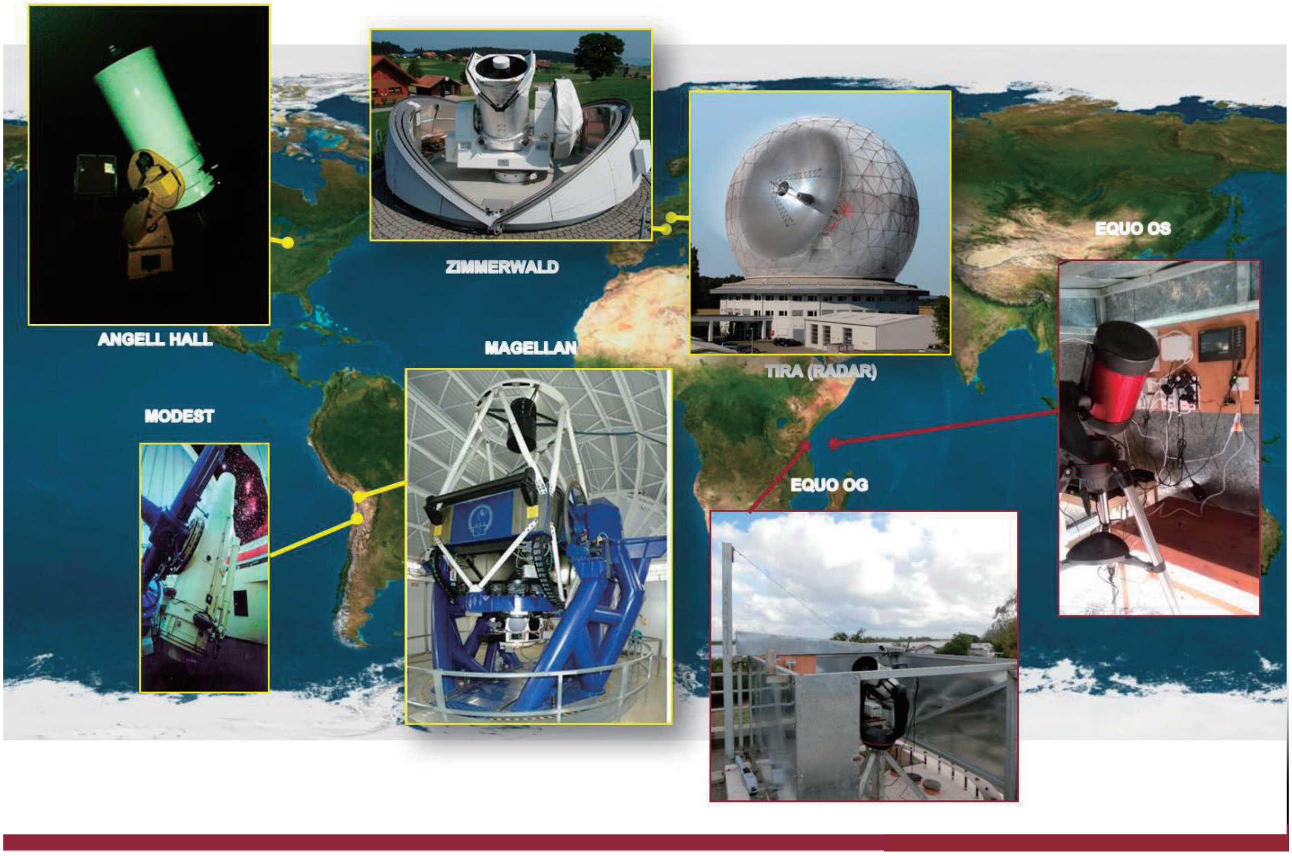
Scientific Optical Network



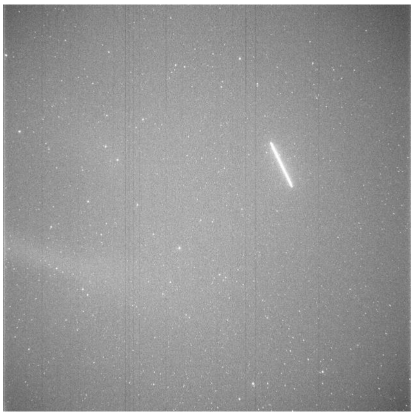
International Collaborations



Introduction to optical space debris observation techniques

- Sidereal tracking
- Target tracking

SIDEREAL TRACKING: Tiangong1



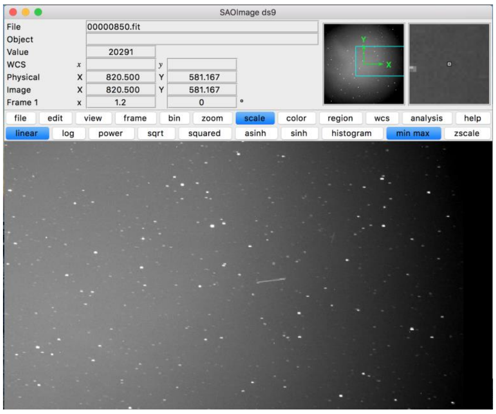
TARGET TRACKING: two GEO satellites

Image analysis for object identification

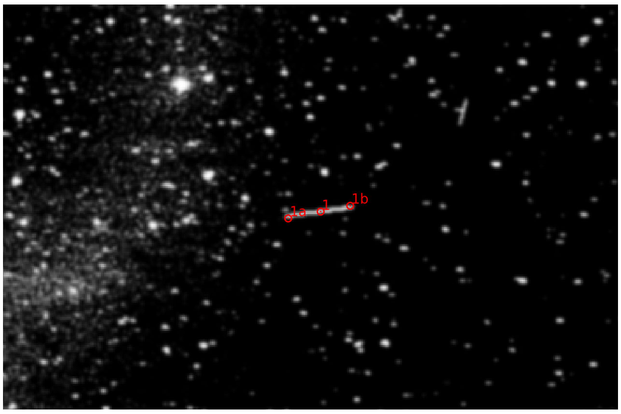
Software for:

- **automatic image processing**
- **object identification** within the star field

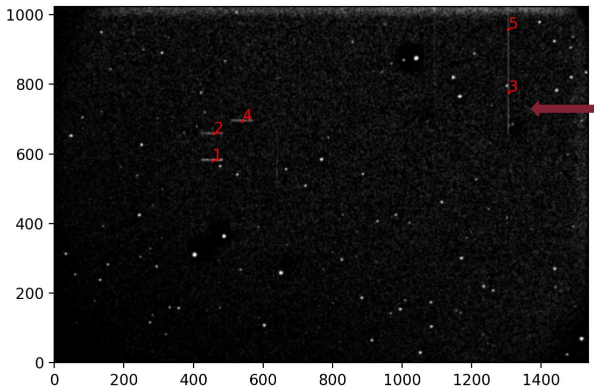
RAW IMAGE



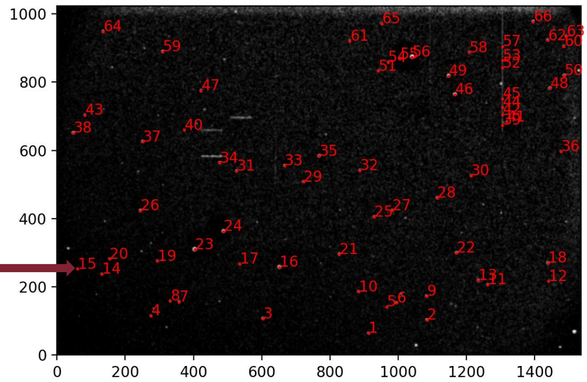
PROCESSED IMAGE: with identified object



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.

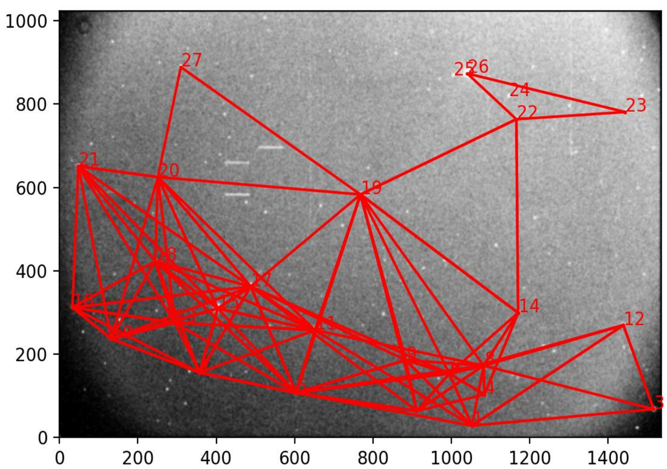
↓

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

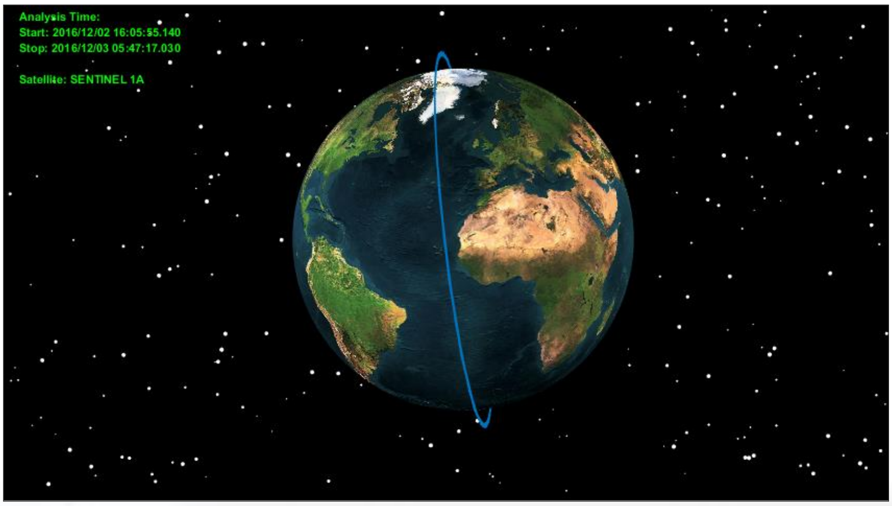
↓

Image and catalogue index are then scanned looking for matching triangles



Orbit Determination

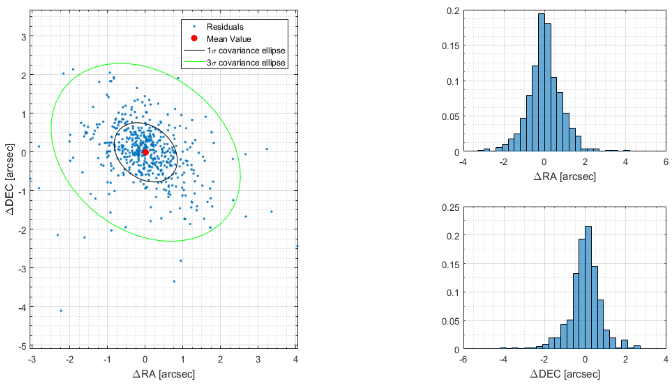
Angular measurements are integrated to evaluate the object orbital parameters



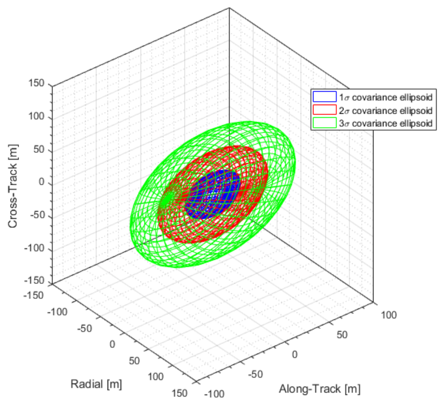
Orbit Determination for instrument calibration

- Comparison of orbit obtained through optical measurements with very accurate GPS satellites' ephemerides

GPS Satellite Residuals

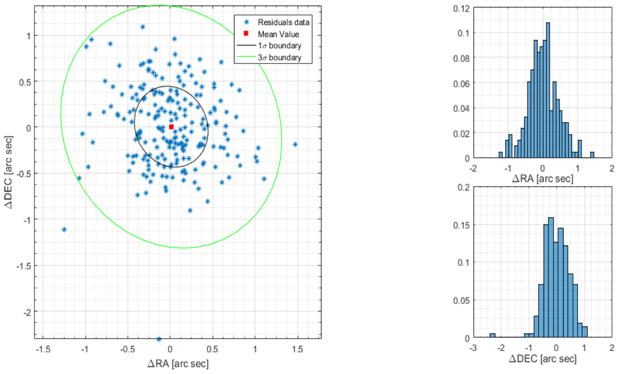


GPS Satellite Covariance Ellipsoid

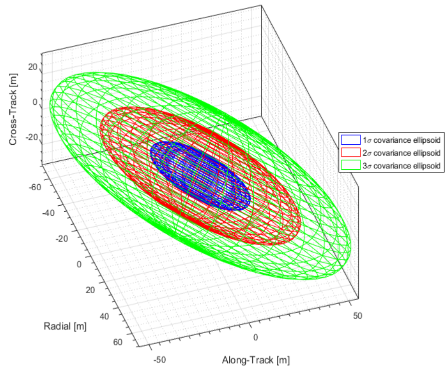


Orbit Determination

Geostationary Satellite Residuals

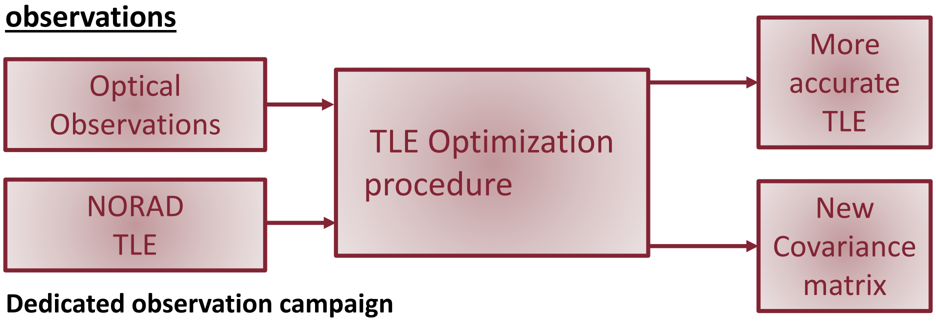


Geostationary Satellite Covariance Ellipsoid



Orbital parameters accuracy improvement

- Up-to-date dynamical state estimation is of paramount importance during re-entry observation campaigns. NORAD Two Line Elements of LEO objects accuracy soon degrades.
- **TLEs accuracy can be improved using a few one-site optical observations**



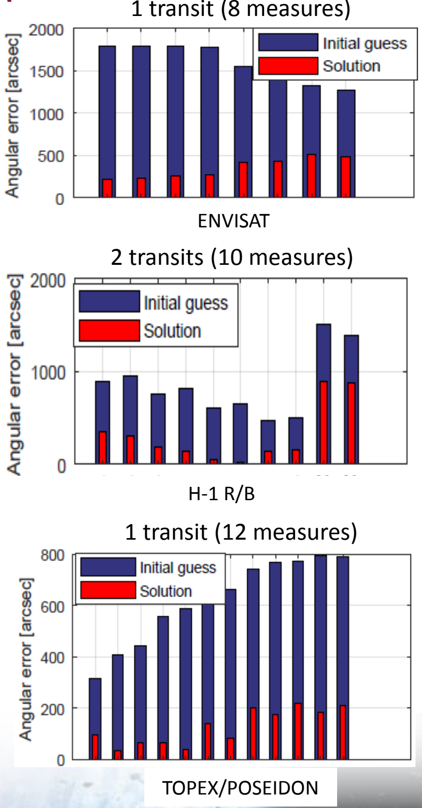
Dedicated observation campaign

Target:

- Envisat (8 observations, 24 March, 2 transits)
- H-1 R/B (9 observations, 27 March, 1 transit)
- Topex Poseidon (8 observations, 2 July, 1 transit)

Observatory: MITO (Rome)

TLE improvement - Test Cases



Orbit determination is performed through a one-night fit span using the most recent TLE as the initial guess.
The new and old TLE residuals are compared after one day.

OBJECT	NORAD TLE	SOLUTION TLE
ENVISAT	1602.56"	353.49"
H-1 R/B	858.75"	315.06"
TOPEX/POS.	628.41"	127.14"

Mean error after one day

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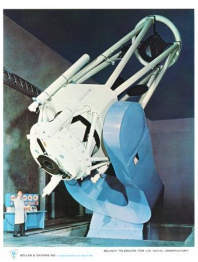
Sapienza Main Activities in Photometry for Attitude Determination

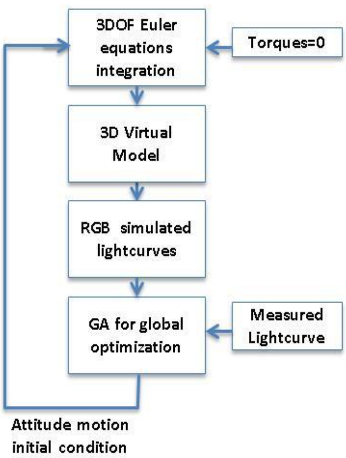
Attitude Determination from Light Curve:

Target: **GSAT-3** (GEO non operative satellite)
The data was obtained on two telescopes:

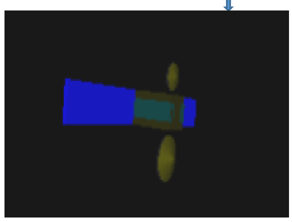
- 0.6-m MODEST in Chile;
- 1.3-m U.S. Naval Observatory Flagstaff telescope.



Piergentili, F., Santoni, F., Seitzer, P., "Attitude Determination of Orbiting Objects from Lightcurve Measurements ", IEEE Transactions on Aerospace and Electronic Systems (Volume: PP, Issue: 99), 2017, DOI: 10.1109/TAES.2017.2649240



GSAT-3 real world

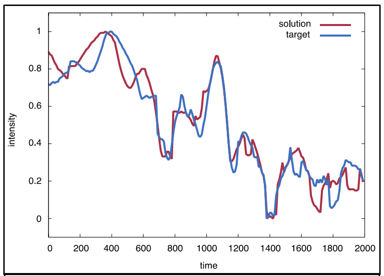


GSAT-3 virtual reality model

Photometry: 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.

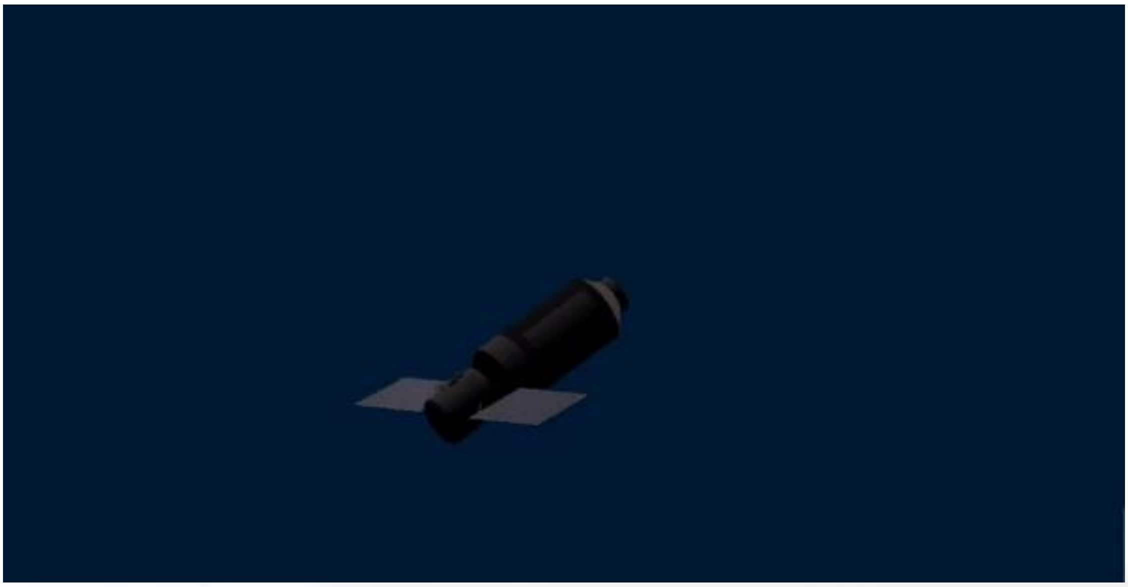
Acquired image



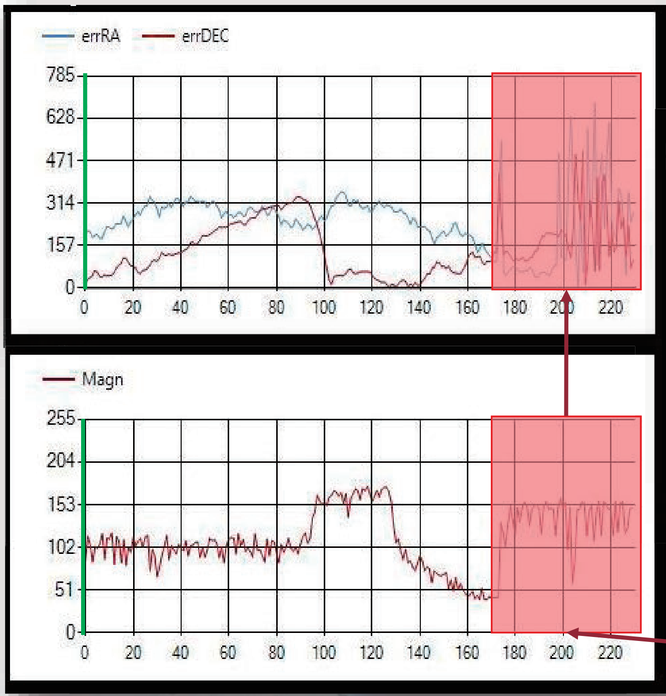
Analysis of the tracklet luminosity

Attitude reconstruction

Tiangong-1 reentry analysis



Real time LEO tracking



Real time tracking of COSMOS 1340:

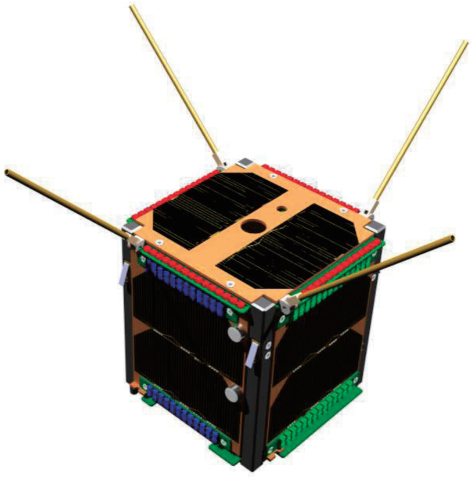
- $T_{exp} = 0.2$ s
- $mag_{sat} = 4.0$

RA error: 230 ± 40 arcseconds

Dec error: 174 ± 21 arcseconds

End of passage

IKUNS-B (LEDSAT) 1U CubeSat



Primary Mission Objective

To **investigate the performances** of a technology based on **LEDs** for the LEO satellite tracking by means of **optical observations** during night-time

Secondary Mission Objectives

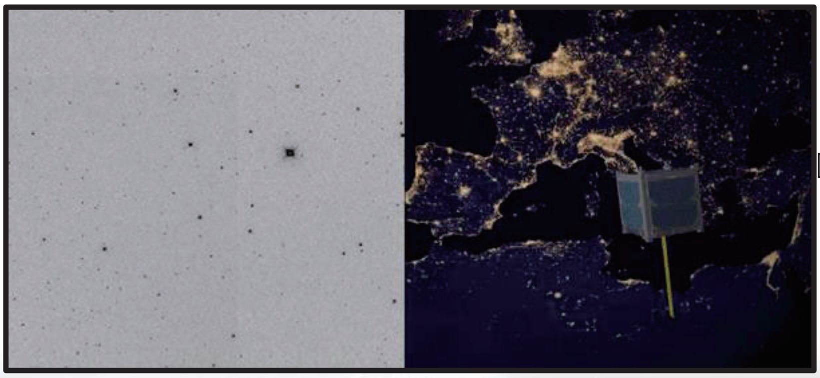
1. To collect photometric optical measurements of a satellite equipped with a technology based on LEDs for getting information about its **attitude**

1. To test a **LED-based optical communication** system to be used as back-up strategy in case of failure of the TT&C subsystem

Nominal Mode

Using the LEDs for orbit determination

Determine orbit using optical observations → Information about the real orbit from GPS, NORAD or laser ranging → Comparison between the gathered data to validate the proposed technique



→ Example with LEDs flashing Morse for R, B and G on the different faces

LEDSAT attitude determination

1. Using the LEDs to get information about the attitude

Tool for attitude determination based on optical measurements already available

- Comparison between the virtual model and the measurements
- Minimization of a cost function to obtain attitude information

Different (orthogonal) patterns will allow to identify the satellite face pointing towards the observer

Estimated attitude is compared with on-board data

GUSDON

Global University Space Debris Observation Network

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6th UNISEC Global Meeting
19-21 November 2018, International Space University
Strasbourg, France

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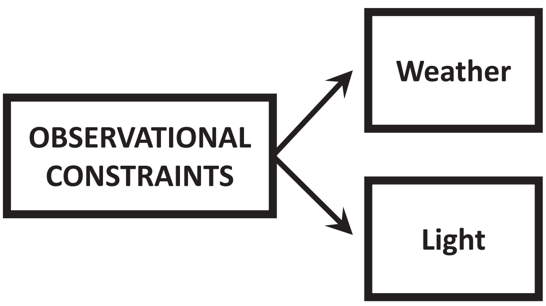
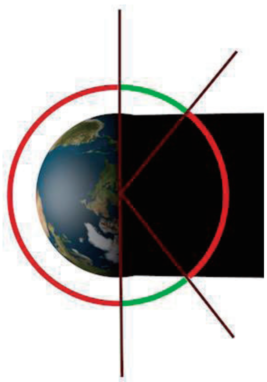
Why many observatories?

Limitations of optical observation:

- Weather conditions
- Light conditions
  observation possible only when the observatory is in the dark and the target is in the sunlight: Observed orbit arc only at dawn and dusk (mainly in LEO)





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Motivation for *GUSDON*

- **Education**
  Stimulate students in space debris activities through
  - hands-on experience
  - international cooperation
- **Research**
  - Increased observation time (weather and visibility)
  - Orbit determination algorithms
  - Multiple-site synchronised observations
    (e.g. light-curve inversion; trianguations….)
  - Share common practices towards scientific standards for calibrated data sharing
- **Enlarge space debris observation community**
  Tool for introducing "newcomers" in space debris observtion (similarities with Cubesats in spacecraft engineering)

GUSDON: hardware

- **Affordable** components can achieve valuable results in debris identification and tracking
- Already existing observation stations can join by adapting their observatories
- "Newcomers" interested in establishing an optical observatory can profit from a reliable**, low cost modular architecture**
- Objective: establish a shared operation standard

GUSDON: hardware

Observatory Standard (low cost) Architecture

- Newtonian telescope (25 cm aperture)
- Large FoV (approx. 2x1.5 degrees);
- Remote operation: PC controlled motorized mount
- High resolution VIS CCD
- Hardware for accurate timing
- (Optional) Shelter design

GUSDON: Data and observation time sharing

- Data distribution principle (baseline), **the entire data set acquired from all the observatories should be made available to all the involved institutions**
- Observation time: can be shared between “own” and “participated ” observation campaigns
- **At least 50% observation time devoted to “participated”**
- Full time devoted to “participated” in critical events of international interest, (e.g. **explosions in orbit or re-entry events**)

Why joining *GUSDON* ?

Space debris research

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

Space debris education

- Students will **familiarize early in their curricula** with the space debris through **hands-on experience**
- Students and researchers will be involved in:
  - ❖ Collection of space debris images and observational campaigns;
  - ❖ Angular measurement extraction and raw data analysis;
  - ❖ Space debris orbit determination;
  - ❖ Advanced topic: space debris attitude determination (photometry, spectroscopy, etc.)

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How to involve people: Training Course in Rome (Planned)

Theoretical Training

- **To become familiar with space debris optical observation**
  - ❖ **applied orbital dynamics**
  - ❖ **astrometry**
  - ❖ **photometry**
  - ❖ **Etc…**
- **To understand the key aspects for a successful observation campaign (exposure, telescope settings, timing, scheduling, prioritization…)**

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Training course in Rome (Planned)

Practical Training

- To become a proficient user of the (standardized) observatory
- To be able to carry out observation campaigns without external support
- To perform basic observatory maintenance

At the end of the course, interested institutions can rent or buy telescopes for on-site training and for kicking off their observations!

Education and Scientific Return

- To understand the major sources of scientific and educational return for all the people to be involved in the observatory network project

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Conclusions

- Making students familiar with space debris **early in their studies** is very important
- Establishing some shared international practices could be very useful
- A **G**lobal **U**niversity **S**pace **D**ebris **O**bservation **N**etwork could :
  - ➢**contribute in spreading space debris knowledge**
  - ➢**be a useful international education and scientific tool**

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One-week Training course in Rome
(official annnouncement shortly)
tentative: 2 – 7 September, Rome, Italy (TBC)

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