SPACE SYSTEMS

SUTED4L: Study for the application of SUrvey TElescope for Debris detection in HLEO orbital belt

2nd NEO and Debris Detection Conference, Darmstadt, 24-26 Jan 2023

SUTED4L study general overview

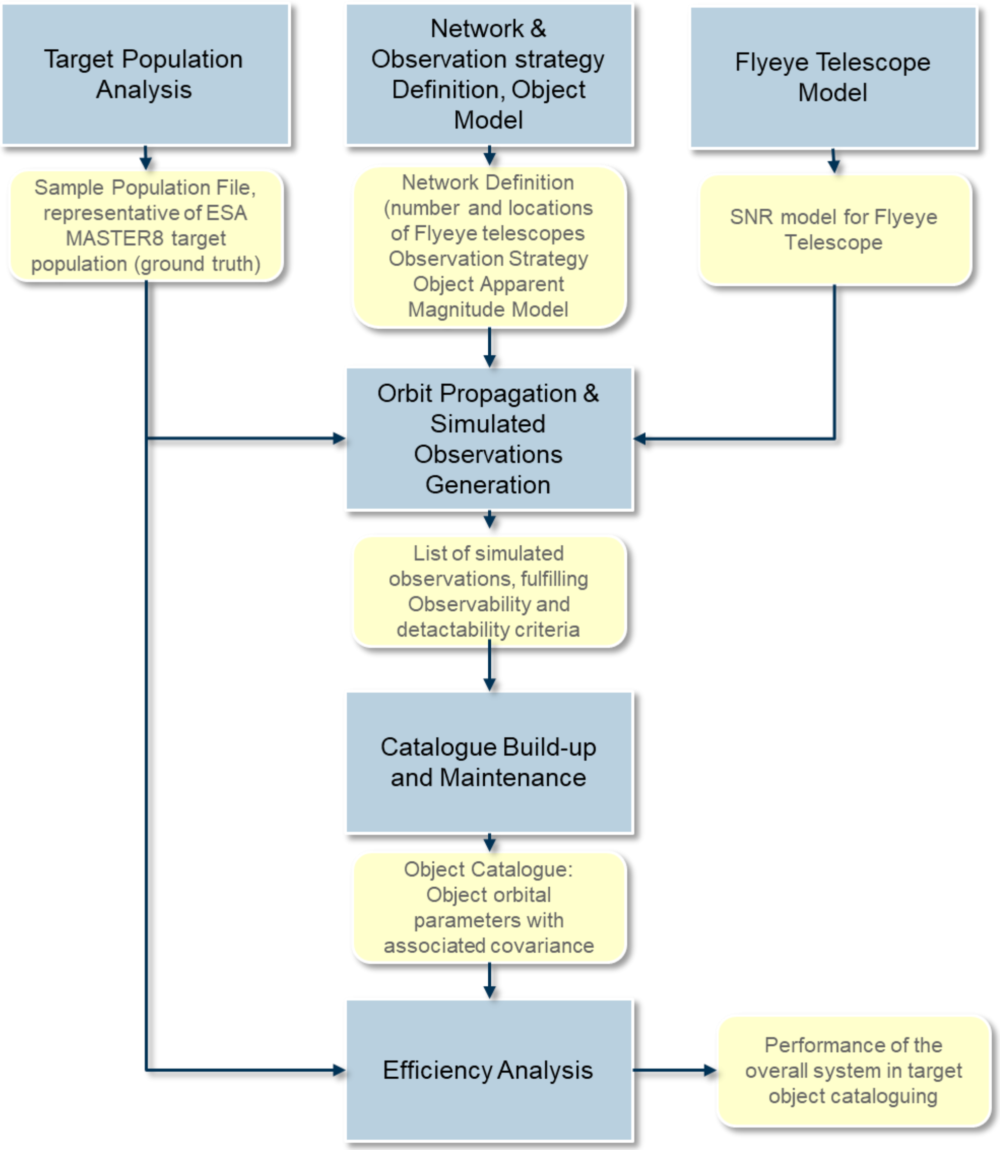
Scope of the on-going SUTED4L study - Study for the application of SUrvey TElescope for Debris detection in HLEO orbital belt - is the analysis and demonstration of the capability of a ground network of Flyeye telescopes to detect and catalogue High-LEO (HLEO) space objects (debris and satellites orbiting between 1000 and 2000 km altitude).

This presentation will describe the fundamental concepts applied in the study, as well as the details of the realistic simulation of observation and applied orbital determination algorithm, producing a realistic emulation of a debris data center operations. The very promising results in catalogue buildup and maintenance, achievable using the Flyeye network, are presented as well.

Study Flow

The simulations allowed to assess the detection performances in a realistic scenario: the term "realistic" means that all the driving difficulties of the task are addressed, so that the obtained results are reliably significant in terms of object population coverage, catalogue build up and catalogue maintenance.

The simulation cycle starts from the generation of the simulated optical measurements, passes through the data processing and ends with the catalogue of orbits, to be compared with the sample population (ground-truth).



Fundamental Study Elements

OHB ITALIA SpaceDyS

Population Model

- extracted from ESA MASTER8 model
- representative of the HLEO objects (orbiting between 1000 and 2000 km altitude), both resident and transient

Observation Strategy definition

- Observation strategy tailored for HLEO objects

Network Definition

- Number of observing sites
- Number of sensors for each site

Optical Architecture

- Detailed SNR model of the actual Flyeye Telescope

SUTED4L

Efficiency Validation

- Analysis ofnetwork and observation strategy efficiency
- Analysis of the cataloguing performances

Catalogue build-up and maintenance

- simulation of a data center behavior

Optical Observation Concept

Observable

An object passing over a station is observable at a specific time if the sun light reflected by the target object can be collectable by the selected telescope.

Detectable

It means that the object (in particular the object trail) can be detected in the acquired image. It depends on the Signal to Noise Ratio (SNR) of the observation.

Depends on...

- **Sun elevation** (station in umbra)
- **Object elevation** (>15° for telescope mechanical constraints)
- **Object lighting** (object directly illuminated by the sun)
- **Moon position** (moon avoidance angle 20°)
- **Meteo condition** (no cloud coverage)

Depends on...

- **Apparent Magnitude** (Object characteristics e.g. albedo, diameter, phase angle, distance)
- **Trail Length** in the acquired image (Object angular speed and exposure time)
- **Observation conditions** (seeing, sky background magnitude, …)
- **SNR model of the telescope** (Optical sensor characteristics: Aperture, CCD sensor characteristics, optical resolution)
- Trail detection SW performances

Main Assumptions and Hypothesis

Cold Start Catalogue

The main assumption is the construction of a catalogue of orbits from scratch, using exclusively the observations obtained from the considered network of Flyeye sensors, operating in survey mode, therefore with **no a-priori knowledge of the objects to be observed**. The maintainability of the constructed catalogue is simulated as well, using only survey observations from the same network

Trail Detection SW

In the SST survey application, the objects are not fixed w.r.t. the sky background and are acquired as trails. This mean that photons coming from the source are shared by the trailed pixel, and the trailing of the object can considerably reduce the SNR obtained on the single pixel (trailing-loss effect). **The availability of an advanced Trail detection algorithm (ATIP SW) is assumed, which integrates the signal spread along the trail**.

Tested in laboratory environment on synthetic images, ATIP will be further developed up to operational SW level as part of the Flyeye SST Network implementation tasks.

Flyeye Telescope: a unique technology

The telescope is based on a patented technology, named Flyeye, which grants high accuracy in an extremely wide Field of View (44 sq. degrees) and the astronomic resolution tailored for the Observatory sites (1.5 arcsec).

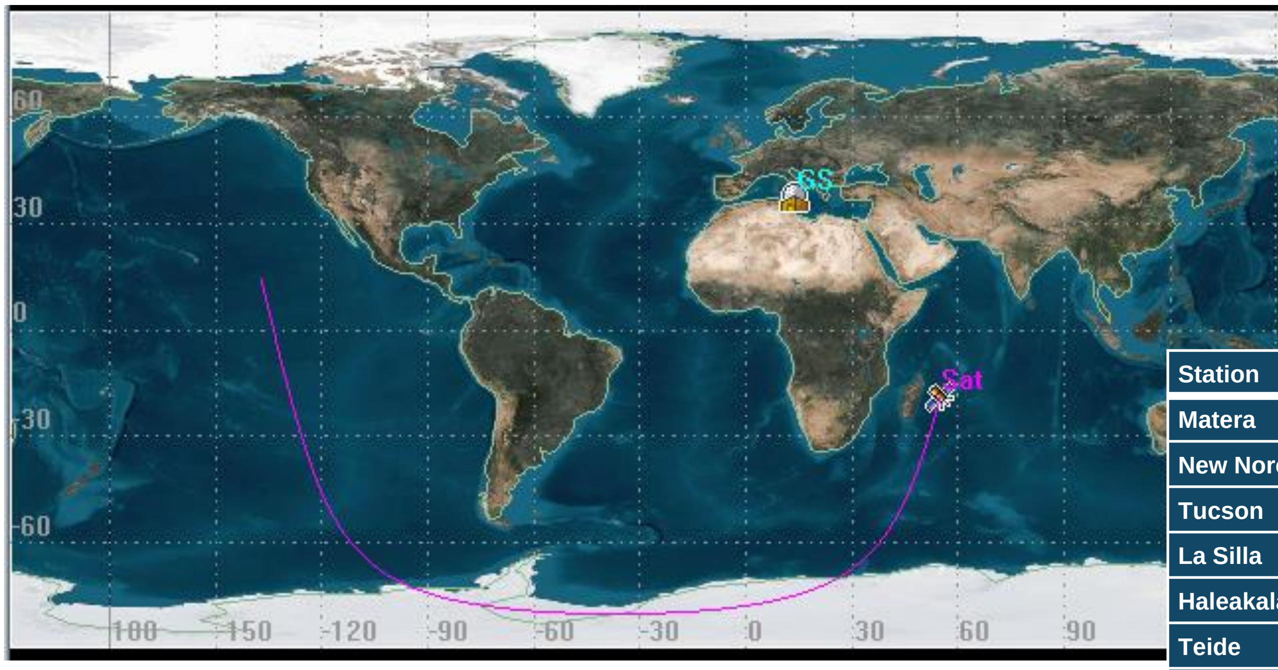
Flyeye Telescope Main Features	
Class Aperture Diameter	one meter
Entrance Pupil Shape	Circular
Field of View	6,7deg x 6,7 deg
Pixel Scale	1.5”x1.5”
Pixel Size	15 µm
Axes maximum speed	7deg/s
Axes maximum acceleration	12deg/s^2
Repositioning time (adjacent FoV), incl. image readout	4s

Flyeye Network

The selection of the telescope network must consider two major constraints:

- The meteorological correlation, to avoid to have the same bad meteorological situation
- Sites on both Earth hemisphere (and at similar latitudes) to average the seasonal effects, mainly to keep quite constant the total amount of observing hours during the nights.

The selected network includes 7 stations, each hosting 3 Flyeye telescopes.



Station	Latitude [deg]	Longitude [deg]
Matera	40.649169	16.704207
New Norcia	-31.048333	116.191944
Tucson	31.958333	-111.596667
La Silla	-29.261167	-70.731333
Haleakala	-20.7083	-156.2571
Teide	28.300917	-16.511806
Malargue	-35.773333	-69.399722

Observation Strategy Selection

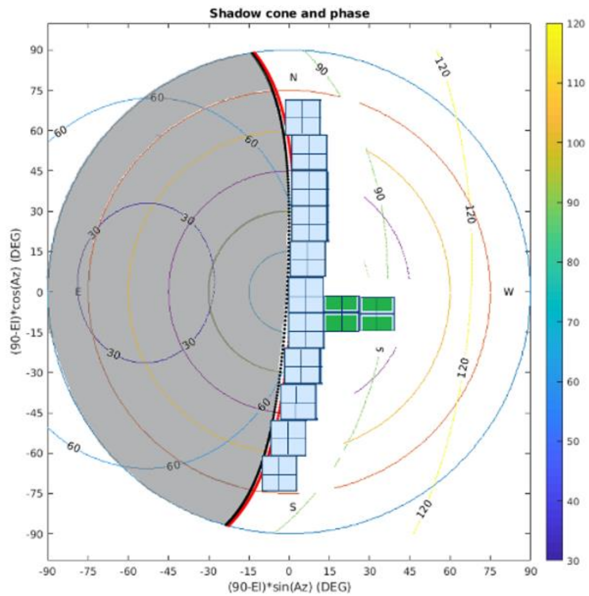
The observation strategy, in order to be effective, should be tailored on the target population we want to consider, depending on their different sky proper motion and observability constraints.

During the SUTED4L study two different approaches have been considered:

- **Equatorial fence**, covering the regions along the equator, which all the objects will pass through
- **Phase-aware fence**, focuses on detecting debris at their most favorable phase angle (the angle observer-target-Sun)

The finally selected strategy is a **mixed approach:**

- ✓ observing the border of the Earth shadow @1000km of altitude, where the debris is brighter (since its phase angle is the minimum possible just outside the shadow)
- ✓ adding a portion of equatorial fence, near to the Earth shadow cone (that shall improve the observability of certain classes of objects, such as a sun-synchronous orbit objects, that are rarely observed with a pure phase aware strategy)

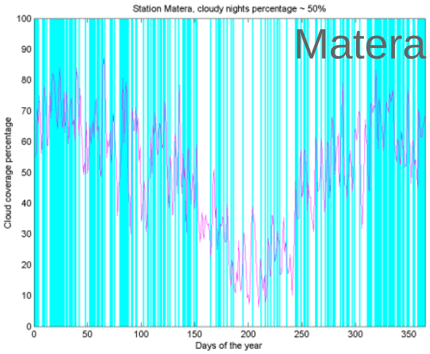


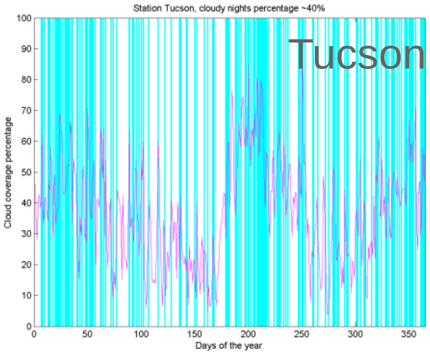
Meteorological factor: Cloud coverage statistics

One of the most relevant parameters affecting the possibility to operate the observatory is represented by the cloud coverage.

A statistical factor representing the mean meteorological conditions registered at the observatory stations is therefore considered in the analysis of the Flyeye network performances. To each night of the year, a *"score index"* is assigned to the station considering the nocturnal cloud coverage averaged in a 5 years time span.

- An observation is considered valid only if the "score index" of the night corresponds to a clear night.
- **Approximately 40-55% of the nights have to be discarded due to bad meteorological conditions.**
- In order to compensate for the meteorological factor, is therefore foreseen a «duplication» of the observing sites





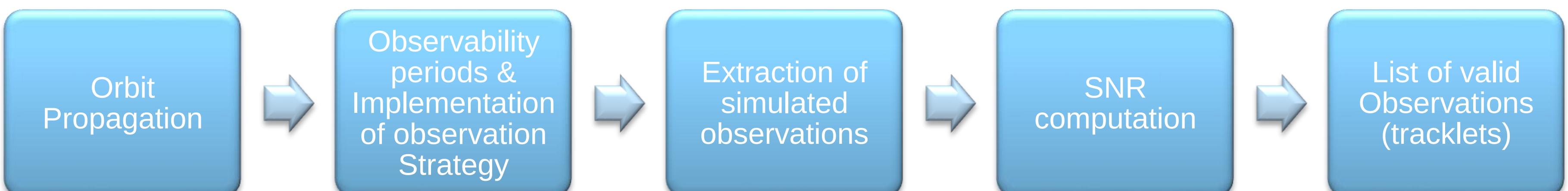
Number of cloudy nights:

- ✓ Matera 50%
- ✓ Teide 42%
- ✓ New Norcia 36%
- ✓ Malargue 52%
- ✓ La Silla 54%
- ✓ Haleakala 43%
- ✓ Tucson 40%.

Simulated observations generation

For each object of the sample population the simulated observations are computed (implementing the selected observation strategy):

- ✓ Starting from its orbital parameters, each object is **propagated**
- ✓ for each observing site, the list of **observability periods** (time intervals in which the object is observable by the station, **implementing the selected observation strategy**) is computed
- ✓ For each observability period, depending on its duration and on the time needed by the Flyeye telescope to scan the target fence, none, one or more **simulated observations are extracted**
- ✓ The Signal-to-Noise-Ratio (SNR) of the acquisition is then determined as function of the **real characteristics of the telescope** and of the apparent magnitude of the object, assuming and **advanced trail detection** image processing algorithm (ATIP)
- ✓ The trail is considered **detectable** only if **SNR_trail>=6**
- ✓ The trail is considered **valid** (and therefore used for subsequent Orbit Determination tasks) only if the “score index” of the night corresponds to a clear night.



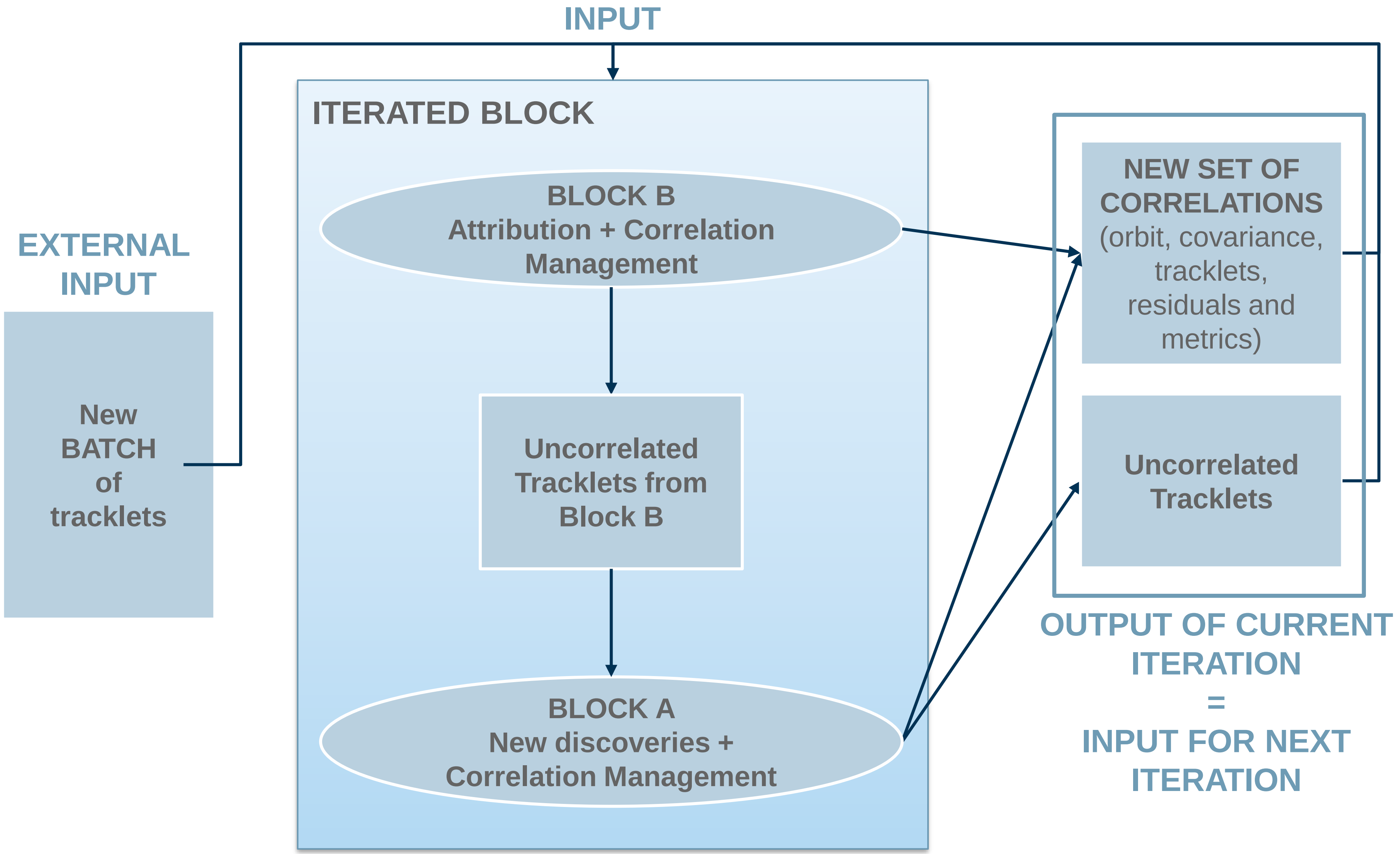
Catalogue build-up and maintenance tasks

Main concepts and definitions

- The entire process of **construction of a catalogue from scratch (*COLD START*)** and of its maintenance using only survey observations (no use of follow-up strategies) was simulated. The data are processed day by day (**simulation of a data center behavior**)
- **Advanced methods for IOD** were applied to find **2-tracklets *correlations*.**
- **The *attribution* of additional tracklets** to a known orbit is performed comparing any new tracklet with the prediction computed using the orbit. The comparison takes into account the predicted uncertainty.
- ***correlation management*** is performed to remove duplicates and merge, if possible, correlations having some tracklets in common**.**
- An object is ***discovered*** if a 3-tracklet correlation has been found for it: it is therefore inserted in the ***provisional catalogue***
- A very important step is the decision of when a correlation contained in the provisional catalogue becomes “good enough” to be inserted in the definitive catalogue. An object is ***catalogued*** if its accuracy 48 hours after the end of the simulation is within a fixed envelope defined in the RTW local orbital frame, i.e. for LEO objects:

$$[40 \text{ m}, 200 \text{ m}, 100 \text{ m}]$$

Catalogue build-up&maintenance: iteration scheme



Simulation Results

Reduced Population sample simulation

For a preliminary assessment of the performances of the network and of the selected strategy, a reduced population of 99 objects greater than 10 cm was randomly extracted from the reference population. The performances are evaluated for a simulation of 2 months.

HLEO	LLET	LEOT	Total
88	4	7	99

Resident objects — Transient objects

HLEO: High-LEO objects
(orbiting between 1000 and 2000 km altitude)
LLET: Low HLEO Transient
(orbiting in HLEO and lower regions)
LEOT: LEO Transient
(orbiting in HLEO and other regions)

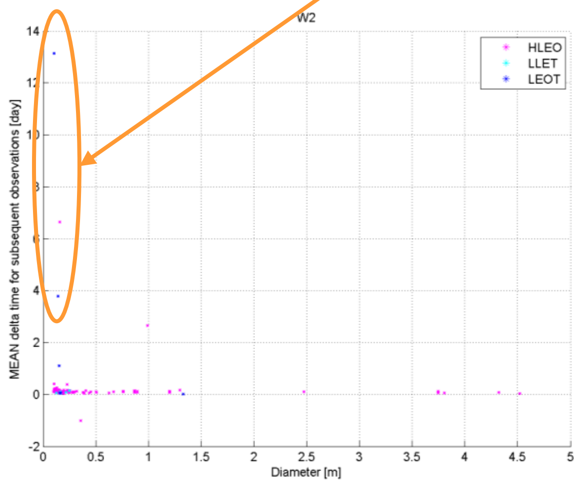
- **Network**: 7 stations, each one hosting 3 Fly Eye telescopes
- **Observation Strategy**: Mixed strategy. Phase aware fence @1000km, plus a portion of equatorial fence @1000km
- **Environmental conditions**: seeing 1.2 arcsec, Vsky=19.5
- **Trail detection threshold**: SNRtrail>6

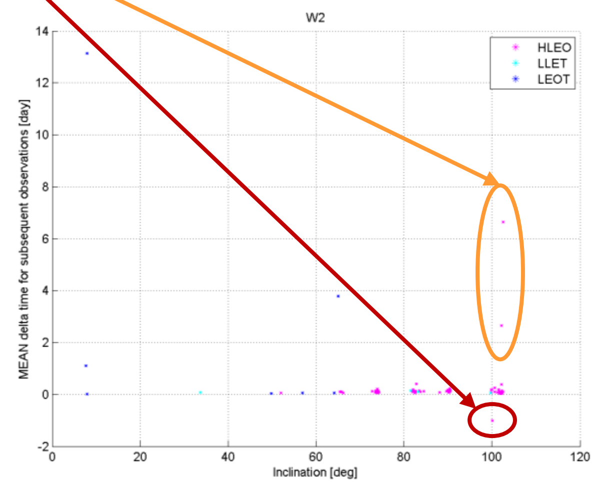
In addition to the cataloguing performances, also a **coverage analysis** have been performed, computing mean, max and STD of duration of gaps between consecutive observations of the same object. Indeed, the time distribution of the observations allow to evaluate the efficiency of the telescope network and related observation strategy, since gaps in the observations could prevent the possibility to catalogue the object or to maintain an already catalogued one.

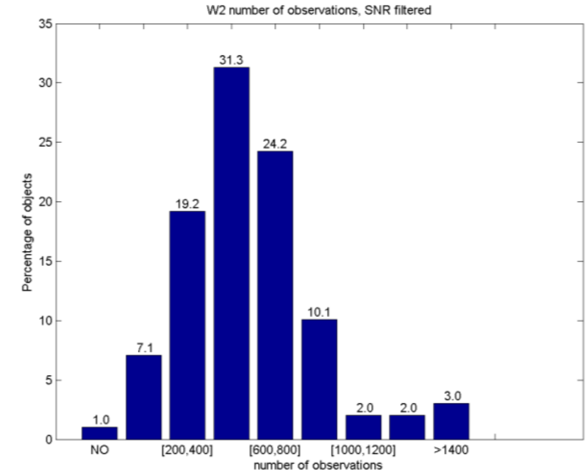
Coverage Analysis of the simulated observations

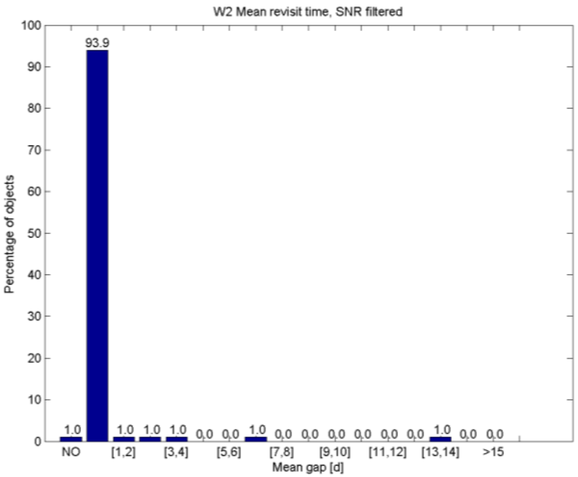
Reduced sample population (99 objects)

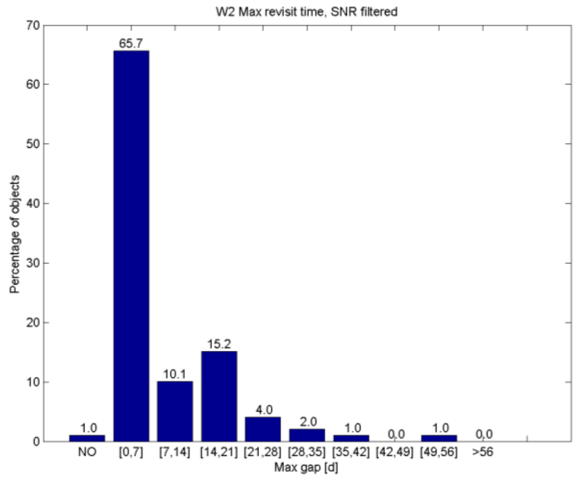
Rarely and never observed objects are among the small transient objects and high inclination resident objects (sun-synchronous orbits).
Negative values corresponds to Not-Observed objects (NO)

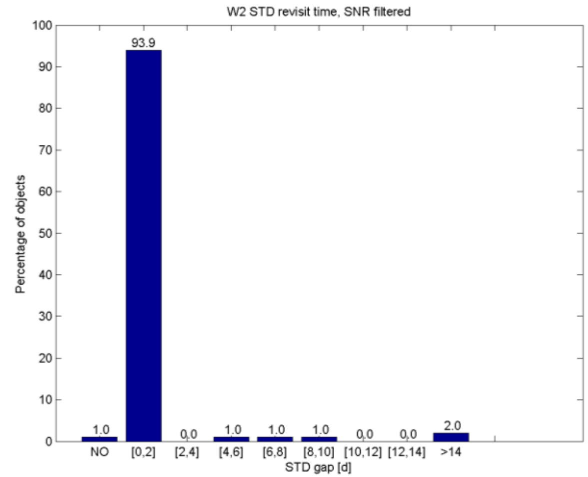












Cataloguing performances
Reduced sample population (99 objects)

Days	After 7 days	After 28 days	After 60 days
Catalogued	64	91	94
Discovered (without dupl.)	86 (84)	95 (93)	99 (95)

Very high percentage of objects (about 94%) with diameter larger than 10cm, both HLEO resident and HLEO transient, can successfully be catalogued within two months of observations.

Full Population sample simulation

OHB ITALIA SpaceDyS

The full population sample includes 999 objects greater than 10 cm, randomly extracted from the ESA MASTER8 model. The performances are evaluated for a simulation of 2 months.

HLEO	LLET	LEOT	Total
874	49	76	**999**

Resident objects (HLEO) — **Transient objects** (LLET, LEOT)

HLEO: High-LEO objects
(orbiting between 1000 and 2000 km altitude)
LLET: Low HLEO Transient
(orbiting in HLEO and lower regions)
LEOT: LEO Transient
(orbiting in HLEO and other regions)

- **Network**: 7 stations, each one hosting 3 Fly Eye telescopes
- **Observation Strategy**: Mixed strategy. Phase aware fence @1000km, plus a portion of equatorial fence @1000km
- **Environmental conditions**: seeing 1.2 arcsec, Vsky=19.5
- **Trail detection threshold**: SNRtrail>6

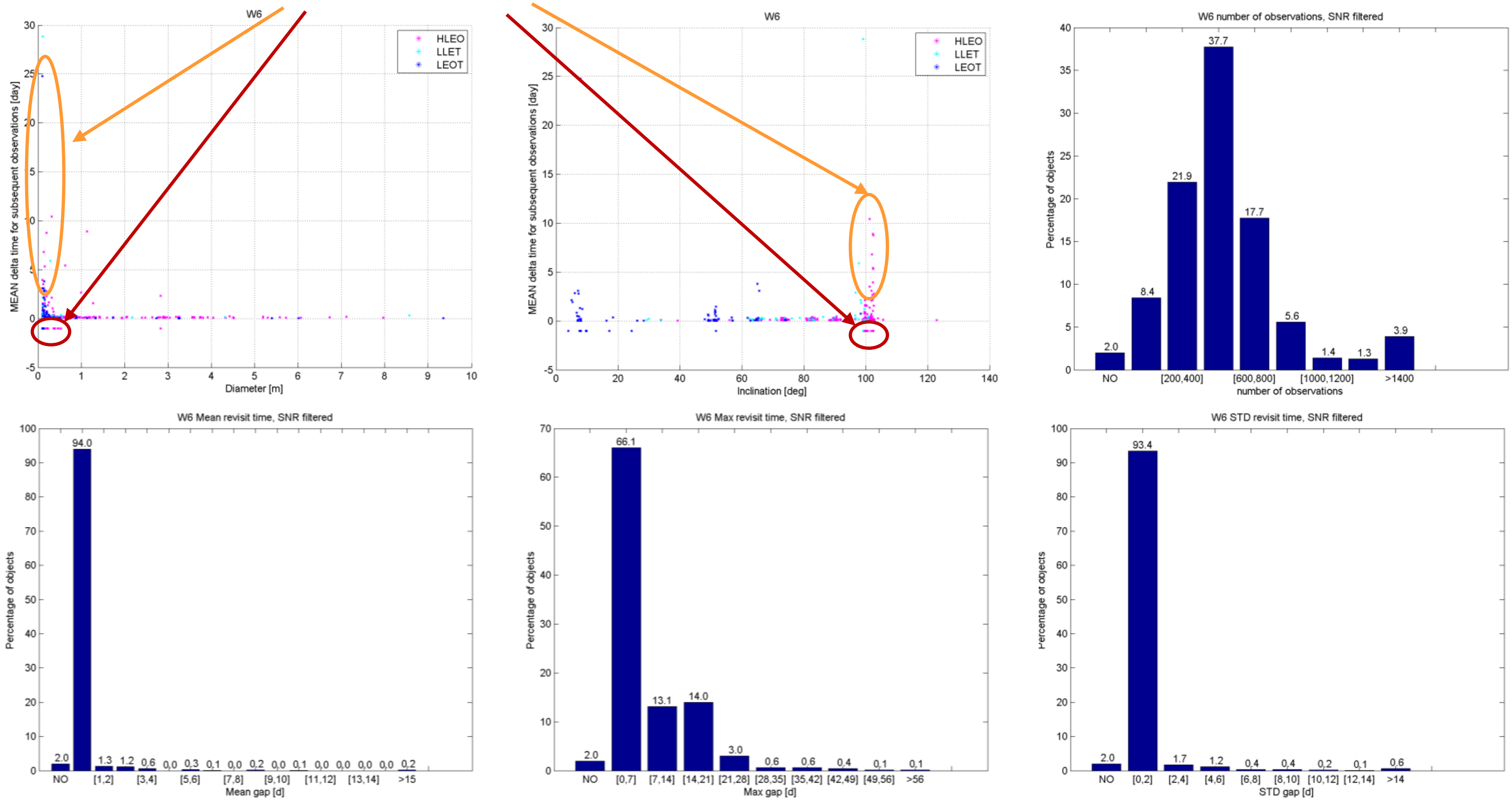
The Orbit Determination and catalogue build-up tasks for the full population sample are ongoing (study to be completed within February 2023)

The results of the **coverage analysis** are available.

Coverage Analysis of the simulated observations

Full population (999 objects)

Rarely and never observed objects are among the small transient objects and high inclination resident objects (sun-synchronous orbits). Negative values corresponds to Not-Observed objects (NO)



Note: ad-hoc observation strategies could be considered to improve the observability of sun-synchronous and transient objects

Conclusions

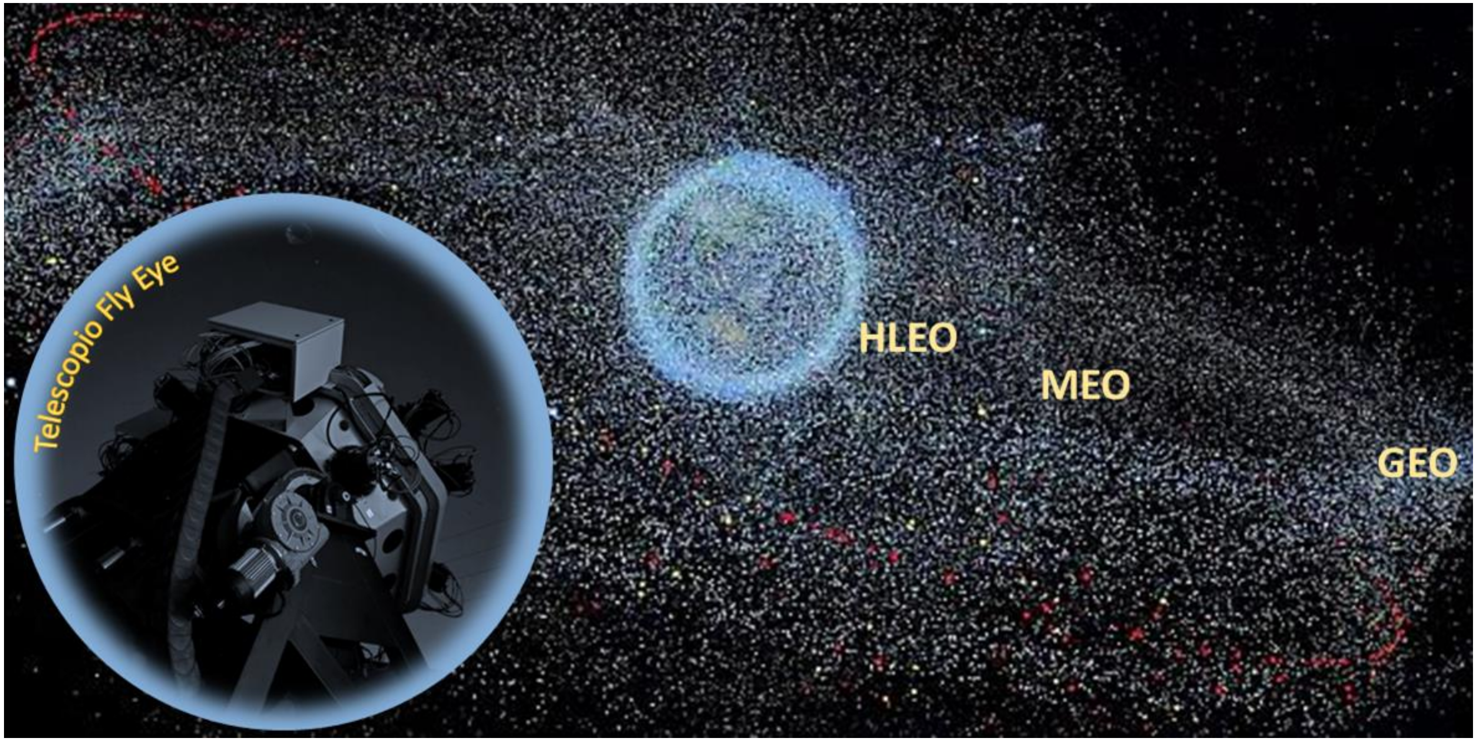
The coverage analysis for the full population sample shows a behavior similar to the reduced sample population one, thus a similar network & observation strategy efficacy is reached. This suggests that the cataloguing performances would be similar as well.

The SUTED4L study therefore demonstrates that:

- With a **Network of 21 Flyeye telescopes** (7 stations, each one hosting 3 Flyeye telescopes)
- Implementing an **Observation Strategy** suitable for HLEO objects survey
- Considering a **true HLEO population sample**, including objects with diameter ≥ 10cm
- Using the **real SNR Flyeye telescope model** for Object Detectability criteria verification
- Assuming the availability of an **advanced Trail detection algorithm (ATIP SW)**
- Exploiting advanced Orbit Determination Algorithms for **COLD START** catalogue Build-up

Very high percentage of objects (>90%) with diameter larger than 10cm,
both HLEO resident and HLEO transient,
can successfully be catalogued within two months of observations.

Thank you for your attention…



Contact point:
OHB Italia: roberta.pellegrini@ohb-italia.it