# An Overview of Innovative Optical Observation Techniques Applied to Daytime and Cislunar Orbits and Real-Time Tracking

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# Reference scenario

## Earth orbit is no longer sparse

The operational baseline for SST/SSA is shifting from catalogue maintenance to continuous monitoring of a rapidly growing population.

### Current debris environment

**≈44’870**

objects regularly tracked by space surveillance networks

**≈15’200**

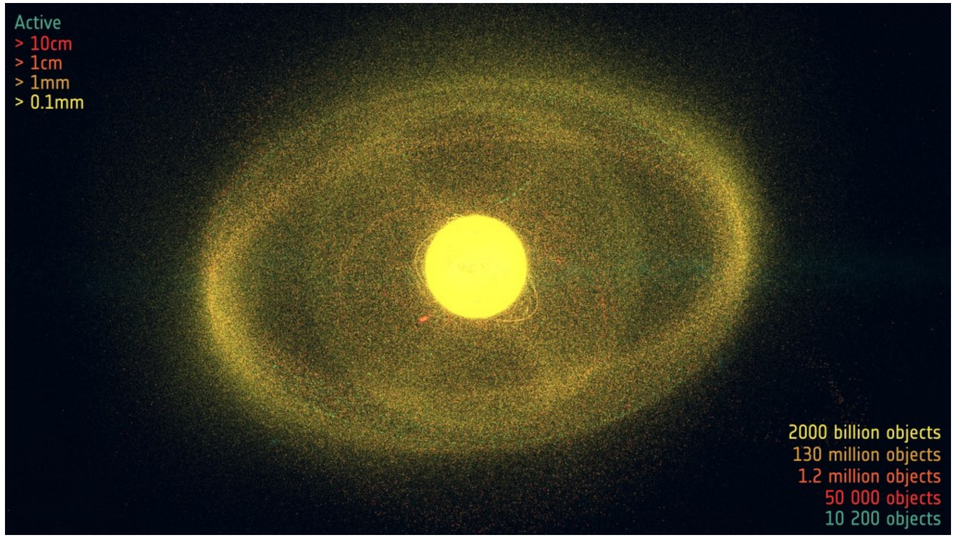
functioning satellites still in space

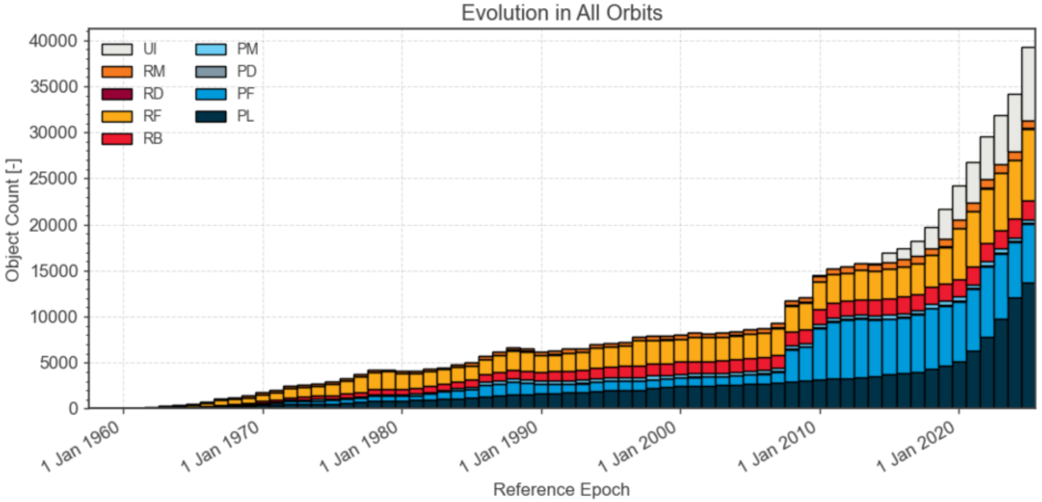
**≈1.2M**

objects estimated between 1–10 cm

Detection, tracking, and cataloguing are becoming coupled problems across crowded LEO, high-altitude Earth orbits, and the emerging cislunar domain.

***more objects and crowded orbitals regimes*** → *more conjunctions, re-entry, fragmentations events* → *need innovative observation techniques* → ***improve the tracking and the observability capabilities of the optical systems***




**Sources:** ESA Space Environment Statistics, last updated 21 Apr 2026; ESA Space Environment Report 2025. Images: ESA Space Safety / ESA Multimedia.

# Index

## *Innovative optical observation techniques*

*Daylight observation, high-altitude detection, and real-time tracking address complementary gaps in current SSA/SST operations. Expand the capability of detection and monitoring with innovative optical observation techniques*

- **Daylight optical observations**

Extend optical data acquisition beyond the night-time window and test astrometric extraction under adverse sky-background conditions.

- **Cislunar detection**

Assess the feasibility of observing faint objects above the GEO ring and toward lunar distances with 25 cm–1 m class sensors.

- **Real-time Stare-and-Chase tracking**

Move from survey-only detections toward sufficient arcs for orbit determination and cataloguing of uncatalogued targets.

**Contribution to the SSA/SST scenario**

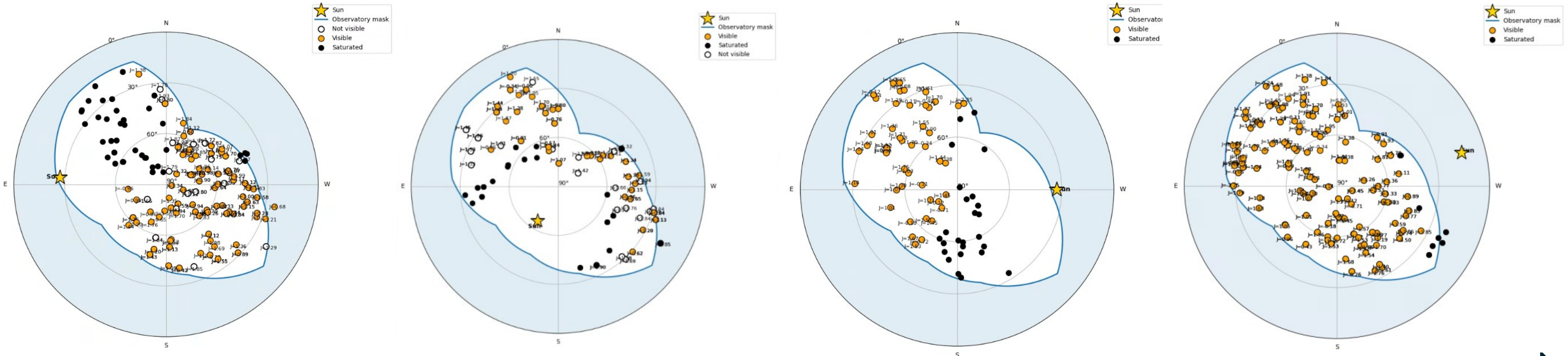
The contribution is not just “more observations”: it is extending the operational envelope of optical SST from nighttime cataloguing to robust acquisition in difficult visibility, geometry, and knowledge conditions.

# Daytime observations

## Stars visibility during daytime, up to 2.5 J mag

**Stars observed**

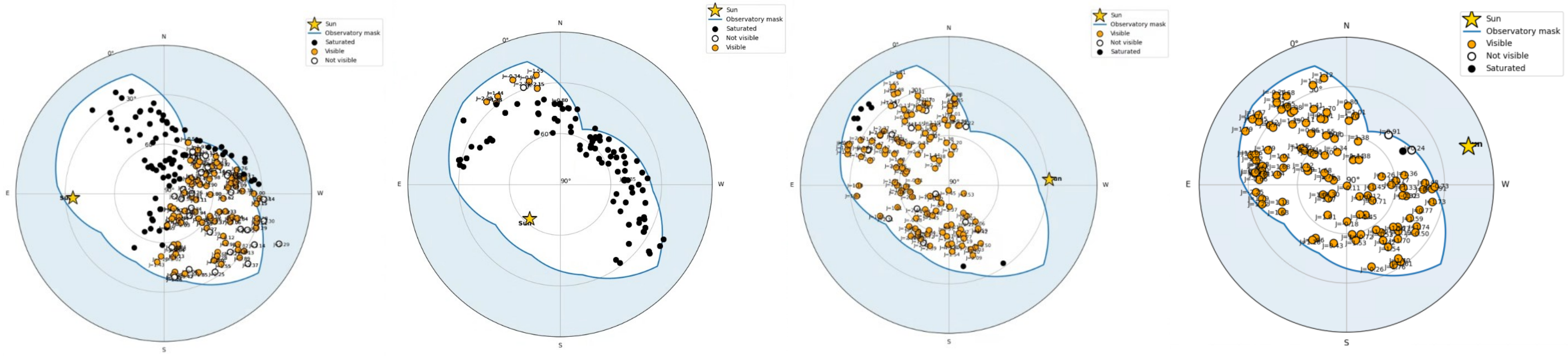
Sun
Observatory mask
Not visible
Visible
Saturated




El Sun 30° | El Sun 60° | El Sun 30° | El Sun 12°

**Stars observed**

Sun
Observatory mask
Not visible
Visible
Saturated




El Sun 30° | El Sun 60° | El Sun 30° | El Sun 12°

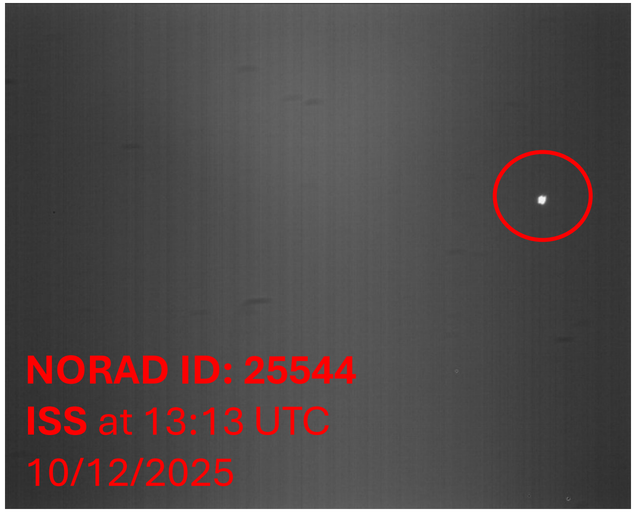
# Daytime observations

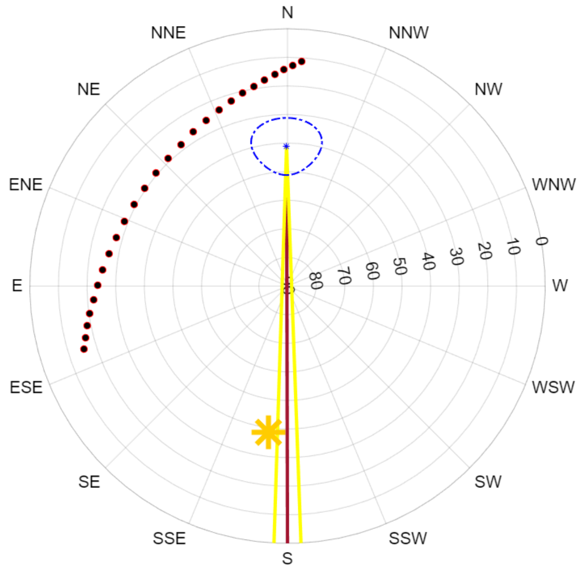
## Target observation test

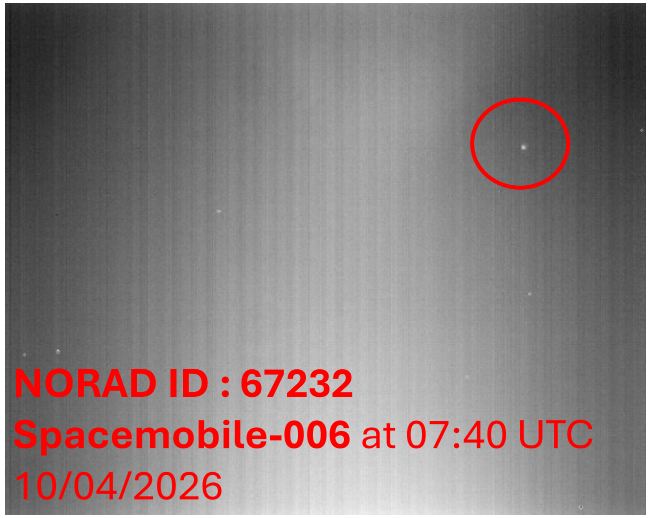
**OBSERVED OBJECTS VISIBLE EVEN AT LOCAL NOON:**

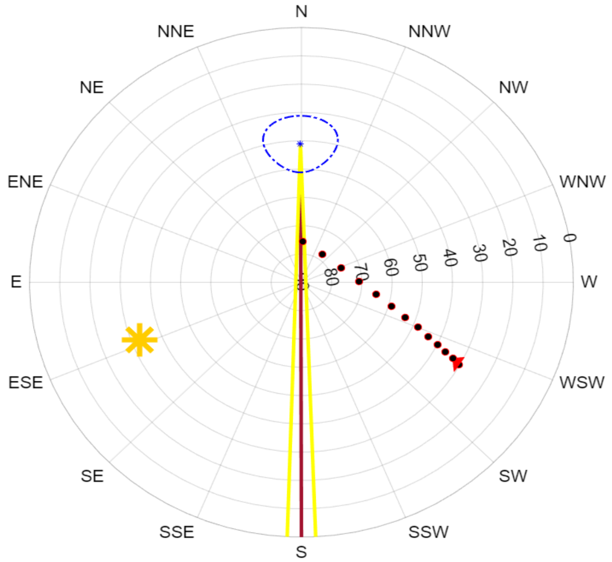
- ISS
- Sl-16
- Bluewalker-3
- Bluewalker-6 / Spacemobile-006

**Satellites Can be Detected during most of their passages.**



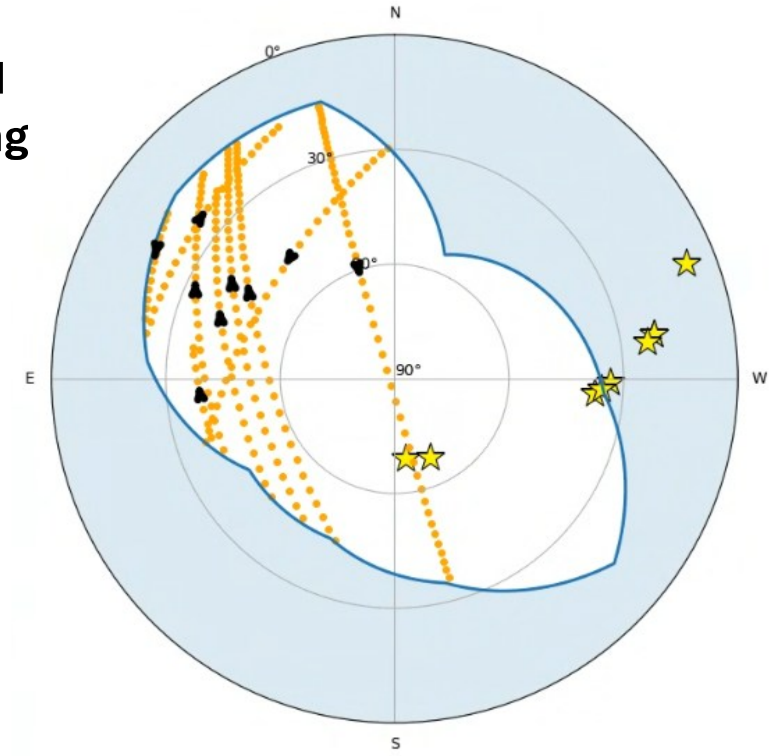
# Daytime observations

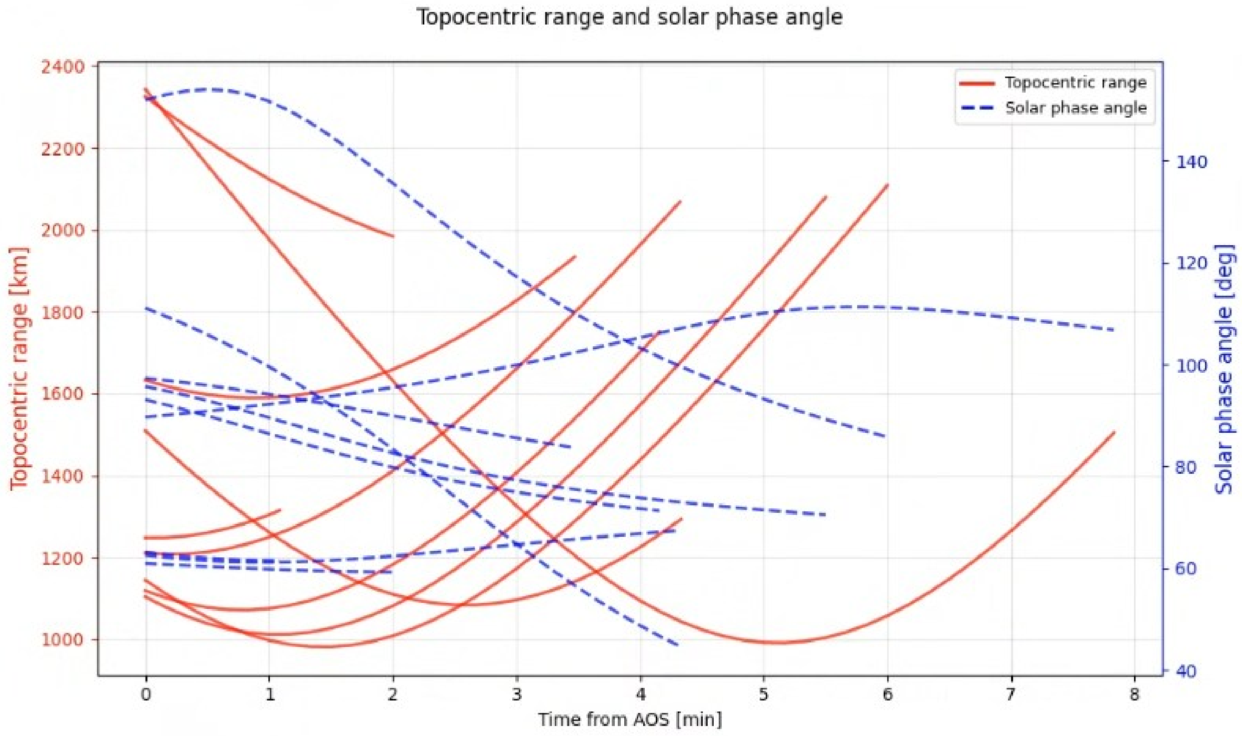
## SL-16 Campaign

| Object parameters | |
|---|---|
| Dry mass | 8.9 tons |
| Diameter | 3.90 m |
| Length | 11.047 m |

| Orbit parameters | |
|---|---|
| Apogee | 850.0 km |
| Inclination | 71.0 ° |
| Period | 101.7 minutes |


**SL-16 observed passages during daytime**



# Cislunar observations

## Reference scenario

The monitoring perimeter is expanding with lunar infrastructure, commercial services, and international exploration architectures.

**What changes for SST/SSA**

- Objects are fainter and farther: over GEO orbits, highly eccentric and lunar-orbit regimes.
- Classical radar contribution decreases as range increases; optical assets become central.
- Tracking cannot rely only on precise a priori ephemerides: discovery-to-cataloguing pipelines are needed.

**Current scenario**

- Artemis II completed a crewed lunar flyby on 1–10 Apr 2026.
- Artemis III is scheduled for 2027; Artemis IV is targeted for early 2028.
- NASA has already awarded 11 Commercial Lunar Payload Services (CLPS) lunar deliveries to 5 vendors, carrying >50 payloads through Nov 2028.

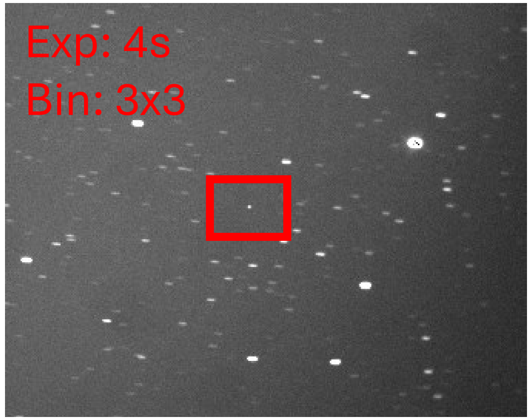
# Cislunar observations

## Selected targets for observations tests

| CISLUNAR OBJECTS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Object** | **TYPE** | **STATUS** | **COSPAR ID** | **NORAD ID** | **ID Horizons** | **TLE** | **Horizons Ephemerides** | **Observed** | **Observatory** |
| ATLAS 5 CENTAUR R/B | Rocket Body | Uncontrolled | 2009-017B | 34714 | | UPDATED | Not Available | | GALHASSIN |
| ARIANE 5 R/B | Rocket Body | Uncontrolled | 199-9066B | 25990 | | UPDATED | Not Available | | SCUDO |
| CLUSTER II-FM5 | Scientific Payload | Re-entry October 2025 | 2000-045A | 26463 | | OLD | Not Available | | SCUDO |
| ARIANE 44P+3 R/B | Rocket Body | Uncontrolled | 1995-062B | 23716 | | UPDATED | Not Available | | GALHASSIN |
| CZ-38 R/B | Rocket Body | Uncontrolled | 2013-070B | 39459 | | OLD | Not available 2021-05-31 21:36:00.001 | | |
| CXO (Chandra Observatory) | X-Ray telescope | Active | 1999-040B | 25867 | -151 | UPDATED | Available until 2026-10-08 12:01:09.182 | | GALHASSIN |
| CLUSTER II-FM7 | Scientific Payload | End of life re-entry August 2026 | 2000-041A | 26410 | | MID | Not Available | | |
| TESS (CICERO 10) | 6U CubeSat | Re-entry 2024 | 2018-088A | 43690 | | OLD | Not Available | | |
| GEOTAIL | Scientific Payload | Deactivated 2022 | 1992-044A | 22049 | | MID | Not Available | | |
| MMS-1 | Scientific Payload | Active | 2015-011A | 40482 | -140482 | UPDATED | Available until 2026-05-14 04:01:11.184 | | |
| INTEGRAL | Gamma-Ray telescope | Active | 2002-048A | 27540 | -198 | MID | Available until 2026-05-12 08:14:13.262 | | |
| CAPSTONE | 25Kg CubeSat | Active | 2022-070A | 52914 | -1176 | OLD | Available until 2026-04-17 00:01:09.186 | | |
| DANURI (KPLO) | Lunar Orbiter | Active | 2022-094A | 53365 | -155 | OLD | Available until 2026-10-31 20:05:53.142 | | |
| Chandrayaan 2 | Lunar Orbiter | Active | 2019-042A | 44441 | -153 -152 | VERY OLD | Available until 2019-09-06 20:28:00.000 | | |
| LRO | Lunar Orbiter | Active | 2009-031A | // | -85 | | Available until 2027-10-11 00:01:09.182 | | |
| TESS | Telescope | Active | 2018-038A | 43435 | -95 | MID | Available until 2027-10-06 13:01:09.182 | | |
| ARTEMIS II – Orion Integrity | Multi-Purpose Crew Vehicle | Re-entry April 2026 | 2026-069A | 68538 | -1024 | OLD | Available until 2026-04-10 23:54:22.858 | | SCUDO, GALHASSIN |

# 25990 - ARIANE 5 R/B

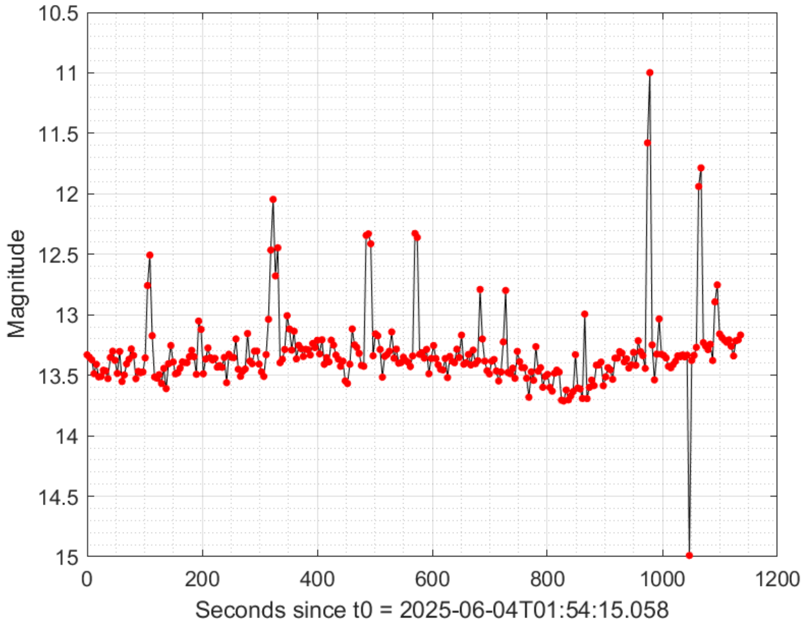
## Observations - 2025-06-04 SCUDO: Sapienza Coupled University Debris Observatory Collepardo, Italy

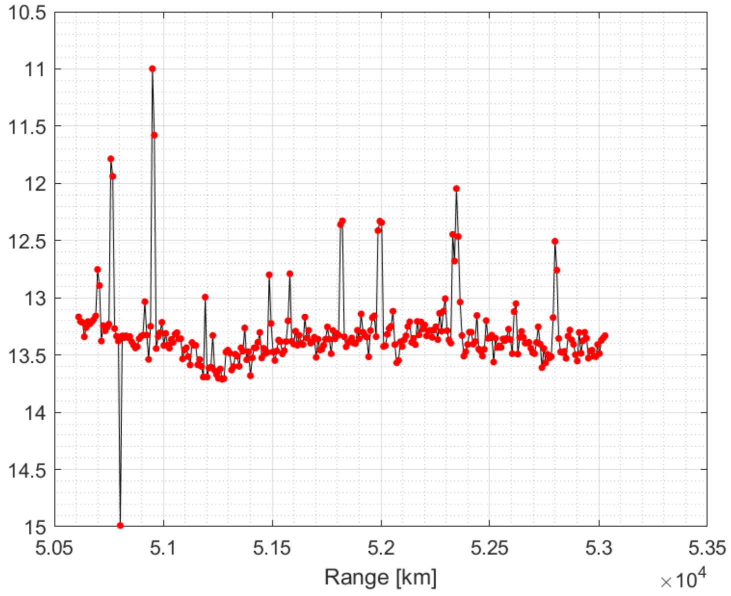


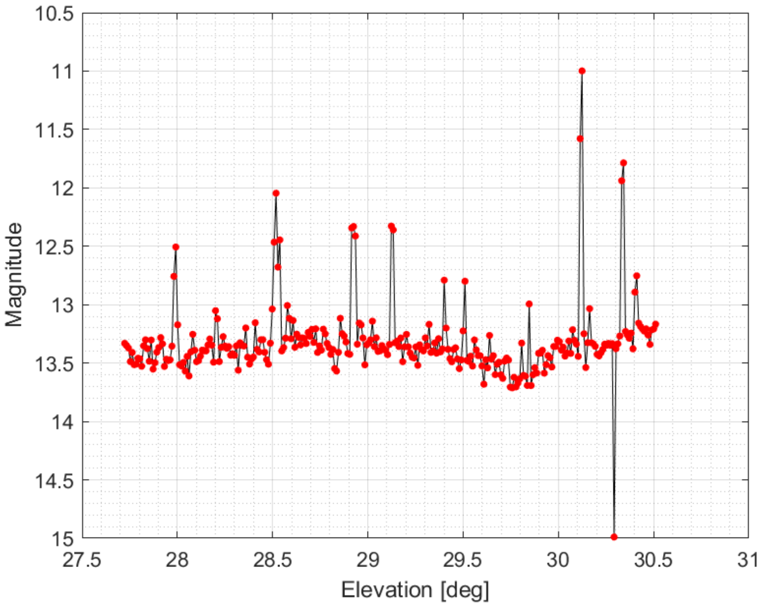

Last stage of the Ariane 5 Rocket

Uncontrolled object

**Observation**:
- Observed: Descending to the perigee
- El =~ 27°-30°
- Lunar Elong =~ 130°
- Range =~ 50'000 Km
- Mean Magnitude =~ 13.5
- Phase Angle =~ 50°

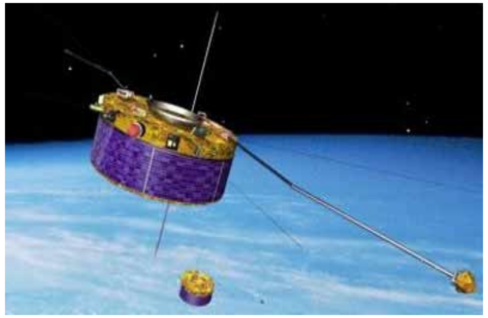


# 26463 - CLUSTER II-FM5

## Observations - 2025-07-21 SCUDO: Sapienza Coupled University Debris Observatory Collepardo, Italy

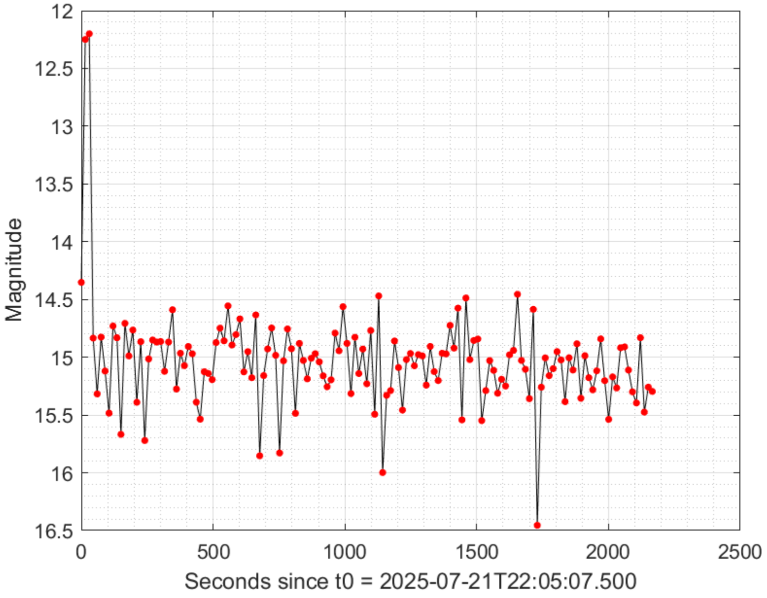
Magnetospheric research project

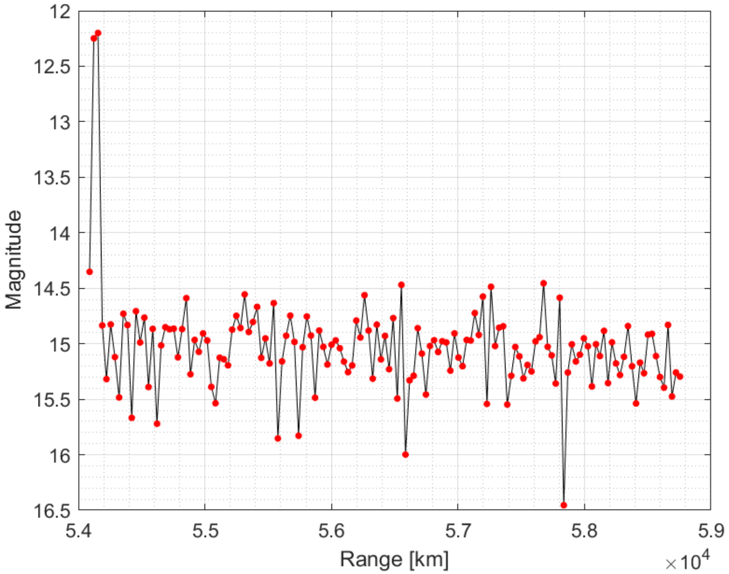
Active @ observation time

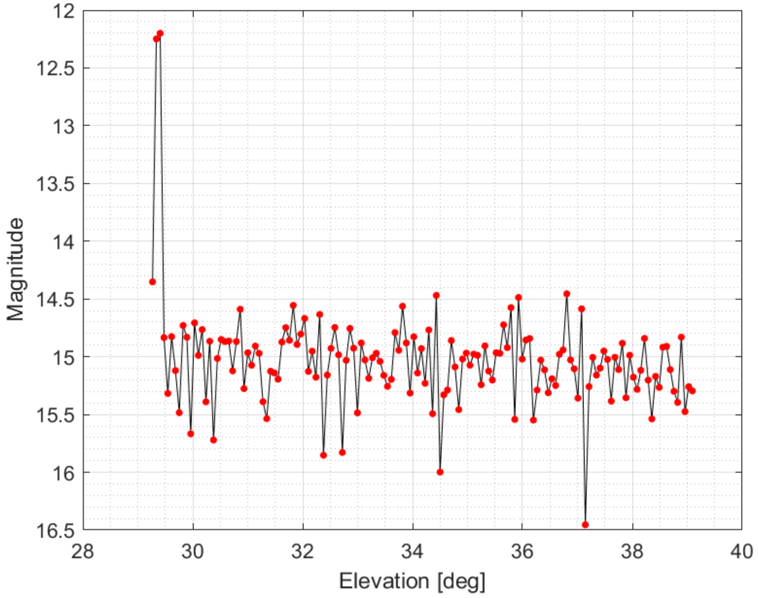
Re-Entry October 2025

**Observation**:

- Observed: Ascending to the apogee
- El =~ 30°-38°
- Lunar Elong =~ 86°
- Range =~ 56’000 Km
- Mean Magnitude =~ 15
- Phase Angle =~ 60°



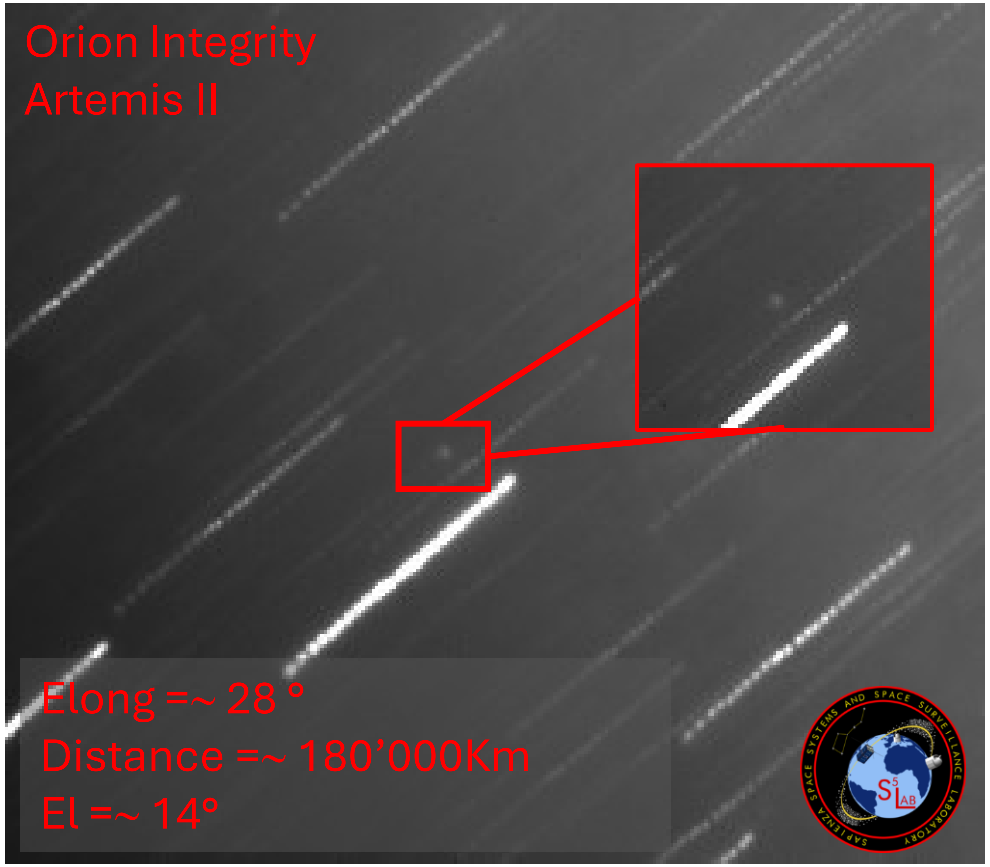



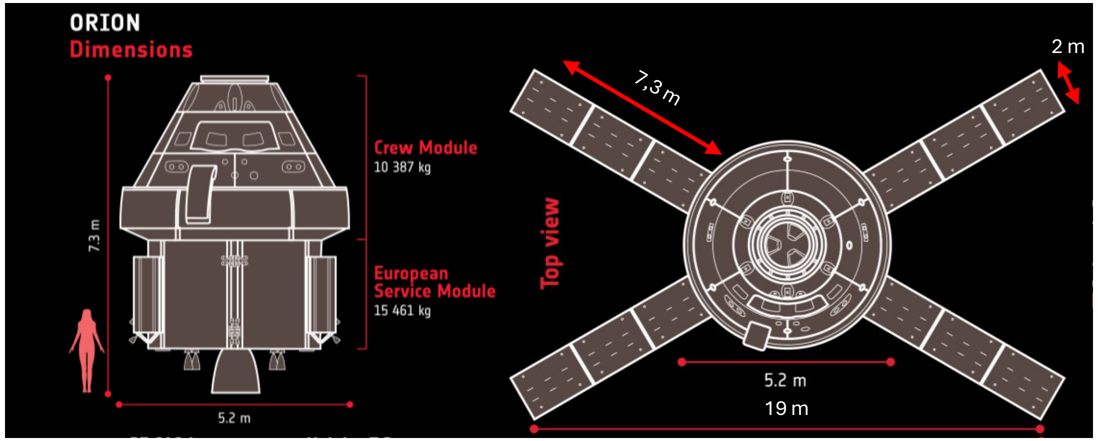



# Artemis 2 Mission – Integrity Observations

## Observations

- **SCUDO:** Sapienza Coupled University Debris Observatory Collepardo (FR), Italy
- **Observed:** 2026-04-10
- **Time:** 03:04-04:00 UTC
- **Telescope**: 1°x1° FoV 1200mm f4,8
- **Stacked:** 128 frame @ 10s, clear
- **Sidereal Tracking**
- **Horizon JPL ephemerides**

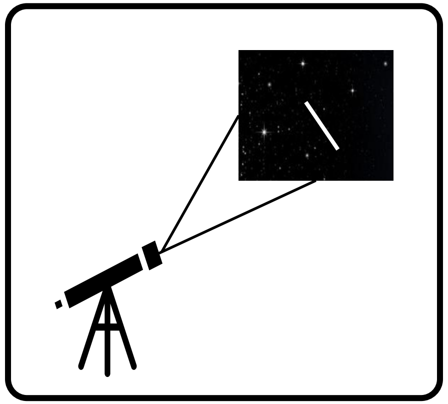


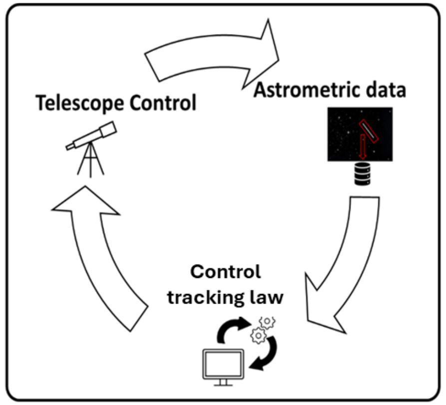
# Real Time Tracking

## State-of-the-art

The state of the art in real-time tracking orbital object with optical systems is refers mostly by the Stare and Chase strategy. The name of the stare and chase was coined after the merge of two observation strategies used in passive-optical systems namely survey and follow-up.



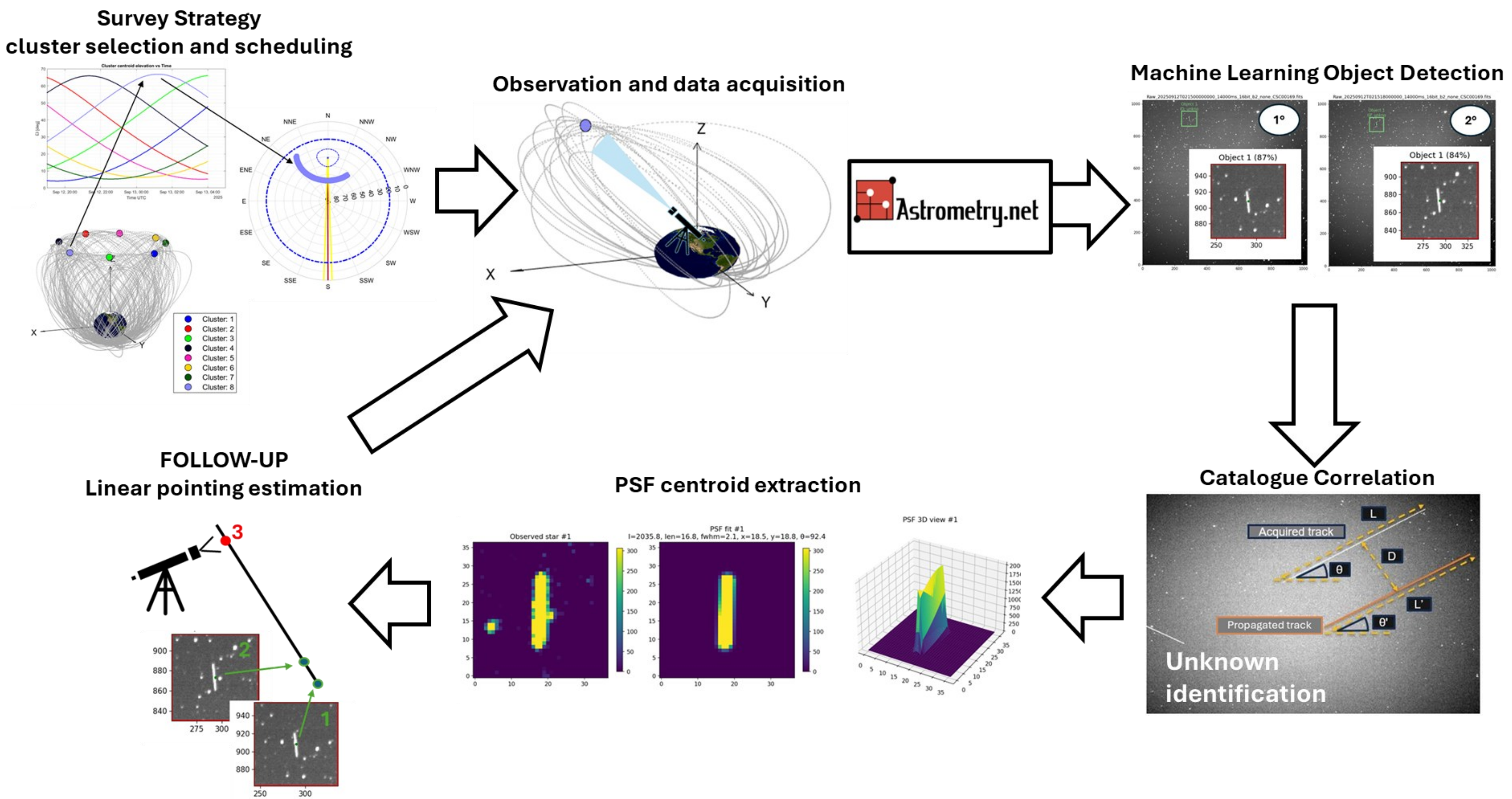
**STARE:** the system remains fixed in an initial pointing direction waiting for the object to cross the field of view.




**CHASE:** the system follows the object using the real time data acquired and integrate it in a control law to improve the tracking or follow the object without any a-priori orbital information.

# Real Time Tracking Pipeline

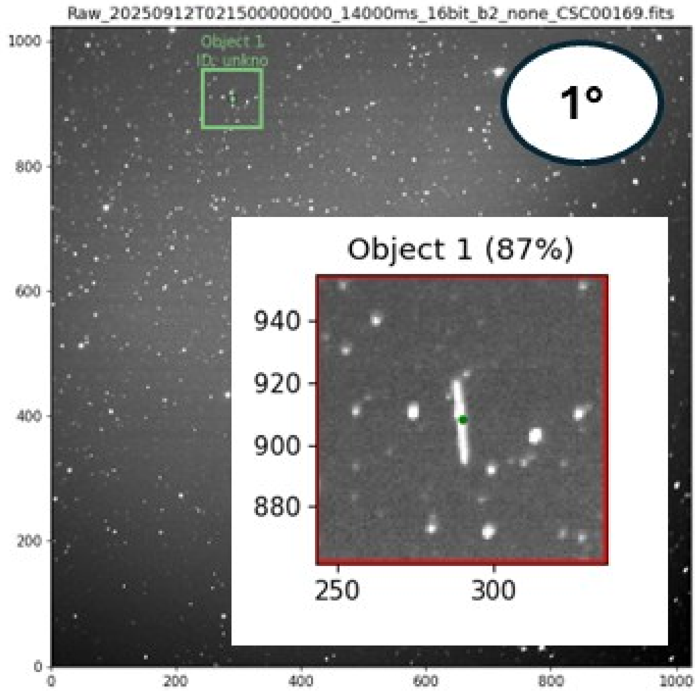
## Linear-Tracking



# Real time tracking

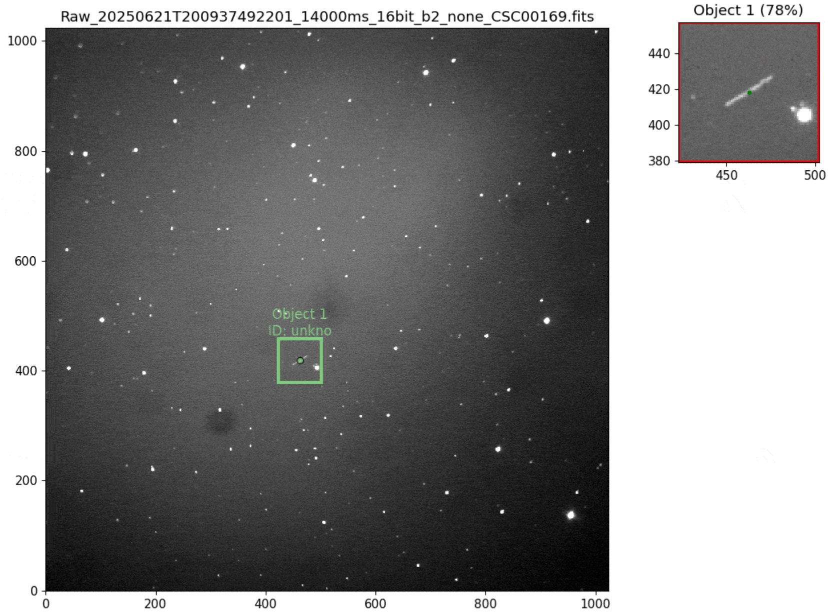
## Real time detections and tracking

### STARE




Stare phase based on a survey method. **First rea-time detection of uncatalogued object initialize the chase phase.**

### CHASE

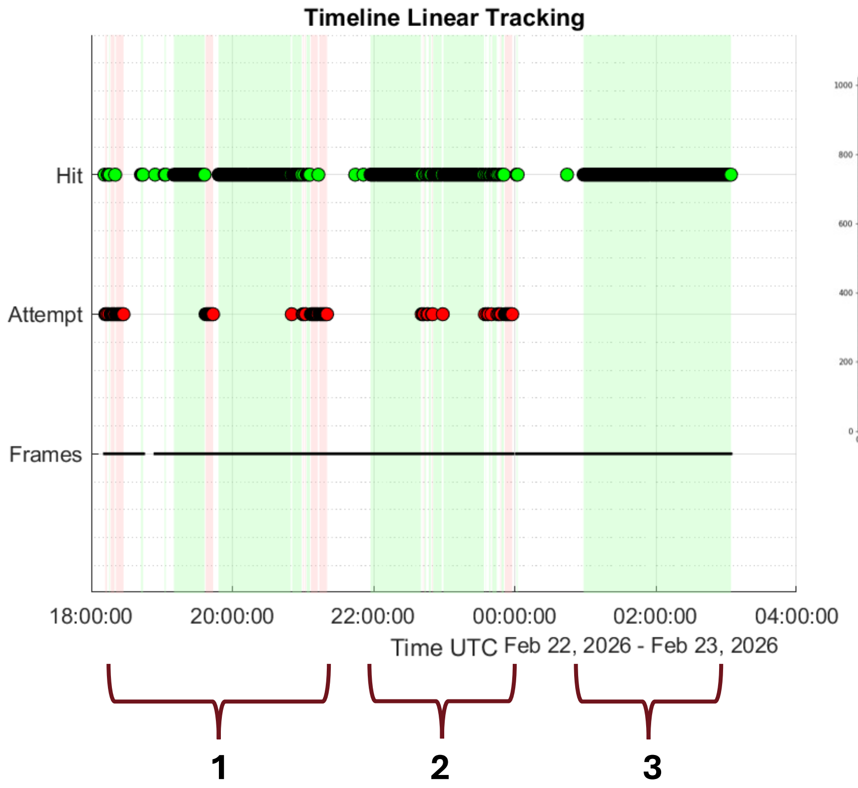



Chase phase start the real time follow up of the uncatalogued object. The video show the linear-tracking method based on a linear estimation for the next pointing.

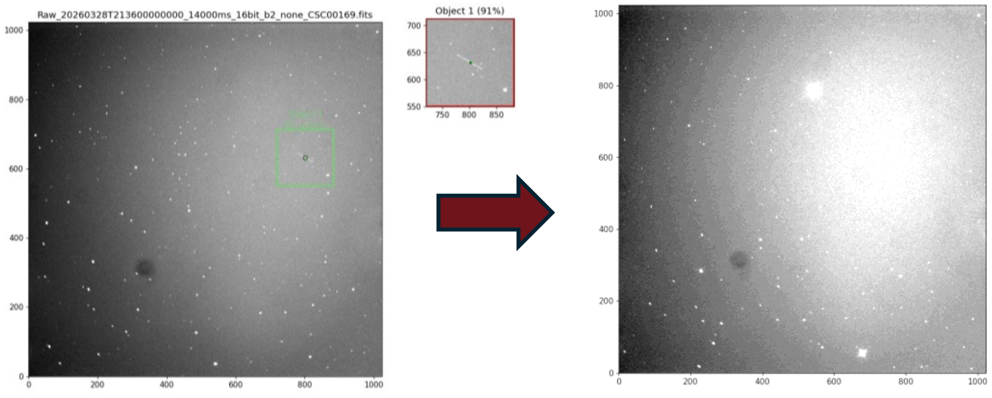
# Real time tracking

## Tracking maintenance

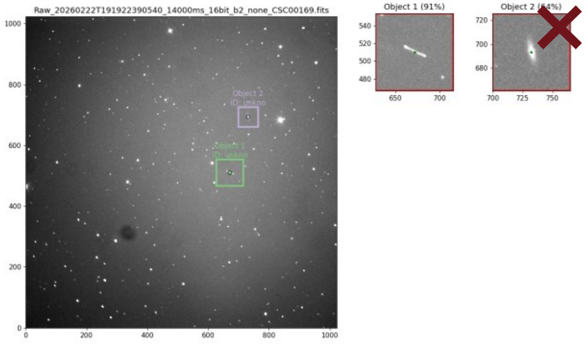
During the chasing phase**, the measurements must be filtered** to preserve track continuity, as **other objects may enter the field of view** together with the target. In addition, the target may be **temporarily lost due to clouds or other external factors** that degrade real-time detection performance. detection.




**Lost detection due to high clouds in the FoV.**




**Outlier detection very elongated galaxy. Discarded by measurements filtering**

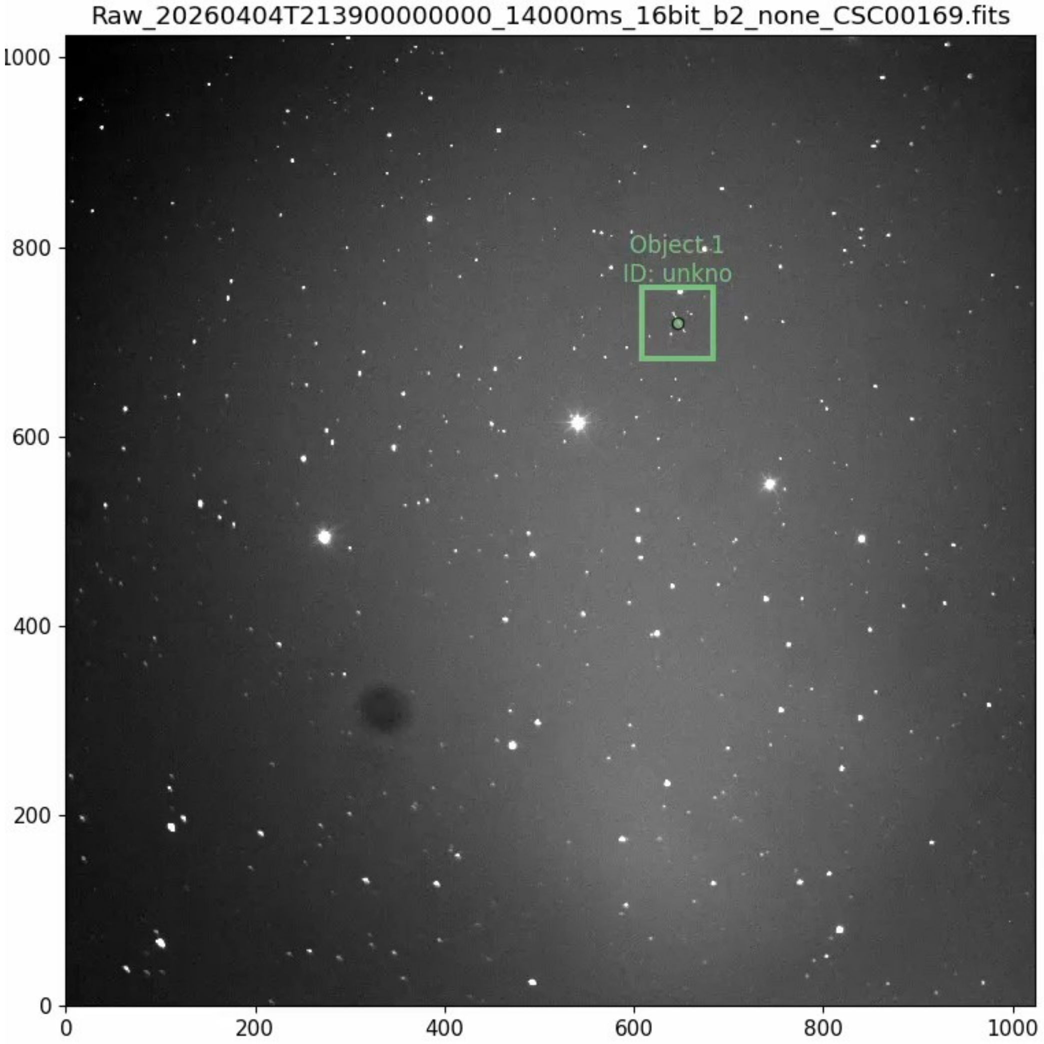


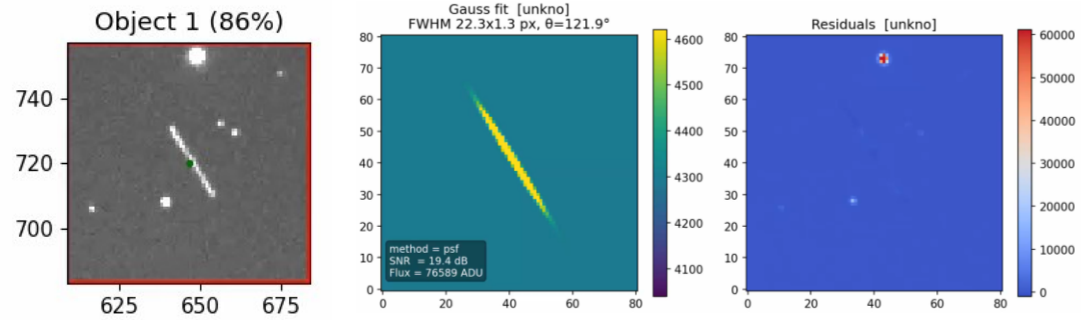

For this chasing phase we can see **three different uncatalogued target chased** during the night. The maximum tracking time for each follow-up it is fixed to **2 hours**.

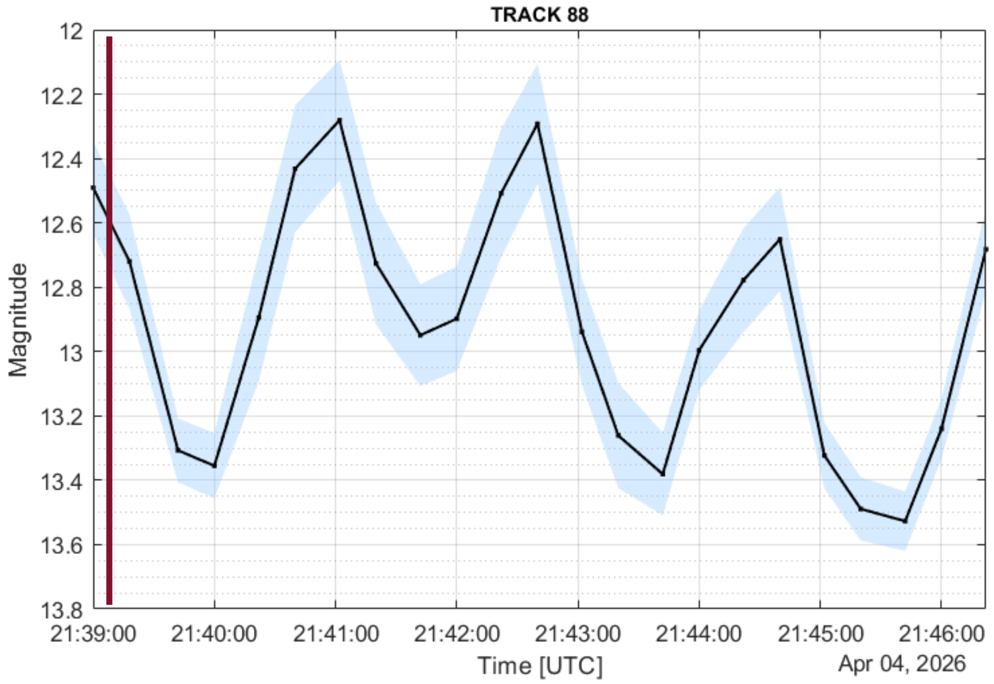
For the **1st and 2nd** tracking we can see different lost of the target and the attempt procedure that try to spot again the target, due to high clouds in the FoV. The **3rd** tracking instead it is maintain without problem for over the length of the visibility.

# Real time tracking

## Real time data acquisition: light curve




**Tumbling uncatalogued object**

# Thank you for your attention


Matteo Rossetti
Andrea Ederle

Lorenzo Cimino
Lorenzo Mariani
Fabrizio Piergentili

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