Updates on LED payloads operations for optical tracking and reconnaissance

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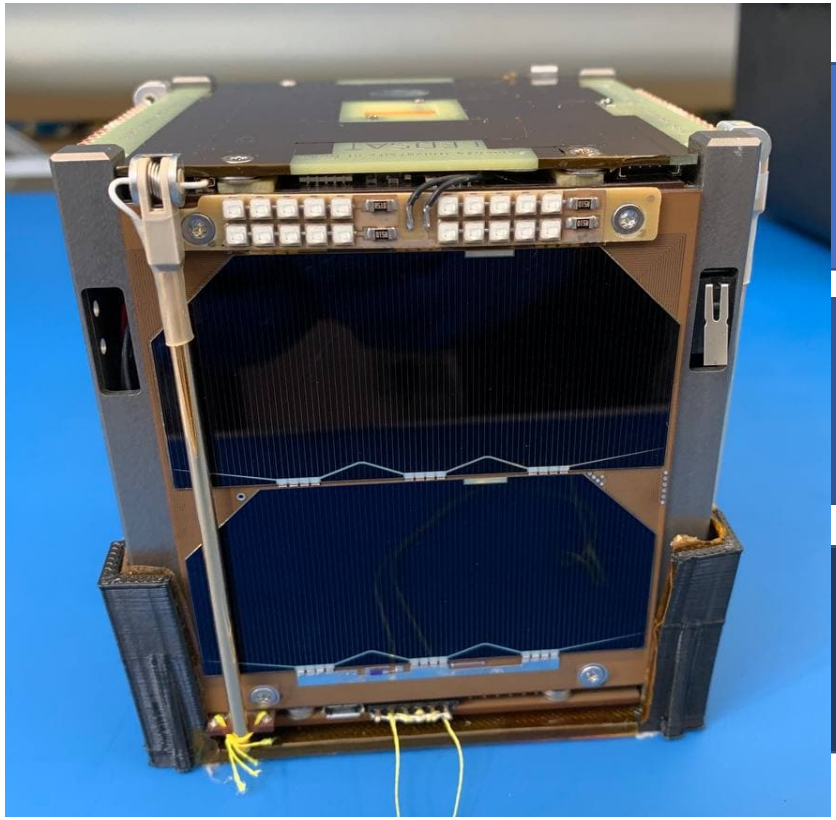
Observation opportunities with LED payloads on nano-satellites



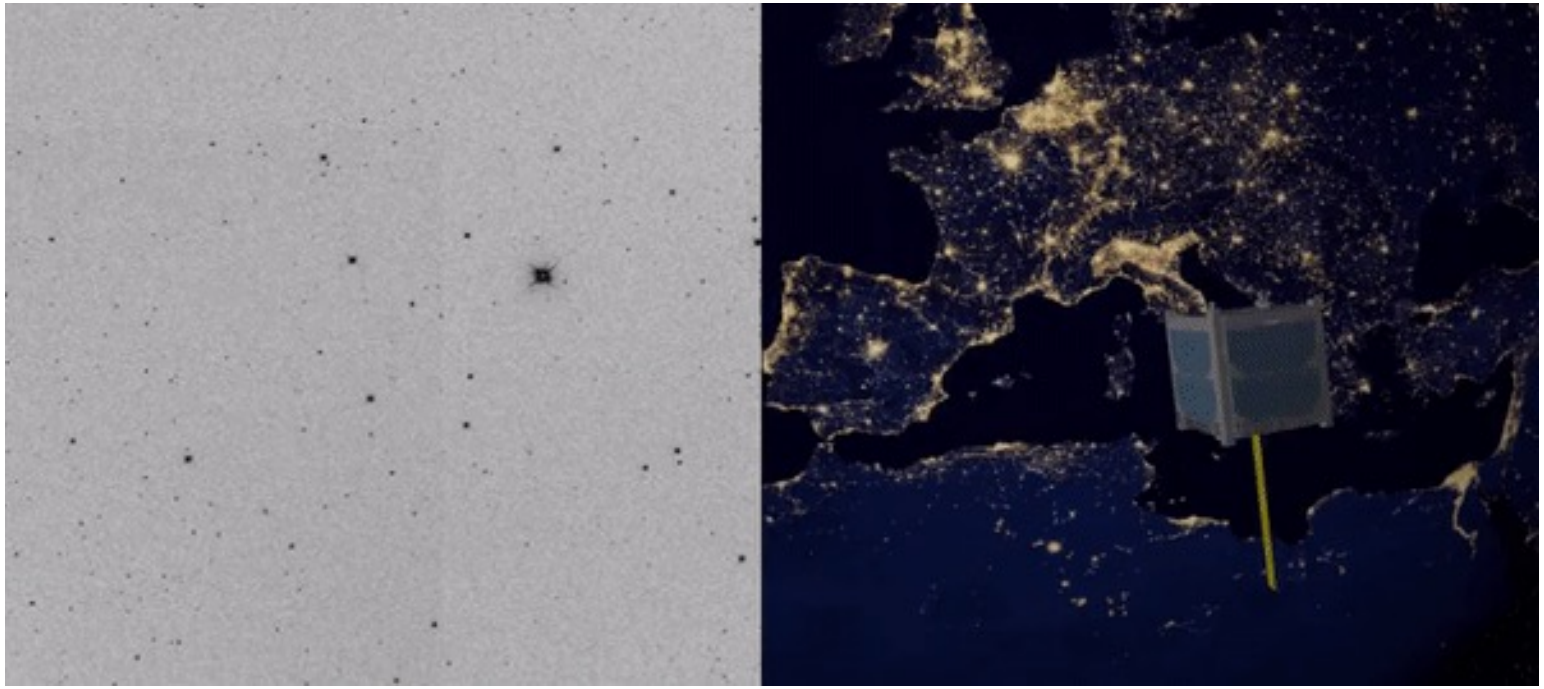
Light-Emitting Diode boards can be mounted on the external surfaces of small satellites

Their operations can be supported by the main subsystems (EPS) of the satellite assembly

The first demonstration has been brought in-orbit by two nano-satellites

LEDSAT

Operations with LEDs

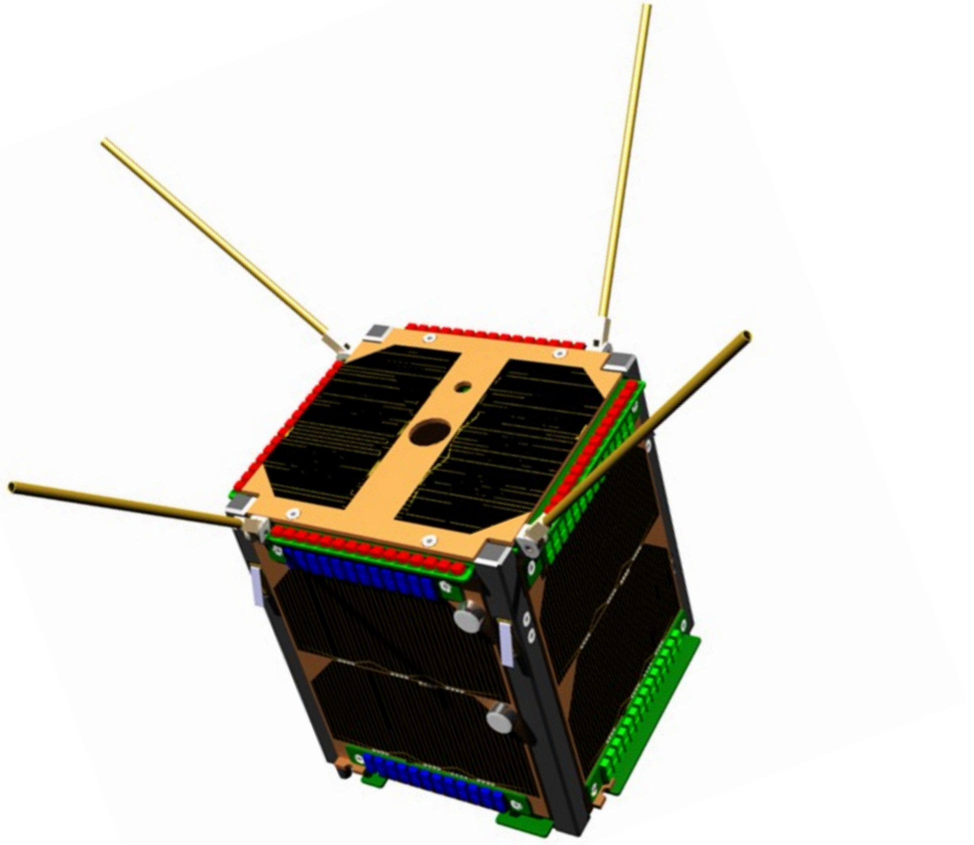


Early payload identification after cluster release

Orbit determination with optical data stand-alone

Attitude Reconstruction through patterns recognition

LEDSAT 1-U CUBESAT



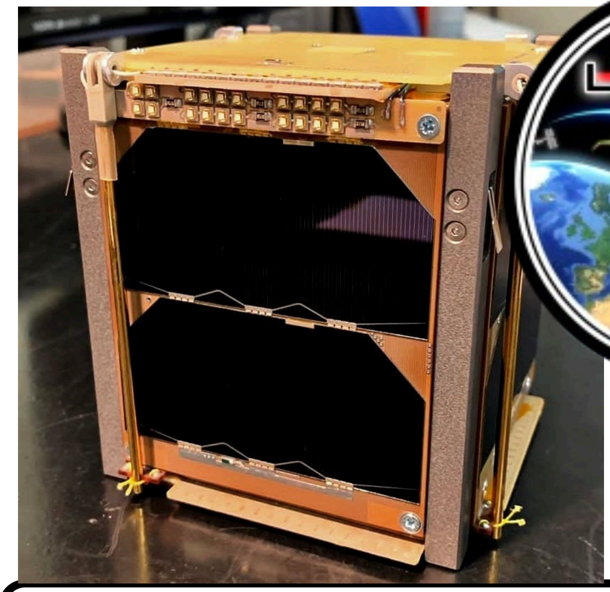
Developed by S5Lab Team of **Sapienza-University of Rome** - and conceived with the **University of Michigan**

Selected during the II Edition of the **ESA Fly Your Satellite**! **Educational Programme** that offered the launch opportunities and technical support

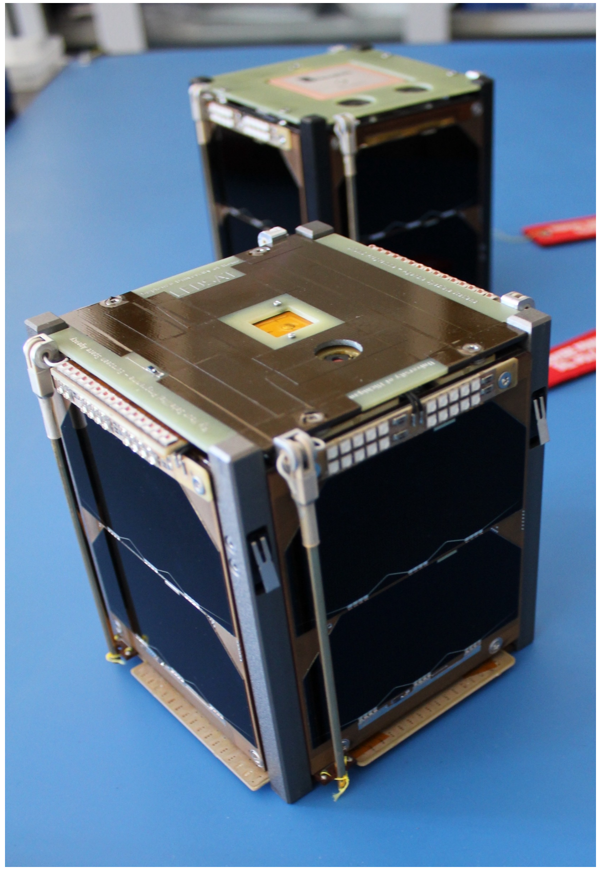
Part of the **Italian Space Agency (ASI) IKUNS Programme** – collaborating with Kenyan Students

S5Lab’s LED-equipped satellites

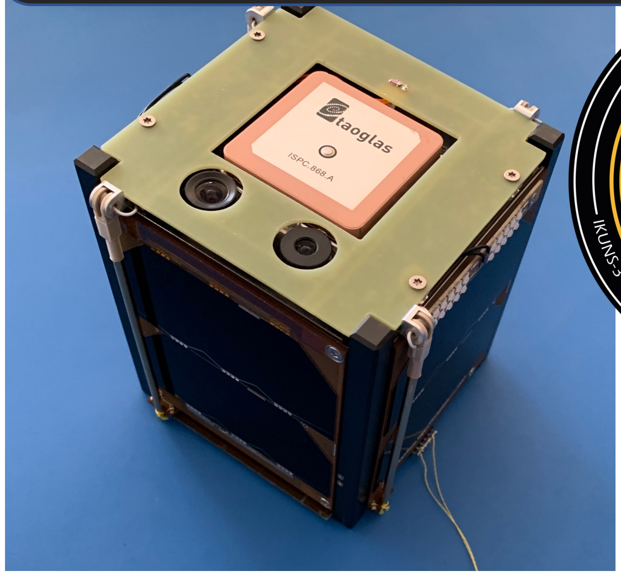
LEDSAT - 49069



- Six LED boards +1 Controller board
- LEDs as primary payload
- Three colors: Red, Green,Blue



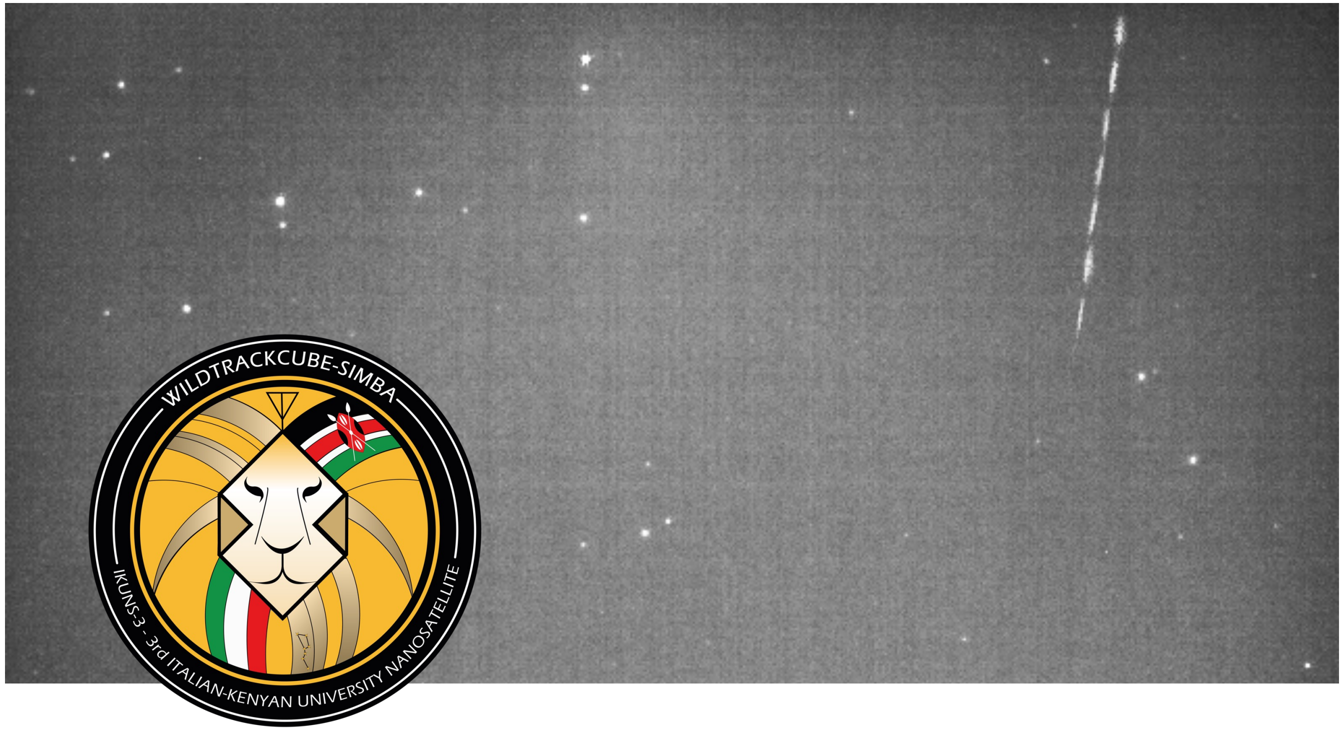
WILDTRACKCUBE-SIMBA - 47941



- Two LED boards + 1 mini-controller
- LEDs as secondary payload
- Blue LEDs only

Early Recognition through LEDs

- LEDSAT was observed one week after launch. The observational data allowed to recognize the object in the launch cluster (4 objects). Identification was confirmed through on-board GPS (49069)
- SIMBA was observed one week after deployment: <u>the first observation allowed to correct the identification of SIMBA to the 18SPCS and in the NORAD Catalogue</u>



OPTICAL RECOGNITION AT THE FIRST AVAILABLE OPPORTUNITY OVER ROME (1 week after deployment)

↓

OBJECT RECOGNITION

↓

CONFIRM THROUGH DOPPLER (SIMBA, LEDSAT) AND GPS (LEDSAT) DATA

↓

REGISTRATION OF OBJECT TO 18 SPCS AND NORAD FOR THE SPACE CATALOGUE

SSA and orbit determination measurements

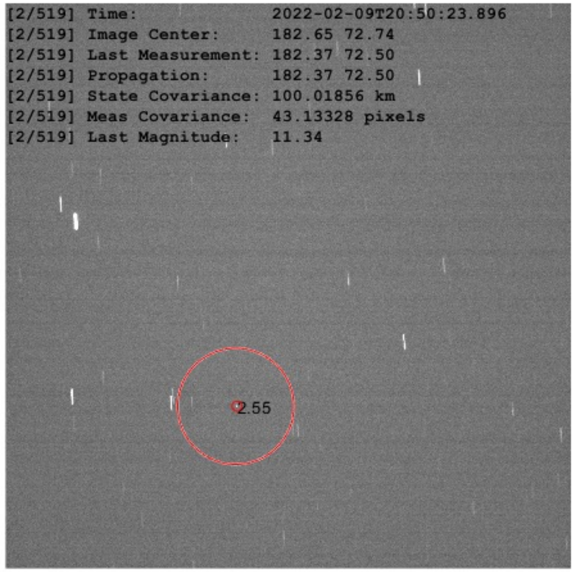
- **With the same techniques, it is possible to track the LED-equipped objects during the whole eclipse phase and to refine the orbit determination;**
- **It is also possible to use the LED-equipped satellite as calibration target for time-keeping devices if the LED flashes are synchronized to the GPS time**
- **Observations have been possible through multiple observatories, involving CNES, University of Michigan, University of Bern and others**

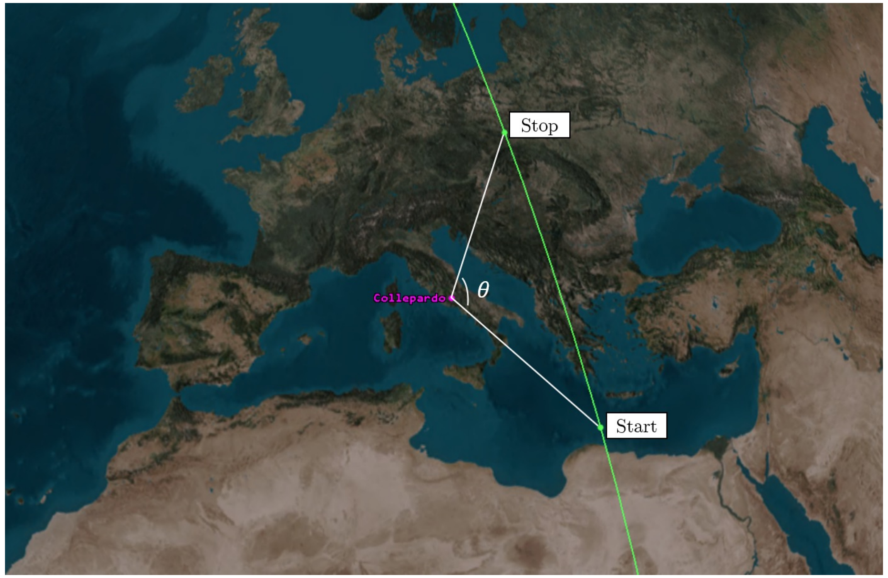
OPTICAL OBSERVATIONS OF THE LED TRACKLETS

OBJECT RECOGNITION (through dots and trails)

ORBIT DETERMINATION REFINITION AND ORB. ELEMENTS IMPROVEMENT

OTHER ANALYSES (time synchronization with flashes, observatory calibration, etc.)

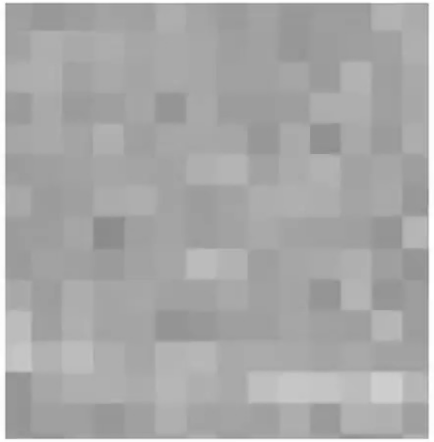




LED tracking

Tracking with automated analysis: real-time

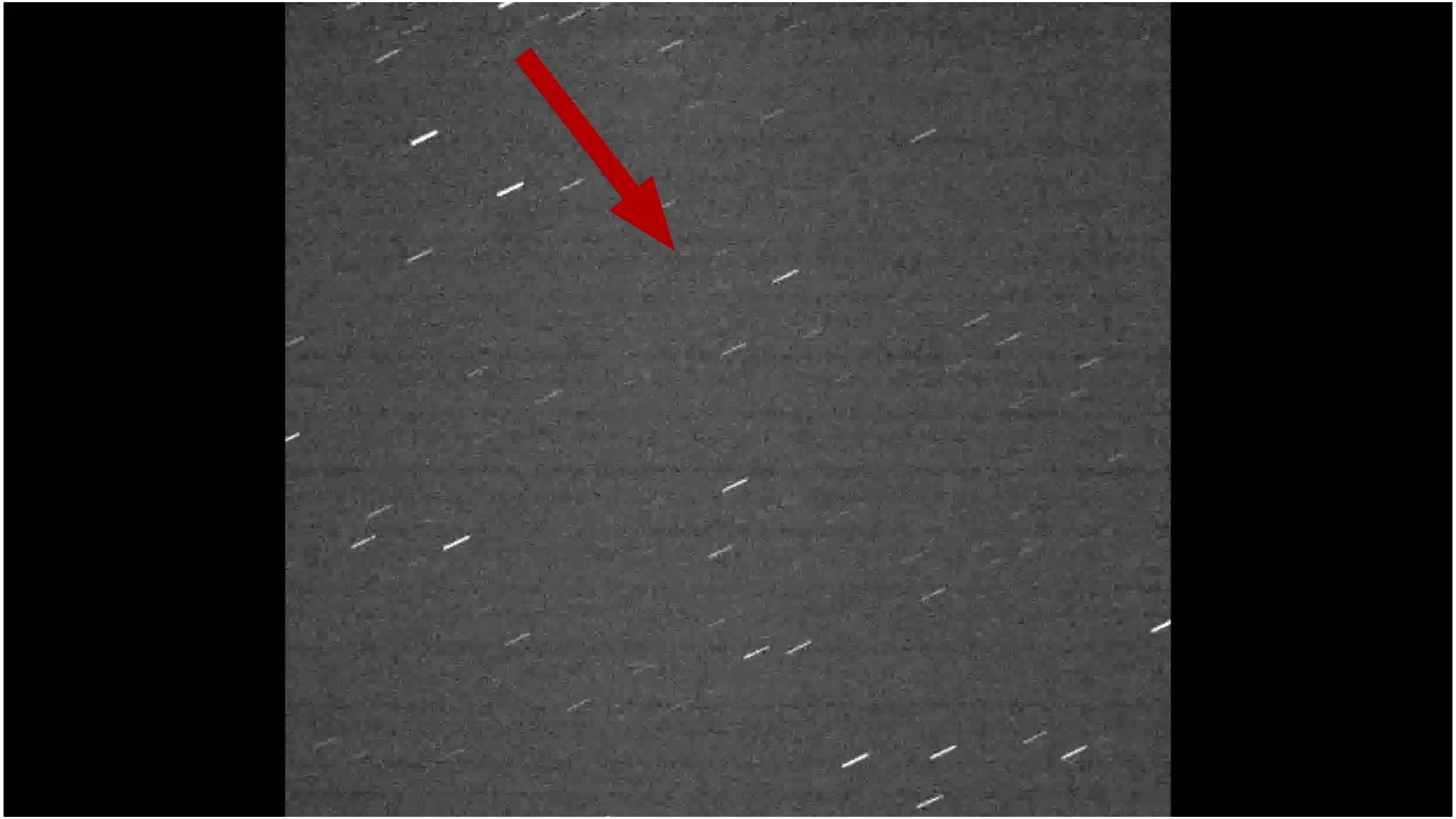
Sped-up tracking



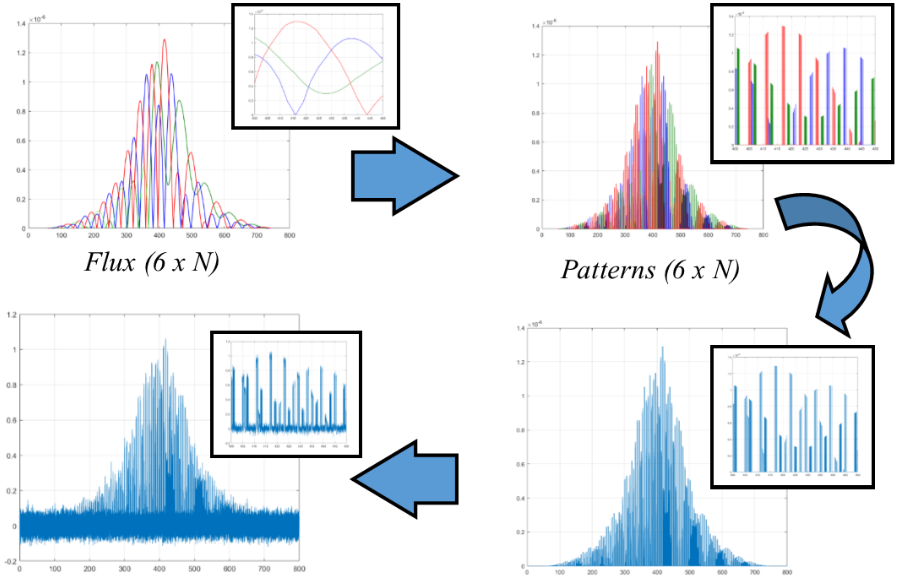
LEDSAT detail

LEDSAT

LED observations



Pattern generation and observations

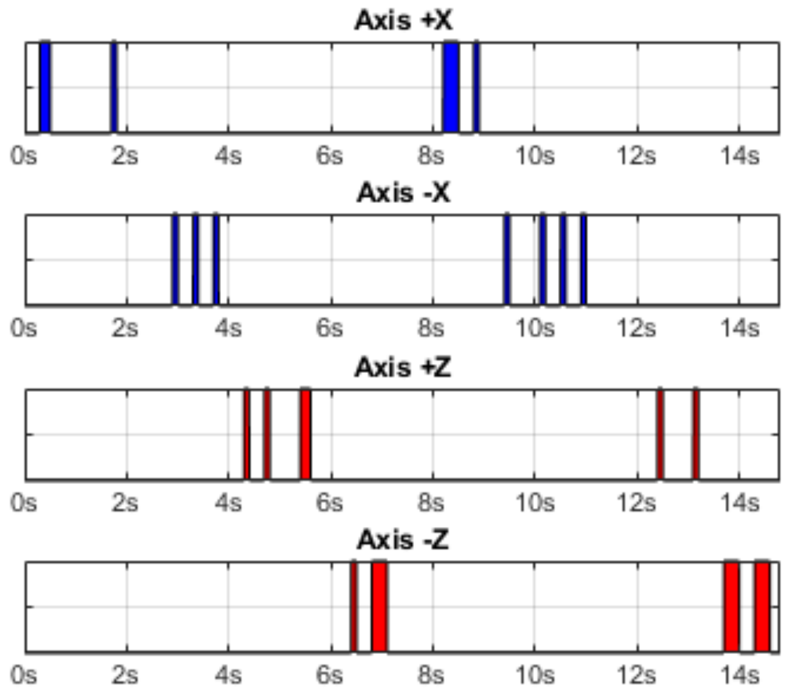


Flux (6 x N)

Patterns (6 x N)

Acquired Flux w/ noise (1 x N)

Acquired Flux (1 x N)

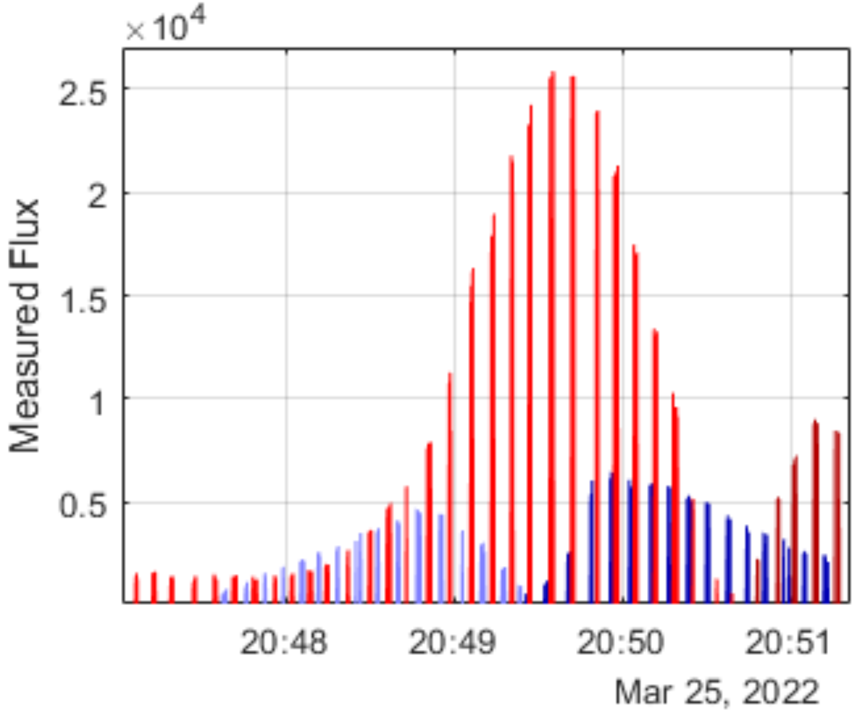


THE OPTIMAL PATTERNS HAVE BEEN VERIFIED THROUGH SIMULATION BEFORE THE MISSION – orthogonal gold codes are used and guarantee 99% of face detection with snr > 10

THE PATTERNS ARE ASSIGNED AND COMMANDED THROUGH GROUND COMMANDED TO DIFFERENT LED PAYLOADS

Pattern generation and observations

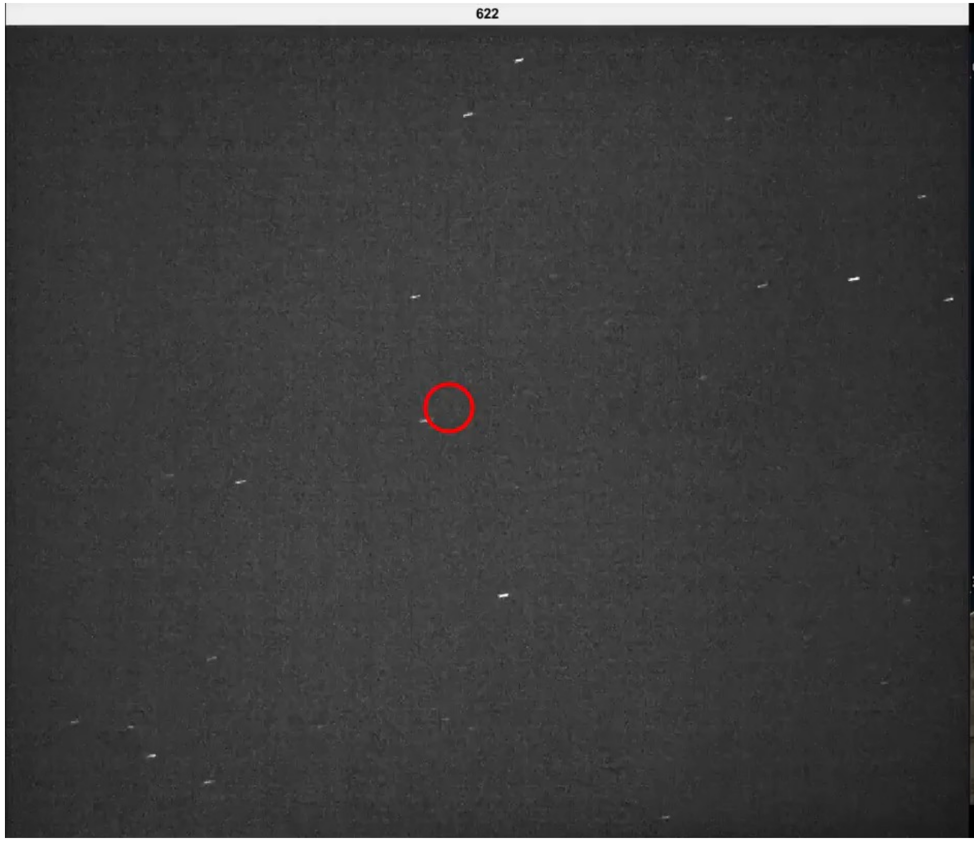
LEDSAT is observed through the S5Lab telescope network – the patterns are acquired in a sCMOS video



The flux generated by the LEDs is analyzed and the faces are recognized. This is used as input for a particle swarm filter for attitude reconstruction.

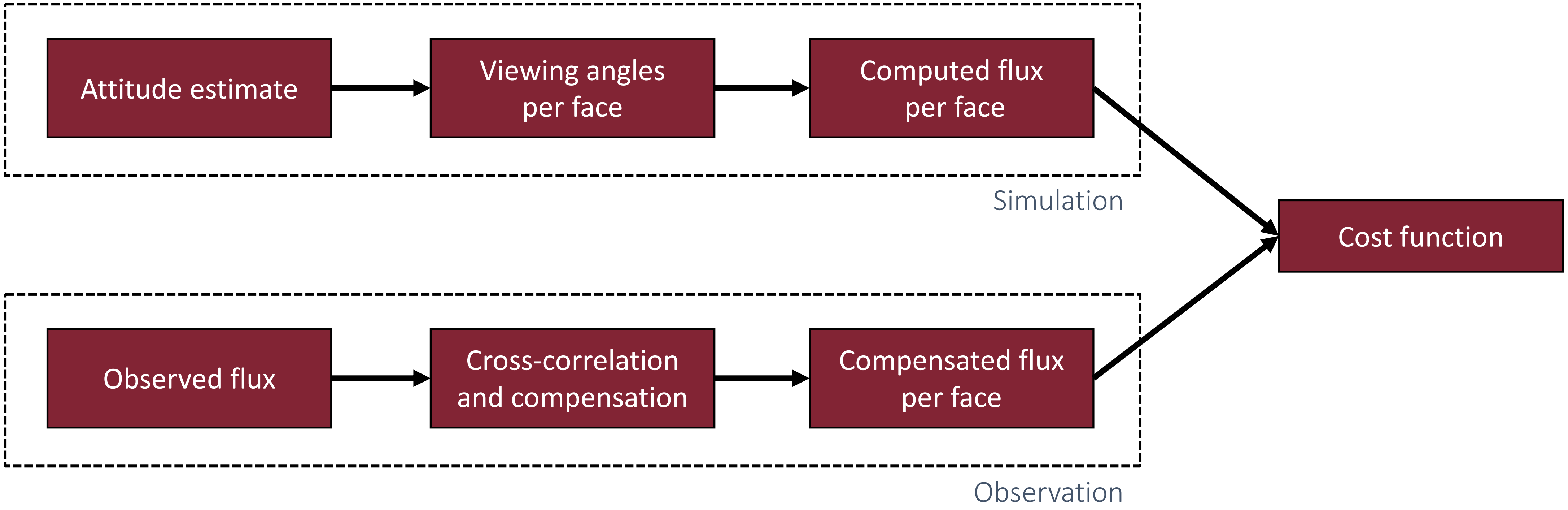
LED Observations: attitude reconstruction via LED optical data stand-alone

LED flashes with different patterns



Attitude with on-board data

Attitude determination process



Attitude determination method

The optical attitude determination is based on a weighted least squares cost function across all flashes, with the weight being the S/N of the flash:

$$J = \frac{1}{N}\sqrt{\sum_j w_j \left(\tilde{f}_j - f_j\right)^2}$$

$\tilde{f}_j$ - observed flash flux

f_j - computed flash flux

The solver uses a constrained Particle Swarm Optimizator, with the following state:

$$X = [\boldsymbol{q}_0, \boldsymbol{\omega}_0, \boldsymbol{d}_s]$$

Composed of the initial attitude $\boldsymbol{q}_0$, angular velocity $\boldsymbol{\omega}_0$ and residual dipole $\boldsymbol{d}_s$.

Attitude determination method

Since the magnetic dipole plays a big role in the attitude of the satellite, it is necessary to estimate it in the optical attitude determination.

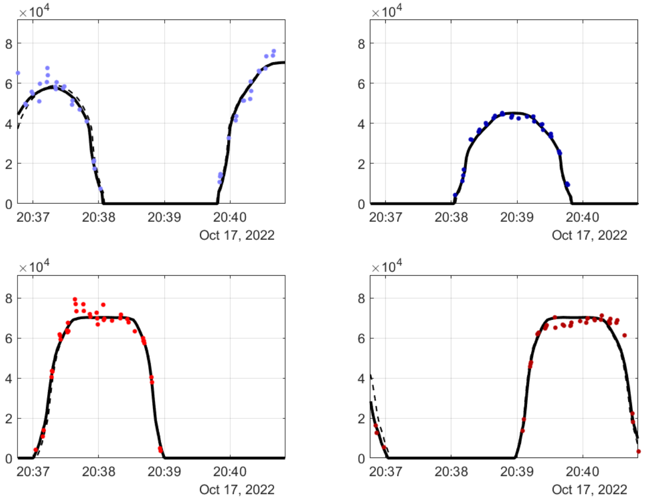
The value of the dipole for each axis is allowed to change up to 15% of the known value, while the angular velocity is allowed to assume any values within ±1.5 deg/s for each axis.

Search bounds for each state variable

Quantity	Bounds
Quaternion	±1 per element
Angular Velocity	±1.5 deg/s per axis
Magnetic dipole	d ±15%$\|d\|$ per axis

LEDSAT

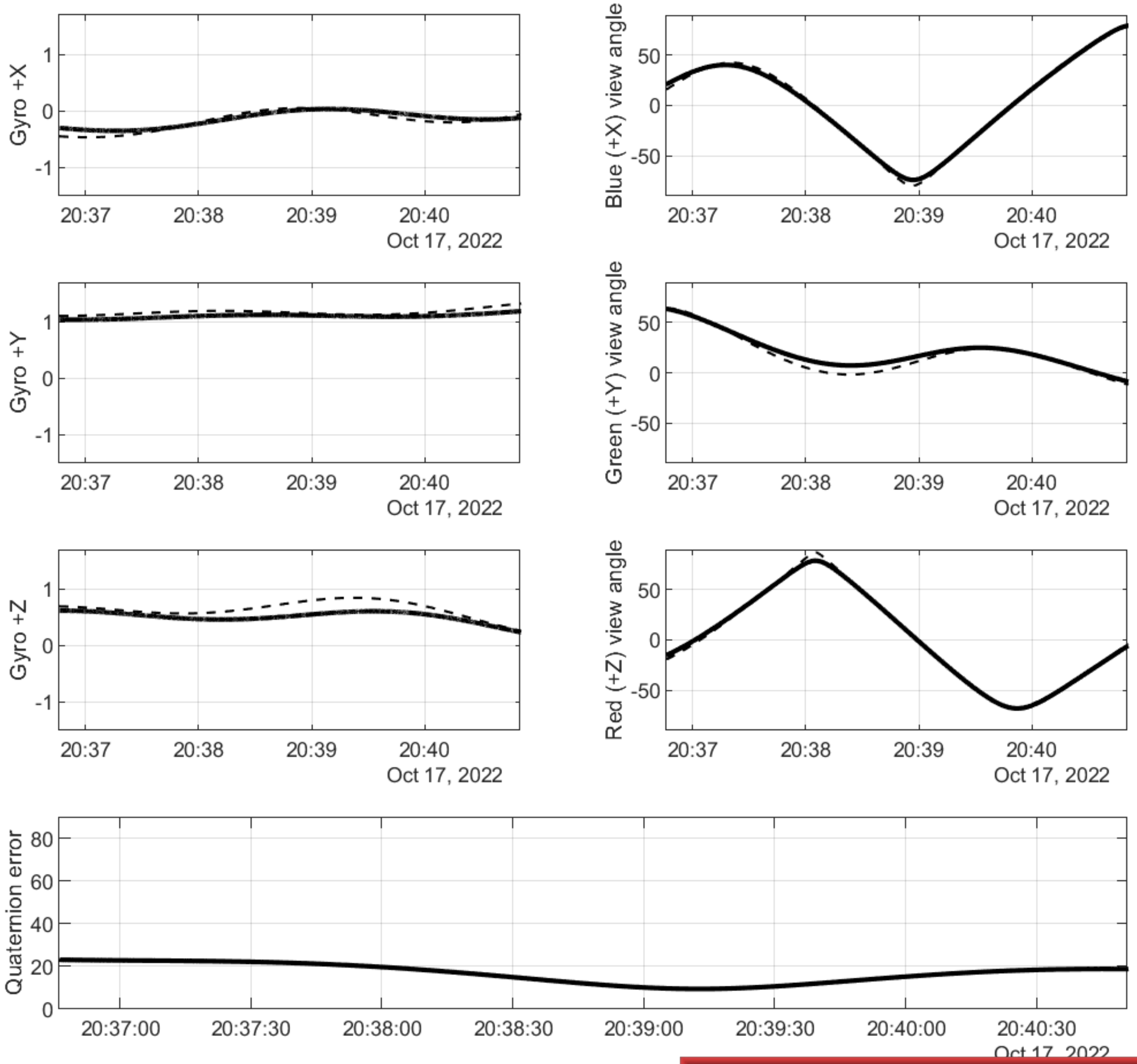
In-orbit testing – Exp 1



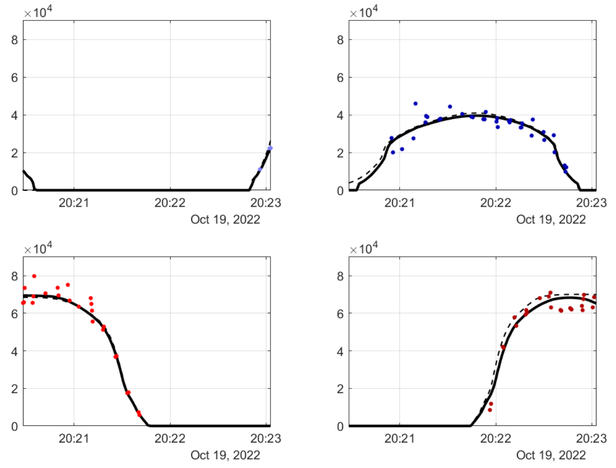
Comparing the obtained attitude, we find that there is an excellent match on the view angles of the red and blue boards,

Expected flux from on board sensors, reconstructed from flashes and measured

Label	Residual Mean	Residual Max	Residual Std. Dev	Unit
Blue view angle	-0.370	5.705	2.343	deg
Green view angle	2.901	9.050	2.343	deg
Red view angle	0.128	8.500	2.121	deg
Quaternion error	17.028	23.330	4.506	deg
Gyro +X	-0.035	0.067	0.062	deg/s
Gyro +Y	0.072	0.135	0.028	deg/s
Gyro +Z	0.128	0.254	0.076	deg/s



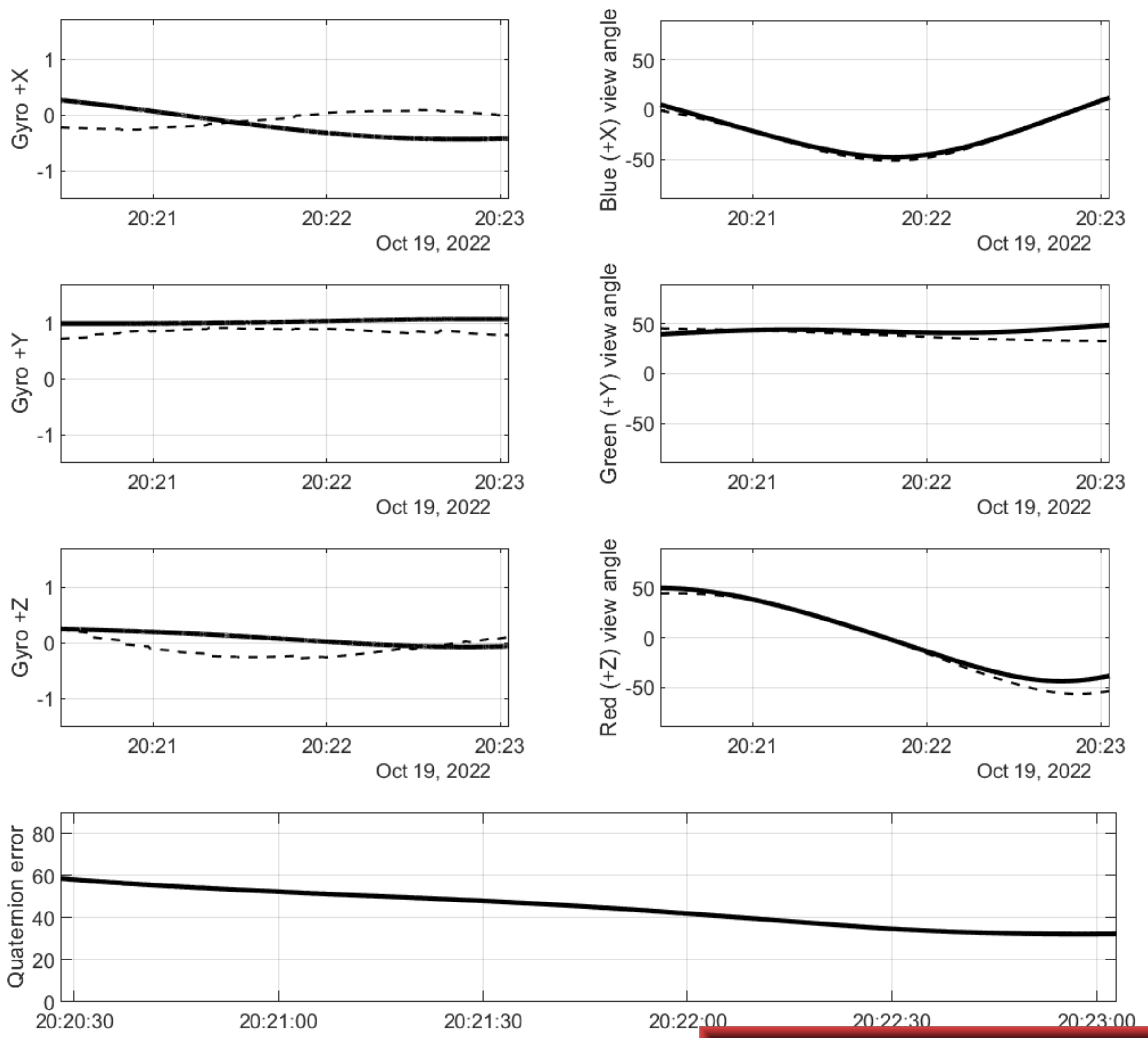
In-orbit testing – Exp 2



In this case, the attitude determination accuracy is diminished – while there is good match between the view angles

Expected flux from on board sensors, reconstructed from flashes and measured

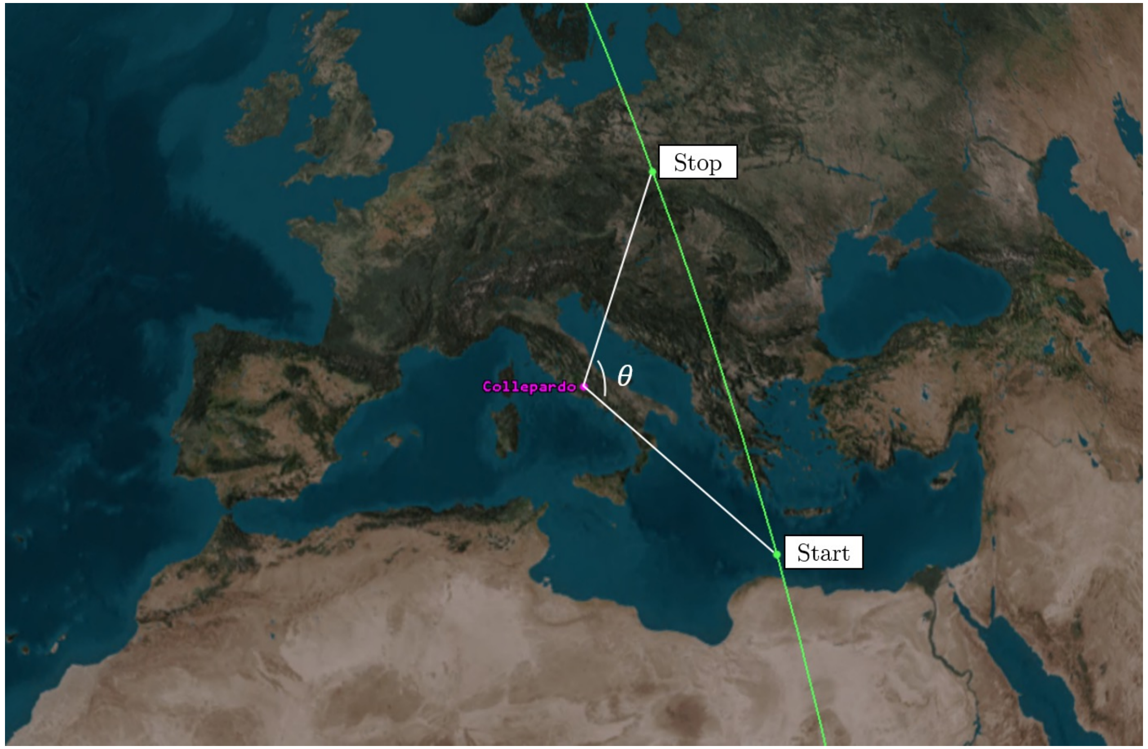
Label	Residual Mean	Residual Max	Residual Std. Dev	Unit
Blue view angle	1.959	6.023	1.430	deg
Green view angle	4.032	16.121	1.430	deg
Red view angle	4.242	15.330	4.447	deg
Quaternion error	44.423	58.527	8.513	deg
Gyro +X	0.098	0.513	0.373	deg/s
Gyro +Y	-0.179	-0.087	0.057	deg/s
Gyro +Z	-0.166	0.165	0.159	deg/s



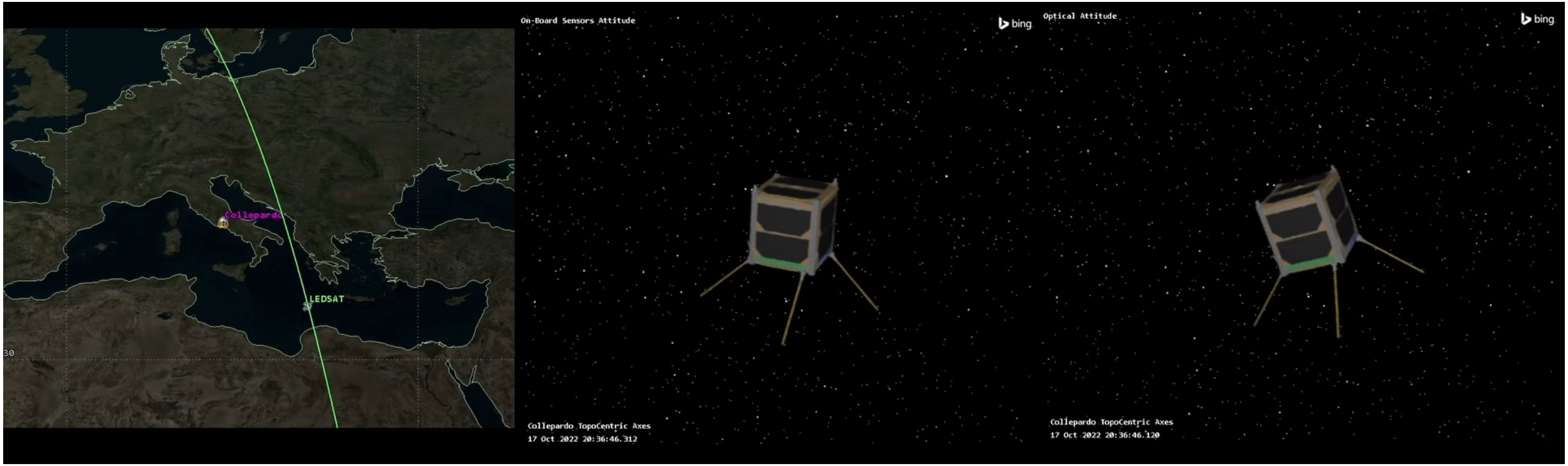
Link with the sky arc length

What these cases show is that the main factor in play is not the duration of the observation, but the change in observation angle throughout the passage.

During higher elevation passages, the station sees the satellite from different point of views, breaking symmetry in the problem.



Attitude visualization – Case 1



Optical attitude determination conclusions

Summarizing what was found:

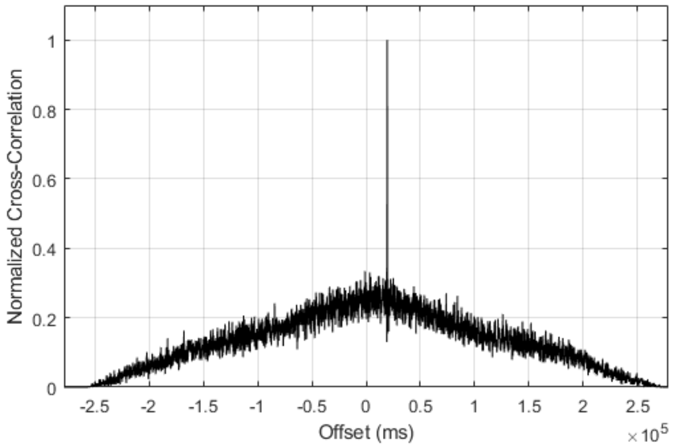
- It is better to prefer higher elevation passages
- The most important sections are the beginning and end of the observation
- It is important to have a short switching time between the flashing faces

LEDSAT flashes timing

- Each flash can be between 10ms and 2s long, with a total pattern duration up to 10 minutes

- The on-board timing of the LEDs delivers:
  - 1 ms relative timing precision
  - <100 ms absolute timing precision

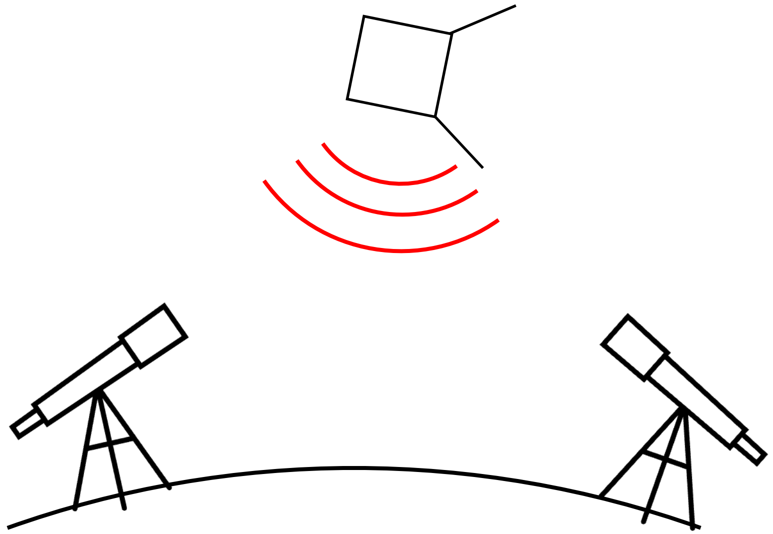
- Cross-correlation of the observed pattern can be used to recover timing precision within a fraction of the frame rate



Concurrent observations

Concurrent observations of LEDSAT from multiple observatories can achieve:

- Accurate relative time synchronization
- Improved orbit determination
- Improved attitude determination



Since the timing of each flash can be recovered accurately, it is simple to correlate measurements from two observatories.
The baseline between the observatory helps with the orbit and attitude determination.

LEDSAT's attitude

The attitude of LEDSAT is controlled via magneto-torquers

The angular velocity can be varied between 0 and 30 deg/s depending on the application

Nominally, the satellite is left tumbling at ~1deg/s

Thank you for your attention!

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