POLITECNICO MILANO 1863

DART Group

FUTURE

(Fully aUtonomous feaTUre Recognition planetary Explorer)

An in-orbit demonstrator for on-board fully autonomous vision-based navigation

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L'impegno italiano nel settore dei CubeSat
Tecnologie e Missioni Future (2° edition)
Agenzia Spaziale Italiana, Roma

Tyvak International
A Terran Orbital Corporation

ALTEC

AIKO
INFINITE WAYS TO AUTONOMY

Project Organization

FUTURE is a mission of the Italian Space Agency developed in the frame of the ALCOR program

Agenzia Spaziale Italiana

Alcor

Prime Contractor

Tyvak International
A Terran Orbital Corporation

Subcontractors

AIKO
INFINITE WAYS TO AUTONOMY

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OUTLINE

- Mission Objectives
- Mission Overview
- Technology Design
- Navigation Algorithms
- Ground Segment Architecture

Mission Objectives

Current operational paradigm

Ground-based spacecraft orbit determination and control

Deep-space navigation relies mostly on DSN and ESTRACK

Radiometric measurements **Range & Doppler**

High accuracy ✓

Higher cost, wrt LEO **(GNSS)** ✗

Antenna slots saturation ✗

Mission Objectives

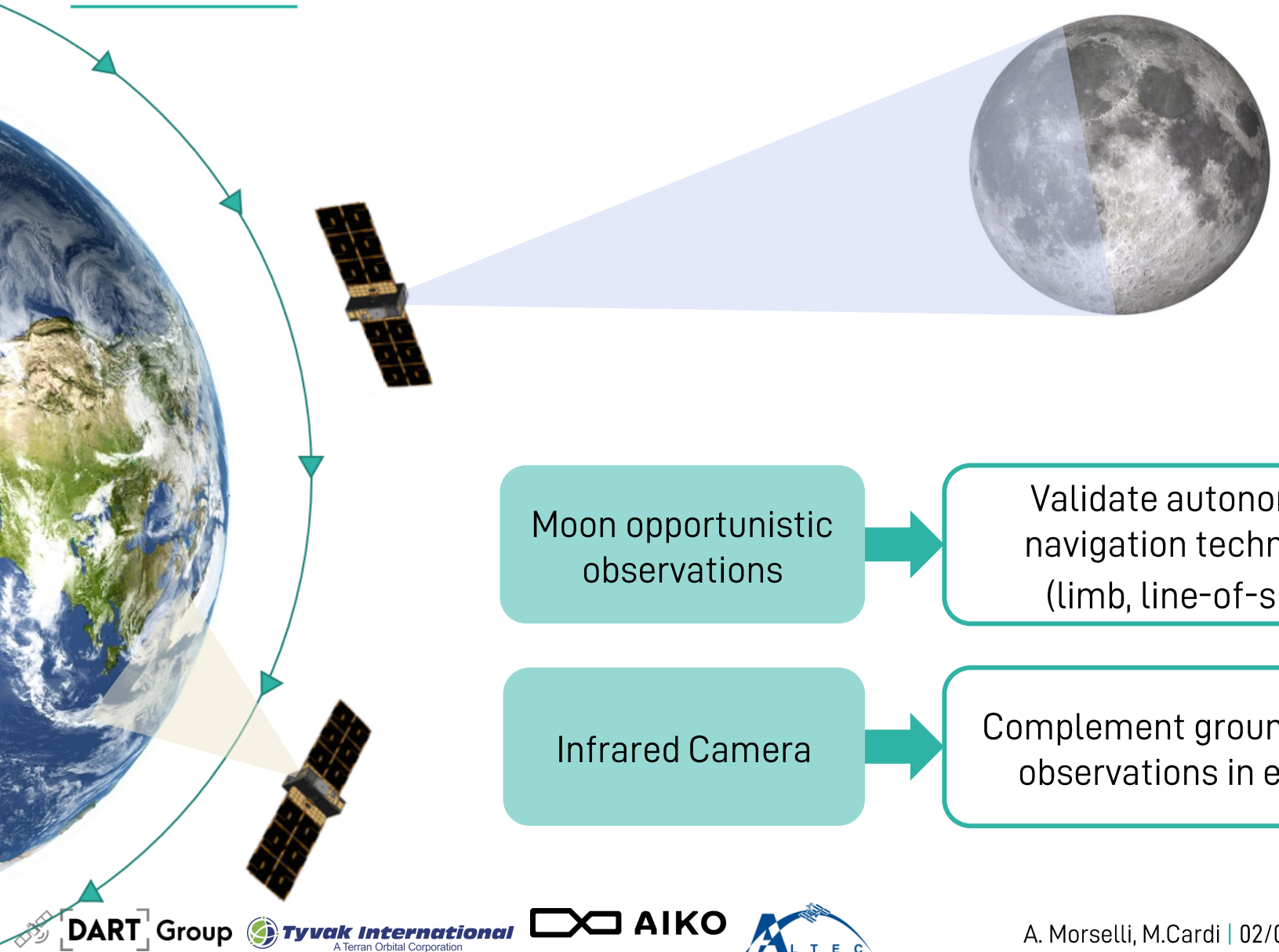
To what extent can we enhance autonomous navigation capabilities exploiting natural features on the surface of a celestial body?

FUTURE

FUTURE is an **in-orbit demonstrator** that will perform autonomous navigation using **visual observations of the Earth** from LEO orbit.

This technology could be adopted on missions beyond LEO, such as planets and moons orbiters, hence enhancing autonomous operations and navigation.

Added Value



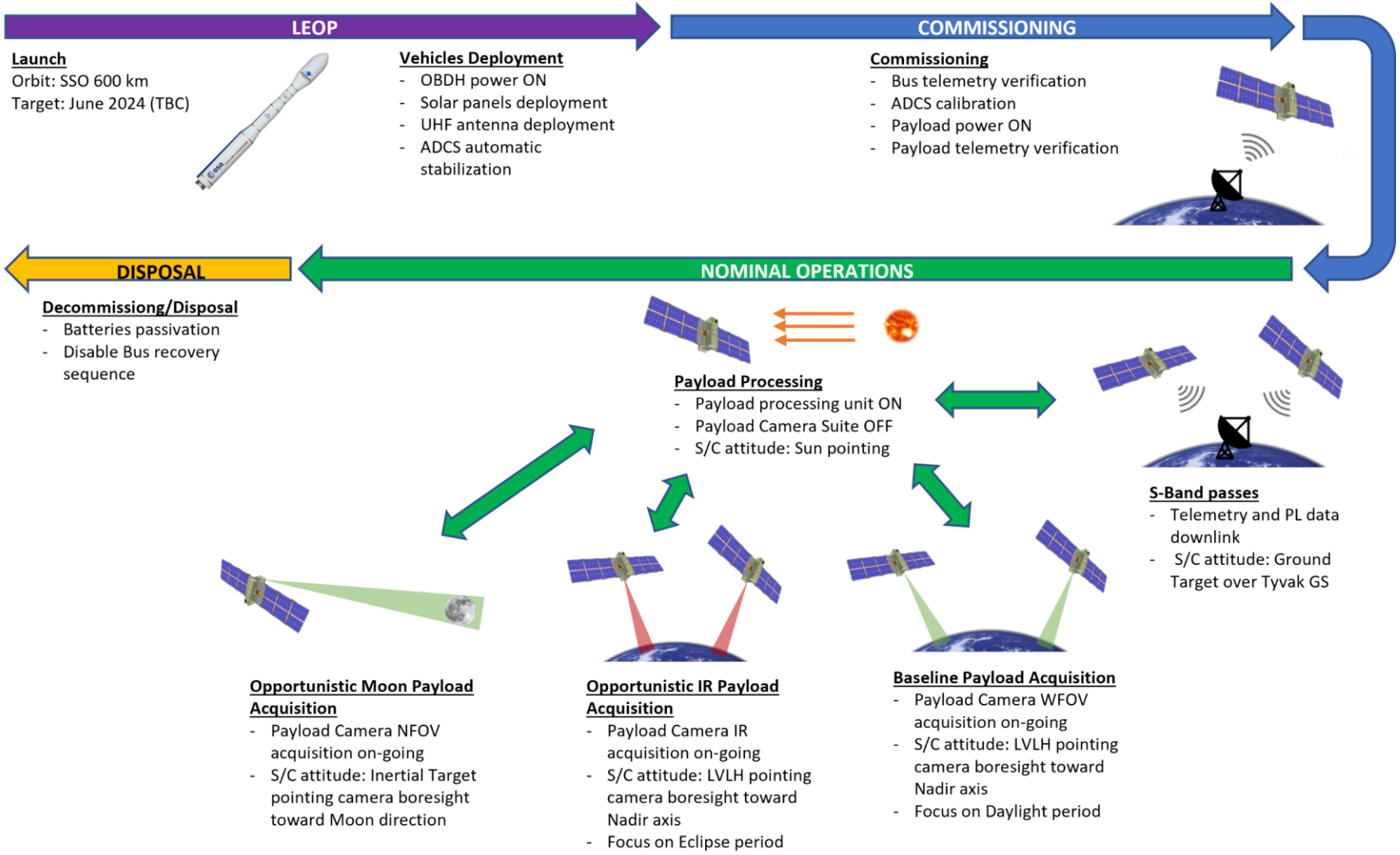
Moon opportunistic observations → Validate autonomous navigation techniques (limb, line-of-sight)

Infrared Camera → Complement ground-based observations in eclipse

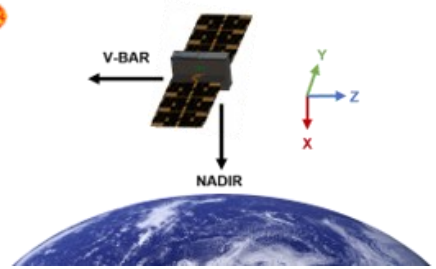
Technology Transfer Beyond LEO

Mission Overview

Concept of Operations

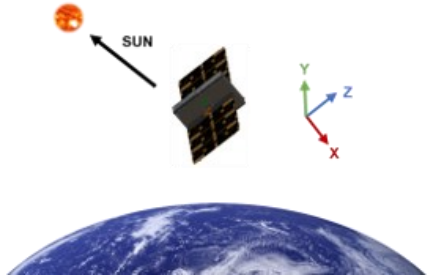


Nominal Operations - Mission Phases



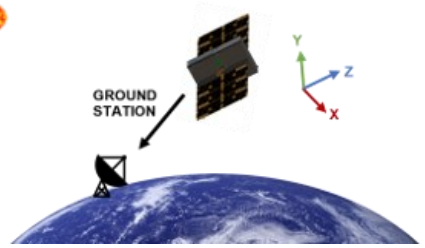
LVLH

(target pointing)



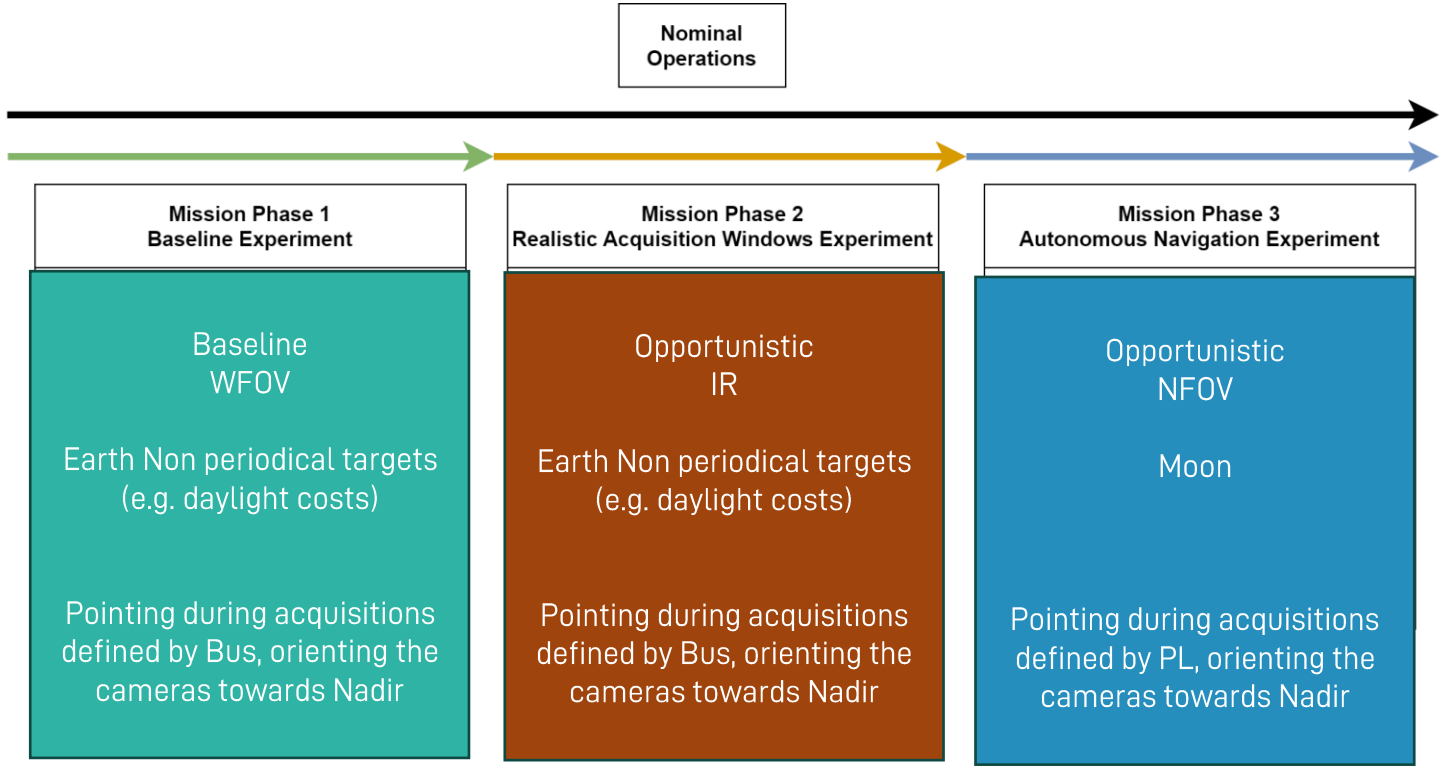
Sun Pointing

(battery charging)



Ground Target

(data download)



Technology Design

Spacecraft overview

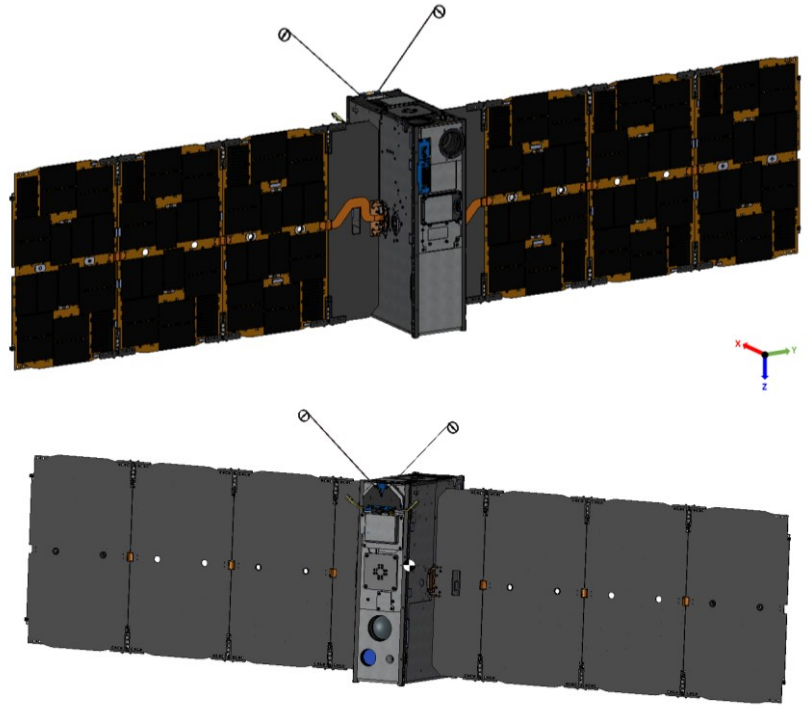
Baseline Architecture

Based on standard Tyvak 6U Triumph Platform, which incorporates Tyvak's last generation avionics (MK-II)

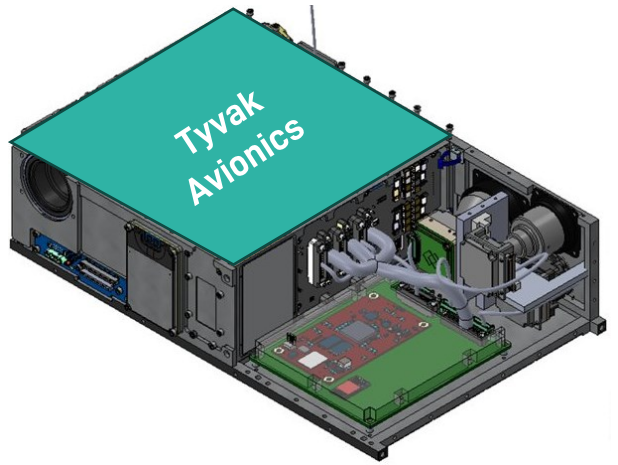
Avionics designed to support satellites applications ranging from 6U CubeSat up to 350kg microsatellites

Specification	Capability
Satellite Mass	~13 kg
Payload Mass	~3 kg
Payload Volume	~3U
Orbit Average Power Consumption (during *EarthAcquisition* mode)	~41 W
Orbit Average Power Generation (during *EarthAcquisition* mode)	~44 W
Radio Configuration Link @ 5° elevation closed with > 3dB margin	UHF TX/RX (baseline at 9.6kbps) S-Band Uplink (baseline at 125kbps) S-Band Downlink (baseline at 1Mbps)
Data Download Capability	HK telemetry + up to 70 images/day

External View

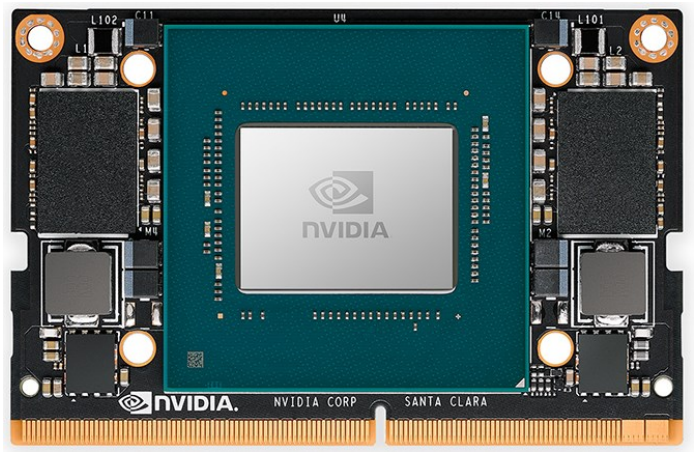


Payload Internal View



Payloads overview

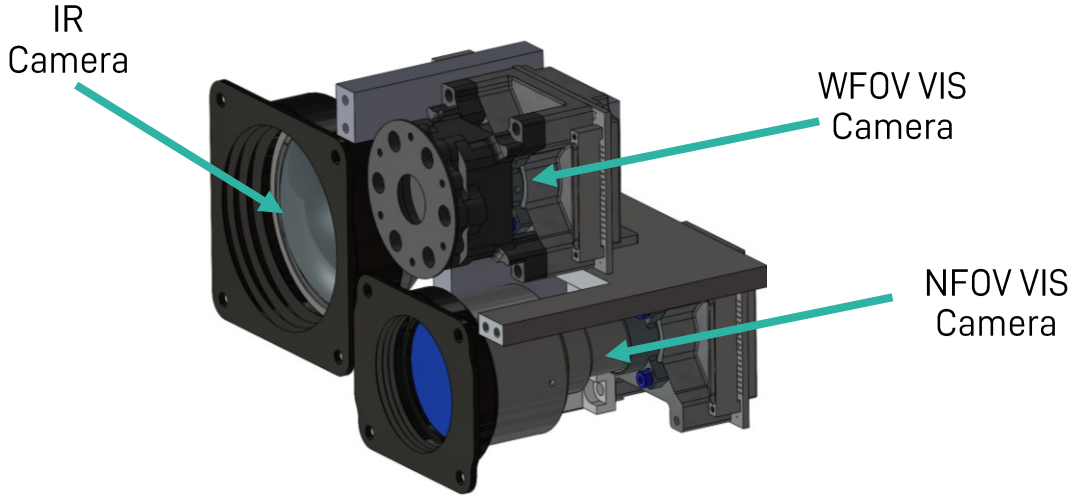
Payload Processing Unit



GPU – NVIDIA XAVIER

NB: LEO Flight Heritage

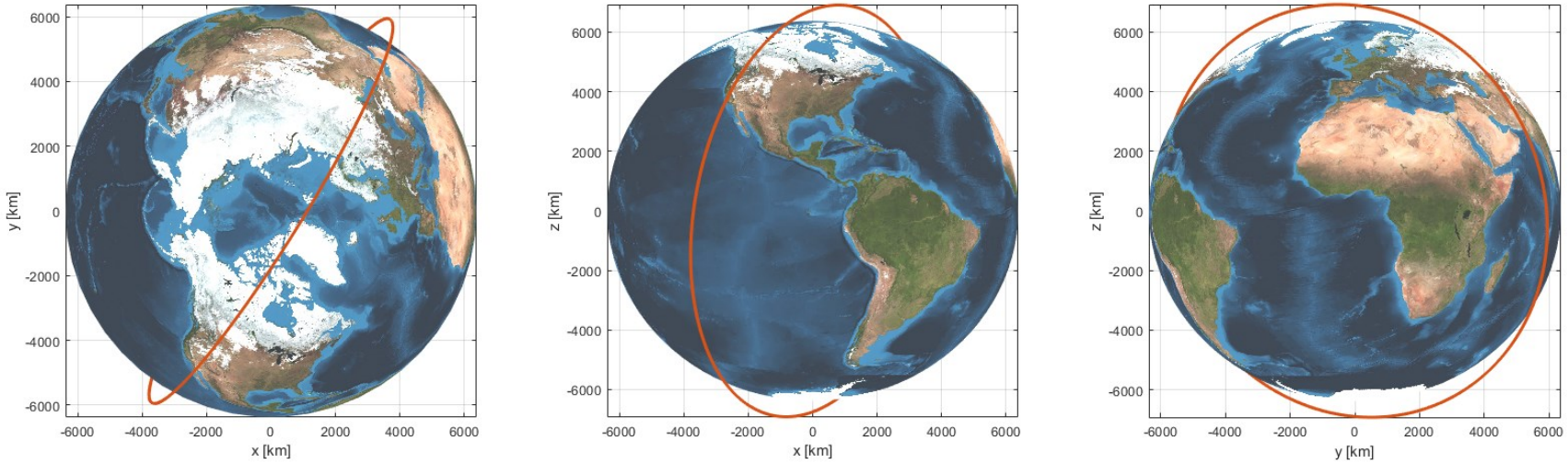
Optical Payload Assembly



Mission Analysis

Operational orbit

SMA [km]	ECC [-]	INC [deg]	RAAN [deg]	T [min]
6976.7	0	97.9	60.5	96.7



NB: Compliant with Vega-C launch opportunity

Coverage analysis

- Coastlines, rivers, lakes
- Simulation: 14 days
- Launch date: 14 June
- VIS (daylight) + IR (eclipse)

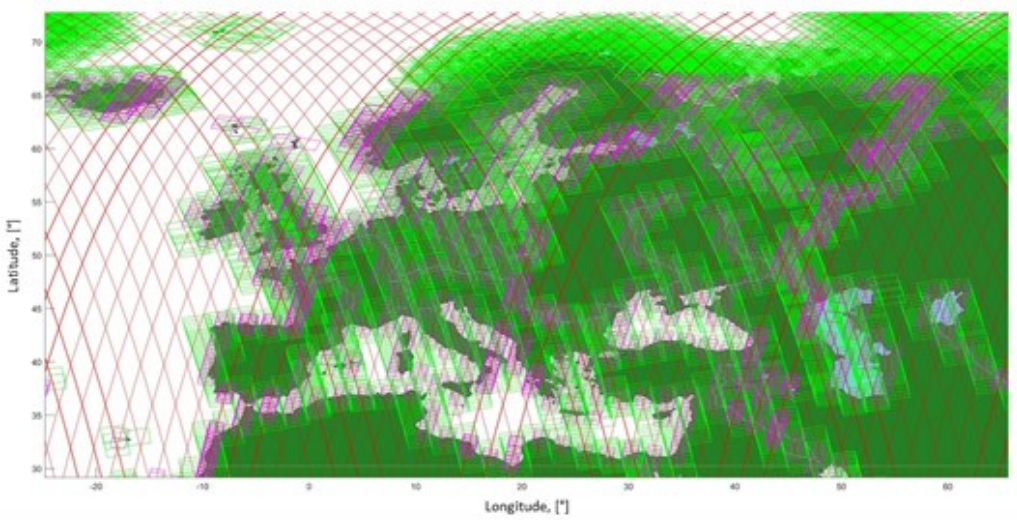
Results

Case	Visibility [%]
Day&night	16.23
Daylight	11.42

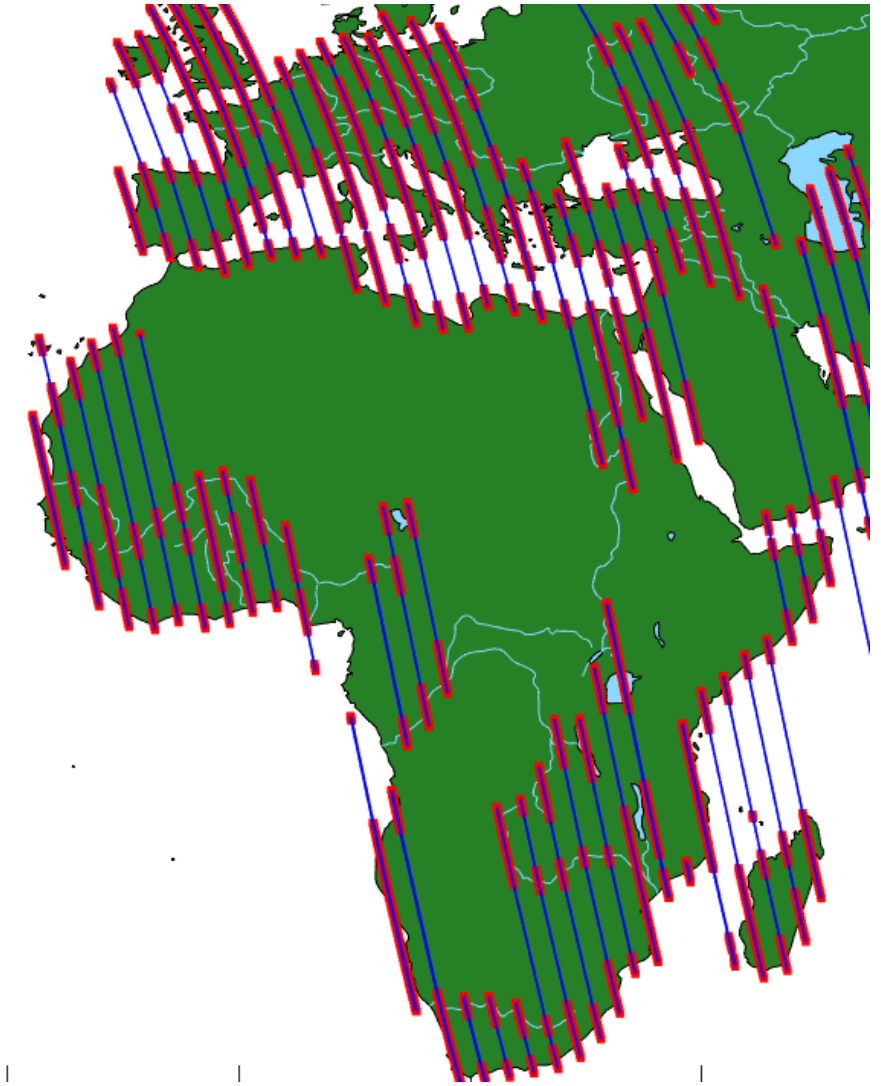
Features detection

- Detection of invariant features:
  - coastlines
  - rivers
  - lakes

Acquisition windows definition



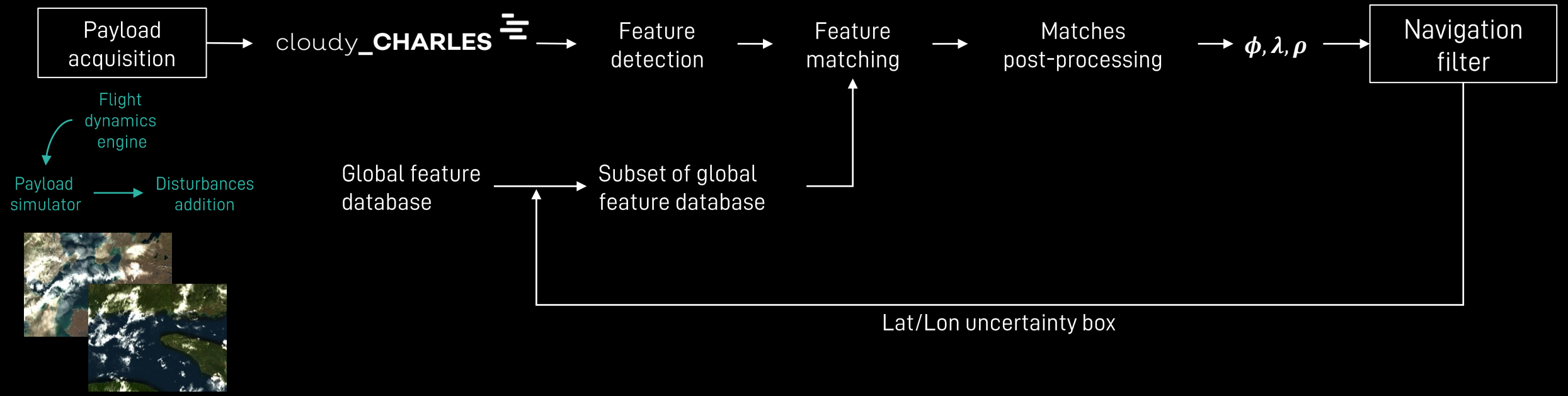
VIS camera in daylight
IR camera in eclipse



Navigation Algorithms

AI Image Processing (AIKO)

- 2-step approach: DL-based feature detection&matching.
- cloudy_**CHARLES** (AIKO product at TRL9) for onboard cloud detection.
- Built a reference database of ≈ **90.000 Earth surface features**.



AI Algorithm performance insights

Dataset

- Synthetically generated exploiting open source EO images adapted to FUTURE-like acquisitions.
- Cloud coverage and illumination gradient disturbances added to the test dataset.

Image Processing performance

	Scene coordinates	Range from scene
Test success rate [%]	>95	≈80
Mean accuracy [km]	5.4	15.3

Computational performance on target HW

- Optimized inference time: < 1 s/frame

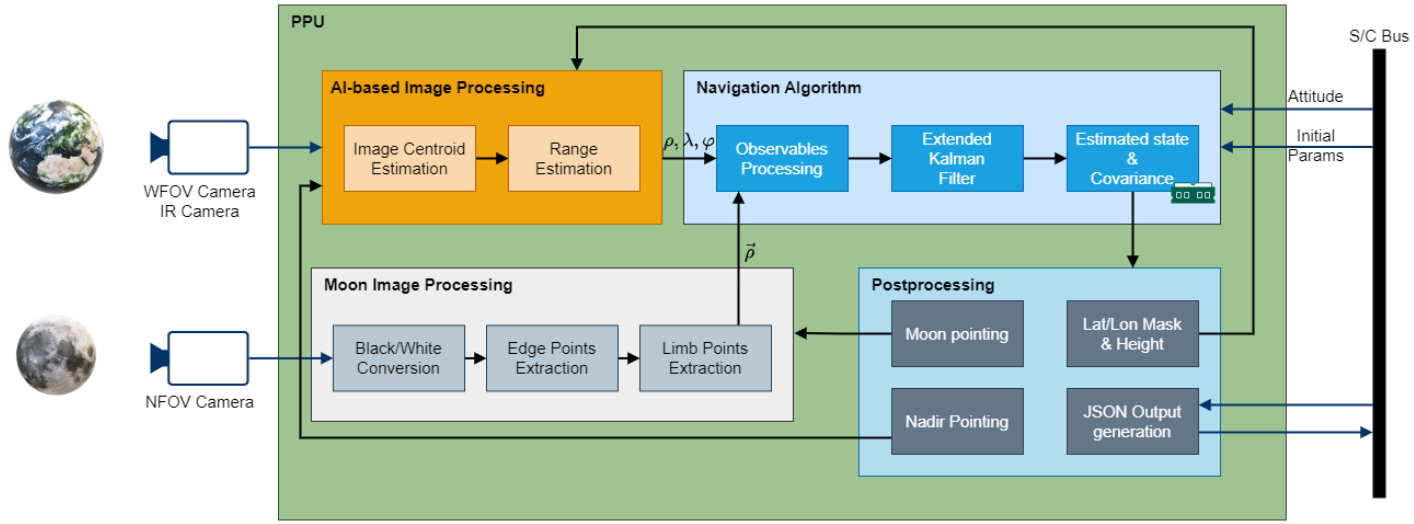
NAV software design

Modules:

- AI-based Image Processing
- Moon Image Processing
  - Black/White conversion
  - Edge Points Extraction
  - Limb Points Extraction
- Navigation algorithm
  - Observables processing
  - State estimation, propagation
  - Kalman Filter
- Post-processing
  - JSON output generation
  - Lat/Lon masking for AI features matching
  - Nadir & Moon Pointing

Interfaces

- S/C bus to exchange commands, outputs, and readings (e.g., attitude), and configurations



Storage:

- Navigation algorithm object code
- AI and Moon IP object code
- External libraries and object code
- Orbit and data files (Moon, configuration, time kernels)
- Output files

Software and Hardware-in-the-Loop testing campaign foreseen in Phases C-D

Navigation Algorithm Performance

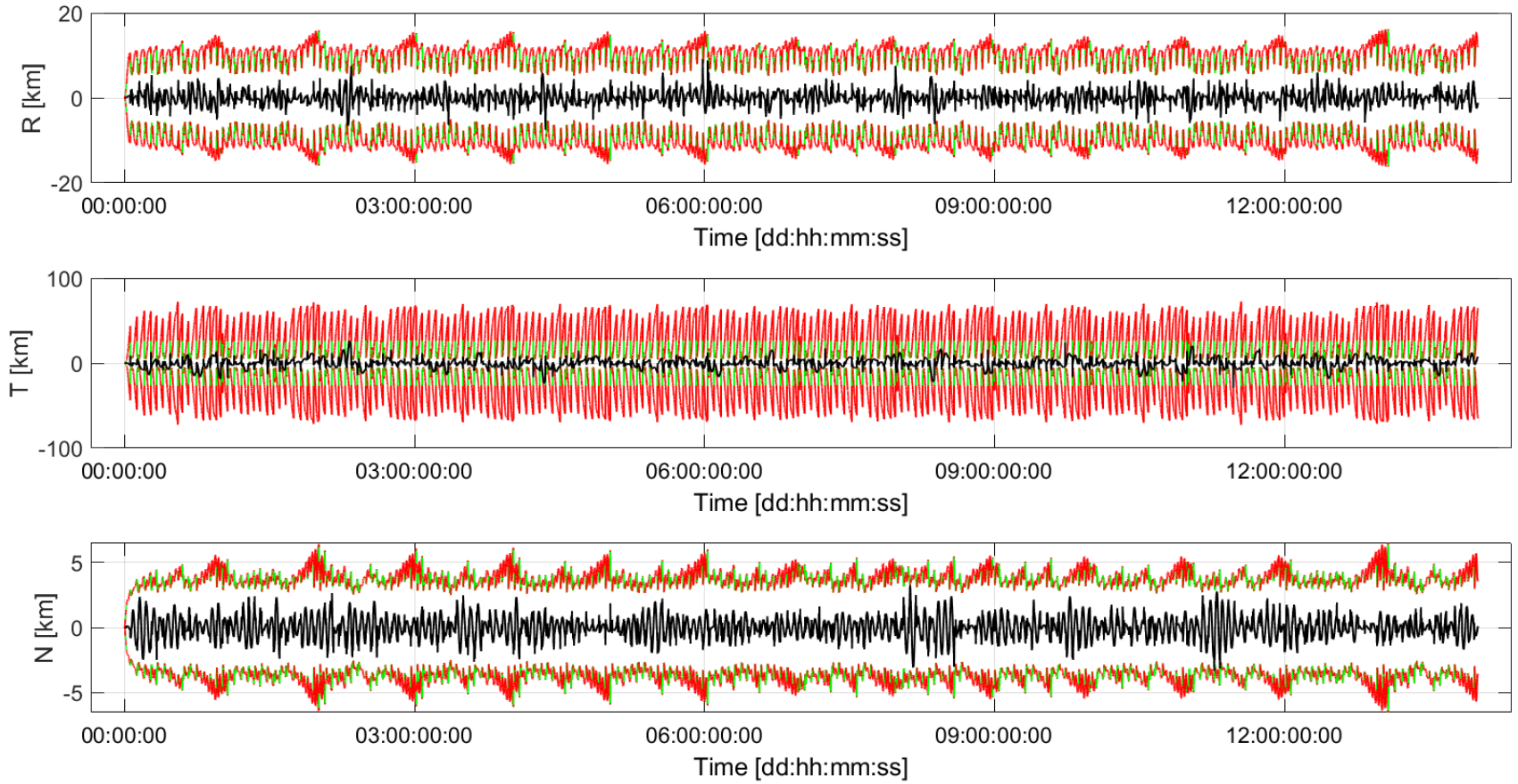
14-days simulation

Green: acquisition windows (Earth)
Red: Propagation Arc

Measurement uncertainty
$1\sigma_R = 25\ km$
$1\sigma_{T,N} = 8\ km$

Acquisition Frequency
5 s

NAV Filter error and covariance



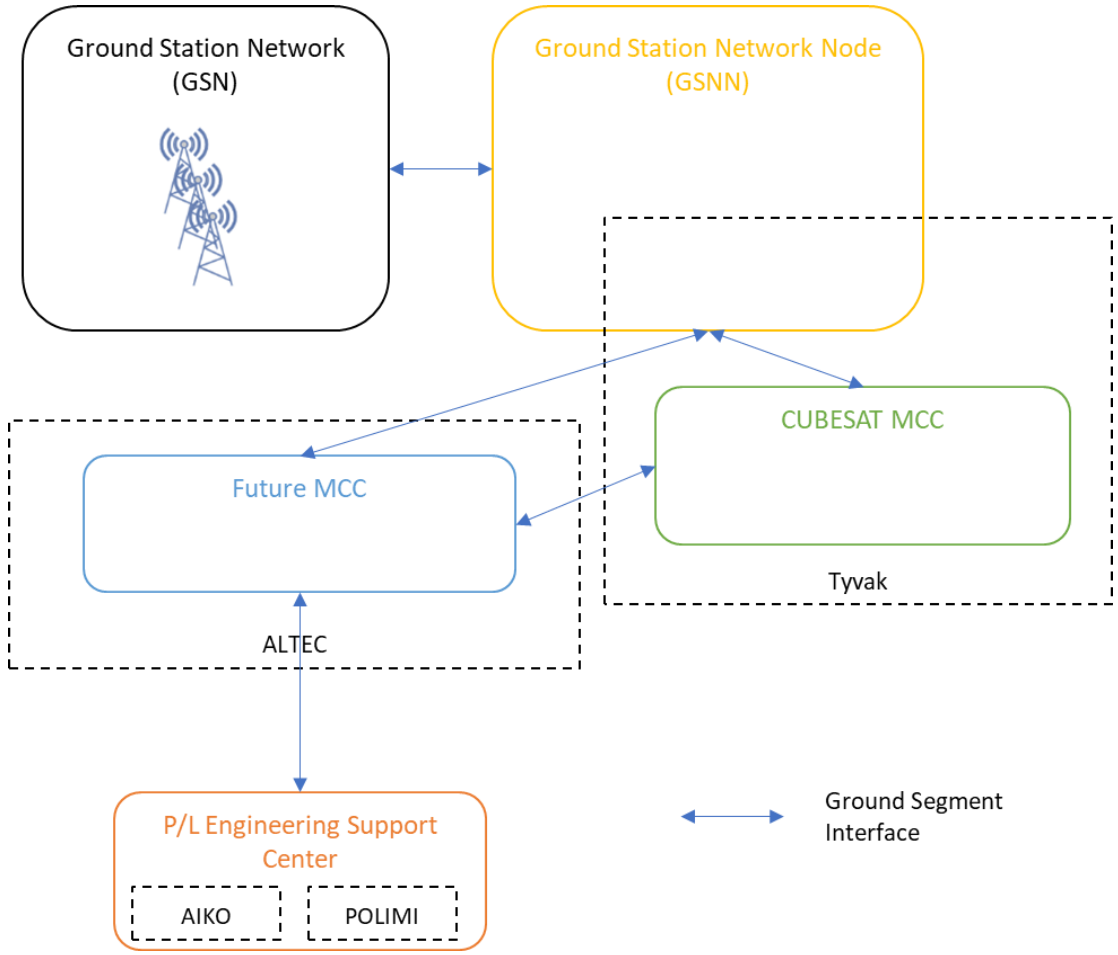
Overall 1σ accuracy: < 6.5 km

Ground Segment Architecture

Ground Segment Design

Ground Segment is organized into
5 main logical elements:

- Ground Station Network (GSN)
- Ground Station Network Node
- Cubesat MCC
- Future MCC
- Future P/L Engineering Suppor Centers



Conclusions and FUTURE works

- Phase B successfully concluded with PDR in November 2023
- Implementation phase to start in September 2024
  - PIL and HITL algorithm validations
- Launch expected in Q3 2026

By demonstrating autonomous navigation techniques in LEO, FUTURE sets the stage for **beyond LEO applications**, in particular for missions **about planets and moons**, so enhancing **autonomous operations and navigation** in proximity of celestial bodies.

FUTURE showcases the potential of visual navigation as a primary navigation tool, paving the way towards enhanced autonomy in space exploration

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