POLITECNICO
MILANO 1863

e.Inspector

VIS-IR imaging for proximity GNC around the VESPA uncooperative debris

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LEONARDO LEAF SPACE

TECHNOLOGY
FOR PROPULSION
AND INNOVATION

DIPARTIMENTO DI
SCIENZE E TECNOLOGIE
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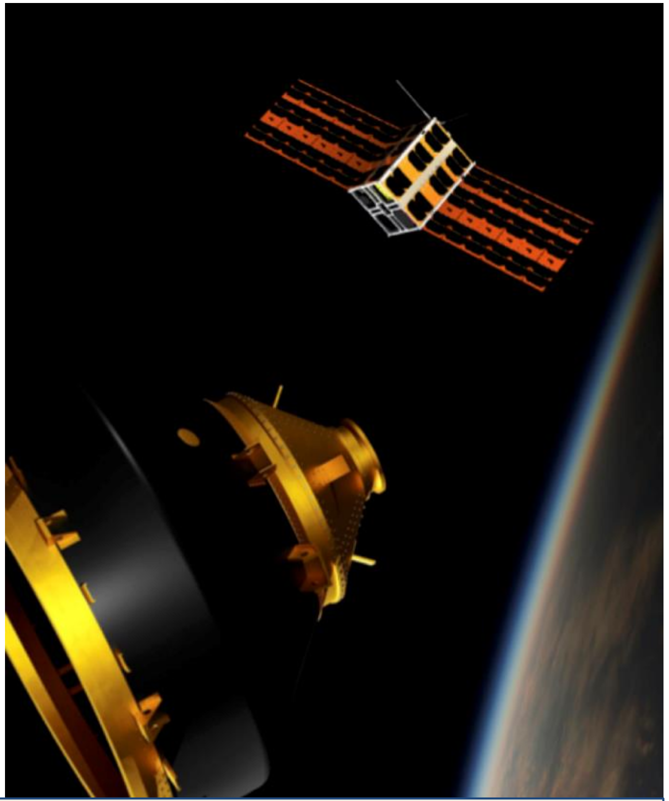
ASI CubeSat Workshop – July 2-4, 2024 Roma

e.Inspector – *in Orbit Servicing*

GOAL

- Fly around a Space Debris – baseline since phase A = VESPA adapter
- Shape and dynamics reconstruction to support Active Debris removal activities

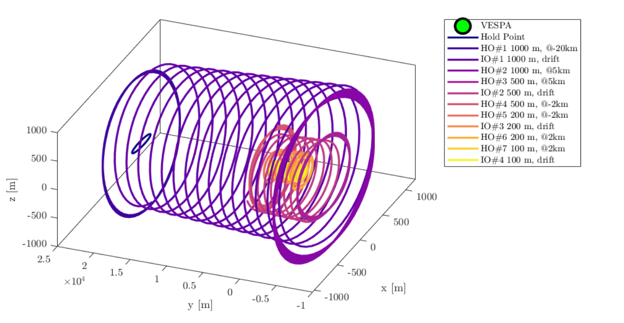
- ***Safe proximity maneuvering** around a non cooperative\not a priori known object*
- ***Zero debris generation***

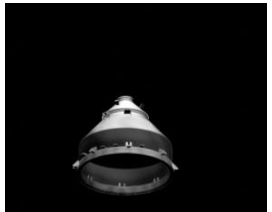


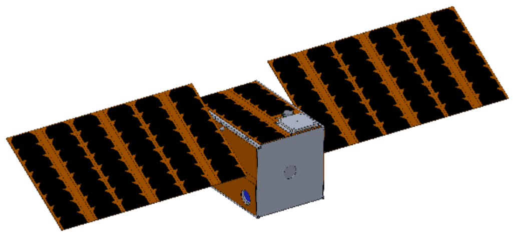
Technology development opportunity

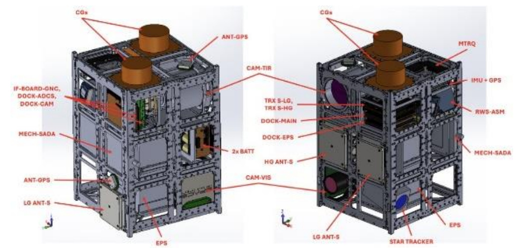
- **Complement** the VIS sensors with **IR imaging** to perform **enhanced relative navigation *on board* in closed loop with control**
- **Cubesat class→ Enhance** that s/c class **GNC capabilities\performance**
- **Boost the low thrust capabilities** – electric propulsion
- **Model Based System Engineering**

Advanced GNC	Image processing –on board sw	System Engineering




Debris target Zoomed VIS synthetic image





e.Inspector – *the TEAM & ROLES*

e.Inspector is financed by **ASI** and developed with **ESA** under GSTP

POLIMI-DAER\

- **PRIME** System\mission engineering, ***multispectral IP-based proximity GNC*** and related HW\SW breadboarding on **PIL and HIL**

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- VIS\IR payload requirements, selection and characterisation\testing

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- Ground segment requirements consolidation, baseline settling

Techonology 4 Innovation – T4i

- Low thrust propulsion customization and qualification for endurances TRL increase

PHASE B

Dec 2022, KO → June-July 2024, PDR

C/D/E/F

e.Inspector – *phase B*

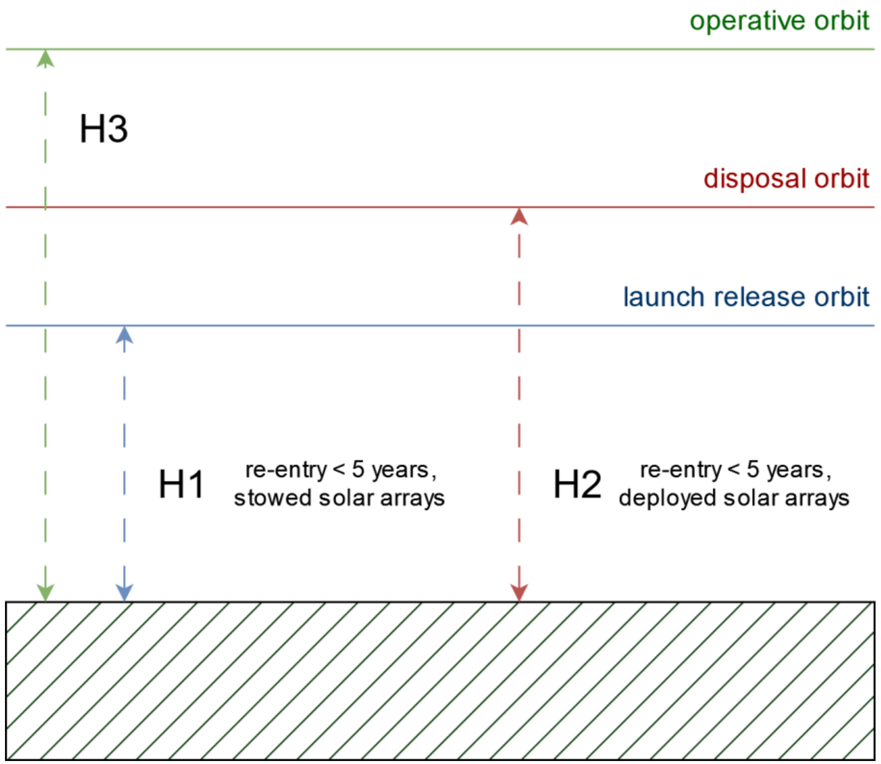
Phase A identified the hot spots of the mission to be

- On board **multispectral image processing** → software\hardware
- **Low thrust** trajectory control **readiness level and reliability**→electric propulsion endurance and cycling
- Prove robustness against debris generation regulations and disposal

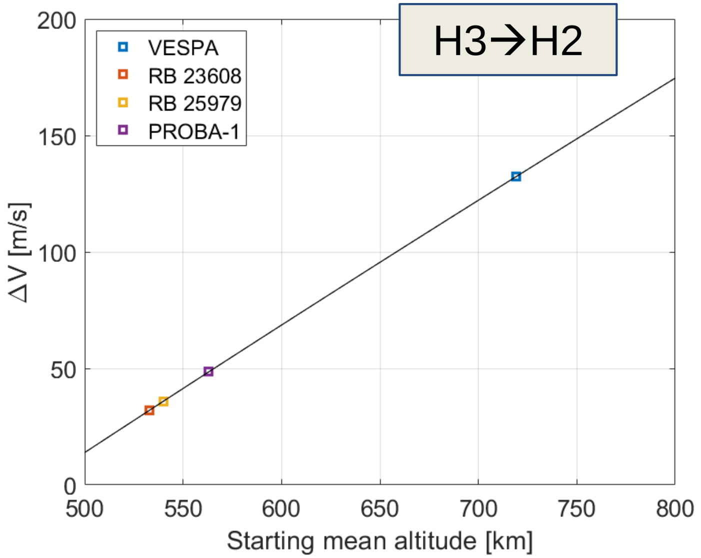
Which translate for phase B into

- Design, develop and test **multispectral IP based** relative navigation **software** ☺
- Define, procure and test the **breadboard for the IP-GNC boards** (PIL-HIL) ☺
- **Assess the validity** of the proposed **image payload** and perform functional tests ☺
- Design and develop the Guidance and Control for all mission phases ☺
- Consolidate the **low thrust** based **mission analysis and launch strategy** ☺
- Define and **run endurance tests** on the thruster baseline **!**
- Perform preliminary **RAMS analysis and deorbiting plan** compliance verification **!**

e.Inspector target selection: *Mission Analysis*



1. H1→**stowed configuration** - **m = 22.9 kg, A = 0.102 m^2** → **H1 = 430 km**
2. H3→**deployed configuration** - **m = 22.9 kg, A = 0.240 m^2** → **H2 = 475 km**
3. The operational orbit, **corresponding to selected target**
   - **NORAD 39162 (VESPA)** → **H3 = 719 km** (i = 98.73°)
   - ***NORAD 23608 (ARIANE RB)*** → ***H3 = 533 km*** *(i = 98.25°)*
   - ***NORAD 25979 (ARIANE RB)*** → ***H3 = 540 km*** *(i = 98.24°)*
   - ***NORAD 26958 (PROBA-1)*** → ***H3 = 564 km*** *(i = 97.92°)*



Baseline thruster

Regulus 50-I2

T=0,45mN; I_{tot}=6300s

Challenges

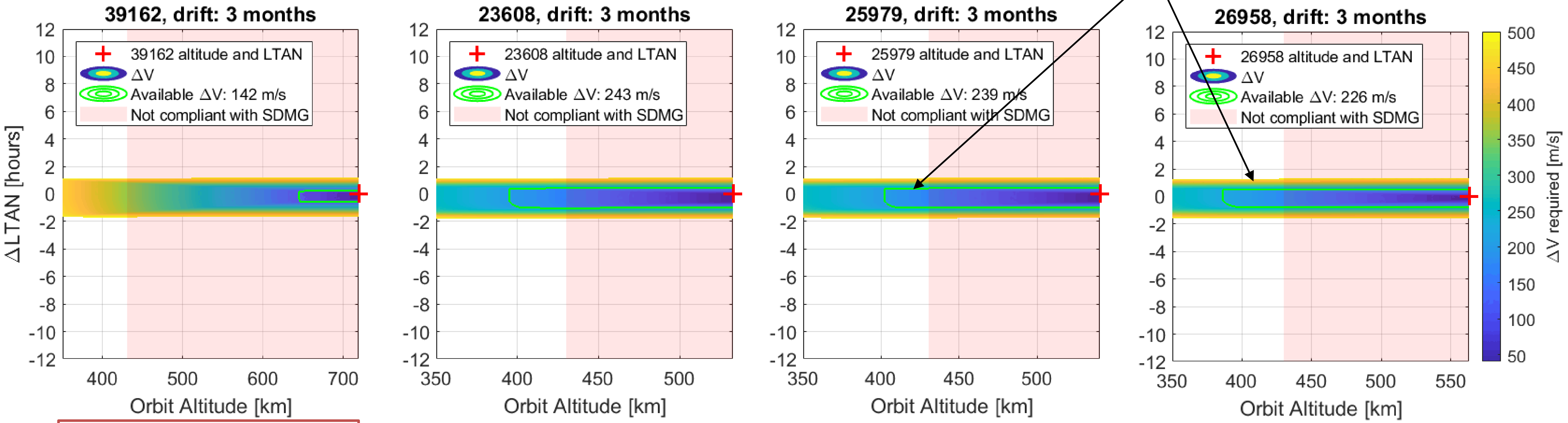
- **5 years re-entry** compliance any
- **Target altitude**
- **Propulsion authority-reliability**\Δv availability

e.Inspector target selection: *Mission Analysis*

Release-to-Operational transfer (H1 → H3)

ΔV Maps as function of the Orbit Altitude and LTAN for different drifting time\targets

Feasible launches lie in the green contour line not crossing the red region



Minimum altitude
655 km

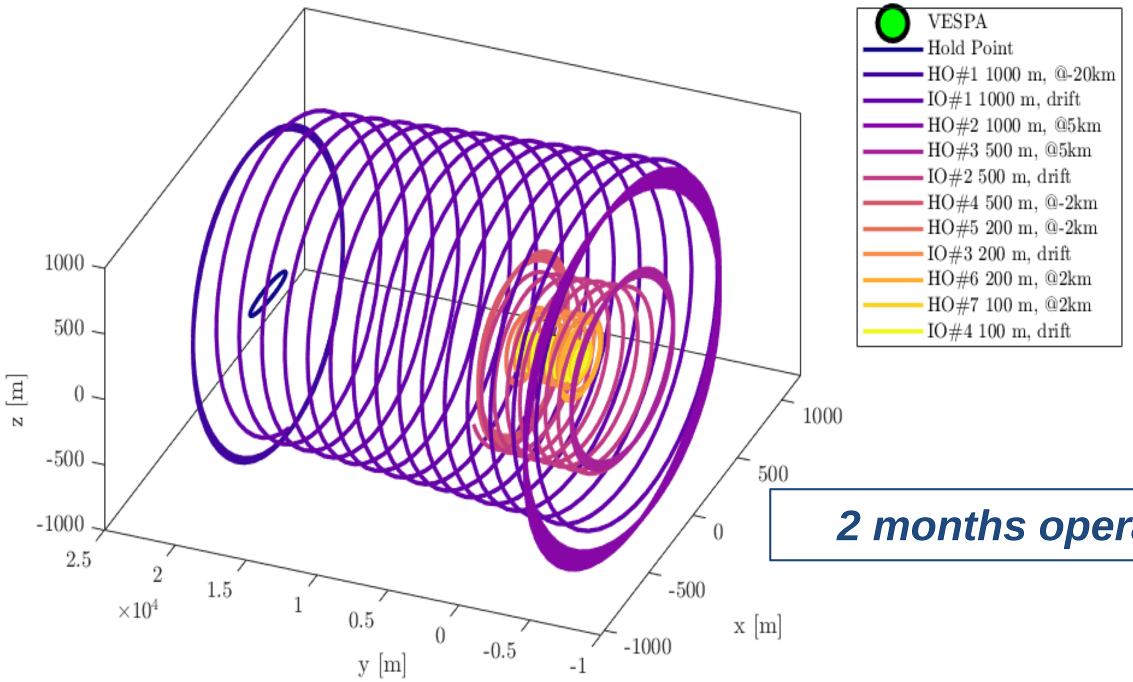
Minimum altitude
398 km

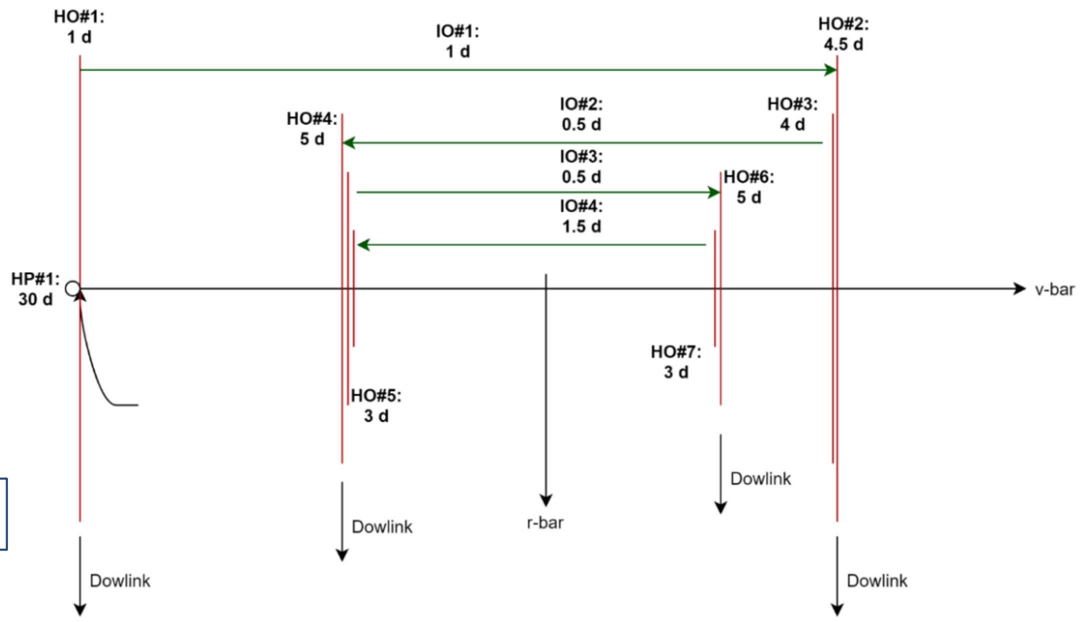
Minimum altitude
405 km

Minimum altitude
388 km

e.Inspector – *flyaround strategy*

Inspection phase from~20 km to 100 m → max resolution requested 1 cm

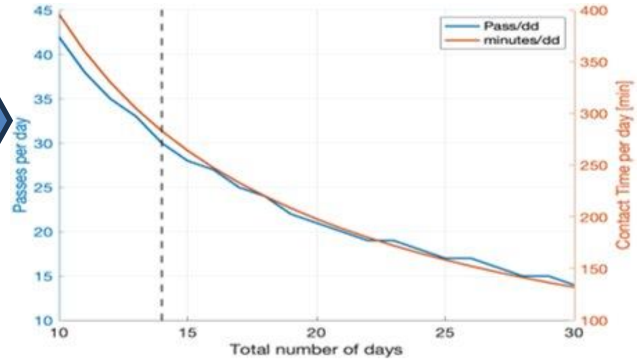




2 months operations

Proximity actuator→Vacco PUC 0.14
4,5nN; 47 Isp;10W

Downlink requirements in Holding Orbit, 18Gb



e.Inspector – *imaging payloads*

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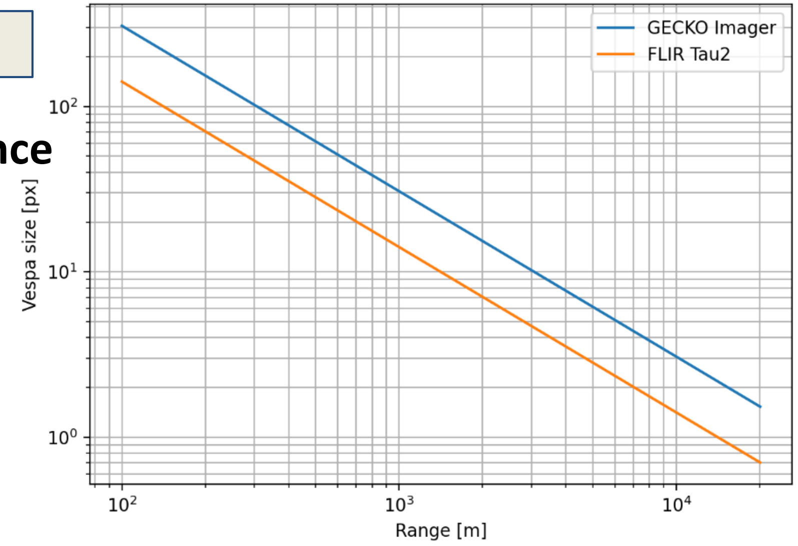
From~20 km to 100 m → max resolution requested 1 cm

VIS imager→**Gecko Imager** from dragonfly

- RGB
- array size 2048 x 2048 pixels
- FOV 9.15 degrees
- flown

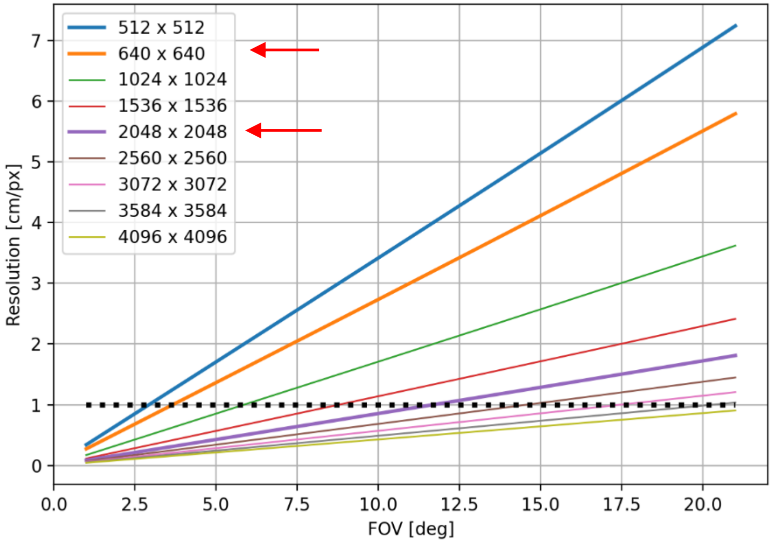
20 km max distance

- 7 (TIR) px
- 15 (VIS) px



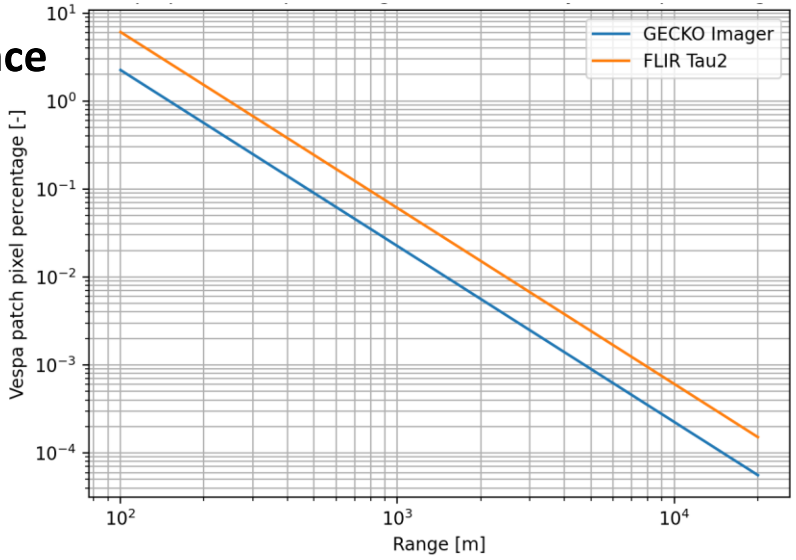
IR imager → **FLIR TAU 2**

- Spectral band 7,5-13,5μm
- array size 640 x 512 pixels
- FOV 6.2 x 5 degrees
- flown

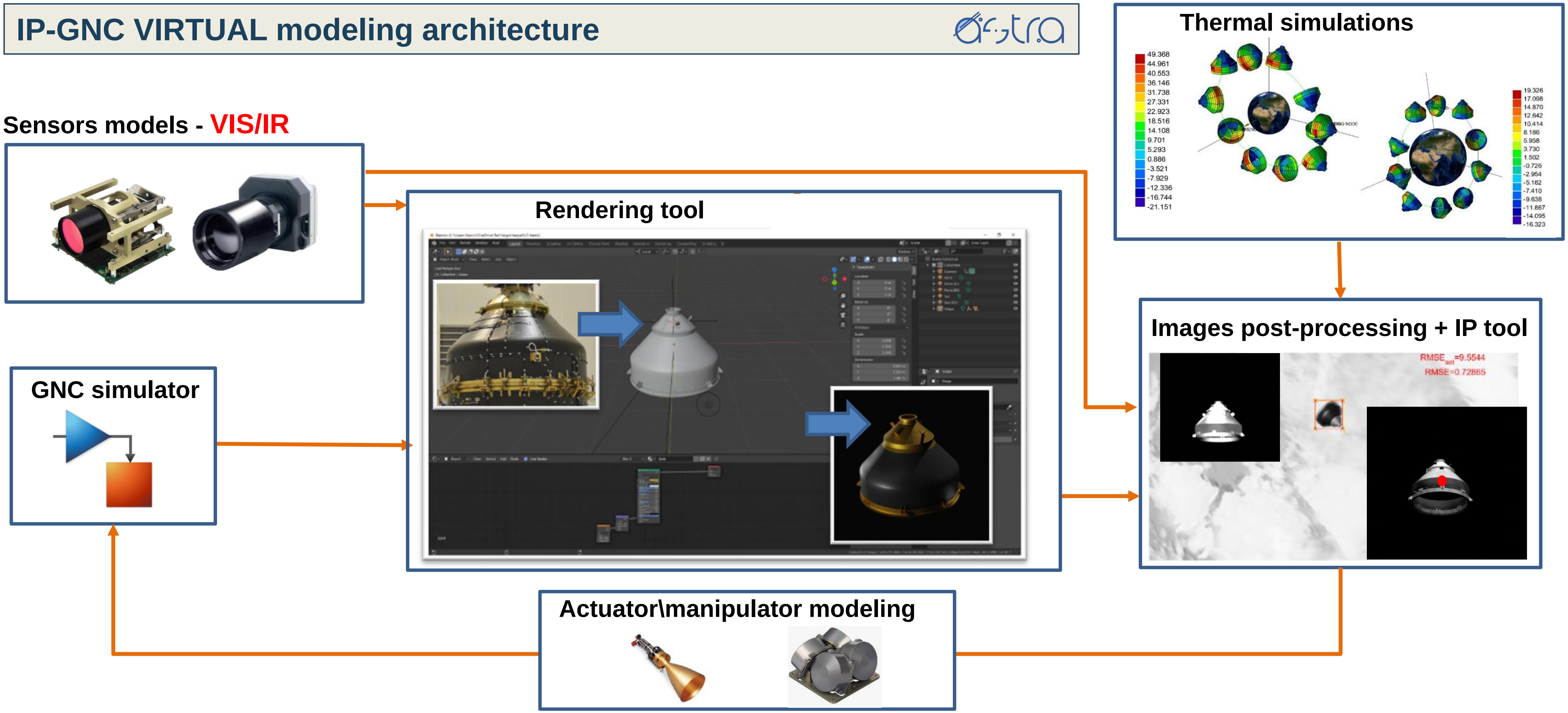


100 m min distance

- 20% (VIS)
- 60% (TIR),

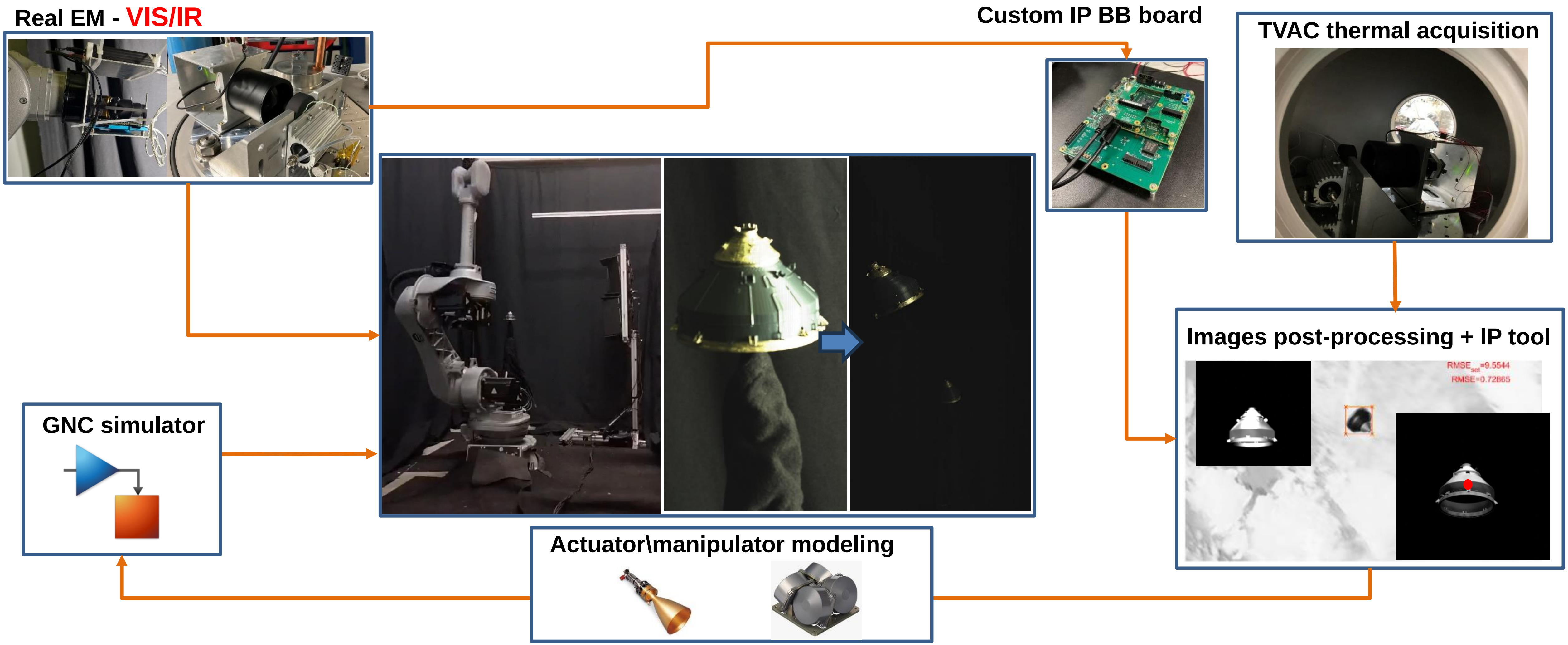


e.Inspector – *Image processing*



e.Inspector – *Image processing*

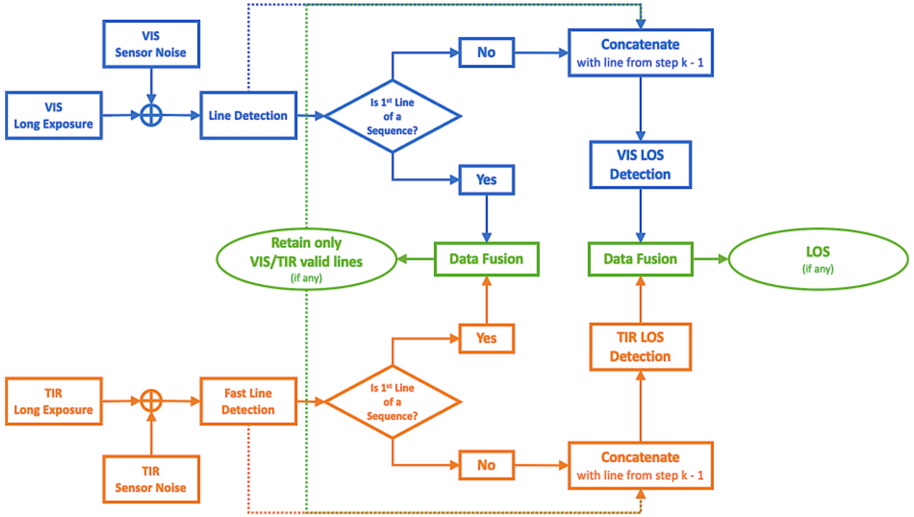
IP-GNC HIL architecture

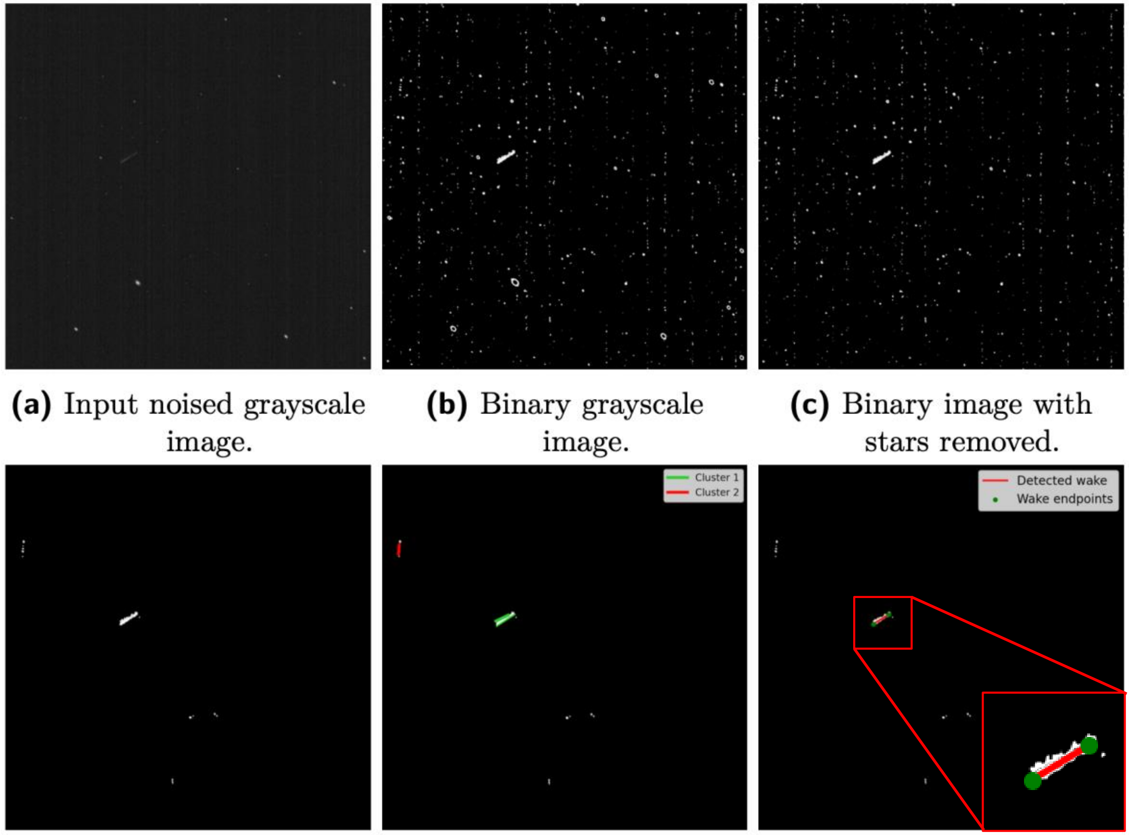


Far Range – Long Exposure – Inertial Pointing

POLITECNICO MILANO 1863 LEONARDO LEAF SPACE T4i TECHNOLOGY FOR PROPULSION AND INNOVATION

Common IP for both VIS and TIR images in Long Exposure - Inertial Pointing mode





(a) Input noised grayscale image.

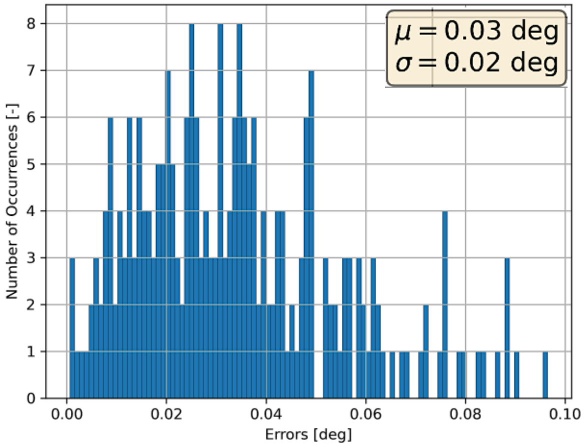
(b) Binary grayscale image.

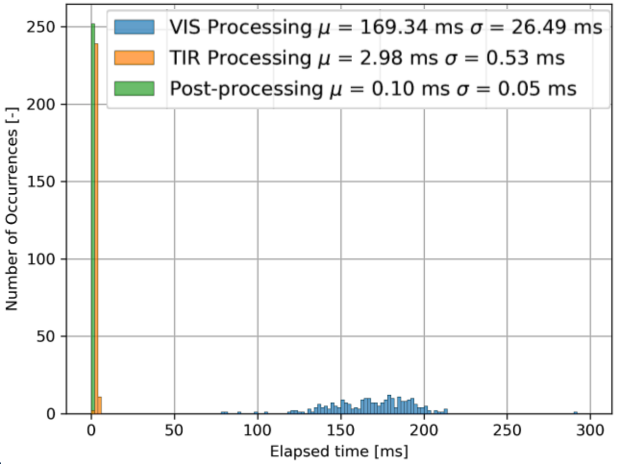
(c) Binary image with stars removed.

(d) Binary image with noise removed.

(e) Lines detected and clusterization outputs.

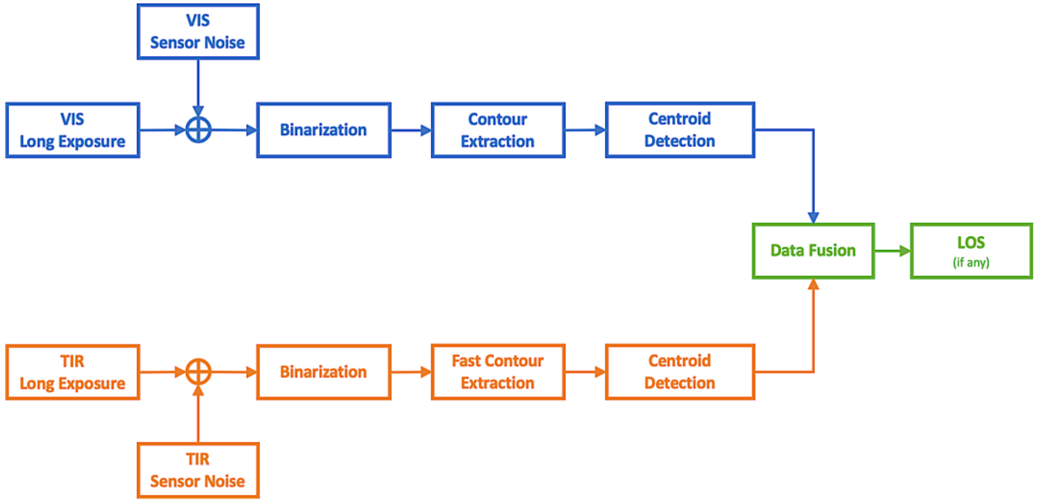
(f) Detected wake and its endpoints.

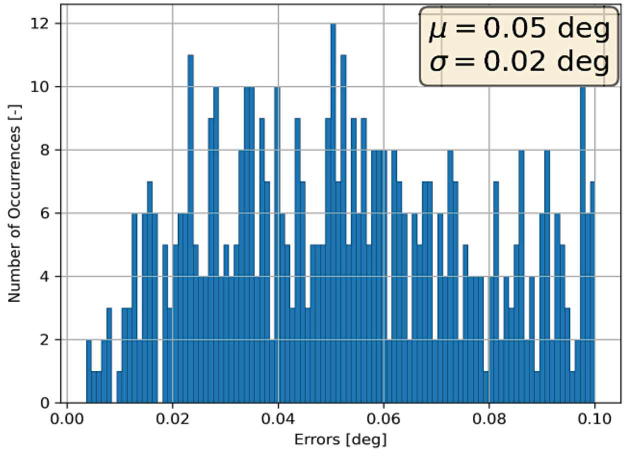


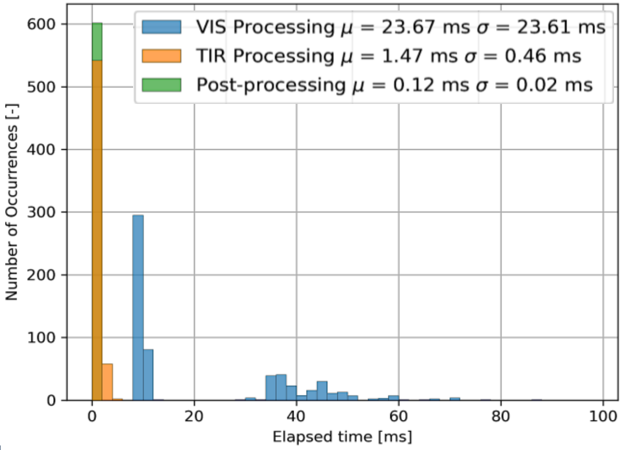


Far Range – Long Exposure – Target Pointing

Common IP for both VIS and TIR images in Long Exposure - Target Pointing mode



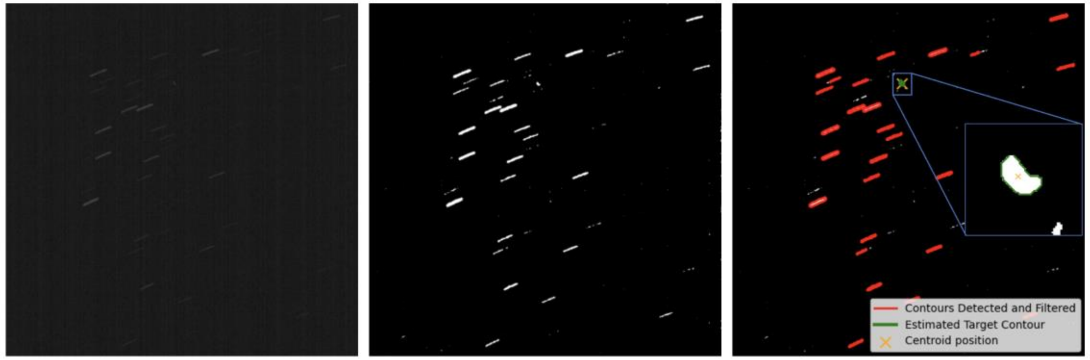




TIR Detailed Processing

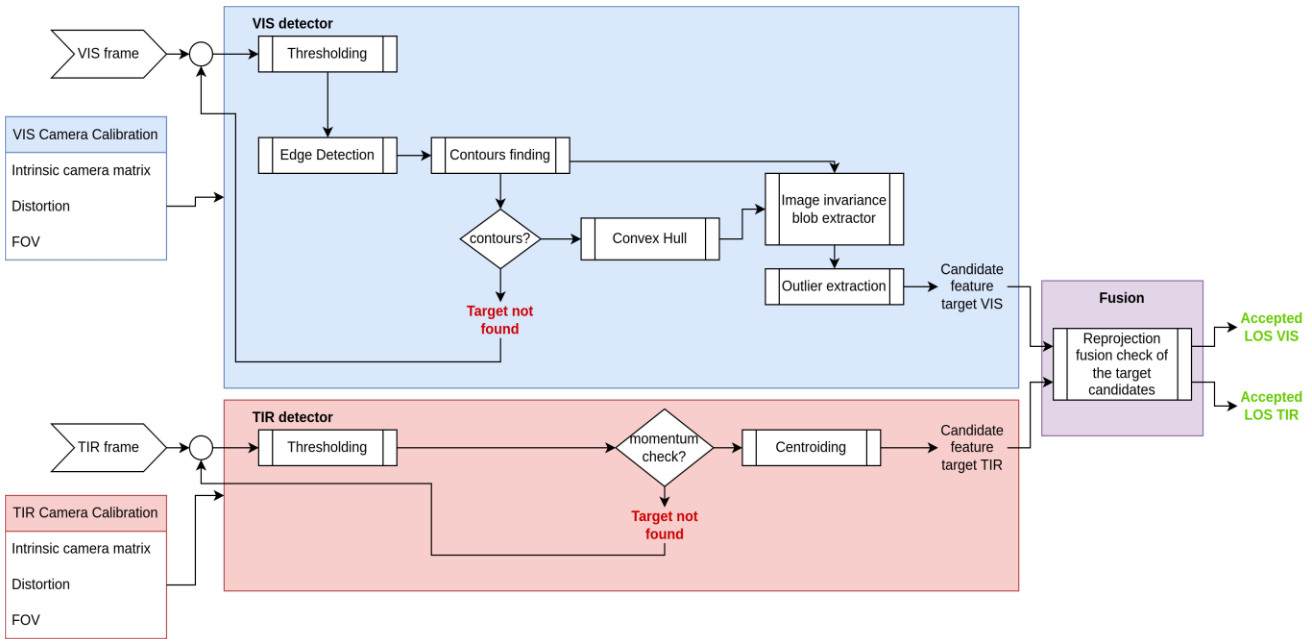
(a) Input noised grayscale image. **(b)** Thresholded binary image. **(c)** Detected contours and computed centroid.

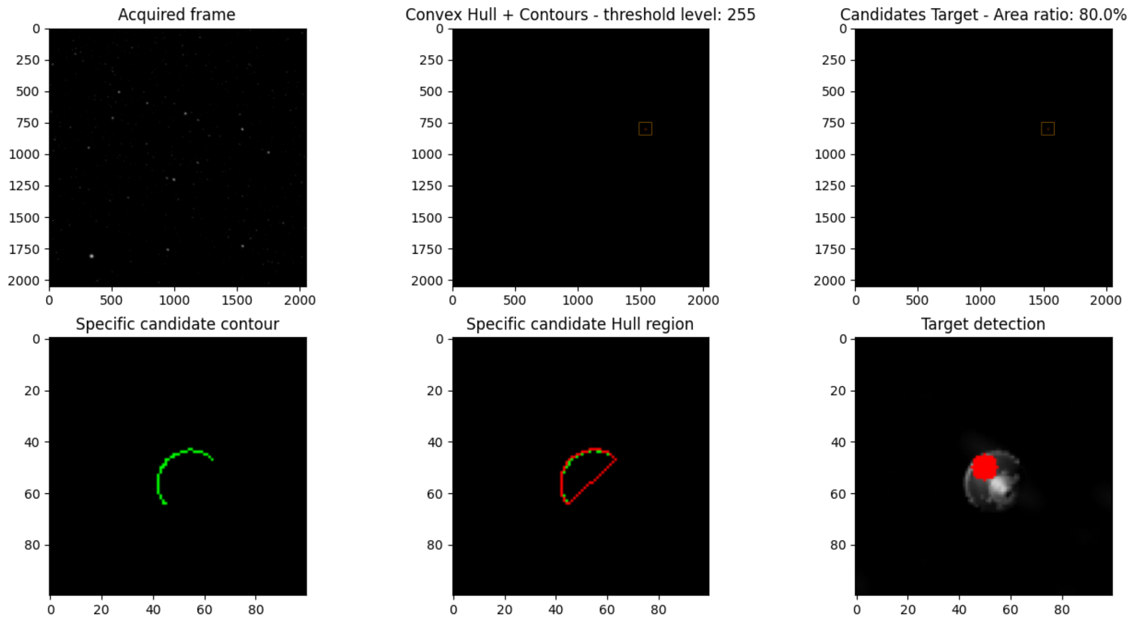
VIS Detailed Processing



(a) Input noised grayscale image. **(b)** Thresholded binary image. **(c)** Detected contours and computed centroid.

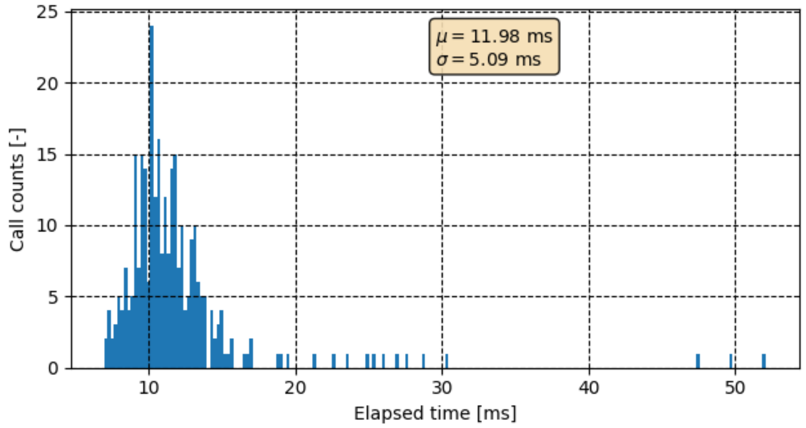
Close Range – IP

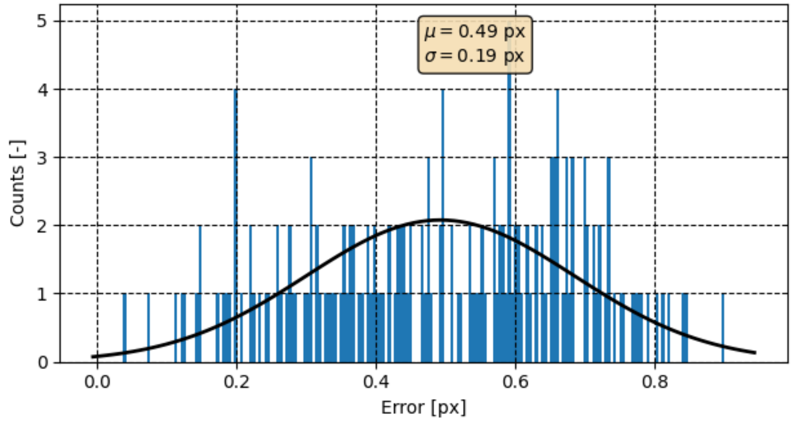




- VIS frame: 2048 x 1024 px
- TIR frame: 640 x 512 px

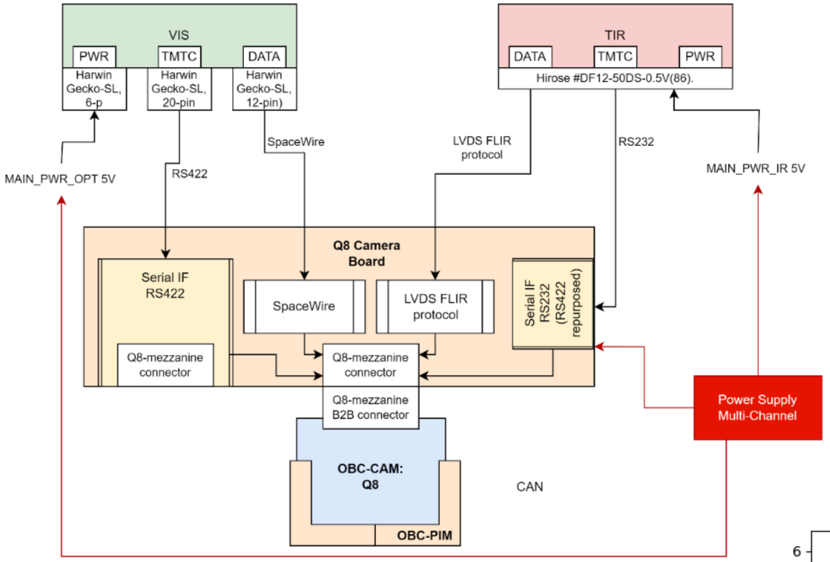
- Frame acquisition: 0.1 Hz

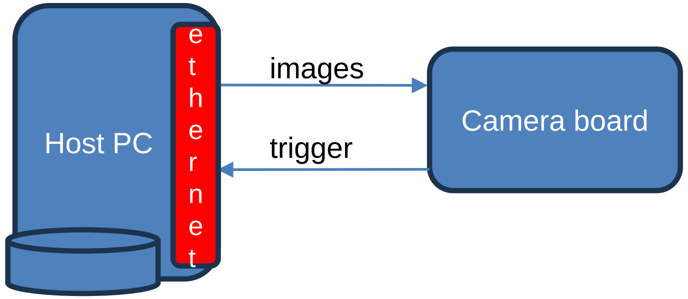


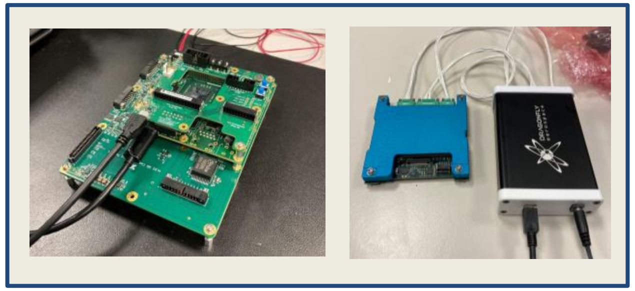


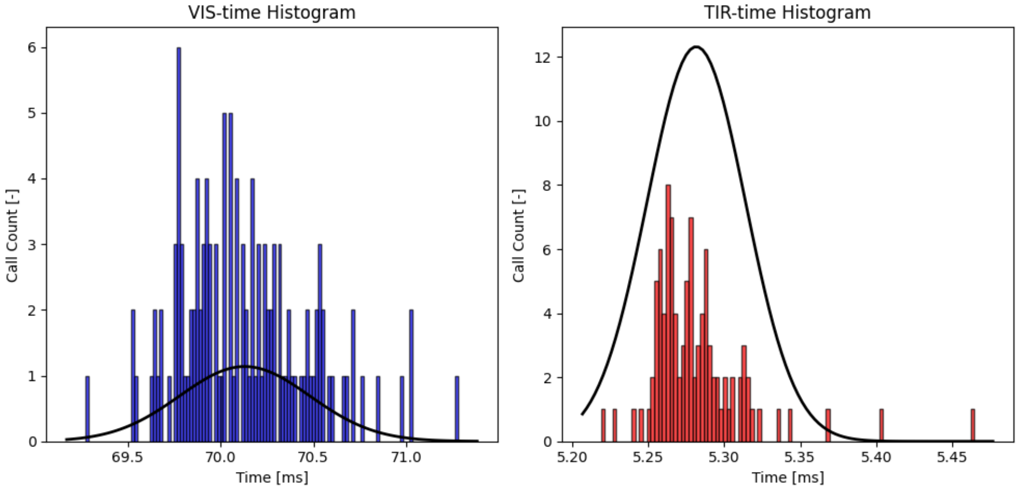
e.Inspector- *PIL breadboarding & testing*

The breadboard has been conceived concurrently with the virtual HIL models to be then substituted with EM PL for E2E tests







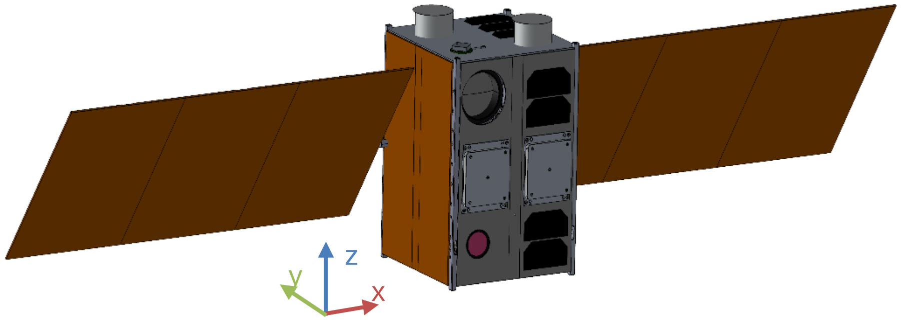


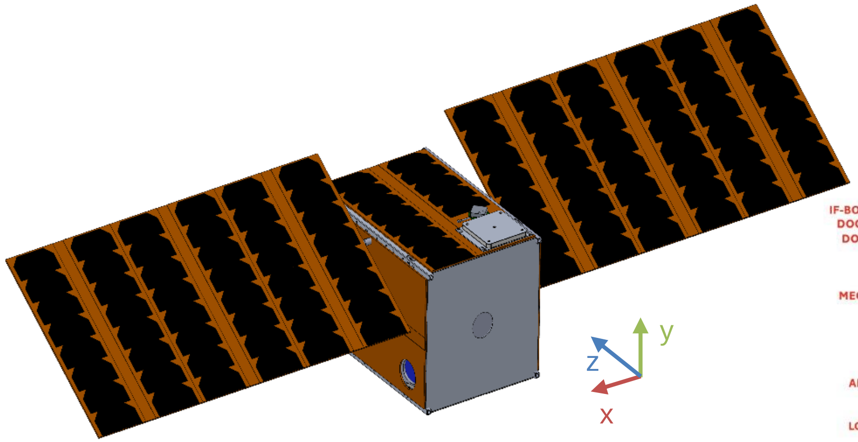
PIL Numerical Accuracy
- Python against C++ range **~10-5 px** in LOS detection

PIL Execution Times
- **VIS centroid** detection **~70.1 ms**
- **TIR** much faster **~5.27 ms**.

e.Inspector – *Space segment sum up*

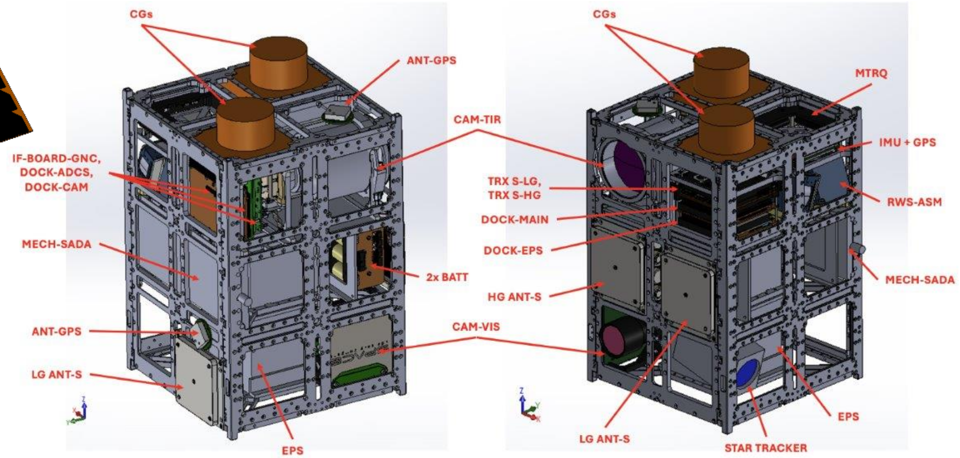
Country	Component	TMTC	TRL
Denmark	Sun sensors Magnetometers Magnetotorquers SLG antenna & transceiver SHG antenna & tranceiver SM OBC MAIN\DOCK-MAIN ACU PCU	ADCS OBDH TMTC EPS	9
the Netherlands	Reaction wheels	ACS	9
Italy	Solar Arrays muSADA	EPS STR\MECHS	9 5
Spain	Solar Arrays muSADA	EPS STR\MECHS	9 8
Italy	Main structure	STR	8
South Africa	VIS camera	PL	9
US	NIR camera	PL	9
the Netherlands	Star tracker	ADCS	9
US	IMU	AODS	9
France\mixed	Cables	ADCS OBDH EPS	9
Italy	Thruster	PS	8
US	cold gas thruster	PS	6
Canada	IP CPU and board	OBDH	9
Germany	deployer	Struct\mechs	9





12U form factor

- Payloads and electronics → 1U + 1U
- Electric propulsion unit (EPU) → 2U
- Navigation instruments → 1U
- ADCS stack & RWs → 1U + 1U
- Solar wings+ SADA



- Wet mass 22,88 kg (margined)
- Max power 130W EOL (margined)

e.Inspector: *System Engineering (MBSE)*

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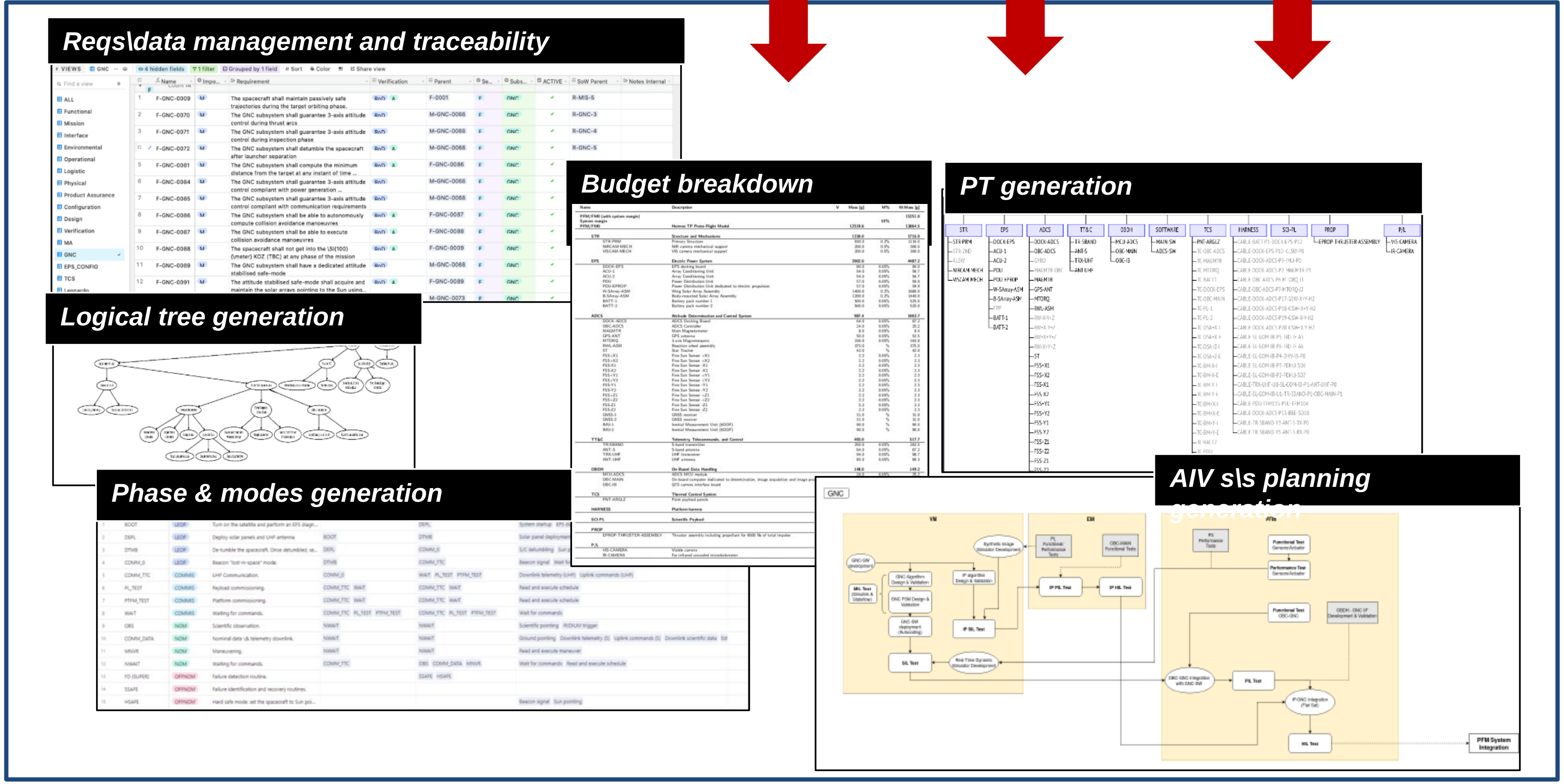
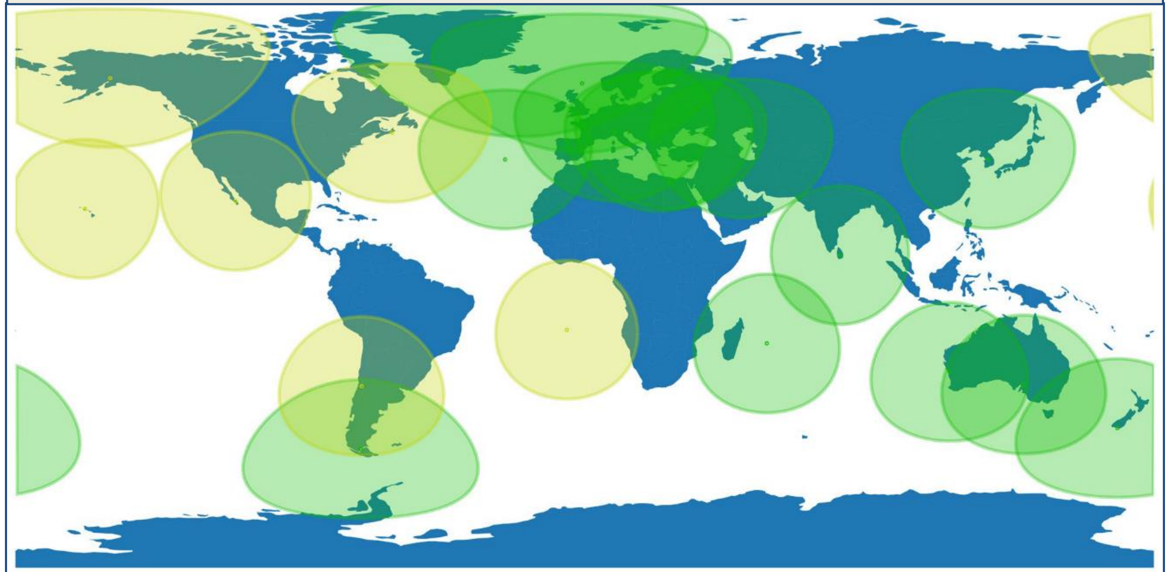
Smallsats → Digital AIDED SE → *from concept to AIV\AIT*

astra — Advanced Space Technologies for Robotics and Astrodynamics

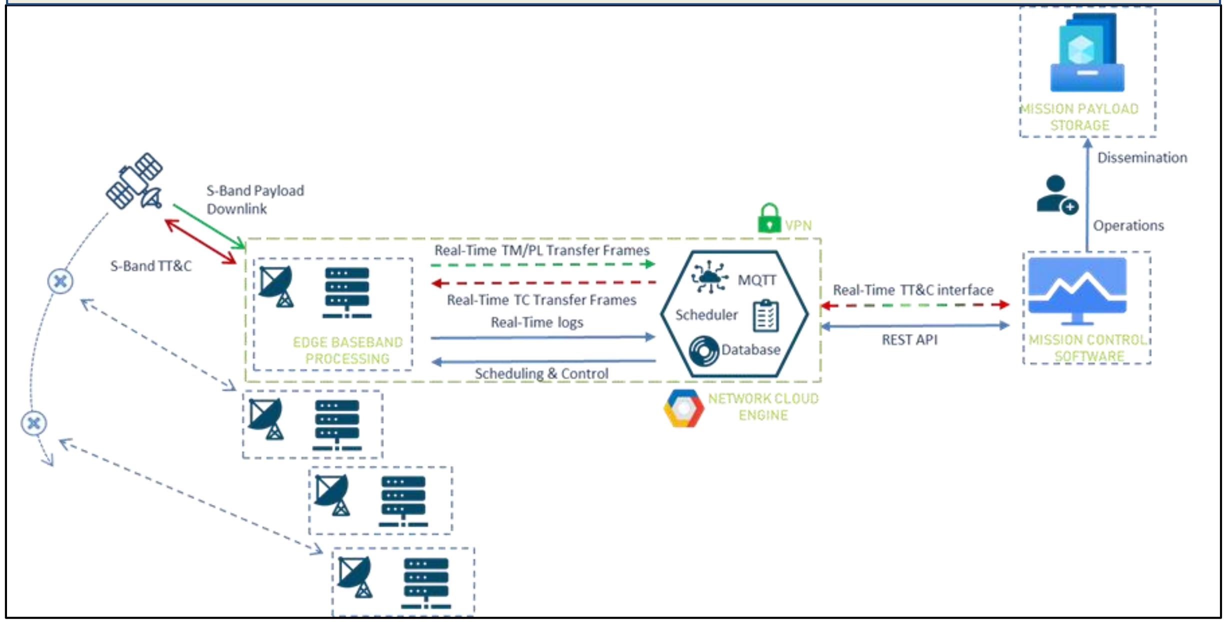


e.Inspector: *Ground segment*

LeafSpace selected stations



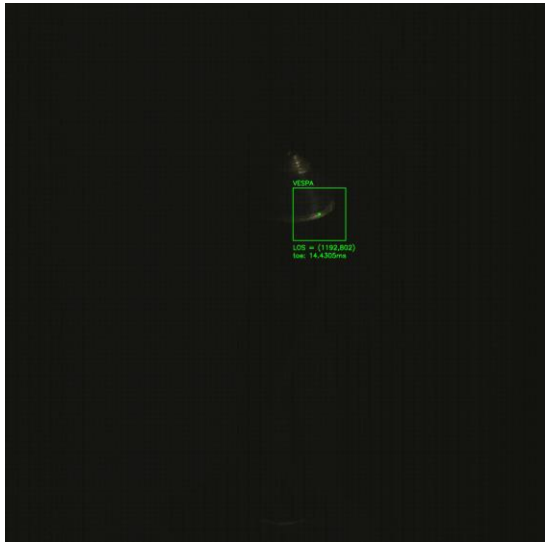
LeafSpace Ground architecture



e.Inspector: final remarks

- **HIL tests – keep going after PDR closure**

  The IP algorithm tested on a sample trajectory taken with the robotic arm highlight the noise from the diffusive light in dark room which creates worse detectable conditions than in space.



- **Early PIL\HIL IP-GNC activities**

  PIL\HIL very beneficial to:
  - confirm the proposed IP architecture while developing the IP SW
  - address customisation for the board
  - Sensors’ characterization
  - SW easily scalable according to the potential change of target

Mission highlights

- TIR +VIS approach confirmed to increase the proximity activities robustness
- 5 years re entry requirements asks for debris target revision
- Low thrust propulsion is a key tech but not representing a short stopper if tech development activities keep going in parallel to phase C – strongly affects the launch date
- Segments and mission design robust to the target change in physical characteristics and orbital location

e.Inspector

VIS-IR imaging for proximity GNC around the VESPA uncooperative debris

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