HORUS
CubeSat-based multi-angle and multi-spectral Earth Observation (EO) system

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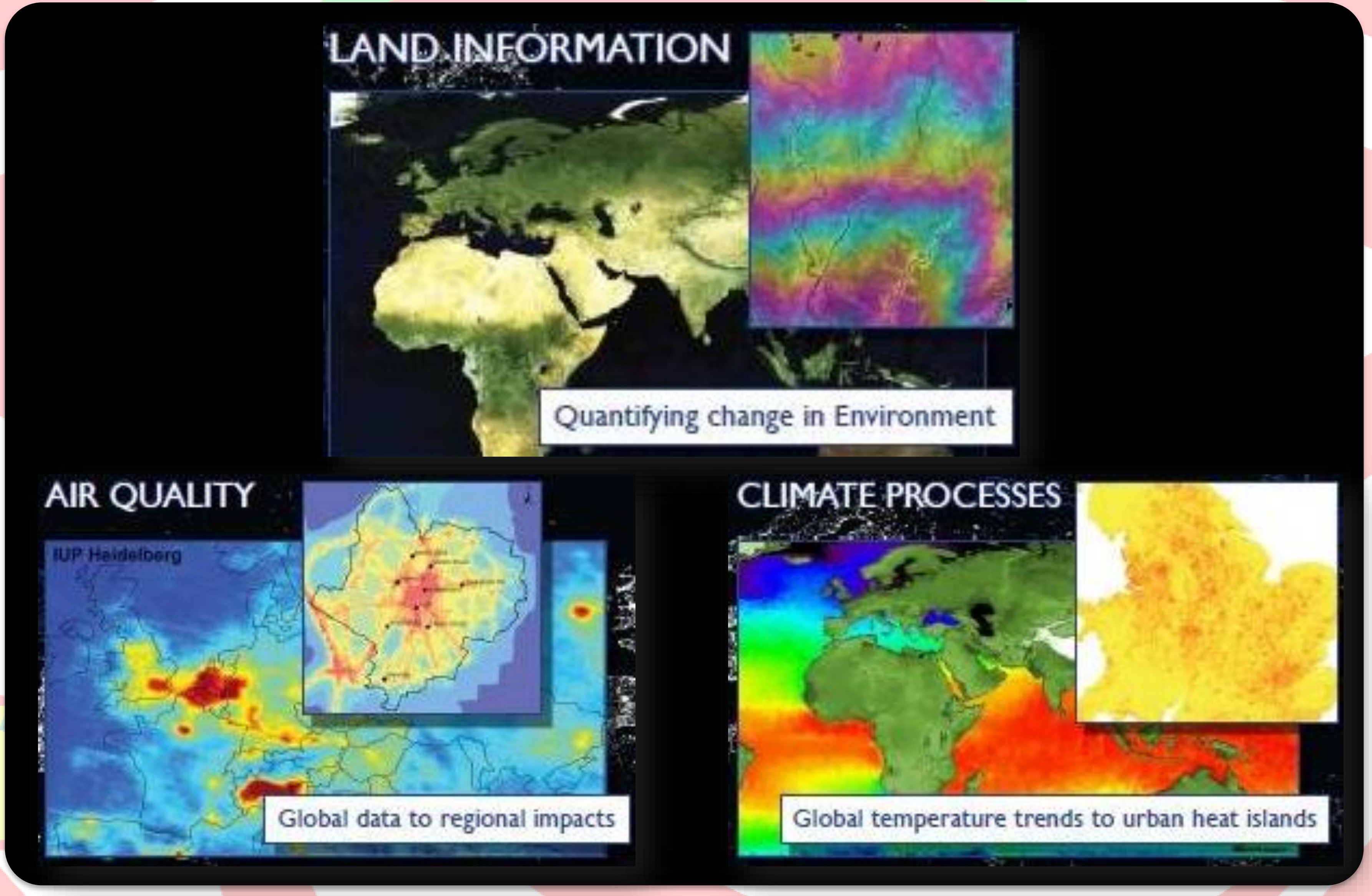
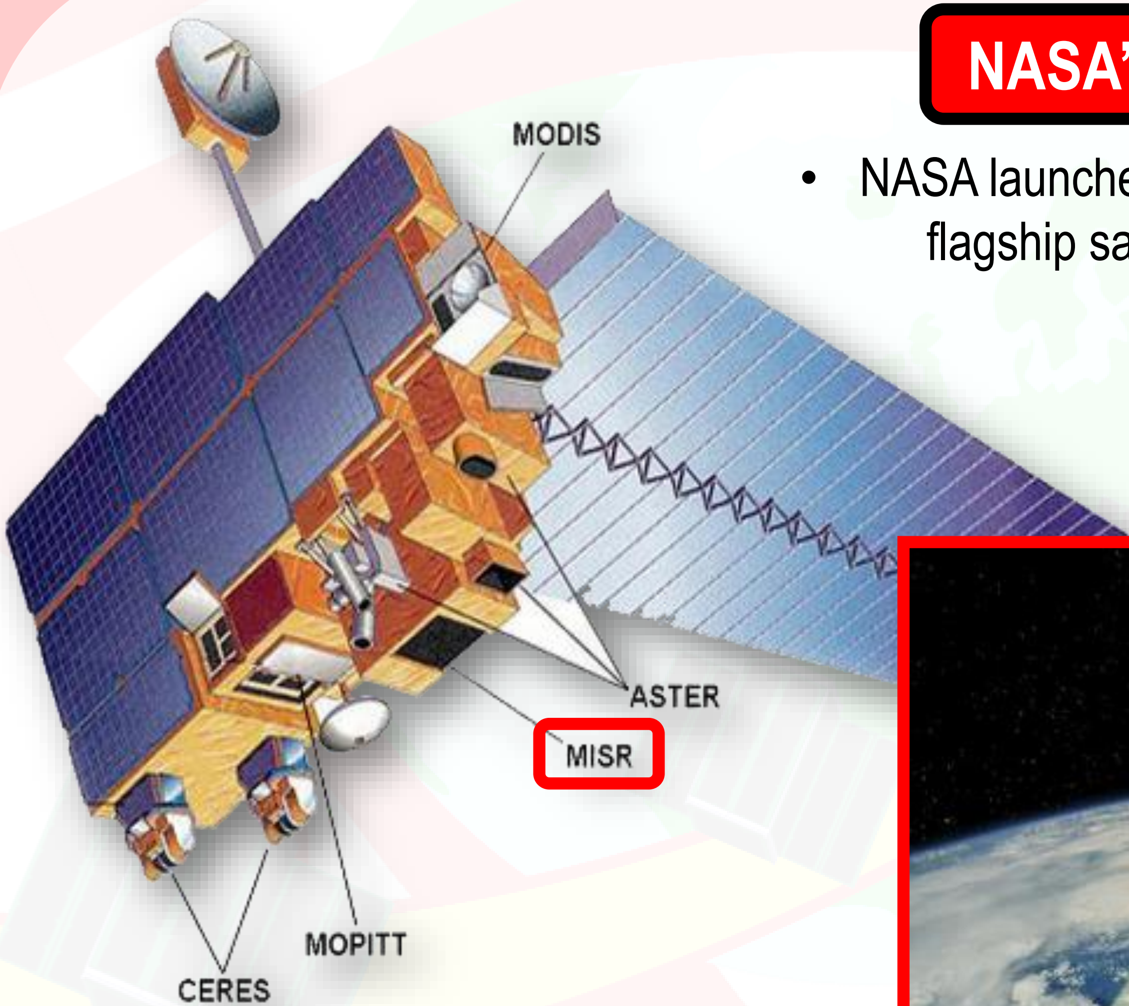
Current Scenario: State Of the Art



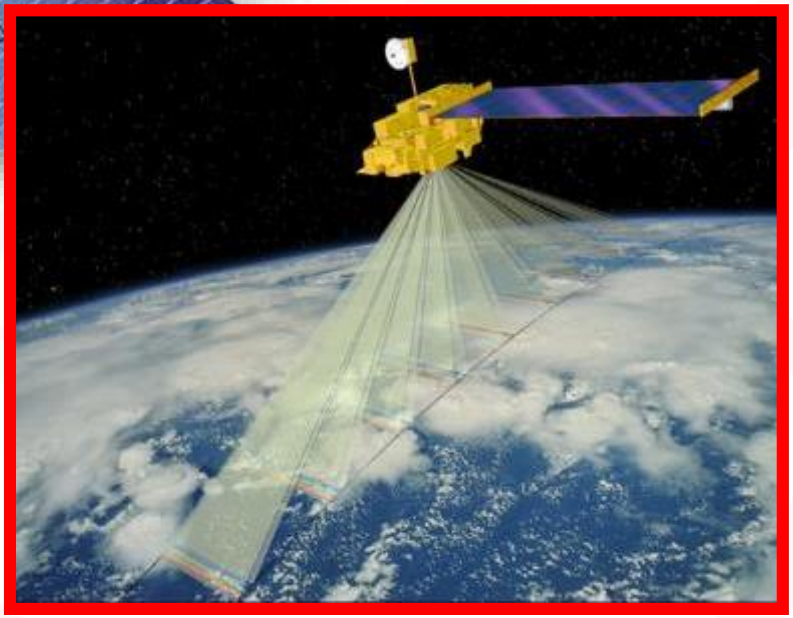
Current Scenario: State Of the Art



NASA's TERRA Satellite

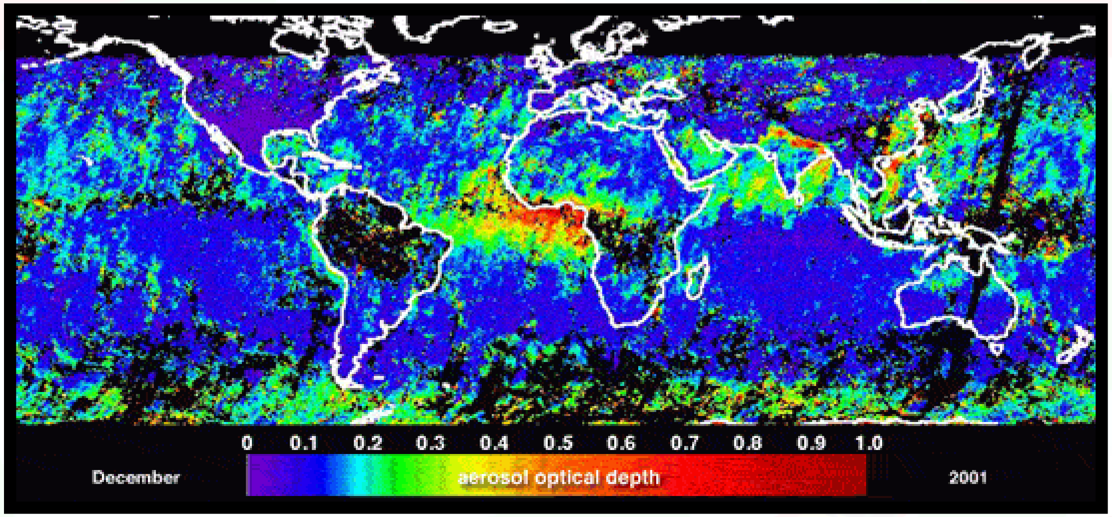
- NASA launched the Earth Observing System's flagship satellite in **December 18, 1999**

MISR



Current Scenario: State Of the Art

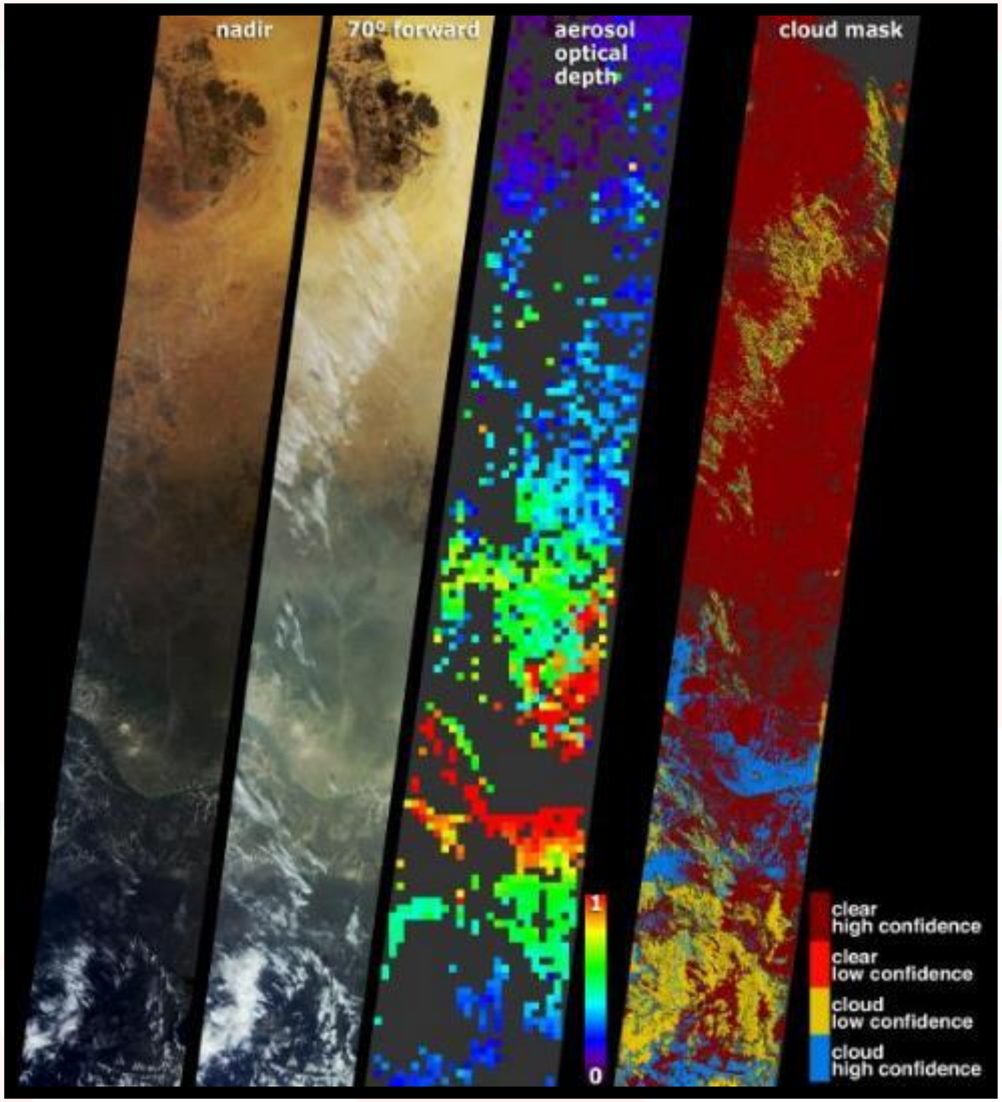
Atmosphere properties



Volcanoes ashes detection

Current Scenario: State Of the Art

Air pollution



From MISR to HORUS cast

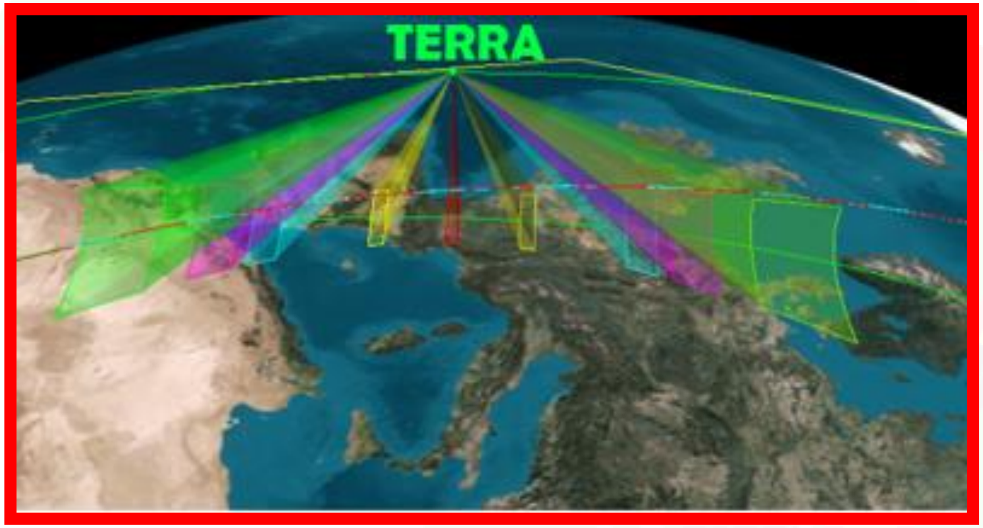
Single satellite with MISR sensor

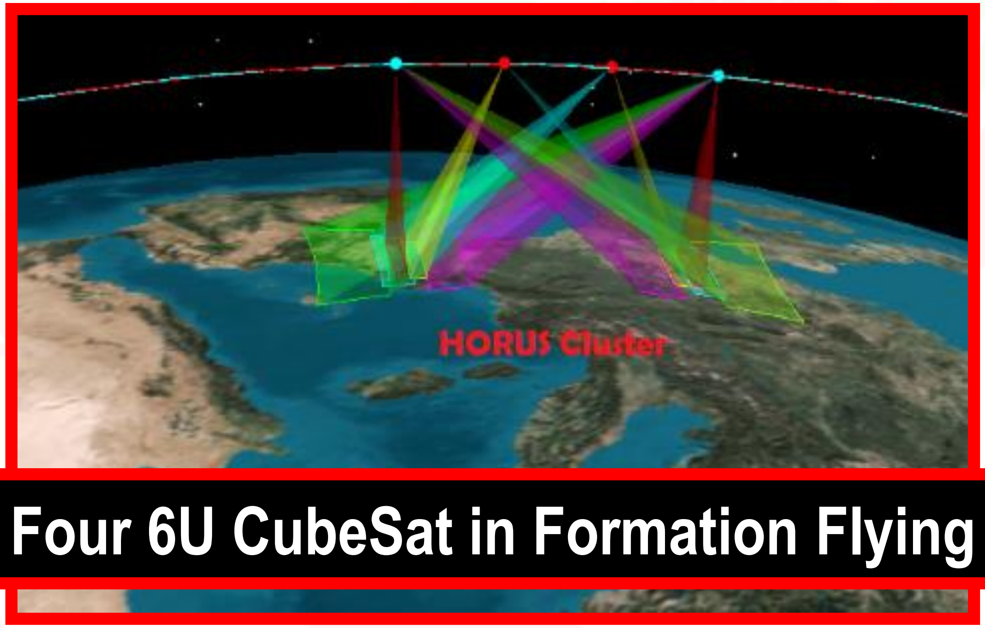
- Measurements only along a restrictive plane with respect to the solar phase → insufficient for accurate analyses
- Angular measurements separated in time by too many minutes along-track → low data reliability

Small Satellites Cluster

- Improvements in time of sampling → higher data reliability
- Possibility to use COTS and standardise items and technologies → cheaper missions

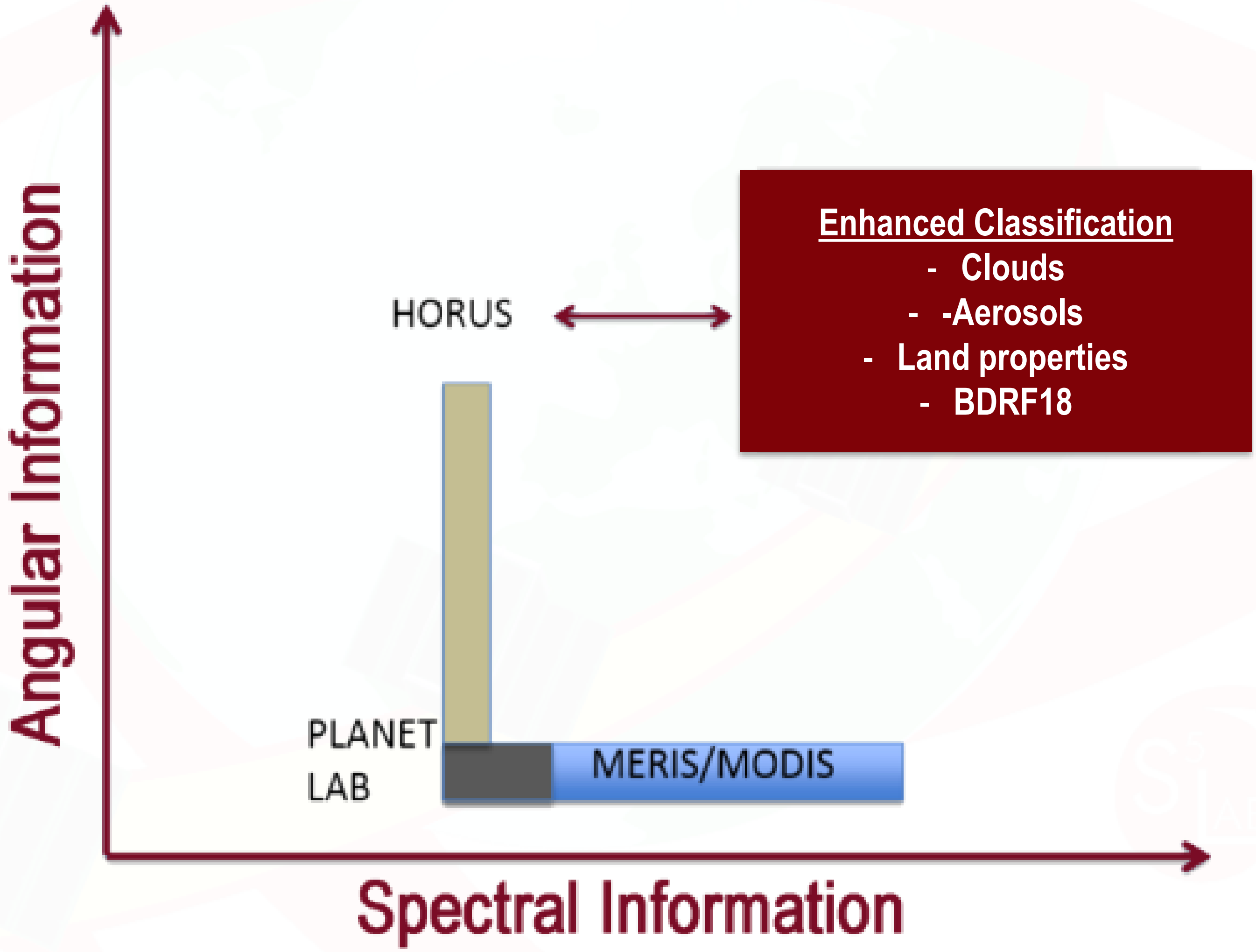
Mission Concept: HORUS Cluster





Four 6U CubeSat in Formation Flying

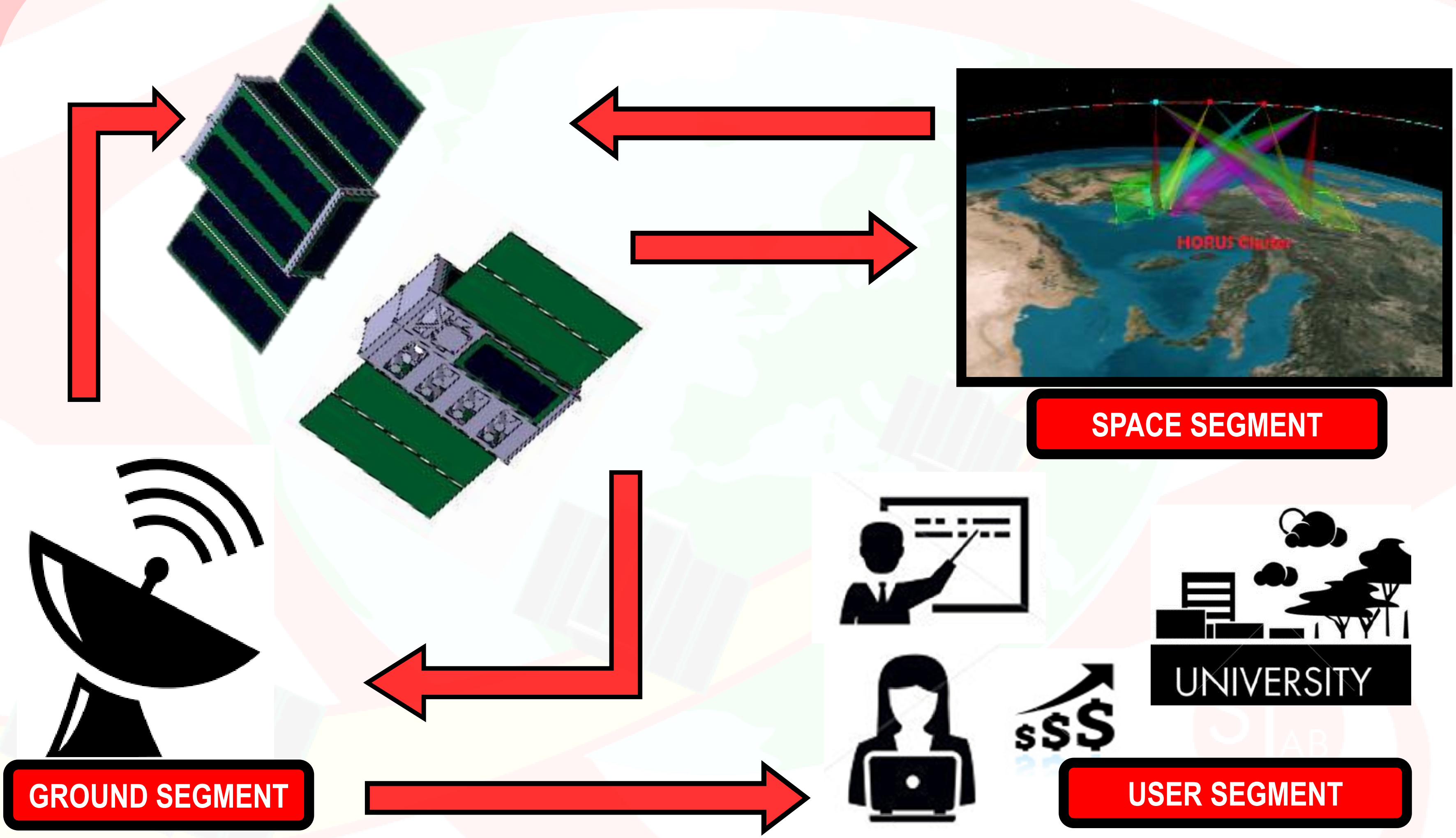
Offered Improvements



Missio Concept: Main Requirements

Spectral performances	Four spectral bands (**RGB and NIR**)
Off-nadir sampling capability	Eight different view-angle forward and afterward in addition to the **Nadir** (**±26.1°, ±45.6°, ±60.0°, ±70.5°**)
Radiometric performances	**High sensitivity** is needed for a wide range of scene reflectance (2% to 100%) without any change in gain
Spatial performances	**Sub-kilometre ground resolution**
Stable pointing	Three-axis stabilization and On-board Orbit Control System
Cluster downlink capacity	The **maximum needed data rate** is around **50 Mbits/s**

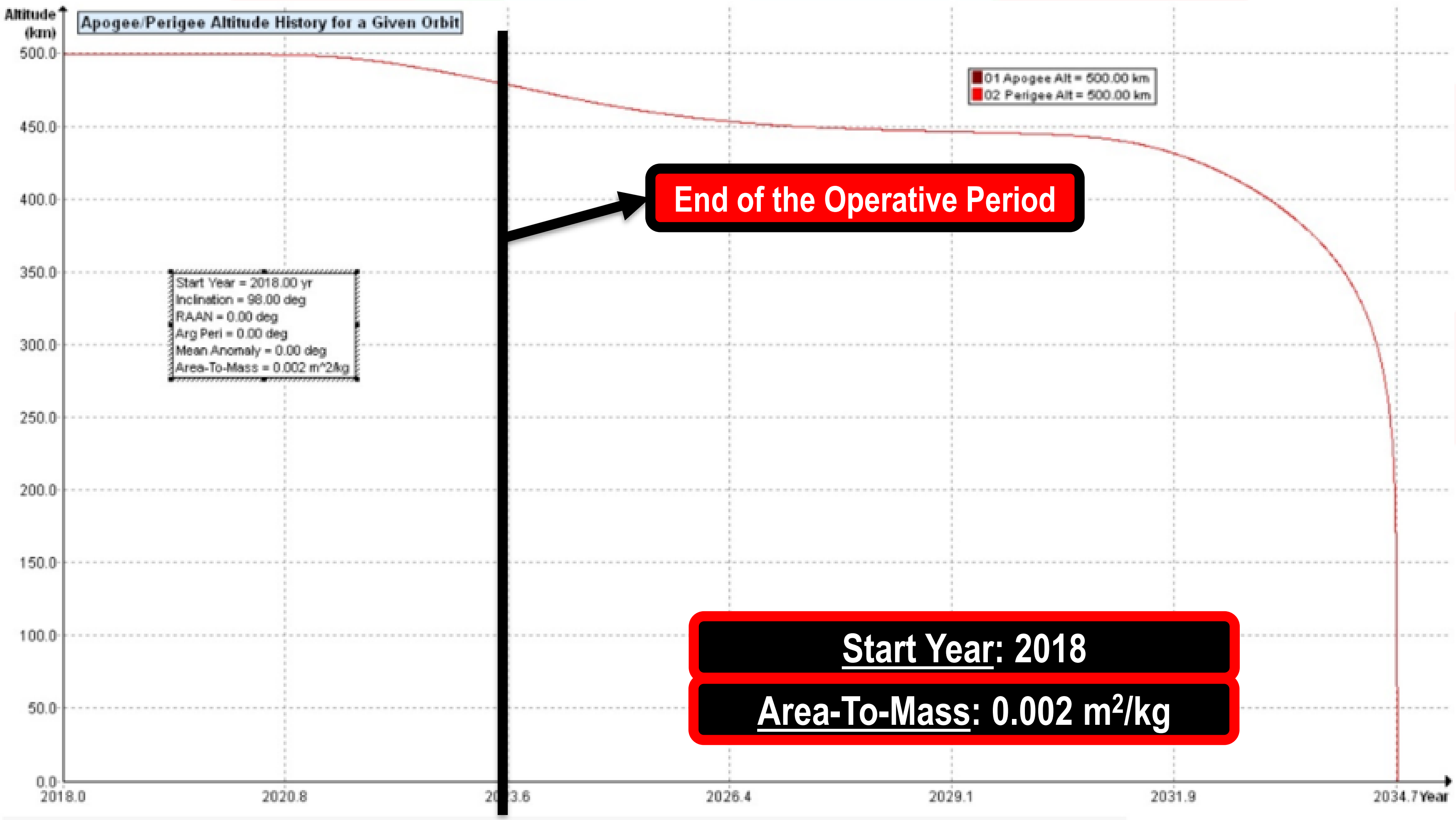
Mission Segments: Main Overview



Space Segment: Orbital Parameters

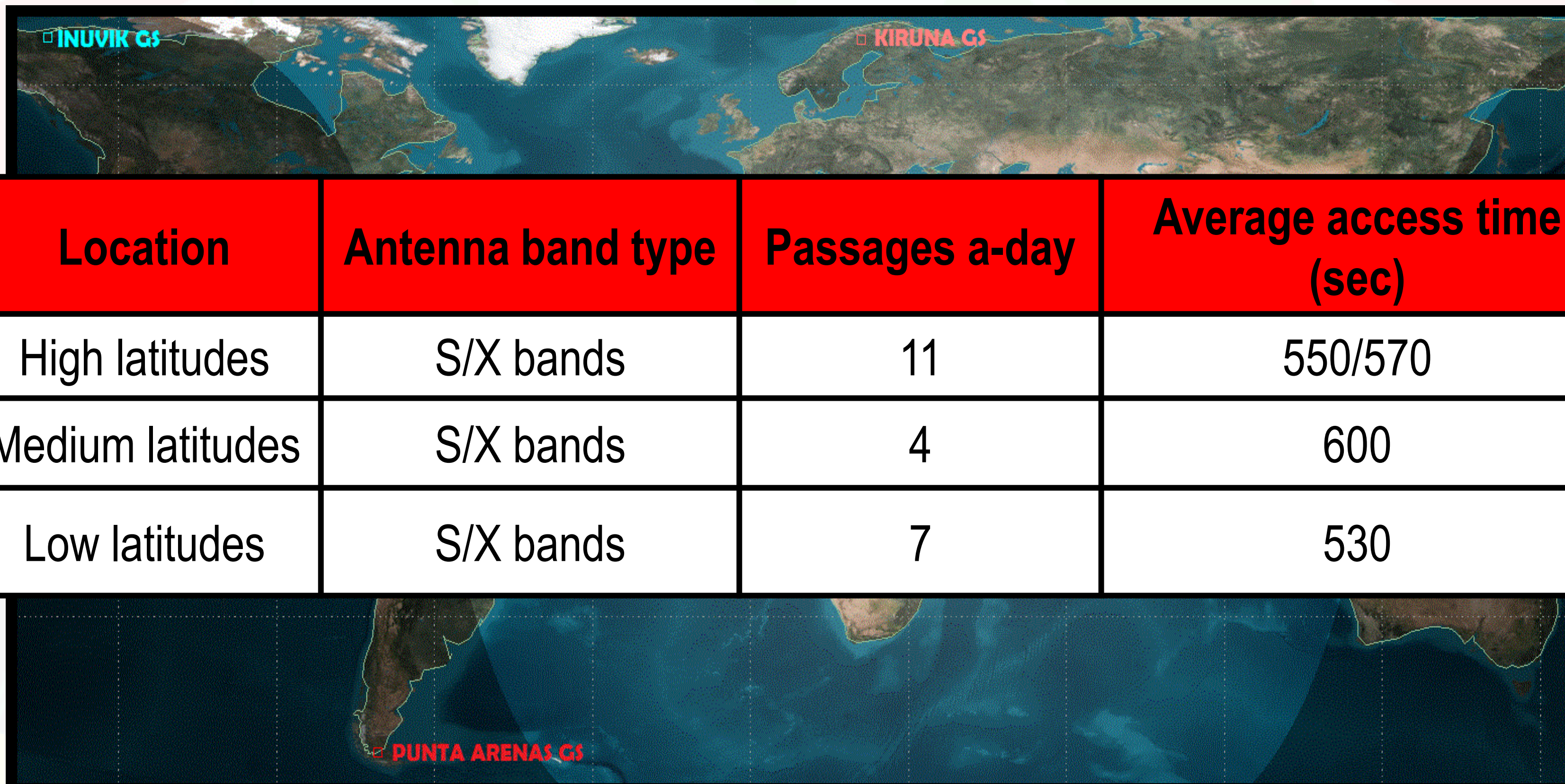
Orbit	SSO
Semiaxis	6856.99 km
Inclination	97.41 deg
Argument of Perigee	68.13 deg
RAAN	200.00 deg
Shift in True Anomaly	2.32 deg
Mean Local Solar Time at DN	10:30 am
Orbital Period	94.18 min
Eclipse Time	35.12 min

Space Segment: Orbit Decay



Groud Segment

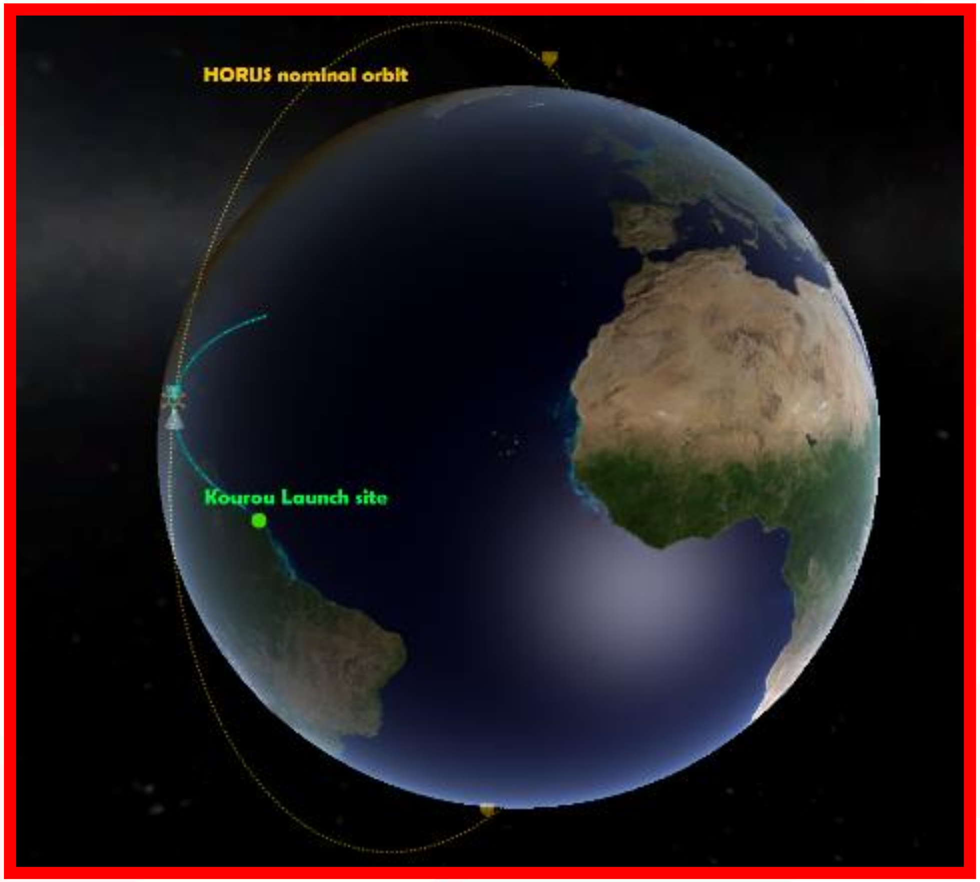
- The HORUS Ground Segment is based on **six Ground Stations** located at high, medium and low latitudes **equipped with S or X-band antennas**



Location	Antenna band type	Passages a-day	Average access time (sec)
High latitudes	S/X bands	11	550/570
Medium latitudes	S/X bands	4	600
Low latitudes	S/X bands	7	530

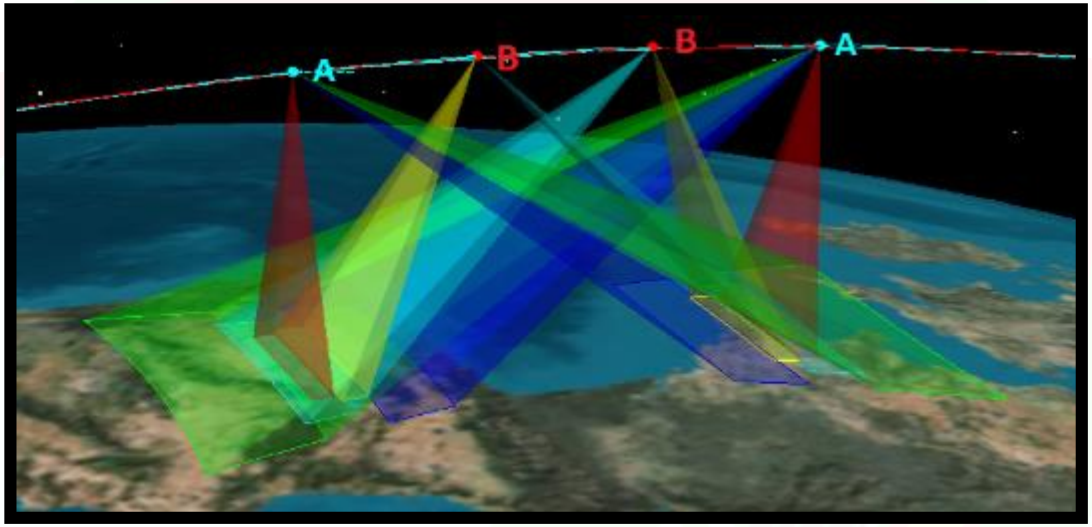
HORUS GS Network

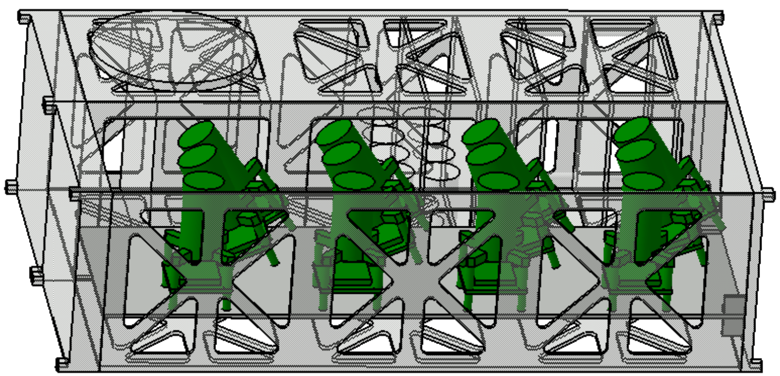
Launch Segment



- **VEGA** (Advanced Generation European Carrier Rocket) was selected as the most suitable launcher to directly reach the required orbit with a very affordable cost

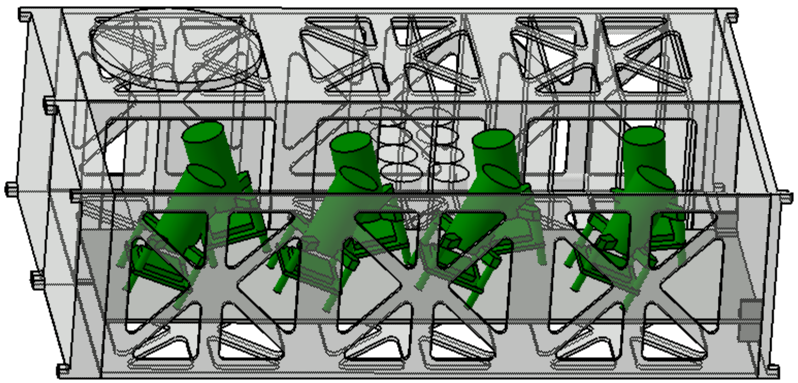
CubeSat Configuration:





- Twelve cameras (0, ±60 and ±70.5 degrees)

Configuration A



- Eight cameras (± 45.6 and ±26.1 degrees)

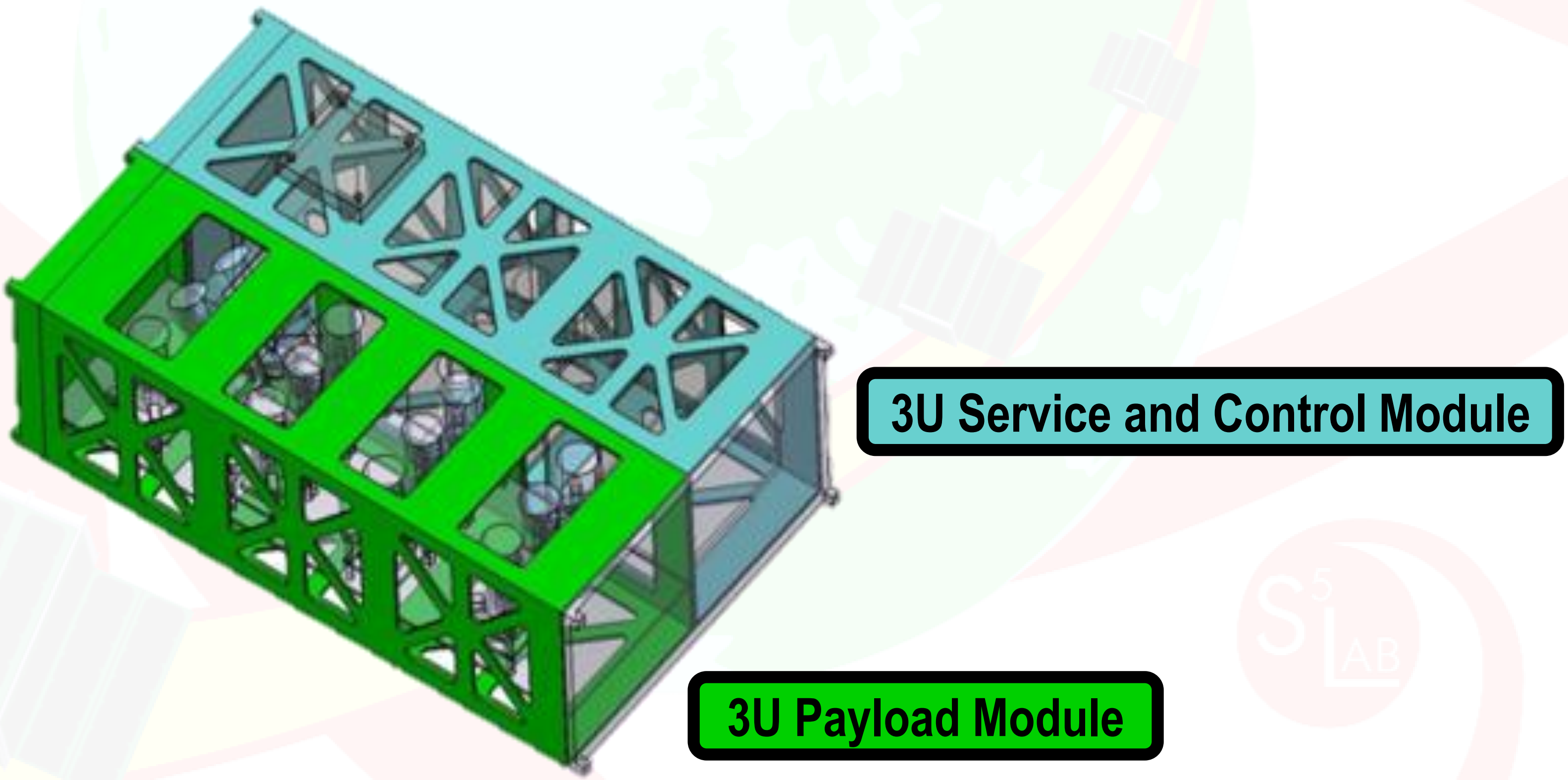
Configuration B

CubeSat Configuration: Mass Budget

Components	Configuration A	Configuration B
Aluminium structure	0.97 kg	
Optical payload	3.0 kg	2.0 kg
ARTICA System	0.40 kg	
OCS	0.30 kg	
TLC	0.20 kg	
Power Control Unit	0.15 kg	
Battery Pack and Aluminium support system	0.60 kg	
OBC	0.40 kg	
ADCS	0.50 kg	
Solar Panels	1.4 kg	
Connections	0.30 kg	
Antenna	0.17 kg	
TOTAL MASS	**9.40 Kg**	**8.40 Kg**

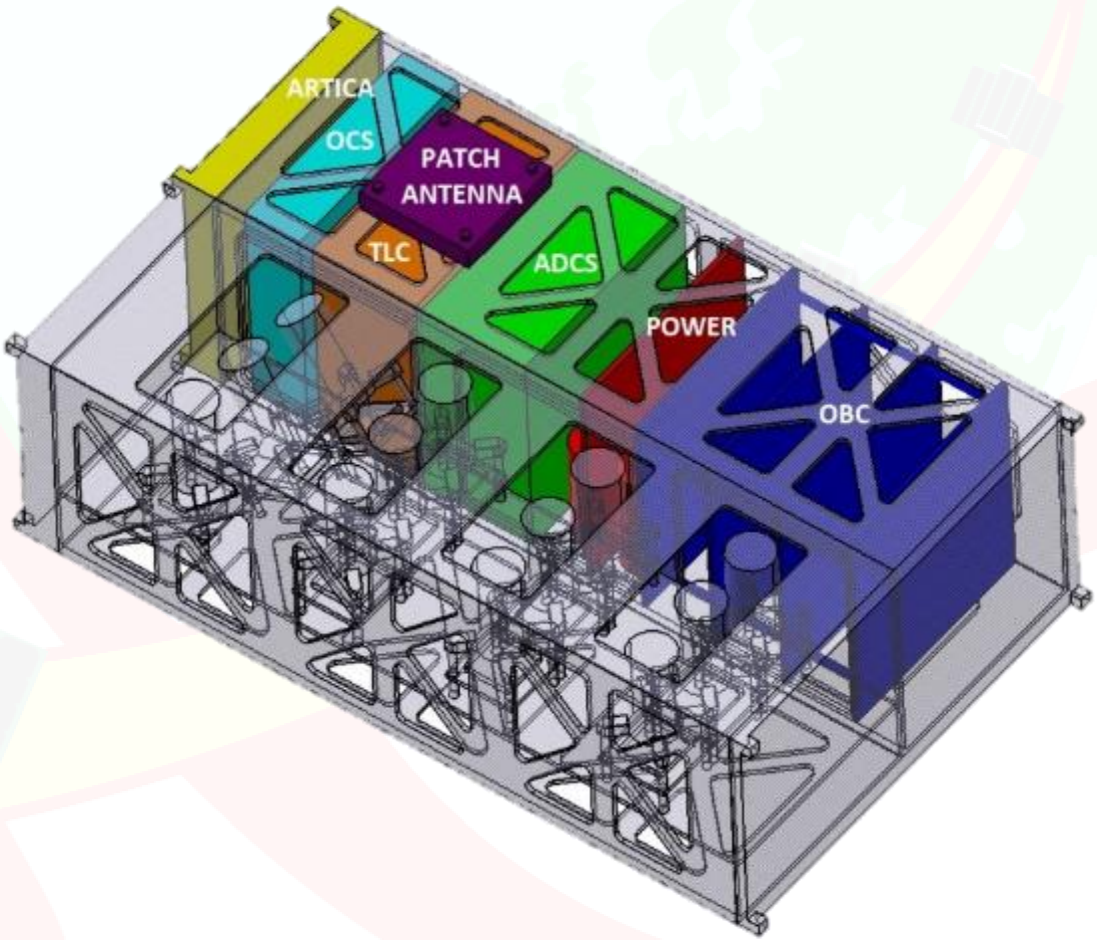
CubeSat Configuration:

- The **6U CubeSat bus** of each HORUS nanosatellite was logically conceived in **two main modules**:



CubeSat Configuration:

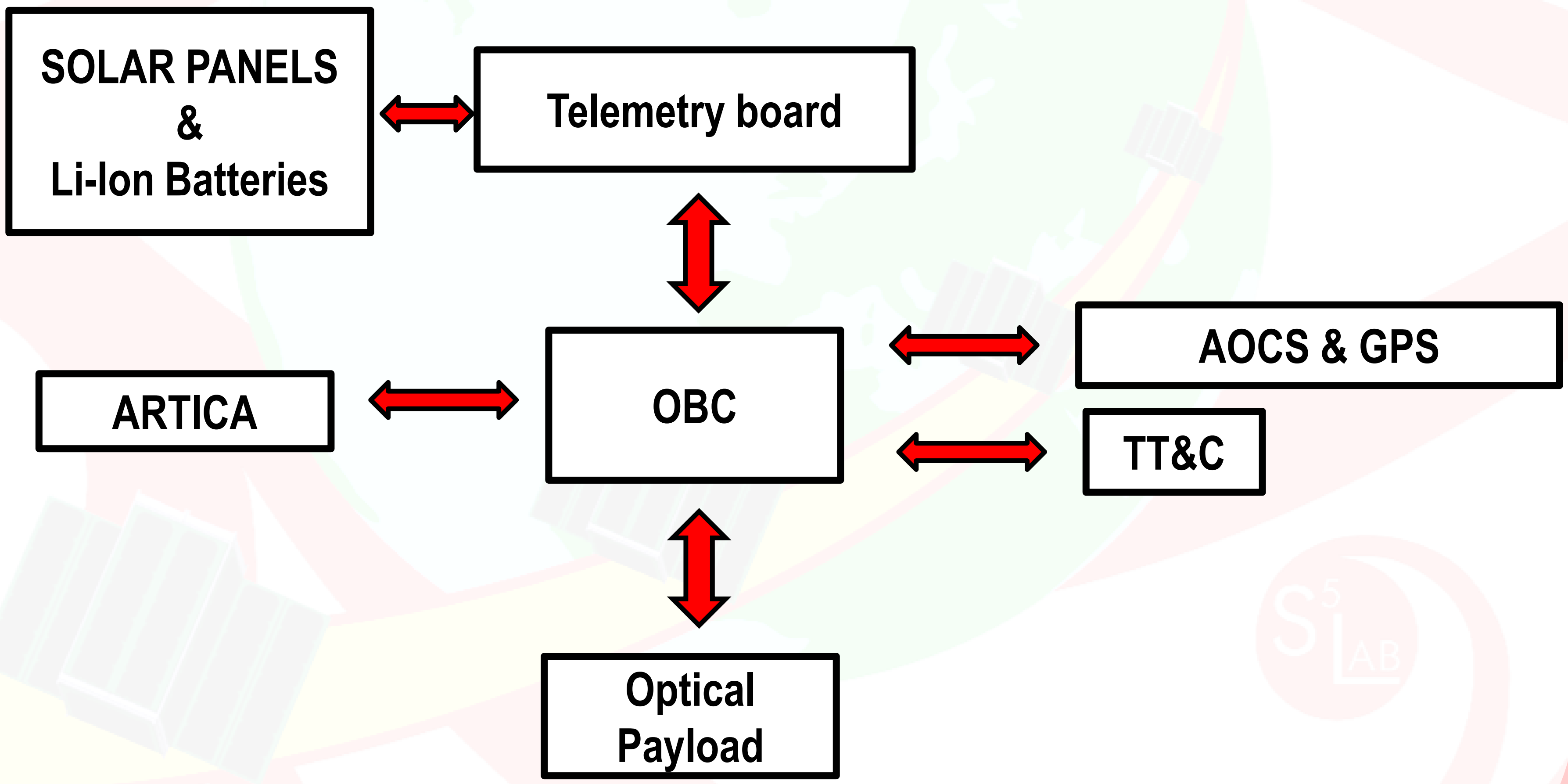
3U Service and Control Module



CubeSat Configuration:

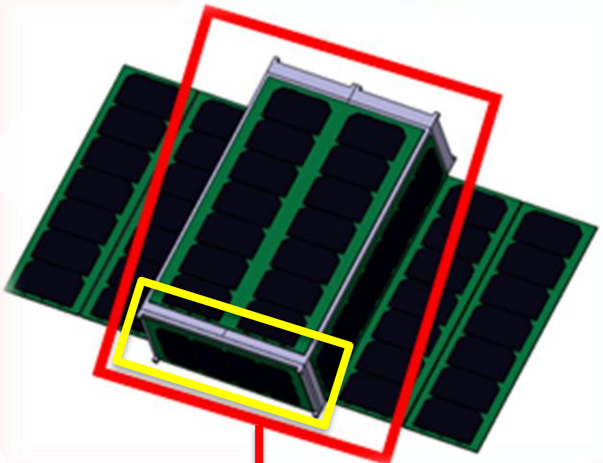
OBC

- Main preliminary scheme:



CubeSat Configuration:

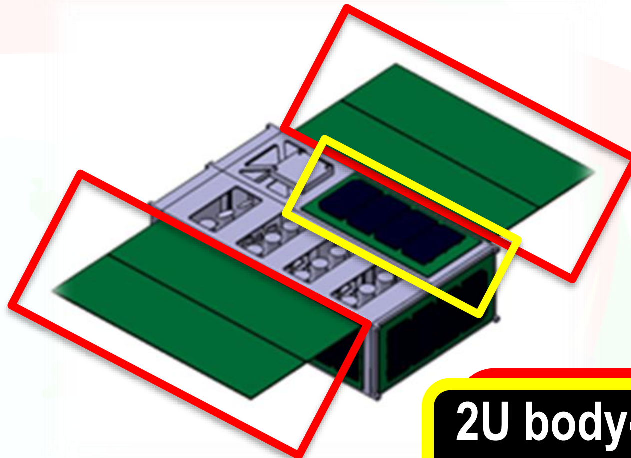
Power Unit



Zenith Pointing face

- 6U body-mounted solar panel

Supplied Power	30 W
Power Peak	41 W



2U body-mounted recovery panels

panels

Deployment mechanism:

- Hinges and torsion springs

Cells type:

- Triple junction cells

CubeSat Configuration:

ADCS

Three-axis stabilization

- Reaction wheel system
  - Three reaction wheels
  - Related weight: 200 grams
  - Maximum torque: ±2-20 mNm
  - Momentum: 0.03-0.06 Nms
- Three magnetorquers (reaction wheels desaturation)

Main sensors

- Star tracker (accuracy of 1 arc second)
- Fine Nadir sensor (accuracy of six arc minute)
- 6 coarse sun sensors
- 1 fine sun sensor

OCS

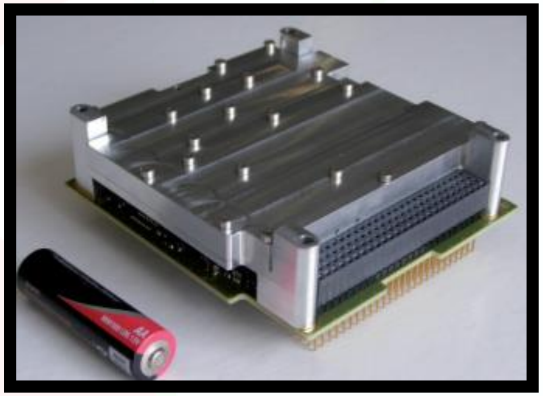
- GPS Receiver
- Cold gas propulsion based (CO_2)
- Specific Impulse: 50 s
- ΔV needed: 8 m/s per year
- Mission duration: 5 years

Nozzle main parameters

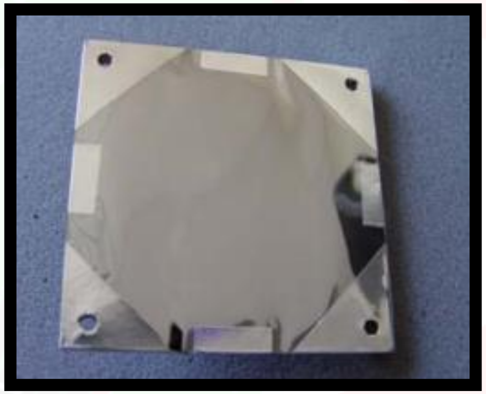
Propellant	CO_2	Exit diameter	3.175×10^{-3} m
Inlet pressure	790 kPa	Nozzle area ratio	17.45
Throat diameter	0.125"	Exit velocity	562 m/s
Mach number @ exit	4.13	Propellant mass flow rate	0.016 kg/s
Thrust		9.04 N	

CubeSat Configuration:

TT&C



X-Band transmitter



Low gain patch antenna

- Communication with GS in all possible Elevation Angles
  - Coverage of a wide area

S-band antenna

- Command
- Back-up data transmission

CubeSat Configuration:

TT&C

QPSK Modulation

↓

High data rate (up to 50 Mbps)

- The **Energy per bit to Noise ratio** (Eb/No) required for this modulation is too high to ensure a positive value for link margin, so a **Convolutional code with a rate of ½ has been selected** to decrease the required Eb/No minimum level

- **A 4.4 dB is the needed Eb/No for a Bit Error Rate (BER) of at least 10-5**

CubeSat Configuration:

Link Budget

WORST-CASE CONDITION

- Main Hypotheses:
  - Visibility condition
  - Elevation angle of 10 degrees
  - GS Antenna diameter: 5 m
  - HORUS Patch Antenna gain: 0 dBi
  - Atmospheric, implementation and transmission line losses considered
  - Antenna pointing error free
  - Variable data rate (from 10 Mbps to 50 Mbps)

CubeSat Configuration:

Link Budget

Features	Symbol	Data	Result
RF Output Power	P_t	3 dBW	
Antenna Gain	G_t	0 dBi	
Free Space Path Loss	L_p	175 dB	
Additional Loss	L_a	5 dB	
Receiver Antenna Figure of Merit	G/T	30 dBK^{-1}	
Boltzmann's Constant	k	-228.6 dBW/(Hz*K)	
Data Rate	R	70 Mbps	
E_b/N_0	E_b/N_0	-	11.6 dB
E_b/N_0 Required for BER= 10^{-5}	$E_b/N_{0\ min}$	4.4 dB	
Link Margin	-	$E_b/N_0 - E_b/N_{0\ min}$	**7.2 dB**

CubeSat Configuration:

ARTICA

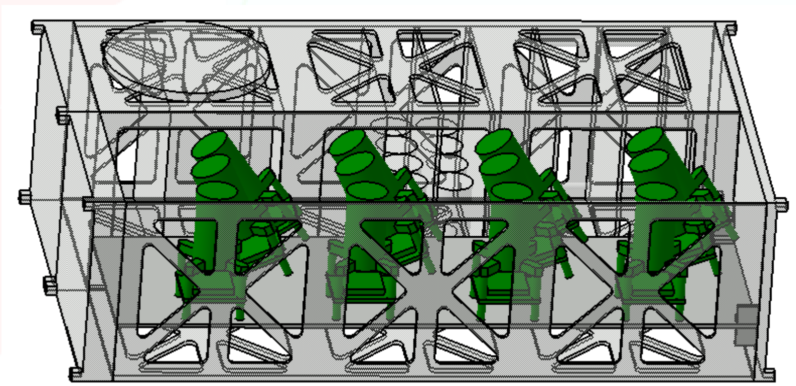
Aerodynamic Re-entry Technology In Cubesats Applications

- **Special polymeric material**
- The **unlocking system** is composed by a **wire and a thermal cutter**

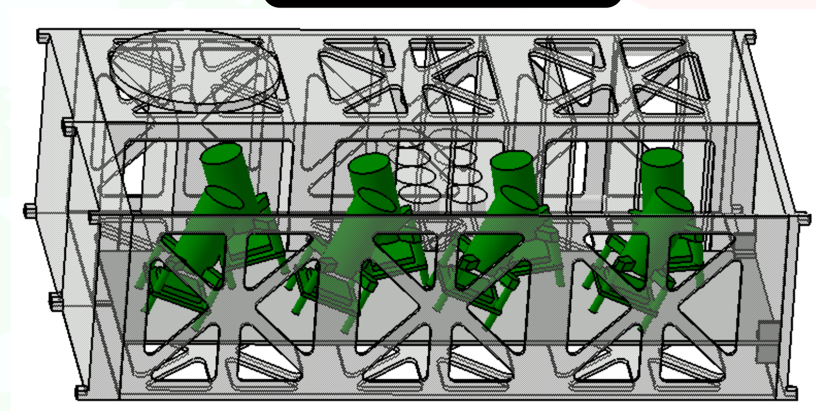
CubeSat Configuration:

3U Payload Module

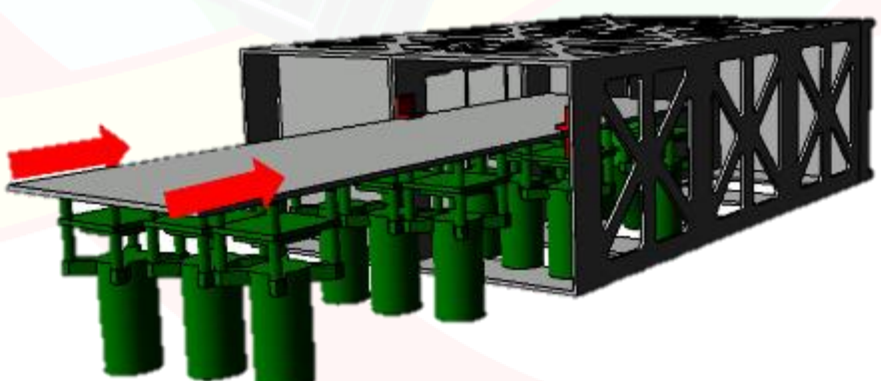
Configuration A



Configuration B



Rail-based system for payload integration



HORUS Optical Payload

Feasibility Study

- Main Hypotheses:
  - Sub-kilometer spatial resolution
  - MISR's 9 view angles
  - Matrix imagers configuration
  - COTS filters (RGB and NIR)
  - Unique focal length
  - Pixel dimension of 7μmx7μm
  - CMOS sensor (2048x1536 pixels)

HORUS Optical Payload

Feasibility Study

- **Main Features:**
  - **Estimated Ground Sample Distance (GSD):**
    - In-track $\in$ [167,404] m
    - Cross-track $\in$ [167,173] m
  - **Cameras common focal length: 21 mm**
  - **MISR Optical Quality Factor (Q) $\in$ [0.1,0.25]**
  - **COTS filters RGB and NIR bands**

HORUS Optical Payload

Main Results

- Common **F#**:

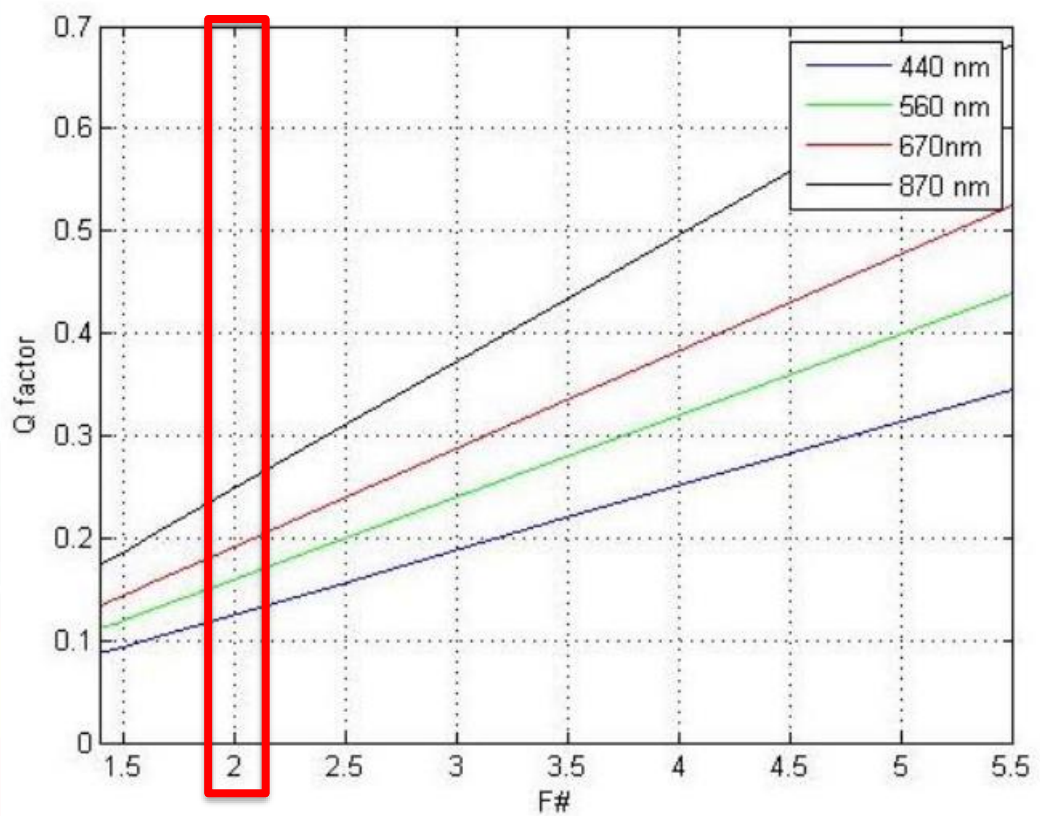
$$F\# = \frac{d \cdot Q}{\lambda}$$

→ **2**

- **Lens Aperture**:

$$D = \frac{f}{F\#}$$

→ **10.5 mm**



HORUS Optical Payload

Spatial Analysis

- **Main Hypotheses:**
  - Diffraction limited device
  - Aberration-free estimation
  - COTS filters RGB and NIR bands
  - MISR's 9 view angles

Resolution at ground

		Observing angles				
		0 deg	26.1 deg	45.6 deg	60.0 deg	70.5 deg
Spectral bands	blue (446 nm)	27.2 m	30.2 m	38.8 m	54.4 m	81.4 m
	green (558 nm)	34.0 m	37.8 m	48.6 m	68.0 m	102.0 m
	red (672 nm)	41.0 m	45.6 m	58.6 m	82.0 m	122.8 m
	IR (866 nm)	53.0 m	59.0 m	75.8 m	106.0 m	158.8 m

- **The sub-kilometer resolution at ground was respected** in each band and in each view-angle
- **Estimated HORUS Quality Factor (Q) ∈ [0.16,0.21]**

HORUS Optical Payload

Spectral Analysis

- A **Momentum Analisys** has been performed to quantify the system Spectral Resolution

	CWL (nm)	Delta λ (nm)	$E_0\left(\frac{W}{m^2 * \mu m}\right)$
B	446.34	40.89	1871.29
G	557.54	27.17	1851.30
R	671.75	20.44	1524.96
NIR	866.51	38.62	969.64

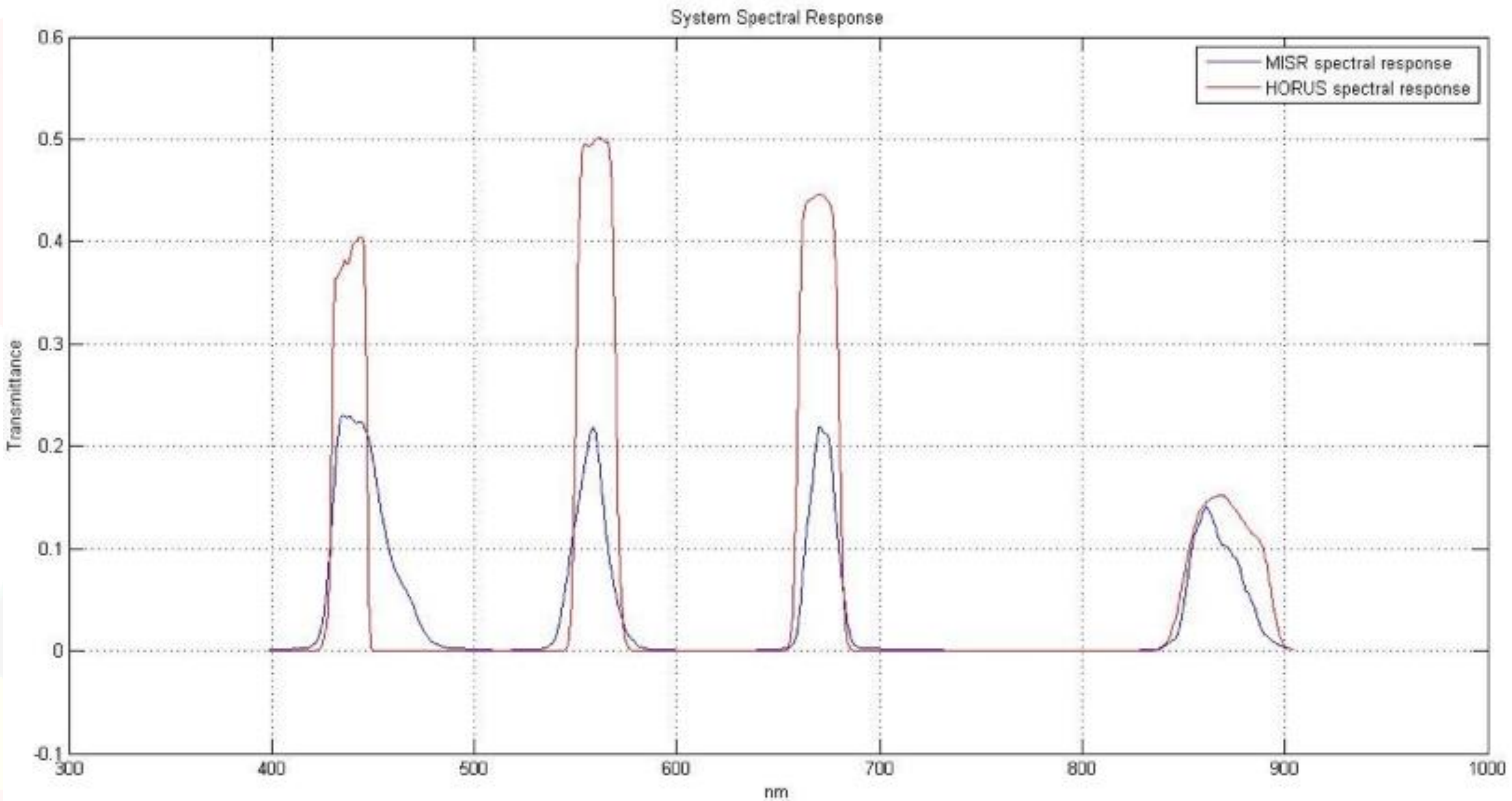
MISR

	CWL (nm)	Delta λ (nm)	$E_0\left(\frac{W}{m^2 * \mu m}\right)$
B	438.36	18.37	1879.5
G	560.15	21.06	1543.5
R	669.73	21.81	1209.6
NIR	870.15	45.04	766.3

HORUS

HORUS Optical Payload

Comparison between the Spectral Responses



HORUS Optical Payload

Radiometric Analysis

- **Main Hypotheses:**
  - HORUS estimated optical features
  - Estimated spectral radiance at the TOA
  - Equivalent reflectance between 2% and 100%

Integration Times

Band type	Int. time (s)
B	8.5×10^{-3}
G	5.7×10^{-3}
R	6.5×10^{-3}
NIR	12.5×10^{-3}

HORUS Optical Payload

Radiometric Analysis

Equivalent reflectance %	Minimum SNR	HORUS			
		Blue	Green	Red	NIR
100	700	861.8	868.7	862.9	865
70	600	719.5	725.3	720.4	722.3
50	450	606.4	611.3	607.2	608.7
20	300	378	381	378.5	379.5
2	100	100	101	100	100

> 100

Dark current noise	4000 e-/pixel/s
Readout noise	50 e-

HORUS Optical Payload

Main Conclusions

- **HORUS** optical payload **will be able to obtain at least the MISR's radiometric capability** in terms of SNR
- The HORUS system needs a **high Full Well capacity in case of 100% reflectance** to observe and analyse the scene without saturation
- the optical payload shall not be fully COTS-based to get all the scientific targets (customised-component CMOS sensor)

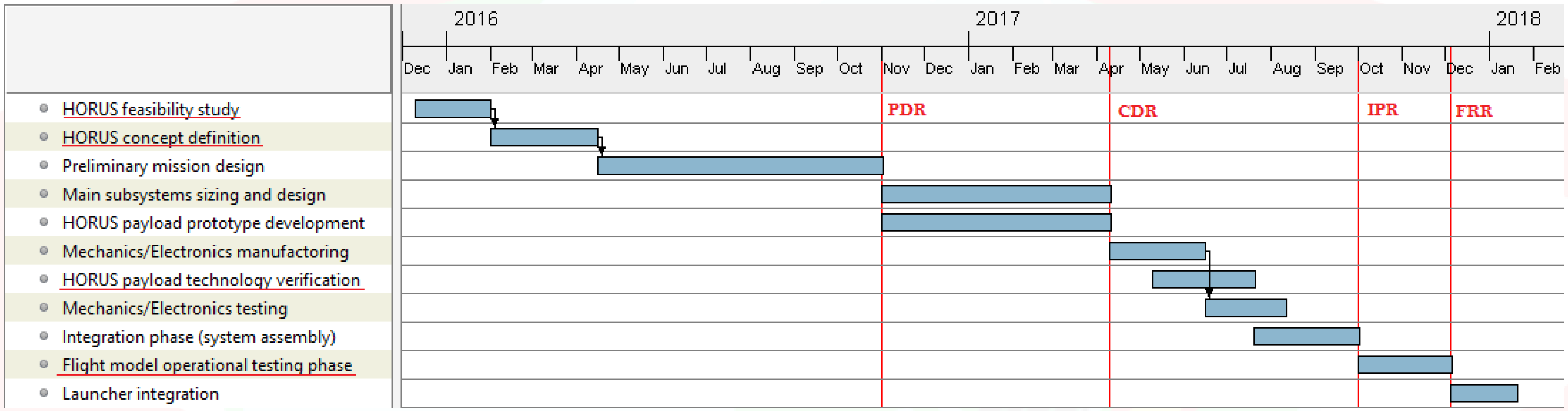
Implementation Plan

Risks Analysis

RISK	PROB.	MITIGATION
Non-nominal performances of HORUS optical payload	Low	Robust and reliable algorithm simulation tools will be used to predict and simulate the HORUS optical payload operational performances
Problems in in-orbit optical system calibration	Low	The HORUS calibration method will be performed taking cue from the MISR techniques of calibration
Problems in OCS operational performances	Low	The design of the HORUS On-Board Computer (OBC) will be based on technology already tested and with an in-orbit flight heritage
Delays in components procurement	Low	After the feasibility analysis and the concept definition, the procurement phase will immediately start to ensure enough time for the components procurement
Insufficient funding for the mission development	Medium	Alternative funding sources and opportunities will be sought and identified

Implementation Plan

HORUS Gantt



Estimated Cost

- **Around 1M€**

(about 20 k€ per Kg)

Thanks for listening!

For further information:
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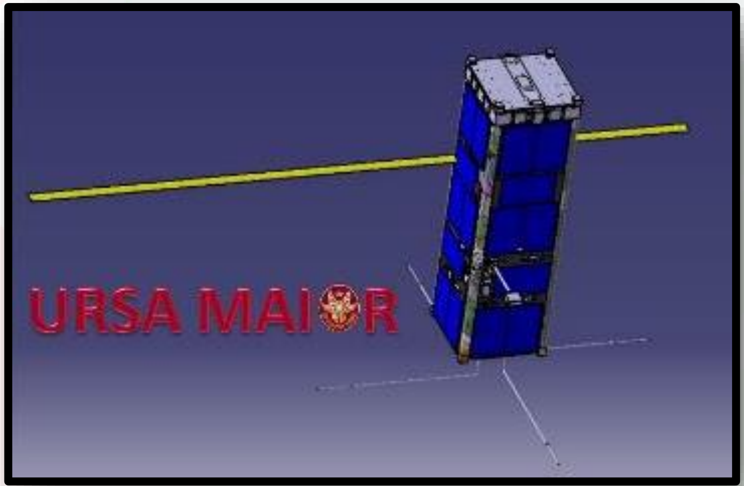
Questions?

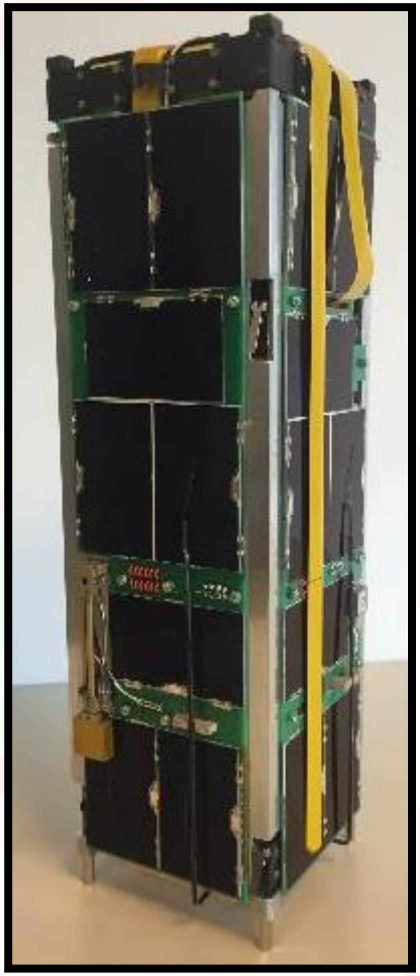
The 4th
Mission Idea Contest
For Micro/Nano-satellite Utilization
From Concept to Reality

Reliability

URSA MAIOR 3U CubeSat

University of Rome la Sapienza Micro Attitude In Orbit testing





3U Flight Unit

QB50 PROJECT

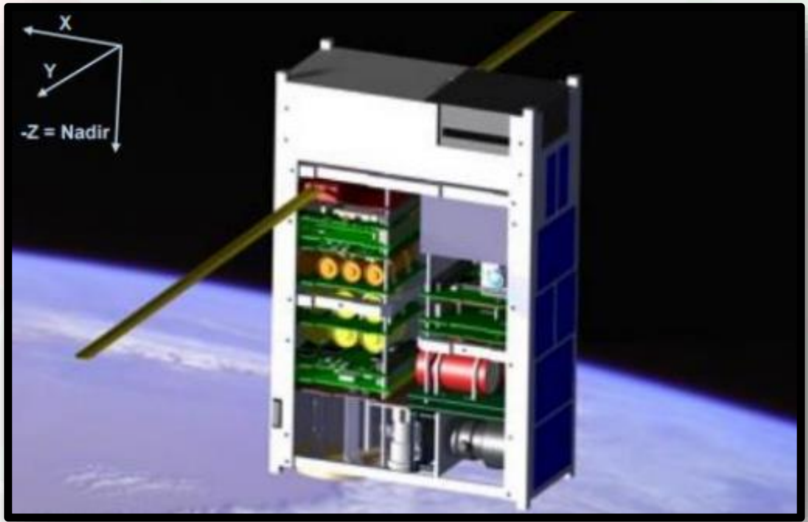
Main Objective: to use a network of 50 CubeSats to study in situ the main features of the lower thermosphere (90-320 km)

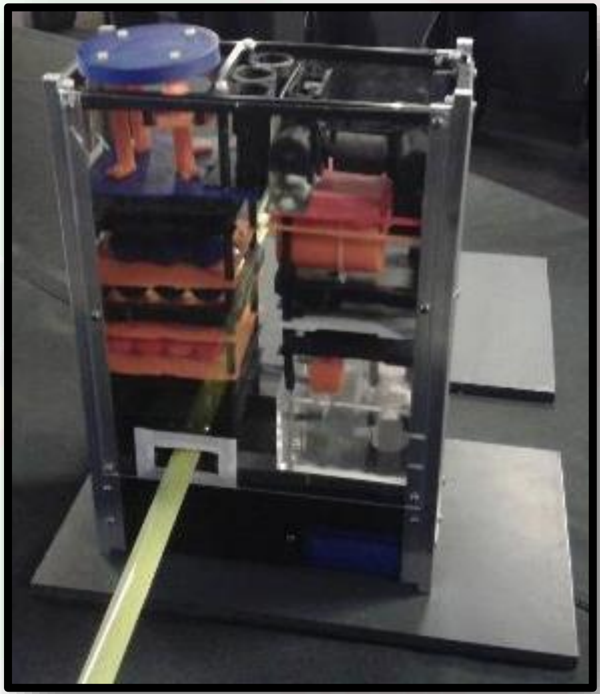
Reliability

IKUNS 6U CubeSat

Italy-Kenya University NanoSatellite

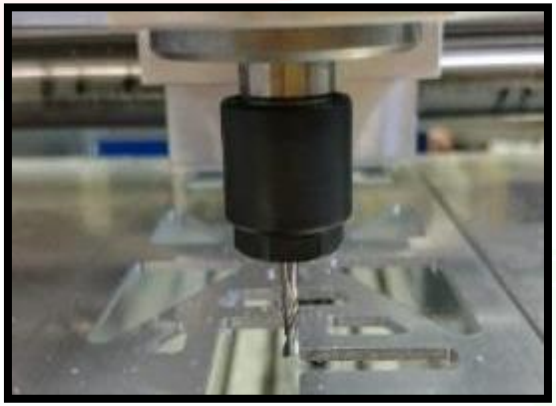
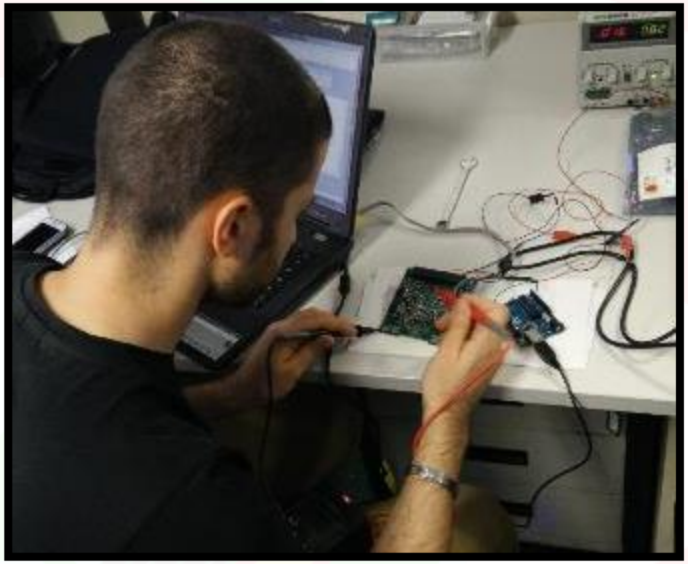
University nanosatellite developed in support of the Italian-Kenyan cooperation in space activities, part of an agreement between Sapienza – University of Rome and the Italian and ASI

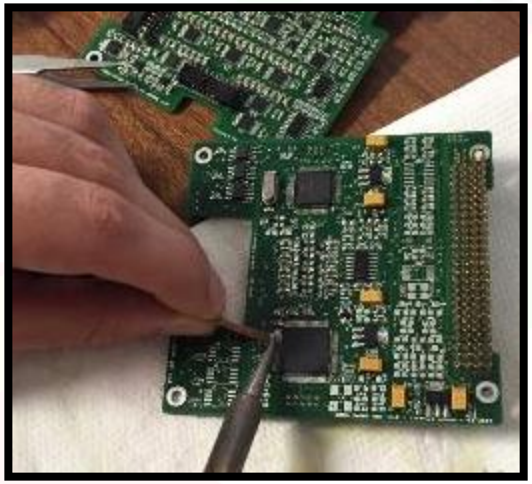


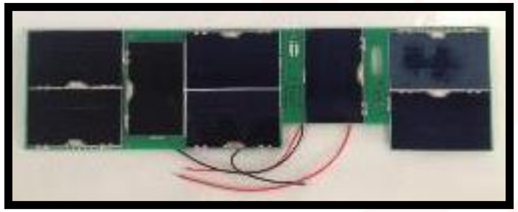


IKUNS 3D-printed Mock-Up

Reliability





Reliability

- **Main selected spectral bands:**

Different Spectral bands

  - **Red** (672 ± 20nm) and **Near-Infrared** (866 ± 20nm) bands provide **vegetated surface identification** and allow performing **marine aerosol studies**
  - Working near the peak of the solar spectrum, the **Green band** (580 ± 15 nm) will be properly used to estimate broadband reflecting properties (**albedos**)
  - The **Blue channel** at 446 nm (± 21nm) provides nearly a **double change in particle size-to-wavelength ratio relative to the near-infrared channel**

Comparison between MISR's and HORUS specral bands

	MISR		HORUS	
	CWL (nm)	FWHM (nm)	CWL (nm)	FWHM (nm)
Blue	442.45	26.99	440	18
Green	557.20	18.01	560	20
Red	671.66	14.79	670	20
NIR	864.87	27.06	870	40

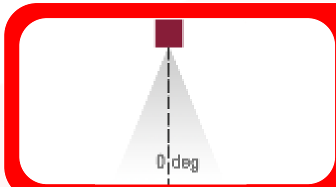
EO potentialities

Cameras	Df	Cf	Bf	Af	An	Aa	Ba	Ca	Da
Angles	70,5	60,0	45,6	26,1	0,0	26,1	45,6	60,0	70,5
443 nm									
555 nm									
670 nm									
865 nm									

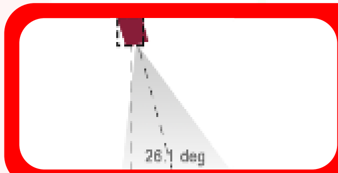
Albedo	
Cloud detection/Features	
Surface classification	
Aerosols	
Comparison	

EO potentialities

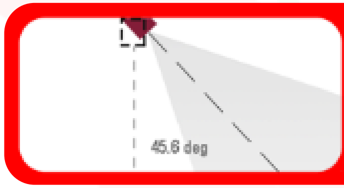
Different view angles



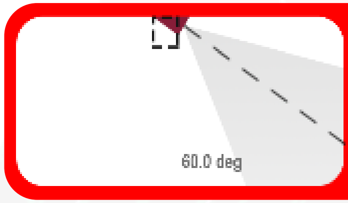
- Imagery less distorted
- Near minimal influence from atmospheric scattering
- Comparison with other cameras' imagery



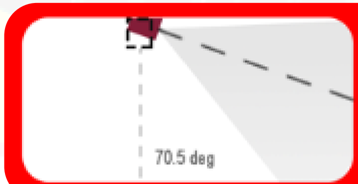
- Optimal base/height ratio
- Indipendent information not distorted by geometric effects



- Optimal aerosol sensitivity
- Optimal groundtrack distance between A-B cameras/ B-C cameras
- Uniform scene lengths for high-resolution targeted observations



- Directionally oriented reflectance variations among many different types of clouds are minimized
- The amount of reflection at each ground point-hemispherical albedo



- Maximal sensitivity to off-nadir effects