Università degli Studi di Napoli Federico II

Dipartimento di Ingegneria Industriale

Il Ruolo delle Piccole Piattaforme nelle Future Missioni Spaziali

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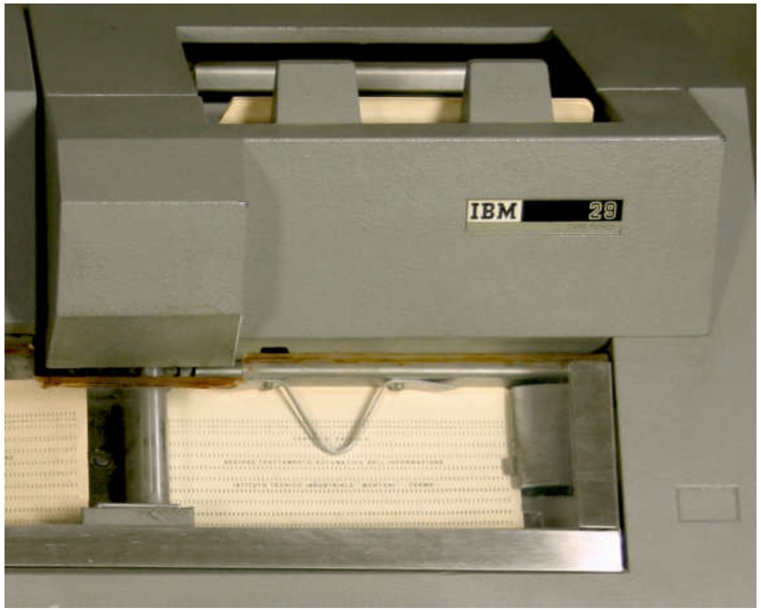
SEMINARI INTERDISCIPLINARI DI CULTURA AERONAUTICA
Napoli, 15 Dic. 2018

- Main Research activities in the space system field:
  - Space System & Mission Design
  - Spaceborne Remote Sensing Missions based on MicroSats and NanoSats
  - Technology Developments for attitude sensors and GNC
  - Spaceborne Bistatic Synthetic Aperture Radar: System Design and Applications
  - **Formation Flying Design and GNC**
  - **On-Orbit Servicing and Active Debris Removal Mission Design**
  - **Spaceborne Distributed Synthetic Aperture Radar**
  - **Space Exploration Missions and Related Technologies**

Technology Evolution and Miniaturization

20-25 years ago

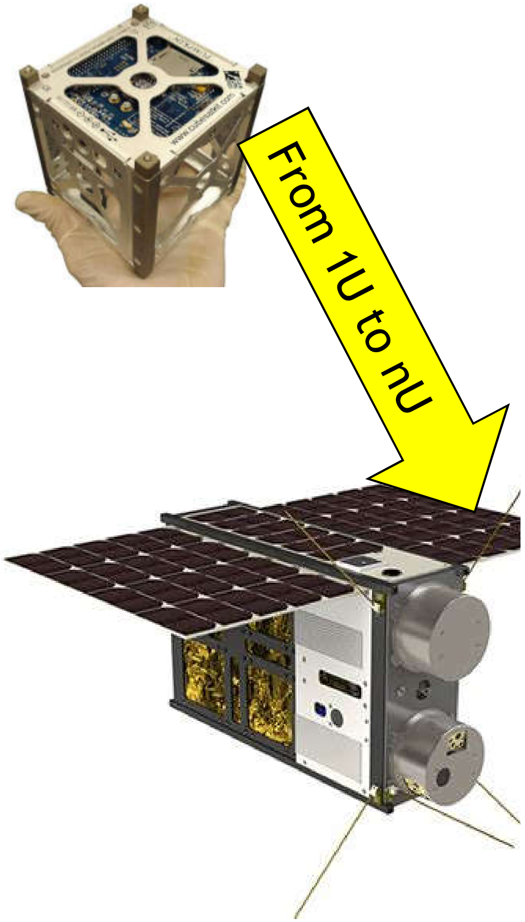


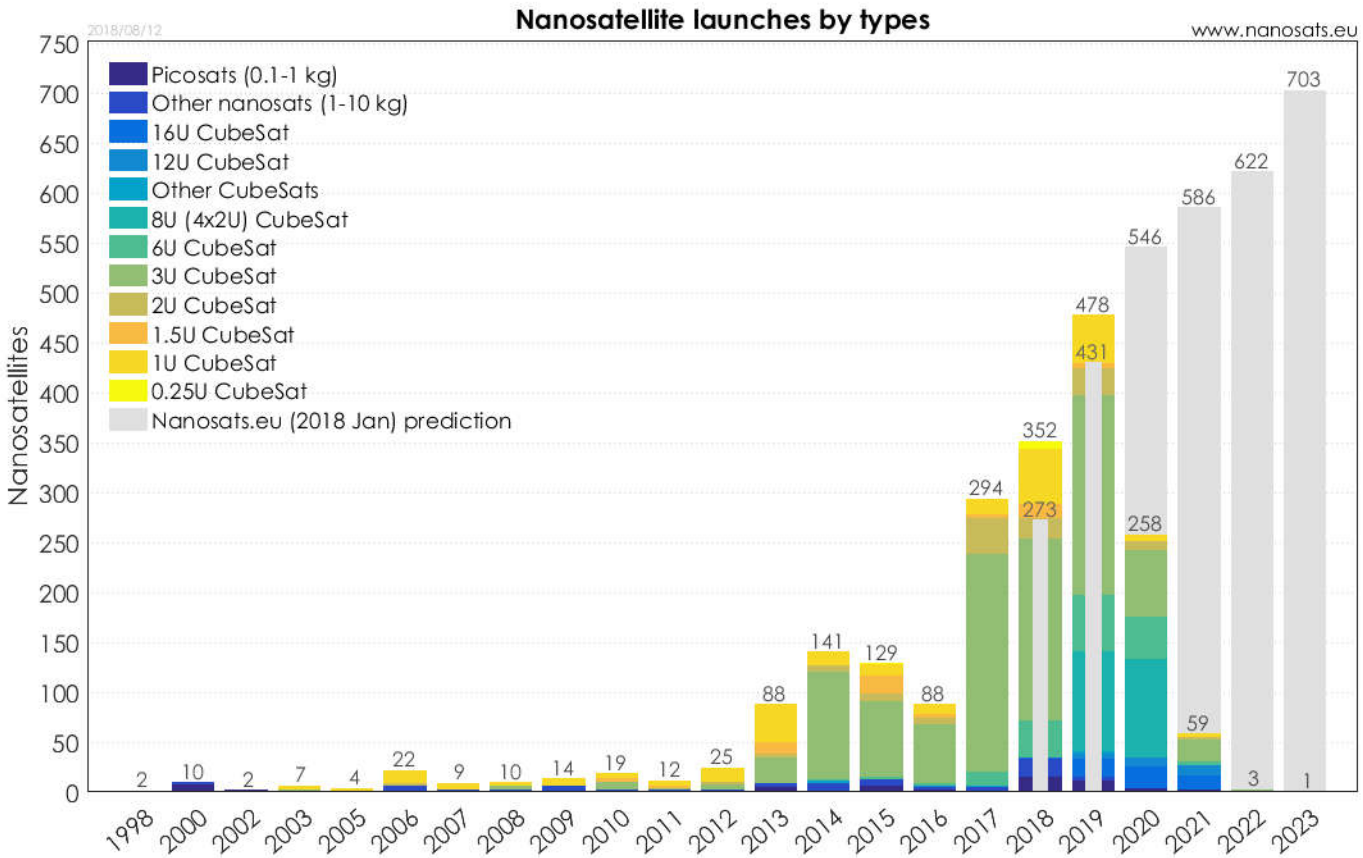
35-40 years ago

Today

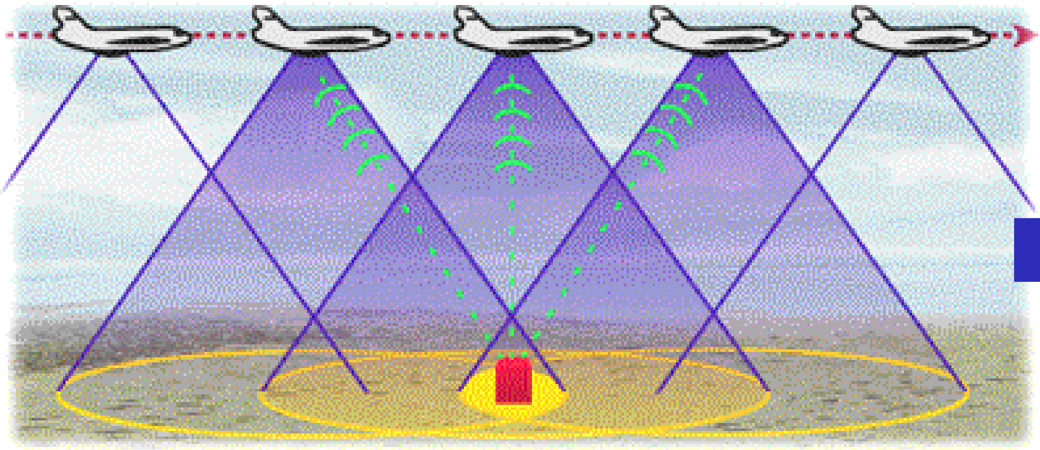
CubeSAT: An Emerging Standard for Advanced Space Missions

- In the last decade, advanced manufacturing techniques (e.g. 3D printing) and miniaturization have attracted many investments, allowing competitive space programs based on microSats and nanoSats
- CubeSAT is becoming a worldwide recognized standard for advanced EO scientific missions (<u>also SAR-based</u>), radio astronomy, IR space telescopes, in-orbit servicing and inspection, space exploration (www.nanosats.eu)





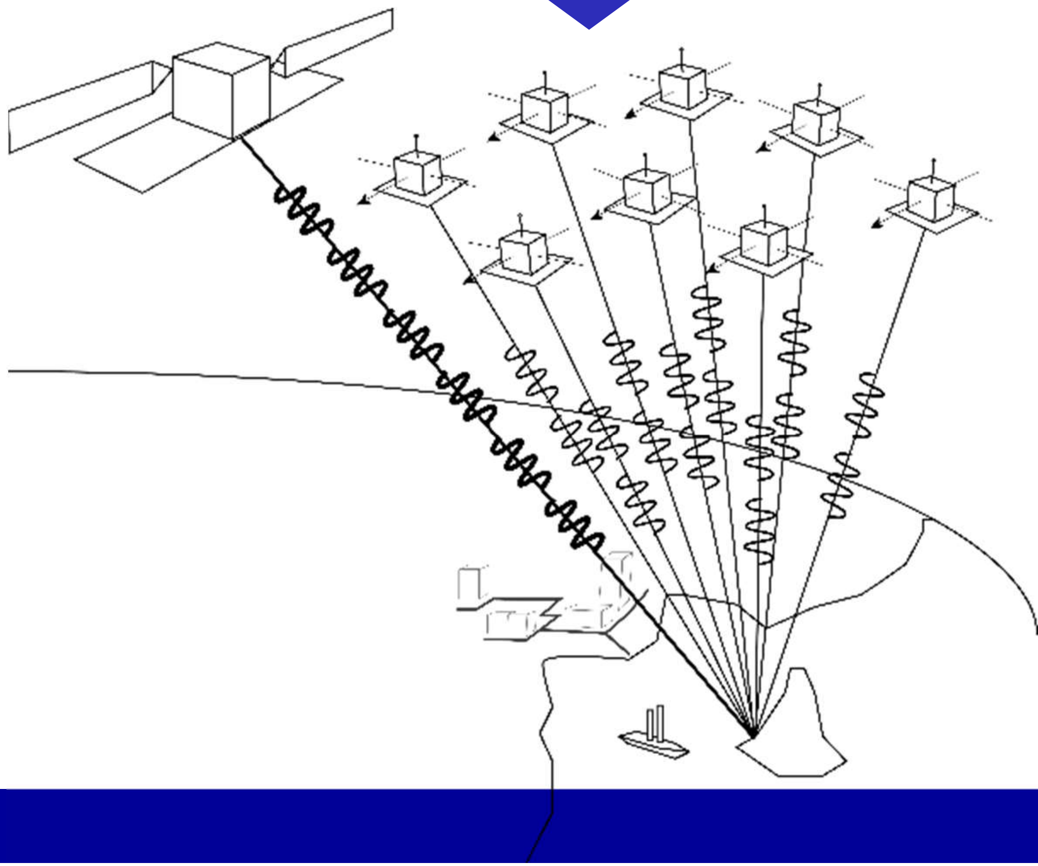
The Concept of Distributed SAR (DSAR) Phase-A study (DSO)



Echo of the signal emitted by the transmitter is collected by many, conveniently distributed **formation flying** small **passive receivers**

The ensemble of locations of the antenna during the illumination of a given target constitute the "synthetic aperture" of the system

The ensemble of synchronized antennas illuminating a given target constitute a distributed synthetic aperture

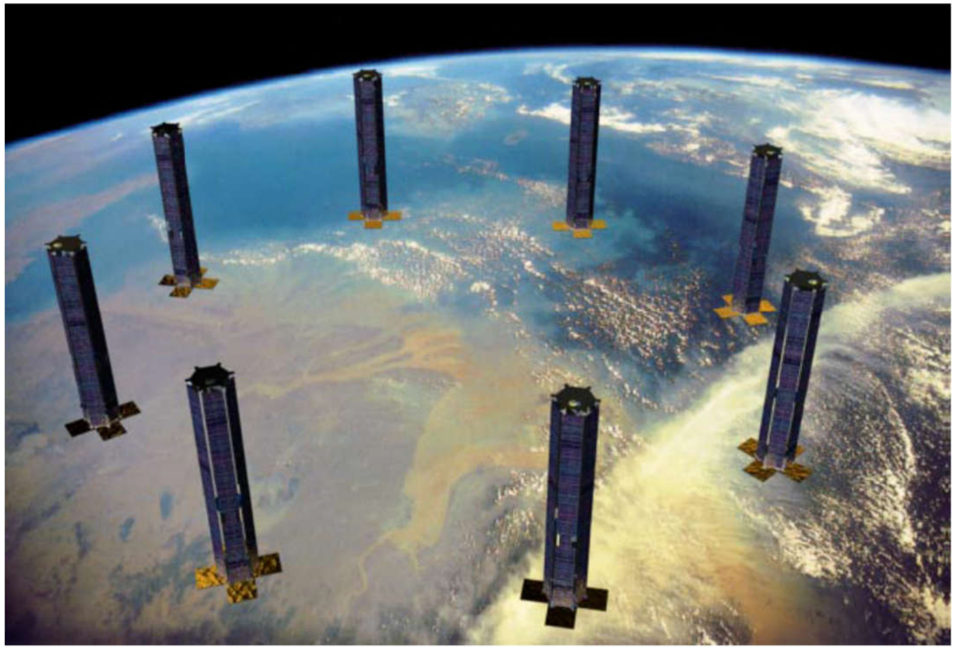


Formation Flying for Earth remote sensing: a new paradigm

From a "**monolithic**" spacecraft

Multi-instrument satellite with multiple science objectives

to a "**virtual**" spacecraft



Data fusion from several sources => more complete answers, not achievable from any single satellite

Signals received by spatially separated receivers allows **new applications** to be considered:

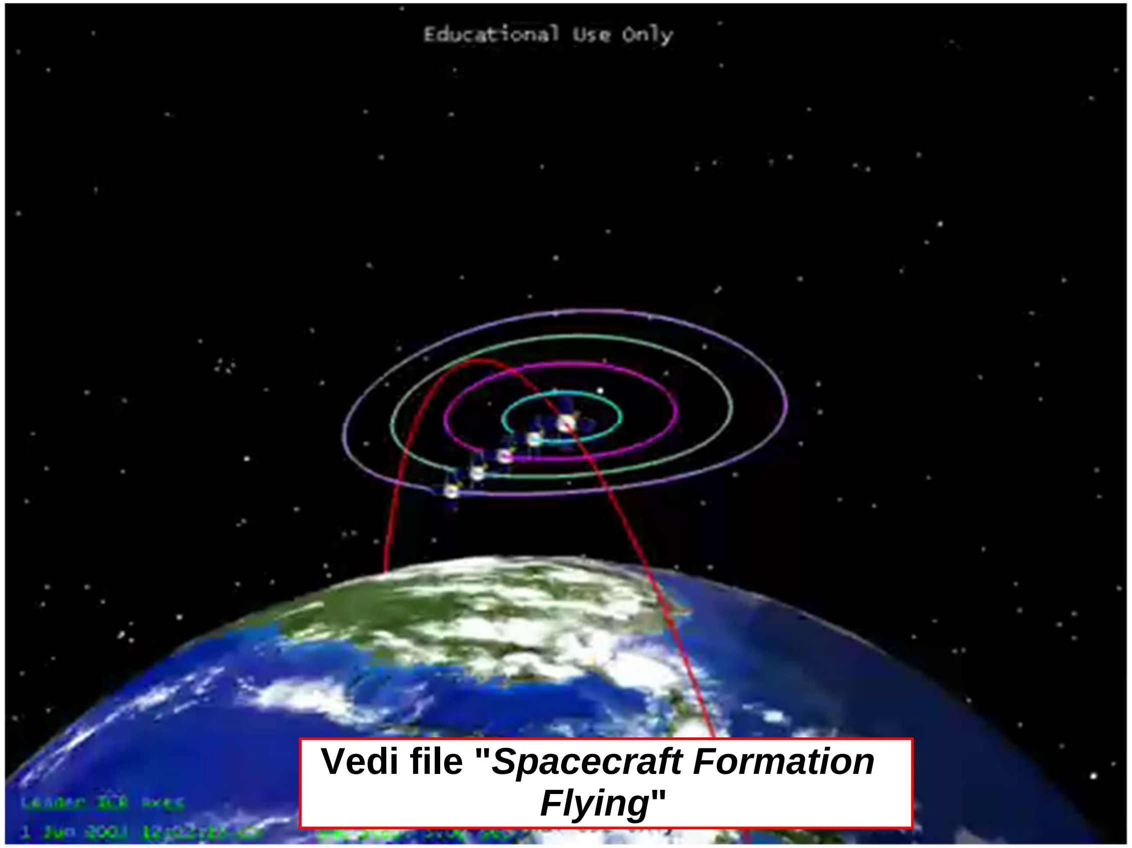
- Coherent **Resolution Enhancement** (CRE
- High-Resolution Wide-Swath (HRWS) imaging
- **Ground Moving Target Indicator** (GMTI) and **3D imaging**
- Miscellaneous: DSAR applications able to accomplish **different goals simultaneously** (i.e. different observation geometries with different formation geometry) exploiting system **redundancy** and **flexibility**.
- **Increased reliability at reduced cost** and **development time scale** at system level

•We need small receivers flying with **separations** in the order of **tens to hundreds meters**.

This requires high-level of coordination: Micro-platform Formation Flying is a new paradigm in space missions

Guidance, Navigation and Control (GNC) technologies are enabling for these applications :

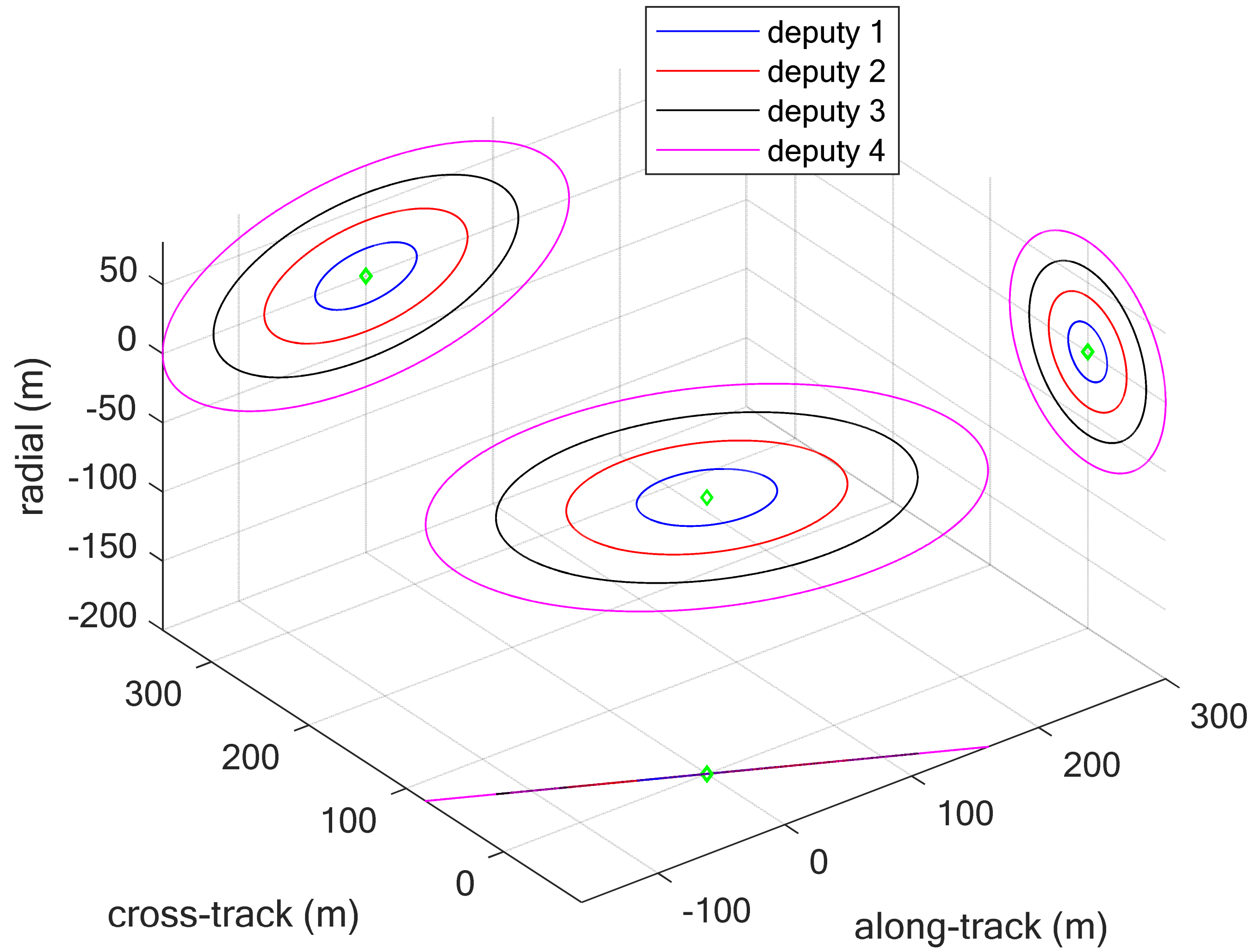
- Design of passively safe relative trajectories
- GPS-based and Vision-based relative positioning



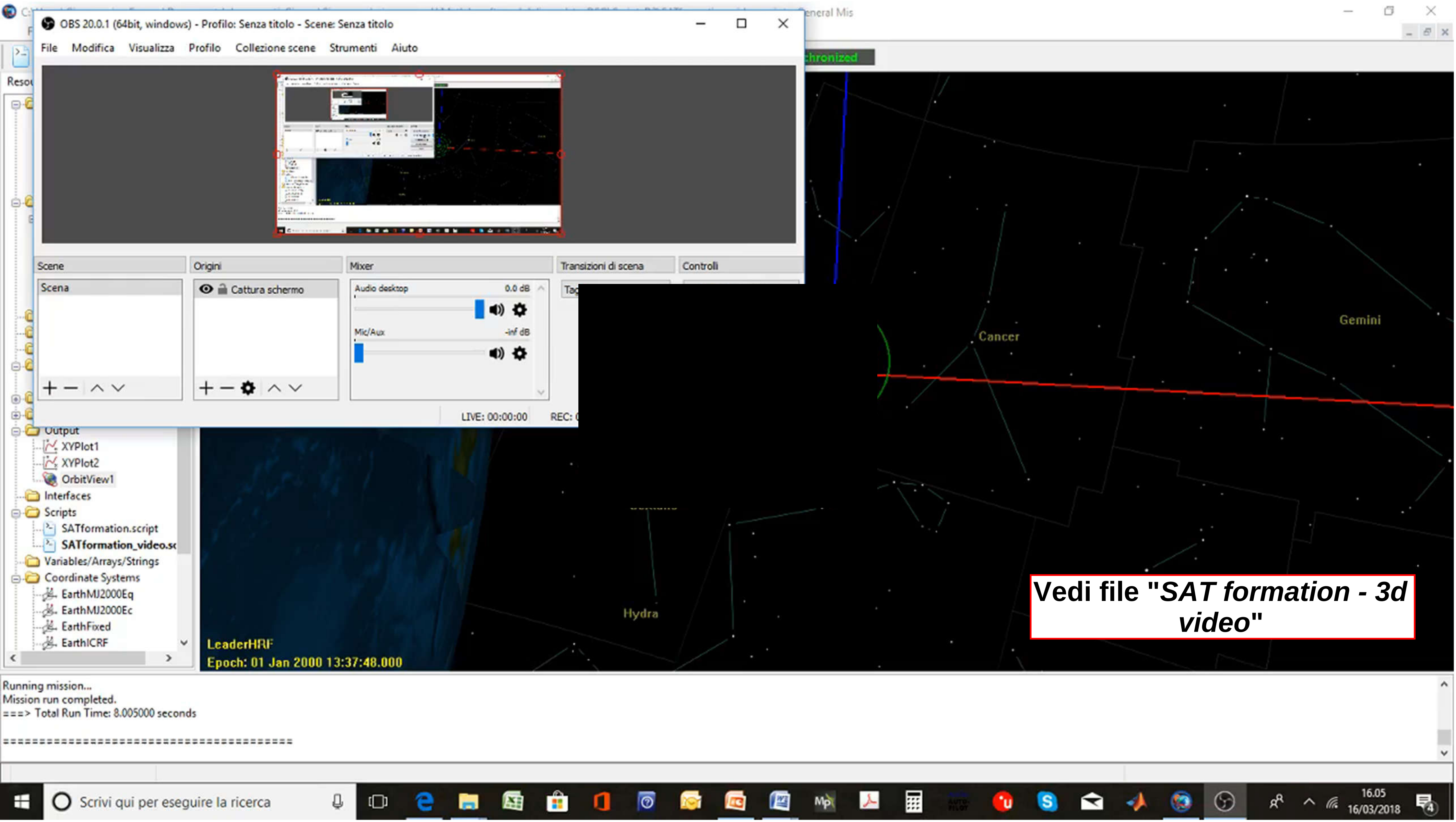
Vedi file "*Spacecraft Formation Flying*"

Safe Along-Track Formation ("safe ellipses" category): aimed at generating **along-track observation geometries.** The formation includes 5 satellites

$$
\begin{bmatrix} x \\ y \\ z \end{bmatrix} \cong \begin{bmatrix} x_{off} + A_x \cos\left(\dot{M}_D t + \varphi_x\right) \\ y_{off} + 2A_x \sin\left(\dot{M}_D t + \varphi_x\right) + t y_{dr} \\ A_z(t) \cos\left[\dot{u}_D t + \varphi_z(t)\right] \end{bmatrix}
$$

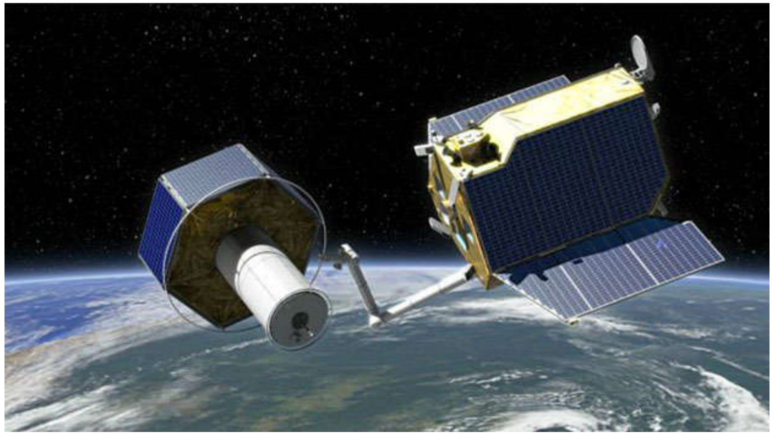


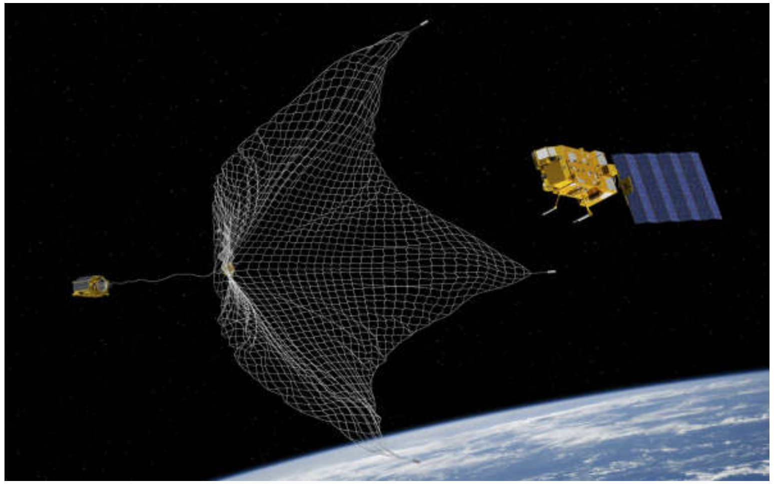
SAT formation - 3d video



Vedi file "*SAT formation - 3d video*"

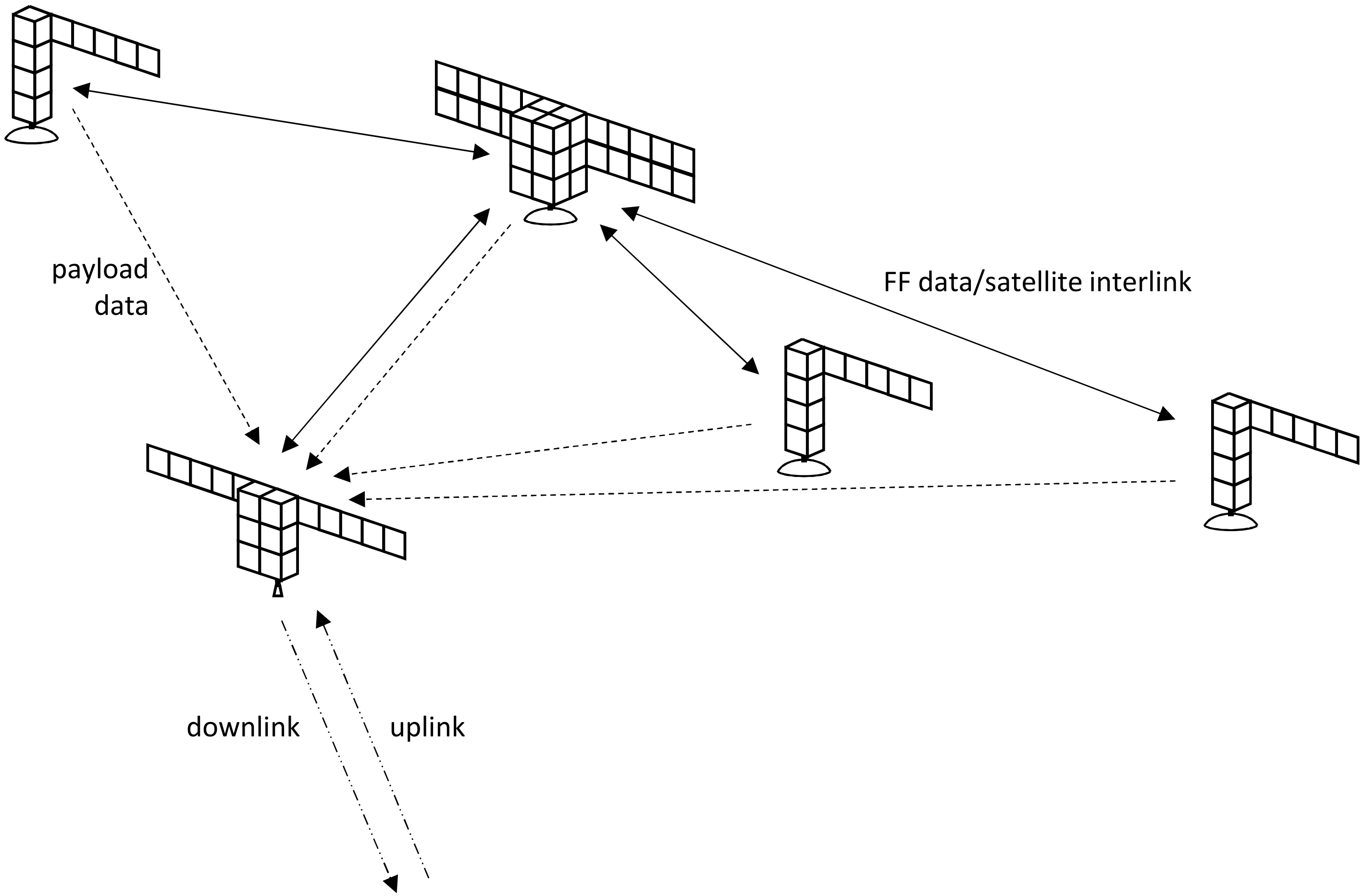
Formation Flying & Close Proximity Flight for On-Orbit Servicing (OOS) and Active Debris Removal Missions– OLOS Phase-A Study



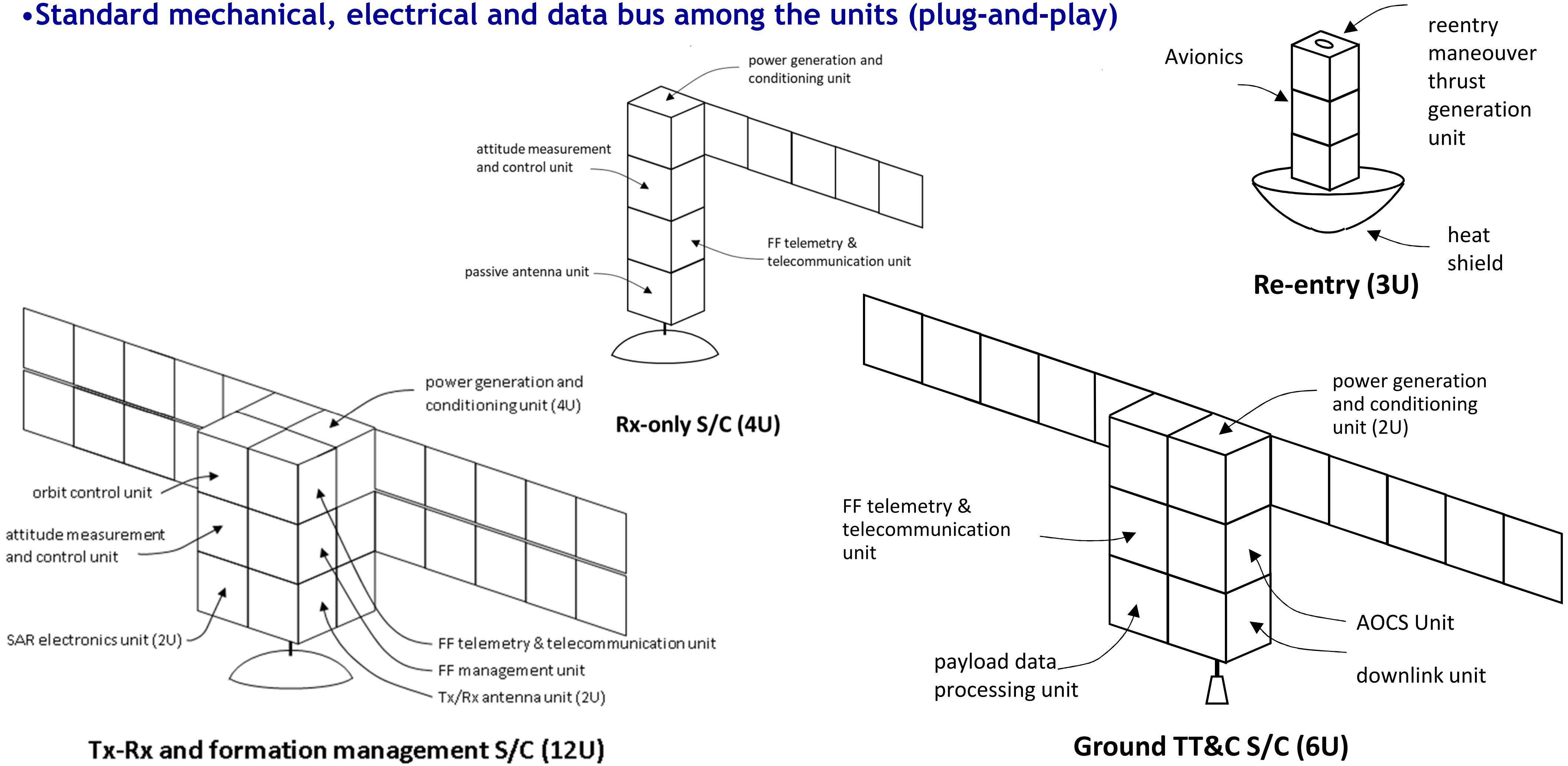


Vedi file "*iBOSS - On Orbit Servicing Concept Video*"

- Other than distributed the system can be **fractionated**:
  - Some satellites of the formation can be dedicated to radar data collection, whereas other satellites can be used to perform different tasks, such as synchronization or data relay either among satellites or to the ground station



- A modular space systems based on assemblies of CubeSat units
- Not a spacecraft based on CubeSat architecture but a spacecraft obtained assembling CubeSats
- Each CubeSat unit is in charge of a function, each CubeSat unit is a subsystem
- Standard mechanical, electrical and data bus among the units (plug-and-play)



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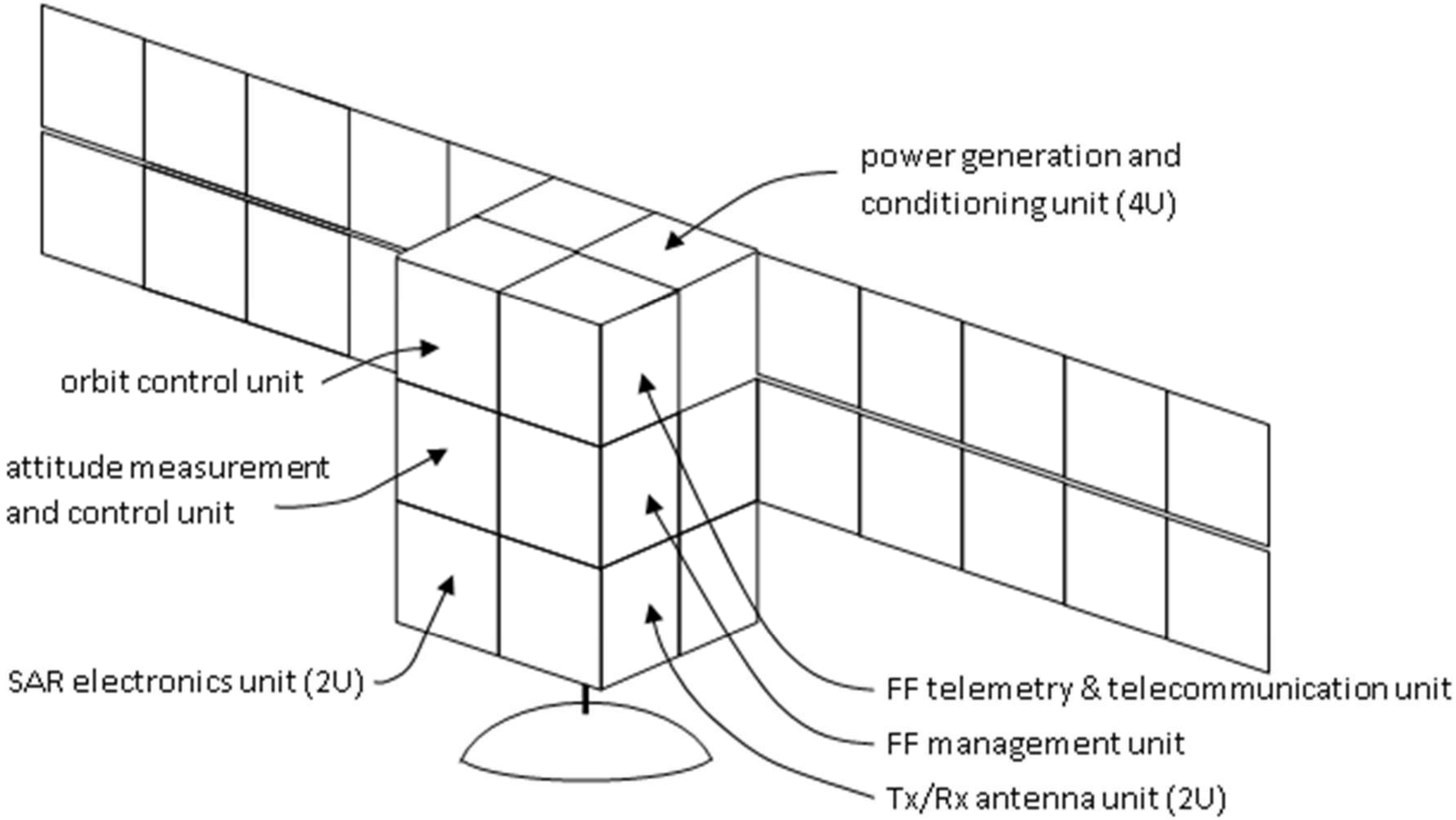

Tx-Rx and formation management S/C (12U)

- A modular space systems based on assemblies of CubeSat units
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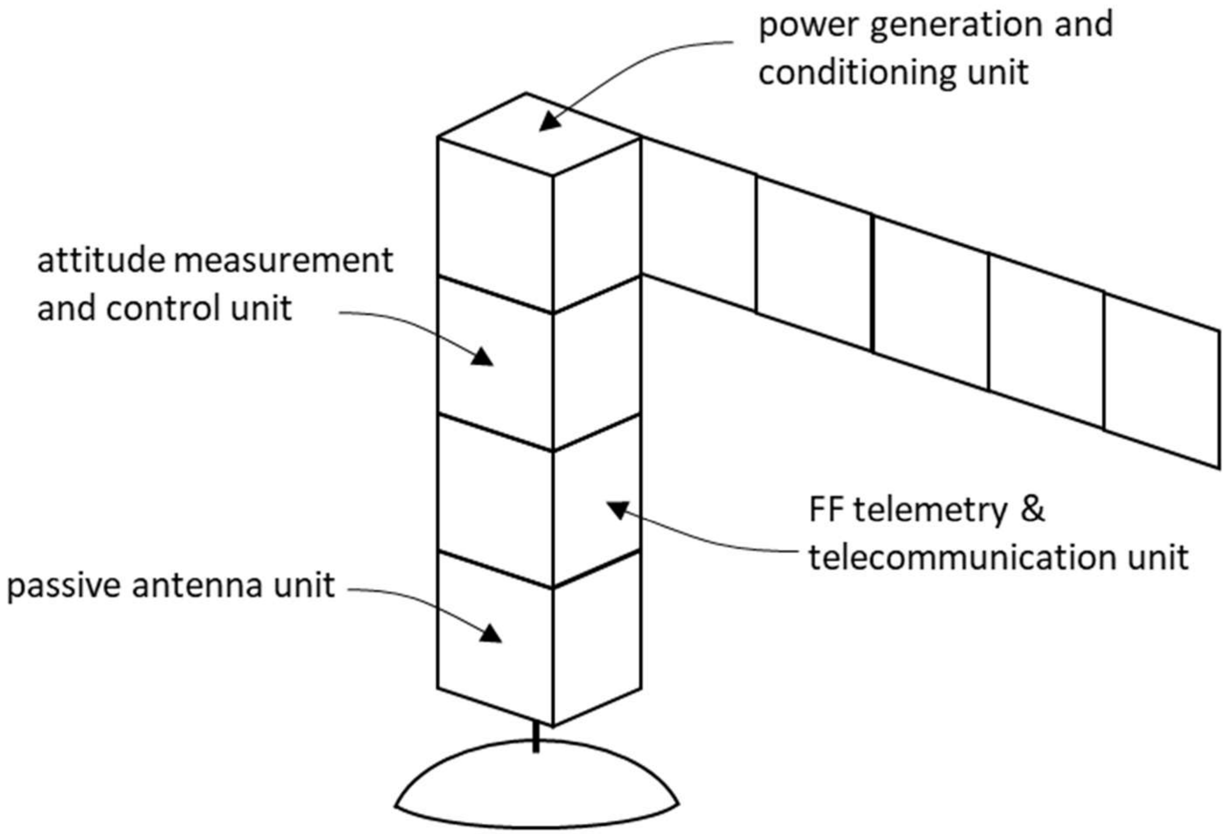

Rx-only S/C (4U)

- A modular space systems based on assemblies of CubeSat units
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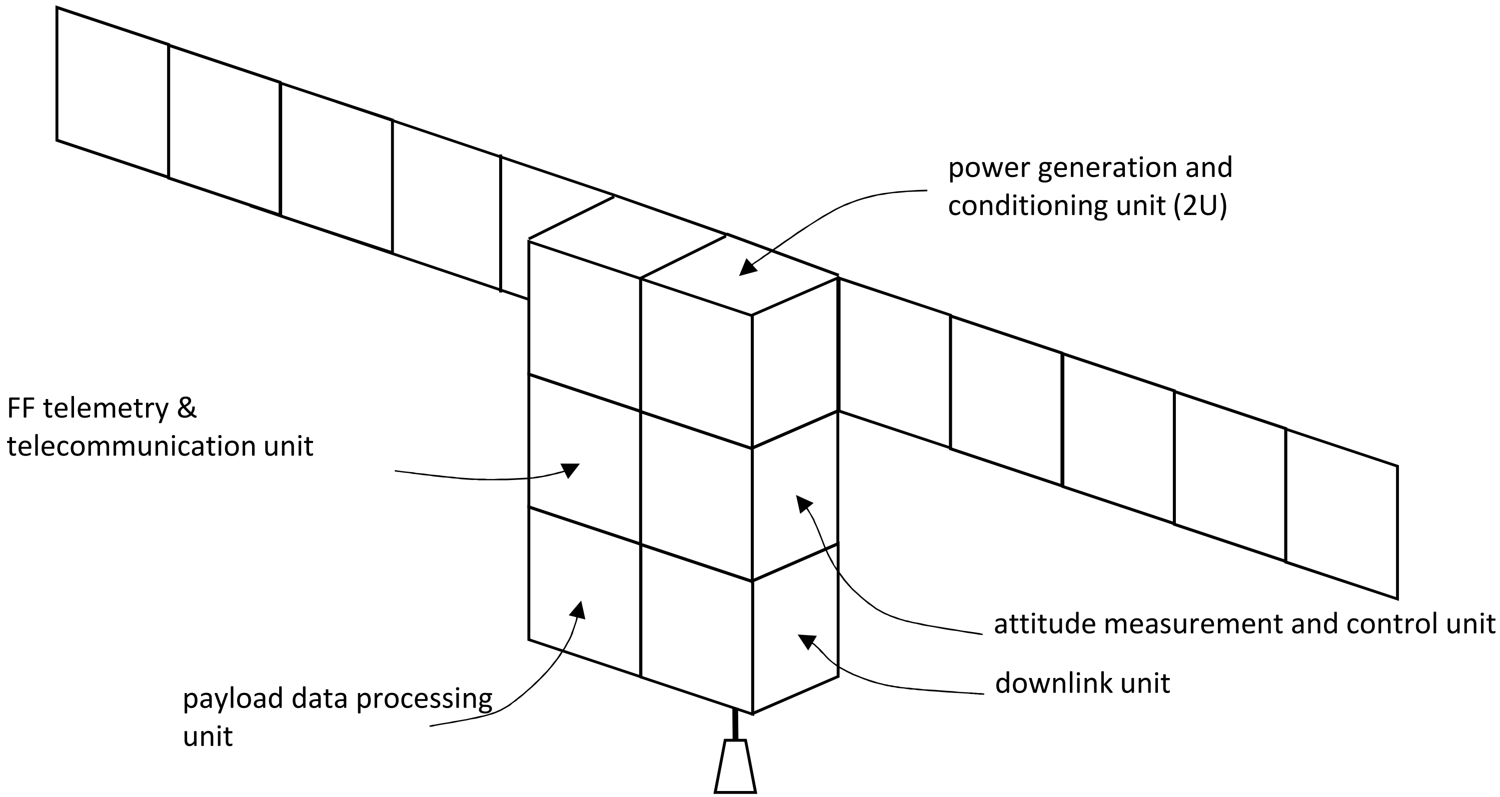
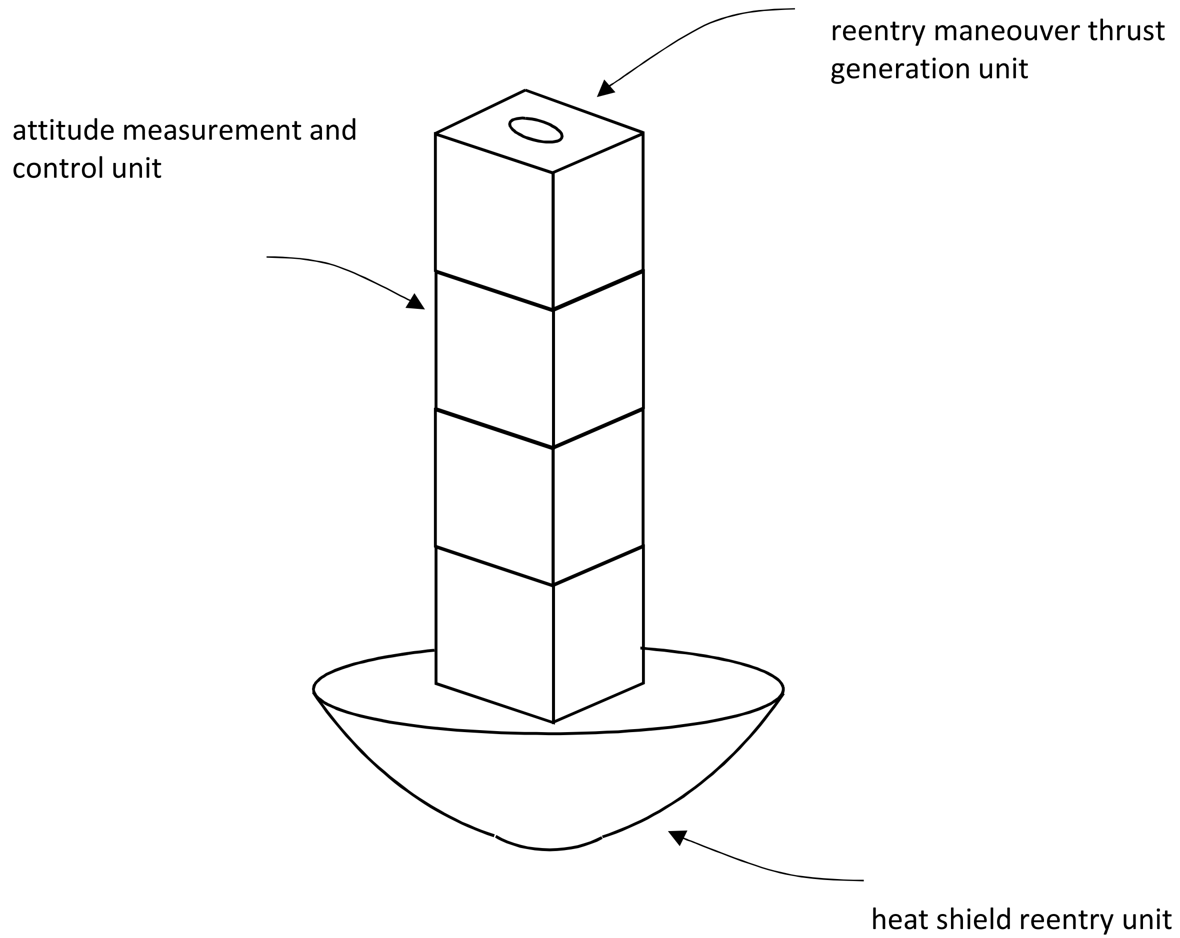
- Standard mechanical, electrical and data bus among the units (plug-and-play)



Ground TT&C S/C (4U)

- A modular space systems based on assemblies of CubeSat units
- Not a spacecraft based on CubeSat architecture but a spacecraft obtained assembling CubeSat
- Each CubeSat unit is in charge of a function, each CubeSat unit is a subsystem
- Standard mechanical, electrical and data bus among the units (plug-and-play)



Reentry (3U)

Motivation

Autonomous relative navigation maneuvers in close-proximity, demanded by FF, OOS, and ADR space missions, require highly fast and accurate target pose estimates

↓

Technical challenges

The target is **uncooperative** →

- not covered with artificial markers at known locations
- freely tumbling
- unable to communicate
- possibly degraded in shape and surface characteristics

↓

Technological and algorithmic solutions

- Electro optical sensors → passive vs. active technologies
- Model-based pose determination algorithms

↓

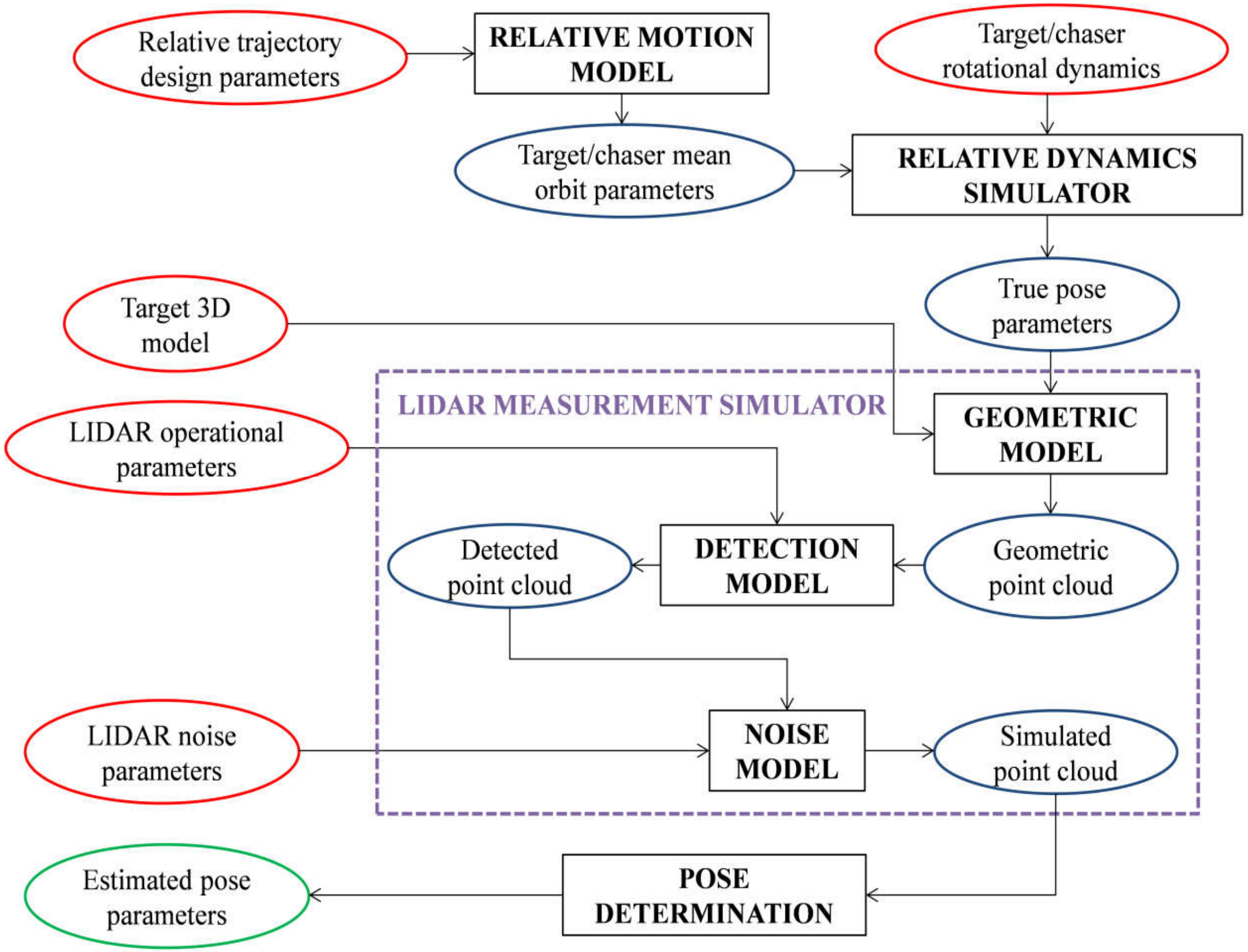
Main objective

Development of original techniques able to overcome current limitations

LIDAR-based techniques

Numerical simulation carried out within a virtual environment capable of realistically reproducing relative dynamics and sensor operation

LIDAR-based pose determination simulator



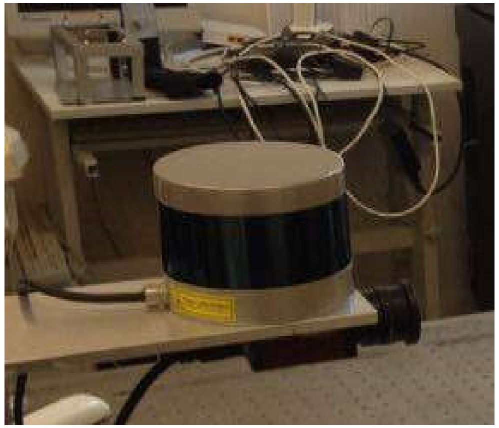
LIDAR-based techniques

Numerical results

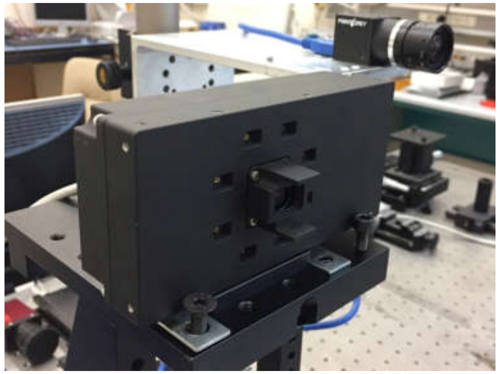
LIDAR-based techniques

Hardware-in-the-loop laboratory tests within a calibrated facility.

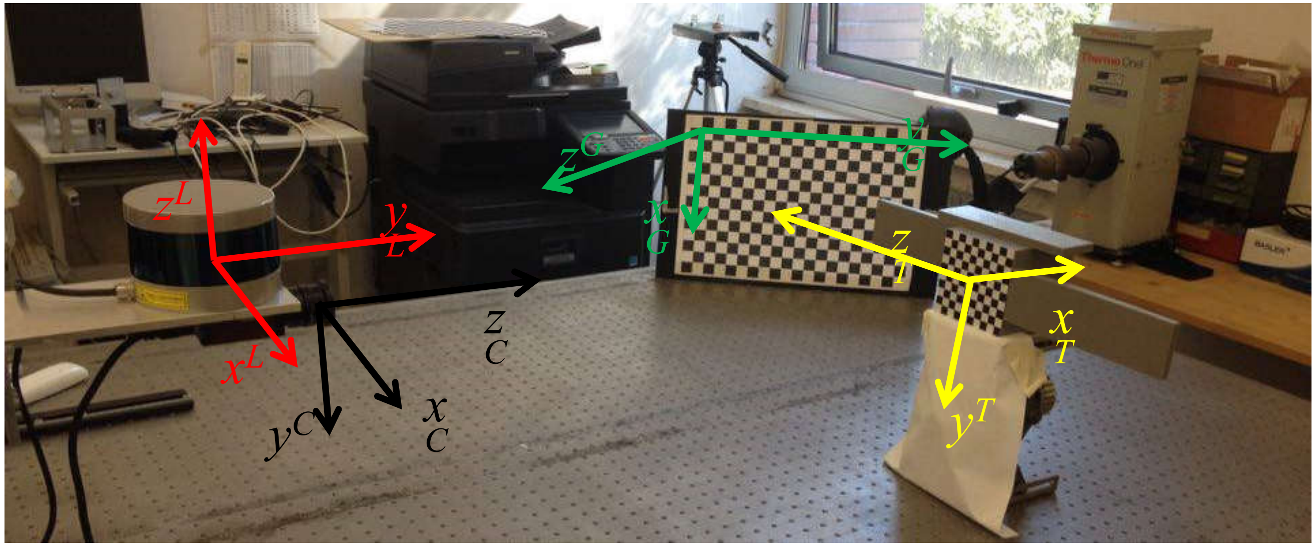
Scanning LIDAR



TOF camera



Sensors	VLP-16 (Velodyne)	tof640-20gm_850nm (Basler)
H-FOV	360°	57°
V-FOV	30°	43°
Resolution	0.1° (H) 2° (V)	0.09°

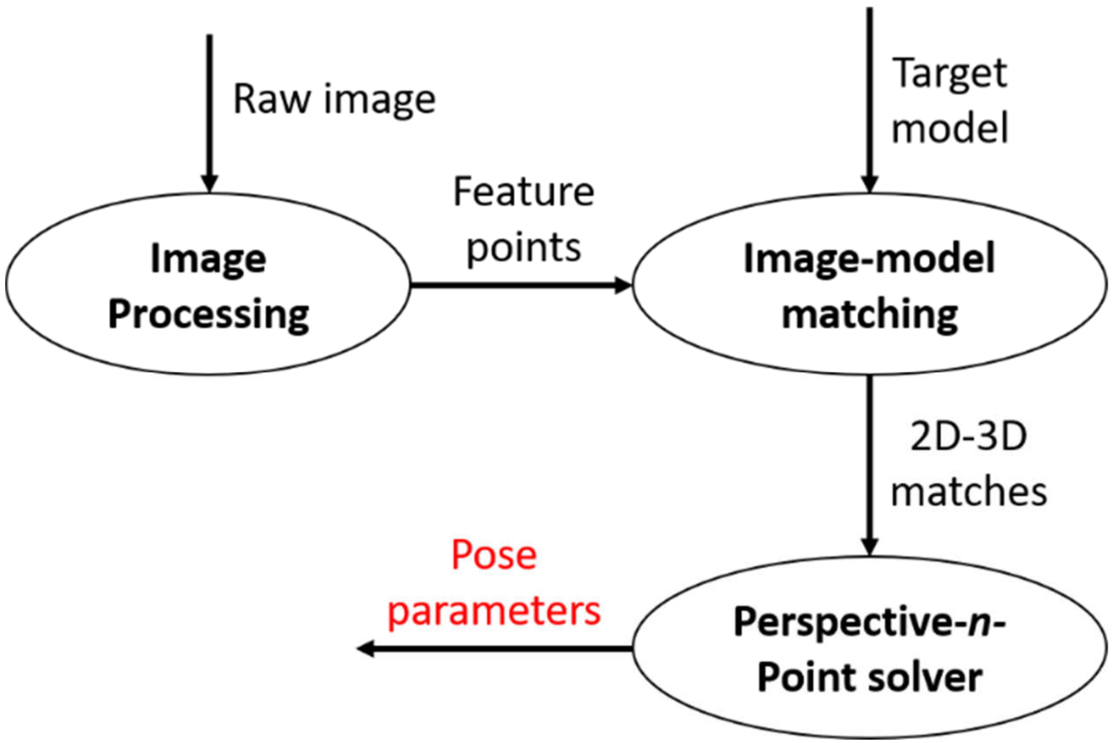


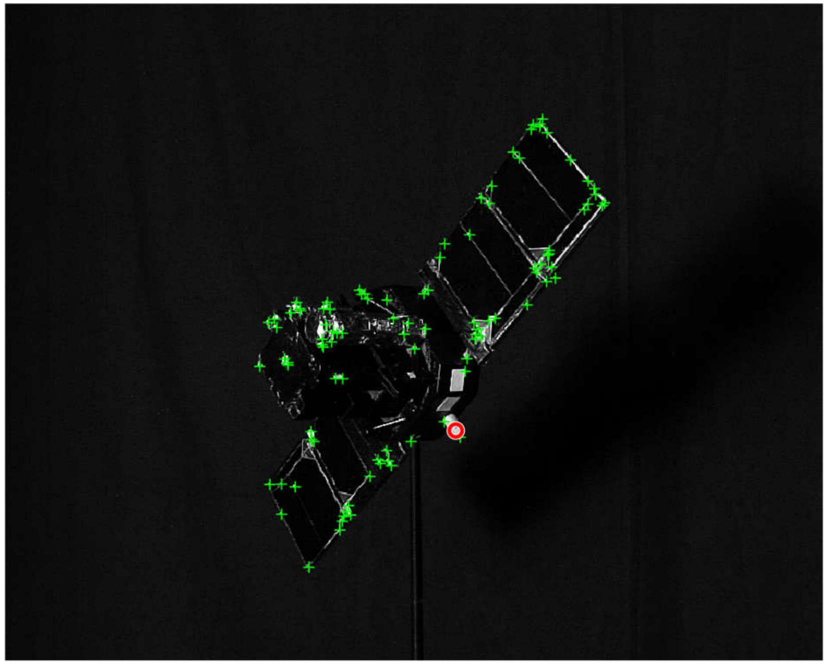
Monocular techniques

Developed in the framework of project VINAG (highly-integrated system for autonomous absolute and relative navigation) funded by ASI.

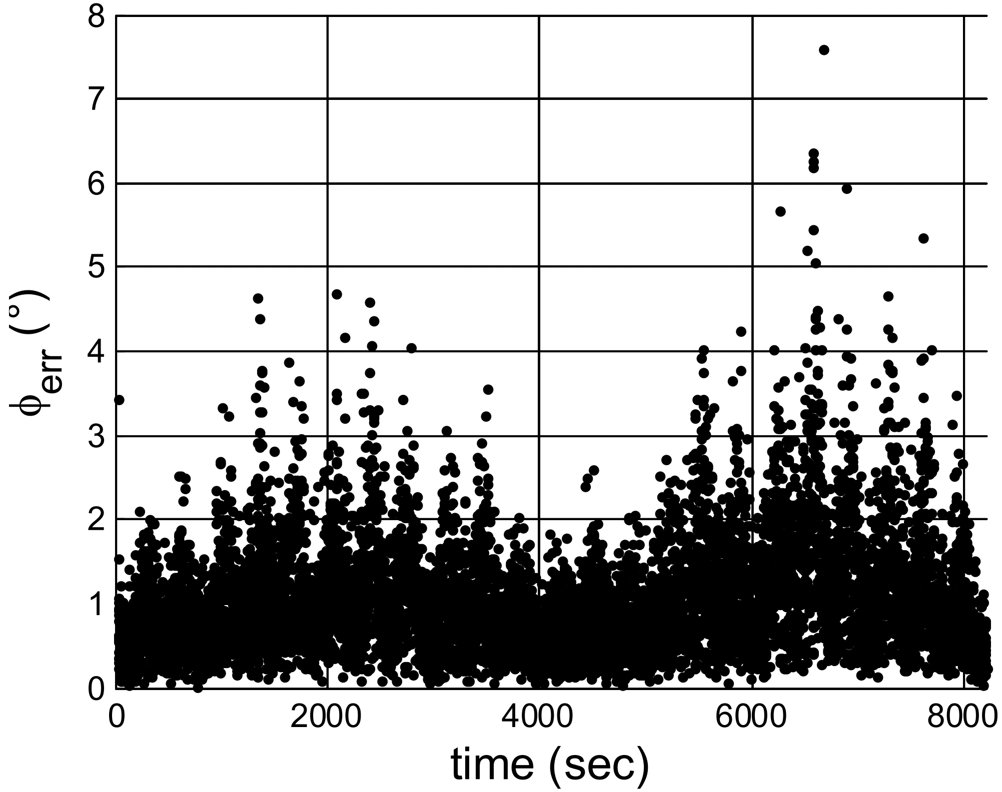
Feature-based algorithms are used for both pose initial acquisition and tracking.

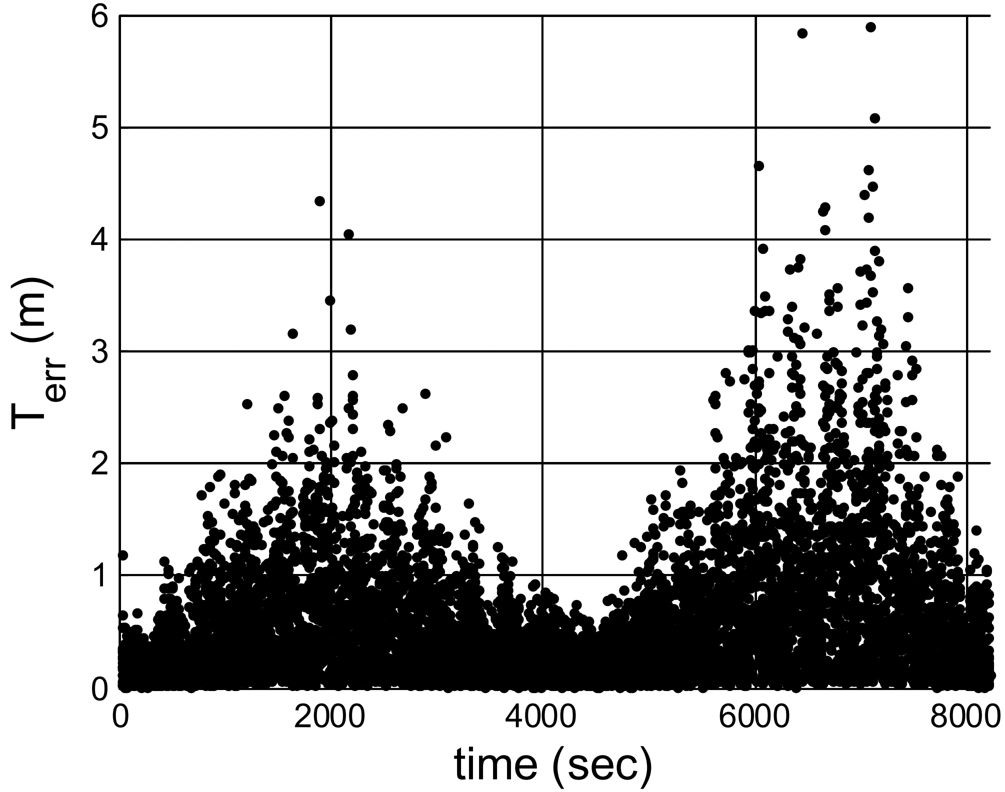
Both for acquisition and tracking 3 on-line steps are required,





Monocular techniques

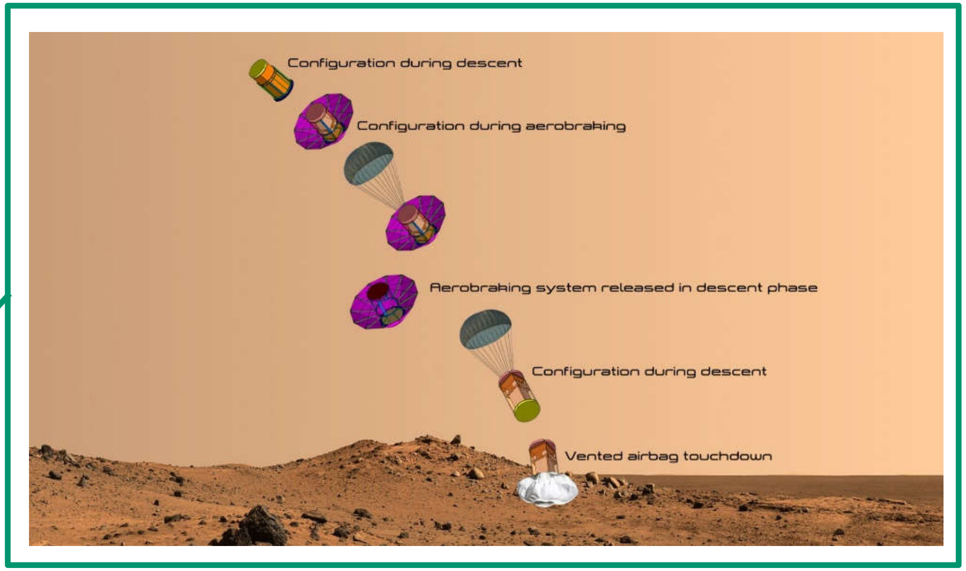




mean = 1.3 °
std = 8.8 °

mean = 3.7 cm
std = 0.8 m

SMS - Small Mars Mission Concept Study- ESA GSP Studies

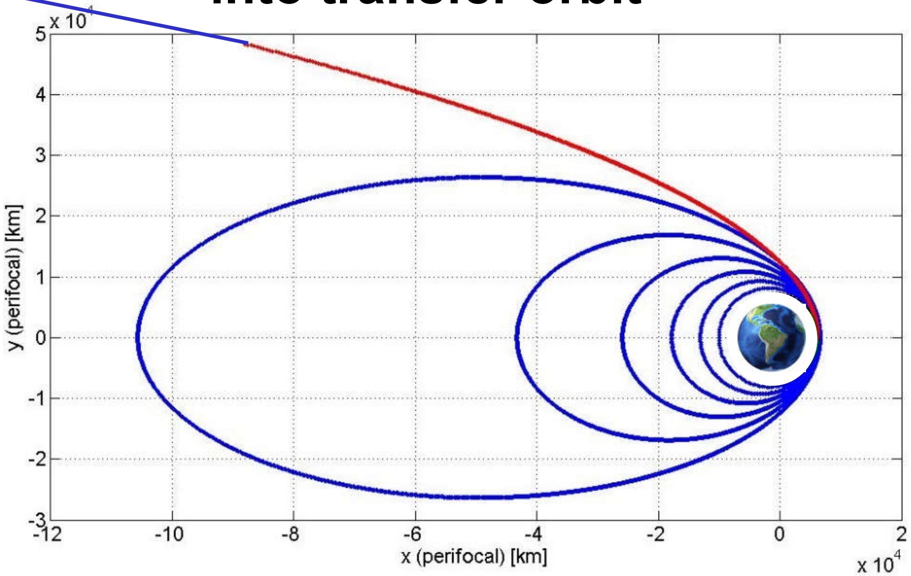


Mars EDL

Mars Arrival

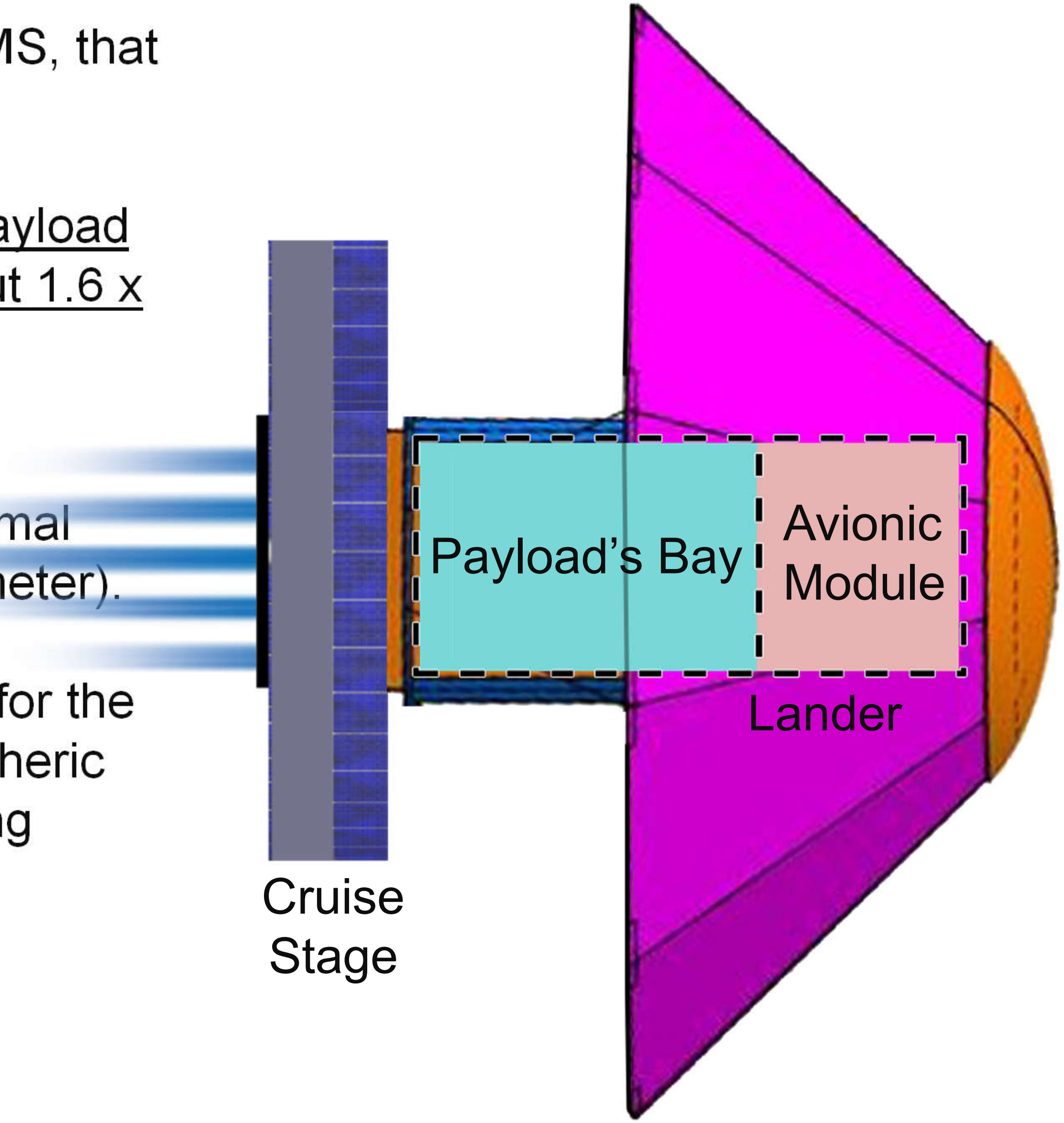
Interplantery cruise

Launch and insertion into transfer orbit

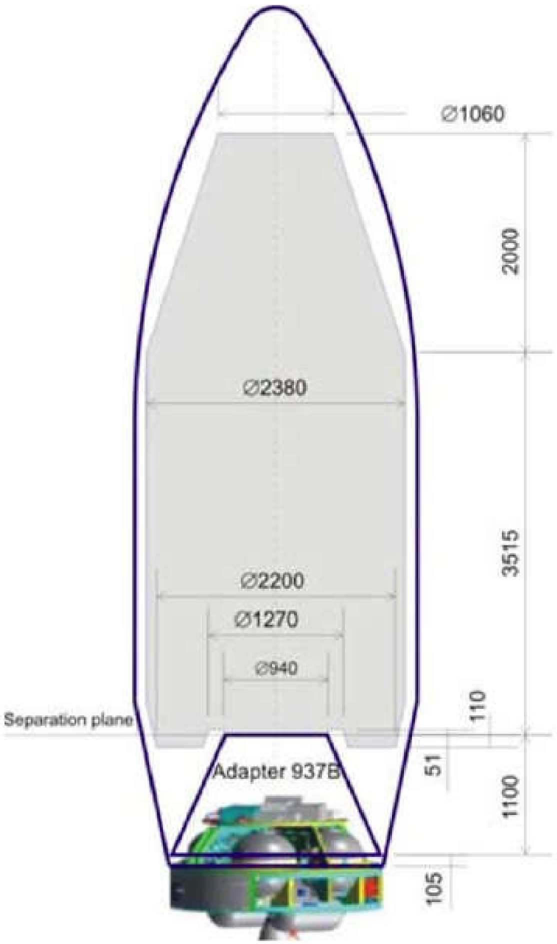


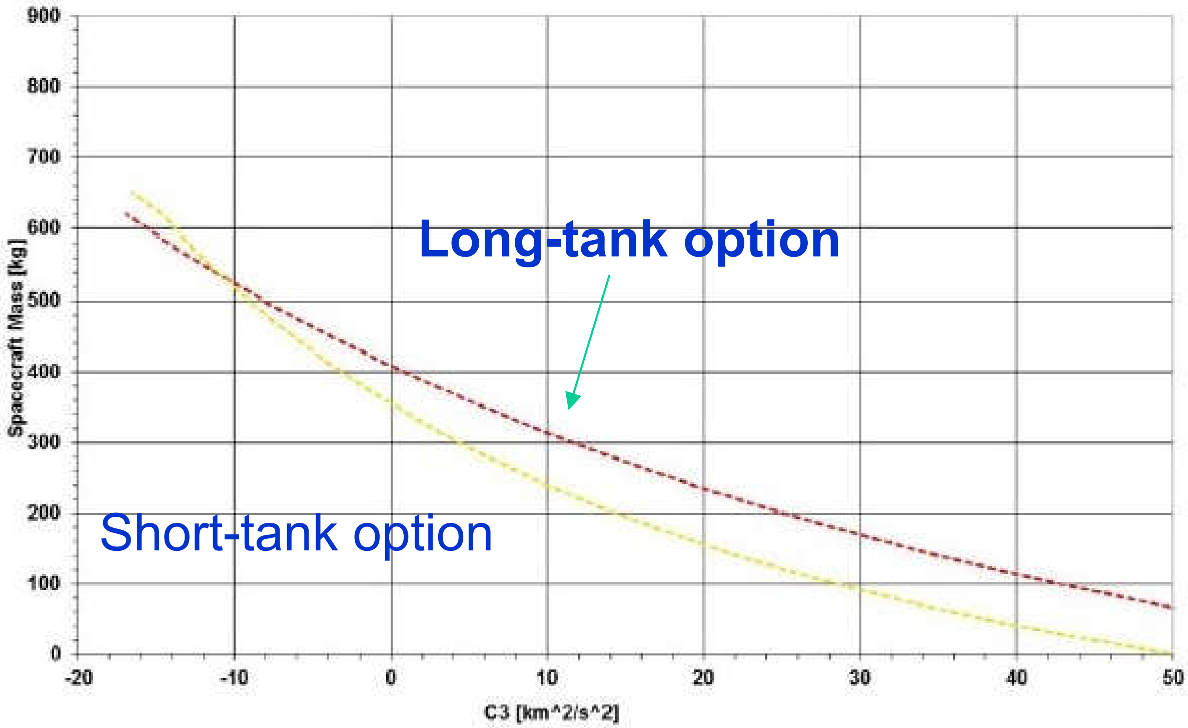
A *modular architecture* is exploited for SMS, that consists of three main elements :

- **Lander Module,** which includes the payload module and the avionics module (about 1.6 x 0.8 m) ;
- **Heat Shield,** for deceleration and thermal protection during EDL (about 3 m diameter).
- **Cruise Stage,** to provide subsystems for the interplanetary trip up to MARS atmospheric entry (traj./attitude corrections, targeting maneuver, solar power, comms)



The overall system mass is about 300kg and fits VEG fairing

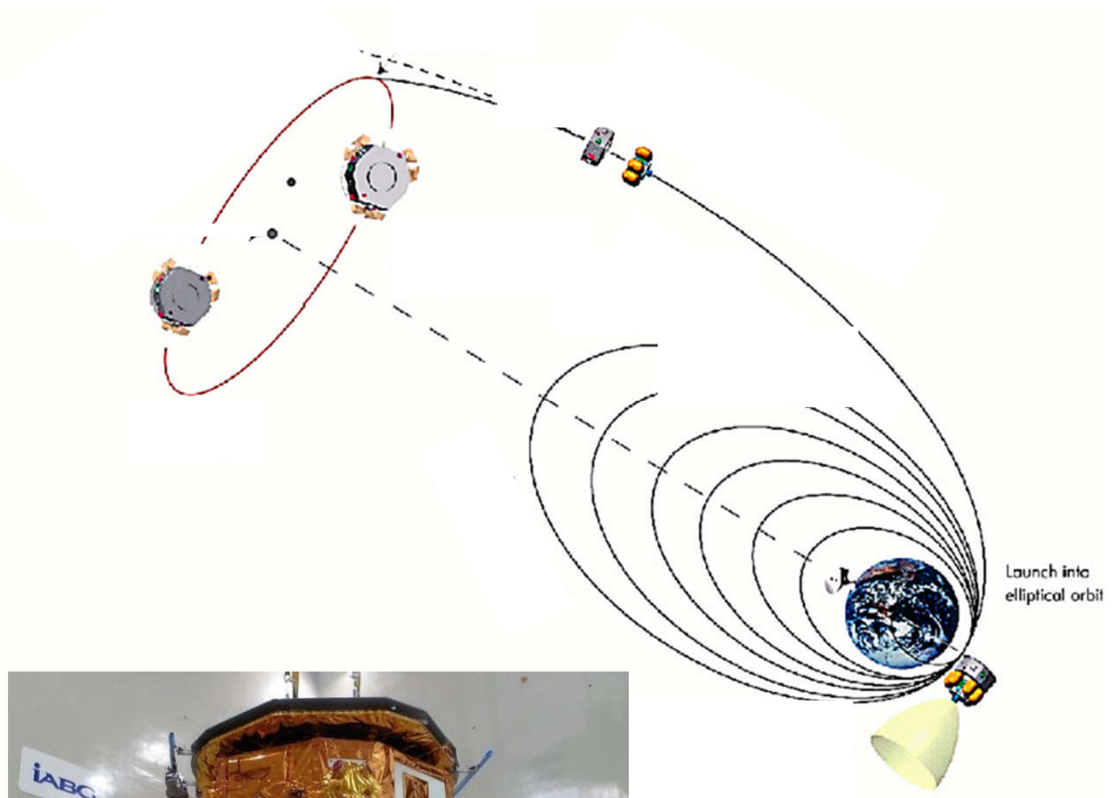


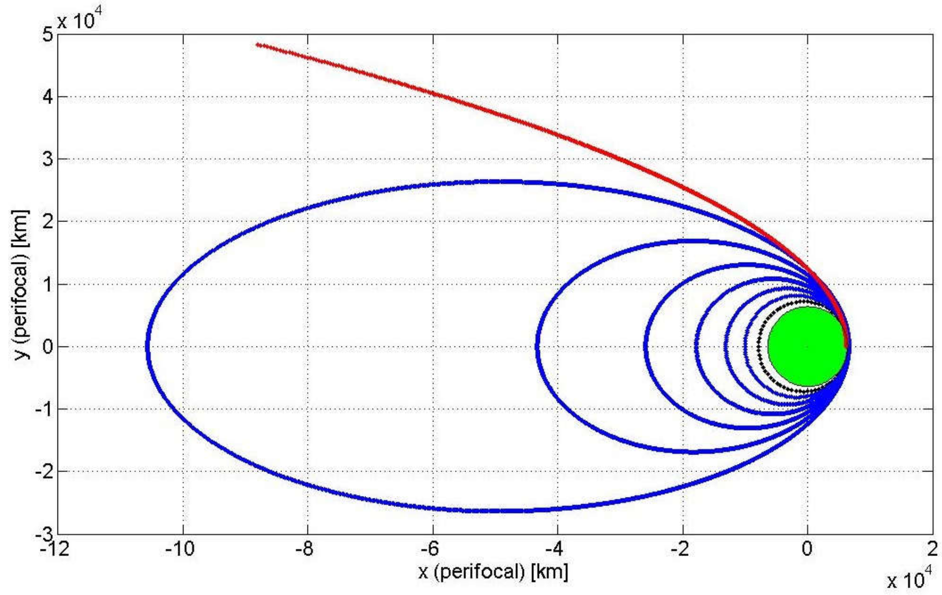


At C_3 = 11 km^2/s^2 launch mass ≤ 320 kg

Max size: 2.2 m x (3.3 + 2.0) m

SMS: The apogee Raising Sequence





5 equal burns of 0.42 km/s

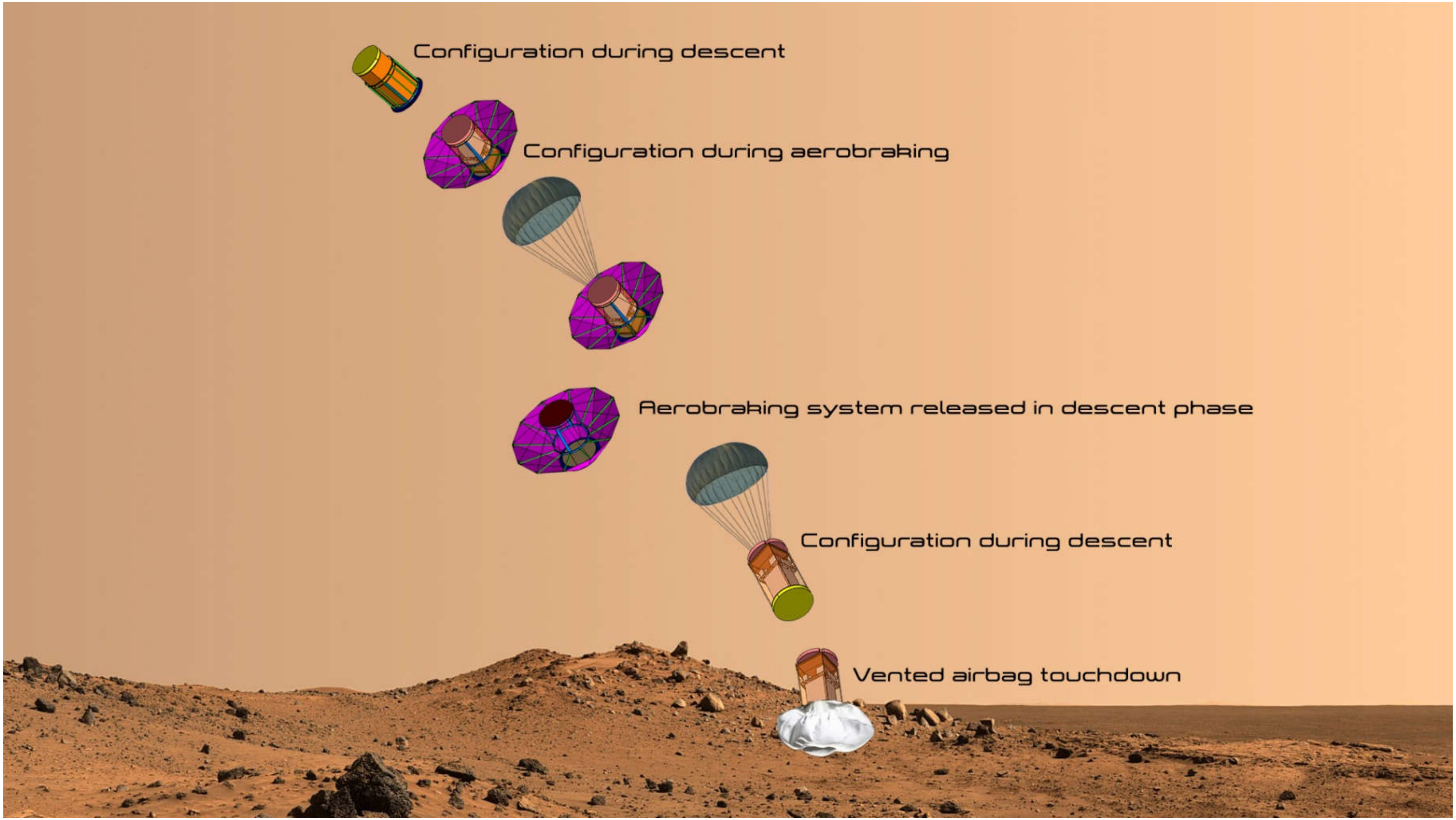
Hyperbolic injection burn 0.83 km/s

Parameter	Value	Units
I_{sp}	321	s
F	400	N
$\dot{m}$	135	g/s

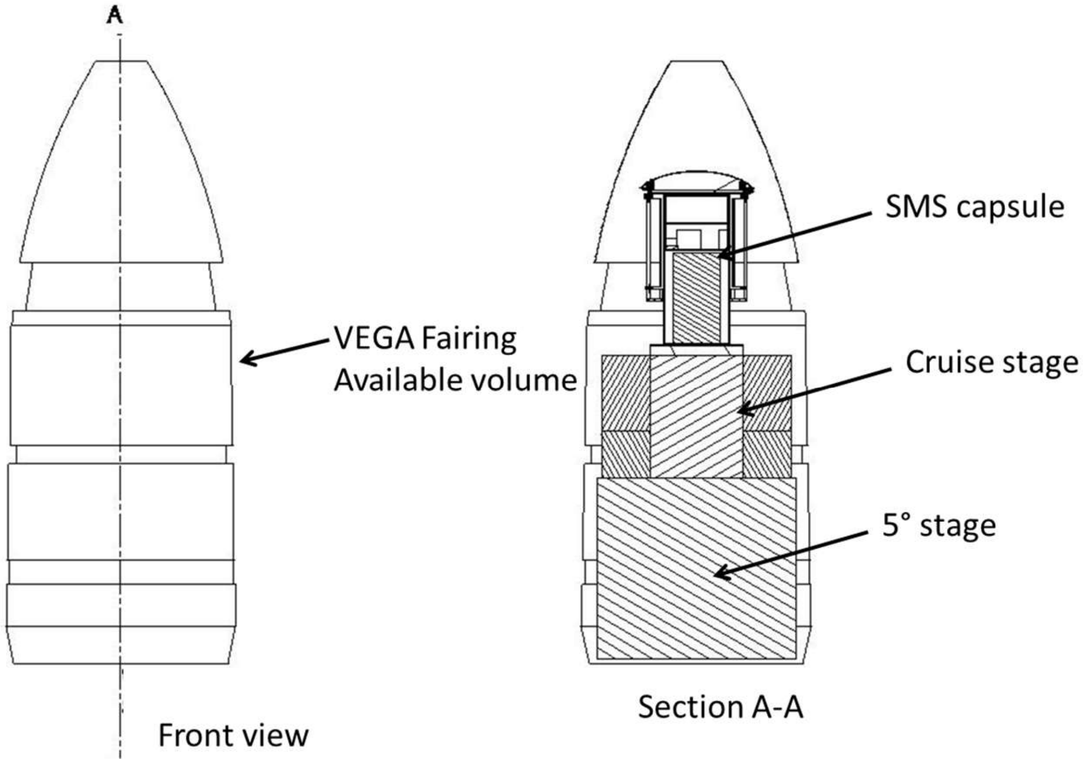
Structural mass = 285 kg

Required propellant ~1 ton

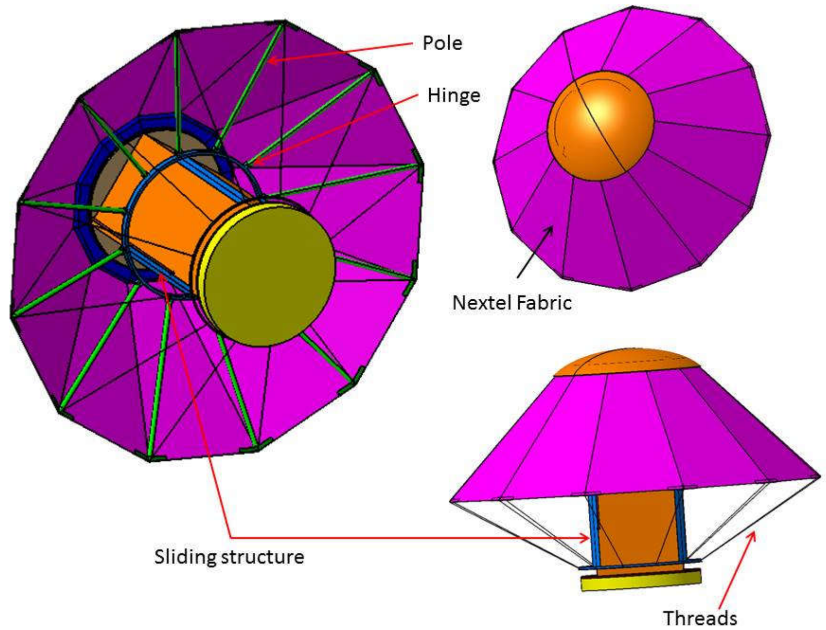
Mars Entry Descent and Landing trajectory (EDL)



SMS: Accommodation in VEGA

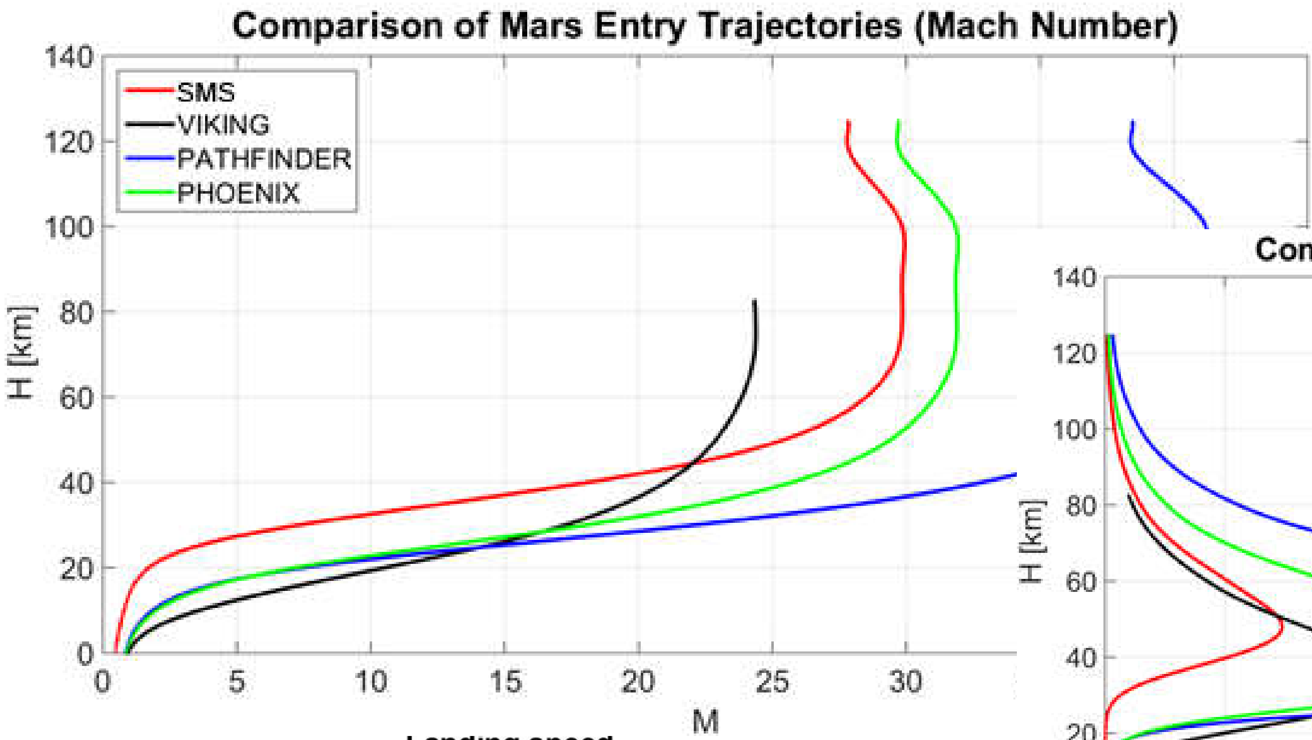


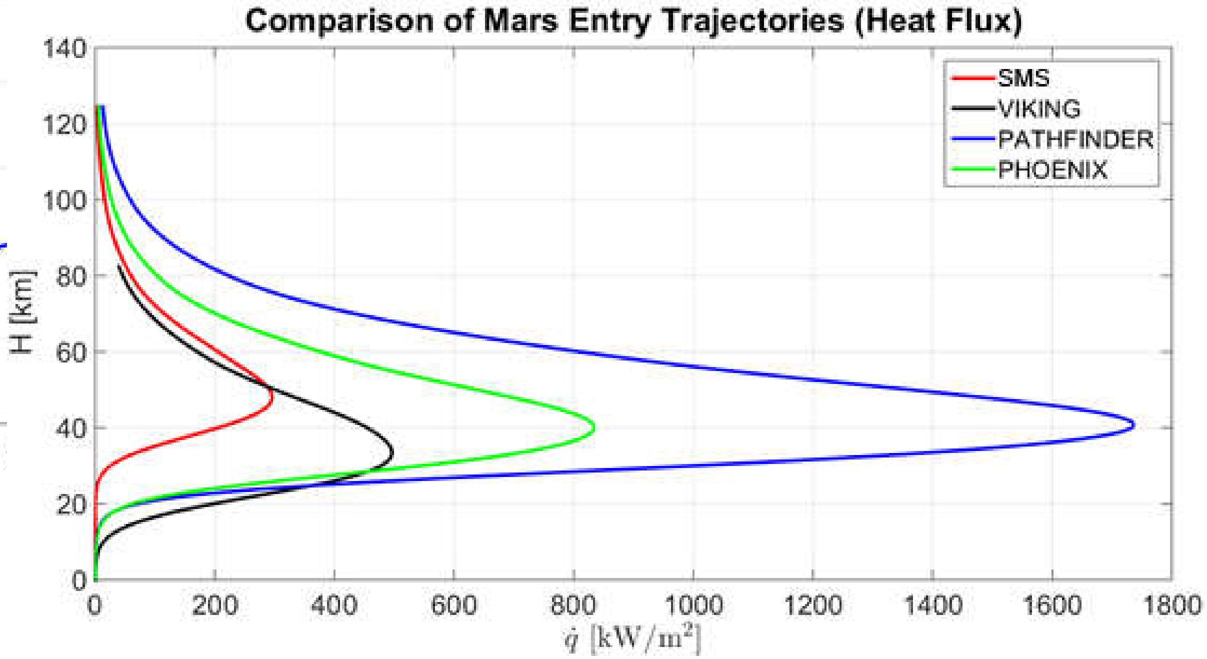
SMS launch configuration

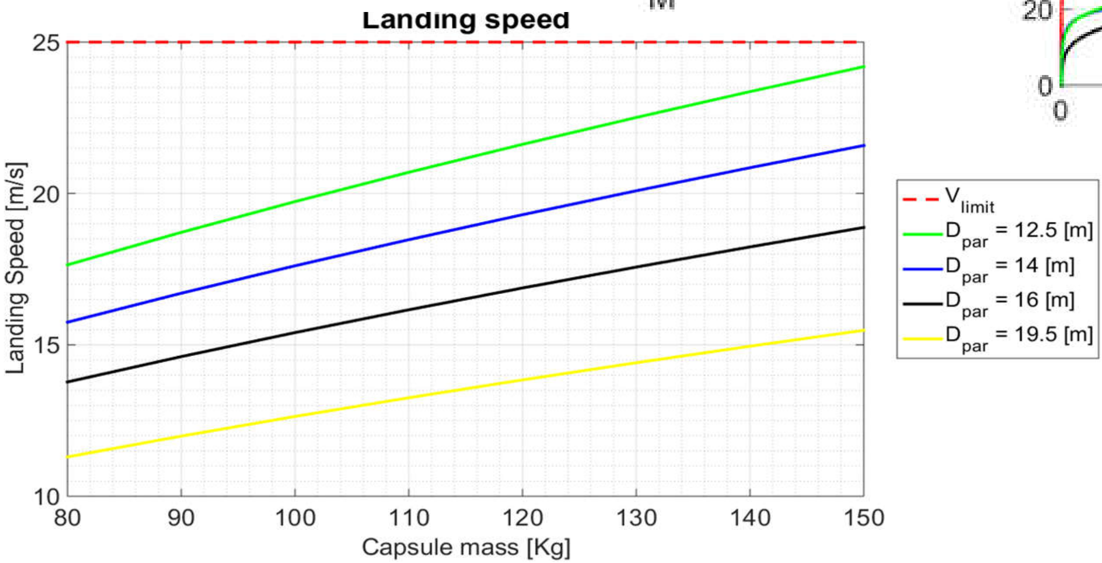


SMS Deployed Configuration

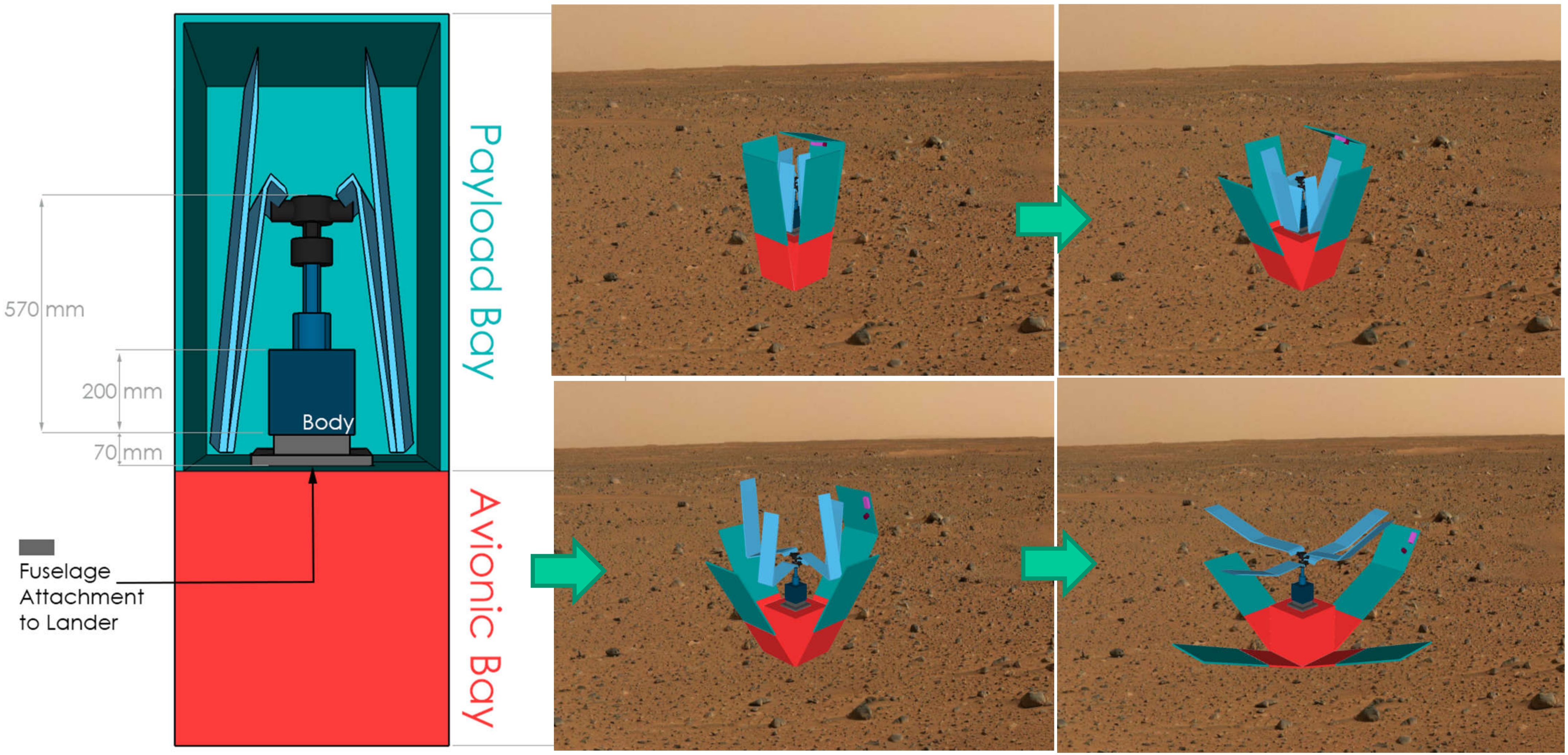
SMS: EDL Comparison

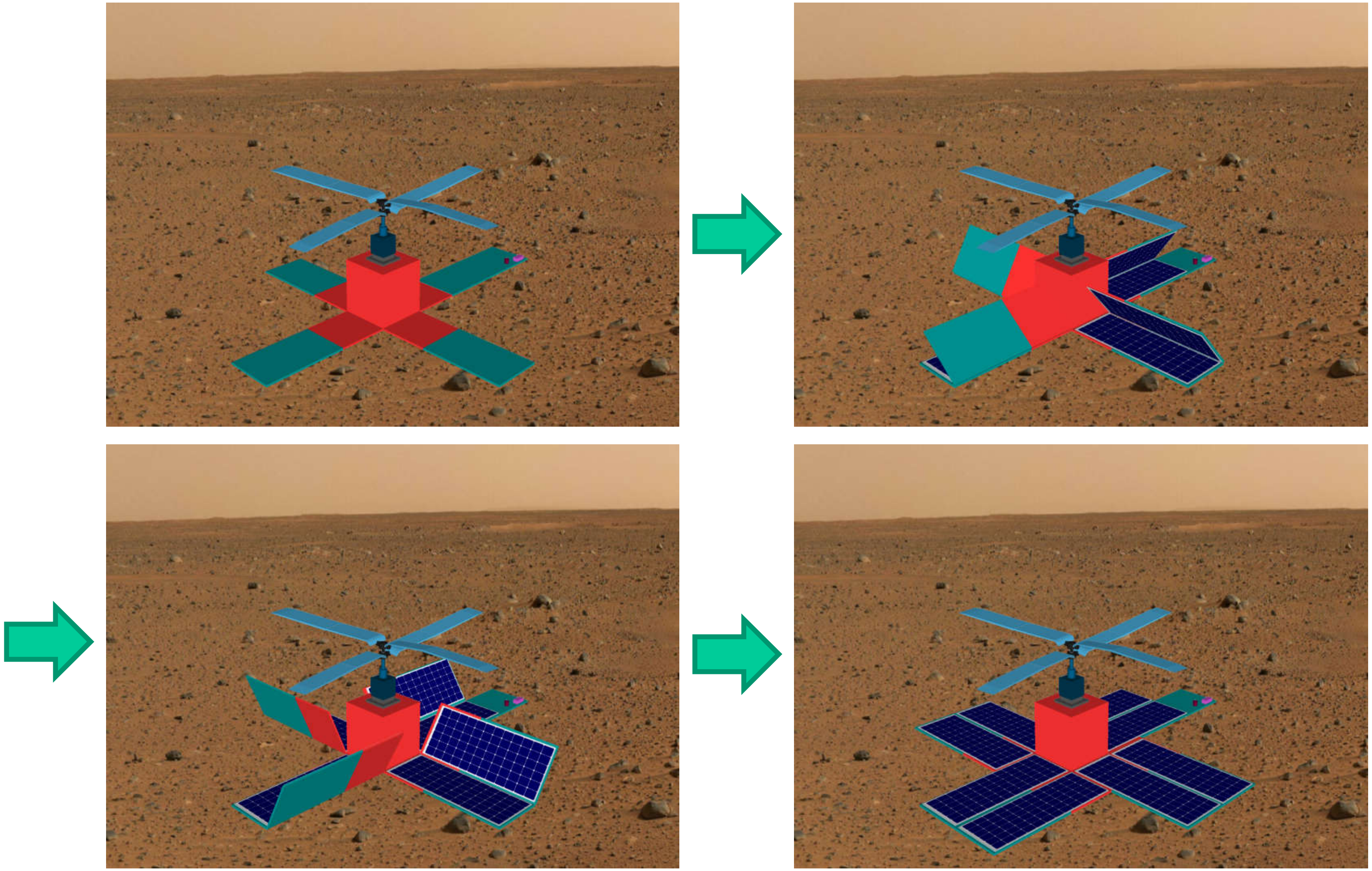






The Payload Bay hosts a small drone (7 kg) for Mars surface explorarion

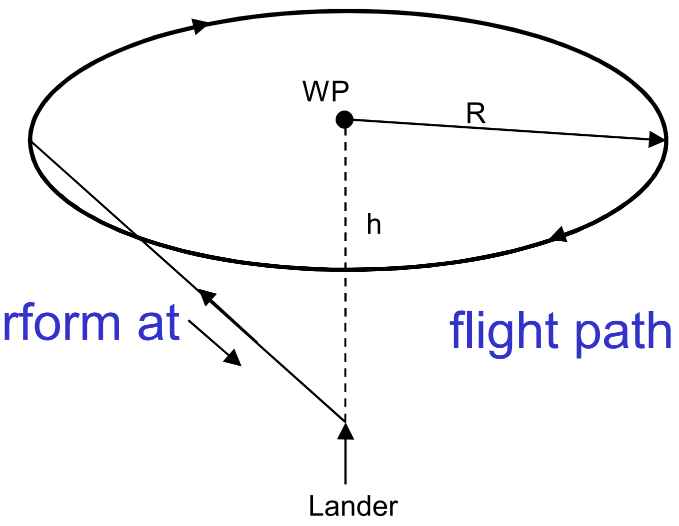




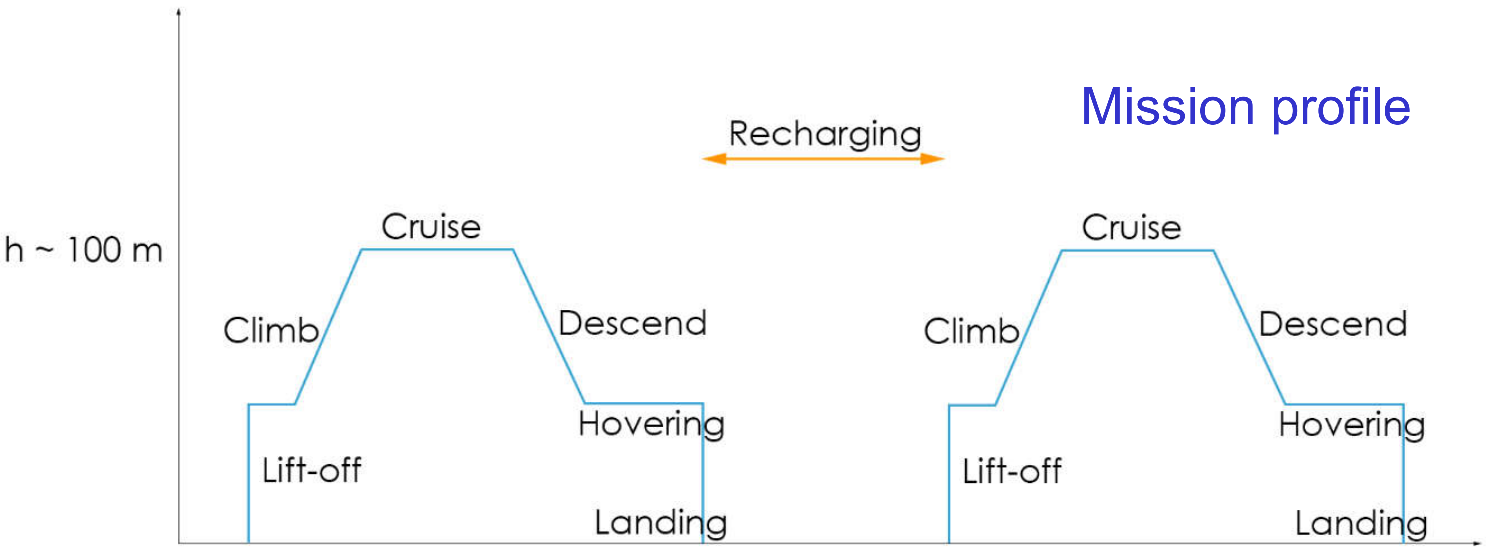
SMS: Drone Mission Profile

A suitable flight path is a loitering with a small radius centred at the Lander. This kind of path also allows to maintain Line-of-Sight (LOS) contact with GS for communication and flight recording.

To show the multi-mission capability, the drone shall perform at least two flights including



- vertical lift-off from GS
- Climb
- cruise
- descent
- hovering
- vertical landing at GS



Future Mars exploration with swarms of cooperating drones and rovers

GRAZIE PER L’ATTENZIONE