SCORE

Scientific mission for Comet Observation, Research and Exploration

WHY LONG PERIOD COMETS?

- **Long Period Comets** are celestial bodies with an orbital period **greater than** 200 years.
- **Long Period Comets** have **not been contaminated** by the various passages in the Inner Solar System.
- **Long Period Comets** have never been deeply explored by previous missions.

↓

- They can bring new important results regarding the **origin and the evolution** of the Solar System an of life on Earth
- Deeper knowledge about the **cometary environment**
- Deeper knowledge about **comets**

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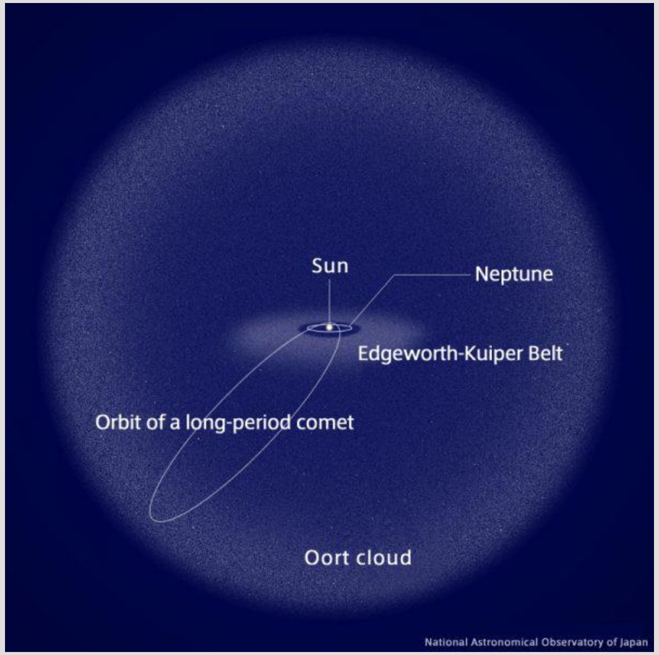
SCORE has been designed with the purpose of intercepting a Long Period Comet in a **flyby scenario** with the use of a **micro-satellite**



Credits: National Astronomical Observatory of Japan (NAOJ)

WHY SCORE?

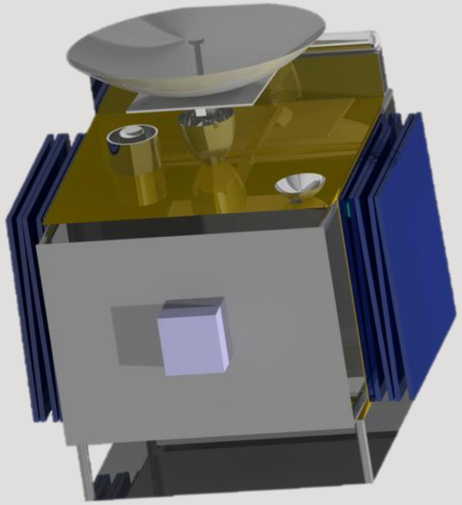
SCORE makes use of a **micro-satellite** with limited mass and size.

- **Deep space exploration missions** have been dominated by large satellites.
- **Micro-satellites** have been popular in the last decades, but mostly for ***Earth Orbiting systems***.

HT400 Electric Thruster

SCORE mission will be an **important test bench for new technologies and subsystems** for micro/nano-satellites:

- Only few others deep space exploration missions used micro-satellites (e.g. MarCO mission)
- **Electric Propulsion** is an innovative technology that can highly increase the maximum distances reachable by micro-satellites.
- The **Shielding against micrometeoroids** provides reliable protection with a limited mass.



MISSION OBJECTIVES

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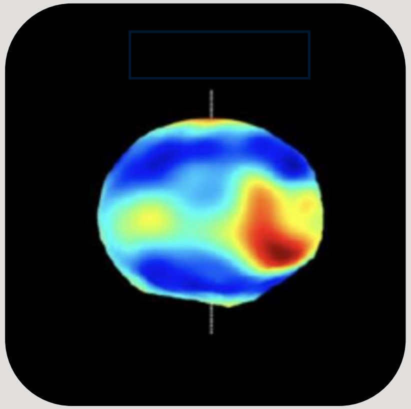
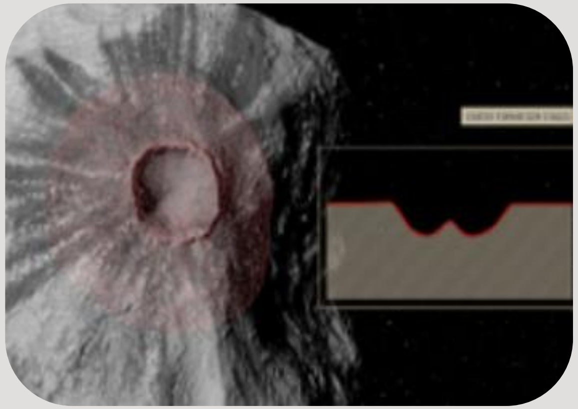
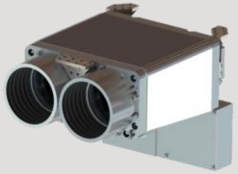
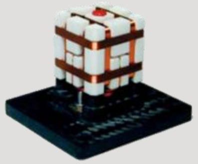

Nucleus Characteristic


Coma Composition

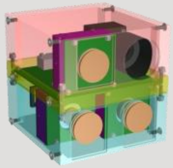

Morphology

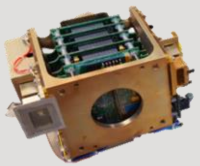

MULTISPECTRAL CAMERA

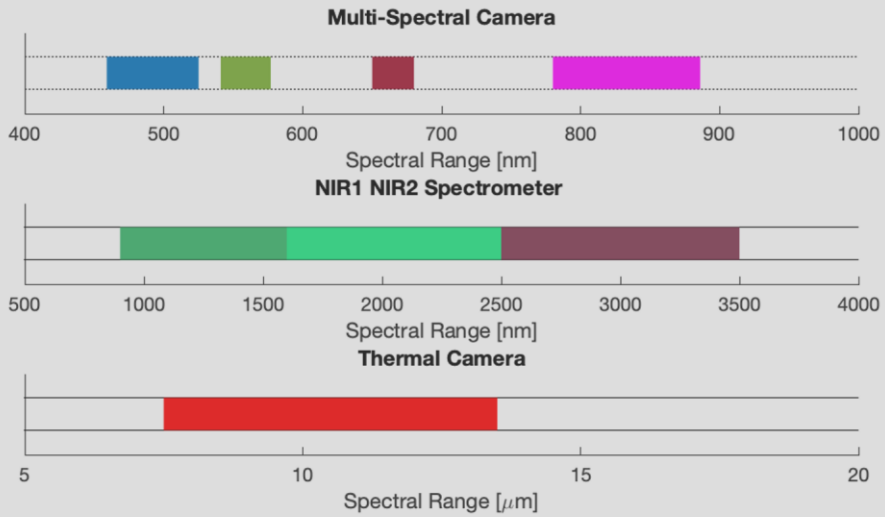

THERMAL CAMERA


FLUXGATE MAGNETOMETER


IMPACT SENSOR


IR SPECTROMETER


MASS SPECTROMETER



MISSION OBJECTIVES

One of main difficulties:

- The **target** Long Period Comet **is uncertain**
- It can be discovered only some years prior to its passage at the **perihelion**

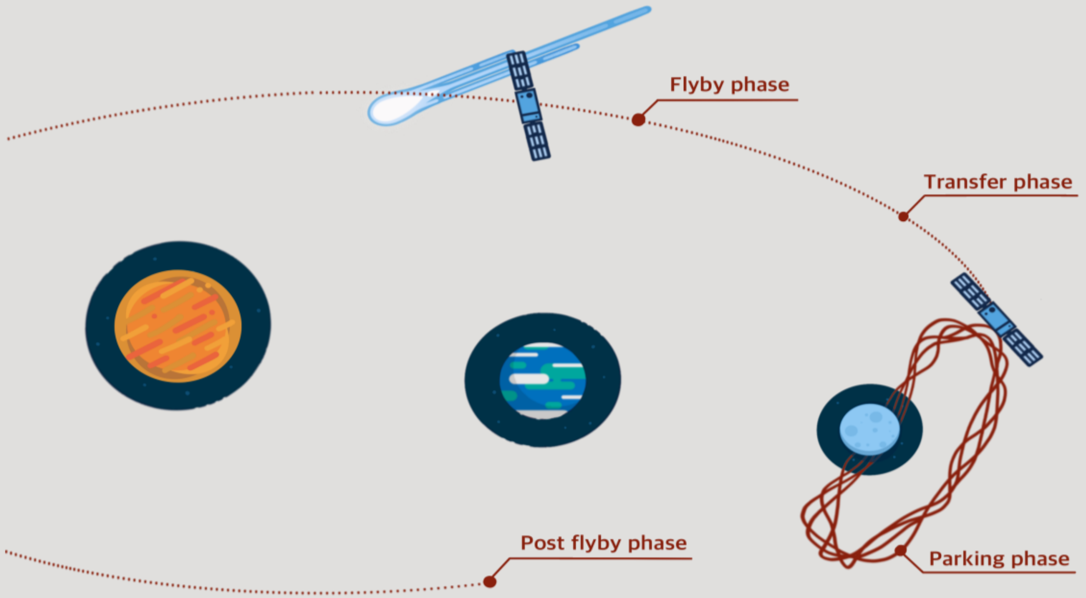
→ **Need of back-up targets** to guarantee a meaningful scientific return of the mission

Back-up target	Orbital period (years)	q (AU)	e	i (deg)	Flyby date (mm/yyyy)	Encountered by:
67P/Churyumov-Gerasimenko	6.45	1.24	0.641	7.04	09/2034	Rosetta (2014)
8P/Tuttle	13.61	1.03	0.820	54.98	03/2035	/
26P/Grigg-Skjellerup	5.31	1.12	0.633	22.36	06/2034	Giotto (1992)
9P/Tempel	5.58	1.54	0.510	10.47	04/2033	Deep Impact (2005) Stardust (2011)
7P/Pons-Winnecke	6.37	1.26	0.634	22.29	09/2033	/

MISSION PHASES

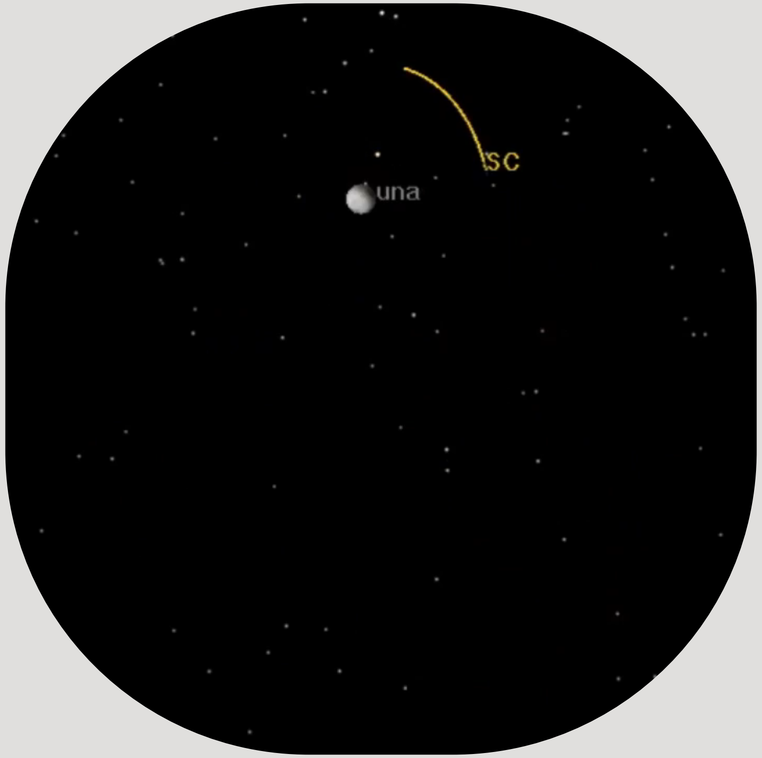
MISSION ARCHITECTURE

- Mission deployed **during 2029** in the cis-lunar space
- Single spacecraft with a wet mass of **100 kg**
- **Region of interest** for the flyby = Sun-centred annulus with radius in between **1 and 1.58 AU**
- Mission deployed on an **L2 southern Near Rectilinear Halo Orbit (NRHO)**
- The **lifetime** of the mission shall not exceed **6 years**



PARKING PHASE

- 16000 km **perilune radius** is chosen for the starting orbit with a **period** of 9.65 days.
- The **NRHO** is stable for **more than 1000 days** without station keeping maneuvers.
- The starting orbit exhibits a **3:1 resonance**.
- Eclipses occur every **1-2 lunar synodic periods** and their duration is short (*~160 min*).
- The **magnitude** of the **Station Keeping maneuvers** is very low (*1 m/s per year*).



PROBABILISTIC ANALYSIS

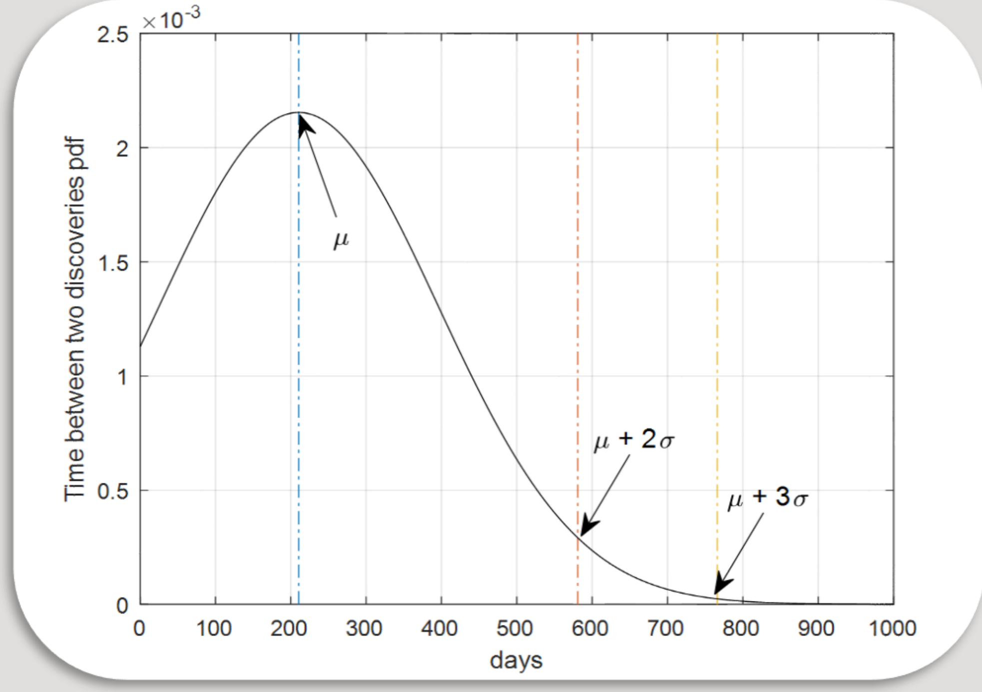
Probabilistic analysis starting from the orbital parameters of **already known** comets <u>necessary</u> to derive a possible orbit of a **generic LPC** that will pass through the plane from 2030.

The **time between two discoveries** has been evaluated from this probabilistic analysis.

The ***maximum* time between two discoveries** is equal to *2.1 years.*

If in this period **no targets** are discovered a transfer towards a ***back-up target*** shall be planned.

μ [days]	**210**
σ [days]	**185**
Maximum time between two discoveries [days]	**765**
Maximum time between two discoveries [years]	**2.1**



DEPARTURE PHASE

DEPARTURE FROM THE MOON

- The **Moon** shall be *in between* the Sun and the Earth.
- **High NRHO perilune radius** ➔ high altitudes comparable to the **Moon *Sphere of Influence (SOI).***

DEPARTURE FROM THE EARTH

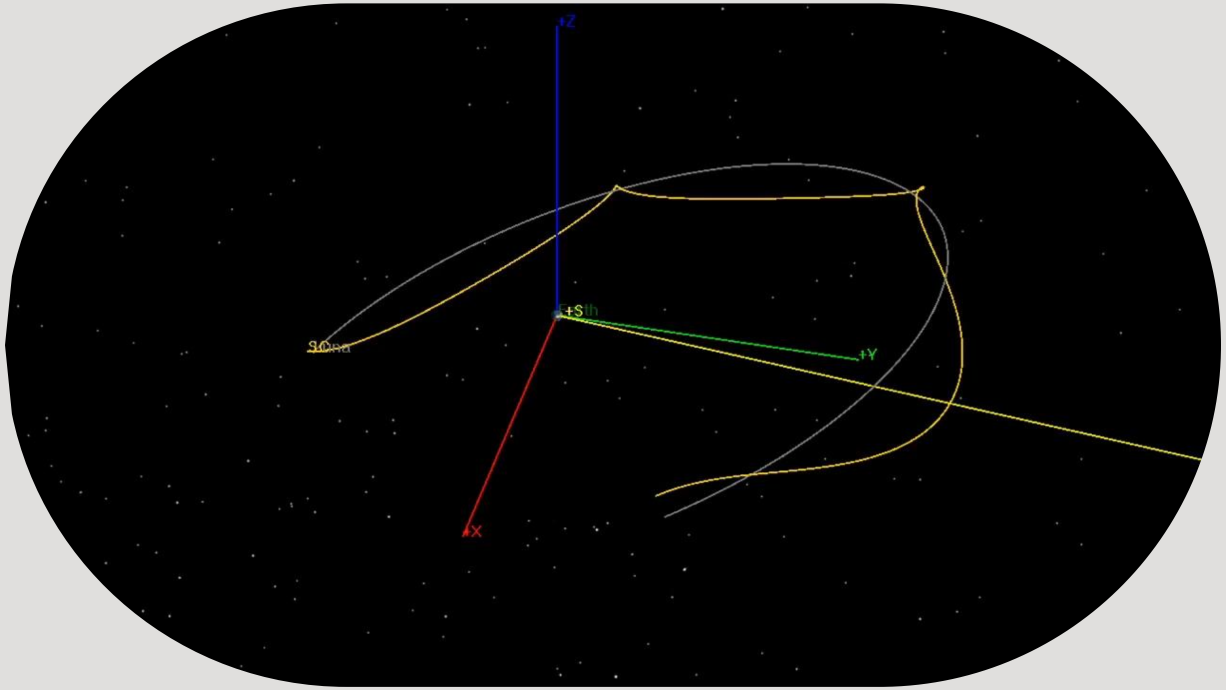
- **Impulsive maneuver** to enter on a *transfer Ellipse*.
- Boundary of the *Earth's SOI* reached in **30.5 days**.
- Impulse of **small magnitude** *concludes* the departure phase ➔ the *interplanetary transfer* towards begins.

Suitable target detected in 2.1 years ➔ satellite **leaves the NRHO.**

Departure maneuver opportunity once every *29.5 days*

Departure performed with **chemical propulsion** *(monomethylhydrazine + mixed oxide of nitrogen MON-3)*

- **Departure delta-V** to leave the *Moon SOI* is low (*30-40 m/s*).
- **Departure delta-V** to leave the *Earth SOI* is of about *200 m/s*.



TRANSFER PHASE

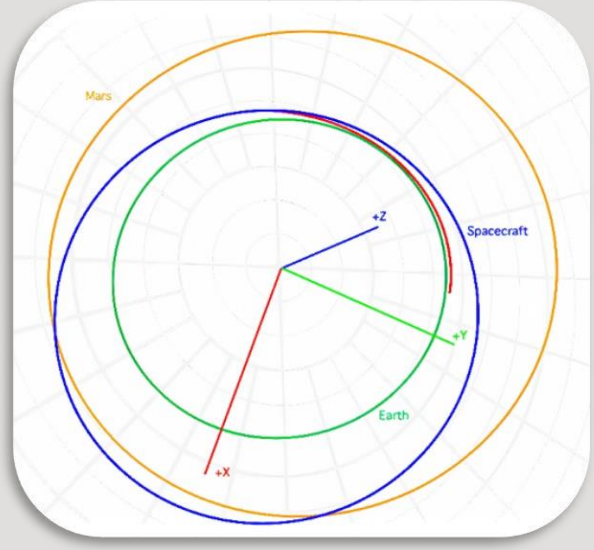
The interplanetary transfer is performed with **electrical propulsion** *(Xenon propellant)*.

Two strategies are proposed:

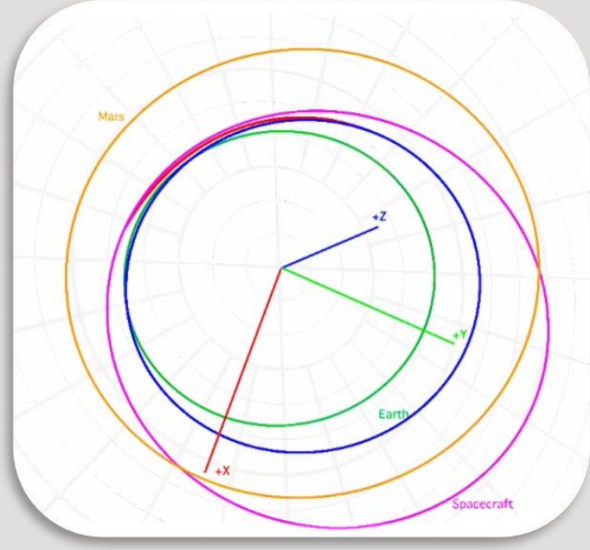
1. **Single finite burn** – Reaching a maximum distance of *1.39 AU from the Sun* in about *1.5 years*.
2. **Double finite burn** – Reaching a distance up to *1.58 AU from the Sun*. The *maximum transfer time is of 2.6 years*.
   The *delta-V* necessary for this strategy is of about *3250 m/s*.

The two strategies differ in terms of **transfer time**, with the first requiring *less time* than the second but covering a *smaller region*.

Depending on the **particular mission scenario**, one strategy may be preferable to the other



Single finite burn strategy



Double finite burn strategy

FLYBY PHASE

Maximum relative velocity	~70 km/s
Average relative velocity	~42 km/s
Average satellite heliocentric velocity	~25 km/s
Maximum satellite heliocentric velocity	~30 km/s

Flyby start: Payload instruments detect the **first scientific data**
Flyby end: Payload instruments **not able to detect data** anymore.
Maximum data obtainable: ~**350 GB**

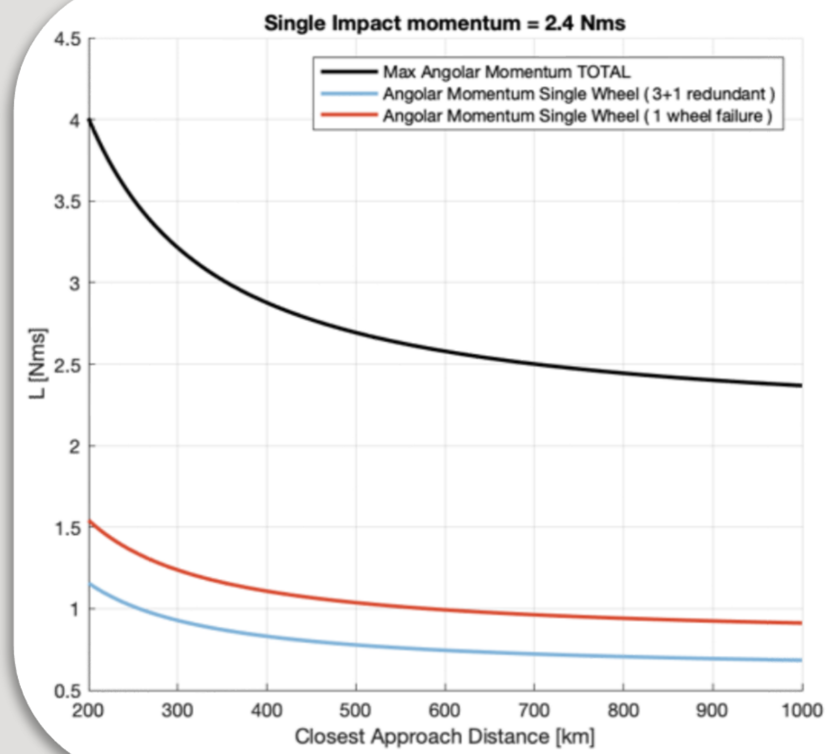
Main role: relative velocity of the satellite with respect to the comet.

Closest approach (CA) distance: ~600 km (*nominally*)

Stabilization ensured for:

- **Small particles impacts** (≤ 10 mg) striking uniformly the satellite
- **100 mg** particles impacts up to a CA distance of 600 km for *1 wheel failure*

Chosen reaction wheels provide *1 N m s* angular momentum



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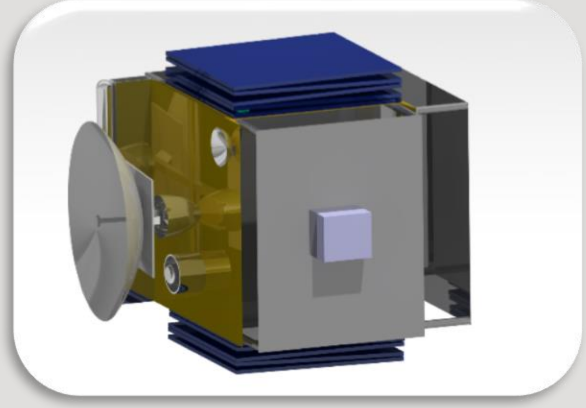
COMETARY ENVIRONMENT

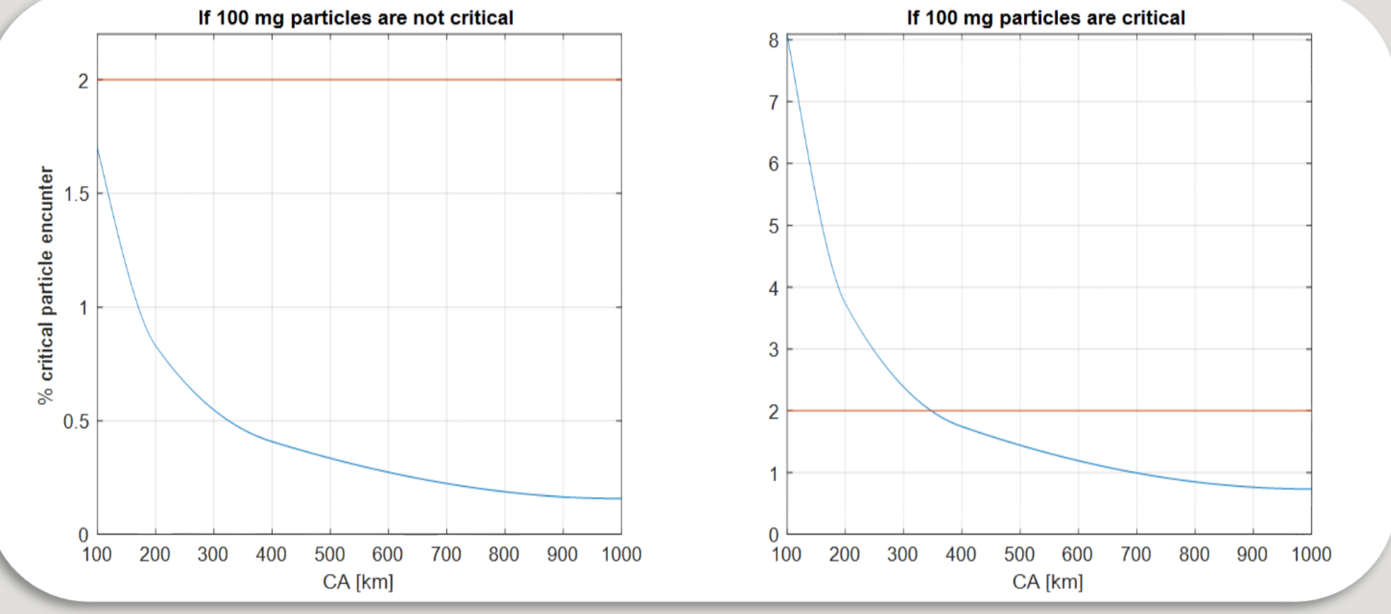
- **Cometary environment** simplified model made starting from Giotto and Rosetta observations.
- **Probability of impact** for particles of a given mass has been obtained for different CA distances.
- **100 mg particles** are not critical up to *flyby velocities of 64 km/s.*
- For **higher velocities**, the CA distance shall be increased.



Double Whipple Shield with:

- 2.5 mm *Kevlar* wall
- 0.3 mm *aluminium* bumper
- 13 cm *spacing*

Designed through *ESABASE2*



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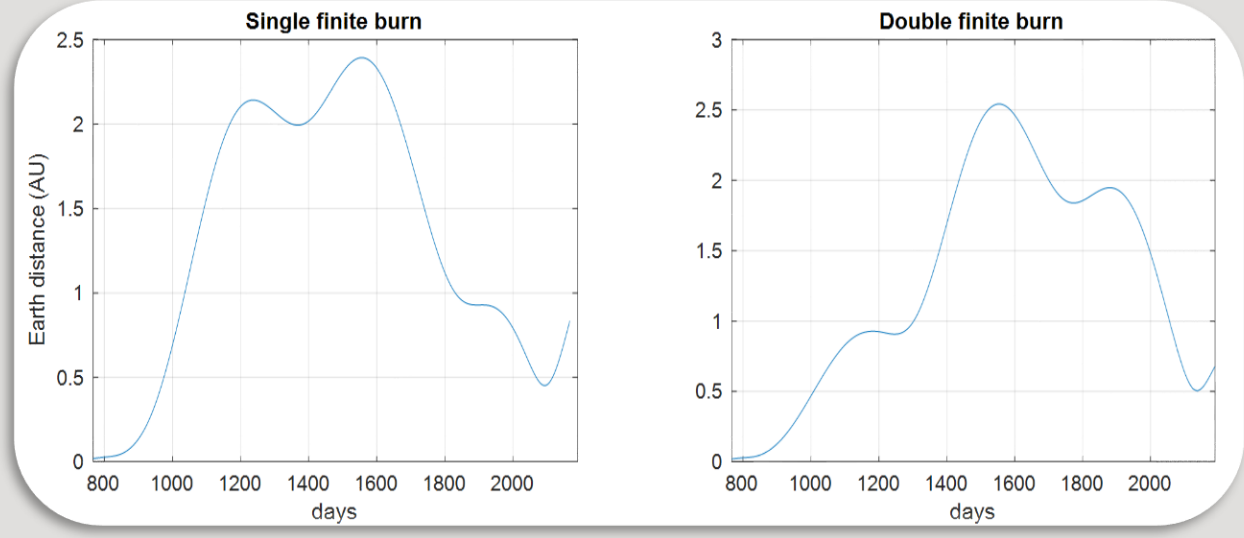
POST-FLYBY PHASE

Data transmission time = *8 hours a day*
Duration of the phase depends on the duration of other phases

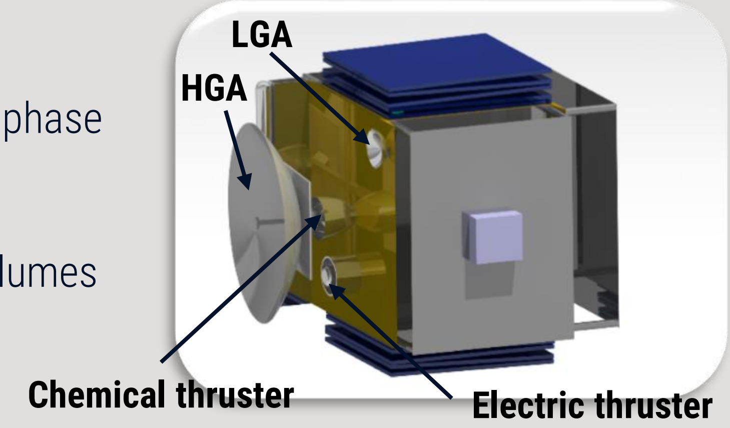
Simulation performed (worst case):
- Parking phase lasts 2.1 years
- Transfer phase lasts 2.6 years

➔ 1.3 years post-flyby duration

30 GB data transferrable
(*worst case*)



Telecommunication characteristics:
- 8.4 GHz *X-band High Gain Antenna* for **data transmission**
- 8.4 GHz *X-band Low Gain Antenna* for **telemetry & command** during the parking phase
- *IRIS V2.1 X-band transponders* for **signal modulation**
- *Travelling Wave Tube Amplifier* to **amplify the power transmitted**
- **HGA mechanism** to protect the antenna from cometary dusts and/or thruster plumes



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SPACE SEGMENT DESCRIPTION

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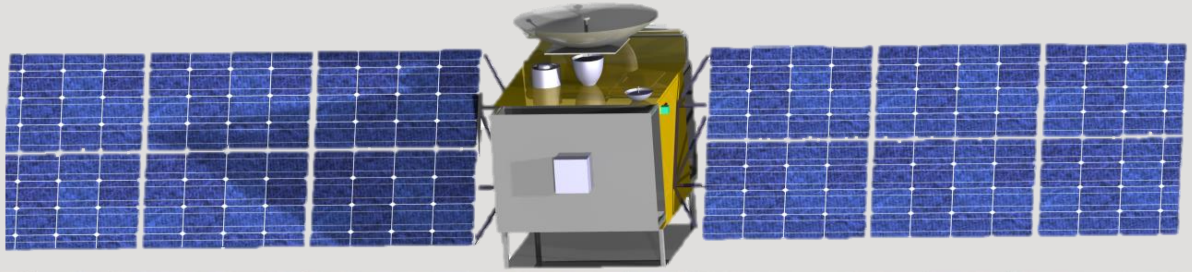
- Different **mission concepts** selected through a **System Engineering** approach
- ***Analytic Hierarchy Process*** to perform *trade-offs* and select the **final concept**
- **Mass & power margins** taken into account according to ***AIAA Regulations***
- **Rough cost estimated** of *35 M$* (includes all mission operations costs)

Mass Budget [kg]		
Structure	13.2	
Thermal Subsystem	0.810	
Attitude Control	6.86	
Power Subsystem	21.5	
Propulsion	4.13	
Telecommunications	6.70	
Payload	7.5	
Total Dry Mass (20% margin)	72.8	
Propellant (chemical | electrical)	11.8	15.4
Total	100.0	

Power Budget [W]				
	Parking	*Transfer*	*Flyby*	*Comm.*
No Margin	83	324	108	168
Margin	45%			
Total	120	472	157	243

Link Budget			
Distance from Earth [AU]	0.5	1	1.5
Data Rate [kbps]	66	16.7	7.4
C/N_0	53.7	47.7	44.2
Volume (without shield) [m^3]	0.102		
Dimensions (stowed) [cm]	86.0 x 78.0 x 77.2		

POWER SUBSYSTEM:
Solar arrays *(2.32 m^2)*
Lithium-Ion secondary batteries
STARBUCK Mini (PCDU)



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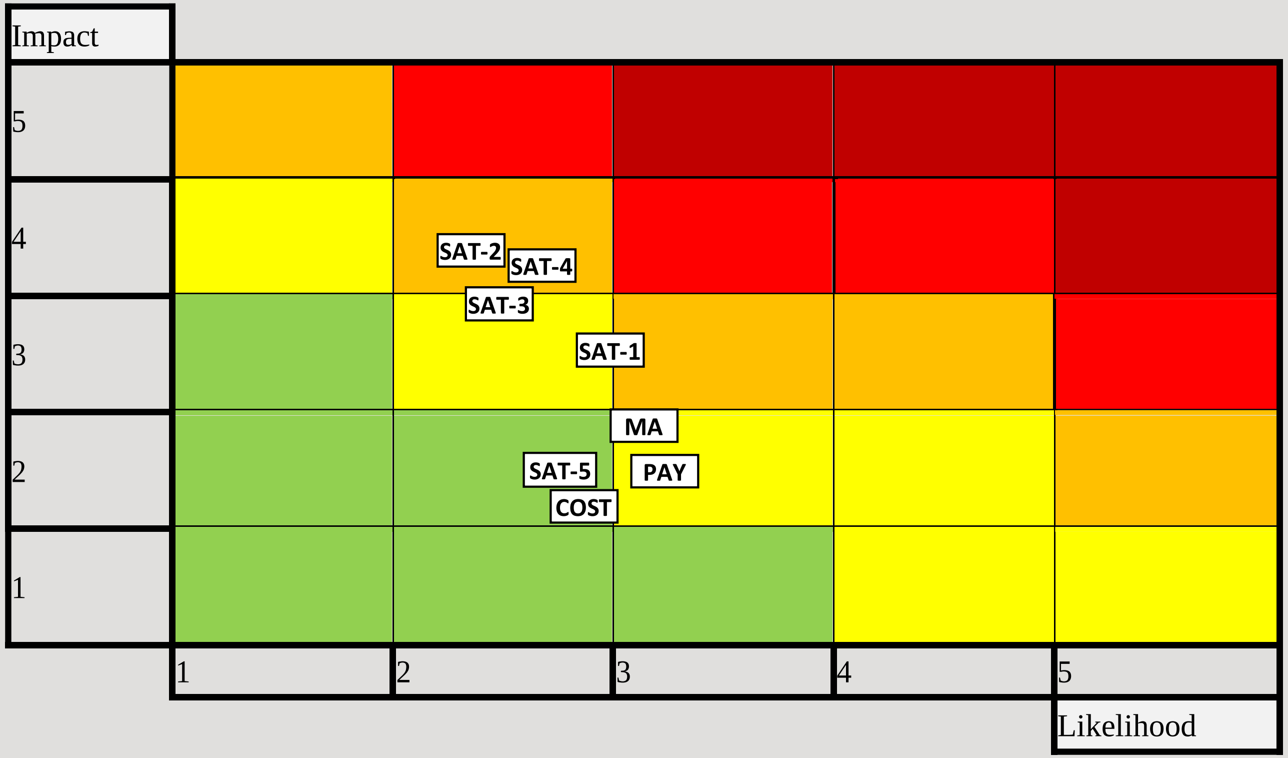
RISKS ANALYSIS



ID	Root Cause Description
PAY	Failure to gather data during the flyby
SAT-1	Failure due to environmental factors
SAT-2	Failure of satellite due to EPS malfunction
SAT-3	Failure in the telecommunication subsystem
SAT-4	Failure in the propulsion subsystem
SAT-5	Failure in the AOCS
MA	Wrong evaluation of orbits or manoeuvres
COST	Costs are higher than expected

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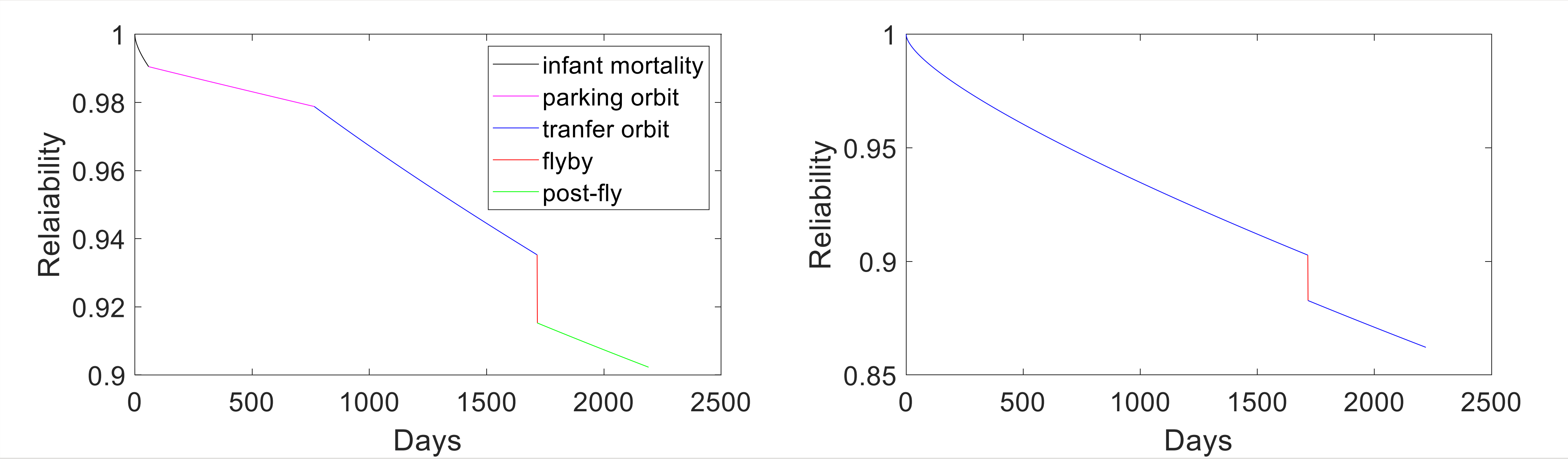
RELIABILITY ANALYSIS

Twofold reliability analysis performed through *Weibull's distributions*:

- **First analysis (a):** specific mission scenario ➔ only *most stressed* subsystem contributes to reliability in each phase.
- **Second analysis (b):** worst case scenario ➔ *all the subsystems* are always considered on

$$0.86 < R < 0.90$$



(a) **(b)**

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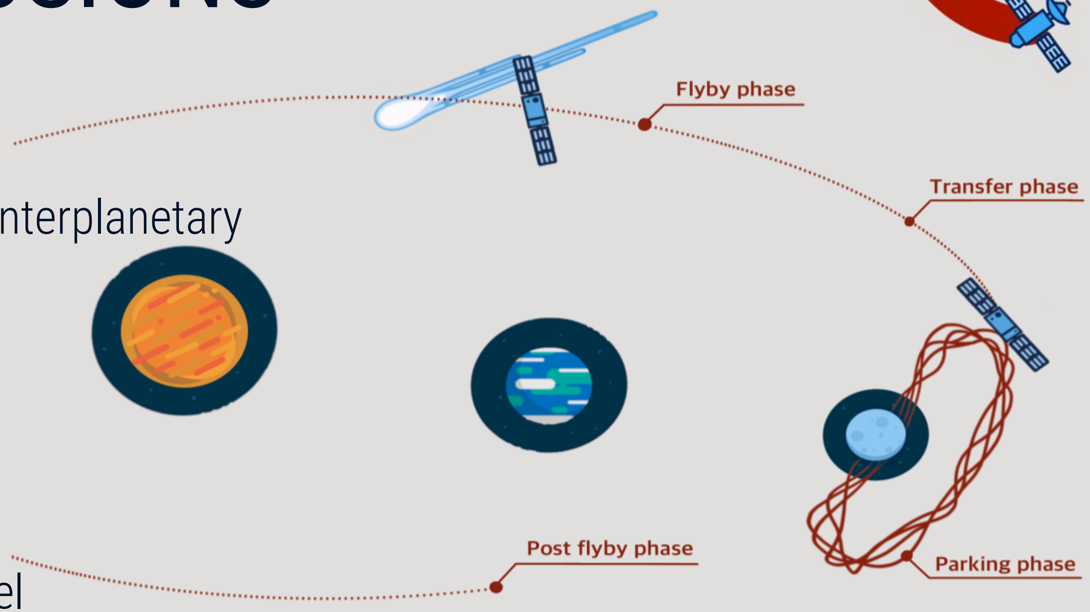
CONCLUSIONS

- Mission *feasible* in terms of risk assessment
- Mission *feasible* in terms of *mass and size constraints*
- Study *demonstrates* the feasibility of future scientific interplanetary missions with micro-nano satellites
- Flexibility of mission phases due of the probabilistic nature of the problem



Critical Aspects of the mission:

- **Cometary environment**: need of a more accurate model
- **Development of the electric thruster (TRL 5):** development carefully monitored
- The **target will be known** once the satellite is on orbit ➔ the specific **mission scenario** will be determined during the mission initial phases.

HT400 Electric Thruster

THANK YOU FOR YOUR ATTENTION!