The 7th Mission Idea Contest

For Deep Space Science and Exploration

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MELCHIOR:
Micro-satellite Explorer to a Long-period Comet in a Heliocentric Inner ORbit

Presentation outline

- MELCHIOR objectives
- Mission analysis
- Probabilistic study
- Payload and Environmental analysis
- 3D Model and Mass budget

Mission objectives

- MELCHIOR is a mission aiming to perform a fly-by to a Long Period Comet (LPC), characterizing its surface, shape, structure and chemical composition by means of a single satellite with a mass lower than 100 kg and an envelope size of 1m x 1m x 1m.
- Scientific community agrees that LPCs may retain a unique physical and chemical record of the processes involved in the formation of planetary systems.
- Given the probability that no suitable target is identified, the short period comet MIDAS 1981 is selected as backup target to ensure a meaningful scientific return.
- The results presented have been obtained by a group of students at the University of Naples "Federico II" and must be intended as representative of Phases 0/A of a space mission design.

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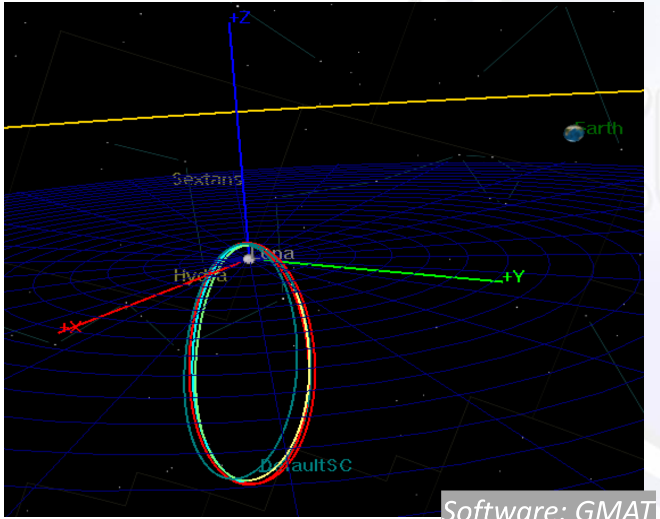
Mission analysis

Parking orbit

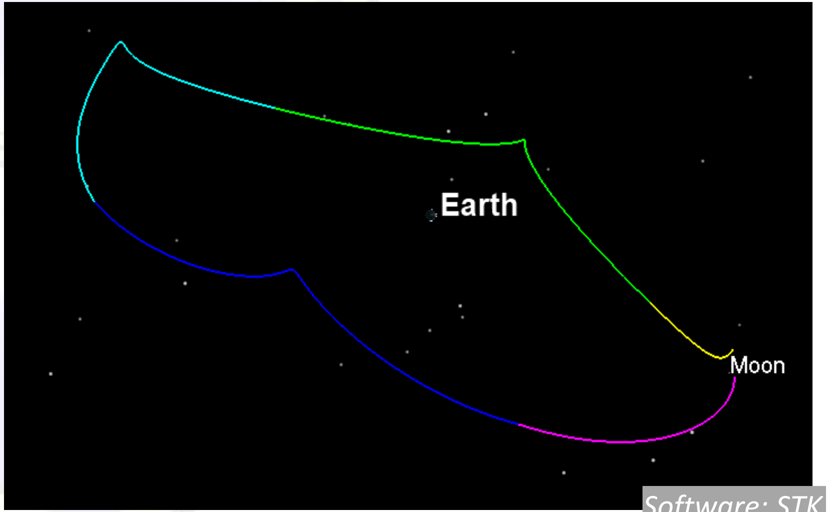
The mission starts before 2030 with a satellite already delivered to a southern Moon-Earth L2 4:1 resonant Near Rectilinear Halo Orbit (NRHO) with a perilune radius of 5931 km, selected for its stability and eclipses avoidance.

Moon fixed reference frame



Software: GMAT

Earth inertial reference frame

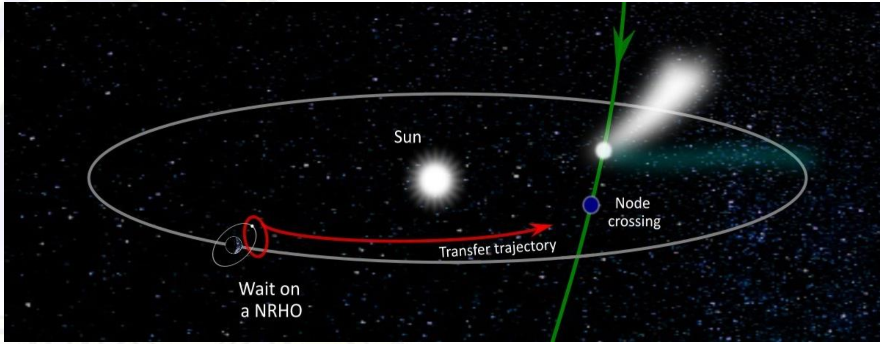


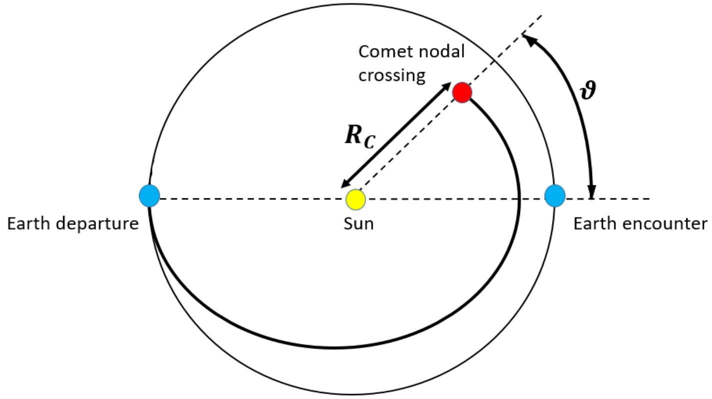
Software: STK

Mission analysis

Heliocentric transfer

- **Reachable area** $= [0.87\ AU, 1\ AU]$ due to the mass and thermal control constraints
- $\boldsymbol{\Delta V_{max}} = 1\ \mathrm{km/s}$ reserved for the 2-impulses heliocentric transfer with the selected chemical propeller





Under some simplifying assumptions, the problem becomes **time-independent** and the transfer can be defined by:

- R_c = Radius of comet's orbit at encounter
- ϑ = Comet-Sun-Earth phase angle at encounter

Mission analysis

Departure from NRHO

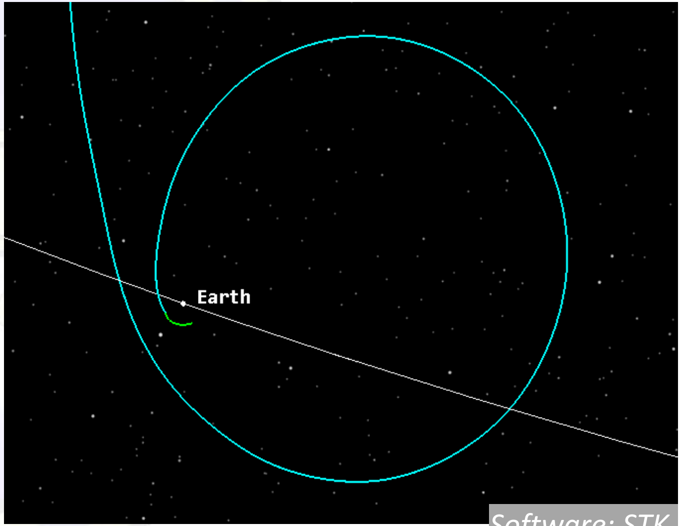
Once the approximations are removed, the position of the Moon along its orbit at the departure from the NRHO has to be taken into account.

Most favourable point:

- Earth-Moon-Sun if $\vartheta > 0$
- Moon-Earth-Sun if $\vartheta < 0$

Applying a tolerance window of ± 3 days from the best condition point, so the satellite may have to wait **up to 23 days** to reach a favourable configuration for the departure from the NRHO.

Example of ΔV applied 9 days after the best condition, unfavorable configuration

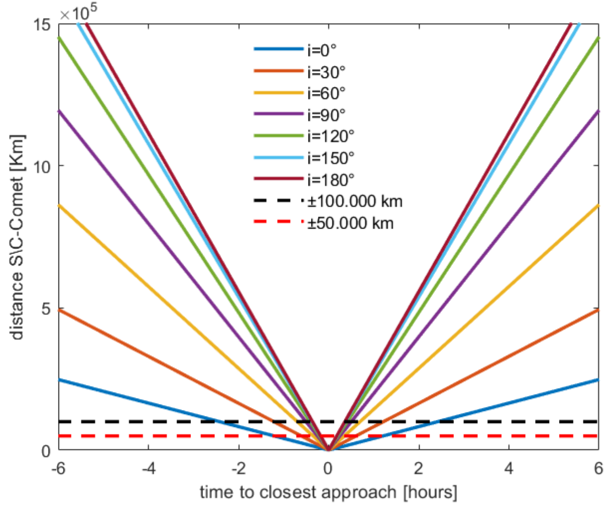


Software: STK

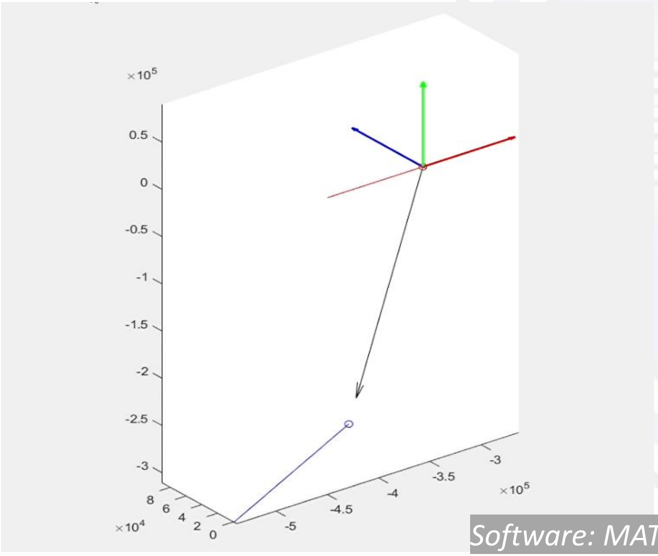
Mission analysis

Fly-by phase

An **estimated duration of the fly-by** can be obtained as a function of comet inclination and payload working range.
The encounter shall take place on the ecliptic plane and the correct pointing is guaranteed by 4 reaction wheels in a pyramidal configuration.



Software: MATLAB



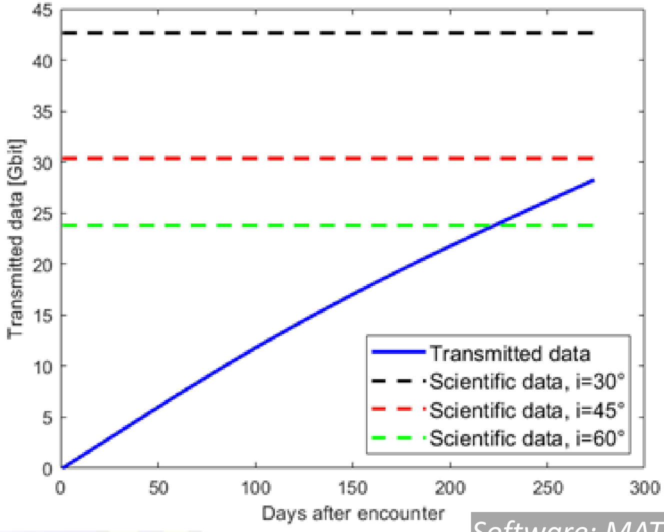
Software: MATLAB

Electrical power is provided by a secondary battery, in case of off-pointing condition of the solar panels.
A **closest approach distance of 1000 km** has been chosen, with the spacecraft placed between the Sun and the target.

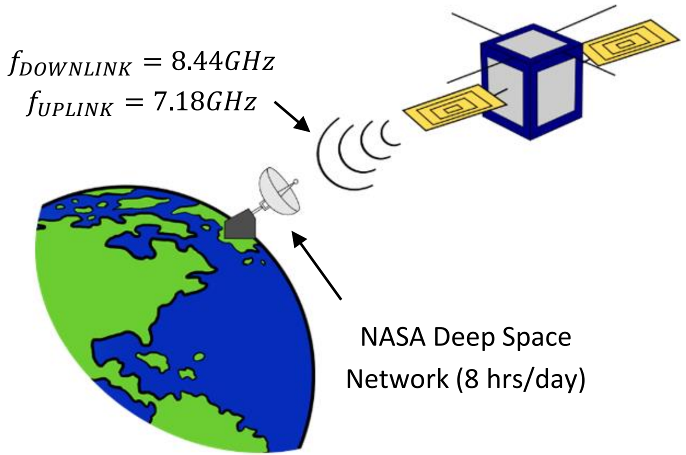
Mission analysis

Post-encounter phase

The driver for this phase is the capability of transmitting the collected data to the selected ground stations.
The trajectory followed by the spacecraft is the one defined by the second impulsive ΔV, since no additional orbital maneuvers are applied.



Software: MATLAB



Distance from the Earth strongly affects the downlink capability: the largest is ϑ, the farthest the satellite will go.
Considering the worst case in terms of distance from the Earth, a **maximum duration of 9 months** is reserved to this phase, guaranteeing download of at least 70 % of the collected data.

Probability study

The unpredictability of the target requires a probabilistic study that, starting from data provided by past detected comets, allows to estimate the probability that an approaching LPC meets the mission constraints, as the **intersection of 3 events**:

- **Event A**: the LPC crosses the ecliptic plane with $R_c \in [0.8 \text{ AU}; 1 \text{ AU}]$
- **Event B**: the LPC crosses the reachable area in terms of ΔV_{max}
- **Event C**: time between LPC detection and perihelion is larger than maximum maneuver time

$$p = \mathrm{P}(\mathrm{A} \cap \mathrm{B} \cap \mathrm{C}) = \mathrm{P}(\mathrm{C}|\mathrm{A},\mathrm{B}) \cdot \mathrm{P}(\mathrm{B}|\mathrm{A}) \cdot \mathrm{P}(\mathrm{A})$$

With an expected value of $n = 24$ LPCs detected/year during the mission, the probability of having at least 1 reachable LPC during the 6 years of the parking phase has been obtained by means of a binomial random variable:

$$P_b = \binom{n}{x} \cdot p^x \cdot (1-p)^{n-x} \longrightarrow \boxed{P_{LPC} = 1 - P_b(0) = 0.906}$$

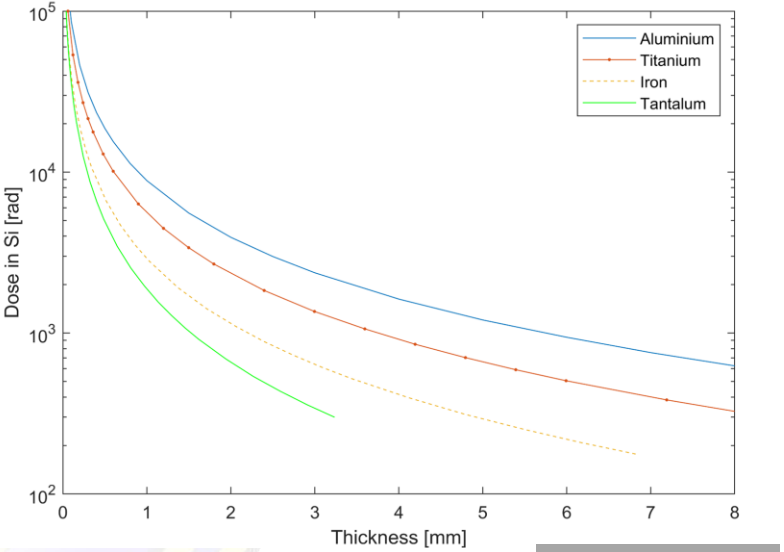
Payload

Six different payload instruments are embarked to collect the highest amount of data at the encounter:

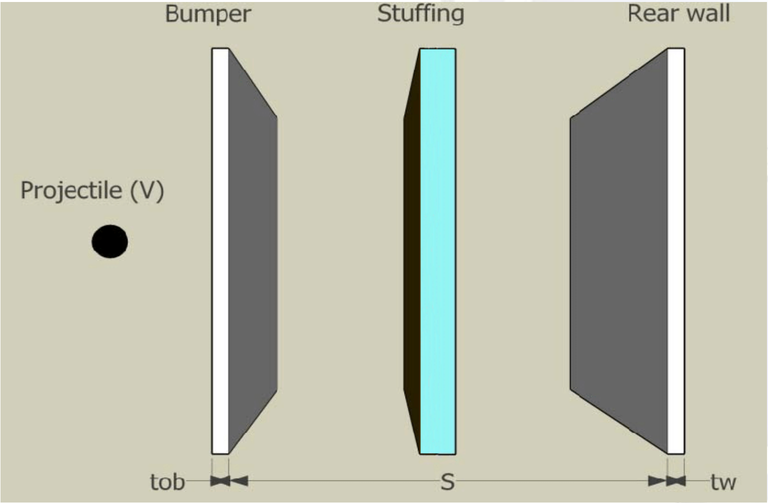
- **Multispectral camera** to analyze the surface of the nucleus;
- **Short Wave Infrared** and **Long Wave Infrared spectrometers** to map chemical composition of nucleus and coma and surface temperature of the nucleus;
- **Mass Spectrometer** to analyze dust particles composition;
- **Dust impact sensor** to study dynamical properties of cometary dust ejected by the nucleus;
- **Flux-gate magnetometer** to study the interaction of solar wind plasma with coma.

Environmental analysis

Shielding against the radiation environment is guaranteed by the of the spacecraft, which resulted to be **1-mm Aluminium box structure** the best material in terms of performance-to-weight ratio.



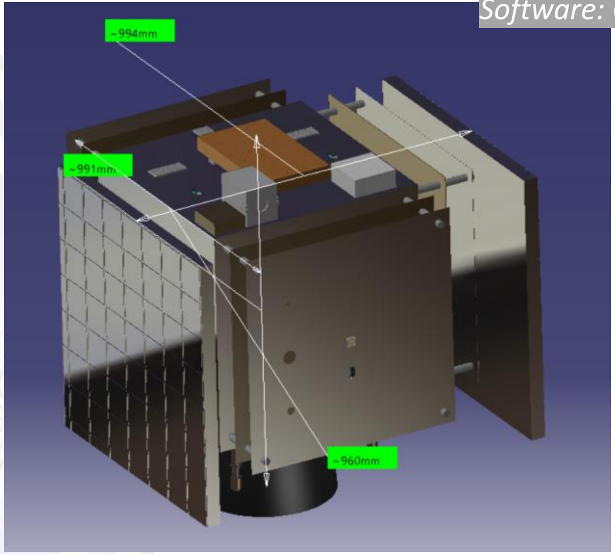
Software: MATLAB



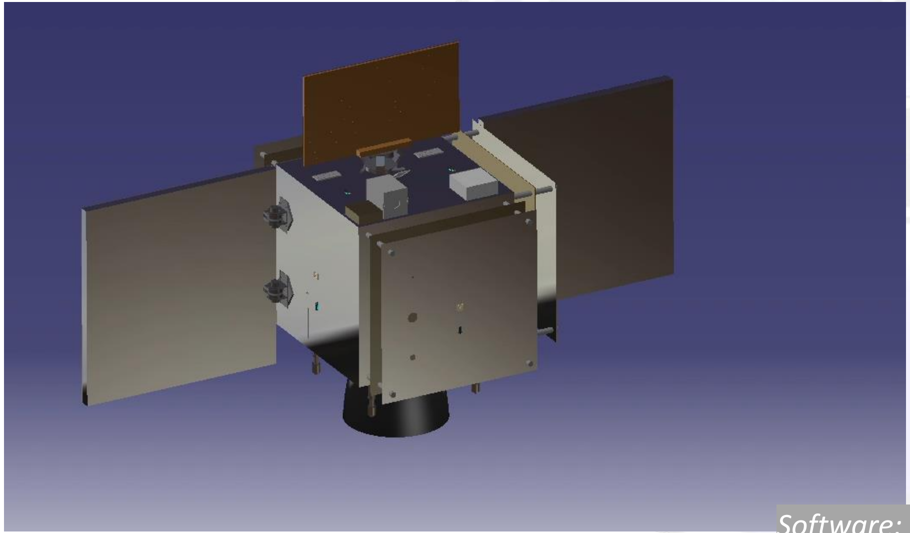
For three faces of the spacecraft, a **stuffed Whipple shielding** has been included to withstand the hypervelocity impacts of micrometeoroids with a size up to 10 mg and a velocity up to 70 km/s.

3D Model

Software: CATIA



Once all the subsystems defined the required equipment by means of off-the-shelf components, a 3D model of the spacecraft has been developed to confirm that the **envelope size constraint of 1m x 1m x 1m is met**.



Software: CATIA

After a possible internal allocation of the equipment, more accurate **estimates of moments of inertia** were obtained for attitude control.

I_x $[Kg \cdot m^2]$	I_y $[Kg \cdot m^2]$	I_z $[Kg \cdot m^2]$
8.792	7.585	8.485

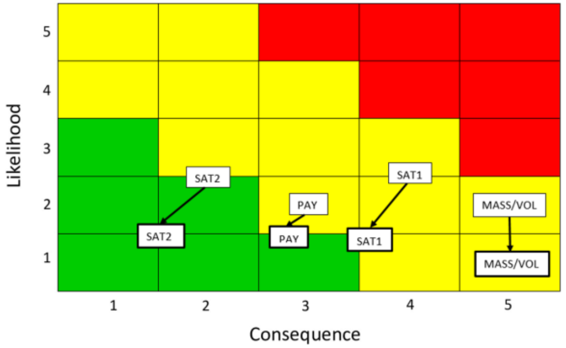
Mass budget

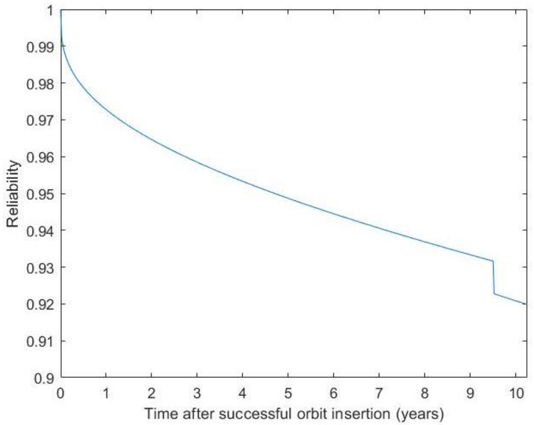
Mass budget related to each subsystem is reported in the Table, where a 20% margin is included for the dry mass, demonstrating the compliance with the mass constraint.

	Mass [kg]
Payload	3.11
Shielding	12.25
TCS	0.5
EPS	14.24
ACS	5.01
Propulsion	10.46
TLC	6.94
Margin (20% of dry mass)	14
Propellant	30
Total	**99.88**

Risks, Reliability and Costs

- A risks analysis has been performed and a proper **mitigation plan** allowed to reduce risks likelihood and consequence.





- The reliability of the system has been modelled by means of a **Weibull distribution**. The feasibility of the mission was confirmed by results above 90% for all the different phases.

- Best case and worst case in terms of total cost of the mission have been obtained considering **Small Satellite Cost Model** and **NASA Instrument Cost Model**.

Best Case [$M]	Average Value [$M]	Worst Case [$M]
93.73	126.72	176.87

Conclusions and open points

- The study demonstrated the feasibility of a mission to perform a fly-by with a Long Period Comet by means of a single satellite with a mass lower than 100 kg and an envelope size of 1m x 1m x 1m.
- A proper analysis has shown that the probability of finding a reachable LPC is larger than 90%. In addition, the selection of MIDAS 1981 as backup target guarantees the scientific return of the mission.
- This work has to be intended as representative of Phases 0/A of a space mission design, so a further investigation is needed for some open points as the 3D Model.
- No maneuvers are baselined during the post-encounter phase, with several implications on the telecommunications subsystem design.
- The possibility of using low-thrust propellers was analyzed but resulted unfeasible in terms of mass constraints and escape from the Moon.

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