



Proposal for the “Comet Surface Interaction” Mission CoSI

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Introduction and Context

In response to the European Space Agency’s call for an M-Class Mission (M8), we will propose a mission to rendezvous with a short period, Jupiter-Family Comet to interact with its surface and rehearse a touch-and-go (TAG) sampling manoeuvre with in-situ sample analysis. The goal is to study the mechanical properties, stratification, and structural embedding of ice in the upper decimetre(s) of the comet’s surface. With a balanced risk approach, risk and gain are gradually increased from early remote characterisation up to the final TAG manoeuvre with in-situ sample analysis.

Science Goals

The main science goals of the mission are the understanding of 1) comet and planet formation and 2) cometary activity. To achieve this, the focus is put on the stratification of the upper decimetre(s) of the surface, its building blocks, mechanical properties, and the homogeneity or distribution of water ice therein. This requires direct interaction of the spacecraft with the surface.

A comet’s surface is in a complex, dynamic state between its primordial properties and its modification through dust and gas activity driven by solar radiation. Activity models try to bridge between this but need to make strong assumptions on structure, strength, and ice amount and distribution. The upper decimetre determines a comet’s interaction with the environment but many things are uncertain. A selection of specific science questions to address both goals above are the existence and nature of pebbles (Blum et al.) and water-ice-enriched blocks (WEBs; Ciarniello et al.), strength stratification and existence of a sub-surface sinter layer (Biele et al.), or the dust-to-ice ratio (Chokroun et al.).

Mission Design and Instruments

Several steps are planned for the study and interaction with the comet’s surface. Ordered by the gradual increase of the risk, these are a) remote characterisation, b) CubeSat impact experiments,

c) TAG rehearsal with back-away thrust interaction, d) TAG manoeuvre with stratified surface removal, and e) TAG manoeuvre with sampling and in-situ analysis. These operations will be performed in this order, but some will be performed multiple times.

Remote sensing implies VIS and NIR study of the surface from ~10 km distance. This covers global spectro-photometric mapping, geologic and compositional characterisation, and many more. Drawing a comparison to previous comets, and in particular 67P will enhance our understanding of the target comet and allow a qualified selection of the interaction sites. To achieve this, the VIS camera (ref. Keller et al., 2007; Sierks et al. 2011) shall feature several colour filters, the NIR instrument must be particularly susceptible for the water ice bands and organics features detection (ref. MIRS; Barucci et al., 2021).

From an altitude in the order of 100 m, a 3u CubeSat is released to impacts into the comet surface with a velocity in the order of 10 m/s. This relatively gentle impact does not pose a threat to the main spacecraft, such that its dynamics can be observed from a low altitude. The impact acceleration shall be recorded via the CubeSat's Inertial Movement Unit (IMU; ref. Hera/JUVENTAS) and transmitted to the orbiter. A few seconds after impact, it shall be possible to release an extra volume of gas to perform a controlled dust-lift experiment. This CubeSat sequence can be repeated with several CubeSats.

Descending to an altitude of a few metres, a TAG rehearsal shall be performed that uses the back-away thrusters before touching the surface. The OSIRIS-REx and Hayabusa2 interactions with asteroid surfaces showed a visible gas interaction with the surface, which will be repeated with OSIRIS-APEX on asteroid Apophis. This is a direct and controlled interaction with the comet's surface to measure strength of the material, which is expected in the order of 1 Pa or less (Attree et al., 2018). This manoeuvre will be used to reveal the first centimetre(s) of the cometary subsurface material.

An actual TAG manoeuvre without sampling is planned with a brush-wheel system (BWS; Goldmann et al., 2025), where rotating brushes are successively wiping surface layers to the sides. In contrast to classical BWS, the brushes shall be 180° to allow observation of the surface from above once per revolution with a synchronised camera. This will reveal sub-surface structure and distribution of water ice through albedo and (RGB) colour variations.

For the final TAG manoeuvre, the BWS rotation is reversed, such that a material fountain is lifted into a transparent sampling cup. The sample will be photometrically analysed at different scales and in stereo with different camera systems. Through the pressure increase measured with a pressure sensor the gas production of the sublimating sample can be measured. The concept was proven with Rosetta/COPS (Balsiger et al. 2007, Pestoni et al., 2021), and with the known sample volume it will be possible to measure the dust-to-ice ratio.

All interaction zones (thrust and BWS) will be studied with VIS and NIR remote sensing during ascent. Several CubeSat and BWS interactions are possible, which allows the distribution of risk through the study of multiple interaction sites.

The target comet shall be known from Earth observations and shall show a reasonably low activity level comparable to or less than 67P. This will allow a temporal mission profile comparable to Rosetta with arrival on the order of 12 months prior to perihelion and the sampling attempt at least 6 months before perihelion, i.e., before activity which would make complex operation impossible. With a successful conclusion of this mission phase, the comet shall be followed up to perihelion via remote observation.

References

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