INSTRUMENTS ON BOARD THE COMET INTERCEPTOR ESA MISSION

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ABSTRACT

Comet Interceptor (Comet-I), selected by the European Space Agency (ESA) in June 2019, is the first Fast-Class Science mission with a short development time and a strict limit for the cost at completion. The Comet-I instruments are expected to be qualified for flight by early 2026.

Comet-I will be launched to the Sun-Earth L2 point sharing an Ariane 6.2 launch with ESA's ARIEL satellite. Comet-I will remain at L2 until its departure to a yet-to-be-discovered new comet or interstellar body. Comet-I will then perform a fly-by of the comet nucleus and will release two small probes (probe B1 provided by JAXA and probe B2 provided by ESA) which will fly closer to the comet nucleus. The mission's primary science goal is to characterise for the very first time with multi-point observations, a Long-Period comet, dynamically new, or an interstellar object.

This paper describes the suite of instruments which are under development, both for the mother spacecraft (S/C A) and for the small probe B2 under ESA responsibility and the main challenges encountered during the initial development of the instruments.

The instruments on board spacecraft A are:

- **CoCa**: Comet Camera - to obtain high resolution images of the comet's nucleus at several wavelengths, developed by a consortium led by University of Bern
- **MANiaC**: Mass Analyzer for Neutrals in a Coma - a mass spectrometer to sample the gases released from the comet, developed by a consortium led by University of Bern
- **MIRMIS**: Modular InfraRed Molecules and Ices Sensor - to measure the thermal radiation released from the comet's nucleus and study the molecular composition of the gas coma, developed by a consortium led by University of Oxford in the UK and VTT in Finland
- **DFP-A**: Dust, Field and Plasma package - to detect and measure charged gases, energetic neutral atoms, magnetic fields, and dust surrounding the comet, developed by a consortium led by CBK in Poland.

The instruments on board probe B2 are:

- **OPIC**: OPtical Imager for Comets - mapping of the nucleus and its surrounding coma and dust environment, developed by University of Tartu in Estonia
- **EnVisS**: Entire Visible Sky coma mapper - to map the entire sky within the comet's coma, using a fisheye lens. It is developed by a consortium led by CNR in Italy and IAA in Spain based on a designed initially developed by MSSL in the UK
- **DFP-B**: Dust, Field, and Plasma - a subset of DFP sensors on spacecraft A, developed by a consortium led by CBK in Poland.

Despite being a fast development mission with very strict programmatic boundaries, Comet Interceptor includes a comprehensive suite of instruments addressing all major topics related to cometary science as requested by the European cometary science community.

The main challenges of the instruments are the need to comply with very low mass and low power allocations. Also, limited time is available for the development which requires the use of technological solutions with high technology readiness level (TRL) in combination with early technology development and breadboarding activities to de-risk the following development phase.

The instruments design was reviewed at a preliminary requirements review (PRR) held by ESA from June to September 2020 and a system requirements review (SRR) held approximately 1 year after that, in May-July 2021. These preliminary reviews confirmed the feasibility and adequacy of the instruments design. The next major milestones are the instrument preliminary design review (PDR) expected in mid-2022, the critical design review (CDR) expected to be completed in 2023 and the delivery of the qualified flight models between the end of 2025 and the beginning of 2026.

1. INTRODUCTION AND MISSION OVERVIEW

Previous comet missions, including ESA’s pioneering spacecraft Giotto [1] and Rosetta [2], encountered short-period comets. These are comets with orbital periods of less than 200 years that have approached the Sun many times along their orbits in relatively recent times and therefore have undergone significant changes. Rosetta’s comet, 67P/Churyumov-Gerasimenko, orbits the Sun once every 6.5 years, while Comet 1P/Halley, visited by Giotto and other spacecraft in 1986, returns to our skies every 76 years.

Comet Interceptor will target a comet with an orbital period larger than 200 years, preference given to targets with approximately parabolic orbits, likely visiting the inner Solar System for the first time – from the vast Oort cloud that is thought to surround the outer reaches of the Sun’s realm. As such, the comet will contain material that has not undergone much processing since the dawn of the Sun and planets. The mission will therefore offer a new insight into the evolution of comets as they migrate inwards from the periphery of the Solar System.

In the past, ‘new’ comets have only been discovered a few months to years before they pass through their closest approach, perihelium, to the Sun, which is too short notice to plan, build and launch a space mission, and for it to travel to the specific object before it moves away from the Sun again.

Recent advances in ground-based surveys mean that the sky can be scanned more deeply and longer notice can be provided. Pan-STARRS (Panoramic Survey Telescope and Rapid Response System) [3] is currently the most proliferous comet discovery machine. The Vera Rubin Telescope (Legacy Survey of Space and Time) [4], currently under construction in Chile, will greatly increase the catalogue of new comets.

The actual fly-by target for Comet Interceptor is not known yet. The mission is therefore being designed for an envelope of possible encounter conditions.

The Comet Interceptor mission is designed for a 6-year mission lifetime with up to 6 months of nominal science operations after encounter. The main mission phases are schematically shown in Figure below.

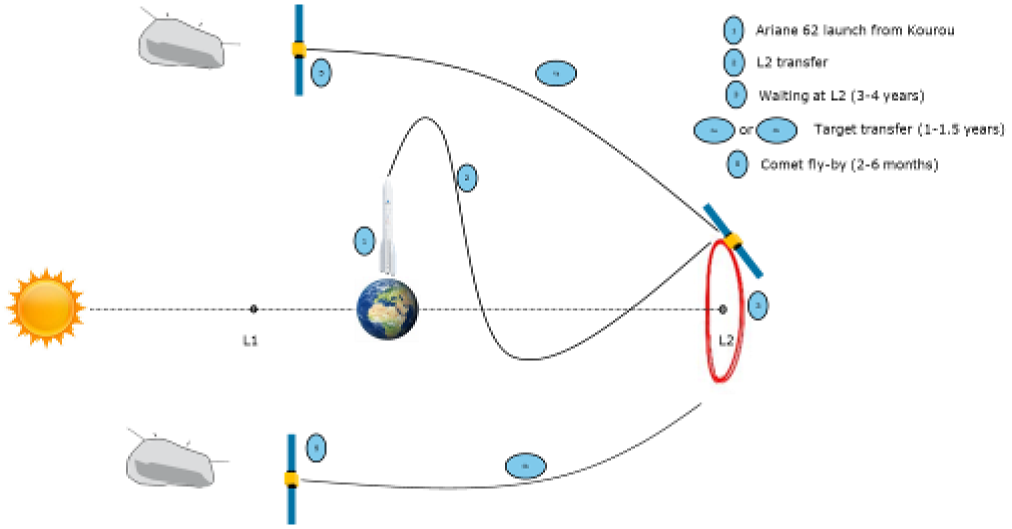

Figure 1 Main mission phases, with indicative durations

The geometry of the main spacecraft and the two probes with respect to the comet during the fly-by phase (with a focus on the closest approach) is presented in the Figure 2 below.
Comet Interreceptor will release two small probes 24-48hr (depending on the relative velocity) before performing the fly-by and reaching the closest distance to the comet nucleus. After their release, the two probes will perform autonomous operations, relaying the scientific data back to the main spacecraft via an intersatellite link for as much time as possible. Following the fly-by, the main spacecraft will downlink to Earth the data acquired by the instruments on board the main spacecraft and the two probes.

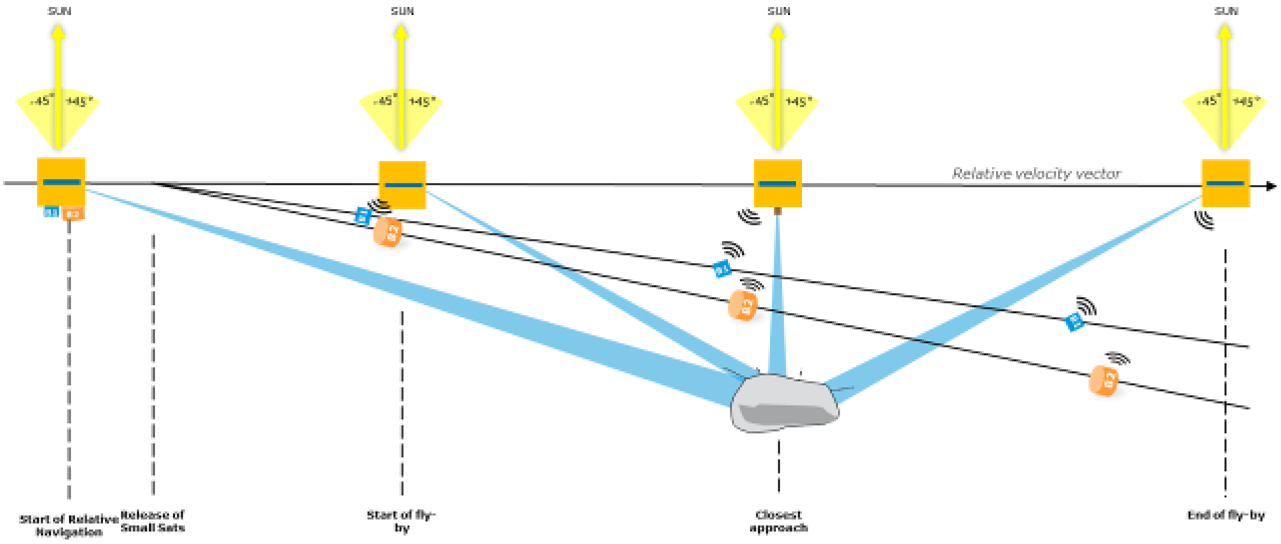

Figure 2 Comet Interceptor fly-by and closest approach

A preliminary mission and spacecraft design was performed in the ESA Concurrent Design Facility (CDF) at the end of 2019 [5]. A parallel competitive phase A/B study is nearing completion (satellite PDR starting in April 2022). ESA expects to select the most suitable industrial design and award the industrial contract to the selected Prime Contractor by end of 2022 to start the detailed spacecraft design phase in early 2023.
The focus of this paper is on the instruments on board of Comet Interceptor spacecraft A and probe B2 reporting on main design and development challenges.

2. SCIENTIFIC OBJECTIVES

The objective of the Comet Interceptor mission is to characterize a pristine comet or interstellar body by performing multi-point observations during a dedicated close-range fly-by.
The science of the mission can be split between two main themes:

- Comet Nucleus Science
- Comet Environment Science

The key questions addressed by the mission are:

- What is the surface composition, shape, morphology, and structure of the target object?
- What is the composition of the coma, its connection to the nucleus (so called “activity”) and the nature of its interaction with the solar wind?

The first theme focuses on the nucleus, aiming at a close-up observation (as opposed to remote sensing from the Earth), measuring the size of the nucleus which is hidden by the coma for observations from Earth and near-Earth based observatories.

Characterisation of the nucleus will provide information on its bulk properties (shape, rotation rate, surface structure etc) which will in turn provide constraints for surface features formation mechanisms and their timescales. There might be craters, depressions, layers, regolith or boulders which could provide unique insights and clues into early surface evolution of the Solar System.

The second theme focuses on the coma, its connection to the nucleus (so called "activity") and the nature of its interaction with the solar wind. Measuring the composition from the nucleus will inform coma chemistry models. Isotopic measurements will include D/H from HDO/H_2O and other isotopes (e.g. of $^{18}O/^{16}O$ in H_2O, $^{13}C/^{12}C$ in CO_2 and $^{34}S/^{32}S$ in OCS and CS_2) if their abundances are sufficiently high to be detected. Mapping the distribution of neutral gasses will inform bulk composition and nucleus inhomogeneity investigations, and probe coma chemistry.

Remote sensing of the large-scale distribution of different species will be combined with in-situ sampling to derive production rates of the individual volatile species during the fly-by. Identification of ion species will enable an assessment of their relationship and abundances in the coma.

In situ mass spectroscopy will detect species that are not observable from Earth. Characterizing the dust in the coma by examining the dust flux and the dust particles physical properties, down to nanometric size, will provide input to test formation models in the early Solar System.

Assessing the structure of boundaries and regions in the plasma environment of a comet with multi-point measurements will address the current limited knowledge associated with the actual 3D shape of boundaries and regions in the coma, and the timescales on which they vary.

Multi-point measurements of plasma particles, magnetic fields and nanometric dust will improve the physical understanding behind mass transfer and the consequences for both the coma and tail. Energetic neutral atom observations will help further understand the role of charge exchange collisions in the transfer of energy and momentum from the solar wind to the coma.

3. THE SUITE OF INSTRUMENTS

In the following part the instruments are shortly described. For further info see also [6], [7], [8], [9].

3.1. COMET CAMERA (CoCa) AND ROTATING MIRROR ASSEMBLY (RMA) ON SPACECRAFT A

The Comet Camera (CoCa), which is developed by a consortium led by University of Bern, is the main imaging instrument onboard the mother spacecraft A. Its science objective is to provide colour imaging of the surface of the nucleus and the dust in the near-nucleus environment over a range of phase angles. The resolution is sufficient to determine the structure and homogeneity of the target comet nucleus. The imager can allow saturation of the nucleus to obtain optimum signal-to-noise ratio for observing the dust coma.

CoCa is built on heritage-based design solutions to achieve high performance at low cost and with a short development time. CoCa comprises a four mirror off-axis telescope developed by TAS-CH, a filter wheel with four broadband filters, a CMOS detector with its proximity electronics which is developed by DLR, thermal control developed by Admatis in Hungary, an electronics unit that controls the instrument which is developed by REMRED and SGF in Hungary, and IAA in Spain.

Full-frame exposures can be acquired at a maximum repetition rate of two images per second if the filter is unchanged. If the filter is moved between exposures, the maximum imaging frequency is 1 Hz. The system is constructed to take over 2500 images during the fly-by. CoCa is intended to observe the comet for approx. 100 hours, prior and after the closest approach, depending on the fly-by velocity. During the encounter, the spacecraft A on-board computer will command CoCa to switch between different operation routines according to a predefined timeline.

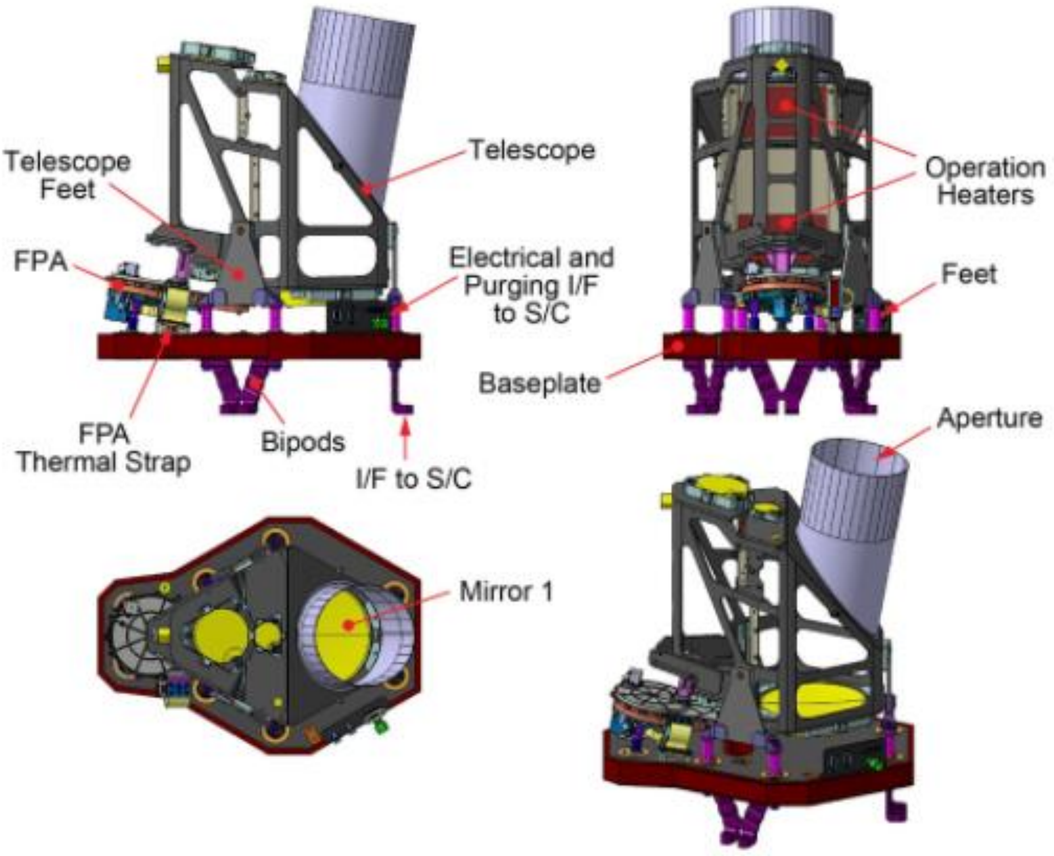

Figure 3 CoCa telescope with focal plane assembly and filter wheel

The Spacecraft A will maintain a fixed attitude with respect to the comet during fly-by so that the dust shield always faces the relative velocity direction and protects the entire spacecraft from possible dust impacts. A Rotating Mirror Assembly (RMA) is therefore needed to keep the CoCa field of view pointed to the comet nucleus. The RMA, developed by CSL in Belgium, is composed of a scan mirror, a mechanism moving the mirror, a baffle protecting CoCa from straylight and also protecting from the dust environment and an electronics unit developed by TAS-CH.

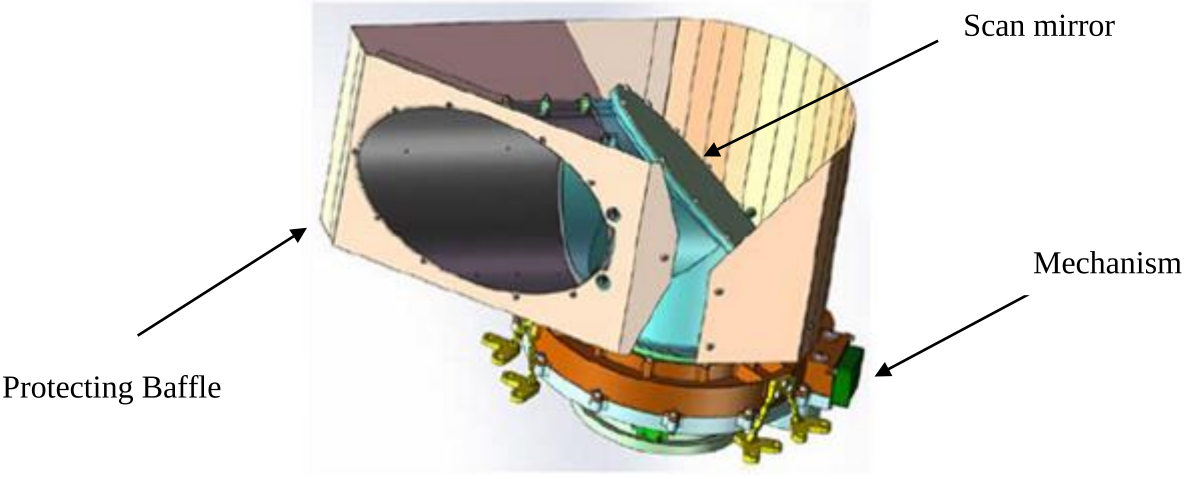

Figure 4 Rotating mirror assembly

3.2. MASS ANALYZER FOR NEUTRALS IN A COMA (MANiaC) ON S/C A

MANiaC, which is developed by a consortium led by University of Bern, consists of two sensors, the Mass Spectrometer Sensor Head Unit (SHU) and the Neutral Density Gauge (NDG). The mass spectrometer is based on the time-of-flight (ToF) principle and will measure in situ volatiles' total and relative abundances in the coma along the fly-by trajectory. These include H_2O, CO_2, CO, and possibly O_2. Depending on the outgassing activity of the target comet, also minor species, such as organic molecules and heavy isotopes of water, can be measured. Furthermore, information on the composition of dust grains may be obtained in case such a particle enters the instrument.
The time-of-flight mass spectrometer and a neutral density gauge are attached to an electronics unit.

Figure 5 SHU (sensor head unit; ToF mass spectrometer), NDG (Neutral Density Gauge), ELU (electronics unit).

During the phase A/B the SHU and NDG were prototyped and extensively tested. The ion source and drift-section/reflectron of the SHU, the grid and repeller of the NDG were mechanically tested for risk mitigation.
The performances of the SHU and NDG have also been verified by testing the prototypes in calibration facility with a molecular beam. The results show compliance to the scientific requirements with good linearity and sensitivity performance.

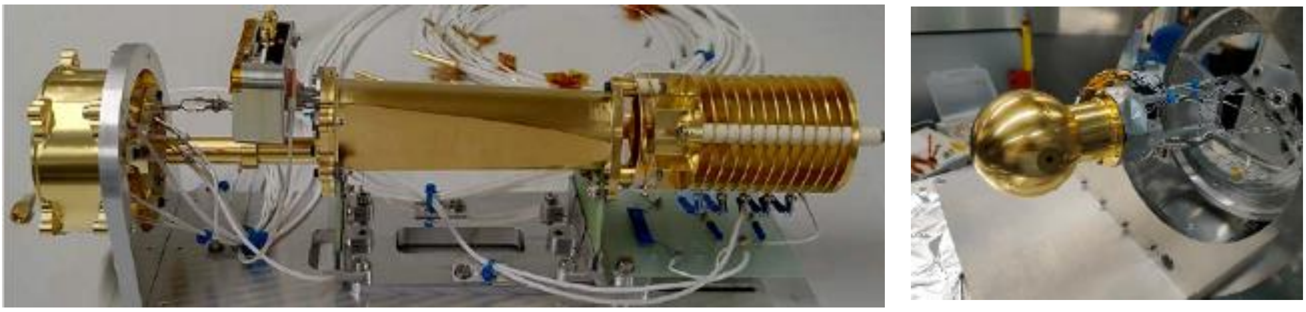

Figure 6 On the left prototype of the mass spectrometers, on the right prototype of the NDG

The electronics unit (ELU) includes 6 boards which are under development:

- Data processing unit (DPU) from IWF (A): Breadboard design ongoing.
- Read out electronic (ROE) from CTI (PL): Breadboard design ongoing.
- High voltage (HV) from IRAP (F): Based on prior design experience.
- Power supply (PSU) from IAA (ES): Breadboard has been manufactured and tested.
- NDG controller and low voltage: from Uni Bern and Swiss industry, design ongoing.

3.3. MODULAR INFRARED MOLECULES AND ICES SENSOR (MIRMIS) ON SPACECRAFT A

MIRMIS, which is developed by a consortium led by University of Oxford, aims to measure the spatial distribution of ices, minerals, gas species and the nucleus surface temperature to investigate the formation and evolution of the nucleus and coma. Compositional diversity could indicate whether the nucleus is a rubble-pile object with a collisional history, or a uniform body formed in a single process. The spectral imaging will reveal various geological structures. Thermal maps will provide information on surface roughness, porosity and also sub-surface temperature structure.

These objectives will be achieved using the two main modules of MIRMIS:

- the thermal infrared imager TIRI module, provided by University of Oxford,
- the MIR (point spectrometer) and NIR (hyperspectral imager) module, provided by VTT Finland.

The main characteristics of MIRMIS are:

- NIR: 0.9-1.7 µm wavelength range, 640 x 512 detector array, 180 µrad instantaneous FoV
- MIR: 2.5 to 5 µm wavelength range, point spectrometer, 2° FoV
- TIRI: 6-25µm wavelength range, 640 x 480 detector array, 260 µrad instantaneous FoV

In the Figure 7 below the MIRMIS instrument is shown which is suspended on flexures to thermally decouple it form the spacecraft. Both modules present a scan mirror at their entrance to ensure the nucleus is maintained in the field of view during fly-by.

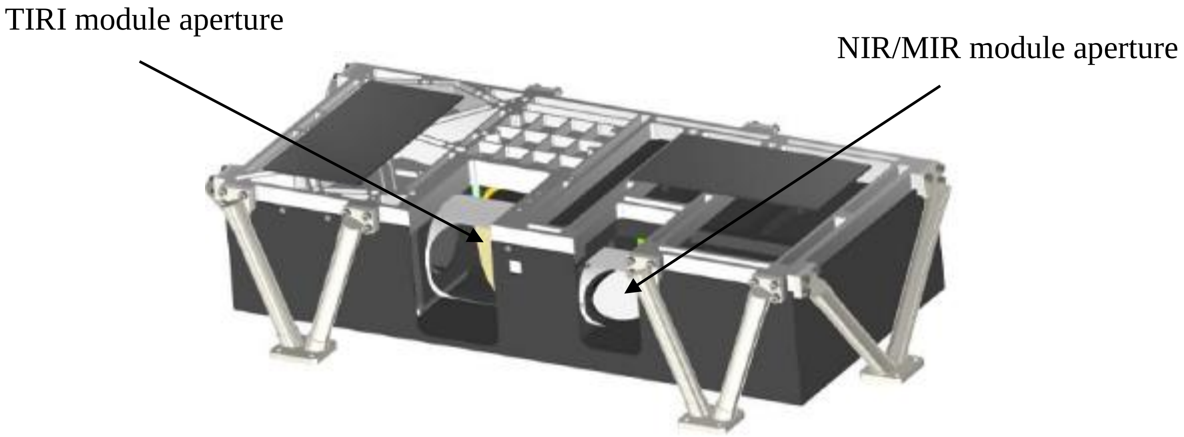

Figure 7 On the left the TIRI module and on the right the NIR/MIR module

During the phase A/B an activity to identify the most suitable detector for the TIRI channel has been performed. Two bolometers from INO and Lynred have been extensively tested. The detector read-out electronics has also been designed and breadboarded. The selected Lynred detector requires the removal of a protective window to increase the sensitivity to longer wavelength.

Also, a new Fabry Perot interferometer for the MIR channel has been prototyped and tested at VTT.

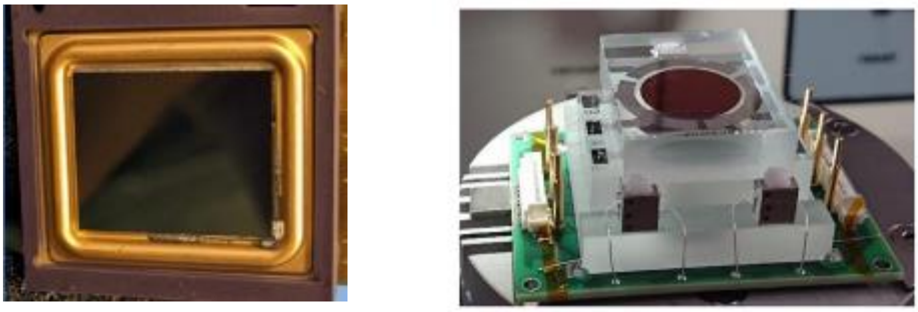

Figure 8 Lynred thermal detector after removing of protective window and FPI prototype

3.4. DUST, FIELD AND PLASMA PACKAGE ON SPACECRAFT A AND PROBE B2

The Dust, Field and Plasma (DFP) package led by CBK in Poland is a combined experiment dedicated to the in situ, multi-point study of the multi-phased ionized and dusty environment in the coma and of its interaction with the surrounding space environment and the Sun.

It is present on both spacecraft A and probe B2, on the latter in a reduced version.

DFP will measure magnetic field, electric field, plasma parameters (density, temperature, speed), the distribution functions of electrons, ions and energetic neutrals, spacecraft potential and the cometary dust. The main objectives are:

- identify boundaries and regions in the cometary environment and its interaction with the Sun and the solar wind (e.g., bow shock, diamagnetic cavity) and to assess their structure,
- map the dust and plasma phases around the target comet,
- assess the mass, momentum and energy transfer in the cometary environment,
- provide simultaneous magnetic field, plasma and dust measurements to identify the interplay between the ionized and dusty phases around a comet and characterize dusty plasma properties,
- map the solar wind – coma interaction,
- describe and map the (i) electron, (ii) negative and positive ion and (iii) energetic neutral atom distribution functions in the vicinity of the comet and in the interaction region with the solar wind,
- identify the electron and ion kinetic processes that mediate the solar wind – comet interactions from ion kinetic scales, down to electron scales.

To enable these multi-point measurements on spacecraft A and probe B2, the DFP is composed of 5 instrumental sensors:

- a fluxgate magnetometer on spacecraft A developed by TU Braunschweig in in Germany
- a fluxgate magnetometer on probe B2 developed by ICL in the UK and IWF in Austria
- a plasma instrument with electric field and nanodust measurement capabilities called COMPLIMENT, developed by CNRS and LPC2E in France, BIRA-IABS in Belgium and IRF in Sweden
- an electron spectrometer called LEES developed by IRAP in France and Charles University in the Czech Republic
- an ion and energetic neutrals spectrometer called SCIENA developed by IRF in Sweden
- a dust sensor on spacecraft A and probe B2 called DISC developed by INAF-IAPS in Italy
- a common data handling unit developed by IAP in Czech Republic
- a common power supply unit developed by CBK in Poland

3.4.1 DFP FGM-A ON SPACECRAFT A

The Fluxgate Magnetometer (FGM) on spacecraft A consists of two fluxgate sensors, the outboard one is merged with a Langmuir Probe (LP). They are mounted on a deployable boom. An electronic card to control the sensors is accommodated in the main electronic unit.

Figure 9 FGM-A boom. On the tip the merged sensor (fluxgate and LP)

3.4.2 DFP COMPLIMENT ON SPACECRAFT A

COMPLIMENT (COMetary Plasma Light InstruMENT) is composed of a merged and a companion probe. The merged probe is mounted on the FGM boom, see previous Figure 9, while the companion probe is mounted on a fixed boom 1m long as shown below in Figure 10.
The probes are used to sample the electric potential and collect ions/electrons from the plasma. A small transmitter is also present to probe the plasma for mutual impedance measurements.

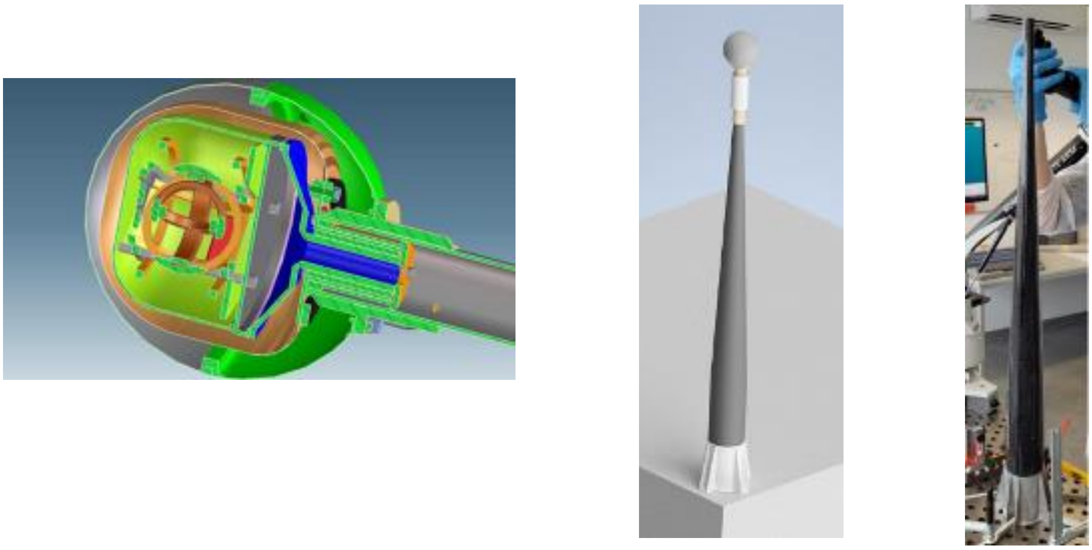

Figure 10 on the left the merged probe (fluxgate + LP) mounted on the FGM-A boom, in the center the fixed COMPLIMENT boom and on the right the boom prototype during assembly and testing

During phase A/B the fixed boom has been prototyped and environmentally tested. The electronics boards have been also breadboarded.

3.4.3 DFP LEES ON SPACECRAFT A

LEES (Low Energy Electron Spectrometer) is a top-hat type electrostatic analyser with a Field-of-View deflector system to allow electrostatic deflection of incoming electrons by up to 70°. Incident charged particles enter the sensor through the exterior electrically grounded toroidal aperture grid. The particles are steered from the arrival direction into the top-hat electrostatic analyser.
The analyser section permits only electrons of the selected energy, from 1eV up to 1 keV, to reach the detector MCPs (MicroChannel Plates). The MCP anode is divided in 16 sections with 22.5° angular resolution. During phase A/B the instrument including electronics has been prototyped.

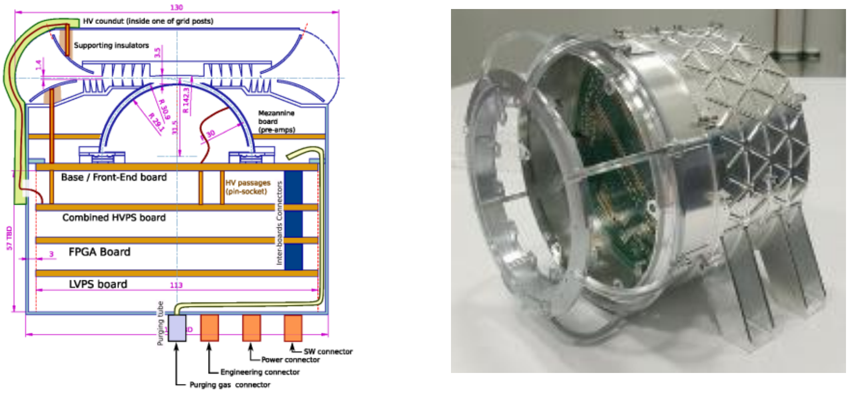

Figure 11 on the left schematic view of LEES, on the right prototype of LEES instrument

3.4.4 DFP SCIENA ON SPACECRAFT A

SCIENA (Solar wind and Cometary Ions and Energetic Neutral Atoms) measures ions in the energy range from a few eV up to 15 keV, and energetic neutral atoms (ENAs) in the solar wind with energy range from 300 eV to 3 keV.

The scientific goal is to understand how the solar wind interacts with and affects the comet environment. Ions are measured in a near 2π hemisphere, whereas the ENAs are observed in a slit 30° wide and 150° long.

The SCIENA instrument comprises a central electronic box connected with the two sensor heads, as shown in Figure 12 below. During phase A/B a prototype of the ENA sensor, including electronics, was built, and successfully tested at a calibration facility at IRF using an ion beam.

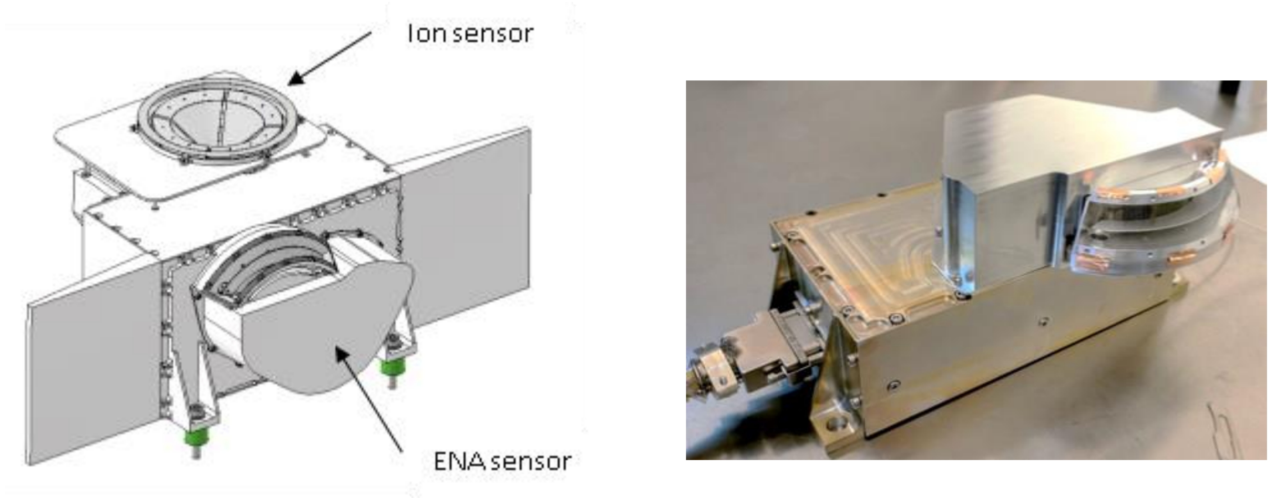

Figure 12 On the left picture of SCIENA, on the right the first prototype of the ENA sensor

3.4.5 DFP DISC ON SPACECRAFT A AND PROBE B2

The Dust Impact Sensor and Counter (DISC) is present on S/C A and on probe B2.

When a dust particle impacts its sensitive surface, the momentum and the mass of the impacting dust particle is measured. DISC will count dust particles with mass >10^{-8} kg

DISC includes a compact dust shield with a layer of aereogel to slow down and stop the cloud of particles penetrating the sensing plate. During phase A/B a prototype has been manufactured and extensively tested to characterise its behaviour with respect to dust impacts.

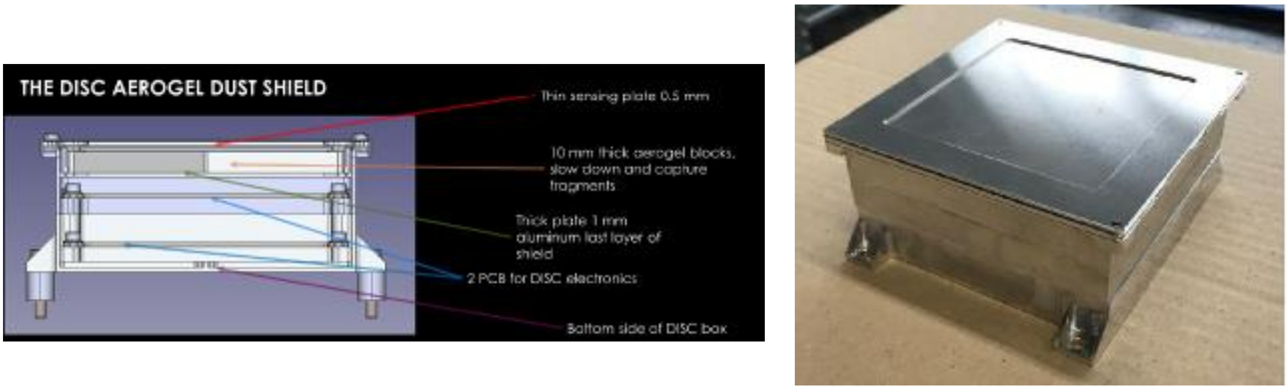

Figure 13 On the left DISC schematic view and on the right DISC prototype assembled

3.4.6 FGM-B ON PROBE B2

Probe B2 will also host two fluxgate magnetometers. It is noted that a magnetometer flies also on probe B1, so the magnetometer is the only instrument present on all three spacecraft. This multi-point capability will allow to assess the 3D structure of the magnetic boundaries and energy transfer through the coma and across boundaries.

Figure 14 One fluxgate magnetometer sensor on the left, with its harness, and its cover on the right

3.5. EnVisS ON PROBE B2

The primary scientific goals of EnVisS (Entire Visible Sky) are to constrain the physical nature of dust particles in the comet coma and tail, and the spatial/temporal variations in that population. It will also determine the three-dimensional structure and nature of ion coma and tail features.
The main features of the instrument which is provided by a consortium led by CNR in Italy are:

- extremely wide field of view 180º x 15º
- spatial resolution: better than 0.2º/pixel
- imaging data in two linear polarimetric channels (0º, 60º)
- imaging data in three filters

The currently baselined filters are:

- one broadband filter, ~550-800 nm with UV block
- two polarizers (0° and 60°), also ~550-800 nm for the analysis of broadband dust at 725nm,

The imaging cadence depends on the instrument operating mode and the share of total probe B2 intersatellite link rate. Data volume/rate reduction techniques will be used and in particular:

- half sky imaging (when all targets are exclusively <90º from ram direction or trailing direction)
- angular resolution reduction through onboard binning
- data compression – lossless preferred

The EnVisS camera acquires multiple framelets as the spacecraft rotates, the image readout is limited to only the regions of the detector in the filter areas. Once the frames are complete, binning of the images occurs within the camera FPGA and the images are stored in the camera built-in flash memory ready for transfer to the Data Handling Unit (DHU) developed by IAA in Spain.

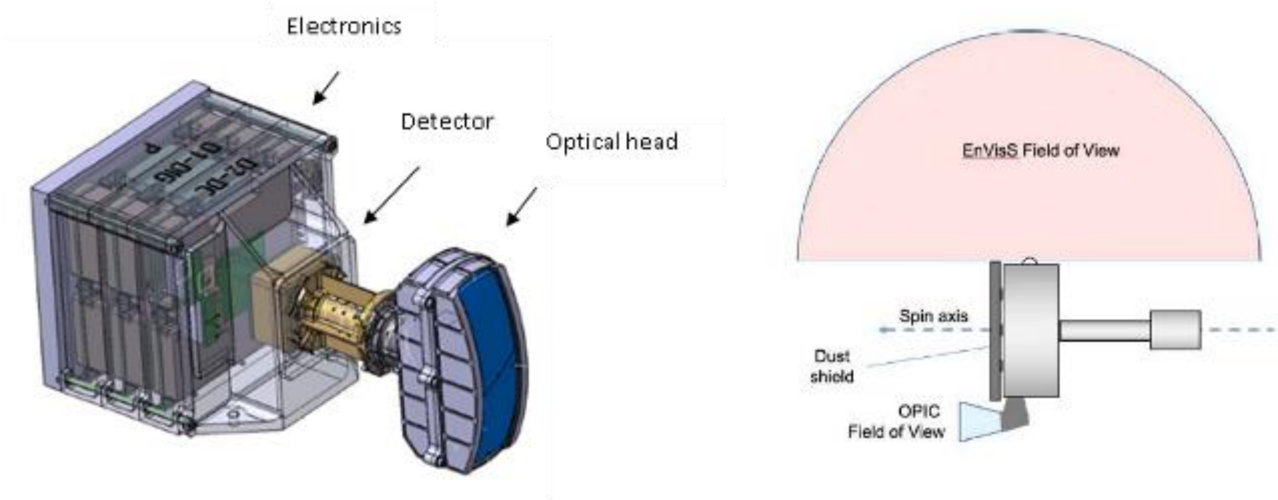

Figure 15 On the left EnVisS design and on the right the accommodation of EnVisS in the Probe B2

During phase A/B a prototype of the EnVisS optical head has been built and will be tested by the end of 2022.

3.6. OPIC ON PROBE B2

The OPIC (OPtical Imager for Comets) camera, which is developed by the University of Tartu in Estonia, aims at taking pictures of the coma and dust environment during the approach, and to photograph the nucleus and near environment during the closest approach phase from approximately 250km distance.
OPIC will take monochromatic images in the visible range while the B2 probe approaches the target. OPIC images will be used to characterize the surface morphology and albedo, determine the surface activity, characterize the dust environment and the nucleus morphology and rotation. OPIC also provides a spatial reference for other instruments of probe B2 and will contribute to improve the nucleus shape model when combined with images of other cameras (e.g., spacecraft A’s CoCa).
During Phase A/B an engineering model has been built and environmentally tested, as shown in the Figure 16 below.

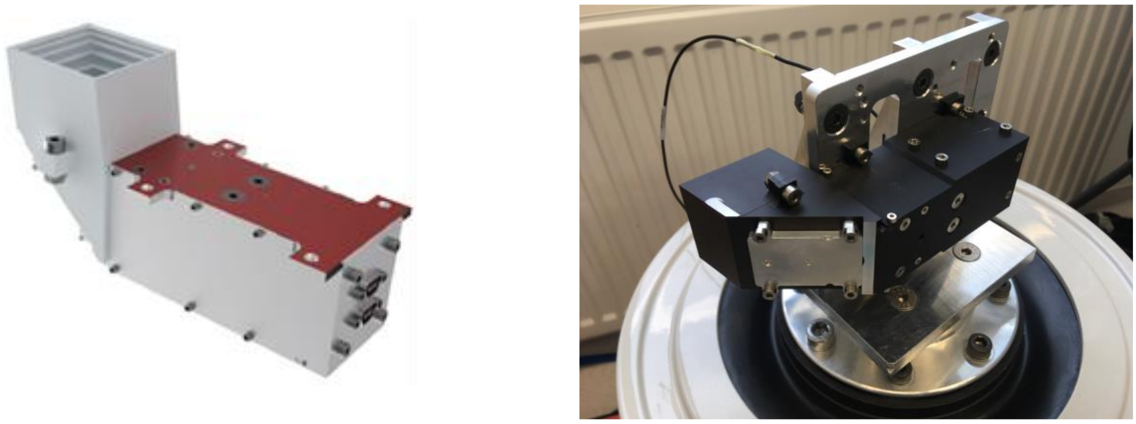

Figure 16 On the left the OPIC instrument and on the right the engineering model during vibration

4. INSTRUMENT MASS AND POWER BUDGET

One of the main challenges of the Comet Interceptor mission is the development of instruments sufficiently light and requiring very little power to fit within the very tight resources available on spacecraft A and probe B2. All instrument teams did an intense effort to reduce the required mass and power to the very minimum.
Table 1 below gives the summary of the available mass and power for each instrument. The mass also includes the internal harness between the units and thermal hardware.

Table 1 Mass and power budget of the instruments

	Instrument/sensor	*Mass [kg]*	*Average power [W]*	*Remark*
S/C A	CoCa	13.5	18.0	
	RMA	11.5	8.0	
	DFP on S/C A	11.3	22.0	Total for all DFP units
	MANiaC	6.8	35.0	
	MIRMIMS	8.8	12.0	
Probe B2	DFP on probe B2	3.5	10.0	
	EnVisS	1.75	8.5	EnVisS and OPIC share a single power unit
	OPIC	0.5		

5. SPACECRAFT ACCOMMODATION CHALLENGES

To accommodate the large number of instruments on board on a relatively small spacecraft has been challenging and required iterations among ESA, the instrument teams, and the candidate Primes.
CoCa requires a stable thermal environment to control the telescope temperature and to guarantee good image quality. Also, CoCa requires a dedicated rotating mirror (RMA) to point the FoV at the nucleus during the fly-by which needs to be accommodated in front of the CoCa telescope.
Pointing of the RMA to the nucleus requires that the spacecraft guidance and navigation system communicates in real time to the RMA electronics the main parameters of the encounter (e.g., distance to closest approach, time to closest approach, fly-by relative velocity) so that the scan mirror can be moved accordingly. MIRMIS also presents two scan mirrors, which need to be kept pointing to the nucleus during fly-by, requiring similar approach as for the CoCa RMA. Also, the co-alignment of the rotation axis of the MIRMIS mirrors with the rotation axis of the CoCa RMA needs to be ensured, as well as the alignment with the navigation cameras.
The sensors of MAniaC need to be accommodated in the front part of the spacecraft just behind the dust shield to be able to measure the incoming particles. This requires some local adaptation of the dust shield striking a compromise between the FoV of the sensors and protection of the sensors.
The sensors mounted on the two booms (FGM-A and COMPLIMENT) must also be located in the front part (avoiding the wake of the spacecraft) which requires local adaptation of the dust shield.
DISC is mounted on the dust shield to measure the incoming dust particles.
SCIENA requires a completely non-obstructed field of view for the ENA sensor and requires the sun to be at a certain angle with the boresight of the instrument. It needs therefore to be accommodated on the sun illuminated spacecraft side. LEES has also a large field of view and the unavoidable obstruction of part of the FoV by the solar arrays has been carefully analysed.
The probe B2 instruments require dedicated openings in the probe’s thermal insulation layer to ensure their required FoV and they are also protected by the probe dust shield.
Another major challenge is the need to ensure sufficient magnetic cleanliness, as required by the magnetometers on board, but still limiting the complexity and the cost of the spacecraft e.g., maintaining heritage of platform units and avoiding implementation of expensive measures.

6. CONCLUSION

A comprehensive suite of instruments for Comet Interceptor addressing all major scientific topics related to cometary science as requested by the European cometary science community is under development.

Despite the large number of instruments and sensors, the mass and power demands of the instrument suite remains compatible with the available resources thanks to an intense design effort by the instrument teams to optimize the instrument design and reduce mass and power demands to a minimum.

Intense work has been performed to accommodate all the instruments on a relatively small spacecraft ensuring compatibility with the requirements of the instruments and complying with the short development time and strict cost at completion of a Fast-Class Science mission.

Several early development activities were performed for the instruments, which were funded mostly via ESA's Science and Technology programme [10] and the ESA PRODEX programme [11]. Many breadboards and prototypes have been manufactured and tested to increase the technology readiness level (TRL) and to de-risk the following development steps.

The current design maturity of the instruments is considered adequate for a preliminary design review with most critical functions having been demonstrated with prototypes in a relevant environment (TRL 6 or higher). The instruments development is on track to conclude the instrument PDR in September 2022. The CDR is then expected to be completed within 2023 and the delivery of the qualified flight models between the end of 2025 and the beginning of 2026.

The authors would like to acknowledge the valuable contributions of all members of the instrument consortium and thank them for their intense effort and dedication to make the Comet Interceptor mission a success.

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8. ACRONYMS

ADMATIS	ADvanced MATerial In Space, Hungary
BIRA-IASB	The Royal Belgian Institute for Space Aeronomy, Belgium.
CBK	Centrum Badań Kosmicznych PAN (Space Research Centre), Poland
COMPLIMENT	COMetary Plasma Light InstruMENT
CNR	National Research Council of Italy
CoCa	Comet Camera
CSL	Centre Spatial de Liege, Belgium
CTI	Creotech instruments S.A. , Poland
CU	Charles University, Prague, Czech Republic
DISC	Dust Impact Sensor and Counter
DFP	Dust, Field and Plasma package on board spacecraft A and probe B2
DLR	German Aerospace Center
FGM-A	FluxGate Magnetometer on Spacecraft A
FGM-B2	FluxGate Magnetometer on Spacecraft B2
FoV	Field of View
IAA	Institute of Astrophysics of Andalusia
IAP	Institute of Atmospheric Physics, Prague, Czech Rep.
ICL	Imperial College London, UK
IGeP TUB	Institute For Geophysics and Extra-terrestrial Physics, Technical University Braunschweig, Germany
IWF	Institut für Weltraumforschung, Austria
LPC2E	Laboratoire de Physique et Chimie de l’Environnement et de l’Espace, France
INAF-IAPS	Institute for Space Astrophysics and Planetology, Rome, Italy
IRAP	Institute for Research in Astrophysics and Planetology, France
IRFK	Swedish Institute of Space Physics, Kiruna, Sweden
IRFU	Swedish Institute of Space Physics, Uppsala, Sweden
IWF	Space Research Institute, Graz, Austria
LEES	The Low-Energy Electron Spectrometer
LP	Langmuir Probe
MANiaC	Mass Analyzer for Neutrals in a Coma
MIRMIS	Modular InfraRed Molecules and Ices Sensor
MSSL	Mullard Space Science Laboratory in the UK
NDG	Neutral Density Gauge
REMRED	REMRED Space Technology, Hungary
SCIENA	Solar wind and Cometary Ions and Energetic Neutral Atoms
SGF	SGF Technology, Hungary
SHU	Sensor Head Unit
UP	Univ. Parthenope, Italy
UPa	Univ. Padova, Italy
TAS-CH	Thales Alenia Space Switzerland
ToF	Time of Flight
TRL	Technology Readiness Level
VTT	Technical Research of Finland