

Rapid Response Today:

The Comet Interceptor Mission

@cometintercept
@einionyn

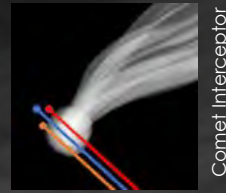


Geraint Jones

UCL Mullard Space Science Laboratory, UK

The Centre for Planetary Science at
UCL/Birkbeck, UK

The Comet Interceptor consortium: Geraint Jones, Colin Snodgrass, Cecilia Tubiana, and >300 others!



University of Oxford, July 2022



What led to Europe funding Comet Interceptor and what lessons can we take away from that process?

cosmic vision

[ESA](#)[SCIENCE & TECHNOLOGY](#)[COSMIC VISION](#)

Missions

[Show All Missions](#)

Cosmic Vision 2015 - 2025

- Cosmic Vision
- Candidate Missions
- Missions of Opportunity

Cosmic Vision themes

- The Hot and Energetic

CALL FOR A FAST (F) MISSION OPPORTUNITY IN ESA'S SCIENCE PROGRAMME

16 July 2018

The ESA Director of Science solicits proposals from the scientific community in ESA Member States for a Fast (F) mission to be launched in the 2026-2028 timeframe.

This Call for a Fast mission aims at defining a mission of modest size (wet mass less than 1000 kg) to be launched towards the Earth-Sun L2 Lagrange point as a co-passenger to the [ARIEL](#) M mission, or possibly the [PLATO](#) M mission. From L2 the mission should reach its target orbit or destination with its own propulsion system.



6-Jul-2022 12:09 UT

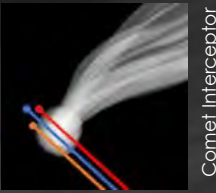
Shortcut URL

<https://sci.esa.int/s/AqBdKJw>



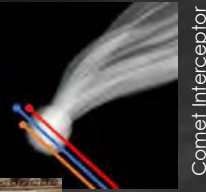
ESA F-class call

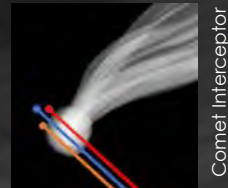
- In July 2018, F-class mission call announced.
- Maximum cost to ESA at completion, excluding launch: €150M.
- ESA member states and other collaborating agencies generally fund instruments and the science teams.
- Shared launch with Ariel exoplanet telescope, to Sun-Earth L2 point, in 2028 (now late 2029)
- Two-stage proposal submission process; only groups downselected in Phase 1 were invited to submit to Phase 2



Comet Interceptor

January 2019: Proposal workshop, Royal Astronomical Society, London

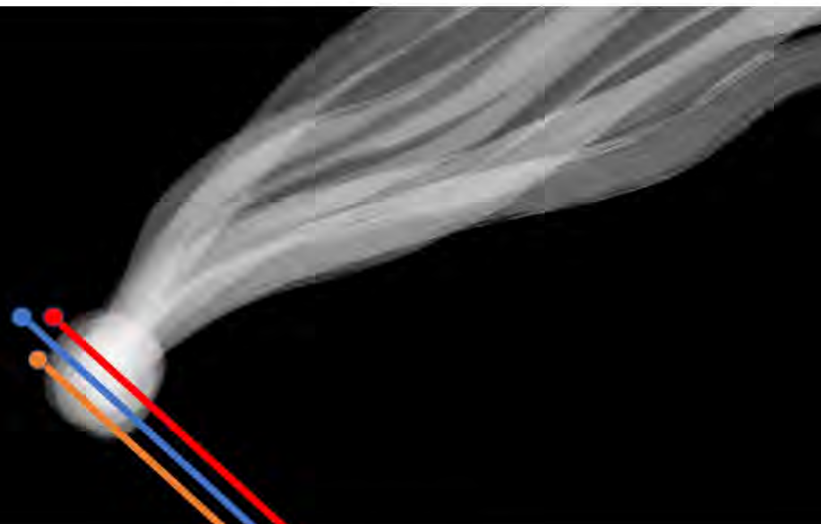




Comet Interceptor

A Mission to a Dynamically New Solar System Object

A Phase-2 Proposal in Response to the
European Space Agency's Call for a Fast Class Mission



Lead Proposer: Geraint Jones
On behalf of the Comet Interceptor Consortium

Mullard Space Science Laboratory, University College London, UK

Deputy Lead Proposer: Colin Snodgrass (U. Edinburgh, UK)

National Co-PIs:

Italy: Alessandra Rotundi, University "Parthenope",
Naples

Estonia: Andris Slavinskis, University of Tartu

Finland: Antti Näsälä, VTT

Sweden: Hans Nilsson, IRF-K

Poland: H. Rothkahl, CBK

Germany: Jean-Baptiste Vincent, DLR Berlin

France: Pierre Henri, LPC2E, Orléans

Switzerland: Nicholas Thomas, Phys. Inst., Univ. Bern

Belgium: Johan De Keyser, Royal Belgian Institute for
Space Aeronomy

Czechia: Ivana Kolmasova

Japan: Ryu Funase, University of Tokyo

Spain: Luisa M Lara, Instituto de Astrofísica de
Andalucía

Austria: Martin Volwerk, Space Research Institute,
Austrian Academy of Sciences, Graz

Netherlands: Stefano Speretta, TU Delft

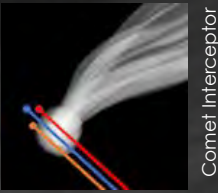
USA: Geronimo Villanueva, NASA Goddard Space
Flight Center



March 2019: Phase 2 proposal submitted

May 2019: Interview by F-class selection panel, ESTEC

June 2019: Mission selected by ESA for further study

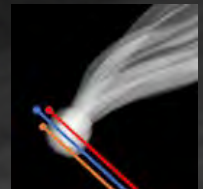
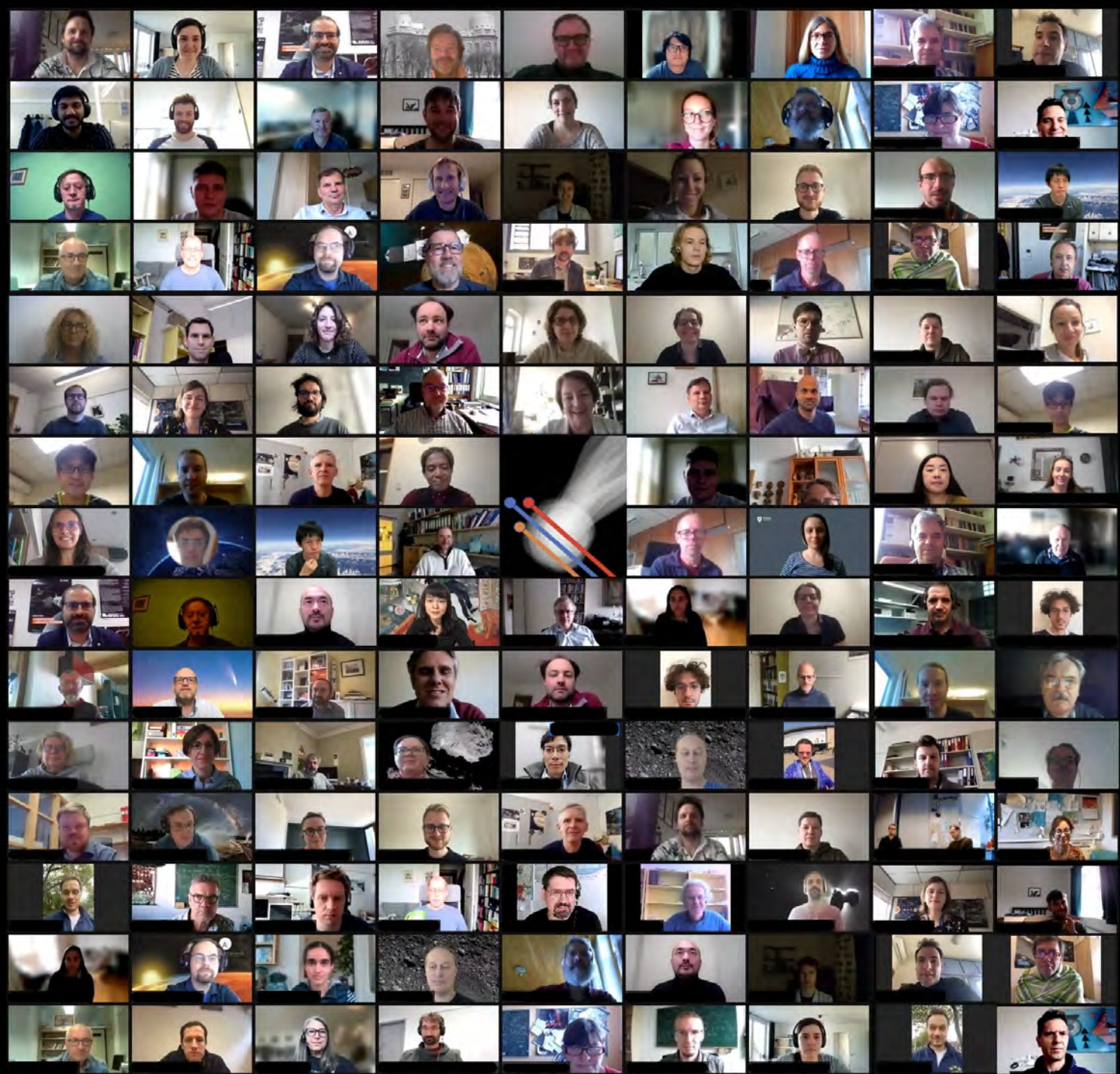


July – December 2019: Concurrent Design Facility study, ESTEC

CDF team verified that proposed concept was viable within cost and mass constraints

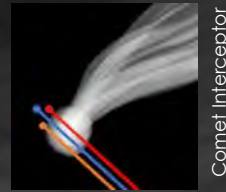


December 2019, first in-person team meeting post-selection, IAA, Granada, Spain



Comet Interceptor

8 June 2022



Comet Interceptor

ESA Mission Adoption

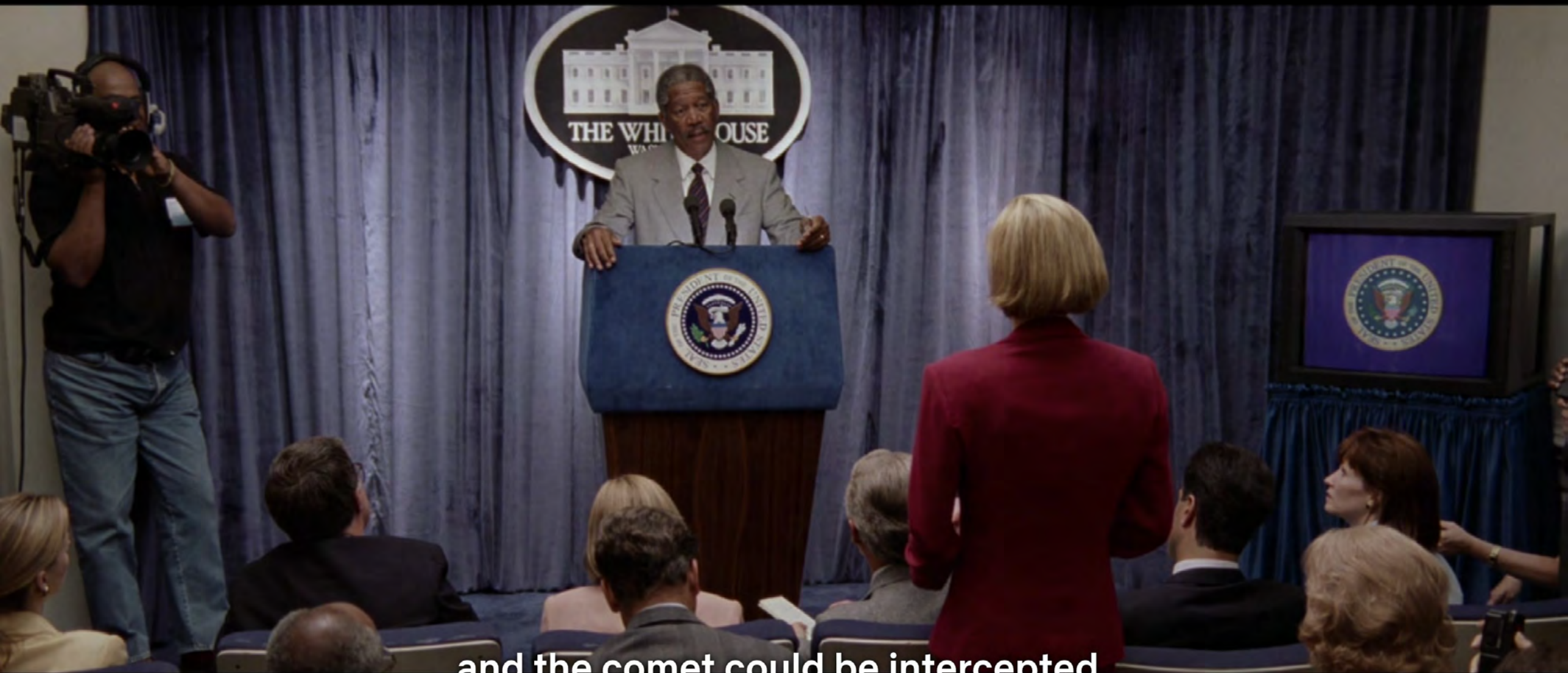
The banner features a dark space background with a bright orange sun on the left, a grey moon, a yellowish-orange planet, and a blue comet streaking across the sky. The Earth is visible in the bottom left corner.

☰ 🔍 → THE EUROPEAN SPACE AGENCY 

SCIENCE & EXPLORATION

Comet Interceptor approved for construction

08/06/2022 8513 VIEWS 130 LIKES



and the comet could be intercepted,

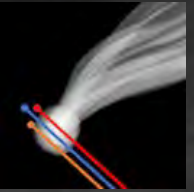
Deep Impact (1998)



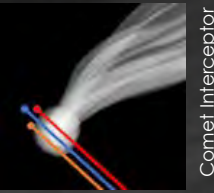
What led to Europe funding Comet Interceptor and what lessons can we take away from that process?

- Comet Interceptor proposed in response to ESA's F-class mission call.
- All missions to be proposed to that call were to be directed to Sun-Earth L2.
- Comet Interceptor found to be a viable, ground-breaking, and scientifically valuable mission whose flexibility imposed no constraints on Ariel launch timing.

What architecture decisions
led to CI today?



Comet Interceptor is a mission targeting a long-period comet, preferably dynamically-new, or an interstellar object.



Comet Interceptor

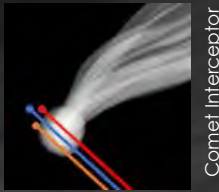
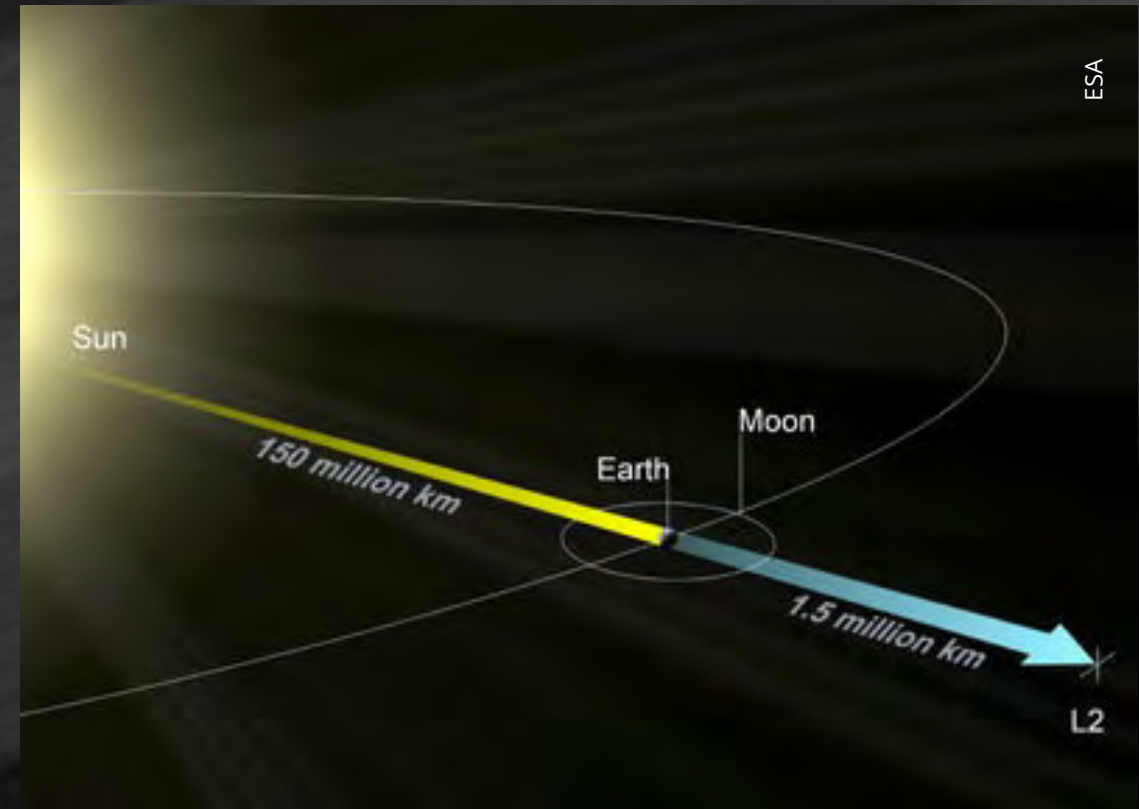
Why?

- All previous comet missions have been to objects that have passed the Sun many times
- Those comets have changed over time, and are covered in a thick layer of dust
- A dynamically-new comet is one that is probably nearing the Sun for the first time
- These object are **pristine**



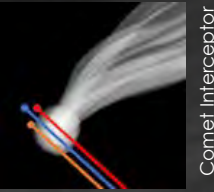
Solution: We Wait, in Space

- We build a spacecraft that can cope with all kinds of comets
- We launch it to a stable 'parking' location in space
- We can respond rapidly to new discoveries - departure from parking location 6-12 months after target discovery



How?

- The only way to encounter a long period comet is to find one inbound very early
- The upcoming Vera Rubin Observatory – LSST - will increase the distance at which comets are discovered inbound
- Even with advance warning, still not enough time to plan and build a spacecraft

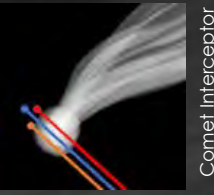


Comet Interceptor

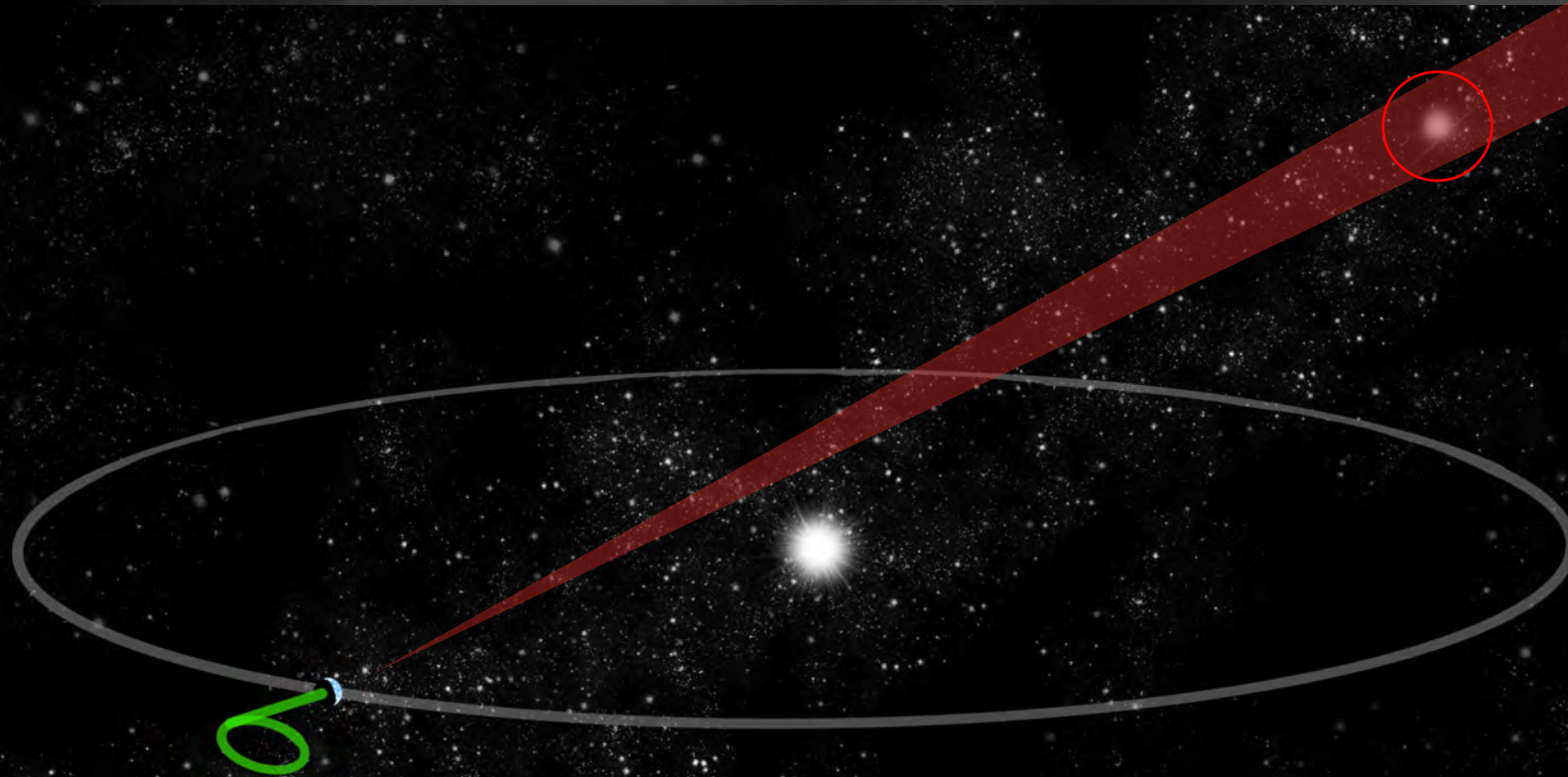
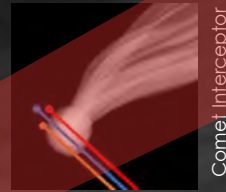


Rubin Obs/NSF/AURA

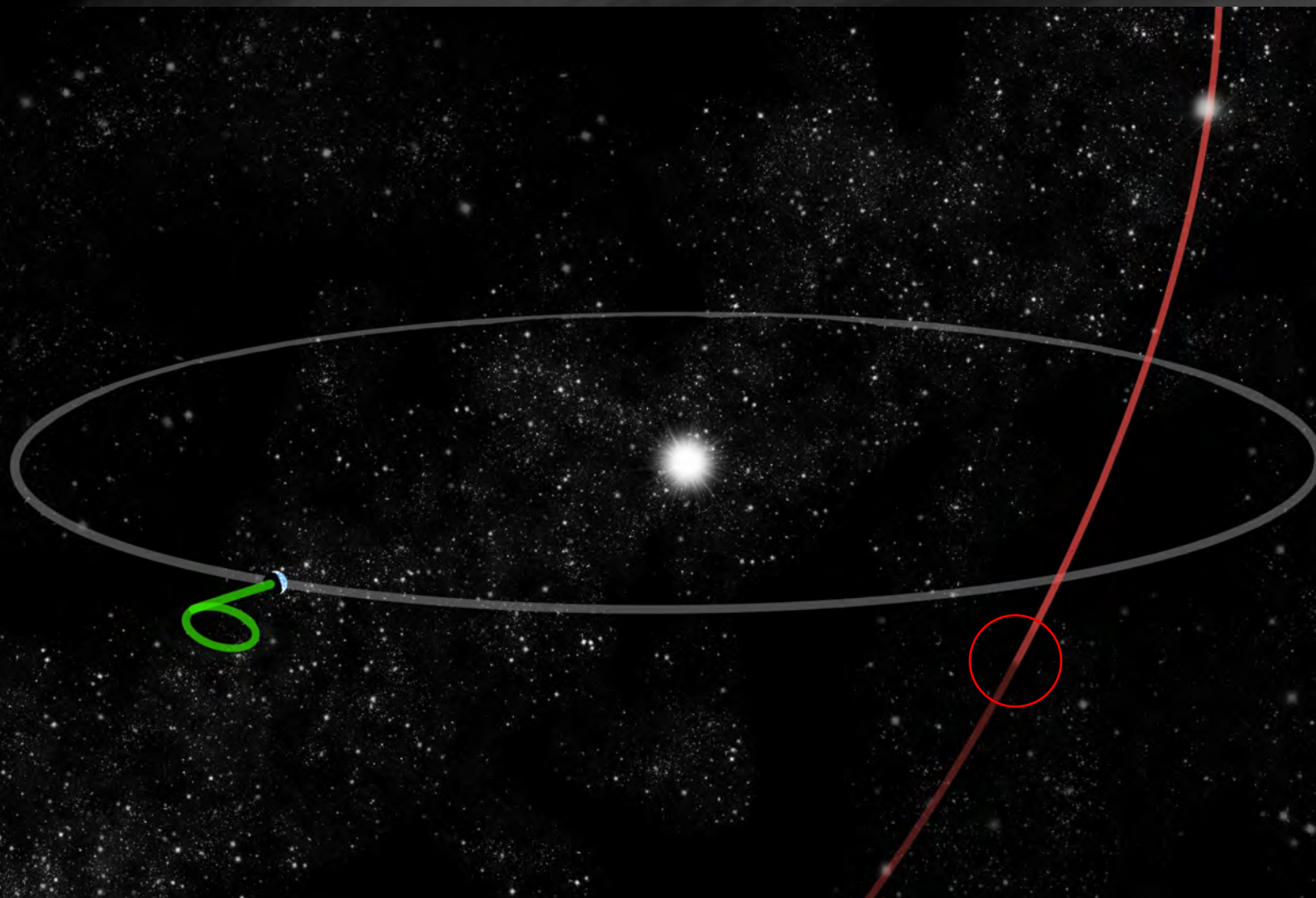
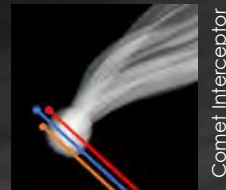
- Mission 'parked' at stable Lagrange point L2 after launch with Ariel
- Waits for up to 3-4 years for new target discovery



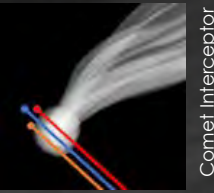
- Target discovered by a ground-based observatory



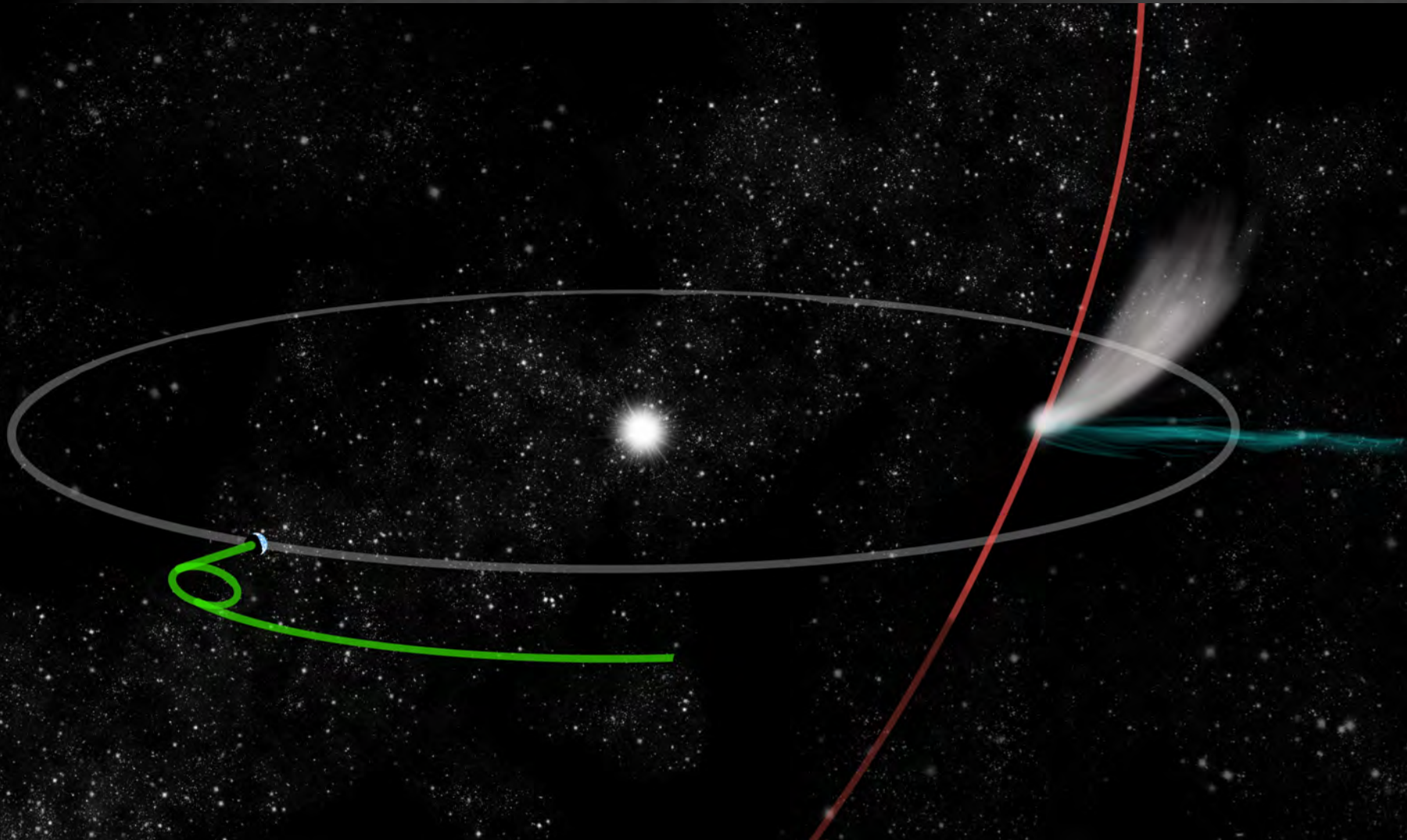
- Orbit computed and ecliptic crossing point predicted



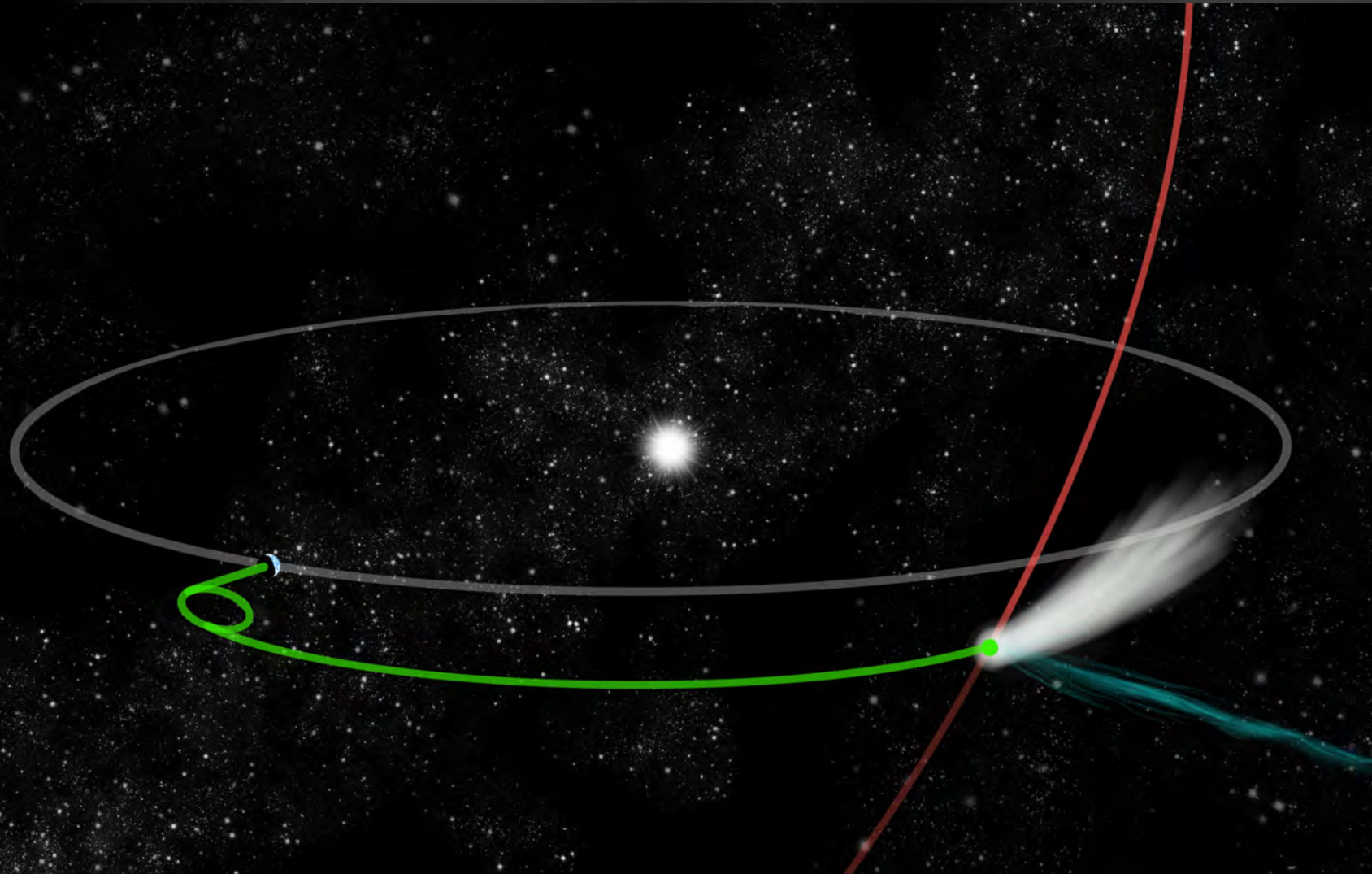
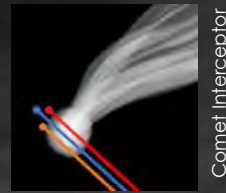
- Comet Interceptor leaves L2 to intercept comet's path



Comet Interceptor



- Encounter with comet close to the ecliptic plane
- Targets like this are being found, e.g. C/2021 P4 (ATLAS), C/2022 E3 (ZTF) could have been reachable if mission was operating now



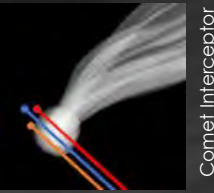
Challenges

- We may encounter comets at > 70 km/s
- We can't predict our path through the comet
- Cost limit means that entire mission will be < 6 years in duration

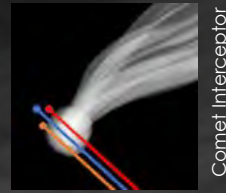
Solutions

- Limited radio link to Earth at encounter
- Dust shielding equivalent to that on Giotto
- Wait at L2 limited to ~ 3 years
- Backup short period comet targets

A mission to short period comet will carry out new science: not repeat of previous missions.



A Multi-Spacecraft Mission



A: main spacecraft

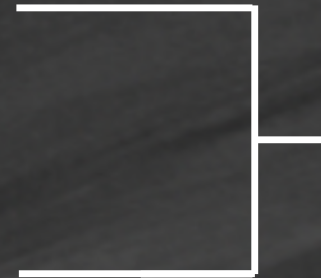
safe / distant measurements
'safe' flyby distance



B1: small probe



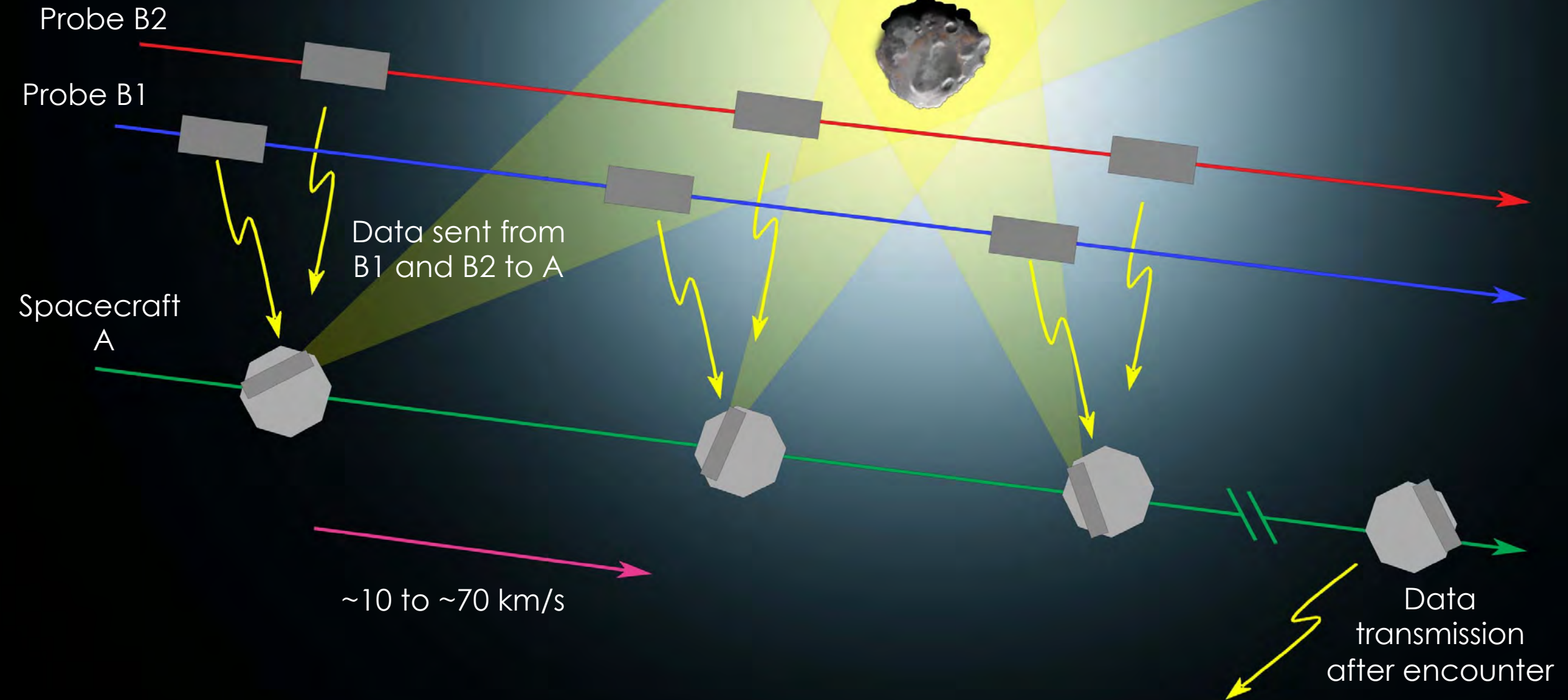
B2: small probe



higher risk / high gain
closer approaches
to nucleus

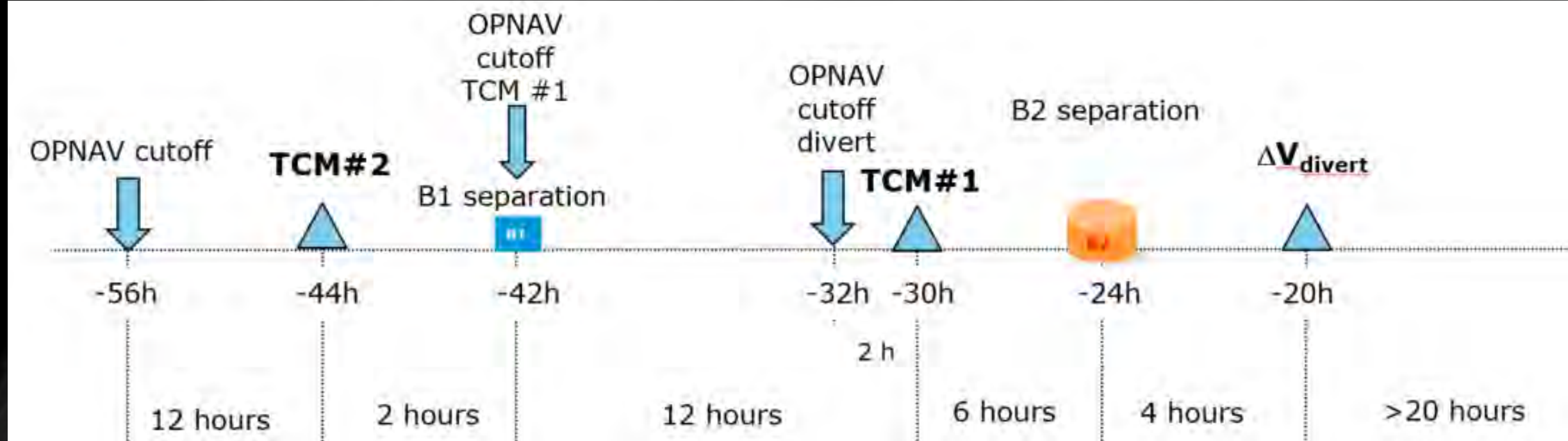
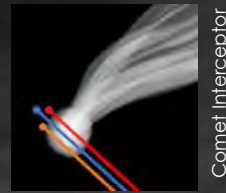
- To separate **time and space variation** in the coma
- To enable **simultaneous** coma + nucleus + solar wind interaction studies at different distances
- To separate **safe / distant** measurements and **high risk / high gain** close approaches

Flyby scenario



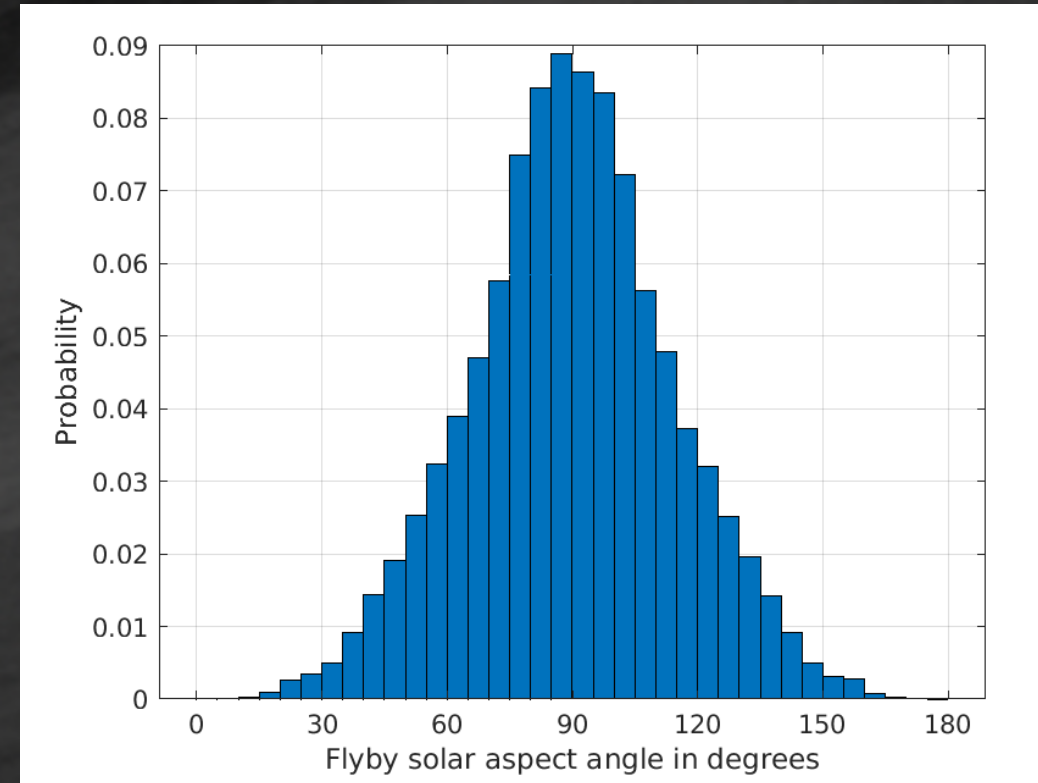
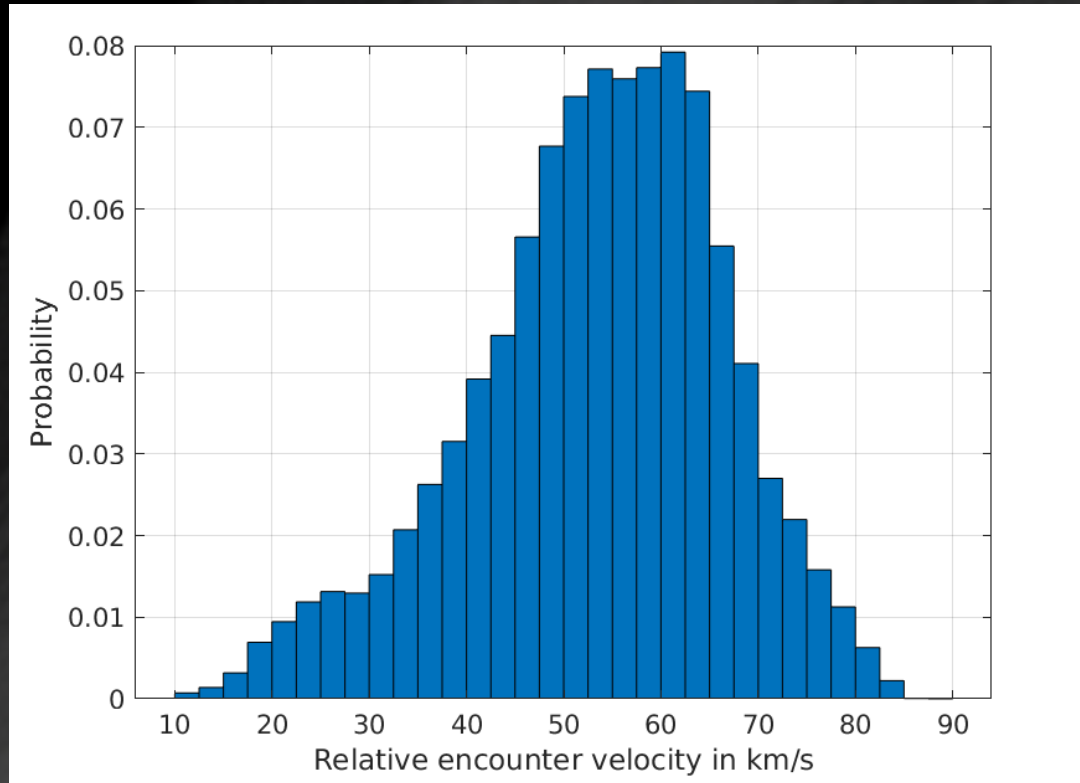
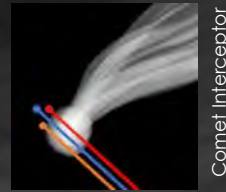
Everything – from S/C B1 and B2 release to end of operations – happens within a few days

Timeline of operations



[Comet Interceptor Definition Study Report, ESA-SCI-DIR-RP-001, 2022; also Jones et al, submitted to Sp. Sci. Rev.]

Probability distributions of encounter velocity and solar aspect angle



[Comet Interceptor Definition Study Report, ESA-SCI-DIR-RP-001, 2022; also Jones et al, submitted to Sp. Sci. Rev.]

Design Driver

Dual launch with ARIEL on A62

Multi-point observation principle

Large payload complement

Target defined at late stage

Maximise probability of reaching a suitable target

Main Implications

Max launch mass limited to 975 kg.

Additional probes to be carried by the main S/C.

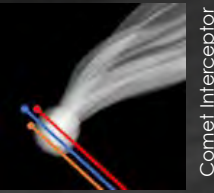
Accommodation of several in-situ and remote sensing units on S/C A and Probe B2.

S/C design compatible with range of possible targets, of encounter conditions and Sun-Earth-Target geometries.

Maximise Delta-V capability.

Navigation & Target tracking capabilities to remain compatible with multiple targets.

High maximum fly-by relative velocity (designed for range 10 to 70 km/s).



Design Driver

Interplanetary mission

Measurements performed during a high relative velocity fly-by

Comet environment

Programmatic constraints from F-class mission call.

Main Implications

S/C operating at $\sim 1\text{-}2$ AU from Earth.

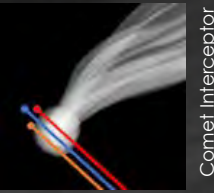
“One-shot” science. Data downlinked to Earth after the closest approach.

Capability of surviving the micrometeoroid and dust environment for a variety of possible targets.

Cost at completion boundaries.

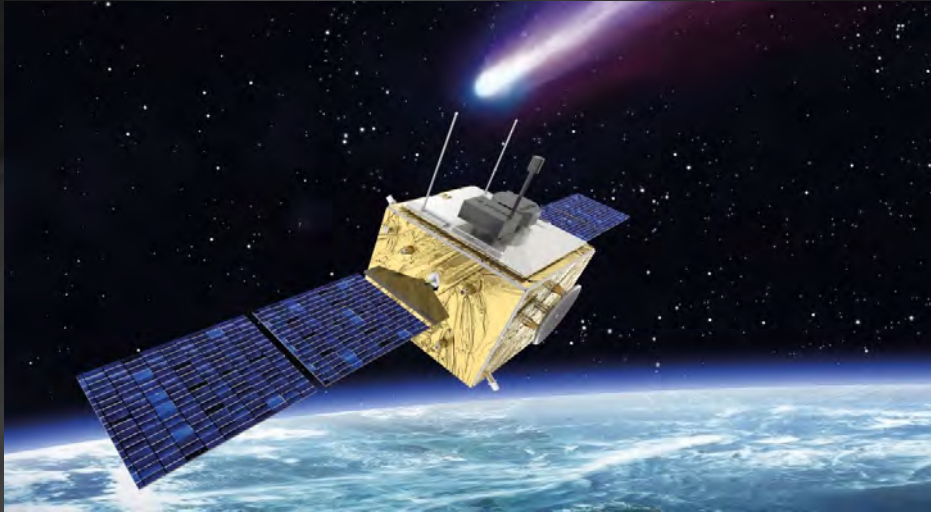
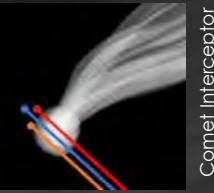
Fast development track.

Incompatibility with dedicated technology developments and need to rely on existing, flight qualified solutions.

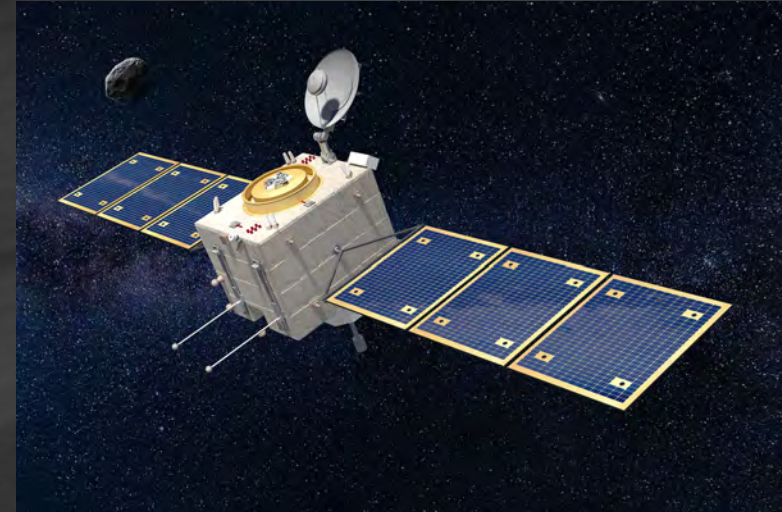


Spacecraft Design

- Two industrial consortia contracted by ESA to design Spacecraft A and B2 (B1 provided by Japan).
- OHB Italia recently selected to be the prime contractor.



Thales Alenia Space UK



OHB Italia

- The overall dimensions of the stowed S/C are $\sim 1.6 \text{ m} \times 1.6 \text{ m} \times 1.5 \text{ m}$
- Wet mass including margins $< 975 \text{ kg}$
- A and probe B1 - 3-axis stabilised. Probe B2 - spin stabilised.
- Propulsion (S/C A): chemical (no propulsion onboard probe B1 and B2).
- Comms: S-band (Inter Satellite Link) & X-band (communication with Earth).
- Data volume from fly-by: $\sim 200 \text{ Gbits}$



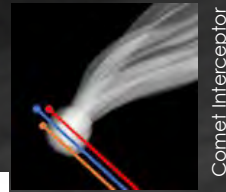
What architecture decisions led to CI today?

- Delivery to L2 was a requirement for the mission from the outset.
- Mass and mission cost cap limited the size, complexity, and duration of the mission.
- Total CI spacecraft mass, including propellant and margins is limited to 975 kg by the presently estimated launcher performance, for a dual launch with Ariel.

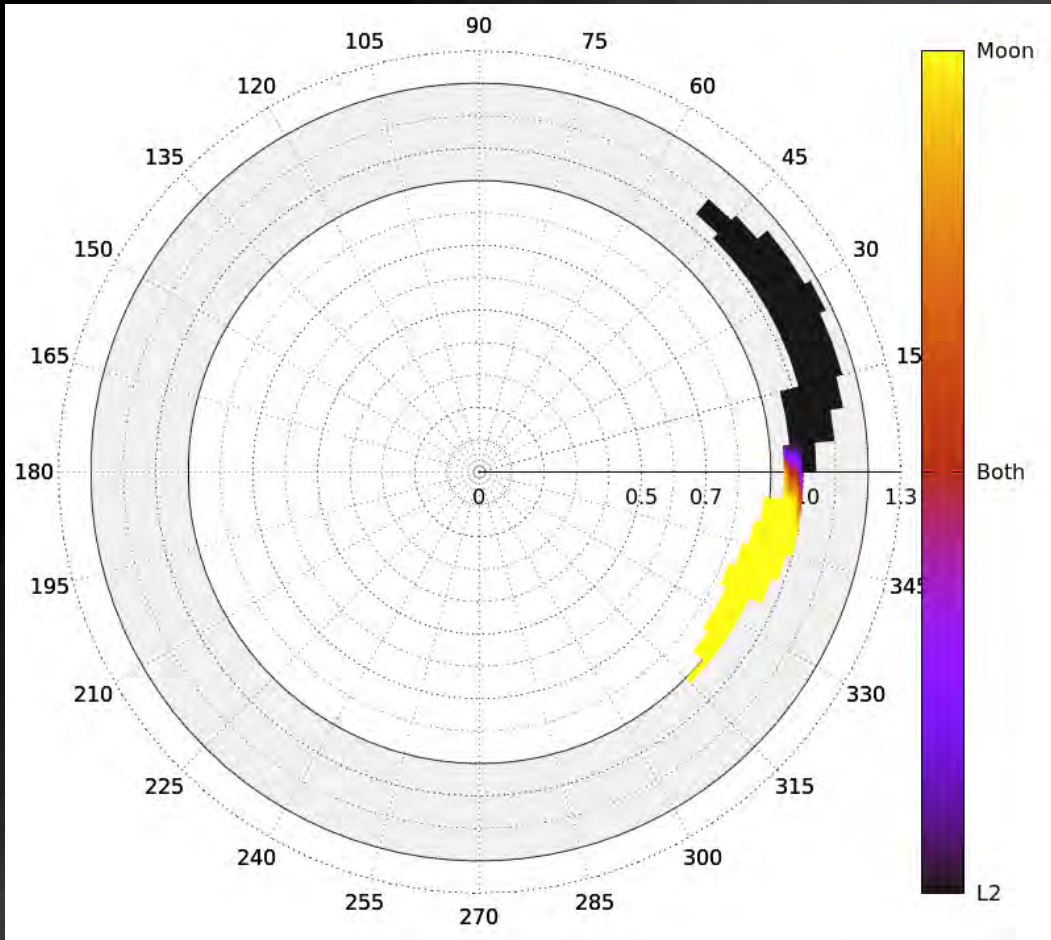


What are the limitations of CI and how might we implement rapid response differently in the future?

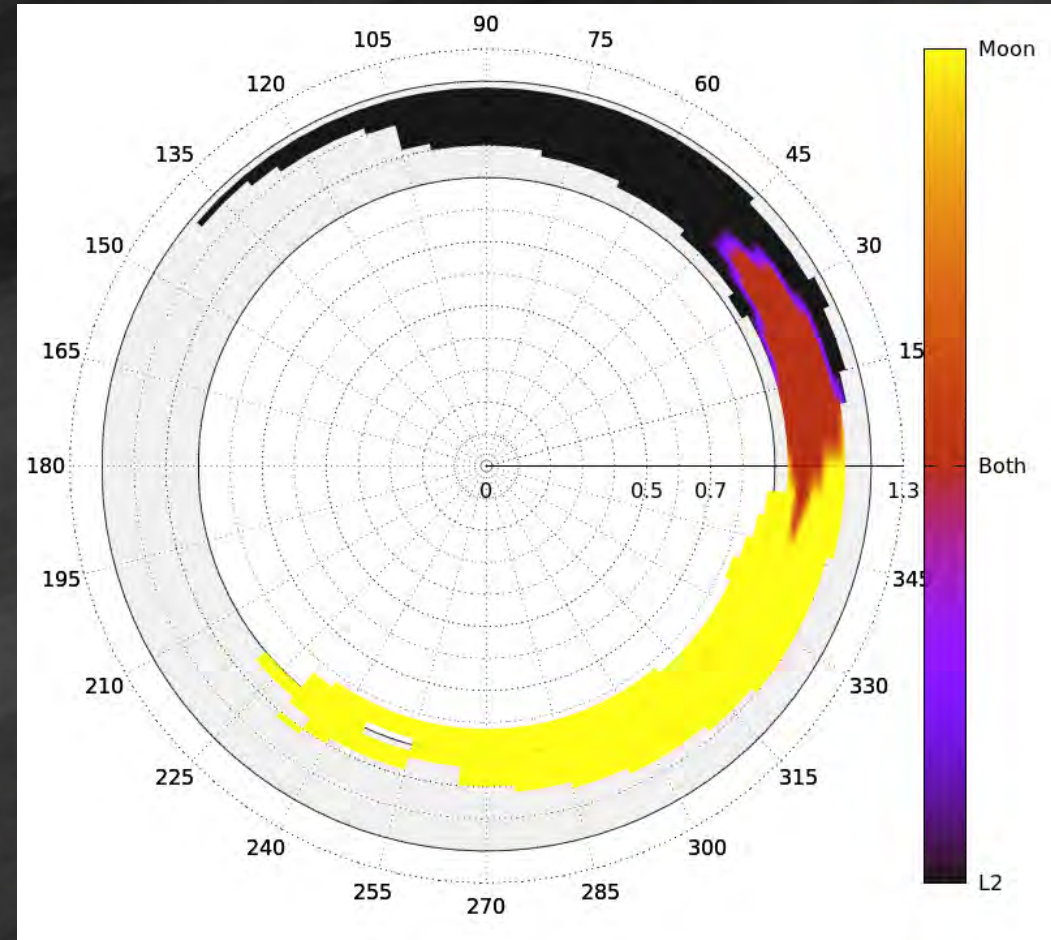
Reachable R-phase angle regions



Comet Interceptor



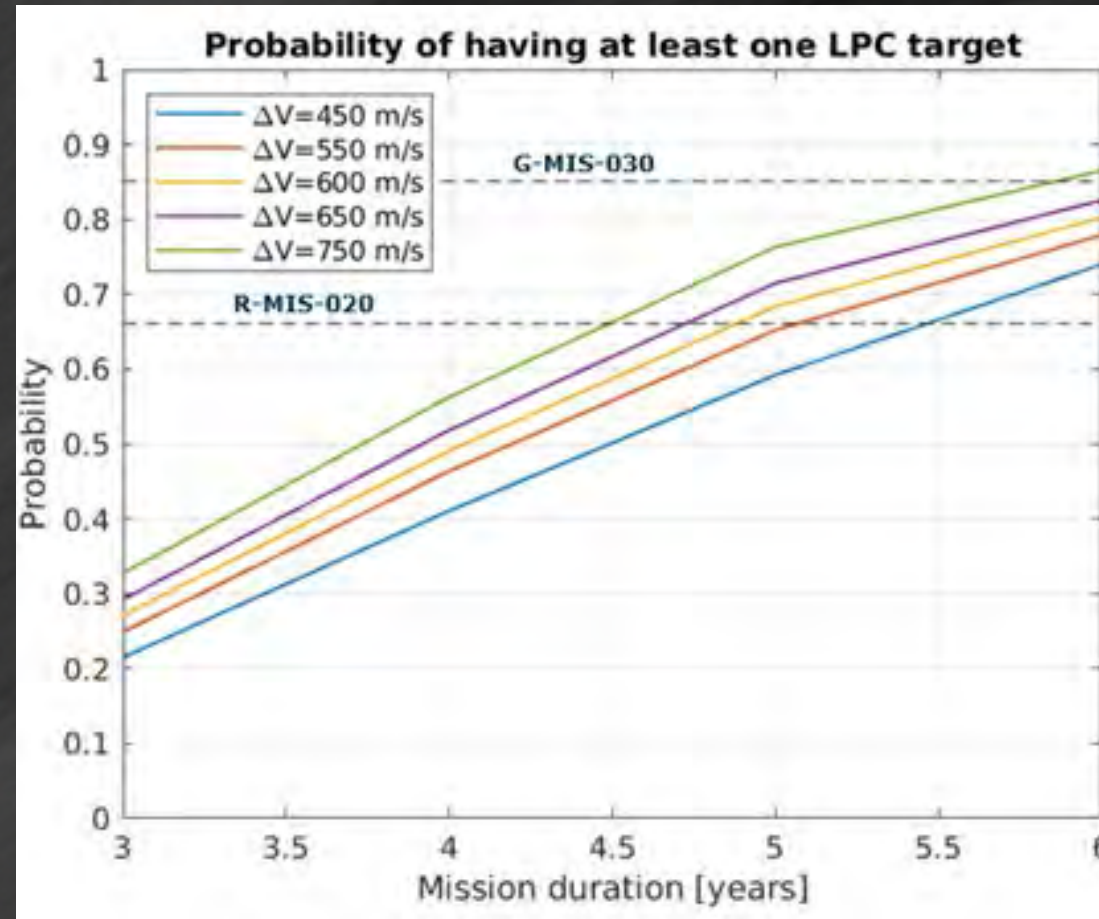
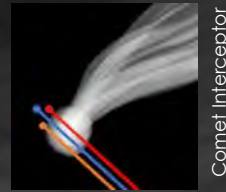
Transfer Time: 1 year



Transfer Time: 3 years

[Comet Interceptor Definition Study Report, ESA-SCI-DIR-RP-001, 2022; also Jones et al, submitted to Sp. Sci. Rev.]

Influence of delta-V and mission duration on probability of at least one LPC target.



Minimum delta-V requirement is 600 m/s.

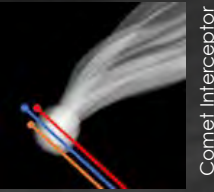
[Comet Interceptor Definition Study Report, ESA-SCI-DIR-RP-001, 2022; also Jones et al, submitted to Sp. Sci. Rev.]

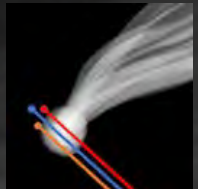


What are the limitations of CI and how might we implement rapid response differently in the future?

- Mass/delta-V constraint limits the number of reachable targets within the mission's duration.
- Thermal design fits reachable heliocentric distance range.
- Mass also limits instrumentation, though mission is carrying a very capable set of scientific hardware.
- For future similar missions: more mass & delta-V; payload?

What instruments are on CI and what science objectives will it address?

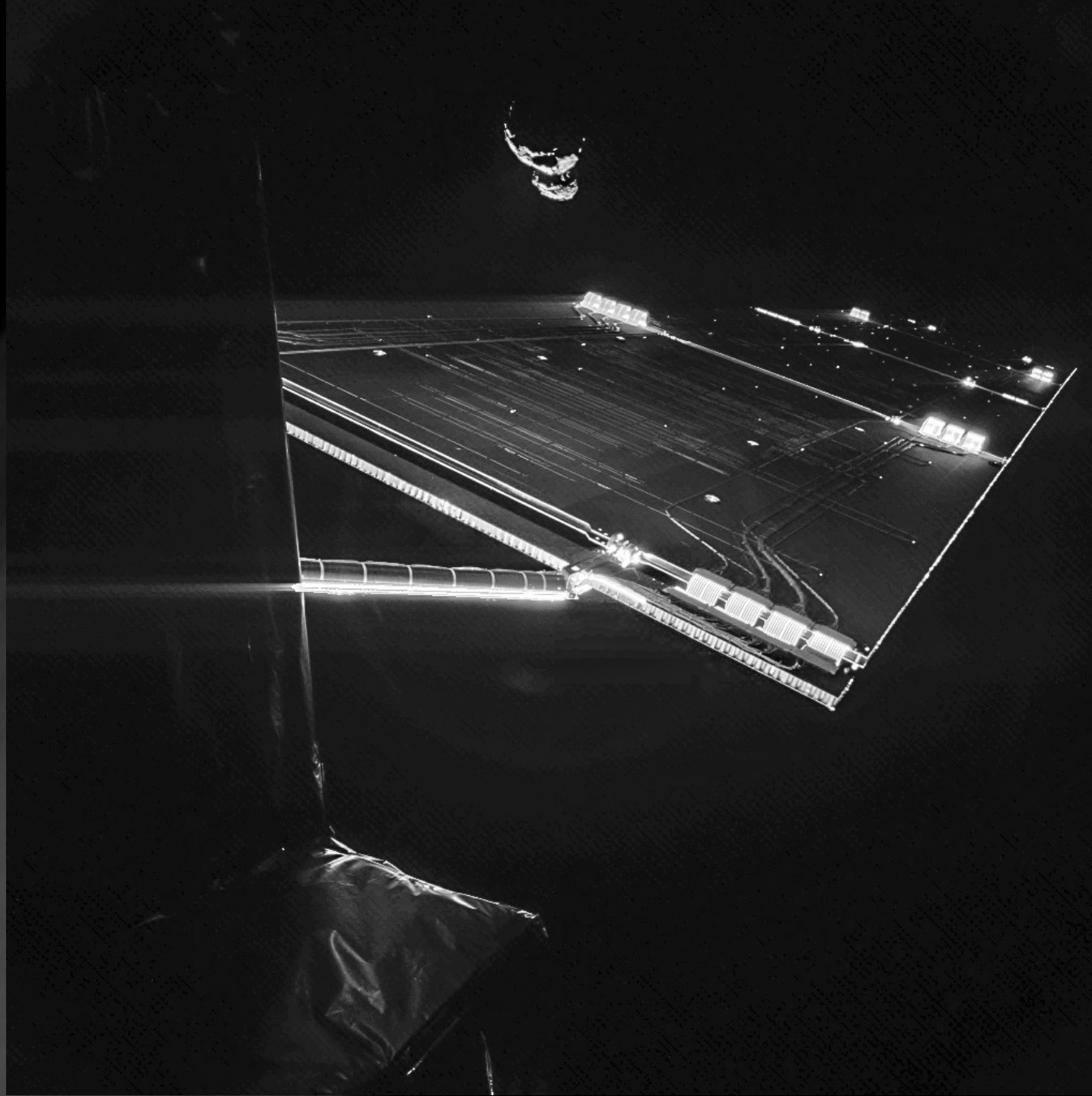




Comet Interceptor



Comet Interceptor



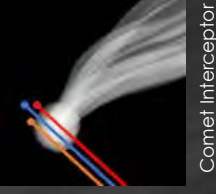
Comet Interceptor

Rosetta and Comet 67P
from CIVA camera on
Philae lander.

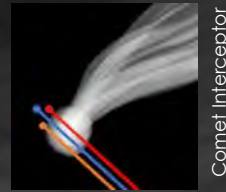
Image taken on 7
September at ~50 km
from the comet.

Rosetta

ESA/Christian Stangl



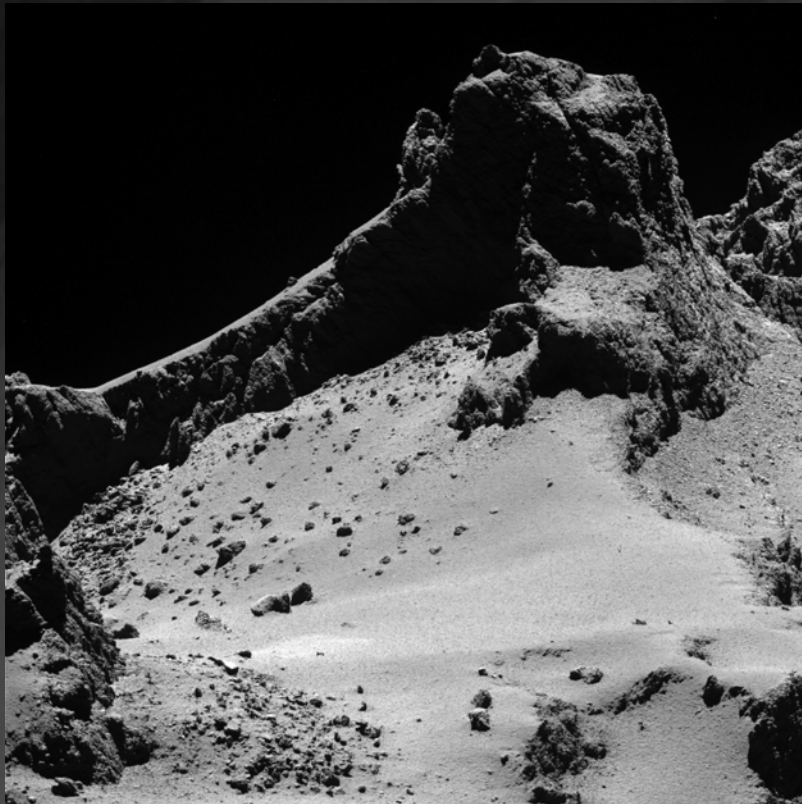
From Rosetta to Comet Interceptor



Rosetta was a huge scientific and engineering success.

First mission to soft-land on a comet & to operate near an active object, for 2.5 years.

Improved our understanding of comets, e.g.:



ESA/Rosetta/MPS for OSIRIS Team

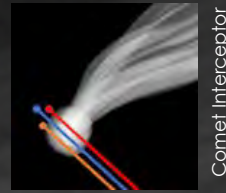
Cometary geology

- A very young research field; received a huge boost from Rosetta.
- Numerous morphological features discovered.

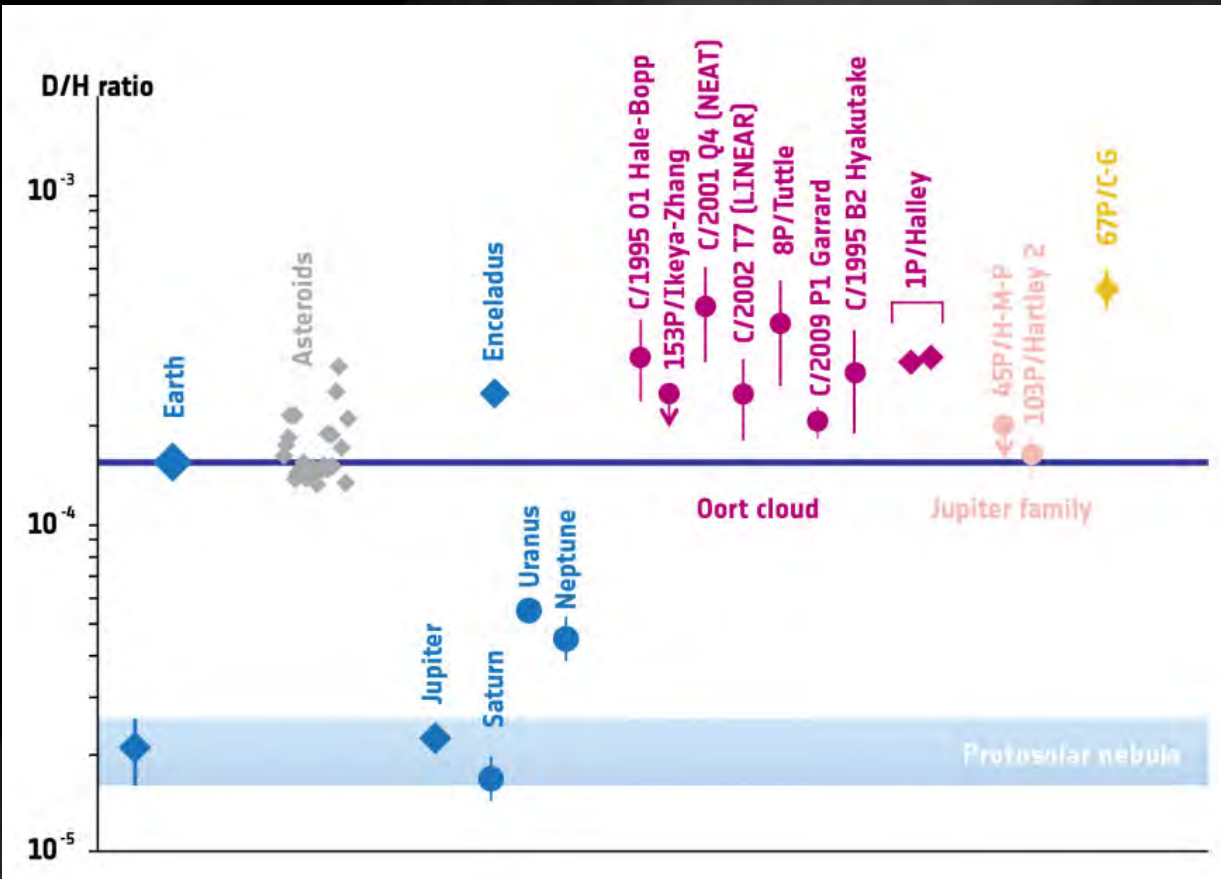
Some of the questions raised

- *How pristine is 67P?*
- *Are the observed pits, terraces, fractures primordial?*
- *How many of the surface features are evolutionary?*

From Rosetta to Comet Interceptor



Comet Interceptor



Data from Altwegg et al. 2014 and references therein

Cometary Composition

- Surprising isotopic ratios observed.
- First detection of molecular O_2 at a comet.

Some of the questions raised

- Is the current composition evolved or primordial?
- Are the differences in composition seen in the coma and solar wind interaction spatial or temporal in origin?

Although hugely successful, Rosetta didn't answer all questions in cometary science!

Science objectives (I)

The primary goals of Comet Interceptor are:

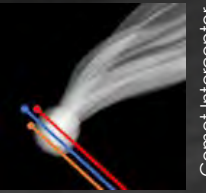
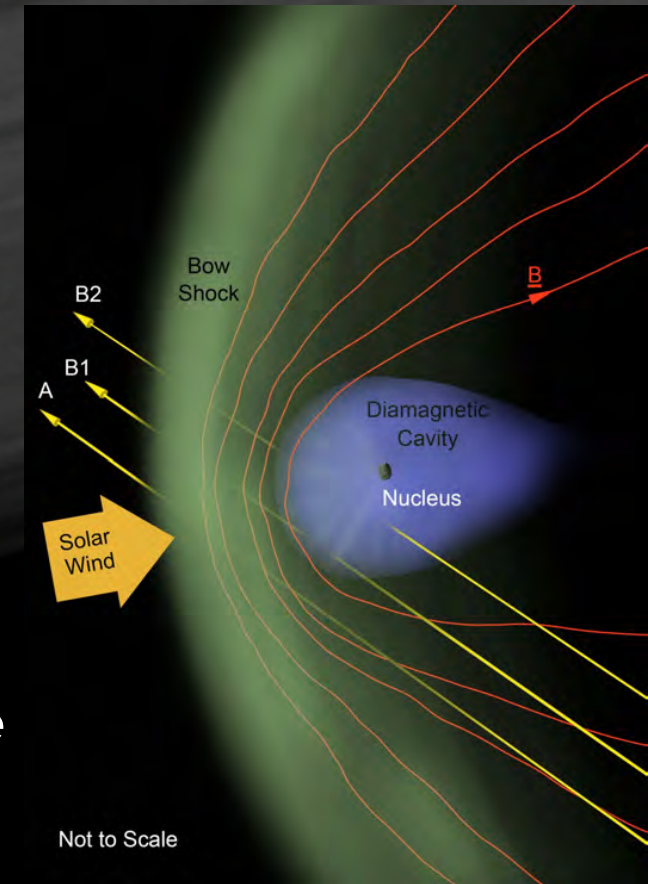
- to provide the **first in-situ characterization** of a long period comet, which could be dynamically-new or an interstellar object.
- to perform the **first simultaneous multi-point exploration** of a cometary coma & nucleus.

The science of the mission is split between two themes:

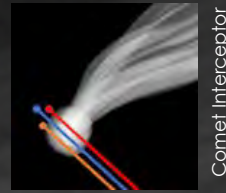
1. Comet Nucleus Science



2. Comet Environment Science



Science objectives (II)

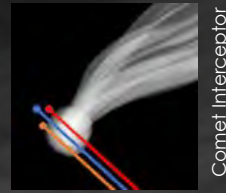


Comet Nucleus Science - *What is the surface composition, shape, morphology, and structure of the target object?*

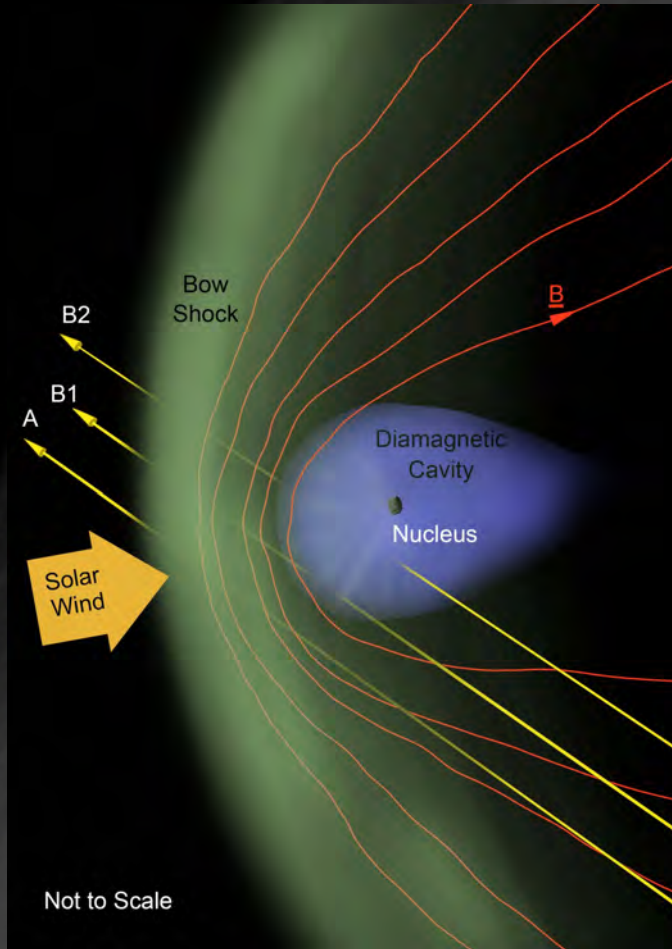


- Investigate which features seen on 67P and other short period comets (layered structures, large pits, terraces) are present on an LPC, i.e. primordial
- Search for large-scale structures that may represent formation processes
- Surface composition: Evidence for e.g. volatile organics that may be absent in more evolved comets?
- Presence of surface ice

Science objectives (III)

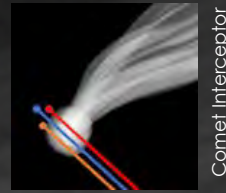


Comet Environment Science - *What is the composition of the coma, its connection to the nucleus (activity) and the nature of its interaction with the solar wind?*



- Is the coma composition different from that measured in SPCs (e.g. more super-volatiles)? Is this difference reflected in surface morphology?
- characterise the coma dust properties, including for the first time with polarimetry: Are they similar to the 67P dust, claimed by some to be primordial?
- Take advantage of multi-point measurements to determine motion and evolution of ion rays & other coma & tail features including dust and gas.
- characterise the plasma environment around the target, determining resulting boundaries & assess energy, mass & momentum transfer.

Comet Interceptor: First F class mission



TAS UK



OHB Italia

- 10 years from 2019 selection to 2029 launch
- ~€150M + shared launch with Ariel at no cost
- 975 kg wet mass
- Fast flyby (~48 hours)

Rosetta

- ~20 years from proposal to launch
- € 1300M
- 2900 kg wet mass
- 2.5 years at the comet



Instruments – ESA spacecraft

Spacecraft A

CoCa - Comet Camera

Visible-NIR; high resolution views of nucleus

PI: Nicolas Thomas, University of Bern, CH

MIRMIS - Multispectral InfraRed

Molecular & Ices Sensor

First thermal IR mapping spectrometer at a comet

PI: Neil Bowles, University of Oxford, UK

Co-PI: Antti Näsilä, VTT, FI

MANiaC - Mass Analyzer for Neutrals in a Coma

Mass spectrometer

PI: Martin Rubin, University of Bern, CH

DFP - Dust, Fields, and Plasma

Multi-sensor fields & particle suite

PI Hanna Rothkaehl, CBK PAN, Warsaw, PL

Probe B2

EnVisS - Entire Visible Sky

All-sky camera for dust polarimetry

PI: Vania Da Deppo, CNR-Institute for Photonics & Nanotechnologies, Padova, IT

Co-PI: Luisa M. Lara, IAA, Granada, ES

OPIC - Optical Periscope for Comets

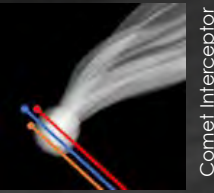
Visible light camera

PI: Mihkel Pajusalu, Tartu Observatory, University of Tartu, ET

DFP - Dust, Fields, and Plasma

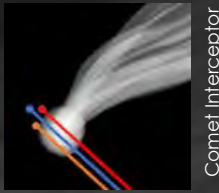
Multi-sensor fields & particle suite

PI Hanna Rothkaehl, CBK PAN, Warsaw, PL



Comet Interceptor

Instruments – JAXA B1 spacecraft



- **WAC/ NAC - Wide Angle Camera / Narrow Angle Camera**

Visible light --> multi-angle imaging in coordination with CoCa and OPIC

PI: Naoya Sakatani, ISAS/JAXA, JP, Deputy-PI: Shingo Kameda, Rikkyo University, JP

- **PS - Plasma Suite**

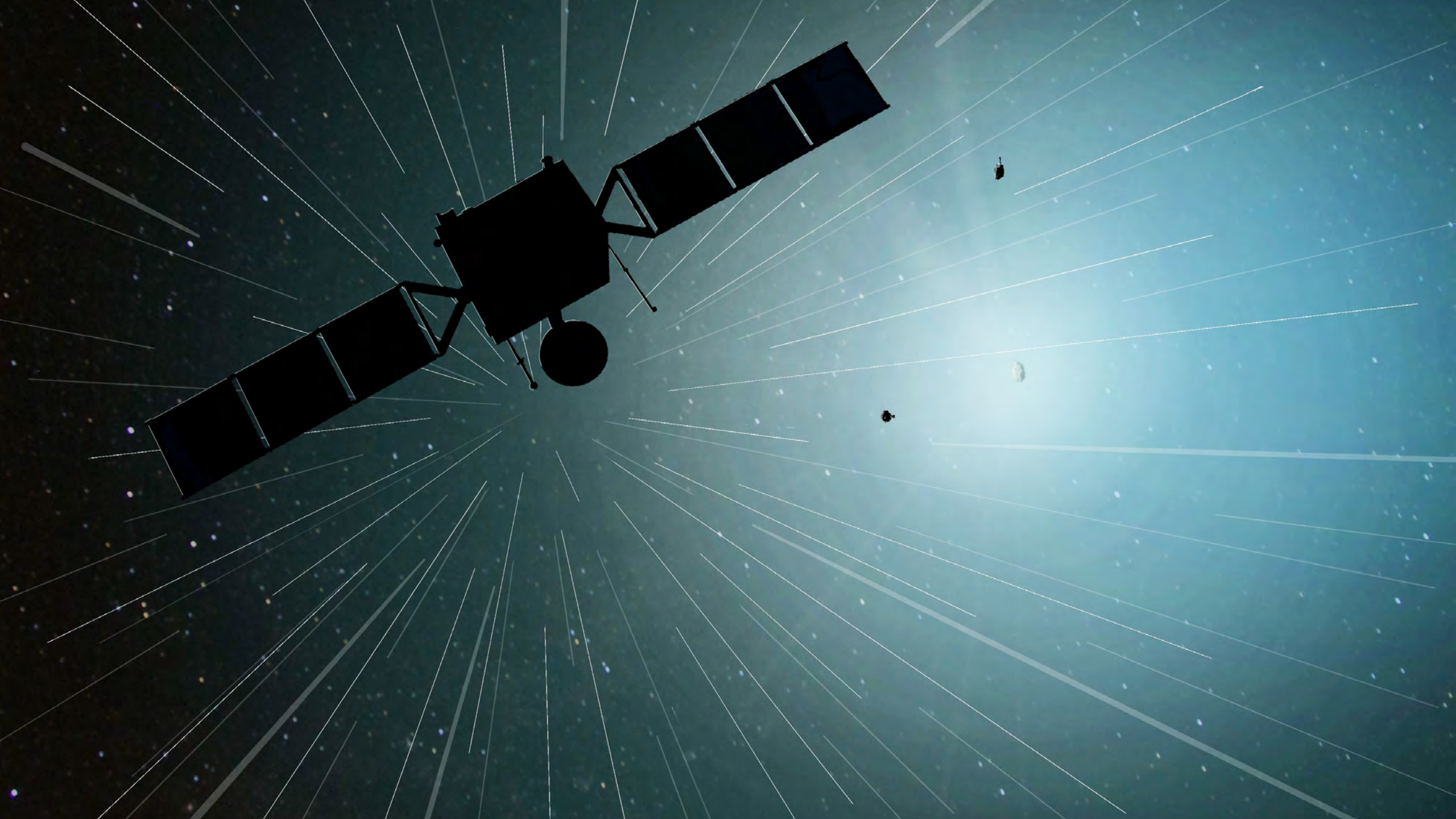
Ion and magnetic field --> multi-point plasma measurements in concert with DFP

PI: Satoshi Kasahara, The University of Tokyo, JP, Deputy-PI: Ayako Matsuoka, Kyoto University, JP

- **HI - Hydrogen Imager**

Ultraviolet light --> multi-wavelength imaging of the gas coma, with CoCa and MIRMIS

PI: Kazuo Yoshioka, The University of Tokyo, JP



Summary

<http://www.cometinterceptor.space/>

 @cometintercept

- Unique, first multi-point measurement of a comet and its environment.
- First dedicated comet mission launch by any agency for >25 years!
- The mission should visit the most pristine object to be encountered so far.
- Formal adoption by ESA took place 8 June 2022, ESA in process of appointing working group members.
- ESA Project Scientist: Michael Küppers.
- Jones, Snodgrass, Tubiana, and 230 co-authors, submitted to *Sp. Sci. Rev.*