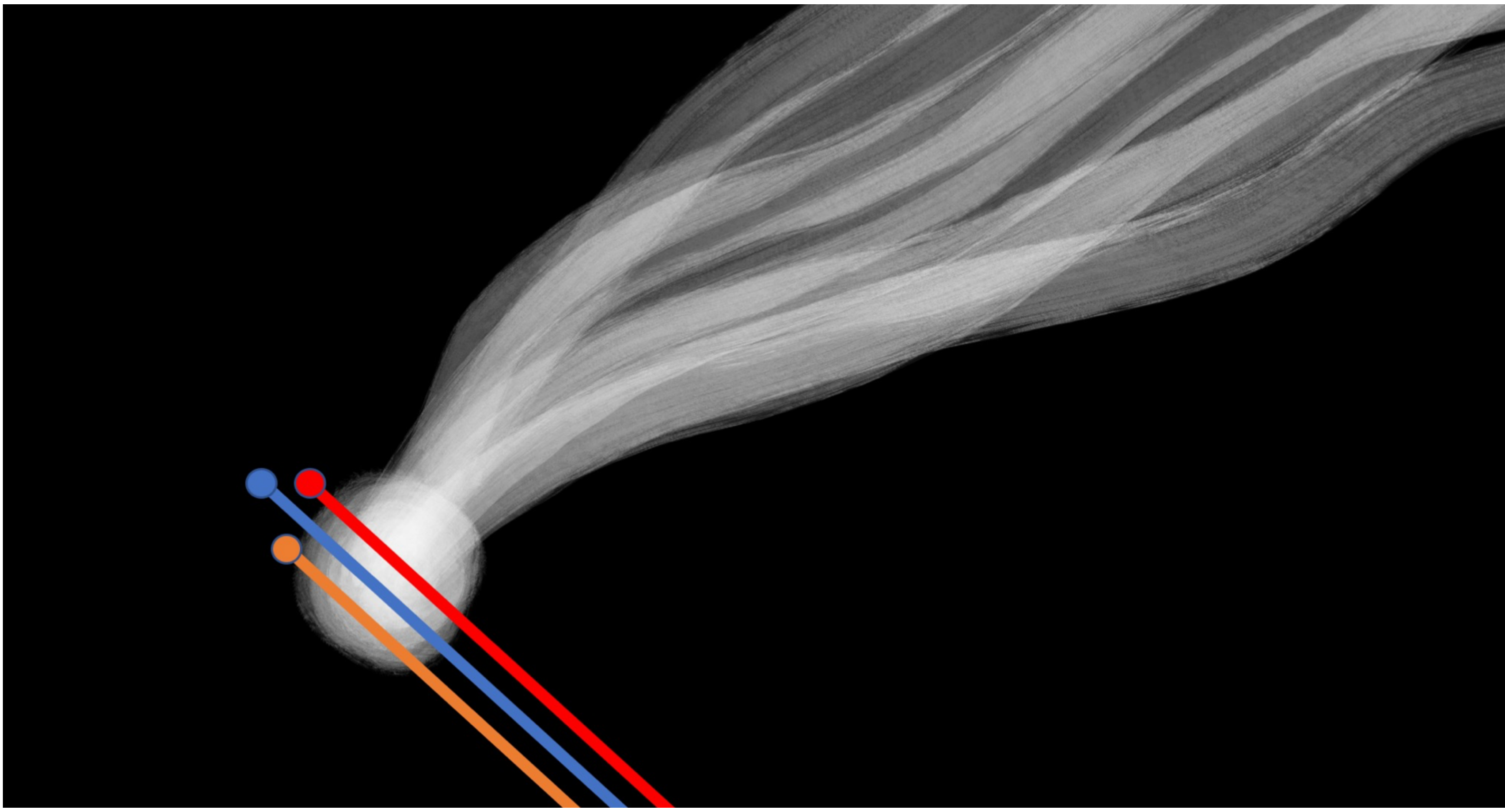
Comet Interceptor

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 Näsilä , VTT
Sweden: Hans Nilsson, IRF-K
Poland: H. Rothkaehl, 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

Lead Proposer: Geraint Jones
Mullard Space Science Laboratory, University College London,
Holmbury St. Mary, Dorking, Surrey RH5 6NT, United Kingdom
Email: g.h.jones@ucl.ac.uk Tel.: +44 1483 204100

The Lead Proposer confirms his availability to support for the study activities by making available at least 20% of his time throughout the study period.

Comet Interceptor Consortium Members

(Country, Institution, Name(s))

Austria
IWF Graz: M. Volwerk, W. Magnes, A. Valavanoglou, O. Roberts.

Belgium
BIRA-IASB: H. Gunell, J. De Keyser;
KULeuven: G. Lapenta

Canada
UWO: P. Wiegert

Switzerland
Phys. Inst., Univ. Bern: D. Piazza, M. Rubin, N. Thomas, P. Wurz, A. Galli

Chile
ESO: C. Opitom

Czechia
IAP: I. Kolmasova, J. Soucek, O. Santolik.
Charles Univ.:J. Safrankova, L. Prech, Z. Nemecek.

Germany
MPS: A. Nathues, C. Tubiana
TUBS-IGEP: C. Götz, I. Richter, K.-H. Glaßmeier, U. Auster
DLR: E. Kuehrt, H. Michaelis, J.-B. Vincent, S. Hviid, S. Mottola
FU Berlin: F. Postberg

Estonia
U. Tartu: A. Slavinskis, M. Pajusalu

Spain
IAA-CSIC: D. Guirado, F. Moreno, J.M. Castro, L.-M. Lara, M. Herranz, Olga Muñoz, P.J. Gutiérrez.

Finland
VTT: A. Näsilä
U. Aalto: E. Tanskanen, J. Praks, M. Alho;
UH: K. Muinonen, T. Kohout, A. Penttilä, M. Granvik.

France
IRAP: A. Fedorov, C. Mazelle, N. Andre, P. Garnier
Obs. Paris: B. Segret, D. Hestroffer
LPC2E, CNRS: P. Henri, O. Le Duff
LAB: S. N. Raymond
LAPLACE: G. Wattieaux

Hungary
MTA CSFK: A. Kereszturi
Wigner RCP: G. Erdos, Z. Nemeth

India
NARL: R. Hajra

Italy
IAPS-INAF: A. Migliorini, A. Longobardo, M.T. Capria, V. Della Corte, V. Zakharov
Uni. Parthenope: A. Rotundi,
INAF: C. Pernechele
DFA, UNIPD: I. Bertini, M. Lazzarin

Japan
KSU: H. Kawakita, Y. Shinnaka;
UT: I. Yoshikawa, R. Funase, S. Kasahara;
Rikkyo U.: S. Kameda

Latvia
BiS: A. Graps

Netherlands
TU Delft: D. Dirkx, E. Gill, S. Speretta

Norway
UiO: C. Simon Wedlund
UiT: I. Mann

Poland
CBK: H. Rothkaehl
UW: K.J. Kossacki

Portugal
IST: Z. Martins

Russia
ISI: M. Riazantseva

Sweden
IRF: A. I. Eriksson, H. Nilsson, J.-E. Wahlund, M. Yamauchi, N. J. T. Edberg, S. Barabash
KTH: M. Ivchenko, T. Karlsson

United Kingdom
UCL-MSSL: A. J. Coates, A. Wellbrock, G. Brydon, G. H. Jones
IC: A. Beth, C. Carr, T. Horbury, M.Galand
QMUL: C. Chen
STFC RAL Space: C. Howe, J. Davies
U. Edinburgh: C. Snodgrass
OU: I. Franchi, S. J. Barber, S. Sheridan
Cranfield U.: J.P. Sanchez
UofG: M. Ceriotti
QUB: M. T. Bannister
U. Cambridge: M. Kama
Birkbeck: M. R. El-Maarry
Univ. Oxford: N. Bowles, S. Calcutt, T. Warren
U. Kent: N. J. Mason, S. Lowry
AOP: S. Bagnulo

United States of America
NASA-GSFC: D. E. Jennings, G. L. Villanueva, M. Jhabvala, S. Aslam
JHUAPL: B. Greenhagen
UCF: K. Donaldson Hanna
UMD: M. Knight, T. Hewagama
IfA, U. Hawaii: B. Boe, K.J. Meech, Y. Ramanjooloo
Gemini Obs.: M. E. Schwamb
JPL: J. Castillo-Rogez
SSI: J. Borovsky
CU / LASP: J. Deca, D. Malaspina
PU & PPPL: H. Ji

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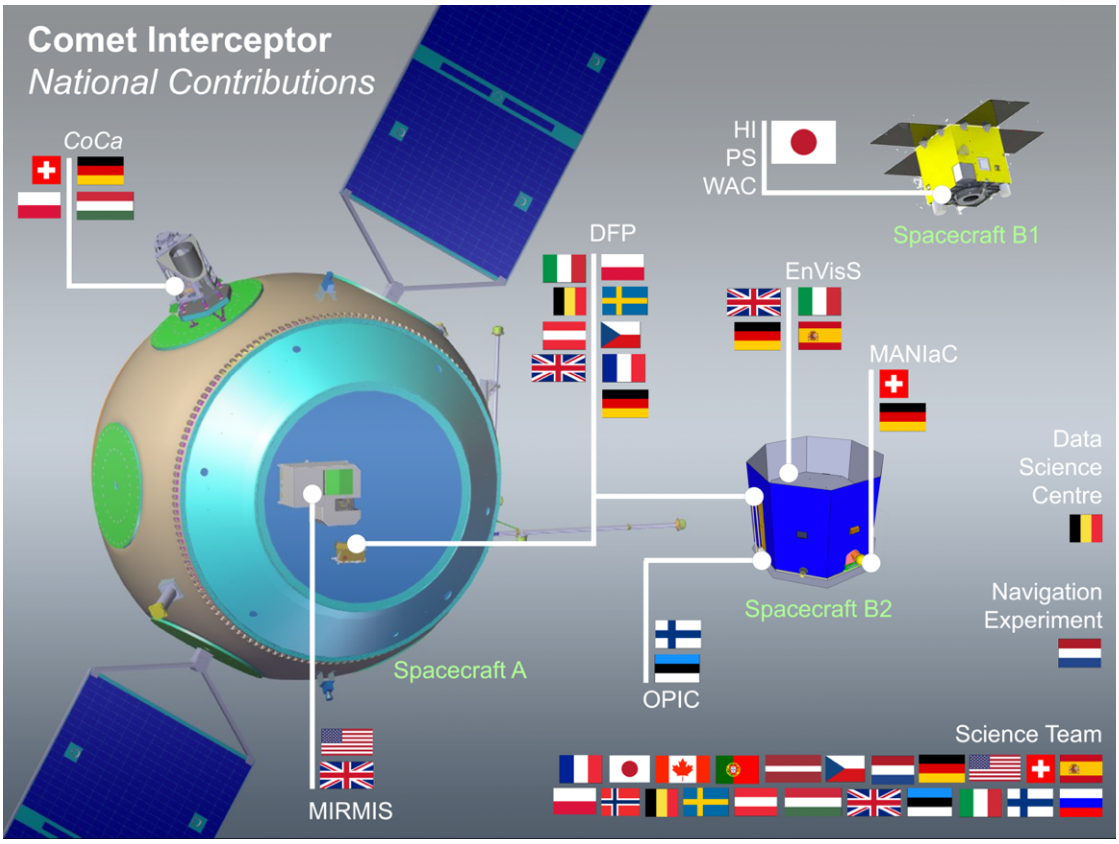
- *Thales Alenia Space (UK):* Stuart Ackerman

2. Executive Summary

A truly pristine comet has yet to be encountered and explored. The huge scientific returns of *Giotto*, *Rosetta*, and other comet missions are unquestioned. However, these ground-breaking endeavours have all explored periodic comets that have approached the Sun many times, and thus undergone surface compositional and morphological modification, and blanketing by thick layers of dust. On Jan 1, 2019, the NASA *New Horizons* mission flew by the Kuiper Belt Object (KBO) 2014 MU$_{69}$ providing a first glimpse of what a comet may look like prior to entering the inner Solar System. It is unlike any of the periodic comets that have been studied by spacecraft, and further supports the need to study such primordial objects in more detail. In 1985, after several years at Earth-Sun L1, *ICE* (*ISEE-3*) was directed to successfully encounter Comet 21P/Giacobini-Zinner. We propose a similar approach to explore a comet very likely entering the inner Solar System for the first time, or, possibly, to encounter an interstellar object originating at another star. Due to the extremely high orbital eccentricities of either type of target, the proposed mission will by necessity be a flyby like *Giotto* rather than a rendezvous like *Rosetta*, but we are able to propose a scientifically compelling mission that combines a first exploration of a new type of target, as was the case for *Giotto*, with unique measurements that go beyond what *Rosetta* achieved, in some areas, within the constraints of the F class call.

The *Comet Interceptor* mission will involve separate spacecraft elements working together to ensure a low-risk, bountiful, interdisciplinary scientific return through unprecedented multi-point measurements. Multiple viewing positions will greatly increase the 3D information provided on the target and its jets/coma. Similarly, *in situ* observations of the cometary environment also benefit from multiple sampling paths. The multiple elements can sample gas composition and density, dust flux, and plasma and solar wind interactions, to build up a 3D 'snapshot' of the region around the target. One spacecraft will make remote and upstream *in situ* observations of the target from afar, to protect it from the dust environment of an active comet, and act as the primary communications hub with Earth for all other mission elements. Two other spacecraft will be deployed to venture closer to the target, carrying complementary instrument payloads, to build up a 3D picture of the comet. This approach will also enable a combination of a low risk and guaranteed baseline science return from the more distant spacecraft with higher-risk but high-gain sampling of the inner coma by the releasable probes, which do not necessarily need to survive the full encounter for mission success.

Long Period Comets (LPCs) from the Oort Cloud have historically been discovered only months (or a few years in the best cases) before they pass their perihelion and return to the distant reaches of the outer Solar System, which is clearly too little time to plan and launch a mission. For *Comet Interceptor*, we instead propose a flexible spacecraft that is designed to encounter an as-yet *unknown* target; the mission will take advantage of the unique opportunity presented by the F class call – the launch to a stable halo orbit around the Sun-Earth L2 point – and wait for the discovery of a suitable comet that it can reach. The timing of the F class call also enables this approach, due to the fact that major new survey telescope facilities (especially the Large Synoptic Survey Telescope, currently under construction in Chile) will greatly increase the distance at which inbound comets are discovered in the 2020s. Based on both the catalogue of historic LPCs and simulations of a large synthetic set of LPC orbits, we find that *Comet Interceptor* will have to wait only 2-3 years for a target it can reach with a reasonable Δv, followed by a short cruise and flyby within a total mission



length of < 5 years, and that in most cases we will have many years warning between discovery and departure from L2 to fully characterise the target comet and its orbit and to calculate optimum transfers. In the highly unlikely case that no such target can be found in time, a backup short period comet (baseline 73P/Schwassmann-Wachmann 3, but others are possible) can be studied, taking advantage of the mission's multi-point capabilities to make unique measurements that would still advance on *Rosetta*'s achievements in mapping the coma and comet/solar wind interaction.

The mission objective is to understand the diversity of comets – after studying 67P, a weakly active Jupiter Family Comet, JFC, in detail, it is important to understand to what degree other comets differ from 67P. The primary goal is to characterize a (likely very active) dynamically new comet, which would broaden our understanding of comet morphology, composition, and plasma environment. Most importantly, such a comet would offer a unique new viewpoint along the evolutionary path of comets from their formation to migration into the inner Solar System, as a relatively unprocessed object that will have been active for only the past few years, rather than a returning comet that has experienced many close approaches to the Sun. Comparison with *New Horizons* images will allow us to assess if primordial small bodies display a singular primordial surface type, or whether they show surface diversity at different size scales. Composition measurements of a fresh surface and coma, in comparison with *Rosetta* results, will tell us about chemical processing as comets evolve. Identifying the sources and mechanisms driving activity on an un-evolved comet surface will add essential constraints to the debate into this topic following *Rosetta*, while comet (and therefore planetary system) formation models can be tested by measuring nucleus, dust and gas properties at a much more primordial object. The unique *simultaneous* multi-point measurements possible from a multi-spacecraft comet flyby will also greatly advance our understanding of the complex 3D structure of the coma, including its composition and chemical reactions, and its link with both the nucleus and the solar wind environment. The latter in particular presents a highly dynamic and poorly understood structure of interacting plasma and fields, which this mission will be uniquely sensitive to, across a wide range of spatial scales.

To achieve these science goals, we propose a carefully selected *limited* payload that is feasible for this class of mission, but still capable of the broad range of measurements required to adequately characterise a new class of object. We make use of high technology readiness level, TRL, instruments, including flight-spare components for heritage, and to control costs where possible. We ensure our highest priority science goals will be achieved by placing three very high TRL instruments (a visible camera based on the *Mars TGO*/CASSIS flight spare; dust, fields and plasma [DFP] sensors with direct *Rosetta* heritage; and an infrared camera based on two that are flying in Earth orbit) on the main spacecraft for a safe, relatively distant, flyby. We make use of (mostly) the same DFP sensors on the sub-spacecraft that will pass much closer, to allow direct comparison, simplicity of design, and the use of high TRL systems. These are complemented by a very high TRL mass spectrometer with *Rosetta* heritage, and two novel low-mass cameras for a small rotating probe, which are the only instruments requiring significant development, but are very simple in design and use high TRL sub-systems with strong flight heritage.

Table 2.1 Spacecraft and their instruments.

Space-craft	Instrument	Description
A ESA	CoCa	Visible/NIR imager
	MIRMIS	NIR/Thermal IR spectral imager
	DFP	Dust, Fields & Plasma (similar on A and B2)
B2 ESA	MANIaC	Mass spectrometer
	EnVisS	All-sky multispectral visible imager
	OPIC	Visible/NIR imager
B1 JAXA	HI	Lyman-alpha Hydrogen imager
	PS	Plasma Suite
	WAC	Wide Angle Camera

The mission is ESA-led, with payload contributions from national agencies in the usual way, and includes significant international contribution, which helps to maximise the science return within the ESA cost cap. One of the released sub-spacecraft will be provided in its entirety by JAXA, including the bus and payload, which presents a straightforward interface between the agencies in terms of integration into the mission. The JAXA spacecraft will have a far-UV imager, a plasma suite, and a wide field camera (all high TRL instruments from previous JAXA missions). We also have a smaller (payload) contribution from NASA, to the infrared camera on the main spacecraft, in collaboration with a European team. A science operations and data centre will be hosted by Belgium.

We present a proposed mission that meets all the requirements of the call, in terms of cost cap, mass budget, and compatibility with the accompanying *Ariel* mission. Furthermore, the concept is robust to any further changes to these requirements, due to its inherently flexible nature: It is robust to any launch delays of *Ariel* as it has no fixed target or launch window. It is designed from the outset to cope with the uncertainty on the launcher performance and therefore available mass; trades and options are presented that can save money and/or mass from our baseline proposal, enabling the requested 'design to cost' approach. The most important trades to be considered in more detail in phase 0/A result from the choice between chemical and electrical propulsion (baseline is electrical), and the resulting cost/mass/Δv/mission-length balance. We present descope options that would still enable the highest priority science to be achieved even if quite drastic cuts in either mass or cost are imposed. On the other hand, should the true Ariane 6.2 performance be better than the conservative values assumed here, this mission also presents straightforward options to take full advantage of this without major redesign, even quite late in the mission development.