**The magnetometer on probe B2 for the Comet Interceptor mission**

Marina Galand, Emanuele Cupido, Aris Valavanoglou, Jedrzej Baran, Chris Carr, Irmgard Jernej, Irene Ruiz Rodriguez, Hanna Rothkaehl, Martin Volwerk

Building upon the heritage from the previous ESA missions, Giotto and Rosetta, the ESA/ Comet Interceptor mission to be launched in 2029 differs from them in several ways. It will be visiting a dynamically-new comet which will be reaching the inner Solar System for the first time: the material released will be as pristine as it can possibly be when reaching 1 AU. Another originality of the mission is that it is composed of three spacecraft: the mother spacecraft A and probe B2 led by ESA and the probe B1 led by JAXA. This will allow multi-point observations, not only for viewing the nucleus and jets, but also to build a 3D picture of the interaction of the solar wind with the cometary plasma. The magnetometer is the only in-situ sensor present on all three spacecraft. The three-point measurements will offer the capability to assess the 3D structure of plasma and field boundaries and the energy transfer through the coma. We will be presenting the progress on the magnetometer on probe B2, part of the Dust, Field and Plasma (DFP) instrument, and will be discussing the related science to be undertaken.

**MIRMIS: Modular Infrared Molecules and Ices Sensor for Temperature and Composition Mapping of a Comet Coma and Nucleus for the Comet Interceptor Mission**

N. E. Bowles[1], A. Vitkova[1], K. Nowicki[1], R. Cole[2], H. Eshbaugh[1], A. Näsilä[2], T. Kohout[3], G. L. Villanueva[4], C. Howe[5], G. H. Jones[6], C. Snodgrass[7], K. L. Donaldson Hanna[8,1], B. T. Greenhagen[9], P. G. J. Irwin[1], S. B. Calcutt[1], R. Evans[1], K. Shirley[1], T. Warren[1], T. Hewagama[4,10], S. Aslam[4], D. E. Jennings[4], A. Akujärvi[2], A. Penttilä[11], J. Temple[1], H. Eshbaugh[1], S. Thirumangalath[2], L. Salonen[2], S. Faggi[4], S. Protopapa[12], A. Kokka[2], D. Korda[3], Maisie Rashman[1], A. Guilbert-Lepoutre[13]

[1]Department of Physics, University of Oxford, UK,
[2]VTT Technical Research Centre of Finland Ltd., Espoo, Finland,
[3]Department of Geosciences and Geography, University of Helsinki, Finland,
[4]NASA Goddard Spaceflight Center, Greenbelt, MD, USA,
[5]STFC RAL Space, Didcot, UK,
[6]MSSL, University College London, UK,
[7]Institute for Astronomy, University of Edinburgh, Royal Observatory, Edinburg, UK,
[8]Department of Physics, University of Central Florida, Orlando, FL, US,
[9]Johns Hopkins Applied Physics Laboratory, Laurel, MD, US,
[10]Department of Astronomy, University of Maryland, College Park, MD, US.
[11]Department of Physics, University of Helsinki, Finland
[12]Southwest Research Institute, San Antonio, USA
[13] Laboratoire de Géologie, Lyon, France

The Comet Interceptor Mission is ESA's first F class mission aiming to perform the first close-range observations of a (yet-undiscovered) long period comet, ideally originating in the Oort cloud. All comets explored by spacecraft so far have been short period comets, which would have previously entered the Solar System and undergone chemical changes thus erasing its original make-up. Long-period comets visiting the Solar System for the first time may contain material from the early Solar System and can provide crucial information on the comet's formation and the history of the Solar System itself. The mission's aim is to launch to the L2 Earth-Sun Lagrange point, where the spacecraft will wait for a suitable target to perform observations.

The MIRMIS instrument is a combined thermal infrared imager and Near-Infrared/Mid-Infrared spectrometer on board of the Comet Interceptor's main spacecraft A, which will fly-by the targeted comet at a distance of ~1000 km allowing approximately 7 minutes of observations. The development of the MIRMIS instrument is a collaboration between the University of Oxford (UK) and VTT (Finland), who provide the NIR/MIR module, and scientists from the University of Helsinki and NASA's Goddard Space Flight Centre, University of Lyon, and Southwest Research Institute. MIRMIS will map the ice, mineral, and gas composition of the target nucleus and coma and the distribution of surface temperatures of the nucleus. Its three modules cover the spectral range of 0.9 to 25 $\mu$m. The Near and Mid Infrared modules (NIR/MIR) will measure spectra in the 0.9 to 5 $\mu$m, covering information on volatiles such as water vapour and organic material. The Thermal Infrared Imager (TIRI) will map the temperature and composition of the nucleus in the range of 6 to 25 $\mu$m, providing key information on the surface and near sub-surface thermal physical properties (e.g. cold traps, boulders/powdered regolith).

The MIRMIS modules are integrated onto a single optical bench and share a common Command and Data Handling Unit and an electrical interface with the spacecraft. The overall envelope of the instrument is 289 x 555.5 x 127 mm and with mass less than 8.8kg, the MIRMIS instrument represents a compact and low mass solution for material and temperature characterisation of planetary surfaces. This presentation outlines the status and progress of the design and development of MIRMIS for the upcoming Comet Interceptor Mission.

**The Power of IFU Observations of Comets and Active Asteroids.**

B. P. Murphy[1] and C. Opitom[1] and C. Snodgrass[1] [1]Institute for Astronomy, Edinburgh University of Edinburgh, Royal Observatory, Edinburgh EH9 3HJ, UK (brian.murphy@ed.ac.uk)

**Abstract:** In the era of billion-dollar missions built to visit and study the active bodies in the Solar System, integral field unit (IFU) astronomy provides an accessible and invaluable option for the simultaneous characterisation of different gaseous species and dust grain regimes across temporal, spatial, and spectral domains. Leveraging these IFU capabilities, we can investigate the complex dust dynamics of active asteroid ejecta plumes and map the gases present in comet comae across various geocentric and heliocentric distances, as demonstrated by Opitom et al. 2020 and 2023, respectively. Through using IFU observations to study these small, active bodies, we can come to a deeper understanding of the fundamental processes that govern different activity-driven phenomena. Here, we present techniques developed by Murphy et al. 2023 and Opitom et al. 2023 that helped process and analyze IFU observations of the Double Asteroid Redirect Test (DART) impact into the binary asteroid Dimorphos, on September 26, 2022, from the Multi-Unit Spectrographic Explorer (MUSE) instrument at the Very Large Telescope.[1-3] The controlled DART impact provided an ideal opportunity to capture the perturbation of an asteroid with MUSE, which allowed us to develop robust gas and dust mapping tools that are applicable to both active asteroids and comets, alike. We aim to apply these tools to our archival MUSE database, which has characterized 30 comets across 487 observations, from 2018 to 2023, which will contribute to a more comprehensive understanding of cometary release mechanisms across various heliocentric distances.

**References:** [1] A. S. Rivkin et al., (2021), *Planet. Sci. J.*, vol. 2, no. 5. [2] A. F. Cheng et al. (2020) *Icarus*, vol. 352, p. 113989. [3] R. Bacon et al. (2010) *SPIE.*, vol 7735, no. 08. [4] C. Opitom et al. (2020) *Astron. & Astrophys. J.,* vol. 644, A143. [5] C. Opitom et al. (2023), *Astron. & Astrophys. J.*, vol 671, L11. [6] Murphy et al. (2023), *Planetary Science Journal.*

**Ion composition around comets**

A. Beth, M. Galand, Z. Lewis (and the ROSINA team)
Department of Physics, Imperial College London, Prince Consort Road, SW7 2AZ, London, UK

While plasma density has been probed during the different cometary missions such as Giotto at 1P/Halley and Rosetta at 67P/Churyumov-Gerasimenko, the actual ion composition remained uncertain until today. Difficult to probe it remotely (except CO+), the best approach is in fact to perform in-situ measurements by sending a mass spectrometer onboard a spacecraft. However, such an instrument has a limited capability at separating ions with respect to their mass as the most expected abundant species may have a mass separation of around 0.02 Da.

This issue was overcome for the first time by the ion mass spectrometer onboard Rosetta, ROSINA (Rosetta Orbiter Spectrometer for Ion and Neutral Analysis)/ DFMS (double focusing magnetic mass spectrometer), that gathered the most impressive amount of ion data made at comets during a major part of the Rosetta escort phase. We have not only unambiguously confirmed the presence of more than 20 ion species, but also assessed their abundance over time as the comet gets more active: some ions appeared, some disappeared, some are present at all time. I will give a review about all the different ions detected so far at comets and discuss how the detection (or not) of a given ion species may affect data interpretation and plasma modelling at comets.

**Comet Chasers: From the Halley and Rosetta Observing Campaigns to Inspiring Future Halley Observers**

Helen Usher, Open University, Cardiff University, Faulkes Telescope Project
Colin Snodgrass, University of Edinburgh
Cai Stoddard-Jones, Paul Roche, Cardiff University
Ben Wooding, St Mary's Catholic Primary School Bridgend
Simon Green, Open University
Richard Miles, BAA
Tony Angel, Harlingten Observatory

My comet journey started with Halley's last apparition, has progressed through my study of the amateur involvement in the Rosetta Mission, and now includes inspiring (through the Comet Chasers project) those who will be able to study Halley at its next apparition.
The Comet Chasers project is an education and outreach project using astronomy (particularly comets) to engage and enthuse students (from age 7 upwards), while teaching curriculum skills. It gives students access to the research-grade telescopes of the Las Cumbres Observatory network through the Faulkes Telescope Project. By working with professional researchers across the world, and amateur astronomers, the project enables students to make scientifically useful observations which supplement research data from other sources. We are currently actively engaged in observing campaigns for comets 29P, 103P and 12P. For 12P, we were the first to identify a large outburst on 5 October 2023 which we reported in ATel 16270. Teachers tell us that students love being part of something big and important, and particularly enjoy seeing their school names in research papers.

We will present details of how an assessment of the effectiveness of amateur and school involvement in observing campaigns including Halley and Rosetta has led to recommendations for future campaigns. The Comet Chasers project has been testing some of those recommendations, and work is also underway with the amateur community. We will present some encouraging outcomes and details of future work.

**Constraining ion transport in the diamagnetic cavity of comet 67P**

Zoe Lewis[1], Arnaud Beth[1], Marina Galand[1], Pierre Henri[2,3], Martin Rubin[4], Peter Stephenson[5]

1 Department of Physics, Imperial College London, UK
2 Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E), CNRS, Université d'Orléans, Orléans, France
3 Laboratoire Lagrange, OCA, UCA, CNRS, Nice, France
4 Physikalisches Institut, University of Bern, Bern, Switzerland
5 Lunar and Planetary Laboratory, University of Arizona, USA

As comet 67P approached perihelion, a magnetic field-free region was sporadically encountered by the Rosetta spacecraft. Within this region, the un-magnetised cometary plasma prevented the interplanetary magnetic field from reaching the comet surface. Within this diamagnetic cavity, unexpectedly high ion bulk velocities were observed, which have been postulated to be caused by acceleration by an ambipolar electric field. This has been further supported by the finding that the assumption of equal ion and neutral velocities in the cavity leads to models overestimating the plasma density, compared to observations by Rosetta Plasa Consortium (RPC) instruments near perihelion.

In this study we have developed a 1D numerical model of the cometary ionosphere to constrain the impact of various electric field profiles on the ion density profile. One of the originalities of this ion acceleration model is the inclusion of three ion species, $H_2O^+$, $H_3O^+$ and $NH_4^+$. The latter is only produced through the protonation of $NH_3$ and only lost through ion-electron dissociative recombination and transport, with particular sensitivity to the timescale of loss through transport. We explore this sensitivity, as well as assessing the modelled total plasma density profile for different outgassing and electric field conditions. Finally, we compare the modelled plasma density to measured electron density from RPC to constrain the size of the electric field required in our model to explain the observations.

**Investigating comet composition at large heliocentric distances**

Léa Fellerec, Edinburgh University

Optical spectroscopy of cometary gases allows to quantify their content in small radicals (OH, CN, $C_2$, etc.), as gas molecules emit light while undergoing various processes in the coma. These molecules are produced through photodissociation of larger molecules ($H_2O$, HCN, etc.) in the coma, providing insight into the composition of the ice. Large spectroscopic surveys in the optical range have been conducted in an attempt to classify comets based on their apparent composition. They mostly agree on two main classes: Two thirds of comets seem “typical” while the remaining third is “depleted in $C_2$”. This is thought to be a primordial feature of these comets, however this taxonomy does not match the dynamical classification separating Kuiper Belt comets and Oort Cloud comets. A few of these studies also report a trend in the observed $C_2$/CN ratio, decreasing with heliocentric distance over their entire samples as well as for individual comets along their orbits. This effect could introduce a bias in the “typical”/“$C_2$-poor” classification, and extensive work would be needed to understand and characterize the mechanisms at play. However, these studies only focus on comets within 2au from the Sun and do not all use the same modelling parameters.

We propose a spectroscopic survey of comets at larger heliocentric distances to investigate potential biases in the carbon-based classification. We have acquired observations of >30 comets with the Isaac Newton Telescope and Very Large Telescope, at distances ranging up to 11au. We will present our aims and data set, as well as possible preliminary results of our study.

**Dust production rates in Jupiter Family Comets: A two-year study with ATLAS photometry**

Fraser Gillan, Queen's University of Belfast

Jupiter-family Comets (JFCs) exhibit a wide range of activity levels and mass-loss over their orbits. We analysed high-cadence observations of 42 active JFCs with the wide-field Asteroid Terrestrial-impact Last Alert System (ATLAS) survey in 2020-2021. This dataset contains JFCs that ATLAS detected brighter than a magnitude limit of ~19.5 in both c and o bands (Tonry et al. 2018). We measured dust production rates of the JFCs using the Afρ parameter (A'Hearn et al. 1984) and its variation as a function of heliocentric distance. While some of these comets have had their Afρ measured before, many have no previously reported measurements in the literature. From our sample, we find a tendency for the JFCs to exhibit maximum Afρ after perihelion, with 254P/McNaught and P/2020 WJ5 (Lemmon) having their maximum Afρ over a year after perihelion. On average, the rate of change of activity with respect to heliocentric distance post-perihelion was shallower than that pre-perihelion. We then tested the variation of the intrinsic activity by compensating for orbital parameters and we present a subset of comets whose measured Afρ have been interpolated and extrapolated to a common distance of 2 au pre-perihelion and post-perihelion. From these Afρ projections, we found no correlation of the intrinsic activity with perihelion distance.

Acknowledgments:
This work uses data from the University of Hawaii's ATLAS project, funded through NASA grants NN12AR55G, 80NSSC18K0284, and 80NSSC18K1575, with contributions from the Queen's University Belfast, STScI, the South African Astronomical Observatory, and the Millennium Institute of Astrophysics, Chile. A.F.G. acknowledges support from the Department for the Economy Northern Ireland postgraduate studentship scheme.

References:
J. L. Tonry et al. "ATLAS: A High-cadence All-sky Survey System". PASP 130.988 (June 2018), p. 064505. doi: 10.1088/1538- 3873/aabadf. arXiv:1802.00879 [astro-ph.IM].
M. F. A'Hearn et al. "Comet Bowell 1980b". AJ 89 (Apr. 1984), pp. 579–591. doi: 10.1086/113552.

**The future of comet observations at UV/blue wavelengths.**

Cyrielle Opitom, University of Ediburgh

The UV/blue optical wavelength range is critical for the study of comets. Some of the brightest emission bands produced by the gas in their coma can be detected in that range. The next generation of UV instruments and missions, in which the UK is either already involved or expected to be, are currently under design and will provide essential tools for the study of comets. These facilites include CUBES, a spectrograph to be installed on the VLT in 2028, covering the near-UV wavelength range at intermediate-high spectral resolution (R~20,000) with high efficiency; CASTOR, a Canadian-led space mission that will provide imaging and low/intermediate resolution multi-object spectroscopy in the UV/optical spectral region over a large field of view; and in the more distant future the Habitable World Observatory.

In this talk, I will briefly present these facilities and the critical role they will play in detecting water across the solar system, measuring isotopic ratios in cometary water to ascertain the origin of water on Earth, and understanding the drivers of cometary activity at different distances from the Sun.

**Solar Wind Interactions with Comet C/2021 A1 using STEREO HI and a Data-Assimilative Solar Wind Model (HUXt)**

Sarah Watson, University of Reading

The NASA STEREO spacecraft, launched in 2006, include two Heliospheric Imagers (HI) which provide a wide-field view of the inner solar system and were developed to obtain images covering the entire Sun-Earth line. They provide a detailed view of the solar wind within the inner solar system and capture solar wind streams and coronal mass ejections (CMEs). These continuous observations of the inner solar system have resulted in the HI cameras often capturing other objects, such as minor planets and comets. On 18 December 2021, Comet Leonard (C/2021 A1) was observed by the STEREO A Heliospheric Imager (HI) camera. During this time, the comet tail exhibited various signatures of interaction with the solar wind including bending, a kink formation and finally a complete disconnection of the tail.

The cause of these interactions was investigated using the HUXt solar wind model (developed at the University of Reading) in combination with solar wind data assimilation techniques. This allows for accurate reconstructions of the solar wind conditions at the comet's location. Coronal mass ejections (CME), stream interaction regions (SIRs) and heliospheric current sheet (HCS) crossings were all considered as potential causes of the tail disconnection. Case studies such as these are important in expanding our understanding of comet-solar wind interactions and demonstrate the utility of data-assimilated solar wind modelling for such studies.

**Halley's Comet and Geomagnetic Disturbances in May 1910.**

S. R. Grant[1,2], G. H. Jones[1,2],
[1]UCL Mullard Space Science Laboratory, UK, [2]The Centre for Planetary Sciences at UCL/ Birkbeck, London, UK,
[1]samuel.grant.20@ucl.ac.uk

Volatile gases ejected from a comet's surface are ionized when in the inner Solar System, and subsequently transported by the solar wind away from the Sun, and are partially visible as an ion tail. In-situ encounters with cometary plasma provide unique information on the composition and behaviour of the comet, sometimes at a significant distance from the comet nucleus. Serendipitous ion tail encounters by spacecraft occur surprisingly frequently but are often missed due to the ambiguity of in-situ plasma measurements.

On 19 May 1910, Halley's Comet transited the Sun with respect to the Earth. The same day, multiple geomagnetic observatories across Earth measured disturbances of varying strength. It has been suggested that this was caused by the Earth crossing through the ion tail of comet Halley [1]. Here, we present results using a method that provides information on the likelihood of serendipitous spacecraft-comet tail encounters. We provide examples of its use with recent comets, and apply the method to the suggested Earth-Halley encounter in 1910. The method uses the solar wind velocity measurements made by the spacecraft, or solar wind velocity estimates, to extrapolate the flow of the solar wind back to the Sun, so that the likelihood of the solar wind flow transporting material from a comet to the spacecraft can be measured.

The geomagnetic disturbances measured on 19 May 1910 could be considered the earliest known in-situ measurements of a cometary ion tail, long before the nature and effects of comets was well understood.


*Figure 1: Slide of Halley's Comet by John Evershed, dated 22 April 1910 [2].*

**References**

[1] C. T. Russell et al., Geomagnetic activity during the passage of the Earth through Halley's tail in 1910. Nature, 333(6171), pp.338-340. (1988)

[2] Glass slides of Halley's Comet, John Evershed, Science Museum Group Collection. (1910, Open Access)

**The ESA *Giotto* mission to Halley's comet: UK involvements & reminiscences**

Andrew Coates (UCL-MSSL) & Simon Green (OU)

*Giotto* made space history as ESA's first solo mission to another planetary body. It encountered Halley's comet on 12-13 March 1986, and the results revolutionized our knowledge of cometary science. The UK played a key role in the mission scientifically, with two instruments led by UK PIs - the Dust Impact Detection System (DIDSY) led by Tony McDonnell of Kent University, and the Johnstone Plasma Analyser (JPA) led by Alan Johnstone, UCL-MSSL, as well as co-i roles. UK industry, specifically British Aerospace, led the industrial team which built the spacecraft. In this presentation we will summarize the *Giotto* mission, especially the UK involvements, remember the encounter itself and what it was like to fly a spacecraft through a historic, fascinating but retrograde comet, present a few key results from JPA and DIDSY, and mention other UK activities such as ground observations and the Comet Halley UK Coordinating Committee (CHUKCC). *Giotto*, which also went on to encounter comet Grigg-Skjellerup in 1992, left a huge legacy for cometary science in Europe, continued by Rosetta and Comet Interceptor.