A White Paper on

Best practices for public engagement with UK space missions

Executive summary

This White Paper (WP) aims to establish a set of 'best practices' for implementing public engagement with UK space missions, starting by gathering the experiences of those involved in engaging the public with missions currently flying and under development. These experiences, their successes and difficulties, are reviewed and key recommendations are provided in the final section of the WP: **a systematic and coordinated way forward, including a secure and sustained funding base, is essential to give momentum to this ever more significant aspect of working with space, engaging the public and society in general with the inspirational qualities of space research.**

The target audience of this WP is intended to be the UK Space Agency (UKSA), UK Research and Innovation (UKRI), the European Space Agency (ESA), UK universities, organisations dedicated to enhancing public engagement with space science, as well as active participants and stakeholders of UK space missions. In particular, this WP should serve to provide to UKSA and UKRI (STFC, NERC, Innovate UK and Research England – many missions are interdisciplinary, with connections to ground based instrumentation, ionospheric physics and Earth observations) **an overview of ongoing outreach activities with which to lobby government for stronger and more sustained financial support**. Public engagement and societal impact should be at the heart of UK space activities.

1) Background research: Mission case studies

Most of the background material covered by this WP was gathered at a meeting (Nov. 2020) of interested parties, involved in space missions with UK leadership and/or involvement, which had been instigated by the UKSA. All contributors were asked how they develop and implement their public engagement activities, how were/are they financially supported, did ESA or other agencies contribute and how/what, etc.

Hinode, STEREO, Solar Orbiter

Lucie Green (Mullard Space Science Laboratory of University College London, MSSL-UCL) introduced the solar physics missions Hinode (a Japan-USA-UK collaborative mission, launched in 2006 and still operating), STEREO (also launched in 2006 and still working) and Solar Orbiter (ESA mission launched in Feb. 2020 which will take images of the Sun from closer than any spacecraft before and for the first time will look at its uncharted polar regions, combining six remote-sensing and four sets of in situ instruments).

Lucie is very active in linking audiences to solar physics missions. There have been Royal Society Summer Exhibitions on both Hinode and STEREO (touring exhibit reached over 15,000 visitors); materials from them can also serve for future outreach occasions. In the context of the Exhibitions, the evening soirées are particularly useful to allow interaction with government and funding bodies representatives. An exhibition on the Sun was held at the Science Museum; collaborations with artists, including poets, have been used to share stories about science and space missions. There have been teacher training sessions, public and school talks, science festivals and especially family events; these can be targeted to small children to start with, leading to raise interest by the older siblings and from that by the parents; this is particularly important especially over a range of ethnic diversity. TV and radio programmes have been far reaching by pitching ideas around important milestones during the missions. Lucie used to spend a lot of time in applying for small pots of money for outreach; now she finds it more efficient to use small amounts from her fellowships.

Richard Harrison (RAL Space), PI of the Heliospheric Imagers (HI) instruments onboard STEREO, added that the STEREO HI Post Launch Support activities include active consideration of outreach. The HI instruments provide the first off Sun-Earth line images of Earth-directed solar ejecta. One key outreach activity involving the HI instruments was a Zooniverse community science project called 'Solar Stormwatch' that attracted many thousands of people who participated in identifying and tracking coronal mass ejections in the first few years of the mission. The project also worked with the Alexander Whitley Dance Company in their Sadler's Wells production of '8 minutes', which was a dance interpretation of solar movies. This was staged in London and on tour to large audiences. The team give talks to schools, astronomy societies, respond to the many calls from the press and media – leading to appearances on national news, Newsnight, Sky at Night in recent years, and at events such as New Scientist Live and the Farnborough and Berlin Airshows – and issue press releases when appropriate. RAL Space has an active programme of releasing tweets, Facebook statements and full news releases whenever appropriate.

Chris Owen (MSSL-UCL – Solar Orbiter Solar Wind Analyser PI) highlighted that there had been a very large and widespread media interest in Solar Orbiter around the time of the launch, with strong support (organisation and coordination of materials and outreach opportunities) by ESA, NASA and UKSA; however, this happened only a few months before the launch, while for the rest it was left to voluntary activities of giving public talks and media interviews. The UKSA declared to have very limited funding for UK-centred outreach, which was disappointing since we missed out on making the most of the fact that UK institutes provided substantial contributions to four of the instruments and that UK industry had the prime role in building the spacecraft. However, ESA produced a lot of useful publicity material, and overall UCL, Imperial and RAL did well with their own campaigns on TV, radio, social media and with newspaper articles. Something similar happened for the first light event last summer, with good ESA engagement and a very high number of contacts made to the story through social media and press outlets. Again, the UK institutes did well riding on that, and also contributed their own great efforts, but it could be argued that UKSA missed out on their brand's share of credit and a combined and coordinated UK-thrust would have been more valuable.

BepiColombo

BepiColombo is Europe's first mission to Mercury. Launched in Oct. 2018, it is on a seven year journey to the smallest and least explored terrestrial planet in our solar system, where it will gather data during its one-year nominal mission, with a possible one-year extension. The mission is joint between ESA and the Japan Aerospace Exploration Agency (JAXA), executed under ESA leadership.

Adrian Martindale (University of Leicester) described large scale presentations on BepiColombo and the Leicester-led Mercury Imaging X-ray Spectrometer (MIXS) at, for example, the Royal Society Summer Science Exhibition and NewScientist Live. The team have also supported a permanent exhibit about BepiColombo in the National Space Centre by donating a full scale model of the instrument constructed from spare parts. The displays offered reading material using touch screens to access information, cartoons and real scientific data about Mercury and the mission. Simple demonstrations targeted across the school curriculum have been created, e.g. a cratering demonstration for younger children as well as hands-on opportunities using an X-ray fluorescence spectrometer to allow visitors to measure the composition of samples or their own possessions (e.g. jewellery). Formal presentations about the mission have been given by the MIXS science team at these events to engage an older or more scientifically literate audience.

Presentation of personal stories, such as how staff got involved, what they do on a normal day and the issues encountered (noting that ESA are sometimes reluctant to see problems receiving publicity!) can have a real impact on young people in GCSE / A-level year groups

and there is strong anecdotal evidence of these events affecting the uptake of STEM courses (through questioning new students and tracking the undergraduate intake). The Royal Society Summer Science Exhibition provided the opportunity to engage with lots of children and the public in a short space of time: it is very time-consuming preparing for it, but the Exhibition allows interaction with lots of people. It was supported by the Widening Participation programme of the University, in the context of its marketing strategy. For similar reasons, industrial partners are keen to participate and publicise their role as well, and industrial sponsorship should be folded into a strategy for proper funding of these important activities.

Also from Leicester, Simon Lindsay talked about the large efforts deployed around launch and mission milestones. Two planetary flybys (Earth and Venus) were used as opportunities to run mini-events and remind the public of the mission during its cruise to Mercury. These have been very successful, aided by the fantastic BepiColombo MCAM pictures. A full-scale model of MIXS has been built using spare parts, as well as a ¼ scale 3D printed model, a 3D printed Mercury, and Lego Bepi. There has been interaction with ESA on the mission outreach, with some contracted tasks (website, posters) receiving small amounts of funding. These outreach activities have led to the mission being picked up by major media companies, e.g. BepiColombo project staff have appeared on all major news networks around the launch. The story has also been told on the BBC Sky at Night, national radio, podcasts, etc.

SMILE

SMILE is a joint mission by ESA and the Chinese Academy of Sciences (CAS) which for the first time will image the Earth's magnetosheath and magnetospheric cusps in soft X-rays produced in the interaction of solar wind ions with neutrals in the Earth's exosphere. At the same time SMILE will image the northern auroral oval in the UV and measure particles and magnetic field in situ. Launch is due at the end of 2024.

Jenny Carter (University of Leicester) reported on her school programme of activities focussed on SMILE. Workshops on magnetic field and aurorae are held for Year 5/6 pupils; those in Year 9 use a magnetometer installed at the school and provided by the British Geological Survey, and link measurements from the magnetometer to Aurora Watch UK. Students get regular updates on the mission, so that they can follow the design, build, test, launch, and can see the human side, showing how problem solving, team working and perseverance are important. They also get to learn about international collaborations. In another project, a STFC Spark Award is used to support science clubs and workshops, culminating in a community, multiple generational 'Space Celebration Event', with the Somalia Community Parents Association (SOCOPA); this is held in conjunction with the Sphere Science company, the National Space Centre and the University of Cambridge. A second STFC Spark Award supports a programme, again with Sphere Science, of magnetism and SMILE science dissemination in primary schools, especially in less privileged and low-science-capital areas of the country. The intention is to extend this programme and run follow-up events. During this time of pandemic STFC have been helpful by extending programmes and Sphere Science have managed the logistics. The SOCOPA event has now moved online to a series of student-led workshops, with families receiving a box of activities before the students deliver the workshop content to them. Jenny initiated the use of a Twitter tag for SMILE news and events: this was setup in the absence of being able to link to an official ESA account. The tag will be superseded by the ESA account when possible. Jenny has also created a SMILE Outlook folder to act as a SMILE-team repository of exciting videos and images: these mark steps in instrument development and testing during the various phases of the mission. Again, the intention is to engage the public to follow the progress of the mission and its payload all the way to launch and beyond. All these activities are on a best effort basis, and fit around research activities or occur at weekends voluntarily.

SMILE websites are based at ESA, CAS and MSSL-UCL. Graziella Branduardi-Raymont (MSSL-UCL – SMILE Co-PI) chairs the SMILE Outreach Working Group and maintains the MSSL website, which links to the various science Working Groups, to SMILE publications, presentations and outreach material, such as the 'Aurora and Spotty' leaflet, offered in English, Spanish and Chinese. The Wikipedia entry for SMILE, kept up to date with the support of ESA, is also in several languages (English, French, Italian, Russian). SMILE Chinese partners are very prolific in producing SMILE T-shirts with logo or national flags, and gadgets (such as a heat sensitive mug). They have a very attractive website and have produced a SMILE video. So far ESA has claimed that outreach support will be given only around launch. However, with the new head of engagement/communications at ESTeC, a change may be coming, and a more proactive involvement.

ExoMars (Rosalind Franklin rover)

ESA's ExoMars comprises two missions: the first – the Trace Gas Orbiter (TGO) – launched in 2016, while the second, carrying a rover and a surface platform, is due for launch in 2022. Together they will address the question of whether life has ever existed on Mars. Installed on the Rosalind Franklin rover are panchromatic cameras (PanCam) that will be our eyes on Mars, the drill that will retrieve pristine soil samples from 2 metres below the surface, and the onboard laboratory that will seek out signs of life.

Andrew Coates (MSSL-UCL, PanCam PI) points out that ExoMars is different from other missions in that it is run as an optional ESA programme, with the UK the second biggest contributor after Italy. In the UK ExoMars is funded by the Aurora/Exploration programme rather than the science programme. It also has a very large industrial as well as academic component. There are huge opportunities for outreach for a rover going to Mars and large public interest. For example, UKSA has an annual competition for Aurora education and outreach; UKSA ran a 'name the rover' public engagement scheme which had over 35,000 entries; UKSA funded some films for schools on ExoMars; MSSL participated in the UKSA stand at Farnborough, including ExoMars, and UKSA had a presence at the Blue Dot festival, with Aberystwyth participation. At ESA (and with Thales-Alenia) there have been press releases and activities around ExoMars TGO launch. Airbus have also hosted press events, e.g. in August 2019 for PanCam installation on the rover. The PanCam team has been very active in outreach, and has an Outreach Working Group which captures people's activities. These include talks to schools, astronomical societies, WIs, etc.; numerous press and media items, podcasts, TV and radio interviews, and projects, such as Lego and Roving with Rosalind. The Twitter site @ExoMarsPanCam already has over 6,600 followers well before launch. For the launch in 2022 UKSA and ESA are expected to be very engaged. UCL has been helpful in providing opportunities for engaging with media and the press. A few active individuals are not always funded, and better coordination ESA-UKSA-Universities would be helpful and produce even better results.

Comet Interceptor

Geraint Jones (MSSL-UCL – Comet Interceptor PI) introduced the mission which will be launched in 2029 to L2 and will be 'parked' there waiting for up to three years for a long-period comet to flyby at a reachable trajectory and speed for an encounter.

The project is clearly at a very early stage; an Outreach Working Group has been set up recently to promote international coordination. Shared resources are easily translatable into multiple languages, e.g. see cartoon strips at STFC-funded astrojots.com. Armagh Observatory is to develop a planetarium show based on the mission and its interdisciplinary science. There would have been a Welsh-language exhibition about the mission in August 2020 if it had not been for the pandemic; now the plan is for a 2021 RAS200 project. Website, Twitter, public talks are all part of the outreach being developed. There are plans to apply to

STFC for small grants as Spark Awards, and to support some outreach from consolidated grant funding. ESA were very successful in running outreach activities for Rosetta, which Comet Interceptor could draw on, but ESA will not dedicate significant effort before mission adoption; after that ESA involvement is expected to be scaled according to the size/cost of the mission (although in the past ESA have become proactive only about two years before launch).

Giant Planet Missions: Cassini, Juno and JUICE

Leigh Fletcher (University of Leicester) described how NASA-ESA missions to the outer planets Jupiter and Saturn have provided a successful platform for public engagement.

Flagship-class missions to the outer solar system are major projects operating over multiple decades, allowing them to build up a substantial following and online presence over many years. The NASA/ESA/ASI Cassini-Huygens mission orbited Saturn from 2004 to 2017, and featured UK hardware involvement in remote sensing, in situ plasma and fields sensing, and direct sampling on the Huygens probe to Titan. The NASA Juno spacecraft will orbit Jupiter from 2016 to 2025, and features scientific co-investigator and participating scientist roles, primarily at the University of Leicester. ESA's Jupiter Icy Moons Explorer (JUICE), due to launch in 2022, was developed with UK leadership, features a UK lead for the magnetometer, and significant scientific co-investigator roles across the country. Whilst these missions are led by international agencies, national funding supports hardware and scientific exploitation, which leads to local opportunities for public engagement, at key points in the mission cycle, or associated with new discoveries. These are usually coordinated with the primary agencies (ESA and NASA) and individual institutions. ESA and NASA both use dedicated engagement departments to develop resources, websites, and to maintain a strong social media presence, which individual scientists, institutions, and science centres (e.g. the National Space Centre) help to disseminate (usually unfunded). Direct UK financial support for Cassini, Juno and JUICE-based engagement has been limited, which is understandable given the wide impact of NASA and ESA in their dissemination. As a result, public engagement and school outreach have relied on the availability and enthusiasm of individual scientists, often acting without any centralised coordination or access to resources. As we advocate below in Section 3(e), provision of curriculum-based resources based on these flagship-class missions, and training for educators (schools and science centres), could greatly increase UK reach.

James Webb Space Telescope

The forthcoming James Webb Space Telescope (JWST) has significant UK hardware roles (particularly via the MIRI instrument), and will contribute a significant planetary science discovery space in addition to its main astrophysical programme.

Leigh Fletcher points out that although JWST is often considered as an astrophysical research facility, its capabilities will produce a wealth of new discoveries in solar system planetary science, following the legacy of Hubble in the visible range. As with the giant planet missions described above, this flagship-class observatory has significant engagement and outreach managed by ESA and NASA as lead funding agencies. Nevertheless, UKSA funding to the Astronomy Technology Centre has permitted a successful programme of UK activities, under the umbrella of 'WebbUK'. These have highlighted UK involvement in the mission, developed resources for schools and science centres, and coordinated public engagement for this mission. It is an excellent example of how coordinated engagement can have a broad reach and benefit, with JWST showcased at the Royal Society Summer Exhibition, and a forthcoming tribute to Hubble (at a virtual Royal Society exhibition) organised by the same team. Crucially, evaluation of the engagement effectiveness seems to have been built into the programme from the outset, showing the value of professional science communicators.

Gaia

Launched in 2013, the ESA mission Gaia is making the largest, most accurate three-dimensional map of our Galaxy, providing unprecedented positional and radial velocity measurements of about one billion stars in the Milky Way and throughout the Local Group. A large amount of scientific results from the mission have been published and the Early Data Release 3 has just taken place.

Floor van Leeuwen and Gerry Gilmore (University of Cambridge) described Gaia outreach activities. Cambridge University webpages have been developed with institutional support and a large amount of people's own time. Exhibition material (posters, small gifts) has been obtained with external funding and support from ESA at times of data releases. Many dedicated exhibitions have been held: Twice at the Royal Society, open days, local science days (Ely Cathedral, Birmingham library) and there has been collaboration with UKSA to provide displays in BEIS HQ. In the early days there was significant industry partnership with Airbus and e2v, especially through staff support which is continuing today. Teachers training days have been held, and collaboration established with national education/student and amateur societies on observational programmes, through science alert follow-ups (external EC funding); in some cases students involved in observations become paper co-authors. A special one-off grant (£40k) was received from STFC for producing a model and display stand materials; cartoon programmes popular with kids at open days and professional films explaining the science of Gaia have been produced by Cambridge University (which had to be paid for!). No dedicated funding has been received except in one-off cases, while engagement with the public has been just on personal best effort basis, plus sometimes using small contributions from separate grants. Gaia has generated high media interest, especially at the BBC.

Euclid

ESA's Euclid will be launched in 2022 and will provide visible and near infrared images, with spectrophotometric measurements, over 15,000 square degrees of the extragalactic sky. The result will be a catalogue of over 3 billion galaxies with high resolution images. These will be analysed to extract weak lensing shape measurement and galaxy redshift information, which in turn will be used to make dark matter and galaxy maps in 3D. The primary science objective is to use these maps to determine the nature of dark energy – that is causing the expansion of the Universe to accelerate, accounts for 70% of its mass-energy content, but which we cannot explain.

Tom Kitching (MSSL-UCL) reported that the outreach in Euclid is not centrally coordinated and is reliant on individual Euclid Consortium members initiatives. This is relatively inhomogeneous across the 15 member countries involved, and ESA. Amongst the member countries the UK is one of the most active. One area of activity is the use of 'artists in residence': an example of this was Lisa Pettibone (artist in residence, 2018-2019 at MSSL) who produced artwork for a public exhibition inspired by her experience at MSSL working with the Euclid team. For REF2021 she provided a testimonial: 'I gained a new understanding about the dark matter and the Universe through working with and observing the work of scientists at MSSL on projects related to the Euclid mission. […] This inspired me to respond to scientific concepts by making work that stimulates sensory experiences in the viewer. […] As a result, I created a series of artworks, including two site-specific installations, sculptures and photographic and screen print imagery. Titled "Emerging Cosmic Landscape", the end-of-residency exhibition was held at Lumen Gallery, London in October 2019'. Interaction with the BBC led to a documentary focussed on the Euclid mission for Horizon: 'The Mystery of Dark Energy' (the film was broadcast on March 30, 2016). The documentary sought to explain dark energy and interviewed Euclid engineers, as well as it covered the work going into testing and building the Visible Instrument (VIS). The film was a great success, with the Sunday Times

calling it ‘fascinating’ and The Telegraph ‘engrossing’. Euclid has also published several articles in the national press (see e.g. https://theconversation.com/uk/search?q=euclid+dark+energy) that have received over 1 million reads. The web presence of Euclid UK is minimal (https://eucliduk.net) and for social media Euclid has a UK account @euclid_uk, a Consortium account @Euclid_EC, and an ESA account @ESA_Euclid, but more could be done to exploit these channels.

LISA

While so far gravitational waves (GW) have been detected only on the ground, for the first time in 2015 with the LIGO detectors, the Laser Interferometer Space Antenna (LISA), a large-class ESA mission, will be the first space-based gravitational wave observatory. LISA will consist of three spacecraft separated by 2.5 million km in a triangular formation, following Earth in its orbit around the Sun. Launch is expected in 2034.

Martin Hendry (University of Glasgow) described the outreach activities associated with LISA. The LISA Consortium (currently more than 1000 members) has an Advocacy & Outreach Working Group (co-chaired by Martin) which coordinates the Consortium communications strategy. Partners in Germany have more funding to support this effort, so collaborating internationally is an effective way to share material and make the most of it – particularly as the Consortium is global in its membership. Martin oversees a Consortium website, social media and YouTube channel, all hosted by the Albert Einstein Institute LISA group in Hannover; in both the UK and more widely, there have been science festival events and exhibitions about LISA (with and without collaboration with other GW/astrophysical communities), GW masterclasses for high school students, online teacher training, audio, visual and web media contributions, printed materials, multilingual outreach and also a mission logo contest. Outreach has also been targeted to the broader academic community, to funding agencies and/or foundations, and to government too. The advantage for LISA is that GW are now much more widely known, thanks to the ground-based detections, but the outreach challenge then becomes making the case for the enormous additional benefits that will follow from opening up more windows on the GW spectrum.

PLATO

PLAnetary Transits and Oscillations of stars (PLATO) is the third medium-class mission in ESA's Cosmic Vision programme. Its objective is to find and study a large number of extrasolar planetary systems, with emphasis on the properties of terrestrial planets in the habitable zone around solar-like stars. PLATO has also been designed to investigate seismic activity in stars, enabling the precise characterisation of the planet host star, including its age.

According to Don Pollacco (University of Warwick), little dedicated outreach is currently taking place but it is expected to start ramping up about two years before launch (due in 2027). There is no explicit funding for outreach in the current grant. All people involved do significant outreach voluntarily. Now Warwick has just opened an ‘Institute for engagement’ so it looks like the University is putting money to words. More people may come in through this and their career progression will include outreach considerations. ESA will not start outreach activities until a few years before launch, UKSA talks of outreach but has no money earmarked for it, STFC does some funding through small awards. The PLATO Consortium has an Outreach Workpackage under the leadership of the PI (Berlin) with the Open University participating. There has been steady interest in exoplanets by the public over the past 10+ years, which is promising. With GW, that of exoplanets is one of most attractive areas for outreach. Personally, Don is particularly interested in disadvantaged schools where pupils may not obviously be going to university, and he will direct his efforts towards them, to show people there is another way. Don also attended a prison visit, organised through the National Space

Centre, with Leigh Fletcher (Leicester) and the feedback and sense of reward returned from this was very strong.

Ariel

The Atmospheric Remote-sensing Infrared Exoplanet Large-survey (Ariel) is the fourth medium-class mission in ESA's Cosmic Vision programme. Due for launch in 2029, Ariel will survey a diverse sample of exoplanets, simultaneously in visible and infrared wavelengths, and study what they are made of, how they formed and how they evolve, by measuring the chemical composition and thermal structures of hundreds of transiting exoplanets.

Giovanna Tinetti (UCL – Ariel PI) stressed that public engagement is an important priority for the Ariel Consortium. Ariel's communication and outreach activities target a wide audience that includes the public at large, as well as focused groups such as school students and amateur astronomers.

Ariel scientists have already started to work with the amateur astronomer community, citizen astronomers and schools encouraging them to undertake a programme of observations to support Ariel's ephemeris refinement. The ExoClock project (https://www.exoclock.space, Kokori et al. 2020, https://arxiv.org/pdf/2012.07478.pdf) aims to facilitate a coordinated programme of ground-based observations to maximise the efficiency of the Ariel mission. The programme also aims to stimulate engagement with citizen astronomers, allowing them to contribute to an upcoming ESA mission. The ExoClock initiative has the explicit rule that all those who upload data for a planetary system will be included on any subsequent publications.

In 2019 Ariel launched a global competition series to find innovative solutions for the interpretation and analysis of exoplanet data. The first Ariel Data Challenge invited professional and amateur data scientists around the world to use Machine Learning (ML) to remove noise from exoplanet observations caused by star-spots and by instrumentation. The Ariel ML contest has been selected as a Discovery Challenge by the European Conference on Machine Learning and Principles and Practice of Knowledge Discovery in Databases (ECMLPKDD). Over 100 international teams participated to the challenge. Outcomes from all three Ariel Data Challenges have been discussed at the ECMLPKDD in Würzburg 16-20 September 2019 and at the EPSC-DPS Joint Meeting 2019, which took place in Geneva during the same week. The winners were awarded at the ECMLPKDD and Ariel Open Conference in ESTeC in January 2020. The results are being published (Nikolaou et al., https://arxiv.org/pdf/2010.15996.pdf). A new Ariel Data Challenge will be launched in April 2021.

Pilot programmes, already underway with secondary school groups in the UK (e.g. ORBYTS programme), have started to produce original, publishable scientific research associated with the characterisation of exoplanetary atmospheres, under the supervision of PhD students and Post-Docs. Initial projects have focused on compiling data points for molecules of interest for modelling the atmospheres of cool stars and exoplanets (e.g. acetylene, titanium oxide, methane). Edwards et al. (2020a, b; https://iopscience.iop.org/article/10.3847/2515-5172/aba42b; https://doi.org/10.1093/mnras/staa1245) published the refined ephemerides of eight exoplanets to be observed by Ariel using a fully robotic telescope network, observations from citizen astronomers and data from TESS; a significant portion of the work was completed by high school students via the ORBYTS programme.

ORBYTS

William Dunn (MSSL-UCL) explained that the ORBYTS (Original Research By Young Twinkle Students) programme was originally created at UCL in the context of the Twinkle exoplanet mission, as outreach for pupils of under-represented communities. ORBYTS partners researchers with schools to offer pupils their first taste of original research. The programme is typically a series of ~12 x 2 hour fortnightly tutorials, bracketed by a 'launch event' at the University (campus tours, talks from academics) and a closing conference, where schools

present their research. Tutors (normally PhD students or Post-Docs) are paid at University demonstrator rates. Alongside other grants, UCL's widening participation department provides funding for state schools in disadvantaged areas, while independent schools pay for themselves and at least one state school. Project average costs are £1000/year. Coordination for the entire programme is through 20% of William Dunn's post-doctoral position and a lot of his own time.

From 2017-2020, the programme had a 100% school retention, expanding through word-of-mouth from 2 to 30 researcher-school partnerships. In schools where these researcher-partnerships occur with pre-16 students (i.e. GCSE) schools report 100% increases in girls taking up physics post-16 (i.e. A-level). Since 2017, the programme has enabled more than 100 school students from low income backgrounds and of more than 40 ethnicities to author scientific papers (Chubb et al. 2018a,b; McKemmish et al. 2017, 2018; Darby-Lewis et al. 2019; Holdship et al. 2019; Edwards et al. 2020a, b; Wibisono et al. 2020; Francis et al. 2020; French et al. 2020). There is also evidence that the programme supports teacher retention.

Originally, ORBYTS focused on molecular astrophysics, with students adopting analysis of molecules of astronomical interest for exoplanet atmospheres. The programme has expanded beyond exoplanet research, to many fields and several universities (Lancaster, Northumbria). Best practice learning and factors that enable ORBYTS impact:

1. Rather than one-off visits, ORBYTS's model utilises repeated, long-term visits. Teachers note that this enables the scientists to become relatable role models for students and has an 'immensely humanising' impact on the science.
2. Low confidence is known as a key barrier to student involvement in science. Active, carefully-scaffolded involvement in research builds a sense of student agency, and is proving to be transformative for student science confidence. Researchers are encouraged to discuss their failures to dispel harmful misconceptions around the requirement for unattainable innate intelligence.
3. 'Raising aspirations' is often cited as a solution for involvement of historically-excluded groups. While this interpretation is potentially a misunderstanding of the context, the underlying research suggests that the key is transparency and ensuring pathways appear accessible. Researchers are encouraged to discuss both their own career (and pathway to this) and careers of colleagues who undertook science degrees and no-longer directly do science. This helps realise students' science prospects.
4. The ORBYTS model is particularly successful in schools with low numbers of physics teachers (9 of the 11 ORBYTS papers came from such schools). In these contexts, the researcher provides scarce subject specialist knowledge which supports teacher CPD. Many teachers comment that without the partnership model, they would not have time or sufficient background to lead these projects themselves. For more advantaged schools, programmes such as the Institute for Research in Schools (IRIS), or material developed as Leigh Fletcher suggests in Section 3(e) below, are possible alternatives.
5. The biggest challenge ORBYTS projects overcome relates to technology. Dunn currently recommends a model that utilises Google Colab. For schools, this removes the need to install specialist software. For enthusiastic students (particularly those from low-income backgrounds) this removes technology barriers, enabling, for example, the student to continue with the project on the bus home on their phone.

ORBYTS proofs a model applicable to many space missions, research groups and schools across the UK. Its continued existence/impact depends tenuously on annual awards of grants.

2) Background research: Additional contributions

Gabby Provan, University of Leicester

Gabby's outreach activities are not on specific missions but focussed on 'Northern lights on Earth and other planets'. At Leicester they have a planeterrella, a planetarium, and run weekly sixth-form homework clubs. There is an ongoing project on the multi-wavelength Universe

'What is not visible is not invisible', a cross curriculum art/science approach to engage with excluded pupils, using the available facilities as well as a thermal camera. Gabby's outreach has been funded by at least 3 STFC small awards and one IoP award. It is difficult to get continuity of outreach with such small pots of money. As part of her UCU trade union role Gabby is funded ½ day a week over a few years to perform union duties. This kind of approach, funding staff to perform part-time outreach activities for a few years, would help the continuity of people and funding that is so desperately needed.

Maria-Theresia Walach, Lancaster University
Doing ground-based research work with SuperDARN, Maria focusses on the study of solar wind-magnetosphere-ionosphere-thermosphere coupling, and connects it with relevant space missions. Her outreach consists of local and regional public events, school projects (within the ORBYTS programme), planetarium shows. Maria raised the issue of the funding structure in the UK which is such that the average researchers are not enticed to do outreach for the conflict between achieving a high rate of scientific publications and volunteering their time for outreach, as also discussed below in Section 3(c).

3) Recommendations

From the above it is clear that a large amount of (mostly personal, voluntary and unpaid) effort is dedicated to engage the public in space research and science by those with a career, or studying, in the field. It is also clear that a limiting factor to continuing and further expansion for these outreach activities is the lack of sustained and organised funding by government agencies and universities. Activities are mostly single mission related, and a more joined-up effort could be expected to produce results in a much more efficient and consistent fashion.

Many members of our space science community carry out ad hoc, unsupported and opportunistic engagements, usually associated with timely events in a mission's lifecycle (e.g. such as those described above). Our community provides social media and magazine contributions, presentations to schools, societies, museums, festivals, exhibitions, TV and radio. Some of the missions have collaborations with very keen amateur observers that also participate in science publications. As recorded above, there is a general concern that these sorts of short-lived interventions offer inspiration but do not necessarily raise aspirations to STEM subjects, which is often seen as a driving goal.

The following is a summary of the main points and key recommendations distilled from the experiences contributed above.

a) Sustained support

Space research offers an outstanding multi-disciplinary opportunity for engaging the public with science, for building the next generation of scientists and engineers, and benefit the UK economy. Funding agencies such as UKSA and UKRI should make the case to government of the importance of outreach and get involved not only around the time of mission launches, but through their build up, and exploitation phase after launch, in order to care for and support continuing education of society. Ignoring this inspirational and educational potential is a lost opportunity for very little cost compared to the main investment.

b) Equitable support distribution

Within UKSA there seems to be a different approach to outreach around the Aurora programme and the Science programme: the former more readily supports missions (e.g. ExoMars) and draws on Tim Peake's popularity. A more equitable distribution of funding inside the Agency for the two programmes would bring benefit to areas of science that currently are

mostly left to marginally funded individual initiatives. In particular a coordinated approach should also take into consideration funded missions under development, such as Euclid and JUICE.

As an example of what already exists, the website (https://www.publicengagement.ac.uk/) of the National Co-ordinating Centre for Public Engagement provides a good amount of information and training opportunities, and lists a number of funding bodies for STEM activities, with the European Geosciences Union (EGU) and STFC grant schemes being the two relevant to our case.

c) Outreach as performance indicator

On one side outreach is thought to be part of academic work, on the other there is no clear allocation of time for it: how to find time to write funding proposals for outreach, while mission/observing/funding for science proposals are pressing? There is tension between the encouragement staff receive by some line managers to get involved in outreach and the universities and funding agencies requirements of high rate of publications. Clearly there is need to find a way to balance the two. The problem is felt especially by established and early career staff, and to a lesser extent by PhD students, who are demonstrating more and more to be keen to engage with the public, which is in itself good news. A way to improve the situation would be to include performance in outreach, with an allocated working time fraction, in job definition and as a condition for career progression. Ultimately, if we want to improve the quality and quantity of outreach, the funding and pressure to do so has to come from research councils.

d) Curating spare hardware

Lucie Green encouraged instrument PIs to make sure important 'first bits' of hardware, not for flight, are kept for outreach and museums. There is a critical need of developing a culture about how to best curate materials, as well as of shining a light on the engineering (e.g. films following the engineering development of Solar Orbiter). In response to this, Richard Harrison pointed out that the engineering model of the SOHO CDS instrument was housed at RAL as part of an operations facility and was used as an 'active' display for numerous visitors over almost 20 years. Other equipment such as the structural model and the earlier CHASE experiment (that flew on Spacelab II) are loaned to the Science Museum. In a similar vein, Graziella points out that the Gas Scintillation Proportional Counter that was part of the Spacelab I payload and returned to Earth on the Space Shuttle Columbia, has been on display at MSSL for almost 40 years!

e) Resources hub

Jenny Carter proposes to establish a 'centralised hub of resources' that are common to all missions, such as that of STEM resources for teachers and students held by the National Space Academy. All missions could contribute and avoid to re-invent the wheel each time, making this a useful database also for funding agencies.

Leigh Fletcher suggests a two-pronged approach to counteract the difficulties in raising aspirations and reaching a wide target audience – develop materials for schools that are aligned with the curricula, can be pre-recorded in short bitesize chunks for teachers to show and motivate a lesson; and work with science centres that employ people specifically for public outreach and engagement. On this last point he mostly works with the National Space Centre and the National Space Academy and recommends collaborating with such Science Centres teams to ensure our efforts have the maximum reach. By training teachers and science communicators to deliver material prepared by mission experts, such content can have a

longer shelf-life and greater reach, because it does not rely on overstretched academics and researchers delivering content in person.

f) Coordination

Importantly, how do we coordinate in an efficient way the myriad of outreach activities that are ongoing by individual efforts? Coordination would provide added value by making activities visible to funding agencies; these could then celebrate outreach efforts like they did for the engagement programme inspired by Tim Peake's mission. A coordinated approach with a 'one-stop shop' as proposed above in (e) would provide essential support when organising outreach and would reveal the diversity of materials, skills and people involved in space. Moreover, how do we demonstrate and measure the impact of our engagement with the public in order to attract further funding?

In addition to funding outreach projects directly, an infrastructure is needed, ideally centrally organised by the UKSA, that coordinates and monitors activities in a professional way, e.g. producing evaluation reports. A team of a couple of people, paid to dedicate at least 50% of their working time to such coordination and reporting for a mission-wide programme of outreach, would be a positive starting point. They would help emphasise the synergy among missions, would reach out to and develop opportunities that would have been missed by researchers busy with their missions, and also could establish a framework and a set of benchmarks to measure impact.

In summary, while we are focussing and continue to work on what is achievable in the short term, with this WP we intend to outline and promote practical and realistic actions for the medium-long term that would lead to a better coordinated, supported and effective programme of public engagement with space science in the UK.

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