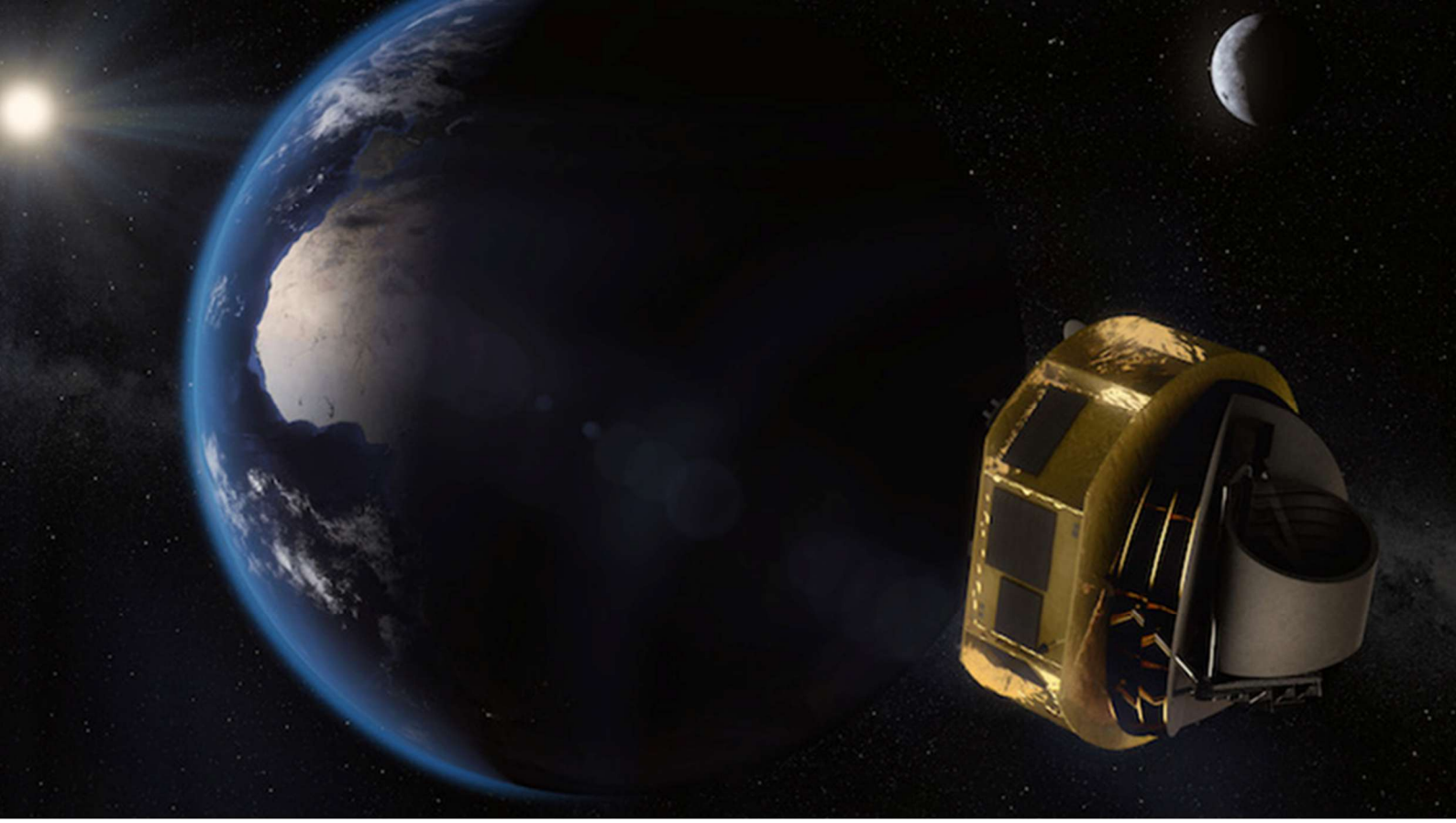

Ariel Monitoring & Evaluation Support

Interim Process & Impact Evaluation

A report for the UK SPACE AGENCY

CONFIDENTIAL

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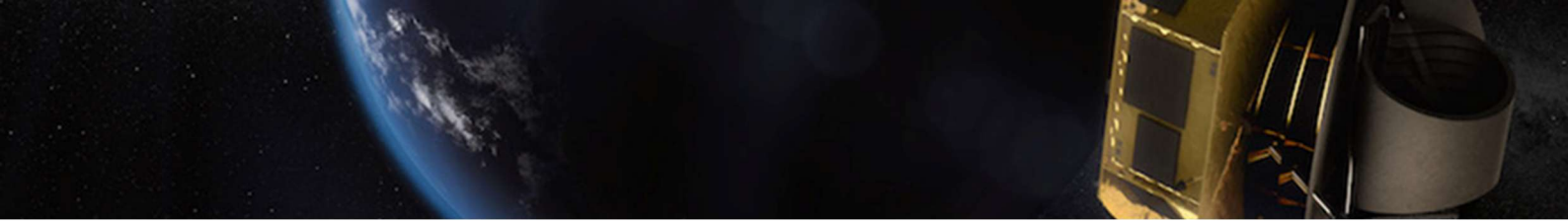
May 2025



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to understand clearly and with certainty

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Acknowledgements

We are grateful to all those within the project team who engaged with us over the course of this study, and for making their time to support the study with interviews. We would particularly like to thank Ryan King from the UK Space Agency for his input and advice over the course of the project. Responsibility for the content of this report remains with **know.**space.

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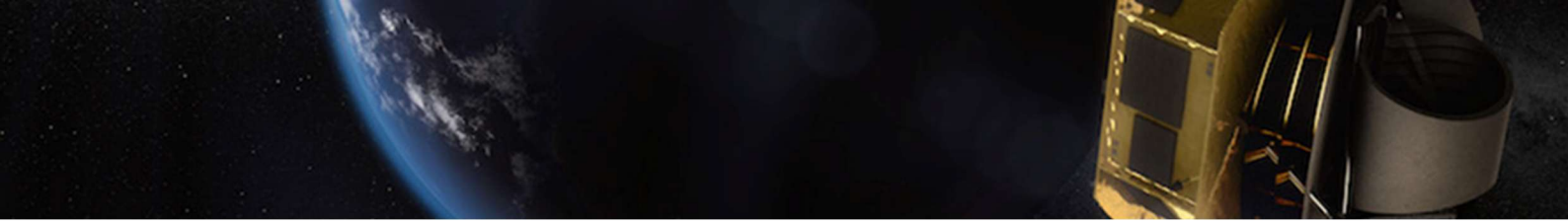

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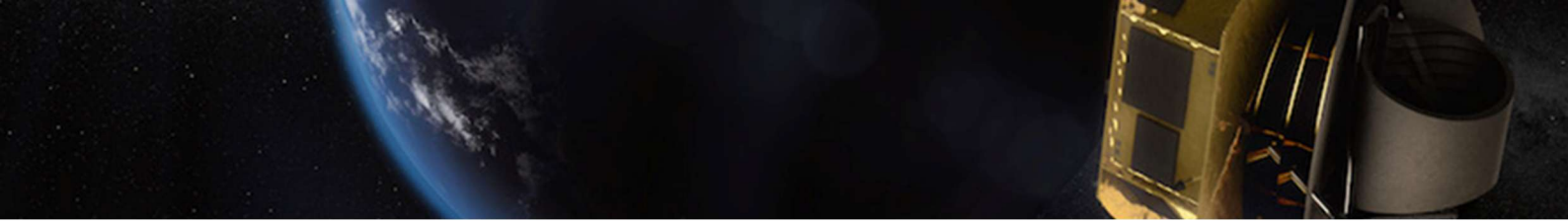


Executive Summary

Introduction

Ariel is the fourth medium-class mission in ESA's Cosmic Vision programme, set to launch in 2029 to study the atmospheres of 1,000 exoplanets. Development of the spacecraft and instruments is ongoing, alongside efforts to prepare the scientific community for future mission data.

Core funding for the mission comes from ESA's space science budget, with additional £30.3m support from the UK Space Agency to ensure UK leadership in science, engineering, and programme management. Led by Principal Investigator (PI), Prof. Giovanna Tinetti (UCL, moving to King's College London), Ariel also involves RAL Space (payload integration, cryogenic cooler), Oxford (optical ground equipment), and UCL/Cardiff (science operations, data processing). UK Space Agency investment aims to deliver impacts aligned with four business case investment objectives:

1. **Scientific leadership**: Secure UK scientific and technical leadership of exoplanet research, data science and space science by nominal end of mission.
2. **International reputation & collaboration**: Enhance the reach and reputation of the UK's space sector.
3. **Inspire, attract, and retain talent** to upskill our workforce.
4. **Stimulate innovation and commercial opportunities** through data science and space technology.

Monitoring and Evaluation (M&E) has been embedded into UK Space Agency governance of Ariel national funding. **know.**space were commissioned in 2023 to provide independent M&E support, to strengthen UK Space Agency understanding of mission progress, the effectiveness of funding, and its impacts. This report, delivered in March 2025, is the final deliverable from this work over the last 2+ years.

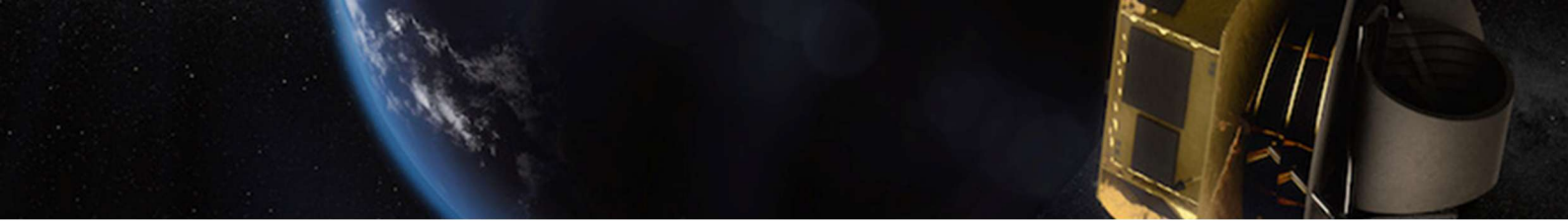
Key findings

While there is a long-term nature to many routes to impact from the mission, the UK Space Agency's national contribution has so far demonstrated **strong initial progress across all four business case investment objectives**. National funding – and the scientific and technical leadership it has secured - has led to greater UK returns from wider Ariel mission funding. Without this funding, a different mission may have been selected by ESA, and if Ariel was still chosen, UK involvement would have been greatly diminished. The benefits we set out are, in our view, **highly additional**.

Funding has **led to an increase in the quantity and quality of UK science outputs**, and has enabled collaboration within and outside the UK. National funding for Ariel has enabled the UK to shape the mission, **provide leadership and influence**, and set foundations for future benefits and potential roles in major missions. However, opportunities are tied to successful mission delivery.

While attribution challenges are inevitable for such missions, **the emerging benefits are sizeable, even if not solely attributable** to UK Space Agency national funding. For example, the emerging impact story on benefits from the Ariel Data Challenge and ExoClock initiatives, which leverage (and in-turn reinforce) the profile of the Ariel mission more, and also feature support aside from UK Space Agency funding.

The UK's leading role on Ariel has helped attract talent to the UK, **growing the skills base**. It has also provided experience to early-career individuals, helping to develop in-demand skills in the space sector. Leadership over Ariel has been used to **signal leadership to investors**, with Ariel-



related start-ups having secured millions in investment. While not wholly attributable to UK Space Agency funding, the events are linked to UK roles and AI/ML capabilities being developed as a result.

The UK Space Agency identified several targets to monitor benefits realisation for UK activities, and we conclude these **targets are largely being met**. In rare cases where they are not, we do not view this as a significant cause for concern, as broader factors (e.g. JWST-related publications) can influence observed trends. While emerging benefits are promising, **many current activities are focused on positioning the UK for future benefits**. Delivery challenges could easily derail the so-far positive view of how the UK is delivering roles and responsibilities on the mission. Our broad conclusion is that **good progress has been made thus far, although there is a long way to go yet.**

While the mission has helped attract and retain talent, **retention risks are ever-present** given its long-term nature. Some stakeholders felt these are exacerbated by **uncertainty over future funding**, with key personnel working on fixed-term contracts and seeking more stability. In some cases there are also **single point of failure risks** regarding knowledge transfer. While these risks have not materialised to date, they could present barriers to the realisation of future benefits.

The commercial benefit story is still at an early stage. In the words of one stakeholder, space science is the 'funnel' through which longer term commercial benefits can unfold from over time. There are promising start-up companies with links to Ariel, with over £14m of external investment secured so far, though with **potential for much larger prizes on offer as a result of ongoing activities**. While there is evidence of initial impact, it is **too early to draw definitive conclusions**.

The high level findings of our process evaluation are that, while there have been challenges with mission development (often beyond UK control), there are **strong working relationships** in place, **with high levels of trust and collaboration** between UK project team members, UK Space Agency and ESA. The UK team is seen as **delivering effectively despite limited resource**. The **Project Management Board** is seen as working well, with **strong expertise and "solution orientation"**.

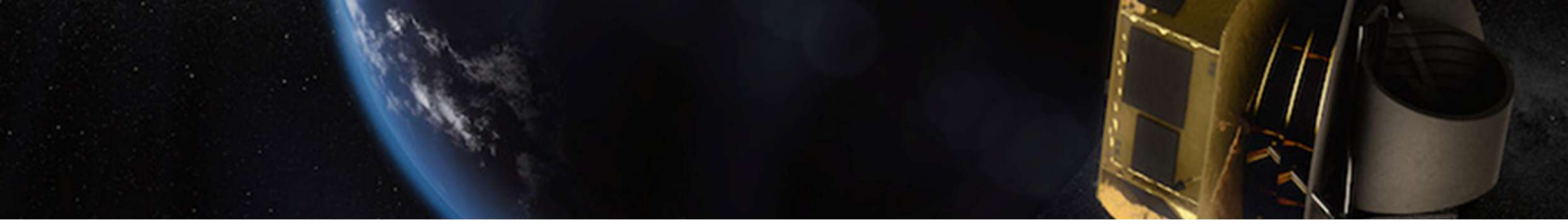
We provide recommendations to improve processes including by continuing robust risk assessments and mitigation planning, strengthening communications, ensuring realism in planning, and streamlining and aligning reporting requirements. We **endorse UK Space Agency and RAL Space implementing the recommendation of the independent 'Sarri review'** to formalise RAL's leadership role in technical areas. While recognising the realities of funding constraints, we also note that **greater resourcing, if possible, would reduce several project delivery risks**.

Performance against the evaluation questions set out in the 2023 M&E framework is positive, with **all impact and process areas rated 'amber' or 'green' in our RAG ratings**. Amber ratings often reflect that insufficient time has passed to assess outcomes definitively. Green ratings typically indicate strong initial progress - caveated by the fact that they reflect positive trajectories rather than significant socio-economic returns achieved to date.

Interim process evaluation

Management and oversight

Working relationships within the Ariel consortium are considered strong by most stakeholders, including interactions between the UK Space Agency, the wider Ariel consortium, and ESA. The UK Space Agency is widely regarded as approachable, responsive, and communicative, while the Project Management Board (PMB) is praised for its technical expertise. Some stakeholders suggested the PMB could utilise this in discussions with ESA and ASI, while recognising this would require further resourcing.



As payload integrator, RAL Space is acknowledged as being **highly competent and dedicated, though stretched thin in terms of resource** and lacking the contractual levers to influence key partners. The Sarri review[2] highlighted the need to formalise RAL's leadership and enhance resource. All stakeholder groups had recurring views that greater realism in early planning, improved delegation of authority and control, and enhanced communications are key to progressing the mission towards successful launch.

Mission delivery

This evaluation focuses on the UK's national investments into Ariel, rather than the broader mission. However, the two are interconnected, with cascading impacts that cannot be entirely separated. **The UK's leadership in Ariel continues to be viewed as key, to the mission's overall success**. Despite broader mission delivery challenges, both scientific and technical progress was noted.

The main mission challenge to date has been technical delays with telescope assembly, led by the Italian contractor Leonardo. While **these delays are not specifically connected to UK Space Agency national funding**, they place pressure on RAL Space's resourcing and leadership of the consortium, and risk becoming a bottleneck that could affect the broader return on investment from UK funding.

Like many evaluations of UK research and innovation investments, we heard how UK-specific funding issues such as **spending review uncertainties** have impacted planning and staff retention. These impacts are real, though we recognise they are largely beyond the control of the UK Space Agency to address. The same is true for broader geopolitical factors – such as the war in Ukraine and the global semiconductor supply shortage – which had implications for broader mission delivery.

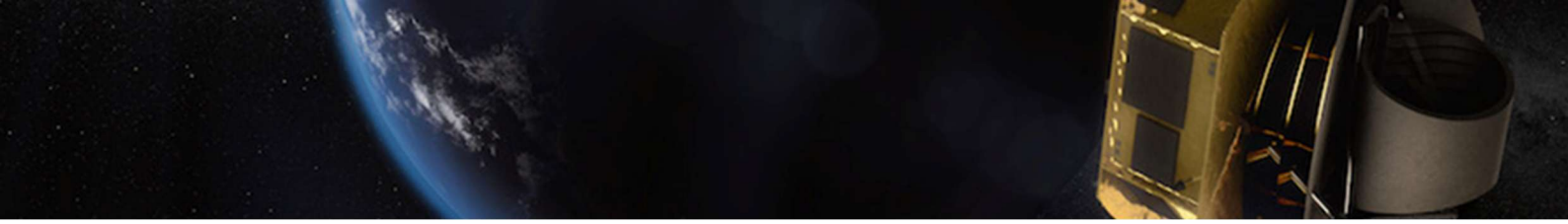
Rising costs within the UK Ariel consortium have required tough conversations around spend and transferring responsibility of elements to ESA. This is true of the active cryocooler system (ACS), where there is a risk of losing UK design IP before the CDR. While previous change control processes were considered broadly reactive, UK Space Agency have now implemented a Change Control Plan. This mechanism is a **good example of the UK Space Agency / the PMB being solution-oriented and proactive** in finding processes to support smoother delivery of the programme.

Administration and resourcing

Examples of institutional resilience have emerged, including **well-managed staff transitions that have enabled the retention of expertise and the continued upskilling of early career-researchers**. UK team members have innovative concepts which could be explored further, which may result in future benefits around commercialisation. M&E activities were **valued for tracking progress and helping form a narrative** to convey impacts to UK Space Agency and other senior stakeholders.

A key concern is resourcing, with team members often **constrained by limited time and budget to pursue broader opportunities**. Reporting burdens were seen by some as disproportionate, such as Researchfish requirements for small/bridging grants and changes in reporting templates. Additionally, given Ariel's long timeline, staff turnover poses a risk to institutional knowledge, highlighting the need for ongoing upskilling within the UK consortium, supported by the UK Space Agency.

[2] Giuseppe Sarri (a project manager from ESA's JUICE mission) was commissioned to undertake a review focused on the delivery of the Telescope Assembly by Leonardo (which is behind schedule), as well as evaluating the management and resourcing of the mission. The review aimed to fix recurring tensions around schedule burdens which have fallen on RAL Space, despite it not having the authority (or appropriate delegations) to hold consortium members accountable.



Interim impact evaluation

Science

Whilst the bulk of the scientific return from UK Space Agency funding will be realised once the mission is operational, we view that **funding has secured UK scientific leadership and led to an increase in both the quantity and quality of science outputs**. We assess Ariel as being broadly on track to achieve scientific objectives, however future activities are required to fully realise objectives:

- Prof. Tinetti, the UK mission PI, is restructuring working groups to enhance participation, maximise science return, and ensure agility to new exoplanet research from other missions such as JWST through pioneering publication and data policies.
- Ariel-related research output has risen annually, despite some fluctuations, with 477 publications since 2018. The annual average has doubled from 43 to 87 during the analysis period. For comparative context, there were an annual average of 33 Gaia publications and 13 CHEOPS publications in the 3 years following launch (in 2013 and 2019 respectively)[3].

The **UK project team is beginning to demonstrate early leadership over Ariel science**. UK Space Agency funding is also enabling contributions from non-funded organisations across the UK:

- The number of Ariel papers with a UK-affiliated first author has increased in both absolute and relative terms. UK authors appeared in 24 papers per year during the baseline, rising to 43 in the analysis period. Overall, 50% of Ariel-related papers feature UK authorship, positioning the UK at the upper end of the UK Space Agency's target range.
- 31 UK organisations have published Ariel-related research, increasing by four in the analysis period. UCL leads (70%), followed by RAL Space (18%), Oxford (8%), and Cardiff (8%). While UK Space Agency-funded institutions dominate, contributions from St Andrews, Open University, and Exeter highlight broader interest in the mission.

There is **increasing activity in the wider field of exoplanet science**, although driven largely by other missions and ground-based observations – Ariel has not significantly influenced this yet.

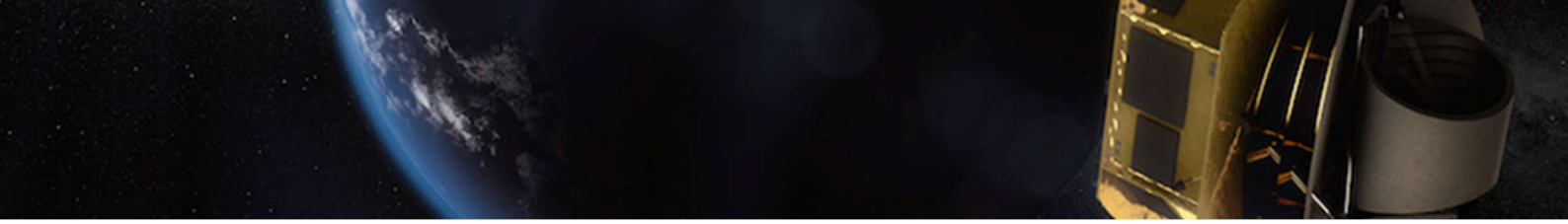
- Ariel will build upon data from exoplanet missions such as JWST, TESS, CHEOPS, and PLATO. The field is growing, with Ariel publications currently making up ~4% of the total.
- UK authors contribute 12-16% of all exoplanet papers, reflecting strong national interest, though not necessarily linked to the UK Space Agency's Ariel funding.

Citations have been growing quickly over our study, but they also take time to materialise, making year-on-year comparisons misleading.

- To date, there have been 5,400 citations on Ariel-related publications with UK involvement, with 70% of these on publications from the baseline. Citations in the analysis period have risen by 900% since 2023, indicating growing visibility of UK Ariel research.
- Ariel-related research has been cited in 614 news articles from outlets such as BBC, Forbes, and CNN, highlighting public interest. While media coverage does not directly indicate research quality, it suggests broader impacts could begin as Ariel starts returning data.

In the absence of UK Space Agency national funding, we view that UK roles, influence and outputs would have been greatly diminished for Ariel, and the mission may not have been selected. One of ESA's other M-Class candidates (such as THOR or XIPE) may have been chosen, leading to a reduction in UK scientific leadership, and a change in mission focus. UK Space Agency funding has been key in driving additional scientific return and positioning UK researchers to exploit mission data.

[3] De Marchi, G. and Parmar, A.N., 2024. *ESA Science Programme Missions: Contributions and Exploitation-ESA Mission Publications*. arXiv preprint arXiv:2402.12818.



Competitiveness & reputation

UK Space Agency investment has fostered international collaboration and **early gains in reputation**, potentially positioning the UK for future missions. However, sustained influence **depends on successful delivery**. Broader reputational impacts will take time to emerge. UK researchers have collaborated widely, both within and beyond the Ariel consortium.

- **Collaboration has increased in both absolute and relative terms** in the analysis period, with over 80% of publications internationally collaborative each year.
- UK authors have collaborated with researchers from 37 countries in the analysis period, up from 32 in the baseline, showing **a growing global network** beyond the Ariel consortium.

There is **early evidence of UK reputational benefits in the view of ESA and the consortium**, although these are linked to delivery expectations, and could change quickly.

- UK leadership roles on Ariel have **increased influence** over technical and scientific decisions, potentially positioning the UK for future space science missions. Early discussions are underway for UK involvement in NASA's Habitable Worlds Observatory and PRIMA mission concepts, with UK team members shortlisted for the latter.
- UK project team members have also received wider recognition, including **18 relevant awards and prizes since** Ariel was selected, including a Knighthood and OBE. Some were given for lifetime contributions, with others more directly linked to the mission.

As benefits are inherently linked to UK leadership roles, we conclude it is unlikely that the same levels of international collaboration, influence, or reputation would exist without UK Space Agency investment.

Skills & inspiration

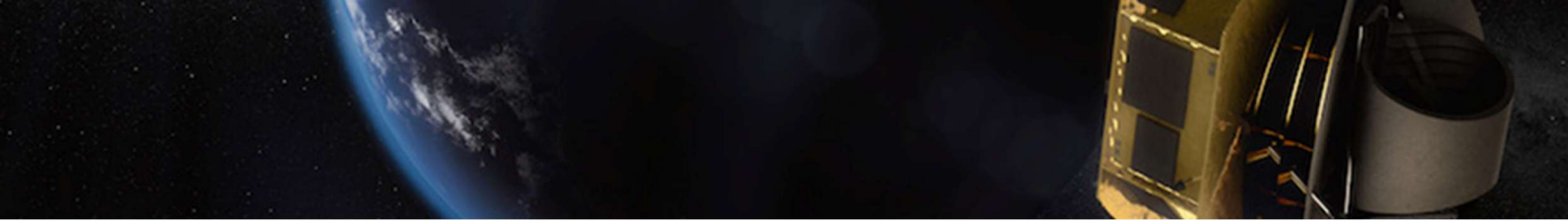
Through Ariel, the UK aims to leverage public interest in exoplanets to attract and develop the space talent pipeline, strengthening human capital in the sector. We view outputs and outcomes regarding upskilling and attraction of talent as **establishing strong foundations** for long-term outcomes and impacts. However, consistent funding of activities is key in ensuring they materialise.

Project teams have conducted engagement activities for diverse audiences which could **sow the seeds for long-term benefits to UK space science and the wider economy**, while also raising the profile of the mission.

- So far, the project team has undertaken at least **155 public engagement activities**, in at least 19 different countries. UK leadership roles have led to invited keynote speeches.
- The nature of these events is as important as their number, and activities include **both high-profile and targeted events**, including major conferences and news appearances.

Two UCL-led initiatives have also played a crucial role in catalysing wider international participation in mission-relevant science, supplemented with targeted initiatives in the UK. **The Ariel Data Challenge (ADC) and ExoClock are two emerging success stories** with further potential impact.

- The ADC has catalysed knowledge spillovers in the realm of **AI and Machine Learning**, and has experienced wider and deeper engagement with each iteration. The challenge has catalysed international and UK-based impacts (e.g. through Hackathons), and collaboration with the data science community is leading to exciting new developments. The challenge has become the largest public exo-atmospheric database, and **one of the biggest astronomy challenges ever hosted on a leading data science competition platform.**
- ExoClock has enhanced participation in astronomy from amateurs and students in conducting observations of exoplanet spectra, increasing **from 160 observers in 2021 to over 450 currently**. It has run several successful collaborations with UK schools and universities, and 10,500 observations have been completed from observers in 71 countries.



Attribution of benefits is complex here, as UK Space Agency national funding does not directly fund ExoClock and Ariel Data Challenge activities – however, without UK roles and leadership in the mission, outcomes would not manifest in the same way, so can be seen as being partly attributable.

Delivery of mission roles and responsibilities have led to **technical and managerial skills development**, attraction and retention of talent, and career progression of scientists and engineers within the project team, helping to build the space talent pipeline. However, uncertainty around **long-term funding poses a future risk** to retention for those on fixed-term contracts.

- There are ~**50 individuals in the UK project team**, with a blend of early career and senior staff. UK management roles have been strengthened to manage the complex international consortium, particularly at UCL and RAL, while technical skills have been developed and showcased in AI, software systems and mechanical engineering, and data modelling.
- **9 staff members have been promoted** as a result of their activities on Ariel, including PhD students, graduates, year-in-industry students and apprentices. Links between academia and industry are emerging, helping to strengthen skills in the wider space sector.

These benefits are inherently linked with delivery of mission roles, secured and financed by the UK Space Agency national contribution. Therefore, there is **strong additionality** associated with them.

Innovation

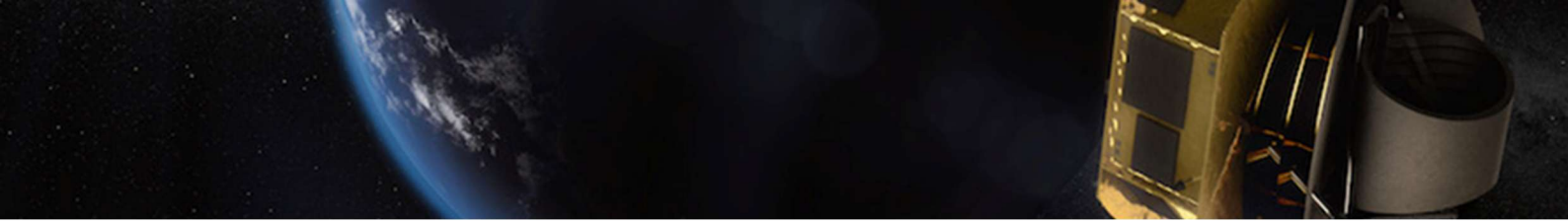
Another key objective of UK Space Agency funding is to **stimulate commercial opportunities across data science and space technology**, and we assess UK mission roles as having **promising early impact** across both areas. Close industrial-academic knowledge exchange in AI/ML, and potential follow-on mission opportunities are two key routes for commercial benefits. £14.6m in contracts and funding has been secured in-part due to Ariel, which could have future productivity benefits.

There are two Ariel-related **start-up companies which have shown promising growth** over the course of our study, Blue Skies Space Limited (BSSL) and Spaceflux. They have been successful in securing contracts, private investment, and creating employment in the UK space sector.

- Scientific leadership over Ariel has supported the growth of BSSL, which was a company inspired by Ariel's design precursor, ECHO. The organisation is **commercialising space research through data access from small satellites**, and is launching its first mission, Mauve, in 2025. They have employed 14 people to date, and UK leadership over Ariel was cited as a key factor in building investor confidence.
- Ariel was also key in establishing Spaceflux, a space situational awareness (SSA) company which **leverages AI/ML techniques developed as part of UK contributions to Ariel**. They have employed 29 new people and secured at least 4 UK government contracts to develop sovereign optical SSA systems, becoming a leading global provider.

Beyond these benefits the project team are also **pursuing commercial opportunities which could lead to sizeable impact** for the UK. Progress in these areas should be tracked over time to see the extent they materialise. We identified other emerging commercial discussions, including:

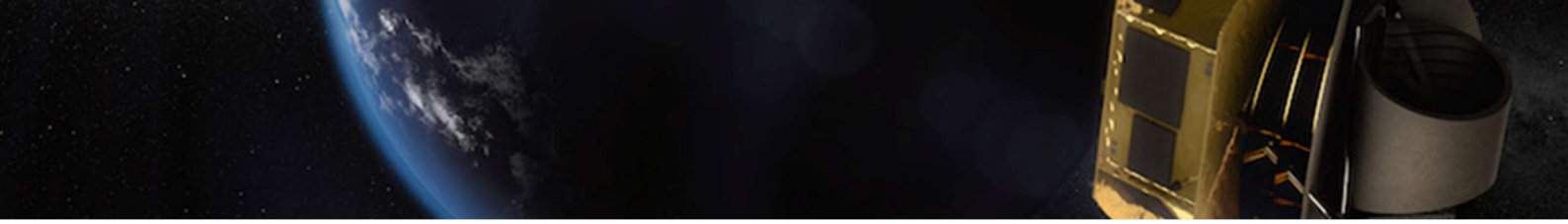
- **3 emerging spin-outs** in development, relating to the ADC, ExoClock, and data processing at Cardiff University, although the latter is not solely linked to Ariel.
- RAL Space and Cardiff University have been shortlisted for involvement on a **$1bn NASA mission concept (PRIMA)**, which is being pursued alongside other large mission roles. The case for UK involvement is strengthened by demonstrating capabilities on space science missions like Ariel (as well as existing heritage from Herschel).
- Ongoing collaboration with industry on the ADC could also lead to commercial benefits and internal hackathon potential. Discussions with **Kaggle, NVIDIA and Google DeepMind** are ongoing to pursue opportunities alongside the 2025 iteration of the ADC.



Next steps

We have tracked a broad range of metrics on an ongoing basis, to identify emerging routes to impact as the mission unfolds. This evidence has underpinned our impact evaluation, built over four iterations of evidence collection, synthesis, analysis and reporting to support ongoing benefits management at UK Space Agency. Inevitably, we are tracking an emerging impact story. However, without consistent evidence collection, there is a high risk that the future evolution of trends are not captured, and **the true impact of UK Space Agency national funding for the Ariel mission will not be known to UK Space Agency**. Ultimately, if data is not collected close to the time the impacts occur, the window of opportunity can close with it often being impossible to 'retrofit' such evidence.

As part of this study, we have interviewed key stakeholders and attended Project Management Board (PMB) meetings, collating perspectives on critical delivery factors, informing our process evaluation. These findings outline how the UK Space Agency's contributions to Ariel have been delivered in practice, identifying key delivery lessons, best practices, and opportunities to optimise implementation. It will be critical to monitor the implementation of the lessons learned from this evaluation, as well as to assess future delivery factors, best practices, and lessons learned throughout the build phase, launch, and operational phases of the Ariel mission. These activities are **vital to ensure the UK captures the full range of benefits from the investment in the future and maximises performance against the mission objectives**.



1 Introduction

1.1 The Ariel mission

The Atmospheric Remote-sensing Infrared Exoplanet Large-survey (Ariel) mission is the fourth medium (M-class) mission in ESA's Cosmic Vision programme, which will analyse the atmospheres of approximately 1000 exoplanets. In doing so, the mission will contribute towards understanding of how planets and atmospheres form, laying the groundwork in the search for life beyond earth. Data from the Ariel mission will also shape a discipline which was identified by the UK space science research base as one of the most important over the next 20-30 years[4].

The mission is currently expected to launch in 2029, alongside the rideshare F-Class Comet Interceptor mission. Development activities for the spacecraft and instruments are ongoing, including manufacturing, assembly, and testing. Alongside this, work is also ongoing to improve the preparedness of the scientific community to leverage the data releases from the mission.

Core mission funding comes through the ESA (mandatory) space science budget. As with other ESA science missions, ESA member states contribute national funding in addition to this 'core' funding, to secure leadership roles for individuals and teams in their country, for example in instrument development or in scientific direction.

It is this national funding that is the focus of this study. The UK Space Agency committed £30.3m through the National Space Science Programme (in addition to £6m towards the Ariel mission study phase) which, coupled with the UK's significant expertise in exoplanet science, has secured a leading role for the UK on the mission. It places the Ariel consortium under UK scientific, engineering and programmatic leadership, representing the first time in a decade that the UK has achieved such a central role in the design, implementation and operations for a mission of this magnitude.

[4] RAND Europe and **know.**space for UK Space Agency 2022. *SWOT Analysis of the UK Space Science Research Base*

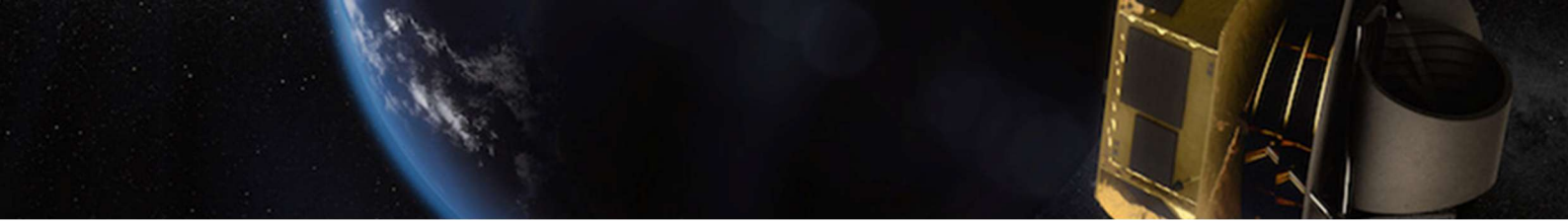
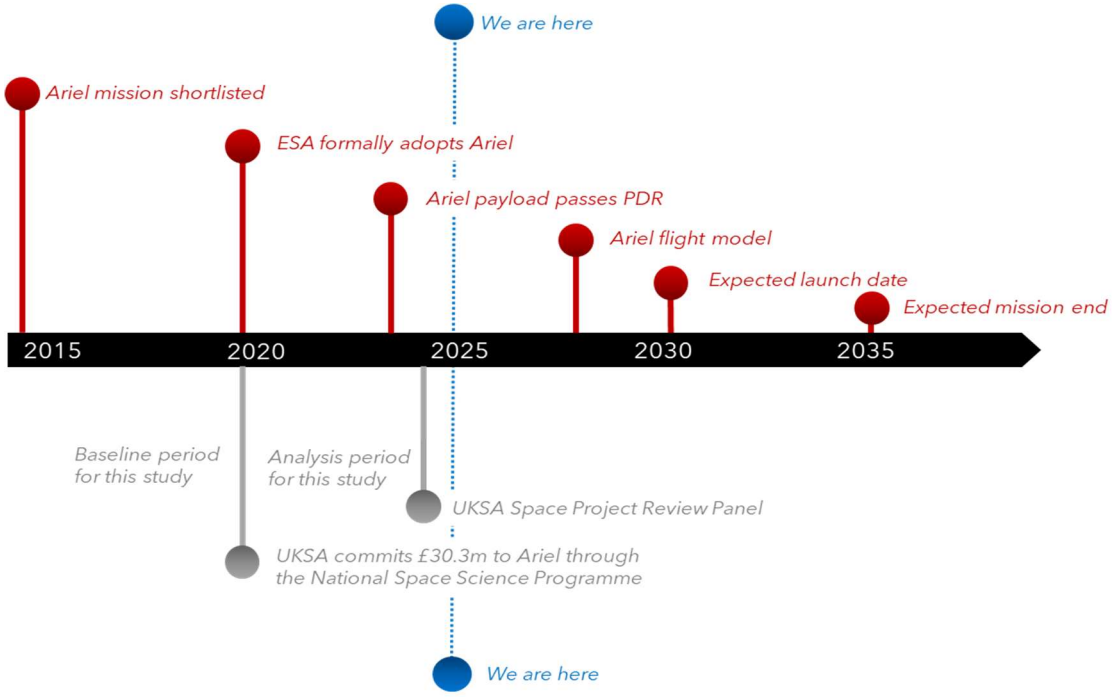


Figure 1 *Overview of key Ariel milestones*



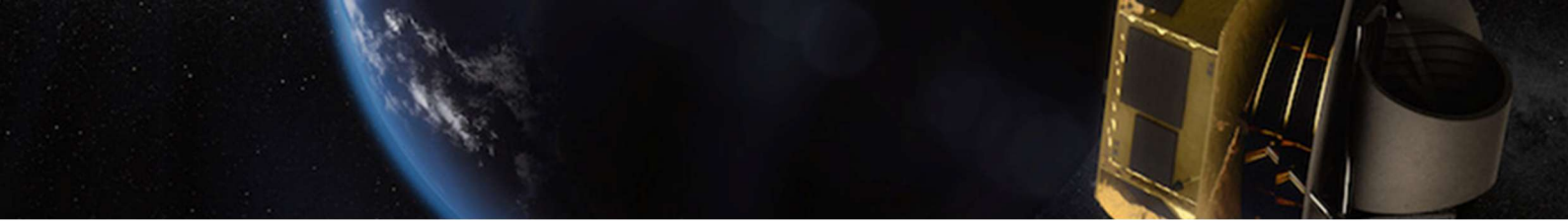
Ariel is led by a UK-based Principal investigator, Professor Giovanna Tinetti (UCL). STFC / RAL Space is leading a consortium of 17 countries building the payload module, which will be assembled and tested in Harwell. UK stakeholders are delivering the cryogenic cooler (STFC / RAL Space), optical ground support equipment (University of Oxford), and science operations and data processing (UCL, University of Cardiff).

1.2 Background to this study

The UK Space Agency's financial commitment to Ariel through the National Space Science Programme aims to deliver benefits and impacts aligned with four investment objectives outlined in the business case, namely to:

1. **Scientific leadership**: Secure UK scientific and technical leadership of exoplanet research, data science and space science by nominal end of mission.
2. **International reputation & collaboration:** Enhance the reach and reputation of the UK's space sector.
3. **Inspire, attract, and retain talent** to upskill our workforce.
4. **Stimulate innovation and commercial opportunities** through data science and space technology.

Monitoring and Evaluation (M&E) has been embedded into UK Space Agency's governance of Ariel national funding to monitor benefits realisation as the mission unfolds. **know.**space were commissioned in early 2023 to conduct these activities for Ariel, to provide a greater understanding of mission progress, the effectiveness of the funding, and the impacts it is producing. This report, produced in March 2025, represents the final deliverable from our M&E support over the last 2+ years.



This study was also designed to feed into and support the UK Space Agency's wider M&E efforts and benefits management, which help the Agency assess progress, maintain accountability, and adjust programme strategies through evidence-based decision-making. This helps to ensure optimal use of public funds to benefit stakeholders across academia, industry, and public sectors, and contributing to the strategic national objectives set out in the National Space Strategy.

Large space science missions are long-term endeavours, and **most of the benefits and impacts associated with UK science return and leadership are only expected to be realised after the mission is operational and returning data**. However, through a regular cadence of data capture, we provide the UK Space Agency with early evidence to assess whether investment objectives are on course to be met. **It will therefore be critical to continue to collect evidence over time**, as the longer term benefits story plays out.

This report includes an interim process and impact evaluation, with the former examining delivery factors which have worked well or require improvement, providing timely recommendations to UK Space Agency as mission progress continues, and the latter aiming to capture the full scope of realised impacts generated by UK Space Agency national Ariel funding to date.

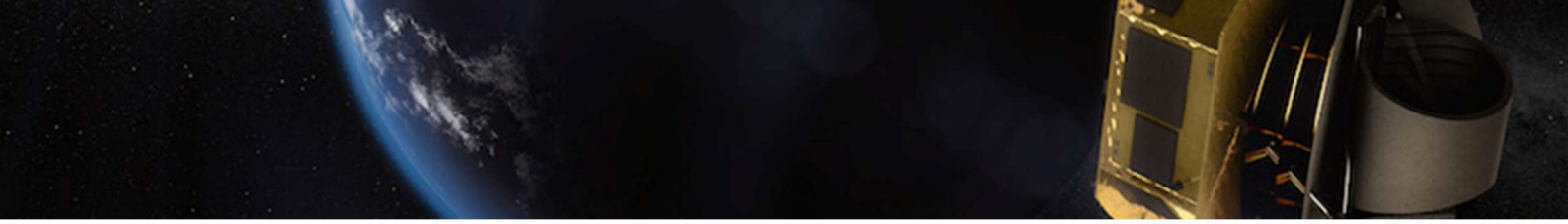
To the extent possible, we have aimed to isolate the impacts of UK Space Agency national funding although inevitably, some impacts, outcomes and benefits are intertwined with wider factors and wider mission funding. Our impact evaluation utilises **baseline** and **analysis** periods for time series data, to provide a point of comparison between metrics prior to and following the announcement of the UK Space Agency's £30.3m funding commitment. Attribution of impacts (i.e. the causal link between funding and observed outcomes) is assessed throughout, and the counterfactual scenario (i.e. what would have happened in absence of the funding) is explored per theme of impact.

1.3 Methodological approach

To track emerging impacts and delivery factors, we conducted 6-monthly benefits management reporting to the UK Space Agency, which followed a broad 4 stage process - data collection, data analysis, synthesis and conclusions. This report includes a final iteration and summary of the 6-monthly reporting process, preceded by September 2024, March 2024, and September 2023 editions, that has been woven into our interim evaluations.

Across the study, we have employed a **mixed-methods approach**. We have utilised stakeholder consultations with individuals from all UK funded organisations in the project team (with no missing perspectives). While interviews provided valuable context, these findings could be influenced by optimism bias. To triangulate evidence, we draw on desk-based research, bibliometric and altmetric analysis as other key data collection methods, which we discuss in more detail in the Annex (section 4). Bibliometric analysis was conducted with our partners Digital Science, leveraging the Dimensions database (the world's largest research dataset), supplemented by UK Space Agency Researchfish data. The time lags associated with publication and citation data are also methodological limitations which require consideration when interpreting bibliometric analysis.

Our **interim process evaluation** uses primary and secondary qualitative data sources to assess the extent to which UK Space Agency funding for Ariel has been delivered in an effective manner. Data collection efforts were driven by five core evaluation questions, for which early progress against has been summarised in Table *1*. The evaluation also employed a **real-time evaluation (RTE)** approach to capture insights on mission delivery and to develop appropriate feedback and



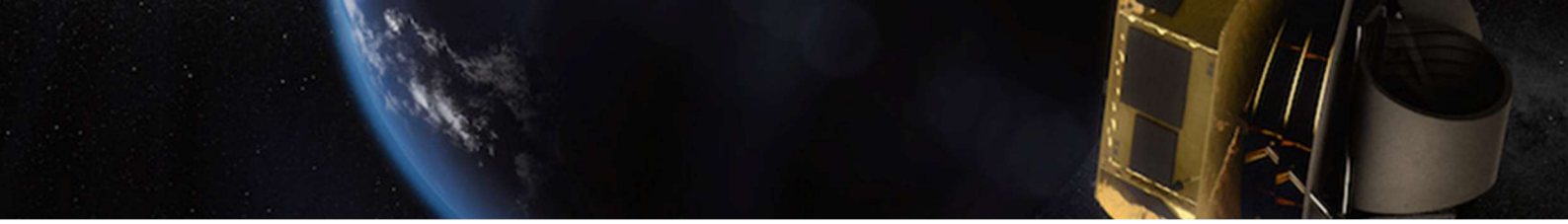
recommendations for subsequent phases of Ariel, as well as other UK Space Agency-funded missions.[5]

Our **interim impact evaluation** also uses a mixed-methods approach to collect **indicator information** at regular intervals, building upon the UK Space Agency's existing work in the (UK Space Agency-internal) Ariel Benefits Realisation Plan. Each indicator has been attributed a **baseline measure** (i.e. initial conditions before UK Space Agency investment), and consistently measured over our study. In practice, the baseline is as much about providing context for future impacts rather than a mechanistic process of 'observed impact minus baseline impact = net impact'. The baseline is developed to provide a general picture prior to UK funding, for context when interpreting future impacts.

In turn, evolution of these trends informed performance against the impact evaluation questions developed at the beginning of the study. These evaluation questions were developed to assess progress against the UK Space Agency's investment objectives, and broadly follow the four impact themes of this study (progress against these evaluation questions is summarised in *Table 2*. We have used **a theory-based evaluation approach**, assessing outcomes from UK Space Agency investment through **contribution analysis**. This approach explores attribution through assessing the contribution an intervention is making to observed results (as measured by indicators) and verifies the intervention's Theory of Change (ToC) and logic model, investigating factors that may influence outcomes. Evidence of contributions is summarised per impact theme, alongside a counterfactual.

To produce a streamlined narrative and understanding of the changes seen from the baseline to the current period, we have synthesised findings from across the 6-monthly reporting process, alongside qualitative insights gathered through stakeholder engagement or desk-based research. We provide broader concluding views across the progress of the Ariel activities, identifying general shifts in trends over this initial analysis period, and whether indicators are on track to meet their targets. Where targets are at risk of not being met, we identify the challenge and provide additional insight. A summary of target performance is provided in Annex (section 4.1).

[5] RTE seeks to address three core questions: (i) *are we doing things right?* (ii) *are we doing the right things?* and (iii) *how do we decide what is the right approach?*



2 Interim Process Evaluation

The process evaluation addresses the **delivery effectiveness of the UK (nationally funded) elements of the Ariel mission to date**, identifies factors which have both aided and hindered progress, and discusses the success of working relationships and management approaches. **The evaluation is intended for internal UK Space Agency use, and feedback from stakeholders was provided on the basis of anonymity (where practicable)**. The evaluation also, where appropriate, identifies lessons and forms recommendations for future mission delivery.[6] These are focused on UK and UK Space Agency involvement and in areas where UK activities can make an impact, recognising the divisions of responsibility between UK Space Agency and ESA in mission delivery. In line with HMG *Magenta Book* principles, the process evaluation aims to answer the question:

"What can be learned from how the Ariel mission has been delivered?"

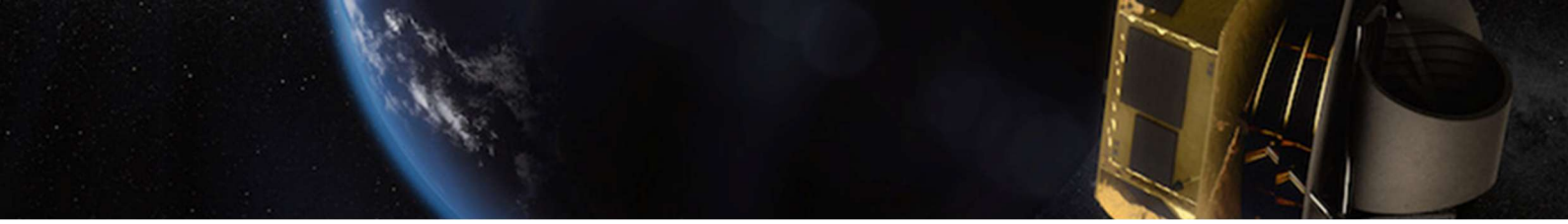
Whilst quantitative data can be useful, it can fail to capture the complexities and nuances of implementation or real-world challenges and successes. Therefore, this process evaluation relies largely on **qualitative insights**, emphasising the experiences and opinions of those involved rather than relying on quantitative indicators.

The recommendations which follow are a combination of suggestions from stakeholders, and **know.**space's own expertise of evaluating similar programmes. Throughout, we have tried to make it clear where **know.**space endorse a recommendation. Where we do not explicitly endorse a recommendation, it may be because we lack the information to confidently do so.

Summary of Key Findings

- Across all stakeholder groups, a **high level of trust and collaboration** was reported between the UK Space Agency, ESA, RAL Space, and the wider Ariel consortium, with ESA noting Ariel as an example of a particularly effective partnership. ESA described the consortium, and its effectiveness, as unusual for such large missions.
- While not a technical delivery body, **UK Space Agency is seen to have gone beyond their typical remit** by engaging in technical aspects of the mission, including key technical reviews such as the Preliminary Design Review (PDR) and the upcoming Critical Design Review (CDR), to maintain oversight and mitigate risk.
- The Project Management Board (PMB) was cited as a central mechanism for **providing technical expertise into the mission**. Members of the board bring hands-on experience of mission design and deployment, as well as practical experience of working with ESA. The PMB is seen as a "**solution orientated"** team.
- RAL Space was identified as a particular strength of the UK's involvement, with stakeholders praising its **technical ability and commitment to the mission**. Stakeholders pointed towards its ability to manage and coordinate efforts across a consortium spread over 16-countries, despite resource challenges and limitations upon its contractual authority.

[6] Recommendations are accompanied by an indication of which stakeholder group(s) have made, contributed to, or endorsed that particular recommendation. Where recommendations are based on the experience of **know.**space – drawing on our experience of programme and mission process evaluation - this too is indicated.

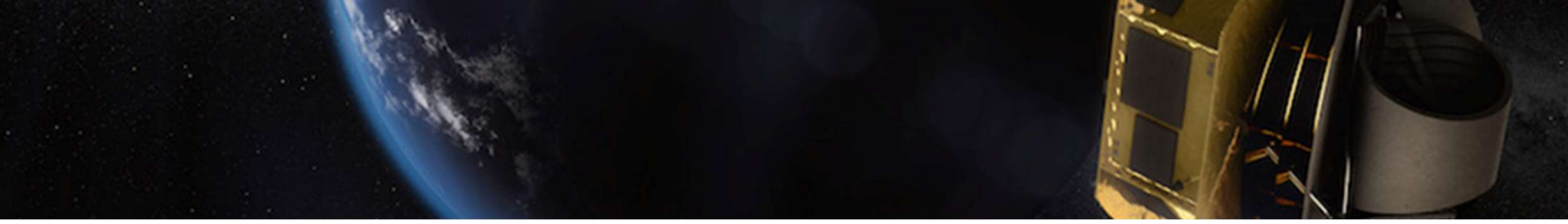


- RAL Space is a critical mission component integrator but **lacks sufficient authority to enforce consortium-wide activities**. Stakeholders noted that while RAL carries significant responsibility, its ability to influence consortium members is "very limited." The Sarri review recommended **formalising RAL's role as a lead technical authority**, acknowledging their need for further resourcing to support them acting as a 'type of prime'. This action seeks to mitigate against challenges caused by delays beyond the control of RAL Space and UK Space Agency, namely the delay in the manufacture of the Telescope Assembly by Italian contractor Leonardo.
- There continue to be delays due to ongoing issues with the **telescope assembly.** These delays have pushed back structural and engineering model timelines, affecting key testing schedules. Nevertheless, **the mission has achieved a number of key milestones**, many of which have been enabled directly or indirectly through UK national funding.
- Geopolitical events, notably the Ukraine conflict and EU Exit, have caused **material shortages** and administrative complexities in the broader mission supply chain. Material shortages, particularly in aluminium, titanium, and semiconductors have delayed component manufacturing which, though beyond the control of the UK Space Agency, could cause pressures on demands for national funding allocations in the future.
- UK Space Agency-funded monitoring and evaluation efforts were highlighted as being useful in evidence gathering for the business case renewal and the emerging impact narrative. Stakeholders described it as being a helpful platform for highlighting both success stories and delivery risks.
- Inefficiencies in process persist due to **administrative burdens and misaligned reporting requirements with both UK Space Agency and ESA**. Stakeholders highlighted that despite having innovative ideas for wider impacts, they are working in a resource-constrained environment and hence do not have the time or budget to pursue most of these concepts.
- **Uncertainty related to UK government funding cycles ('cliff edge' effects) continue to create risks for long-term planning**, staff retention, and broader mission financial resilience. This is not a challenge unique to Ariel, and is understood to be outside of the UK Space Agency's control.

2.1 Management and oversight

The **overall working relationship within the Ariel consortium is considered strong** by most stakeholders, particularly with respect to interactions between the UK Space Agency, the wider Ariel consortium, and ESA. **UK Space Agency is widely regarded as approachable, responsive, and communicative and keen to foster strong working relationships**, while the PMB is praised for its technical expertise and solution-orientated approach. Some stakeholders suggested the PMB could utilise their technical know-how further, for discussions with ESA and ASI, but with the recognition that this would require further resourcing.

As payload integrators, RAL Space is acknowledged as being **highly competent and dedicated, though stretched thin in terms of resource and lacking the necessary contractual levers to influence and direct key partners** despite bearing significant mission coordination



responsibilities. The Sarri review[7] in particular highlighted the need to formalise RAL's leadership role in technical areas, and additional resourcing requirements.

Across all stakeholder groups there is a recurring view that greater realism in early planning, improved delegation of authority and control, and improved communications are key to progressing the mission towards a successful launch.

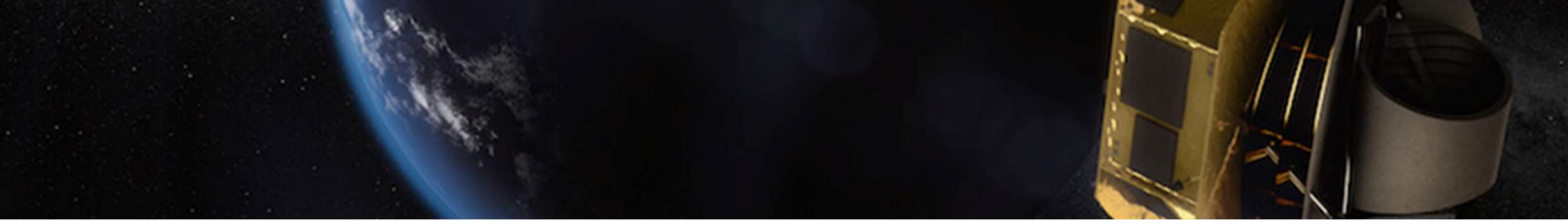
Management and oversight recommendations

- **Conduct early capability and risk assessments**. Where feasible, UK Space Agency should introduce more rigorous capability and risk assessment procedures at the start of missions, to identify potential technical, institutional, and resource limitations that may lead to future cost overruns or delays. Strong mitigation measures should be set out in the risk register, agreed by all key stakeholders, and consistently monitored and updated. *[Stakeholder recommendation].*
- **Consider frequency of Project Management Board (PMB) meetings.** Whilst regular PMB meetings are productive, frequent quarterly changes in schedule/budget/design for a long-running mission pose challenges. UK Space Agency could consider implementing shorter, more dynamic PMB meetings between full-board sessions to resolve specific issues and respond to emerging risks more efficiently. *[know.space and stakeholder recommendation].*
- **Consider further utilising the technical expertise of the PMB for ESA / ASI engagement.** There is recognition that UK Space Agency is not a technical delivery body, but this can also limit its wider engagement when seeking resolution to key mission challenges. UK Space Agency could harness existing technical expertise of the PMB to engage with ESA and ASI with delegated authority. This may require moving PMB members towards a non-executive position where they are funded at a low level to increase programme management resource. *[Stakeholder recommendation].*
- **Implement Sarri Review recommendations.** This includes enhancing resourcing support for RAL to enforce its role as a lead technical authority and behave more like a prime contractor in its relationship with Leonardo. *[know.space and stakeholder recommendation].*
- **Ensure Sarri recommendation implementation is effective.** While RAL should demonstrate willingness to ESA to implement recommendations, a 6-month progress review (with supporting evidence) should be held. At this point, either positive progress on the telescope assembly / relationship with Leonardo can be evidenced, or RAL / UK Space Agency / ESA should consider alternate solutions. *[know.space and stakeholder recommendation].*
- **Outline a 'plan B' for addressing issues explored in Sarri Review.** To ensure further slippage of the scheduling does not occur, additional options should be identified and agreed upon, concurrent to implementing the Sarri Review recommendations. This means after 6 months, if these recommendations are not providing success, a 'plan B' can immediately be actioned. *[know.space and stakeholder recommendation].*

2.1.1 The UK Space Agency

There was a consensus that **the UK Space Agency was both approachable and responsive**. Stakeholders generally expressed a positive relationship with UK Space Agency, acknowledging

[7] Giuseppe Sarri (a project manager from ESA's JUICE mission) was commissioned to undertake a review focused on the delivery of the Telescope Assembly by Leonardo, as well as the organisation of the consortium, specifically seeking to evaluate the management and resourcing of the mission.



the agency's **proactive approach** to dealing with requests. Communication, and a desire to foster an open and cooperative working environment, were highlighted as particular strengths for the UK Space Agency Ariel team.

> *Our relationship with the UK Space Agency has been absolutely fantastic.*

Over the two-year evaluation period, the project team consistently conveyed that it was easy to work alongside UK Space Agency, and that while some frustrations arose regarding aspects such as funding uncertainty, they also recognise the broader constraints within which the Agency must operate.

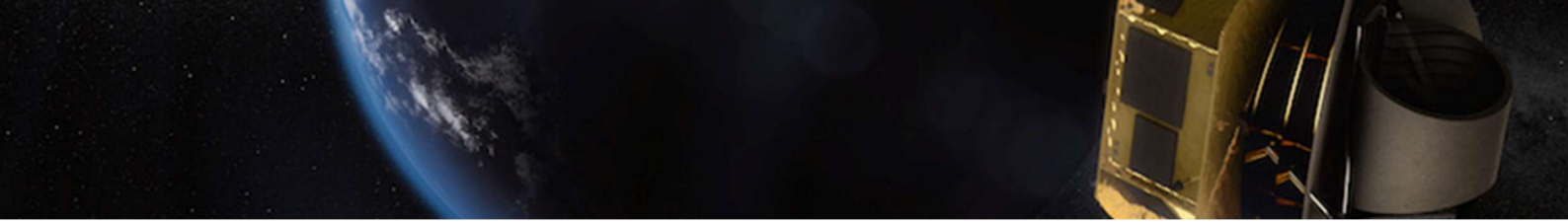
Stakeholders also noted that the UK Space Agency has been actively engaging with ESA, as well as playing a role in finding solutions to help empower RAL Space with the necessary drivers to minimise schedule slippage and reduce overall delivery risks. Where challenges have arisen, **UK Space Agency has aimed to be proactive in finding solutions** to best of their abilities – noting that Ariel is a broad and complex mission, with certain elements being outside of their remit.

One of the limitations for UK Space Agency is the fact that it is **not a technical delivery body** – nor is that one of its objectives. Instead, the Agency aims to add value in oversight and management, seeking to be involved where there is significant risk exposure. Understanding the intricacy of Ariel, this means that **UK Space Agency has tried to be visible in ESA's technical reviews**, including the Preliminary Design Review (PDR) and soon-to-be Critical Design Review (CDR), despite the Agency usually not having presence in these meetings on other missions. Nonetheless, this means that there will always be engineering and technical-leaning conversations where UK Space Agency will not be directly involved, since they do not have the scope nor always the in-house expertise. Often, they leverage the knowledge within the Office of Chief Engineer at UK Space Agency or utilise the external technical expertise of PMB members. However, when impactful technical challenges occur, such as with the telescope assembly[8] – one of the missions three primary instruments - carried out by Leonardo, some stakeholders expressed the view that it would be **helpful to have the UK Space Agency more embedded into the conversations with ESA and the Italian Space Agency (ASI)**. Barring that, and understanding that ESA and ASI are more technical entities than UK Space Agency, there was a suggestion that **PMB experts could support in these discussions** (see below).

Another concern raised was whether the UK Space Agency was delegating appropriate authority to its programme managers to make decisions at an appropriate level. Certain procedural aspects within the UK Space Agency can, we heard, risk leading to a reduction in flexibility and an adherence to process, increasing the administrative burden of those managing the mission and limiting their ability to act decisively. This challenge is compounded by the size of the UK team being smaller than many of its counterparts in agencies running similar-sized missions.

For the time being, reputational risk for the UK or UK Space Agency has not been a major concern for wider stakeholders, especially as delays on the mission are understood to stem first and foremost from some of the Italian activities. However, there is still uncertainty around the business case renewal and the Space Projects Review Panel (SPRP), leading to concerns around the outcomes if UK were to withdraw from the mission. While most stakeholders did not think this is likely to occur, the 'worst case scenario' was perceived to be impactful not only for UK leadership, but for the viability of the mission overall.

[8] Whilst outside of UK Space Agency's control, a variety of reasons were given for the delay in manufacturing the telescope assembly, including the late contracting of Leonardo onto the project, and a late realisation that specific components and parts aren't manufacturable as designed. It was noted that this isn't necessarily an unusual or unprecedented situation.



2.1.2 Project Management Board (PMB)

The PMB was welcomed by stakeholders as being a "**solution-orientated**" governance body. The role of the PMB in providing external technical support was highlighted as a particular strength, harnessing a range of expertise from across the UK space sector, as well as the fact that many members have first-hand experience of navigating ESA missions.

> *… when it comes to key decision points, external technical expertise is vital.*

One of the ways in which this expertise could be leveraged further is in discussions within the wider Ariel ecosystem. As noted previously, the UK Space Agency is not a technical body, but PMB members outlined how this know-how does not need to be 'in-house' at the agency, but could instead be harnessed through the PMB itself, who could then **engage with ESA or ASI for technical discussions, acting with some sort of delegated authority from the UK Space Agency.**

However, a challenge with this approach would be with the limited resourcing provided to PMB members, who currently receive day rates for activities such as PMB meetings. Stakeholders expressed that they **do not always have the time to monitor project cost growth and schedule slippage beyond scheduled meetings,** especially due to the size of the consortium and how many elements of the mission are still evolving. If members also began providing technical oversight in ESA or ASI meetings, then a shift towards a non-executive position may be necessary, where they are funded at a low level to provide a certain number of days per year for programme management. This would require more resources in an already resource-constrained environment.

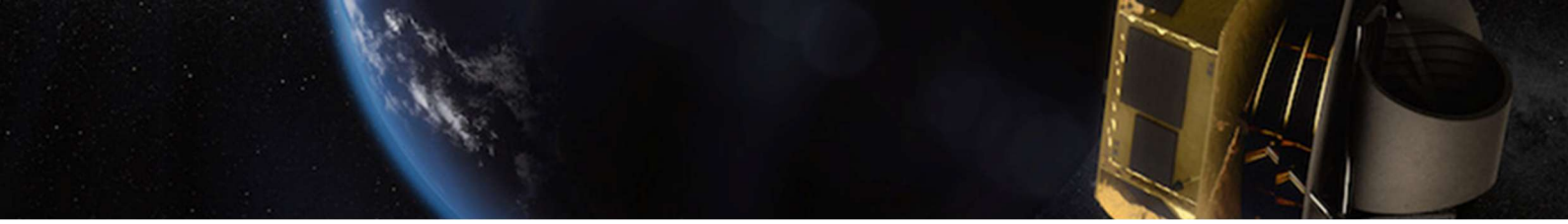
Despite broadly positive views of the PMB members and their ability to help find solutions, there was a concern that some of the processes set out within the PMB are seen as a formality, or as an extra layer of bureaucracy hindering the progression of the mission.

> *There is a cultural concern that PMBs are seen as an inconvenience – the sense that they are something in the way, rather than a fundamental part* [of the process].

This was especially noticeable at the October 2024 SPRP, where the original quality of proposals was not robust enough for a formal decision-making process. We heard that clearer justification and more granular descriptions of cost increases were required, with the opinion that if the project team was requesting such significant cost increases, they should appreciate the need for more effort in conveying the details and rationale. **Buy-in from the team around these PMB processes is important for future SPRP meetings**, leading into the business case renewal.

2.1.3 RAL Space

There is, notwithstanding administrative and funding challenges, **recognition that the Ariel mission has been well-managed**. One stakeholder noted that Ariel has been the "best process they have experienced", with good cooperation within the consortium. There is a consensus view that RAL Space are both competent and effective in their work - their work is seen as impressive, particularly given the resource constraints under which they are operating. Throughout the mission there has been a common acceptance that they are managing a very complex and large



consortium (of over 16 countries, 600+ scientists and engineers, and international collaborations with NASA, JAXA and CSA).

> - *RAL are very competent. They know their business.*
> - *[RAL] have overcome every problem except for Italy.*

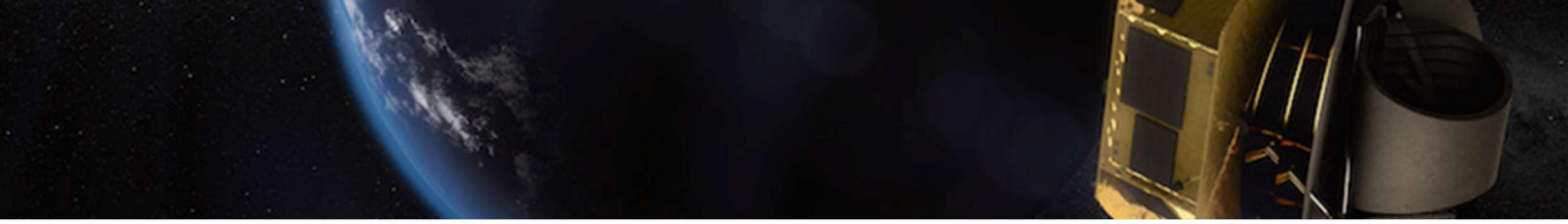
One of the main challenges associated with RAL Space is a criticism that too much was expected of too few at the organisation. Multiple stakeholders suggested at the start of the mission that the team was too lean, leading to overstretch and contributing to delays. A recurring tension arises from the fact that scheduling burdens often fall upon RAL Space despite it **not having the authority, or appropriate delegations, to hold consortium members accountable**. Stakeholders highlighted how RAL is a "couple of layers removed" from key decisions and suggested that earlier involvement from manufacturing authorities could have prevented some of the downstream problems. RAL was often praised for doing a good job "under difficult circumstances," but there was consensus that they were **set up to coordinate, not to drive,** which does not allow them to resolve conflicts easily.

> - *RAL need to be able to influence Leonardo, and they are a couple of layers away. I'm not sure I could have expected anything more from RAL – with an injection of resources they can be more in control and in a better place to make decisions.*
> - [The] *burden is falling on a small number of people to deliver a complex programme.*

The relationship between RAL Space and ESA is seen as a particular strength, though a concern raised was that the UK Space Agency were not always kept well-informed regarding discussions between the two. It was noted that, on occasion, decisions were being made that could impact the programme, especially expenditure, without UK Space Agency involvement. This could be interpreted as demonstrating a need for improved communication and understanding between RAL Space and UK Space Agency especially, to close the feedback loop and ensure nothing is committed to ESA before being discussed by UK Space Agency and the PMB. One solution was to put a 'change control' process in place across the UK consortium partners (see section 2.2.3).

More recently, constructive dialogue and working between UK Space Agency and ESA resulted in the commissioning of an independent review by Giuseppe Sarri (a project manager from ESA's JUICE mission). This review focused on the delivery of the Telescope Assembly by Leonardo as well as the organisation of the consortium, specifically seeking to evaluate the management and resourcing of the mission. Sarri made a series of recommendations, aiming to '**enforce the role of RAL as lead technical authority**', and recognising that this would require a "**change in mindset in RAL and [Leonardo]" to work together**.

> *Guisseppe* [from ESA] *was surprised by the number of staff* [RAL Space] *had to manage this – he thought we would need 10 more to be doing what we are doing.*



Amongst several other recommendations, the Sarri review set out the following areas of improvement to enforce RAL's role:

- Implement a larger team at RAL, covering all disciplines;
- Work on the mindset of RAL to be a fast driver in taking decisions; and
- Work on the mindset of Leonardo to accept RAL as a "kind of prime".

Additionally, it outlined that direct decision and reporting processes between RAL and Leonardo must be established, albeit with ongoing monitoring from the funding agencies. These recommendations formalise actions already being undertaken by RAL, having previously developed a "shadow engineering team" model to follow activities carried out by delayed partners (such as Leonardo), and **behaving more like a prime contractor without formally being one**. RAL also plans to increase the team by several FTEs, financially-supported by ESA, which will allow them to manage in a more hands-on way.

Whilst these recommendations are welcomed by the UK Space Agency and RAL, there are reservations as to whether these actions will fix the underlying delivery issues. Therefore, planned mitigation actions include **setting up a progress review after 6 months of implementing the Sarri recommendations**, and **ensuring that a "plan B" option is developed to safeguard against further stagnation of progress**.

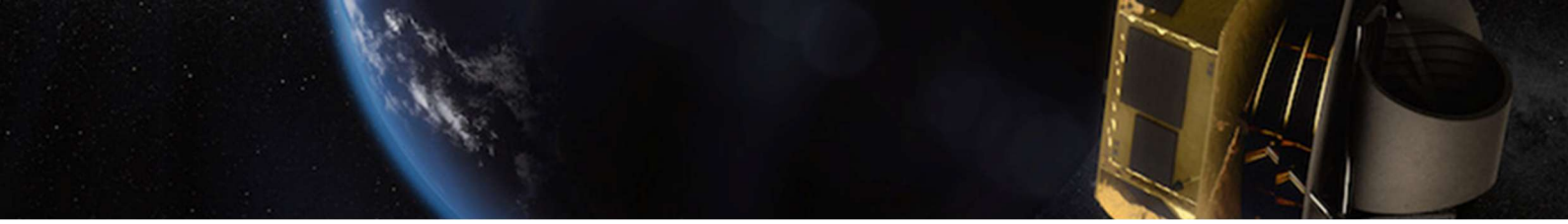
Indeed, a consistent message raised by consultees was that the constraints regarding resourcing at RAL, as well as the lack of contractual levers for them to utilise against those consortium partners failing to deliver, were known from the start of the mission. This includes being raised in the Gate 0 Review of the business case. This suggests that a more rigorous risk assessment procedure could have been established from the start, to identify potential technical, institutional and resource limitations. For risks that impact the critical pathway, it would be beneficial to **proactively formulate actionable mitigation measures or set out feasible 'plan B' options, agreed by all key stakeholders, and consistently monitored and updated.** It should be noted, however, it is beyond the scope of individual funding agencies to assess risks across the entire mission, particularly given the size of the Ariel consortium. In these cases, it is expected that ESA reviews of the mission proposal will identify such risks in addition to or in excess of those identified by national level assessments, due to greater resource availability and increased visibility across the whole mission.

2.1.4 ESA

By nature of its size and structure, engagement with ESA can be complex. However, the UK Space Agency, RAL Space and the wider consortium all agree that there is a strong working relationship with ESA – an opinion shared in return by the ESA Ariel team.

> "
> - *ESA is a fixed-process entity, but we've had experienced good collaboration and spirit; this comes from the top and propagates through the rest of the team.*
> - *The relationship between all parties including ESA is very good.*

Indeed, one stakeholder expressed how this was not always the norm with space missions, and in their experience, there can often be a tense relationship amongst consortium members and ESA, due to competing priorities or demands. The pragmatic and respectful approach across the different actors on Ariel was highlighted as a strong example of the positive working relationships



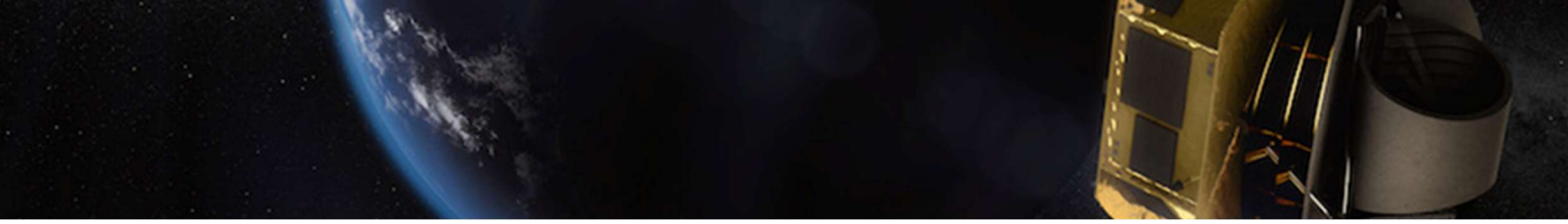
and attitudes of the people involved, with recognition that this trickled down from the consortium leadership – such as RAL Space, and the Ariel Mission PI, Prof. Tinetti.

> *There is a good level of mutual respect on Ariel in general – a key positive for the mission.*

ESA have also shown to be flexible to challenges arising on the mission, including taking responsibility of the costs for the cryocooler electronics away from the UK national costs, as well as commissioning the Sarri review to find workable solutions to current schedule challenges. Upcoming areas where ESA is planning to step in further include the active cryocooler system, as well as supporting the additional FTEs required at RAL to manage the consortium more effectively.

However, these decisions from ESA can, we heard, often be quite reactive in nature. The setup of the mission, with a consortium driving the delivery of the payload rather than ESA itself, is not the norm for such complex missions as Ariel. A reflection within UK Space Agency was how this means that UK Space Agency itself is carrying an arguably **disproportionate level of external risk.** In response to challenges within the Ariel mission, the expected provision of additional ESA-funded resource at RAL Space has meant that UK Space Agency and ESA have effectively engaged in a 'risk-sharing' model. It should be emphasised, however, that this was a reactive, rather than planned, development. If a similar mission were to occur in the future, the Agency should push for more of a 'risk-sharing model' with ESA when establishing the working relationship.

Leadership changes within ESA have at times, according to stakeholders, disrupted continuity and clarity in decision-making. While collaboration has been largely effective, occasional misunderstandings between ESA departments have occurred, leading to delays. A notable tension has concerned the issue of **ownership with respect to data and preparatory science activities**, particularly regarding project elements such as the Exoplanet Database (ExoDB). There have been instances where ESA's role and ownership expectations have caused frictions, necessitating clarifications of authority and intellectual property rights, although this is predominantly in relation to the consortium overall rather than with specific UK actors.



2.2 Mission delivery

To note, the focus of this evaluation is on the UK's national investments into Ariel, rather than the broader Ariel mission. However, the two are inevitably interconnected, with cascading impacts that cannot be entirely separated. **The UK's leadership in Ariel continues to be viewed as both central, and key, to the mission's overall success**. Despite broader mission delivery challenges, both scientific and technical progress has been noted. The **collaborative culture of UK-funded organisations, and the high quality of preparatory science activities are seen as strengths by consortium partners and ESA**.

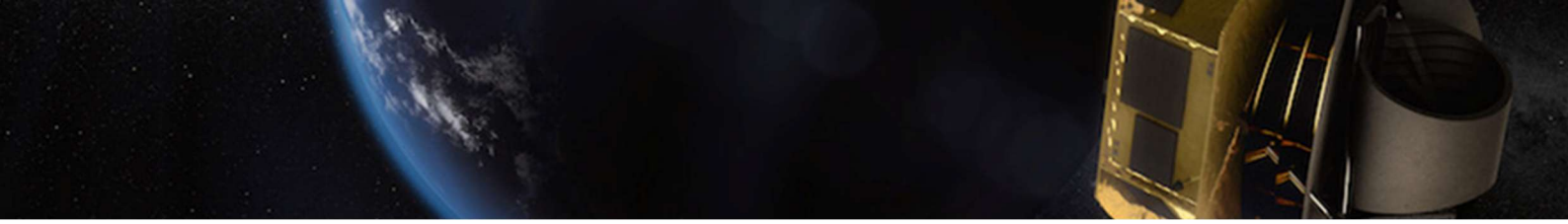
The most significant challenge on the mission to date pertain to the technical delays associated with the telescope assembly, led by the Italian contractor Leonardo. While **these delays are not specifically connected to UK Space Agency national funding**, they have provided additional pressure on RAL Space's resourcing and leadership of the consortium. Furthermore, they risk becoming a bottleneck that could affect the broader return on investment from UK funding, and add to pressures on testing and integration.

In common with many evaluations on UK research and innovation investments, we heard how UK-specific funding issues such as **spending review uncertainties** have impacted planning and staff retention. These impacts are real, though we recognise that they are largely beyond the control of UK Space Agency to address. The same is true for broader geopolitical factors – such as the ongoing war in Ukraine and the global semiconductor supply shortage – which have had implications for broader mission delivery.

Rising costs within the UK Ariel consortium, have required tough conversations around spend and transferring responsibility of elements to ESA. This is true of the active cryocooler system (ACS), where there is a risk of losing UK design IP before the CDR. While previously change control processes within the PMB were considered broadly reactive, with late-stage budget adjustments, UK Space Agency have now implemented a Change Control Plan. This mechanism appears to be easy for the UK project team to use, and is a **good example of UK Space Agency / the PMB being solution-oriented and proactive in finding processes to support smoother delivery of the programme**.

Mission delivery recommendations

- **Sustain established improvements within the delivery process**. UK Space Agency should build on the improvements already made in relation to its Change Control Plan and milestone delivery. These refinements should be institutionalised and applied to future mission phases to prevent any reoccurrences. Risks to activities not on the critical pathway should still be monitored closely for budget / schedule slip. *[know.space recommendation].*
- **Establish regular technical check-ins and contingency planning**. Implement regular technical check-ins to assess delivery risks and ensure contingency plans are in place around known pressure points. These check-ins should also monitor and address risks such as single points of failure. *[Stakeholder recommendation].*
- **Ensure early alignment of ambition and resources**. UK Space Agency should regularly review balance between the ambition of investment objectives from funding and available resources, to ensure the scientific and technical ambitions can be delivered within the available resourcing. *[know.space and stakeholder recommendation].*
- **Support efforts to enhance internal communication at RAL.** RAL is a large organisation, with different reporting branches (e.g. Space and Technology). In some cases, lack of robust communication has led to cost increases not being discovered rapidly enough /



disagreements on costing elements. Closer internal communication, supported by UK Space Agency where necessary, could be beneficial. *[know.space recommendation].*

- **Consider providing more dedicated funding towards outreach activities.** Activities such as the ADC and ExoClock have proven beneficial and successful in upskilling and engagement activities. However, they are not directly tied to UK Ariel investment, and risk future de-scoping (resource constraints) or being shifted into other countries. If UK Space Agency wishes to maintain strong UK leadership, and realise future benefits in-country, it could consider providing more dedicated funding towards outreach. *[know.space and stakeholder recommendation].*

2.2.1 Schedule

The **main driver for overall success in this mission will remain the successful deployment of the Ariel mission**. While care should be taken to separate the UK's national investments – the focus of this evaluation – from broader mission delivery challenges that are not related to this funding, they are inevitably interlinked due to UK's leadership role on the mission.

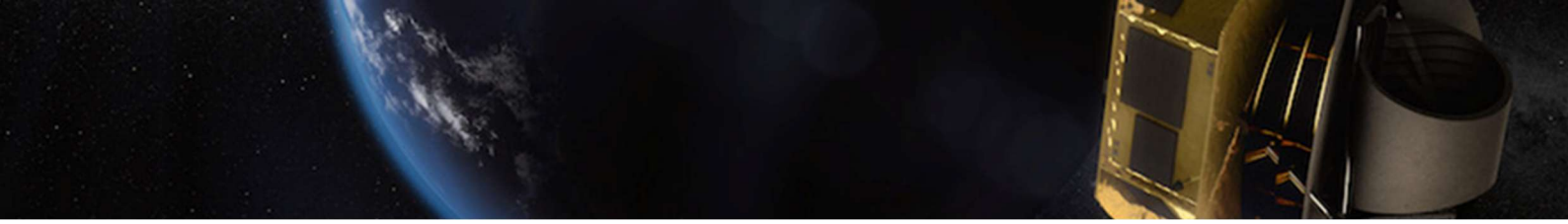
Whilst much of the mission has progressed steadily, one of the most significant obstacles has been the delays related to the Telescope Assembly, which one stakeholder described as a "sore thumb which sticks out", and **causing significant bottlenecks for overall mission delivery**. These delays have pushed back the structural and engineering model timelines, threatening key testing schedules. For example, such delays forced the adoption, in late 2024, of a revised schedule approach involving refurbishing an Engineering Model to flight standards to mitigate schedule impacts.

It is important to note that the Telescope Assembly is being led by Leonardo and ASI, and the **control of these actors (and overseas contractors in general) is beyond the power of the UK Space Agency.** However, it demonstrates the structural challenge in RAL's ability oversee the consortium in a more managerial rather than coordinator position, as well as impacting their role as payload integrator.

In terms of timeline impact, estimates vary, with some stakeholders suggesting that even if recovery measures are successful, the launch date will slip. We heard, for example, that Ariel had previously managed to recover lost time but had again slipped back by at least 5 of the 8 months. One consultee explained how "for a long time, it has been that every month of the project leads to a 1-month delay," illustrating the relentless knock-on effect of the telescope issues on the rest of the programme.

> *"The payload will be later. There's likely to be a launch delay of between a few months and a year – between 9 and 12 months.*

These delays are also having an impact on testing and integration timelines. Assembly and integration work at RAL has been delayed whilst waiting for the telescope assembly, **compressing the test schedule and leaving less buffer to absorb downstream risks**. The structural and engineering models for the telescope are also behind schedule, stalling key activities such as system-level qualification and environmental testing. RAL Space noted that although much of the rest of the payload is progressing, the telescope delays make it difficult to maintain momentum along the critical pathway. **There is, therefore, a risk that a compressed schedule could lead to rushed testing or deferred issues that impact long-term performance or reliability**. While this



is not a result of UK Space Agency national funding, it does inevitably have an influence on its future impact.

> *This has placed pressures on test readiness. Schedule slips mean less time to absorb any problems we identify during integration.*

Furthermore, launch delays carry a broader risk beyond lags in the realisation of benefits: they could also materially reduce the overall benefits themselves. Scientific returns, reputational gains and broader opportunities are often time-sensitive, particularly in a competitive international environment where overlapping science missions and technological advancements can shift the value of any contribution or finding. Extended delays could risk Ariel losing its competitive edge, in turn diminishing the UK's ability to maintain its scientific leadership and secure future mission opportunities. For example, scientific leadership may be reduced if other exoplanet-focused missions are launched before Ariel and 'capture the headlines', or Ariel being operational may come too late for the UK project team to leverage their proven knowledge and heritage on the mission for securing roles on other sizeable international missions.

Several stakeholders emphasised that whilst Leonardo are the primary cause of the delays, **the UK is inextricably linked to some of the reputational and financial consequences due to its leadership role**, especially regarding consortium management and outcomes that impact successful delivery of activities carried out by UK consortium member. It was suggested that repeated changes to the timeline, and the associated costs may force difficult choices elsewhere in the UK space science programme, as **Ariel's cost and complexity escalate beyond original estimates**.

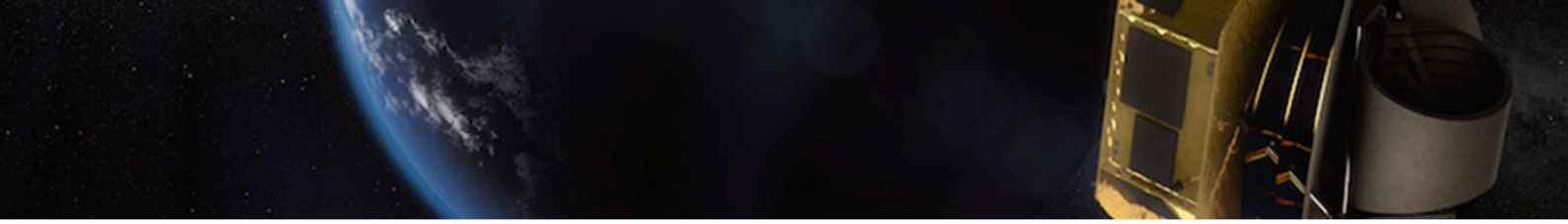
It was highlighted that it took 'too long' for the scope and seriousness of the Italian challenges to be fully recognised by all stakeholders, exacerbated by Leonardo joining the programme late in the design process. **Therefore, more robust risk assessment activities enacted from the start of the mission could have been beneficial.**

The outcomes of the Sarri review, with ESA willing to support more FTE at RAL so that they can play a stronger 'prime' role and thereby work more closely with Leonardo, will hopefully halt schedule slippage further. However, there is still uncertainty around the effectiveness of these proposed solutions. A 'lesson learned' by the UK Ariel team through these delay challenges is that more frequent progress reviews, to ensure solutions are impactful, will help alleviate these concerns. Additionally, that **alternative options should be set out, in case issues continue to arise**.

These delays have sparked broader reflection on how the mission was structured, particularly in terms of partner readiness and early industrial engagement. UK Space Agency highlighted how it is the responsibility of the consortium in the formative phases of the mission to ensure the members have the correct capabilities to deliver. **A robust 'capabilities assessment' earlier in the programme may have reduced some of these concerns,** identifying weaknesses in contributors before responsibilities were formalised. For future missions where the UK is seeking to play a similar leadership role, UK Space Agency should consider requiring more in-depth capabilities assessments for proposed consortiums.

2.2.2 Funding

One of the recurring concerns raised by stakeholders is the **unpredictability generated by the UK government's spending review cycles,** which has been especially significant for the Ariel team in the lead up to March 2025. The so-called "cliff edge" effect - where decisions are subject to



changes based on broader government priorities - creates significant risks for project continuity and delivery. Missions like Ariel operate on long timescales, **requiring stable financial backing over multiple years**. The current approach forces research teams to **operate under considerable uncertainty**, making it difficult to plan with confidence.

> *The project team is dealing with considerable uncertainty related to the spending review cliff edge – it could become an issue for delivery, and for the retention of staff.*

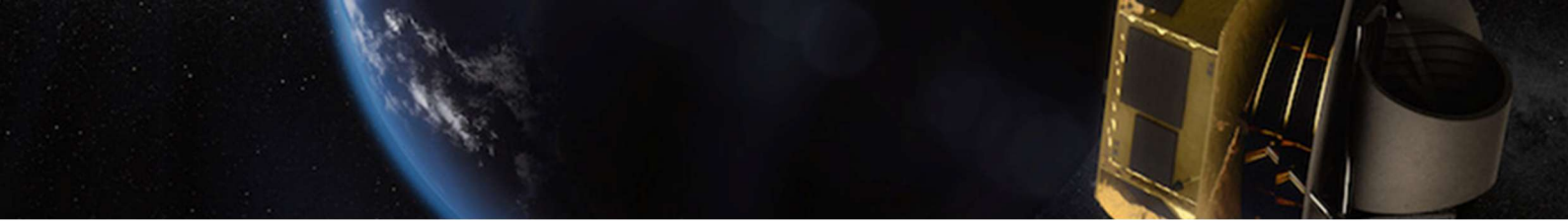
This uncertainty has a direct impact on staff retention, where consultees described how they had to scramble for ways to maintain certain people within their teams. Researchers and engineers, understandably, seek job security to remain engaged with a project, yet the uncertainty of funding means that **there is a risk that some could seek opportunities elsewhere, potentially leading to a loss of expertise**. If the UK aims to maintain its broader leadership in exoplanet research and space science, some stakeholders recommended that (while recognising the limitations that the UK Space Agency face) the UK should seek to implement a more consistent and predictable funding strategy for long-term missions. Upskilling the new generation is key for maintaining institutional knowledge around exoplanets, but this will be put at risk if early career staff cannot find roles, do not want to risk the employment uncertainties, or seek better paid / reliable positions within the private sector.

> *The bottlenecks are not ideas, but funding.*

We heard that the original business case, and subsequent funding approvals, were premised on the fact that Ariel "was at the top end of what they [UK Space Agency] were willing to fund" and that cost increases **risk having knock-on effects to the broader UK Space Agency space science programme**. This is not unique to UK Space Agency, and it was reported that most other countries are at the limit of "what they would like to fund into Ariel", creating possible tensions going forward, particularly if costs continue to escalate.

Though beyond the direct control of UK Space Agency, there are potential mitigation options. While **fiscal realities will inevitably constrain the art of the possible**, we heard suggestions and requests for further multi-year funding commitments from UKRI and UK Space Agency, establishing contingency reserves to bridge funding gaps, and encouraging industry partnerships to supplement public investment where appropriate. As of March 2025, a number of stakeholders highlighted that there is a **6-month bridging period in place**, to ensure continued funding in advance of the next spending review. Though broadly welcomed, this is generally seen as a short-term solution that fails to address the broader impacts of funding challenges and raises question about the additional administrative burden and continued uncertainty that accompanies such approaches. Solutions may be outside the control of the UK Space Agency, but the issues these pose were highlighted as real.

It was also highlighted that the **budget was set before the recent inflationary challenges experienced globally**, with several stakeholders observing that it is challenging for the mission to contain these cost increases "even within schedule margins." There were concerns in the initial phases of the mission that both the overall level of funding for the mission, as well as the level of budget contingency built into the costs, were too low.



> *Starting at this low base has meant that when we look at cost reduction in order to meet budgets, there are no work packages to jettison.*

Furthermore, there have been **challenges with rising costs within the UK consortium, which could have key ramifications on UK investment.** For example, as flagged in the October 2024 SPRP, the ACS forecast a £3m increase due to schedule delay, travel and shipping costs, longer test durations, and facility usage costs. These were driven by an 'aggressive original schedule' combined with an 'underestimated complexity' in the design. This has, in turn, led to decisions being made regarding ESA taking over responsibility of the development of the ACS, since these costs had risen above UK Space Agency's ability to fund.

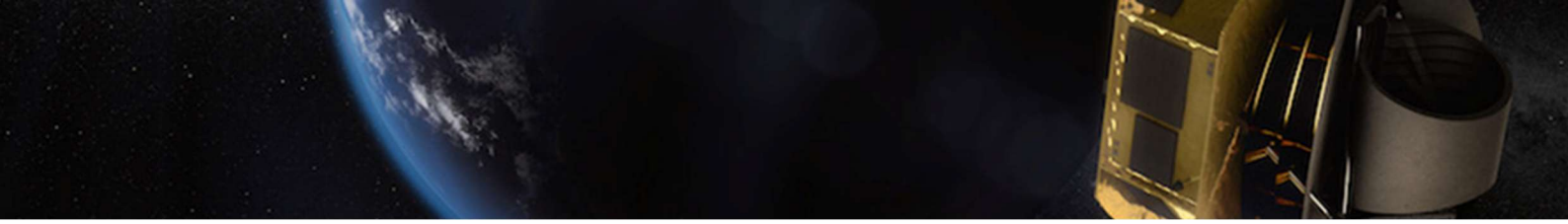
> *Every time ESA has to step in and help with funding, the country* [the UK] *takes a hit reputationally.*

Ongoing reporting had not captured the impacts of the ACS delays effectively, because it only monitored milestones in-year rather than longer-term, which is where most of the ACS milestones fall. There was an element of communication failure between the branches of RAL (Space and Technology) additionally, which could have otherwise helped catch the rising costs earlier. This **demonstrated the need for more robust mitigation measures**, as well as **stronger internal communication measures within RAL's structure**. Furthermore, shifting the funding to fall within ESA's remit risked some level of impact and return on investment, with RAL highlighting that *when* to transfer the responsibility was key. **To maintain UK design intellectual property (IP) across the ACS system, it will need to be transferred to ESA leadership no earlier than post Critical Design Review stage.** The benefit of retaining the IP is that it will lay the groundwork for future benefits for RAL Space / a UK organisation, helping it maintain leadership in the realm of cryocooler against other European competitors.

Beyond key hardware elements, several stakeholders – particularly those involved in the ExoClock and ADC initiatives – noted that there is little-to-no support provided under the UK Ariel investment for wider outreach activities. While small funding pools exist to support these efforts, driven primarily through other UK Space Agency and STFC small grants, **their scale is often insufficient to maximise impact**.

> - *Without going crazy, prize money could be increased: this would be helpful in increasing returns and engagement, but we can't do this within the current UK Space Agency and STFC funding settlements or rules.*
> - *This is a very good investment for little money to reach a lot of people.*

In response to these funding challenges, stakeholders have responded by establishing not-for-profit organisations to access alternative funding steams, though doing so in itself also comes with considerable administrative challenges and overheads. Of particular note, one of these not-for-profits will be established outside of the UK. As a result of restrictive funding mechanisms, **there is now a distinct possibility that future impacts will be realised beyond UK borders.** Since these



are a strong success story for wider Ariel initiatives, with UK organisations strongly at the helm, stakeholders suggested how **UK Space Agency could consider providing more dedicated funding towards outreach activities.** This would allow impacts to both be maintained within the country, and also to grow, with consultees noting that there are large ambitions for these projects, but are impacted by resource constraints.

2.2.3 Change control plan

Recognising that earlier risk-sharing and gateway monitoring would have been appropriate, and to manage pressures around budget and scheduling, UK Space Agency set out the Ariel Change Control Plan.

This control plan set out the **formal processes through which significant changes to UK Space Agency-funded national contributions to Ariel are 'raised, assessed, approved or rejected'** through the PMB. The aim is not to supersede or duplicate pre-existing mechanisms at consortium, ESA, and funding agency level, but rather to enhance the processes by ensuring the UK Space Agency PMB has input into any decision that can impact UK Space Agency-funded activity prior to formal acceptance.

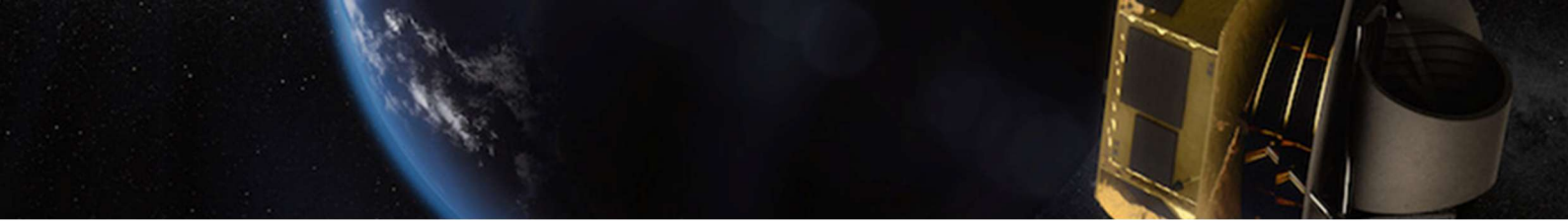
These change categories cover:

- **Scope:** *Material change in scope to UK delivery activities, i.e. addition or removal of work packages, including changes resulting in diversion of effort from established work packages/increased cost*
- **Schedule:** *Formal revisions to the payload module master schedule (including deployment of schedule margin)*
- **Cost:** *Changes impacting on Whole Life Cost estimates and/or use of UK Space Agency-held contingency*
- **Expenditure:** *Nearer term changes to spend rates that could affect in year affordability, i.e. under/overspend, and working allowance spend above project threshold*
- **Investment objectives / benefits:** *Changes that could affect achievement of business case objectives and/or realisation of their underlying benefits*

The change control plan also set out the thresholds to determine how the approval process is enacted, providing minor, moderate and major ranges across the change categories above, and who would be the decision-making entity.

In the 15th PMB meeting (March 2025), RAL presented a test run of the Ariel Change Control Request Form, submitting a change control request for the value of £627,000 for financial year 2024/25. This change was driven by a number of factors, including staff effort miscalculations, cleanroom rental, unplanned work and minor hardware and procurement issues. Whilst the changes do not directly impact on the scope or staff profile of the mission, it does increase the whole life cost. It is expected that some of the overspend will be absorbed into the 2025/26 National Satellite Test Facility (NSTF) testing budget, though a further control note is expected, which may raise the budget needs for that year beyond current allocations. One of the costs, pertaining to 'Cleanroom rental for Suite A', may be negotiated down after discussion internally at RAL Space. However, this was also flagged as an example where **improved internal communication between different elements within RAL could be beneficial.**

Of note, the March 2025 request specifically states that if the change were not to be approved, that "some activities would have to stop", **which would directly jeopardise project delivery and the achievement of business case objectives and benefits**. This suggests a significant tightness within the mission budget, with little remaining contingency for further cost change.



Overall, the Change Control Plan mechanism appears to be easy for the UK project team to adhere to, and is a good example of **UK Space Agency / the PMB being proactive in finding processes to support smoother delivery of the programme**.

2.2.4 Preparatory science activities

A challenge in large scientific collaborations is maintaining engagement whilst also preventing counterproductive competition. Within the consortium, this was observed to require careful management, with **innovative thought-leadership from Ariel PI, Prof. Tinetti.**

> *The working groups were moving slowly with no pressure, which was a risk; we wanted to take the opportunity to train and lead new scientists while keeping momentum.*

To mitigate this risk, working groups have – during the lifetime of the mission - undergone restructuring. The broad approach that was adopted was to encourage alignment and ensure all teams remain engaged, through establishing hybrid 'science interest group structure'. These have been designed to **foster collaboration** by permitting code and model sharing across groups and **encouraging autonomy in forming collaborations within, and beyond, the consortium**.

Ariel PI Prof. Tinetti is continuing work to **develop and enhance collaboration opportunities.** In doing so it is hoped that this new approach will minimise overlap and empower a larger research community to scrutinise results and invariably improve research outcomes and impact.

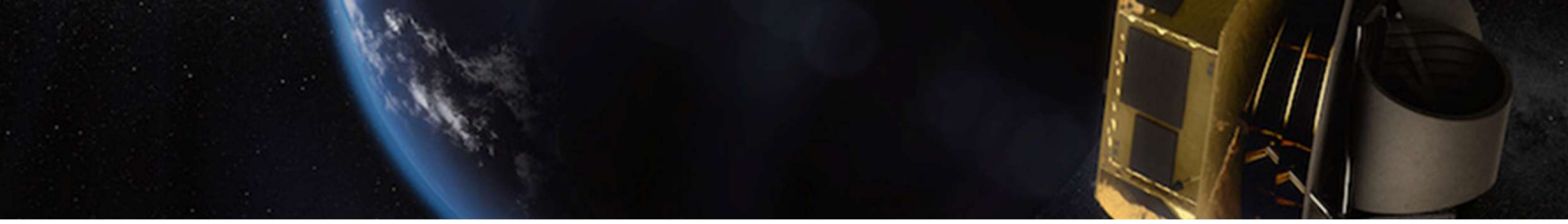
> *NASA are already looking at new ways to do things – they really appreciated the open science and outreach activities.*

The preparatory science activities have been identified as a particular strength, with one stakeholder suggesting that preparations are proceeding "incredibly well" and **could yield greater impact than larger NASA missions**. Whilst not all of this is directly related to UK Space Agency investment, the leadership of PI role of Prof. Tinett combined with the process of restructuring of the working groups into special interest groups, will hopefully lead to long-term impacts for research, including for those in the UK.

2.2.5 Wider geopolitical context

Ariel is inherently an international mission, bringing together expertise from a number of partner nations and organisations, and hence faces wide geopolitical challenges. While many of these do not have direct links to UK investment specifically into the mission, **it is important to understand the context within which the UK consortium members (and the mission overall) must operate**, as these may impact progress for the team.

The mission has increasingly faced challenges to its broader supply chain due to events beyond its control, particularly in the wake of the ongoing conflict in Ukraine, inflationary challenges, and broader material shortages. Stakeholders noted challenges in the supply of raw aluminium and titanium as a result of the conflict in Ukraine, whilst a global shortage of semiconductors and their components has also contributed to delays in component development and manufacturing.



> *The shortage of materials due to the Russia-Ukraine war was cited as a key reason for delays in Italy. It's now starting to seem that this was a convenient event for the Italians.*

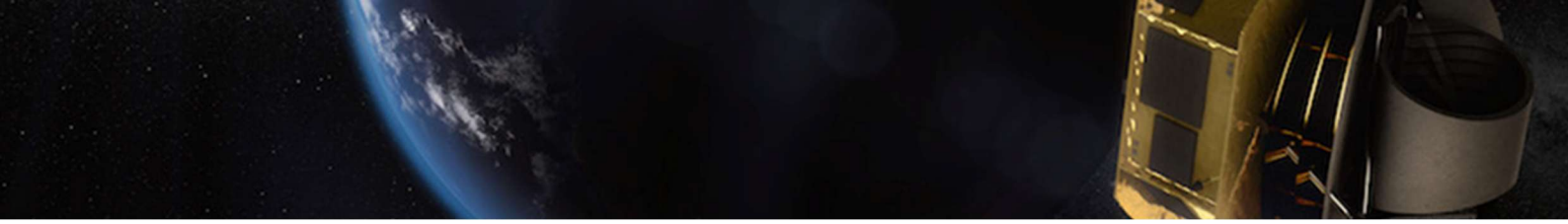
The UK's departure from the European Union has also introduced complexities in the progression of the mission, with certain administrative challenges to consider, such as work visas or impacts to overall costs. However, stakeholders stressed that while these were inconvenient, they were able to navigate them successfully and maintain overall progress.

As described in section 2.2.1, the timeline for activities, including for UK consortium members, has been impacted by delays from an Italian contractor. One stakeholder suggested that post-COVID economic pressures in Italy have strained Leonardo's ability to meet its contractual obligations, whilst another felt Leonardo was overstretched due to taking on more projects than they had capacity for. Since the contract with Leonardo is directly with ASI, this means that certain contractual mechanisms are beholden to relationships between Italian actors, despite affecting wider mission activities and RAL's responsibility to lead the consortium.

There is also a **slight concern that financial uncertainty with respect to future UK Space Agency funding for the Ariel mission could lead to European partners stepping in to take over parts of the project**, with one stakeholder suggesting that the "Max Planck Institute could get together and buy the UK out of this [Ariel]," potentially **displacing UK leadership**.

> *If the UK withdrew* [from Ariel]*, it would probably end the mission. The perception of the UK as a trusted partner would be negatively affected, impacting future opportunities.*

Despite these pressures, there remains a view within the academic community that participation in Ariel as supported by the UK Space Agency national investment has enhanced the UK's standing within the international community, building trust with partners like NASA and ESA.



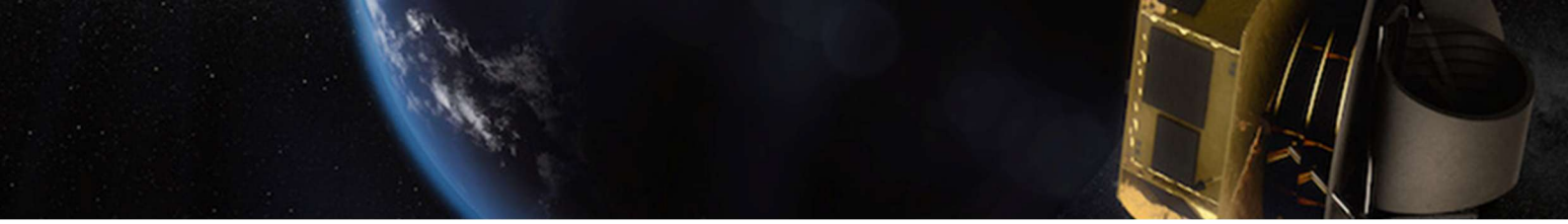
2.3 Administration and resourcing

The administration and resourcing of the Ariel mission reflects a complex landscape that bridges both national and pan-consortium requirements. Like many other elements of this evaluation, the two cannot be entirely separated, and are inevitably interconnected. Nevertheless, the mission continues to benefit from strong institutional expertise, and the UK's broader reputation within the space sector, supported by UK Space Agency funding. Positive examples of institutional resilience have emerged, including **well-managed staff transitions that have enabled the retention of expertise and the continued upskilling of early career-researchers**. UK team members have innovative concepts that they wish to explore further, some of which may result in future benefits realisation around commercialisation. **Monitoring and Evaluation activities were valued for tracking progress and helping form a narrative** to convey impacts to the UK Space Agency and other senior stakeholders.

However, a key area of concern is resourcing constraints, where team members oftentimes find themselves **too limited in time and budget to explore wider opportunities**. Overheads, such as reporting mechanisms, can place disproportionate administrative burdens on the UK Ariel team, who have highlighted that these were not always factored into the budget. There are also risks pertaining to institutional knowledge retention; since Ariel is a long-term mission, **the likelihood of staff turnover (through retirement, new roles) can be high**, and hence upskilling should continue to be a focus for the UK Ariel consortium team, supported by UK Space Agency.

Administration & resourcing recommendations

- **Consider providing additional / dedicated administrative support**. UK Space Agency should, where possible, allocate additional resources to support reporting requirements and broader administrative requirements experienced by stakeholders. Where possible, UK Space Agency should continue to identify areas for further streamlining of administrative processes. *[Stakeholder recommendation].*
- **Consider providing additional resource (time) towards pursuing wider impacts.** The project team is understandably focusing resourcing on direct project activity. Many have innovative opportunities they wish to develop, such as commercialisation and broader knowledge spillovers. From other evaluations, we have identified how spillovers can be a sizeable proportion of total benefits. Dedicated resource support to pursue these could build a stronger long-term impact narrative for Ariel in the future. *[know.space and stakeholder recommendation].*
- **Manage institutional knowledge continuity**. The UK Ariel project team, with UK Space Agency support, should establish strategies for retaining and transferring institutional and technical knowledge throughout the lifecycle of Ariel. Upskilling early-career researchers can ensure the loss of any one profile (e.g. through retirement, new jobs) does not overly impact mission progress. *[know.space recommendation].*
- **Reassess the role and suitability of Researchfish**. UK Space Agency should evaluate the effectiveness and efficiency of Researchfish in capturing impact data. If the system continues to impose burdens without delivering commensurate value, alternative methods to capture impacts should be explored. *[know.space and stakeholder recommendation].*
- **Streamline small grant reporting requirements in Researchfish**. UK Space Agency should review the inefficiencies caused by the number of follow-on/bridging funding grants required for the same programme (such as Ariel) into Researchfish. *[know.space and stakeholder recommendation].*



- **Streamline and maintain consistency around reporting.** UK Space Agency should streamline reporting mechanisms with ESA's where feasible, or where this is not possible, should maintain consistency in format / focus of its reporting, to alleviate administrative burden on the project team. *[know.space and stakeholder recommendation].*
- **Continue monitoring and evaluation efforts**. We recommend monitoring and evaluation efforts continue throughout the remainder of the Ariel mission. Stakeholders highlighted the value of M&E in identifying areas requiring support, showcasing impact, and informing broader decision-making. The process has enabled UK Space Agency to track progress, and provided a rare formal opportunity for project teams to reflect on their contributions. *[know.space and stakeholder recommendation].*

2.3.1 Staff resourcing

Staff within the consortium were considered by wider stakeholders to be motivated and talented individuals, with an entrepreneurial mindset in finding ways to produce best outcomes. The Ariel PI's innovative thinking through her leadership on the preparatory science activities, and the drive within the consortium towards potential opportunities with artificial intelligence and machine learning were especially highlighted.

Overall, project team members were inspired by new ideas, and had concepts that they wished to explore further, some of which could have potential commercial benefits in the future if brought to fruition. Furthermore, UK Ariel organisations have been approached by other actors for opportunities on potential future missions, demonstrating wide recognition of their reputation.

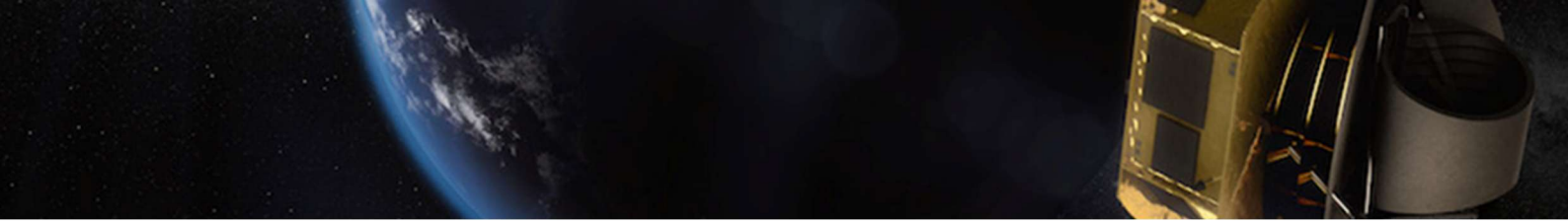
However, one of the key challenges in the realising these opportunities was around the resourcing constraints that the team is feeling – intertwining funding and FTE associated with the mission. Understandably, not all of this is related to UK Space Agency investment, but there is a cascading impact across the team due to multiple pressures.

One stakeholder highlighted how cost-cutting measures had removed extra administrative support. This feeds into a wider barrier that we heard, around people being too busy on administrative activities and overheads, or too light on FTE, that they barely have enough time to focus on mission activities – and hence, **were too resource-constrained to explore wider opportunities**. In some cases, this has resulted in opportunities being turned down.

Furthermore, the burden of financial uncertainty has led to **staff costs being underwritten by project teams themselves**. Due to the fragmented and inconsistent nature of available grants, teams have had to cover salaries through unstable or self-sourced funding, creating additional uncertainty.

> *"We have had to underwrite staff costs due to the disjointed funding model. We will lose out to people who are able to obtain and leverage UKRI grants, which can last longer, for other projects.*

Stakeholder feedback also highlights the extent to **which project teams are taking on unpaid or voluntary work to maintain mission-related activities**. Tasks such as preparing newsletters, coordinating working groups, and reviewing literature are critical for the success of the mission or for capturing wider awareness in mission activities. And yet, they are often undertaken outside of



with a reliance of people going 'above and beyond'. **This reliance on additional efforts of individual people is arguably unsustainable in the long run,** reflecting an underlying issue that administrative and outreach activities are not adequately supported in the wider picture.

As stated, many of these are not tied to UK Space Agency funding, but provide rationale as to why there may be limitations in the impact narrative throughout the mission. If feasible, considering the inclusion of funding for administrative burdens / overheads and communication activities could ensure wider non-research activities could be adequately explored, leading to wider benefits realisation in the longer term. We heard how greater collaboration and alignment between funding bodies, including between UK Space Agency and UKRI (STFC), could help provide a more stable financial conditions for research teams.

2.3.2 Institutional expertise and reputation

There is recognition amongst wider stakeholder groups that the UK organisations being supported by UK Space Agency to deliver on the Ariel mission are **providing strong institutional expertise and reputation to the consortium**, with certain high-profile team members helping draw in wider interest through keynote speeches, publications and wider outreach activities.

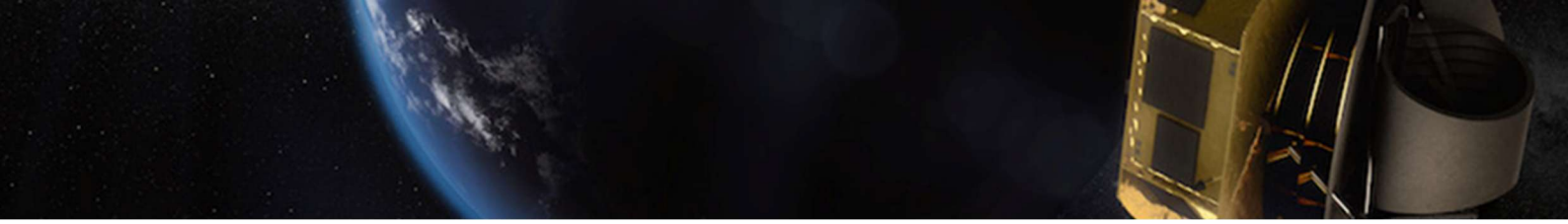
However, one recurring concern from interviewees was the **risk of single points of failure** within the team, and **risk of institutional knowledge loss**, which can be particularly relevant for missions spanning many years.

For example, one stakeholder raised a risk around the small team at RAL – describing how they work over capacity to deliver the complex integrator role, but that if one or two core people from the institution were suddenly unavailable, it would have significant implications for project delivery. To a certain degree, this specific risk has been alleviated thanks to the Sarri review recommendations, where pressure on leadership at RAL should be lessened with more FTE support.

> - *The team at RAL seem to be working at 120% for years…that's just not sustainable over a long time.*
> - *If they … fall over from being burnt-out, then there's a significant knock-on impact to the project.*

For missions that run for over a decade, from selection through to launch and operation, staff turnover at relevant institutions can be expected. **Where uncertainties arise is when people in key leadership roles choose to retire or transfer to other organisations**, thereby risking a drain of institutional know-how and a loss of high-profile figureheads for the mission. According to one stakeholder, this is particularly true for academia, which is more likely to rely on individual expertise, rather than companies, which seek to maintain organisational knowledge regardless of staff.

> - *The strength of the person ultimately defines the performance of the institution – the institution could*



> *almost become worthless if the people are not up to* [the task].
>
> - *It is a single point of failure risk – if anybody leaves, this has large impacts.*

Staff retirement can be mitigated with enough warning, and indeed this has already been demonstrated within the UK Ariel consortium team. Prof. Matt Griffin has since retired from his role as the Head of the Astronomy Instrumentation Group at Cardiff University, acting instead as an Emeritus Professor and member of the group instead. However, he remains Co-PI on the mission, with the plan to remain for at least two more years, allowing for his expertise to be further leveraged and for other staff members at Cardiff to continue being upskilled.

A new role does not inherently mean negative outcomes. In fact, it could potentially bring benefits to both the consortium and the wider UK research base by providing promotions and expanding institutional knowledge. Ariel PI, Prof. Tinetti's new role at King's College London is one such example, where her promotion to Vice Dean (Research) for the Faculty of Natural, Mathematical & Engineering Sciences brings more full-time equivalent time for her role on Ariel, as well as helping deepen the knowledge of astrophysics at King's College. However, if she had chosen a new role at an institution outside of the UK, the impact narrative would have been very different, as she is a key profile for the UK consortium.

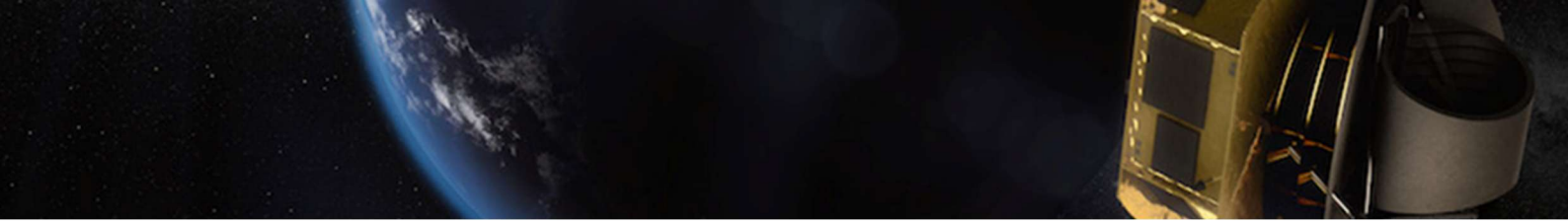
Staff retiring or leaving for new organisations – especially roles external to the UK – can indeed cause a loss to UK investment, or an impact on UK influence and reputation within its relevant field. Examples highlighted to date within the UK Ariel team have either been mitigated or brought forth positive outcomes. Nevertheless, as Ariel is still several years away from launch and operation, these risks could still occur. Therefore, UK Space Agency and partner organisations should **consider establishing a long-term strategy to transfer institutional and technical knowledge, by upskilling the younger generations** throughout the lifecycle of the Ariel mission.

2.3.3 Regular reporting to UK Space Agency and ESA

Stakeholders recognised the rationale and necessity behind reporting requirements, with a general acceptance that oversight and transparency are necessary. However, there were broader frustrations at the amount of administrative burdens more in-depth tasking brought, such as the exercise of working through the attribution of cost and preparing for the SPRP, as well as the fact that **not all of these activities had been factored into initial overhead costs** for the team.

> “
>
> - [The] *exercise…with attribution of cost was difficult, but I understood the purpose and understood why.*
> - *It is all far too much, but it's not unreasonable.*

Throughout our evaluation period, a number of stakeholders highlighted the **misalignment of reporting requirements between UK Space Agency and ESA, which imposed an ongoing administrative burden**. This was in reference to *what* information needed to be reported, *how* the information was presented, and the *timing* at which the reporting was expected. This created what some stakeholders felt was a constant demand for administrative obligations.



It was suggested that harmonising these processes, or finding ways to streamline reporting, could significantly improve efficiency across the mission. Nonetheless, since ESA is a large, process-driven organisation with strict reporting rules, often that meant the project team was hoping that UK Space Agency would shift their administrative approach instead. Whilst members of the PMB acknowledged the high amount of reporting demanded of the consortium for ESA, this led to a concern, we heard, that UK participants **sometimes perceived the UK reporting as an "additional tax" rather than a priority**, despite the fact that UK Space Agency is the funding body for their roles.

> - *Reporting requirements are out of sync with ESA; it creates a constant administrative burden.*
> - *The only thing paying for them is UK Space Agency – the only cost impact is to the UK.*

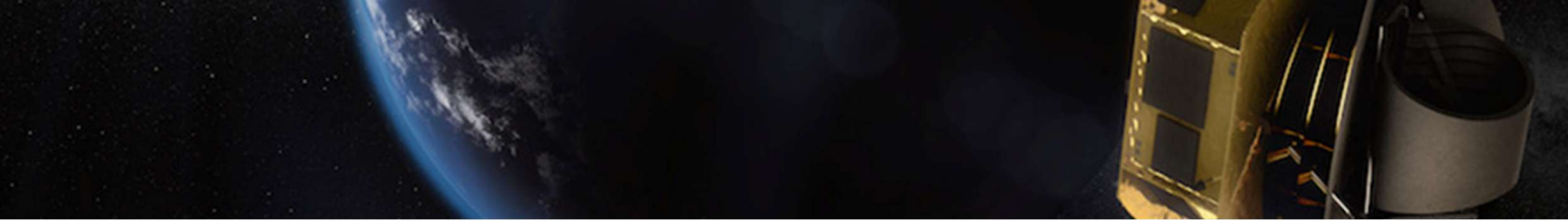
This highlights the need to impress upon the UK consortium members that UK Space Agency reporting is as important, if not more so, than ESA demands.

Towards the end of this evaluation period, project team members focused on the fact that they have, for the most part, gotten used to the reporting systems and what is being asked of them. The key concerns were around keeping consistency at this stage and not changing the process again once a routine has been established, with interviewees explaining how the time taken to learn new reporting elements was part of the administrative burden.

> - *Don't let them change the system again – that is where the overhead is.*
> - [We are] *spending so much time fixing processes* – [the] *cognitive load is too high.*
> - *It takes a lot of brainpower and time to* put [something new] *in place and get used to it.*

Therefore, the UK Space Agency should **seek to streamline reporting further**, or where this is not possible, it should **aim to maintain consistency now in the format and focus of its reporting**, to help ensure the project team settles into a regular cadence rather than constantly having to adapt. Of note, the UK Space Agency conducted a project delivery workshop at RAL in early 2023 involving all space science projects, where the Ariel delivery team were asked to identify any process changes they would like to see implemented. It was noted that no significant changes were highlighted, and that feedback suggested current approaches and reporting requirements were 'helpful'. UK Space Agency also host annual 'Stop-Start-Continue' reviews where they seek feedback from stakeholders and delivery teams to identify further changes and opportunities for improvements in processes, demonstrating that the Agency is proactively seeking to implement lessons learned where possible.

An additional concern raised around reporting was on the topic of the Researchfish reporting. Whilst consultees generally understood the benefits of using the platform, and the importance of having a consistent approach to capturing some of the grant impacts, they highlighted that for those with a high number of small follow-on / bridging grants for the same programme, this meant needing to attribute impacts against each of these small grants. This both **watered-down**



the impact narrative and also put an unnecessary burden on the grant recipient. They explained how inputting so many details across so many grants took too much time, and hence the depth at which they could provide information was limited; if there were fewer 'small grants' to input, then the impact narrative could be more robustly set out.

This concern was raised at the 14th Ariel Project Management Board meeting (June 2024), with **UK Space Agency agreeing to carry out a "full cleanse" ahead of the 2025 Researchfish submission window**. However, it was flagged to us by stakeholders in March 2025 (the closing of the submission window) that this had not been done. Hence, **UK Space Agency should consider again working with Researchfish to streamline some of the reporting requirements**. Furthermore, UK Space Agency could explore the overall effectiveness and efficiency of Researchfish in capturing impact data and reflect on whether alternative methods to capture impacts should be explored if it does not deliver commensurate value.

2.3.4 Monitoring and Evaluation (M&E)

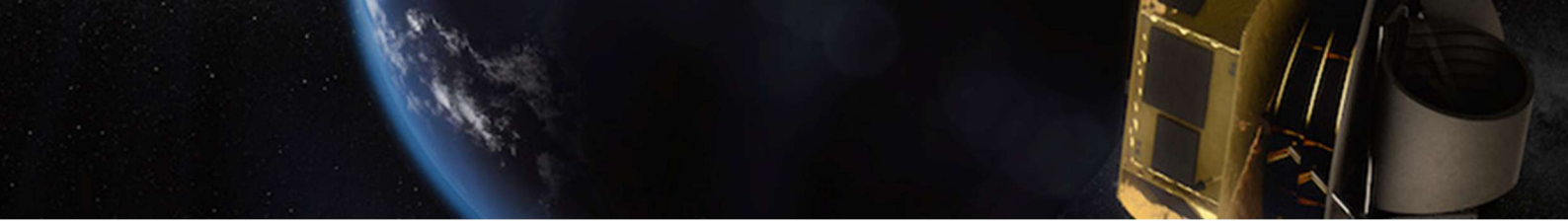
M&E activities have played a central role in providing UK Space Agency with an ongoing, structured understanding of benefits realisation across the mission. By tracking progress against defined targets, the process has enabled UK Space Agency to proactively identify areas that may require additional support, as well as areas where processes and approaches are working well.

Stakeholders reported that they found engaging with the M&E team valuable, not only as a means of highlighting success stories and demonstrating broader impact, but also as a mechanism for feeding insights back to UK Space Agency. It was noted that **for some, the M&E process represented one of the few formal opportunities they had to reflect on their contributions to the mission**.

> - *We need to put the whole story together.*
> - *Sometimes* [the project team] *need*[s] *help presenting narratives and the whole picture to DSIT.*

More broadly, and in contexts where the impact of research is inherently difficult to quantify – such as 'science of the sake of science' – **direct conversations with research teams proved essential for capturing intangible benefits.** These discussions ultimately provided a clearer and more nuanced view of the mission's progress, and of its broader impact. This aims to be particularly useful in developing evidence-based approaches to communicating the impacts of Ariel to senior stakeholder groups and business case submissions, in an easily digestible format.

Overall, Ariel has been at the forefront of implementing monitoring and evaluation so early on within its lifecycle, being the first mission of its kind within the UK Space Agency to begin capturing impacts right from its initial phases. For our evaluation, we have been able to collect data in a consistent and timely manner across the last two years, which helps to identify timeseries trends and measure progress against the targets. This avoids the pitfalls associated with ex post evaluations, where missing data often lessens the impact narrative, which is an issue we as evaluators have witnessed on other missions (e.g. within our Gaia Interim Impact Evaluation). Therefore, we recommend that **UK Space Agency continues M&E efforts throughout the Ariel lifecycle,** to collate an in-depth narrative across all impact themes regarding the value Ariel brings for the UK's investment.

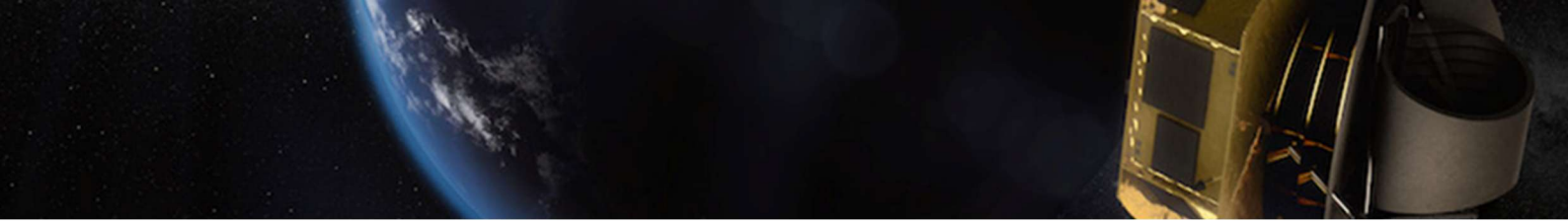


2.4 Performance against process evaluation questions

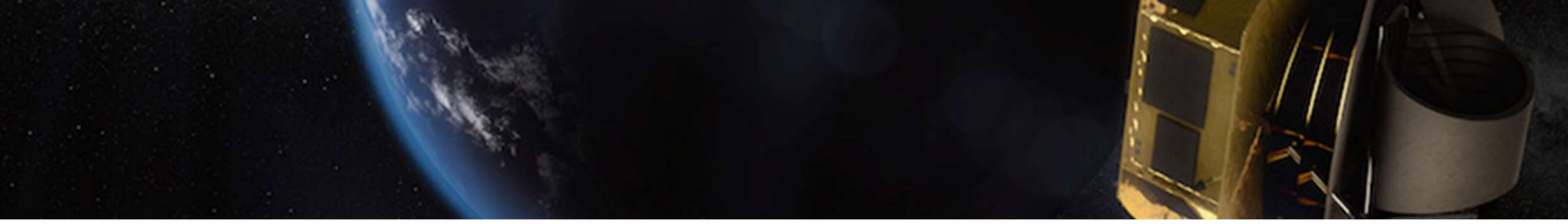
Below, we provide a high-level overview of the performance of the mission's processes against the evaluation questions set out in the original M&E framework report. Further information on the Red-Amber-Green (RAG) assessment process can be found in the Annex.

Table 1 *RAG Rating on current progress in process evaluation questions*

Evaluation Question	RAG rating	Performance
Are UK-funded Ariel activities being delivered as expected?		UK-funded activities are broadly on track, particularly in preparatory science activities. However, delivery has been impacted by significant delays in manufacturing, particularly around the telescope assembly (Italian contractor). RAL have consistently done good work, but their constrained resourcing means that they are now requiring additional support to deal with the aforementioned delays / broader consortium management. While core milestones have been met, rising costs (e.g. on the ACS) have prompted discussions around viability of who takes responsibility of ownership, since it is beyond the ability of UK Space Agency to continue funding. For the ACS, this is now likely to be ESA. Multiple re-design efforts at Oxford have caused concerns within some PMB members. UK Space Agency is perceived as being both responsive and approachable, whilst the 'solution-oriented' mindset of the PMB is welcomed by the project team.
How has the wider international context influenced delivery?		External geopolitical and economic developments have created persistent delivery challenges. The Ukraine conflict has disrupted access to key materials like aluminium and titanium, while EU Exit has introduced administrative complexities around supply chains. Inflation and post-pandemic economic pressures have impacted also contractor performance, most notably at Leonardo. Delays from actors such as Leonardo have a cascading impact across the consortium. There is a reflection that perhaps a 'capabilities assessment' should have been more robustly carried out by the consortium in the early stages, to ensure all actors could deliver as expected. These factors, though largely beyond UK Space Agency's control, have had significant impacts on timelines and overall costs, highlighting the importance of international risk planning in future mission design. More broadly however, there is understanding that the key elements driving delays (and associated fallout) do not stem from UK leadership, and hence there is no perceived risk to reputation as yet.
What delivery factors have helped or hindered progress against outputs and objectives?		Several factors have shaped progress: strong collaboration between UK Space Agency, RAL Space, and ESA, as well as proactive scientific coordination and leadership, have helped maintain momentum. Individuals and organisations within the UK Ariel consortium are recognised for their expertise, reputation and leadership. A strong positive and collaborative mindset at all levels has allowed for difficult conversations to occur without being 'personal', in order to come to appropriate solutions. Beyond external factors (such as the telescope assembly), stakeholders highlighted how risks regarding low funding levels and resource constraints at RAL were already known during initial phases of the mission, and should have had stronger mitigation measures / 'plan B's put in place. Administrative burdens around reporting, the lack of overheads costed out, and people having too little time to explore wider spillover activities underscores the



Evaluation Question	RAG rating	Performance
		resource-constrained environment within which the team work. An underestimation of system engineering challenges and a lack of risk reporting beyond the in-year elements meant that rising costs on the ACS were not communicated efficiently. In more recent times, the uncertainty regarding the spending review has led to concerns around staff retention.
What project-wide working practices and interfaces have worked well, and / or could be improved upon in the future?		Governance mechanisms such as the PMB and a positive and continually developing collaborative culture within the consortium have been highlighted as particular strengths. Effective communication between UK Space Agency and ESA, and between technical teams, have improved over time. The Change Control Plan set up by UK Space Agency has been tested at the most recent PMB, with positive feedback. This process should ensure impactful decisions are not being made without UK Space Agency / PMB input. It is understood that UK Space Agency is not a technical body; however, some stakeholders highlighted that it could be useful to have UK Space Agency's 'voice' in the room more in discussions with ESA / ASI. Or indeed, that the PMB could be supported to provide technical expertise in this area. Also, whilst the PMB is effective, having properly in-depth conversations take time, and resolutions cannot always be formed in the time given for the quarterly PMB meetings. Streamlining interfaces and institutionalising lessons from current practices will improve delivery agility and cross-organisational alignment.
Are any delivery changes needed, and how would / could they be implemented?		Much of the delivery mechanisms and working practices within the UK Ariel project team are working well. Areas where things could improve include having 'interim' (and lighter touch) meetings between the quarterly PMB meetings, to ensure there is enough time to come to a resolution and identify solutions to identified challenges. Furthermore, in leveraging lessons learned from previous challenges, the team could consider setting out more actionable mitigation measures for any risk that threatens the critical pathway, thereby having an agreed approach to trigger immediately if one of these risks came to pass. UK Space Agency could support RAL in enhancing the internal communication within its organisation, to ensure there are no more rising costs which could be identified and negotiated at an early timeframe. Administrative burdens, especially around reporting elements, was a key area of concern. Simpler solutions include ensuring alignment of reporting between UK Space Agency and ESA wherever possible, and limiting changes to the reporting format so that people do not need to learn new ways of implementing things. More complex solutions to implement would be around resource support, which of course comes with a cost that may not be addressable by the UK Space Agency. Indeed, many of the constraints on the delivery team were focused around 'time' and 'money', including on administrative elements but also for wider spillover activities. These may be challenging for UK Space Agency to address, or indeed be outside of its remit.



3 Interim Impact Evaluation

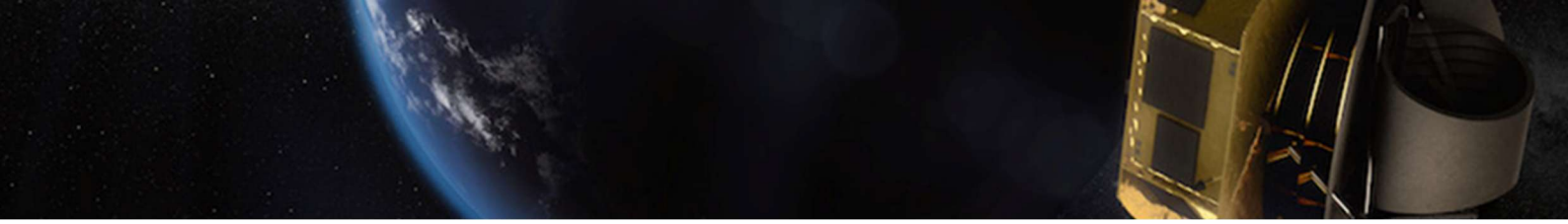
Our impact evaluation and benefits management activities throughout this study have collected, analysed and synthesised a combination of primary and secondary data and evidence. We draw upon indicator insights, qualitative contextual information, and quantitative non-indicator information to report early outcomes and impacts **across four broad categories that align to the UK Space Agency business case objectives for the investment:**

3.1 Science

As a space science mission, a core objective of UK Space Agency funding for the Ariel mission is to **enhance the strength of the UK scientific community in exoplanet science – which is one of the fastest growing areas of astronomy**. Moreover, as UK Space Agency contributions have secured scientific leadership roles for UK-based researchers on the mission, most notably through PI Prof. Tinetti, another core objective is to **shape the mission science around UK research strengths and interests**.

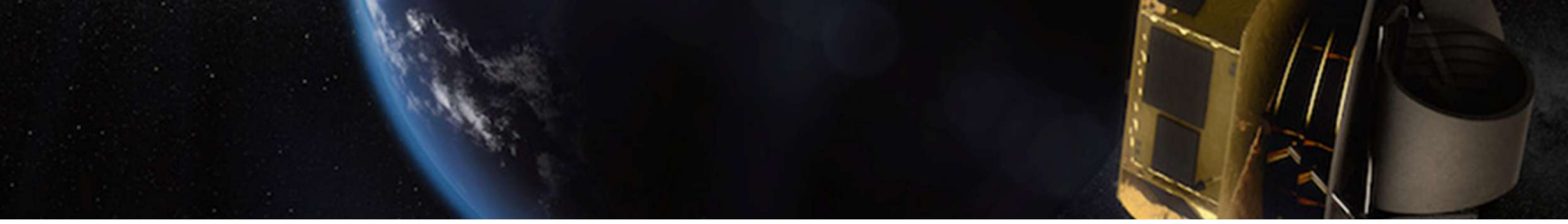
> - *A space mission like Ariel is seen by everybody as truly ambitious. They are fantastic achievements which are recognised by everyone – engineers, politicians, and the public. And we have the status of leading such a mission.*
> - *Exoplanet science is becoming dominant within space science; it is strategic for us to step into such a scientifically significant mission.*
> - *We are positioning the UK to build on its strengths in exoplanet science with Ariel, alongside complementary missions like Cheops and Plato.*

As the latest in a fleet of ESA exoplanet and exoplanet-applicable missions, it is essential that preparatory science for the Ariel mission **is agile to emerging developments in the field of exoplanet science**, to ensure the mission is leveraging cutting-edge techniques. Therefore, stakeholder stressed the importance of the scientific objectives, target selection process, and analytical techniques used to characterise exoplanet atmospheres needing to build upon findings from previous and ongoing missions (such as JWST, Plato, Cheops, Roman), as well as research underpinned by ground-based observatories.



Summary of key findings

- **We view that national funding has secured UK scientific leadership and led to an increase in both the quantity and quality of science outputs -** while there is a long way to go, we assess Ariel as being broadly on track to achieve (and even surpass) scientific objectives at this stage. However, future development and scientific exploitation will be required to realise these objectives fully.
- **Scientific management of Ariel by the UK mission PI is ongoing, and aims to catalyse greater participation in the mission through novel approaches –** current working group restructuring is expected to enhance participation and collaboration within the exoplanet research community. Ariel PI, Prof. Tinetti, is trialling first-of-a-kind publication policies and incentives to maximise science returns in the future.
- **There is rising Ariel-related research output year-on-year, although these are initial shifts in a longer-term picture –** a total of 477 Ariel-related publications have been identified since 2018, and the level of research output has generally increased annually, with some year-on-year fluctuations. In the baseline the average number of publications per year was 43, and this has since doubled to 87 per year during the analysis period.
- **Contributions from UK authors are beginning to demonstrate early UK leadership over Ariel science –** the number of Ariel papers which have a UK affiliated first author has risen in both absolute and relative terms between the baseline and analysis periods. UK authors (1st or otherwise) have appeared in an average of 24 publications a year in the baseline, increasing to 43 in the Analysis period. Half of all Ariel-related papers feature UK authorship, placing it at the upper end of UK Space Agency's target window.
- **Organisations in the UK project team are the key contributors to Ariel-related research, although UK Ariel funding is driving contributions from across the UK –** a total of 31 UK organisations have produced an Ariel related publication, rising by 4 in the analysis period. UCL are the leading contributors (70%), followed by RAL Space (18%), Oxford University (8%), and Cardiff (8%). While UK Space Agency-funded organisations are the key contributors, publications from universities such as St Andrews, the Open University, and Exeter (among others) also demonstrate wider interest in the mission.
- **As an exoplanet mission, Ariel is situated in a growing field of research but has not significantly influenced the wider field yet –** for context, there is growing research activity year-on-year in the wider field of exoplanet science, of which Ariel publications currently comprise approximately 4%. UK authors are featured in between 12-16% of all exoplanet science publications, indicating wider interest in the UK, although this is not necessarily attributable to the UK Space Agency's national contributions to the Ariel mission.
- **Citations take time to materialise and are weighted towards older publications, but they have been growing quickly over the course of our study –** time lag effects make year-on-year comparisons misleading, but to date, there have been 5400 citations on Ariel related publications with UK involvement. 70% of these have accumulated on publications in the baseline, but citations on analysis period publications have risen by 900% since September 2023. This indicates wider interest in UK authored Ariel research and could be seen as a signal of high-quality research. An upcoming Ariel Blue Book publication (to be released in 2026), is expected to accumulate a significant number of citations as a reference document for the mission.
- **Ariel related publications by UK researchers have also received considerable wider attention, although the most popular publications currently leverage data from**



previous and ongoing missions – wider attention can be seen through altmetrics analysis, as the top cited publications have also been referenced in at least 614 news articles, including BBC, Forbes, CNN, National Geographic, New York Times, and Al Jazeera. This demonstrates wider interest in Ariel-relevant science, but is not by itself a reflection of research quality. This attention indicates the wider impacts for (and interest of) the general public which could be seen in the long-term, when Ariel is returning data.

- **Despite efforts from the project team, minimal levels of follow-on funding for UK universities have been secured to date, although this may rise in the coming years –** UK universities have secured a total of £113,000 in funding, primarily through sponsorship of the Ariel Data Challenge from Google's AI and Machine Learning platform Kaggle. Ariel scientists have been applying for other large research grants and fellowships but have been ultimately unsuccessful so far. They will re-apply in the future, after being shortlisted previously. Follow-on funding is expected to rise post-launch, as researchers secure funding for scientific exploitation of Ariel data.
- **In absence of UK Space Agency national funding, not only would UK roles, influence and outputs be greatly diminished, but the mission may well not have been selected –** while researchers would have conducted other research, UK Space Agency national investment has been key in driving additional scientific return and positioning UK researchers to exploit Ariel data from other missions (as well as data from future exoplanet missions).

3.1.1 Publications, research output, and UK involvement

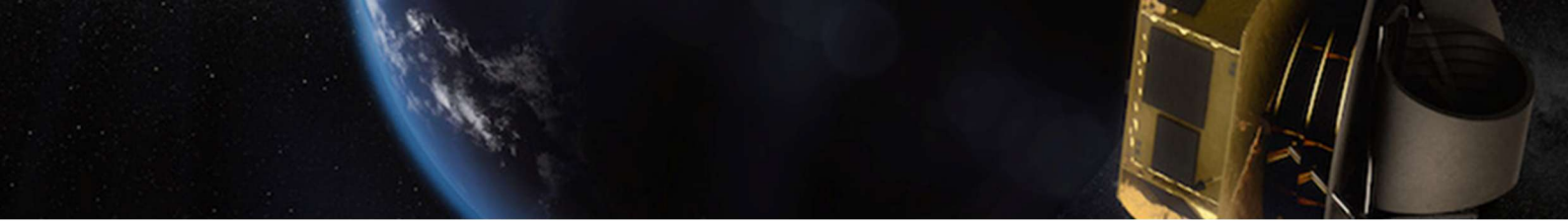
Preparatory science activities to support the Ariel mission

The science activities within the Ariel consortium are being managed by Prof. Tinetti, as overall PI for the mission. While the mission is still years from launch, she has been driving forward and shaping preparatory science activities within the consortium. In doing so, she is aiming to increase Ariel-related research outputs, ensuring the research community is prepared to leverage Ariel data effectively and **maximise the science returns in the future**.

Ariel is a **mission with a complex consortium of organisations from 16 countries**, which require structures to promote collaboration and provide opportunities for the next generation of scientists to work on mission-relevant science. As with any long-term space science mission, it is this next generation which will be leveraging Ariel data in years (and perhaps decades) to come.

> *"Science preparation is going incredibly well – in the face of bigger NASA missions, this one has the potential for bigger scientific impact.*

To catalyse research activity and international collaboration across the Ariel consortium, Prof. Tinetti is implementing innovative working group restructuring processes. In a departure from typical ESA missions, **Prof. Tinetti is replacing working groups with a hybrid 'science interest group' structure**. The intention is to foster additional collaboration by permitting code and model sharing across groups, so researchers have greater autonomy in forming collaborations within (and external to) the consortium. Stakeholders felt that some previous ESA missions relied too heavily on siloed groups of researchers, which could lead to reduced data access/sharing, and limits to wider engagement with the mission. Current plans are for a central software to host datasets, and for the consortium to identify and volunteer for priority areas of research. The



restructuring will also aim to minimise overlaps in research areas, while also enabling a larger community to scrutinise results, and lead to better research outcomes – hence maximising the science return for the mission.

> *Intermediate science at this stage of the mission is essential. If the science is changing, we don't want things to become obsolete. We need to build a collaborative network of scientists to keep momentum.*

The 'science interest groups' structure is inspired by **ongoing research at UCL to identify publication and data policy best practices**, including from other international space science missions and related fields, such as particle physics. These lessons will then inform Ariel-specific policies, with an approach that aims to make researchers more motivated, while also catering for more junior / early career researchers, who often appreciate more flexible working structures. These plans are currently being finalised, and are expected to come into effect in the following months. This novel approach has also received interest from NASA, who may adopt a similar approach in future missions, such as for the Nancy Grace Roman Space Telescope mission.

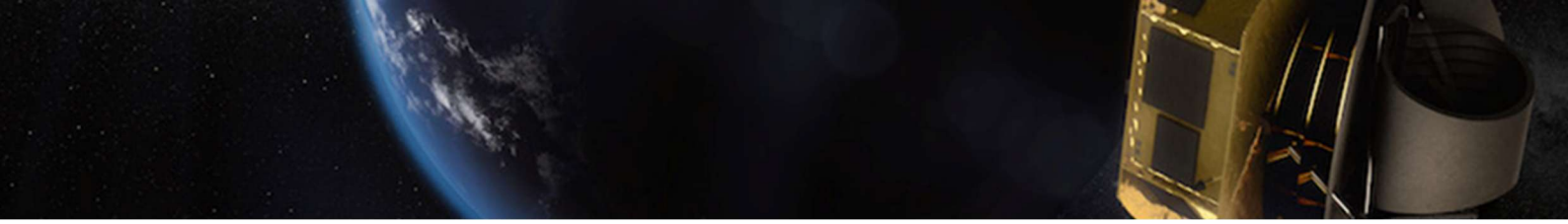
Alongside restructuring groups and amending publication policies, Prof. Tinetti is also increasing incentives for participation at this stage of the mission through a proposed **Ariel 'Blue Book'**. This will be used to iteratively update the scientific objectives of the mission based upon wider science being undertaken with other mission data, such as JWST. The Blue Book will ensure developments in target candidate selection, analytical approaches, and data modelling are reflected in the mission as they have evolved beyond publication of the Ariel Red Book in 2020 (when the mission was formally selected). To date, a total of 137 publications spanning the course of the Ariel mission are expected to inform the Blue Book, alongside additional publications which are in development[9].

Current science management activities also aim to provide **profile-raising benefits for the mission as a whole over the longer term**. Highly cited publications relating to the mission science or outreach activities can help to catalyse further interest and engagement, helping to build the community of researchers with an interest in Ariel years before it launches. We assess developments in Ariel-related research output and impact (in the form of citations and wider attention) below; however, many of the benefits associated with UK led science management activities are expected to accrue **beyond the timeframe of this study (ending March 2025)**, as these changes are implemented.

Ariel scientific publications

One measure of the level of research activity within the science consortium (as well as wider interest in the Ariel mission) is the number of scientific publications which have been released. At this early stage of the mission, our study has monitored developments in publication activity over the past 7 years in collaboration with our partners, Digital Science. All publication data comes from Digital Science's Dimensions.ai database, and further detail on the methodological approach can be found in Annex 4.2.3. While not all publications related to the mission are solely/directly attributable to the UK Space Agency's national investment, this time series data provides trends prior to and following UK contributions to the Ariel mission.

[9] A catalogue of publications which will inform the Blue Book can be found here: https://ui.adsabs.harvard.edu/public-libraries/sJ-WJsW8TSWicaF2WJ8haA

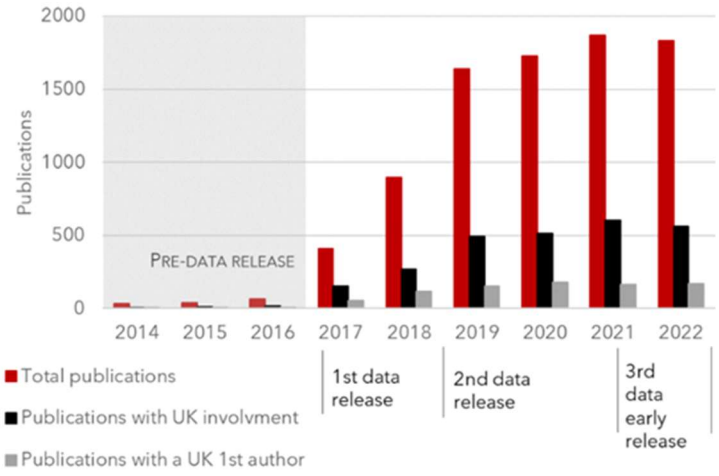


Since 2018, we have recorded **growing momentum in the number of Ariel-related scientific publications**, with some year-on-year fluctuations. These publications have various links to the mission, including technical overviews of the payload and various instruments, databases and analytical tools for analysis of exoplanet data, preparatory science on potential target exoplanets, and updates on Ariel-related citizen science programmes.

> *In terms of publications, we have seen a good rate. I hope the new way of doing things will boost the number of publications further in the future, and now is the right time in the mission to trial this approach.*

While this initial trajectory is promising, we are currently assessing initial developments in a far longer-term picture. Publication trends vary across missions; however, we would expect to see activity clustered around data releases from the Ariel mission. While the magnitude or rate of new publications may differ, our evaluation of publications linked to the Gaia mission provides useful context for Ariel – as the bulk of new publications began to materialise 4 years post mission launch, when data was released to the scientific community.

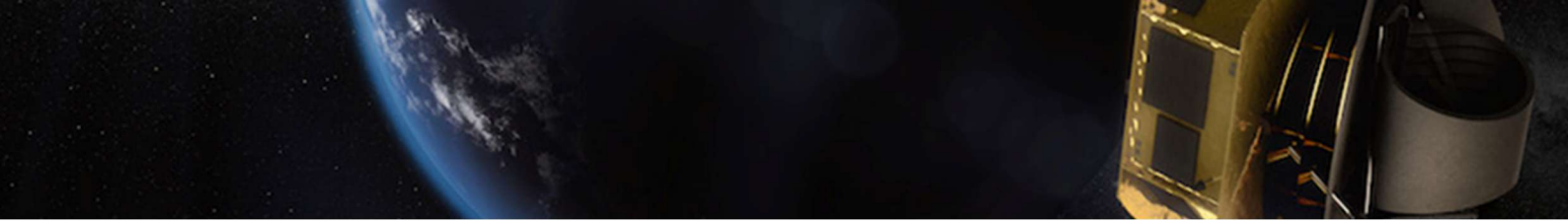
Figure 2 *know.space analysis of Gaia publications per year*



*Source: know.space **Gaia Interim Impact Evaluation** (derived from NASA ADS using ESA publication data)*

A total of **477 Ariel-related publications have been recorded over this period**. Within this data, we see an initial peak in 2020, which coincides with the lead-up to and successful adoption of the Ariel mission. Following this, there is a broad upward trend in the number of publications per year, with this peak being exceeded in 2022, and then again in 2024. The drop in publications in 2023 is a notable exception to this trend, which could be driven by the cyclical nature of writing and publishing research, delivery milestones on the mission, or publications being clustered around major international conferences.

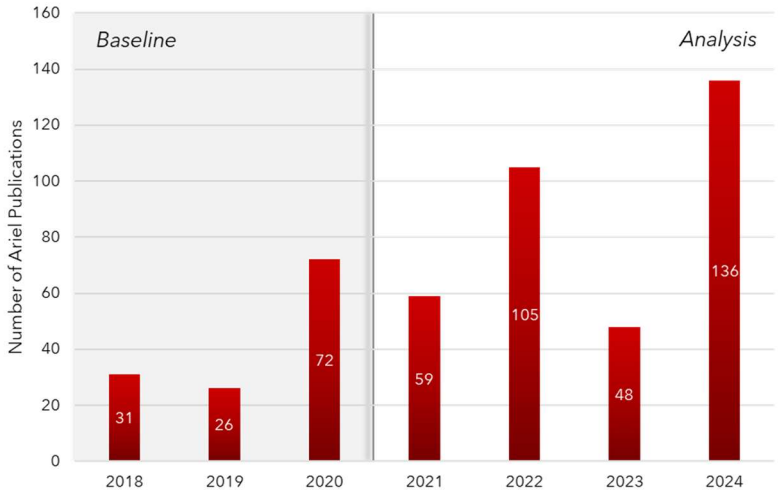
Within the baseline period (the window prior to the UK Space Agency national investment), the average number of publications per year was 43. **This has since doubled to an average of 87 per year** in the analysis period. While this increase in Ariel-related publications is not solely attributable to UK Space Agency's investment in the mission, it does indicate growing research output at this early stage. This increase is also in-part attributable to the UK's ongoing science management activities, as discussed above. In the near term, there is potential for an uptick in



publications due to the science working group restructuring. In the coming years, we would expect to see the number of Ariel related publications increase significantly around launch, and then yet more sizeable increases following Ariel data releases, when the outputs of the mission are analysed by the scientific community.

While differences in budget, timeframe, and objectives mean mission comparisons are not always direct, evidence suggests that Ariel research activity is strong relative to other ESA missions. For context, there were an annual average of 33 Gaia publications and 13 CHEOPS publications per year in the 3 years following mission launch (in 2013 and 2019 respectively)[10].

Figure 3 *Number of Ariel-related publications per year since 2018*



There is limited impact to measure from these publications as yet. Much of the focus has been around raising awareness of the mission and highlighting key technological details (e.g. mission description papers, instrument and data model publications, etc.), as well as discussing findings related to AI processing applied to exoplanet data (e.g. through ADC activities). The true scientific impact or main bulk of 'discoveries' will occur once the mission is operational.

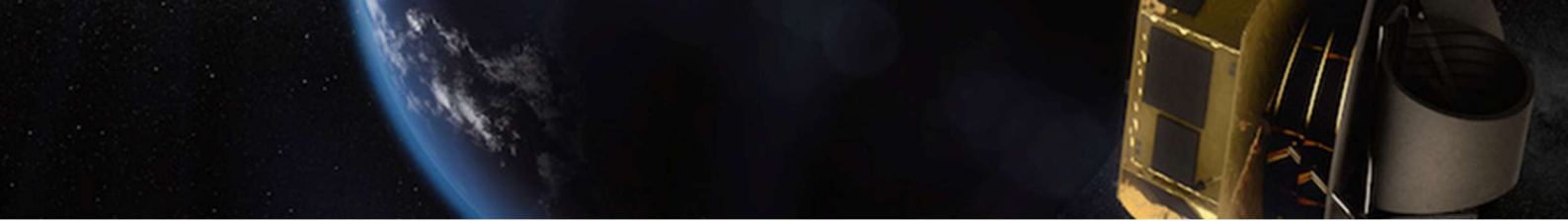
UK authorship in Ariel publications

As the number of Ariel-related scientific papers has increased, so has UK involvement. **The number of these papers which have a UK affiliated researcher listed first has risen in both absolute and relative terms between the baseline and analysis periods**. For instance, UK researchers were listed as first authors in an average of 12 publications per year between 2018 and 2020, and this has since **risen to an average of 27 per year between 2021 and 2024**.

Within the data, there are several UK first authors who occupy **scientific and engineering leadership roles** (for example, mission PI, Prof. Tinetti, and the Ariel Consortium manager Paul Eccleston). Additionally, there are several papers led by UCL researchers who are leading related activities, such as the development of databases which could be used to analyse the outputs of the mission in the future.

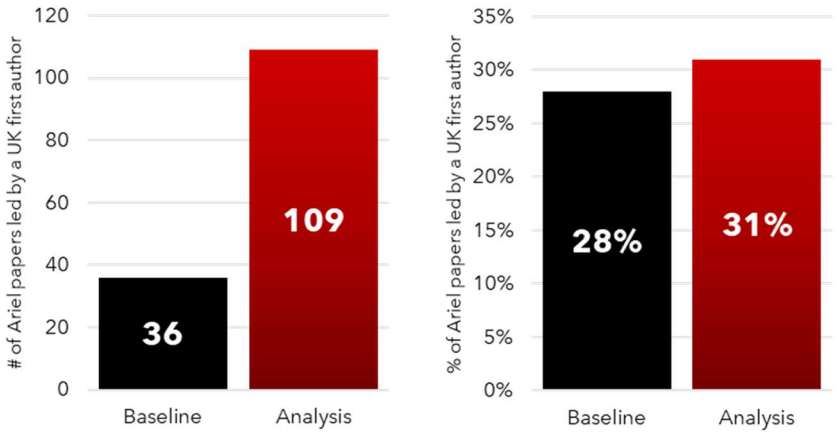
Conventions for the order that co-authors are listed on publications vary by field and journal, and do not necessarily equate to being the lead author in all cases. However, we view that these

[10] De Marchi, G. and Parmar, A.N., 2024. *ESA Science Programme Missions: Contributions and Exploitation-ESA Mission Publications*. arXiv preprint arXiv:2402.12818.



trends indicate a **high and rising level of UK leadership** on scientific publications relevant to the mission at this initial stage.

Figure 4 *Number and percentage of Ariel papers led by a UK first author*



Looking at UK authorship in Ariel related publications more generally, we also see strong representation across both the baseline and analysis periods. **UK authors helped produce an average of 24 publications a year in the baseline period, compared to 43 a year in the analysis period**. This trend mirrors wider trends of increased international research output relating to the mission (as illustrated in *Figure 3*), meaning UK-authored publications still occupy a similar relative share of a growing body of research. While there is some year-on-year fluctuation, 2024 and 2022 saw the greatest number of UK authored Ariel publications.

This indicates positive early UK engagement with Ariel preparatory science and other mission-relevant research activities, and is **at the upper end of UK Space Agency's target window** (to maintain 30-50% UK authorship on Ariel publications) within their benefits realisation plan. While these figures support the notion that the UK is showcasing early scientific leadership, we are still dealing with relatively small numbers of publications (due to the early nature of the Ariel mission) and hence expect the number of papers to continue to rise, especially once the mission is operational. Moreover, a smaller sample size can also skew year-on-year trends significantly. The slight decrease in the percentage of Ariel papers which are UK-authored highlights the diversification of Ariel related research across the consortium following formal selection of the mission, where there were fewer publications, but they were generally authored by those in leadership roles on the mission.

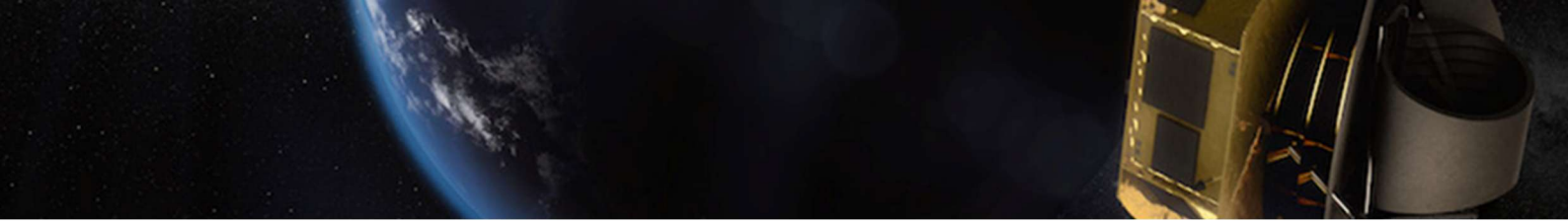
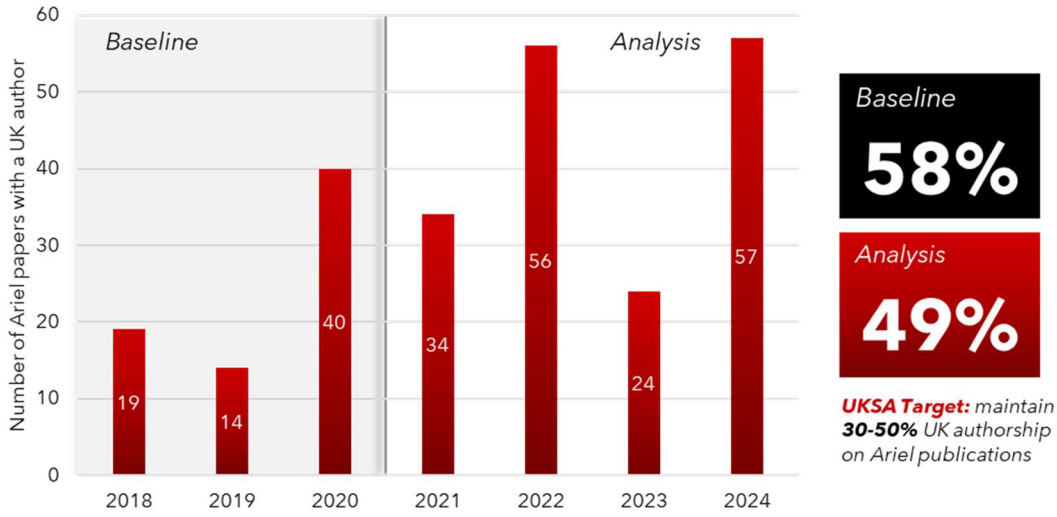


Figure 5 *Number and percentage of Ariel-related papers with a UK author published per year*



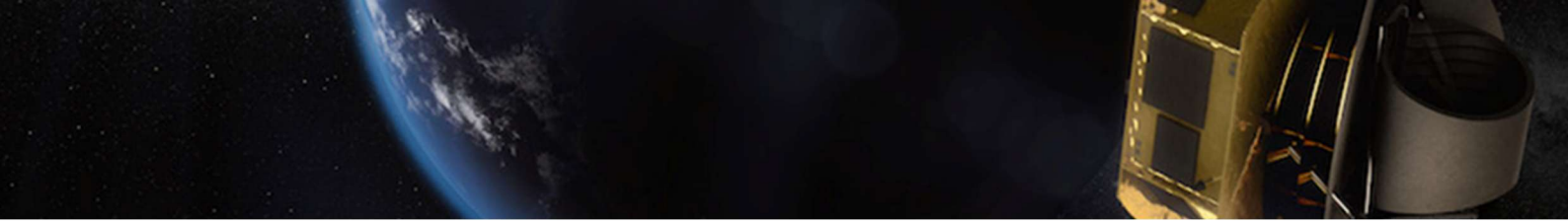
Within the UK, **at least 31** universities, research performing organisations, and companies have been involved in producing scientific publications relevant to the mission in the analysis period, compared to 27 in the baseline. As expected, UK members of the project team are the key contributors, however there is also evidence of wider UK activity relevant to the mission.

Since 2018, **UCL has been the biggest UK contributor to Ariel-related publications**, with researchers co-authoring two thirds (67%) of UK Ariel publications in the baseline, followed by 70% of publications in the analysis period. This reflects the key lead scientific actors at UCL working on Ariel, as well as their role leading relevant initiatives such as the Ariel Data Challenge and ExoClock.

While UCL are likely to continue playing a key role in the future, the Ariel PI, Prof. Tinetti has accepted the role of Vice Dean at King's College London, as a promotion from her current position at UCL, and will assume the role in June 2025. This will help **raise the profile of King's College London within the realm of space science**, firstly by increasing the knowledge base within astrophysics and exoplanet science, and secondly by positioning another UK university to play a key role in the Ariel mission. Prof. Tinetti told us how she expects to have a positive impact on Ariel science, by enabling her to dedicate a greater proportion of her time to the mission (relative to other responsibilities, such as teaching). We heard that the position should also support the retention of current UK-based Ariel researchers, as Prof. Tinetti will have more flexibility to offer permanent positions. The new role also offers dedicated time to pursue cross-disciplinary knowledge spillovers, such as from the Ariel mission into AI, Machine Learning and biomedical communities.

RAL Space are the next highest contributors within the analysis period, featured in 18% of UK Ariel-related publications, followed by the University of Oxford and Cardiff University (8% each). These trends also reflect the key roles of these organisations on the Ariel mission in instrument and hardware development, as well as integration of the payload. However, at this stage of the mission, project team members have mentioned how **tight delivery schedules have restricted their ability to publish Ariel-related papers**. While these trends are promising, it is also worth considering that publications are less of a priority for these organisations within the build phase of the mission.

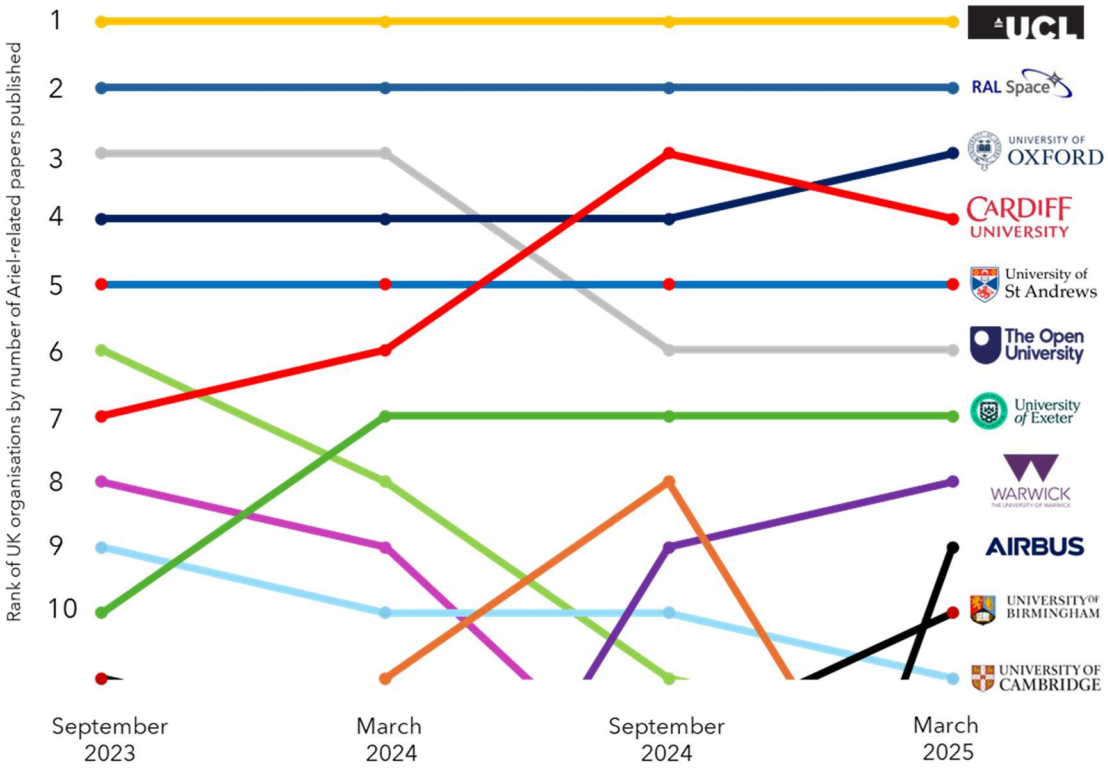
Taking the trend of rising research output (as measured by the number of publications) for UK-authored Ariel research, and the strong contributions from the UK project team, we assess that



UK Space Agency's contributions to the Ariel mission have increased the quantity of relevant research produced in the UK. This suggests positive progress against the scientific objective for the mission so far, although we are still at relatively early stages when considering the potential for future science exploitation of Ariel mission data.

Beyond the immediate project team, there is also strong representation from other UK universities, most notably the University of St Andrews (6% of publications in the analysis period), the Open University (5%), and the University of Exeter (5%). While total publication numbers are modest at this stage, this provides **an initial indication of where spillover scientific impacts could potentially accrue** in the wider UK research community, as researchers from these institutions are following developments on the Ariel mission.

Figure 6 *Top 10 UK organisations producing Ariel publications in the Analysis period*



When looking at the geographical distribution of UK organisations who have produced Arel-related publications since 2018, we see a relatively broad spread of organisations across the UK. **The South East and London have joint highest representation**, with 8 organisations each. Following this, Scotland, the West Midlands, and the South West of England all have 3 organisations who have produced at least one Ariel-related publication. The East of England is represented by 2 organisations, and Wales, the East Midlands, the North West of England, and Yorkshire and the Humber are represented by one. A full overview of UK organisations producing Ariel research is provided below.

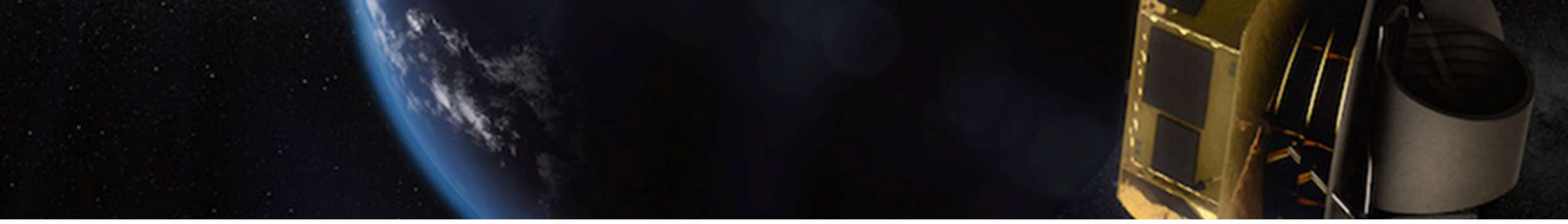
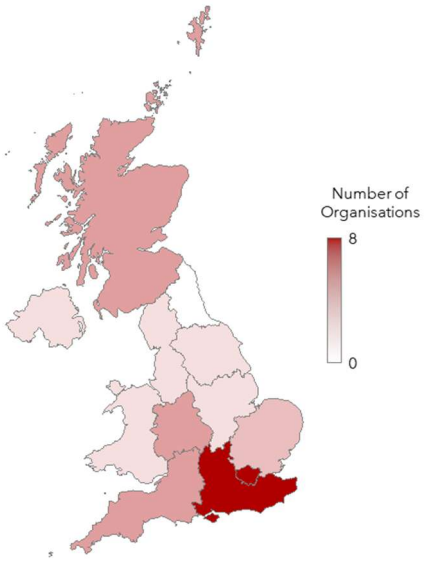


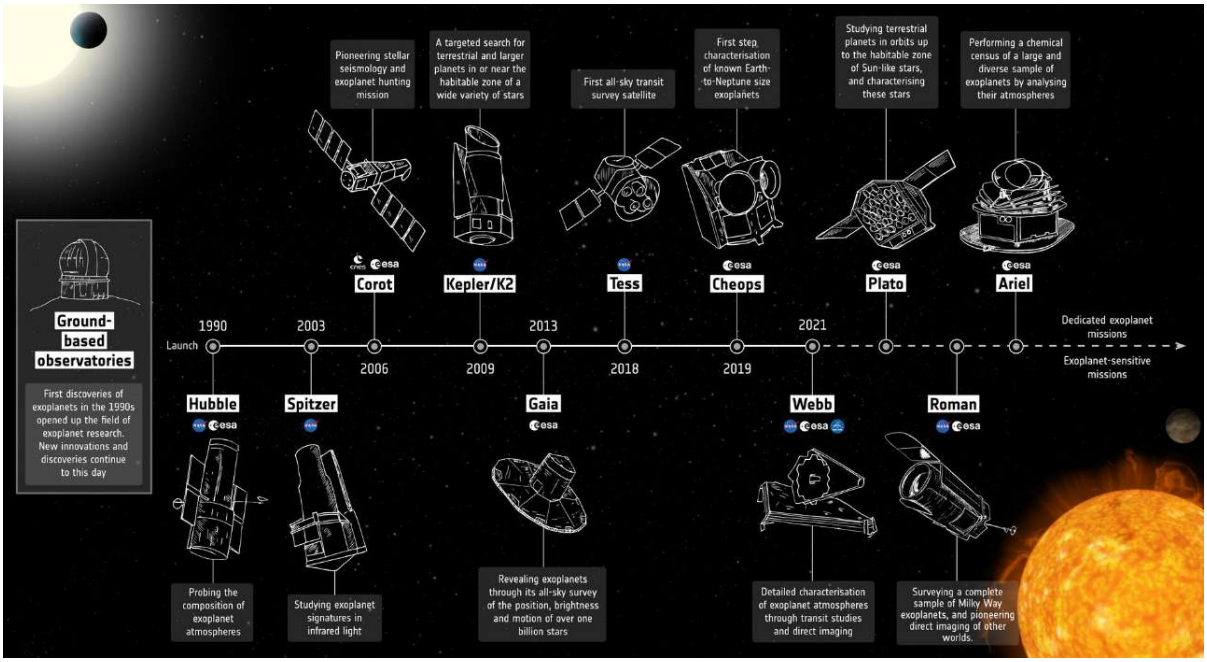
Figure 7 *Regions with organisations which have produced an Ariel-related publications since 2018*



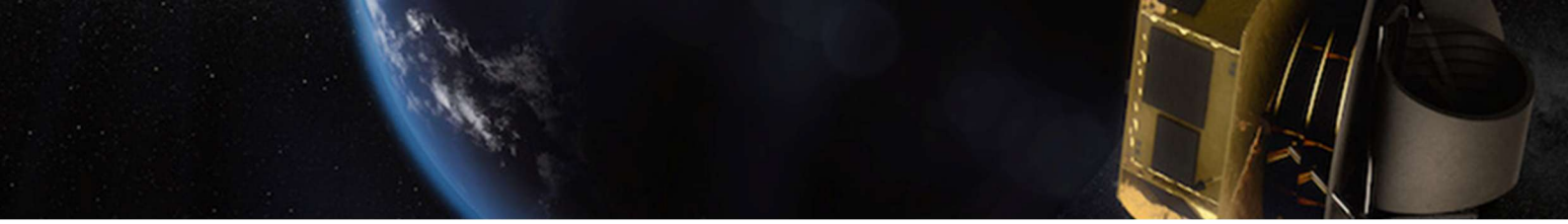
Publication trends in exoplanet science

Over the long term, **the Ariel mission aims to revolutionise the field of exoplanet science** through systematic study of the atmospheres of around 1000 planets. Ariel data will be used to build upon other sources, such as the James Webb Space Telescope (JWST), TESS, CHEOPS, and PLATO with unprecedented detail, and could inform the upcoming NASA Habitable Worlds Observatory mission, which will search for potentially habitable exoplanets.

Figure 8 *A timeline of relevant exoplanet science data sources*



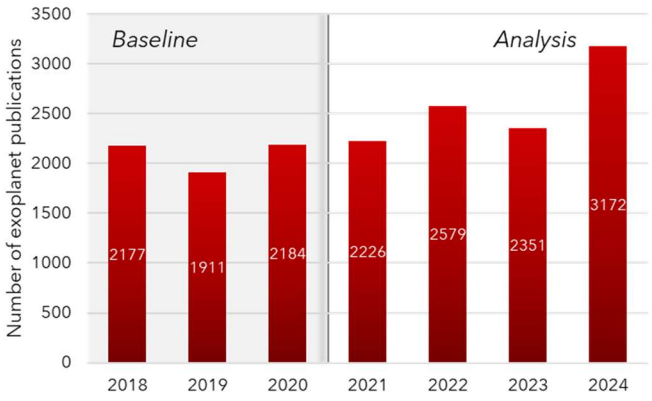
Source: ESA



Of course, **not all current developments in the field of exoplanet science are directly linked to UK Space Agency national funding for Ariel**. However, it is useful to track activity over time to gauge the influence of the Ariel mission once it is operational. It is expected that the Ariel mission will generate enhanced research activity and new discoveries in the coming years, by enabling researchers to move from detection of exoplanets to detailed atmospheric analysis.

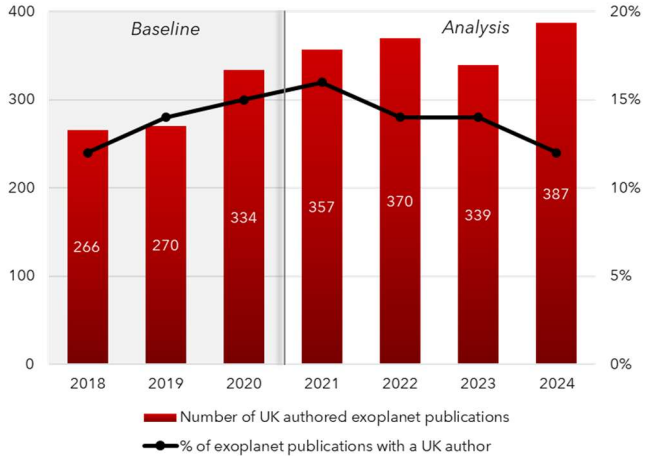
As illustrated in *Figure 9*, there has generally been **a steady increase in the number of exoplanet publications released per year since 2018**. There has been a trend of increased research activity in the field, reaching almost 3,200 publications in 2024. While Ariel may have had some impact in the number of researchers studying exoplanets, publications often leverage datasets from JWST, Gaia, and other missions. For context (and perhaps unsurprisingly given that this is a mission still in its build phase), **Ariel-related publications only account for ~4% of all exoplanet publications released in 2024**, although we would expect to see this change significantly following Ariel mission data releases in future years.

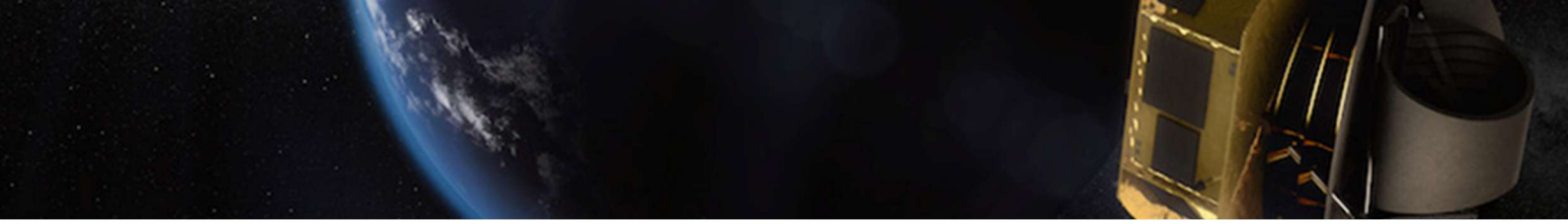
Figure 9 *Number of exoplanet publications released per year since 2018*



Within the growing field of exoplanet science, **UK authors have also been publishing more research year-on-year**, releasing an average of 290 publications a year over the baseline period, compared with 363 over the analysis period. Their relative share of publications has remained relatively similar as global levels of output have risen, with UK authors featured in 12-16% of all exoplanet-related publications. Trends in UK authorship of exoplanet publications are also influenced by trends in data availability from other missions, as well as other funding sources to participate in missions or access observatories and ground-based telescope networks.

Figure 10 *UK authored exoplanet publications per year and percentage of global share*





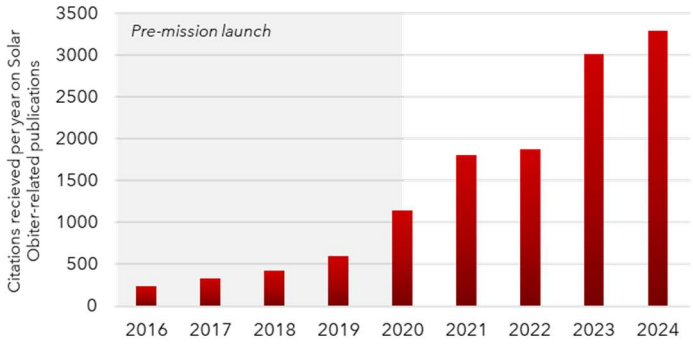
3.1.2 Citations and evidence of research impact

To capture early evidence of the influence and scientific impact of Ariel publications, we have measured citation performance over time. Citations have limitations in their value for measuring research quality, though they provide an indication of the reach and influence of publications. If viewed in the appropriate context, they offer a proxy measure for research impact which can then be complemented by other sources.

Interpretation of year-on-year citation trends can be misleading, as there is a **significant time lag** associated with them. It takes time for other researchers to read the initial publication, carry out their own research, write the citing publication, progress through peer review, get accepted by a journal, and then be published. While this skews the dataset towards older publications (such as those in the baseline period), we also provide alternative metrics (such as the Field Citation Ratio) which benchmark publications against those published at a similar point in time.

While caution must be taken in drawing comparisons between missions given differences in size, budget, and objective, citation trends in the ESA Solar Orbiter[11] mission provide useful context for the trajectory of citations in the run-up to mission launch. The mission launched in 2020, with routine science operations beginning in 2021. As *Figure 11* illustrates, there is a considerable uptick in citation activity when the mission is operational – rising from 600 citations in 2019 to over 3,000 by 2023. While numbers are likely to vary, this trend highlights the growing scientific impact of the mission as more data and results become available to the research community.

Figure 11 *Citations per year on Solar Orbiter-related publications*



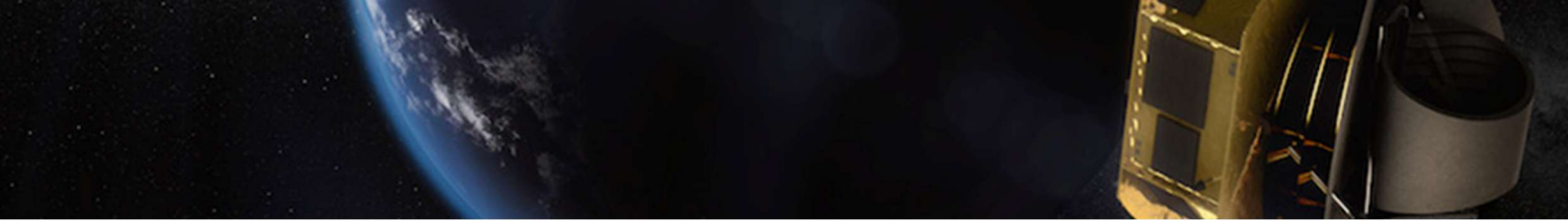
Source: know.space analysis of Dimensions.ai data

UK authored Ariel publication citation performance

In total, we have identified **over 5,400 citations on Ariel-related publications with UK involvement since 2018**. Almost 70% of these have occurred on publications released within the baseline period, although this is to be expected considering they have had longer to materialise. While lower in overall terms, citations on publications in the analysis period have been accumulating at an increasing rate over the timeframe of our study – rising over 900% from the 533 citations recorded in September 2023 to present (March 2025).

While the sample size of Ariel-related publications produced by UK authors continues to grow, **we are still dealing with relatively small numbers at this stage of the mission**. Moreover, with a high proportion of publications produced recently (as illustrated in *Figure 5*), we would expect

[11] *The ESA Solar Orbiter mission is taking the closest ever images of the Sun, including the polar regions, measuring the composition of the solar wind, and investigating areas of origin.*



to see further increases in citations for publications which have been released to date, once time lag effects become less pronounced. Given these limitations, it is too early to comprehensively assess citation performance of publications produced within the analysis period.

To control for the biases inherent in measuring citations year-on-year, and to account for different citation trends across fields of research, we provide Field Citation Ratio (FCR) metrics, where:

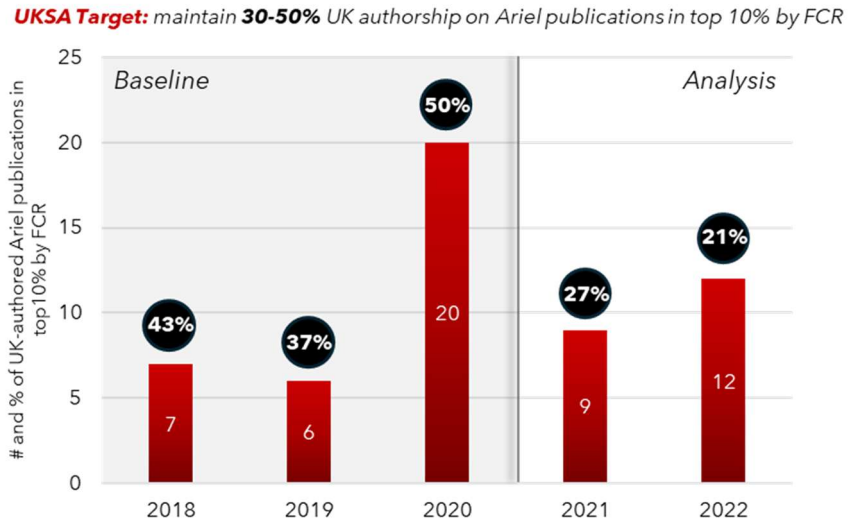
$$\text{Field Citation Ratio} = \frac{\text{\# of citations}}{\text{Average \# of citations in the same field of research and year}}$$

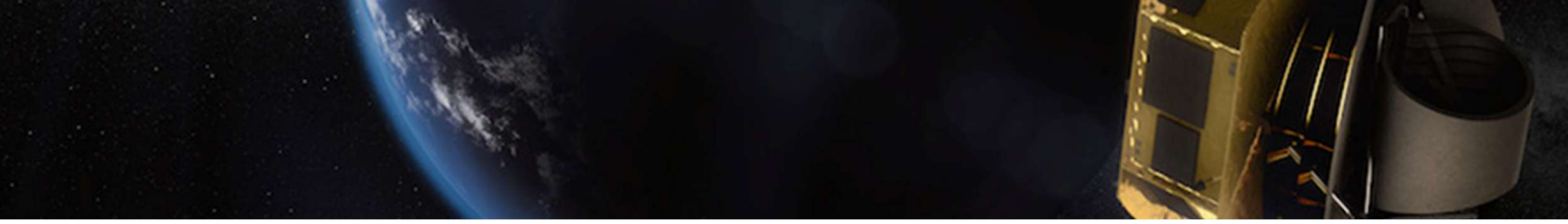
Digital Science calculate the FCR for publications which are over two years old, and hence have had sufficient time to be cited. This helps to mitigate skews in the data set which could arise due to large proportions of new publications remaining uncited.

As shown below in *Figure 13*, UK-authored **Ariel publications performed particularly well relative to similar publications in 2020**, coinciding with the formal adoption of the Ariel mission by ESA. A higher proportion of these publications received 50+ citations relative to the years prior to - and following - 2020. In the most recent years we have data available, the percentage of publications which feature in the top cited 10% by FCR **has fallen outside of UK Space Agency's target window**. This is likely due to higher citation performance of other exoplanet-related publications, such as those leveraging JWST data, accumulating higher citation counts. This is to be expected at this stage of the mission, where Ariel publications are not yet leveraging data from the mission directly. We do not view it as a significant cause for concern, but an aspect that should continue to be monitored over time.

Several publications **fall just below the citation threshold in 2021 and 2022**, and the total number of publications per year is small, so a few extra citations to a small number of publications could have a considerable impact on any FCR based metrics in the future. A publication that is currently "underperforming" in terms of citations is in no way a predictor of future low citation counts and impact. As explained by our partners at Digital Science, **FCR metrics are expected to display noisier trends in the first 5 years post-publication**, and hence these trends should be monitored in future to assess how these trends change over time.

Figure 12 *Number & percentage of Ariel-related publications with UK authors in top 10% by FCR*





Within these total figures, there are several examples of high-performing publications across both periods. Below are the **top 5 cited Ariel-related publications with UK authorship** across the baseline and analysis periods (in terms of FCR, as well as total citation count). A FCR of 1 indicates that a publication has received the same number of citations as the average paper in its field of research, while an FCR of 2 demonstrates the paper has received double the average.

It is notable that **all 10 publications feature involvement (and in many cases 1st Authorship) from UCL researchers** based in the Centre for Space Exochemistry Data (CSED). These publications also feature contributions from the Universities of Oxford, Cambridge, Warwick, Cardiff, Leicester, Cardiff, Exeter, Imperial, Queen Mary, Edinburgh, Bristol, Leeds and Royal Holloway (among others).

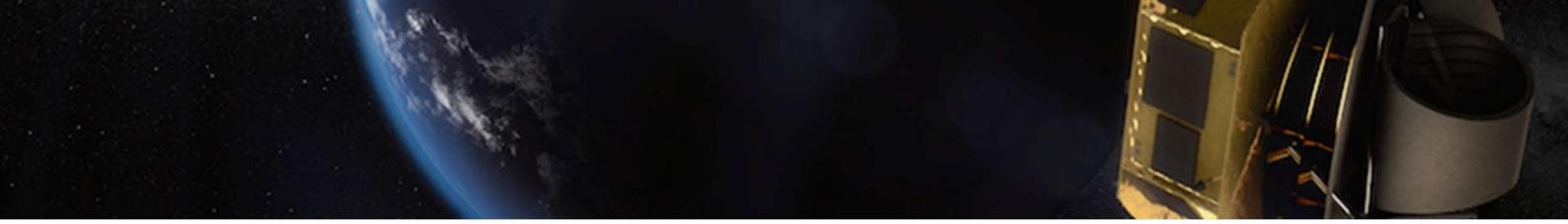
Baseline

	Author/Date	Publication Title	Citations	FCR
1	E. Kempton, *et al.* 2018	A Framework for Prioritising the TESS Planetary Candidates Most Amenable to Atmospheric Characterization	**429**	**109**
2	G. Tinetti, *et al.* 2018	A Chemical Survey of Exoplanets with Ariel	**344**	**87**
3	A. Tsiaras, *et al.* 2018 (inc. G. Tinetti)	A Population Study of Gaseous Exoplanets	**266**	**73**
4	A. Tsiaras, *et al.* 2018 (inc. G. Tinetti)	Water vapor in the atmosphere of the habitable-zone-eight-Earth-mass planet K2-18 b	**306**	**72**
5	J. Tennyson, *et al.* 2020	The 2020 Release of the ExoMol Database: Molecular Line Lists for Exoplanet and Other Hot Atmospheres	**178**	**54**

Analysis

	Author/Date	Publication Title	Citations	FCR
1	D. Feinstein *et al.* 2023	Early Release Science of the exoplanet WASP-39b with JWST NIRISS	**159**	**102**
2	A. F. Al-Refaie., *et al.* 2021	TauREx 3: A Fast, Dynamic, and Extendable Framework for Retrievals	**134**	**52**
3	D. Turrini *et al.* 2021 (inc. G. Tinetti)	Tracing the Formation History of Giant Planets in Protoplanetary Disks with Carbon, Nitrogen, and Sulphur	**142**	**46**
4	Mugnai L. V., *et al.* 2021	ARES. *V No Evidence for Molecular Absorption in the HST WFC3 Spectrum of GJ 1132 b	**70**	**24**
5	A. Kokori. *et al.* 2022	ExoClock Project II: A Large-scale Integrated Study with 180 Updated Exoplanet Ephemerides	**53**	**24**

Within the baseline period, the top 5 UK-authored Ariel publications received **a total of over 1,500 citations, representing 41% of all citations total in that period**. The highest cited paper in the period features members of the project team, and identifies transmission and emission



spectroscopy metrics which can be used to identify high priority targets for exoplanet atmosphere studies, including Ariel and ground-based observations. This paper has received widespread attention within the research community, being cited **109 times the average for a paper in astronomical sciences**. The other publications include target identification studies for the Ariel mission, atmospheric analysis of exoplanets leveraging Hubble Space Telescope data, and the release of an Ariel database – ExoMol – which can be used for spectral characterisation and simulation, helping to atmospheric models of exoplanets, brown dwarfs and cool stars.

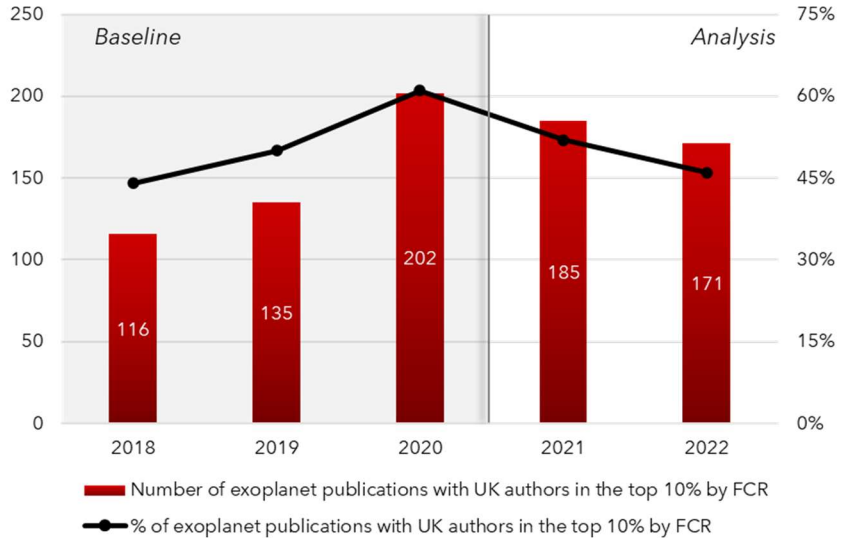
In the analysis period, the top 5 UK-authored publications to date have amassed **558 citations, comprising 34% of the total**. Citations for the top publications are understandably lower in the analysis period relative to the baseline, though the top 5 also occupy a lower share of the overall total. This suggests that the analysis period features a **broader spread of cited publications relative to the baseline**. As citations often exhibit a 'snowballing' effect – i.e. where highly cited papers receive higher visibility (and hence further citations), there is potential for a wide range of publications to accumulate a high level of citations in the future.

The top cited paper in the analysis period, by Feinstein *et al.* analysed the first exoplanet atmosphere (WASP-39b) using JWST. While not specifically related to the Ariel mission, the publication applies common techniques (e.g. transit spectroscopy), features UK members of the Ariel project team, and leverages ucl-exoplanets github models (which are discussed in more detail in section 3.4.7). The publication was also cited **over 100 times the average**, as measured by FCR. Other highly cited publications from the analysis period include software tools developed for the Ariel mission, which help researchers conduct atmospheric analysis of exoplanets, as well as a peer reviewed publication featuring contributions from an Ariel citizen science outreach programme, ExoClock (further detail provided in section 3.3.4).

Wider citation trends

In the wider field of exoplanet science, UK researchers have demonstrated disproportionately high citation impact relative to the number being produced between 2018 and 2022. As illustrated in *Figure 10*, UK authors are featured in **12-16%** of all exoplanet publications, yet (as shown below) they are consistently featured in **45-60%** of the top cited papers. This demonstrates significant citation impact for UK researchers working on science relevant to the Ariel mission, although these trends are also influenced by trends in JWST, Gaia, Cheops, Tess, and other exoplanet missions, as well as ground-based observation data. For context, Ariel-related publications comprised approximately 15% of all exoplanet research published by UK authors in 2022.

Figure 13 *Number and percentage of exoplanet publications with UK authorship in the top 10% by Field Citation Ratio (FCR)*



Over the timeframe we have studied (2018 to 2022), publications from exoplanet science have consistently occupied **between 17-22% of the top cited publications** of the top 10% by FCR. This demonstrates strong global interest and visibility of exoplanet science within wider fields, such as space science, astronomical science, or physical chemistry, for example.

Additional evidence of scientific impact

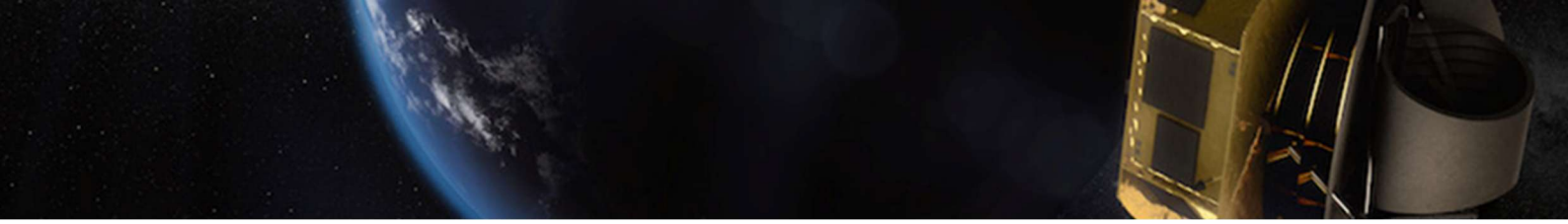
To complement analysis of publication numbers and citations, Altmetrics are a tool that can help identify activity around publications beyond direct citations, as articles are often shared, mentioned, and discussed in many different forums and contexts. Altmetrics can be used as a way to measure the level of online activity surrounding a particular piece of research output, but it is not a measure of the quality of the research or researcher.

The Altmetric Attention Score is part of the Digital Science portfolio, and is calculated through the weighted count of all attention a research output has received, based on three main factors:

- **Volume:** score rises as more people mention the article. The weight only counts one mention from each person per source.
- **Source:** each 'category' of mention contributes a different weight to the final score, e.g. a newspaper article is weighted more strongly than a blog post, which is stronger than a tweet.
- **Authors:** considers how often the author of each 'mention' discusses scholarly articles, whether there's a bias towards a particular journal / publisher, and the audience they leverage.

We have assessed the altmetric attention of the top 10 cited publications across both the baseline and analysis periods of this study. We find evidence of publications which have received **considerable online attention**, demonstrating wider engagement with exoplanet science produced by UK-based researchers.

The highest impact publications we have identified are scientifically relevant to the Ariel mission and were produced by UK Ariel consortium members. However, generally (although not exclusively) these publications make use of existing datasets from other missions, such as JWST,



Hubble and Spitzer. **While these impacts cannot solely be linked to the Ariel mission (as they rely on inputs from other missions), the science directly dovetails into Ariel**, informing spectroscopic and photometric analysis of exoplanet atmospheres, as well as current target identification activities.

In the baseline period, there has been modest attention across the top 10 cited publications, although one publication in particular received considerable international attention. A 2019 publication authored by Dr Angelos Tsiaras, Prof. Ingo Waldmann, Prof. Giovanna Tinetti, Prof. Jonathan Tennyson and Prof. Sergey Yurchenko of UCL, titled '*Water vapour in the atmosphere of the habitable-zone eight-Earth-mass planet K2-18 b*' received an attention score of 3479 – **placing it in the top 0.006% of publications ever recorded, and as the highest altmetric score of any physics publication that year**. To provide additional context behind these numbers, the publication was referenced in at **least 353 news articles**, including *CNN, Forbes, BBC, Al Jazeera, Business Insider, National Geographic, New York Times, FOX News*, and many others, as well as being referenced in 21 Wikipedia pages. As explained in interviews with the authors, the popular interest in this publication is likely due to its implications for the possibility of extraterrestrial life. For context, the other 9 top cited publications in the baseline received a combined altmetric attention score of 194, being referenced in 9 news articles and 2 Wikipedia pages.

In the analysis period there is a broader base of publications with high altmetric impact, although none have reached the levels of attention seen with the 2019 publication mentioned above. **The top 3 articles have received attention scores of 616, 292 and 205 respectively**, being referenced in a total of 152 news articles (including *Wired, COSMOS magazine, Earthsky, The Conversation*, and *the Chinese Academy of Sciences News*). The top publication is the previously mentioned 2023 Feinstein *et al.* paper, followed by a UCL-led 2022 publication which analyses 25 Hot-Jupiter Atmospheres[12], and also includes contributions from Queen Mary University of London, University of Exeter, and researchers from France, Italy, USA, Japan, and Switzerland. The latter publication is one of the largest ever surveys of exoplanet atmospheres undertaken[13], and was ranked in the top 0.5% of publications released in *The Astrophysical Journal* at a similar time. The third publication, authored by Dr Quentin Changeat and Billy Edwards at UCL, analyses the emission spectrum of a Hot Jupiter, focusing on exoplanet KELT-39b by leveraging Hubble data.

The top 5 UK authored Ariel publications had a combined attention score of 1,151 in the analysis period, which has **roughly doubled since we first recorded this information in September 2023**. While the equivalent score in the baseline remains higher (3,607), this is largely driven by one publication, and scores have remained relatively similar across our study, rising by a total of 46 since September 2023. Broadly, **these figures illustrate how exoplanet research is of interest to the wider public, although they cannot be used to infer the quality of Ariel-related research**, or UK Space Agency's potential role in enhancing it.

Additional funding secured by UK universities as a result of Ariel

Another potential benefit of UK academic leadership over the Ariel mission is the potential to leverage additional grant funding, studentships and sponsorships for participating universities. In the long-term, Ariel is expected to catalyse additional funding opportunities for science exploitation research – i.e. grants leveraged to analyse datasets from future Ariel data releases.

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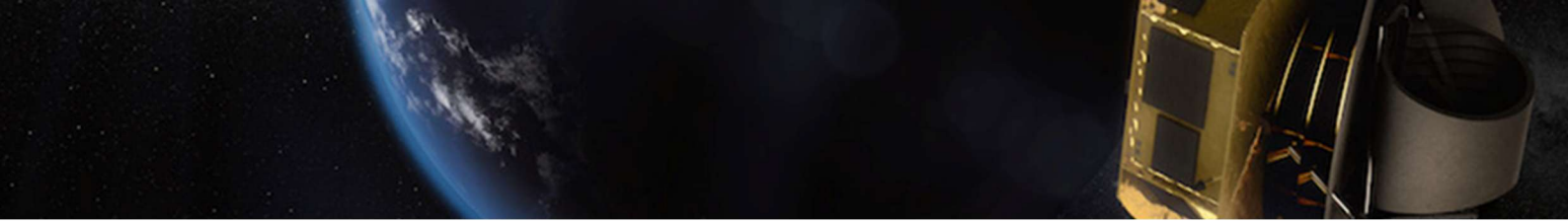
[12] Changeat, Q., Edwards, B., Al-Refaie, A.F., Tsiaras, A., Skinner, J.W., Cho, J.Y., Yip, K.H., Anisman, L., Ikoma, M., Bieger, M.F. and Venot, O., 2022. *Five key exoplanet questions answered via the analysis of 25 hot-Jupiter atmospheres in eclipse*. The Astrophysical Journal Supplement Series, 260(1), p.3.

[13] UCL News, 2022. *Mysteries of gas giants known as 'hot Jupiters' unravelled.* Available at: https://www.ucl.ac.uk/news/2022/apr/mysteries-gas-giants-known-hot-jupiters-unravelled



To support interim activities for Ariel, beyond UK Space Agency funding, universities have secured:

~£113,000 additional funding secured for UK universities

As well as significant **in-kind contributions**

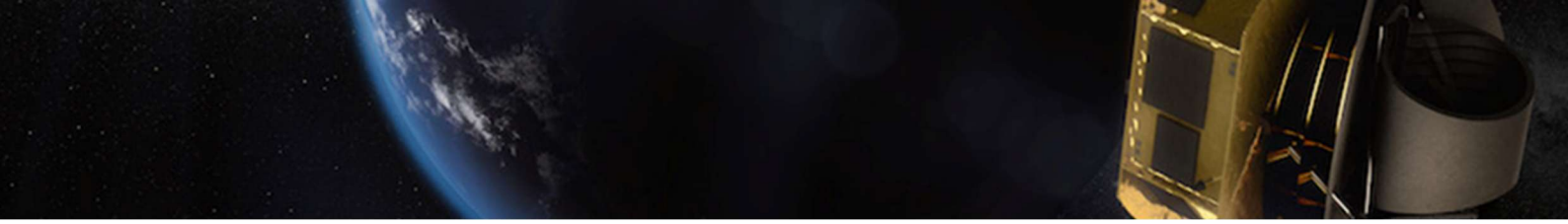
The majority of this funding support comes from sponsorship of the previous and upcoming Ariel Data Challenges, which have twice received $50,000 (~£38,000) in sponsorship money from Google's data science and machine learning platform, Kaggle. Other financial contributions have also previously come from CNES (£1,500). In addition to this, the Data Challenge team also receive significant in-kind support to help run the challenge across each iteration. This includes staff time and software engineering support from Kaggle, ESA, The Institute of Astrophysics in Paris, Cardiff University, and University of Rome Sapenzia, as well as computing support offered by DiRAC. The Ariel Data Challenge is discussed in more detail in section 3.3.3.

In addition to the funding which has been secured to date, researchers at UK universities are pursuing other opportunities, such as individual research fellowships and grant funding opportunities. Researchers at UCL and Cardiff have been narrowly unsuccessful in securing Future Leaders Fellowships, European Commission Synergy grants, and Royal Astronomical Society grants, despite being shortlisted. They will seek to re-apply for these grants in future rounds, and **this is something which will be important to track in the future**. For context, these figures do not include wider follow-on funding and contract revenue to other non-academic UK project team members and activities in start-ups which have links to the Ariel mission. These are discussed in more detail in section 3.4.4.

3.1.3 Counterfactual

In a scenario without the UK Space Agency's £30.3m national contribution, stakeholders felt there was **a high likelihood that Ariel may not have been selected as the fourth medium-class mission in ESA's Cosmic Vision programme**. In this scenario, one of the other two candidates, the Turbulence Heating ObserveR (THOR) or the X-ray Imaging Polarimetry Explorer (XIPE) could have taken Ariel's place. These missions have different scientific objectives to Ariel, and are not related to exoplanet science. In the absence of Ariel, there were likely to be some UK roles in these two missions (and beyond), but stakeholders typically viewed that they would not have maintained the same degree of UK scientific leadership. XIPE was expected to be led by an Italian consortium and instrument principal investigators. THOR had not assigned principal investigator roles, though the mission proposal phase featured significant involvement from the Swedish Institute of Space Physics.

Without the UK Space Agency's investment, Ariel may still have been selected over THOR or XIPE, although this would have required a withdrawal of key UK mission roles, as discussed in the Business Case for the national contribution. This would have **prevented the UK from shaping the mission around its scientific objectives**, and the overall scientific capability of the mission could potentially have been reduced, given the reduced involvement of UK scientists. Considering the central role of the UK Ariel project team in producing scientific publications to date, we view that it is highly likely that **mission-relevant research output in the UK would be significantly reduced in absence of UK Space Agency investment**. The latest data shows that Ariel-related publications make up about 4% of all exoplanet-related publications globally. However, the mission is more significant for UK researchers, as approximately 15% of UK-authored exoplanet publications are linked to Ariel.



Of course, in absence of UK Space Agency support, researchers would be working on other projects. It is likely that exoplanet research in the UK would follow trends in the wider field, shifting from identification of exoplanets towards characterisation. However, without a concrete mission focus, researchers would have to leverage previous mission and ground-based observation data sources. As they would also not be as closely involved in preparatory science (such as database and software development), they would not be as well positioned to leverage upcoming Ariel data releases. This may also disadvantage UK researchers in exploitation of Nancy Grace Roman Space Telescope, PLATO, or Habitable Worlds Observatory data, and lead to researchers relocating from the UK to other countries.

3.1.4 Conclusions

At this interim stage, we assess how **outcomes and impacts to date have supported progress against the UK Space Agency's strategic objectives for the Ariel mission**. While there is a long way to go, we assess Ariel as being broadly on track to achieve (and potentially surpass) scientific objectives at this stage, although future development and scientific exploitation will be required to realise these objectives fully. Below, we assess performance against the relevant evaluation questions posed at the beginning of our study, including:

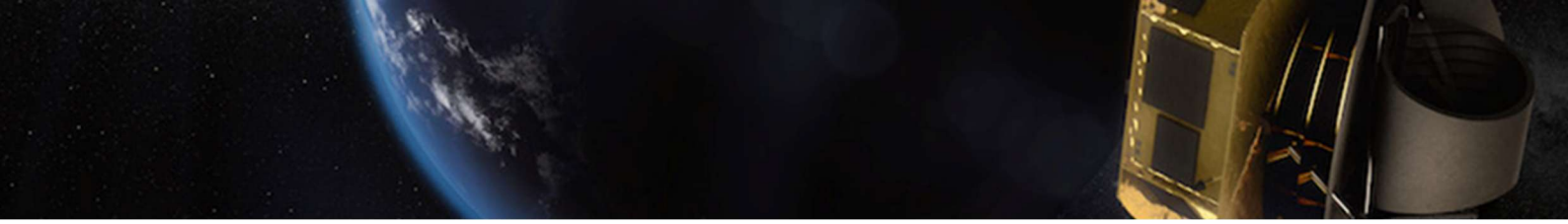
To what extent has UK Space Agency investment in Ariel enabled the UK to shape mission science and data around UK research strengths and interests?

To date, UK Space Agency national investment into Ariel has secured UK scientific leadership over the mission, helping PI Prof. Tinetti to shape preparatory science activities through restructuring of science interest groups, as well as other responsibilities within her PI role, and through key conversations with ESA. While the bulk of scientific impacts associated with these roles are likely to materialise over longer timescales, evidence of UK influence is already seen with contributions to target identification and selection research (e.g. exoplanet cataloguing), database and software development, leading roles in complimentary science activities, as well as AI and machine learning tools to exploit Ariel data in the future.

To what extent has UK Space Agency investment led to an increase in the quantity or quality of science outputs in the UK?

There is a growing body of Ariel related publications being produced every year, highlighting a **rising quantity of science outputs**. The Ariel consortium features organisations from 16 countries, and UK-based authors have contributed to half of all Ariel-related publications, demonstrating a leading role over publications to date, which is at the upper end of UK Space Agency's benefits realisation target window. The majority of these UK-authored publications come from the UK project team, most notably from UCL. For members of the UK project team producing hardware or overseeing the build phase of the mission (e.g. RAL Space, and the University of Oxford), publications are not necessarily the priority at this stage, as they are more concerned with assembly integration and testing activities, however we still see significant contributions to Ariel publications. As exoplanets are a growing area of astrophysics, we are seeing promising developments which could have wider impact across the space science community, however **the more robust answers will follow mission launch**.

While we are limited in our ability to make year-on-year comparisons with citation data, there is evidence of high impact UK-authored Ariel publications, including mission/instrument summaries, database development, and preparatory science which leverages data from other missions, across the baseline and analysis periods. The level of citations indicates wider interest (despite UK authored publications falling outside of UK Space Agency's target window as measured by FCR overall), and could be linked to the quality of the publications being produced. However, any assessment of UK Space Agency national investment in enhancing the quality of



science outputs relevant to the Ariel mission must also consider the wider context of funded activities. For instance, the quality of UK contributions to the Ariel mission are likely to be enhanced through technical upskilling of researchers, technicians, engineers working on the mission, as discussed in section 3.3.5. Moreover, UK researchers have placed significant emphasis on catalysing greater participation in the Ariel mission, which over the long-term is expected to **enhance the quality of mission-relevant science, through enabling greater collaboration, and closer scrutiny of results**. For this reason, outreach initiatives such as the Ariel Data Challenge and ExoClock are key UK-led routes to enhancing the quality of future research. These initiatives are discussed further in sections 3.3.3 and 3.3.4 respectively.

To what extent has UK Space Agency investment led to more international research grants and awards?

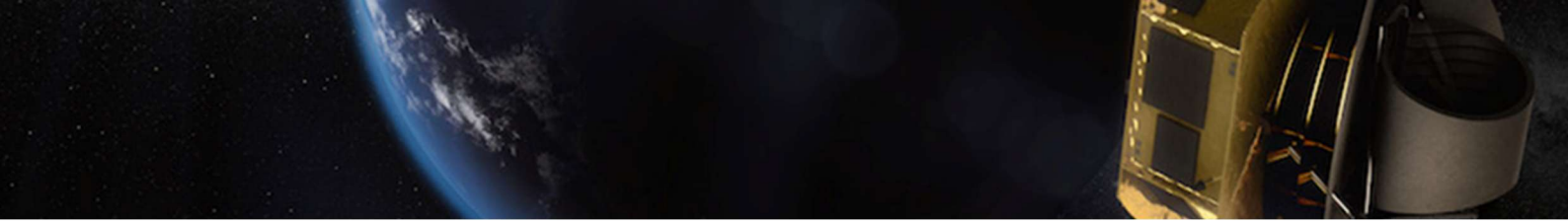
There is little evidence to date that Ariel has directly led to follow-on grant funding for UK universities, although **this is an early assessment of a longer-term picture**. The UK's investment into the Ariel mission has led to some initial progress in securing sponsorships, which have supported the continued growth of the Ariel-focused outreach initiatives led by UK researchers. Moreover, there is evidence of awards, prizes and wider recognition to the UK project team, as discussed in more detail in section 3.2.2. However, the bulk of international research grants are expected to be secured in the longer term, as they are **likely to focus on exploitation of mission data, once Ariel is launched and operational**. There are ongoing efforts to secure large international grants and funding opportunities for the science team, although these have had limited success to date. Scope to pursue these opportunities is likely to be enhanced in the coming years, as Prof. Tinetti's new role at King's College London will offer greater support to pursue cross-disciplinary research opportunities relevant to the Ariel mission.

3.2 UK Competitiveness & Reputation

Another core strategic objective of the Ariel mission is to **enhance the reach and reputation of the UK's space sector, by collaborating internationally and leading the delivery of cutting-edge space capabilities**. The UK's national investment into the Ariel mission seeks to lead to stronger international partnerships which can, through securing leading roles on the mission, showcase UK capabilities internationally. In turn, the objective is to enhance the UK's competitiveness, including for future exoplanet and space science missions.

Many of the impacts associated with UK roles on the mission are **highly contingent on successful ultimate delivery**, meaning it is too early to assess these comprehensively. For instance, reputational benefits to UK organisations associated with leading the mission are inevitably intertwined with how the Ariel mission is perceived internationally, which in turn is influenced by whether the mission is successful in delivering on its objectives. We present initial impacts in these areas below, while recognising the long-term nature of the impacts, and the likelihood that they will evolve considerably over time.

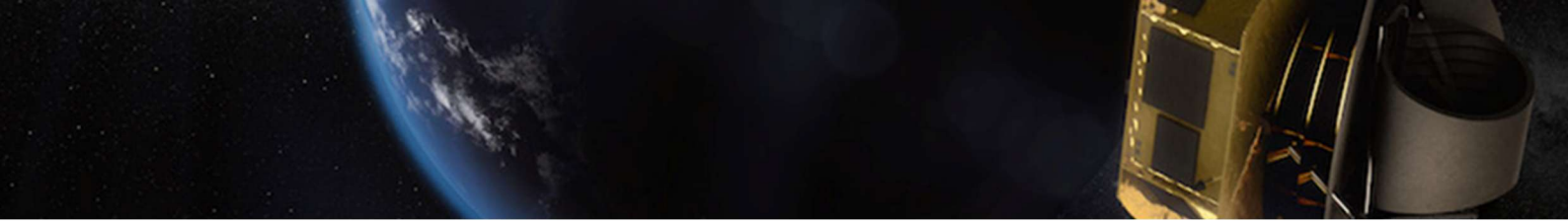
> • *This mission definitely helps to improve UK competitiveness – these types of missions are generated through networks. Being at the centre of this means we are working with academic and industrial teams from across Europe, which builds links, and will lead to future opportunities.*



- *The main benefit [of UK Space Agency national funding] is that it gives us control, and leads to greater UK influence. The UK is seen as leading the mission.*
- *At the end of the day, we can shape the mission. There are many ways to drive where the mission is going, and we can tie this in with the UK academic community and think about how best to use our soft power.*

Summary of key findings

- **There is strong evidence of high levels of international collaboration attributable to UK Space Agency's national investment, and early signs of reputation and influence impacts –** indicating good progress against the evaluation questions. These impacts could help to position the UK for future missions, although early reputation and leadership is dynamic, and contingent on successful delivery. As UK reputation could change in the coming years, there is a long way to go before we can assess broader reputational impacts.
- **UK-authored Ariel research is inherently internationally collaborative -** and collaboration has risen in absolute and relative terms in the analysis period. The number of publications which are internationally collaborative year-on-year remains consistently above 80%, providing early evidence of UK scientific competitiveness and delivery of mission science through the use of international partnerships.
- **UK researchers have collaborated with countries both within and beyond the Ariel consortium -** UK authors have collaborated with researchers from 37 different countries in the analysis period, which has risen from the 32 identified in the baseline, generally featuring 25 different countries per year. This highlights a growing base of collaborators and highlights the global competitiveness of Ariel-related research arising from the UK. Italy, France, and the United States are the three key collaborating countries across both periods, highlighting strong consortium contributions. However, there is also evidence of wider collaboration beyond the 16 countries within the Ariel consortium.
- **The UK is developing leadership and influence over Ariel, although the wider impacts of this are part of an emerging picture –** UK leadership roles on the mission funded by UK Space Agency have led to enhanced influence over technical and scientific decisions on the mission. This may, in turn, position the UK well for roles in future space science missions. Early discussions are ongoing for UK involvement on the NASA Habitable Worlds Observatory and PRIMA mission concepts, with UK project team members shortlisted for involvement on the latter. Promising developments should be tracked in coming years, as this is still very much an emerging impact story.
- **The UK project team have received wider recognition in the form of awards, although attribution to UK Space Agency's national investment varies per award –** these include at least 18 awards since Ariel was selected, including a knighthood and OBE, as well as prestigious fellowships. Some were given for lifetime contributions, while others are more directly linked to the mission.
- **There is early evidence of reputational benefits to the UK, although this is associated with increased expectations, and could change quickly depending on future delivery –** stakeholders expressed cautious optimism over reputational benefits to



the UK to date. While the UK is regarded positively within the Ariel consortium and by ESA, reputation is likely to be influenced by the fulfilment of future mission roles and responsibilities, and is therefore constantly evolving.

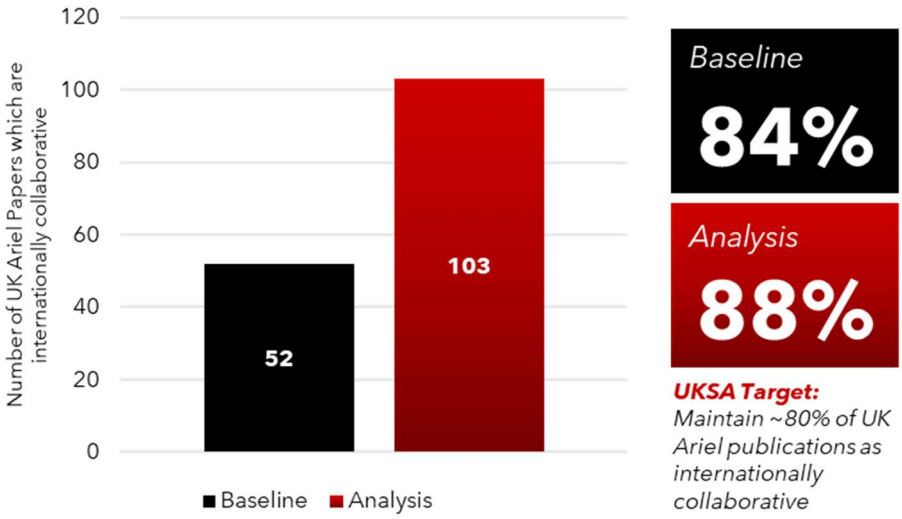
- **In a scenario without UK Space Agency investment, we conclude it is unlikely that we would see the same levels of international collaboration, influence, or reputation** – these outcomes and benefits are inherently linked to UK leadership roles, which would not have materialised without UK Space Agency's national funding. As such, we view the observed benefits are highly attributable to UK Space Agency support.

3.2.1 Collaboration

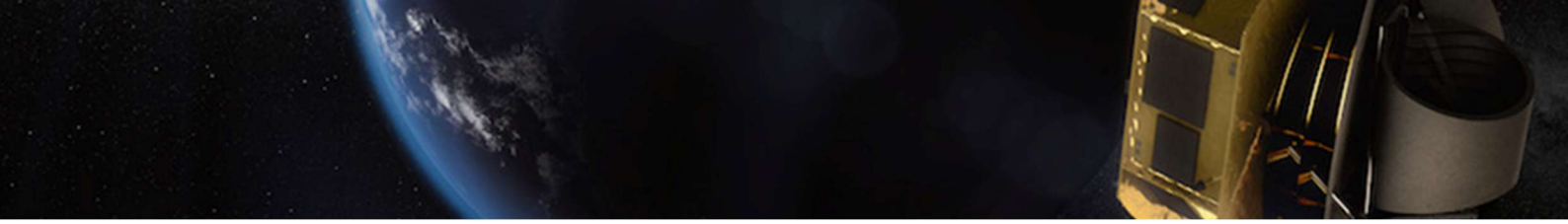
Ariel is **inherently internationally collaborative**, with a consortium that features contributions from over 600 scientists and engineers from 16 countries, including ESA member states as well as NASA and JAXA. As a science mission, one core measure of international collaboration is through co-authorship of scientific publications, which provides a quantitative measure of the key international networks of collaboration, and how they have evolved over time. International collaboration within a high-profile international science mission could lead to other strategic benefits over the longer term, such as enhanced profile and visibility of UK research performing organisations, closer ties with allied nations, and **soft power** benefits associated with becoming a sought-after partner in space activities.

For publications with author affiliation information, we see consistently high levels of international collaboration in UK-authored Ariel publications, which have risen in both absolute and relative terms in the analysis period. This also represents a 9% increase since September 2024, due to a combination of new publications, as well as new author affiliation information being recorded within the Dimensions database. This places the metric firmly above the target for UK Space Agency benefits realisation, and demonstrates **high levels of ongoing international collaboration**.

Figure 14 *Number and percentage of UK Ariel-related publications which are internationally collaborative*



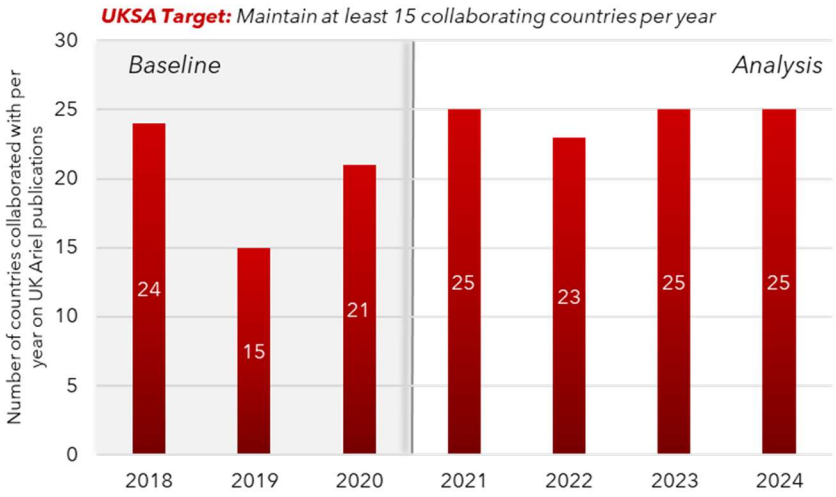
In total, UK authors have collaborated with researchers from **37 different countries** across the analysis period, up slightly from 32 countries in the baseline. Generally, there has been a stable



number of collaborating countries, at a maximum of 25 per year in the analysis period. The collaborators have varied slightly year-on-year, with relatively stable levels of international collaboration, surpassing UK Space Agency's target measure across the timeframe. This also highlights that UK researchers have consistently collaborated with researchers beyond the 16 nations in the Ariel consortium (which includes ESA member states, the US, Canada, and Japan).

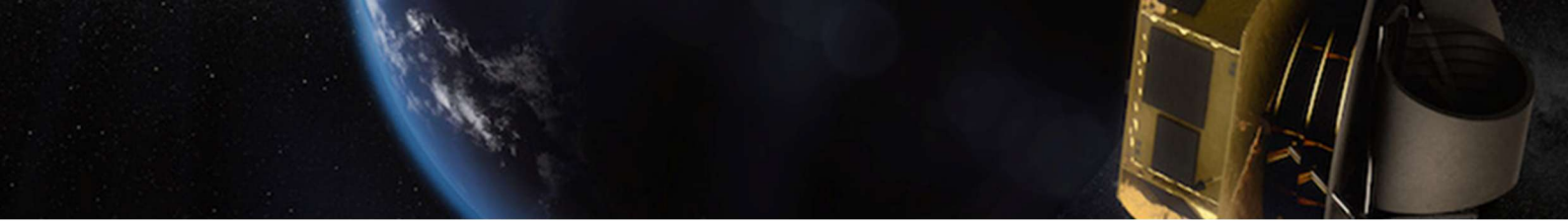
Throughout the study period, UK project team members noted that international collaborations have delivered clear profile-raising benefits, including invitations to speak at conferences and workshops in new geographic regions. Stakeholders also highlighted the longer-term potential for deeper institutional links, such as joint PhD programmes or research group partnerships with overseas universities. These connections not only strengthen the UK's academic network but may also support talent attraction by encouraging international researchers and students to engage with UK-based organisations and Ariel-focused research.

Figure 15 *Number of collaborating countries per year on UK Ariel publications*



Perhaps unsurprisingly, the top collaborating countries as measured by the number of co-authored publications features strong involvement from Ariel consortium members. **Italy is the most frequent collaborator for UK-authored Ariel-related publications**, mirroring trends first identified in the baseline period, followed by France and the United States. The top 10 collaborating countries have not shifted significantly over the course of our study (2023-25). Wider collaborations with Australia and Chile are also notable, considering they are not formally involved in the mission. These are likely due to the presence of ground-based telescopes (such as European Southern Observatory and SKA telescopes) in these countries. Ireland and China have dropped out the top 20 in the last 6 months, and have been replaced by Greece and Sweden.

	Baseline			Analysis		
	Country	#	%	Country	#	%
1	Italy	**29**	**38**	Italy	**65**	**38**
2	France	**24**	**32**	France	**44**	**26**
3	United States	**15**	**20**	United States	**38**	**22**
4	Netherlands	**15**	**20**	Netherlands	**32**	**19**
5	Belgium	**12**	**16**	Germany	**26**	**15**
6	Austria	**11**	**14**	Spain	**26**	**15**



7	Germany	**10**	**13**	Austria	**18**	**11**
8	Spain	**9**	**12**	Portugal	**17**	**10**
9	Switzerland	**7**	**9**	Switzerland	**15**	**9**
10	Australia	**6**	**8**	Belgium	**14**	**8**
11	Poland	**5**	**7**	Japan	**10**	**6**
12	Canada	**5**	**7**	Australia	**7**	**4**
13	Chile	**4**	**5**	Canada	**7**	**4**
14	Czechia	**4**	**5**	Czechia	**7**	**4**
15	Ireland	**3**	**4**	Poland	**6**	**4**
16	United Arab Emirates	**3**	**4**	Denmark	**5**	**3**
17	Japan	**3**	**4**	Chile	**5**	**3**
18	China	**2**	**3**	Estonia	**5**	**3**
19	Hungary	**2**	**3**	Greece	**5**	**3**
20	Greece	**2**	**3**	Sweden	**5**	**3**

Beyond direct collaboration, we also tracked the countries which have cited Ariel publications by UK authors the most. Authors from a total of **96 countries have cited UK Ariel publications in the analysis period**, up from 66 in the baseline. Across both periods, the United States has cited UK Ariel publications the most, indicating wider interest and engagement with the Ariel mission. This is followed by France, Italy, Germany, the Netherlands and Spain (in both periods, although absolute citation numbers are higher in the baseline period). This spread of citations can be interpreted as evidence on how UK research is valued and interacted with internationally.

Several visits from UK project team members to NASA and Washington could have influenced these trends, as well as NASA's recent call for scientists for participation in the Ariel mission. This call, to support Ariel preparatory science, aims to enhance US research activity through the Contribution to Ariel Spectroscopy of Exoplanets (CASE) project, which provides optical and near-infrared science capabilities and fine guidance sensors for Ariel, complementing activities in the wider consortium[14].

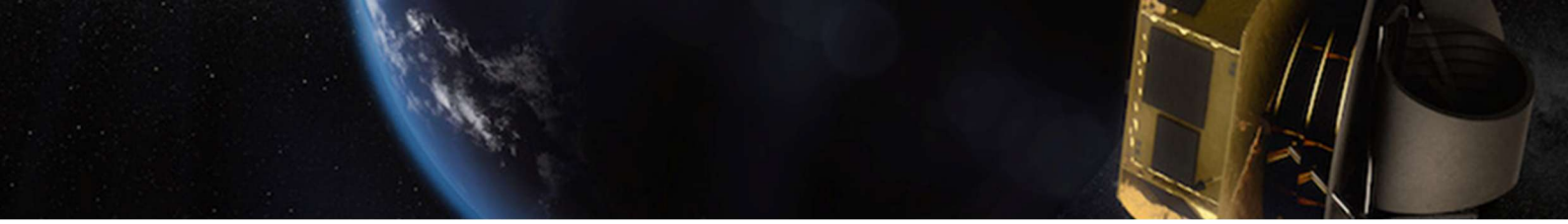
As discussed in section 3.3.5, RAL Space are responsible for coordination of subsystem delivery, integrating components across an international consortium comprised of 16 countries. Outreach initiatives such as such as ExoClock and the Ariel Data Challenge (discussed in more depth in section 3.3) are also highly international, with both drawing participants from over 70 countries.

3.2.2 Reputation and Influence

Reputational benefits are inevitably intertwined with sustained international collaboration and UK influence over the Ariel mission. Evidence of reputation and influence can arise at both individual and organisational levels, extending to broader aspects such as perceptions of the UK's space science strength, the reputation of UK Space Agency and the government, and the UK's capabilities compared to international counterparts.

There are several complexities to measuring concepts such as reputation or influence, as they are often subjective concepts, which are dynamic and constantly evolving. Moreover, perceptions of

[14] NASA. 2024. *New Opportunity: D.21 U.S. Contributions to Ariel Preparatory Science*. Available at: https://science.nasa.gov/researchers/solicitations/roses-2024/amendment-60-new-opportunity-d-21-u-s-contributions-to-ariel-preparatory-science/



organisations in the UK project team are likely to be impacted by previous delivery heritage, which makes attributing the specific impact of UK Space Agency national investments into the Ariel mission less straightforward.

> *I wouldn't say that the UK's reputation is solely tied to Ariel, there are other factors too, like contributions to the space science budget. ESA think the contributions from the UK are going well.*

UK leadership

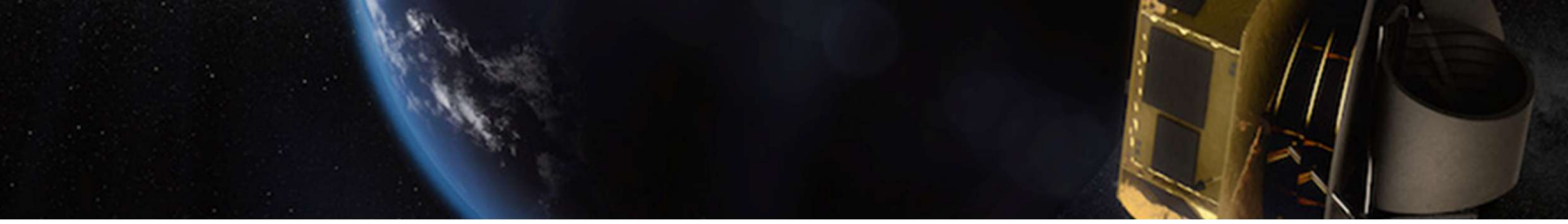
UK leadership roles on the Ariel mission ensure direct involvement in decision-making in relation to the scientific priorities, instrumentation, and payload assembly. The UK Space Agency's investment into Ariel intends to enhance UK reputation and influence over the mission, in turn strengthening the country's role within future space science missions and exoplanet science. While further outcomes and benefits are likely to materialise over the long-term, we have identified **initial shifts in UK reputation and influence which are directly attributable** to the UK Space Agency's investments.

> *A key benefit to the UK is that it closely links the science community to the things which are being delivered. It is better for us to be higher in the process, where we have direct influence on decisions with ESA and scientists.*

Across science management activities, there are several examples of UK influence being leveraged to shape the direction of the mission. Ongoing research into potential target candidates will **underpin the direction of the mission science** undertaken in the future, while data analysis approaches will be inherently linked to the **tools and datasets being developed by the UK project team**. By defining the scientific outcomes of the Ariel mission, these roles position UK researchers at the forefront for future science exploitation of Ariel mission data, and could in turn influence the UK's role and reputation within exoplanet science, a trend which could extend to roles in future missions.

There is early evidence of UK influence beyond the Ariel consortium as a result of the key mission roles held by UK researchers, which could in turn enhance the global reputation of the UK in exoplanet science. For instance, UK Ariel researchers visited the first exoplanet conference hosted in China, where there is significant investment and interest in Ariel-relevant science. Ongoing collaboration with Chinese universities has been possible at this interim stage due to initiatives such as ExoClock and the Data Challenge, as well as visits to Chinese universities from key team members. Similar evidence is also seen in the US and Japan, where UK Ariel researchers have been invited to give talks in these countries, highlighting UK expertise over the mission, and helping to drive continued contributions from NASA and JAXA. Ariel PI Prof. Tinetti has accepted a Visiting Professor position at the University of Tokyo, which could lead to closer partnerships between UK and Japan-based researchers undertaking mission-relevant science. While these routes to impact are early stage, potential pathways to enhanced UK soft power and the attraction of international talent are emerging, which will be important to track in future.

From a technical perspective, RAL Space have also increased their leadership capabilities through the Ariel mission, which could in turn influence their reputation within the consortium



with actors such as ESA and the Italian Space Agency (ASI), and the wider consortium. As overall integrators for the payload, they were responsible for overseeing the design of a highly ambitious interface of different subsystems, which other future missions aim to replicate:

> *As a satellite architecture, Ariel has influence on other missions. Ariel is forming the blueprint for other satellites in terms of the design and implementation of future missions.*

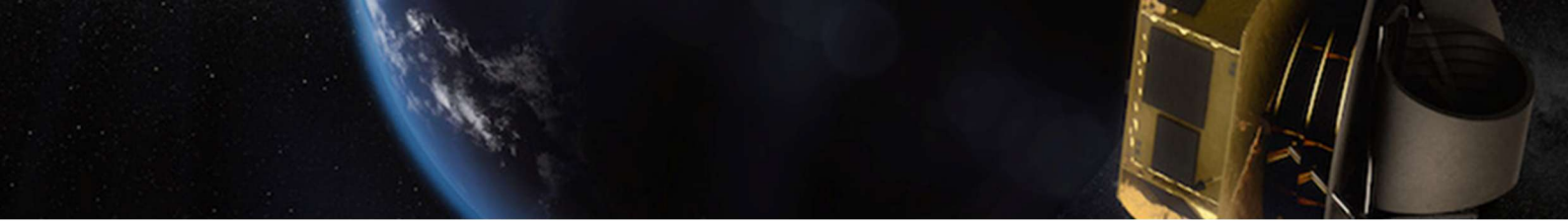
Due to delivery challenges in some (non-UK) areas of the consortium, which have cost and schedule implications for the rest of the mission, **RAL Space's responsibilities and influence over the consortium are likely to increase significantly** in the run-up to launch. While RAL have overall responsibility for integration of the payload, their role to date has primarily been to coordinate progress between consortium members, rather than explicitly manage their progress (a role which is typically used in other space science missions). Indeed, as mentioned by several stakeholders, they lacked the contractual levers to do so with the way the consortium has been organised.

However, in close consultation between RAL, ESA senior management, UK Space Agency, and ASI, an independent review was commissioned by Guiseppe Sarri (former JUICE[15] project manager). The recommendations from this review include **further reinforcing RAL's role as the lead technical authority**, enabling them to assume a role similar to an 'industry prime' for the mission. While these recommendations should not be treated as a panacea for stabilisation and recovery of the schedule slips which have been seen to date, they demonstrate trust in the capabilities offered at RAL and could ultimately enhance UK leadership in key decision-making processes relating to the Ariel payload. However, whether this development benefits RAL and the UK's reputation in the longer term depends largely on whether they fulfil these roles and responsibilities successfully, as reputational enhancements are inevitably linked with successful delivery in the future.

Across the UK project team, stakeholders have cited roles on Ariel as **key reputational drivers at an organisational level**, often linked to the visibility that the mission offers to international counterparts. However, many stakeholders also expressed **caution in assessing reputational improvements this soon in a long-term mission**. As the RAL example demonstrates, any reputational improvements at an organisational level could quickly be undone if key mission roles are not delivered as expected. While these pose future risks to the reputation of UK organisations, there was cautious optimism with respect to how UK organisations are perceived internationally, both within the consortium, with ESA, and beyond.

> - *Reputationally this mission is key. We have a long track record of space missions, but we need to continue this to remain competitive. Our previous skills carved a role for us on Ariel, which in turn will pave the way for future missions*
> - *We have worked closely with the ESA management team to deal with challenges, deepening these relationships.*

[15] ESA's Jupiter Icy Moons Explorer (JUICE), will make detailed observations of the giant gas planet and three ocean bearing moons. It launched in 2023, and will arrive at Jupiter in 2031.



This has undoubtedly improved our reputation as they are more aware of who we are, and what we can do.

- *The rest of the consortium and ESA have a huge amount of respect and confidence in the UK to deliver. With this confidence comes expectation. Expectation that the UK will do what it takes to solve any challenges that come their way."*

Future mission opportunities

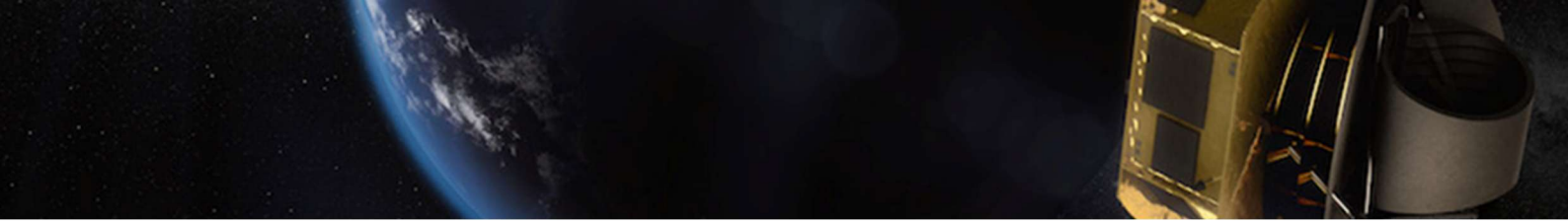
At this stage of the mission, many in the UK project team are understandably **prioritising commitments to the Ariel mission over applications for future missions**. While informal discussions are ongoing over potential future mission roles, these are long-term developments which are unlikely to see considerable activity in the short term. Moreover, as benefits from Ariel to the reputation and influence of the UK are contingent on successful delivery heritage, it is too soon to truly assess how the UK leadership roles on Ariel will translate into future mission opportunities.

A shortlist for the next ESA M-Class mission has been determined, although all three candidates are scientifically distinct from Ariel. They include M-Matisse, which aims to study the habitability of Mars, Plasma Observatory, which could explore the plasma environment around Earth, and Theseus, aimed at investigating high-energy, short-lived cosmos events.[16] No project team members have expressed interest in roles for these missions to date, which is unsurprising given the difference in scientific focus. The upcoming L-Class Advanced Telescope for High-Energy Astrophysics (NewAthena) mission has different science goals, target objects and wavelength ranges to Ariel, but also features a space-based observatory, and may provide routes for potential involvement from RAL Space to provide a backup cryocooler solution, as discussed in section 3.4.6.

Over the long-term, Ariel science is expected to dovetail into an **upcoming NASA mission – the Habitable Worlds Observatory**, which is planned for launch in the 2040s. The mission, like Ariel, will use a telescope to search for and characterise potentially habitable exoplanets, using spectroscopy techniques to search for chemical biosignatures in these planets' atmospheres. While discussions around UK involvement are at an early stage (as discussed in section 3.4.6**)**, there have been several visits between RAL and NASA JPL to discuss collaboration opportunities. The UK's heritage on Ariel (both scientifically, and from a payload management perspective) is likely to be a key factor in securing a role on this mission and others. While it is **too early to assess realised opportunities for future mission involvement**, UK project team members are in ongoing discussions for involvement in another large NASA mission concept – PRIMA, which is discussed in more detail in section 3.4.6, alongside other leads for future missions.

> "
>
> - *Every involvement like this builds capability, status and reputation, putting groups in pole position for the next big project.*

[16] ESA. 2023. Final three for ESA's next medium science mission. Available at: https://www.esa.int/Science_Exploration/Space_Science/Final_three_for_ESA_s_next_medium_science_mission



- *We have gained the trust of US collaborators at NASA due to Ariel. It gives us something to bring to the table, and it also builds confidence in UK Space Agency and the rest of the consortium as partners.*

Wider recognition of UK project team members

Throughout our study, we have also tracked the number of **awards and prizes** secured by the project team since Ariel's selection, to monitor wider recognition given to key individuals. Involvement in the Ariel mission benefits both the project and the individuals contributing to it. On one hand, having team members who receive lifetime achievement awards enhances Ariel's reputation and credibility within the scientific community. On the other, these awards also benefit the recipients, elevating their professional standing and opening doors to prestigious career opportunities.

Several of these awards are the function of multiple inputs (e.g. lifetime contributions), while others are more specifically related to Ariel activities. In total, **we have identified a total of 18 relevant awards**, including:

- ***Royal Astronomical Society Fowler Award,*** *Professor Ingo P. Waldmann, 2019*

The Fowler Award is awarded to individuals who have made a particularly noteworthy contribution to geophysics within 10 years of completing their PhD. Dr Waldmann was awarded the prize for his role in the 'vanguard of developing the statistical theory of exoplanet observations and their interpretation'.[17]His research has improved the reliability of exoplanet atmospheric analysis (a crucial aspect of Ariel mission science) through the use of Machine Learning. This research could make Ariel instrument design more efficient, and reduce bias and error in the analysis of future mission data.

- ***Knight of the Order of Merit of the Italian Republic****, Professor Giovanna Tinetti, 2020*

The Order of Merit of the Italian Republic (*Ordine al merito della Repubblica Italiana)* is the highest-ranking honour of the Republic, awarded for 'merit acquired by the nation' in the fields of literature, the arts, economy, public service, and social, philanthropic and humanitarian activities, as well as long and conspicuous service in civilian and military careers.

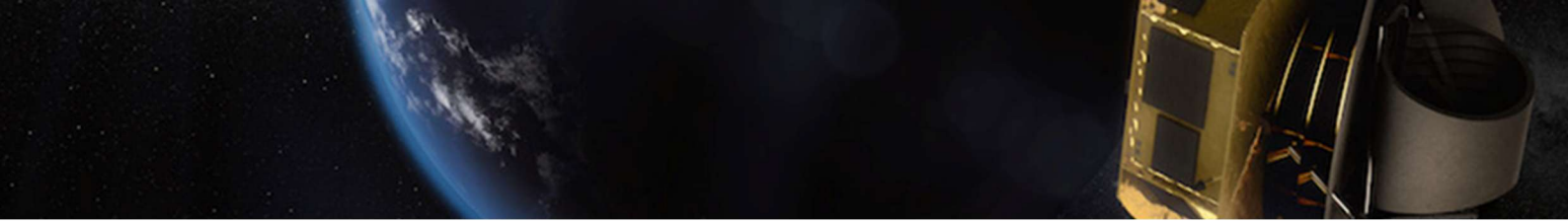
- ***Monte-Carlo "Woman of the year" Prize****, Professor Giovanna Tinetti, 2021*

The Monte-Carlo "Woman of the Year" award is an international prize aimed at celebrating women from internationally for personal or professional activities across a variety of sectors. In 2021, the theme of the Prize was "Women and Scientific research".

- ***Fellow of the Alan Turing Institute****, Professor Ingo P. Waldmann, 2021*

Turing Fellows are scholars with proven research excellence in data science, artificial intelligence (AI) or a related field, whose research would be significantly enhanced through active involvement with the Turing network of universities and partners.

[17] Royal Astronomical Society, 2019. Citation for the 2019 RAS Fowler Award (G): Dr Ingo Waldmann. Available at: https://ras.ac.uk/sites/default/files/2019-01/awards/Fowler%20Award%20-%20Ingo%20Waldmann.pdf



- ***L'Oréal-UNESCO Women in Science Rising Talent Prize 2021**, Dr Nour Skaf, 2021*

The L'Oréal-Unesco for Women in Science Rising Talent Prize is a national programme offering up to five post-doctoral women scientists a grant of £15,000 each, as well as offering a number of opportunities designed to help further establish women's research careers. Dr Nour Skaf, UCL-CSED Honorary PhD student, was awarded the prize for her research about direct imaging of extrasolar planets.[18]

- **Sir Arthur Clarke Award**, *Professor Giovanna Tinetti, 2023 and Professor Jonathan Tennyson, 2025*

The Sir Arthur Clarke award is an esteemed British prize which is given annually, to recognise notable contributions to space activities in the UK. Nominations are made by members of the public, while shortlisted candidates and winners are selected by a panel of judges. Prof. Tinetti won the individual Academic Study/Research prize for her role as principal investigator of Ariel, as well as her role as head of the Astrophysics group at UCL[19]. Professor Jonathan Tennyson also received this award for his work advancing the ExoMol project, which catalogues molecule interactions with light to enable atmospheric analysis of exoplanets.

- **Officer of the Order of the British Empire (OBE)**, *Professor Adrian Michael Cruise, 2023*

Professor Adrian Michael Cruise, a Project Management Board member for the Ariel mission, was recognised in the New Years Honours list in 2023 for his services to space, which include recent roles on the Rosalind Franklin Mars rover and Ariel, as well as his research on Gravitational Waves.[20]Ariel is one mission noted in the public announcement of the award, though this title is only partly attributable to UK Space Agency investment into the mission, as it was awarded for decades of contributions to space science.

Alongside these notable external awards, several project team members have received organisation-level recognition for their Ariel-related research, outreach activities, and engineering work. These include **Jon Darius Memorial Prizes** (postgraduate physics research awards), **UCL Outreach and Engagement Awards**, and **internal UKRI awards**.

3.2.3 Counterfactual

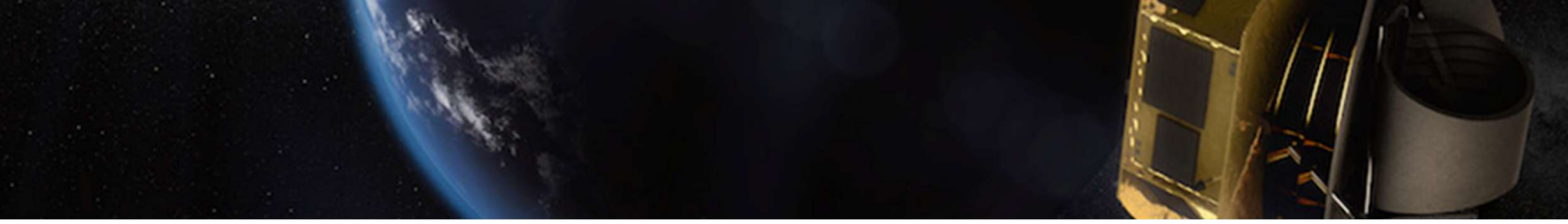
In a scenario without UK Space Agency investment, it is unlikely that we would see the same level of international collaboration, influence, or reputation. These outcomes and benefits are inherently linked to UK leadership roles, which would not have materialised without UK Space Agency's national funding.

In a scenario where the Ariel mission was not selected, international collaboration between UK authors in scientific publications would likely still occur. Nevertheless, given the top collaborating countries are members of the Ariel consortium, we assess there to be **high additionality between the UK's leadership roles on the mission and co-authorship trends in mission-relevant science**. Indeed, it is likely that in absence of leadership roles secured by the UK's investment, talented researchers and engineers could relocate internationally in search for similar opportunities, in turn reducing the UK's influence and reputation. Moreover, other forms of international collaboration, such as co-ordination of payload integration, as well as the outreach

[18] UCL, 2021. *Congratulations to Nour Skaf, SCED Honorary PhD Student.* Available at: https://www.ucl.ac.uk/space-exochemistry-data/news-0

[19] The British Interplanetary Society, 2023. *Sir Arthur Clarke Awards*. Available at: https://www.bis-space.com/what-we-do/honours-and-awards/arthurs/

[20] UK Space Agency, 2024. *Professor Adrian Michael Cruise awarded OBE for services to space*. Available at: https://www.gov.uk/government/news/professor-adrian-michael-cruise-awarded-obe-for-services-to-space



initiatives such as ExoClock and the Data Challenge would not have been possible (at least to the same extent) without UK Space Agency investment.

The same is true for UK influence and reputation, which is inherently linked to the leadership roles the UK project team holds on the mission. While previous delivery heritage also plays a factor in securing future mission opportunities for the UK, **benefits arising from roles on the Ariel mission are in our view highly attributable to UK Space Agency support**. The UK's reputation and influence in exoplanet science (and space science more broadly) – at the individual, organisational, and national level - is dynamic, and a function of multiple inputs, of which the Ariel mission is only one. However, where improvements in reputation and influence are tied to successful delivery of objectives within the Ariel mission, there are strong links between the UK Space Agency investment and these benefits.

3.2.4 Conclusions

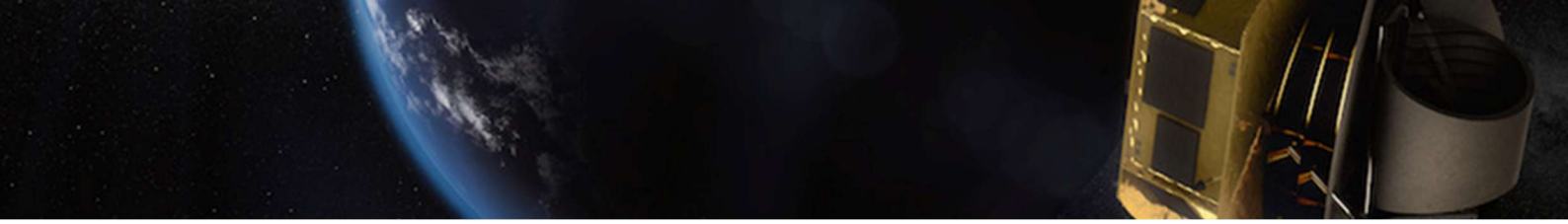
The Ariel mission requires high levels of international collaboration and coordination, and UK Space Agency national funding has placed UK researchers, scientists and engineers at the forefront of discussions around the mission. In turn, this has contributed to **early signs of wider reputation and influence** of the technical and managerial decisions made on the mission. Early signs of enhanced UK reputation are emerging, though **future improvements are contingent on successful delivery of mission roles**. It will therefore be important to monitor how reputation evolves over the duration of the mission. Below, we assess preliminary performance against this study's evaluation questions, as set out in the Ariel M&E Framework, to assess progress against UK Space Agency's benefits realisation objectives at this interim stage of the mission.

To what extent has the UK's National investment in Ariel led to a greater quantity or quality of international collaborations and partnerships?

There is strong evidence of high levels of international collaboration which are attributable to UK Space Agency's investments. This is demonstrated through analysis of co-authored publications, which indicate that over 80% of UK authored publications feature international collaboration. This includes authors from beyond the project team, although **UK researchers have primarily been collaborating with researchers from Italy, France, and the United States** to produce Ariel-related research within the consortium. International collaboration on the mission is also seen through other forms, such as ongoing integration of instrument assembly, testing, validating and manufacturing activities across a consortium of over 600 scientists and engineers, as well as through the outreach initiatives such as the Ariel Data Challenge and ExoClock, which have attracted international recognition and participation. Future international partnerships could be strengthened between the UK and Japan through Prof. Tinetti's new visiting professorship at the University of Tokyo, which could catalyse uptake of Ariel-related research, enhance the UK's visibility and influence in space science internationally, and potentially attract talent to the UK.

What difference have UK Space Agency contributions made so far in enhancing reputation and influence of the UK space sector?

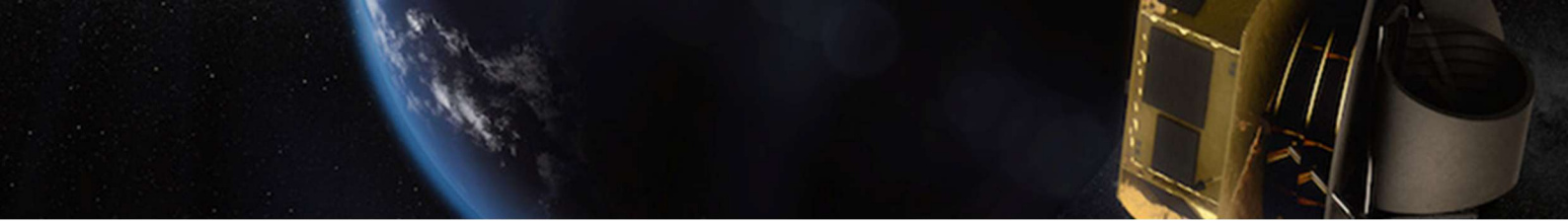
UK leadership roles have enhanced the influence of the UK project team over the mission science, and ongoing payload developments demonstrate UK influence in systems engineering is high and set to increase further as a result of close working arrangements with ESA. Stakeholders have generally expressed **cautious optimism over the reputational benefits** of UK roles on the mission at an individual, organisational, and national level, stating that progress has been strong to date, as the project team has received wider recognition in the form of awards and prizes, and have been invited to give keynote speeches internationally. Over the long term, this could lead to soft power benefits in terms of influencing international norms in the space science community, and could lead to enhanced attraction of talent, but these impacts are inherently linked to



successful delivery of roles on the mission, which are still ongoing. To date, it appears the UK is perceived positively by ESA and the wider consortium of 16 countries, although this comes with an enhanced expectation to deliver, and hence could pose a reputational risk if roles are not fulfilled as expected in the future. It will be important to track how these trends evolve over time, as reputation and influence are evolving concepts with potential long-term benefits.

Has the UK Space Agency investment sustained or increased UK competitiveness in future Space Science and exoplanet missions?

Preliminary evidence indicates that **Ariel is being leveraged as a marker to enhance the UK's standing for future potential exoplanet missions**, and Ariel is the latest mission (and arguably one of the most significant, given the number of UK leadership roles) which helps to showcase UK capabilities and demonstrate heritage on complex science missions, strengthening the case for future mission involvement. Early conversations are ongoing around future mission roles, including the NASA Habitable Worlds Observatory mission, which is scheduled for launch in the 2040s, and the PRIMA mission concept. While progress is promising in these areas, it is still too early to assess how Ariel will lead to enhanced UK influence on future missions such as these.



3.3 Skills & Inspiration

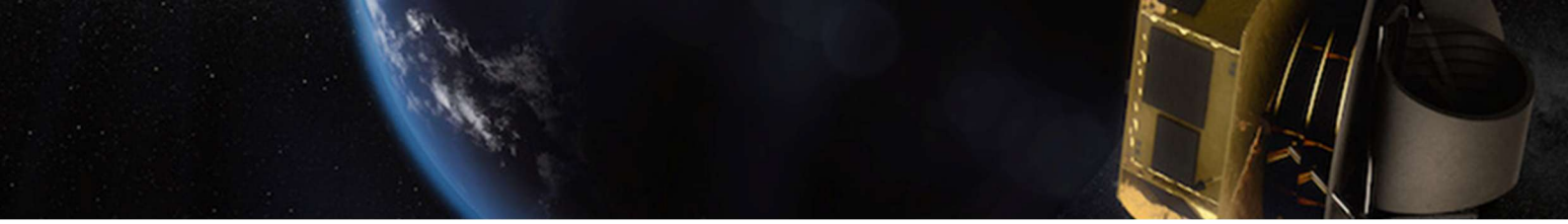
A key long-term goal of the Ariel mission is **to inspire and develop the UK's space talent pipeline**. Exoplanet science is a rapidly growing field that captivates public interest and widespread media attention, due to its role in uncovering how planets form, their potential habitability, and the origins of life in the universe. By leading the Ariel mission, the UK aims to leverage the profile of the mission to attract and retain scientific talent, strengthening human capital and capabilities in the space sector.

Moreover, characterising the atmospheres of exoplanets requires analysing the light spectra of transiting planets within large datasets. Artificial Intelligence (AI) and Machine Learning (ML) are expected to play a crucial role in transforming data analysis, detection methods, and characterisation techniques. The Ariel mission could **significantly enhance the UK's expertise in data science, advanced computing, and AI/ML**, potentially driving positive spillover effects across other sectors of the UK economy.

> - *Setting up the Ariel Data Challenge, the hackathons, and ExoClock have brought in new scientists and trained them in how to use this data. This certainly feels above the norm for space missions.*
> - *Strong technical and managerial capabilities have both been essential. Demonstrating these simultaneously on Ariel is what puts us in conversations for roles on future NASA missions.*
> - *There are huge upskilling opportunities and early career assistance at RAL. People learn complex skills across engineering and technician roles, and there is a blend of senior experts, graduates, and apprentices across the team.*

Summary of key findings

- **Observed outputs and outcomes regarding skills development, attraction of talent, and wider outreach initiatives are promising –** and are establishing strong foundations for upskilling the space talent pipeline, however consistent funding of these activities is a key risk in ensuring longer-term outcomes and impacts materialise.
- **Project team members have hosted and presented at a range of conferences, and have conducted extensive outreach and engagement activities –** these activities, in turn, help sow the seeds for long-term benefits to UK space science and the wider economy. So far, the project team have undertaken at least 155 relevant public engagement activities, including major conferences, news appearances, and STEM engagement programmes for families and students. These events could contribute to

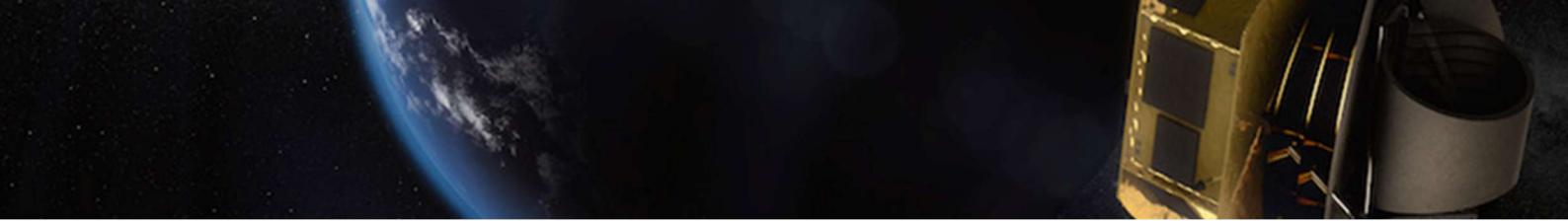


inspiring and attracting the next generation to pursue careers in the space sector, as well as raise the profile and visibility of the Ariel mission, and the UK's leading role within it.

- **The Ariel Data Challenge has been an emerging success story for the mission, catalysing increasing levels of international participation from the AI/ML community –** the 5th edition of the Data Challenge marked a significant increase in participation, both in terms of the number of participants, but also in the depth of their engagement. The challenge has catalysed international and UK-based impacts, and the ongoing collaboration with Kaggle could lead to exciting new developments in the realm of AI and Machine Learning.
- **The ExoClock project has also played a central role in enhancing visibility and participation in astronomy, engaging amateurs and students in Ariel-relevant science –** ExoClock has seen rising participation and increasing numbers of observers (from 160 in 2021, to over 450 currently). ExoClock has run several successful collaborations with UK-based schools and universities. 10,570 observations have been completed to date, from observers in 71 different countries – the UK is the second highest contributor behind France.
- **The attribution of benefits is often more complex here, as the UK Space Agency national funding does not specifically fund outreach, engagement or the ExoClock and Ariel Data Challenge activities** – however, without the UK roles and leadership in the mission, the observed outcomes would not manifest in the same way, so can be seen as being linked / attributable to the national funding in this regard.
- **Delivery of mission roles and responsibilities has led to technical and managerial skills development across the UK project team –** UK management roles on Ariel have led to enhanced project management processes at UCL and RAL to manage the complex international consortium. The project team have developed and showcase various technical skills essential for space missions, including traceability work, computer-aided design, and software, mechanical, and systems engineering.
- **The UK's role in Ariel has helped to attract and retain talent, though uncertainty around future funding poses a risk in the opposite direction –** approximately 50 individuals are currently working across the UK Ariel project team, with a blend of early career and senior roles. The mission has been cited as a key driver of retention, given the appeal of Ariel as a high-profile space mission. However, others have cited uncertainty around fixed-term contracts as a barrier to recruitment and retention of staff.
- **UK Space Agency investment into the Ariel mission has also supported career progression of scientists and engineers, helping to establish a skilled pipeline for future space activities -** at least 9 staff members have been promoted as a result of their activities on Ariel, primarily through the pipeline of PhD students at UCL, which have led to new postdoctoral research fellows and professors. RAL Space have supported significant progression through year-in-industry, graduate and apprentice roles. Career progression has also included routes between academia and industry, with ongoing links between Ariel researchers and related spinout and startup companies.

3.3.1 Project team conferences and public engagement activities

To raise the profile and awareness of the Ariel mission, UK project team members have presented and hosted at a variety of events and keynote speeches to catalyse wider interest. These outreach events are targeted at **a diverse range of audiences** from different backgrounds and seniority levels across industry and academia, as well as talks for the general public and families.



We may be underrepresenting the number and breadth of engagement activities undertaken by the project team, as these are best estimates from information available to us through interviews, data supplied by project teams, and Researchfish (see annex for more detail on evidence sources). For example, it is unlikely that our figures capture all university open days and tours offered by RAL, despite these events being important routes to inspiring the next generation of prospective and current students.

We have seen a considerable increase in outreach and engagement activities relevant to the Ariel mission in recent years. This is to be expected, as the further Ariel progresses and the closer it comes to launch, the more interest the mission will receive. **While UK Space Agency's national investment does not directly fund outreach activities, there is a clear link given that without the UK roles, many of these activities would not take place in the same way** (e.g. invites may not be received for speaking opportunities). There is evidence that UK members of the project team have been proactive in organising and conducting these opportunities as the mission has progressed through major milestones, and in many cases, have been invited to give talks internationally. For instance, Prof. Tinetti has been invited to give talks and seminars at a minimum of 9 international conferences and workshops a year since 2021, with more outlined for later this year. Pre-2018, there were a total of 24 noted events in which UK project team members participated. From 2020 to the present day, we have identified:

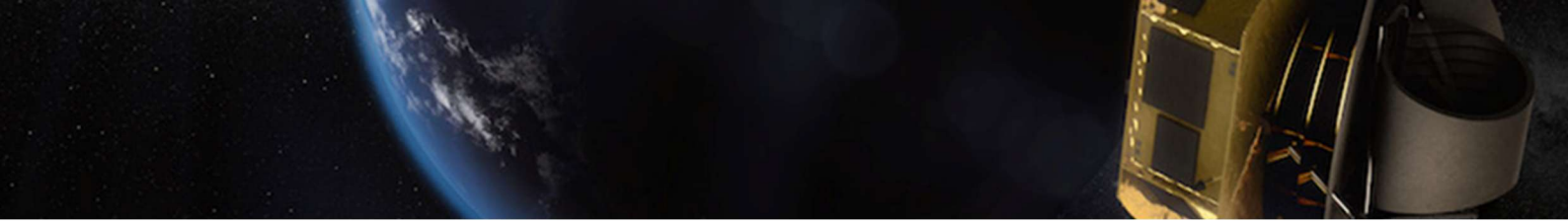
At least **155 public engagement** activities undertaken by the Ariel project team since 2020

Including workshops and conferences in **19 countries**

Engagement targets a **range of audiences**, including academia, students, industry, and families

The *nature* of engagement activities is at least as important as their *number*. Within these total figures, we see significant UK project team representation at **major international space science and instrumentation conferences**. By presenting at these events, individuals could help to catalyse wider participation in the Ariel mission. Moreover, by showcasing UK capabilities to an international audience, these events could help to strengthen the UK's position in securing future space science mission roles. Examples of notable conferences include:

American Astronomical Society Division for Planetary Sciences Conference (Texas 2023)
Organised by the largest professional society of planetary scientists in the world, this conference attracted approximately 900 scientists, students, and space agency representatives, including NASA, ESA and JAXA. Prof. Tinetti and Paul Eccleston presented an Ariel overview as part of the Future Missions session alongside ESA representatives.
European Astronomical Society Conferences (Padova 2024, Krakow 2023, Valencia 2022)
This annual conference attracts ~1500 participants annually to present research findings and discuss advancements in astronomy, and is regularly attended by Prof. Tinetti, who is an invited speaker.
Society of Photo-Optical Instrumentation Engineers (SPIE) Conference (Yokohama, 2024)



This technical conference attracts more than 2000 engineers and scientists, making it the largest conference in ground and space-based instrumentation. Several presentations were given by RAL, UCL, and Oxford project team members, who presented mission and instrument level updates.

Alongside large conferences intended for a technical audience, the project team have also appeared on **UK-based and international news, television and radio fora to discuss exoplanets and the Ariel mission** (alongside JWST and others). While less directly relevant to UK Space Agency funding, these appearances are crucial for raising the profile of Ariel-relevant science to the wider population. For example, Dr Subhajit Sarkar from Cardiff University has appeared on BBC News, News9Live (India), Le Parisien (France), and others, while Prof. Tinetti has appeared in the Guardian Science Weekly Podcast, BBC Sky at Night, and various BBC Radio channels.

The Ariel project team have also been involved in wider initiatives which provide opportunities for students, families, and young people to learn about the Ariel mission, aiming to stimulate curiosity and inspire young people to learn more about the surrounding science, potentially igniting an interest in pursuing STEM subjects and careers:

Harwell Open Day (RAL Space)

While not Ariel-specific, RAL participates in the Harwell Open Day, where the public visit the campus on tours, and engage with interactive stands and workshops. The event is aimed primarily at the general public, and it attracted approximately 10,000 visitors (including 2000 students) in the 2024 edition. Ariel formed one of the 'featured mission' stands, which gave information on the mission, as well as exoplanets more broadly.

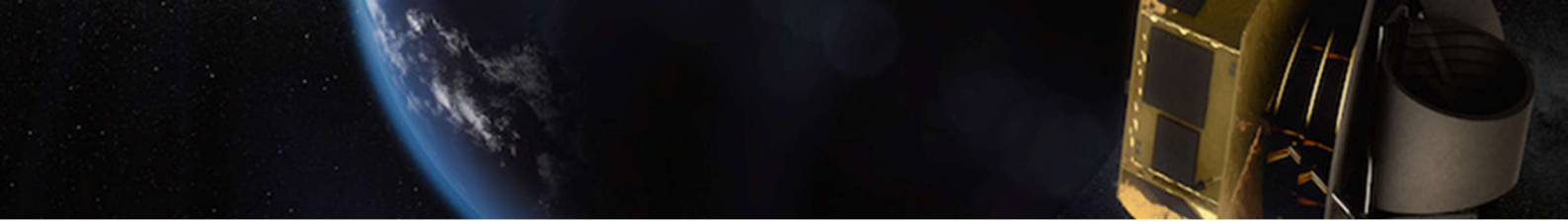
ORBYTS (UCL)

UCL's ORBYTS programme is an initiative which aims to address systemic diversity issues in STEM subjects, as well as shortages of science teachers. The ORBYTS programme has run several projects with pupils from historically disadvantaged schools, with exoplanet-themed projects, as well as ongoing links with other UCL outreach activities (such as ExoClock, which is discussed in case study below). ORBYTS also partnered with Great Ormond Street Hospital to create scientific projects for students with long-term health issues, with associated toolkits and graphics.

School Engagement Programme (Cardiff University)

Cardiff University also received STFC grant funding to pilot a school engagement programme, engaging with teachers in schools in underserved communities. This has involved provision of educational materials and support. Internal staff changes have delayed the wider rollout of in-person school engagement; however, they have continued to consult with teachers to develop lesson plans, and plan to upscale this initiative in the future. These activities are intended to form a Research Excellence Framework (REF) 2029 case study in the future.

In addition to the conferences and public engagement activities captured above, there are two start-up companies which have close links to the Ariel mission – Blue Skies Space Ltd and Spaceflux. While their activities are not counted in the totals above, representatives from these companies (which are discussed in more detail in 3.4.1) have travelled internationally to exhibit at industrial conferences. Examples include Space Tech Expo (Bremen), Dubai Airshow, Tech Crunch Disrupt SDA (San Francisco), IAC 2024 (Milan), and Amos 2024 (Hawaii).



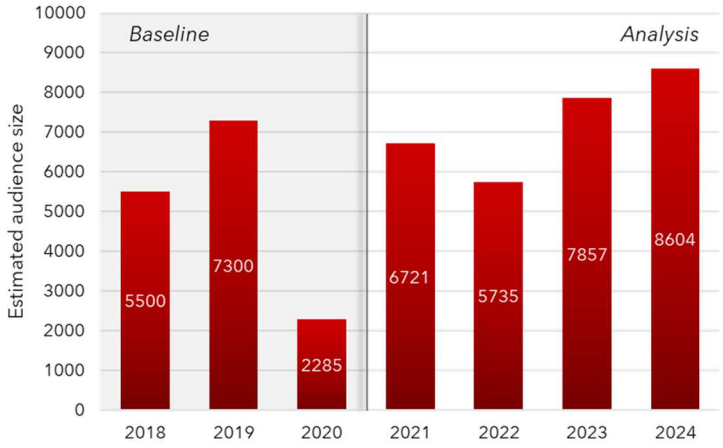
3.3.2 Wider UK involvement in international conferences

Beyond contributions from the UK Ariel project team directly, we have also tracked the level of participation in international exoplanet conferences by UK-affiliated speakers since 2018. While **these trends are not directly attributable to UK Space Agency investment in Ariel**, they provide additional context around the level of influence UK researchers may have in the field of exoplanet science, and how this may shift over time as a result of leadership roles in space science missions.

This data has been extracted using the exoplanet.eu list of meetings and conferences. We identify conferences with UK-affiliated speakers (when possible) and estimate audience sizes based on available attendee lists and statistics. Where precise numbers are unavailable, we provide conservative estimates. These figures reflect potential engagement rather than exact audience counts, as we cannot determine attendance at individual speeches.

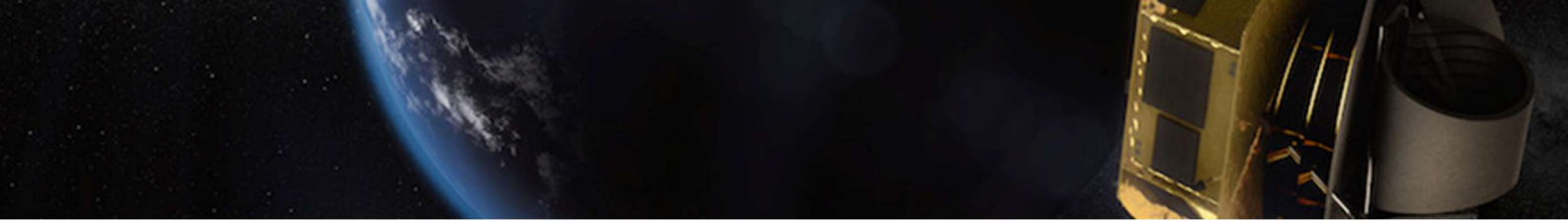
Across the time series, there have been relatively consistent audience sizes for international exoplanet conferences, aside from COVID-19 pandemic affected years. While these figures are approximations, there is evidence of slight **year-on-year increases in audience size relative to the baseline**, with the last two years surpassing pre-pandemic levels. While Ariel's influence on these trends is likely to be modest, figures suggest there is a relatively active and growing scientific community (in the UK, and internationally) who may be influenced by Ariel in the future.

Figure 16 *Estimated audience size across international exoplanet conferences featuring a UK-affiliated speaker*



The diversity of outreach and engagement activities related to the Ariel mission is notable. **Two UCL-led citizen science programmes have been especially successful in engaging the wider community in Ariel-related science over the timeframe of our study**. In doing so, both programmes aim to grow the research community which will benefit from Ariel data in the coming years. We present case studies of the Ariel Data Challenge and ExoClock below, which have both contributed to raising the global profile of the Ariel mission, encouraging international participation and collaboration, and catalysing additional benefits for the UK.

These initiatives **not entirely attributable to UK Space Agency investment**, as while funding has been allocated to key personnel who are driving these initiatives, their continued growth has also relied heavily on voluntary and in-kind contributions from other sources. However, without the UK roles and leadership in the Ariel mission, the observed outcomes would not manifest in the same way, so there is a strong link to the national funding and emerging impacts from both



initiatives in this regard. We provided recommendations for supporting routes to future impact from these activities in sections 2.2 and 2.3.

3.3.3 Case Study: The Ariel Data Challenge

Context

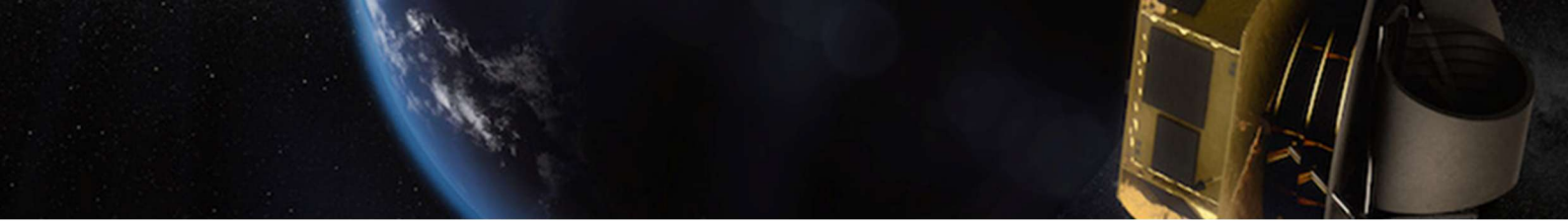
The Ariel Data Challenge (ADC) is an ongoing initiative led by the UCL Centre for Space Exoplanet Data (CSED), which has been successful **in encouraging wider participation in astronomical data analysis relevant to the Ariel mission**. The challenge was established to encourage AI and machine learning experts to construct innovative models to extract exoplanet signals from simulated observations. In doing so, the challenge is encouraging increased research activity in the application of AI and Machine learning techniques to exoplanet research, which could help to strengthen the research community in areas which support longer-term complementary science objectives for the Ariel mission. Currently, the ADC is **the world's largest exo-atmospheric science database**. Moreover, the challenge pushes participants to develop and showcase highly demanded AI and Machine Learning skills, attracting teams from both academia and industry.

Since 2019 there have been five iterations of the ADC, and it has witnessed **growing global popularity with every edition**, despite the rising complexity of the challenge. The ADC PI, Gordon Kai Yip, alongside support from Bex Coates, a Science Communication Officer at UCL, have been instrumental in running and promoting the challenge. It has also been bolstered by support from others at UCL CSED, the University of Cardiff, and other partners. Across iterations, the ADC has attracted sponsorship from ESA, UK Space Agency, CNES, and the DiRAC High Performance Computing Facility, which has helped to provide incentives for participation (e.g. prize money, conference opportunities, computing support, and promotional activities).

Trends in participation

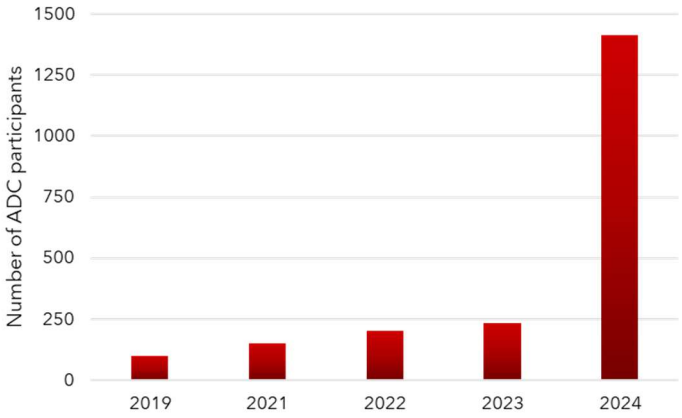
The rising participation with each data challenge (as illustrated below) is partly due to the team's evolving communication strategy. For instance, the team has introduced live leaderboards and social media posts to raise the profile of the challenge and stimulate competition between participating teams (through the re-submission of improved solutions). Notable changes to the ADC communication strategy began in 2023, where the team were able to attract 32 more participants than the 2022 edition, despite the challenge running for significantly less time (2 months, rather than the previous 4).

Figure 17 *ADC 2023 Promotional Materials*

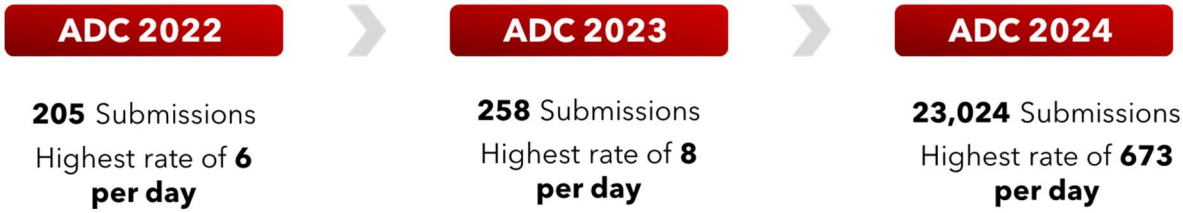


This was followed by the 2024 edition of the challenge, which attracted **over 6 times the number of participants**. This increase was largely due to the ADC's partnership with Kaggle, Google's data science and machine learning platform. The competition was hosted on the Kaggle website, and it became a featured competition on their homepage for the duration of the challenge, making the ADC visible to the world's largest online AI and machine learning community. Alongside visibility benefits, the partnership with Kaggle also attracted funding support, as Kaggle provided $50,000 (£38,000) of prize money, representing a significant increase from the £4,300 incentive offered in the 2023 edition. There are also additional incentives, such as medals won through participation in ADC 2024, which are standardised awards which are recognised across the community and can hence boost the employability of data scientists.

Figure 18 *Number of participants in the Ariel Data Challenges*

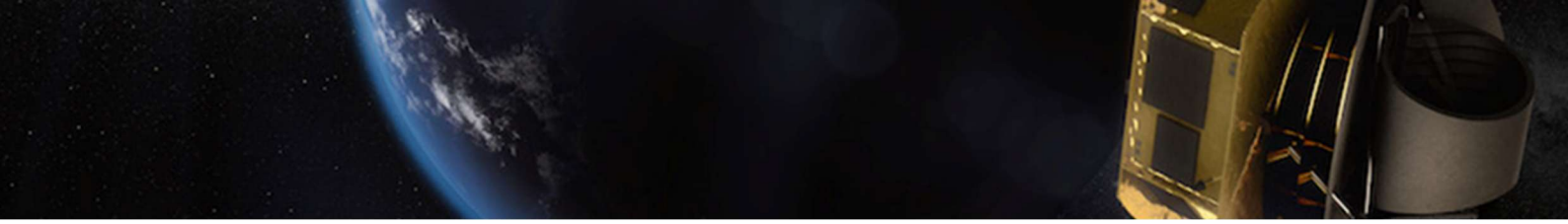


Alongside a rise in the overall number of participants, there is also evidence of **deeper engagement with the challenge** as it has evolved, especially in the 2024 iteration. This can be seen through the number of teams which are re-submitting improved solutions, in order to increase their score and leaderboard position. For context, the winning 6 teams of ADC 2024 submitted a total of 914 entries, and the recent challenge recorded 89 times more submissions than the previous edition.



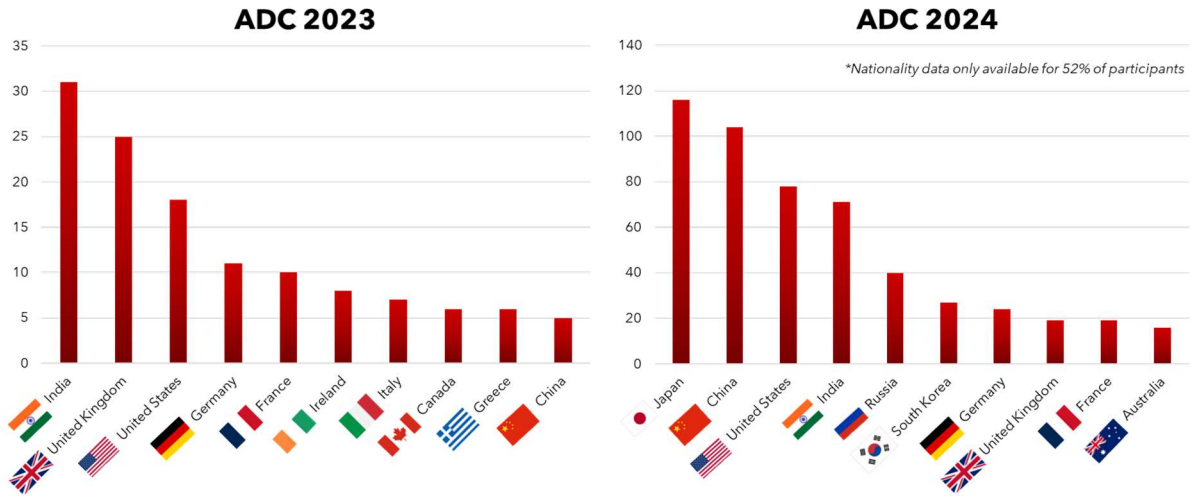
The global reach of ADC

Since its inception, the ADC has attracted an international community of participants from both AI / Machine learning and astronomy backgrounds. In the most recent iteration, there were participants from **at least 77 countries**, up from 50 in 2023, and 35 in 2022. These figures may also be an underrepresentation of the true figures, considering over half of participants (in the 2024 edition) have not provided nationality or affiliation information when registering for the challenge. While our ability to make direct comparisons is limited, *Figure 19* illustrates some of the key contributors to the previous two data challenges. India, the UK, the US, and Germany have been key contributors across both challenges, while Japan and China have risen to become leading nations (noting the limited sample size) in the most recent iteration.



Hosting the 2024 edition of the challenge on Kaggle was a **key factor in widening international participation** with the challenge. For instance, the strong representation from Japan in the most recent edition of the challenge (despite not featuring in the top 10 countries in ADC 2023) was attributed to the strong Kaggle challenge community in Japan by the eventual winners of ADC 2024. There is also evidence of **wider online media coverage**, which has raised the profile of the ADC. For instance, ADC 2024 was featured in at least 35 press releases promoting the challenge, which were published in 7 different languages. The growing international involvement could potentially translate into reputational benefits for the UK, although the rising global popularity of the ADC in 2024 has not necessarily led to growing participation from UK teams (although we lack the data to determine this fully).

Figure 19 *Number of ADC participants by nationality*



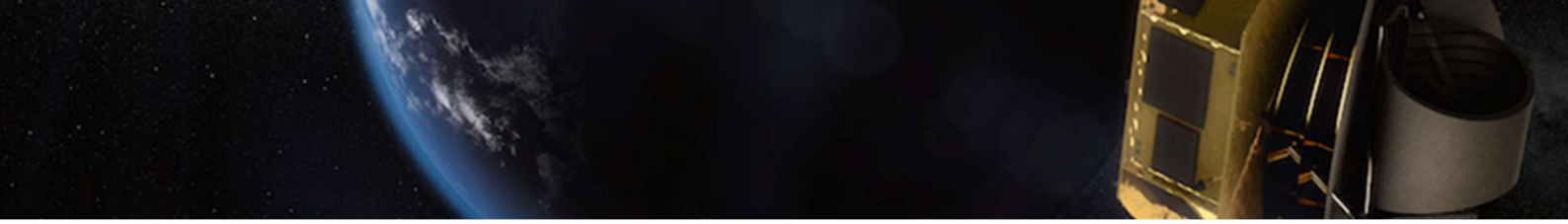
This combination of factors has attracted a range of participants from both industry and academia. For ADC 2024 the Ariel Data Challenge PI Kai Yip, disseminated a survey (including questions we have co-developed with him) to understand the background of participants participating in the Data Challenge better. With only 64 responses, **the survey is not statistically significant nor a comprehensive assessment of the participants**. However, there is some limited evidence that ADC 2024 managed to reach a much wider audience from the AI and Machine Learning community, and many would have been participating in a space-mission related data challenge for the first time.

48% of ADC 2024 survey respondents are **from industry**, while **27% are students**

98% of respondents are participating in the challenge **for the first time**

80% of respondents are **from the AI / ML community**

37% of respondents are **25-34 years old**, and **25%** are below the age of 24



Benefits to the UK

While the ADC manages to attract a global participant base, the challenges have also brought benefits to the UK directly. The challenge has provided **significant leadership opportunities for the PI and supporting staff** within the UK Ariel project team, enabling valuable **experience in the management and delivery of international challenges**, as well as the **opportunity to present and publish** research underpinned by the findings of the challenges.

Moreover, **at least 44 UK-based teams have participated in the last two data challenges**, including teams from academia and industry. While participants are not required to provide personal information, we have found evidence of teams from companies such as Facebook and Altium Ltd, as well as universities such as Imperial College London, Oxford University, and the Open University. At this relatively early stage of the mission, **the Data Challenge has helped to build and engage a highly-trained community of AI and Machine Learning specialists** with the technical skills necessary for complementary science activities for the Ariel mission. In doing so, the data challenges have played a crucial enabling role in enhancing the size of the research community, and the reach of future Ariel mission data beyond astronomy.

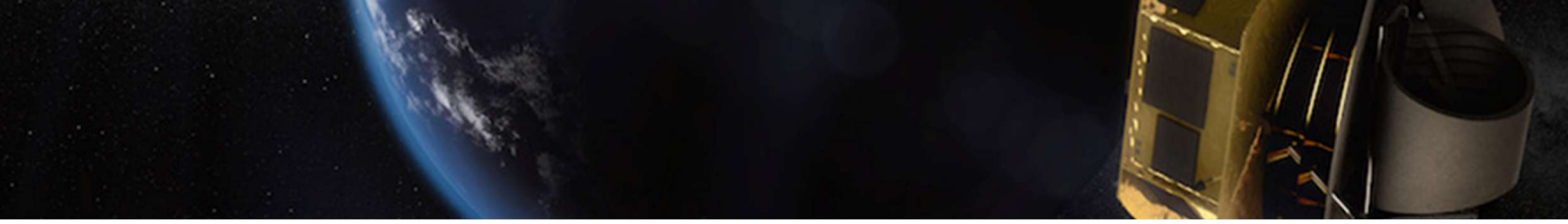
While the challenge is typically run over several months and hosted online, the ADC team have also supplemented this with more direct engagement in the form of **in-person hackathon events, including at the Harwell campus in Oxfordshire** (as well as an ESA Hackathon in Madrid, and smaller events in Portugal). The Hackathon in Harwell provided an opportunity for approximately 40 participants to gain exposure to simulated data from the Ariel mission, identify and correct stellar spots in light curves through machine learning driven solutions, and present their findings. The event also featured guest speakers from the Ariel consortium, including Ariel PI Prof. Tinetti and ML Analytics (the first winners of the data challenge) lead data scientist Luis Simones. **All participants felt the event taught them something new, and 94% would be interested in attending a future event**.

These emerging benefits for UK researchers, as well as UK-based participants in the ADC and hackathons, are **indirectly linked to the UK Space Agency national contribution to the mission**. UK Space Agency funding has supported key roles, reinforcing the UK's leadership in Ariel and contributing to the establishment of the Ariel Data Challenge within the UK. However, these outcomes have also been shaped by additional inputs, including voluntary efforts from key personnel, as well as in-kind and financial support from Italy, France, and the US, which have also played a role in delivering benefits within the UK.

The future of the ADC

As measured by the number of teams participating, ADC 2024 **was the second biggest competitive astronomy themed data challenge ever hosted on Kaggle**. Taking into account the number of iterations, the number of re-submissions by participating teams, and the level of prize money available, there is a credible case that the Data Challenge is in fact the biggest astronomy themed competition. Building on the success of the 2024 edition, the ADC team are already planning the future stages of the challenge, as well as the next UK-based hackathon event. Their close relationship with Kaggle has continued, and the team has secured sponsorship for the 2025 edition, which will include **contributions from Kaggle themselves, or NVIDIA, who are highly active in AI and Machine Learning**. These collaborations are likely to lead to continued profile-raising of the challenge and the wider Ariel mission globally. The next iteration is aimed at progressing from a synthetic data set to more realistic mission candidate samples.

The ADC team are also preparing another in-person Hackathon event in the UK, which is aimed to be a **precursor event to the Ariel Open Science conference**, which will take place at the ESA ECSAT centre in Harwell in 2026. By hosting the hackathon in the lead up to the conference, the



intention is to build momentum and wider interest around the conference, raising the profile of the Ariel mission further in the UK AI and Machine Learning and Astronomy research communities. By supporting bi-directional knowledge spillovers between AI and exoplanet research, the challenge raises the potential of **enhancing scientific exploitation of Ariel mission data** through the implementation of new techniques, while also supporting **commercial application of new techniques** developed to participate in the challenges, which could lead to the generation of new products and services with welfare-enhancing and productivity benefits across a range of sectors.

The ongoing collaboration with Kaggle is also leading to **new opportunities for ADC Hackathon events**. While still at a discussion stage, the ADC team has been approached by Google's British-American AI research laboratory DeepMind to produce an internal hackathon. As a subsidiary of Alphabet, DeepMind develop AI systems and algorithms to solve complex societal challenges. Most notably, **DeepMind researchers won the 2024 Nobel prize in Chemistry** for their AlphaFold AI system, which can predict the structure of proteins, a solution which could unlock more efficient vaccines, speed up cancer therapy, and design entirely new proteins[21]. While further details are confidential and cannot be shared, this collaboration could strengthen DeepMind's research in identifying biosignatures on exoplanets, and further demonstrates the rising prominence of the Ariel Data Challenge.

Over the longer term, the aspiration of the Data Challenge and Hackathon format is to create a **financially-sustainable spinout** which utilises a similar framework to run online and in-person challenges across other research domains. The team have already been approached by other researchers (including PLATO[22] team members and non-space scientists) and are investigating UKRI proof-of-concept funding and UCL innovation enterprise grants to pursue this idea. They have also established a not-for-profit organisation which could support future sponsorship opportunities – named PLANETAI CIO.

Key takeaways

The Ariel Data Challenge is a success story from the UK's involvement in the Ariel mission so far. Growing global engagement with the challenge is helping to refine analysis and interpretation of exoplanet spectra, through expanding cross-sector collaboration and expanding industry engagement. The challenge has begun to support innovation beyond traditional space science research communities, **leveraging wider AI and Machine Learning developments to support relevant research for UK-led aspects of the Ariel mission – such as scientific and ground segment preparation**.

The ADC has already become one of the most successful astronomy challenges ever hosted on Kaggle, which could secure future reputational benefits to the UK. The team has also undertaken several targeted UK-specific initiatives, such as the CSED Hackathon in Harwell, and potential partnerships with industry. Given the rising success of the challenge globally**, there is potential to expand these UK-based initiatives further with funding support, to maximise and solidify the scientific and economic benefits of the initiative in the UK**. For instance, the ADC has already proven that it can support spin-ins to the space sector (and roles on the Ariel mission) from AI and Machine Learning companies. Further financial support to foster knowledge exchange with UK companies, through use of the targeted Hackathon format, or open innovation labs, could lead to further commercial benefits for the UK, while strengthening UK leadership in space science and AI.

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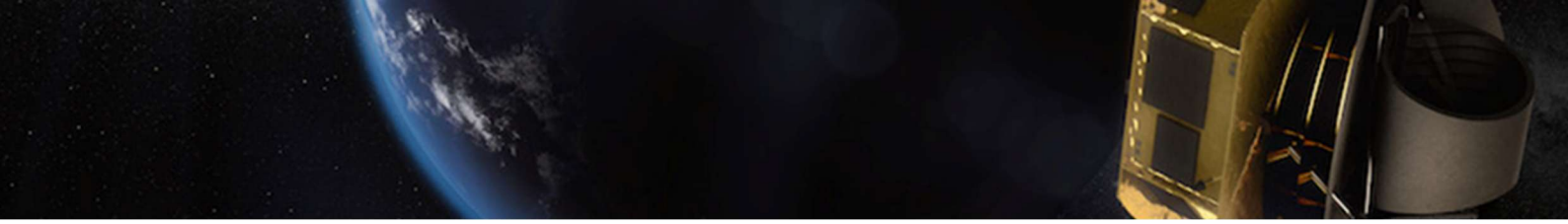
[21] MIT Technology Review. 2024. *Google DeepMind leaders share Nobel Prize in chemistry for protein prediction AI*. Available at: link

[22] ESA's PLAnetary Transits and Oscillations of stars (PLATO) mission is planned for launch in 2026, and will use 26 cameras to study exoplanets in the habitable zone of sun-like stars.



3.3.4 Case Study: The ExoClock programme

Context

ExoClock is a project led by the Ariel Ephemerides working group, featuring significant involvement from Anastasia Kokori at UCL, who is a PhD student funded by UK Space Agency's national contribution to the Ariel mission. In the words of the team, the project **"aims to democratise the field of exoplanet research by enabling public participation in support of ESA's Ariel space mission"**[23]. To do this, the team have created educational tools, guides, and workshops to enable amateur astronomers and students to contribute to research relevant to the mission.

By participating in the project, observers support a catalogue of up-to-date information on exoplanet transit times and stellar variability of host stars, helping to ensure that the Ariel large-scale survey of exoplanets is as efficient as possible. ExoClock also provides **educational tools, monthly newsletters, and individualised feedback to train participants**, teaching students and amateurs early skills in data analysis, synchronous observations, project management, and collaboration.

Growth of the ExoClock project

Like the Data Challenge, ExoClock has now been running for six years, and has continued to **record growing participation with each year**. There are many ways for individuals to engage with ExoClock. The programme supports observers, who are individuals defined as having conducted 'at least one direct telescope observation' under the project. In addition to this, there are a wider pool of participants who are not technically observers, but may have signed up to ExoClock to receive training and educational materials to help them complete their first observation. Participants can support the project in other capacities also, such as conducting literature reviews.

Looking specifically at observers, ExoClock has steadily increased observer participation in the programme, starting from 11 in 2019, **and rising to 453 in 2024**. These observers are primarily amateur astronomers or students. Across the time series ExoClock has maintained around 70% amateur engagement. In total, **observers have completed 10,570 observations through ExoClock** using small and medium-scale telescopes, of which 8,188 were completed by amateurs.

[23] Pantelidou, G. and Kokori, A., 2024, September. ExoClock Unlocked: Fostering Public Engagement in Exoplanet Research. In *Europlanet Science Congress 2024* (pp. EPSC2024-142).

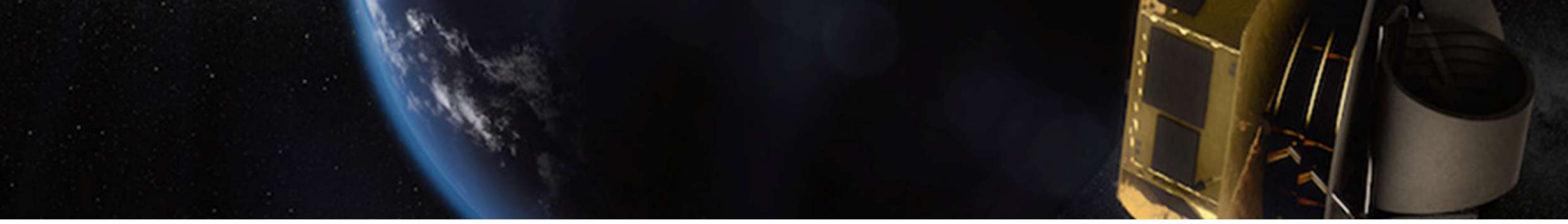
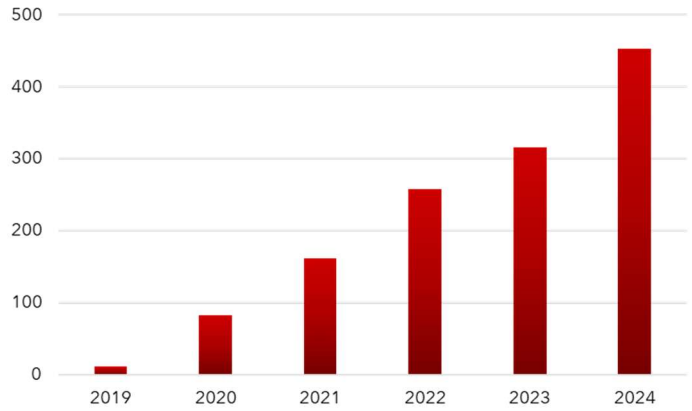
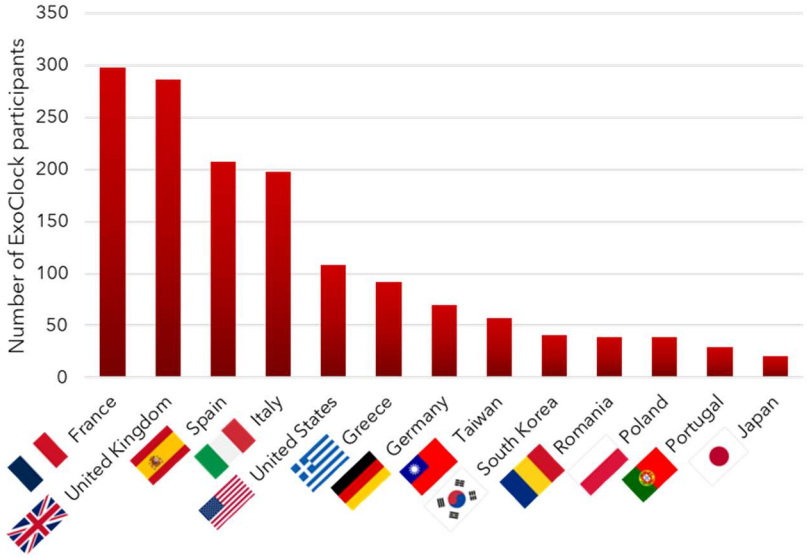


Figure 20 *Number of observers participating in Ariel's ExoClock programme*



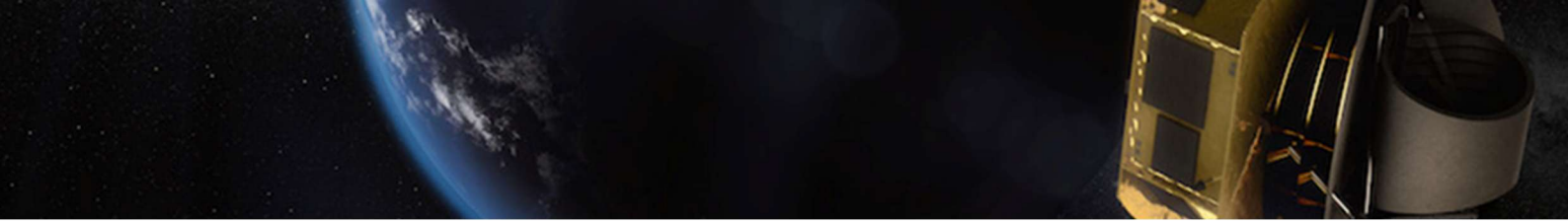
The wider pool of ExoClock participants currently stands at 1,840 and is also 70% amateur. Like the Data Challenge, ExoClock has reached an international audience of participants from a range of backgrounds, helping to raise the global profile of the Ariel mission, and provide hands-on experience for students and amateur astronomers in data analysis and observational astronomy, which is inspiring individuals to participate in Ariel-relevant science, and could sow the seeds for future careers in space science. Currently, the **project has involved a total of 71 countries**, including significant contributions from France, the UK, Spain and Italy.

Figure 21 *Number of ExoClock participants by nationality*



Lowering the barriers to entry for observers

To inspire the next generation of potential space scientists, the ExoClock project has placed significant emphasis on **making the project more accessible to schools, students and amateurs**. In doing so, ExoClock has enhanced participation from individuals who are interested in astronomy, but do not have access to a small or medium size telescope. They have done so through the formation of several partnerships, which have boosted the reach and influence of the challenge. For instance, the ExoClock team has partnered with Las Cumbres Observatory to run the "ExoClock unlocked" project, which hosts 25 telescopes in 7 sites across the world. No prior experience is required, and the participants will learn how to observe exoplanet transits, analyse



the data, and become a co-author in future ExoClock publications. The ExoClock unlocked project has received over 150 applications.

The widespread popularity of the project can also be seen in the responses recorded by participants who have reflected on their experiences with ExoClock so far:

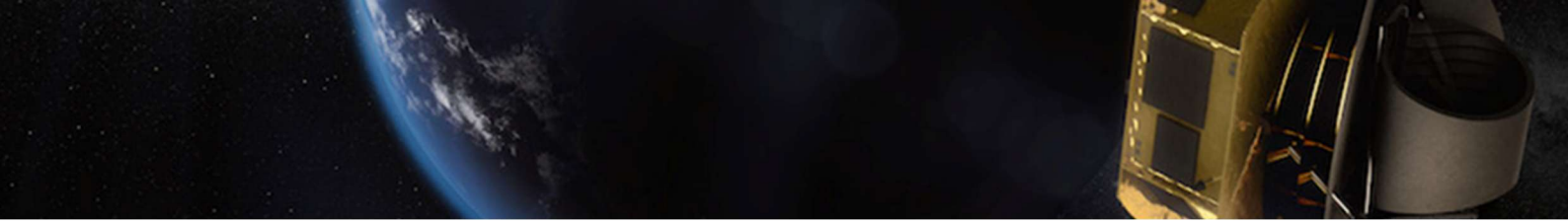
> - *After having analysed HAT-P-7b's transit, I was very motivated to do more analysis. I wish I could do more of this work, and I am now wondering how I can make this dream a reality.*
> - *Exploring exoplanets can be challenging, but every single second of the whole process was captivating.*
> - *One important thing I learned was how to work in an international team, across multiple time zones. It is great to get feedback on our work from professionals and overcome the difficulties of observations together.*

While the impact of the ExoClock programme is global, the UK is the 2nd largest contributor in terms of observer numbers, **driven largely by the team's UK-specific initiatives**. For instance:

- **ExoClock has been integrated into a final year BSc Astrophysics module at the Open University**, where over 150 students have now performed time-series photometry using the Open Science Observatory's remotely operated telescopes in Tenerife.
- **ExoClock has supported a mentorship programme between Hampshire Astronomical Group and the University of Portsmouth**, where students are able to leverage the group's telescopes to submit exoplanet transit observations. Exoplanet research was named by the university as the subject which is attracting the largest number of students to this mentorship programme over the past 15 years.
- **Experiments for nearby schools are being planned at the Greenwich Royal Observatory**, featuring a new telescope that will be used for the first time to support the ExoClock project.

ExoClock project is also partnered with other UCL outreach and education initiatives, such as ORBYTS – **an organisation which tackles systemic diversity issues in UK science**, as well as shortages of science teachers, by partnering researchers with secondary school pupils. ExoClock and Ariel related projects have been delivered in partnering schools, helping to provide role models for aspiring female scientists.

In the future, there are discussions ongoing for **enhanced collaboration between UCL's three Ariel-related outreach and citizen science initiatives** – the Data Challenge, ExoClock, and ORBYTS. Under the umbrella of "Ariel-Edu", these projects cover a range of potential audiences, and could therefore have far-reaching impacts in inspiring wider engagement with the Ariel mission, and potentially laying the foundations for enhanced uptake of STEM subjects in the UK.



Supporting amateur contributions to academic research

To date, there have been **three core publication outputs** from the ExoClock project, which have monitored ephemerides of Ariel candidate targets for the mission. These publications were released in reputable journals such as *Experimental Astronomy* and *The Astrophysical Journal*, and have credited amateur astronomers and students as co-authors.

To date, **160 amateurs and students have been listed as co-authors in ExoClock publications**, although this number is set to increase significantly with the next publication, which will feature at least 340 co-authors. For context, these three publications have also amassed a total of **125 citations**, demonstrating wider interest from researchers in exoplanet science. The upcoming ExoClock publications will feature **30,000 data points on 620 planets**, which is considerably more than the 18,000 data points on 450 exoplanets which were included in the most recent publication.

Contributions from amateur astronomers and students are also recognised through awards, such as those provided to contributors at the annual ExoClock meetings and newsletters, as well as participation awards given to pupils in ExoClock initiatives undertaken in schools.

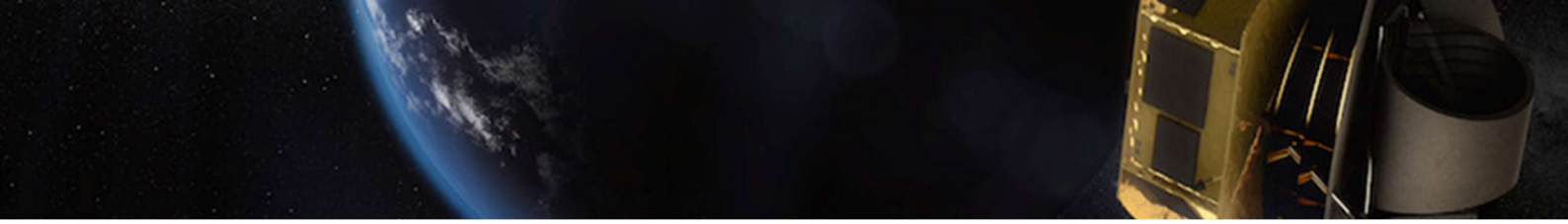
Figure 22 *Certificates awarded to amateur and student participants in ExoClock*

ExoClock activities currently rely heavily on voluntary commitments from the team, which may present constraints on future growth of the programme, due to time commitment limitations. The ExoClock programme catalyses sustained engagement through ongoing review and feedback on data from participants, and there are concerns that current growth in participants may not be sustainable. The ExoClock team are pursuing additional grant funding opportunities, and are in the process of establishing a not-for-profit organisation to attract external sponsorship.

Key takeaways

The ExoClock project has successfully built a global community of participants and observers, supporting amateurs and students to conducting observations of exoplanet spectra. Through newsletters, reviews, and targeted initiatives, the project has inspired teams from the UK to work collaboratively in scientific areas which are closely related to the Ariel mission, **building key skills in data analysis, observations, and international collaboration**. These outcomes are indirectly linked to UK Space Agency's national contribution to the mission, which in-part funds PI Kokori's activities, and has secured UK leadership over the Ariel mission more widely.

In the longer term, ExoClock could attract students to pursue careers in space science in the UK, by providing them with early exposure to the research which underpins scientific publications. This could grow the exoplanet research community in the UK and internationally, and potentially enhance scientific exploitation of Ariel mission data in the coming years and decades. These longer-term benefits could be crucial in enhancing UK space science research competitiveness,



and could have spillover benefits to wider sectors, as broadening participation in STEM subjects could address skills shortages in other high value added sectors of the economy.

3.3.5 Skills development

Project management and coordination skills development within the project team

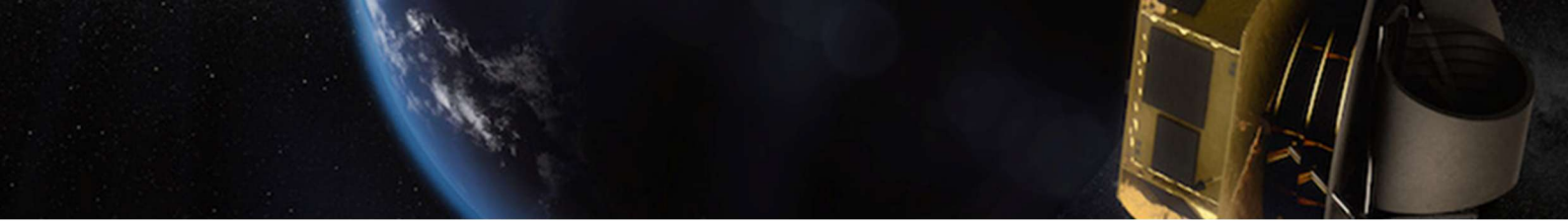
Within the UK project team, we heard how UK Space Agency national investment into the Ariel mission has provided **unique learning opportunities from a project and consortium management perspective**. UK leadership roles held in the science working groups and in the assembly, integration, and testing of the payload place UCL and RAL Space at the forefront of preparatory science and build phase elements of the mission. Currently, the UK leads coordination of over 600 scientists and engineers in the wider Ariel payload consortium.

RAL Space have strong existing heritage in mechanical and systems engineering. They have previously led the integration and coordination of the JWST MIRI imager and spectrometer, and were development leads for the SPIRE instrument on the Herschel instrument. On Ariel, the RAL Space project team are responsible for overall consortium project management, which they have described as a **continuous learning process from a technical and managerial perspective**. RAL Space act as an integrator for 65 partnering institutes from 16 ESA member state countries, while also managing a total of 136 suppliers and subcontractors.

> *"In an independent review, Giuseppe Sarri [from ESA] felt RAL were managing the consortium well. He was surprised what we were achieving with our team, and thought we would need 10 more people to be doing what we are.*

To coordinate delivery of instrument designs, prototypes, subsystems, and hardware, they have repurposed project management tools (such as ECLIPSE Suite), risk registers, and milestone trackers to monitor and align progress across the consortium, while also managing budgets and spend forecasts. In addition to this, the RAL team have managed a close relationship with ESA, as well as with UK Space Agency and the Ariel Programme Management Board. In coordinating a mission of this scale and complexity, RAL have developed new internal processes (which have not been necessary for previous projects) to track the schedules of multiple suppliers. We heard how development and demonstration of these managerial capabilities on Ariel **could help RAL secure future mission leadership roles**. The delivery heritage and contacts established (e.g. by working more closely with ESA and ASI) through managing a complex international space science mission could strengthen RAL's position for future contracts, although this is likely to be contingent on successful delivery of the Ariel payload in the coming years.

At UCL, a core focus of their activities at this stage of the mission has been the management and coordination of the various scientific working groups and citizen science activities (such as the Data Challenge and ExoClock). They have also played a key role in building momentum with scientists through consortium meetings and open science events. To support international collaboration, UCL have also hired an intern specialised in diplomacy, who is supporting the science management activities at UCL through **research into publication and data policy**, identifying good practices and lessons learned from previous space missions with large consortia. This should in turn establish a strong platform for collaboration among scientists in the Ariel consortium which are not member states, and therefore **support scientific contributions from the USA, Japan, and Canada in particular**.



> *So far, leading such a significant mission, the preparatory science, and growing the community, these are the clear benefits.*

Scientific management of the Ariel mission also involves ongoing risk management to ensure the scientific return from the mission is optimised. For instance, Prof. Tinetti is currently considering establishing legal safeguards for the Ariel consortium, to protect and maximise science contributions to the mission. The consortium is not currently a clear entity from a legal perspective, in comparison to ESA or other National Space Agencies. While this has never been done on a space mission before, it may be necessary support wider contributions to the mission, rather than relying solely on multi-lateral agreements for access rights when data releases occur later in the mission.

Technical and digital skills development within the project team

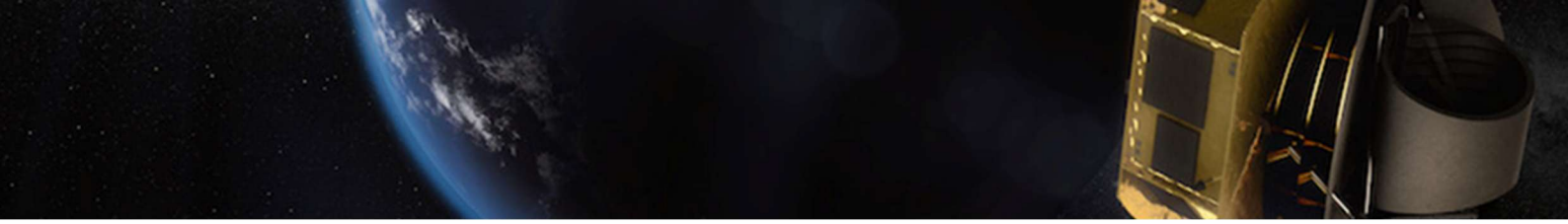
UK roles on the Ariel mission have also provided a pathway to develop high value-added technical skills which are essential to support mission delivery. These skills are often, although not exclusively, developed by early career researchers, graduates, and apprentices who are working as junior engineers, technicians, and software developers for the mission. For many, **the UK's involvement in Ariel has provided individuals with the opportunity to work on a space mission for the first time**.

At the University of Oxford, early career workers are gaining experience as computer-aided design (CAD) technicians, which is supporting hardware assembly and manufacturing of the optical ground support equipment (OGSE). Alongside CAD work, the team at Oxford are developing software and mechanical engineering skills which are applicable to Ariel, but also to other space science missions, such as Ariel's rideshare Comet Interceptor.

Within the technology team at RAL, graduate schemes and apprenticeships have been a key route to upskilling**, supporting a future pipeline of mechanical engineers and technicians**. These schemes have enabled individuals to obtain experience in brazing and welding, as well as develop skills in certifying and traceability work, which are **essential processes for any space mission, and can be taken forward throughout their careers**.

> *One of our technicians has become an experienced welder. Through Ariel, she has got up to speed with ECSS [European Cooperation for Space Standardisation] requirements. This is a massive opportunity for her, and ESA and Airbus were very complementary of her work.*

Cardiff University also have several postdoctoral researchers and PhD students who are applying **digital skills in software development, simulations and data analysis to support the Ariel mission**. While these skills are pre-existing to a large extent, they are being applied to create new tools and processes to enhance atmospheric retrievals, end-to-end instrument simulators, instrument calibration, and data reduction pipelines. Researchers at Cardiff, as leads of the complementary science activities for the mission, are also defining alternative scientific use-cases and developing tools which could support non-exoplanet related research from Ariel data, all while working within the constraints and requirements of the Ariel spacecraft. They are in close consultation with instrument scientists and ESA to define future observation calls for alternative research areas, such as brown dwarves, light curves, protoplanetary discs, and asteroids. For



several researchers at Cardiff University, this is their first exposure to a space science mission, and therefore provides (we heard) **crucial experience in consortium management and navigating ESA processes**.

Development of these technical skills can support career progression of staff working on the mission (as discussed below). They can also benefit organisations by addressing capability gaps, which can be utilised on other projects beyond Ariel, and thereby help organisations to secure **future contract and mission opportunities**. The technical skills developed to deliver Ariel are also niche in-demand skills for the wider UK space sector, and could therefore play a role in **addressing wider skill gaps in the UK space ecosystem** and beyond.

3.3.6 Employment and career progression linked to Ariel

~50 individuals working in the UK Ariel project team, including academics, students, engineers and apprentices

At least 9 promotions of researchers and engineers across RAL and UCL, demonstrating a growing talent pipeline

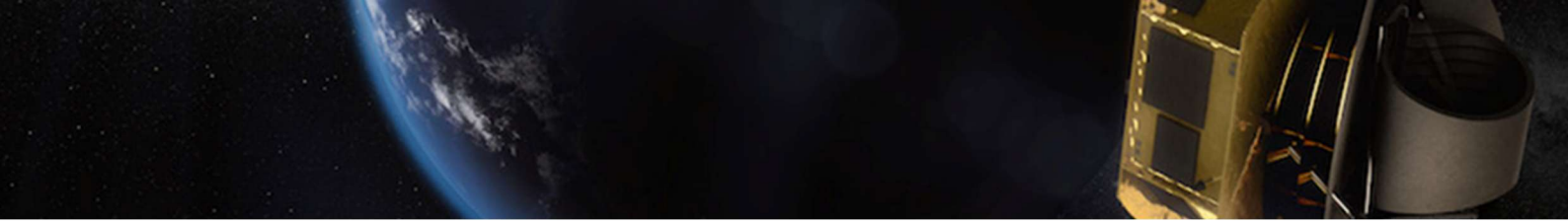
Attraction and retention of staff

There are **approximately 50 individuals** currently working across the Ariel project team in the UK, including permanent staff, PhD students, graduate engineers, and apprentices. Across the funded organisations, UK-based teams generally feature a balanced level of experience, with a strong pipeline of new staff members. The Ariel mission was cited as a key factor in attracting and retaining talent within their organisations:

> - *It has been great to have an incredible, and stable, team. We have only had 1 person leave since 2020, who retired. We normally have a 7% turnover rate. People enjoy working with a large consortium and are proud to work on a mission of this scale.*
> - *We have brought on a postdoc who is key in dataset preparation. He was definitely drawn exclusively by Ariel. He came from Italy but was willing to relocate, meaning we have brought a high-calibre skillset to the UK.*

Generally, stakeholders regarded the UK's role on Ariel as key for early-career individuals, by providing a rare opportunity to **gain direct exposure to a high-profile space mission, as well as interactions with ESA, industry, and an international consortium**.

The team at RAL are undertaking more in-house manufacturing than initially expected, offering a key route for early career progression within the production team. There are **at least 12 apprentices currently working in the workshop** on diverse tasks, of which some include manufacturing components for Ariel. Skills development at RAL Space has facilitated knowledge spillovers to other divisions within RAL Space and STFC, as well as the wider science and innovation ecosystem. For example, some early career workers have gone on to work at organisations such as the Civil Aviation Authority, and in the tech industry.



> *Ariel is the advertisement, and it is a big attractor. All new graduates wanted to be on Ariel.*

However, while Ariel is regarded by many as a strong incentive for the attraction and retention of talent, others have cited the **uncertainty around fixed-term contracts as a key barrier to recruitment and retention of staff**, especially at universities. Many within the project team do not have permanent positions, and therefore face frequent uncertainty and pressure to secure additional grants, which risk detracting from mission delivery. Indeed, one factor influencing Prof. Tinetti's decision to move to King's College London is the opportunity to offer more permanent positions to Ariel-focused researchers with AI and Machine Learning expertise.

Moreover, project team members generally felt that their organisations could not offer competitive salaries relative to the private sector, posing a risk to retention for early-career researchers and engineers working on the Ariel mission. While staff are motivated by a range of incentives, and knowledge spillover between academia and industry can have additional benefits for the UK space sector, **retention challenges could introduce potential for disruption to long-term mission progress, and could lead to skills gaps** in the project team.

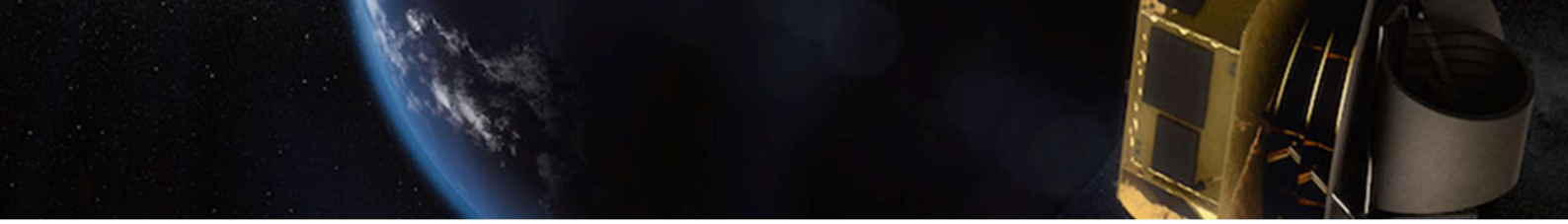
Promotions and career progression

Across the timeframe of our study, roles on the Ariel mission have enabled significant career progression. In total, we have found evidence of **at least 9 promotions** which are attributable to Ariel activities. These are roughly evenly split between early career development of engineers at RAL Space, and academics at UCL, who have progressed from PhD students to postdoctoral research fellows and associate professors.

For example, a RAL Space graduate has been promoted **from graduate to senior engineer**, as a result of managing work packages on Ariel, through which he has received chartership. Meanwhile at UCL, Ingo Waldmann was promoted to Professor, and has since taken a secondment to found an Ariel related start-up company – Spaceflux, which is discussed in more detail in section 3.4.1.

UK funded organisations have helped **maintain a pipeline of researchers and engineers who could support the Ariel mission for years to come**. At the University of Oxford, PhD students from a range of prior backgrounds (including non-STEM subjects, such as English Literature) have been trained in CAD design and have gained experience working with the wider Ariel consortium, including Portuguese partners. Throughout our study, this has created a throughput of talent equipped with technical skills and international collaboration experience, which could be leveraged in the wider UK space sector and beyond. RAL's year-in-industry programme, graduate scheme, and apprenticeship programme is contributing to development of components and materials for the mission, while also enabling the training of the next generation of mechanical and system engineers. At UCL, a new cohort of PhD students in data analytics are providing support to the mission and may progress to permanent positions in the future.

> *We have a postdoc who is travelling to NASA JPL and the National Astronomical Observatory of Japan working on simulations. This is great for the mission, as it ties us closer to these research communities. It is also great for his career. He is publishing lots of research, and he needs to publish to become a permanent staff member.*



Engaging early-career professionals in high-profile missions can help to transfer knowledge, thereby **preventing skills gaps from emerging** as senior staff retire. It is also an essential factor in contributing to the Ariel business case objective of inspiring, attracting and retaining talent to upskill the UK workforce. Over long-term missions such as Ariel, effective knowledge transfer is key for enabling future benefits in the coming years/decades, by preventing single points of failure risks. This risk is prominent within the UK and has been seen in our evaluations of other UK roles on space science missions, whereby the knowledge and capabilities offered by a core team member are lost when these individuals move on.

Additionally, we heard how exposure to real-world mission challenges provide highly specialised technical expertise and heritage which is difficult to obtain, equipping the next generation to drive future space science or commercial opportunities. Investing in early-career talent not only strengthens the workforce but also enhances national and international competitiveness, with potential for spillovers to other sectors of the UK economy.

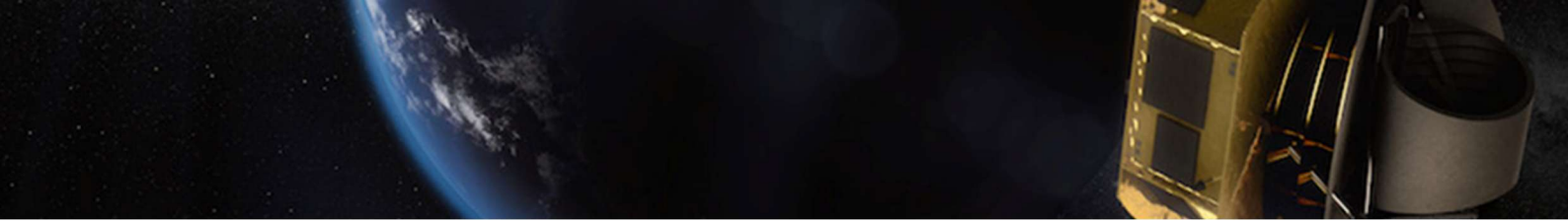
3.3.7 Counterfactual

In a scenario without UK Space Agency support for the mission, **project team contributions to the Ariel Data Challenge and ExoClock are unlikely to have materialised to the same extent.** While both initiatives are not directly funded by UK Space Agency, they are linked to UK scientific leadership roles on the mission, which were secured with the national contribution. Moreover, if the Ariel mission itself was not selected, these initiatives are unlikely to have unfolded to the same extent. UCL researchers could have continued to contribute towards citizen science programmes in absence of the mission (e.g. ORBYTS, which has projects beyond Ariel or exoplanet-related science), though these projects are likely to be **limited by reduced financial and technical resources**, and therefore would have evolved with a different scope and direction.

For instance, the Ariel Data Challenge's focus on widening participation to the AI and Machine Learning community would be severely reduced without **ongoing UK-led work on simulated mission datasets**. Similarly, ExoClock's objective of increasing amateur astronomical observations is likely to be significantly reduced without a core mission focus, which is a strong incentive for participation (e.g. by enabling amateurs to be co-authored in scientific publications which support the Ariel mission). In turn, **de-scoped equivalents of these outreach activities are unlikely to have received such levels of international participation**, and may lead to weaker preparation for Ariel's scientific goals.

In a scenario where leadership of the overall Ariel mission shifted to another member state, there is also a risk that UK participation in outreach activities would also be transferred, with these roles (and potentially key individuals) being relocated away from the UK. In this scenario UK contributions to preparatory science activities would be significantly reduced, and UK-specific initiatives (such as the Data Challenge Hackathons, and ExoClock partnerships with schools and universities) would be lost. This **may reduce the scope of future UK engagement and interest in the mission** and would limit the extent to which the mission can be used to inspire the next generation of researchers in relevant fields.

In terms of public engagement activities, such as conferences, news appearances and outreach events, additionality differs by event. Researchers were not directly funded to conduct these activities and would likely have attended conferences in absence of UK Space Agency support. However, **key mission roles are likely to have played a 'stamp of approval' effect**, meaning UK researchers are invited to give talks and keynote speeches which they would not have otherwise. Some initiatives, such as RAL's Harwell open day, would have materialised anyway, but without an Ariel focus.



In terms of skills development, it is likely that **skills would have evolved in different directions without UK Space Agency support** for the mission. However, UK Space Agency support has exposed UK project teams to new challenges and opportunities inherent with delivering a complex international space science mission. Enhancements in **project management and coordination skills are unlikely to have materialised to the same extent** at RAL and UCL, given the UK contribution was essential in securing these leadership roles. Technical skills could be developed in the delivery of subsystems for other missions, although **it is uncertain whether alternative opportunities would have been secured at a comparable scope** for early-career individuals. In terms of attraction and retention of talent as well as career progression, it is likely that some individuals would have been promoted in absence of UK Space Agency support, however the attraction and retention of a skilled pipeline of researchers may not be as strong without the incentive of a major space science mission, and **there is a risk that skills and capability gaps may have emerged over time**.

3.3.8 Conclusions

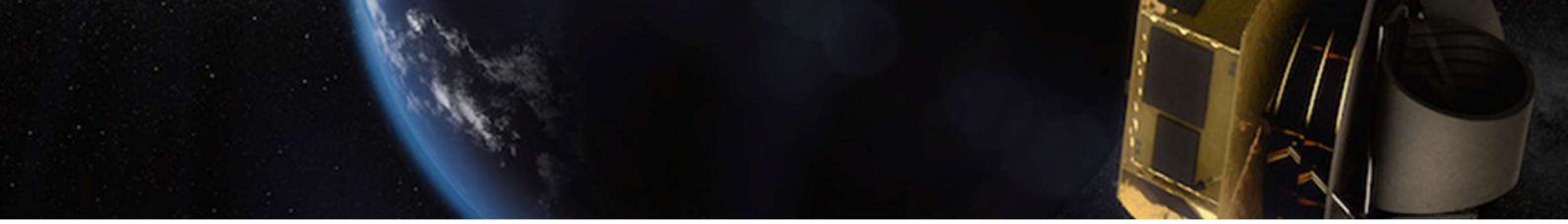
At this early stage of the mission, the UK's roles on the Ariel mission have led to **progress in attracting and retaining talent in the UK**, by using the mission as a key driver of activities in AI and Machine Learning (e.g. through the Data Challenge) and astronomy (including through ExoClock), as well as other mechanical and systems engineering and piece part manufacturing. Benefits to the UK are seen within direct impacts to the project team, complemented by potential indirect impacts of inspiring the next generation through outreach and engagement activities, including the Data Challenge and ExoClock, which have the potential to support a broader base of skills development in the UK, and underpin future impacts. However, potential recruitment and retention challenges due to funding uncertainty, as well as single point of failure risks across UK project team organisations are the key risks for these emerging impacts over the longer term. Below, we assess performance against the evaluation questions which were developed within the Ariel M&E Framework report, in order to track interim progress in benefits realisation associated with UK Space Agency investment.

How effective have Ariel-related communications activities been in terms of breadth and extent of reach?

The public engagement and outreach related activities undertaken by UK project team members (which are not directly funded by the national funding, but that are clearly linked) have **successfully reached a range of audiences**, from researchers and engineers at technical conferences, to appearances on news channels and television for reaching the general public. At this stage of the mission, the number of events attended by the project team is sizeable and has been driven by invitations to UK consortium members to give keynote talks internationally. However, the nature of each engagement activity is at least as important of the number. We assess activities to date as likely to have positive impacts in raising the global profile of the Ariel mission, with the **breadth of audiences and cadence of activity particularly notable** – as each platform has a purpose. Based on previous trends in exoplanet science, we expect future public communications to be centred around the generation of new discoveries on the Ariel mission, meaning significant media attention is likely to follow analysis of future Ariel data releases. **At this stage of the mission lifecycle, we are only able to observe the initial outputs of these activities – the outcomes and impacts will materialise over longer timeframes.**

How successful have Ariel's Data Challenges and ExoClock programmes been in engaging students in the UK?

Both the Data Challenge and ExoClock have been highly successful routes to enhancing participation – with stakeholders frequently citing their innovative approaches to enhancing participation in mission-relevant science and techniques. Several stakeholders have noted that



these activities are unique to space science missions at a comparable level of maturity, and credit these initiatives as instrumental in enhancing preparedness and awareness of Ariel within the wider research community and industry.

While UK-led, both initiatives are **inherently global**, with participation in each of the initiatives seen in over 70 countries. Nonetheless, both the Data Challenge and ExoClock have maintained a core emphasis on **enhancing UK engagement through targeted in-person initiatives**, such as Hackathon events, and projects in UK schools, universities, and observatories. While students certainly benefit from these activities, the Data Challenge has also been particularly successful in engaging industry. Future collaboration potential with UK-based members of DeepMind (the 2024 Nobel prize winners in chemistry) is an example of the reach of the challenge into the AI and Machine Learning industry, which could support cross sector knowledge spillovers between exoplanet science and AI/ML. In turn, this could lead to enhanced analytical techniques for the Ariel mission, as well as the development of new or enhanced products and services from UK companies over the long term. It will be important to track these impacts in future.

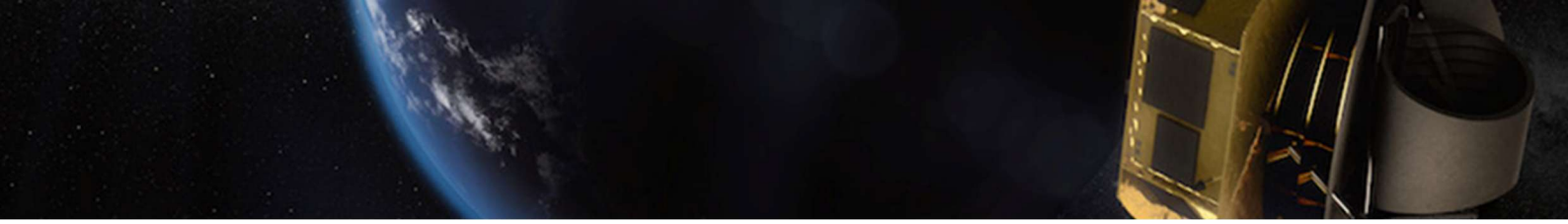
To what extent has the UK Space Agency investment supported the upskilling of students and researchers directly involved in Ariel to date? What are future expectations as the mission progresses?

UK project team members have maintained a **pipeline for early-career individuals to obtain exposure to a large space-science mission**, including cohorts of PhD students at universities, but also graduates, year-in-industry placements, and apprenticeships at RAL Space. To date, there have been at least 9 promotions for team members directly involved in the Ariel mission, demonstrating an evolution of roles and responsibilities within the 2-year timeframe of our study. The Ariel mission has been cited as a key factor in attracting and retaining staff, including early-career researchers, despite the challenges associated with fixed-term contracts. Given the significant investment in training early-career staff for these roles, the mission contributes to enhancing UK capabilities by developing talent rather than relying solely on senior hires. However, the long-term impact on workforce stability and retention may depend on continued opportunities beyond the mission itself, as well as consistent sources of funding.

These trends are likely to continue into the future, with a steady cohort of PhD students working on mission relevant science and techniques. Future upskilling opportunities could increase in the run up to, and following launch, where the emphasis will move from preparatory science to **interpretation and exploitation of Ariel mission data**. These future trends are likely to be contingent on the availability of grant funding from other sources, such as UKRI, however the emphasis on open science and incentivising collaboration – driven largely through top-down efforts from the PI – are expected to provide upskilling opportunities for researchers in astronomy and AI machine learning fields, which could provide longer term productivity enhancement and support advances in the generation of new scientific knowledge and spillover application potential.

To what extent has the UK Space Agency national investment in Ariel upskilled the space talent pipeline to date?

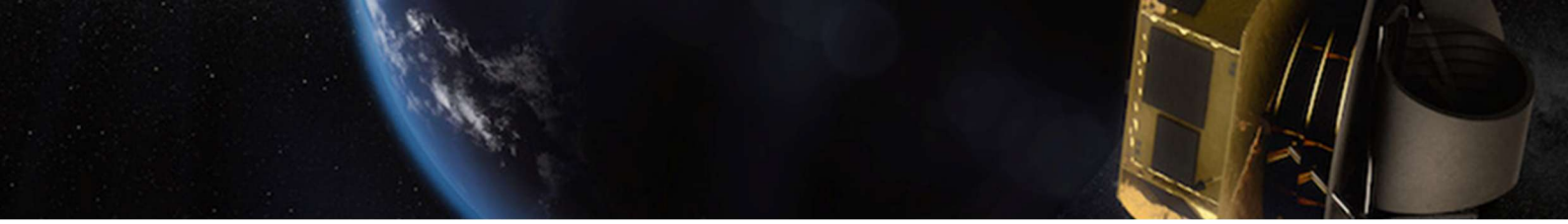
These initial steps, while promising, are a **small part of a longer-term strategy required to address skill and capability gaps within the UK space sector**. For instance, the Ariel mission is playing a central role in developing AI and Machine Learning skills, both through the ongoing preparatory science activities, as well as wider outreach through the Ariel Data Challenge and Hackathon events. This is perceived to be a **key skills gap in the UK space sector**, with 72% of respondents to the *2023 Space Sector Skills Survey* reporting gaps in software and data skills – driven largely by a lack of AI and Machine Learning (41%) and data analysis and modelling (36%)



skills[24]. While we are at an early stage of the true routes to impact, these initiatives are sowing the seeds for addressing these capability gaps in the longer term.

The same is also true of other core skills relevant to the Ariel mission. While systems engineering was cited as a core skills area being developed at RAL, **systems engineering is cited as the most challenging area to recruit for in the wider UK space sector**, where demand is high and there are significant challenges in finding suitable staff. UK Space Agency national funding for the Ariel mission can be credited with enhancing competencies in these critical skills gaps, although to date these skills have largely been leveraged to fulfil mission roles and requirements. In the longer term, these skillsets can be leveraged for future missions, projects and spillover opportunities (early evidence of this is seen through the Ariel-related start-up companies, discussed in section 3.4.1).

[24] Space Skills Alliance, know.space, 2023. *Space Sector Skills Survey 2023*. Available at: https://assets.publishing.service.gov.uk/media/650078401886eb0013977223/Space_Sector_Skills_Survey_2023_final2.pdf



3.4 Innovation

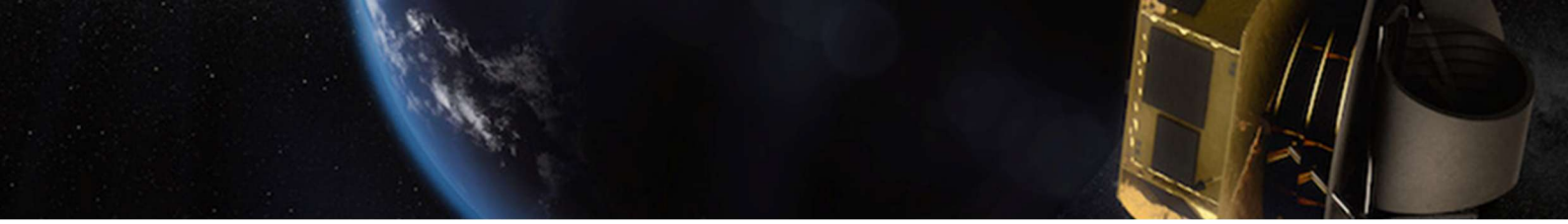
This section investigates Ariel's role in **stimulating innovation and commercial opportunities through technology development and research related to the mission**. At this stage of the mission, direct roles and responsibilities, such as instrument development and preparatory science, are understandably the priority for the UK project team. Given we are monitoring trends within a mission that is not due to launch until 2029, it is inevitable that many commercial opportunities will not unfold or be realised until the mission is at a more advanced stage.

However, there have been promising early developments in the spillover of knowledge and techniques developed for the mission to other applications, with some early commercial opportunities being identified and leveraged through start-up and spin-out companies, as well as through new contracts and potential mission roles. Recognising many opportunities will only occur on timescales beyond this evaluation, we have also tracked commercial exploratory discussions throughout the timeframe of our study, which will require monitoring in the future to identify where potential benefits have been realised.

> - *There is a nexus of entrepreneurialism in the consortium, with very talented people doing a lot to make these things happen. They are leading to some impressive outcomes already.*
> - *Science missions like Ariel are the funnel which enable longer term spillovers and economic returns.*

Summary of key trends

- **We assess the UK contributions to the Ariel mission as having a promising early impact in stimulating commercial opportunities across both data science and space technology.** Notably, close industrial-academic knowledge exchange in AI and data science, and potential follow-on mission opportunities for space technology are two key routes for commercial benefits.
- **The Ariel mission has catalysed follow-on contracts and funding for UK industry, supporting the growth of the UK space sector.** In total, at least £14.6m in contracts and follow-on funding has been secured by UK organisations at least in-part as a result of Ariel. This largely stems from recent developments at Blue Skies Space and Spaceflux, but also revenues secured by the University of Oxford, as well as facility and equipment upgrades at RAL.
- **Scientific leadership over the Ariel mission has supported the growth of Blue Skies Space (BSSL).** BSSL was founded in 2014, inspired by Ariel's design precursor, ECHO. The organisation is pioneering a commercial approach to space science by developing small satellites for exoplanet and stellar research. Their upcoming missions, Mauve and Twinkle, will meet data demands for the global scientific community. UK leadership in Ariel was cited as a key factor in building investor confidence. The company has also contributed to UK space sector growth, employing 14 staff and facilitating knowledge exchange between academia and industry.
- **Ariel was also key in establishing Spaceflux, a space situational awareness (SSA) company which leverages AI/ML techniques developed as part of UK contributions**



to the Ariel mission. Founded in 2022, Spaceflux has rapidly expanded to become a leading global provider of SSA capabilities for the UK. They have secured at least 4 UK government contracts, including Project NYZ, delivering the UK's first sovereign optical SSA system. To support growth, Spaceflux has grown to 31 staff (at the time of writing), including senior industry leaders.

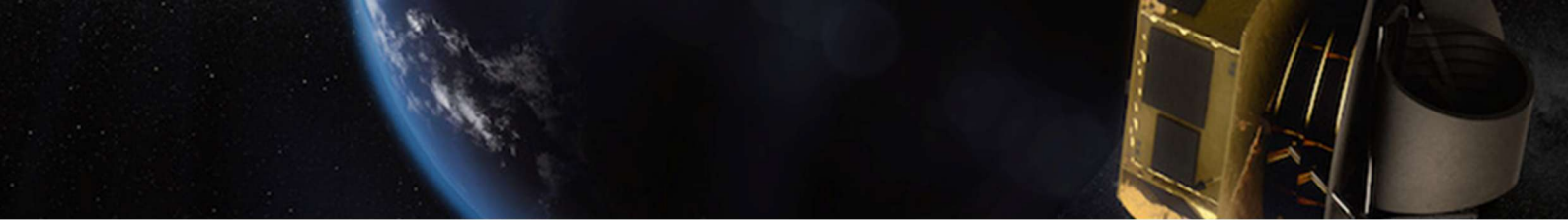
- **Beyond the project team, UK Space Agency investment into Ariel has led to wider benefits to the UK supply chain.** RAL Space have spent £1.2m on procurements to industry in the UK, primarily to companies in the South East (32%), but also in Northern Ireland (16%) and London (11%). These could catalyse additional economic benefits for UK suppliers.
- **Over the longer term, the project team are also pursuing commercial opportunities which could lead to sizeable impacts for the UK.** We have identified 4 emerging commercial discussions which could provide broader economic benefits to the UK over the longer term. Progress in these areas should be tracked to see the extent to which these opportunities materialise. They include the abovementioned developments at BSSL and Spaceflux, 3 emerging spin-out companies, Cardiff and RAL Space being shortlisted for involvement on a $1bn NASA mission (PRIMA), and industry involvement with the Data Challenge. An additional 4 opportunities are identified, although these are less advanced at the time of writing this report (March 2025).
- **We assess that many of the preliminary commercial benefits seen to date are unlikely to have materialised in the same way without UK Space Agency support.** UK roles on the Ariel mission have been strong contributors to the continued success of both related start-up companies, and was UK Space Agency funding was linked to follow-on funding secured at RAL, although these impacts cannot be considered solely attributable. Ongoing commercial discussions are also linked to UK roles on Ariel, alongside previous delivery heritage on other space science missions.
- **At this very early stage, the cost of the UK's investment into Ariel exceeds monetisable UK benefits.** The Net Present Social Value (NPSV)/ Departmental Expenditure Limit (DEL) is -0.82 if only realised costs are included and -0.92 if we include expected future mission costs. Two large investment investments into an Ariel-related start-up, BSSL, drive benefit to date. The negative NPSV/DEL should not be a cause for concern given the early stage at which this assessment has been carried out and the importance of non-monetisable benefits in driving overall impact.

3.4.1 Start-up companies linked to Ariel

Two of the most notable and mature commercial developments related to the Ariel mission are the UCL-linked start-up companies that have benefitted from technical and knowledge-based spillovers from the Ariel mission: Blue Skies Space Limited and Spaceflux.

Both companies adapted aspects of cutting-edge technology developments and expertise developed through the Ariel mission into commercial markets in different sectors, in turn generating high value jobs in the UK economy and generating private investment. Beyond commercial benefits, both companies maintain close ongoing links to the Ariel mission and could benefit the mission further through complementary provision of data from ground-based and in-space data of Ariel target candidates.

Below, we provide an overview of both companies in case-study form, outlining outcomes, benefits and impacts which have occurred over the timeframe of our study, isolating the role of the UK Space Agency national investment into the Ariel mission to the greatest extent possible.



3.4.2 Case Study: Blue Skies Space Limited

Context and overview

Blue Skies Space Limited (BSSL) is a start-up company **founded in 2014**, hence predating the Ariel mission (and UK Space Agency's national investment). The company was established by UCL researchers when formulating the predecessor mission concept to Ariel – ECHO – and is producing small satellites that can provide space science data to the community on exoplanets and stellar activity (although exploitation of the data will depend entirely on the users).

This commercialised approach to space science is the first of its kind, whereby BSSL work with leading satellite manufacturers to deliver small satellites that will meet data demands in the user community. The data access model comprises of direct observation time or annual memberships, enabling faster access to the scientific community, while also facilitating collaborative science programmes through their portal, Stardrive. The company provides increased data availability for the astronomy community, mitigating the temporal data gaps left by long lead-times for larger space science missions.

Recent developments

2 upcoming satellite launches
Mauve and Twinkle

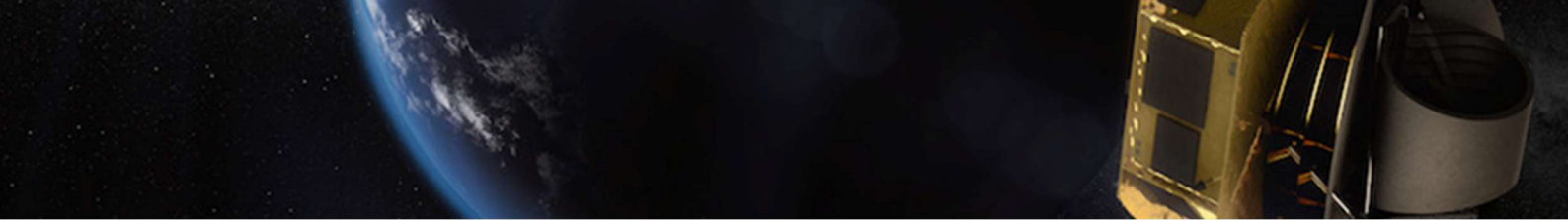
11 countries featured in the science consortia

BSSL have two upcoming space satellites which will secure future revenue opportunities – Mauve and Twinkle. The former is **scheduled for launch in October 2025** on a SpaceX Falcon 9 rocket within the Transporter-15 mission, and the payload has been successfully tested and shipped for satellite integration. Mauve is a Ultra Violet satellite which will be used primarily for stellar science, and will enable a collaborative 3-year survey of stars within our galaxy, including their magnetic activity, flares, and the potential impact on the habitability of neighbouring exoplanets.

By providing data on UV spectra, Mauve bridges the data gap since previous observations from the International Ultraviolet Explorer (IUE) in 1996 and the Galaxy Evolution Explorer (GALEX) in 2013[25]. The Mauve survey programme includes a range of international consortium members who will leverage the data, such as the National Institute of Astrophysics in Italy (INAF), Boston University (USA), the National Astronomical Observatory of Japan, Rice University (USA), Vanderbilt University (USA), and Western University (Canada). The University of Kent and the Europlanet network will also help to maximise the scientific return from the satellite.

BSSL's next satellite will be Twinkle, which will comprise of a visible and infrared spectroscopy satellite to study exoplanets, stars, and solar system objects through a multi-year collaborative survey. The extrasolar survey will enable atmospheric analysis of exoplanets to **complement the Ariel mission** (and JWST). The consortium includes Cardiff University, Centro de Astrobiología (Spain), the Origins Excellence Cluster and Ludwig-Maximilians University in Munich (Germany), the Alternative Energies and Atomic Energy Commission (France), as well as the universities of Nanjing (China), National Tsing Hua University (Taiwan), Ohio State (USA), Central Lancashire, Delaware (USA), Toronto (Canada), Southern Queensland (Australia), and Vanderbilt (USA).

[25] BSSL, 2025. *Mauve*. Available at: https://bssl.space/mauve/



Commercial benefits

Secured ~£5m in investment including Japanese and UK-based investors, as well as EU funding

Has grown to ~20 employees including ex NASA, Airbus, SSTL and UCL staff across the UK and Italy

While BSSL has not generated revenues yet, the company has secured economic benefits for the UK in the form of public and private investment. In 2024, BSSL secured £2.3m of investment in their pre-series A investment round, including significant investment from SPARX Group - a partnership of seven Japanese companies who have developed a 'Space Frontiers' fund, including Toyota, Mitsubishi Heavy Industries, and five banks. This investment follows a UK Department of Business and Trade-supported visit to Japan. In total, **BSSL has raised approximately £5m** since inception, with other sources of investment including SFC Capital (UK), as well as grant funding from Horizon Europe and other sources[26].

While UK Space Agency support for the Ariel mission was not the only factor in securing these contracts and investment, **UK leadership over the mission was cited as a key factor in providing confidence to investors**:

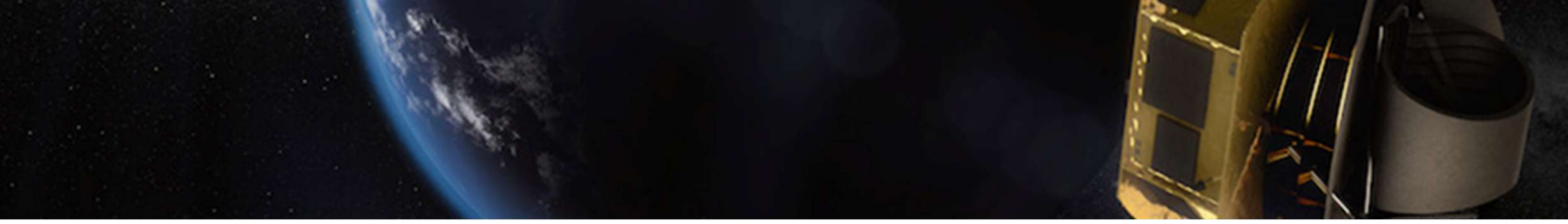
> - *These successes were only possible because we have leadership. Her [Ariel PI Prof. Tinetti] leadership of an ESA mission is an immediate 'tick in the box' for investors, which demonstrates we know what we are doing.*
> - *For a company at our stage, investment and grants are less about what you have delivered, and more about the perception of the team. Giovanna's [Tinetti] leadership provides this confidence.*

BSSL has also catalysed employment benefits, helping to attract talent to the UK, and contributing to the growth of the UK space sector. The company currently has 14 employees, as well as 6 founders, advisers and supporting staff roles across the UK and Italy, including ex NASA, Airbus, SSTL and UCL staff. This growth in employment will (we heard) help BSSL to scale, innovate, and pursue additional opportunities, and has already supported knowledge exchange between academia and industry.

Ongoing links to the Ariel mission

Since inception, BSSL has been strongly linked to the Ariel mission (despite predating UK Space Agency national contributions) and this has continued over the timeframe of our study. Scientifically, there are **significant crossovers between the Twinkle concept and Ariel**, which leverage similar spectroscopic techniques, will both conduct atmospheric analysis of exoplanets, and experience similar challenges – thereby providing opportunities for mutual learning between BSSL and the Ariel project team. Moreover, BSSL has hired staff from UCL, who were able to get direct exposure applying these techniques on a space mission due to Ariel:

[26] Techcrunch. 2024. UK satellite startup Blue Skies Space wants to sell astronomy data 'as a service'. Available at: https://techcrunch.com/2024/08/07/uk-satellite-startup-blue-skies-space-wants-to-sell-astronomy-data-as-a-service/



> *We have got access to some excellent members of staff as an indirect result of the Ariel mission.*

BSSL have also benefitted from knowledge exchange within the Ariel/ESA ecosystem. Through Prof. Tinetti's leadership role, as Ariel PI, she has developed knowledge of the directions the broader space science is heading in, which have helped to **identify priority use cases and market opportunities** in a strategic advisory capacity.

> *If it wasn't for the leadership opportunities the UK has on Ariel, I don't think we would have come up with the idea for the business.*

Stakeholders from BSSL also felt there was potential for future mutual benefit with the Ariel mission, as Mauve and Twinkle **could be leveraged to analyse parts of the Ariel target catalogue**, helping to validate Ariel data while also providing additional observation time to a wider pool of researchers outside of the Ariel consortium.

3.4.3 Case Study: Spaceflux

Context and overview

Spaceflux are the second UCL-led start up linked to the Ariel mission. They were founded in 2022, established by three AI and Machine Learning and Astrophysics researchers at UCL. In 2024, Ariel scientist Prof. Ingo Waldmann took a secondment from UCL to pursue Spaceflux's continued growth as Chief Technology Officer, although he still provides support and advisory services to initiatives such as the Ariel Data Challenge. **Spaceflux have leveraged AI and Machine Learning capabilities developed for exoplanet science and astronomy to provide space domain awareness (SDA) capabilities**. The company provides a proprietary global network of sensors and AI data analysis to monitor space infrastructure and debris risks.

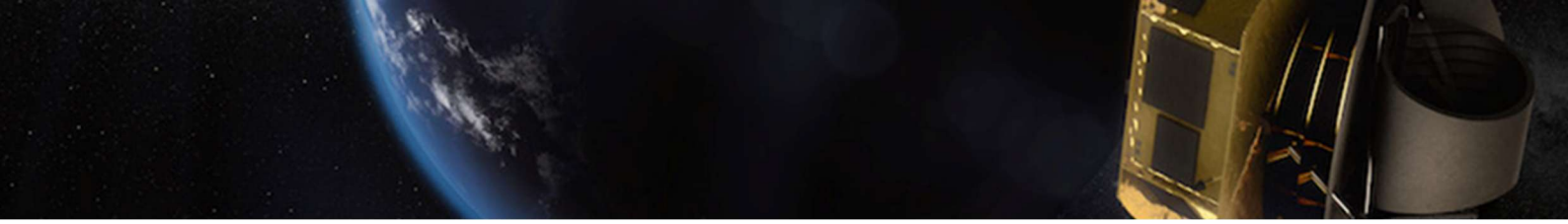
Recent developments

1st company in the world to report the Intelsat 33e fragmentation event

Strengthening **UK Space Domain Awareness (SDA)** capabilities through AI

Since inception in 2022, Spaceflux have significantly enhanced their tracking and characterisation capabilities through improved sensors and an improved data analytics platform – CORTEX. The company have now established telescopes in Spain, Cyprus, Australia, the US, and Africa, and have also established Spaceflux Labs, which is a London-based unit dedicated to cutting-edge R&D between the nexus of academia and industry (also led by Prof. Waldmann). In 2024, Spaceflux labs tracked the breakup of geostationary communication satellite Intelsat 33e, becoming the **first company in the world to report the fragmentation event.**[27] Spaceflux are

[27] Spaceflux. 2025. *Navigating the Fallout: A Case Study on Spaceflux's Role in Tracking the Intelsat 33E Fragmentation.* Available at: https://spaceflux.io/navigating-the-fallout-a-case-study-on-spacefluxs-role-in-tracking-the-intelsat-33e-fragmentation-2/



the only contracted commercial provider of geostationary satellite tracking data for the UK MoD and UK Space Agency, offering world-leading SDA and SSA capabilities.

Commercial benefits

Secured ~£5m in contracts from UK Government to develop testbeds and enhance sensor network

Has grown to ~31 employees including an ex-Google data scientist, orbital analysts and AI / ML experts

The recent success of Spaceflux is closely linked to **four major contracts** that they have secured with UK Space Command, Dstl, and UK Space Agency, which total approximately £5m, and that have significant follow-on potential. One contract was awarded for 'Project NYZ', delivering the UK's first sovereign optical SSA system, which was installed and commissioned in Cyprus in 2024. Another was for an Infra-Red telescope testbed which could enhance satellite and space debris tracking with 24 hour monitoring and **could position Spaceflux for future contract opportunities** with the UK government and other customers.

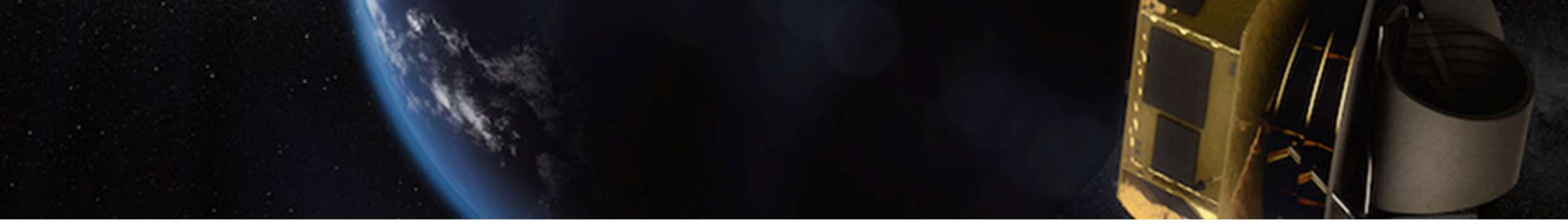
Spaceflux have also been working to secure additional investment and expand their client base further. They were named as one of ten international companies on the 2024 Seraphim Space Camp Accelerator, which provides a three-month course of networking and mentoring support in order to catalyse investment. Spaceflux, like BSSL, have also attended trade visits to Japan, although we have no evidence of additional investment which has been secured as a result of these activities to date.

To deliver on these contract opportunities and catalyse additional growth, Spaceflux have hired **approximately 28 staff members across the last three years**. These hires cover a range of roles and seniority levels, including recruiting a new head of product from Google, and a Chief Strategy Officer who previously worked at Cisco and Serco at Director level, as well as orbital analysts, data scientists, and project managers. To support the continued growth of the company, and to ensure a pipeline of AI and Machine Learning and SSA capabilities, the company also have several initiatives in the pipeline through their 'Spaceflux Labs' endeavour:

> - *We are setting up a permanent internship scheme with universities, starting with the UCL Centre for data intensive science and industry (DISI).*
> - *We also want to co-fund PhD opportunities to work across both Ariel and space situational awareness sciences. We have laid the groundwork for this with the establishment of Spaceflux Labs.*

Ongoing links to the Ariel mission

While there are a multitude of factors to consider when assessing the growth of Spaceflux, it is clear that Ariel played a fundamental role in the formation of the company. While at UCL, Spaceflux's three co-founders first met when working on Machine Learning solutions to calibrate Ariel datasets:



> *It would definitely have been harder to establish Spaceflux without Ariel. We all met while working on Ariel. The knowledge base within the team is also a key element.*

Moreover, the skills and capabilities which are now being leveraged in and SDA and SSA context were initially developed for Ariel, with one founder stating they use "similar data cases", demonstrating how mission-driven innovation for Ariel can be repurposed in other aspects of the space sector and reinforce UK leadership in emerging sectors of the space economy. As mentioned previously, Spaceflux aims to provide industry opportunities, through internships and PhD co-funding schemes for researchers at UCL working AI applications relevant to the Ariel mission and SSA. These opportunities could translate into long-term strategic benefits for the UK, through strengthening a high-skilled workforce across SSA, AI, and space science , which could help to boost the UK space economy and strengthen the UK's national security.

Spaceflux, like BSSL, also aims to complement Ariel, demonstrating **ongoing close links between these start-up companies and the mission**. Spaceflux will provide ground-based data sources from their telescope network, helping to validate observations made by the Ariel telescope. They have stated that these contributions to the mission will be given to the consortium free of charge, but access to this data is typically priced conservatively at ~£2,000 an hour (at a preferential rate).

> - *We can use our telescopes to provide continuous observations of the star/planet systems before and during Ariel observations. Given the size of our network, we can provide continuous coverage across the whole sky.*
> - *The long period photometric observations are useful for Ariel science as they allow us to disentangle signals originating from the star and the planet.*

3.4.4 Contracts awarded to UK industry which are linked to the Ariel mission

£14.6m **In contracts and follow-on funding to UK industry** in-part attributable to Ariel (including RAL Space)

In total, we have identified at least £14.6m in contracts or follow-on funding to UK industry (including RAL Space and the University of Oxford) which have been secured in-part due to UK Space Agency investment into Ariel. Roughly ¾ of this total is comprised of contracts and funding awarded to Ariel-related start-up companies BSSL and Spaceflux, although due to the defence-related nature of Spaceflux's contracts, our figures may be an underestimation based on the data available to us. In terms of attribution, **UK Space Agency support for the Ariel mission is strongly linked, but is not the only factor in securing these contracts, funding, and investment events**. Both start-up companies are closely linked to the Ariel mission, but have also received wider support to pursue and secure these opportunities.

The remainder of this total is follow-on funding secured by RAL Space to **finance facility upgrades**, such as a new acoustic test facility, brazing furnace, and vacuum pipe equipment. The Ariel mission was identified as a 'key strategic need' for in-house testing capabilities within the business case, although this was also strengthened by the fact that it will be used in the future for

commercial satellite testing. RAL also secured UKRI World Class Laboratories Fund support for additional facilities, where Ariel helped to justify this funding, but may have not been the only factor in securing this funding.

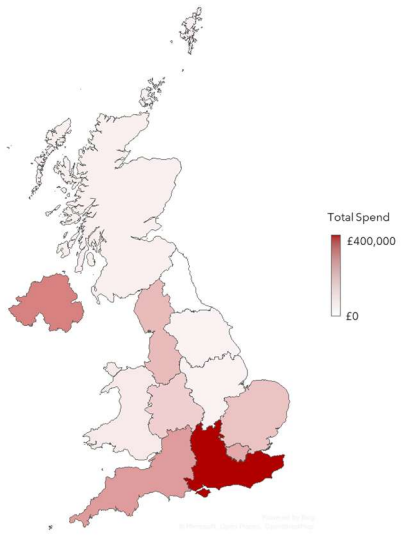
The University of Oxford generated approximately £300k in FY2023/24 by **selling optical coatings to consortium partners at CNES**, via Oxford's Infrared Multilayer Laboratory (IML). Although not solely attributable to UK Space Agency funding, this opportunity arose through partnerships formed within the Ariel consortium. The same team at the University of Oxford also sold £150k worth of filters to a US-based company, supported by their involvement in Ariel's rideshare mission, Comet Interceptor. These successes demonstrate how UK space science can drive early export opportunities for UK organisations, with the potential for future repeat business.

These developments illustrate **promising early commercial impacts** of the Ariel mission, with the potential for further contracts and funding opportunities outlined in the future. Moreover, this funding will help to strengthen the UK's capacity to undertake R&D activities in the future, as RAL's new facilities can be used on other projects in the future, reducing reliance on facilities in France or Germany.

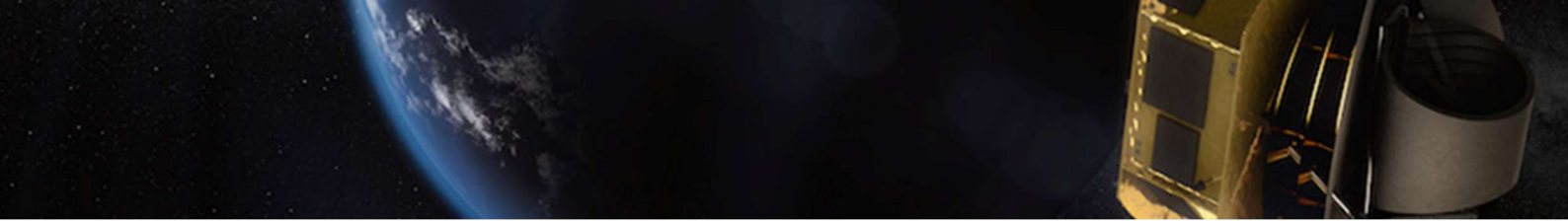
3.4.5 Wider benefits to UK suppliers

Beyond related start-ups and benefits to UK project team members, Ariel has provided **additional contract opportunities for suppliers**, representing realised benefits to UK industry as a result of the UK's prominent position on Ariel. RAL Space have awarded **£1.2m in contracts to UK suppliers since 2020**, including 136 different companies. Examples of suppliers include companies which specialise in etching, sensors, optics, bearings, and precision tooling. For context, these procurements have not been counted in the total above, since they are funded through the UK's national contribution to the mission. However, they do provide a useful indication of how Ariel funding has been allocated beyond the immediate project team, and the regional distribution of these impacts. These contracts have therefore stimulated activity in the wider UK sector and economy.

Figure 23 *RAL Space Contractor Spend on Ariel per Region and Devolved Administration*



As illustrated in *Figure 23*, the majority of RAL procurements (32%) have occurred in the South East of England, which is likely due to the close proximity to RAL as well as the cluster of aerospace companies and suppliers in the area. Moreover, heritage and expertise in engineering



from automotive racing was also cited as a likely factor for the concentration of suppliers in the South East. 16% of RAL's purchase spend (£200k) was secured by companies in Northern Ireland, while 11% was allocated to London companies. Supplier contracts from RAL Space were awarded to all regions except for the North East of England. This indicates a relatively broad spread of contracts across the UK, including to regions without organisations holding UK leadership roles on the mission.

These contracts provide revenue streams to the UK's space supply chain, which could allow suppliers to expand operations, invest in new capabilities, and support/grow their workforce. The capabilities to generate high-specification space components could also be leveraged in other high-tech industries, providing another route to technical and knowledge spillovers from Ariel. These benefits are likelier to materialise for more sizeable contracts, such as the **5 which exceed £50k** - including organisations from Northern Ireland, the South East, North West, and East of England, and London.

In total, 64% of RAL Space's contractor spend was UK-based, while £747k was spent overseas, largely in Spain (this was cited as due to significantly lower costs than comparable UK suppliers). Without UK leadership over the Ariel mission, these contracts to UK companies through RAL Space are unlikely to have materialised to the same extent. While the trends above have highlighted contractor spend to date, it will be important to track how this spending has evolved over time, as well as the wider impacts catalysed within the UK supply chain.

3.4.6 Other commercial opportunities formed from UK-led Ariel activities

While realised commercial benefits indicate a promising early trajectory for the mission, there are other potential benefits linked to UK Space Agency's national investment in the Ariel mission **which may accrue over longer time horizons**. Throughout the timeframe of our study, we have tracked early exploratory discussions held by members of the UK project team to track initial 'needle shifts' in commercial benefits which could materialise as a result of involvement in the Ariel mission. Some of these are likely to run their course or fade over time, while others could (and in some cases have) mature(d) into more concrete arrangements. In order to support benefits realisation in these areas, we have provided recommendations to UK Space Agency in section 2.3.

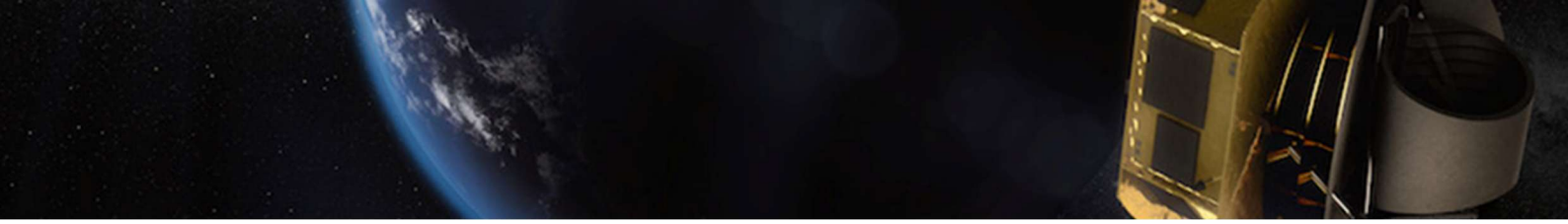
For context, we have defined two broad tiers for these opportunities: (i) **well-defined commercial opportunities** which have formalised over our study, and (ii) **early exploratory discussions** which are yet to materialise (or may rely on interdependencies), but that could provide avenues for fruitful commercial involvement and/or collaboration in the future. In total, we identify **4 formal collaboration opportunities currently being discussed or beginning to materialise**, illustrating good progress against the UK Space Agency benefits realisation target of 1-5 commercial exploratory discussions by 2029, and featuring additional progress in the last 6 months. Additionally, there are 4 opportunities which have the potential to lead to benefits for UK organisations, the wider space sector, and the UK economy, although these are still early-stage.

Well-defined commercial opportunities

1. Industry partnerships with the Ariel Data Challenge (ADC)

The ADC's strong ties to industry have helped to elevate the profile of the challenge, and are strengthening AI and Machine Learning contributions from industry to the mission, thus generating spin-ins to the space sector, as well as future sponsorship and contract opportunities.

For instance, Portuguese AI and Machine Learning company ML Analytics were the first winners of the Ariel Data Challenge and had no prior experience in the space sector (previously working



predominantly in finance). They have since won two ESA contracts to formally join the Ariel consortium at a value of €171,600, and have supported recent Data Challenges and the Harwell Hackathon with in-kind support, guest speaker appearances, and judging responsibilities. This highlights the potential that a UK-based company could also follow a similar trajectory.

The collaboration with Kaggle has also secured significant sponsorship money and in-kind support. For example, Kaggle helped to introduce identify verification to the challenge as it grew in popularity, to safeguard the integrity of teams and prevent individuals from creating multiple accounts. There are also ongoing discussions with Nvidia and DeepMind around future challenge involvement and internal hackathon events illustrate future indicate **concrete spin-in, sponsorship and contract potential**.

2. Recent Spaceflux and Blue Skies Space company growth

As illustrated in the case studies above, Ariel activities have catalysed the growth of both Ariel-related start-up companies, which have secured ~£10m in contracts, investments and grant funding since inception. These developments should be considered as realised commercial opportunities, though there is significant potential for continued company growth in the coming years, for example linked to Mauve satellite data access and the Spaceflux infra-red testbed proof-of-concept currently being developed for Dstl.

3. Additional Ariel-related spin-out companies

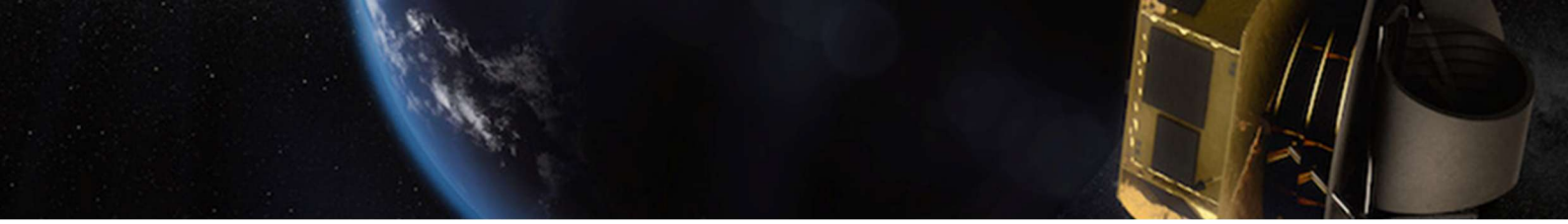
UK involvement in the Ariel mission has also catalysed early progress through 3 early-stage spin-out companies, which have the potential to attract investment, create jobs in high-value added sectors of the UK economy, and lead to mutually beneficial knowledge exchange between the mission and industry.

Firstly, the Ariel Data Challenge and ExoClock project both have long-term aims of financial sustainability through the establishment of not-for-profit spin-out companies. The former has made more tangible progress towards this aim, with the establishment of PLANETAI CIO – an entity which may help the ADC team to navigate funding bottlenecks and spin-out the business model of the Data Challenge to other priority fields of research and sectors (e.g. climate modelling). A similar approach is being pursued with ExoClock, in order to grow the team and potential reach of the project further, although this has not been established at time of writing this evaluation (March 2025).

Additionally, Cardiff have established a spin-out company called Sequestim Ltd, which leverages filters and cryogenic detectors for security imaging. If successful, the company would provide 'walk through' security detectors, significantly speeding up security checks in high-footfall settings such as airports, train stations, and large events. The hardware leveraged to develop demonstrator systems are not attributable to the Ariel mission – they are linked to other activities at Cardiff, such as involvement on the ESA Herschel mission. However, two Ariel project team members are leveraging the skills in data handling and processing from the Ariel ground segment to train AI software to identify signatures of potentially hazardous objects. The company is currently seeking investment, and if successful, could capture market share within a large terrestrial market, benefitting in part from involvement on the Ariel mission.

4. University of Cardiff and RAL Space selected for involvement in the shortlisted NASA PRIMA mission

The University of Cardiff and RAL Space, alongside the University of Sussex and Imperial College London, are involved in one of two proposals shortlisted for NASA's next $1bn probe mission – the Probe far-Infrared Mission for Astrophysics (PRIMA) mission. PRIMA and the competing



proposal will each receive $5m from NASA to conduct a 12-month mission concept study, and Cardiff are currently in discussions with NASA to define the scope of mission involvement, which could include contributions to the ground segment and/or potential specialist hardware components. RAL Space are expected to lead the ground segment activities at this 'discussion stage'.

To caveat, both RAL and Cardiff were involved in the Herschel mission, which is cited as similar in scientific objectives to PRIMA by the Astrophysics Programme Lead at RAL Space, Dr Chris Pearson.[28] While involvement in the Ariel mission was cited by stakeholders as strengthening the case for UK involvement, their involvement is likely due to the heritage of both organisations across several space science missions, of which Ariel is the most recent example.

Early exploratory discussions

1. UK involvement in the NASA Habitable Worlds Observatory mission

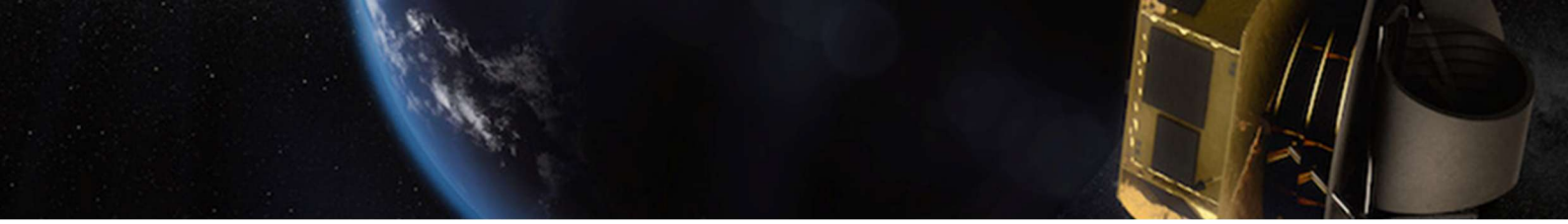
Preliminary discussions are ongoing between RAL Space and NASA JPL for involvement in the upcoming Habitable Worlds Observatory (HWO) mission, outlined for launch in the 2040s. The mission, like Ariel, will use a telescope to search and characterise potentially habitable exoplanets, and will use spectroscopy to search for chemical biosignatures in these planets' atmospheres. This mission has been cited by several stakeholders in the UK consortium as a strategic priority for future involvement beyond the Ariel mission. Representatives from RAL have travelled to JPL to discuss collaboration opportunities, although these discussions are at a preliminary stage.

2. Other RAL Space mission opportunities

RAL have been approached by NASA, who have invited them to submit an expression of interest for the potential upcoming Black Hole Explorer mission. The opportunity would be to provide a cryocooler solution which would explicitly replicate the system being developed for Ariel. The contract is for approximately £10.6m (~$14m), which would be distributed between RAL and their partner, OHB. This opportunity is still at an early stage but could potentially lead to follow-on work which is directly attributable to RAL's role on the Ariel mission and help safeguard their global leadership in cryocooler technology. These discussions are directly related to the growing UK-US collaboration within the Ariel consortium, which have led to more visits, discussions, and potential follow-up opportunities between NASA and UK project team members.

RAL Space are also exploring the possibility of producing a cryocooler solution for the L-class Cosmic Vision 'NewAthena' mission, which would be as a backup solution for the United States' primary solution. RAL Space would leverage their cryocooler expertise, developed in-part through the Ariel mission. While RAL Space are European leaders in developing Joule-Thomson (JT) cryocoolers, they are likely to face competition from a collaboration featuring Japan, who are also developing a JT cryocooler, and France, who would develop the pre-cooling tube system. If successful, RAL Space will secure a contract in the order of hundreds of thousands, which may not lead to a mission role, but is of strategic importance to the UK in maintaining and developing cryocooler expertise at RAL. This contract opportunity comes after RAL were close to signing a cryocooler contract with ESA for the original concept of Athena. However, this fell through and was subsequently allocated to NASA, due to cost reductions and rescoping of the mission at ESA into 'NewAthena'.

[28] STFC, 2024. *NASA selects proposal involving UK scientists for further study, as they seek to address 'secrets of the Universe'*. Available at: https://www.ralspace.stfc.ac.uk/Pages/prima-shortlisted-for-nasa-mission.aspx



At the time of writing, very early discussions were also ongoing within the Ariel consortium around potential commercial applications of the Ariel spacecraft. Representatives from RAL said these discussions have been put on hold for the time being in order to prioritise delivery of the Ariel mission.

3. UK AI Business Case Opportunity

There are preliminary discussions led by Prof. Tinetti on developing an academic-industrial AI focused business case, to build upon existing strengths within the Ariel team and wider data-intensive science community, and support knowledge spillovers between academia, industry, and government. This could include (but not be limited to) leveraging networks established between the project team and DeepMind. The proposal would align with the recent DSIT *AI Opportunities Action Plan*, which aims to ramp up AI adoption across the UK by investing in the foundations of AI[29], and was endorsed by the Prime Minister in January 2025. Developments in this area are only recently emerging, and should be tracked to see how they evolve.

4. Potential patent opportunities for AI exoplanet model applications to medical science

While still in the early stages, UCL postdoctoral associate Ahmed Al-Refaie is investigating potential knowledge transfer from AI applications in modelling exoplanet atmospheres to the field of medical science, where AI is becoming increasingly widespread as a tool for pattern recognition in diagnosis. These conversations are preliminary, although could result in a patent, leading to potential future licencing revenues, or IP to support future spin-outs.

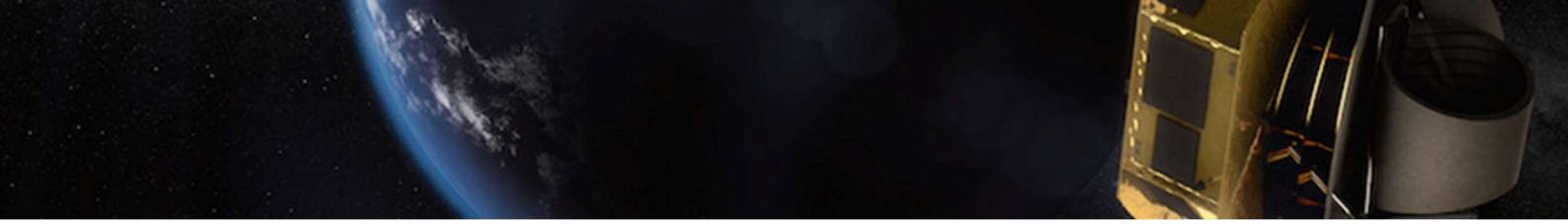
3.4.7 Ariel software, databases and code development

UK roles in ground segment development and preparatory science are **strengthening UK capabilities in software, AI and Machine Learning**. Following the scientific data releases post launch, it will be possible to track engagement from the wider scientific community with UK-developed open source databases. Databases, simulators, and repositories are currently in development, and are being tested and refined in stages. It is too early to track wider engagement with these sources, as they are still in beta versions, or are not expected to be the primary methods for disseminating data to the wider community. Currently, the ADC represents the largest publicly-available dataset for exo-atmospheric studies, although other databases and simulators are currently being refined, including:

- **exodb.space:** an Ariel exoplanet database which includes a catalogue of exoplanets and stars, with accompanying data on mass, radius, equilibrium temperature, and other characteristics.
- **arielmission-space github repositories:** including *"Mission_Candidate_Sample"* which is the repository for target candidates, and *"ExoSim2"*, which is an exoplanet observation simulator tailored for spectro-photometric observations.
- **ucl-exoplanets github repositories:** including "*TauREx3*", a Bayesian inverse atmospheric retrieval framework for exoplanets, all relevant datasets for the Ariel Data Challenge, and other exoplanet and transit light-curve modelling tools. To date, *TauRex3* has been downloaded over 40,000 times, and has supported over 40 publications. It has also been the main code of service for approximately 75% of new exoplanet PhD theses worldwide.[30]

[29] DSIT, 2025. *AI Opportunities Action Plan*. Available at: https://www.gov.uk/government/publications/ai-opportunities-action-plan/ai-opportunities-action-plan

[30] UCL. 2025. *Ahmed Al-Refaie – Bio*. Available at https://profiles.ucl.ac.uk/39726-ahmed-alrefaie/about



While these tools and algorithms are central to meeting the scientific objectives of the Ariel mission, they have already demonstrated significant start-up, spin-out and spillover potential for commercial applications, as demonstrated by the early commercial success stories such as Spaceflux, as well as developments in the Ariel Data Challenge.

3.4.8 Preliminary Economic Insights

The **economic evaluation for the UK investment into the Ariel mission is currently planned for launch + 1.5 years, and is not within the scope of this project**. However, we provide some preliminary evidence of early economic impacts, with the caveat that at this relatively early stage of the mission, we would expect more sizeable economic impacts to occur in the years following launch. Furthermore, as the Ariel mission is primarily a science mission, **monetised return on investment is a narrow metric through which to analyse performance** of the mission.

At a high level, we compare the costs of UK investment into Ariel to the UK benefits delivered so far from this investment. At this stage, we have not compared benefits against the original Value for Money (VfM) analysis (outlined in the business case for UK Space Ageny funding) comprehensively, and focus exclusively on observed benefits, as this is not a full VfM evaluation. The benefits we quantify fall into the following categories:

- **Leveraged external investment** – focusing primarily on non-UK investment such as Series A funding secured by BSSL (with attribution assumption as discussed below), which represents an in-flow of new investment into the UK economy. We do not include investment such as additional UK Space Agency/UKRI grants awarded, as in a counterfactual scenario these would go to other UK organisations.
- **The value of job creation** – building off research on the wage premia effect associated with the support and creation of space sector jobs[31], we assume that in the absence of Ariel investment, those in roles created through funding would instead be working in similar roles outside the sector, earning different (lower) salaries. A wage premia approach supposes that the economic value of job creation lies in creating new, better paid roles, rather than new jobs per se.
- **The value of publications and citations** - using a space-specific[32] estimate of the benefit of such publications and citations, adjusted for year of publication. Broadly, this methodology attempts to estimate the value of publications using the cost to authors and publishers as a proxy for the lower bound on the benefit of publishing a paper. This methodology is clearly a strong simplification[33] but provides an advance on assuming the economic benefit of publications is nil. It has been used in research and innovation evaluations such as for the Large Hadron Collider at CERN.[34]

At present there is no evidence of new **revenues and internal investment** attributable to the UK Space Agency national investment in Ariel. If evidence of these arises in future, these can and should be built into this analysis, which is intended as a foundation based on initial emerging impacts.

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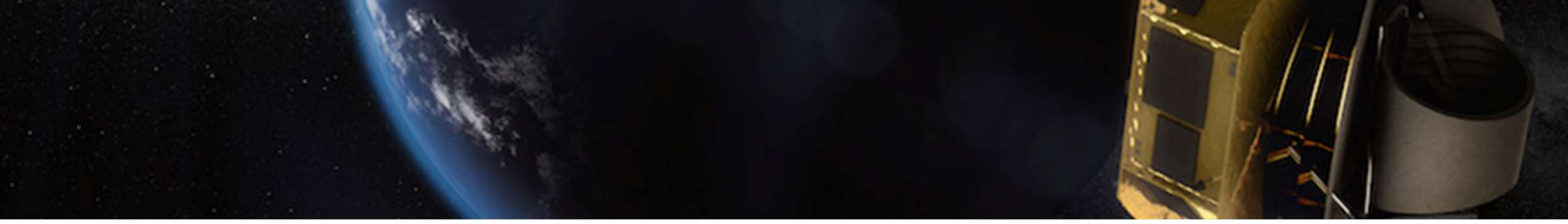
[31] know.space (2023) *Estimation of Wage Premia associated with UK Space Agency funding* [unpublished]

[32] We use an earth observation-specific estimate in the absence of a space science-specific estimate. Morretta et al. (2022). *The socio-economic value of scientific publications: The case of Earth Observation satellites*. Available at : https://centrejeanmonnet.unimi.it/wp-content/uploads/2021/10/The-socio-economic-value-of-scientific-publications-The-case-of-Earth.pdf

[33] Using an average across publications will obscure differences in the value of different publications. This approach also fails to capture any benefits of publications which exceed private costs, e.g. spillover benefits.

[34] See for example Florio et al (2015), *Cost-Benefit Analysis of the Large Hadron Collider to 2025 and beyond*. Available at: https://arxiv.org/abs/1507.05638



Our central analysis covers the 2022/23 to 2024/25 period for which we have data on realised costs and benefits. We also provide estimates based on forecast costs up to 2033/34 being included. All costs and benefits are adjusted to current prices (2024/25), and future costs are discounted using the standard 3.5% discount rate recommended by the HMT Green Book. All benefits are subject to a 90% additionality adjustment[35], reflecting that some of this activity may have taken place in the absence of UK investment into Ariel. Attribution shares are also applied to key benefits (see below for the attribution shares applied to individual benefits).

We estimate that **UK contributions to Ariel since 2022/23 have generated at least[36] £2.9m in real, discounted benefits to date**. This total is driven by activity in Ariel-related start-ups, notably two large foreign external investments to Ariel-related start-up BSSL: £2.3m in Series A funding and £2.6m in Horizon Europe funding, appropriately discounted, deflated and attribution adjusted[37] (with assumed 50% attribution[38]). Job creation in Ariel-related start-ups further contributes to economic benefit, with evidence of at least **43 UK jobs created** to date. We assume 50% attribution[39] for these jobs and estimate that each job is associated with a £8.5k wage premia, i.e. on average those in roles created in Ariel-related start-ups earn £8.5k more than they otherwise would. This leads to £340k in benefit using the wage premia approach.

The 137 Ariel-related publications (2022/23-2024/25) are valued at least £610k, making this the second largest benefit category. On average, a publication is assumed to be worth at least £18.4k to the researcher(s) and £570 to the publishers[40]. We assume 50% leakage[41] i.e. 50% of benefits occur outside the UK, and 50% attribution, since publications are expected to be a result of multiple factors, rather than stemming from Ariel investments alone. The 1,666 citations generated, similarly adjusted for leakage and attribution, are valued at £64k. Each citation is assumed to be worth £170 in benefit[42]. This is a proxy for the increased influence within the scientific community which comes from more citations.

[35] This is a necessarily arbitrary assumption reflecting our conclusion that many impacts are unlikely to have materialised at all, or at least to the same extent without the UK's national contribution to the Ariel mission. It is however a subjective assumption and we recommend that any future economic evaluation (which is beyond the scope of this study) should consider appropriate assumptions in more depth.

[36] Not all benefits could be monetised

[37] Although this investment could be considered as turnover, we do not apply a turnover:GVA ratio to these totals since they represent a 100% injection into the UK economy.

[38] This is a necessarily arbitrary assumption to reflect that Ariel support was not the only factor leading to these investments. If attribution were assumed (say) to be 25%, then the benefits in this category would be halved.

[39] Again, this is a necessarily arbitrary assumption to reflect that Ariel was not the only factor leading to the creation of these jobs.

[40] These are averages based on the cost of researcher time and publisher costs. See Morretta et al. (2022). *The socio-economic value of scientific publications: The case of Earth Observation satellites*. Available at: https://centrejeanmonnet.unimi.it/wp-content/uploads/2021/10/The-socio-economic-value-of-scientific-publications-The-case-of-Earth.pdf

[41] This is an arbitrary assumption to reflect that whilst all the publications included relied on some UK involvement, many were internationally collaborative and therefore some benefit will be realised outside of the UK.

[42] This figure was derived by considering the opportunity cost of time used by a scientist to read and cite another's work. See Morretta et al. (2022). *The socio-economic value of scientific publications: The case of Earth Observation satellites*. Available at: https://centrejeanmonnet.unimi.it/wp-content/uploads/2021/10/The-socio-economic-value-of-scientific-publications-The-case-of-Earth.pdf

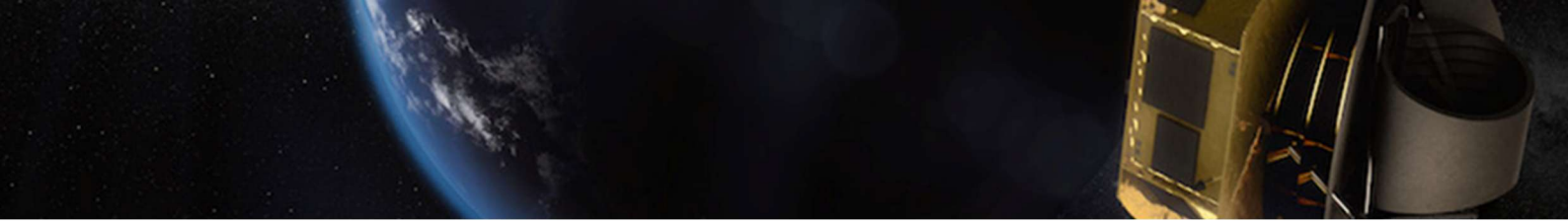
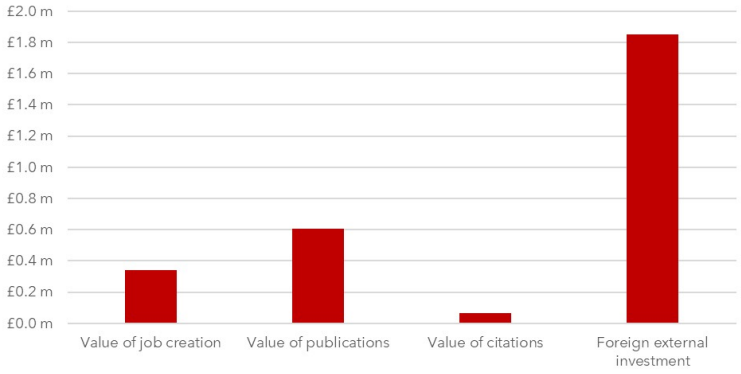


Figure 24 *Real discounted benefits of Ariel*



Whilst it is too soon to meaningfully present full VfM results, we provide early estimates of the extent to which Ariel contributions are on track to deliver VfM. We find that the **Net Present Social Value (NPSV)[43] is currently -£13.1m** if we only include realised costs to date of £16.0m[44]. This indicates that the costs of Ariel currently exceed the monetisable benefits. While **all future costs are subject to review**, if we include current expectations on profile out to 2033/34 (a further £22.0m in total, real PV terms) this falls to -£32.5m. Reflecting this, **the NPSV/Departmental Expenditure Limit (DEL)[45] is -0.82, including just realised costs, falling to -0.92 if we include expected costs (subject to review) to 2033/34**.

Differences in methodology at business case stage and the early nature of this evaluation limit our ability to make useful comparison with anticipated benefits. Nonetheless, our analysis shows that, **as expected, the largest economic benefits come from Ariel-related start-ups** and our **negative NPSV/DEL is in line with expectations at business stage**.

At business case stage, a 'monetisation of commercial spinouts' methodology was used to estimate the potential economic impact of Ariel. It was assumed that Ariel would support three to four startups per year[46] over the 2022/23 to 2039/40 period which would on average generate £300k per year in revenue. In total, £22.7m in revenues were expected of which £2.9m would be realised by the time of writing. This would translate to an **expected £6.3m in real discounted GVA over the full period and an expected NPV[47]/DEL of -0.75**[48]. The business case notes that most of the expected benefits of Ariel investment cannot be 'satisfactorily monetised or included in a quantified VfM assessment', so these totals will underestimate the potential benefit from the UK's contributions to Ariel. The negative NPV/DEL is not taken as an indication of poor value for money.

By comparison, we find no evidence of revenues generated to date, though we do quantify other benefits worth a real discounted total of £2.8m, giving an NPSV of -0.82, focussing on costs to date, or -0.92, including future costs. **The NPSV/DEL we calculate is negative and similar to**

[43] Net Present Social Value is simply total discounted social benefits minus total discounted social costs (i.e. both public and private).

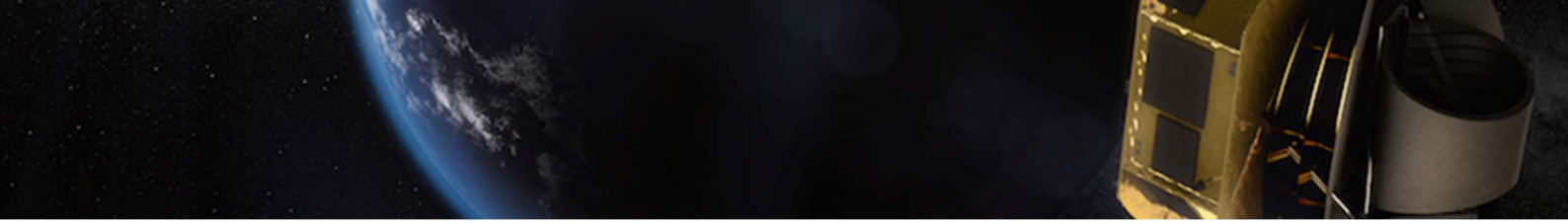
[44] Note this total is presented in real terms, so will differ from accounting totals.

[45] DEL is the cost to HMG, in this case UK investment into Ariel. The NPSV/DEL ratio, or Net Present Social Value (NPSV) to Departmental Expenditure Limit (DEL) ratio, captures the net benefits of an intervention relative to government expenditure.

[46] New startups are created throughout this period but many fail, meaning there are fairly consistently three to four startups at any one time.

[47] NPV or Net Present Value is similar to NPSV or Net Present Social Value, but focuses on private financial benefits rather than encompassing social benefits.

[48] We note that the business case refers to an NPV/DEL of -0.75 in one place and -0.72 elsewhere. We cannot ascertain which of these numbers is correct.



expectations, but the benefits driving these totals differ since they are **driven primarily by new external investment rather than revenues**, and we also monetise a broader range of impacts. The number of start-ups supported is similar to what was anticipated, with evidence of five Ariel-related start-ups active today, of which two are generating notable economic activity. Methodological differences aside, it is still too early to meaningfully compare expectations to realised benefits.

Whilst the NPSV/DEL is currently negative, **we do not view that this should be cause for concern given the early stage at which this assessment has been carried out and the importance of non-monetisable benefits in driving overall impact**. Investment (which drives much of the observed benefit to date) is intended as a means to generate future benefits, such as new revenues. At this stage of Ariel / related start-up companies' lifecycle, we are not yet at a point where these have realised. As with the broader impact evaluation, it will therefore be important to track these if and when they emerge in coming years. We also recognise that choices of assumptions (e.g. 50% of external investment attributable to Ariel) are subjective and the results presented here would vary with different choices.

3.4.9 Counterfactual

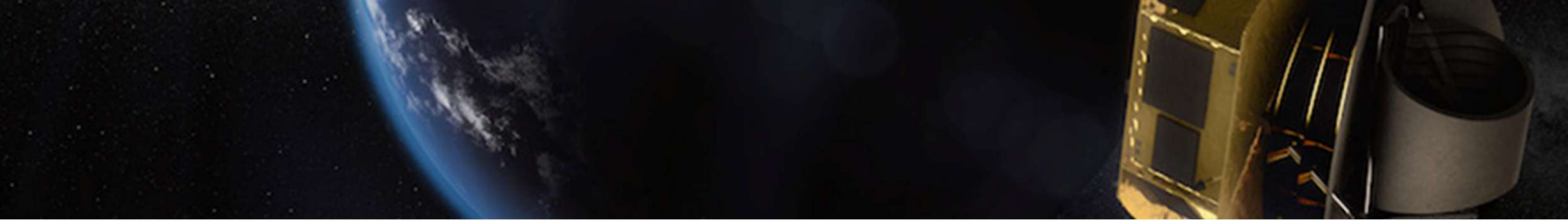
UK Space Agency funding for the Ariel mission has contributed to some realised commercial benefits to date, with the potential for more sizeable impacts in the future. While estimating the additionality of national contributions to these impacts is challenging and context-dependent, it is likely that these benefits would not have materialised in the same way if not for UK Space Agency support.

Both UCL-led startups were **established directly due to roles on the Ariel mission**, although in the case of BSSL, the idea was initially formulated before the UK Space Agency's national contribution. Nonetheless, skills and leadership developed and demonstrated within the Ariel mission have been **strong contributors to the continued success of both companies**, and in both cases directly informed company objectives. The contract opportunities and investments secured by both companies are strongly linked to the capabilities of the teams, **and prominent roles on Ariel have been used to signal leadership and experience to investors**.

With respect to the follow-on funding secured by RAL Space, Ariel was cited as a key strategic driver for required facility upgrades. However, due to their value for future projects and missions, UK Space Agency national investment **cannot be treated as the sole contributor to this additional funding.** In terms of benefits to RAL's suppliers, there is a far stronger link between benefits and UK Space Agency's investment. These companies are being funded indirectly through this contribution, and any improvements in organisational capacity, skills or job creation linked to these contracts could be highly attributable to UK Space Agency support, although we lack evidence of these impacts beyond the allocation of contracts at this stage.

In terms of future commercial opportunities, developments in establishing not-for-profits linked to ExoClock and the Data Challenge **are unlikely to have materialised without UK Space Agency investment**. Sequestim Ltd is less directly linked to the Ariel mission, and is likely to have been established anyway. However, inputs from the ground segment activities undertaken on the Ariel mission are likely to be essential in securing future benefits, as developments are required across both the hardware and software to produce a highly reliable product which could be utilised in a security context.

The case for UK roles within the PRIMA consortium was strengthened by the Ariel mission, but is also likely to have been influenced significantly by prior UK roles on the Herschel mission. UK Space Agency national contributions are linked insofar as they have enabled Cardiff and RAL Space to retain and develop PRIMA-relevant expertise through Ariel, while also strengthening UK



leadership in space science more broadly. The interconnected nature of space missions was highlighted by several stakeholders, where **roles on one mission were often regarded as essential prerequisites for securing another**.

3.4.10 Conclusions

While innovation-related benefits from space science missions typically accrue over long time horizons, there have already been some **realised and potential commercial benefits arising from prominent UK roles on the Ariel mission**. The project team, while understandably often prioritising roles and responsibilities on the mission itself, have begun to leverage their capabilities and expertise in mission-relevant fields (such as AI, Machine Learning and exoplanet science) to pursue commercial opportunities through start-ups, spin-outs, and knowledge spillovers. Below, we evaluate progress based on the relevant research questions to this section, designed to track interim benefits realization from UK Space Agency investment.

What difference has Ariel made so far in stimulating innovation and commercial opportunities through data science and space technology?

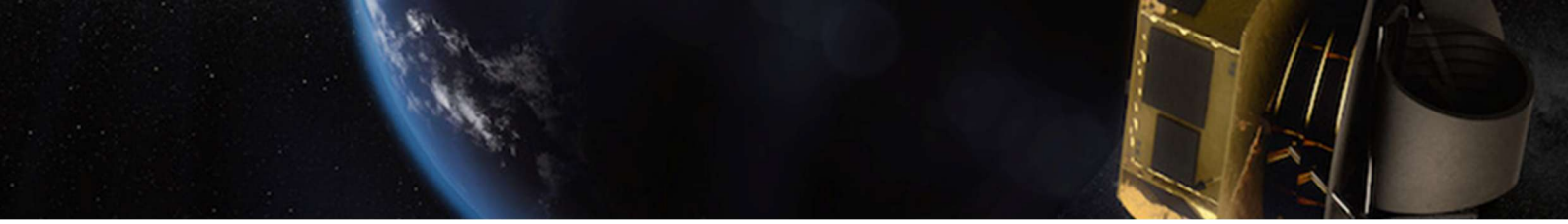
We assess the UK contributions to the Ariel mission as having a **promising early impact** in stimulating commercial opportunities across both data science and space technology. Notably, close industrial-academic knowledge exchange in AI and data science, and potential follow-on mission opportunities for space technology are two key routes for commercial benefits. There is evidence of contracts, investment and funding to companies which are unlikely to have existed (at least to the same extent) without UK involvement. In turn, this has supported the continued growth of the space sector, with **Ariel-related companies creating a total of 43 jobs**, as well as a further 9 founder, director, and advisory roles. These companies have helped to maintain the pipeline of high-skilled jobs in the UK Space Sector, notably through the establishment of PhD co-funding schemes and internships, while also attracting talent in senior positions from organisations such as NASA, Google, Airbus, and Cisco.

To what extent has UK Space Agency investment led to new technologies or services coming closer to market? Has it supported knowledge and technology spillovers to non-space sectors?

At BSSL and Spaceflux, recent contracts and investment have led to new services reaching market, with further services set to come online this year with the launch of the Mauve satellite. As a result of the unique business models of both Ariel-related start-ups, these services currently have specific user communities within the space sector (i.e. government, defence, and the space science research community). However, other earlier stage commercial opportunities have been identified, largely through application of AI and Machine Learning techniques for pattern recognition in alternative use cases, such as security and biomedical sciences. These potential technology spill-overs into non-space sectors will be important to track in the future, even if it is too early to capture their impact in this current evaluation.

Has UK Space Agency investment led to successful commercial exploitation of space science?

While the mission is still at an early stage, the start-ups and emerging spin-out companies linked to the UK contributions to the Ariel mission demonstrate a **range of commercial exploitation opportunities**, albeit with limited realised commercial benefits so far to date. The commercialised data access model of BSSL is arguably the most direct evidence of commercial exploitation of Ariel-related science, although Spaceflux's digital assets also stem from mission-



relevant science, and they have grown from a startup of 3 people to the primary commercial provider of SSA capabilities in the UK in 2 years, demonstrating rapid commercial exploitation.

Moreover, the Data Challenge has broadened contributions to Ariel-relevant AI and Machine Learning activities, which could provide second order spillover applications for the participants in these challenges. Techniques developed to participate in the Data Challenge could be subsequently applied to a range of terrestrial applications, especially as an increasing number of teams participating in the challenges are not astronomers to begin with. Close links between companies emerging from the UK Ariel ecosystem are being maintained, and there is potential for future knowledge exchange to lead to enhanced commercial exploitation in the future, including (but not limited to) the potential AI business case under development by Prof. Tinetti.

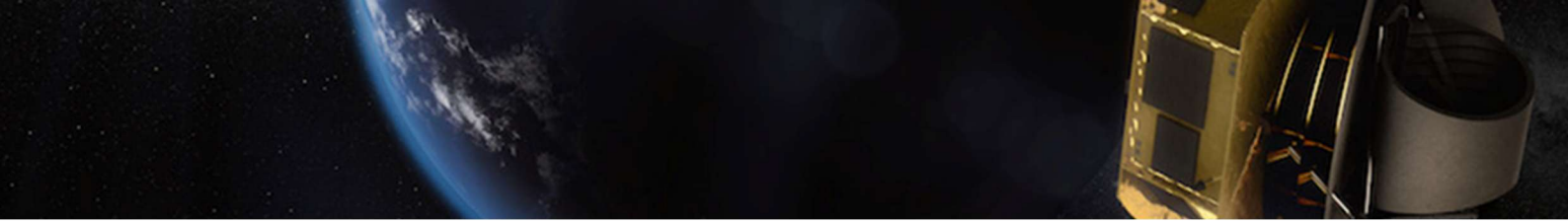
3.5 Performance against impact evaluation questions

Below, we provide a high-level overview of the impact of the UK Space Agency national investment into Ariel against the evaluation questions set out in the original M&E Framework. Not all evaluation questions are fully addressed – this is to be expected, since some of the benefits will only emerge in the longer-term, and hence it is too early to capture these in our evaluation to date. We utilise a Red-Amber-Green (RAG) assessment process[49] to provide a high-level summary of progress against each impact evaluation question.

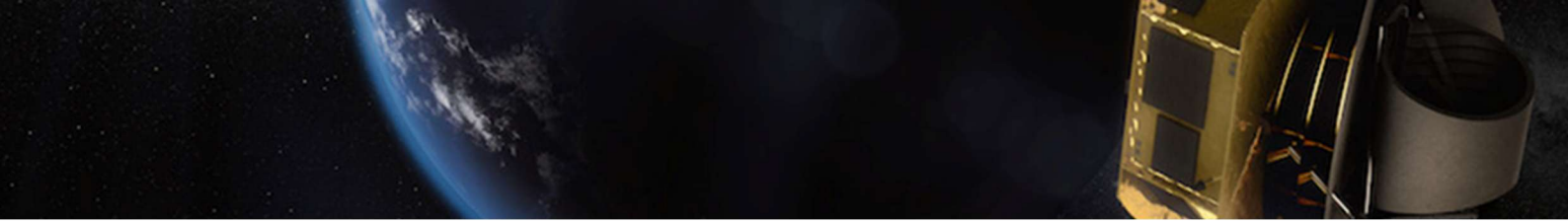
Table 2 *RAG Rating on current performance against impact evaluation questions*

Evaluation Question	RAG rating	Performance
Is the programme on track to achieve its scientific aims, as defined by the UK-led science team?		UK Space Agency national investment into Ariel has enabled Prof. Tinetti and the wider team to shape the direction of the preparatory science being undertaken prior to the mission. The bulk of scientific aims of Ariel will only materialise over longer timescales – i.e. post mission launch, when the community analyses data releases from the mission. However, ongoing efforts led by UK researchers are ensuring the consortium stays agile to new developments in the wider field of exoplanet science, meaning scientific aims and objectives are considered to be on track at this interim stage. There is a broader risk that the performance of Ariel instruments across the consortium could also affect the quality of the science which can be undertaken on the mission, although with delivery unfolding, it is too early to assess any potential implications of instrument performance on mission science.

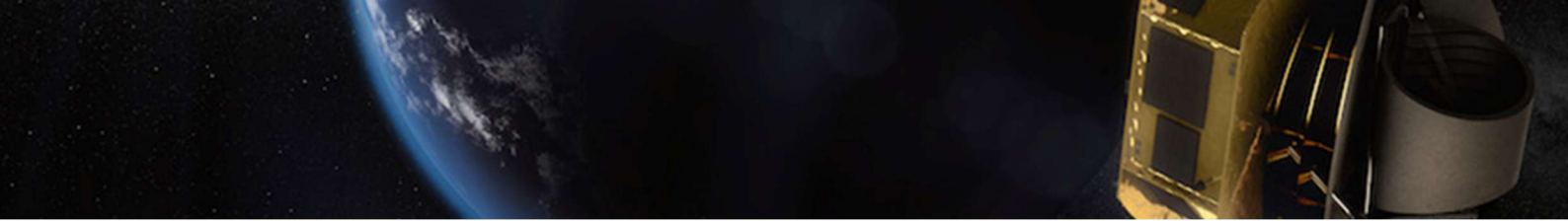
[49] Our Red-Amber Green assessment process includes 3 success categories against the relevant impact evaluation question at the interim stage of our evaluation: **Addressed**, **Partially Addressed**, **Not Addressed**



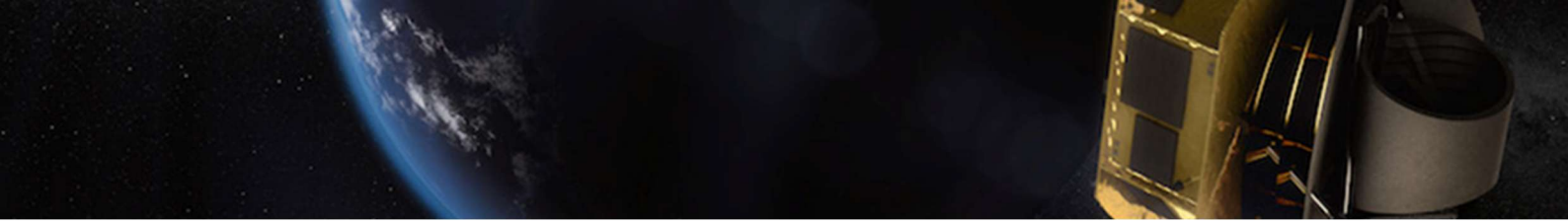
Evaluation Question	RAG rating	Performance
What difference has the UK's national investment into Ariel made to securing UK scientific and technical leadership of exoplanet research, data science, and space science by nominal end of mission?		UK leadership roles have underpinned UK influence over preparatory science and payload development / integration activities on the mission. While the wider mission is inherently international, UK leadership has shaped the direction of the wider consortium. This trend is set to increase further as the mission unfolds. From a science management perspective, greater influence is expected through the implementation of science working groups. In terms of payload delivery, recent challenges with contractors in other countries mean RAL have been instructed by ESA to behave more 'like an industry prime', assuming a greater management role over the progress of different subsystems. UK based researchers are also instrumental in developing the AI and Machine Learning aspects of the mission, from simulated datasets to databases for target selection and cataloguing. While initial progress is promising, it is too early to assess how UK leadership over the Ariel mission has translated into wider scientific and technical leadership in space and data science. Indeed, it is too early to assess shifts in UK leadership over the sub-field of exoplanet science. While there is evidence of initial impacts which could lay the foundation for broader UK influence, this is highly dependent on future development stages and subsequent exploitation of Ariel mission data.
What difference has the UK's national investment in Ariel made so far in enhancing the reach and reputation of the UK's space sector?		Leadership roles within the UK project team have catalysed early influence over Ariel mission science, as well as systems engineering. Ongoing work to fulfil these roles and responsibilities mean the UK is perceived positively by ESA and the wider consortium. However, reputational benefits are inherently linked to successful delivery over the entire duration of the mission. Stakeholders are cautiously optimistic about the reputational benefits to the UK, as while progress has been strong to date, further work is required before delivery could be considered successful. Moreover, this perception comes with the expectation that the UK will step up to resolve any future challenges which arise. At this stage of the mission, many within project teams are primarily focused on Ariel delivery. However, discussions are ongoing with members of the UK Ariel project team around roles on two large NASA mission concepts, alongside other opportunities. Current roles on Ariel are being used as a marker for the managerial and technical expertise of UK organisations, which could expand the UK's international space science presence over the longer term.
What difference has Ariel made so far to inspiring, attracting, and retaining talent to upskill the UK workforce?		UK Space Agency investment has been instrumental in attracting and retaining staff within the UK project team, and stakeholders have cited the mission as a key factor behind low rates of turnover, as well as international researchers relocating to the UK. Through the training of students, graduates, apprentices, and year-in-industry students, UK organisations are sowing the seeds for future impact by supporting the next generation of space scientists and engineers in the sector. These impacts should be interpreted as initial steps required to address wider skill and capability gaps in the UK space industry, although it is notable that two key competencies supported by Ariel – AI and Machine Learning and System Engineering, are two of the most in-demand skillsets for UK space companies. Beyond the immediate project team, outreach initiatives such as ExoClock and ADC have attracted significant global participation, helping to build skills and capabilities in areas directly relevant to Ariel mission science. We heard from several stakeholders that these initiatives have led to impacts which are 'above the norm' for a space science mission at this stage of maturity. These initiatives are UK-led, but inherently global in terms of the



Evaluation Question	RAG rating	Performance
		upskilling impacts for participating teams and observers. However, both have also supplemented core activities with targeted UK-specific initiatives, ensuring high levels of UK participation. These have emerged as two crucial routes to developing the capabilities required for future exploitation of Ariel data. Other outreach events conducted by the project team have helped to potentially inspire student audiences towards pursuing further study/apprentices which support future careers in STEM fields. Continued funding support for project team members who are on fixed term contracts, as well as support for outreach initiatives such as the Ariel Data Challenge and ExoClock are key potential risks in terms of securing some of these potential long-term benefits. Uncertainty over future contracts was cited as a potential barrier to retention, alongside uncompetitive salaries relative to the private sector, although individuals are motivated by a range of incentives.
What difference has Ariel made so far in stimulating innovation and commercial opportunities through data science and space technology?		Close academic-industry collaboration, and a 'nexus of entrepreneurialism' has led to promising initial impacts in stimulating commercial opportunities, with further sizeable impacts possible in the coming years. There is evidence of contracts, investment and funding to companies which are unlikely to have existed (at least to the same extent) without UK involvement. However, this is still an emerging impact story of which we are at a relatively early stage. In turn, this has supported the continued growth of the space sector, with Ariel-related companies creating a total of 43 jobs, as well as a further 9 founder, director, and advisory roles. Both companies retain close links to the Ariel mission, through common staff, as well as PhD co-funding schemes and internships. Opportunities for further knowledge spillovers into industry are also in the pipeline, with 3 spin out companies which could lead to further commercialisation opportunities. The development of key data-intensive science skills to support Ariel mission science has been a key route to innovation and commercial exploitation, and this (among other routes) will be a key avenue to monitor in the coming years.
How have different stakeholders (such as direct funding beneficiaries, research users outside of the Ariel consortium, non-exoplanet scientists, general public) been impacted differently by Ariel?		ExoClock and the Data Challenge have provided a key pathway for those outside of the Ariel consortium to participate in mission-relevant research, and over the longer-term, the intention is to prioritise open access to Ariel mission data, to encourage wider participation in, and scrutiny of, Ariel science. Engagement from the general public is anticipated to grow around and following mission launch. There have been high altmetric impacts for publications from UK project team members, though these publications primarily leverage data from previous missions, such as Hubble and JWST. This supports the view of stakeholders that exoplanet science is of interest to the wider public, and indicates there could be more sizeable impacts of future Ariel science in the longer-term.
To what extent would observed outcomes have happened in the absence of the UK Space Agency investment?		While additionality is context-dependent, many impacts across the four themes above are unlikely to have materialised at all, or at least to the same extent without the UK's national contribution to the Ariel mission. Notable examples include benefits associated with the UK's leadership roles (ranging from project management skill development to attracting investment and contracts in Ariel-related start-up companies). For other emerging impacts, the mission has been cited as one factor among several inputs. Future mission involvement, for example, should be understood as the next evolution in a sequence of roles associated with previous space science missions. Although UK leadership positions on Ariel are likely to strengthen the case for future mission involvement, project team



Evaluation Question	RAG rating	Performance
		members also possess previous delivery heritage on missions such as JWST, Herschel, Planck, and others.
What are the key lessons learned from the [impact] evaluation?		UK Space Agency investment into the Ariel mission has led to important outputs and outcomes, alongside initial impacts which are unfolding gradually over the course of our study. While these are promising developments, there is a long-term payoff with many, such as scientific breakthroughs, reputational benefits, and influence over the broader space science research base and sector. To fully realise these benefits, sustained resource and financial commitments will be essential to fully exploit the potential impacts underpinned by UK leadership roles on the mission. There are also lessons in ensuring future evaluations employ a long-term, holistic view. Focusing solely on the immediate scientific outputs of a space mission risks overlooking its broader benefits for upskilling the workforce, and leveraging space science to stimulate commercial opportunities. A short-sighted approach that measures success purely through near-term scientific discoveries would fail to capture the full return on investment, particularly in how space missions contribute to the UK's broader strategic position in space science, technology, and industry.



4 Annex: Data Collection

4.1 Overview of target metrics

Below, we provide an overview of UK Space Agency's target metrics for benefits realisation for the national investment into the Ariel mission. We have monitored progress in each of the target metrics over the duration of our study, and find strong performance across the target list. The only exceptions are the percentage of Ariel publications with a UK author in the top 10% as measured by Field Citation Ratio (FCR), which is discussed in depth in section 3.1.2, and the number of UK companies participating in the Ariel Data Challenges, which is not known, since Kaggle does not require participants to fill out this information, and we have a small sample size of team survey responses.

Table 3 *UK Space Agency benefits realisation targets*

ID	Indicator	Target	Sep-23	RAG	Mar-24	RAG	Sep-24	RAG	Mar-25	RAG
S3	# and % of Ariel papers with a UK author (first or otherwise)	30%-50% of all Ariel papers to include a UK author	47%		49%		51%		49%	
S6	# and % of Ariel publications with a UK author in top 10% by Field Citation Ratio	And 30%-50% of Ariel papers with UK author to have a 10% Field Citation Ratio ranking (for relevant fields of research)	28% (with lag in data)		35%		21%		21%	
C1	# and % of Ariel papers with a UK author that are internationally collaborative	~80% of all Ariel papers with a UK author to include collaboration with at least one other country	76%		79%		79%		79%	
C2	# of countries collaborated with for UK Ariel publications	At least 15 countries collaborated with per year for Ariel publications	34		35		37		37	
HC7	# of participants in ExoClock programme	Year-on-year increase in # of participating observers in ExoClock citizen science programme	258 (2022) 315 (2023)		No Change		420		453	
HC8	# of participants in Ariel Data Challenges	Year-on-year increase in # of participants in Ariel Data Challenges	~200 (2022) 232 (2023)		No Change		735 (ongoing)		1400	
IN1	# of UK companies participating in Ariel Data Challenges	Year-on-year increase in # of UK companies participating in Ariel AI and Machine Learning Data Challenges	11 (2023)		No Change		No change (ongoing)		Not provided by teams	
IN4	# of new commercial exploratory discussions regarding potential collaborations formed from UK-led Ariel activities	1-5 commercial exploratory discussions over interim period (to 2029), 5-10 commercial exploratory discussions over longer-term period (to 2034)	0 (+2 early stage)		3 (+3 early stage)		4 (+3 early stage)		4 (+3 early stage)	

4.2 Data collection methods

Across the timeframe of our study, we have conducted 6-monthly benefits management reporting to UK Space Agency, which followed a broad 4 stage process - data collection, analysis, synthesis and conclusions. We designed this approach to be broadly replicable at regular intervals, enabling time series data to be collected and updated iteratively. Below, we summarise our data collection methods, employed for this interim impact and process evaluation, as well as the preceding September 2024, March 2024, and September 2023 6-monthly reports.

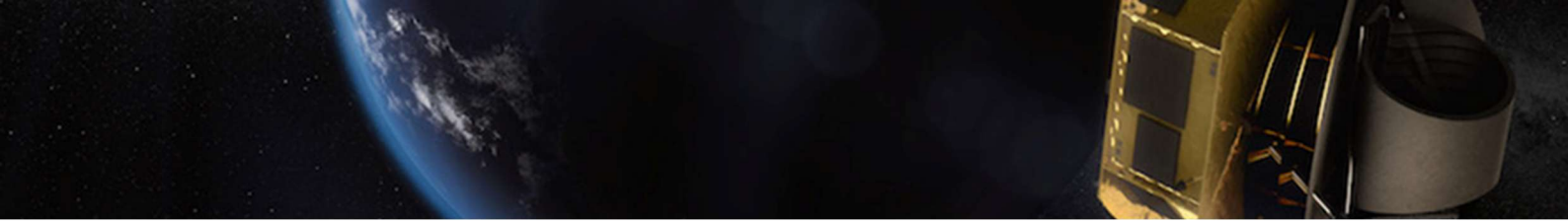
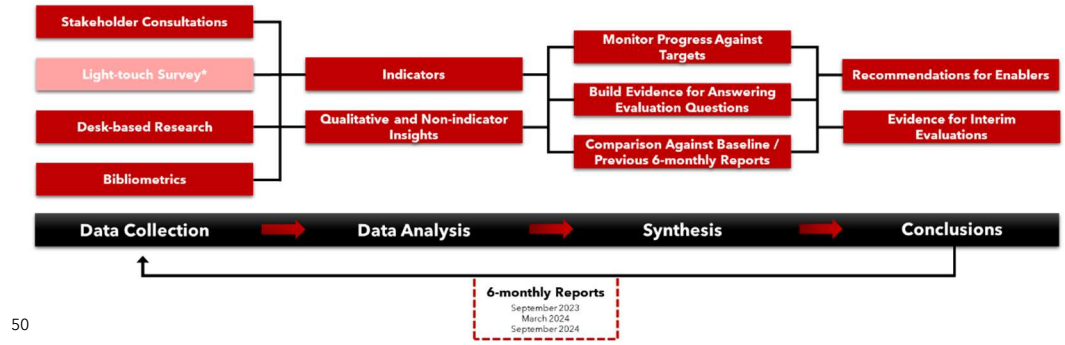


Figure 25 *Schematic for 6-monthly reporting process*



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4.2.1 Stakeholder consultations

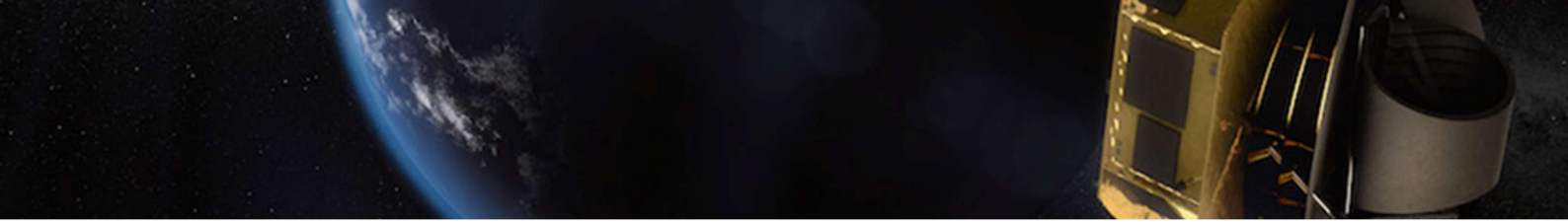
Interviews

Throughout our study, we have interviewed the core project team on a 6-monthly basis, from March 2023 to March 2025, in order to track emerging developments. We have drawn upon a wider range of stakeholders in order to validate our approach at the beginning of the study, as well as to capture wider impacts and process insights in preparation for the interim evaluation. We have conducted **approximately 44 interviews with 21 individuals over the duration of our study**.

For this interim impact and process evaluation, we re-engaged with key members of the project team, to gather updates on the mission, inform our indicators, and obtain important contextual information. Below is an overview of the 15 interviews we held since delivery of our September 2024 update, which were used to inform this report.

Organisation	Role
UCL / KCL	Ariel Mission PI
RAL Space	Ariel Consortium Manager
RAL Space	Cryogenics
Oxford University	Technical team coordinator
Cardiff University	Simulations Working Group Lead / Developer of ExoSim/ArielSim and Ariel Data Reduction Pipeline
Cardiff University	Ariel Co-PI
UCL	Ariel Data Challenge PI
UCL	ExoClock Admin
University of Birmingham	Project Management Board
Strathclyde University	Project Management Board
ESA	Head of Science Projects
ESA	Ariel Project Manager
UK Space Agency	Lead Space Science Programme Manager
Blue Skies Space Ltd	CEO
UCL	Developer of TauREx3

*While we kept the option of a survey open for large parts of our study, we decided (with agreement from UK Space Agency) to redirect efforts towards interviews, which focused on obtaining deeper insights. Follow-up email questions were asked in specific instances to obtain quantitative information.



Previous contributions to our evaluation (in addition to those listed above) include:

Organisation	Role
UCL / Spaceflux	Deputy Director of UCL Centre for Space Exochemistry Data (CSED) / Co-founder & Director of Spaceflux
RAL Space	Cryogenics
UK Space Agency	Head of Space Science
Queens University Belfast	Ariel SPRP
Airbus	Head of Science Programs
UCL	Ariel Data Challenge Outreach and Engagement Officer

Wider meetings

Throughout the course of our study, we have also presented findings at Ariel **Project Management Board** (PMB) meetings. The PMB meeting provided an opportunity to receive any questions / feedback on our approach, as well as providing valuable insights on UK project team progress and delivery challenges. It also allowed us to prime the project teams for stakeholder engagement periods, including interviews and follow-up emails.

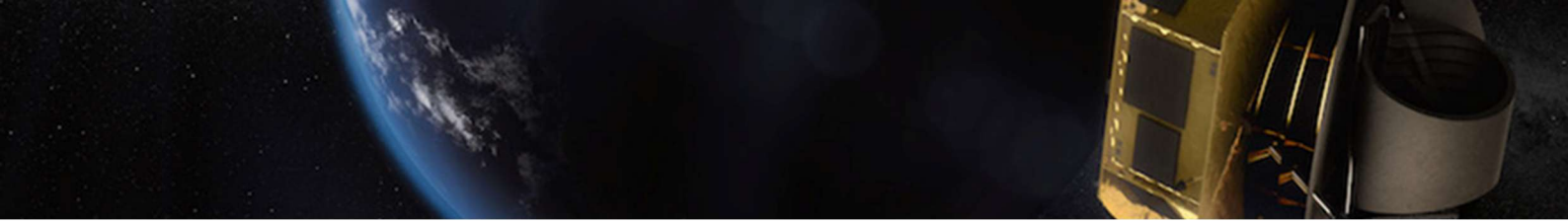
4.2.2 Desk-based research

We conducted additional desk-based research to collect data for each iteration of the 6-monthly updates, as well as for additional information included within this interim impact and process evaluation. This included publicly available online information such as exoplanet.eu, Kaggle, and ResearchGate profiles of key project team members. Desk-based research also included all prior editions of Researchfish data, which was used to fill any gaps in interview and bibliometric data.

4.2.3 Bibliometrics

To capture scientific and collaboration-related impacts arising from Ariel, we conducted bibliometric analysis with our partners, Digital Science. To ensure metrics are captured consistently over time, and hence enabling comparison, we have replicated the same keyword search identification process which was deployed for the baseline period and was repeated through four 6-monthly updates. Separate keyword search strings were created for exoplanet science and Ariel related papers, which were developed in consultation with mission PI, Prof. Tinetti.

- The search string used for **exoplanet related** publications was: "EXOPLANET" OR "EXO-PLANET" OR ("TRANSIT SPECTROSCOPY" AND "PLANET") OR "HOT JUPITER" OR "SUPER EARTH" OR ("SUPER EARTH"AND ("EMISSION SPECTRA" OR "PHASE CURVES" OR "TRANSMISSION SPECTRA" OR "PROTOPLANETARY" OR "PLATO" OR "CHEOPS" OR "TESS" OR "KEPLER" OR "HUBBLE SPACE TELESCOPE" OR "JWST" OR "ARIEL" OR "SPITZER" OR "NANCY ROMAN"))
- Filtered by the following fields of research: "51 Physical Sciences", "40 Engineering", "37 Earth Sciences", "46 Information and Computing Sciences", "34 Chemical Sciences", "49 Mathematical Sciences", "31 Biological Sciences"
- For **UK exoplanet related publications**, the same search string and field of research classifications were applied, with the additional criteria that one or more co-authors were affiliated to a UK based organisation.
- For **UK Ariel publications**, the same approach was applied as for UK exoplanet related publications, with the addition of "AND ARIEL" to the search string, to capture the subset of publications related to the Ariel mission.



Annually, this was also supplemented by additional publication data provided by the project team through Researchfish. The bibliometric analysis leverages the dimensions.ai database, which is the world largest research information dataset. There are minor differences in the number of publications reported in previous years for some metrics, which is due to additional publications being identified within these years which didn't exist on the Dimensions database before. This is due to the dynamic nature of the database, where publication records are backfilled continuously as new source titles are made available.

4.2.4 Altmetrics

Altmetrics are a tool that can help identify activity around publications which could demonstrate research impact beyond citations, as articles are often shared, mentioned and discussed in many different forums and contexts. It is not a method to replace traditional citation / citation-based metrics, but acts as a complementary approach to show interest in research that cannot be measured in a citation count.

The Altmetric Attention Score is part of the Digital Science portfolio, and is automatically calculated through the weighted count of all attention a research output has received, based on three main factors:

- **Volume**: score rises as more people mention the article. The weight only counts one mention from each person per source.
- **Source**: each 'category' of mention contributes a different weight to the final score, e.g. newspaper article is weighted more strongly than a blog post, which is stronger than a tweet.
- **Authors**: considers how often the author of each 'mention' discusses scholarly articles, whether there's a bias towards a particular journal / publisher, and the audience they leverage.[51]

It is best used as a way to quickly measure the level of online activity surrounding a particular piece of research output; it is not a measure of the quality of the research or researcher.

In order to capture altmetrics data for our research, we extracted the DOIs of the top 10 cited publications in the relevant period and scope, and ran them through the altmetric.com bookmarklet. This provided us with an altmetric attention score, the number of Mendeley readers, and the rank of the publications within the same journal published in the same three month period. The bookmarklet also provides us with additional information on the number of news articles, Wikipedia articles, blog posts, and social media posts in which the article is mentioned.

[51] Altmetric Ltd., 2023. *The donut and altmetric attention score.* Available at: https://www.altmetric.com/about-us/our-data/donut-and-altmetric-attention-score/

…now you **know.**