

The UK Fireball Alliance – building an all-sky UK meteor observatory

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Thematic Area: The Solar System & Planetary Environments (Planetary)



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White paper submitted to the UK Space Frontiers 2035 programme

November 2025

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The UK Fireball Alliance (UKFAI) is a collaboration of camera networks that aims to record meteors and fireballs and recover freshly fallen meteorites in the UK. Established in 2018, the UKFAI has advanced our knowledge of Solar System formation, helped develop robust plans for planetary defence, and engaged diverse audiences with UK planetary science.

With initial support from the STFC, the UK has the densest meteor and fireball coverage in the world underpinned by a network of researchers and citizen-scientists with expertise in meteor data analysis and meteorite search methods. Further investment in the UKFAI is now urgently required to unlock an opportunity to create an all-sky national meteor observatory that delivers world-class cross-disciplinary science driven by innovation and a highly skilled workforce. By building new partnerships with government bodies, space agencies, and industry, the UKFAI will boost UK leadership in planetary science and shape the narrative for the planetary defence and space debris challenges facing society.

1. Scientific Motivation

Nearly ~300 tonnes of extraterrestrial material enters Earth's atmosphere every day [1]. Ranging from micron-sized particles to objects several metres in diameter, this material produces bright streaks in the sky known as meteors and fireballs that can be recorded by cameras. Characterising meteoroids that “burn-up” in the atmosphere is important for quantifying the flux of extraterrestrial material to the Earth. Any larger rocks that survive to the ground are called meteorites and can be used to understand the composition of asteroids and planets. The UK Fireball Alliance (UKFAI) is a collaboration of camera networks that aims to record meteors and fireballs and recover freshly fallen meteorites in the UK.

Under favourable observing conditions, the UKFAI networks can record between 5000 to 10,000 single-station meteor detections in a night. Multiple observations of the same event are used to determine the mass, velocity, trajectories, and orbits of extraterrestrial dust and rocks entering the atmosphere over the UK. In 2021, data from the UKFAI was critical to calculating the pre-atmospheric orbit, initial meteoroid size and mass, and fall position of the Winchcombe carbonaceous chondrite, a rare type of meteorite containing signatures of extraterrestrial water and organics (Fig. 1, [2]).

Established in 2018, the UKFAI has become a key facility for understanding:

Small Body Populations Calculating the pre-atmospheric orbit and physical properties of objects entering the atmosphere provides important information about the contemporary abundance and sources of extraterrestrial materials being delivered to Earth. Continuous observations enable cosmic dust and meteoroid population models to be developed and refined, facilitating the discovery of new meteor streams and a risk assessment of potentially hazardous near-Earth objects (NEOs). For example, the UKFAI was part of an international collaboration that observed 2023 CX1, a ~1 m diameter asteroid detected only hours before entering the atmosphere and later recovered as meteorites in northern France [3].

Solar System Geology Accurately determined pre-atmospheric orbits directly link meteorite falls to their parent bodies [4], context that is lacking for >99% of the meteorites in our collections. Well-

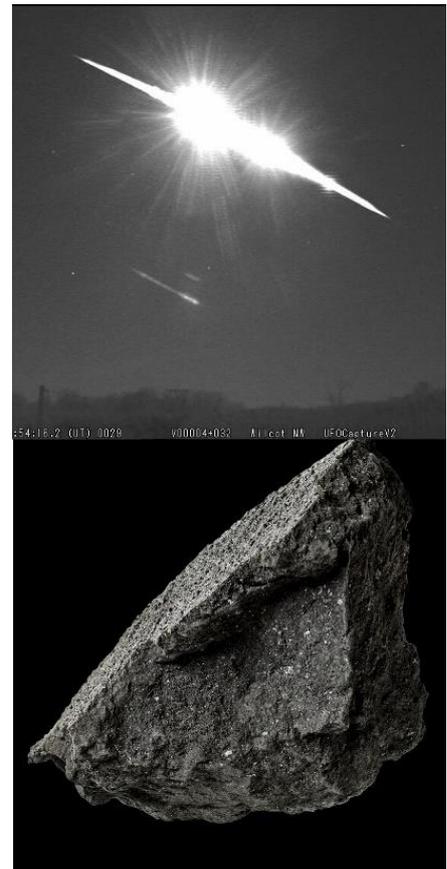


Figure 1. Top: Video image of the Winchcombe fireball. Bottom: A fragment (~2 cm) of the Winchcombe meteorite, the first samples of which were recovered ~12 hours after the fall.

constrained fall positions and strewn fields enable the rapid recovery of meteorites before any significant modification in the terrestrial environment. Pristine meteorites with known orbits are therefore complementary to samples returned (at great expense) from other planetary bodies by space missions. Detailed laboratory analysis of meteorite falls with orbits helps to construct a geological map of the Solar System, which is crucial for understanding the evolution of planets.

The goals of the UKFAI address key questions highlighted in the STFC's [Roadmap for Solar System Research](#), including:

- How did the Solar System form and evolve?
 - o *What was the composition of the protoplanetary disk? What are the timescales and processes of planet formation?*
- What are the conditions for life and how widespread are they?
 - o *What is the impact record of the Solar System and how has it evolved? What is the origin of water and organic matter on Earth?*
- How does our Solar System compare to other planetary systems?
 - o *Is the structure of our Solar System unique? Do all Solar Systems form and evolve in the same way?*

2. Objectives

For many years the UKFAI worked as an essentially unfunded pilot project led by planetary and citizen-scientists who volunteer their time. The UKFAI committee is comprised of researchers (early- to mid/late-career stages), curators, citizen-scientists, and engagement specialists based at institutions across the UK and has a representative from each camera network. In 2023, the UKFAI received an urgency grant (Grant No. ST/Y004817/1) from the STFC to (i) upgrade parts of the existing networks, (ii) extend and support the geographic reach of the networks, and (iii) continue integration of different camera systems to facilitate data sharing. Funds have been used to replace old camera systems and install new cameras, providing near-complete coverage of the skies above the UK (Fig. 2). The UKFAI has also developed specialist meteorite recovery packs (e.g., with curation-grade consumables) and promotional materials (e.g., [website](#), business cards, information leaflets) that have supported meteorite searches in England and Scotland. These efforts are an important step towards achieving an all-sky national meteor observatory that will enable breakthroughs in our understanding of small body populations and the geology of the Solar System.

The UKFAI now aims to build on this initial success through four objectives:

1) Maintaining UK strength in meteorite searches Modelling suggests that ~1 or 2 small (<500 g) meteorites should land in the UK each year [5]. Since the historically important fall of Winchcombe in 2021, the UKFAI has carried out four meteorite searches (near Shrewsbury, Stoke-on-Trent, Cheltenham, and Ben Alder). Although no meteorites have been recovered from these events (yet!), the searches have allowed the UKFAI to develop an efficient response pipeline that often results in search teams arriving in the area within days of a fall [e.g., 6]. Furthermore, the searches have been used to refine best practice and train early career researchers and citizen-scientists, while meteorite recovery packs are now available at institutions throughout the UK.

2) Expanding UK meteor and fireball science Several of the UKFAI networks host >10 years of observations suitable for scientific research, with the potential to explore 'big data' mining, machine learning methods, and AI applications. To start exploiting the existing dataset and build UK capability, the UKFAI have initiated a PhD project investigating dark flight modelling through funding from the University of Manchester. The UKFAI has also taken steps to build a UK meteor and fireball science community by organising a RAS Specialist Discussion meeting (*Meteor Science in the UK*, 2022) and giving invited talks at other national workshops (e.g., *Impact Earth! Protecting the UK and Further Afield from Impacts by Near Earth Objects*, RAS, 2023; *Space Debris Activities Academic Working Group*, UKSA, 2023).

3) Tackling the Space Debris Crisis As the near-Earth environment becomes more crowded and humanity is increasingly reliant on space-based infrastructure, accidental collisions and uncontrolled satellite re-entries pose a considerable risk to the UK. Modern camera systems are highly sensitive, making it possible to locate and track artificial objects from the ground [7]. With the incorporation of spectroscopy, camera networks may also be suitable for estimating the composition and contribution of metals to the upper atmosphere [8]. In February 2025, the UKFALL camera networks recorded debris from a Space X Falcon 9 rocket re-entering the Earth's atmosphere over the UK [9].

4) Developing cross-disciplinary scientific observations The UKFALL camera networks are continuously monitoring the skies (usually during night but daytime observations are also possible), capturing a wide range of events and phenomena of scientific interest beyond meteors and fireballs. For example, in 2024 the UKFALL networks recorded the spectacular aurora event over the UK, helping to better understand responses to geomagnetic storms [10]. Several camera systems may even be sensitive enough to detect astronomical events such as extrasolar flares and supernovae. The continuous all-sky observations from multiple stations means that the UKFALL networks will likely be the first on the sky to constrain atmospheric phenomena from the local to the cosmological [11].

3. Strategic Context

The goals of the UKFALL are fully aligned with the STFC's aim to answer "*How do stars and planetary systems develop and how do they support the existence of life?*". The strategic importance of meteor and fireball camera networks is highlighted as a "Key Mission and Requirement for the Planets and Life Theme" in the Roadmap for Solar System Research. An all-sky national meteor observatory is also relevant across the wider UKRI research landscape including NERC (*Impact Processes on Earth*) and the UK Space Agency (UKSA) (*Mission Planning and Space Situational Awareness*).

The characterisation of asteroid 2023 CX1 clearly demonstrated the ability of the UKFALL to contribute to planetary defence by quantifying the impact hazard risk to the UK. In the UK, planetary defence efforts include the National Space Operations Centre (NSpOC) and its link to the International Asteroid Warning Network (IAWN), while the UK was a founding member of the Space Mission Planning Advisory Group (SMPAG). Asteroid impacts do not yet feature on the UK's national risks register; however, planetary defence has become a critical area for many governments and space agencies, with events such as Chelyabinsk in 2013 (the meteoroid was ~20 m in diameter) expected to occur every few decades, potentially causing regional-scale effects including severe injuries and tens of millions of pounds worth of damage to infrastructure. Internationally, there has been significant investment in the detection and monitoring of the NEO population (e.g., the risk from asteroid 2024 YR4) and ways to mitigate a future asteroid impact risk (e.g., NASA's DART and ESA's Hera and missions).

The UKFALL is also strategically relevant to the emerging risk of space debris. A key finding from the recent [House of Lords UK Engagement with Space committee](#) was "*Space debris represents a fundamental challenge to the future safety of the space environment. There are over a million pieces of debris in-orbit which could harm a satellite...*". The [National Space Strategy](#) and [Space Industrial Plan](#) highlight the reliance of UK daily life on space infrastructure, with recent analysis indicating that satellites and other space-based services underpin 18% of the UK's GDP (~£454 billion). Satellite technology is therefore critical to the UK and loss of access would cost the economy on the order of



Figure 2. Top: Cameras in the SCAMP (l) and UKFN (r) networks. Bottom: UKMN cameras provide coverage across most of the UK.

£1 billion per day [12]. By continuously tracking and monitoring satellites and re-entries over the UK, an all-sky national meteor observatory is a key tool for understanding the space debris risk.

Finally, the UKFAI is aligned with UKRI, the STFC's, and the UKSA's engagement strategies, which aim to ensure that the benefits of UK research are shared widely and create opportunities for inspiring the next generation of highly skilled workers that will be crucial to the future economic growth of the UK. For example, the UKFAI fully leveraged the extensive national and international media interest in the Winchcombe meteorite fall [e.g., 13] to engage people with STFC-funded planetary research. Samples of Winchcombe are on public display in four museums, including as part of the Natural History Museum's (NHM, London) "Space: Could Life Exist Beyond Earth?" exhibition. In the ~18 months following the fall, UKFAI members visited ~1500 school students in the Winchcombe area, attended the Cheltenham and British Science Festivals, and led a stall at the Royal Society Summer Science Exhibition, which was visited by 766 school students, 76 teachers, and 5007 members of the public. More recently, the UKFAI is supporting the STFC-funded "Asteroids - Do Look Up!" project, which is inspiring students at >20 schools across the UK by enabling them to observe meteors and collect micrometeorites.

4. Proposed Approach

An all-sky meteor observatory is a relatively low-cost (<£20k/year excluding personnel costs), high reward national facility. The installation of new cameras over the last two years means that most of the required infrastructure is already in place, with few gaps remaining in the coverage over the UK (Fig. 2). Most camera systems are inexpensive (<£500) and once installed need little maintenance beyond cleaning of housing units and the occasional replacement of parts. Nevertheless, the UKFAI has ongoing operating costs including data storage and website hosting, the production of promotional materials, insurance, and travel and subsistence to support meteorite search teams. Furthermore, to maintain the operational health of the networks and fully capitalise on the available datasets requires sustainable long-term training and support for technicians and researchers, contributing to the UK's need for highly skilled workforce.

The STFC urgency grant (ends in 2026) has enabled the UKFAI to support a PDRA, which has been pivotal in expanding the networks to their current status, refining expertise in meteorite searches, and working towards using the data for wider scientific research. The UKFAI proposed to continue supporting the networks through an application to the STFC Astronomy Large Awards, but these have subsequently been paused. The Astronomy Small Awards remain an option for science exploitation but would not support the underpinning infrastructure, while the UKFAI does not yet fully meet the criteria for the STFC Projects Peer Review Panel (PPRP) or Infrastructure Fund projects.

A funding mechanism through UKRI, the STFC and/or the UKSA for the UKFAI is time critical as the next meteorite-dropping event could occur at any moment, while the UK risks falling behind the international community in addressing concerns regarding planetary defence and space debris.

Over the next ~5 years, the UKFAI aims to:

1) Maintain strength in meteorite searches by exploring funding opportunities through specialist societies (e.g., RAS, Geological Society) to create a formalised programme for training researchers and citizen-scientists in meteorite recovery and investigate the use of new technologies (e.g., drones) in search efforts.

We also very strongly support the goals of the UK Cosmochemistry Network (UKCAN), which aims to provide the UK meteorite sample analysis community with the appropriate curation and analytical facilities needed to maintain UK leadership in extraterrestrial sample analysis [14].

2) Expand UK meteor and fireball science by establishing a thriving meteor and fireball community through cross-disciplinary DTP/CDTs, increasing the number of applications for science exploitation

funding, attracting talent to the UK through fellowship schemes (e.g., Future Leaders, Ernest Rutherford), and collaborating with the UK's impact [15] and airburst specialists [16]. In this way, the UKFAI will strengthen the UK skills base and contribute to a workforce capable of confronting societies biggest challenges.

3) Tackle the space debris crisis through increased advocacy of the camera networks, enabling closer collaboration with the government, the UKSA, and experts in the field [17] to track and monitor satellites and re-entries above the UK, thereby protecting UK space infrastructure and mitigating potential risk to the economy and environment.

4) Develop cross-disciplinary observations and cultural relevance by using schemes such as the UKRI cross research council response mode to launch a series of pilot studies aimed at determining the effectiveness of the camera systems for characterising events such as aurora, atmospheric sprites, and extrasolar flares, and quantifying the role and importance of citizen-science in society.

5. UK Leadership & Capability

The UKFAI includes the citizen-science led UK Meteor Network (UKMN, the largest contributor to the Global Meteor Network (GMN)), the Network for Meteor Triangulation and Orbit Determination (NEMETODE), and the AllSky7 network, and the academic-led System for the Capture of Asteroid and Meteorite Paths (SCAMP, an extension of FRIPON), and the UK Fireball Network (UKFN, part of the Desert Fireball Network (DFN)). The networks are comprised of nearly 300 individual cameras, giving the UK the densest meteor and fireball coverage of anywhere in the world. The camera systems range from low-cost digital cameras connected to a Raspberry Pi to sophisticated all-sky DSLRs, allowing the networks to record both very faint meteors and the brightest fireballs. Data are stored on local servers and cloud environments and are typically available to the public within ~24 hours of an event. In some instances (e.g., known meteor showers), detections are uploaded to network [websites in real-time](#), enhancing public engagement, while for meteorite-dropping fireballs the UKFAI initially retain data to establish a recovery plan and prevent a “goldrush” in the local area. Most of the networks have been operating for >10 years and have significant experience in the acquisition and analysis of meteor and fireball data. As already noted, the extensive dataset produced by the networks has contributed to our understanding of the early Solar System [2], the NEO population and asteroid impact risk [3], and electromagnetic storms [10].

In addition, the UKFAI has established itself as an international leader in the recovery of freshly fallen meteorites [e.g., 6]. For example, the UKFAI has created a rigorous response pipeline for conducting meteorite searches in the challenging UK environment. This includes development of a converter program and standard data exchange format to facilitate rapid data-sharing between the different camera systems [18], a set of prepared press releases, information handouts for local communities and landowners, and curation and engagement plans, and specialist meteorite recovery packs and a network of trained researchers and citizen-scientists. The preparedness of the UKFAI enabled most of the Winchcombe meteorite to be recovered within one week of the fall, preserving a pristine sample described in detail in 14 papers as a special issue of the peer-reviewed journal *Meteoritics and Planetary Science* [19].

Winchcombe was the first meteorite recovered in the UK since 1991 and the UKFAI ensures that it won't be another 30 years until the next one.

6. Partnership Opportunities

International Networks Meteor and fireball camera networks are expanding rapidly across the world. The UKFAI already has excellent collaborations with the GMN, FRIPON, and DFN and will maintain these by sharing data, best practice, and technological developments and through collaborative workshops. A long-term vision is to establish global meteor and fireball detection capabilities that continuously monitor the arrival of extraterrestrial material at Earth and significantly increases the number of recovered meteorite falls with pre-atmospheric orbits.

Funding Bodies Astronomy and planetary science in the UK is mostly funded by the STFC, but there is clearly scope for the UKFAI to support research and innovation in other areas. For example, atmospheric observations are a key topic for NERC and institutions such as the Met Office and the National Centre for Atmospheric Science (NCAS). A move towards cross-disciplinary funding programmes can unlock opportunities to establish UKFAI as a national cutting-edge infrastructure, enabling UKRI to deliver world-class people and places.

Space Agencies ESA is committed to planetary defence and asteroid exploration through its Planetary Defence Office, which supports activities including large-scale NEO surveys and missions such as Hera and Ramses. The UKSA and NSpOC are now working alongside ESA to identify and monitor NEOs. The UKFAI can form part of the UK's critical infrastructure for planetary defence with the excellent coverage enhancing UK leadership in this area and facilitating collaborations between academic institutions, space agencies, and the space industry.

UK Asteroid Community The UK has a long tradition of curating and analysing meteorites [14]. Data from the UKFAI enabled the rapid recovery of the Winchcombe meteorite, which was analysed by >100 researchers from >20 UK institutions and companies. Laboratory analyses of extraterrestrial samples are underpinned by the UK's state-of-the-art analytical facilities and the UKCAN. The UK also hosts world-leading expertise in remote observations using ground- and space-based telescopes, with new facilities such as JWST and Vera C. Rubin Observatory set to transform our understanding of asteroids [20].

Satellite Companies The Harwell Space Cluster includes >100 space organisations, many of which have interests in the launch and operation of satellites and space communication services that are crucial for the UK economy. Notably, the STFC-funded National Satellite Test Facility (NSTF) opened at RAL Space in 2024. With spaceports making it easier than ever for UK academia and industry to access the space environment, the risks associated with space debris and uncontrolled re-entries will become increasingly important, requiring the development of effective monitoring and mitigation strategies [17].

Industry The development of cameras with higher resolution, faster responses, and novel capabilities will provide opportunities to work alongside companies to drive innovation and economic growth. For example, the UKFAI recently partnered with Ring to explore ways in which doorbell cameras, which are now common throughout the UK, can be adapted to capture meteor and fireball data. Over the next ~10 years, there will be an increasing need for highly sensitive cameras suitable for tracking satellite movements.

Specialist Societies It is highly likely that the next UK meteorite will be recovered by citizen-scientists. Working with specialist societies such as the RAS and Geological Society is an important step towards promoting the goals of the UKFAI and training citizen-scientists in meteorite recovery methods. In addition, citizen-scientists are also encouraged to install their own cameras, offering a simple and effective way to participate in UK planetary science.

Wider Engagement Meteors and fireballs often produce spectacular images and videos that capture the public's attention and are reported by national and international media outlets. Furthermore, many people report seeing meteors and fireballs with their own eyes, record them with cameras, or potentially take part in meteorite searches, giving them a "hands-on" experience that makes a meaningful contribution to research. There are many opportunities for the UKFAI to collaborate with museums, galleries, and education centres to create scientific exhibitions, displays, and activities, and to work with media organisations such as the BBC to produce documentaries and films promoting STEM subjects.

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