# CATCHING A FALLING STAR (OR METEORITE) – FIREBALL CAMERA NETWORKS IN THE 21st CENTURY

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Have you ever seen a shooting star? Have you ever seen a fireball? They are the spectacular fiery result when space dust and rocks enter our atmosphere. Meteors (also known as shooting stars) are specks of dust that leave a trail of light as they burn up in the atmosphere. Fireballs are caused by larger bits of material, making them significantly brighter, and can last several seconds in duration. Fireballs and meteors hit the atmosphere at velocities of tens of kilometres per second. Friction from the air heats the surface of the rock, melting and ablating it, giving the impression of a ball of fire. A meteorite is the surviving material from a fireball. Meteorites give planetary scientists information about the origin and evolution of the Solar System: from how the first solids formed all the way through to the accretion of planets. Meteorites provide a scientifically priceless record, but their impact is reduced because we have no spatial context to interpret their compositional data. Imagine trying to understand the geology of a continent if all you had to work with was a collection of random rocks dumped in your yard. That is where we are with meteorites. We know meteorites come from space, mostly from the asteroid belt. We can pinpoint their precise origin in the Solar System by determining the orbit that they were on before they hit our atmosphere. However, this is only possible if we are able to track the fireball before it lands. Combining the orbit with the recovered meteorite is a major step towards interpreting the record of early Solar System processes that meteorites contain.

## Camera Networks

Fireball camera networks are designed to recover meteorites with orbits. The first network, based in the Czech Republic, became active in 1959 and continues to operate as part of the European Fireball Network (Oberst et al. 1998). In the 60s, 70s, and 80s, two other networks were operational in North America, covering parts of the US (Prairie Meteorite Network; McCrosky et al. 1978) and Canada (Meteorite Observation and Recovery Project; Halliday et al. 1996). Despite covering over a million square kilometers of the Earth's surface, only a handful of meteorites have been recovered. This is unfortunate because the promise of these camera networks is very great—knowing the spatial context (an

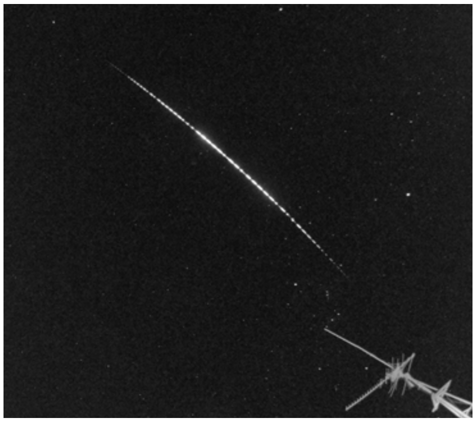

**FIGURE 1** Fireball over Perenjori, 260 km north of Perth (Western Australia). The camera was set up on Perenjori Primary School as part of the Fireballs in the Sky outreach program.

orbit) bridges the gap between meteorite and asteroid research, with the potential to revolutionize both fields. Although the methodology employed in these earlier networks is sound, they are limited by their location: temperate zones where vegetation and weather conditions are not well suited for meteorite preservation or retrieval. It is hard to spot a meteorite in a cornfield, on the tundra, or in a forest. Moreover, meteorites weather away quite rapidly on Earth (Bland et al. 1998); even brief exposure to rain will affect the primordial record they hold (Jenniskens et al. 2012).

## The Desert Fireball Network

Deserts are exceptionally suited to finding meteorites due to the lack of plant cover and because the environmental conditions limit degradation (Bland et al. 2000). Around 80% of all meteorites have been found in deserts. Could a network sited in a desert deliver greater numbers of meteorites with orbits? The benefit is that searching should be easier. The major difficulty is building hardware to survive and operate autonomously for extended periods in a harsh environment. To test the concept, a trial network of four film cameras in the Nullarbor desert of Western Australia was established in 2007 (Bland et al. 2012). Australia was considered ideally suited for the network because of clear skies and arid environmental conditions. Prior to this project, there were no known southern hemisphere meteorites with orbits, or indeed any extended campaigns observing southern hemisphere fireballs (FIG. 1). The initial Desert Fireball Network (DFN) covered only a small area (172,000 km$^2$), but by 2010, two meteorites had already been recovered (Bunburra Rockhole and Mason Gully) using trajectory information calculated from fireball images. The images also allowed us to determine the precise pre-atmosphere orbits for these rocks (Bland et al. 2009; Towner et al. 2011). Bunburra Rockhole was an especially interesting find—a unique basaltic achondrite with an Aten-type near-Earth object orbit (Bland et al. 2009). This achievement has allowed us to upgrade and expand the DFN.

Currently, DFN has 32 camera stations covering ~1.3 million km$^2$. The cameras are fully autonomous systems, capable of operating for 12 months without maintenance and storing all images collected over that period. Each station incorporates a 36-megapixel full-format digital and low-light video camera run by an embedded computer. The package is an intelligent imaging system, which calibrates its own optics, modifies observations based on cloud conditions, automatically recognizes fireball events, and pre-processes the data prior to uploading it to the project server. The data pipeline includes image processing to determine fireball position at sub-pixel level, triangulation and fireball trajectory modelling, and dark flight trajectory modified by weather and forecast climate modelling. The final facility will incorporate 70 stations extending over twice the present area to record meteorite falls, track re-entry of space debris, and determine landing sites for each.

## Citizen Science

DFN is a natural outlet for community outreach/engagement because of the widespread interest in fireballs and meteorites. Fireballs get more and more media coverage, especially in the age of expanding use of dashboard and security cameras. Fireballs in the Sky (FITS) is a citizen science project linked to the DFN (www.fireballsinthesky.com.au) with the goal of sharing the research and involving the global public. School students and the general public are encouraged to contribute and interact with scientists as the program develops, essentially becoming members of Fireballs in the Sky community. There are a number of ways to engage with the team: e-newsletters, a blog, Facebook (www.facebook.com/fireballsinthesky), and Twitter (@fireballssky). A smartphone app (www.fireballsinthesky.com.au/download-app) has been developed so that the public can record and share their fireball sightings with scientists, participating in real-time research (FIG. 2). The app works around the world, allowing orbital data to be confirmed from anywhere on the planet, even if no meteorite is found. Users receive updates on the specific event that they witnessed. A recent upgrade adds details on meteor showers throughout the year and provides users a display directing them to the specific location in the sky for that shower.

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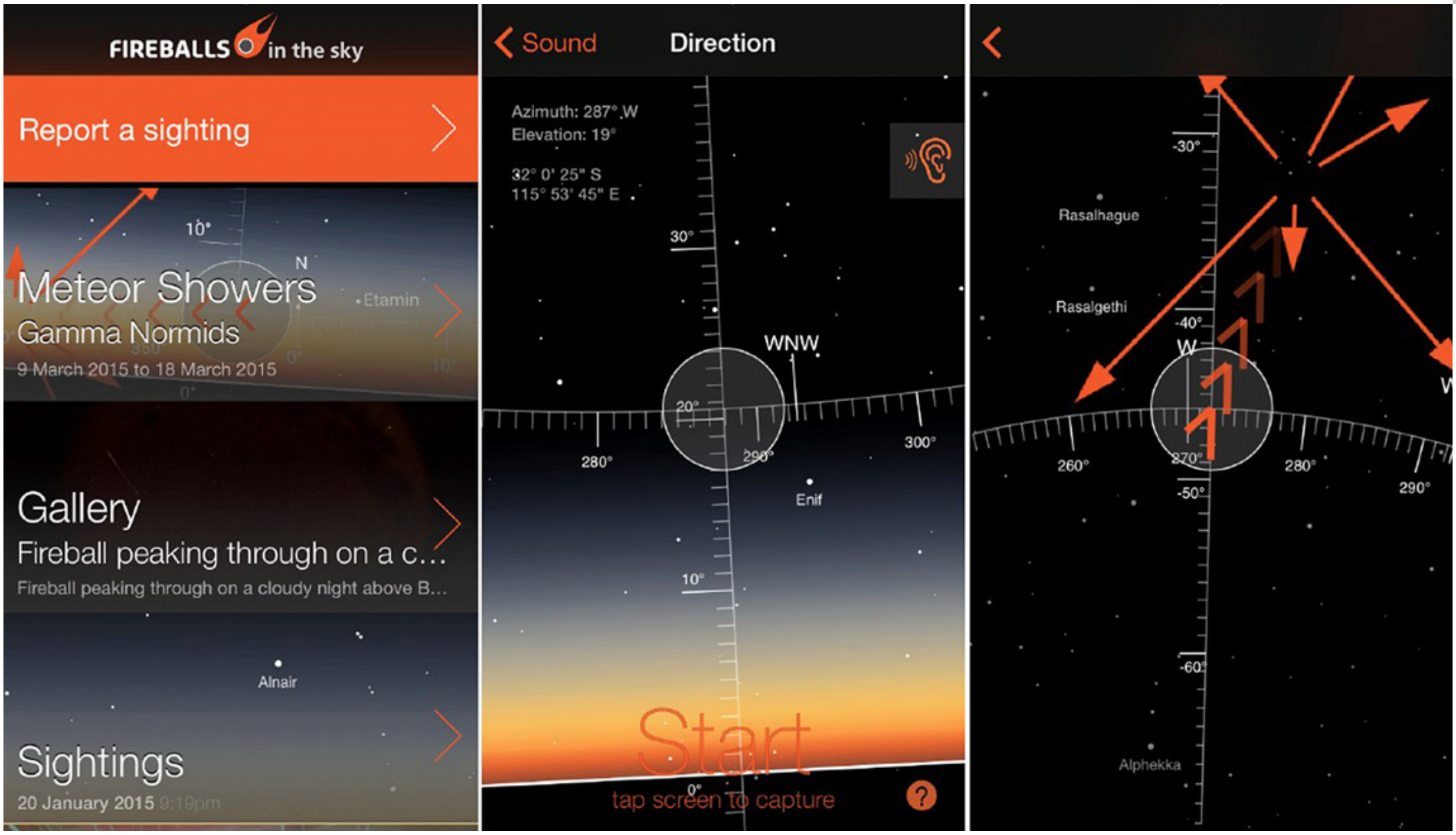


**FIGURE 2** Three screenshots illustrating the main features of the Fireballs in the Sky smartphone app. (**LEFT**) The menu screen allows a user to report a sighting, to find current and upcoming meteor showers in their area, and get up-to-date news on what's happening with the DFN research team. (**MIDDLE**) To record a sighting, the user points the phone at the start and end positions in the sky and "draws" the path of the fireball. The user is then prompted to edit the created simulation by adjusting duration, brightness, shape, and colour of the fireball before reaching a summary page. Because it is a simulation, not a video, this is done after the fireball has burned out. With multiple reports, a sighting can be confirmed and will be listed on the app for users to check. (**RIGHT**) Once a user selects a meteor shower, the app will provide data such as expected peak, zenith hourly rate, and Moon phase. The app will then direct the user to the best area to look in the sky, in real time.

Finally, with technologies invented for the next generation digital observatories, we are developing an inexpensive "kit" fireball camera station that would allow interested amateurs to plug in a digital camera and have their own advanced fireball observatory. A versatile interface will allow users to customize camera settings, schedule operations, and download imagers using Wi-Fi. The ability to use it for daytime photography means that the system can be adapted for multiple functions outside of fireball observations.

The goal of DFN is to increase recovery of meteorites with orbits: a growing, lasting resource for the research community. It is our hope that with the smartphone app and new home kit hardware, the public can make a real contribution to the field and participate in this research as it happens.

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