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## The Winchcombe Meteorite - One year on

Áine Clare O'Brien<sup>1</sup>, Annemarie Pickersgill<sup>1</sup>, Luke Daly<sup>1</sup>, Laura Jenkins<sup>1</sup>, Cameron Floyd<sup>1</sup>,  
Pierre-Etienne Martin<sup>1</sup>, Lydia Jane Hallis<sup>1</sup>, Ashley King<sup>2</sup>, Martin Lee<sup>1</sup>

1. School of Geographical and Earth Sciences, University of Glasgow

2. Natural History Museum of London

On Sunday 28th February 2021 at 9:54 pm, when Britain was in the grips of the COVID Alpha variant, an enormously bright fireball (a meteor that lasts for one second or longer) was seen in skies across the UK and North West Europe. That night, Twitter erupted with videos of the space rock streaking through the atmosphere as it broke into pieces. It was a shooting star so bright and so widely observed, that thanks to doorbell cameras and dark sky cameras alike, it ended up being the most well-recorded fireball ever.

That evening the Wilcock family of Winchcombe, Gloucestershire, were having a quiet night in (as many of us were during Spring 2021..!) when their daughter heard a loud clattering noise. Thinking nothing of it, she went to bed. Little did she know, their lucky guinea pigs had narrowly missed a fateful end.

The planetary science community meanwhile were gradually realising something very exciting might well have just happened. Thanks to footage from the network of all-sky cameras, amateur astronomers, and meteoriticists known as the UK Fireball Alliance (UKFALL), as well as the myriad tweets, it was quickly becoming clear that this fireball might well have dropped a stone over the UK. Thankfully, a year or so before COVID hit, the Alliance was formed in anticipation of such an event, and a plan was put into action. Data was shared between amateur astronomers and professional scientists, and trajectory modellers quickly worked out that a small black rock was probably sitting on the ground somewhere in the Cotswolds.

On the 1st of March, Ashley King of the Natural History Museum (NHM) appeared on national TV telling residents of the area to keep an eye out for new small dark rocks in places they shouldn't be. It being peak lockdown, we of course could not ask the public to go out searching for them. This started a huge amount of excitement and enthusiasm amongst Cotswold locals as they set about searching in their gardens. Undoubtedly with pubs and restaurants closed and social mixing still banned, there weren't many permitted activities one could do at this point in time, and so, with some people perhaps having a little more free time on their hands than usual, we were inundated with images of potential meteorites on people's lawns, most of which turned out to be 'meteorwrongs'...

Back to the Wilcock family of Winchcombe. That Monday morning, they had seen Ashley's press appearance, and left their house to find a shattered pile of coal-like dirt on their driveway (feeling relieved that it had not fallen only a few meters over, where it might have seriously injured their guinea pigs Parsnip, Nutmeg and Ted!) and were diligent enough to scoop it up using clean sterile utensils and contacted the UK Meteor Observation Network (UKMON) with some photographs. After colleagues at the NHM and UKMON filtered through the photos, our colleague Richard Greenwood from the Open University was able to visit the Wilcocks, and straight away 'his knees went wobbly' as he realised what they had scooped up. Not only was this certainly a space rock but he was sure this was a CM ("Mighei-like") chondrite. These are rare types of carbonaceous chondrite meteorites that Richard and

Ashley both happen to have studied extensively throughout their careers. The word was kept as quiet as possible so as not to encourage people to break lockdown restrictions to go searching for pieces - naturally, this meant lots of people heard about it straight away.

At this point, thanks to the combined efforts of the UKFAI, and the modellers of the Global Fireball Observatory at Curtin University, Australia we knew: a) it was a rare meteorite, b) there were likely more pieces to be found and c) the location of the likely strewn field (fall zone) of any more pieces. We therefore urgently needed to get a search team together to find and collect any other pieces, and crucially in a COVID-safe way.

By Wednesday, Ashley had joined Richard to scour the Wilcocks' driveway for fragments and meet other residents with potential finds. Meanwhile scientists from across the UK - with the necessary health and safety approvals in hand - headed for the Cotswolds. Our team from the University of Glasgow had approval to travel at 4:30 pm on Wednesday 3rd March, at which point we began the 340 mile journey to Winchcombe - in separate cars and household bubbles to minimise the risk.

Driving down on that Wednesday evening was surreal. I hadn't stayed anywhere other than my top floor flat in months, and I was going to be seeing colleagues I hadn't seen for over a year for something unbelievably exciting, yet still with all the anxiety of travelling for the first time during a pandemic. Luckily searching for meteorites outside was already a socially distanced activity - by pure coincidence the optimum separation to do this happens to be 2 metres apart!

From Thursday 4th to Monday 9th March, planetary scientists from across the UK scoured the ~4 square km strewn field searching for fragments of the meteorite. This involved getting into small socially distanced teams and walking slowly in a straight line up and down fields, similar to forensic levels of detail. Luckily we had a few seasoned searchers in our midst - Luke Daly (Glasgow), Katie Joy (Manchester), Romain Tartese (Manchester), and Natasha Stephen (Plymouth). They had all been a part of multiple space rock searches in Australia or the Antarctic in the past, and rapidly trained the rest of us in the art of spotting small dark rocks in places they shouldn't be. The mathematical modelling was so precise that we had a guide not only of where to search, but of approximately what mass the fragments would be in a given area. This helped us somewhat, as we knew whether we were looking for a 'first sized piece' or a 'thumbnail sized piece' of stone, but when searching for small dark objects in the fields, most of what you find turns out to be sheep poo.

After two days of searching Cotswold fields with the enthusiastic agreement from so many unbelievably kind locals, and with many bruises and muddy leggings, we had no luck - and there were no pubs open in which to drown our sorrows. However, early on the morning of Saturday 6th March, Mira Ihasz, a member of the Glasgow team, found the largest intact piece of the Winchcombe meteorite sitting in a sheep field. Mira had joined us for the search as a member of Luke's household bubble, and is not a planetary scientist. She had been very uncertain as she tentatively asked for a second opinion when she saw the fragment of the meteorite in the ground, especially as it was sat next to some sheep's wool.

Luke straight away realised that it stood out from the many sheep stools in the field, and we set about digging the specimen out of the tiny impact pit it had made in the ground. After

speaking to the gracious landowner who agreed straight away to donate the precious sample to the NHM, we all immediately celebrated the beautiful find, with one of the neighbours even giving us some whisky to congratulate us!

Over that first week or so in the aftermath of the fireball, the people of Winchcombe and the surrounding area found a few other pieces of the meteorite in their gardens, and got in touch with the museum. Having seen our guidance of what to do if you think you've found a meteorite (don't pick it up with your bare hands, use gloves if you can, wrap it in fresh foil, don't put it near a magnet, and if possible collect some of the soil/environment that it fell onto in a separate container), they got in touch with the NHM and the Fireball Alliance and we were able to collect over 500 g of verified pieces of the Winchcombe meteorite.

Within that first week, isotopic data was collected by the Open University confirming that it was a CM2 carbonaceous chondrite, the first of its kind to fall in the UK. CM2 chondrites are exciting because they are clay-rich meteorites that contain water and organic matter, and as they are older than the Earth these rocks provide a window into the early Solar System's history. The asteroids Ryugu and Bennu, recently visited by the Hayabusa2 and OSIRIS-REx sample return missions, are made up of the same material as carbonaceous chondrites. Because Winchcombe's atmospheric entry was captured on so many cameras, its orbit has been calculated meaning we know exactly where in space it came from (it was the asteroid belt). Added to this, the piece which landed on the Wilcock's driveway was collected within hours, and not rained on, therefore preserving a near-pristine sample. Planetary scientists had just completed the cheapest sample return mission ever!

Since its fall in March, scientists across the UK have treated analysis of the Winchcombe meteorite just like a sample return mission too, with collaborative teams set up across institutions based on different areas of expertise. Teams have been analysing the magnetism of the stone, the organic content, even finding weathering products (likely from the short time the stone has spent on Earth)!

A variety of techniques have been applied to study the Winchcombe samples. Scanning Electron Microscopy (SEM), coupled with Energy Dispersive X-ray Spectroscopy (EDS), has been used to produce maps that show the chemical make-up of the meteorite. Through SEM-EDS, many different types of minerals have been identified, ranging from crystals of olivine to calcite, and the water-bearing mineral serpentine. Some of the objects that can be identified in this way are the enigmatic Calcium-Aluminium-rich refractory Inclusions (CAIs). These refractory objects are amongst the first solids to have ever formed in the Solar System! They are being extensively studied through Electron Backscatter Diffraction (EBSD) in order to try to understand the intricacies of their origins through their complex mineralogy. X-ray Computed Tomography (XCT) has also been used to non-destructively explore and analyse the interiors of the numerous chips and identify the optimum orientations for cutting the different samples for future analyses. We've even been studying organic molecules similar to those that make up the building blocks of life on Earth, inside Winchcombe!

Winchcombe represents only the fifth carbonaceous chondrite with a known orbit, and the first ever from the UK. It is also the first meteorite fall to be recovered in the UK in 30 years, but with the UKFall now up and running, and the huge success of Winchcombe, it hopefully won't be another 30 years until the next one!

Suggested end note in italics maybe? : 'Mira's fragment' of Winchcombe is now on display at the Natural History Museum in London, with another smaller piece on display in the Winchcombe village museum, too. You can also see the mini 'crater' the first piece left in the driveway itself at the NHM, after the Wilcock family kindly agreed to it being dug out and placed on permanent exhibition.