The Iberian fireball of 4 January 2004

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According to the American Meteor Society, 'fireball' is a term for a very bright meteor, generally brighter than magnitude −3 or −4, which is about the same magnitude as the planet Venus viewed in the morning or evening sky. If the fireball explodes in a bright terminal flash, which typically extinguishes with visible fragmentation, it is then known as a 'bolide', from the Greek word for a throwing spear. This paper describes the circumstances of the recent dramatic fireball sighting over the Iberian peninsula. This event provides a textbook example of such an event, with the usual attendant public excitement, media confusion and cultural misconceptions.

In a recent article,[1] Cockell emphasises the scientific and social importance of a coordinated, multidisciplinary response to the entry into the atmosphere of small asteroidal or cometary bodies that have the potential to collide with the earth. It is well known that each year thousands of tonnes of extraterrestrial material rain down on our planet. Indeed several thousand meteors of fireball magnitude enter the earth's atmosphere every day. The vast majority of these events, however, take place over the oceans and uninhabited regions, and a good many are masked by daylight. Additionally, the brighter the fireball, the rarer is the event. Experienced observers can expect to see only a single fireball of magnitude −6 or greater in two hundred hours of observing, whilst a fireball of magnitude −4 can be expected about once every twenty hours or so. Over the last decade, fireballs have been observed for example over the Netherlands, Denmark and the UK (October 2001), over the Mississippi river valley (April 2001), over Norway, Sweden, Denmark and Germany (December 1999), over the northeast of Honshu island in Japan (March 1998), over Oakland County, MI, USA (January 1997) and over the North Sea (May 1994).

The spectacular fireball seen recently over the Iberian peninsula, and the accompanying and subsequent social and institutional reactions, provide a textbook case study in appropriate and inappropriate reactions to such episodes, of terminological confusion (meteoroids, bolides, meteors, meteorites, etc.), of mistaken public conceptions and, in broad terms, of the need for a 'taskforce' capable of providing an appropriate and adequate response. The Spanish Centre for Astrobiology, and in particular one of the authors of the present paper (JMF), were the research centre and researcher respectively appointed by the Spanish Higher Scientific Research Council and Ministry of Science and Technology to coordinate investigation of the event. This paper is the first publication to deal with its scientific aspects.

BOLIDES AND METEORITE FRAGMENTS

At approximately 1646 UT (universal time) on 4 January 2004, a large meteor entered the earth's atmosphere over Spain, at an estimated velocity of fifteen to twenty kilometres per

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second. The event was witnessed and/or heard by hundreds of individuals, and sightings were reported across the whole Iberian peninsula, from the northwest Atlantic coast of Portugal and Spain to the Balearic islands in the Mediterranean. It could even be seen from the south of France. Because of the bolider's impressive brightness and associated detonations, many calls were received by emergency lines, by state and local police, fire departments and the media.

Preliminary calculations of its trajectory[2] indicate that the bolide appeared first over the south of León province, before heading in a northeasterly direction over the city of León at an altitude of around eighty kilometres towards Santander, and finally exploding at around thirty kilometres altitude shortly thereafter, over the north of Palencia province. Nevertheless, caution is required, as new observations and pictures which could modify this initial analysis continue to be received from eyewitnesses. The possibility that the fireball was associated with satellite debris was considered, although this was ruled out by all experts consulted mainly on the basis of the meteor's speed and the absence of suitable decay candidates (this was checked with the US Strategic Command).

The brightest fireballs may be seen over an area of a quarter of a million square kilometres or more, but locating a meteorite is rarely easy (the term 'meteorite' is reserved for a meteoroid that has landed on earth). A typical fireball first appears at a height of a hundred or so kilometres above the earth, and extinguishes at a height of around twenty kilometres. On 4 December 1974, the brightest fireball ever recorded appeared in the skies over Sumava (now in the Czech Republic). Its brilliance rivalled that of the sun, yet no fragments were ever recovered.[3]

Nonetheless, there are rare occasions when a clear correspondence can be established between a fireball and particular meteoritic fragment(s). For instance in 1959, a fireball of magnitude around −19 passed in front of eleven meteor cameras again near Prague (the 'Pribram event'). It was possible to deduce an accurate trajectory and velocity in the atmosphere, and from these data to estimate the preterrestrial orbit of the body.[4] Nineteen meteoritic fragments were recovered, totalling almost ten kilograms of olivine-bronzite chondrite. Another impressive event occurred in Peekskill, NY, USA on 9 October 1992. Not only did the meteorite (in technical terms, a 12.4 kilogram H6 monomict breccia meteorite) announce its arrival by hitting a parked car, but in addition the fireball that preceded the fall was recorded by at least sixteen independent videographers. During a luminous flight time that exceeded forty seconds, the fireball covered a ground path of some seven or eight hundred kilometres.[5] A further recent event in which it was possible to connect a fireball with a meteorite was the Neuschwanstein fireball of 6 April 2002:[6] a first meteoritic fragment (1.7 kilograms, EL6 enstatite chondrite) was found on 14 July 2002 by two young amateur astronomers, and a second (1.6 kilograms) was recovered on 27 May 2003.

According to the recent update of the meteorite catalogue of the National Museum of Natural Sciences in Madrid (the most important Spanish collection[7]), which includes some meteorites not represented in the collection, of a total of twenty-eight Spanish meteorites (including twenty-two 'falls', four 'finds' and one pseudometeorite), only in four cases were there unequivocal links between fireballs and meteoritic fragments. The last meteorite recovered in Spain fell in Reliegos (León province)[8] on 28 December 1947, and the last Spanish meteorite to be incorporated into the international catalogue (in 1998) was 'Valencia', an H5 chondrite forming part of the rock collection of the Department of Geology of the University of Valencia.[9] In this context it is also worth noting that while more than forty bolides have been found in Spain in the last five years, not a single meteoritic fragment has been recovered.

MISTAKEN SOCIAL CONCEPTIONS

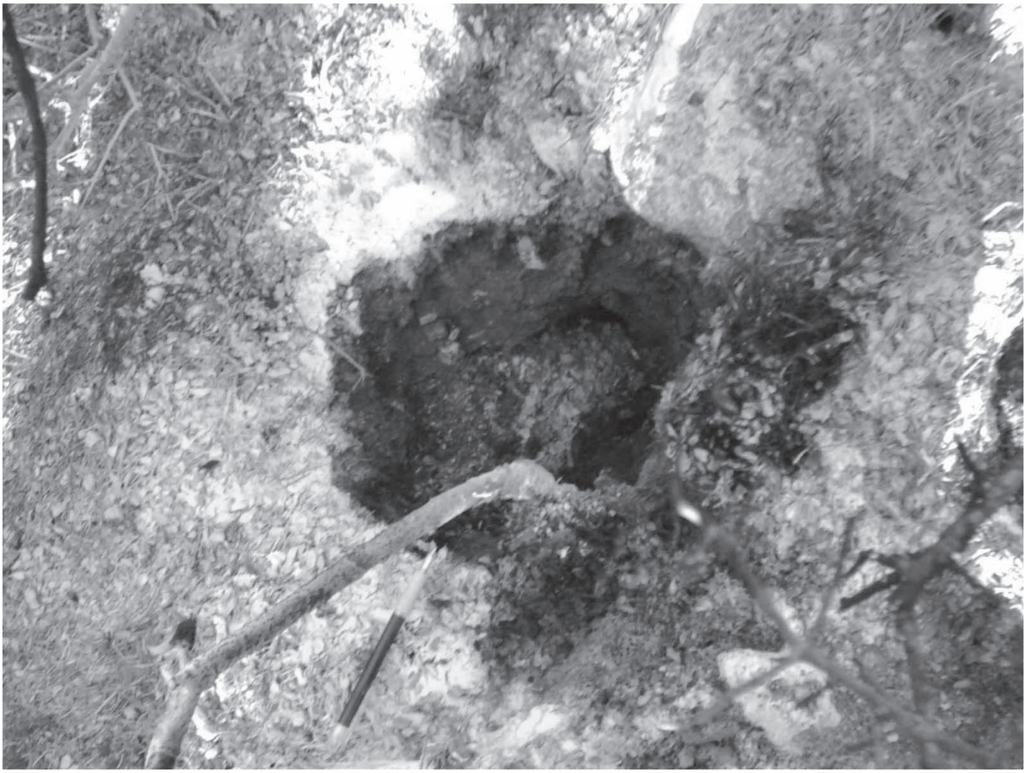
The usual pattern, of an absence of a verifiable connection between fireballs and meteorites, was followed in Spain in January 2004. Several field campaigns were carried out in northern Spain in the two weeks following the fireball event of 4 January, in the hope both of identifying evidence of impacts and of recovering meteoritic fragments that could be related to the event. Teams including personnel from the Guardia Civil and museums as well as students, geologists and amateur astronomers began searching parts of provinces including León, Palencia, Guadalajara, Castellón, Zamora, Salamanca, Cuenca and Castellón.

One of the most widely held popular misconceptions about bolides and meteoritic falls is that meteors hit the ground as flaming fireballs. In this perspective, otherwise unexplained fires could be the result of impact. However, most experts agree that small rocks hitting the ground should not be hot, and we certainly do not see big fires starting when meteorites hit the earth (at least not as a direct result of the temperature of the body). Moving towards earth, meteors are cold. As they fall, they lose three to six millimetres of surface mass per second through ablation. The melted material and metal, heated to over 1800ºC, is swept away from the meteor, carrying away the accumulating surface heat so efficiently that the interior remains cool. Only a very thin layer on the outer surface melts,

1 Area cordoned off by the Guardia Civil around the ground fire at Minglanilla (Cuenca province) a layer known as the 'fusion crust'. In fact, according to the American Meteor Society[10] the ablation process, which occurs over the majority of the meteor's path, is a very efficient method of heat dispersal, which was copied effectively for use during the early manned space flights at atmospheric reentry. Thus meteors are cold when they hit the ground, or certainly not so warm that they cannot be held in the hand.[11]

Nevertheless, the relation between fires and fireballs remains controversial. In the scientific literature, alleged meteor related fires have been attributed alternatively to geoelectrical discharges or to ignition of erupting terrestrial gases.[12] A recent paper on the circumstances surrounding the Trans-Alabama superbolide of 5 December 1999 (the term 'superbolide' is used in preference to 'bolide' or 'bright fireball' because the object was detected by satellite, and showed a brightness on video recordings of magnitude −17 or brighter[13]) suggests that a few real meteoritic events result in 'impossible' effects – that is, they apparently start ground fires.[14] The explanation proposed for simultaneous ground fires and superbolide passage is an electrical discharge due to the ionised wake of the incoming object.

During the fireball event of 4 January 2004, eyewitnesses reported numerous ground fires in different Spanish provinces, apparently related to the passage of the bolide. One of these fires, reported in the locality of Minglanilla (Cuenca), was specifically investigated by the authors of this article, because in addition to the fire (Fig. 1), local environmental technicians interpreted some holes as possible impact structures (Fig. 2). Detailed inspection of the area, along with mineralogical and geochemical analysis of the terrain, in



2 Small cylindrical hole of around thirty centimetres diameter in the region of the ground fire at Minglanilla, which was erroneously associated with meteorite impact fact revealed no evidence of meteoritic fragments or structures or other anomalies, and any relation with meteorites or impact cratering processes was therefore ruled out.

There was real euphoria in Spain over the possibility of recovering meteorite fragments, and everybody wanted to collaborate in the search. Because many people were keen to send in any old black rock for mineralogical and geochemical analysis, we were obliged to elaborate some guidelines, with the minimum requirement of writing a short report explaining the circumstances of the find or fall, to be sent to the Centre for Astrobiology via some authority, local police or Guardia Civil. This allowed us to filter out many possible hoaxes and jokes, to better assess which might be the most promising samples, and to have some idea prior to analysis of the possible origin of material in relation to geological maps, the existence of slag generating industries, etc. A website was also constructed to keep people informed about the event (see tierra.rediris.es/merge/bolide_Spain).

Two possible meteorite candidates from the provinces of Zamora and León were received at the Centre for Astrobiology for identification. Unfortunately, neither turned out to be a meteorite. The first was a typical iron rich vacuolar slag (Fig. 3), and the second an iron rich alloy (without nickel). Recently, the National Museum of Natural Sciences in Madrid has received and analysed a couple of small fragments (42.03 and 21.76 grams) displaying an iron–nickel composition with traces of chromium, iron sulphide and some silicates, which have been identified as stony irons. These were sent in by a journalist who claimed to have found them 'after following the path of the fireball through various villages in the mountains of Palencia'. Other small chondritic fragments (identified as L6 chondrites) have also been recovered. To find out whether or not they are related to the fireball of 4 January will require further investigation.

3 Vacuolar slag found in Zamora which was confused with a meteoritic fragment

Since prehistoric times fireballs and meteorites have been considered by numerous cultures and peoples to have something of the essence of the divine. Today we recognise them as natural physical events and fragments of other planetary bodies, some more primitive than our own planet, which can help to guide our search for the origin and evolution of our solar system, in some cases with significant astrobiological implications. Indeed it can be said, without doubt, that they provide important new opportunities for research and discovery. Spectacular events such as the Iberian fireball of 4 January 2004 remind us that our planet is in constant interaction with outer space, and we must do our best to understand the scientific and social implications of this fact.

NOTES

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