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Identifying the progenitor bodies of meteorites: Backward integration of NEO and FJC comets

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Abstract

A continuous monitoring of fireball activity all over Spain is being completed. This involves recording meteor events over a very large surface area of 500,000 km^2 with new CCD and video cameras operated by the Spanish Meteor and Fireball Network (SPMN). Through the use of these new techniques the SPMN can obtain trajectory and orbital information that provide new clues regarding the dynamical processes that deliver meteorites to the Earth. It transpires that the main asteroid belt is not the only source of these fireballs, Near Earth Objects (NEOs) and Jupiter Family Comets (JFCs) play also a role. To obtain more information in this regard, we are developing new software to compare the orbits of large meteoroids reaching the Earth with those of the members of NEO and JFC populations. By numerically integrating their orbits back in time it may be possible to identify meteoroids delivered by other mechanisms like such as catastrophic disruptions or collisions.

1 Introducción

The SPanish Meteor and Fireball Network (SPMN) is a project to study meteor and fireball events occurring over Spain and the bordering countries [1]. Network operations started in 2004 using high-resolution all-sky CCD cameras from a number of different stations located around the Mediterranean coast [2, 3]. Over the years, these stations have been complemented by using video systems that are the main type of detectors currently operative [4]. The active group working on these projects consists of astrophysicists, chemists, and geologists working together to collect information on meteors and fireballs but with particular emphasis on the recovery of meteorites. Large fireballs can be the precursors of meteorite falls and modern technology can be applied to track their atmospheric trajectories, and predict probable landing sites. To do this it is necessary to record the luminous trail from at least two different locations. The different SPMN recording stations currently operative are in Fig. 1. From the atmospheric trajectory and the computed initial velocity and geocentric radiant the heliocentric orbit can be determined. Due to the difficulty of recording meteorite-dropping bolides, orbital information has so far only been only computed for nine meteorites, the last one being the Villalbeto de la Peña meteorite in Spain [5]. Meteorites are valuable samples of other solar system bodies, but usually are recovered without information regarding their progenitors. Obtaining orbital information for meteorites that might land at some future date is vital if we are to understand the dynamical processes that deliver meteorites to the Earth. Recent results suggest that the main asteroid belt might not be the only source, Near Earth Objects (NEOs) [6] and Jupiter Family Comets (JFCs) [7] populations may also be significant.

Consequently, the SPMN meteorite recovery program is designed to obtain as much information as possible of the atmospheric transit of the progenitor meteoroid. We are putting all our effort in obtaining records of large fireball events to obtain the heliocentric orbits of new meteorites. It is obviously a big challenge because meteorite-dropping bolides are typically unexpected events that produce a luminous phase (the fireball) for a very short time interval of only a few seconds. Obtaining dynamic information regarding meteorite-dropping bolides is crucial in order to obtain information concerning the physical mechanisms that are placing meteorites on orbits that can lead to collision with the Earth. Similar mechanisms are expected to be playing a role in the delivery of largest bodies, particularly Near Earth Objects (NEOs) to the Earth Environment. We are also setting up portable stations capable to monitor future encounters with NEOs like e.g. 2008TC3. An example of mobile video station appears in Fig. 2.

2 Meteorite recoveries: Villalbeto de la Peña and Puerto Lápice daylight bolides

In 2004 the SPMN had already created the infrastructure necessary to compile the casual records of a remarkable daylight fireball that had been obtained, and promoted the recovery of meteorites associated with the event. The event, on January 4, 2004,, was called Villalbeto de la Peña after the village where the first meteorites were found and resulted in the first recovered meteorite fall in Spain for 56 years. A casual video recording and several photographs allowed a determination of the fireball trajectory, its released energy, and strewnfield reconstruction to be made [8]. From the determination of the radiant position in the sky and the computed initial velocity, the heliocentric orbit of the meteoroid was also obtained. This became only the ninth orbit of a meteorite-producing

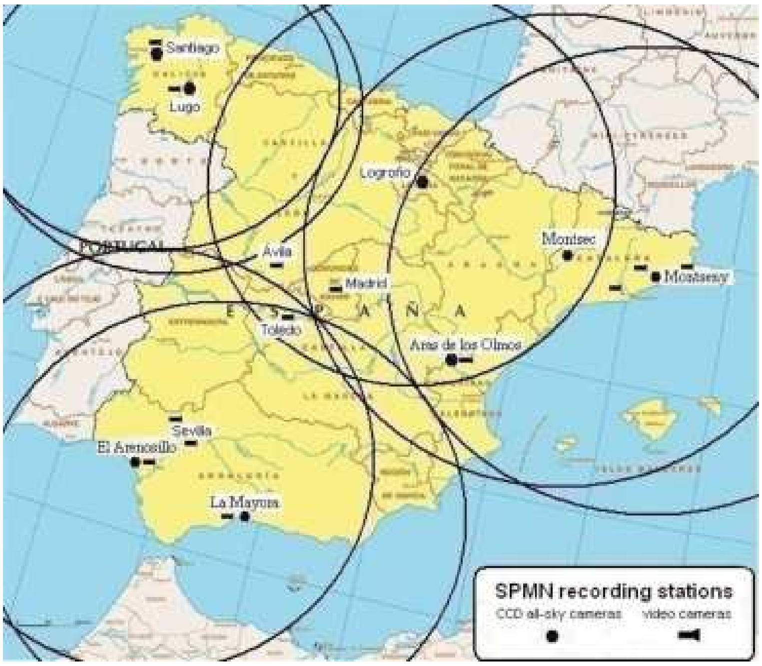

Figure 1.— The SPMN stations currently operating with the different imaging systems that are being used also shown. The circles represent the 400-km wide fireball detection areas optimally covered from each station, although the detection limit for bright bolides is about 550 km.

Figure 2.— A mobile SPMN recording station. a) System control table. b) Different sound and video detectors.

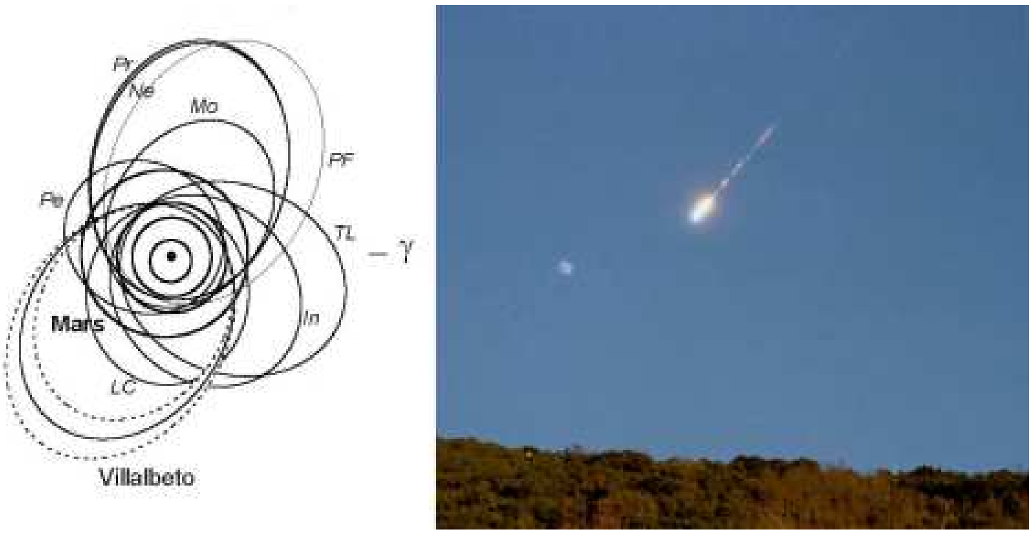

Figure 3.— Left: The heliocentric orbit of Villalbeto de la Peña meteoroid compared with the orbits of previously determined meteoroids dropping meteorites: Pr̦ibram (Pr, recovered in 1959), Lost City (LC, 1970), Innisfree (IN, 1977), Peeskill (PE, 1992), Tagish Lake (TL, 2000), Morávka (Mo, 2000), Neuschwanstein (Ne, 2002), Park Forest (PF, 2003), and Villalbeto de la Peña (2004). Only in the case of Villalbeto de la Peña orbit the uncertainty in the velocity is shown. Right: The Villalbeto de la Peña bolide after its main fragmentation photographed from Santa Columba de Corueño (León) by María M. Robles.

fireball to be obtained (Fig. 3) [5]. Three years later, on May 10, 2007 SPMN participated in the recovery of Puerto Lápice eucrite type meteorite after giving community data about the impressive daylight bolide that gave rise to the meteorite fall [9]. To date, the SPMN homepage (www.spmn.uji.es) receives thousands of visits every month, and has become an updated reference of the fireball events that have occurred all over Spain, and bordering countries. Our homepage is also playing a role in popularizing astronomy, and meteorite studies among the public.

3 Identifying Earth-impacting debris from NEOs

Halliday was pioneer in suggesting the existence of groups of meteorite-producing bolides [11]. Meter-sized bodies suffer significant gravitational and non-gravitational perturbations (e.g. the Yarkovsky effect) that can produce an extremely fast evolution of the meteoroid orbits. The possible common origin of Pribram and Neuschwanstein meteorites was recently claimed on the basis of their orbital similarity [12], but the fact that they are different meteorite types keeps this result controversial. The association of Pribram and Neuschwanstein meteorites was dynamically investigated recently [13], and the conclusion was that the timescales for orbital decoherence are too short (104 to 105 years) in comparison with the derived age of both meteorites. However it has also been shown that meteorite streams on high inclination orbits might exists for longer than this [14]

To obtain new information regarding this topic, fireball networks need to modify their mode of operations. First, the "classical" coverage of fireball events during the night should be accompanied by daylight monitoring using the video techniques (see Fig. 4). By doing this, data sampling would be more complete and not biased towards those celestial sources (radiants) detectable during the night. Second, the different networks operating around the world should cooperate to search for paired fireball events. In this way, the chance of recording paired bolides would be significantly increased. Third, the area of coverage of fireball networks should be expanded through the use of new video techniques. Fourth, a wide cooperation with the minor body community should be relevant to identify particular asteroids as source of meteorites.

A particularly interesting research topic that should be explored is the identification of the main mechanisms that are producing large meteoroids from NEOs and other populations. While it is believed that collisions in the main asteroid belt are the main source of meteorites, other processes operating in other populations can also be significant contributors. There is growing evidence that many comets and small asteroids can have a rubble-pile structure. Such weakly-bounded aggregates would suffer disruption during close approaches to any massive bodies. Such scenario would be common for NEOs suffering close approaches with the terrestrial planets and the tidally-induced fragmentation of an NEO could lead to production of debris crossing the orbit of the Earth in much shorter timescales than those measured for delivery from the main asteroid belt. To obtain evidence regarding this we are carrying out a search among the meteoroid orbits obtained by the SPMN network and comparing them with those of currently catalogued NEOs (taken from the NeoDys catalogue). To test the link between the meteoroids and the NEOs, we perform numerical integrations of the orbits backwards in time. Using the Mercury 6 program [15] a hybrid symplectic integrator widely used in Solar System dynamics studies. To confirm a common origin between the meteoroids producing the fireballs and the NEOs, the orbits are usually integrated back in time for at least 100,000 years. Perturbations from the planets Venus, Earth, Mars, Jupiter and Saturn are included. When a good orbital match is found, and the evolution of the main orbital elements occurs in parallel, it is safe affirming that a common origin is likely.

By using that dynamic procedure we have obtained evidence that some NEOs could be a source of meteorites. We found that NEO 2002NY40 was probably the source of at least two of three bright bolides recorded from several stations by the Finish and Spanish Fireball networks in 2006. These meteoroids were forming a complex with other NEO called 2004NL8 that would be a source of LL chondrites to the Earth [6]. We suggested that the origin of this complex would be the disintegration of a progenitor asteroid during a close approach to the Earth or Mars, but several scenarios are open [16].

Figure 4.— A daylight fireball imaged with a color video camera from Sevilla SPMN station. The event took place on Sept. 12, 2008 at 5h41m35.6s UTC.

4 Catastrophic disruptions: A way for delivery of meteorites from comets?

It is generally accepted that amongst the NEO population there are many dormant or extinct comets. The boulders observed during disruption of comet C/1999 S4 LINEAR [17] were tens of meters in size and are far bigger than the cometary meteoroids that reach the Earth during meteor showers. The catastrophic disruption of a comet nucleus could produce dense and tough meteoroids released from the deep interior of the nucleus. These meteoroids could have very different physical properties from those that produce meteor showers which are essentially surface dust grains. Such particles released by sublimation of ices during perihelion passages of their parent comets have maximum sizes of few centimeters. Larger particles cannot be lifted off the cometary surface as gravity is stronger than gas drag for them [18].

On July 11, 2008 a fireball of magnitude −18 was recorded over Salamanca province (Spain), ending with very bright flares at a height of about 22 km over a town called Béjar after which this event was named [7]. Three SPMN video cameras recorded the event together with a professional photographer (see Fig. 5). Fireball deceleration in the atmosphere suggests that the meteoroid approximately had an initial mass of 1.8 metric tons. Assuming a spherical shape, and the typical density of chondrites (2200 kg?m-3) this would correspond roughly to a 1.2 meter-sized meteoroid. After analyzing the observations, we discovered that the fireball followed an orbit more similar to Jupiter Family comets than asteroids. Further, the orbit was quite similar to the mean orbit of the Omicron Draconids, a meteoroid stream possibly produced during the catastrophic

Figure 5.— The Béjar superbolide photographed from Torrelodones (Madrid) by Javier Pérez Vallejo.

disruption of comet C/1919 Q2 Metcalf. The JFCs originate in the trans-Neptunian region and TNOs have been recently suggested a source of meteorites [19]. There is a reasonable probability (about a 10%) of having an Earth-crossing JFC. Fragments of JFCs can reach the Earth provided the geometry is favorable, and some of these fragments could be high-strength materials from the nucleus interior, and it follows that some of the chondritic meteorites, particularly in the CI-class [20] that we find on Earth, could be coming from comets. The parent body of Tagish Lake meteorite has been identified as a D-type dark asteroid formed in the outer part of the main belt [21]. Such a body could be an example of a main belt comet exhibiting sporadic activity like 133P/Elst-Pizarro [22]. We should recognize that cometary nuclei can show significant diversity, depending on their formation location and evolutionary history, and that their decaying products also deliver diverse materials to the Earth.

Although catastrophic disruptions of comets are relatively frequent, it is obviously that having the debris left by the disruptive events crossing the Earths orbit a short time after the disruption is a much rarer event. The probability of having the correct geometry for this is small, but fortunately not zero. The opportunity to study such an event is expected over the next few years [23]. Comet 73P/Schwassmann-Wachmann was observed suffering progressive disruption between 1995 and 2006, while encounters with these dust trails will occur in 2011, 2017, and 2022. The meteor shower associated with this comet produces weak meteor rates, but fireballs have being frequent in the last few years. The best geometric conditions to observe the recent debris from the 1995 disruption will occur on May 31, 2022 (Table 6g of [23]). A global campaign to study this shower over the years up to 2022 would provide very important clues on the demise of comets. In particular, a study of the physical properties (bulk density, dynamic strength, etc. . .), and composition of the fireballs can also provide information regarding the decay products and their subsequent evolution before reaching the Earth [24, 25].

5 Conclusions

CCD and video techniques are providing significant break-throughs in the study of bright fireballs during their interaction with the terrestrial atmosphere. Fireball monitoring can now be achieved in broad daylight as well as during the night. The new techniques can reduce or eliminate some of the biases of data sampling obtained by previous fireball networks. Accurate orbital data can provide valuable information on the physical mechanisms that are producing meter-sized meteoroids in heliocentric orbit. Fireball studies also provide information on the physical properties (bulk density, dynamic strength and porosity), and bulk chemistry of meteoroids. Many questions regarding the origin of meter-sized meteoroids are still open, and are sharing common problems with NEO studies. Further progress in our knowledge on the regions source of meteorites will require a collaborative effort with other researchers from parallel disciplines.

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