A METEORITE-DROPPING SUPERBOLIDE FROM THE CATASTROPHYCALLY DISRUPTED COMET C1919Q2 METCALF: A PATHWAY FOR METEORITES FROM JUPITER FAMILY COMETS.

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Introduction: It is widely accepted that cometary nuclei are composed of a mix of volatile ices and meteoritic materials. In a series of seminal papers F. L. Whipple tried to explain how the irregular internal structure of each nuclei would be able to explain the nongravitational forces, and how the continuous sublimation of the ice species would lead to explain the origin of meteoroid streams [1,2,3]. Not essential progress was made until that the approach of a cruise of international spacecrafts to comet 1P/Halley allowed to achieve the first direct view of a cometary nucleus [4]. At that time several models were built to explain the main features observed in 1P/Halley nucleus under the main concept that cometary nuclei were born from the accretion of weakly bounded ice-rich cometesimals [5, 6]. A similar view was extracted from the 81P/Wild 2 fragile aggregates recovered by Stardust mission [7]. Obviously, particles recollected in the coma of a comet are biased towards those fragile aggregates that are lifted off from ice-rich regions by the sublimated gas drag. Many cometary meteoroid streams crossing the Earth were formed in this way, but not all. Catastrophic disruption of cometary nuclei is also a regular mechanism of producing meteoroid streams [8, 9, 10]. Interestingly, this mechanism is able to produce large boulders as observed e.g. during the disruption of comet C/1999 S4 LINEAR [11]. It was believed that the large fragments released by these break-up events will proceed to faint in the coma due to suffer a cascade fragmentation. Obviously remote observations are not able to decipher if the final product of these events are mm- or m-sized meteoroids. In a recent paper [12] we identified a meter-sized meteoroid that was probably produced during the disintegration of comet C1919Q2 Metcalf. It produced a very bright fireball, with a maximum brightness of magn. –18 that was observed over much of Spain as well as parts of Portugal, and France on July 11, 2008 at 21:17:39 UTC. Fortuitously, it flew over many of the instruments operated by the SPanish Meteor and Fireball Network (SPMN) so that accurate measurements of its properties were recorded. Here we summarize both these observations and the deductions made from them regarding the nature and origin of the body that gave rise to this fireball.

Methods: Observations of the Béjar superbolide were made from three SPMN video stations located in the South of Spain (Andalusia) using high-sensitivity 1/2" black and white CCD video cameras (Watec, Japan) and 1/3' progressive-scan CMOS sensors attached to modified wide-field lenses covering a 120×80 degrees field of view. By chance an additional wide-field picture of this bolide was taken by J. Pérez Vallejo, a professional photographer from Torrelodones (Madrid) (Fig. 1). Coordinate measurements on the images were obtained for comparison stars and the bolide by using our recently implemented *AMALTHEA* software package [10]. From the sequential measurements of the video frames and the trajectory length, the velocity of the bolide along the path was obtained. The pre-atmospheric velocity V_∞ was found from the velocity measured at the earliest part of the fireball trajectory.

Results and discussion: From the astrometric measurements of the images the atmospheric trajectory, velocity and height were obtained. The bolide overflew Salamanca province ending over a town called Béjar from which the event has been named [12]. Once obtained the height and velocity of the meteoroid along the luminous path we realized that it displayed an unexpected high strength despite its cometary origin. This is shown by the pattern of successive fragmentation, each producing a bright flare, but obviously leaving a surviving fragment until the next fragmentation (Fig. 1). The recorded height of each outburst seen in that picture were 40.5, 38.2, 33.2, and 26.8 km. The aerodynamic pressures experienced by a meteoroid producing flares at these given heights imply material strengths of 2.3, 3.2, 6.6, and 14 MPa respectively. Those are loading pressure values about three orders of magnitude higher than those expected for survival of cometary materials [13, 14].

The heliocentric orbit of Béjar bolide was computed from the time of the fireball, its initial velocity, and the position of its geocentric radiant. The derived orbital elements were given in [12]. Of particular interest are the date July 11, the perihelion distance, 1.01 AU and the inclination, 43.8° the eccentricity, 0.775, and the semi-major axis at 4.5 AU. From these, the period at 9.5 years and aphelion distance at 8 AU can be deduced. This orbit is unlike Near Earth asteroid orbits, and indeed those of other fireballs, where aphelion is within the main asteroid belt that we have mentioned but is typical of Jupiter Family Comets (JFCs). We should note that JFCs probably originate in the trans Neptunian region [15] and have been recently suggested as source of meteorites reaching the Earth [16]. This raises the possibility that the Béjar meteoroid was associated with a comet. Additional support for this comes from the similarity of the orbit to that of the Omicron Draconid meteor shower, from which an outburst of activity was just observed on July 4, 2008 [12]. Other four other superbolides were detected on July 8, 10, 11 and 12 on other locations around the globe by US satellites [17]. Not so surprising because this meteoroid stream was likely produced by the disintegration of comet C 1919 Q2 Metcalf [18].

From the value of the deceleration, the mass of the Béjar meteoroid of about 1.8±0.5 metric tons was estimated in [12], with a diameter of about 1m. This large and dense meteoroid has important repercursions on the structure of comets. In fact, one of the models created to explain the features observed in comet 1P/Halley is known as the icy-glue model [4]. It naturally predicts the existence of refractory boulders with similar compositions to carbonaceous chondrites, cemented by highly porous, ice-rich, materials that would act as a "glue" [4]. The model has not received wide support due to the apparent "lack" of evidence for a population of "refractory boulders" from disrupted comets [19], but is also true that detecting meter-sized dark fragments of comets is one of the present challenges for telescopic monitoring programs.

Conclusions: Dense cometary meteoroids capable of producing meteorite-dropping bolides seems to be feasible. These high-strength boulders would be released during the fragmentation of a cometary nucleus as opposed to the grains ejected by normal outgassing. There is an important difference between the two mechanisms. In the former, material from deep inside the original cometary nucleus forms part of the stream as opposed to the fragile grains released during outgassing. We concluded in [12] that the Béjar progenitor meteoroid was sufficiently large and of high enough tensile strength to produce meteorites. If so, for the first time meteorites can be tied to the fragmentation of a comet nucleus. If we are correct, despite of being rare events, there is room to say that a few meteorites present in terrestrial collections would have origin in comets.

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Figure 1. The Béjar superbolide as imaged by J. Pérez Vallejo from Torrelodones (Madrid) [12].