BRIGHT BOLIDE OVER SPAIN PRODUCED BY A METEOROID DYNAMICALLY ASSOCIATED WITH POTENTIALLY HAZARDOUS ASTEROID 2017 DN109. E. Peña-Asensio[1,2], J.M. Trigo-Rodríguez[2,3], A. Rimola[1], J. Izquierdo[4], A.J. Robles[5], V. Ibañez[5], M. Aznar[5], A. Lasala[5], J. A. Reyes[5], S. Pastor[5], L. Orduña[5], C. Palomeque[5], M. Mérida[5], M. Yuste[5], J. Real[5], M. Ronquillo[5], J. Ribas[5], C. Guasch[5], F. J. Galindo[6], M. Chiore[6] and V. Cayuelas-Mollá[5]. [1]Universitat Autònoma de Barcelona (UAB), Bellaterra, Catalonia, Spain. eloy.pena@uab.cat, [2]Institute of Space Sciences (CSIC), Campus UAB, Carrer de Can Magrans s/n, 08193 Cerdanyola del Vallés, Barcelona, Catalonia, Spain, [3]Institut d'Estudis Espacials de Catalunya (IEEC), Ed. Nexus, Barcelona, Catalonia, Spain, [4]Dpto. de Astrofísica y CC. de la Atmósfera, Facultad de Ciencias Físicas, Universidad Complutense de Madrid, 28040 Madrid, Spain, [5]Red Española de Investigación sobre Bólidos y Meteoritos (SPMN). [6] Observatorio Astrofísico de Javalambre (OAJ), CEFCA, Teruel, Spain.

Introduction: Near-Earth asteroids (NEAs) are mostly delivered to Earth by dynamic resonances from the main asteroid belt, but some are associated with disrupted asteroids and evolved comets that cross the terrestrial planets and are often affected by planetary gravitational perturbations in short time-scales [1,2,3]. These parent bodies may undergo different physical processes and eject centimetre-sized meteoroids that acquire Earth-crossing orbits. Some of these fragments eventually end up impacting our mesosphere at hypervelocity, which generates the so-called bolides by forming a large luminous column of ionized gas when the air molecules ablate the outer layers [4,5]. This implies that small astronomical bodies NEAs represent a source of impact hazard in the short term, not because of the danger of collision but projectiles capable of irradiating enormous amounts of energy during their aerobraking as nicely exemplified by Chelyabinsk [6].

Study case: From the Spanish Meteor Network (SPMN), we continue incessantly capturing and analyzing bright events over the sky of the Iberian Peninsula and the Spanish islands [7]. Our 2021 catalogue of events compiles about 4,000 bolides. Data reduction is performed automatically thanks to our *3D-FireTOC* pipeline, a Python code for moving object tracking, accurate astrometry, multi-station trajectory calculation and heliocentric orbit computation with error propagation [8], which also handles curved trajectories [9].

On May 16, 2021, at 22h 31m 46s UTC, 4 SPMN stations captured in high detail a great bolide flying over the province of Teruel in Spain (Table 1) that was catalogued as SPMN160521. The bolide reached a maximum apparent magnitude of -11±1 and was recorded from more than 500 km away. The starting velocity was 87.3±0.5 km at 35.3±0.4 km/s and a terminal height of 43.2±0.5 km at 15.3±1.0 km/s with a trajectory slope with respect to the local horizon of 21.26±0.16 º.

Figure 1 shows the overlapped video of 3 of the stations, which captured the entire atmospheric flight of the SPMN160521 event illuminating the sky for more than 4 seconds. In Figure 2, it can be seen a scaled representation of trajectory made by the *3D-FireTOC* software.

Station	Longitude	Latitude	Alt.
Estepa	04º 52´ 36" W	37º 17´ 29" N	537 m
Teruel	01º 10´ 13" W	40º 21´ 00" N	100 m
OAJ	01º 00´ 59" W	40º 02´ 32" N	1957 m
Benicàssim	00º 02´ 19" E	40º 02´ 03" N	15 m

Table 1. SPMN stations recording SPMN160521.

Figure 1. SPMN160521 bolide recorded from Benicàssim (left), Teruel (middle) and Javalambre (right).

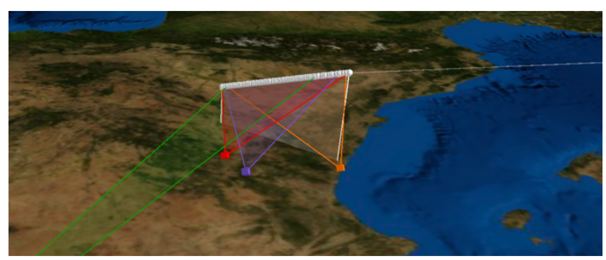

Figure 2. SPMN160521 atmospheric reconstruction.

The calculation of the orbital elements indicates that the meteoroid comes from one of the most densely populated areas of the asteroid belt. The computed heliocentric orbit is considerably eccentric (0.888±0.005) with an inclination of 13.4±0.5º, an orbital period of 2±0.1 years and a ratio of revolutions to Jupiter of almost 6:1. All calculated orbital parameters, observed and geocentric radiant, observed, geocentric and heliocentric velocity are shown in Table 2. Figure 3 shows the orbit in the Solar System with the uncertainty together with some interiors planets and the main belt of asteroids.

Radiant and velocity			
	Observed	Geocentric	Heliocentric
R.A. (º)	257.38±0.06	258.36±0.07	206.8±0.5
DEC. (º)	-14.36±0.20	-15.97±0.22	6.61±0.21
V_∞ (km/s)	35.3±0.4	33.2±0.4	34.34±0.26
Orbital parameters			
a (AU)	1.59±0.05	**ω (º)**	318.80±0.14
e	0.888±0.005	**Ω (º)**	55.98340±0.00010
q (AU)	0.178±0.003	**i (º)**	13.4±0.5

Table 2. SPMN160521 radiant, velocity and orbital parameters.

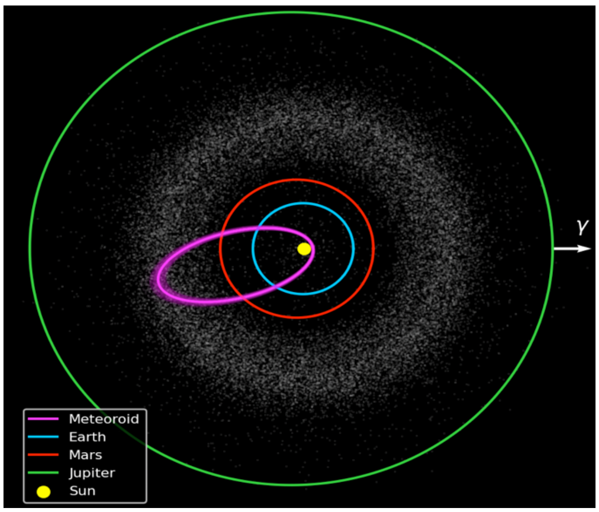

Figure 3. SPMN160521 heliocentric orbit.

In addition, we study the possible dynamical associations with a parent body in the Minor Planet Center (MPC) and International Astronomical Union (IAU) catalogue for both established and working meteor showers and also for currently known Near-Earth Objects (NEOs). Having into account the evolution of the meteoroid orbit and the orbits of parent body candidates, we computed the evolution four orbit dissimilarity criteria for 20,000 years: D_{SH} [10], D_J [11], D_D [12], D_H [13]. The best candidates are presented in Table 3. Remarkably, only candidates are found among the NEAs database, which could be due to fortuitous associations since the list of NEAs is much larger (over 27,000 asteroids). However, within the margins of error, the associations seem robust, although an analysis of the false positive rate would be required to confirm them. Figure 4 shows the time evolution of the dissimilarity criteria for the possible associated objects.

NEA	**D_{SH}**	**D_J**	**D_D**	**D_H**
2005 HC4	0.156	1.40	0.426	0.448
2019 JA7	0.158	0.95	0.198	0.234
2015 DU180	0.189	0.93	0.110	0.206
2017 DN109	0.158	1.09	0.095	0.172

Table 3. NEA parent body candidates for SPMN160521.

Conclusions: The SPMN020121 had its origin in the main asteroid belt. According to these results, the most favourable parent asteroid candidate is 2017 DN109 that exhibits a remarkably low D_D value over the time. Other possible parent bodies could be 2015 DN180 and 2019 JA7 if we use alternative criteria. This reinforces the idea that NEOs, beyond the medium-term collision hazard, represent a current cosmic source of impact hazard in the short term [3]. Fireball monitoring from ground-based networks, open the door for the possible recovery of fresh meteorites from NEAs and PHAs, our best laboratory proxies to understand the physico-chemical properties of these challenging bodies [14-15].

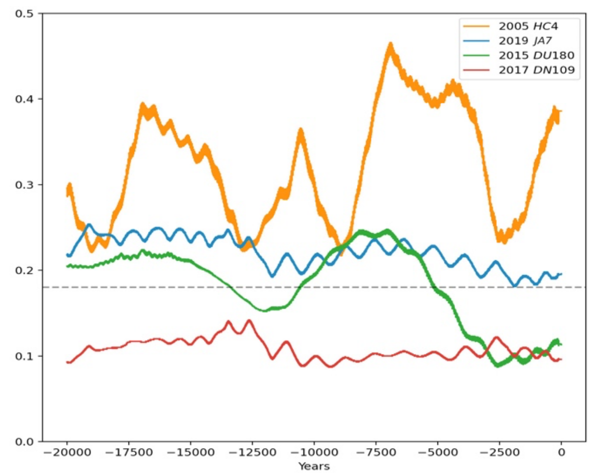

Figure 4. 20,000 years backward integration of D_D for the parent body candidates. Typical cut-off is plotted.

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