LARGE FIREBALLS DURING THE SPRING OF 2022 IN SPAIN: 2 METEORITE FALLS AND MINOR SHOWERS AS SOURCE OF IMPACT HAZARDS. E. Peña-Asensio[1,2], J.M. Trigo-Rodríguez[2,3], M. Corretgé-Gilart[4], D. Koschny[5], R. Kresken[6], P. Ramírez-Moreta[7], J. Ibáñez-Insa[8], A. Rimola[1], J. Donet[9], V. Ibáñez[9], J. M. Serna-García[9], C. Alcaraz[9], A. J. Robles[9], A. Núñez[9], R. López[9], J. A. de los Reyes[9], S. Pastor[9], A. Fernandez[9], A. Lasala[9], A. Gómez[9], J. Gómez[9], R. López[9], F. J. García[9], C. Guasch-Besalduch[9]. [1]Universitat Autònoma de Barcelona (UAB), [2]Institute of Space Sciences (CSIC), [3]Institut d'Estudis Espacials de Catalunya (IEEC), [4]Universitat Politècnica de Catalunya (UPC), [5]TU Munich, [6]ESOC/ESA Planetary Defence Office (OPS-SP), [7]ESAC/ESA Planetary Defence Office (OPS-SP), [8]Geosciences Barcelona (GEO3BCN-CSIC), [9]Red Española de Investigación sobre Bólidos y Meteoritos (SPMN-CSIC).

Introduction: Due to sublimation by high temperatures or tidal forces exerted by the Sun, rubble pile asteroids and cometary aggregates suffer fragmentations in their passage through the perihelion, scattering meteoroids throughout their orbit that constitute the so-called meteoroid streams [1,2]. After experiencing orbital perturbations, impacts with dust and other meteoroids, or experiencing non-gravitational effects, some meteoroids undergo time scale decoherence and end up impacting the Earth's atmosphere as sporadic events [3].

There are hundreds of minor showers with lower activities as well as thousands of near-Earth asteroids (NEAs), many of them poorly studied, that can produce bright meteors and potentially meteorite dropper events [4,5]. The months between January and April are especially relevant from the meteor science point of view as meteorite fall rates display a peak during the beginning of spring [6]. Unfortunately, the weather during winter and spring is usually not helpful for fireball monitoring. However, the months of February and March 2022 were especially clement in the Iberian Peninsula so the Spanish Meteor Network (SPMN-CSIC) was able to analyze several stunning fireballs, many of them associated with minor meteoroid streams and one with a NEA. The SPMN stations involved in this work are: Alpicat-Lleida, Barx-La Drova, Benicàssim, Calar Alto, Cebreros (ESA), Corbera, Estepa, GranTeCan, La Murta, Monfragüe, Morata del Jalón, Olocau, Playa Blanca-Lanzarote, Puertollano, and Sant Mateu.

Methodology: We used our *3D-FireTOC* Python code that automates the atmospheric trajectory reconstruction from multiple recordings by using the intersection of planes method [7,8]. We have now implemented the accurate IAS15 high-order N-body integrator with an adaptive time step included in the REBOUND package to compute the heliocentric orbit considering J2 and J4 gravitational harmonics of the Earth and the Moon [9].

We performed a backward integration of the meteoroid orbits over 10,000 years evaluating the orbital dissimilarity criterion D_D evolution to check the dynamic association with parent candidates. We assume that an association is robust enough if it remains below the cut-off (0.18 in this case) for 5,000 years, minimizing the probability of being a random association [10].

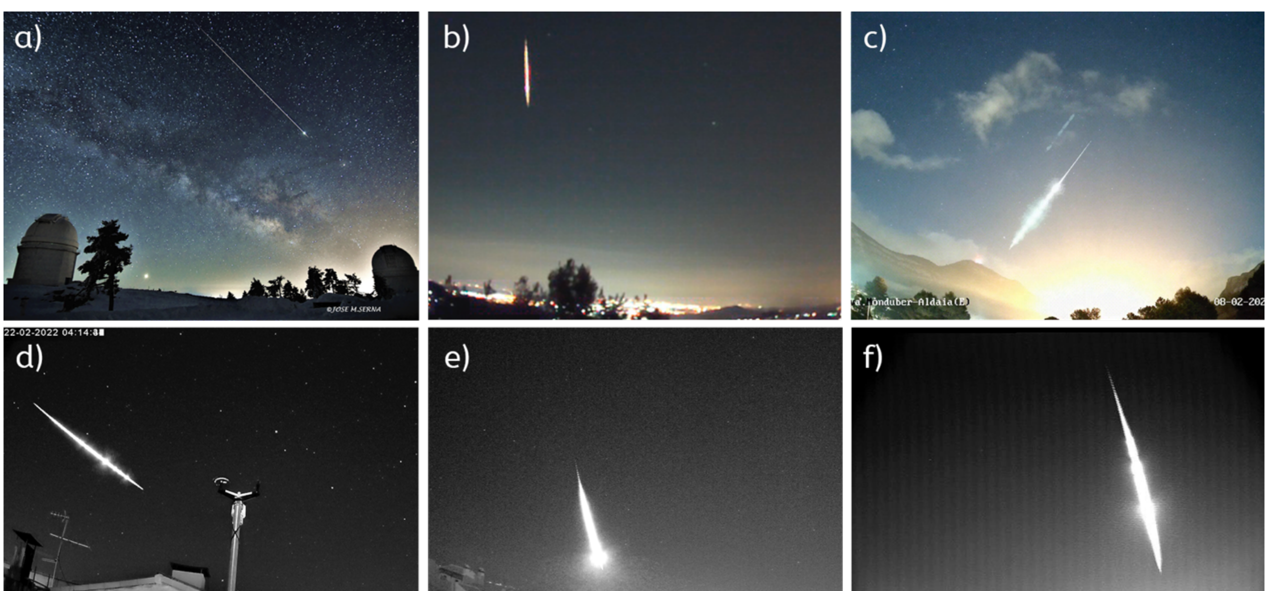

Figure 1. Blended frames of some events: a) SPMN090322C from Calar Alto by José M. Serna, b) SPMN060222 from Corbera, c) SPMN080222B from Barx, d) SPMN220222 from Alpicat, e) SPMN180222 from Estepa, and f) SPMN110222 from Madrid.

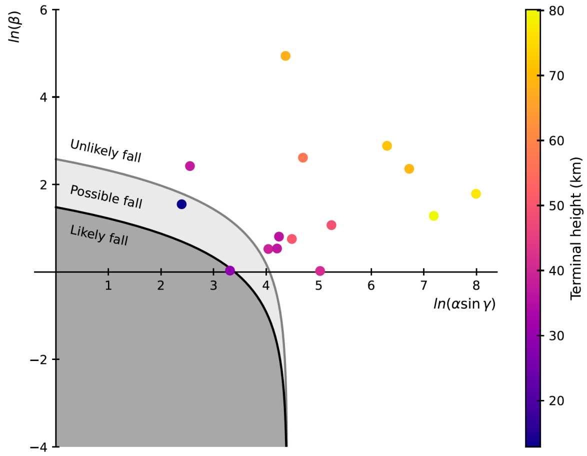

Figure 2. 15 fireballs analyzed based on the α-β criterion.

SPMN code	Association	D_{min}	t_D (y)	S_{min} (au)	$V_{S,min}$ (km/s)
60222	ρ Geminids	0.176	180	0.186	4.7
080222A	o Leonids	0.174	90	0.231	4.6
080222B	Southern δ Leonids	0.018	8720	0.129	0.8
110222	ω Cassiopeiids	0.101	10000	0.087	9.6
140222B	March Cassiopeiids	0.121	1610	0.145	10.2
180222	Southern δ Leonids	0.07	240	0.278	13.2
220222	Northern α Leonids	0.09	10000	0.05	5.8
010322A	2019 CV2	0.099	2640	0.264	6
010322B	2017 FM91	0.092	9990	0.104	6.6
080322A	2007 DZ40	0.073	800	0.144	3.1
080322B	February Hydrids	0.168	600	0.37	15.9
090322B	72 Ophiuchids	0.136	9990	0.811	14.3
090322C	March Cassiopeiids	0.084	110	0.34	10.9
100322	Draconids	0.106	2080	0.37	5.1
120322	λ Leonids	0.125	1300	0.083	7.4

Table 1. Parent body and meteoroid stream for each event with the minimum D_D value, the years that fulfill the D_D threshold, the minimum encounter distance, the required ejection velocity at the time of minimum distance.

From the well known dynamic third-order time-dependent system for modeling meteor deceleration and assuming an isothermal atmosphere, we computed the ballistic coefficient (α) and mass loss parameter (β). These dimensionless parameters describe the atmospheric flight and estimate the meteor fate, that is, the likelihood of producing meteorites [11].

Results and conclusions: We found a significant percentage of bright meteors dynamically associated with minor meteor showers. Although the ejection velocities are compatible with typical collisions of small objects in the inner Solar System, it does not strictly imply that these meteoroids were ejected recently from their meteoroid stream or parent body as not very close encounters were found during the period of time considered in this work.

The high number of minor showers producing fireballs should not come as a surprise as such a percentage of meteors associated with meteoroid streams is not rare [12]. Our resuts are in agreement with the superbolides detected from space, 23% of which may be asociated with meteoroid streams or near-Earth objects [13].

In summary:

- Among the 169 bright meteors recorded during the spring of 2022, 2 were meteorite dropper events.
- We identify the minor showers o Leonids, Southern δ Leonids, ω Cassiopeiids, Northern α Leonids, and 72 Ophiuchids, and the asteroid 2017 FM91 as sources of large projectiles during Feb. and Mar.
- Meteoroid streams can be efficient producers of large meteoroids as they account for the ~27% of the fireballs.
- Near-Earth objects could be a greater source of impact risk than previously believed.
- It is needed to extend the study of minor showers as, although they are not very active in terms of the number of meteors, our work indicates that they also produce large bolides.
- Our findings, extended in [14], support the idea that certain meteoroid streams associated with these events may represent a short-term impact hazard.

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