

**SPECTROSCOPIC AND DYNAMICAL ANALYSIS OF AN EARTH-GRAZER FIREBALL OBSERVED IN DECEMBER 2021.** J. Izquierdo<sup>1</sup>, J.M. Madiedo<sup>2,3</sup>, J.L. Ortiz<sup>2</sup>, J. Aceituno<sup>4</sup>, E. de Guindos<sup>4</sup>. <sup>1</sup>Dpto. de Física de la Tierra y Astrofísica, Universidad Complutense de Madrid, 28040 Madrid, Spain. <sup>2</sup>Instituto de Astrofísica de Andalucía, CSIC, Apt. 3004, Camino Bajo de Hueter 50, 18080 Granada, Spain. <sup>3</sup>Observatorio Galileo, 41012 Sevilla, Spain. <sup>4</sup>Centro Astronómico Hispano-Alemán, Calar Alto (CSIC-MPG), E-04004 Almería, Spain.

**Introduction:** The majority of meteoroids that intercept our atmosphere are completely ablated at high altitudes and do not reach the ground. Under some circumstances, however, they survive as meteorites. But meteoroid survival is also possible when these particles enter the atmosphere almost tangentially and only a portion of their mass is destroyed as a consequence of the ablation process. In these rare cases, the meteoroid can leave the atmosphere with a fusion crust, and follow a modified orbit around the Sun. These Earth-grazing events are not abundant in the scientific literature [1-6]. In this work we present the preliminary analysis of a mag.  $-6\pm 1$  Earth-grazing fireball observed in the framework of the Southwestern Europe Meteor Network (SWEMN) and its SMART project on 2021 December 4. The emission spectrum of this bolide was also recorded.

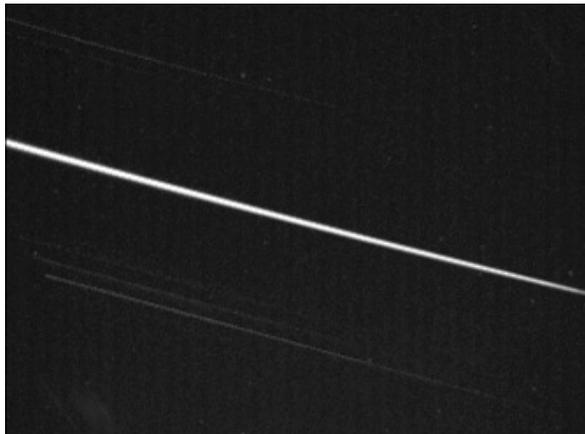


Figure 1. Sum-pixel image of the SWEMN20211204\_040806 Earth-grazing fireball as imaged from the Calar Alto Astronomical Observatory (Almería, Spain). The first order emission spectrum is also shown.

**Instrumentation and methods:** The fireball discussed here was recorded from several meteor observing stations operating from Spain in the framework of the SWEMN meteor network and the SMART project. Most of these stations employ an array of low-lux CCD video cameras manufactured by Watec Corporation (models 902H and 902H2 Ultimate). These devices monitor the night sky and some of them operate in a fully autonomous way by means of software developed by the second author [7]. For meteor spectroscopy we have employed transmission diffraction gratings at-

tached to the objective lens of some of these cameras. The atmospheric trajectory and orbital data were derived from the images of the fireball by employing the SAMIA software, and the emission spectrum was analyzed with the CHIMET package [7], both of them developed by J.M. Madiedo.

**The 2021 December 4 event:** A slow-moving fireball (Figure 1) was recorded by our systems on Dec. 4 at 4h08m06 $\pm$ 1s UT. The bolide, which was included in the SWEMN digital database [8] under the code SWEMN20211204\_040806, was also widely observed by casual observers located in Portugal, Spain and Morocco. Excluding the initial and ending phases, the luminosity of the event was practically constant along its atmospheric path. Our photometric analysis reveals that its peak luminosity was equivalent to an absolute magnitude of  $-6\pm 1$ . The total duration of the luminous phase of this event was of around 15 seconds.

**Preliminary results:** Our analysis show that the luminous phase of this event began at a height  $H_b=99.7$  km over the north of Morocco. The meteoroid hit the atmosphere with an initial velocity  $V_\infty$  of about 23 km/s and a zenith angle of around  $86^\circ$ . The calculated apparent radiant was located at the equatorial coordinates  $\alpha=64.8^\circ$ ,  $\delta=-24.4^\circ$ . The geocentric velocity derived for the progenitor meteoroid was  $V_G=20.6$  km/s. The height of the bolide decreased slowly while it overflew the Mediterranean Sea following a northeast direction, reaching its perigee (minimum height over the sea) when the projection of its trajectory was located between the coasts of Almería (southeast of Spain) and Algeria. Then, its height increased slowly while the event continued heading towards the Balearic Islands (Spain). Finally, the fireball ended over the Mediterranean Sea at an altitude of about 100 km, over a point located at about 85 km southeast from Ibiza (Balearic Islands, Spain). At that location, the meteoroid left the atmosphere and followed a modified orbit.

a (AU)	e	q (AU)	i ( $^\circ$ )	$\omega$ ( $^\circ$ )	$\Omega$ ( $^\circ$ )	$T_J$
10.5	0.91	0.885	22.6	37.9	71.9172	1.5

Table 1. Orbital parameters (J2000) of the progenitor meteoroid before impacting our planet.



Figure 2. Projection on the ground of the atmospheric trajectory of the bolide discussed in this work.

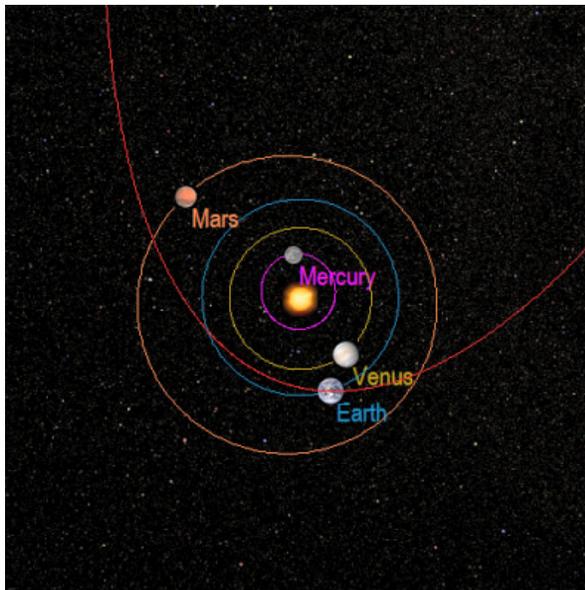


Figure 3. Projection on the ecliptic of the orbit of the progenitor meteoroid before its encounter with our planet.

The total length traveled by the fireball in the atmosphere was of about 760 km. The projection on the ground of this atmospheric trajectory is shown in Figure 2. The parameters of the heliocentric orbit followed by the meteoroid before its encounter with our planet (Figure 3) are listed in Table 1. These data confirm the sporadic nature of the event. The value of the Tisserand parameter with respect to Jupiter ( $T_J = 1.5$ ) reveals that the meteoroid was following a cometary orbit.

The emission spectrum of the bolide contains typical contributions found in meteor spectra, such as lines produced by several neutral iron multiplets, the Mg I-2 triplet and the and Na I-1 doublet. The in-deep analysis of this spectrum is currently in progress, and from it we

will obtain key information about the nature of the meteoroid.

**Conclusions:** We have presented here the results obtained from the preliminary analysis of a sporadic mag.  $-6 \pm 1$  Earth-grazing fireball recorded from Spain by the Southwestern Europe Meteor Network on 2021 December 4. The event started over the north of Morocco and overflew the Mediterranean Sea. It ended over the Mediterranean, at a height of about 100 km over a point located at about 85 km northeast from Ibiza. At that point the meteoroid, which followed a cometary orbit before its encounter with our planet, left the atmosphere with a fusion crust, and continued its path around the Sun following a modified orbit. The emission spectrum of the bolide and the final orbit of its progenitor meteoroid are currently under analysis.

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