# The Southwestern Europe Meteor Network: notable meteors spotted between December 2022 and January 2023

**J.M. Madiedo[1], J.L. Ortiz[1], J. Izquierdo[2], P. Santos-Sanz[1], J. Aceituno[3], E. de Guindos[3], P. Yanguas[4], J. Palacián[4], A. San Segundo[5], D. Ávila[6], B. Tosar[7], A. Gómez-Hernández[8], Juan Gómez-Martínez[8], Antonio García[9], and A.I. Aimee[10]**

[1] **Departamento de Sistema Solar, Instituto de Astrofísica de Andalucía (IAA-CSIC), 18080 Granada, Spain**
madiedo@cica.es, ortiz@iaa.es, psantos@iaa.es

[2] **Departamento de Física de la Tierra y Astrofísica, Universidad Complutense de Madrid, 28040 Madrid, Spain**
jizquierdo9@gmail.com

[3] **Observatorio Astronómico de Calar Alto (CAHA), E-04004, Almería, Spain**
aceitun@caha.es, guindos@caha.es

[4] **Departamento de Estadística, Informática y Matemáticas e Institute for Advanced Materials and Mathematics, Universidad Pública de Navarra, 31006 Pamplona, Navarra, Spain**
yanguas@unavarra.es, palacian@unavarra.es

[5] **Observatorio El Guijo (MPC J27), Galapagar, Madrid, Spain**
mpcj27@outlook.es

[6] **Estación de Meteoros de Ayora, Ayora, Valencia, Spain**
David_ayora007@hotmail.com

[7] **Casa das Ciencias. Museos Científicos Coruñeses. A Coruña, Spain**
borjatosar@gmail.com

[8] **Estación de Registro La Lloma, Olocau, Valencia, Spain**
curso88@gmail.com

[9] **Estación de Meteoros de Cullera (Faro de Cullera), Valencia, Spain**
antonio.garcia88@joseantoniogarcia.com

[10] **Southwestern Europe Meteor Network, 41012 Sevilla, Spain**
swemn.server@gmail.com

We present in this report the analysis of some of the notable meteors registered in the framework of the Southwestern Europe Meteor Network between December 2022 and January 2023. These were recorded from Spain. Their peak brightness ranges from mag. –7 to mag. –10. The emission spectrum of one of them is also presented. Bright meteors included here were produced by different sources: the sporadic background, major meteoroid streams, and poorly-known streams.

## 1 Introduction

The Southwestern Europe Meteor Network (SWEMN) conducts the SMART project (Spectroscopy of Meteoroids by means of Robotic Technologies), which started operation in 2006 to analyze the physical and chemical properties of meteoroids ablating in the Earth's atmosphere. For this purpose, we employ an array of automated cameras and spectrographs deployed at meteor-observing stations in Spain (Madiedo, 2014; Madiedo, 2017). This allows to derive the luminous path of meteors and the orbit of their progenitor meteoroids, and also to study the evolution of meteor plasmas from the emission spectrum produced by these events (Madiedo, 2015a; 2015b). SMART also provides important information for our MIDAS project, which is being conducted by the Institute of Astrophysics of Andalusia (IAA-CSIC) to study lunar impact flashes produced when large meteoroids impact the Moon (Madiedo et al., 2015; Madiedo et al., 2018; Madiedo et al., 2019; Ortiz et al., 2015).

We include in this report a preliminary analysis of a series of notable fireballs recorded from Spain in the framework of the SWEMN network along December 2022 and January 2023. This work has been fully written by AIMEE (acronym for Artificial Intelligence with Meteoroid Environment Expertise) from the records included in the SWEMN fireball database (Madiedo et al., 2021; Madiedo et al., 2022).

## 2 Equipment and methods

The events presented here have been recorded by using Watec 902H2 and Watec 902 Ultimate cameras. Their field of view ranges from 62 × 50 degrees to 14 × 11 degrees. To record meteor spectra we have attached holographic diffraction gratings (1000 lines/mm) to the lens of some of these cameras. We have also employed digital CMOS color cameras (models Sony A7S and A7SII) operating in HD video mode (1920 × 1080 pixels). These cover a field of view of around 70 × 40 degrees. A detailed description of this hardware and the way it operates was given in previous works (Madiedo, 2017). Besides digital CMOS cameras manufactured by ZWO (model ASI185MC) were used. The atmospheric paths of the events were triangulated by means of the SAMIA software, developed by J. M. Madiedo. This program employs the planes-intersection method (Ceplecha, 1987).

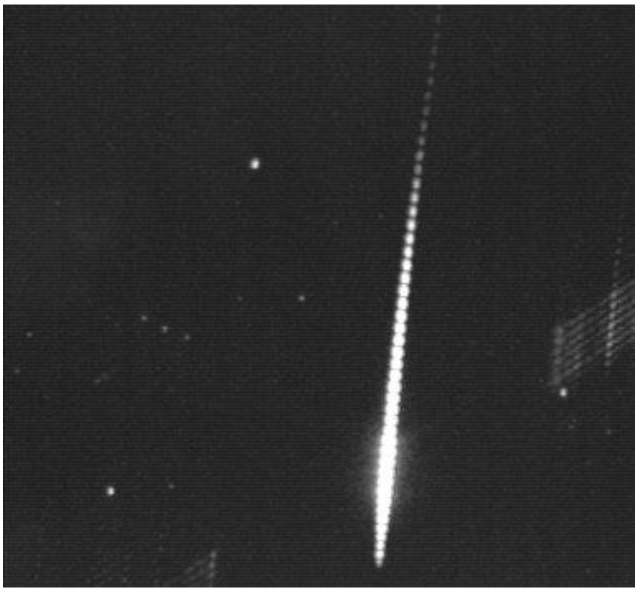

*Figure 1* – Stacked image of the SWEMN20221215_033111 meteor.

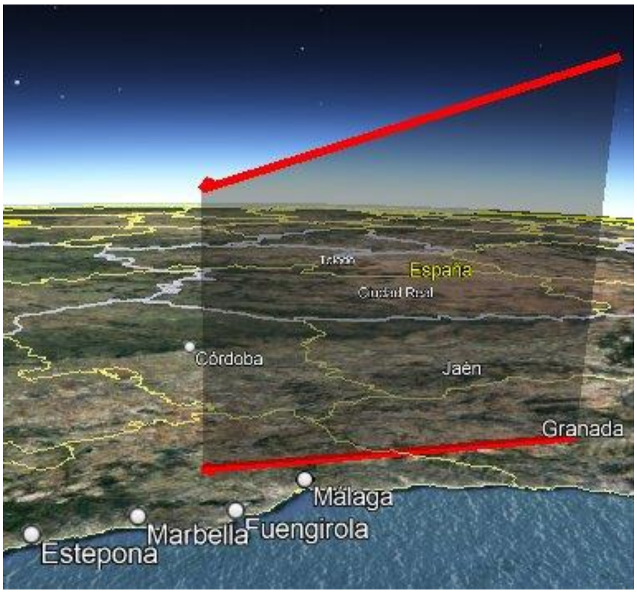


*Figure 2* – Atmospheric path of the SWEMN20221215_033111 event, and its projection on the ground.

## 3 Description of the 2022 December 15 fireball

On 2022 December 15, at $3^h31^m11.0 \pm 0.1^s$ UT, SWEMN meteor stations captured this bright bolide (*Figure 1*). The peak luminosity of this bright meteor was equivalent to an absolute magnitude of –8.0 ± 1.0. It was included in the SWEMN meteor database with the code SWEMN20221215_033111.

### Atmospheric trajectory, radiant and orbit

According to our analysis, this event overflew the provinces of Granada and Málaga (south of Spain). The initial altitude of the meteor yields $H_b = 107.0 \pm 0.5$ km, and the fireball ended at a height $H_e = 74.6 \pm 0.5$ km. The equatorial coordinates of the apparent radiant yield $\alpha = 216.52^o$, $\delta = +19.32^o$. Besides, we deduced that the meteoroid collided with the atmosphere with a velocity $v_\infty = 59.2 \pm 0.3$ km/s. *Figure 2* shows the calculated atmospheric path of the bright meteor and its projection on the ground. *Figure 3* shows the orbit in the Solar System of the progenitor meteoroid.

*Table 1* – Orbital data (J2000) of the progenitor meteoroid before its encounter with our planet.

| | | | |
|---|---|---|---|
| $a$ (AU) | 99.5 ± 246 | $\omega$ (°) | 98.1 ± 00.8 |
| $e$ | 0.99 ± 0.01 | Ω (°) | 262.810958 ± $10^{-5}$ |
| $q$ (AU) | 0.562 ± 0.003 | $i$ (°) | 108.5 ± 0.2 |

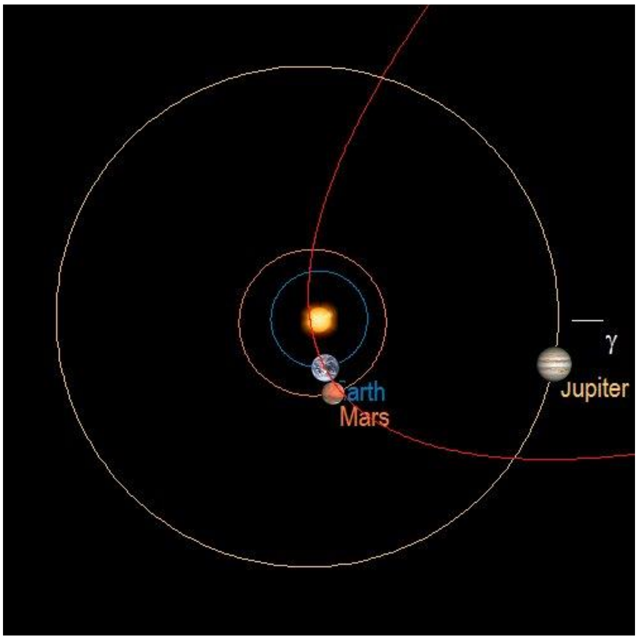


*Figure 3* – Projection on the ecliptic plane of the orbit of the progenitor meteoroid of the SWEMN20221215_033111 event.

We named this fireball “Alora”, since the event was located over this locality during its final phase. The orbital parameters of the parent meteoroid before its encounter with our planet are included in *Table 1*. The geocentric velocity of the meteoroid was $v_g = 57.8 \pm 0.3$ km/s. The Tisserand parameter with respect to Jupiter ($T_J = -0.24$) suggests that the particle followed a cometary (HTC) orbit before impacting our atmosphere. By taking into account these orbital data and the radiant position, it was deduced that the bolide was generated by a sporadic meteoroid.

*Figure 4* – Stacked image of the SWEMN20221217_225012 event.

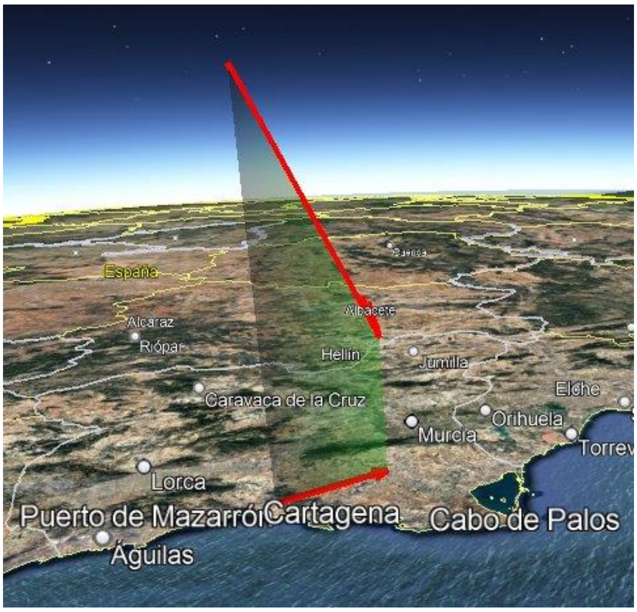


*Figure 5* – Atmospheric path of the SWEMN20221217_225012 event, and its projection on the ground.

## 4 The 2022 December 17 meteor

This bright fireball was spotted on 2022 December 17 at $22^h50^m12.0 \pm 0.1^s$ UT from the meteor-observing stations located at Huelva, La Hita (Toledo), Calar Alto, Sierra Nevada, La Sagra (Granada), and Sevilla (*Figure 4*). It had a peak absolute magnitude of –9.0 ± 1.0. The code given to the bolide in the SWEMN meteor database is SWEMN20221217_225012. A video containing images of the event and its atmospheric trajectory was uploaded to YouTube[32]. The fireball was also witnessed by a wide number of casual observers who reported it on social networks.

### Atmospheric path, radiant and orbit

It was concluded having analyzed the atmospheric trajectory of the bolide that this event overflew the region of Murcia (southeast of Spain). Its initial altitude was $H_b = 86.0 \pm 0.5$ km. The fireball penetrated the atmosphere till a final height $H_e = 30.4 \pm 0.5$ km. From the analysis of the atmospheric path, we also concluded that the apparent radiant was located at the position $\alpha = 45.61°$, $\delta = +15.06°$. The meteoroid hit the atmosphere with an initial velocity $v_\infty = 14.8 \pm 0.3$ km/s. The calculated atmospheric path of the bright meteor is shown in *Figure 5*. The heliocentric orbit of the meteoroid is drawn in *Figure 6*.

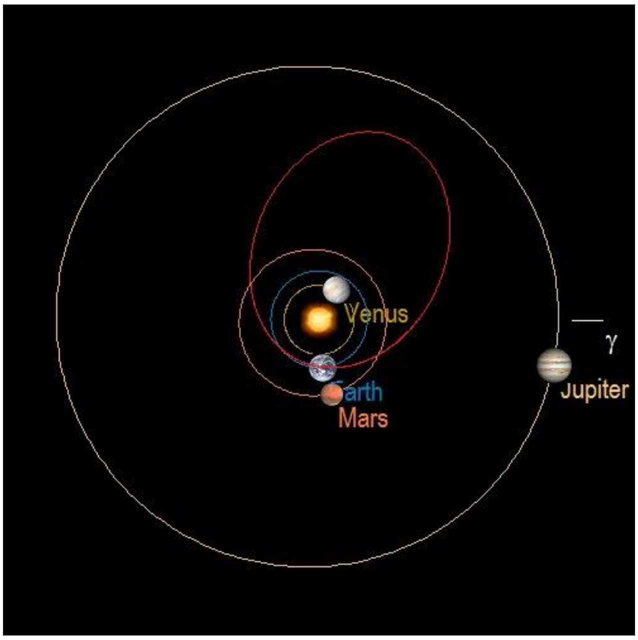


*Figure 6* – Projection on the ecliptic plane of the orbit of the parent meteoroid of the SWEMN20221217_225012 meteor.

The bright meteor was named "Molino de Carrasco", since the bolide overflew this locality during its initial phase. *Table 2* shows the orbital parameters of the parent meteoroid before its encounter with our planet. The value calculated for the geocentric velocity was $v_g = 10.0 \pm 0.4$ km/s. The value found for the Tisserand parameter with respect to Jupiter ($T_J = 3.14$) suggests that the meteoroid followed an asteroidal orbit before colliding with the Earth's atmosphere. These parameters and the derived radiant do not match any of the streams listed in the IAU meteor database. Consequently, it was concluded that the bright meteor was linked to the sporadic background.

*Table 2* – Orbital data (J2000) of the progenitor meteoroid before its encounter with our planet.

| | | | |
|---|---|---|---|
| $a$ (AU) | 2.5 ± 0.1 | $\omega$ (°) | 28.0 ± 00.4 |
| $e$ | 0.62 ± 0.02 | $\Omega$ (°) | $85.545184 \pm 10^{-5}$ |
| $q$ (AU) | 0.939 ± 0.002 | $i$ (°) | 1.41 ± 0.02 |

## 5 The 2022 December 22 fireball

We recorded this bright fireball from the meteor-observing stations located at Huelva, La Hita (Toledo), Calar Alto,

[32] https://youtu.be/In5Q2bLeGeI

Sierra Nevada, La Sagra (Granada), and Sevilla. The bright meteor was captured on 2022 December 22, at $5^h35^m10.0 \pm 0.1^s$ UT. The event, that showed various flares along its trajectory in the atmosphere, had a peak absolute magnitude of –7.5 ± 0.5 (*Figure 7*). These flares appeared as a consequence of the sudden disruption of the meteoroid. The code given to the fireball in the SWEMN meteor database is SWEMN20221222_053510. A video showing images of the bright meteor and its luminous path was uploaded to YouTube[33].

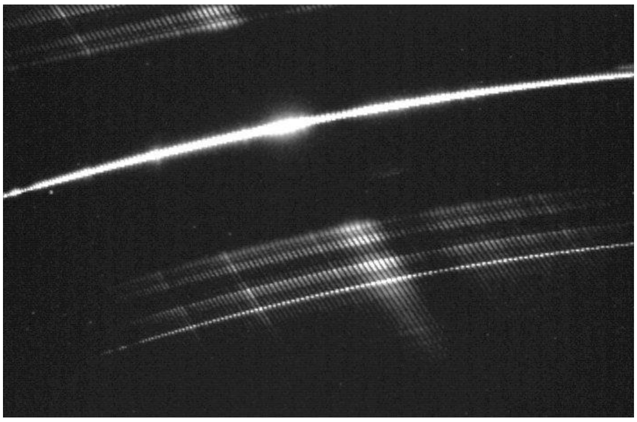

*Figure 7* – Stacked image of the SWEMN20221222_053510 bolide.

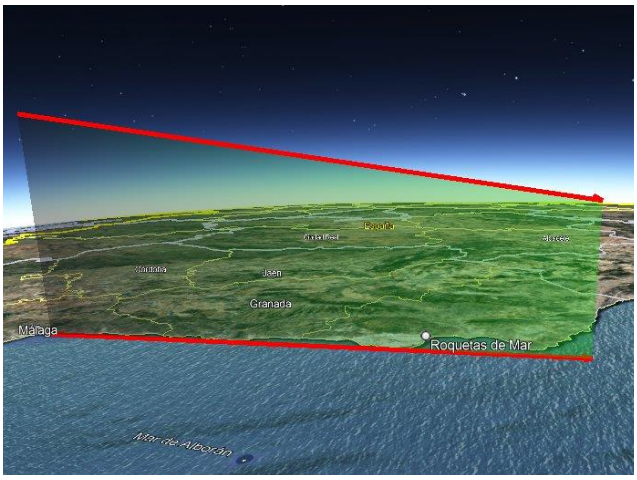


*Figure 8* – Atmospheric path of the SWEMN20221222_053510 fireball, and its projection on the ground.

**Atmospheric path, radiant and orbit**

It was found from the calculation of the luminous path of the fireball that this event overflew the Mediterranean Sea. Its initial altitude was $H_b$ = 89.5 ± 0.5 km. The bolide penetrated the atmosphere till a final height $H_e$ = 54.6 ± 0.5 km. The position found for the apparent radiant corresponds to the equatorial coordinates $\alpha$ = 87.53º, $\delta$ = +6.64º. The entry velocity in the atmosphere obtained for the parent meteoroid was $v_\infty$ = 20.2 ± 0.3 km/s. The obtained trajectory in the atmosphere of the bright meteor is shown in *Figure 8*. The heliocentric orbit of the meteoroid is shown in *Figure 9*.

*Table 3* shows the parameters of the orbit in the Solar System of the progenitor meteoroid before its encounter with our planet, and the geocentric velocity derived in this case was $v_g$ = 17.3 ± 0.4 km/s. From the value obtained for the Tisserand parameter referred to Jupiter ($T_J$ = 3.28), we found that before colliding with the Earth's atmosphere the particle was moving on an asteroidal orbit. Radiant and orbital data do not match any of the meteoroid streams in the IAU meteor database. So, we concluded that this meteor was also produced by the sporadic background.

*Table 3* – Orbital data (J2000) of the progenitor meteoroid before its encounter with our planet.

| | | | |
|---|---|---|---|
| $a$ (AU) | 2.24 ± 0.06 | $\omega$ (º) | 64.6 ± 00.4 |
| $e$ | 0.66 ± 0.01 | Ω (º) | 90.008927 ± $10^{-5}$ |
| $q$ (AU) | 0.759 ± 0.005 | $i$ (º) | 11.0 ± 0.1 |

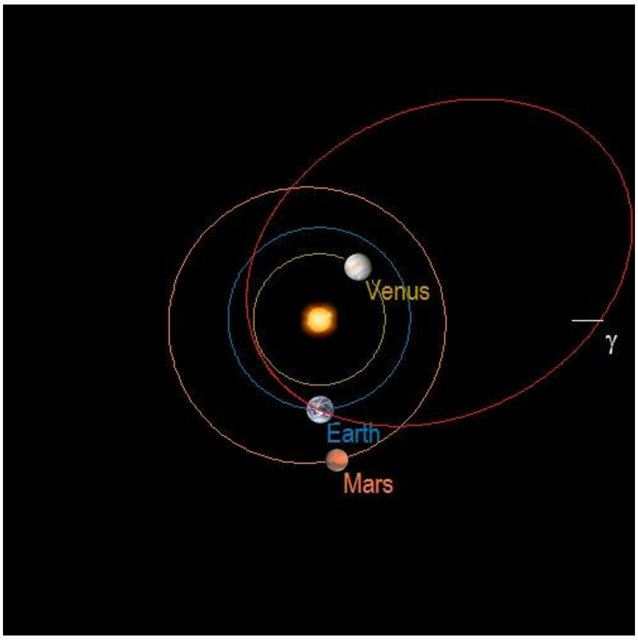


*Figure 9* – Projection on the ecliptic plane of the orbit of the parent meteoroid of the SWEMN20221222_053510 event.

## 6 Description of the 2023 January 4 event

This bright fireball was captured on 2023 January 4, at $6^h12^m18.0 \pm 0.1^s$ UT (*Figure 10*). Its peak brightness was equivalent to an absolute magnitude of –9.0 ± 1.0. It displayed a bright flare at the terminal point of its trajectory in the Earth's atmosphere as a consequence of the sudden break-up of the meteoroid. The code given to the bolide in the SWEMN meteor database is SWEMN20230104_061218.

**Atmospheric path, radiant and orbit**

By analyzing the trajectory in the Earth's atmosphere of the event it was inferred that this bright meteor overflew the province of Granada (Spain). The meteoroid started ablating at a height $H_b$ = 108.3 ± 0.5 km, and the terminal point of the luminous path was located at a height $H_e$ = 65.5 ± 0.5 km. The equatorial coordinates of the apparent radiant yield $\alpha$ = 227.78º, $\delta$ = +47.67º. The meteoroid stroke the atmosphere with an initial velocity

[33] https://youtu.be/7ViH_OJHTtw

$v_\infty = 42.9 \pm 0.3$ km/s. *Figure 11* shows the calculated path in the atmosphere of the event. The heliocentric orbit of the meteoroid is drawn in *Figure 12*.

This bright meteor was named "Rambla del Agua", because the bolide overflew this location during its final phase. The parameters of heliocentric orbit of the parent meteoroid before its encounter with our planet can be found in *Table 4*, and the geocentric velocity yields $v_g = 41.3 \pm 0.3$ km/s. According to the value derived for the Tisserand parameter referred to Jupiter ($T_J = 2.48$), the particle was moving on a cometary (JFC) orbit before impacting the atmosphere. These values and the calculated radiant position confirm that the bolide was linked to the Quadrantids (IAU shower code QUA#0010). The proposed parent body of this shower is 2003 EH1 (Jenniskens et al., 2016).

*Table 4* – Orbital data (J2000) of the progenitor meteoroid before its encounter with our planet.

| | | | |
|---|---|---|---|
| *a* (AU) | 2.3 ± 0.1 | *ω* (º) | 171.9 ± 00.1 |
| *e* | 0.59 ± 0.01 | Ω (º) | 283.297723 ± $10^{-5}$ |
| *q* (AU) | 0.97973 ± 0.00007 | *i* (º) | 73.6 ± 0.3 |

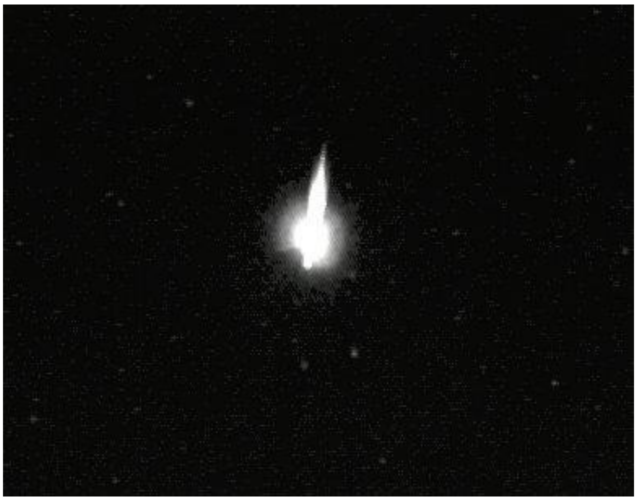

*Figure 10* – Stacked image of the SWEMN20230104_061218 bolide.


*Figure 11* – Atmospheric path of the SWEMN20230104_061218 event, and its projection on the ground.

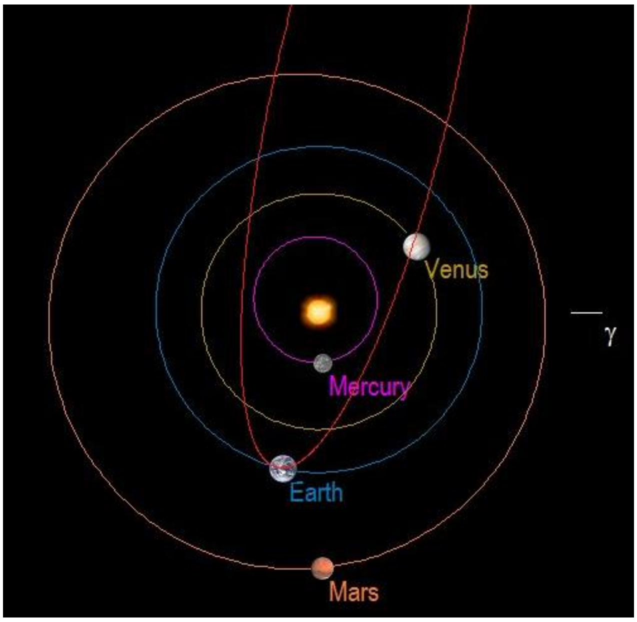


*Figure 12* – Projection on the ecliptic plane of the orbit of the parent meteoroid of the SWEMN20230104_061218 meteor.

## Emission spectrum

The emission spectrum of the fireball was also recorded by employing the video spectrographs operated by the SWEMN network. This signal was calibrated in wavelength by employing typical lines appearing in meteor spectra, and then corrected by taking into account the sensitivity of the recording device. *Figure 13* shows the calibrated spectrum and the most remarkable contributions identified in it.

The majority of these contributions correspond to neutral iron (Fe I), which is typical in meteor spectra (Borovička, 1993; Madiedo, 2014). In this case, several multiplets of Fe I have been identified. The most important ones are Fe I-4 at 393.3 nm, Fe I-43, Fe I-42, Fe I-41, Fe I-21, and Fe I-15. The most important contributions, however, correspond to the H and K lines of Ca II-1, which appear blended in the signal. The emission lines of the Na I-1 doublet (588.9 nm) and the Mg I-2 triplet (516.7 nm) are also very significant. The analysis of the relative intensities of these lines will provide key information about the nature of the meteoroid.

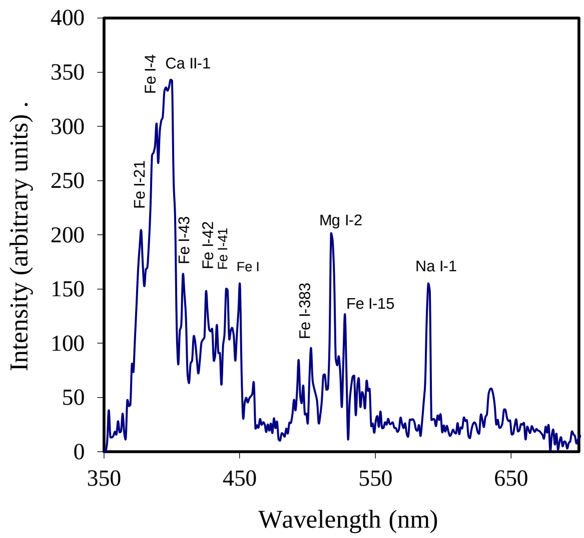


*Figure 13* – Emission spectrum of the SWEMN20230104_061218 event.

## 7 The 2023 January 11 event

This bright event was captured on 2023 January 11, at $2^h17^m04.0 \pm 0.1^s$ UT. Its maximum luminosity was equivalent to an absolute magnitude of $-9.0 \pm 1.0$ (*Figure 14*). The code assigned to the bright meteor in the SWEMN meteor database is SWEMN20230111_021704. The bolide can be viewed on this YouTube[34] video.

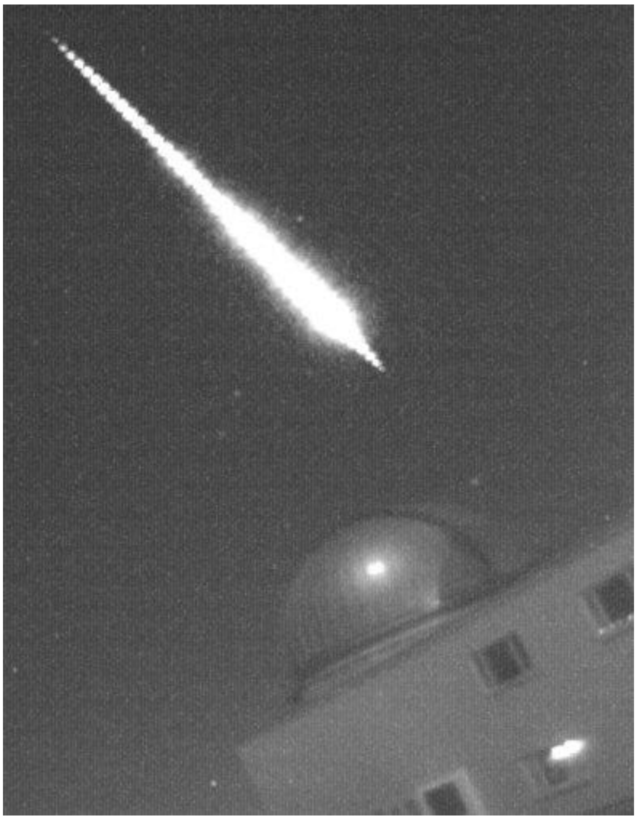

*Figure 14* – Stacked image of the SWEMN20230111_021704 bolide.


*Figure 15* – Atmospheric path of the SWEMN20230111_021704 meteor, and its projection on the ground.

### Atmospheric path, radiant and orbit

This bolide overflew the provinces of Córdoba and Jaén (south of Spain). The luminous event began at an altitude $H_b = 95.7 \pm 0.5$ km. The meteor penetrated the atmosphere till a final height $H_e = 41.4 \pm 0.5$ km. The position found for the apparent radiant corresponds to the equatorial coordinates $\alpha = 136.84°$, $\delta = +20.15°$. The meteoroid impacted the atmosphere with an initial velocity $v_\infty = 35.1 \pm 0.3$ km/s. The obtained atmospheric trajectory of the fireball is shown in *Figure 15*. The orbit in the Solar System of the meteoroid is shown in *Figure 16*.

*Table 5* – Orbital data (J2000) of the progenitor meteoroid before its encounter with our planet.

| | | | |
|---|---|---|---|
| $a$ (AU) | 1.63 ± 0.04 | $\omega$ (°) | 316.8 ± 00.2 |
| $e$ | 0.888 ± 0.004 | $\Omega$ (°) | 290.294840 ± $10^{-5}$ |
| $q$ (AU) | 0.183 ± 0.003 | $i$ (°) | 5.2 ± 0.1 |

This bolide was named "Baena", because the event was located over this locality during its initial phase. *Table 5* shows the orbital parameters of the progenitor meteoroid before its encounter with our planet. The geocentric velocity of the meteoroid was $v_g = 33.3 \pm 0.3$ km/s. From the value derived for the Tisserand parameter referred to Jupiter ($T_J = 3.69$), we found that the particle followed an asteroidal orbit before colliding with our atmosphere. These data and the calculated radiant position confirm that the event was produced by the zeta Cancrids (IAU code ACZ#0604). The proposed progenitor body of this shower, which peaks around January 2, is asteroid 2011YX62 (Segon et al., 2014).

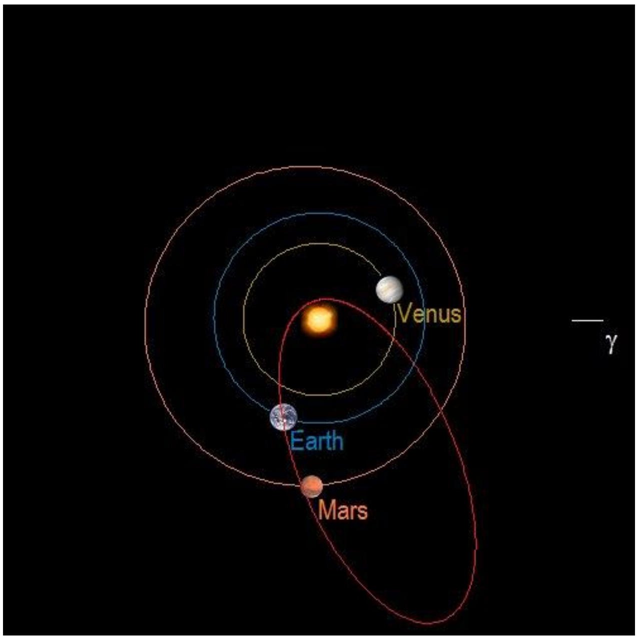


*Figure 16* – Projection on the ecliptic plane of the orbit of the SWEMN20230111_021704 event.

[34] https://youtu.be/Gfpj8yf_fcc

*Figure 17* – Stacked image of the SWEMN20230115_215222 event.

## 8 Analysis of the 2023 January 15 event

On 2023 January 15, at $21^h52^m22.0 \pm 0.1^s$ UT, SWEMN meteor stations spotted this bright meteor (*Figure 17*). The peak luminosity the bolide was equivalent to an absolute magnitude of $-8.5 \pm 0.5$. Its code in the SWEMN meteor database is SWEMN20230115_215222. A video containing images of the bolide and its luminous path was. uploaded to YouTube[35].


*Figure 18* – Atmospheric path of the SWEMN20230115_215222 bolide, and its projection on the ground.

### Atmospheric path, radiant and orbit

It was concluded as a result of the analysis of the luminous path of the event that this fireball overflew Spain and the Gulf of Cádiz. The luminous event began at an altitude $H_b = 73.7 \pm 0.5$ km. The event penetrated the atmosphere till a final height $H_e = 39.1 \pm 0.5$ km. The equatorial coordinates inferred for the apparent radiant are $\alpha = 113.39°$, $\delta = +21.68°$. The pre-atmospheric velocity found for the meteoroid yields $v_\infty = 23.8 \pm 0.3$ km/s. The obtained atmospheric trajectory of the bolide is shown in *Figure 18*. The orbit in the Solar System of the meteoroid is shown in *Figure 19*.

*Table 6* – Orbital data (J2000) of the progenitor meteoroid before its encounter with our planet.

| | | | |
|---|---|---|---|
| $a$ (AU) | 2.3 ± 0.1 | $\omega$ (º) | 81.86 ± 00.04 |
| $e$ | 0.73 ± 0.01 | Ω (º) | $114.908219 \pm 10^{-5}$ |
| $q$ (AU) | 0.627 ± 0.003 | $i$ (º) | 0.59 ± 0.01 |

We named this bolide "Puente Carrera", because the event overflew this location in Spain during its final phase. The parameters of the heliocentric orbit of the progenitor meteoroid before its encounter with our planet are included in *Table 6*. The geocentric velocity of the meteoroid was $v_g = 20.9 \pm 0.3$ km/s. From the value calculated for the Tisserand parameter with respect to Jupiter ($T_J = 3.11$), we found that before entering our atmosphere the particle was moving on an asteroidal orbit. By taking into account these values and the derived radiant location, the event was linked to the ρ-Geminids (IAU meteor shower code RGE#0094) (Madiedo, 2015b). Since the ρ-Geminids reach their peak on January 16, this fireball was captured during this activity peak.

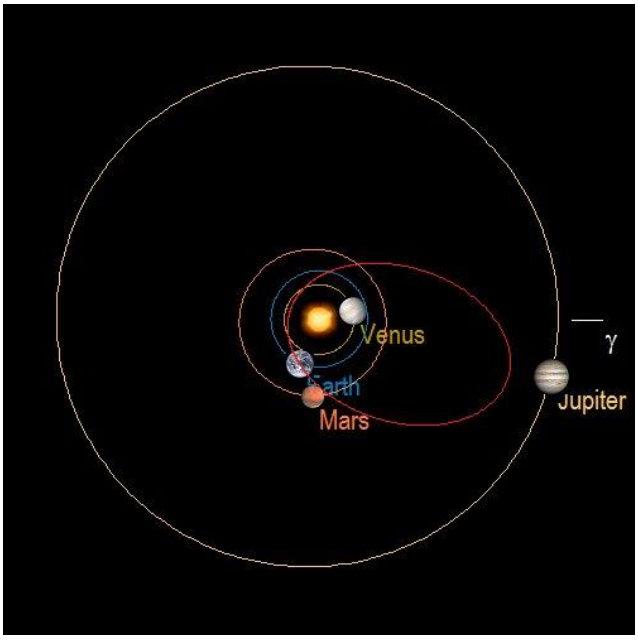


*Figure 19* – Projection on the ecliptic plane of the orbit of the parent meteoroid of the SWEMN20230115_215222 bolide.

## 9 Analysis of the 2023 January 20 event

This bright event was captured on 2023 January 20 at $23^h42^m24.0 \pm 0.1^s$ UT from the meteor-observing stations located at Huelva, La Hita (Toledo), Calar Alto, Sierra

[35] https://youtu.be/_N6tlXAY06g

Nevada, La Sagra (Granada), Sevilla, and El Aljarafe (Sevilla). The bright meteor had a peak absolute magnitude of –10.0 ± 1.0 (*Figure 20*). The event was included in our meteor database with the code SWEMN20230120_234224. The bolide can be viewed on this YouTube[36] video.

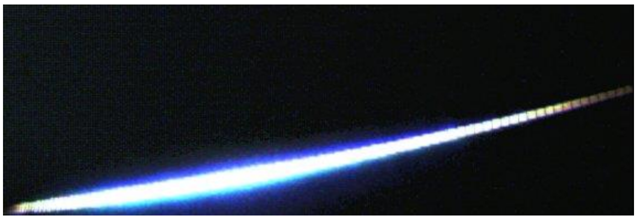

*Figure 20* – Stacked image of the SWEMN20230120_234224 meteor.

**Atmospheric path, radiant and orbit**

This fireball overflew the province of Badajoz (Spain). The luminous event began at an altitude $H_b$ = 93.6 ± 0.5 km. The bright meteor penetrated the atmosphere till a final height $H_e$ = 29.5 ± 0.5 km. The equatorial coordinates of the apparent radiant yield $\alpha$ = 119.08º, $\delta$ = +11.98º. The entry velocity in the atmosphere obtained for the parent meteoroid was $v_\infty$ = 24.5 ± 0.3 km/s. *Figure 21* shows the obtained trajectory in the atmosphere of the bolide and its projection on the ground. The orbit in the Solar System of the progenitor meteoroid is shown in *Figure 22*.

*Table 7* – Orbital data (J2000) of the progenitor meteoroid before its encounter with our planet.

| | | | |
|---|---|---|---|
| *a* (AU) | 2.5 ± 0.1 | *ω* (º) | 81.85 ± 00.09 |
| *e* | 0.75 ± 0.01 | Ω (º) | 120.318450 ± $10^{-5}$ |
| *q* (AU) | 0.620 ± 0.003 | *i* (º) | 7.16 ± 0.07 |

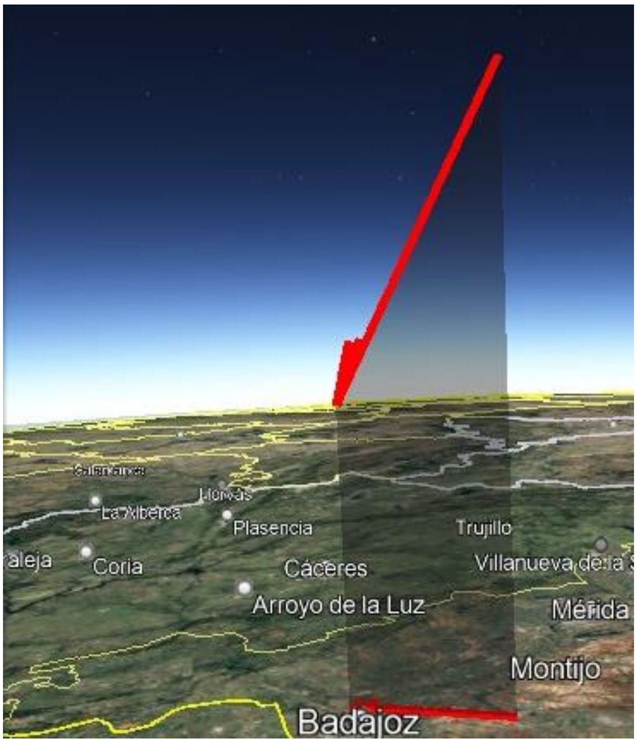


*Figure 21* – Atmospheric path of the SWEMN20230120_234224 meteor, and its projection on the ground.

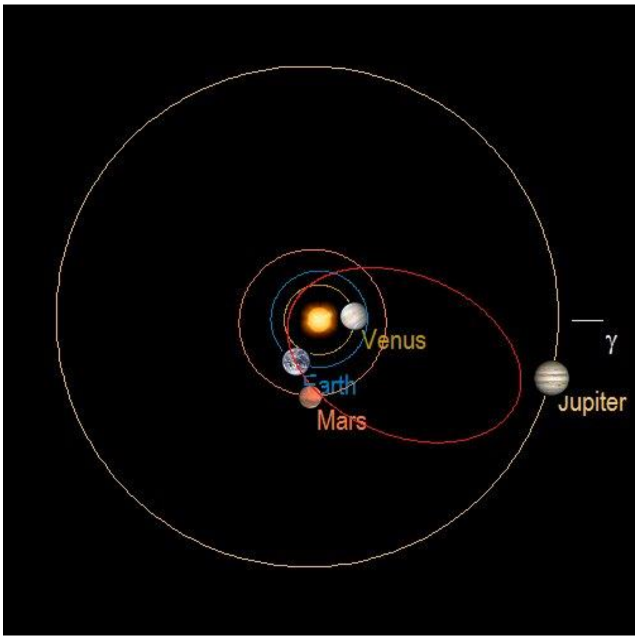


*Figure 22* – Projection on the ecliptic plane of the orbit of the parent meteoroid of the SWEMN20230120_234224 meteor.

We named this bolide “La Albuera”, because the fireball was located near the zenith of this locality during its initial phase. The orbital data of the meteoroid before its encounter with our planet are listed in *Table 7*. The geocentric velocity obtained for the particle yields $v_g$ = 21.9 ± 0.3 km/s. The value calculated for the Tisserand parameter with respect to Jupiter ($T_J$ = 2.95) suggests that before entering our atmosphere the particle was moving on a cometary (JFC) orbit. Radiant and orbital data do not match any of the meteoroid streams in the IAU meteor database. So, we concluded that this bolide was produced by the sporadic background.

## 10 Conclusions

Here we have discussed some of the most important fireballs recorded by our meteor-observing stations along December 2022 and January 2023. Their maximum brightness ranges from mag. –7 to mag. –10.

The “Alora” fireball was recorded on December 15. Its peak absolute magnitude was –8.0. The fireball was produced by a sporadic meteoroid and overflew the provinces of Granada and Málaga (south of Spain). Before colliding with our planet’s atmosphere, the particle was moving on a cometary (HTC) orbit.

Next, we have discussed the “Molino de Carrasco” fireball. This was recorded on December 17 and its peak absolute magnitude was –9.0. The meteor was also produced by a sporadic meteoroid and overflew the region of Murcia (southeast of Spain). Before striking our planet’s atmosphere the meteoroid was moving on an asteroidal orbit. At the terminal stage of its luminous phase, this deep-penetrating fireball was located at an altitude of about 30 km.

[36] https://youtu.be/YYjZuF5qR9c

The third event analyzed in this report was a bright meteor recorded by our meteor-stations on December 22. It was associated with the sporadic component. With a peak absolute magnitude of –7.5, it overflew the Mediterranean Sea. Before striking our atmosphere, the meteoroid was moving on an asteroidal orbit.

The fourth fireball discussed here was a bolide recorded on January 4 which was named “Rambla del Agua”. This Quadrantid (QUA#0010) meteor event had a peak absolute magnitude of –9.0 and overflew the province of Granada (south of Spain). The analysis of the emission spectrum of the meteor was also performed. This spectrum exhibits the contributions generated by Na I-I, Mg I-2, Ca II-1 and several Fe-I multiplets.

Next, we have analyzed the “Baena” event, which was recorded on January 11. This zeta Cancrid (ACZ#0604) bolide had a peak absolute magnitude of –9.0 and overflew the provinces of Córdoba and Jaén (Spain). The meteoroid followed an asteroidal orbit before impacting the Earth’s atmosphere. At the final stage of its luminous phase this deep-penetrating meteor was located at an altitude of about 41 km. This suggests an asteroidal nature for this poorly-known meteoroid stream.

The next bolide analyzed in this report was an event which was recorded on January 15 named “Puente Carrera”. This ρ-Geminid (RGE#0094) meteor had a peak absolute magnitude of –8.5 and overflew Spain and the Gulf of Cádiz. The particle was moving on an asteroidal orbit before hitting our planet’s atmosphere. The ending altitude of this deep-penetrating bolide was of about 39 km.

The last meteor presented in this work was the “La Albuera” event, which was recorded on January 20. This sporadic meteor had a peak absolute magnitude of –10.0 and overflew the province of Badajoz (Spain). The meteoroid was moving on a cometary (JFC) orbit before impacting our planet’s atmosphere. The terminal altitude of this deep-penetrating bolide was of about 29 km.

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