



Composite image of the September Epsilon Perseid outburst on September 10, 2026, observed from Stewartville, Ontario, Canada. Camera: Canon 6D with a 14mm f/2.8 lens, ISO 3200. The composite was created from continuous 20-second exposures taken between 05h00m and 08h00m UT. Most of the meteors in the image appeared between 06h00m and 07h00m UT. © Pierre Martin

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|----------------------------------|------------------------------------|
| ■ New meteor showers | ■ Sporadic meteors |
| ■ Beta-Cepheids (BCE#701) | ■ Eccentrids of the Jupiter family |
| ■ Fornacids (FOR#1066) confirmed | ■ Sept. epsilon-Perseids outburst |
| ■ July Phoenicids (PHE#176) | ■ CARMELo reports |

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Establishing new meteor showers: Procedure and results

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A report is presented to announce the decision by the IAU Commission F1 to approve the proposed established status for 59 meteor showers selected by the F1 Working Group following an evaluation. The decision was announced by the Central Bureau for Astronomical Telegrams in CBET No. 5765 on 2026 October 20 (Kokhirova et al., 2026).

We are reporting 59 newly established meteor showers listed in the IAU Meteor Data Center (MDC)¹.

The IAU Working Group on Meteor Shower Nomenclature (WG)² started the evaluation procedure using the May 2026 version of the MDC, in which 152 showers fulfilled the essential criteria³ for becoming candidates. The MDC team selected 85 of the best candidates. For 12 showers, inconsistencies between the Lookup Tables and mean values were identified (081/SLY, 101/PIH, 136/SLE, 410/DPI, 520/MBC, 535/THC, 581/NHE, 587/FNC, 593/TOL, 651/OAV, 854/PCY, 752/AAC), and for 6 showers, other problematic solutions were found (107/DCH, 150/SOP, 199/ADC, 253/CMI, 555/OCF, 574/GMA).

The remaining 67 showers were evaluated by the WG members. During this process, another shower was suggested for evaluation (701/BCE), bringing the total number of showers considered to 68.

The evaluation was based on the expertise of the WG members, their knowledge of the weaknesses of individual candidates as reported in the scientific literature, and discussions within the WG. In the end, 59 candidates were approved by a vote of the WG members. For 9 showers (47/DLI, 149/NOP, 256/ORN, 424/SOL, 456/MPS,

M2023-U2, 558/TSM, 567/XHY, and 900/BBO), issues were identified, so the establishment process was postponed until more solutions or information become available.

The 59 showers approved by the WG members were subsequently approved by the IAU Commission F1 (Meteors, Meteorites and Interplanetary Dust)⁴ and assigned the official names proposed by their discoverers:

40/ZCY (zeta-Cygnids);
340/TPY (theta-Pyxidids);
423/SLL (Southern Librids-Lupids);
450/AED (April epsilon-Delphinids);
451/CAM (Camelopardalids);
465/AXC (August xi-Cassiopeiids);
488/NSU (November sigma-Ursae Majorids);
497/DAB (December alpha-Bootids);
505/AIC (August iota-Cetids);
514/OMC (omega-Capricornids);
515/OLE (omicron-Leonids);
516/FMV (February mu-Virginids);
517/ALO (April lambda-Ophiuchids);
543/TTB (22-Bootids);
546/FTC (43-Cassiopeiids);
556/PTA (phi-Taurids);
557/SFD (64-Draconids);

¹ <https://www.iaumeteordatacenter.org/>

² <https://www.iau.org/WG276/WG276/Home.aspx>

³ https://ceresiaumdc.ta3.sk/shower_status_criteria

⁴ <https://www.iau.org/CommissionF1/CommissionF1/Home.aspx>

563/DOU (December omega-Ursae Majorids);
 568/FCV (14-Canum Venaticids);
 570/FBH (February beta-Herculids);
 571/TSB (26-Bootids);
 575/SAU (63-Aurigids);
 578/TUM (theta-Ursae Majorids);
 580/CHA (chi-Andromedids);
 582/JBC (January beta-Craterids);
 583/TTA (12-Taurids);
 590/VCT (10-Canum Venaticids);
 591/ZBO (zeta-Bootids);
 594/RSE (Serpentids-Corona Borealis);
 595/TTT (13-Taurids);
 602/KCR (kappa-Craterids);
 610/SGM (68-Geminids);
 644/JLL (January lambda-Leonids);
 665/MUC (May upsilon-Cygnids);
 701/BCE (beta-Cepheids);
 707/BPX (beta-Pyxidids);
 715/ACL (alpha-Camelopardalids);
 722/FLE (15-Leonids);
 727/ISR (iota-Serpentids);
 758/VOL (Volantids);
 798/ACD (August Caelids);
 783/ILU (iota-Lupids);
 803/LSA (lambda-Sagittariids);

810/XCD (October Cetids);
 812/NAA (November alpha-Aurigids);
 818/OAG (October Aurigids);
 827/NPE (nu-Pegasids);
 835/JDP (June delta-Pavonids);
 842/CRN (A-Carinids);
 860/PAN (psi-Andromedids);
 877/OHD (omega-Hydrids);
 889/YOP (Y-Ophiuchids);
 893/EOP (eta-Ophiuchids);
 915/DNO (delta-Normids);
 924/SAN (62-Andromedids);
 1044/EPU (epsilon-Ursae Minorids);
 1046/PIS (29-Piscids);
 1146/DHO (delta-Horologiids);
 M-01212 (xi-Serpentids; preliminary designation
 M2023-F3).

Reference

Kokhirova G., Hajduková M., Janches D., Jopek T.J., Koseki M., Neslušan L., Rudawska R., Vaubaillon J., Vida D. and Ye Q. (2026). “New established meteor showers”. CBET 5765, 2026 October 20, D.W.E.Green, editor.

New meteor shower in Cetus (M2026-R1)

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A new meteor shower on a Halley-type comet orbit ($T_J = -0.35$) has been detected during about one day ($\lambda_\odot 115.0^\circ$ – 116.2°) in 2026, by the Global Meteor Network. In total, 49 meteors from 2019–2026 belong to the new shower from a radiant at R.A. = 36.7° and Decl. = -17.7° , with a geocentric velocity of 63.5 km/s. Maximum activity occurred at $\lambda_\odot = 115.5^\circ \pm 0.25^\circ$ (July 18). The shower is also present in GMN data of 2024 and, marginally, 2023. The new meteor shower has been listed in the IAU-MDC Working List of Meteor Showers under the preliminary name-designation: M2026-R1.

1 Introduction

A routine screening of the Global Meteor Network radiant density maps revealed an unexpected and unidentified activity source in the constellation of Cetus on 17–18 July 2026. A first analysis revealed 54 meteors of this possible meteor shower of which 37 remained for further analysis

after removal of all outliers. The shower had a geocentric radiant with coordinates R.A. = 36.6° , Decl. = -18.5° (equinox J2000.0) at its discovery. The median Sun-centered ecliptic coordinates were $\lambda_g - \lambda_\odot = 271.9^\circ$, $\beta_g = -31.1^\circ$. The geocentric velocity was 62.2 ± 0.2 km/s. The new meteor shower was reported to the IAU-MDC and registered under the temporary identification M2026-R1.

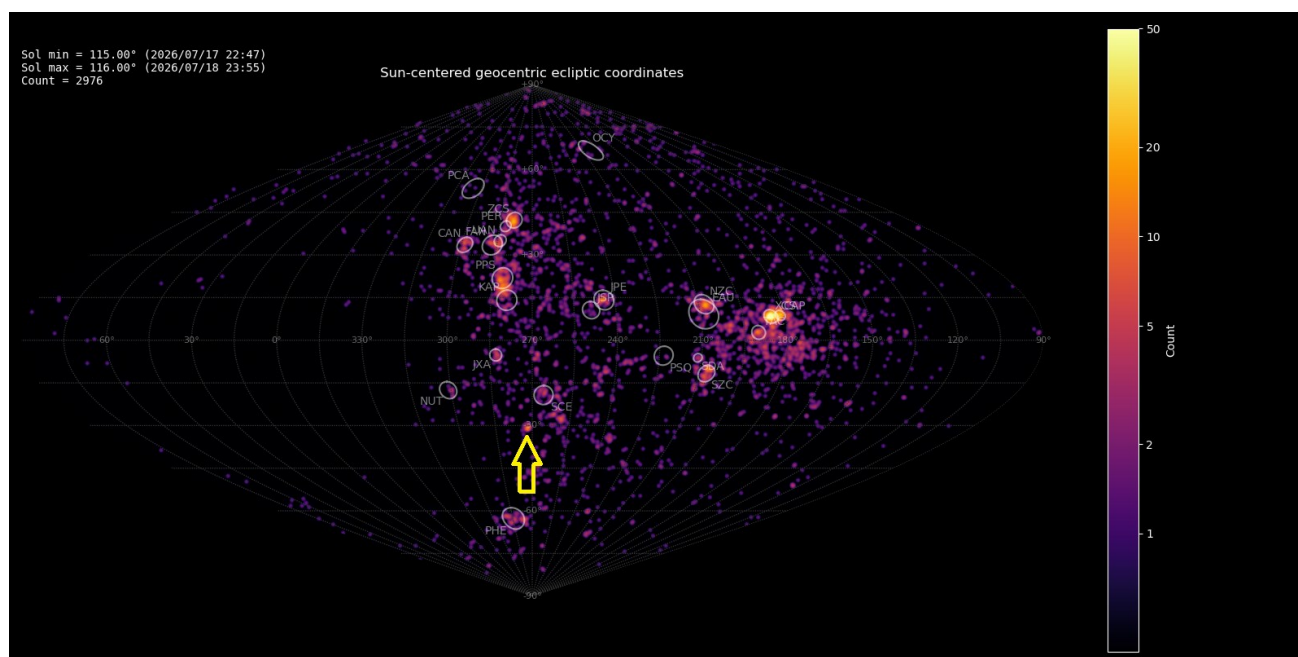


Figure 1 – Radiant density map with 2976 radiants obtained by the Global Meteor Network during the 17th–18th July, 2026. The position of the possible new shower M2026-R1 in Cetus in Sun-centered geocentric ecliptic coordinates is marked with a yellow arrow.

2 Shower classification based on radiant

The first analysis has been done using the tool RadiantMap developed by Milan Kalina. This tool makes it possible to select radiants on the radiant density map (Figure 2) within a range in solar longitude to run automatically the meteor shower association tools developed by Denis Vida and Damir Šegon. Figure 2 shows no known activity expected according to the IAU-MDC Working List of Meteor Showers (Jopek and Kaňuchová, 2017; Jenniskens et al., 2020) at the region of interest, marked by a yellow circle. The MDC solutions closest to M2026-R1 are M2025-P1 (Šegon et al., 2025; 7.2° away, $D_D = 0.247$, $D_{SH} = 0.717$), TCT#598 (8.2° , no orbit), FOR#1066 (12.6° , $D_D = 0.133$, $D_{SH} = 0.403$), SCE#1070 (12.1° , $D_D = 0.143$, $D_{SH} = 0.417$), RER#738 (14.9° , $D_D = 0.155$, $D_{SH} = 0.427$) and ERI#191 ($D_D = 0.165$, $D_{SH} = 0.449$ against Jenniskens, 2023), with D values relative to the radiant-method orbit in Table 1. The maximum-sigma test of Jopek et al. (2024) separates all of them from M2026-R1: they differ by 6° to 19° in $\lambda_g - \lambda_o$ (limit 5°), and those with orbits by 14° to 51° in ω (limit 9°).

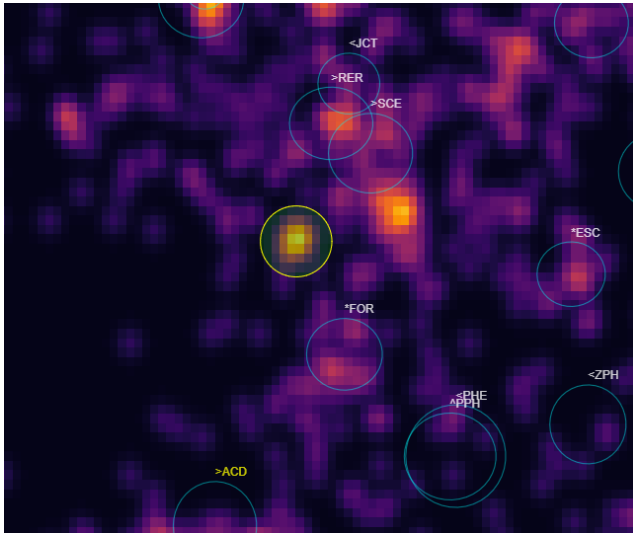


Figure 2 – Screenshot from RadiantMap with the selected region of interest for the unknown activity source in 2026 at $\lambda_o = 116^\circ$, marked in the yellow circle.

The RadiantMap tool initially selected 54 meteors within the region of interest. About 15% of the candidates are duplicate solutions of the same meteor. They were not removed, but the activity in 115.0° – 116.2° remains significant without them (Section 3). The initial radiant offset threshold is 4.35° and the v_g deviation threshold 2.5 km/s. Using these values to remove outliers, 37 meteors remained for final analysis. The final median dispersion is 1.7° giving an association radius ($\times 2.5$) of 4.2° (Vida et al., 2021, implemented in the RadiantMap tool). 98 GMN-cameras in 9 countries (Australia, Brazil, Croatia, Czech Republic, Hungary, New Zealand, Poland, Slovakia and the United States) contributed data to this dataset for the radiant

based analysis. The shower parameters as obtained by the radiant method for 2026 are listed in Table 1.

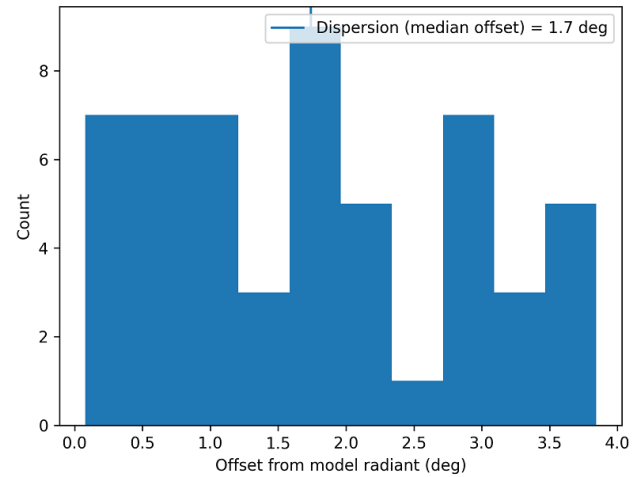


Figure 3 – Offsets of the 54 candidate radiants from the first drift fit (first pass, before outlier removal); the median offset is 1.7° .

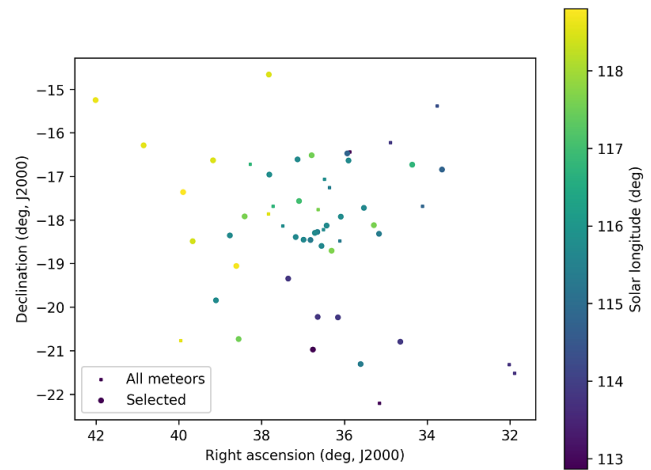


Figure 4 – The radiant distribution in 2026 during the solar longitude interval 112.8° – 118.8° in equatorial coordinates.

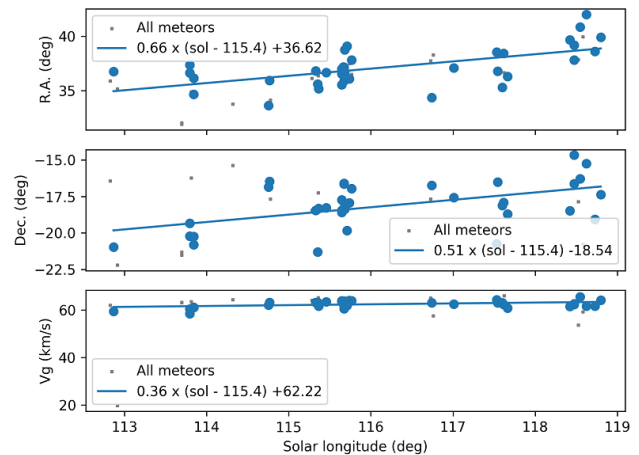


Figure 5 – The radiant drift in 2026.

Figures 4 and 6 show the relatively compact radiant of M2026-R1 whose activity occurred above the minimal level of detectability only between solar longitude 115.0° and 116.2° .

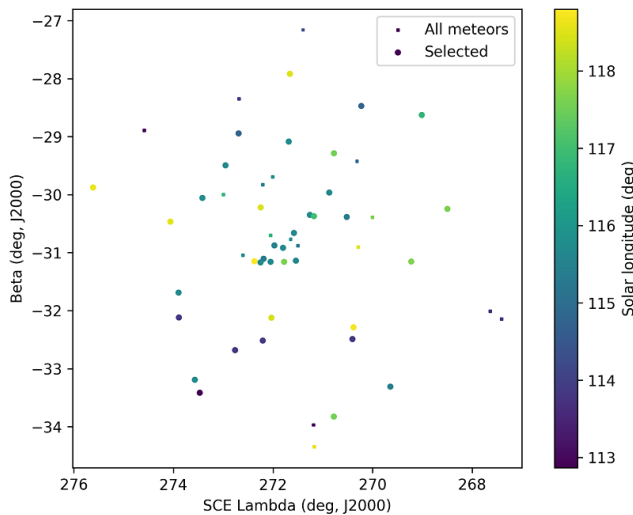


Figure 6 – The radiant distribution during the solar-longitude interval $112.8^\circ - 118.8^\circ$ in Sun-centered ecliptic coordinates.

3 Shower classification based on orbits

A completely independent meteoroid stream search has been applied to orbit data obtained between solar longitude 112° and 119° during the years 2019–2026. The method has been described in detail in a separate publication (Roggemans et al., 2026a). 70217 orbits were available within this time interval and a final mean orbit has been computed by the method of Jopek et al. (2006) for the thresholds $D_{SH} < 0.125$ and $D_D < 0.05$ and $D_J < 0.125$ (Southworth and Hawkins, 1963; Drummond, 1981; Jopek, 1993). The Rayleigh fit failed in this case. The threshold was chosen as a safe criterion to assess the similarity among these high-eccentricity retrograde orbits. The resulting mean orbit based upon 49 meteors recorded from 2019 until 2026 is listed in Table 1.

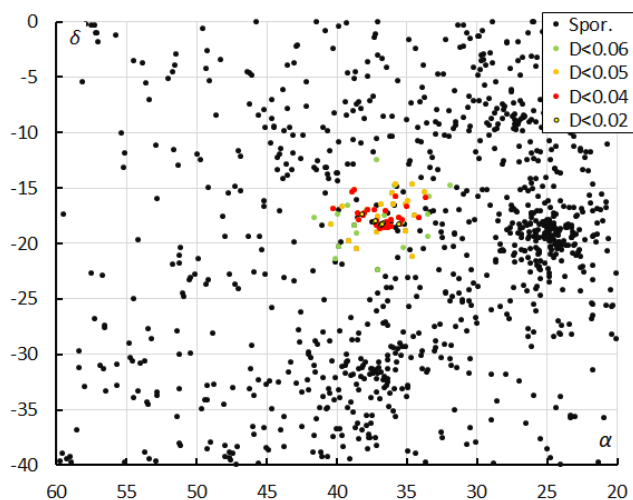


Figure 7 – The radiant distribution during the solar-longitude interval $114.5^\circ - 116.5^\circ$ in equatorial coordinates, color-coded for different threshold values of the combined similarity criteria.

Figures 7, 8, and 10 to 13 plot the combined thresholds $D_{SH} < 0.15$ and $D_D < 0.06$ and $D_J < 0.15$ (marked as $D_D < 0.06$), $D_{SH} < 0.125$ and $D_D < 0.05$ and $D_J < 0.125$ (marked as $D_D < 0.05$), $D_{SH} < 0.10$ and $D_D < 0.04$ and $D_J < 0.10$ (marked as $D_D < 0.04$) and $D_{SH} < 0.05$ and $D_D < 0.02$ and $D_J < 0.05$ (marked as $D_D < 0.02$).

A radiant concentration is visible between $\lambda_\odot$ 114.5° and 116.5° (Figure 7) but beyond this period nothing stands out of the background activity. The eta-Eridanids appear at the same declination west of the new activity. Just south of it are the Fornacids (FOR#1066). The radiant of M2026-R1 is more distinct in the geocentric Sun-centered ecliptic coordinates (Figure 8). The dark cluster right of M2026-R1 are the eta-Eridanids, which have their maximum twenty days later. The concentration south of these is the Fornacids.

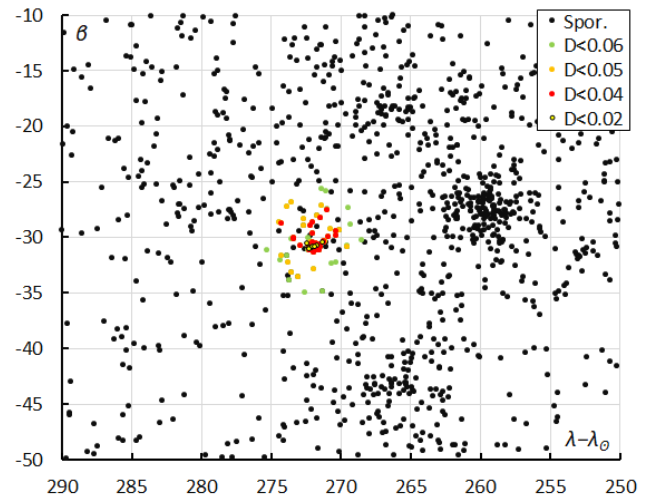


Figure 8 – The radiant distribution during the solar-longitude interval $114.5^\circ - 116.5^\circ$ in Sun-centered geocentric ecliptic coordinates, color-coded for different threshold values of the combined similarity criteria.

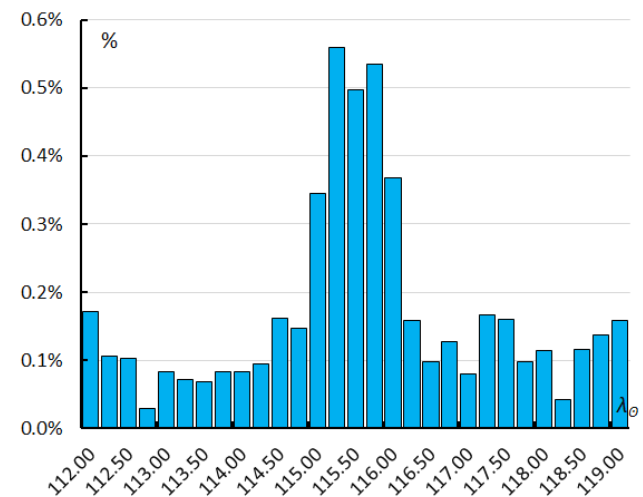


Figure 9 – The percentage of M2026-R1 meteors relative to the total number of meteors recorded in 2019–2026.

The number of shower meteors as a percentage relative to the total number of meteors recorded in a 24 hours interval results in the profile plotted in Figure 9. The highest percentages occurred at $\lambda_\odot = 115.5^\circ \pm 0.25^\circ$ although similar orbits were detected during the entire search window $\lambda_\odot = 112^\circ$ until $\lambda_\odot = 119^\circ$. The possible shower members outside the about one day ($\lambda_\odot$ $115.0^\circ - 116.2^\circ$) interval are likely sporadic meteors that fit the similarity criteria by chance. The radiant based method suffered contamination with sporadics that fit the radiant and geocentric velocity selection criteria (41 candidates against

27 expected sporadics over 112.1° – 118.8° in 2026, but 15 against 4.8 within 115.0° – 116.2°), but with a heliocentric velocity that is slightly lower than for M2026-R1 meteors. The presence of meteors with a lower heliocentric velocity results in a mean orbit with a lower eccentricity and consequent shorter semi-major axis. The activity period in *Table 1* is the search window and represents mainly sporadic contamination beyond the about one day ($\lambda_\odot$ 115.0° – 116.2°) activity.

We also counted GMN orbits within 4° of the Sun-centered radiant ($\lambda_g - \lambda_\odot = 271.9^\circ$, $\beta_g = -31.1^\circ$) with v_g within 10% of 62.2 km/s, after quality cuts and removal of duplicates, in the window 115.0° – 116.2° of each year. The expected number of sporadics was obtained from the fraction of all orbits in the same selection outside this window ($\lambda_\odot$ 105° – 126° , same year) times the number of all orbits inside it, and P is the Poisson probability of at least the observed number arising from this background alone. The shower fraction was 4.7 per mille in 2023 (5 meteors, 1.4 expected, $P = 0.013$), 7.3 in 2024 (8, 1.9 expected, $P = 0.0009$), 3.2 in 2025 (7, 4.1 expected, $P = 0.13$) and 5.5 in 2026 (15, 4.8 expected, $P = 0.0002$), with one meteor in 2019 and none in 2020–2022. With the same selection, the 2019–2026 data also show a weaker excess between solar longitude 118.5° and 121.5° : 58 meteors against 36.1 expected ($P = 5 \times 10^{-4}$). Its relation to M2026-R1 is not yet clear.

4 Orbit and parent body

The diagram of the inclination i versus the longitude of perihelion Π shows quite some dispersion in both inclination and longitude of perihelion (*Figure 10*). The dense cloud between 270° and 280° in longitude of perihelion and near 110° in inclination are the zeta-Cassiopeiids (ZCS#444).

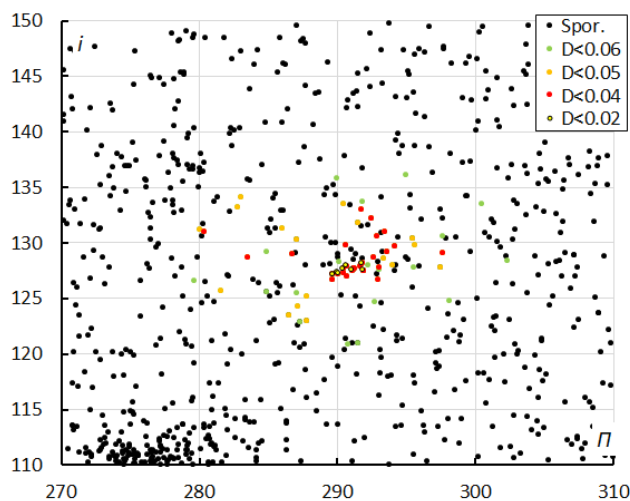


Figure 10 – Inclination i versus the longitude of perihelion Π color-coded for different classes of D-criteria thresholds, for $\lambda_\odot$ between 114.5° – 116.5° . Spor. = sporadics.

The eccentricity e versus the longitude of perihelion Π appears dispersed in e and in Π (*Figure 11*) because of the sensitivity of the eccentricity for the uncertainty on the velocity measurement for high eccentricity values. The

diagram e versus i (*Figure 12*) also shows a large dispersion. The diagram with the perihelion distance q versus i (*Figure 13*) shows a dense concentration at the upper limit for the perihelion distance. The ascending node lies at 1.013–1.014 AU and the argument of perihelion is about 355° , so the perihelion sits just inside the node and q of about 1.01 AU follows from the encounter geometry. The q concentration is expected for any stream met at this node and says little about compactness.

Table 1 – Comparing solutions derived by two different methods, RadiantMap-method based on radiant positions for 2026 as reported to the IAU MDC, and the orbit association method (2019–2026) for $D_{SH} < 0.125$ and $D_D < 0.05$ and $D_J < 0.125$ ($D_D < 0.05$). H_b , H_e , H_p are the begin-, end- and peak-brightness heights and Mag_{Ap} is the average peak absolute magnitude, normalized to 100 km. The RadiantMap 2026 selection includes orbits with $e > 1$. The D-criteria based method eliminated all $e > 1$.

	RadiantMap method 2026	Orbit method 2019–2026 $D_D < 0.05$
$\lambda_\odot$ ($^\circ$)	115.4	115.6
λ_{ob} ($^\circ$)	112.1	112.1
λ_{oe} ($^\circ$)	118.8	118.9
α_g ($^\circ$)	36.6	36.7
δ_g ($^\circ$)	−18.5	−17.7
$\Delta\alpha_g$ ($^\circ/\lambda_\odot$)	+0.66	+0.70
$\Delta\delta_g$ ($^\circ/\lambda_\odot$)	+0.51	+0.13
v_g (km/s)	62.2	63.5
H_b (km)	109.5	109.9
H_e (km)	96.1	95.8
H_p (km)	100.9	100.0
Mag_{Ap}	−1.6	−1.6
λ_g ($^\circ$)	27.27	27.5
$\lambda_g - \lambda_\odot$ ($^\circ$)	271.87	272.0
β_g ($^\circ$)	−31.11	−30.5
a (A.U.)	7.316	12.6
q (A.U.)	1.011	1.012
e	0.862	0.920
i ($^\circ$)	127.1	128.7
ω ($^\circ$)	355.2	354.5
Ω ($^\circ$)	296.2	295.7
Π ($^\circ$)	291.5	290.2
T_J	−0.01	−0.35
N	37	49

The orbit-based solution removed orbits with too low heliocentric velocities at each step of the iteration procedure until it converged on the final mean orbit listed in *Table 1*. This solution has a higher eccentricity, larger semi-major axis and slightly higher inclination because of the higher heliocentric velocity with a median $v_h = 41.0$ km/s as the iteration removed all outliers below 40.12 km/s and above 41.66 km/s so that no $e > 1$ orbits remain in the threshold class $D_{SH} < 0.125$ and $D_D < 0.05$ and $D_J < 0.125$. The

radiant based method has a median $v_h = 40.1$ km/s with outliers between 37.22 km/s and 43.22 km/s and contains considerable sporadic contamination. The semi-major axis remains poorly constrained (about 10–15 AU) because it depends on how near-parabolic and hyperbolic orbits are treated.

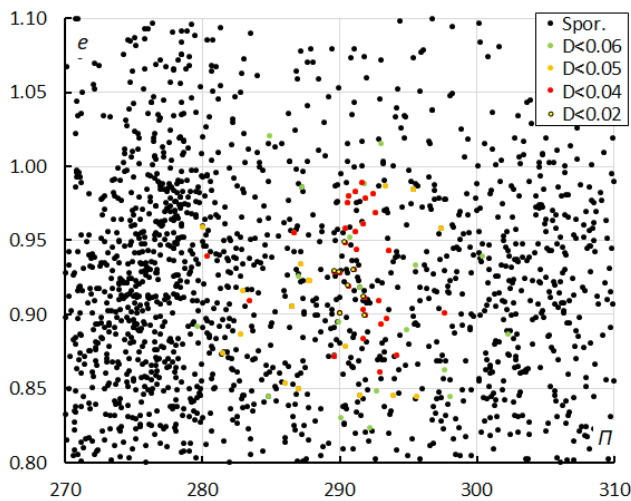


Figure 11 – Eccentricity e versus the longitude of perihelion Π color-coded for different classes of D-criteria thresholds, for $\lambda_\odot$ between 114.5° – 116.5° . Spor. = sporadics.

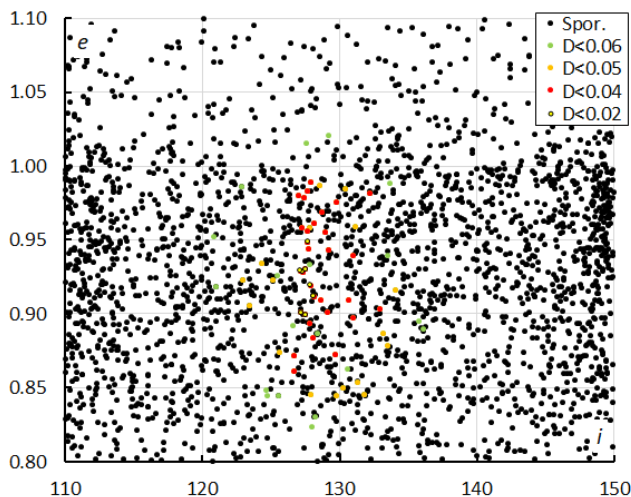


Figure 12 – Eccentricity e versus the inclination i color-coded for different classes of D-criteria thresholds, for $\lambda_\odot$ between 114.5° – 116.5° . Spor. = sporadics.

With a Tisserand value relative to Jupiter of -0.35 , this is a Halley-type comet orbit (Tancredi, 2014; $T_J = -0.01$ and $P = 19.8$ years for the radiant method, $T_J = -0.35$ and $P = 44.7$ years for the orbit method). The descending node lies at 13.3 A.U. for the radiant method (between the orbits of Saturn and Uranus) and at 23.1 A.U. for the orbit method (between the orbits of Uranus and Neptune) (Figure 14). With a high eccentricity, the slightest observational or instrumental uncertainty on the velocity results in a huge difference in aphelion. The radiant method identification includes some meteors with smaller heliocentric velocities that result in a mean orbit with a lower eccentricity. The orbit based mean orbit (blue in Figure 14) is probably the best representative orbit for this shower. The meteoroid

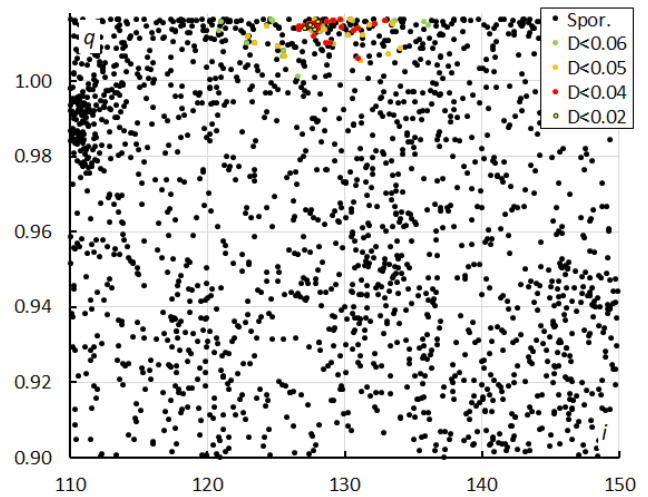


Figure 13 – Perihelion distance q versus the inclination i color-coded for different classes of D-criteria thresholds, for $\lambda_\odot$ between 114.5° – 116.5° . Spor. = sporadics. The q axis ends at 1.018 AU.

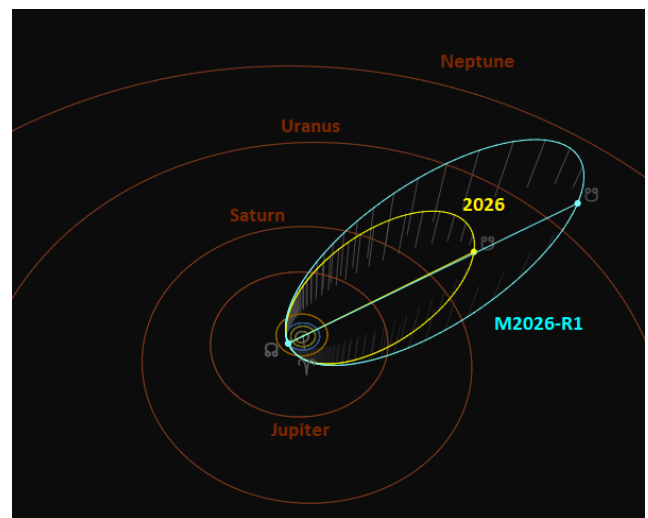


Figure 14 – The radiant determined solution for 2026 (yellow) and the orbit determined solution for 2019–2026 (blue). (Plotted with the Orbit visualization app provided by Pető Zsolt).

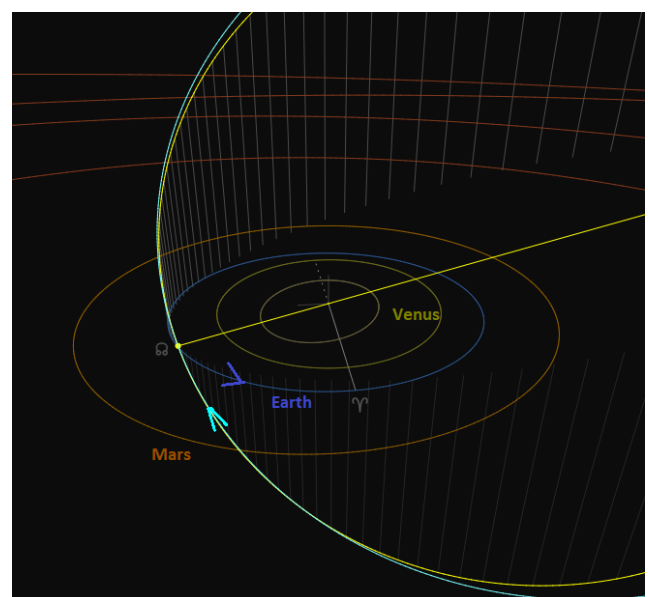


Figure 15 – Close-up in the inner Solar system with the radiant determined solution for 2026 (yellow) and the orbit determined solution for 2019–2026 (blue). (Plotted with the Orbit visualization app provided by Pető Zsolt).

stream M2026-R1 with its retrograde orbit encounters the Earth orbit at its ascending node close to its perihelion (Figure 15).

A search for a possible parent body based upon the mean orbit of the radiant method did not result in any positive match, the ten best results are listed in Table 2. The D_{SH} values are between 0.41 and 0.80 for the top ten and none of the candidates passes within 0.05 AU of the Earth's orbit near $\Omega = 296^\circ$.

Table 2 – Top ten matches of a search for possible parent bodies with $D_D < 0.30$, based upon the mean orbit derived from the orbit method (Table 1, 2019–2026). JPL ELEMENTS.COMET⁵ (2026-10-26).

Name	D_D
C/2013 UQ4 (Catalina)	0.160
C/1874 G1 (Winnecke)	0.162
C/2013 A1 (Siding Spring)	0.171
C/1500 H1	0.187
273P/Pons-Gambart	0.188
C/1110 K1	0.200
C/1852 K1 (Chacornac)	0.210
C/2018 N1 (NEOWISE)	0.218
C/1947 S1 (Bester)	0.221
C/2020 R4 (ATLAS)	0.256

5 Conclusions

The radiant density maps show a distinct concentration of the M2026-R1 radiant on July 18 in 2026. M2026-R1 was also detected in 2024 and marginally in 2023 at about the 2026 level, so it may be a weak annual shower. Similar orbits were detected with the orbit-based method during about a week and in previous years. Although a distinct concentration is visible in radiant positions, the diagrams with the orbital elements i versus II , e versus II , e versus i show a relatively large spread which comes mainly from v_g errors near the parabolic limit, while the core radiant is compact (median offset 0.66° for the 15 members with solar longitude $115.0^\circ - 116.2^\circ$) and the main activity lasts about one day ($\lambda_\odot 115.0^\circ - 116.2^\circ$) each year. Only the perihelion distance q appears as a concentration. M2026-R1 is a barely detectable footprint of a dust remnant of an unknown Halley-type comet. Future observations may reveal whether this activity becomes stronger or drops back below the threshold of detectability. The revised solution (annual activity) will be submitted to the MDC as an additional solution of M2026-R1.

Acknowledgments

This report is based on the data of the Global Meteor Network (Vida et al., 2020a; 2020b; 2021) which is released under the CC BY 4.0 license⁶. We thank all 927 participants in the Global Meteor Network project for their contribution

and perseverance. A list with the names of the volunteers who contribute to GMN has been published in the 2025 annual report (Roggemans et al., 2026b). The following 160 cameras contributed to paired meteors by either of the two methods used in this study:

AU0003, AU000D, AU000F, AU000U, AU000V, AU000W, AU000Z, AU001A, AU001B, AU001Q, AU001U, AU002B, AU0038, AU0039, AU004L, AU004Q, BR000F, BR000J, BR000Q, BR000S, BR0013, BR001H, BR001W, BR002C, CZ000Q, CZ000R, ES0019, ES001H, HR0002, HR000S, HR001Z, HR0027, HR002J, HR002X, HU0001, HU0003, HU0009, HU000B, HU000F, KR0016, KR001P, KR001Z, KR002C, MX0001, MX0003, NZ0001, NZ0003, NZ0004, NZ0007, NZ000M, NZ000N, NZ000Q, NZ000W, NZ000Z, NZ0012, NZ0014, NZ0017, NZ0018, NZ001H, NZ001Q, NZ001R, NZ001S, NZ001V, NZ001Z, NZ0020, NZ0022, NZ0023, NZ0025, NZ0026, NZ0027, NZ002A, NZ002C, NZ002D, NZ002E, NZ002H, NZ002J, NZ002K, NZ002L, NZ002N, NZ002P, NZ002R, NZ002S, NZ002U, NZ002W, NZ002X, NZ002Y, NZ0030, NZ0033, NZ0034, NZ0035, NZ0036, NZ0037, NZ0038, NZ003A, NZ003B, NZ003C, NZ003E, NZ003G, NZ003H, NZ003N, NZ003Q, NZ003R, NZ003S, NZ003U, NZ003X, NZ003Y, NZ0040, NZ0042, NZ0044, NZ0045, NZ004A, NZ004D, NZ004H, NZ004L, NZ004N, NZ004S, NZ004T, NZ004V, NZ004X, NZ004Y, NZ0051, NZ0059, NZ005B, NZ005C, NZ005D, NZ005G, NZ005H, NZ005J, NZ005K, NZ005L, NZ005Q, NZ005S, NZ005T, NZ005U, NZ005Y, NZ005Z, NZ0061, NZ0065, NZ0068, NZ006F, NZ006J, NZ006K, NZ006M, NZ006N, NZ006P, NZ006V, NZ0073, NZ007C, NZ007E, PL0008, SK0006, US0004, US0007, US0008, US0009, US003T, US0066, USL006, USL00C and USL00M.

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⁵ <https://ssd.jpl.nasa.gov/dat/ELEMENTS.COMET>

⁶ <https://creativecommons.org/licenses/by/4.0/>

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New meteor shower in Camelopardalis (M2026-S1)

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A new meteor shower on a retrograde Halley-type comet orbit ($T_J = 0.31$) was detected in 2026 by the Global Meteor Network, with activity above the sporadic background between solar longitude 164° and 168° . The radiant-method solution, based on 109 meteors selected between solar longitude 161.5° and 168.5° , gives a radiant at R.A. = 93.3° and Decl. = $+69.3^\circ$ ($\lambda_\odot = 165.0^\circ$) in the constellation of Camelopardalis, with a geocentric velocity of 54.3 km/s. The new meteor shower has been listed in the IAU-MDC Working List of Meteor Showers under the temporary name-designation: M2026-S1.

1 Introduction

The Perseids are beyond doubt the best observed and studied meteor shower but still its precise activity period remains a topic of debate. The activity period for the solutions listed by the IAU-MDC (Jopek and Kaňuchová, 2017; Jenniskens et al., 2020)⁷ varies a lot among different

researchers. The longest activity period covers almost two months, from solar longitude 115° until 175° (Jenniskens, 2023). The GMN shower reference considers Perseid activity until $\lambda_\odot = 150^\circ$. A radiant concentration appears on the radiant density map close to the theoretically expected Perseid radiant at $\lambda_\odot = 166.0^\circ$, but the orbits are different from those of the Perseids.

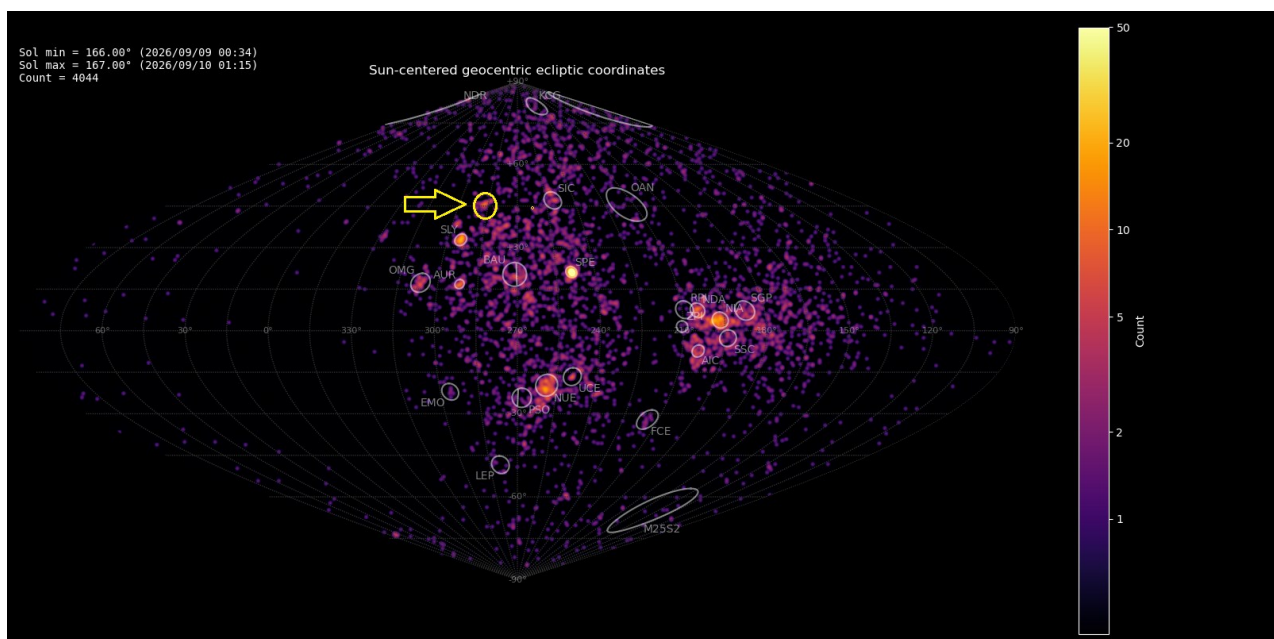


Figure 1 – Radiant density map in sinusoidal projection with 4044 radiants obtained by the Global Meteor Network between solar longitudes 166° and 167° in 2026. A concentration is visible in Sun-centered geocentric ecliptic coordinates which was identified as a new meteor shower with the temporary identification M2026-S1, marked in yellow on the map.

⁷ https://www.ta3.sk/IAUC22DB/MDC2022/Roje/pojedynczy_obiekt.php?porz=00066&kodstrumienia=00007

Using the RadiantMap tool (Kalina, unpublished) in Mercator projection with the expected shower radiants according to the IAU-MDC Working List of Meteor Showers in *Figure 2*, the unexpected activity becomes better visible than in *Figure 1*.

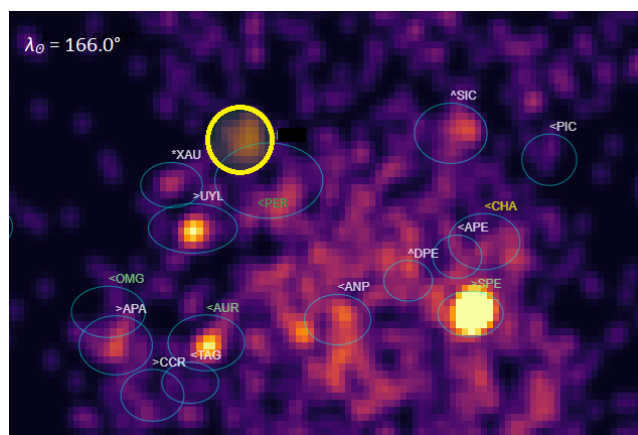


Figure 2 – Screenshot from the RadiantMap with the selected region of interest at $\lambda_O = 166^\circ$ for the unknown activity source in 2026 marked in the yellow circle. The circles are the expected radiants of the IAU-MDC Working List. Just left of the yellow circle is the xi-Aurigid radiant (XAU#205). The expected Perseid radiant is just below the new activity.

2 Shower classification based on radiants

The RadiantMap tool found 164 meteors. The sample includes a few duplicate solutions which were not removed in the analysis. The radiant offset threshold is 6.5° and the v_g deviation threshold 2.0 km/s. Using these values to remove outliers, 109 meteors remained for final analysis. The final median dispersion is 2.1° giving an association radius ($\times 2.5$) of 5.2° . This selection includes a considerable sporadic background: in 2026 about 60% of the meteors within 6.5° of the Sun-centered radiant in 161.5° – 168.5° are expected from the sporadic level in the flanks. The 55 meteors within 2.5° of the radiant in 164° – 168° (about 28% background) give practically the same radiant, R.A. = 92.0° , Decl. = $+69.5^\circ$ and $v_g = 54.9$ km/s at $\lambda_O = 165.0^\circ$, with a median dispersion of 1.24° .

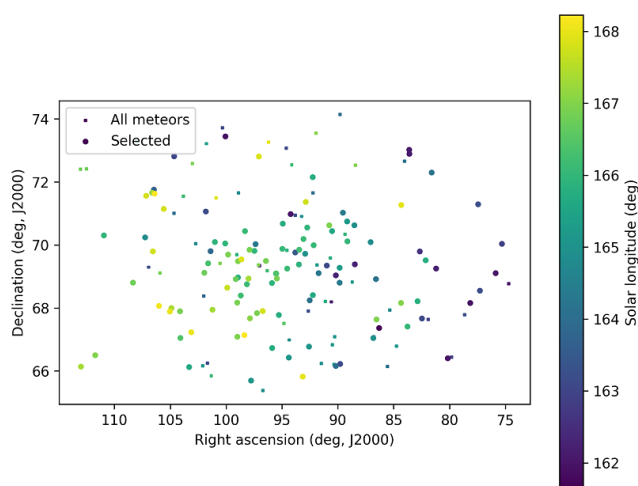


Figure 3 – The radiant distribution during the solar-longitude interval 161.5° – 168.5° in equatorial coordinates.

The closest shower in the IAU-MDC Working List is the xi-Aurigids (XAU#205). The solution by Jenniskens (2023), $\lambda_O = 165.9^\circ$, R.A. = 111.6° , Decl. = $+61.4^\circ$, $v_g = 55.8$ km/s, lies 10.9° from the M2026-S1 radiant with $\Delta v_g = +1.5$ km/s, and its orbit gives $D_D = 0.175$ and $D_{SH} = 0.48$ relative to the radiant-method orbit. The maximum-sigma test of Jopek et al. (2024) rejects a duplicate: $\Delta(\lambda - \lambda_O) = 10.8^\circ$ (limit 5°), $\Delta\beta = 6.9^\circ$ (limit 3°) and $\Delta\omega = 27.5^\circ$ (limit 9°) exceed the limits, while $\Delta v_g = 1.5$ km/s, $\Delta\Omega = 0.5^\circ$ and $\Delta i = 4.8^\circ$ are within them.

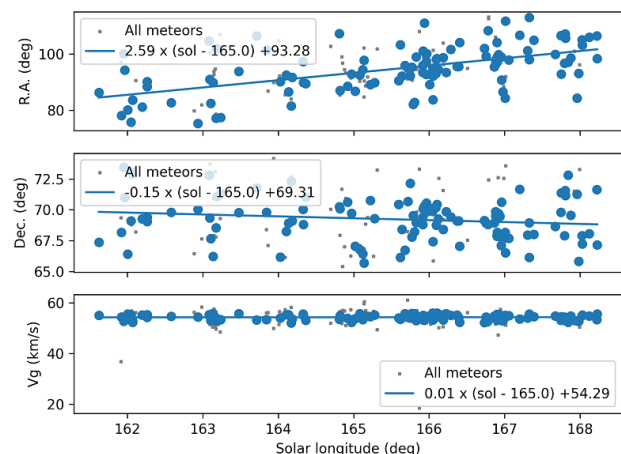


Figure 4 – The radiant drift.

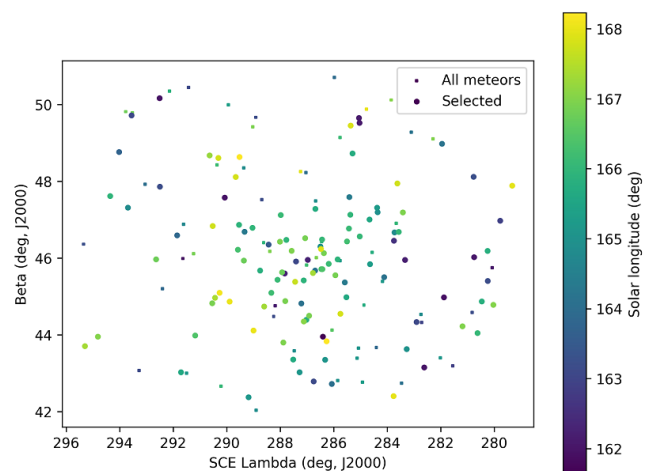


Figure 5 – The radiant distribution during the solar-longitude interval 161.5° – 168.5° in Sun-centered geocentric ecliptic coordinates.

The radiant plot in equatorial coordinates is shown in *Figure 3* and the radiant drift in *Figure 4*. The radiant distribution in Sun-centered ecliptic coordinates is plotted in *Figure 5*. The shower parameters as obtained by the GMN radiant-based method are listed in *Table 1*.

3 Shower classification based on orbits

A completely independent meteoroid stream search has been applied to orbit data obtained between solar longitude 161° and 171° during 2019–2026. The method has been described in detail in a separate publication (Roggemans et al., 2026a). 124694 orbits were available within this time interval and a final mean orbit has been computed by the method of Jopek et al. (2006) for the thresholds $D_{SH} < 0.125$ and $D_D < 0.05$ and $D_J < 0.125$ (Southworth and Hawkins,

1963; Drummond, 1981; Jopek, 1993). *Figure 6* shows the D_D distribution of the 2026 RadiantMap candidates. Duplicate solutions of the same meteor were not removed; they make up about 2% of the orbits near this radiant (5 of 219 in 2019–2026). The resulting mean orbit based upon 198 meteors for 2019–2026 is listed in *Table 1*. *Figures 7, 8, 10 and 12* plot the combined thresholds $D_{SH} < 0.15$ and $D_D < 0.06$ and $D_J < 0.15$ (marked as $D_D < 0.06$), $D_{SH} < 0.125$ and $D_D < 0.05$ and $D_J < 0.125$ (marked as $D_D < 0.05$), $D_{SH} < 0.10$ and $D_D < 0.04$ and $D_J < 0.10$ (marked as $D_D < 0.04$) and $D_{SH} < 0.05$ and $D_D < 0.02$ and $D_J < 0.05$ (marked as $D_D < 0.02$).

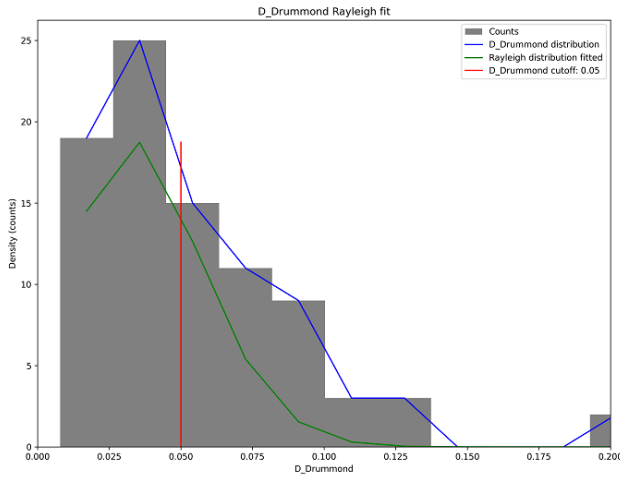


Figure 6 – D_D distribution of the 2026 RadiantMap candidates with a Rayleigh curve; $D_D < 0.05$ was adopted.

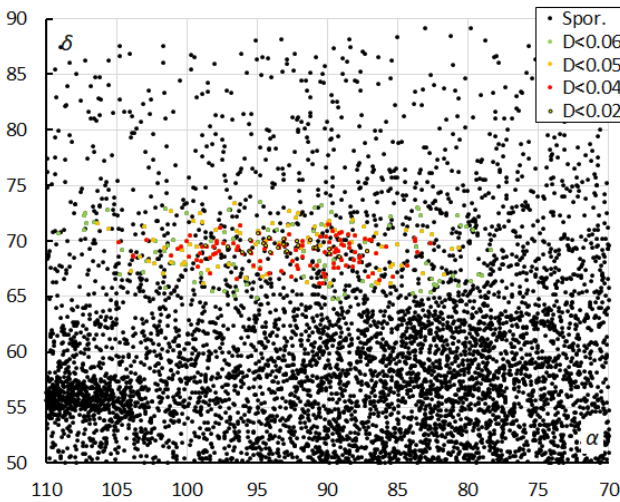


Figure 7 – The radiant distribution during the solar-longitude interval 161° – 171° (2019–2026) in equatorial coordinates, color-coded for different threshold values of the combined similarity criteria.

The radiant in geocentric equatorial coordinates (*Figure 7*) appears stretched in Right Ascension because of the high declination and map projection. The diffuse concentration just below and to the right of the M2026-S1 meteors is due to late Perseids. The dense concentration near declination +55° and Right Ascension 105°–110° are meteors identified as September Lyncids (SLY#81) by GMN. In *Figure 2* this activity has been labelled as UY-Lyncids (UYL#705). This looks like a duplication or mix-up in the Working List of Meteor Showers. The SLY#81 solution of Shiba (2023) and

UYL#705 of Jenniskens (2023) pass all six maximum-sigma limits of Jopek et al. (2024) ($\Delta(\lambda-\lambda_\odot) = 0.17^\circ$, $\Delta\beta = 0.25^\circ$, $\Delta v_g = 0.50$ km/s, $\Delta\omega = 0.40^\circ$, $\Delta\Omega = 0.20^\circ$, $\Delta i = 0.60^\circ$), so they are duplicate candidates. The SLY#81 solution of Molau and Rendtel (2009) at $\lambda_\odot = 167^\circ$ belongs to the same group. The SLY solutions at $\lambda_\odot = 186^\circ$ (Decl. +48°, v_g 65–67 km/s) are a different source. In the geocentric Sun-centered ecliptic coordinates (*Figure 8*) the radiants appear more compact.

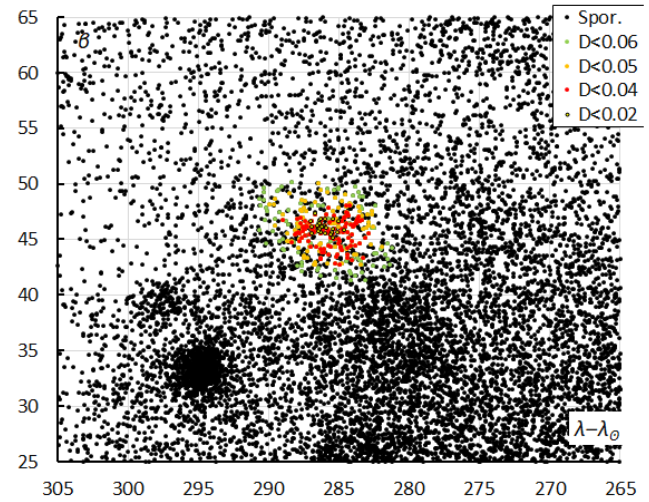


Figure 8 – The radiant distribution during the solar-longitude interval 161° – 171° (2019–2026) in Sun-centered geocentric ecliptic coordinates, color-coded for different threshold values of the combined similarity criteria.

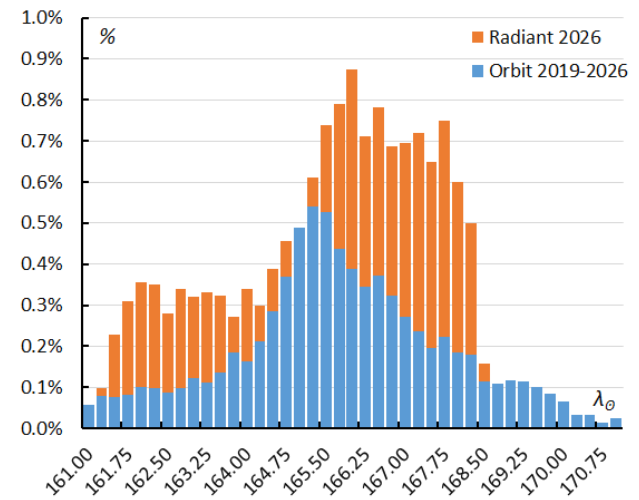


Figure 9 – The percentage of shower meteors relative to the total number of meteors with the beginning point at northern latitudes, with a bin-width of 1° in steps of 0.25° in solar longitude. The orange bars display the 2026 radiant-method selection and blue the 2019–2026 orbit-method selection.

The number of shower meteors as a percentage relative to the total number of meteors recorded with the beginning point at northern latitude results in the profile plotted in *Figure 9*. The highest percentage occurred at $\lambda_\odot = 165.5 \pm 0.5^\circ$. Outside the peak, orbits similar to the shower orbit occur over the whole search window at about the sporadic level. To find the activity limits, the 2026 profile was recomputed over the wider window $\lambda_\odot = 155^\circ$ – 185° in 0.5° bins, for meteors within 2.5° of the Sun-centered radiant ($\lambda-\lambda_\odot = 286.7^\circ$, $\beta = +46.0^\circ$) with v_g

48.9–59.7 km/s, after quality cuts and removal of duplicate solutions, relative to all orbits with the same quality cuts and a beginning point at northern latitudes. The background, 0.12%, is the pooled percentage in the outer quarters of the window (155°–162.5° and 177.5°–185°). Four bins between 164.0° and 167.0° are more than 3σ above this background, with marginal excesses at 164.5°–165.0° and 167.5°–168.0°, and the peak is in the 165.5°–166.0° bin ($1.06 \pm 0.28\%$). The pooled 2019–2026 data give the same limits and peak bin. The activity therefore covers about 4 days (164°–168°); the plateau of about 0.3% in the radiant-method profile at 161.5°–164.5° is at the sporadic level of the wider RadiantMap selection. Relative to all northern orbits in 161°–171°, the yearly orbit-method counts correspond to 2.2, 1.2, 1.7, 2.4, 2.1, 2.0, 1.6 and 2.5 per mille for 2019 to 2026, so the shower was about as strong in earlier years, although it was only noticed in 2026. The number of M2026-S1 meteors identified by the D-criteria based method per year was 2019: 4, 2020: 5, 2021: 17, 2022: 16, 2023: 34, 2024: 33, 2025: 23 and 2026: 66. In 2026, 55 meteors lie within 2.5° of the radiant in 164°–168° against 15.4 expected from the 161°–164° and 168°–171° flanks (Poisson $P = 5 \times 10^{-15}$).

4 Orbit and parent body

Radiant method in *Table 1*: λ_0 is the reference solar longitude of the radiant and drift, as reported to the IAU MDC; the highest percentage is at 165.5°. λ_{0b} and λ_{0e} are the limits of the detection windows; activity above the sporadic background is 164°–168° (see *Section 3*).

The diagram of the inclination i versus the longitude of perihelion Π shows a diffuse distribution (*Figure 10*). This is mainly due to a considerable scatter in longitude of perihelion and its drift during the shower activity. The longitude of perihelion shows a drift of 0.79° per degree in λ_0 (*Figure 11*). The scatter on the longitude of perihelion is much larger than the uncertainties on the measured values, the one-sigma errors have been plotted in *Figure 11*. The M2026-S1 orbits have similar perihelion distances as the Perseids but appear at a distinctly lower inclination (*Figure 12*). Late Perseids lie to the right of the new shower at inclinations of 110° to 115°.

The Tisserand value relative to Jupiter indicates this is a Halley-type comet orbit (Tancredi, 2014; $T_J = 0.31$ and $P = 33$ years for the radiant method, $T_J = 0.11$ and $P = 63$ years for the orbit method), with an inclination $\sim 100^\circ$ on a retrograde orbit steeply inclined to the ecliptic plane. The shower encounters the Earth at its descending node while the ascending node is close to Saturn's orbit (8.1 AU for the radiant method and 10.4 AU for the orbit method; *Figure 13*). The uncertainty on the semi-major axis explains the difference in the position of the ascending node, inside the orbit of Saturn for the radiant method and outside for the D-criteria based method.

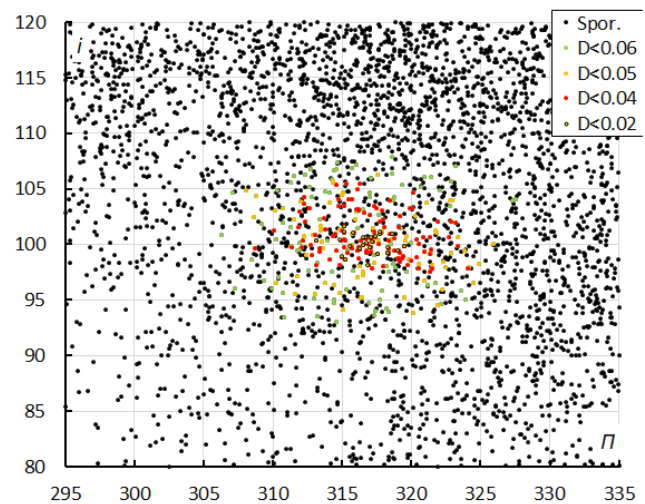


Figure 10 – Inclination i versus the longitude of perihelion Π color-coded for different classes of D-criteria thresholds, for λ_0 between 161° – 171° (2019–2026). Spor. = sporadics.

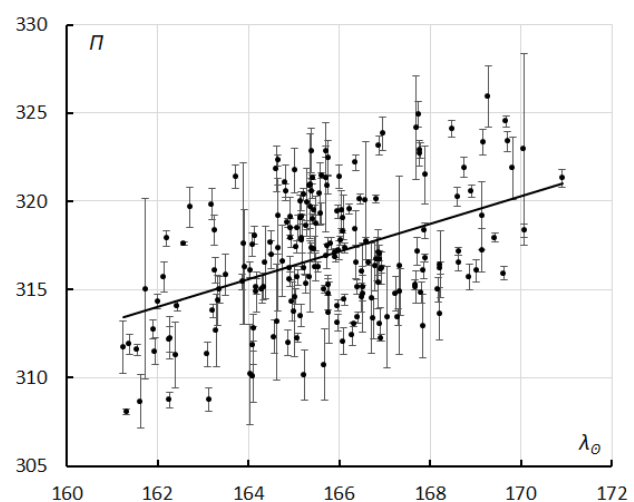


Figure 11 – The variation in longitude of perihelion Π as a function of solar longitude.

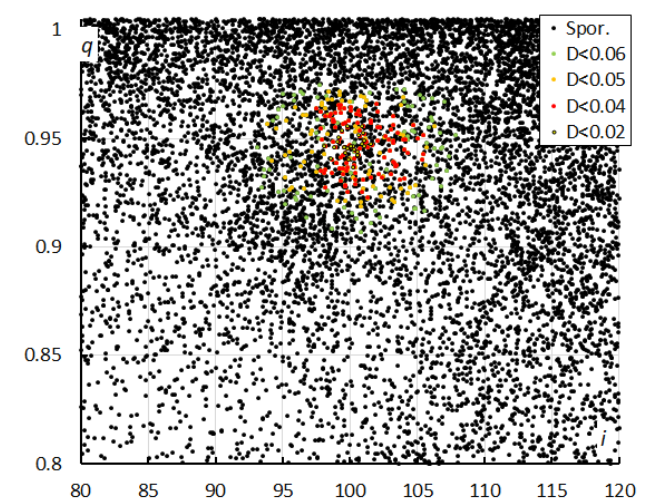


Figure 12 – Perihelion distance q versus the inclination i color-coded for different classes of D-criteria thresholds, for λ_0 between 161° – 171° (2019–2026). Spor. = sporadics.

Table 1 – Comparing solutions derived by two different methods, GMN-RadiantMap tool and the D-criteria based orbit association for $D_{SH} < 0.125$ and $D_D < 0.05$ and $D_J < 0.125$ ($D_D < 0.05$). H_b, H_e, H_p are the begin-, end- and peak-brightness heights and Mag_{Ap} is the average peak absolute magnitude, normalized to 100 km.

	Radiant method 2026	Orbit method 2019–2026 $D_D < 0.05$
λ_O (°)	165.0	165.6
λ_{Ob} (°)	161.5	161.2
λ_{Oe} (°)	168.5	171.0
α_g (°)	93.3	92.3
δ_g (°)	+69.3	+69.4
$\Delta\alpha_g$ (°/ λ_O)	+2.59	+2.29
$\Delta\delta_g$ (°/ λ_O)	−0.15	+0.07
v_g (km/s)	54.3	54.9
H_b (km)	107.3	108.7
H_e (km)	94.8	95.7
H_p (km)	99.5	100.8
Mag_{Ap}	−0.8	−1.0
λ_g (°)	91.66	91.2
$\lambda_g - \lambda_O$ (°)	286.66	285.8
β_g (°)	+46.02	+45.9
a (A.U.)	10.387	15.8
q (A.U.)	0.936	0.945
e	0.910	0.940
i (°)	99.4	100.4
ω (°)	148.9	151.2
Ω (°)	165.4	165.7
Π (°)	314.4	317.0
T_j	0.31	0.11
N	109	198

A search for parent bodies (*Table 2*) did not result in a positive match. The shower has a perihelion distance and argument of perihelion similar to those of the Perseids ($q = 0.94$ vs 0.95 AU, $\omega = 149^\circ$ vs 150°), but differs in inclination (99° vs 113°) and node (165° vs 140°). Against the Perseid orbit of Jenniskens (2023), $D_D = 0.18$ and $D_{SH} = 0.50$. The parent body of the Perseids, 109P/Swift-Tuttle, appears among the best matching candidate objects but with too poor similarity. 109P has $D_D = 0.19$ but $D_{SH} = 0.53$, and its descending node is at 1.01 AU but at longitude 319° , 26° from where the Earth meets M2026-S1 (345.4° , $r = 1.005$ AU). No candidate in *Table 2* passes near 1 AU at that longitude (C/2002 Y1: 0.88 AU at 346° ; C/1994 N1: 1.48 AU; C/1929 Y1: 0.70 AU), which supports the negative result. Stream modelling may prove if there is any possible physical relationship between this source and 109P/Swift-Tuttle.

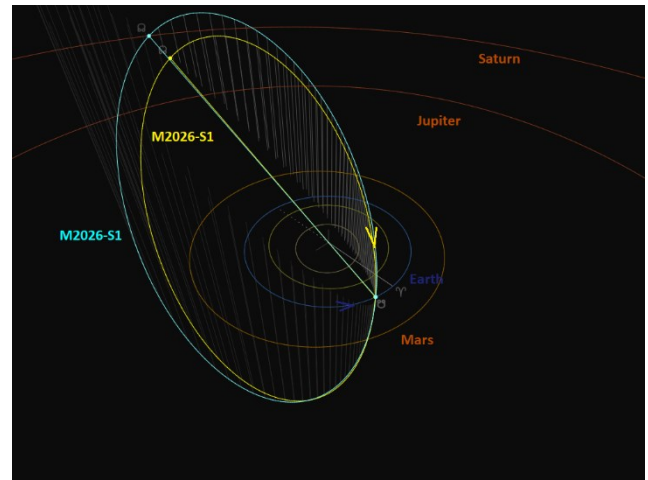


Figure 13 – Comparing the radiant determined shower solution for M2026-S1 (yellow) with the orbit determined solution for M2026-S1 (blue). (Plotted with the Orbit visualization app provided by Pető Zsolt).

Table 2 – Top ten matches of a search for possible parent bodies according to the Drummond criteria, based upon the mean orbit derived from the RadiantMap classification method on 2026 data. Reproduced with JPL ELEMENTS.COMET of 2026-09-28.

Name	q (AU)	e	i (°)	ω (°)	Ω (°)	D_D	D_{SH}
C/2002 Y1 (Juels-Holvorcem)	0.714	0.997	103.78	128.82	166.22	0.18	0.42
C/1994 N1 (Nakamura-Nishimura-Machholz)	1.140	1.000	94.38	123.07	158.91	0.18	0.49
109P/Swift-Tuttle	0.960	0.963	113.45	152.98	139.38	0.19	0.53
C/1840 E1 (Galle)	0.749	1.000	79.85	138.04	188.27	0.22	0.59
C/2002 Q2 (LINEAR)	1.303	0.978	96.77	125.47	154.29	0.22	0.55
C/2002 Q3-A (LINEAR)	1.305	0.994	96.86	125.70	154.19	0.22	0.56
C/2002 Q3 (LINEAR)	1.306	0.998	96.90	125.70	154.15	0.22	0.56
C/2025 T1 (ATLAS)	1.109	1.000	123.43	114.14	140.50	0.25	0.74
C/1939 V1 (Friend)	0.945	0.997	92.95	126.78	197.11	0.25	0.70
C/1929 Y1 (Wilk)	0.672	0.999	124.51	157.49	179.97	0.26	0.57

5 Conclusion

This GMN meteoroid orbit data case study documents a new activity source with a radiant in Camelopardalis and a Halley-type comet orbit. The best activity occurred around $\lambda_{\odot} = 165.5 \pm 0.5^{\circ}$. The shower caught attention in 2026 but shower members were found each year since 2020, clearly from 2022 onward. The new shower has been reported to the IAU-MDC and received the preliminary designation M2026-S1.

Acknowledgments

This report is based on the data of the Global Meteor Network (Vida et al., 2020a; 2020b; 2021) which is released under the CC BY 4.0 license⁸. We thank all 927 participants in the Global Meteor Network project for their contribution and perseverance. A list with the names of the volunteers who contribute to GMN has been published in the 2025 annual report (Roggemans et al., 2026b). The following 554 cameras contributed to paired meteors used in this study:

AT0002, BA0003, BE0001, BE0003, BE0004, BE0005, BE0006, BE0008, BE0009, BE000A, BE000B, BE000C, BE000G, BE000H, BE000J, BE000K, BE000L, BE000M, BE000N, BE000P, BE000Q, BE000S, BE000T, BE000U, BE000V, BE000W, BE000X, BE0011, BE0012, BE0014, BE0015, BE0017, BE001A, BE001B, BG0003, BG0005, BG000B, BG000D, CA0009, CA000B, CA000E, CA000F, CA000L, CA000R, CA000Y, CA0011, CA001A, CA001D, CA0021, CA0022, CA0026, CA0027, CA002F, CA002J, CA002Q, CA002R, CA002U, CA002V, CA0031, CA0032, CA0035, CA0036, CA0037, CA003E, CAC0B1, CAC0B4, CAWE08, CAWEC2, CAWEC3, CZ0001, CZ0002, CZ0003, CZ0004, CZ0007, CZ0009, CZ000A, CZ000D, CZ000F, CZ000H, CZ000J, CZ000L, CZ000N, CZ000P, CZ000Q, CZ000R, CZ000U, CZ000X, CZ000Z, CZ0012, DE0004, DE0005, DE0006, DE0007, DE0008, DE0009, DE000B, DE000C, DE000G, DE000P, DE000R, DE000V, DE000W, DE000X, DE000Y, DE0011, DE0014, DE001D, DK0002, DK0003, DK0004, DK000B, DK000D, DK000J, DK000R, ES0002, ES0003, ES0004, ES0005, ES000D, ES000E, ES000H, ES000K, ES000L, ES000T, ES000V, ES000Z, ES0013, ES0016, ES001D, ES001J, ES001M, FR0003, FR0006, FR000A, FR000F, FR000G, FR000H, FR000P, FR000R, FR000X, FR000Y, FR000Z, FR0012, FR0013, FR0016, FR0019, HR0001, HR0002, HR0004, HR000D, HR000K, HR000M, HR000N, HR000P, HR000S, HR000V, HR0017, HR0018, HR001E, HR001H, HR001Q, HR001U, HR001Z, HR0024, HR0025, HR0027, HR002D, HR002J, HR002L, HR002V, HR002W, HR002X, HR002Z, HU0001, HU0002, HU0003, HU0004, HU0005, HU0006, HU0007, HU0008, HU000A, HU000B, HU000C, HU000D, HU000E, HU000F, IE0004, IE000N, IT0001, IT0004, IT000B, KR0004, KR0005, KR0009, KR000A, KR000B, KR000D, KR000E, KR000G, KR000H, KR000J, KR000K, KR000N, KR000P, KR000Q, KR000S, KR0011, KR0012, KR0014, KR0018, KR001H,

KR001N, KR001U, KR001Y, KR001Z, KR0020, KR0021, KR0022, KR0024, KR0025, KR0026, KR0027, KR0028, KR002A, KR002B, KR002C, KR002D, KR002E, KR002G, KR002H, KR002J, KR002K, KR002L, KR002P, KR002Q, KR002R, KR002T, KR002U, KR002V, KR002W, KR0036, KR0038, KR003A, KR003G, KR003J, KR003M, KR003N, KR003P, KR003R, KR003T, KR003W, LU0001, MD0002, MX0001, MX0003, NL0003, NL0009, NL000B, NL000C, NL000D, NL000G, NL000H, NL000L, NL000M, NL000N, NL000P, NL000Q, NL000T, NL000Z, NL001E, PL0005, PL0008, PL000A, PL000B, PL000C, PL000D, PL000L, PL000M, PLM008, PLM00B, RO0001, RO0002, RO0003, RO0004, RO0005, RO0006, RO0007, RO000A, RO000B, RO000E, RO000G, RO000H, RO000N, RO000R, RO000U, RO000V, RO000W, RO000Y, RO0011, RO0012, RO0016, RO001E, RO001F, RO001L, RU0003, RU0004, RU0007, RU000H, RU000Q, RU000T, RU0019, SI0001, SI0002, SI0006, SK0002, SK0003, SK0005, SK0006, UA0008, UA0009, UK0001, UK0006, UK0009, UK000D, UK000F, UK000H, UK000J, UK000P, UK000S, UK000U, UK000Z, UK001K, UK001M, UK001S, UK001U, UK001X, UK001Y, UK0020, UK0022, UK0024, UK0026, UK002F, UK002K, UK002L, UK002Q, UK002U, UK0030, UK0032, UK0034, UK0035, UK003B, UK003D, UK003E, UK003J, UK003P, UK003X, UK003Y, UK003Z, UK0041, UK004B, UK004C, UK004D, UK004E, UK004M, UK004N, UK004R, UK004U, UK004V, UK0050, UK0051, UK0057, UK005C, UK005G, UK005H, UK005N, UK005S, UK005V, UK0062, UK0063, UK0067, UK006C, UK006D, UK006E, UK006L, UK006P, UK006U, UK006X, UK006Z, UK0070, UK0072, UK0074, UK0078, UK0079, UK007A, UK007E, UK007H, UK007N, UK007P, UK007Q, UK007R, UK007U, UK007Y, UK007Z, UK0080, UK0082, UK0084, UK0085, UK0086, UK0087, UK0088, UK0089, UK008A, UK008B, UK008F, UK008R, UK008U, UK008V, UK008W, UK008X, UK0092, UK0096, UK0099, UK009A, UK009D, UK009F, UK009G, UK009K, UK009P, UK009Q, UK009S, UK009V, UK009W, UK00A0, UK00A4, UK00AD, UK00AE, UK00AJ, UK00AM, UK00AP, UK00AT, UK00AU, UK00B1, UK00B2, UK00B6, UK00BA, UK00BB, UK00BC, UK00BF, UK00BH, UK00BK, UK00BW, UK00C1, UK00C6, UK00CA, UK00CC, UK00CK, UK00DB, UK00DN, US0001, US0003, US0004, US0005, US0006, US0007, US0008, US0009, US000C, US000D, US000E, US000H, US000K, US000L, US000M, US000N, US000P, US000R, US000U, US001L, US001N, US001P, US001U, US001Z, US002A, US002D, US002L, US002W, US002X, US0030, US0035, US0036, US0038, US0039, US003G, US003M, US003N, US003P, US003T, US003Y, US0045, US004N, US004Q, US0055, US005B, US005F, US005H, US005J, US005W, US005X, US005Y, US0061, US0062, US006B, US006D, US007F, USC0B3, USC0G1, USC0G4, USC0G5, USC0H1, USC0H5, USL001, USL003, USL004, USL005, USL007, USL008, USL00A, USL00B, USL00C, USL00D, USL00E, USL00F, USL00G, USL00H, USL00J, USL00L, USL00M,

⁸ <https://creativecommons.org/licenses/by/4.0/>

USL00N, USL00P, USL00Q, USL00V, USL011, USL013, USL014, USL015, USL017, USL018, USL019, USL01A, USL01B, USL01C, USL01D and USL01E.

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Beta-Cepheids (BCE#701) confirmed

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A concentration of radiants has been recorded by GMN during a search window between 149° to 157° since 2022 from a source at R.A. 324° and decl. +76° with a geocentric velocity of 39.5 km/s. The activity exceeded the background between 151.5° and 154.0°, maximum at $\lambda_0 = 153.25 \pm 0.25^\circ$. The activity has been identified as the beta-Cepheids (BCE#701), a Mellish-type meteoroid stream. This case study confirms the annual activity of this shower; with these solutions the IAU MDC has meanwhile listed the beta-Cepheids as an established shower.

1 Introduction

In 2025 and 2026 a short duration shower appeared on the GMN radiant density maps, situated north of the established shower August gamma-Cepheids (AGC#523)⁹ (Figure 1). This activity is known as the beta-Cepheids (BCE#701)¹⁰. It was first reported from CAMS data of 2010–2013 (Jenniskens et al., 2016) and has been detected in CAMS

data since then (Jenniskens, 2023). The beta-Cepheids lie close to the August gamma-Cepheids but differ in velocity, radiant, eccentricity and inclination. Beta-Cepheids have a higher eccentricity and about 10° lower inclination. Both showers may be related. In this case study, Global Meteor Network data have been analyzed in order to check if the shower fulfills the criteria to be nominated for established status.

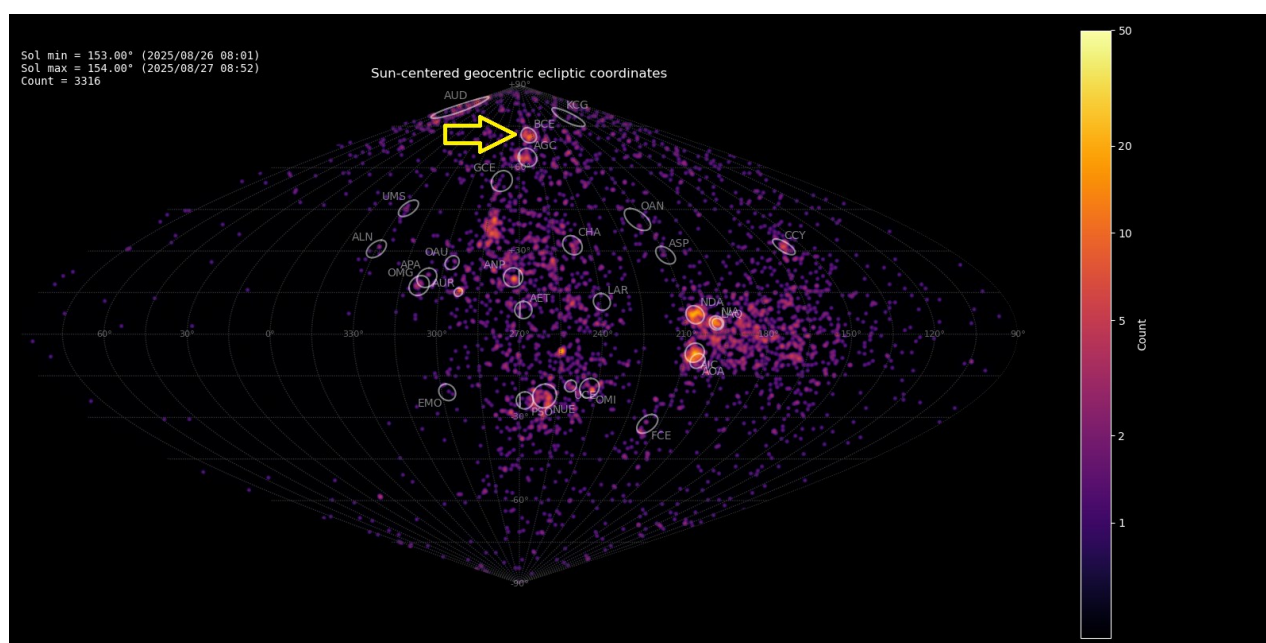


Figure 1 – Radiant density map with 3316 radiants obtained by the Global Meteor Network during solar longitude 153.0° to 154.0° in 2025. The position of the beta-Cepheids in Sun-centered geocentric ecliptic coordinates is marked with a yellow arrow.

⁹ https://www.ta3.sk/IAUC22DB/MDC2022/Roje/pojedynczy_obiekt.php?porz=01472&kodstrumienia=00523

¹⁰ https://www.ta3.sk/IAUC22DB/MDC2022/Roje/pojedynczy_obiekt.php?porz=01845&kodstrumienia=00701

2 Shower classification based on radiant

The radiant-based shower analyses have been done separately for 2025 and 2026 using the tool RadiantMap developed by Milan Kalina. This tool makes it possible to select radiants on the radiant density map (Figure 2) within a range in solar longitude to run automatically the meteor shower association tools developed by Denis Vida and Damir Šegon. The analyses generate the graphics used in this study, the final mean orbit and related parameters, the files required for reporting new solutions to the IAU-MDC (Jopek and Kaňuchová, 2017; Jenniskens et al., 2020) and a check-up for possible parent bodies. Figure 2 shows that the actual activity is slightly shifted relative to the expected activity based upon earlier observations. The tool is still being tested and not (yet) publicly available.

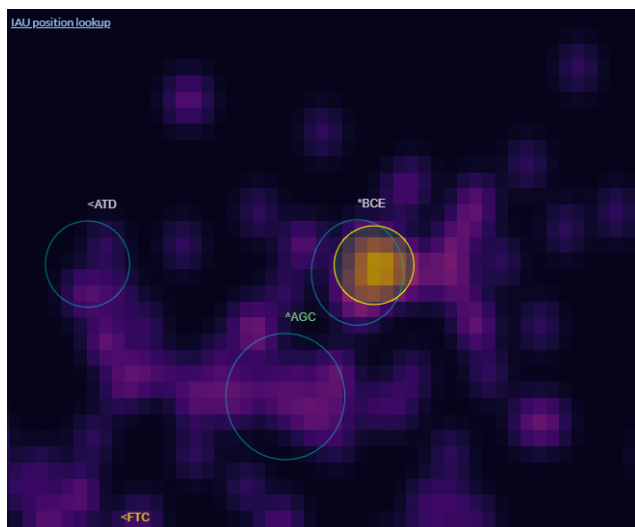


Figure 2 – Screenshot from RadiantMap with the selected region of interest for the BCE-activity at $\lambda_{\odot} = 153^{\circ}$ in 2026.

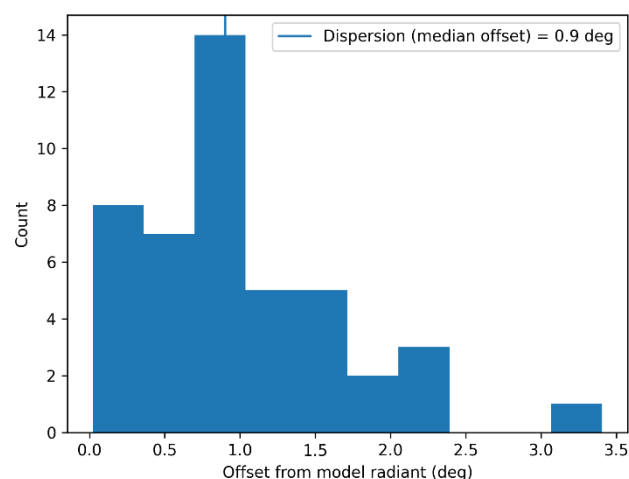


Figure 3 – First pass: offsets of the 45 initial 2025 candidates from the first drift fit. The median (0.90°) $\times 2.5$ sets the 2.25° outlier threshold; the final dispersion of the 32 members is 0.52° .

The RadiantMap tool initially found 45 meteors after initial filtering of the 2025 data. The radiant offset threshold is 2.25° and the v_g deviation threshold 2.28 km/s. Using these values to remove outliers, 32 meteors remained for final analysis. The final median dispersion is 0.52° giving an association radius ($\times 2.5$) of 1.3° : RadiantMap fits the

radiant drift to the 45 meteors in the region of interest, removes meteors more than 2.5 times the median offset (2.25°) from the drifting radiant or more than 2.28 km/s off in v_g , and refits. For the 2026 data, the radiant offset threshold is 1.744° and the v_g deviation threshold 2.0 km/s. Using these values to remove outliers, 32 meteors of the initial 40 meteors remained for final analysis. The final median dispersion is 0.561° giving an association radius ($\times 2.5$) of 1.4° (Vida et al., 2021 as implemented in RadiantMap). 538 GMN-cameras in 28 countries (Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Canada, Croatia, Czech Republic, Denmark, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, South Korea, Spain, Switzerland, Ukraine, United Kingdom and the United States) contributed data for these datasets for the radiant and orbit based analyses. The shower parameters as obtained by the radiant method for 2025 and 2026 are listed in Table 2.

Figure 4 shows a scattered distribution of beta-Cepheid radiants which is due to the high declination and projection of the map.

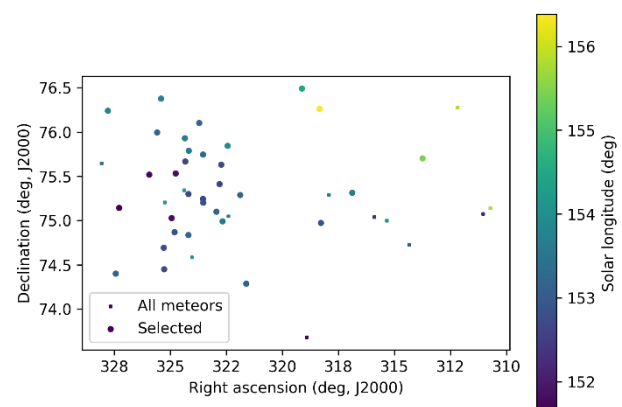


Figure 4 – The radiant distribution in 2025 during the solar-longitude interval $151.6^{\circ} - 156.4^{\circ}$ in equatorial coordinates.

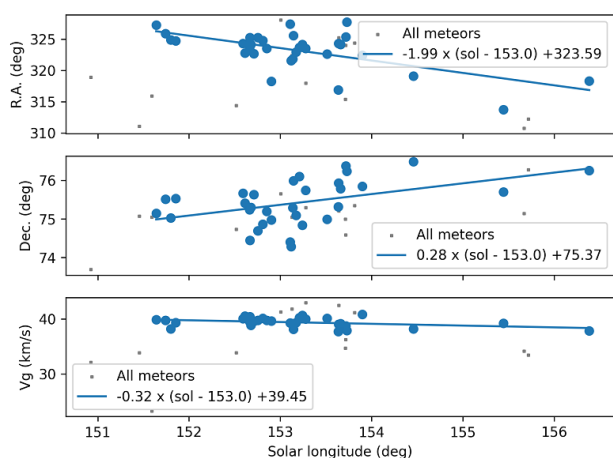


Figure 5 – The radiant drift in 2025.

3 Shower classification based on orbits

A complete independent meteoroid stream search has been applied to orbit data obtained between solar longitude 149° and 157° during the years 2019–2026. The method has been described in detail in a separate publication (Roggemans et

al., 2026a). 78493 orbits were available within this time interval (downloaded on 06/09/2026, 11:34 am). At that time most of the 2026 orbits had not yet been processed: the extract contains 4598 of the 17357 orbits now available for 2026 in this interval, while 2019–2025 are complete. The 2026 contribution to the orbit-based solution is therefore underrepresented, but the 2026 radiant-based solution, based on the complete data, agrees with it closely ($D_D = 0.010$). A final mean orbit has been computed by the method of Jopek et al. (2006) for the thresholds $D_{SH} < 0.125$ and $D_D < 0.05$ and $D_J < 0.125$ (Southworth and Hawkins, 1963; Drummond, 1981; Jopek, 1993), chosen from *Figure 8*, where the next weaker class already reaches the edge of the August gamma-Cepheid cluster. The resulting mean orbit based upon 242 meteors recorded from 2019 until 2026 is listed in *Table 2*. Duplicate solutions of the same meteor were not removed from the orbit data; in the selection used for *Table 1* they make up about 1% and do not affect the results.

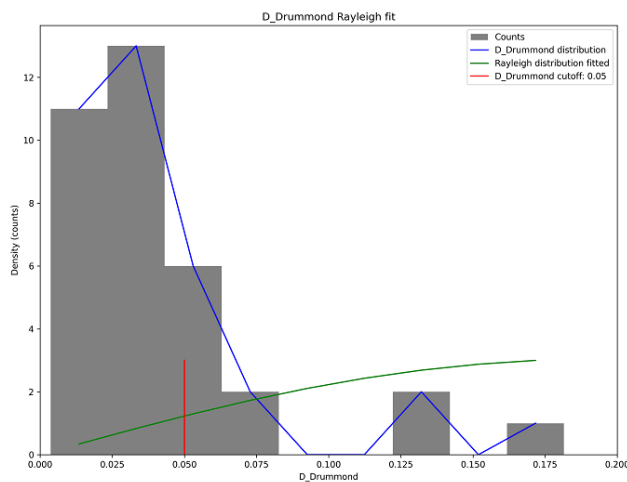


Figure 6 – D_D distribution of the 2026 RadiantMap candidates.

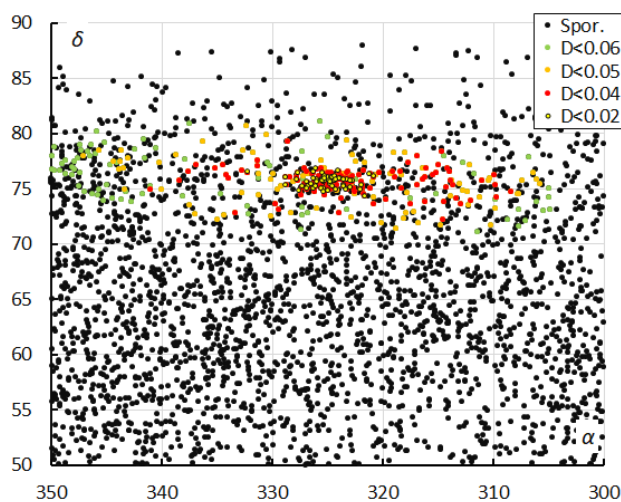


Figure 7 – The radiant distribution during the solar-longitude interval 149° – 157° in equatorial coordinates, color-coded for different threshold values of the combined similarity criteria.

Figures 7, 8 and 10 to 13 plot the combined thresholds $D_{SH} < 0.15$ and $D_D < 0.06$ and $D_J < 0.15$ (marked as $D_D < 0.06$), $D_{SH} < 0.125$ and $D_D < 0.05$ and $D_J < 0.125$ (marked as $D_D < 0.05$), $D_{SH} < 0.10$ and $D_D < 0.04$ and

$D_J < 0.10$ (marked as $D_D < 0.04$) and $D_{SH} < 0.05$ and $D_D < 0.02$ and $D_J < 0.05$ (marked as $D_D < 0.02$).

The radiant appears stretched in R.A. due to the high declination and map projection (*Figure 7*). The August gamma-Cepheids appear at the same declination east from the beta-Cepheids. The compactness of the radiant is more distinct in the geocentric Sun-centered ecliptic coordinates (*Figure 8*). The dark cluster just below the beta-Cepheids are the August gamma-Cepheids, which have their maximum two days later. Orbits with thresholds $D_{SH} < 0.15$ and $D_D < 0.06$ and $D_J < 0.15$, marked in green in *Figure 8*, appear at the edge of the August gamma-Cepheids cluster, indicating that these threshold values are too tolerant to distinguish these meteors from the beta-Cepheids.

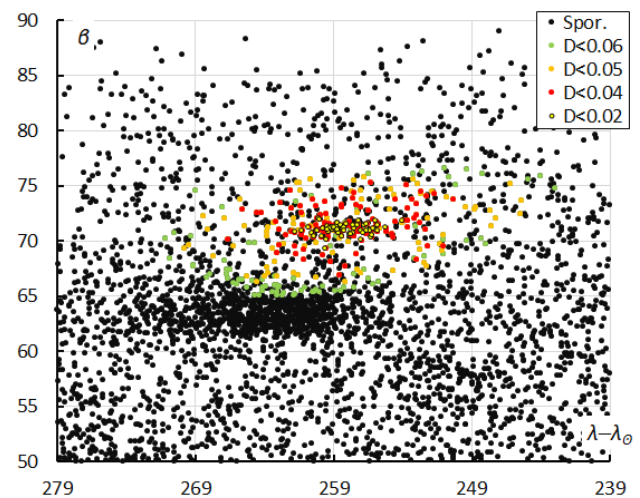


Figure 8 – The radiant distribution during the solar-longitude interval 149° – 157° in Sun-centered geocentric ecliptic coordinates, color-coded for different threshold values of the combined similarity criteria.

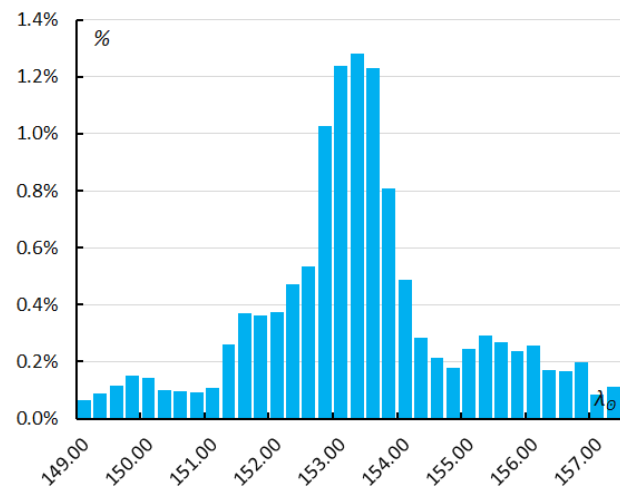


Figure 9 – The percentage of beta-Cepheid meteors relative to the total number of meteors recorded at the northern hemisphere in 2019–2026 identified with the D-criteria based method. Bin width is 1° in solar longitude counted in 0.25° steps.

The number of shower meteors as a percentage relative to the total number of meteors recorded in a 24 hours interval at the northern hemisphere results in the profile plotted in *Figure 9*. Best percentages occurred at $\lambda_0 = 153.25 \pm 0.25^\circ$ and similar orbits were found during the entire 8-day search

window from $\lambda_O = 149.1^\circ$ until $\lambda_O = 157.0^\circ$. In a separate profile with 0.5° bins (northern stations, same selection as *Table 1*), the bins more than 3σ above the background of 0.12% run from 151.5° to 154.0° (about 2.5 days), with the peak at 153.0° – 153.5° (2.0%); the bins outside 151.5° – 154.0° (0.07–0.22%) are at the background level. Possible shower members outside 151.5° – 154.0° are most likely sporadic meteors that fit the similarity criteria by chance. The results obtained by the radiant based classification method for 2025 and 2026 and the orbit method for 2019–2026 are in good agreement.

4 Orbit and parent body

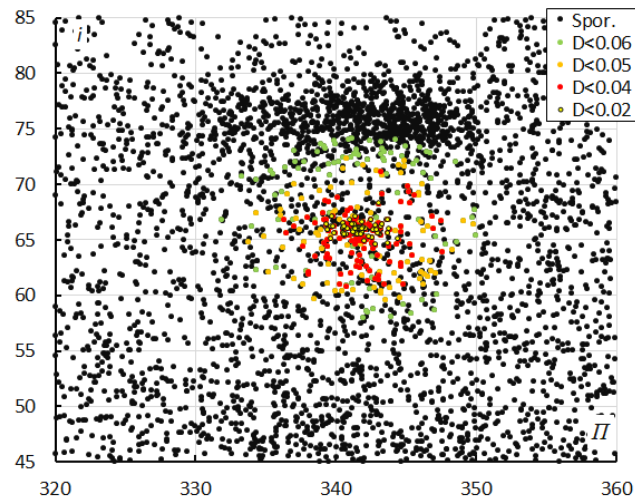


Figure 10 – Inclination i versus the longitude of perihelion Π color-coded for different classes of D-criteria thresholds, for λ_O between 149° – 157° . Spor. = sporadics.

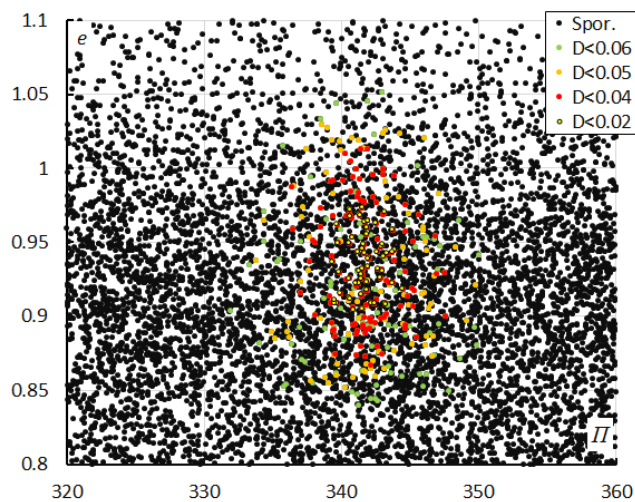


Figure 11 – Eccentricity e versus the longitude of perihelion Π color-coded for different classes of D-criteria thresholds, for λ_O between 149° – 157° . Spor. = sporadics.

The diagram of the inclination i versus the longitude of perihelion Π shows a clear concentration (*Figure 10*). The dense cloud at 75° inclination are the August gamma-Cepheids. The eccentricity e versus the longitude of perihelion Π appears dispersed in e versus Π (*Figure 11*) because of the sensitivity of the eccentricity for the uncertainty on the velocity measurement for high eccentricity values. The diagram e versus i (*Figure 12*)

shows the spread too as well as the August gamma-Cepheids, which have a lower eccentricity and 10° higher inclination. The diagram with the perihelion distance q versus i (*Figure 13*) shows a dense concentration about 10° left from the August gamma-Cepheids with the same perihelion distance.

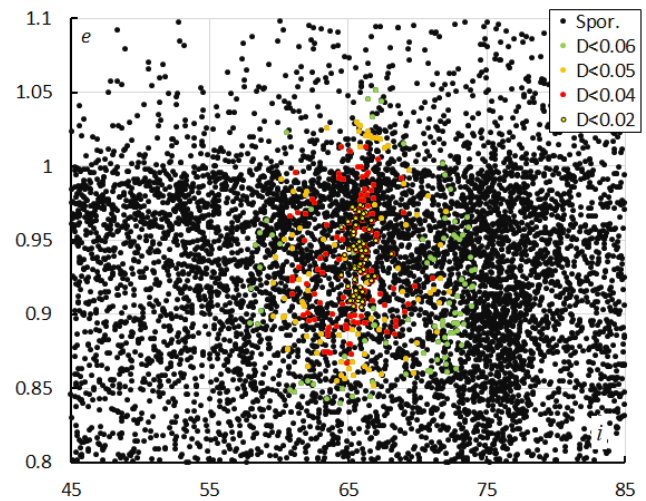


Figure 12 – Eccentricity e versus the inclination i color-coded for different classes of D-criteria thresholds, for λ_O between 149° – 157° . Spor. = sporadics.

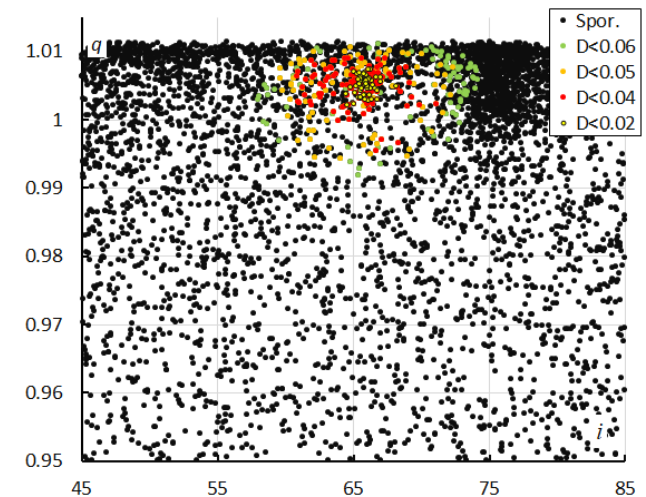


Figure 13 – Perihelion distance q versus the inclination i color-coded for different classes of D-criteria thresholds, for λ_O between 149° – 157° . Spor. = sporadics.

Table 1 – Number of BCE-meteors per year within the activity window 151.5° – 154.0° , and per mille of all northern orbits, with a Poisson test against the 149° – 151.5° and 154.0° – 157° flanks.

Year	Meteors	Per mille of all orbits	Significance
2019	2	4.8	not significant ($p = 0.37$)
2020	4	3.5	not significant ($p = 0.19$)
2021	4	3.0	marginal ($p = 0.03$)
2022	12	5.5	$p = 2e^{-10}$
2023	22	10.6	$p = 2e^{-9}$
2024	39	13.0	$p = 1e^{-21}$
2025	42	7.4	$p = 2e^{-20}$
2026	31	10.0	$p = 1e^{-17}$

The number of beta-Cepheids per year within the activity window 151.5° – 154.0° , also as per mille of all northern orbits, with a Poisson test against the 149° – 151.5° and 154.0° – 157° flanks, is listed in *Table 1*. All years: 156 meteors where 24.2 are expected from the background, $p = 3e^{-71}$, about 15% sporadic contamination. The shower is recorded each year since 2022 (weakly in 2021), with fairly stable activity from 2023 on. This proves the annual nature of the activity. Jenniskens (2023) mentions a possibly episodic behavior but the covered range in years with GMN data is too short to assess any possible periodic activity.

These numbers come from a separate radiant-based selection on the complete GMN data: meteors within 2.5° of the radiant in Sun-centered coordinates ($\lambda - \lambda_\odot = 258.6^\circ$, $\beta = +71.1^\circ$) with $35.5 < v_g < 43.5$ km/s, convergence angle $\geq 10^\circ$, radiant error $\leq 1^\circ$ and v_g error $\leq 10\%$, after removal of duplicate solutions. The background is the fraction of all northern orbits in the same selection in the flanks 149° – 151.5° and 154.0° – 157° .

Table 2 – Comparing solutions derived by two different methods, RadiantMap-method for 2025 and 2026, and the orbit association method for $D_{SH} < 0.125$ and $D_D < 0.05$ and $D_J < 0.125$ ($D_D < 0.05$). H_b , H_e , H_p are the begin-, end- and peak-brightness heights and Mag_{Ap} is the average peak absolute magnitude, normalized to 100 km. The orbit-method limits 149.1° – 157.0° are the search window.

	Radiant method 2025	Radiant method 2026	Orbit method 2019–2026 $D_D < 0.05$
$\lambda_\odot$ ($^\circ$)	153.1	153.2	153.2
λ_{Ob} ($^\circ$)	151.6	150.1	149.1
λ_{Oe} ($^\circ$)	156.4	153.8	157.0
α_g ($^\circ$)	323.6	324.8	324.3
δ_g ($^\circ$)	+75.4	+75.6	+75.7
$\Delta\alpha_g$ ($^\circ/\lambda_\odot$)	-1.99 ± 0.45	-0.05 ± 0.61	$+0.08 \pm 0.35$
$\Delta\delta_g$ ($^\circ/\lambda_\odot$)	$+0.28 \pm 0.10$	$+0.28 \pm 0.09$	$+0.42 \pm 0.06$
v_g (km/s)	39.5	39.4	39.5
H_b (km)	104.4	104.1	104.3
H_e (km)	93.7	93.4	92.5
H_p (km)	97.6	98.0	96.9
Mag_{Ap}	−0.2	+0.1	−0.2
λ_g ($^\circ$)	50.7	51.8	51.8
$\lambda_g - \lambda_\odot$ ($^\circ$)	257.6	258.6	258.6
β_g ($^\circ$)	+71.3	+71.0	+71.1
a (A.U.)	16.1	12.0	14.7
q (A.U.)	1.004	1.005	1.003
e	0.938	0.916	0.932
i ($^\circ$)	65.2	65.6	65.4
ω ($^\circ$)	188.9	188.5	188.4
Ω ($^\circ$)	153.2	152.7	153.3
Π ($^\circ$)	342.0	341.2	341.8
T_J	0.84	0.94	0.86
N	32	32	242

Table 3 – Top ten matches of a search for possible parent bodies with $D_D < 0.30$, based upon the mean orbit derived from the radiant classification method on 2025 data. JPL SBDB/ELEMENTS.COMET of 2026-09-06.

Name	D_D
C/1977 R1 (Kohler)	0.214
C/2013 G5 (Catalina)	0.218
C/1940 O1 (Whipple-Paraskevopoulos)	0.232
2024 RK16	0.244
2020 HU6	0.247
C/1919 Q2 (Metcalf)	0.249
2017 NW5	0.254
C/1965 S2 (Alcock)	0.255
(361861) 2008 ED69	0.257
2021 QA	0.257

With a Tisserand value relative to Jupiter of 0.84, this is a Mellish-type shower. The ascending node is between the orbits of Uranus and Neptune (*Figure 14*). With an eccentricity close to the hyperbolic limit, the slightest observational or instrumental uncertainty on the velocity results in a huge difference in aphelion. The meteoroid stream encounters the Earth orbit at its descending node close to its perihelion (*Figure 15*).

A search for a possible parent body did not result in any positive match, the ten best results are listed in *Table 3*. The negative result is firm: D_{SH} against all ten candidates is 0.52–0.71, and none crosses the ecliptic near 1 AU at the stream’s node longitude (333°); C/1977 R1 crosses at 1.011 AU but at longitude 2.5° , 29° away.

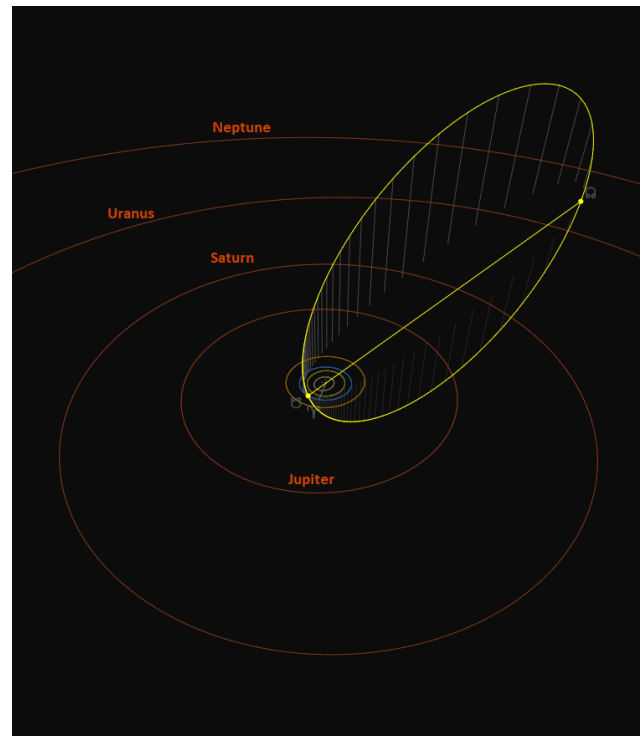


Figure 14 – The orbit determined solution for 2019–2026 (yellow). (Plotted with the Orbit visualization app provided by Pető Zsolt).

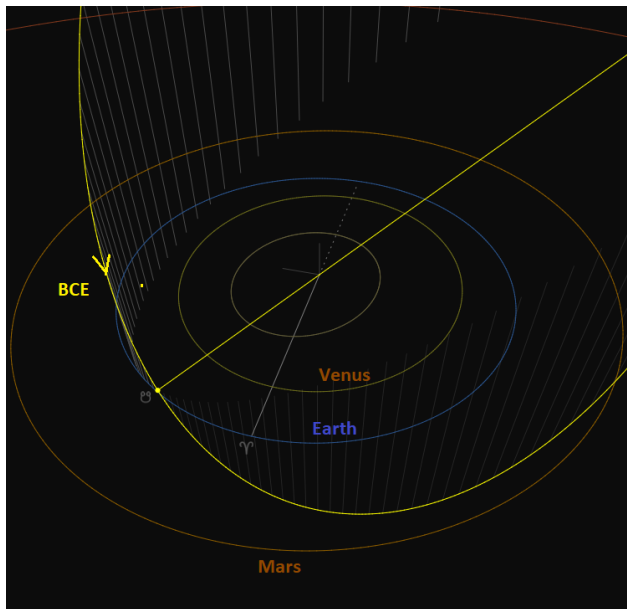


Figure 15 – Close-up in the inner Solar system with the orbit determined solution for 2019–2026 (yellow). (Plotted with the Orbit visualization app provided by Pető Zsolt).

5 Conclusions

The existence and annual nature since 2022 of the beta-Cepheids have been confirmed. Over 2019–2026, 156 meteors fall within the activity range 151.5° – 154.0° where 24.2 are expected from the background: Poisson p about $3e^{-71}$, with about 15% sporadic contamination. This study provides some extra solutions to document this shower. The activity duration is between solar longitude 151.5° and 154° with best rates at $\lambda_{\odot} = 153.25^{\circ} \pm 0.25^{\circ}$. The shower may be related to the nearby August gamma-Cepheids; only dynamical modeling can tell. No parent body could be identified. This case study confirms the annual activity of this shower; with these solutions the IAU MDC has meanwhile listed the beta-Cepheids as an established shower.

Acknowledgments

This report is based on the data of the Global Meteor Network (Vida et al., 2020a; 2020b; 2021) which is released under the CC BY 4.0 license¹¹. We thank all 927 participants in the Global Meteor Network project for their contribution and perseverance. A list with the names of the volunteers who contribute to GMN has been published in the 2025 annual report (Roggemans et al., 2026b). The following 538 cameras contributed to paired meteors used in this study:

AT0004, BA0002, BA0003, BA0004, BA0005, BE0002, BE0003, BE0005, BE0006, BE0007, BE0008, BE000A, BE000B, BE000C, BE000D, BE000G, BE000H, BE000J, BE000L, BE000M, BE000Q, BE000R, BE000S, BE000T, BE000U, BE000V, BE000X, BE000Z, BE0012, BE0015, BE0016, BE0018, BE0019, BE001A, BG0002, BG0003, BG000A, BG000B, BG000C, BG000H, BG000J, BG000L, CA0005, CA000D, CA000E, CA000L, CA000P, CA000Q, CA000U, CA000V, CA000W, CA000Y, CA0012, CA001A, CA001C,

CA001G, CA001H, CA0021, CA0022, CA0026, CA0027, CA002F, CA002J, CA002K, CA002L, CA002R, CA002U, CA002V, CA0031, CA003E, CA003Y, CA003Z, CAC0A1, CAC0B1, CAC0B2, CH0002, CH0003, CH0004, CH0005, CZ0001, CZ0007, CZ000E, CZ000H, CZ000L, CZ000M, CZ000N, CZ000Y, DE0001, DE0004, DE0005, DE0006, DE0007, DE0008, DE000B, DE000J, DE000K, DE000Q, DE000S, DE000W, DE000X, DE0011, DE0013, DE0016, DE0017, DK0001, DK0003, DK0004, DK0007, DK000A, DK000B, DK000D, DK000F, DK000G, DK000L, DK000Q, DK000T, ES0001, ES0004, ES000N, ES000U, ES000W, ES000Z, ES0016, ES001A, ES001F, FR0003, FR0006, FR000A, FR000F, FR000G, FR000H, FR000K, FR000R, FR000V, FR000X, FR000Y, FR000Z, FR0011, FR0012, FR0013, FR0014, FR0015, GR0002, GR0003, GR0004, GR0007, GR0008, HR0001, HR0002, HR000D, HR000J, HR000K, HR000M, HR000P, HR000S, HR000T, HR000U, HR000W, HR0010, HR0017, HR0018, HR001A, HR001E, HR001M, HR001S, HR001Z, HR0024, HR0027, HR002D, HR002E, HR002J, HR002L, HR002M, HR002R, HR002W, HR002X, HR002Z, HU0001, HU0002, HU0003, HU0004, HU0006, HU0007, HU0008, HU0009, HU000B, HU000D, HU000E, HU000F, IE0004, IE000J, IT0001, IT0004, IT0007, KR0004, KR0005, KR000A, KR000D, KR000E, KR000F, KR000G, KR000R, KR000S, KR0011, KR0013, KR0014, KR0017, KR001C, KR001J, KR001Q, KR001S, KR001T, KR001U, KR001W, KR0020, KR0022, KR0023, KR0027, KR0028, KR002C, KR002D, KR002E, KR002J, KR002L, KR002N, KR002S, KR0038, KR003A, KR003K, KR003L, KR003M, KR003N, KR003Q, LU0001, NL0009, NL000B, NL000C, NL000D, NL000G, NL000K, NL000M, NL000P, NL000Q, NL000R, NL000S, NL000T, NL000U, NL000Z, NL0017, NL001A, NL001B, PL000D, PL000G, PL000L, PLM005, PT0002, RO0001, RO0002, RO0006, RO000T, RO0019, RU0001, RU0002, RU0003, RU0008, RU000F, RU000K, RU000L, RU000M, RU000N, RU000Q, RU0013, RU0014, RU0019, SI0001, SI0002, SK0003, SK0004, SK0005, SK0006, UA0001, UA0002, UK0001, UK0006, UK0008, UK0009, UK000C, UK000D, UK000F, UK000H, UK000S, UK000T, UK000U, UK000Y, UK001K, UK001L, UK001N, UK001P, UK001Q, UK001R, UK001S, UK001T, UK001U, UK001Z, UK0020, UK0022, UK0026, UK0027, UK0029, UK002C, UK002F, UK002G, UK002J, UK002K, UK002P, UK002Q, UK002T, UK002W, UK002X, UK002Z, UK0030, UK0031, UK0032, UK0033, UK0034, UK0035, UK003B, UK003C, UK003D, UK003E, UK003F, UK003G, UK003J, UK003L, UK003M, UK003N, UK003P, UK003U, UK003W, UK003X, UK003Z, UK0041, UK0045, UK0049, UK004B, UK004C, UK004D, UK004E, UK004F, UK004G, UK004J, UK004R, UK004V, UK0050, UK0051, UK0057, UK005F, UK005H, UK005L, UK005N, UK005P, UK005S, UK005V, UK0060, UK0067, UK006B, UK006C, UK006D, UK006E, UK006P, UK006S, UK006T, UK006V, UK006X, UK0070, UK0073, UK0074, UK0077, UK0079, UK007A, UK007B, UK007E, UK007G, UK007H, UK007J, UK007L, UK007N, UK007P, UK007Q, UK007R, UK007U, UK007V, UK007Y, UK007Z, UK0082, UK0083, UK0084, UK0085, UK0086, UK0087, UK0089, UK008B, UK008G, UK008H, UK008J, UK008Q, UK008R, UK008V, UK008W, UK008X, UK008Z, UK0092, UK0096, UK0098, UK0099, UK009A, UK009C, UK009D, UK009E, UK009G, UK009J, UK009K, UK009M, UK009P, UK009Q, UK009S, UK009T, UK009V, UK009W, UK00A0, UK00A1, UK00A3, UK00A4, UK00A5, UK00AB, UK00AE, UK00AG, UK00AK, UK00AL, UK00AN, UK00AP, UK00AT, UK00B0, UK00B1, UK00B2, UK00B5, UK00B6, UK00BH, UK00BK,

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UK00BW, UK00C1, UK00C2, UK00C6, UK00CC, UK00CE, UK00CJ, UK00CK, UK00CQ, UK00CT, UK00D6, UK00D7, US0001, US0002, US0004, US0005, US0006, US0007, US0008, US000A, US000C, US000D, US000E, US000G, US000H, US000J, US000L, US000P, US000U, US001P, US0020, US002N, US002Q, US002W, US002X, US002Y, US0035, US0037, US0039, US003N, US003Q, US004B, US004C, US004E, US004J, US004M, US004N, US004Q, US0050, US0054, US005E, US005P, US005X, US006A, USC0G1, USC0H3, USC0H4, USL001, USL002, USL003, USL005, USL006, USL007, USL008, USL00A, USL00B, USL00C, USL00D, USL00E, USL00F, USL00G, USL00H, USL00J, USL00K, USL00L, USL00M, USL00N, USL00P, USL00Q, USL00U, USL014, USL016, USL017, USL019, USL01A, USL01B, USL01D, USL01E and USV003.

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Fornacids (FOR#1066) confirmed

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A diffuse activity source in the constellation Fornax has been found in the Global Meteor Network data with significant activity between 12 and 22 July ($\lambda_{\odot}$ 110°–120°; search window 12 July to 1 August) from a large radiant at R.A. 40.9° and decl. -29.6° ($\lambda_{\odot} = 119.2^{\circ}$) with a geocentric velocity of 57.0 km/s. The activity has been identified as the Fornacids (FOR#1066), a Halley-type meteoroid stream. This shower has been recorded by GMN since 2021, and significantly every year since 2024. This case study confirms that this annual meteor shower fulfils the criteria required to be nominated for established status by the IAU-MDC.

1 Introduction

The IAU-MDC Working List of Meteor Showers (Jopek and Kaňuchová, 2017; Jenniskens et al., 2020) lists a poorly known diffuse activity south of the established eta-Eridanids (ERI#191). This activity was first detected by Jenniskens (2023) in CAMS data from the Southern Hemisphere, listed as the Fornacids (FOR#1066)¹², MDC

lists an unpublished solution from 2022. This shower is not included in the GMN reference list used for preliminary shower identification of paired meteors. A case study has been made using the radiant identification method on the 2026 observations and the orbit identification method on the 2019–2026 data. 280307 orbits were available between solar longitude 108° and 130° during these years.

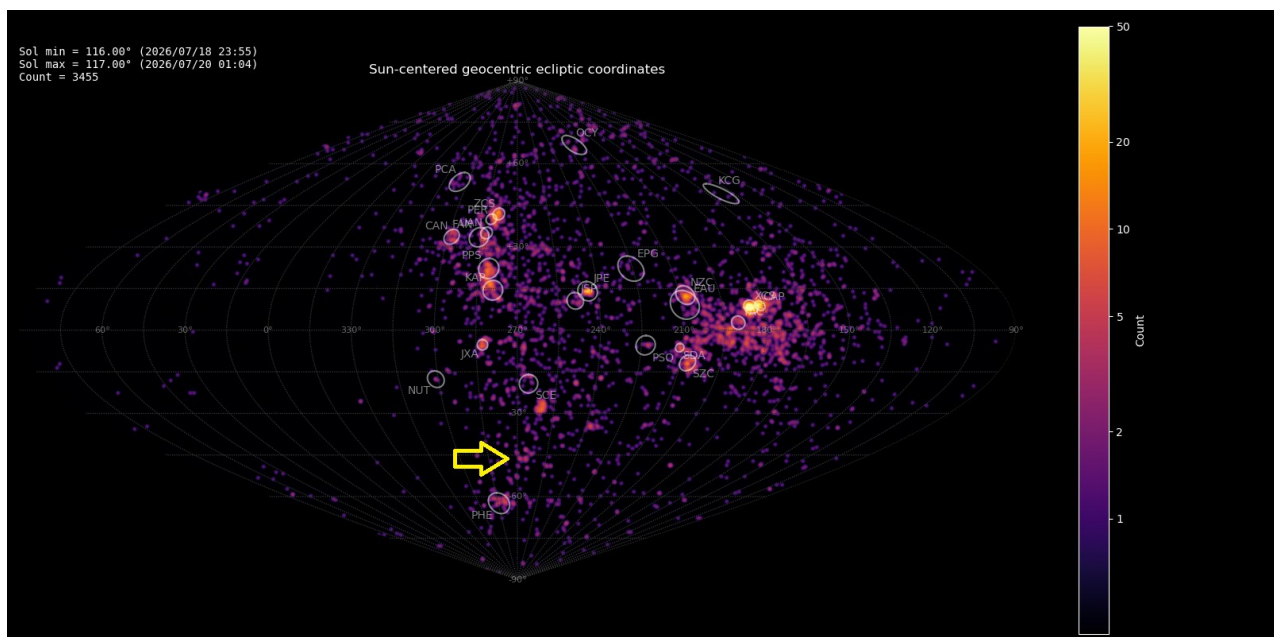


Figure 1 – Radiant density map with 3455 radiants obtained by the Global Meteor Network during solar longitude 116°–117°, 2026. The position of the Fornacids in Sun-centered geocentric ecliptic coordinates is marked with a yellow arrow.

¹² https://www.ta3.sk/IAUC22DB/MDC2022/Roje/pojedynczy_o_biekt.php?lporz=02434&kodstrumienia=01066

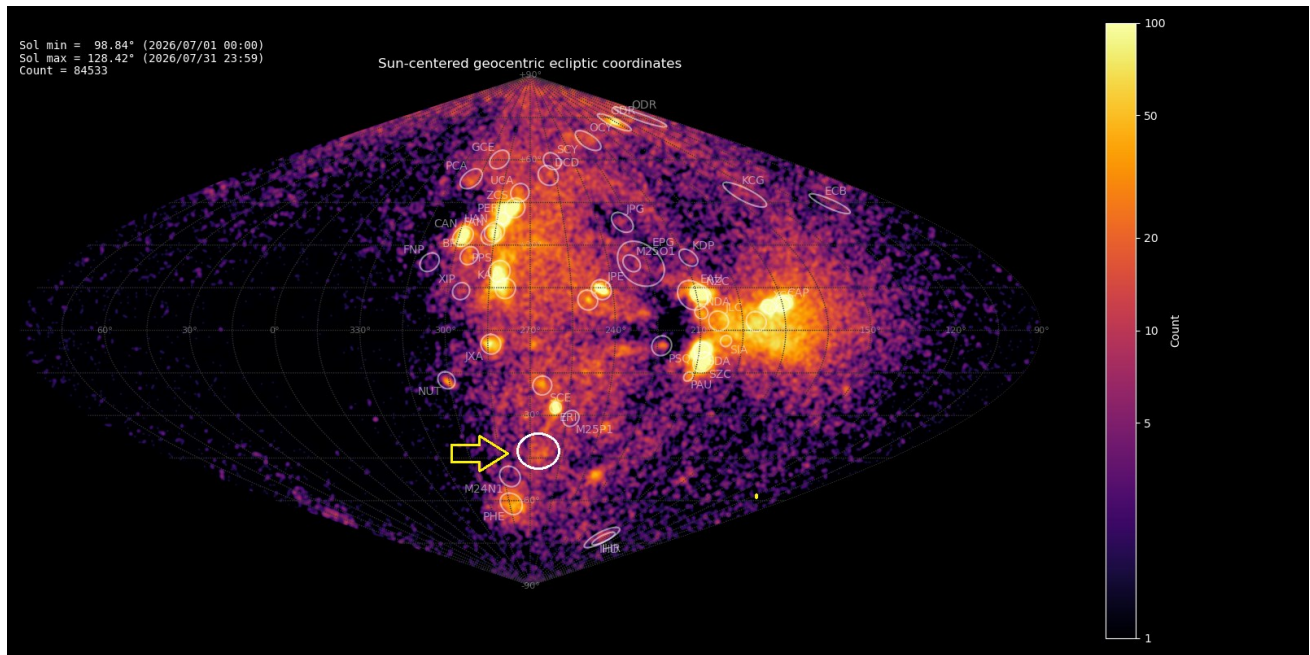


Figure 2 – Radiant density map with 84533 radiants obtained by the Global Meteor Network during July, 2026. The position of the Fornacids in Sun-centered geocentric ecliptic coordinates is marked with a yellow arrow.

2 Shower classification based on radiants

The activity is barely visible on the daily radiant density maps (Figure 1) and appears as a dispersed cluster of radiants on the monthly plot (Figure 2). The Global Meteor Network RadiantMap tool, developed by Milan Kalina, enables the visualization of the observed activity with the theoretical radiant positions based upon the IAU-MDC reference list (Figure 3).

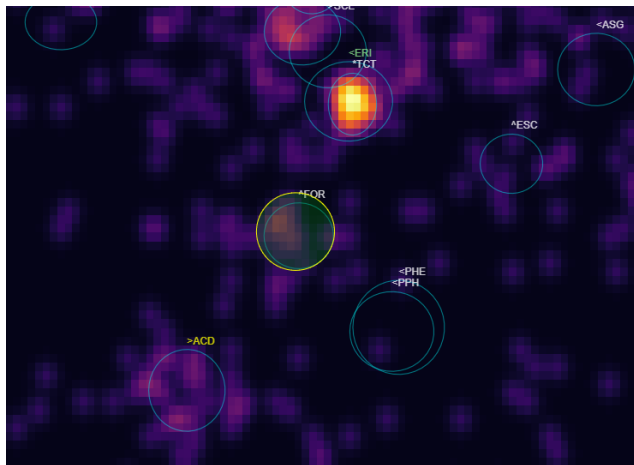


Figure 3 – Screenshot from RadiantMap at $\lambda_0 = 120^\circ$ in 2026 with the selected region of interest for the FOR-activity in Sun-centered ecliptic coordinates in Mercator projection.

A weak and diffuse activity is difficult to extract from the background activity. The RadiantMap tool initially selected 248 meteors within the region of interest. The sample includes some duplicate solutions which were not removed in the analysis. The radiant offset threshold is 6.31° and the v_g deviation threshold 2.0 km/s. Using these values to remove outliers, 166 meteors remained for final analysis. The final median dispersion is 2.4° giving an association radius ($\times 2.5$) of 6.0° (Vida et al., 2021, implemented in the

RadiantMap tool). The final mean orbit solution has a geocentric velocity $v_g = 57.0$ km/s, the velocities of the 166 selected meteors are within the range of 54.8 to 59.2 km/s. The heliocentric velocities are in the range of 37.1 to 43.3 km/s and include hyperbolic orbits.

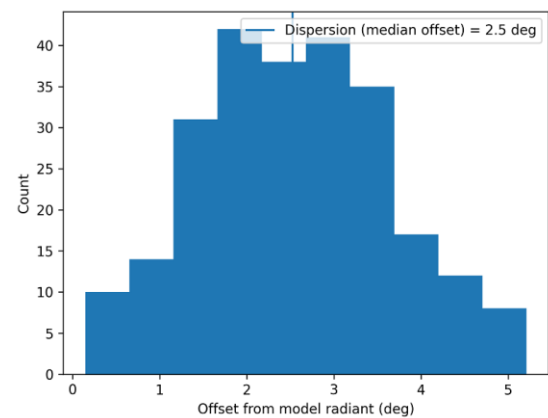


Figure 4 – Median radiant offset of 2.5° showing the 248 initial candidates (2026).

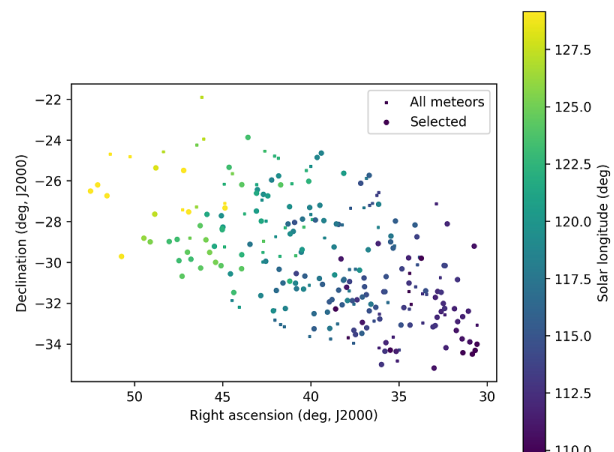


Figure 5 – The radiant distribution in 2026 during the solar-longitude interval $109.8^\circ - 129.2^\circ$ in equatorial coordinates.

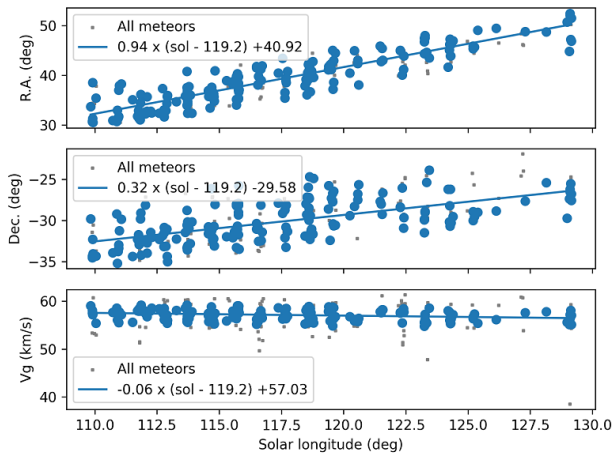


Figure 6 – The radiant drift in 2026.

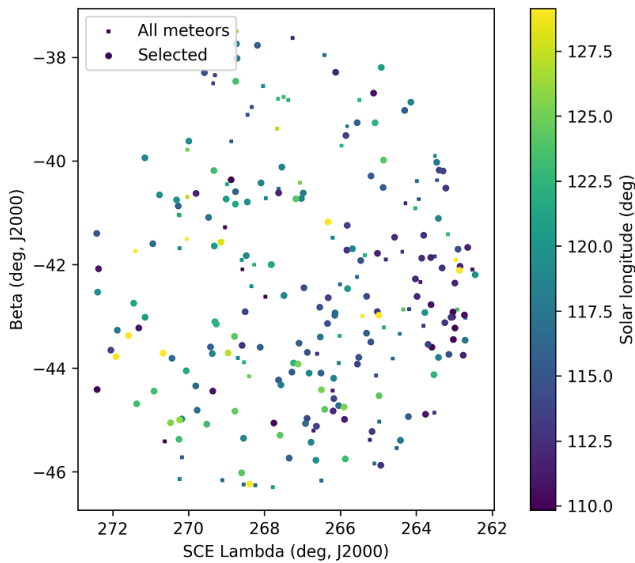


Figure 7 – The radiant distribution in 2026 during the solar-longitude interval 109.8° – 129.2° in Sun-centered geocentric ecliptic coordinates.

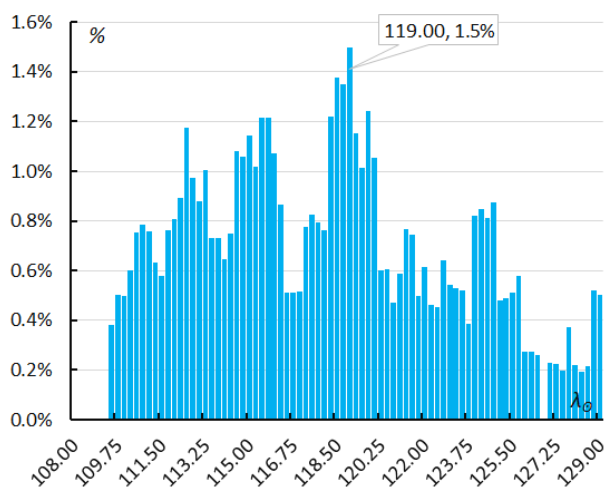


Figure 8 – The percentage of Fornacid-meteors for the radiant shower identification method for meteors relative to the total number of all meteors recorded in 2026 that had their beginpoint at southern latitude.

The velocity tolerance may be too tolerant in this case to exclude contamination with sporadics. The radiant drift is very obvious in the plot in equatorial coordinates

(Figure 5). The results for the radiant drift are in Figure 6. In Sun-centered geocentric ecliptic coordinates there is no radiant drift visible, but the radiant is very diffuse (Figure 7).

The relative activity as a percentage of all meteors recorded south of the equator per degree in solar longitude (Figure 8) shows an irregular profile for the radiant determined activity with best percentages at $\lambda_{\odot} = 119^{\circ}$. A profile over the wider interval, $\lambda_{\odot} 98^{\circ}$ – 140° (1° bins, southern-hemisphere cameras as the denominator) gives a background of 0.59%, the mean fraction in the outer quarters of the interval, and a maximum of 1.97% at $\lambda_{\odot} 118^{\circ}$ – 119° . Bins more than 3σ above the background run from $\lambda_{\odot} 110^{\circ}$ to 120° (12 to 22 July 2026); 124° – 125° is marginal.

As a fraction of all orbits from southern-hemisphere cameras in $\lambda_{\odot} 110^{\circ}$ – 125° , the Fornacids reached $9.6 \pm 1.4\%$ in 2023, $11.9 \pm 1.1\%$ in 2024, $11.3 \pm 0.8\%$ in 2025 and $12.2 \pm 0.9\%$ in 2026. The excess over the background is highly significant from 2024 on, marginal in 2023 ($P = 0.009$) and not significant in 2022. 2021 shows 5 meteors against 0.5 expected, but from only 138 orbits. There were no southern-hemisphere data in this window in 2019–2020.

The significance of the activity was tested against the sporadic background (criterion C3 of Hajduková et al., 2023). Within 5° of $\lambda_g - \lambda_{\odot} = 267.0^{\circ}$, $\beta_g = -43.0^{\circ}$ and v_g between 51.5 and 62.9 km/s, 197 meteors were recorded by southern-hemisphere cameras between $\lambda_{\odot} 110^{\circ}$ and 125° in 2026, against 93.2 expected from the flanks (98° – 110° and 125° – 140°), a Poisson probability of $6 \cdot 10^{-21}$. About half of these meteors are therefore expected to be sporadic, which illustrates the contamination problem of a diffuse radiant.

3 Shower classification based on orbits

A complete independent meteoroid stream search has been applied to orbit data obtained between solar longitude 108° and 130° during the years 2019–2026. The method has been described in detail in a separate publication (Roggemans et al., 2026a). 280307 orbits were available within this time interval and a final mean orbit has been computed by the method of Jopek et al. (2006) for the thresholds $D_{SH} < 0.125$ and $D_D < 0.05$ and $D_J < 0.125$ (Southworth and Hawkins, 1963; Drummond, 1981; Jopek, 1993), chosen as safe thresholds for this type of highly inclined, retrograde Halley-type orbit. The resulting mean orbit based upon 180 meteors recorded from 2021 until 2026 is listed in Table 2.

The orbit method failed to cover the entire activity period. The reason is that the strict threshold of the D-criteria rejects real shower meteors because the D-criteria are time dependent, while the orientation of the meteoroid orbit planes changes during the shower activity. The angle between the orbital planes changes. The longitude of perihelion changes by 0.76° per degree in solar longitude. For a diffuse activity source with a large dispersion, the D-

criteria based orbit method is not suitable for activity periods longer than about a week.

Figures 9 to 12 plot the combined thresholds $D_{SH} < 0.15$ and $D_D < 0.06$ and $D_J < 0.15$ (marked as $D_D < 0.06$), $D_{SH} < 0.125$ and $D_D < 0.05$ and $D_J < 0.125$ (marked as $D_D < 0.05$), $D_{SH} < 0.10$ and $D_D < 0.04$ and $D_J < 0.10$ (marked as $D_D < 0.04$) and $D_{SH} < 0.05$ and $D_D < 0.02$ and $D_J < 0.05$ (marked as $D_D < 0.02$). The sporadic background (black dots) was limited to 2023–2026 because no Fornacid meteors were recorded in 2019–2020 and only one each in 2021 and 2022 in the orbit-method selection.

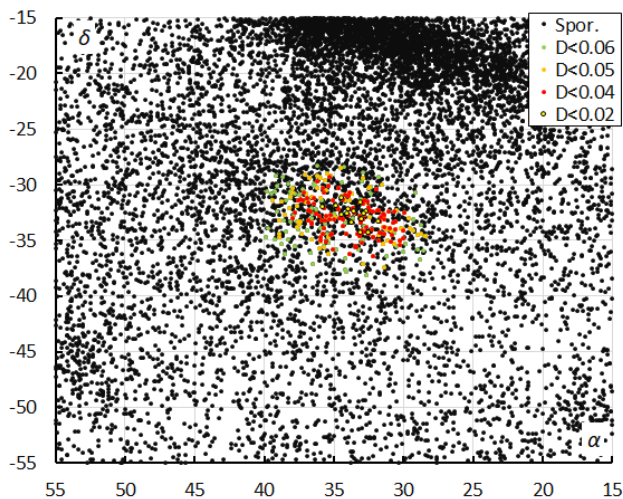


Figure 9 – The radiant distribution during the solar-longitude interval $108.0^\circ - 130.0^\circ$ in equatorial coordinates, color-coded for different threshold values of the combined similarity criteria in 2023–2026.

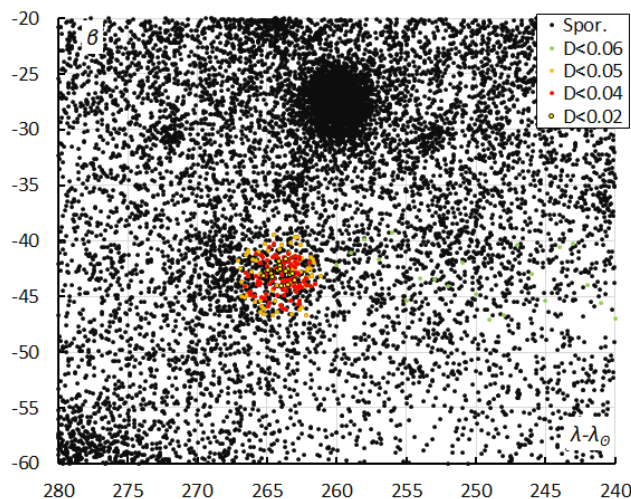


Figure 10 – The radiant distribution during the solar-longitude interval $108.0^\circ - 130.0^\circ$ in Sun-centered geocentric ecliptic coordinates, color-coded for different threshold values of the combined similarity criteria in 2023–2026.

The iteration based on the D-criteria threshold with $D_{SH} < 0.125$ and $D_D < 0.05$ and $D_J < 0.125$ converged to a solution that is only valid for shower members between solar longitude 108.1° and 119.5° , which is the activity before the maximum. This selection effect is well visible in Figure 9 where a concentration of radiants east of the selected radiants are the remaining Fornacids during the second part of the activity period. This is more visible in the

Sun-centered ecliptic coordinates in Figure 10. The radiant is diffuse, which is due to the large dispersion on the orbits. The dark concentration north of the Fornacids are the eta-Eridanids. Some other concentrations are visible too.

The case of the Fornacids shows that the solution depends upon the method used and that the D-criteria may not be suitable for all cases. With a diffuse radiant, the radiant method risks contamination from sporadics, while the D-criteria-based method fails to determine a reference orbit valid for the entire activity period.

A way to improve the radiant-based shower identification could be to add a filter to remove outliers in heliocentric velocities by using only orbits with $e < 1$. The parabolic limit in July is 41.8 km/s. Removing all hyperbolic orbits for the radiant based selected meteors we obtained a solution that is slightly different from those obtained by the orbit method, but still covering the entire activity period (see Table 2). Another run of the D-criteria iteration was applied on 89836 meteors available within solar longitudes 115° and 123° , 4° before and after $\lambda_0 = 119^\circ$ using the threshold class $D_{SH} < 0.15$ and $D_D < 0.06$ and $D_J < 0.15$ which is more tolerant for dispersed stream like the Fornacids.

Looking at the geocentric and heliocentric velocity ranges of the different solutions in Table 1, the geocentric velocity range is comparable for all four samples. The heliocentric velocity range for the radiant method has ~ 6.2 km/s difference between the lowest and highest velocity, while the orbit determined solution for $\lambda_0 108^\circ - 119^\circ$ has only 1.7 km/s difference. Using a more tolerant threshold for the D-criteria with $D_{SH} < 0.15$ and $D_D < 0.06$ and $D_J < 0.15$ for $\lambda_0 115^\circ - 123^\circ$, the difference between the lowest and highest heliocentric velocities is still as low as ~ 2.1 km/s.

Table 1 – The geocentric and heliocentric velocities for four different solutions.

	Min.	Med.	Max.	Min.	Med.	Max.
	v_g	v_g	v_g	v_h	v_h	v_h
Radiant	54.77	57.28	59.17	37.11	41.02	43.31
Radiant $e < 1$	54.77	57.00	59.06	37.11	40.87	41.73
Orbit $108^\circ - 119^\circ$	54.72	57.24	59.53	40.33	41.25	42.06
Orbit $115^\circ - 123^\circ$	54.01	56.94	59.68	39.93	41.02	42.03

4 Orbit and parent body

The diagram of the inclination i versus the longitude of perihelion Π shows a diffuse distribution (Figure 11). The D-criteria identified Fornacids represent only half the activity period. Such a large spread in longitude of perihelion and inclinations fails to fit the D-criteria threshold. On the other hand, the radiant based method failed to identify Fornacids that fit the D-criteria threshold but did not fit the assumed radiant size. The dark concentration at left are mainly zeta-Cassiopeiids (ZCS#444) and Perseids (PER#7). A diagram with eccentricity against inclination is not helpful in this case as

the inclination range is saturated with zeta-Cassiopeiids and Perseids.

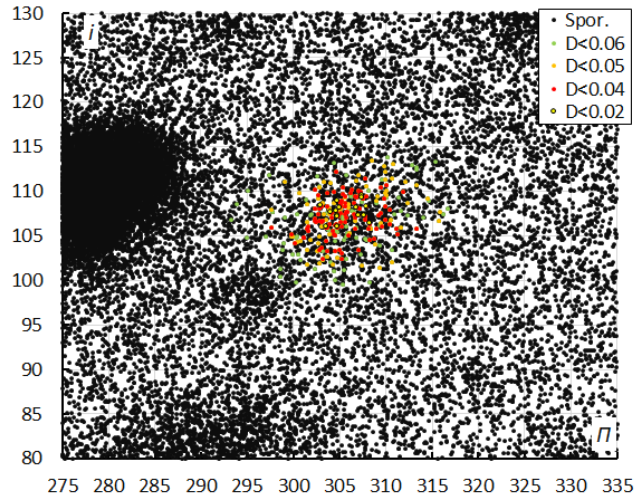


Figure 11 – Inclination i versus the longitude of perihelion Π color-coded for different classes of D-criteria thresholds, for $\lambda_{\odot}$ between $108.0^{\circ} - 130.0^{\circ}$ in 2023–2026. Spor. = sporadics.

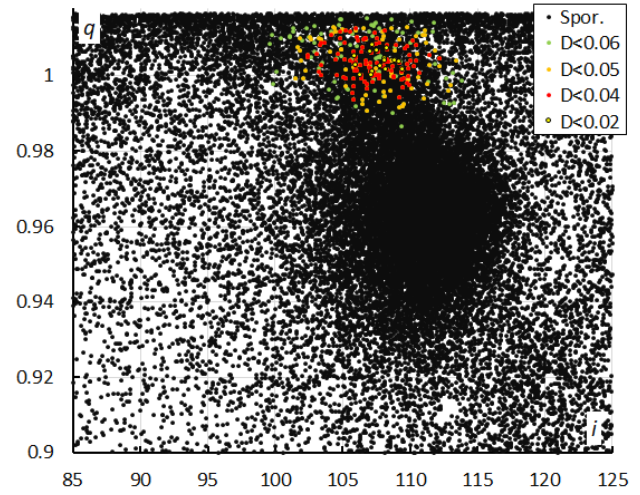


Figure 12 – Perihelion distance q versus the inclination i color-coded for different classes of D-criteria thresholds, for $\lambda_{\odot}$ between $108.0^{\circ} - 130.0^{\circ}$ in 2023–2026. Spor. = sporadics.

Table 2 – Comparing solutions derived by two different methods, radiant method for 2026 and the radiant method limited to $e < 1$. The orbit method for $D_{SH} < 0.125$ and $D_D < 0.05$ and $D_J < 0.125$, 2021–2026, that covers only $108.1^{\circ} - 119.5^{\circ}$ in solar longitude. The orbit method applied on a selection limited to solar longitude $115.0^{\circ} - 123.0^{\circ}$ with $D_{SH} < 0.15$ and $D_D < 0.06$ and $D_J < 0.15$. λ_{ob} and λ_{oe} of the radiant columns are the limits of the search window. R.A./Dec. are drift values at the $\lambda_{\odot}$ given; compare the columns in $\lambda_g - \lambda_{\odot}$ and β_g . H_b , H_e , H_p are the begin-, end- and peak-brightness heights and Mag_{Ap} is the average peak absolute magnitude, normalized to 100 km.

	Radiant method 2026 unfiltered	Radiant method 2026 $e < 1$	D-criteria 2021–2026 ($\lambda_{\odot}$: $108.1^{\circ} - 119.5^{\circ}$) $D_D < 0.05$	D-criteria 2021–2026 ($\lambda_{\odot}$: $115.0^{\circ} - 123.0^{\circ}$) $D_D < 0.06$	Jenniskens (2023)
$\lambda_{\odot}$ ($^{\circ}$)	119.2	117.4	113.0	118.7	117.0
λ_{ob} ($^{\circ}$)	109.8	109.8	108.1	115.1	108
λ_{oe} ($^{\circ}$)	129.2	129.1	119.5	123.0	129
α_g ($^{\circ}$)	40.9	38.6	33.9	40.9	39.5
δ_g ($^{\circ}$)	−29.6	−30.1	−32.9	−30.4	−31.2
$\Delta\alpha_g$ ($^{\circ}/^{\circ}\lambda_{\odot}$)	+0.94	+0.94	+0.84	+0.82	+1.07
$\Delta\delta_g$ ($^{\circ}/^{\circ}\lambda_{\odot}$)	+0.32	+0.33	+0.46	+0.55	+0.45
v_g (km/s)	57.0	57.0	57.2	56.9	57.2
H_b (km)	107.9	107.8	108.7	108.6	111.8
H_e (km)	95.1	95.4	94.8	94.6	94.6
H_p (km)	99.5	99.7	99.3	99.3	99.2
Mag_{Ap}	−0.8	−0.8	−1.1	−0.9	+1.8
λ_g ($^{\circ}$)	26.5	24.1	17.3	25.9	
$\lambda_g - \lambda_{\odot}$ ($^{\circ}$)	267.3	266.9	264.3	267.4	266.4
β_g ($^{\circ}$)	−42.7	−42.9	−43.1	−43.2	−43.3
a (A.U.)	10.3	8.5	18.5	13.7	18.7
q (A.U.)	1.005 ± 0.006	1.004 ± 0.006	1.001 ± 0.005	1.008 ± 0.004	1.001 ± 0.004
e	0.903 ± 0.097	0.881 ± 0.086	0.946 ± 0.038	0.926 ± 0.046	0.946 ± 0.120
i ($^{\circ}$)	108.1 ± 2.8	108.2 ± 3.0	107.3 ± 2.6	107.0 ± 3.6	107.2 ± 2.19
ω ($^{\circ}$)	7.1 ± 5.9	7.0 ± 5.9	12.6 ± 2.9	6.2 ± 2.2	8.1 ± 3.01
Ω ($^{\circ}$)	297.3 ± 5.0	297.4 ± 5.0	293.1 ± 2.5	298.8 ± 3.7	297.0 ± 5.30
Π ($^{\circ}$)	304.4 ± 6.3	304.4 ± 6.4	305.7 ± 3.4	305.0 ± 3.9	305.0 ± 3.01
T_j	0.13 ± 0.50	0.24 ± 0.44	-0.08 ± 0.22	0.02 ± 0.26	-0.07 ± 0.38
N	166	142	180	174	207

The diagram of the perihelion distance versus inclination (Figure 12) shows a clear concentration in perihelion distances for the Fornacids within a range of 0.991 to 1.013 AU. Moreover, the radiant-based Fornacids are within a similar range of 0.993 to 1.016 A.U. With the argument of perihelion ω of about 7° the encounter is almost at perihelion, so q is close to the node distance (1.009–1.013 AU for the Table 2 orbits) and cannot exceed the Earth's distance in July. The narrow q range is therefore mostly geometry. The spread in eccentricity (0.578–1.147), inclination (102.6° – 115.6°) and longitude of perihelion (285.4° – 327.4°) is much larger for the radiant identified Fornacids than for the D-criteria based solutions with eccentricity (0.865–1.027), inclination (101.5° – 113.4°) and longitude of perihelion (297.6° – 315.9°). The explanation for this is mainly the very diffuse nature of this meteoroid stream and the selection effect by the D-criteria method.

Table 2 shows the solution found with the two different methods. The first column is the result as derived from the RadiantMap method. The large diffuse radiant may include contamination with sporadics. As an experiment a new solution was calculated after removing outliers in heliocentric velocity by removing all hyperbolic orbits. The resulting solution in the second column covers the entire activity period but still includes too low eccentricity orbits. Both D-criteria based solutions cover the activity period only partially because the large dispersion on the Fornacid orbits fails to fit the similarity criteria for the entire activity period.

All four GMN solutions are within all six limits of the maximum-sigma test against FOR#1066/000 (Jopek et al., 2024). Several other entries of the IAU-MDC list lie near the Fornacids. The iota1-Fornacids (IFR#1169), only 1° – 2° away in R.A./Dec., should not be used: this entry is flagged for reference problems and repeats the 77-Cetids (SCE#1070) record (same $\lambda_0 = 128.4^\circ$, $v_g = 67.5$ km/s, $N = 305$, q , e , ω and Ω ; only R.A., Dec. and i differ). The 77-Cetids themselves (R.A. 37.7° , Dec. -6.4°) are 22° away in Sun-centered coordinates, 11° later in solar longitude and 10.5 km/s faster. M2026-R1 is 12.3° away at $\lambda_0 = 115.4^\circ$ with $v_g = 62.2$ km/s ($D_D = 0.122$, $D_{SH} = 0.376$), and M2024-N1 is 13.9° away at $\lambda_0 = 102.8^\circ$ ($D_D = 0.19$). Both are separate showers according to the maximum-sigma test (Jopek et al., 2024).

The Tisserand value relative to Jupiter suggests a Halley-type meteor shower (Tancredi, 2014). The retrograde orbit is steep on the ecliptic plane and crosses the Earth orbit at its ascending node (Figure 13). The descending node is situated between 15 and 25 AU, between the orbits of Saturn and Neptune (30.7 AU for Jenniskens, 2023). Figure 14 shows three solutions listed in Table 2 in the inner solar system. The different solutions are still in good agreement, but the orbit solution (108.1° – 119.5°) is the exception: $D_{SH} = 0.137$ – 0.164 ($D_D = 0.051$ – 0.060) against the other GMN solutions, which is larger than the D_{SH} threshold of 0.125 used for the selection. The two D-criteria based solutions differ by $D_{SH} = 0.164$ due to the difference in node (293.1° vs 298.8°). The other GMN solutions agree

with each other within $D_{SH} = 0.022$ – 0.058 and with Jenniskens (2023) within $D_{SH} = 0.049$ – 0.070 .

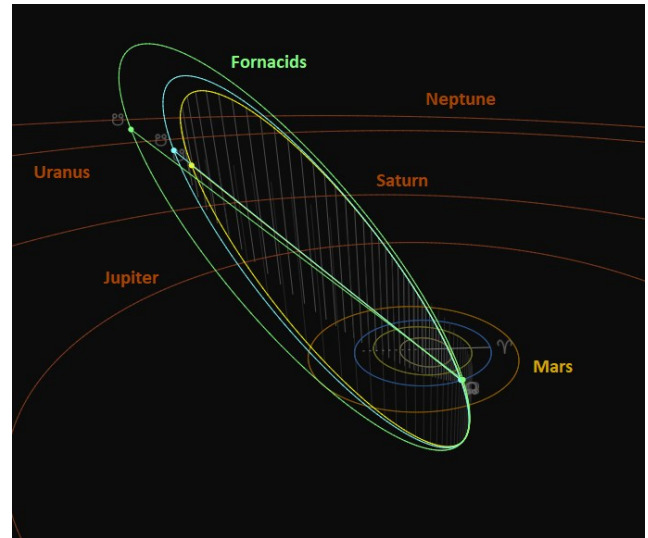


Figure 13 – The radiant determined solution for 2026 (blue), limited to $e < 1$ (yellow) and the D-criteria based method for solar longitude 115° to 123° (green). (Plotted with the Orbit visualization app provided by Pető Zsolt).

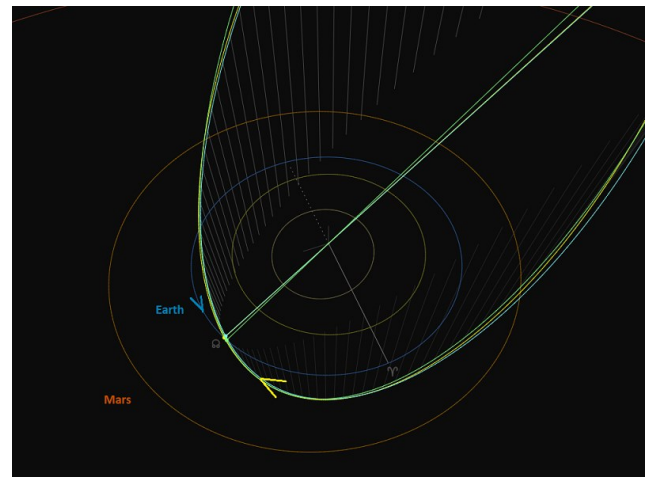


Figure 14 – Close-up in the inner Solar system with the three solutions near the Earth orbit. (Plotted with the Orbit visualization app provided by Pető Zsolt).

Table 3 – Top ten matches of a search for possible parent bodies with $D_D < 0.30$, based upon the mean orbit derived from the radiant classification method on 2026 data. JPL ELEMENTS.COMET (retrieved 2026-09-28).

Name	D_D	D_{SH}
C/1500 H1	0.137	0.375
C/1852 K1 (Chacornac)	0.211	0.617
C/2013 A1 (Siding Spring)	0.211	0.559
C/1886 J1 (Brooks)	0.213	0.610
C/1925 G1 (Orkisz)	0.225	0.572
273P/Pons-Gambart	0.231	0.623
C/2008 A1 (McNaught)	0.233	0.628
C/2013 UQ4 (Catalina)	0.233	0.699
C/2020 H2 (Pruyne)	0.254	0.659
C/1912 R1 (Gale)	0.258	0.652

A search for a possible parent body did not result in any positive match, but the ten best results are listed in *Table 3*. The diffuse nature of this meteoroid stream indicates this is probably an old and dispersed cometary dust trail.

5 Conclusions

The existence and annual nature of the Fornacids have been confirmed. With the significance test the annual nature is confirmed for 2024–2026 and marginally in 2023, at a constant normalized level of 10–12%. Nothing significant in 2022 or 2021 while 2019 and 2020 had no southern hemisphere coverage.

The limits of 109.8° and 129.2° in *Table 2* are the edges of the RadiantMap window, not measured activity limits. The wider-window GMN profile gives significant activity from 110° to 120° (124°–125° marginal). The large diffuse radiant and large dispersion on the orbits proved a challenge for the shower identification methods. While the radiant based method suffers contamination with the sporadic background, the D-criteria based method fails to cover the entire activity period. The solutions obtained via different methods agree with those published by Jenniskens (2023). The Tisserand value relative to Jupiter and the high ablation heights between 108 and 99 km for a geocentric velocity of 57.0 km/s indicate a cometary origin but no parent body could be identified with any certainty. The solutions obtained by the Radiant method 2026 (unfiltered) and the orbit method for 2021–2026 (λ_0 : 115.0°–123.0°) with $D_D < 0.06$ have been reported to the IAU-MDC.

Acknowledgments

This report is based on the data of the Global Meteor Network (Vida et al., 2020a; 2020b; 2021) which is released under the CC BY 4.0 license¹³. We thank all 927 participants in the Global Meteor Network project for their contribution and perseverance. A list with the names of the volunteers who contribute to GMN has been published in the 2025 annual report (Roggemans et al., 2026b). The following 284 cameras contributed to paired meteors used in this study:

AU0002, AU0003, AU0004, AU0006, AU000A, AU000B, AU000C, AU000D, AU000E, AU000R, AU000S, AU000U, AU000V, AU000W, AU000Z, AU0010, AU0011, AU001A, AU001B, AU001C, AU001E, AU001F, AU001K, AU001L, AU001P, AU001Q, AU001R, AU001S, AU001V, AU001W, AU001X, AU001Z, AU0028, AU0029, AU002A, AU002B, AU002E, AU0030, AU0035, AU003E, AU003H, AU003J, AU0040, AU0041, AU0042, AU0043, AU0046, AU0047, AU0048, AU004H, AU004J, AU004K, AU004M, AU004Q, AU004R, BR0001, BR000F, BR000G, BR000Q, BR000T, BR000Y, BR0029, BR002A, BR002B, BR002C, MX0006, MX000A, NZ0001, NZ0002, NZ0003, NZ0004, NZ0007, NZ0008, NZ0009, NZ000B, NZ000D, NZ000F, NZ000G, NZ000H, NZ000J, NZ000K, NZ000L, NZ000M,

NZ000N, NZ000P, NZ000Q, NZ000R, NZ000S, NZ000U, NZ000W, NZ000X, NZ000Y, NZ000Z, NZ0010, NZ0011, NZ0012, NZ0013, NZ0014, NZ0015, NZ0016, NZ0017, NZ0018, NZ0019, NZ001A, NZ001C, NZ001D, NZ001E, NZ001G, NZ001H, NZ001J, NZ001K, NZ001L, NZ001N, NZ001P, NZ001Q, NZ001R, NZ001S, NZ001V, NZ001X, NZ001Z, NZ0020, NZ0021, NZ0022, NZ0023, NZ0025, NZ0026, NZ0027, NZ0028, NZ0029, NZ002B, NZ002C, NZ002D, NZ002E, NZ002F, NZ002G, NZ002H, NZ002J, NZ002K, NZ002N, NZ002P, NZ002Q, NZ002R, NZ002S, NZ002T, NZ002U, NZ002V, NZ002W, NZ002X, NZ0030, NZ0032, NZ0033, NZ0034, NZ0035, NZ0036, NZ0037, NZ0038, NZ0039, NZ003A, NZ003B, NZ003C, NZ003E, NZ003F, NZ003G, NZ003H, NZ003K, NZ003N, NZ003Q, NZ003R, NZ003S, NZ003T, NZ003U, NZ003V, NZ003W, NZ003X, NZ003Y, NZ003Z, NZ0040, NZ0041, NZ0042, NZ0044, NZ0045, NZ0049, NZ004A, NZ004B, NZ004C, NZ004D, NZ004E, NZ004F, NZ004H, NZ004J, NZ004L, NZ004N, NZ004R, NZ004S, NZ004T, NZ004U, NZ004Y, NZ0051, NZ0059, NZ005A, NZ005B, NZ005C, NZ005D, NZ005E, NZ005F, NZ005G, NZ005J, NZ005K, NZ005L, NZ005M, NZ005N, NZ005Q, NZ005R, NZ005S, NZ005T, NZ005U, NZ005Y, NZ005Z, NZ0061, NZ0063, NZ0065, NZ0066, NZ0067, NZ0068, NZ0069, NZ006A, NZ006B, NZ006C, NZ006D, NZ006E, NZ006F, NZ006G, NZ006H, NZ006J, NZ006K, NZ006L, NZ006M, NZ006N, NZ006Q, NZ006R, NZ006S, NZ006T, NZ006U, NZ006V, NZ0073, NZ007B, NZ007C, NZ007D, NZ007E, NZ007F, US0002, US0004, US0005, US0009, US000C, US000G, US000H, US000J, US000K, US000R, US001R, US001Z, US0021, US003P, US005K, US005W, USL004, USL009, USL00A, USL00B, USL00E, USL00F, USL00N, USL00Z, USL013, USL016, USL018, USL01A, ZA0002, ZA0007, ZA000A, ZA000C, ZA000D and ZA000F.

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July Phoenicids (PHE#176) and psi-Phoenicids (PPH#769)

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The July Phoenicids and psi-Phoenicids have radiants that overlap in Sun-centered ecliptic coordinates, and the orbits for the available modern solutions in the IAU-MDC Working List of Meteor Showers are very similar. We recommend merging the solutions under a single entry in the Working List.

1 Introduction

The July Phoenicids (PHE#176) were first recognized in 1957 by Weiss (1960a) and observed in 1958 data (Weiss, 1960b) using the Adelaide radar observations. Detections during five sessions between 1953 and 1958 led Weiss to conclude this shower may be classed as permanent. The shower was added to the IAU-MDC Working List of

Meteor Showers (Jopek and Kaňuchová, 2017) by Jenniskens (2006) based on Cook (1973). This shower has never been detected by optical (visual, photographic or video) techniques and no activity from this source has been detected from Global Meteor Network low-light camera data. A new solution for this shower has been obtained by Jenniskens (2023) based upon SAAMER radar observations for 2017 to 2019.

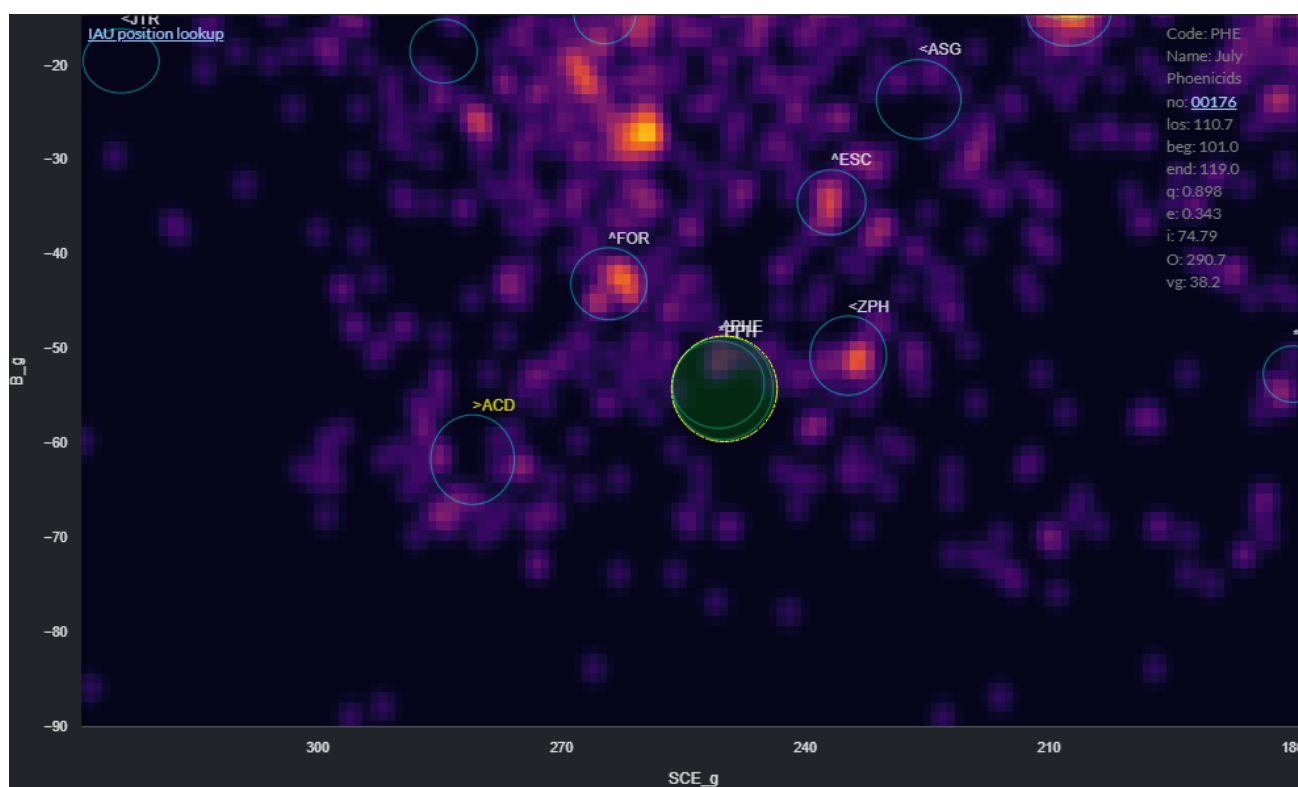


Figure 1 – GMN RadiantMap for $\lambda_0 = 112^\circ$ in 2026 with the radiants for PHE#176 and PPH#769 within the yellow circle.

The psi-Phoenicids (PPH#769) were discovered and reported by Pokorný et al. (2017) using the data from 2012 to 2015 of the Southern Argentina Agile MEteor Radar (SAAMER) but it was not recognized as a solution for the July Phoenicids. This shower was confirmed by Greaves (2026a) using 2020 to 2023 SAAMER data and identifying 899 radar orbits as psi-Phoenicids. This solution has been reported to the IAU-MDC. The psi-Phoenicids were reassessed by Greaves (2026b) against the newly released PANSY radar meteor orbit dataset (Vierinen et al., 2026) using D-criteria. A total of 156 orbits fitted the criteria and provided further independent confirmation of this shower and this solution has also been reported to the IAU-MDC.

2 Overlapping radiants

During a routine check-up, the RadiantMap tool for $\lambda_O = 112^\circ$ in 2026 in Sun-centered geocentric ecliptic coordinates shows the PHE radiant and the PPH radiant overlapping each other (*Figure 1*). Some neighboring shower radiants show distinct activity, for instance the zeta-Phoenicids (ZPH#768), the Fornacids (FOR#1066) and the eta-Sculptorids (ESC#1067) but no clear activity can be seen at the position of the PHE and PPH radiants.

Comparing the available solutions in *Table 1* for both shower entries it appears that the psi-Phoenicids are identical to the July Phoenicids. The first solution taken from Cook (1973) is misleading. Cook based his data on two papers by Weiss (1960a, 1960b) where only radiant positions, radiant drift and hourly rates were derived. Cook (1973) does not state the source of the adopted velocity; his range of orbital elements corresponds to the Weiss radiant combined with an assumed speed of about 44–50 km/s. The original publication by Cook mentions a range for the orbital elements with semi-major axis between 2.5 AU and ∞ , eccentricity between 0.62 and 1.00, perihelion distance 0.96 to 0.97 AU, inclination between 82° and 87° , argument of perihelion between 24° and 31° and an ascending node at 289.6° . The MDC lists an arbitrary end-member of Cook's range which does not match its own v_g so that the MDC entry is internally inconsistent. Recomputing the orbit with the currently known geocentric velocity shows that the Weiss radiant is the psi-Phoenicid radiant: the Southworth and Hawkins (1963) D_{SH} and Drummond (1981) D_D values are in good agreement (* in *Table 1*). The modern solutions agree closely with each other ($D_{SH} = 0.007$ – 0.055). The Jenniskens (2023) solution for PHE#176 and the Pokorný

Table 1 – The solutions listed in the IAU-MDC Working List of Meteor Showers for the July Phoenicids and the psi-Phoenicids. The solution for Cook (1973) recomputed with $v_g = 38.2$ km/s (*) has been added. The D_{SH} and D_D values are given for each solution with Cook, 1973 (*) as reference orbit. Pokorný et al. (2017) is based on SAAMER data from 2012 to 2015, Jenniskens (2023) is based on SAAMER data from 2017 to 2019, Greaves (2026a) is based on SAAMER data from 2020 to 2023, Greaves 2026b is based on PANSY radar data from 2025 January 26 to 2026 July 26.

	PHE#176 Cook, 1973	PHE#176 Cook, 1973(*)	PHE#176 Jenniskens, 2023	PPH#769 Pokorný et al. 2017	PPH#769 Greaves 2026a	PPH#769 Greaves 2026b
λ_O (°)	110.30	110.30	110.7	111	111.4	110.6
λ_{Ob} (°)	101.70	101.70	101.0	98	–	107.4
λ_{Oe} (°)	116.70	116.70	119.0	120	–	114.9
α_g (°)	31.58	31.58	29.1	30.1	29.9	29.8
δ_g (°)	−47.78	−47.78	−48.3	−46.9	−47.2	−47.0
$\Delta\alpha_g$ (°)	0.94	0.94	0.88	0.84	–	–
$\Delta\delta_g$ (°)	0.38	0.38	0.58	0.59	–	–
v_g (km/s)	47	38.2 (*)	38.2	37.6	37.3	37.7
λ_g (°)	2.83	2.83	0.3	2.32	1.84	2.02
$\lambda_g - \lambda_O$ (°)	252.53	252.53	249.6	251.32	250.44	251.41
β_g (°)	−55.03	−55.03	−54.4	−53.73	−53.89	−53.65
a (AU)	∞	1.36	1.34	1.26	1.26	1.26
q (AU)	0.97	0.927	0.897	0.890	0.888	0.891
e	1.0	0.320	0.339	0.291	0.295	0.293
i (°)	87.00	74.9	74.8	74.8	74.48	75.0
ω (°)	23.89	50.3	58.9	63.3	63.65	62.8
Ω (°)	290.30	290.3	290.7	291	291.06	290.6
Π (°)	314.19	340.6	349.6	354.3	354.71	353.4
T_J	–	4.07	4.32	4.39	4.38	4.37
D_{SH} (*)	–	–	0.062	0.085	0.087	0.081
D_D (*)	–	–	0.037	0.056	0.052	0.053
N	n.a.	n.a.	6887	673	899	156

et al. (2017) solution for PPH#769 are within all six limits of the maximum-sigma duplicate test of Jopek et al. (2024): the differences are 1.7° in $\lambda_g - \lambda_o$, 0.7° in β_g , 0.6 km/s in v_g , 4.4° in ω , 0.3° in Ω and 0.0° in i (limits 5° , 3° , 2.5 km/s, 9° , 7.5° and 5°). Both Greaves (2026a; 2026b) solutions are also within all six limits.

Without lookup tables and with data that do not match the values in the cited reference, the solution by Cook (1973) does not fulfill the current requirements to be listed in the Working List of Meteor Showers¹⁴ (Hajduková et al., 2023). The three SAAMER solutions use different years (2012–2015, 2017–2019 and 2020–2023), and Greaves (2026b), based upon PANSY data, is the only confirmation with a different instrument. Note that the inset in Figure 1 is the 2022 MDC submission by Jenniskens but the actual publication in Jenniskens (2023) is different and has been included in Table 1. Also, in Jenniskens (2023) the semi-major axis $a = 1.34$ AU does not equal $q/(1-e)$ (1.357 AU) and $T_J = 4.32$ does not follow from its own a , e and i , which give 4.13.

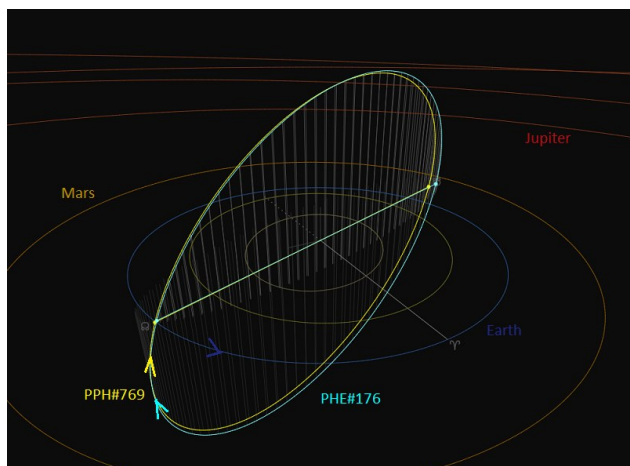


Figure 2 – The solution by Pokorný et al. (2017) for PPH#769 (yellow) compared to the solution by Jenniskens (2023) for PHE#176 (blue). (Plotted with the Orbit visualization app provided by Pető Zsolt).

3 Conclusion

The psi-Phoenicids (PPH#769) are another solution for the July Phoenicids (PHE#176). Therefore, it is recommended to keep the PHE#176 designation, remove the Cook solution (or flag it as radiant-only), and move the PPH#769 solutions under #176 (Jenniskens et al., 2020). The solution cited for Cook (1973) agrees with the original observations published by Weiss (1960a; 1960b) for the radiant position and the activity period, but the listed geocentric velocity has never been measured and is an estimate. The orbital elements listed in the MDC are an arbitrary end-member of the range given by Cook (1973) and do not match the listed geocentric velocity. No activity from this source has been detected from Global Meteor Network low-light camera data (Vida et al., 2020a; 2020b; 2021).

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¹⁴ https://www.ta3.sk/IAUC22DB/MDC2022/Dokumenty/new_reports.php

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Tau-Cetids identified as early eta-Eridanids

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The tau-Cetids (TCT#598) were included in the IAU-MDC Working List of Meteor Showers without an orbit solution. This study shows that the tau-Cetids coincide with the start of the eta-Eridanids. The reference orbit computed for the tau-Cetids agrees with the orbit of the early eta-Eridanids, and the best parent-body match is the proposed parent of the eta-Eridanids, C/1852 K1 (Chacornac). The entry for the tau-Cetids should be moved as a new solution under the eta-Eridanids (ERI#191), and TCT#598 listed with the removed showers as a duplicate. The early eta-Eridanid activity has been investigated: continuous daily activity is visible in the GMN radiant maps from $\lambda_O \approx 111^\circ$, and the orbit-based sample of the early eta-Eridanids starts at $\lambda_O = 111.6^\circ$.

1 Introduction

The epsilon-Eridanids were known as a minor shower by Australian visual observers since the 1980s (Wood, 1985). A more formal discovery as the eta-Eridanids was presented at the Meteoroids conference in Kiruna, Sweden by Ohtsuka et al. (2001). Since then, different researchers have investigated the eta-Eridanids and the solutions differ a lot for the activity duration of the shower. In the GMN shower

reference table, the activity starts at $\lambda_O = 118^\circ$ when the radiant in equatorial coordinates is in the constellation of Cetus. In Sun-centered geocentric ecliptic coordinates, the radiant position is very stable with almost no drift during the long activity period (*Figure 2*). Browsing the radiant density maps with the IAU-MDC radiant data, the tau-Cetids (TCT#598) radiant coincides with the eta-Eridanids (ERI#191) radiant position between solar longitude 115° and 121° (*Figures 1 to 3*).

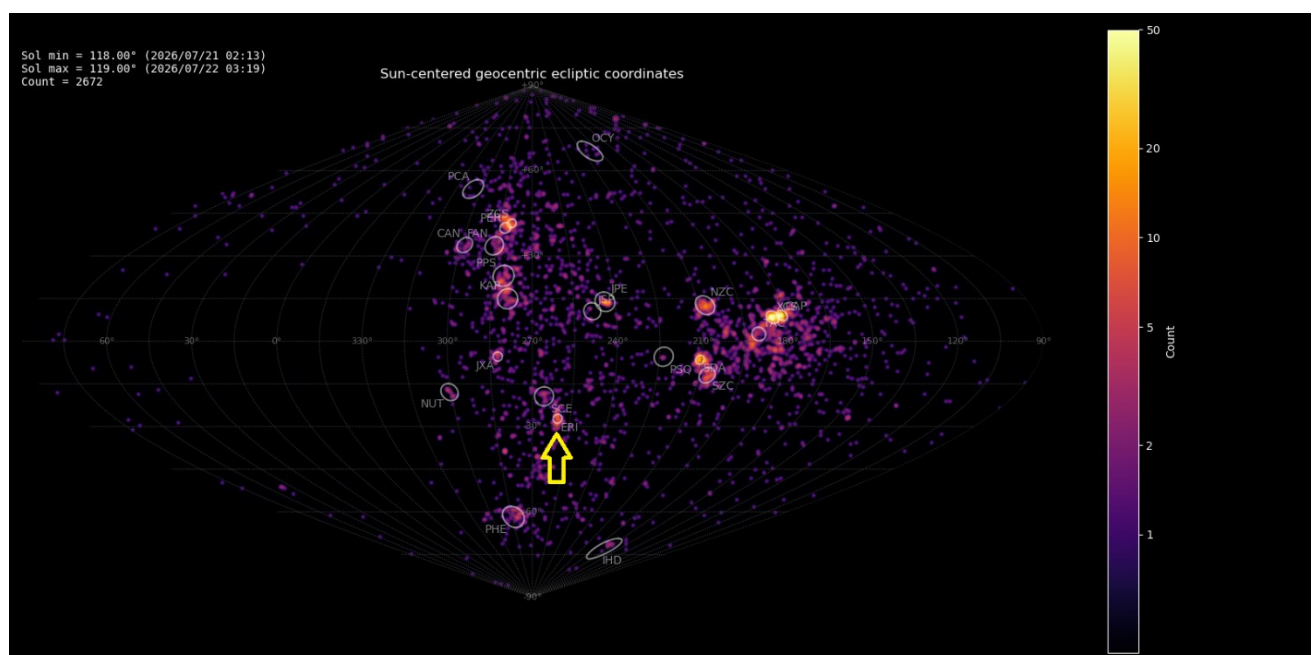


Figure 1 – Radiant density map with 2672 radiants obtained by the Global Meteor Network between solar longitudes 118° – 119° in 2026. The position of the tau-Cetids and eta-Eridanids in Sun-centered geocentric ecliptic coordinates is marked with a yellow arrow.

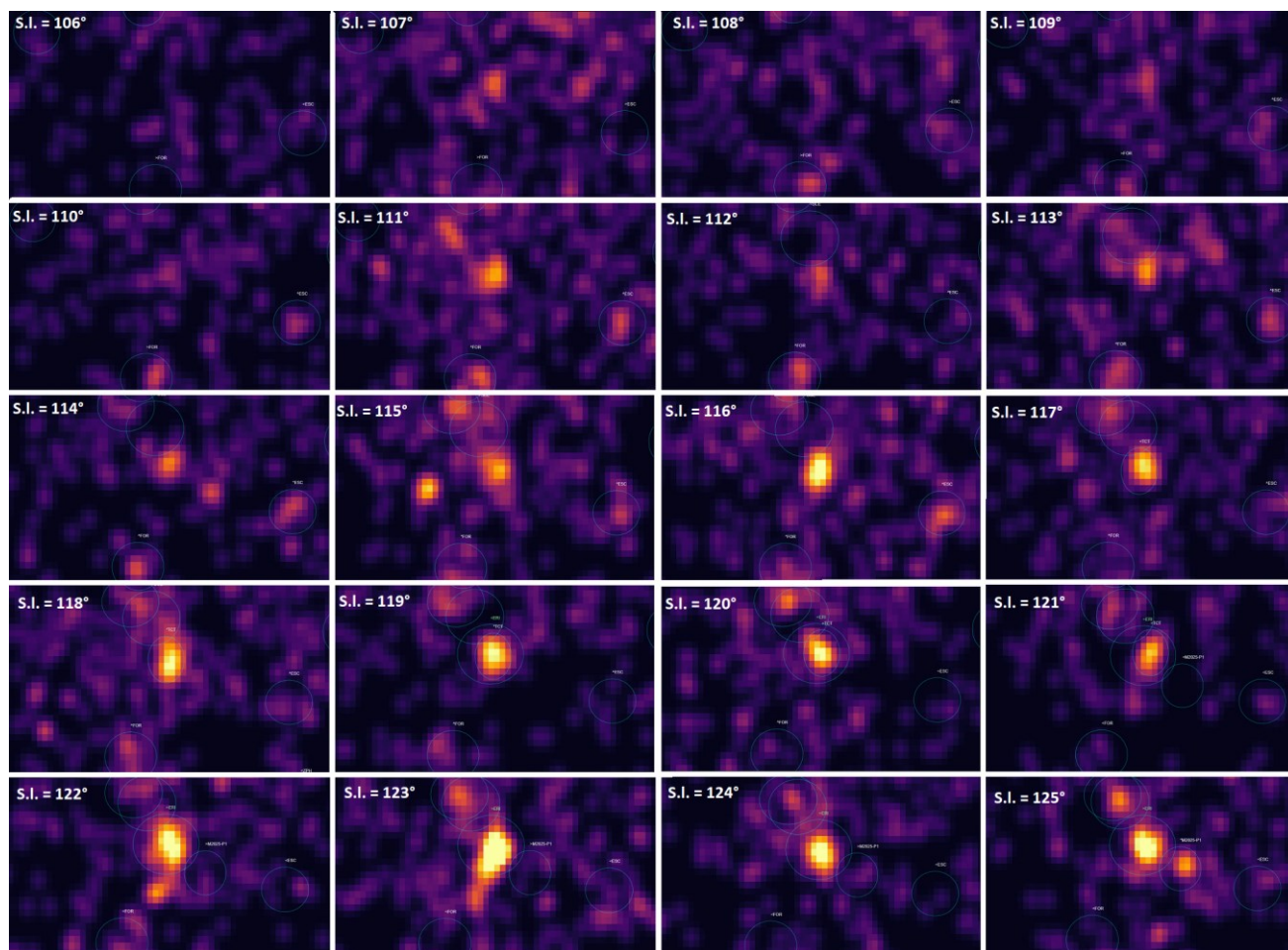


Figure 2 – The daily variation on the GMN RadiantMap from $\lambda_0 = 106^\circ$ to $\lambda_0 = 125^\circ$, centered on the ERI#191 radiant in Sun-centered geocentric ecliptic coordinates. The position of the tau-Cetids coincides completely with the eta-Eridanids radiant.

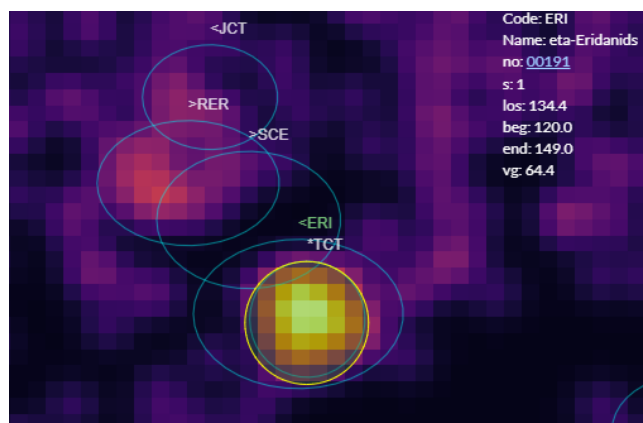


Figure 3 – Screenshot from the RadiantMap with the selected region of interest for the tau-Cetids alias eta-Eridanids activity source in 2026, marked in the yellow circle. Close-up at $\lambda_0 = 119^\circ$. The ERI circle and the inset are the Jenniskens (2023) solution.

2 Shower classification based on radiants

The RadiantMap tool allows the visualization of the meteor shower radiants in different coordinate systems and different projections with either the GMN shower references or the actual IAU-MDC Working List of Meteor Showers. The radiant viewer displays the actually observed radiant density and compares this directly to the different

theoretical reference sources. Figure 2 shows the evolution of the radiant density distribution near the eta-Eridanids¹⁵ radiant. This plot displays several interesting features. From $\lambda_0 = 111^\circ$ we see continuous activity at the ERI-radiant position, confirming the start of the shower activity at $\lambda_0 = 110.75^\circ$ as listed in the IAU-MDC list by Shiba (2023b), however the cited reference page 107 mentions solar longitude 114° to 158° as activity period. Some very weak activity is present at the radiant position from $\lambda_0 = 107^\circ$ onward. The snapshot for $\lambda_0 = 117^\circ$ shows that the early eta-Eridanid activity is labelled as TCT or tau-Cetids. At $\lambda_0 = 119^\circ$ this activity coincides with the eta-Eridanids radiant. Figure 3 shows a close-up with the tau-Cetids completely embedded within the radiant of the eta-Eridanids. Some other interesting features appear in Figure 2. At $\lambda_0 = 115^\circ$ the radiant of the recently discovered shower M2026-R1 appears to the left of the ERI-radiant (Roggemans et al., 2026a). In the frames from $\lambda_0 = 121^\circ$ to $\lambda_0 = 123^\circ$ a so far unknown activity appears just south of the ERI-radiant, and in the frame $\lambda_0 = 125^\circ$ we see that the new shower M2025-P1 produced again activity in 2026 (Šegon et al., 2025).

The tau-Cetids were reported based on single-station video camera measurements where triangulated trajectories were

¹⁵ https://www.ta3.sk/IAUC22DB/MDC2022/Roje/pojedynczy_o_biekt.php?lporz=00643&kodstrumienia=00191

not available (Molau and Kerr, 2014). A possible explanation for this duplicate entry is in the MDC record itself: when the tau-Cetids were added (December 2013), the only ERI solutions were Ohtsuka et al. (2001) and SonotaCo (2009; λ_0 124.1°–147.4°). Only the later solutions (Jenniskens et al., 2016; Shiba, 2023b) cover the TCT period. Shiba (2023a, Table 2, page 120) listed TCT as a synonym for ERI. In order to test whether the tau-Cetids are actually the eta-Eridanids, a radiant and orbit-based analysis has been made.

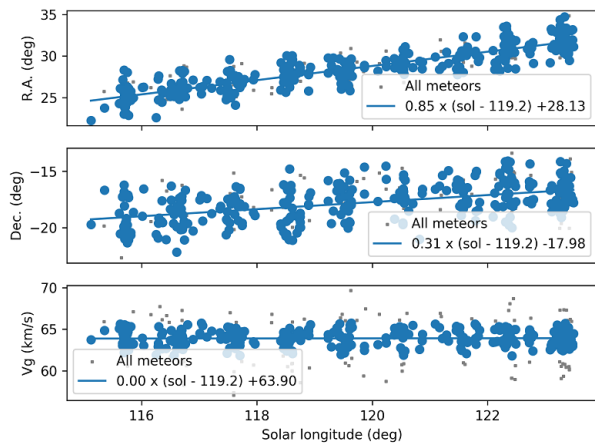


Figure 4 – The TCT-radiant drift in 2026.

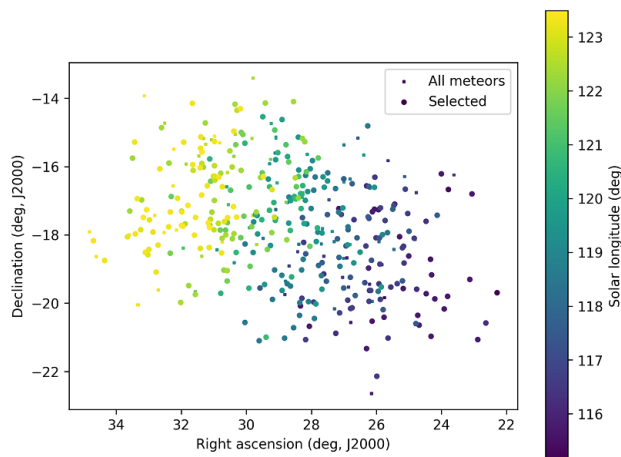


Figure 5 – The radiant distribution in 2026 during the solar-longitude interval 115.1° – 123.5° in equatorial coordinates.

The radiant drift computed for the solar-longitude interval 115.1° – 123.5° aligns the expected tau-Cetids activity perfectly with the early eta-Eridanids (Figure 4). This radiant drift is also very obvious in the radiant plot in equatorial coordinates (Figure 5). In Sun-centered geocentric ecliptic coordinates the shower radiant contracts into a rather stable compact area (Figure 6). The radiant drift in Sun-centered ecliptic coordinates is negligible during the long activity period of the eta-Eridanids.

Since the original discovery of the tau-Cetids was without orbital elements, it is difficult to prove any association. The best we can do is to compute the mean orbit for the selection of meteor radiants that coincide with the assumed tau-Cetids region of interest. Duplicate solutions of the same meteor were not removed. In a comparable selection of the 2026 data, 49 of 421 orbits (12%) were duplicates;

removing them changes the radiant by less than 0.03°, v_g by 0.03 km/s and the orbital elements by less than 0.15°.

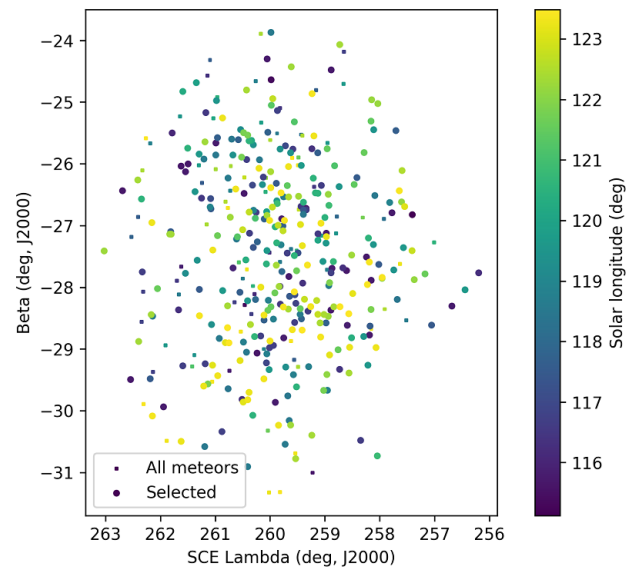


Figure 6 – The radiant distribution in 2026 during the solar-longitude interval 115.1° – 123.5° in Sun-centered ecliptic coordinates.

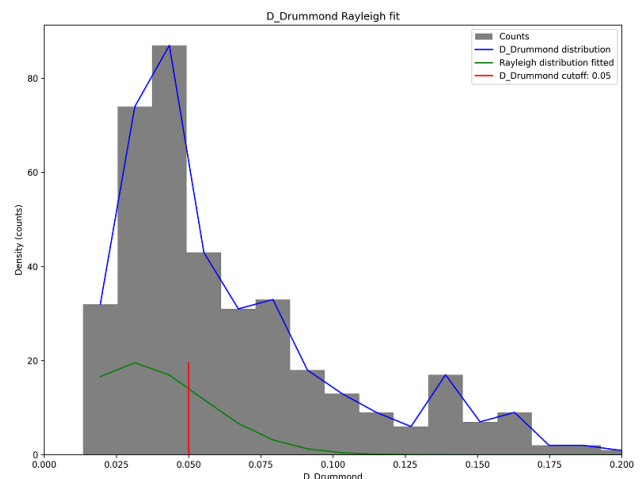


Figure 7 – D_D distribution of the 2026 RadiantMap candidates with a Rayleigh curve; $D_D < 0.05$ was adopted.

The RadiantMap tool (M. Kalina, unpublished; Vida et al., 2021) selected the meteors in the region of interest of Figure 3 (radius 4.0°) between $\lambda_0 = 115.1^\circ$ and 123.5° , fitted a linear radiant drift, removed the meteors more than 4.1° (2.5 times the median offset) from the drifting radiant or more than 2 km/s from the fitted v_g , and refitted the drift. Using the 2026 data, initially 397 possible shower members were selected and after removal of outliers, 310 members remained for final analysis. The final median dispersion of the 310 members is 1.6°, giving an association radius (2.5 times) of 3.9°. The resulting mean orbit obtained for the radiant method is listed in Table 1.

3 Shower classification based on orbits

A complete independent meteoroid stream search has been applied to orbit data obtained between solar longitude 108° and 130° during the years 2019–2026. The method has been described in detail in a separate publication (Roggemans et

al., 2026b). 280307 orbits including trajectory duplicates were available within this time interval and a final mean orbit has been computed by the method of Jopek et al. (2006) for the thresholds $D_{SH} < 0.125$ and $D_D < 0.05$ and $D_J < 0.125$ (Southworth and Hawkins, 1963; Drummond, 1981; Jopek, 1993), based upon *Figure 7* obtained by the radiant method. The resulting mean orbit for 918 meteors was identified as eta-Eridanids recorded between solar longitude 111.6° and 128.5° . Limiting the selected orbits to the activity period of the tau-Cetids (118° to 121° in solar longitude), 223 meteors remain to compute a mean orbit for the meteors that fit within the given TCT activity period, see *Table 1*.

The radiant drift of meteors within the TCT-activity period fits perfectly with the radiant drift for the early eta-Eridanids (*Figures 8 and 9*).

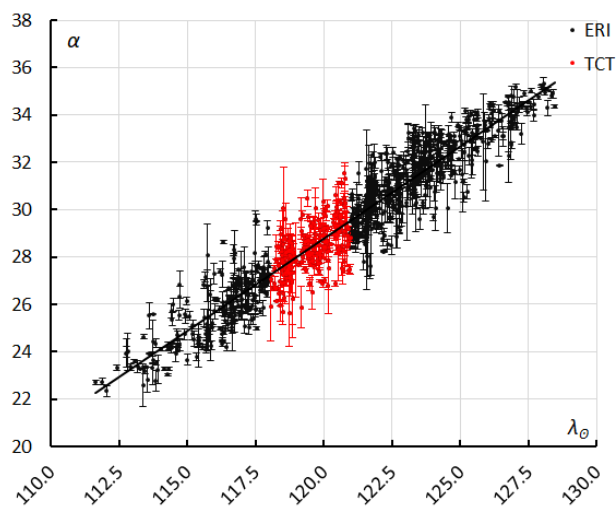


Figure 8 – The radiant drift in Right Ascension, meteors within the TCT activity period are marked in red.

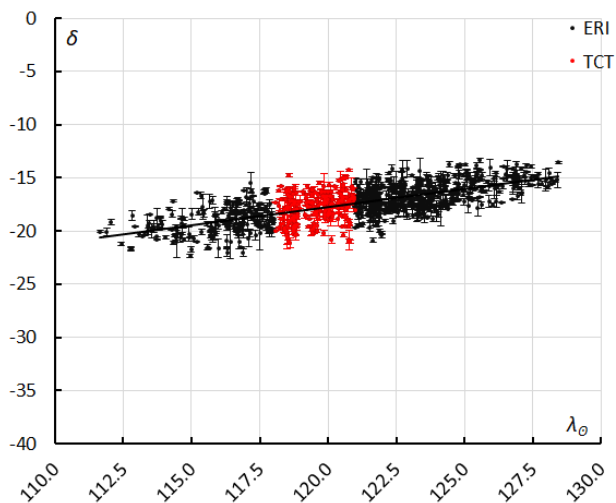


Figure 9 – The radiant drift in declination, meteors within the TCT activity period are marked in red.

The number of ERI-meteors as a percentage relative to the total number of meteors recorded in 1° bins, with steps of 0.25° in solar longitude results in the profile plotted in *Figure 10*. The activity of the ERI-meteors seems to fluctuate with successive sub-peaks, these could be statistical variations in a single year of data. This irregular

activity is also visible in *Figure 2* as the intensity of the radiant density fluctuates from day to day.

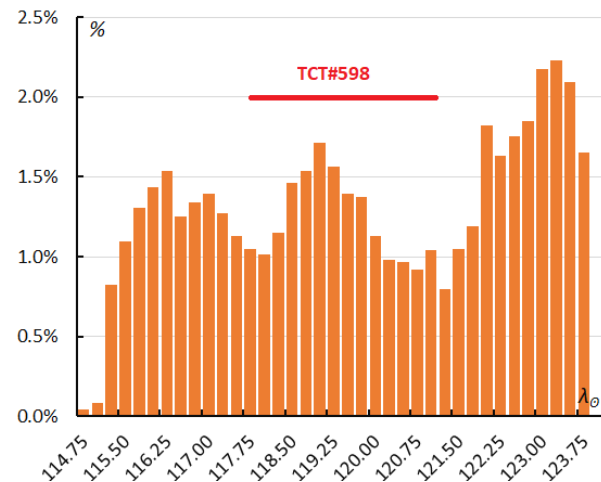


Figure 10 – The percentage of TCT (alias ERI)-meteors relative to the total number of meteors recorded in 2026 (radiant method).

4 The orbit and parent body

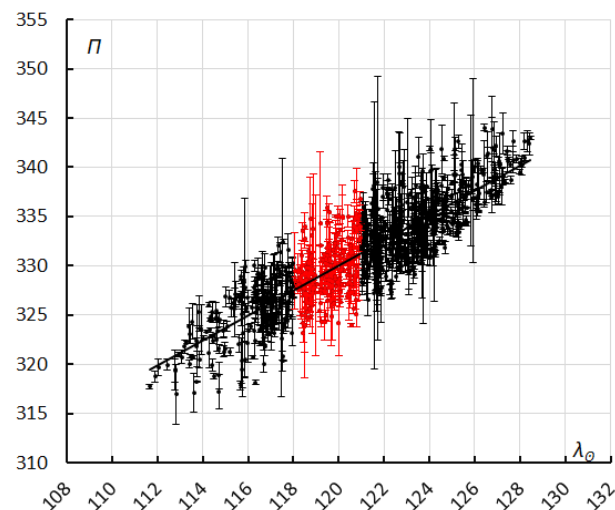


Figure 11 – The change in longitude of perihelion Π as a function of the solar longitude, meteors during the TCT activity are marked in red.

The shower identification methods are not suitable to cover very long duration shower activity using a single mean orbit as a reference. The reason is that the orientation of the meteoroid stream orbit changes during the transit of the Earth. In the case of the eta-Eridanids, the orbit is very stable in perihelion distance, eccentricity, inclination and argument of perihelion, while the node, and with it the longitude of perihelion, increases by about 1° per degree of solar longitude. A selection with a single reference orbit favors orbits with a smaller argument of perihelion before and a larger one after the reference solar longitude, which makes the slope of Π in *Figure 11* appear steeper than 1. The orbits identified as tau-Cetids fit perfectly within this trend and this drift fits well with the solutions for ERI given in the MDC entry at solar longitudes 137.0° (Jenniskens et al., 2016), 138.57° (Shiba, 2023b) and 134.4° (Jenniskens, 2023).

Table 1 – Comparing solutions derived by two different methods, TCT based on radiant positions for 2026, TCT based on the orbit association method for $D_D < 0.05$ for 2019–2026 and the first 17 days of eta-Eridanids activity. H_b , H_e and H_p are the begin, end and peak-brightness heights, and Mag_{Ap} is the median peak absolute magnitude. The range of the activity covered are chosen windows for TCT or the limits where the single reference orbit stops matching, none of them is an activity limit. α_g and δ_g are the drift-fit values at $\lambda_O = 119.2^\circ$ for the radiant method (*Figure 4*).

	TCT radiant method 2026	TCT orbit method 2019–2026 $D_D < 0.05$	ERI orbit method 2019–2026 $D_D < 0.05$
λ_O ($^\circ$)	119.6	119.6	121.3
λ_{Ob} ($^\circ$)	115.1	118.0	111.6
λ_{Oe} ($^\circ$)	123.5	121.0	128.5
α_g ($^\circ$)	28.1	28.4	29.6
δ_g ($^\circ$)	–18.0	–17.7	–17.4
$\Delta\alpha_g/\lambda_O$ ($^\circ/^\circ$)	+0.85	+0.72	+0.78
$\Delta\delta_g/\lambda_O$ ($^\circ/^\circ$)	+0.31	+0.41	+0.34
v_g (km/s)	63.9	64.1	64.0
H_b (km)	110.4	111.6	111.4
H_e (km)	97.0	98.1	97.7
H_p (km)	102.1	102.3	102.3
Mag_{Ap}	–1.0	–1.1	–1.2
λ_g ($^\circ$)	19.4	19.3	20.8
$\lambda_g - \lambda_O$ ($^\circ$)	259.8	259.8	259.7
β_g ($^\circ$)	–27.5	–27.4	–27.5
a (A.U.)	12.5	14.3	14.0
q (A.U.)	0.948	0.949	0.946
e	0.924	0.934	0.933
i ($^\circ$)	131.9	132.1	132.0
ω ($^\circ$)	30.1	30.0	30.2
Ω ($^\circ$)	299.9	299.6	300.9
Π ($^\circ$)	329.9	329.6	331.2
T_J	–0.37	–0.43	–0.42
N	310	223	918

With a Tisserand parameter relative to Jupiter $T_J = -0.42$ and a period of about 52 years, this is a Halley-type comet orbit (Tancredi, 2014) with a retrograde inclination of 132° . The orbit solutions in *Table 1* for the TCT activity period and the early ERI activity agree. The independent evidence is the continuity of the orbits through the tau-Cetid period. Mean orbits from the GMN 2026 data, selected by radiant position without a reference orbit, keep ω between 29.4° and 30.4° and i between 131.4° and 132.5° from $\lambda_O = 111^\circ$ to 140° , while Ω increases from 293.1° to 317.3° and Π from 322.5° to 347.3° . The last values match the published eta-Eridanid solutions ($\Omega = 317.7^\circ$, $\Pi = 346.1^\circ$, Jenniskens et al., 2016; $\Omega = 318.6^\circ$, $\Pi = 346.5^\circ$, Shiba, 2023b). This is also obvious in the plotted version of the orbits (*Figure 12*). The maximum-sigma duplicate test (Jopek et al., 2024) between the solutions in *Table 1* and the ERI solutions in

the MDC fails only on the node, because the TCT and early ERI orbits refer to solar longitudes 13° – 19° earlier.

A search for possible parent bodies reveals C/1852 K1 (Chacornac) as the best match ($D_D = 0.118$, $D_{SH} = 0.284$), which is also the parent body proposed for the eta-Eridanids (Ohtsuka et al., 2001).

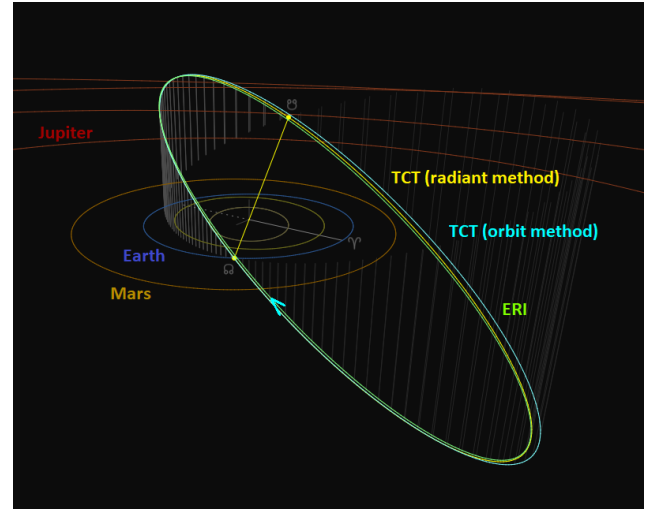


Figure 12 – The solutions for 2026 with the radiant method (yellow), for the orbit method applied to TCT 2019–2026 (blue) and for the first weeks of ERI-activity 2019–2026 (green). (Plotted with the Orbit visualization app provided by Pető Zsolt).

Table 2 – Top ten matches of a search for possible parent bodies with $D_D < 0.25$, based upon the mean orbit derived from the radiant classification method on 2026 data. Reproduced with JPL ELEMENTS.COMET of 2026-09-28.

Name	D_D	D_{SH}
C/1852 K1 (Chacornac)	0.118	0.284
C/2020 H2 (Pruyne)	0.153	0.393
C/2013 UQ4 (Catalina)	0.163	0.477
273P/Pons-Gambart	0.184	0.503
C/1877 G1 (Winnecke)	0.186	0.490
C/2020 R4 (ATLAS)	0.206	0.602
C/1886 J1 (Brooks)	0.215	0.624
C/1947 S1 (Bester)	0.228	0.533
C/1994 G1-A (Takamizawa-Levy)	0.234	0.618
C/1946 K1 (Pajdusakova-Rotbart-Weber)	0.236	0.674

5 Conclusion

The RadiantMap tool shows that the tau-Cetids (TCT#598) radiant coincides with the eta-Eridanids radiant at the start of its activity. Global Meteor Network data allowed computation of the missing reference orbit for the TCT-entry in the IAU-MDC Working List of Meteor Showers which agrees with the orbit of the early eta-Eridanids. Both share the same parent-body candidate, C/1852 K1 (Chacornac) as best match although the D-criteria values for the TCT orbit are above the association limits. The parent body association for the Jenniskens (2023) solution at the eta-Eridanids maximum fits much better with $D_D = 0.05$.

The early eta-Eridanids activity has been investigated and continuous activity is visible from $\lambda_{\odot} \approx 111^{\circ}$ (Figure 2), with very weak activity at the radiant position from $\lambda_{\odot} = 107^{\circ}$. The eta-Eridanid radiant shows almost no drift in Sun-centered geocentric ecliptic coordinates.

The entry for the tau-Cetids (TCT#598) should be moved as a new solution under the eta-Eridanids (ERI#191), and TCT#598 should be listed with the removed showers as a duplicate of ERI#191.

Acknowledgments

This report is based on the data of the Global Meteor Network (Vida et al., 2020a; 2020b; 2021) which is released under the CC BY 4.0 license¹⁶. We thank all 927 participants in the Global Meteor Network project for their contribution and perseverance. A list with the names of the volunteers who contribute to GMN has been published in the 2025 annual report (Roggemans et al., 2026c). The following 732 cameras in 34 countries (Antarctica, Austria, Australia, Bosnia Herzegovina, Belgium, Bulgaria, Brazil, Canada, Chile, Croatia, Czech Republic, France, Germany, Greece, Hungary, Israel, Italy, Japan, Malaysia, Mexico, Netherlands, New Zealand, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, South Africa, South Korea, Spain, Switzerland, United Kingdom and the United States) contributed to paired meteors used in this study:

AQ0003, AQ000A, AT0004, AU0001, AU0002, AU0003, AU0004, AU0006, AU000A, AU000B, AU000C, AU000D, AU000E, AU000F, AU000G, AU000L, AU000Q, AU000R, AU000S, AU000T, AU000U, AU000V, AU000W, AU000X, AU000Y, AU000Z, AU0010, AU001A, AU001B, AU001C, AU001D, AU001E, AU001F, AU001G, AU001K, AU001L, AU001N, AU001P, AU001Q, AU001R, AU001S, AU001T, AU001U, AU001V, AU001W, AU001X, AU001Y, AU001Z, AU0028, AU0029, AU002A, AU002B, AU002C, AU002D, AU002E, AU002F, AU0030, AU0031, AU0035, AU0038, AU003E, AU003F, AU003H, AU003J, AU0040, AU0042, AU0043, AU0045, AU0046, AU0047, AU0048, AU004B, AU004H, AU004K, AU004L, AU004M, AU004Q, AU004R, AU004U, BA0001, BA0005, BE0005, BE000D, BE000H, BE000L, BE000P, BE000T, BE000U, BE000Z, BE0010, BE0011, BE0012, BE001A, BE001B, BG0001, BG0003, BG0004, BG0008, BG000B, BG000D, BG000G, BG000L, BR0001, BR0002, BR0003, BR000F, BR000G, BR000J, BR000Q, BR000S, BR000T, BR000W, BR000Y, BR0013, BR0014, BR0015, BR001F, BR001H, BR001J, BR001M, BR001R, BR001T, BR001W, BR0021, BR0029, BR002B, BR002C, CA0005, CA0009, CA000F, CA000L, CA000P, CA000Q, CA000R, CA000W, CA0012, CA0015, CA001A, CA001R, CA0022, CA0023, CA002F, CA0036, CA003C, CAC0B1, CAC0B4, CAC0B6, CAWEC1, CH0002, CH0003, CH0005, CL0002, CL0003, CZ0007, DE0001, DE0002, DE0005, DE0008, DE0009, DE0015, DE0016, ES0001, ES0003, ES0005, ES0006, ES0008,

ES000B, ES000C, ES000D, ES000E, ES000F, ES000H, ES000N, ES000P, ES000Q, ES000T, ES000U, ES000V, ES000W, ES000X, ES000Z, ES0013, ES0016, ES0019, ES001A, ES001D, ES001F, ES001J, FR0006, FR000G, FR000V, FR000X, FR000Y, FR000Z, FR0011, FR0013, GR0002, GR0003, GR0004, GR0006, GR0007, GR0008, GR0009, HR0001, HR0002, HR0004, HR0006, HR0008, HR000D, HR000F, HR000H, HR000J, HR000K, HR000M, HR000P, HR000Q, HR000R, HR000S, HR000T, HR000V, HR000Z, HR0010, HR0016, HR0018, HR001A, HR001E, HR001G, HR001X, HR001Z, HR0024, HR0025, HR002D, HR002F, HR002H, HR002J, HR002K, HR002L, HR002M, HR002R, HR002T, HR002V, HR002W, HR002X, HR002Y, HR002Z, HU0001, HU0002, HU0003, HU0004, HU0007, HU0008, HU000B, HU000D, HU000E, IL0002, IL0004, IL000A, IT0001, IT0004, IT0008, JP0005, JP0006, KR0002, KR0003, KR0004, KR0005, KR0006, KR0007, KR0008, KR000A, KR000B, KR000C, KR000E, KR000F, KR000H, KR000J, KR000K, KR000L, KR000N, KR000P, KR000R, KR000S, KR000Z, KR0010, KR0011, KR0012, KR0013, KR0015, KR0016, KR0017, KR0018, KR0019, KR001A, KR001B, KR001C, KR001D, KR001E, KR001F, KR001G, KR001H, KR001J, KR001K, KR001N, KR001P, KR001Q, KR001U, KR001W, KR001X, KR001Y, KR001Z, KR0022, KR0023, KR0024, KR0025, KR0027, KR0028, KR0029, KR002A, KR002B, KR002C, KR002D, KR002E, KR002F, KR002G, KR002H, KR002J, KR002N, KR002P, KR002Q, KR002R, KR002S, KR0039, KR003A, KR003B, KR003C, KR003D, KR003E, KR003F, KR003H, KR003K, KR003M, KR003N, KR003R, KR003X, MX0003, MX0007, MX0009, MX000D, MY0005, MY0009, NL0006, NL000Z, NL0010, NZ0001, NZ0002, NZ0003, NZ0004, NZ0007, NZ0008, NZ0009, NZ000A, NZ000B, NZ000D, NZ000F, NZ000G, NZ000H, NZ000J, NZ000K, NZ000L, NZ000M, NZ000N, NZ000P, NZ000Q, NZ000R, NZ000S, NZ000T, NZ000U, NZ000V, NZ000W, NZ000X, NZ000Y, NZ000Z, NZ0010, NZ0011, NZ0012, NZ0013, NZ0014, NZ0015, NZ0016, NZ0017, NZ0018, NZ0019, NZ001A, NZ001B, NZ001C, NZ001D, NZ001E, NZ001G, NZ001H, NZ001J, NZ001K, NZ001L, NZ001N, NZ001P, NZ001Q, NZ001R, NZ001S, NZ001V, NZ001W, NZ001X, NZ001Z, NZ0020, NZ0021, NZ0022, NZ0023, NZ0024, NZ0025, NZ0026, NZ0027, NZ0028, NZ0029, NZ002B, NZ002C, NZ002D, NZ002E, NZ002F, NZ002G, NZ002H, NZ002J, NZ002K, NZ002L, NZ002N, NZ002P, NZ002Q, NZ002R, NZ002S, NZ002T, NZ002U, NZ002V, NZ002W, NZ002X, NZ002Y, NZ0030, NZ0032, NZ0033, NZ0034, NZ0035, NZ0036, NZ0037, NZ0038, NZ003A, NZ003B, NZ003C, NZ003E, NZ003F, NZ003G, NZ003H, NZ003K, NZ003L, NZ003M, NZ003N, NZ003Q, NZ003R, NZ003S, NZ003T, NZ003U, NZ003V, NZ003W, NZ003X, NZ003Y, NZ003Z, NZ0040, NZ0041, NZ0042, NZ0044, NZ0045, NZ0046, NZ0049, NZ004A, NZ004B, NZ004C, NZ004D, NZ004E, NZ004F, NZ004H, NZ004J, NZ004L, NZ004M, NZ004N, NZ004R, NZ004S, NZ004T, NZ004U, NZ004V, NZ004X, NZ004Y, NZ004Z, NZ0051, NZ0059, NZ005A, NZ005B, NZ005C, NZ005D, NZ005E,

¹⁶ <https://creativecommons.org/licenses/by/4.0/>

NZ005F, NZ005G, NZ005H, NZ005J, NZ005K, NZ005L, NZ005M, NZ005N, NZ005Q, NZ005R, NZ005S, NZ005T, NZ005U, NZ005Y, NZ005Z, NZ0061, NZ0063, NZ0065, NZ0066, NZ0067, NZ0068, NZ0069, NZ006A, NZ006B, NZ006C, NZ006D, NZ006E, NZ006F, NZ006J, NZ006K, NZ006L, NZ006M, NZ006N, NZ006P, NZ006Q, NZ006R, NZ006S, NZ006T, NZ006U, NZ006V, NZ0073, NZ007B, NZ007C, NZ007D, NZ007E, NZ007F, PL000A, PL000B, PL000E, PL000N, PLM005, PT0002, PT0003, RO0001, RO000A, RO000C, RO000H, RO000Y, RO0019, RU0001, RU0002, RU0003, RU0004, RU0007, RU000B, RU000E, RU000F, RU000L, RU000M, RU000N, RU000Q, RU0011, SI0001, SI0002, SI0005, SI0006, SK0005, UK0001, UK0006, UK0009, UK000H, UK000T, UK001K, UK0024, UK0025, UK002Z, UK0038, UK003J, UK003M, UK003Z, UK004B, UK004F, UK004J, UK0051, UK0055, UK005H, UK0078, UK0089, UK008V, UK008X, UK009C, UK009G, UK009S, UK009W, UK00A1, UK00A5, UK00AM, UK00C7, UK00CE, UK00CJ, US0001, US0002, US0003, US0004, US0005, US0006, US0007, US0008, US0009, US000A, US000C, US000D, US000E, US000G, US000H, US000J, US000K, US000L, US000M, US000N, US000P, US000R, US000U, US000V, US001P, US001R, US001Z, US0020, US0021, US0022, US0023, US002A, US002B, US002D, US002R, US002X, US0030, US0035, US0036, US0038, US0039, US003G, US003M, US003N, US003Q, US003S, US003T, US004B, US004C, US004J, US004N, US004P, US004Q, US0055, US005A, US005B, US005C, US005D, US005E, US005F, US005H, US005N, US005W, US005X, US005Y, US005Z, US0061, US0062, US0066, USC0G4, USC0G5, USL001, USL002, USL003, USL004, USL005, USL006, USL008, USL009, USL00A, USL00B, USL00C, USL00D, USL00E, USL00F, USL00G, USL00J, USL00K, USL00L, USL00M, USL00N, USL00P, USL00Q, USL00V, USL00Z, USL011, USL012, USL013, USL014, USL015, USL016, USL018, USL019, USL01A, USL01B, USL01C, USL01D, USL01E, USV002, USV003, ZA0001, ZA0002, ZA0006, ZA0007, ZA0008, ZA000A, ZA000C and ZA000D.

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Sporadic meteors Part II

Properties of sporadic meteors

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Based on the Global Meteor network (GMN) (Vida et al., 2020a, 2020b, 2021) observations, we examined the physical properties and magnitude distribution of sporadic meteors and proposed the challenges for future video observations to gain insight into the physical properties of meteoroids.

It has been confirmed that sporadic meteors fall into two distinct categories based on their beginning heights. Although Ceplecha (1958) previously noted this phenomenon, the split is more clearly defined by magnitude than by meteor velocity; following Ceplecha's convention, this paper designates the group with lower beginning heights as Group A and the group with higher beginning heights as Group C. While Ceplecha further subdivided these groups, no clear distinctions emerged other than the fact that both Group A and Group C can be split into two subgroups based on a geocentric velocity threshold of 50 km/s. This threshold corresponds to the division between prograde and retrograde orbits; it is considered an apparent effect resulting from geometric constraints required to intersect Earth's orbit, rather than a difference in the physical properties of the meteoroids.

Group A exhibits unique characteristics: the brighter the meteor, the lower its beginning height; furthermore, slow-moving, bright meteors penetrate to lower altitudes before extinguishing. Since meteor magnitude results from the meteoroid's kinetic energy, the fact that Group A meteoroids retain this energy down to lower altitudes indicates they are denser and more robust than those in Group C. While Group C meteoroids are presumed to originate from comets based on their orbital characteristics, it cannot be definitively stated that all Group A meteoroids originate from asteroids; the distribution of orbital elements suggests that some of them actually have cometary origins.

Since the magnitude ratio – which is directly linked to the mass distribution of meteoroids – cannot be determined through video observations, the slope of the linear section of the logarithmic distribution of meteor counts versus magnitude was analyzed. The results showed that the slope increases with geocentric velocity. It was also estimated that Group A exhibits a steeper slope than Group C. Furthermore, a trend of the slope increasing with geocentric velocity was observed within the individual groups as well.

Compared to visual observations, the detection rate of meteors via video observation varies significantly with magnitude; this accounts for why the magnitude ratio calculated from the slope far exceeds generally accepted values. The magnitude data obtained from video observations are problematic, representing a photometric system issue that requires resolution. Furthermore, this detection rate is estimated to be higher for Group C than for Group A, a discrepancy presumably caused by differences in the appearance of the video images between the two groups. For video observation to be utilized not only for meteor shower monitoring but also for research into the physical properties of meteoroids, it will be necessary to consider how to handle these differences in meteor imagery.

In Part I, it was noted that sporadic meteors include contaminants from meteor showers; specifically, the presence of 0001GEM and 0005SDA meteors was identified within Group A. However, it was confirmed that this influence is negligible and does not affect the conclusions drawn in this paper.

1 Introduction

Records concerning meteors tend to focus primarily on meteor showers. While data such as appearance times, radiant, velocities, and orbital elements receive attention, other records often go unused. However, these records contain data that allow for the investigation of the physical properties of meteoroids without relying on spectroscopic observations. In this paper, based on GMN observations, we examine the physical properties of “sporadic meteors” by analyzing their beginning heights and magnitude ratios in video observations. Additionally, we evaluate the characteristics of GMN observations by comparing them with data from the SonotaCo network (SonotaCo, 2009, 2016, 2017, SonotaCo et al., 2021).

2 Groups of sporadic meteors observed in the distribution of beginning and end heights

2.1 Two groups in the beginning heights

Ceplecha (1958) classified sporadic meteors into groups A, B, C1, and C2 based on their beginning heights; indeed, the distribution of beginning heights of sporadic meteors reveals the existence of multiple populations among sporadic meteors. Differences in beginning heights are known to stem from the physical properties of the meteoroids, and the author has pointed out that meteor showers with lower beginning heights exhibit higher degrees of sodium depletion (Koseki, 2025). Thus, the beginning height serves as a significant clue for understanding the physical properties of meteoroids.

The beginning heights of meteors vary depending on both their magnitude and velocity. Advances in video observation technology have led to the accumulation of vast amounts of data, making it possible to separately investigate the relationships between beginning height and speed or magnitude. In the following discussion, we utilize a large dataset from GMN.

We examine the relationship between magnitude and beginning height by grouping the data into sets of 10000 meteors based on geocentric speed (referred to as “ $mag-H_B$ ”), and the relationship between speed and beginning height by grouping them into sets of 10000 meteors based on magnitude (referred to as “ v_g-H_B ”). Similarly, the corresponding metrics for the end heights are designated as “ $mag-H_E$ ” and “ v_g-H_E ”.

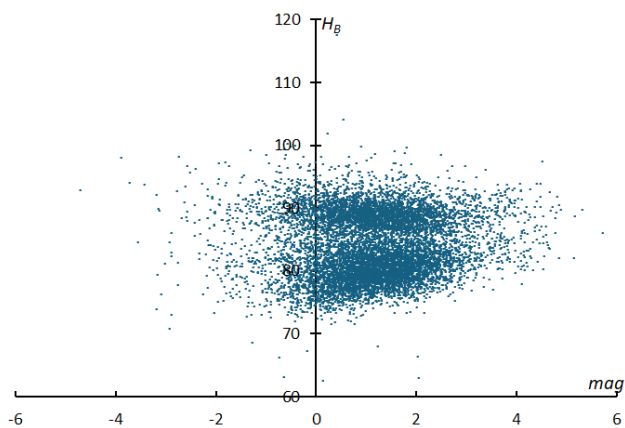


Figure 1 – Relationship between magnitude and beginning height ($mag-H_B$ diagram) for the data subset with a median geocentric velocity of 10.19 km/s, selected from datasets binned by increments of 10000 objects based on geocentric velocity.

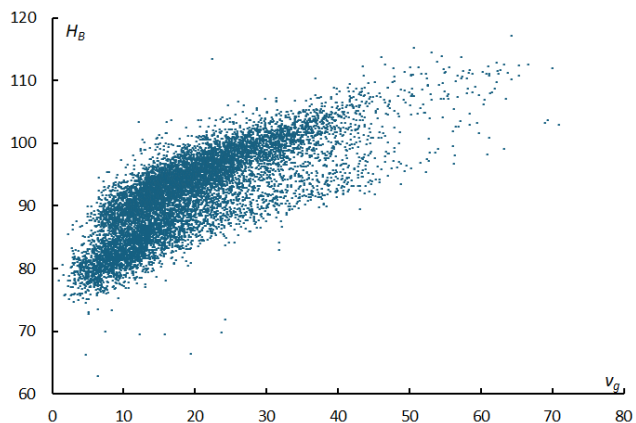


Figure 2 – Relationship between velocity and beginning height (v_g-H_B diagram) for the data subset with a median magnitude of +3.37, selected from datasets binned by increments of 10000 objects based on magnitude.

Figure 1 shows the $mag-H_B$ diagram with a median velocity of 10.19 km/s, while Figure 2 shows the v_g-H_B diagram with a median magnitude of +3.37. Both figures indicate the existence of two groups, but the separation is clearer in the $mag-H_B$ diagram than in the v_g-H_B diagram. Here, following Ceplecha’s terminology, we designate the group with lower beginning heights as Group A and the group with higher heights as Group C (hereinafter simply referred to as A and C). Ceplecha’s “Group B” will be discussed later. Although

Ceplecha’s classification is based on the relationship between pre-atmospheric velocity and the beginning height, this paper divides the meteors into groups A and C using $mag-H_B$. The data used by Ceplecha were limited to photographic meteors captured by Super-Schmidt cameras; due to the insufficient sample size, it was not possible to examine the relationship between the beginning height and magnitude in detail.

Although the boundary is clearer for $mag-H_B$, it is still necessary to determine exactly how that boundary is defined. Here, we examine a dataset where the boundary is difficult to define, using a $mag-H_B$ diagram with a median velocity of 29.59 km/s. First, we arrange 10000 data points in order of magnitude, divide them into ten groups of 1000, and analyze the distribution of beginning heights. Figure 3 shows the distributions for some of these ten groups – derived from the dataset with a median velocity of 29.59 km/s – along with the overall average distribution (indicated by a thick solid line).

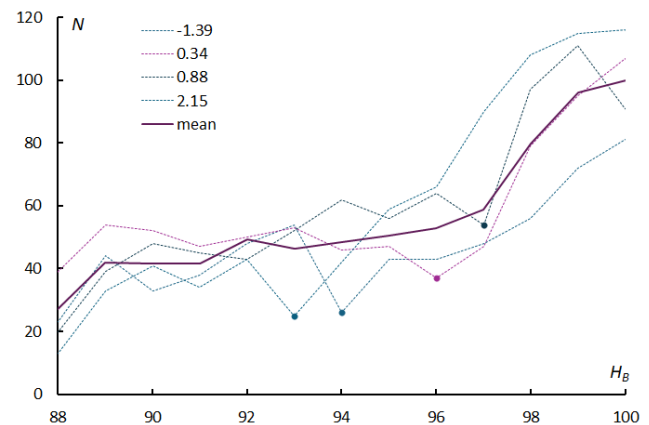


Figure 3 – An analysis of beginning height distribution for the data subset shown in Figure 4 with a median geocentric velocity of 29.59 km/s. The plot shows the overall average distribution (thick solid line) and the extrema (filled circles) for subsets of the distribution (dashed lines) consisting of 1000 meteors sorted by magnitude, and the legend indicates the median magnitude.

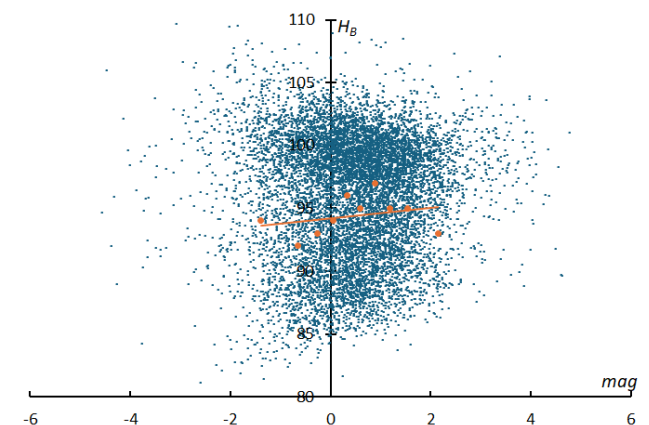


Figure 4 – Relationship between magnitude and beginning height for the data subset with a median velocity of 29.59 km/s, selected from datasets binned by increments of 10000 objects based on geocentric velocity. Filled circles represent the extrema of the distribution shown in Figure 3 across all ten groups, and the dashed line indicates the regression line.

In the individual distributions (dashed lines), the presence

of group A – characterized by low beginning heights – is evident around $H_B = 90$ – 92 km, allowing for the identification of the extrema (filled circle) that serves as the boundary. However, these extrema become indistinct in the overall average (solid line). *Figure 4* shows the extrema for these ten groups plotted on a $\text{mag}-H_B$ diagram with a median velocity of 29.59 km/s.

It also appears that another group is embedded between the lower group A and the upper group C. While this could potentially correspond to Ceplecha's group B, we will defer the discussion of group B for later and, for the present analysis, divide the data into two groups: A and C. Although *Figure 4* shows a regression line based on extrema, attempts to use this line as the boundary between A and C across various velocity ranges revealed that it could be inappropriate depending on the conditions. Therefore, the boundary between A and C is defined here simply as the average of the ten extrema.

2.2 Geocentric velocity and beginning height: Grouping based on the $\text{mag}-H_B$ diagram

To investigate the relationship between geocentric velocity and the beginning height, it is necessary to construct $\text{mag}-H_B$ diagrams grouped by velocity in increments of 10000 meteors and to establish the boundary between groups A and C for each, as previously described. *Figure 5* illustrates how this boundary (average value) varies with velocity. Since the beginning height itself increases with velocity, it is natural for the boundary to rise as well; however, the data deviate from the regression line (dashed line), showing an upward bulge in the 30–50 km/s velocity range. Whether this phenomenon is related to Ceplecha's group B will be examined later.

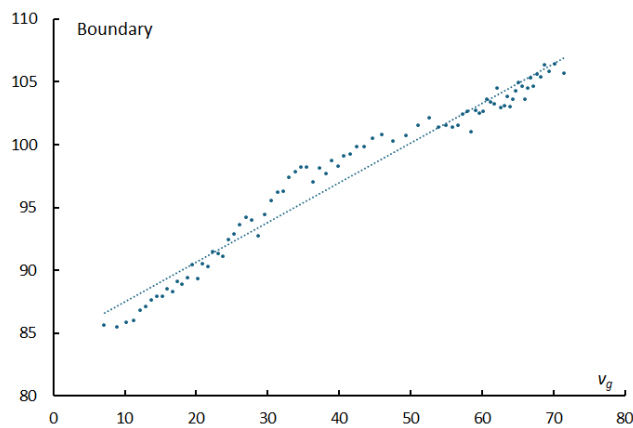


Figure 5 – Variation with velocity of the A–C boundary, determined for each $\text{mag}-H_B$ diagram constructed by grouping data into 10000-event bins based on geocentric velocity. The upward bulge relative to the regression line may suggest the presence of Ceplecha's group B.

Figure 6 shows how the number of meteors classified as A or C based on boundary shown in *Figure 5* varies with velocity. Although Ceplecha subdivides group C into C1 (centered around 30 km/s) and C2 (50 km/s and above), the data in this graph reflect that same pattern. The increase in the number of group A meteors in the 30–40 km/s range could potentially indicate the presence of Ceplecha's group

B. As illustrated by the distribution at 29.59 km/s in *Figure 4*, this is the velocity range where the boundary between groups A and C becomes indistinct. While detailed group classification will be addressed later, we will not delve into it here and will limit the analysis to the two categories: A and C.

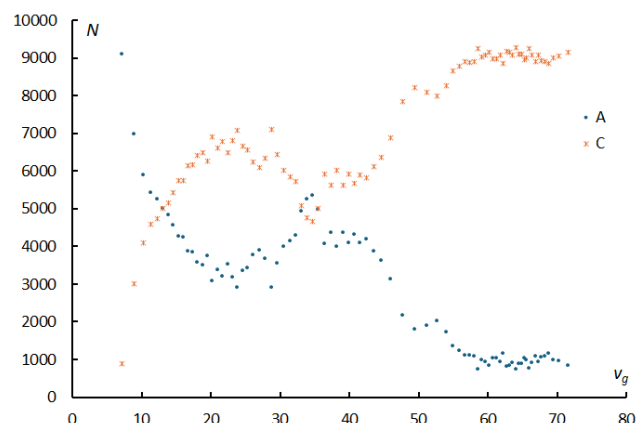


Figure 6 – Variation with geocentric velocity in the number of meteors classified as A or C based on the boundaries (*Figure 5*) defined by the $\text{mag}-H_B$ diagram, with data binned by geocentric velocity into groups of 10000.

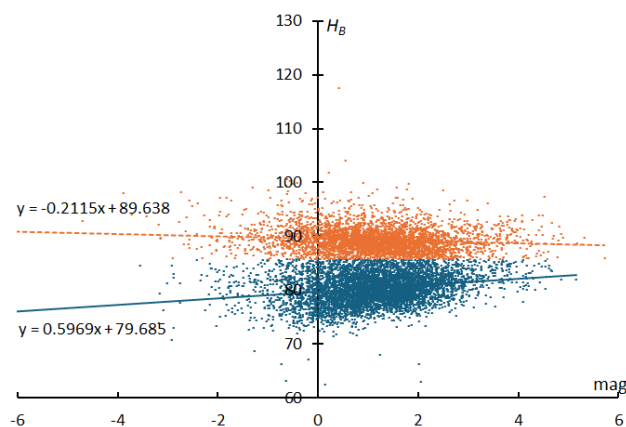


Figure 7 – Relationship between magnitude and beginning height for the data subset with a median velocity of 10.19 km/s, selected from datasets binned by increments of 10000 objects based on geocentric velocity. Data points above the boundary shown in *Figure 5* are designated as C, and those below as A.

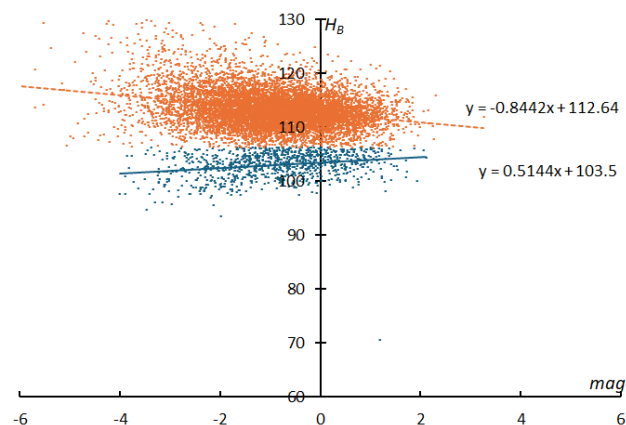


Figure 8 – Relationship between magnitude and beginning height for the data subset with a median velocity of 70.17 km/s, selected from datasets binned by increments of 10000 objects based on geocentric velocity. Data points above the boundary shown in *Figure 5* are designated as C, and those below as A.

Here, we present $\text{mag}-H_B$ diagrams for cases with median velocities of 10.19 km/s (Figure 7) and 70.17 km/s (Figure 8). As observed in Figure 6, the beginning height rises with increasing velocity, causing the boundary between types A and C to shift upward. Furthermore, as seen in Figure 7, it is evident that higher velocities lead to a decrease in the proportion of group A and an increase in the ratio of group C.

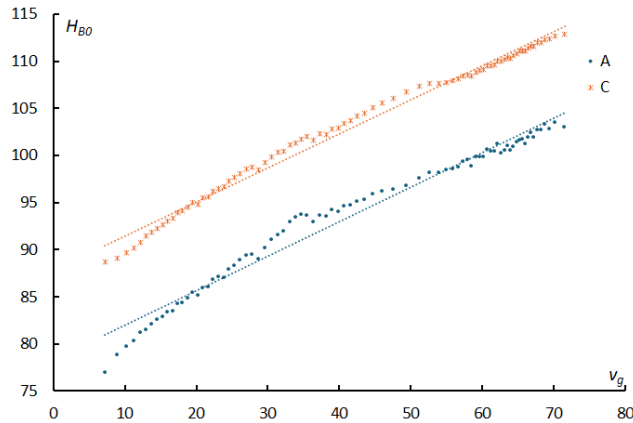


Figure 9 – Variation with geocentric velocity of the intercepts (the beginning height H_{B0} at $\text{mag} = 0$) of the regression lines for A and C in the $\text{mag}-H_B$ diagrams binned by increments of 10000 objects based on geocentric velocity (see Figures 7 and 8).

Figure 9 shows how the beginning height H_{B0} – determined at the intercept where magnitude (mag) is 0 from the linear regression lines derived for groups A and C – varies with velocity (refer lines shown in Figures 7 and 8). First, it should be noted that the beginning height H_{B0} rises as velocity increases. Regardless of velocity, the altitude difference between the beginning height of groups A and C remains approximately 10 km, indicating a clear distinction between the two. Furthermore, reflecting the fact that for both groups A and C, the boundary line shown in Figure 5 is curved, the altitude difference follows a gentle curve rather than a straight line. Additionally, the curve for group A exhibits a bulge-like feature in the 30–40 km/s range; this may suggest the presence of a mixed-in population corresponding to Ceplecha’s group B.

Ceplecha uses the logarithm of velocity in his beginning height distribution plots. This is logical, given that the square of the velocity serves as a fundamental parameter when considering the physical properties of meteoroids. However, when velocity is plotted logarithmically in Figure 9, the beginning heights for cases A and C trace an arc that deviates significantly from a straight line. It should be noted that the relationship between velocity and beginning height shown here does not correspond to what would be predicted based on the square of the velocity.

The most notable feature in the distribution plots of beginning heights – as shown in Figures 7 and 8 – is that the slopes of the regression lines for groups A and C have opposite signs. As illustrated in Figure 10, the slope is positive for group A and negative for group C across all

velocity ranges. While it is understandable that brighter meteors (like those in group C) originate from larger meteoroids and have higher beginning heights, the fact that brighter meteors in group A have lower beginning heights is special. In general, the luminous energy of a meteor is derived from the conversion of the meteoroid’s kinetic energy; in other words, the energy for light emission comes from the reduction of the meteoroid’s mass and velocity. The fact that light emissions from Group A meteoroids do not occur until they penetrate to low altitudes implies that neither their mass nor their velocity decreases significantly. This indicates that Group A meteoroids possess unique physical properties. Please also refer to the trends observed in the disappearance altitudes shown in Figure 18.

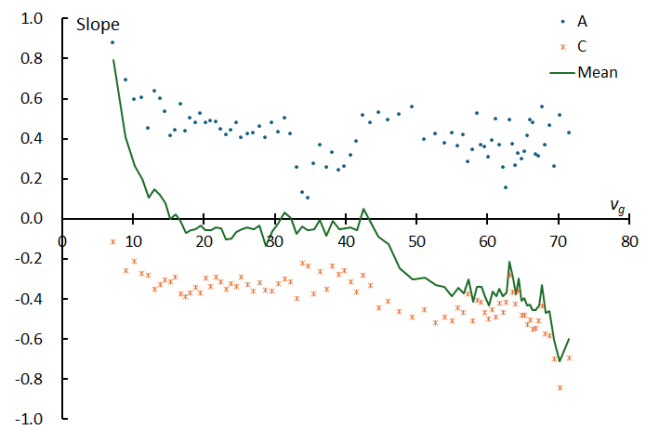


Figure 10 – Slopes of the regression lines for groups A and C in the $\text{mag}-H_B$ diagrams binned by increments of 10000 objects based on geocentric velocity (see Figures 7 and 8). The thick solid line represents the weighted mean of the slopes, calculated based on the meteor counts for groups A and C.

Furthermore, as shown in Figure 10, the slope of A decreases with velocity. Here, too, a reduction in the slope is observed in the 30–40 km/s range compared to the surrounding velocity ranges, suggesting the presence of group B meteors, as hypothesized by Ceplecha. The absolute value of the slope for group C increases, and the distribution plot of beginning heights shows a more pronounced downward trend toward the right. The fact that brighter meteors emit light at higher altitudes as velocity increases reflects the physical characteristics of group C meteoroids: specifically, that at higher speeds, the rates of mass and velocity loss become drastically higher.

The thick solid line in Figure 10 represents the weighted mean of the slopes, calculated based on the meteor counts for groups A and C. Although the author previously noted that the slope of the beginning height with respect to velocity shifts from positive to negative at approximately 45 km/s for sporadic meteors as a whole (Koseki, 2025), it is now evident that this observation stems from the failure to distinguish between groups A and C. These groups exhibit opposite slopes: at lower velocities, the dominance of group A results in a positive slope, whereas at higher velocities, the dominance of group C leads to a negative slope.

2.3 Meteor magnitude and beginning height: v_g - H_B diagram

We constructed v_g - H_B diagrams by dividing meteors into groups of 10000 based on magnitude, and applied the grouping derived from the mag - H_B diagram. Figure 11 shows the group with a median magnitude of $mag = -1.50$, while Figure 12 shows the group with $mag = +0.42$.

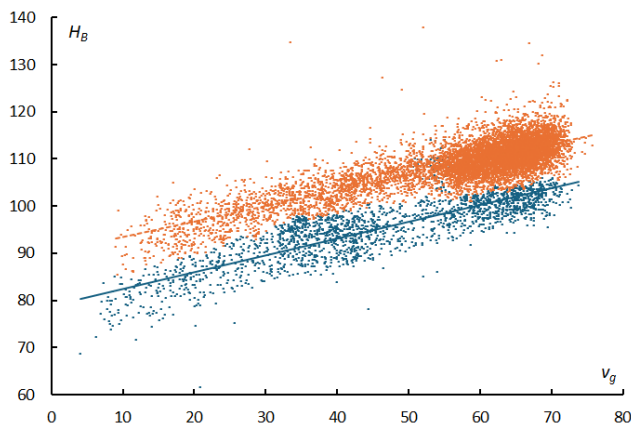


Figure 11 – Relationship between velocity and beginning height (v_g - H_B diagram) for the data subset with a median magnitude of $mag = -1.50$, selected from datasets binned by increments of 10000 objects based on magnitude. The grouping from the mag - H_B diagram (see Figure 5) is applied here; the upper section corresponds to group C, and the lower section to group A.

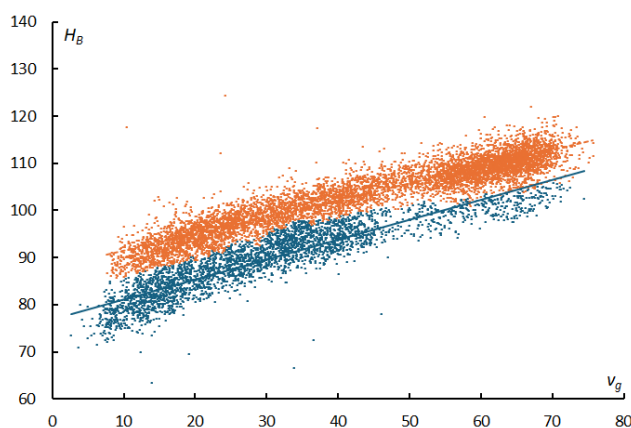


Figure 12 – Relationship between velocity and beginning height (v_g - H_B diagram) for the data subset with a median magnitude of $mag = +0.42$, selected from datasets binned by increments of 10000 objects based on magnitude. The grouping from the mag - H_B diagram (see Figure 5) is applied here; the upper section corresponds to group C, and the lower section to group A.

A clear split is also evident in the v_g - H_B diagram, confirming the validity of the split identified via the mag - H_B method. Furthermore, as previously noted regarding the mag - H_B classification, it is clear that both groups A and C are subdivided into several populations based on velocity. In both groups A and C, meteors with velocities exceeding 50 km/s form a distinct population. Additionally, group A exhibits two populations – one near 40 km/s and another below 20 km/s – while in group C, the population with velocities below 50 km/s (corresponding to Ceplecha's C1 group) is centered in the 20–30 km/s range.

Ceplecha's grouping is not based on v_g - H_B diagrams categorized by magnitude, as the number of meteors is

small. However, v_g - H_B diagrams sorted by magnitude – such as those shown in Figures 11 and 12 – would make it possible to classify sporadic meteors in greater detail. Here, we merely point out the potential for further subdividing groups A and C.

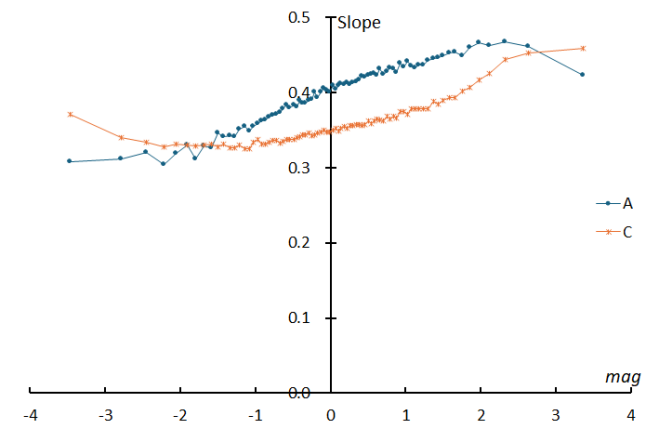


Figure 13 – Variation with geocentric velocity of slopes of the regression lines for A and C in the v_g - H_B diagram binned by increments of 10000 objects based on magnitude (see Figures 11 and 12).

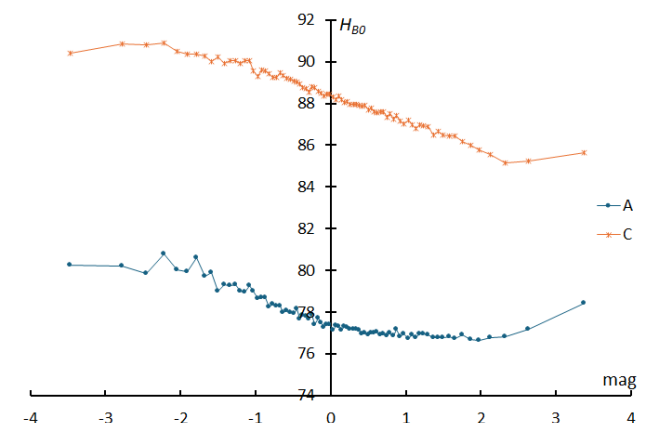


Figure 14 – Variation with geocentric velocity of the intercepts of the regression lines (the hypothetical beginning height H_{B0} at $v_g = 0$) for groups A and C in the v_g - H_B diagrams binned by increments of 10000 objects based on magnitude (see Figures 11 and 12).

Figure 13 shows how the slopes of the regression lines presented in Figures 11 and 12 vary with velocity. As seen in Figure 13, the slopes are nearly identical for groups A and C regardless of velocity; consequently, the regression lines for both groups in the v_g - H_B plots (Figures 11 and 12) are roughly parallel. Because the distributions of A and C are nearly parallel, the difference in the beginning height (H_{B0}) at a hypothetical velocity of $v_g = 0$ km/s remains constant at approximately 10 km (Figure 14). However, as shown in Figures 11 and 12, the boundary is not strictly linear. This is because, as noted regarding the mag - H_B diagram, the boundary between groups A and C does not change linearly with velocity (Figure 5).

Figure 15 shows the magnitude distribution of groups A and C, indicating that group A contains a higher proportion of faint meteors, while group C contains more bright ones. Naturally, for meteoroids of the same mass, higher speeds result in greater brightness; this aligns with the velocity

distribution shown in *Figure 6*, where group A consists largely of slow meteors and group C of fast ones. Although the proportion of group C increases again in the range of the faintest meteors, this point will be addressed later in 4.1.2 *On the existence of Group B*.

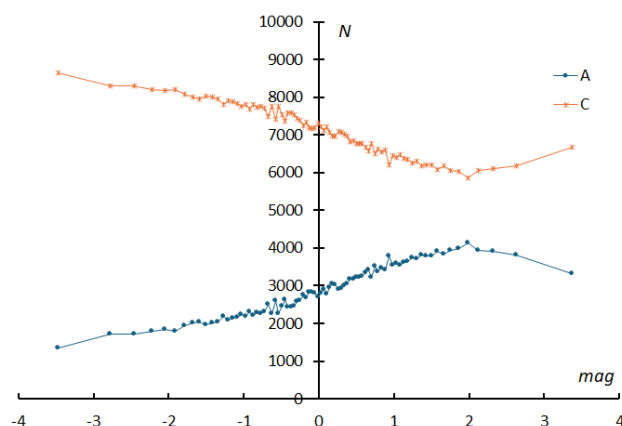


Figure 15 – Magnitude distribution of meteors classified as A or C based on the boundary defined by the $mag-H_B$ diagram (*Figure 5*). This distribution reflects the fact that type A predominates among slow meteors, while type C predominates among fast meteors.

2.4 Geocentric velocity and end height: $mag-H_E$ diagram

We constructed $mag-H_E$ diagrams by dividing meteors into groups of 10000 based on velocity and applied the grouping derived from the $mag-H_B$ diagrams. *Figure 16* shows the case with a median velocity of 10.19 km/s, and *Figure 17* shows the case with a median velocity of 60.19 km/s.

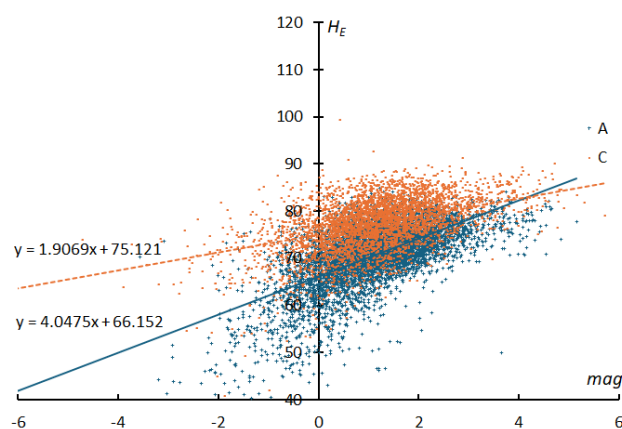


Figure 16 – Relationship between magnitude and end height ($mag-H_E$ diagram) for a data subset with a median velocity of 10.19 km/s, selected from datasets binned by increments of 10000 objects based on geocentric velocity. Classification based on the $mag-H_B$ diagram is applied; the upper group corresponds to C, and the lower group to A.

Although it is difficult to distinguish between A and C because they overlap, the regression line for C lies above that for A across all velocity ranges. The separation into two distinct groups, A and C, is also evident from the end height. However, unlike the clear separation observed with $mag-H_B$ and v_g-H_B , the groups distinguished by $mag-H_B$ show considerable mixing of A and C in the $mag-H_E$ distribution. Even if physical properties such as density, hardness, and

thermal conductivity are identical, their light curves and end heights are thought to vary depending on factors such as structure and shape.

It is noteworthy that the slower and brighter the object, the lower the altitude at which group A meteors disappear as seen in *Figure 16*. The absence of this trend in *Figure 17* suggests that slow-moving, high-mass group A meteoroids are even more robust than other group A meteoroids.

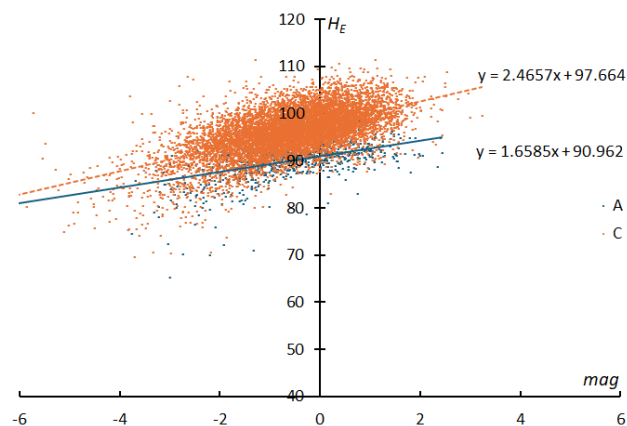


Figure 17 – Relationship between magnitude and end height ($mag-H_E$ diagram) for a data subset with a median velocity of 60.19 km/s, selected from datasets binned by increments of 10000 objects based on geocentric velocity. Classification based on the $mag-H_B$ diagram is applied; the upper section corresponds to group C, and the lower section to group A.

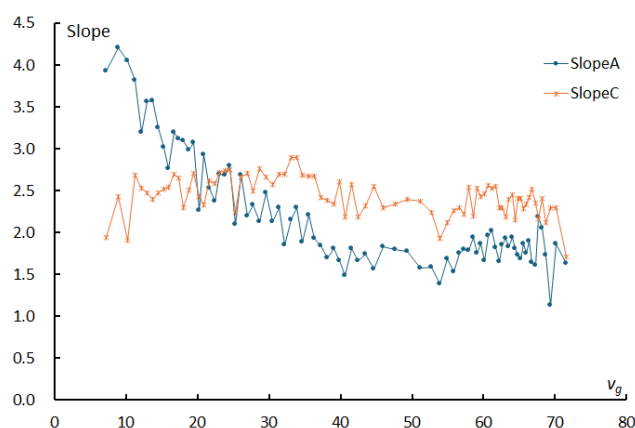


Figure 18 – Variation with geocentric velocity of the slopes of the regression lines for A and C in the $mag-H_E$ diagrams binned by increments of 10000 objects based on geocentric velocity (see *Figures 16 and 17*).

Figure 18 illustrates the relationship between velocity and the slope of the regression line shown in the $mag-H_E$ diagrams (see *Figures 16 and 17*) for the entire dataset. As shown, the slope for category C remains nearly constant regardless of velocity, whereas the slope for group A decreases as velocity increases. In other words, group A exhibits a steeper slope on the $mag-H_B$ diagram at low speeds, and meaning that the end height is lower for brighter meteors. This indicates that the distribution shown in *Figure 16* represents a general trend in the low velocity range. Regarding the slope of the end heights for sporadic meteors as a whole, the slope is steep at lower speeds because group A predominates, whereas it becomes shallower at higher speeds as the proportion of group C

increases. The author previously reported that the slope for H_E decreases with velocity because that analysis averaged the data from both groups (Koseki, 2025).

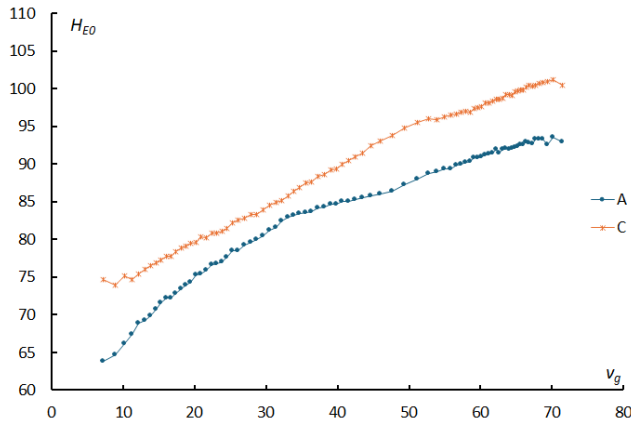


Figure 19 – Variation with geocentric velocity of the intercepts (the beginning height H_{B0} at $mag = 0$) of the regression lines for A and C in the $mag-H_E$ diagrams binned by increments of 10000 objects based on geocentric velocity (see Figures 16 and 17).

Figure 19 shows the intercepts of the approximate lines presented in Figures 16 and 17 (for cases A and C, respectively), illustrating how the end height H_{E0} at $mag = 0$ varies with velocity. While end height H_{E0} for a $mag = 0$ meteor increases with velocity, the pattern of this change differs between A and C due to differences in slope. In case C, the end height rises at a nearly constant rate relative to velocity; in contrast, case A follows a curved path, approaching the values of C at a velocity of around 30 km/s. Figure 20 illustrates the difference in H_{E0} between C and A to highlight this relationship more clearly. The fact that the difference in disappearance altitude between A and C narrows near 30 km/s may suggest the existence of the group designated as “B” by Ceplecha.

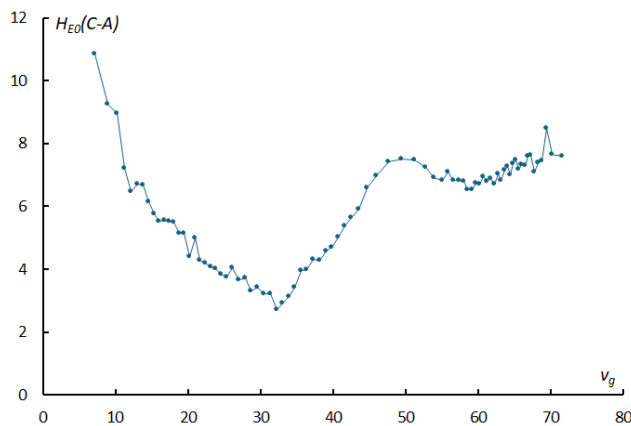


Figure 20 – Variation with geocentric velocity of the difference in the end height H_{E0} (at $mag=0$) between A and C shown in Figure 19.

2.5 Meteor magnitude and end height: v_g-H_E diagram

We constructed v_g-H_E diagrams by dividing meteors into groups of 10000 based on magnitude and applied the grouping derived from the $mag-H_B$ diagrams. Figure 21 shows the group with a median magnitude of -3.47 , while

Figure 22 shows the group with a median magnitude of $+3.37$.

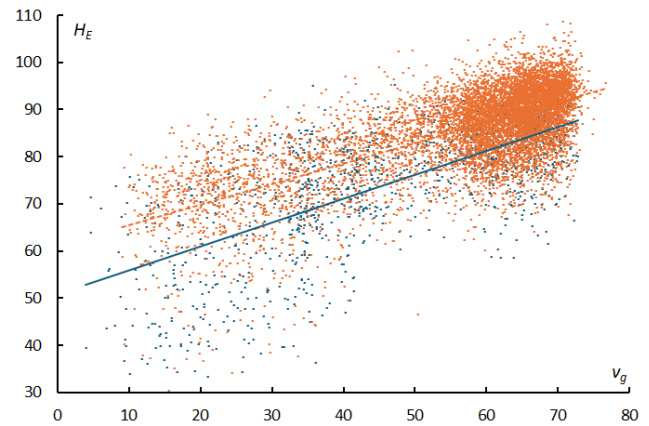


Figure 21 – Relationship between velocity and end height (v_g-H_E diagram) for the data subset with a median magnitude of $mag = -3.47$, selected from datasets binned by increments of 10000 objects based on magnitude. Classification based on the $mag-H_B$ plot is applied; the upper section corresponds to group C, and the lower section to group A.

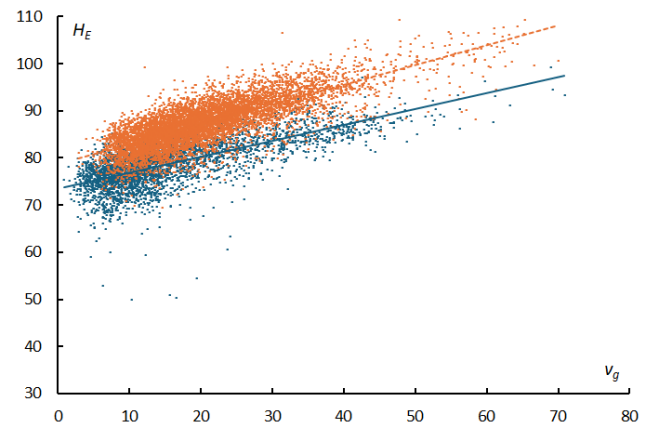


Figure 22 – Relationship between velocity and end height (v_g-H_E diagram) for the data subset with a median magnitude of $mag = +3.37$, selected from datasets binned by increments of 10000 objects based on magnitude. Classification based on the $mag-H_B$ plot is applied; the upper section corresponds to group C, and the lower section to group A.

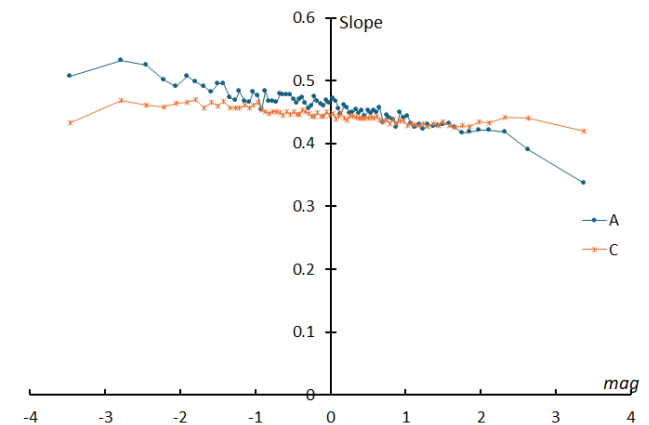


Figure 23 – Variation with geocentric velocity of the slopes of the regression lines for A and C in the v_g-H_E diagrams binned by increments of 10000 objects based on magnitude (see Figures 21 and 22).

As with the $mag-H_E$ diagrams, the plot for group C is superimposed over that of group A, making it somewhat

difficult to distinguish between them; however, the regression lines reveal that, overall, the end height for group C is higher than that for group A.

Figure 23 shows how the slopes of the regression lines presented individually for A and C in $mag-H_E$ diagrams (see Figures 21 and 22) vary with geocentric velocity. While the slopes for A and C are nearly identical, they decrease slightly as magnitude drops; however, the rate of this decrease is greater for A than for C. Stated differently, for group A, meteors with lower magnitudes (i.e., brighter meteors) exhibit a significant difference in end height depending on velocity, indicating that some bright, slow-moving meteors in group A penetrate to lower altitudes. This finding corroborates the point raised regarding Figure 16. It is also worth noting that in Figure 21, a significant number of slow-moving meteors are distributed below the regression line.

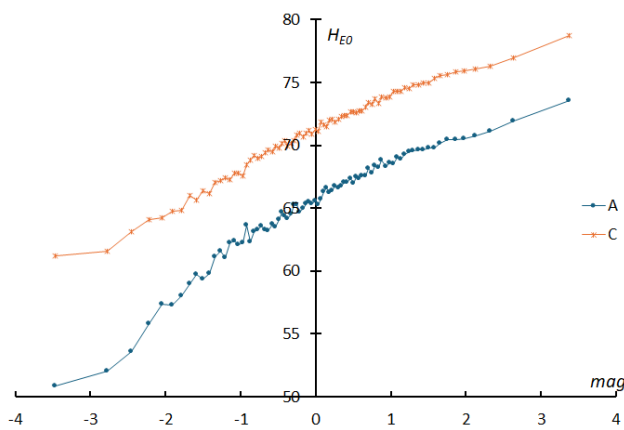


Figure 24 – Variation with geocentric velocity of the intercepts of the regression lines for groups A and C in the v_g-H_E diagrams binned by increments of 10000 objects based on magnitude (see Figures 21 and 22). Variation of the hypothetical beginning height H_{E0} at $v_g = 0$.

Figure 24 shows variation with geocentric velocity of the intercept of the regression line on the v_g-H_E plot, representing the variation in a hypothetical end height H_{E0} where the geocentric velocity is 0 km/s. For meteors fainter than magnitude -1 , the difference in end height between groups A and C – expressed as the difference in the hypothetical altitude H_{E0} – is approximately 6 km; however, this difference increases for brighter meteors. This indicates that, among brighter meteors, a larger proportion of group A compared to group C penetrates to lower altitudes.

2.6 Changes in group activities

Figure 25 illustrates the annual activity patterns of each group, normalized to a value of 10000 for each. No significant difference is observed between the activity of the two groups. Although a sharp increase in the number of meteors for Group A occurs at $\lambda_\odot = 262^\circ$, this is, as noted in Part I, due to the GMN's strict criteria for meteor shower identification, which result in a considerable number of Geminids being classified as sporadic meteors. While the impact of shower identification criteria is evident, it can be concluded that there are no fundamental differences in annual activity between Groups A and C. The influence of

meteor shower identification will be discussed in greater detail in Section 4.3.2 *Distribution of orbital elements by groups*.

To examine whether group activity varies from year to year, long-term observations with a stable number of recorded events are required; therefore, data from the SonotaCo network are used here. Figure 26 illustrates the relationship between magnitude and the end height ($mag-H_E$ diagram) in the lowest velocity range ($0.0 < v_g < 12.5$), where the groups are most clearly defined.

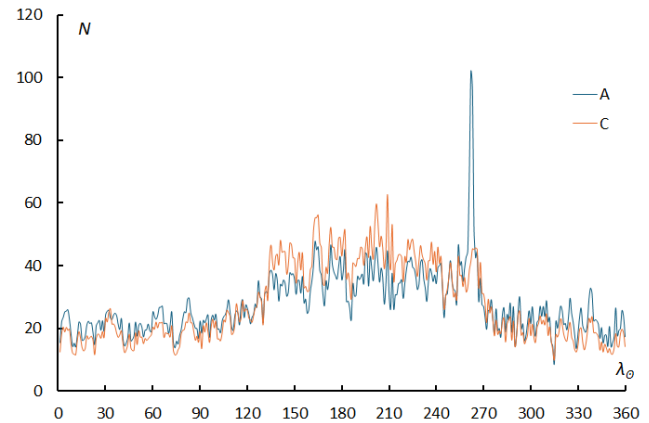


Figure 25 – Variation in meteor counts for Group A and Group C with solar longitude. The total counts for each group have been normalized to 10000.

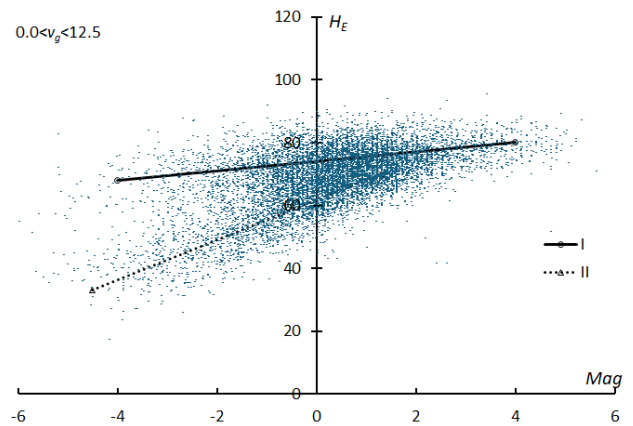


Figure 26 – Relationship between magnitude and end height ($mag-H_E$ diagram) in the lowest-speed range ($0.0 \text{ km/s} < v_g < 12.5 \text{ km/s}$), based on the SonotaCo network dataset binned by magnitude in increments of 10000.

In the region brighter than magnitude 0, the distribution splits into two, with the groups appearing to intersect around magnitude $+2$. These correspond to Cep-lecha's Groups A and C; here, however, we will tentatively designate the upper group as Group I and the lower group as Group II. Figure 27 shows the classification based on proximity to the following center lines: for Group I, the line connecting $(Mag, H_E) = (-4.0, 68)$ and $(Mag, H_E) = (+4.0, 80)$; and for Group II, the line connecting $(Mag, H_E) = (-4.5, 33)$ and $(Mag, H_E) = (+1.3, 70)$.

The table below shows the number of meteors classified into these two groups, counted year by year.

Table 1 – The number of meteors classified into these two groups, counted year by year.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
I	81	81	107	111	94	94	124	107	97	122	113	136	142	190	239	318
II	69	101	106	106	111	101	136	110	95	144	110	132	154	171	217	233

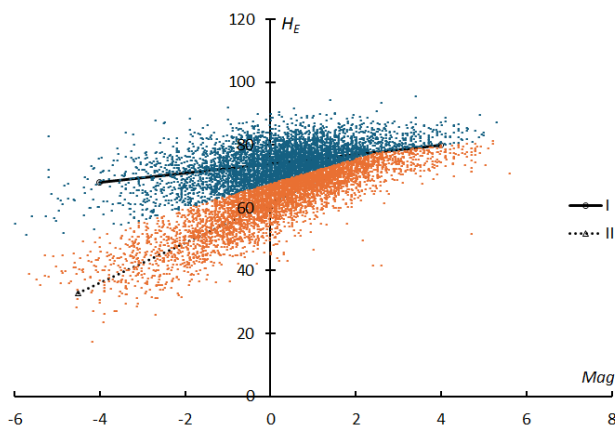


Figure 27 – The bifurcation observed in the distribution of end heights (Figure 26) based on SonotaCo network data. The upper group is designated as Group I and the lower group as Group II; classification was based on proximity to the line connecting $(Mag, H_E) = (-4.0, 68)$ and $(Mag, H_E) = (+4.0, 80)$ for Group I, and the line connecting $(Mag, H_E) = (-4.5, 33)$ and $(Mag, H_E) = (+1.3, 70)$ for Group II.

No year-to-year differences are observed in groups I and II. It is evident that the phenomenon of the end height splitting into two occurs every year. Although details are omitted here, no differences are found between groups I and II regarding annual activities, the distributions of the radiant points, or other such parameters.

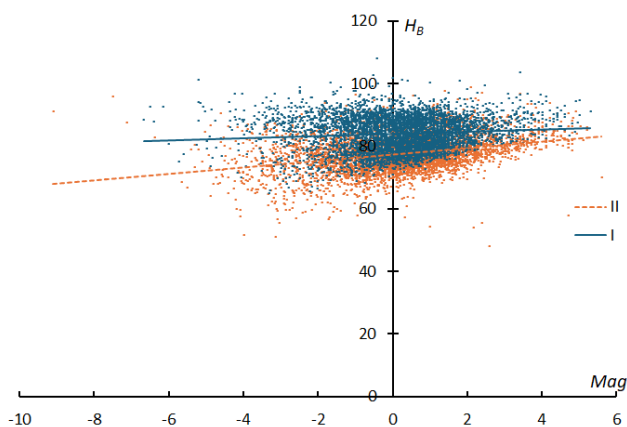


Figure 28 – Distribution of beginning heights for groups I and II, separated based on Figure 26. Although less distinct than the distribution of end heights, group I is distributed at higher altitudes and group II at lower altitudes.

The beginning height for the meteors classified as I and II are as shown in Figure 28. It can be seen that the Type II meteors, which have lower end heights, also have lower beginning heights, though this distinction is not as distinct as in the cases of $mag-H_B$ and v_g-H_B , which are classified based on beginning height.

As previously discussed, a high beginning height for Group C does not necessarily imply a high-end height, nor does a low beginning height for Group A always correspond to a low-end height; conversely, it is also confirmed that meteors with low end heights do not necessarily have low beginning heights. As discussed in Sections 2-4 and 2-5, this is likely because, even within a group where the meteoroids share similar physical properties – such as density and hardness – differences in characteristics like shape lead to variations in meteor light curves, thereby resulting in differences in the beginning and end heights.

3 Magnitude ratio

Since the era of visual observation, the magnitude ratio has attracted attention as a clue for investigating the mass distribution of meteoroids. Fundamentally, it is assumed that if N_0 represents the number of magnitude 0 meteors, the number of meteors of magnitude m (denoted as N) can be expressed as $N = N_0 \times r^m$, where r is the magnitude ratio. Consequently, taking the logarithm of both sides yields $\log N = \log r \times m + \log N_0$; thus, on a logarithmic plot, the number of meteors appears as a linear function (a straight line) of the magnitude (m). In reality, however, the distribution of meteor numbers takes on a bell-like shape, as shown in Figures 29 through 32 below.

Regardless of the observation method employed, the relationship between the meteor detection rate and meteor magnitude becomes a critical issue. While the detection rate should depend on meteor velocity as well as magnitude, the influence of velocity was not considered in visual observations due to limitations in the amount of data. To circumvent the issue of detection rates, an approach involving the use of the linear portion of the magnitude distribution – when plotted on a logarithmic scale – has been adopted. This study employs that method.

3.1 Slope of the magnitude distribution and magnitude ratio

As previously discussed, there are differences in the magnitude distributions between GMN and the SonotaCo network (Part I, Figures 10 & 11). Here, we will re-examine how these differences in magnitude distribution affect the resulting magnitude ratios. We will also consider specific issues associated with magnitude ratios derived from video observations.

Two examples based on GMN observations are presented: one with $17 \text{ km/s} < v_g < 23 \text{ km/s}$ (Figure 29) and the other with $57 \text{ km/s} < v_g < 63 \text{ km/s}$ (Figure 30). The mean geocentric velocities are 20.0 km/s and 60.2 km/s, respectively. The magnitude ratio is determined by applying a linear regression to the range indicated by circles within the magnitude distribution. This range was selected based

on the criterion that the slope of the line is steepest over a magnitude span of 2; the specific ranges used for the linear regression are $-2.8 < mag < -0.8$ for *Figure 29* and $-6.0 < mag < -4.0$ for *Figure 30*. The overall mean magnitudes are $+0.73$ and -0.58 , respectively, indicating that the shift in mean magnitude associated with geocentric velocity influences the choice of the regression range. The slopes of the lines are 0.679 and 0.771 , yielding magnitude ratios of 4.77 and 5.90 , respectively.

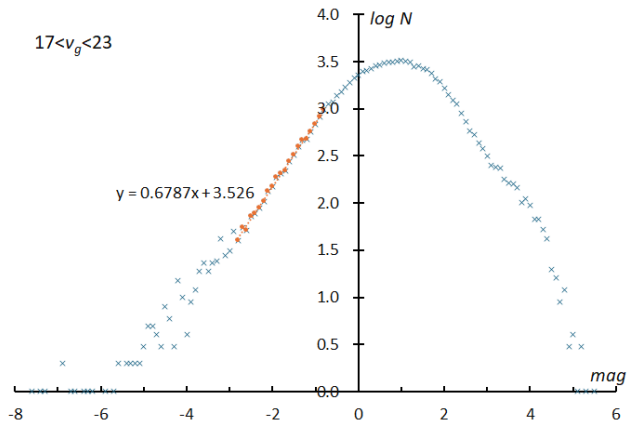


Figure 29 – Magnitude distribution in the range of $17 < v_g < 23$ km/s based on GMN observations. The regression line indicates the segment with the steepest slope within the 2-magnitude range (marked by filled circles).

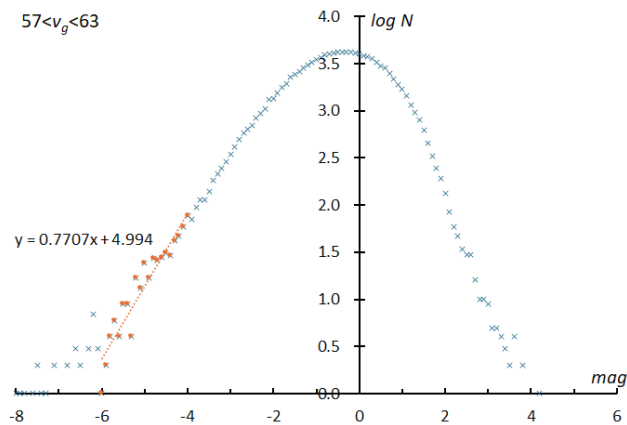


Figure 30 – Magnitude distribution in the range of $57 < v_g < 63$ km/s based on GMN observations. The regression line indicates the segment with the steepest slope within the 2-magnitude range (marked by filled circles).

As with the GMN data, we present two examples from SonotaCo network observations: $17 < v_g < 23$ km/s (*Figure 31*) and $57 < v_g < 63$ km/s (*Figure 32*). SonotaCo network observations from 2020 onwards have captured a larger number of meteors fainter than magnitude $+3$ compared to those from 2007–2019 (Part I, *Figure 2*). However, since this analysis focuses on the magnitude distribution of bright meteors, we treat all SonotaCo network observations from 2007 through 2022 as a single dataset.

The mean geocentric velocities are 20.0 km/s and 60.3 km/s, respectively. The magnitude ratio is determined by applying a linear regression to the range indicated by circles within the magnitude distribution; the ranges used for this linear regression are $-6.3 < mag < -4.3$ and

$-5.8 < mag < -3.8$, respectively. Although the overall mean magnitudes are -0.01 and -0.79 respectively, an inverse relationship is observed between the change in mean magnitude associated with geocentric velocity and the regression ranges. This appears to be linked to the difference in detection rates between GMN and SonotaCo Net, as discussed in *3.4 Detection Rate*.

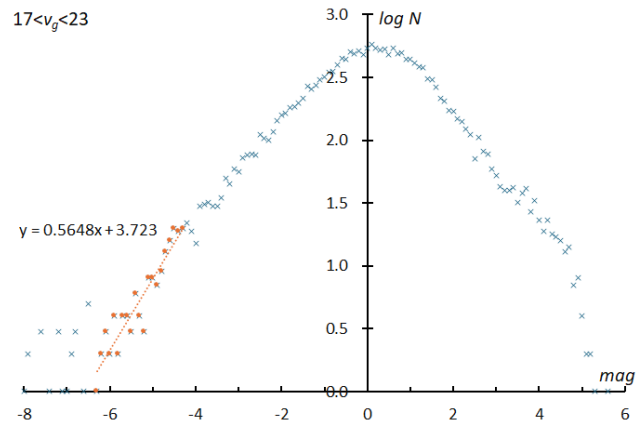


Figure 31 – Magnitude distribution in the range of $17 < v_g < 23$ km/s based on SonotaCo network observations. The regression line indicates the segment with the steepest slope within the 2-magnitude range (marked by filled circles).

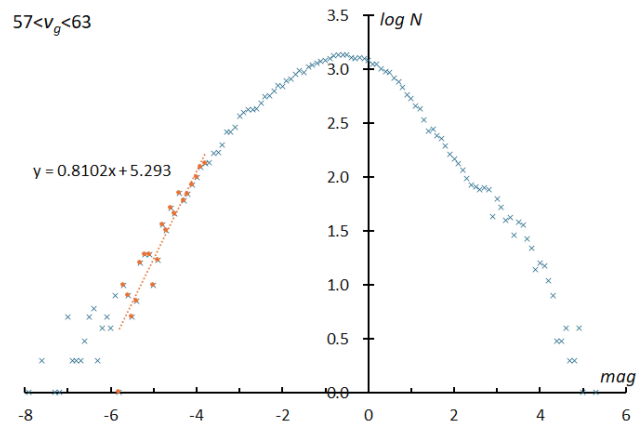


Figure 32 – Magnitude distribution in the range of $57 < v_g < 63$ km/s based on SonotaCo network observations. The regression line indicates the segment with the steepest slope within the 2-magnitude range (marked by filled circles).

The slopes of the respective lines are 0.565 and 0.810 , yielding magnitude ratios of 3.67 and 6.46 ; these values differ significantly from those derived from GMN data. The fact that the GMN magnitude distribution exhibits a peak with a steeper slope than that of the SonotaCo network (Part I, *Figures 10 & 11*) influences the estimated magnitude ratios. Furthermore, regarding the range where linear approximation is applicable ($17 < v_g < 23$ km/s), the magnitude range is $-2.8 < mag < -0.8$ for GMN, whereas it is $-6.3 < mag < -4.3$ for the SonotaCo network; this difference is likely attributable to GMN capturing a larger number of slow, faint meteors (Part I, *Figure 8*).

In either the GMN or SonotaCo network case, the value represents a high magnitude ratio for sporadic meteors compared to those derived from visual observations (Kresáková, 1966). While Part I noted the issue of photometric scales in video observations, it is evident that

the detection rate must also be considered when determining the magnitude ratio.

3.2 Magnitude distribution of meteor showers and sporadic meteors

Before addressing the issue of detection rates, it is worth noting that the magnitude distribution of sporadic meteors serves as a useful benchmark when examining the magnitude distribution (magnitude ratio) of meteor showers. For further details on this method, please refer to *20 meteor showers observed on video: What can be seen from comparing meteor showers with data from SonotaCoNet and GMN* (Koseki, 2025).

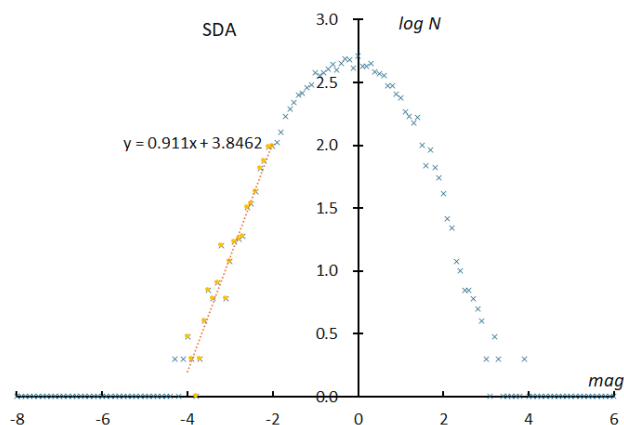


Figure 33 – Magnitude distribution by GMN observations for 0005SDA Southern delta-Aquariids based. The regression line indicates the segment with the steepest slope within the 2-magnitude range (marked by filled circles).

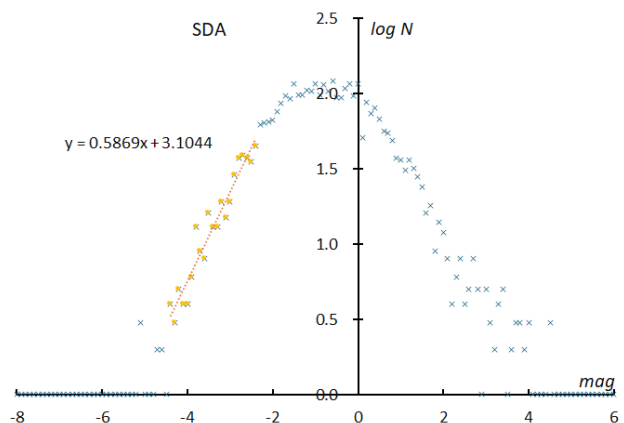


Figure 34 – Magnitude distribution by SonotaCo network observations for 0005SDA Southern delta-Aquariids based. The regression line indicates the segment with the steepest slope within the 2-magnitude range (marked by filled circles).

As an example, the magnitude distribution of the 0005SDA Southern delta-Aquariids is shown using GMN (Figure 33) and SonotaCo network (Figure 34). In the SonotaCo network, the slope of the linear regression is 0.587 in the range $-4.4 < mag < -2.4$, and the estimated magnitude ratio from this is $r = 3.86$. On the other hand, in the case of GMN, the slope is 0.911 in the range $-4.0 < mag < -2.0$, and the magnitude ratio is $r = 8.15$, which is not only significantly different from the SonotaCo network estimate, but also significantly different from the generally held belief that the magnitude ratio of meteor showers is smaller than that of sporadic meteors.

Here, we assume that the detection rate is the same for both shower meteors and sporadic meteors, provided their geocentric velocities are identical. If this assumption holds, the ratio of the number of shower meteors to the number of sporadic meteors is expected to follow an exponential function more closely than the raw observed meteor counts alone. Figure 35 (GMN) and Figure 36 (SonotaCo network) show the logarithm of the ratio of the number of Southern delta-Aquariids meteors to the number of sporadic meteors within a geocentric velocity range of ± 3.0 km/s of the shower's velocity.

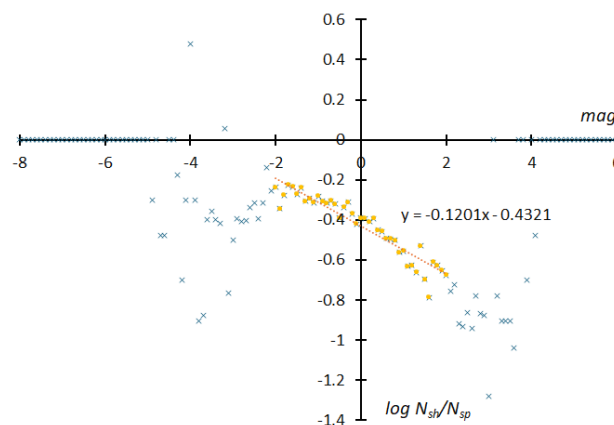


Figure 35 – A graph of the logarithm of the ratio of the number of 0005SDA Southern delta-Aquariids meteors to the number of sporadic meteors within a geocentric velocity range of ± 3.0 km/s of the shower's velocity, based on GMN observations. The range where the slope of the regression line is greatest is indicated by circles.

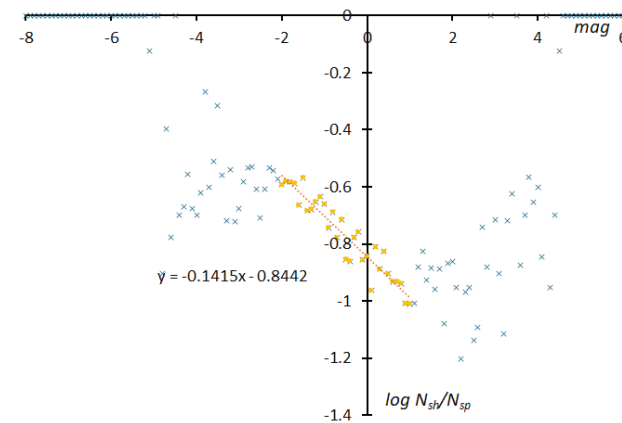


Figure 36 – A graph of the logarithm of the ratio of the number of 0005SDA Southern delta-Aquariids meteors to the number of sporadic meteors within a geocentric velocity range of ± 3.0 km/s of the shower's velocity, based on SonotaCo network observations. The range where the slope of the regression line is greatest is indicated by circles.

The steepest slope of the regression line is, for GMN (Figure 35), -0.1201 in the range $-2.0 < mag < +2.0$, and for SonotaCo network (Figure 36), -0.1415 in the range of $-2.0 < mag < +1.0$. Compared to the raw magnitude distribution graphs examined earlier, the range over which linear approximation can be applied is wider in both cases, extending to significantly fainter meteors. This range corresponds to the vicinity of the peak in the magnitude distribution – the interval with the highest number of

meteors – indicating that the observational data are being utilized effectively.

The assumption that “*detection rates are identical for both meteor showers and sporadic meteors, provided their geocentric velocities are the same*” proves to be valid. When the goal is simply to grasp the characteristics of the magnitude distributions of meteor showers, the slope $r_{sh/sp} = \log(N_{sh}/N_{sp})$ – derived from the ratio of shower meteor counts to sporadic meteor counts – serves as useful information regarding magnitude distribution obtained from video observations (Koseki, 2025).

Furthermore, assuming a magnitude ratio of sporadic meteors of $r = 4.0$, the magnitude ratio of the 0005SDA Southern delta-Aquariids is $r = 2.89$ in GMN and $r = 3.03$ in SonotaCo network, which are in good agreement and consistent with known values from visual observations. In this way, by comparing with the magnitude distribution of sporadic meteors, it is possible not only to estimate the magnitude ratio in ranges with a large number of meteors, but also to compare SonotaCo network and GMN, which have different photometric scales. In addition, observations since 2020, when SonotaCo network began to capture fainter meteors, can be used directly for comparison with sporadic meteors, making them highly useful.

On the other hand, in the graphs comparing the data to sporadic meteors (Figures 35 and 36), the data points within the range where the magnitude ratio was derived directly from the magnitude distribution not only fail to fit a regression line but also exhibit significant scatter. This suggests that the directly derived magnitude ratios are based on a small number of meteors, resulting in unstable values with high variability. The issues regarding the scatter of the slopes and magnitude ratios derived from magnitude distributions will be re-examined in 4.2 Groups and the slope of the magnitude distribution.

3.3 Linearity of the slope of the magnitude distribution expressed in logarithmic form and the range for determining the slope

The discussion thus far has proceeded on the premise that the magnitude distribution, when expressed logarithmically, can be approximated by a straight line; let us now verify the linearity of this distribution. Specifically, we examine whether the graph remains linear across the entire range of magnitudes. Figure 37 illustrates the relationship between the slope of the magnitude distribution (*Slope*) and the midpoint value (*Midmag*) of the magnitude range used for the linear approximation.

While the *Slope* appears to decrease as the *Midmag* value increases (i.e., as the object becomes fainter), this is an illusion. When the data are separated based on geocentric velocity, using the boundary as $v_g = 36$ km/s, the individual trends run nearly parallel to the horizontal axis. The apparent variation of the *Slope* with the *Midmag* is likely attributable to the fact that the *Slope* itself varies according to geocentric velocity.

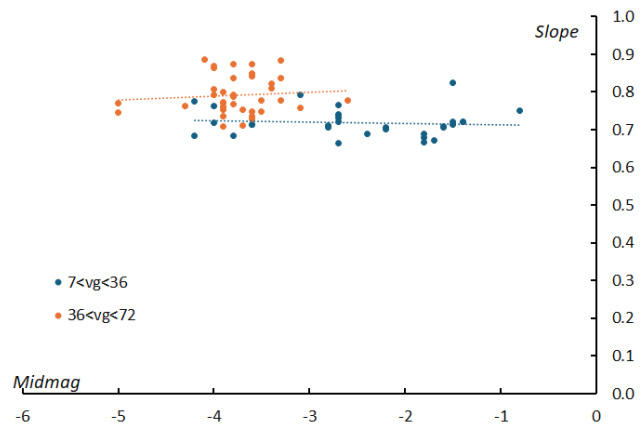


Figure 37 – Relationship between the midpoint value of the magnitude range (*Midmag*) used to determine the regression line in the magnitude distribution and its slope (*Slope*) (see Figures 29–32).

Thus, no correlation is observed between the slope of the magnitude distribution (*Slope*) and the magnitude range (*Midmag*) used for determining *Slope*. Consequently, the slope of the magnitude distribution can be considered constant, regardless of the range used for the linear fit. This implies that the relationship $N = N_0 \times r^m$ holds within magnitude ranges such as -6 to 0 .

However, it should be noted that variations in the slope are observed even for the same *Midmag* value. The dispersion observed in each of the two groups (Figure 37) – divided based on geocentric velocity – can be regarded as representing the error in the slope estimated via this method. Furthermore, the indication in Figure 37 that the slope of the magnitude distribution increases as geocentric velocity rises will be examined in detail later in Section 3.5 *Geocentric velocity and magnitude ratio*.

3.4 Detection rate

Part I, Figure 8 demonstrated a strong relationship between the mean magnitude and geocentric velocity of sporadic meteors, showing that mean magnitude decreases (i.e., becomes brighter) as geocentric velocity increases. This is clearly attributable to the lower detection rate of meteors with high geocentric velocities and high apparent angular velocities. However, we examine whether the detection rate is the sole cause or if the magnitude distribution itself varies according to geocentric velocity.

We define the “*detection rate*” as the ratio of the total number of meteors actually observed within a 0.5-magnitude interval to the total number of meteors within that same interval (the number estimated from the straight line derived as shown in Figures 29–32). Figures 38 and 39 show the relationship between the detection rate (expressed as a percentage) and meteor magnitude for the ranges $7 < v_g < 13$ km/s and $47 < v_g < 53$ km/s, respectively. As previously noted, the number of meteors can be expressed as an exponential function of magnitude. The magnitude ranges used to determine the slope of the magnitude distribution are indicated in Figures 38 and 39 by a line connecting two circles in the upper-left area.

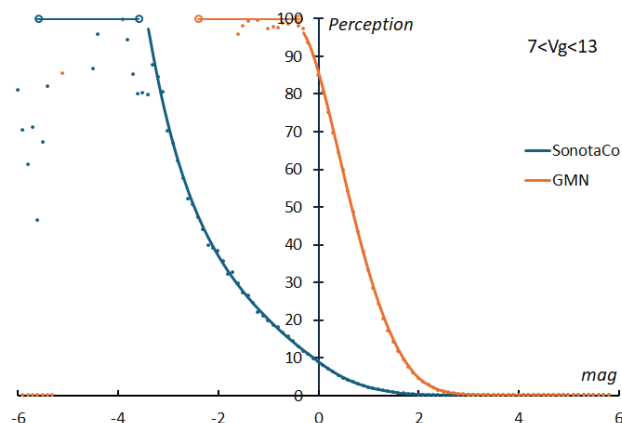


Figure 38 – Comparison between the GMN and the SonotaCo network regarding the detection rate – defined as the ratio of actually observed meteors to the estimated number of meteors derived by extrapolating the regression line obtained from the magnitude distribution plot within the range of $7 < v_g < 13$ km/s.

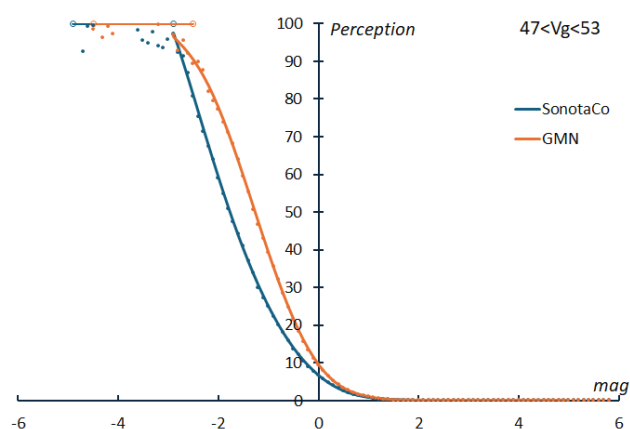


Figure 39 – Comparison between the GMN and the SonotaCo network regarding the detection rate – defined as the ratio of actually observed meteors to the estimated number of meteors derived by extrapolating the regression line obtained from the magnitude distribution plot within the range of $47 < v_g < 53$ km/s.

As shown in Figure 38, the detection rate of the SonotaCo network is significantly lower than that of GMN at low velocities. However, as velocity increases, this difference diminishes; Figure 39 reveals that the detection rates of the SonotaCo network and GMN become nearly equivalent. It is evident that the difference in average magnitude between the SonotaCo network and GMN – shown in Part I, Figure 9 – is primarily attributable to the difference in their respective detection rates.

Figure 40 compares the GMN detection rates – determined as described above – across different geocentric velocities using the smoothed curves as shown in Figures 38 and 39. Fundamentally, as velocity increases, the detection rate curve shifts to the left along the x -axis; in other words, it shifts downward along the y -axis. This indicates that the detection rate decreases as velocity increases. Although only GMN data is presented here, the same general trend applies to the SonotaCo network. The downward slope of the graph in Part I, Figure 9, occurs because, at higher velocities, the detection rate for meteors fainter than magnitude 0 drops below 10%, resulting in a higher proportion of bright meteors among those captured.

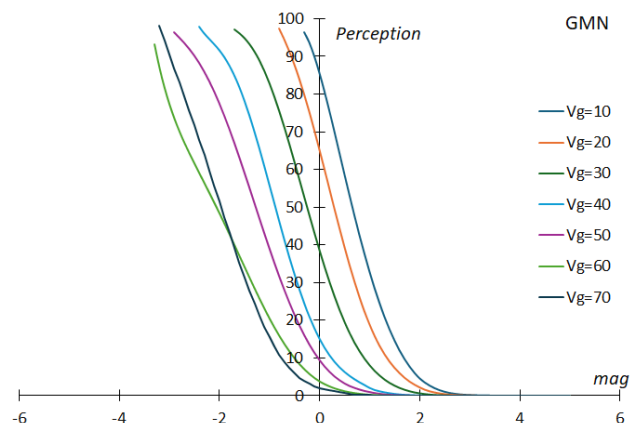


Figure 40 – Variation in GMN detection rate with geocentric velocity, represented by the smoothed curves as shown in Figures 38 and 39.

As geocentric velocity increases, the apparent angular velocity rises, causing a sharp drop in the detection rate for faint meteors. On the other hand, meteors with low geocentric velocities exhibit slow apparent angular velocities; as they remain on the light-detecting element for a longer period, they are likely recorded as being brighter than they actually are. Consequently, it is thought that even meteors with low average magnitude have a high detection rate if their geocentric velocity is low. The rapid decline in detection rate associated with geocentric velocity is likely largely attributable to the characteristics of the photometric systems used in video observations.

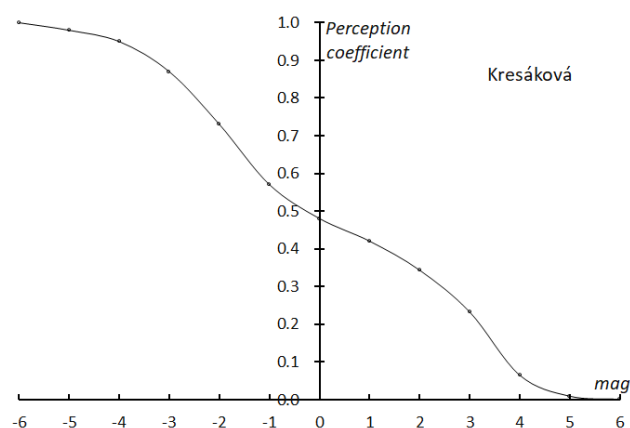


Figure 41 – Relationship between magnitude and detection rate (perception probability) derived from visual observations (Kresáková, 1966). Differences in detection rate due to meteor velocity are not considered; the data represent an aggregate of meteors with various velocities.

Figure 41 shows the relationship between detection rate (perception coefficient) and magnitude as determined by visual observation (Kresáková, 1966). It can be seen that the slope is shallower compared to those in Figures 38–40. The rapid variation of detection rate with magnitude is also a characteristic of the photometric systems used in video observations and is considered to stem from differences in sensitivity compared to the naked eye.

This sharp change in detection rate in video observations relative to magnitude is thought to be the reason why the slopes of the magnitude distributions in Figures 29–34 –

and the resulting magnitude ratios – differ significantly from those obtained through conventional visual observation. *Figure 38* shows that the slope of the GMN detection rate is steeper than that of the SonotaCo network. This is also the reason why the slope of the magnitude distribution in *Figures 29–34* is steeper for GMN than for the SonotaCo network.

While the relationship between meteor detection rates (perception probability) and geocentric velocity has not been a focus in visual observations, it is likely that perception probabilities vary significantly with geocentric velocity in visual observations, just as they do in video observations. Consequently, it is estimated that magnitude ratios calculated under the assumption of a constant detection rate – independent of geocentric velocity – are underestimated when geocentric velocity is high and overestimated when it is low.

Just as the apparent average magnitude of sporadic meteors varies in video observations due to changes in detection rates linked to geocentric velocity, the average magnitude observed visually is likely also significantly influenced by geocentric velocity. The fact that the Perseids and the Leonids are characterized by many bright meteors (low magnitude ratio), while the Giacobinids are characterized by many faint ones (high magnitude ratio), is largely attributed to the effects of geocentric velocity; therefore, one must be aware of the possibility that these observations do not reflect the actual distribution of meteoroids.

There are numerous challenges involved in determining the mass distribution of meteoroids through video observation. Detection rate is one such issue; while discussions have proceeded based on the assumption of linearity in the logarithmic meteor magnitude distribution, it is also desirable to conduct experiments using the actual video cameras and measurement software employed in practice. Although *Section 4.2 Groups and the slope of the magnitude distribution* notes the difference in detection rate between Group A and Group C, detection rate is also thought to vary depending on factors such as angular velocity and visual characteristics – the presence of a wake or a tail, or short-lived train – suggesting a wide range of necessary experiments.

3.5 Geocentric velocity and magnitude ratio

Let us now return to the issue raised at the beginning regarding the relationship between geocentric velocity and magnitude ratio. *Figure 42* shows the relationship between the slope of the linear portion of the magnitude distribution and the geocentric velocity.

In *Figure 42*, the slope of the magnitude distribution is clearly steeper for GMN than for SonotaCo Net; however, as previously mentioned, this is largely attributable to the difference in photometric scales between the two. Furthermore, the fact that the slopes of the regression lines for the two datasets differ in *Figure 42* suggests that the photometric scale varies depending on the geocentric velocity (apparent angular velocity) and that the nature of

this variation differs between GMN and SonotaCo network. If the photometric scale does indeed vary with velocity, this implies a distortion in the magnitude distribution itself. Consequently, the observation that the slope increases with higher geocentric velocities or higher magnitudes could potentially be an artifact.

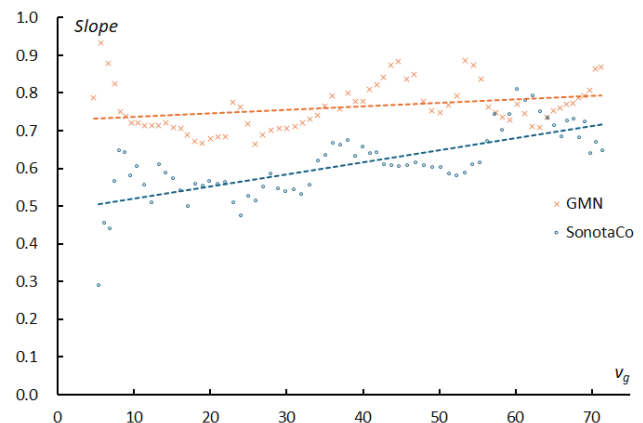


Figure 42 – Relationship between the slope of the regression line in the magnitude distribution (*Slope*) and geocentric velocity (v_g) based on observations by GMN and the SonotaCo network.

However, although not definitive, data from both GMN and the SonotaCo network show a tendency for the slope of the magnitude distribution to increase with geocentric velocity. Furthermore, as previously mentioned, even when the midpoint value (*Midmag*) of the magnitude range – used for the linear fit – is the same, meteors with higher geocentric velocities tend to exhibit steeper magnitude distribution slopes (*Figure 37*). This trend is observed in both the SonotaCo network and GMN datasets. Thus, it is highly likely that the slope of the magnitude distribution itself varies in relation to geocentric velocity. In *Section 4.2. Groups and the slope of the magnitude distribution*, we will categorize meteors into Group A and Group C based on differences in the beginning height and examine whether the slope of the magnitude distribution increases with geocentric velocity.

While the slope appears to fluctuate in a wave-like pattern alongside changes in geocentric velocity, this trend is not consistent between GMN and SonotaCo network. We will also examine whether such fluctuations actually exist in *4.2. Groups and the slope of the magnitude distribution*.

In any case, the magnitude ratios estimated from the *slope* values obtained via GMN and SonotaCo network video observations are significantly higher than those known from visual observations; consequently, it is necessary to resolve the issue of how the photometric scale is influenced by velocity and magnitude. Furthermore, regarding video observations, one must consider not only factors such as the photometric scale, the wavelength-dependent sensitivity of the image sensor, and the lens aperture ratio and focal length, but also issues related to the upgrading or changing of the equipment used.

4 Discussions

4.1 Groups among sporadic meteors

Group B, as defined by Ceplecha (1958), exists solely within the velocity range of 27.5–43.7 km/s. As previously noted, the existence of a group – embedded within groups A and C – has been hypothesized for the 20–40 km/s range. First, we examine the existence of groups other than A and C, while also considering the validity of the A and C classifications.

4.1.1 On Ceplecha's classification

There are several differences between Ceplecha's (1958) study and the present investigation:

1. Ceplecha used Super-Schmidt data and covered a narrow magnitude range, consisting of five categories spanning from $mag < 0$ to $mag > +1.7$.
2. Ceplecha used only data with a radiant zenith distance (ZR) greater than 0.5.
3. Ceplecha used v_∞ instead of v_g .
4. Ceplecha used a logarithmic scale for v_∞ when constructing the v_∞ - H_B diagram.

Although Ceplecha also generated distributions based on magnitude, he primarily relied on distribution plots using the complete dataset due to the narrow magnitude range involved. While Ceplecha asserted that group C does not exist at velocities of 15 km/s or lower, the presence of group C is evident below 15 km/s in Figure 12, and numerous members of group C appear in the distribution plots for fainter magnitudes. Furthermore, although Ceplecha treated Group A as a single entity, it is evident from Figures 11 and 12 that Group A is actually subdivided into A1 and A2, corresponding to the C1 and C2 subgroups. Ceplecha's claims regarding the absence of group C below 15 km/s and the classification of group A as a single population appear to stem from the factors described in (1).

While (2) is necessary when calculating the physical properties of meteoroids, the resulting difference is considered to be minor, as Ceplecha himself has noted; it merely slightly increases the scatter in the v_g - H_B diagram.

Regarding (3), while v_∞ is used to calculate parameters such as meteoroid density, there is no significant difference unless one is calculating the physical properties of the meteoroid itself.

To verify (4), a logarithmic scale was tested on the v_g - H_B diagram; however, the distribution became curved instead, failing to yield the linear relationship depicted by Ceplecha. It is believed that (1) also plays a role in this result.

In addition to these differences in research methodology, significant distinctions between Ceplecha's work and the present study include the use of film for Super-Schmidt observations versus CMOS sensors for video observations, as well as differences in photometric techniques. We simply note that the impact of these variations in imaging media and photometry is substantial.

4.1.2 On the existence of Group B

Figures 43 through 50 present a selection from the 82 sets of beginning height distributions prepared in the same manner as the 29.59 km/s distribution (Figure 3) used to define the boundary between groups A and C. The data were divided into eight sets such that the velocity difference within any single figure is 10 km/s or less; additionally, similar distributions with adjacent velocities were omitted to avoid cluttering. Each distribution consists of 10000 meteors, and the vertical axis represents the number of meteors within 1 km/s geocentric velocity bins. The values shown in the legends indicate the median velocities of the meteors used to generate the beginning height distributions.

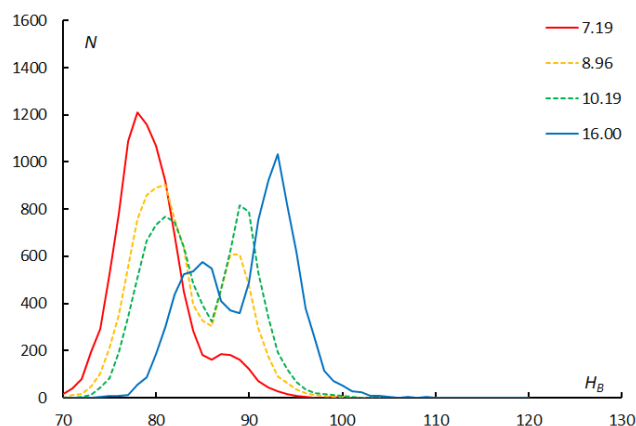


Figure 43 – Distribution of the number of meteors per kilometer of beginning height, based on the mag - H_B diagram for the selected range of $v_g < 16.4$ km/s. The legend indicates the median velocity for the range used to generate the mag - H_B diagram.

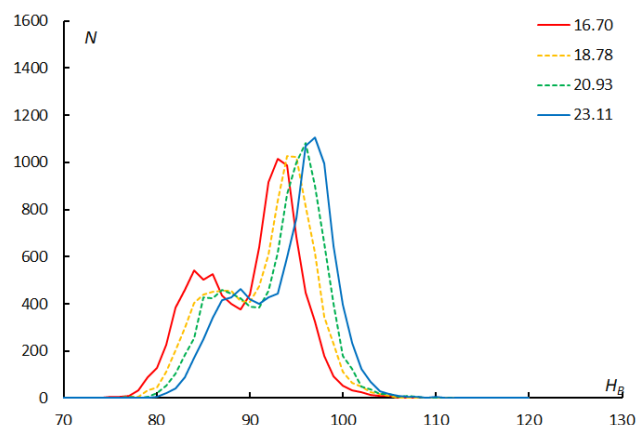


Figure 44 – Distribution of the number of meteors per kilometer of beginning height, based on the mag - H_B diagram for the selected range of $16.4 < v_g < 23.5$ km/s. The legend indicates the median velocity for the range used to generate the mag - H_B diagram.

Figure 43 shows the most dramatic changes in distributions of A and C in relation to velocity. At the lowest velocity of 7.19 km/s, type A (characterized by lower beginning height) overwhelmingly predominates; however, the number of type C increases rapidly, and the relative numbers of A and C reverse within this range. Naturally, it is evident that the beginning heights for both A and C rise as velocity increases. Furthermore, in all the distributions, the boundary (the trough) between A and C is clearly defined.

In *Figure 44*, the number of A decreases, and the trough marking the boundary between A and C gradually becomes indistinct.

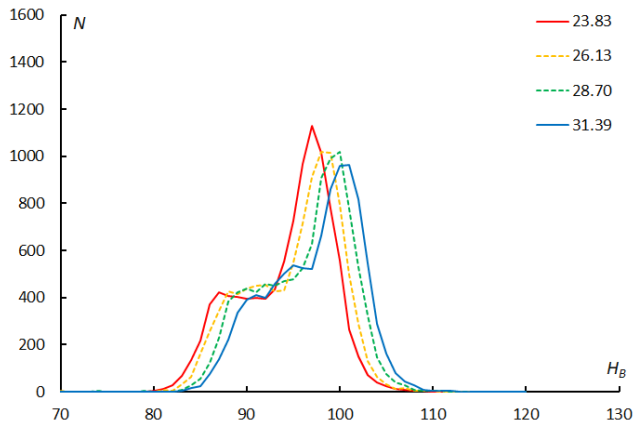


Figure 45 – Distribution of the number of meteors per kilometer of beginning height, based on the *mag-H_B* diagram for the selected range of $23.5 < v_g < 31.8$ km/s. The legend indicates the median velocity for the range used to generate the *mag-H_B* diagram.

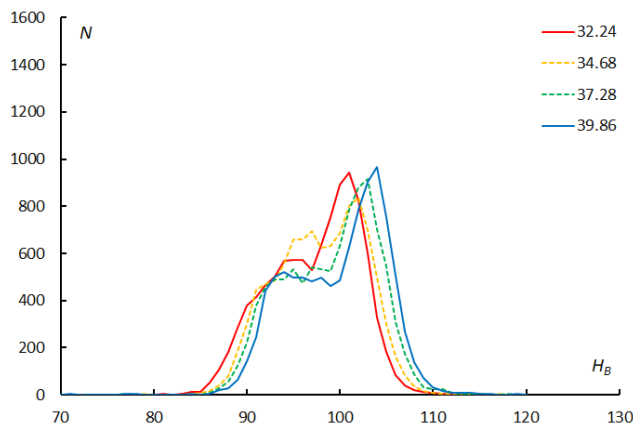


Figure 46 – Distribution of the number of meteors per kilometer of beginning height, based on the *mag-H_B* diagram for the selected range of $31.8 < v_g < 40.3$ km/s. The legend indicates the median velocity for the range used to generate the *mag-H_B* diagram.

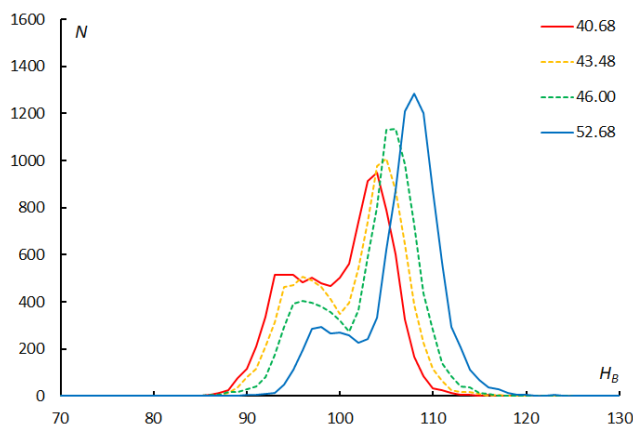


Figure 47 – Distribution of the number of meteors per kilometer of beginning height, based on the *mag-H_B* diagram for the selected range of $40.3 < v_g < 53.4$ km/s. The legend indicates the median velocity for the range used to generate the *mag-H_B* diagram.

In *Figure 45*, the increase in C shifts to a decrease, while A shows a slight increase. Consequently, the boundary between A and C ceases to be a trough and instead takes on a plateau-like shape.

In *Figure 46*, while A increases, the peak height of C remains substantially constant, and the presence of a trough – marking the boundary between A and C – becomes discernible once again.

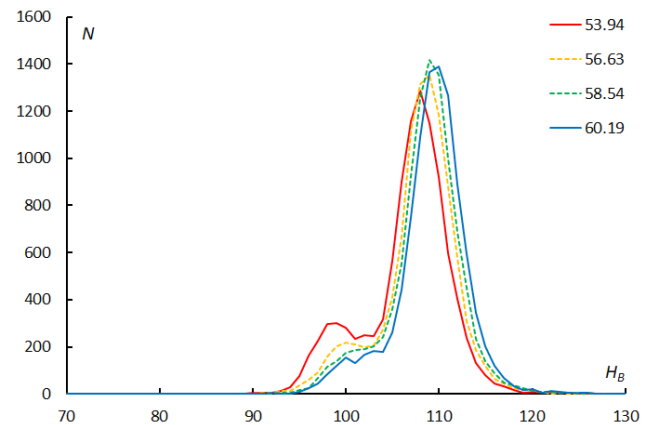


Figure 48 – Distribution of the number of meteors per kilometer of beginning height, based on the *mag-H_B* diagram for the selected range of $53.4 < v_g < 60.5$ km/s. The legend indicates the median velocity for the range used to generate the *mag-H_B* diagram.

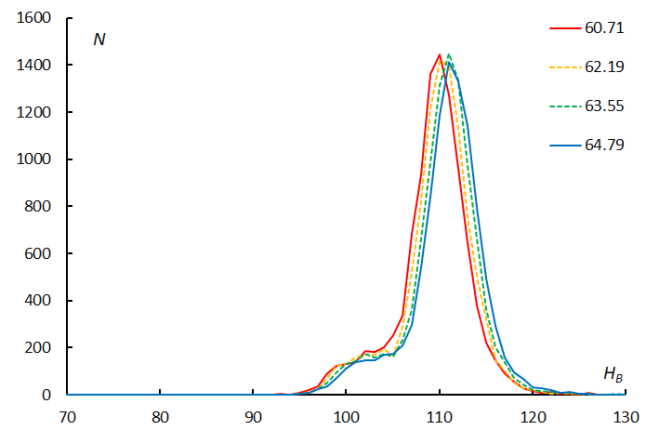


Figure 49 – Distribution of the number of meteors per kilometer of beginning height, based on the *mag-H_B* diagram for the selected range of $60.5 < v_g < 65.0$ km/s. The legend indicates the median velocity for the range used to generate the *mag-H_B* diagram.

In *Figure 47*, A begins to decrease and C to increase again; the trough serving as the boundary between A and C is relatively distinct.

In *Figure 48*, the number of A decreases, and the trough marking the boundary between A and C becomes indistinct.

In *Figures 49 and 50*, the number of A is low, and the terrain transitions from a trough to a plateau and then into a slope leading to A.

The existence of a separate group is inferred to fill the valley observed in the 20–40 km/s velocity range. *Figure 51* shows the distribution of beginning heights for a dataset of 10000 meteors with a median velocity of 34.68 km/s. Compared to the previously shown distribution with a median velocity of 29.59 km/s (*Figure 4*), the boundary between groups A and C is even less distinct, and the data appear to be divisible into three groups. *Figure 52* shows a portion of the beginning height distributions in 1 km bin created for each of ten groups – each containing 1000 data points – formed

by sorting the data from *Figure 51* by magnitude (see *Figure 3*).

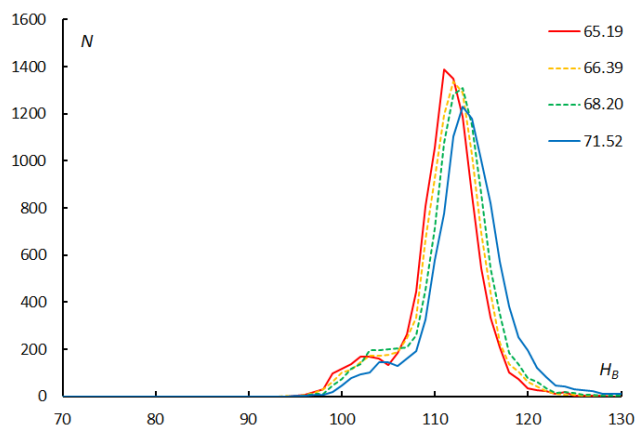


Figure 50 – Distribution of the number of meteors per kilometer of beginning height, based on the *mag-H_B* diagram for the selected range of $65.0 \text{ km/s} < v_g \text{ km/s}$. The legend indicates the median velocity for the range used to generate the *mag-H_B* diagram.

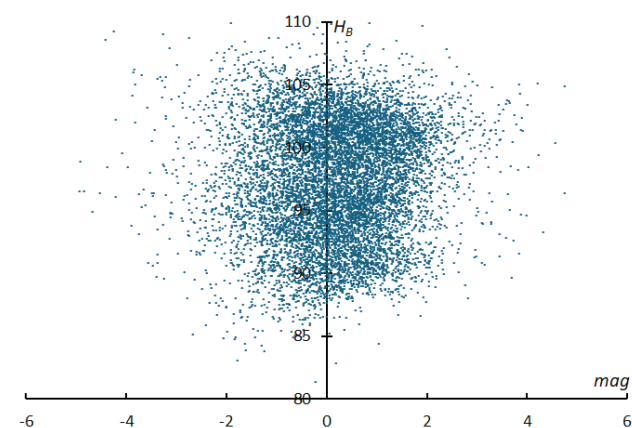


Figure 51 – Relationship between magnitude and beginning height for the data subset with a median velocity of 34.68 km/s , selected from datasets binned by increments of 10000 objects based on geocentric velocity.

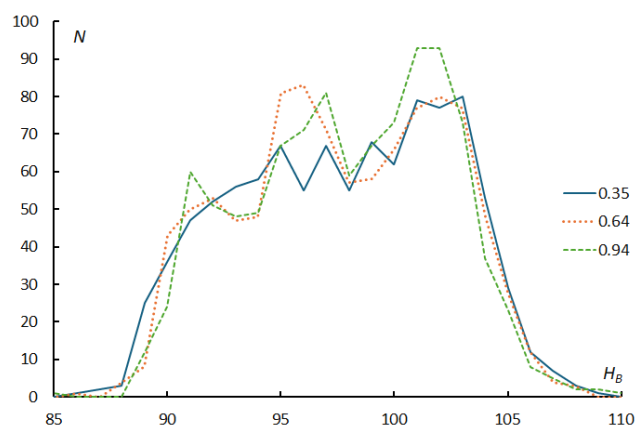


Figure 52 – Beginning height distribution for a subset of the 10 groups, each consisting of 1000 meteors, shown in *Figure 51* (the legend indicates the median magnitude).

For the case with a median magnitude of 0.35, an uneven plateau extends to the left from peak C (located at a beginning height 103 km), while peak A – expected to appear about 10 km below peak C – is not observed. In contrast, for the cases with median magnitudes of 0.64 and 0.94, a peak identified as A is visible near a beginning

height of 91 km, and an additional peak, higher than A, is observed near 96 km.

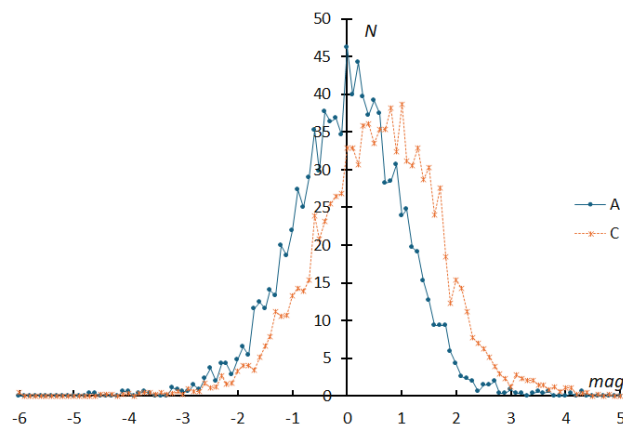


Figure 53 – Magnitude distribution of meteors included in the *mag-H_B* and *mag-H_E* distributions of median velocity $v_g = 29.59 \text{ km/s}$. The counts for both A and C are normalized to 1000.

Figure 53 shows the magnitude distribution of group A and group C meteors included in the beginning height distribution (*Figures 3 and 4*) with a median velocity of $v_g = 29.59 \text{ km/s}$. Since the numbers of A and C differ and also vary, the numbers of both A and C are normalized to 1000 in *Figure 53*. The noticeable irregularities in the distribution are due to the small number of meteors; the underlying shape is considered to be a smooth, bell-like curve.

In *Figure 53*, the distribution of C is clearly shifted toward the fainter end relative to A. Although not shown here, this same trend is observed in the distributions for the adjacent velocity ranges of 20.20 km/s and 39.86 km/s . Regarding *Figure 15*, it was noted that group C is prevalent among bright meteors, decreases as brightness diminishes, but increases again at even lower brightness levels. This phenomenon is thought to stem from an anomaly in the magnitude distribution within the $20\text{--}40 \text{ km/s}$ range. It is possible that confusion between groups A and C is occurring in this velocity range, or alternatively, that a distinct population exists.

In the velocity distribution for groups A and C (*Figure 6*) derived from the *mag-H_B* diagram, it was noted that the number of group A meteors increases in the $30\text{--}40 \text{ km/s}$ range, suggesting the existence of group B possibly. Therefore, an approximation curve (in this case, a fourth-degree curve) is generated for the variation in A – excluding the data in the $20.20\text{--}53.94 \text{ km/s}$ range – to estimate the hypothetical variation of A (see *Figure 54*). The difference between this curve and the distribution of group A shown in *Figure 6* is labeled “B?” in the figure. While this component is considered to correspond to Cepveda’s group B, it is difficult to distinguish individual meteors belonging to this group from those in groups A or C. The question of whether to establish a distinct “Group B” category will be further discussed in section 4.3.2. *Groups and orbital element distributions.*

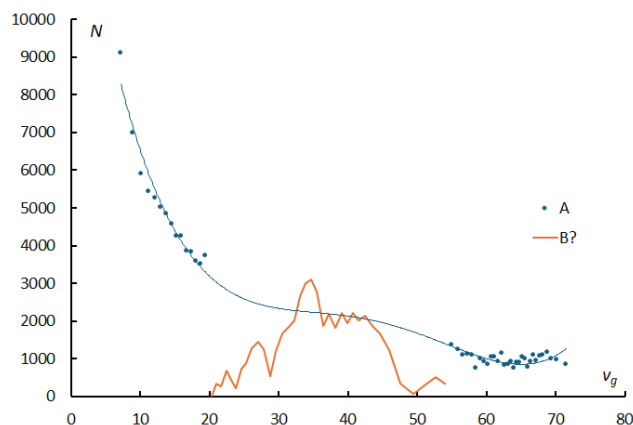


Figure 54 – The peak-shaped line labeled "B?" indicates the possibility of Ceplecha's Type B classification. It represents the difference between the actual distribution of Group A and the fourth-order approximation curve derived from the Group A data (filled circles), excluding the 20.20–53.94 km/s range shown in Figure 6.

4.2 Groups and the slope of the magnitude distribution

We previously pointed out that the slope of the magnitude distribution increases with geocentric velocity and that this change in slope may fluctuate rather than increasing uniformly with velocity; here, we examine the relationship between these factors and the groups.

As shown in Figure 6, the numbers of meteors in Groups A and C vary significantly depending on the geocentric velocity. First, we examine the issues associated with determining the slope of the magnitude distribution from a small number of meteors.

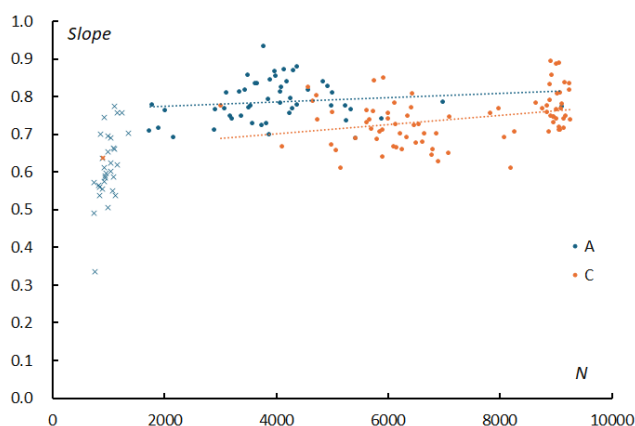


Figure 55 – Relationship between the slope of the magnitude distribution and the number of meteors for each group. The 'x'-marks indicate cases where the number of meteors is 1500 or less.

Figure 55 shows the relationship between the slope of the magnitude distribution for each group and the respective number of meteors, based on data partitioned into sets of 10000 by geocentric velocity, as illustrated in Figures 11 and 12. Geocentric velocity ranges with fewer than 1500 meteors are marked with 'x'-marks. The slopes for meteor counts of 1500 or less (indicated by 'x') are clearly smaller than that for counts exceeding this value. This indicates that the criterion used when calculating the slope for the entire sporadic meteor population – specifically, identifying the

slope of the line is steepest over a magnitude span of 2 – is insufficient for determining slopes on a group-by-group basis. Therefore, it should be noted that the group-specific slopes calculated below are subject to greater uncertainty than those calculated without grouping the data.

Figure 55 shows linear approximations (as dotted lines) for Groups A and C based on data with meteor counts of 1500 or more; a trend is observed wherein the slope of the magnitude distribution increases as the meteor count rises. This suggests that, even for data sets with 1500 or more meteors, there is a possibility that the calculated slope will be shallower when the meteor count is lower. However, in Figure 56, even with a sample of approximately 9000 meteors for Group C – a number close to the 10000 used to create Figure 42 – here is considerable scatter in the slope of the magnitude distribution. It is reasonable to attribute this spread to the limitations of this method, which relies on the slope of the line is steepest over a magnitude span of 2. As noted in 3.2 *Magnitude distributions of meteor showers and sporadic meteors*, this demonstrates the instability inherent in determining the slope of the magnitude distribution from a range characterized by low meteor counts and high variability. Therefore, the apparent trend that *the slope decreases as the meteor count decreases* can reasonably be attributed to the margin of error. Similarly, the apparent sharp increase in the slope of the magnitude distribution for Group C at a geocentric velocity of around 70 km/s (Figure 56) is likely an artifact. Furthermore, the oscillations observed in the relationship between the slope of the magnitude distribution for sporadic meteors as a whole and their geocentric velocity (Figure 42) are also considered to be artifacts resulting from constraints applied when determining the slope of the magnitude distribution.

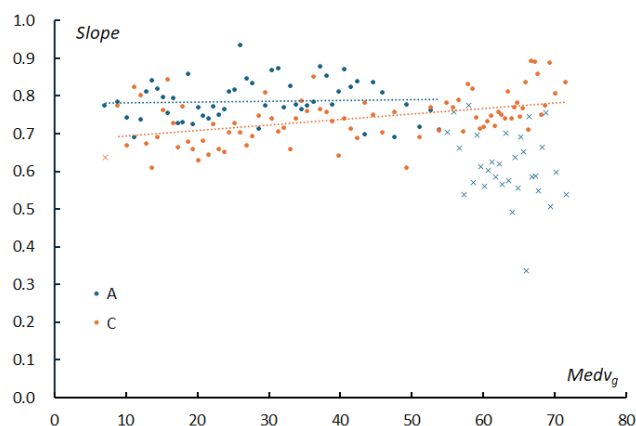


Figure 56 – Relationship between the slope of the magnitude distribution and geocentric velocity for each group. Data points representing 1500 or fewer meteors are marked with an 'x'.

Next, let us examine the relationship between geocentric velocity and the slope of the magnitude distribution for each group (Figure 56). In this figure, data points representing meteor counts of 1500 or fewer are marked with 'x'-marks. Additionally, regression lines for the data excluding these points are indicated by dotted lines. For both Group A and Group C, a trend is observed in which the slope of the magnitude distribution increases as the geocentric velocity

increases. This aligns with the trend observed for sporadic meteors as a whole (*Figure 37*).

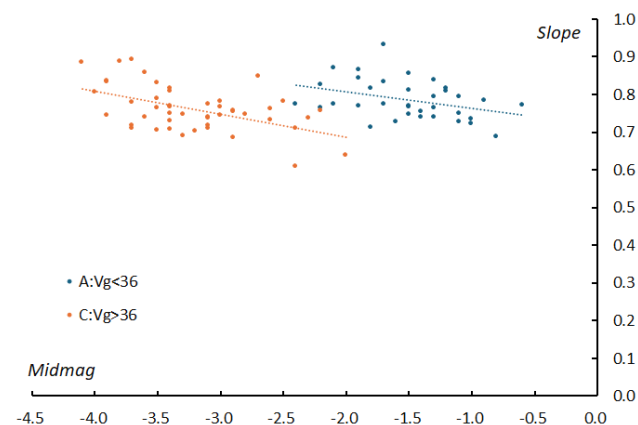


Figure 57 – Relationship between the midpoint value of the magnitude range (*Midmag*) used to determine the regression line in the magnitude distribution and its slope (*Slope*), shown by group. Consistent with *Figure 36*, only the ranges of $v_g < 36$ km/s for group A and $v_g > 36$ km/s for group C are shown. The dotted lines indicate the respective regression lines.

Like *Figure 37*, *Figure 57* illustrates the relationship between the midpoint value (*Midmag*) of the magnitude range used for linear approximation and the slope; however, unlike *Figure 37*, the slope increases as *Midmag* decreases for both groups A and C, suggesting that the slope varies depending on the magnitude range employed. Although the geocentric velocity range is divided into two categories – $v_g < 36$ km/s and $v_g > 36$ km/s – this 36 km/s threshold was determined based on changes in the number of samples in groups A and C; in *Figure 57*, group A corresponds to $v_g < 36$ km/s and group C to $v_g > 36$ km/s.

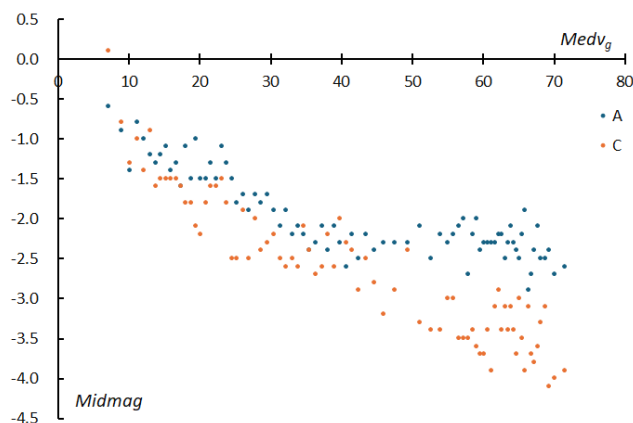


Figure 58 – Relationship between geocentric velocity and the midpoint value of the magnitude range (*Midmag*) used for linear approximation of the magnitude distribution, shown by group.

To verify the relationship shown in *Figure 57*, *Figure 58* illustrates how “*Midmag*” – the magnitude value used to determine the slope – varies with the median geocentric velocity “*Medvg*” of the samples used to construct the magnitude distributions. For both groups A and C, *Midmag* decreases significantly as the geocentric velocity increases. This indicates that the difference in *Midmag* observed in *Figure 57* stems from variations in geocentric velocity; in other words, the change seen in *Figure 57* implies that the

slope increases as the geocentric velocity rises. In fact, the reason *Midmag* appeared constant within the $v_g < 36$ km/s and $v_g > 36$ km/s ranges in *Figure 37* was that those data sets were mixtures of groups A and C.

Next, let us examine the relationship between the slope of the magnitude distribution and the groups. In *Figure 55*, Group A is positioned above Group C; it is inferred that the slope of the magnitude distribution is steeper for Group A than for Group C. *Figure 56* also shows a tendency for Group A to be positioned above Group C. *Figure 57* likewise suggests that the slope of the magnitude distribution is steeper for Group A than for Group C.

Let us examine the specific magnitude distributions. *Figure 59* shows the slopes of the magnitude distributions calculated for the range $25.7 < v_g < 26.5$ km/s, with the data divided into Group A and Group C. The slope of the regression line in the indicated range is clearly steeper for Group A than for Group C.

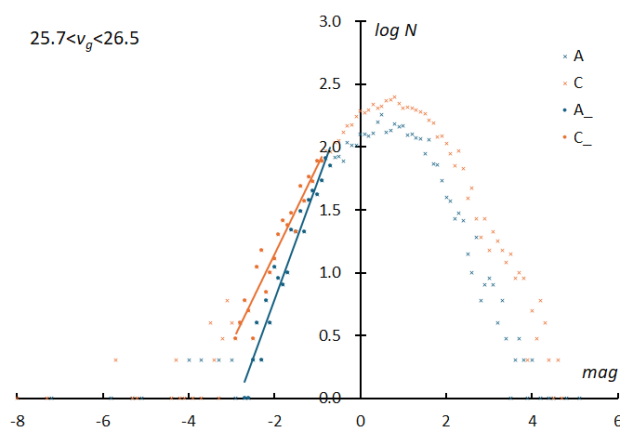


Figure 59 – Magnitude distribution by group in the velocity range $25.7 < v_g < 26.5$. A₋ and C₋ indicate the segments used for linear regression.

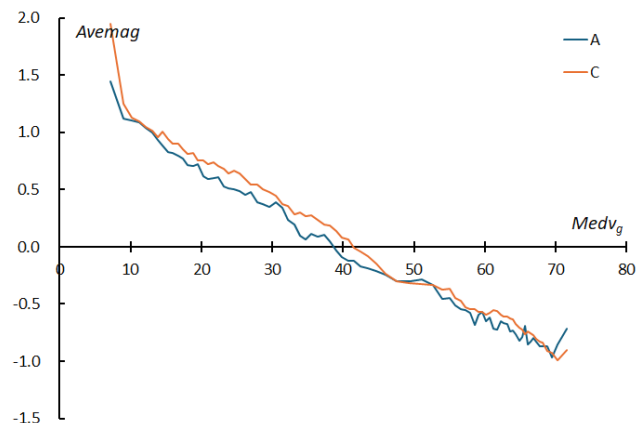


Figure 60 – Relationship between geocentric velocity and average magnitude of sporadic meteors, shown by group.

However, a comparison of the average magnitudes of Group A and Group C reveals an interesting finding. *Figure 60* illustrates the relationship between geocentric velocity and average magnitude for both groups. If the slope of the magnitude distribution (magnitude ratio) were steeper, the proportion of faint meteors would be higher, and the average magnitude would consequently be greater. Yet, *Figure 60* shows that the average magnitude of meteors

in Group C exceeds that of Group A across nearly the entire range. This finding contradicts the indication from the three previously discussed figures (*Figures 55–57*) that Group A tends to exhibit a steeper magnitude distribution slope. As shown in *Figure 6*, the number of meteors in Group A exceeds 700 even in the high geocentric velocity range – a sample size sufficient to consider the average values statistically significant – so it is highly probable that the average magnitude of Group C is indeed greater than that of Group A.

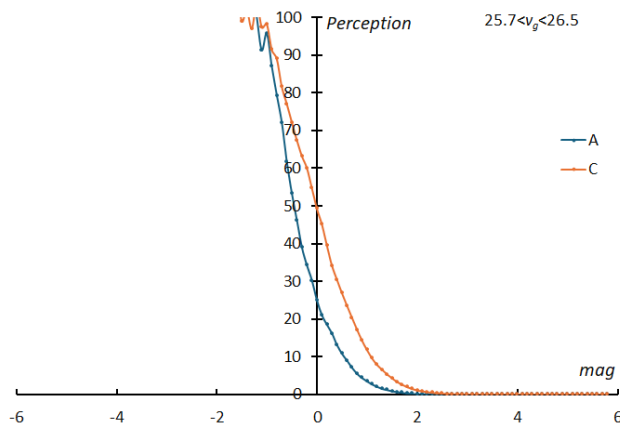


Figure 61 – Detection rates by group in the geocentric velocity range $25.7 < v_g < 26.5$ km/s.

We examine the detection rate as a possible reason for the conflicting relationship between the slope of the magnitude distribution and the mean magnitude with respect to geocentric velocity. *Figure 61* compares the detection rates for groups A and C within the same geocentric velocity range ($25.7 < v_g < 26.5$ km/s) shown in *Figure 59*. The detection rate for group C is higher than that for group A across the entire range. This indicates that, even for group C – which is characterized by a lower magnitude ratio – a large number of faint meteors are detected, resulting in a higher mean magnitude. The increase in the number of faint meteors in group C observed in *Figure 15* is also thought to be partly attributable to this higher detection rate. As shown in *Figure 40*, the meteor detection rate varies with geocentric velocity, but it is also believed to differ depending on the group. Therefore, it is not possible to determine the slope of the magnitude distribution (magnitude ratio) from the mean magnitude without accounting for these group-dependent differences in detection rates.

As discussed above, observational results confirm that the slope of the magnitude distribution is steeper for Group A than for Group C, and that for both groups, the slope increases with geocentric velocity. This finding reinforces the view that the slope of the magnitude distribution increases with geocentric velocity for sporadic meteors as a whole. we will conclude this section by considering the remaining issues.

It has been stated that referring to the magnitude distribution of sporadic meteors is effective for comparing the slope (magnitude ratio) of a meteor shower's magnitude distribution. However, if the magnitude distribution of

sporadic meteors varies by group, then using the overall sporadic meteor magnitude distribution for a shower considered to be close to Group C presents a problem.

It has been shown that the detection rate varies not only with geocentric velocity but also depending on the group (reflecting the physical properties of the meteoroids). While this implies that the pattern of variation in detection rate with geocentric velocity also differs by group, we will not delve further into this matter here.

It should be noted that the fact that detection rates differ among groups – even for meteors of the same speed and magnitude – may imply differences in meteor light curves and, by extension, differences in the physical properties of the meteoroids themselves. In visual observations, features such as “tails” and “short-lived trains” or “wakes” often attracted the observer's attention. Similarly, in video observations, what is actually detected is the phenomenon of the “meteor” rather than the “meteoroid” itself; the presence or absence of features like tails and short-lived trains likely influences the detection of meteor images. Consequently, it is to be expected that detection rates will vary depending on meteoroid physical properties or group differences, a factor that ultimately likely affects the observed magnitude distribution as well.

Furthermore, as previously discussed, there are issues regarding meteor photometry that significantly affect detection rates. While we compared the magnitude distributions of GMN and SonotaCo network (*Figures 29–32*) and examined differences in detection rates (*Figures 38 and 39*), improvements in photometry and photometric systems are considered essential for investigating the physical properties of meteoroids. There are likely issues with directly applying the method derived from conventional photographic photometry to calculate meteoroid mass based on meteor luminosities obtained through video observation. The fact that the slope of the magnitude distribution varies depending on geocentric velocity or shower suggests that existing methods for estimating meteoroid properties based on magnitude and deceleration may also need to be revised.

At this point, it is worth noting that the slope of the magnitude distribution is estimated to be steeper for Group A than for Group C. A steeper slope in the magnitude distribution implies that, regarding the mass distribution of the meteoroids, Group A contains a higher proportion of low-mass particles. This suggests that the origins of the meteoroids in Group A and Group C differ.

4.3 Groups based on beginning height and orbital elements

4.3.1 Differences in radiant point distribution and velocity by groups

Orbital elements are a mapping derived from the radiant point and velocity; therefore, we first examine how the relationship between the elongation from the Earth's apex and the velocity distribution differs between the Group A

and Group C populations, as shown in *Figure 21* of Part I. *Figure 62* shows the distribution for Group A, and *Figure 63* shows that for Group C. Here, we again employ the metaphor of a fish – comprising a head, fin, and body – that was used in Part I to describe the overall distribution of the combined Groups A and C. In the Group A distribution shown in *Figure 62*, the “head” tapers, the “fin” are distinct, and a concentration of meteors in the lower part of the “body” – resembling pelvic fins – becomes prominent. In the Group C distribution shown in *Figure 63*, the “head” appears larger, the “fin” are less conspicuous, and the lower “body” section is more streamlined. Although Groups A and C are fundamentally intermixed, these differences in velocity distribution naturally result in corresponding differences in their orbital distributions.

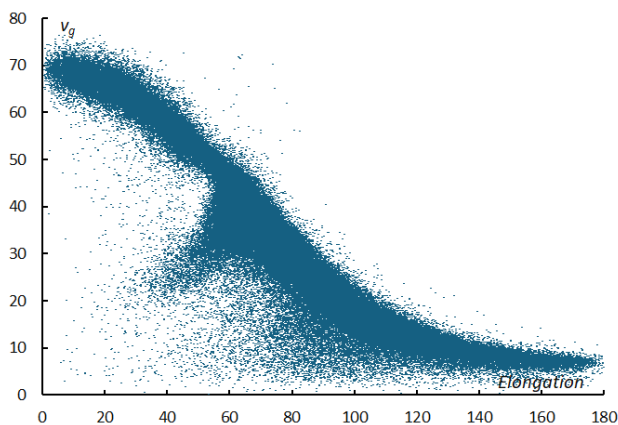


Figure 62 – Geocentric velocity distribution of meteors classified as group A, plotted against the elongation (see Part I *Figure 21*).

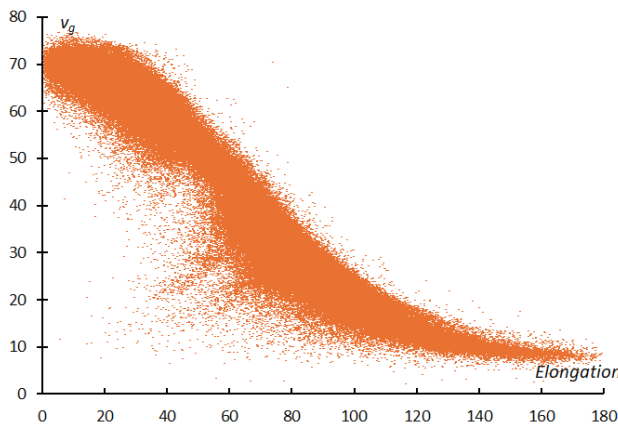


Figure 63 – Geocentric velocity distribution of meteors classified as group C, plotted against the elongation (see Part I *Figure 21*).

Next, using the radiant distribution centered at $(\lambda - \lambda_0, \beta) = (270^\circ, 0^\circ)$ – which was also employed in Part I – let us examine how groups A and C relate to the populations classified by radiant distributions. As shown previously, the central circle represents the Apex source; the upper and lower ellipses represent the Toroidal source; the left ellipse represents the Helion source; and the right ellipse represents the Anti-Helion source (ANT). Here, only the characteristic ranges of geocentric velocity are shown.

First, let us compare the distributions for the range of geocentric speeds $30 < v_g < 40$ km/s; *Figure 64* represents

Group A, while *Figure 65* represents Group C. In both cases, the distribution spans the ANT, the Toroidal source, and the region connecting them. In Group A, radiant points are concentrated at the ANT, with “outflows” extending upward and downward to the left. These outflows – analogous to “fin” in the fish metaphor – will be discussed in detail in the next article, Part III. In Group C, these “outflows” are less prominent, and the Toroidal source constitutes the dominant feature.

Next, we compare the distributions for meteors with geocentric velocities exceeding 60 km/s ($v_g > 60$ km/s); *Figure 66* shows Group A, and *Figure 67* shows Group C. A clear difference is evident here, revealing that Group C is dominant in the Apex source. In terms of the aforementioned “fish” analogy, this corresponds to the “head” in Group C being significantly larger than that of Group A. Furthermore, the high number of meteors in Group C indicates a north-south split in the Apex source, and a protrusion is visible in the upper-left section of the distribution. This feature consists of Perseid meteors that were classified as sporadic by the GMN. While the impact of Geminid meteors classified as sporadic by the GMN on the analysis in this paper is examined at the end, it is considered that there is no significant impact in the case of Perseids either.

4.3.2 Distribution of orbital elements by groups

Let us examine how the differences observed in the geocentric velocity distribution (based on elongation) and the radiant distribution in $(\lambda - \lambda_0, \beta)$ coordinates manifest when comparing orbital elements. In all the graphs below, the meteor counts for groups A and C have been normalized to 10000.

Regarding the eccentricity distribution (*Figure 68*), a key characteristic is that while the majority of group C consists of highly elongated orbits with $e > 0.8$, group A exhibits a distinct additional cluster around $e = 0.6$. We subdivide Group A into two groups – “Ar” (rounded: $0.5 < e < 0.7$) and “Ae” (elongated: $0.8 < e < 1$) – to examine their respective characteristics. Ar and Ae are each normalized to 10000, and the distributions of perihelion distance (*Figure 69*) and the reciprocal of the semi-major axis ($1/a$) (*Figure 70*) are shown.

In terms of perihelion distance q , group “Ar” shows a concentration at $q = 1$ AU, while the distribution of the reciprocal of the semi-major axis ($1/a$) is concentrated around 0.5 AU^{-1} .

In contrast, the perihelion distribution for group “Ae” is notable for a prevalence of objects with $q < 0.3$ AU; regarding the reciprocal of the semi-major axis, two distinct clusters are evident – one around $1/a = 0.2 \text{ AU}^{-1}$ and the other around $1/a = 0.5 \text{ AU}^{-1}$. The latter corresponds to the group with $q < 0.3$ AU, while the former corresponds to the group with q near 1 AU.

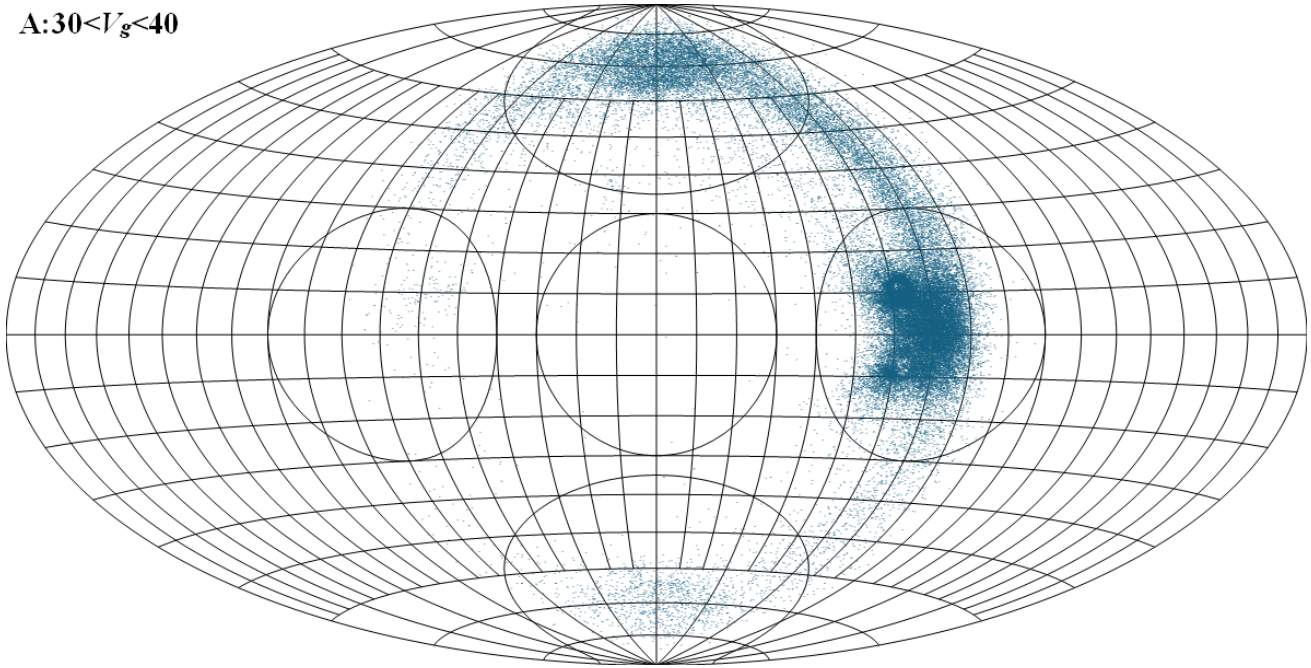
A: $30 < V_g < 40$ 

Figure 64 – Distribution map of meteors classified as group A in the geocentric velocity range $30 < v_g < 40$ km/s based on solar longitude, centered on $(\lambda - \lambda_0, \beta) = (270^\circ, 0^\circ)$. ANT, Helion, Toroidal (north and south), and Apex sources are indicated by circles with a radius of 30 degrees in the figure.

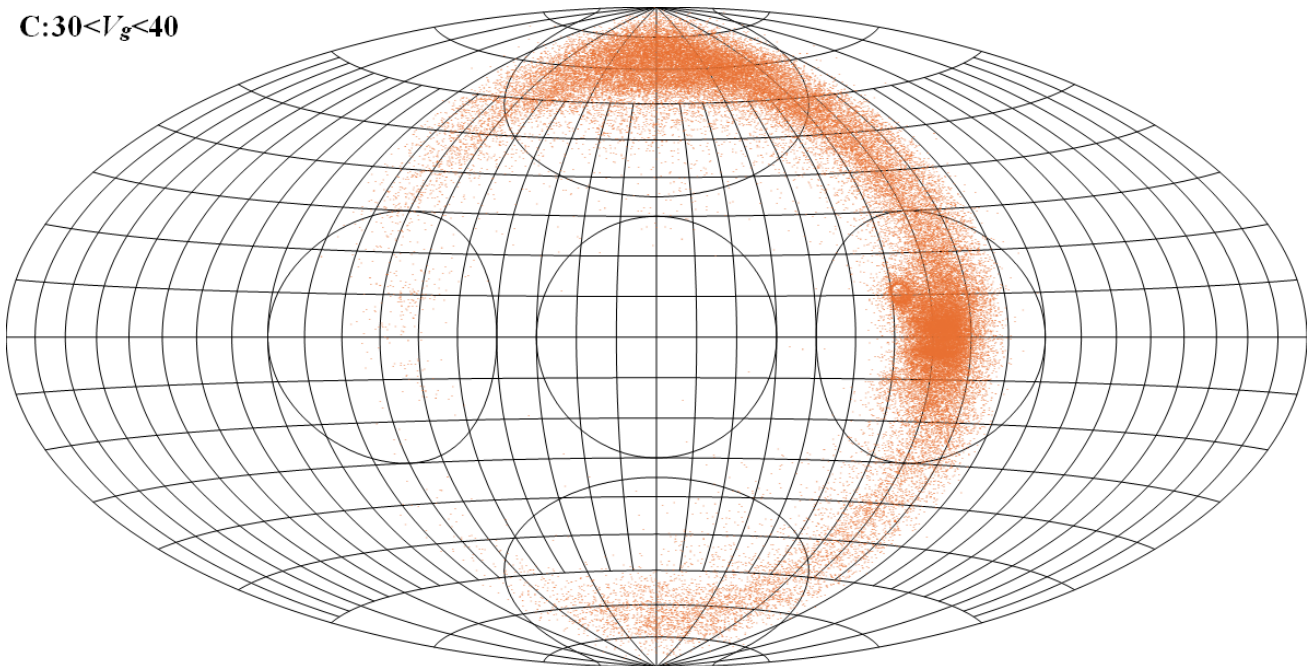
C: $30 < V_g < 40$ 

Figure 65 – Distribution map of meteors classified as group C in the geocentric velocity range $30 < v_g < 40$ km/s based on solar longitude, centered on $(\lambda - \lambda_0, \beta) = (270^\circ, 0^\circ)$. ANT, Helion, Toroidal (north and south), and Apex sources are indicated by circles with a radius of 30 degrees in the figure.

A: $60 < V_g$

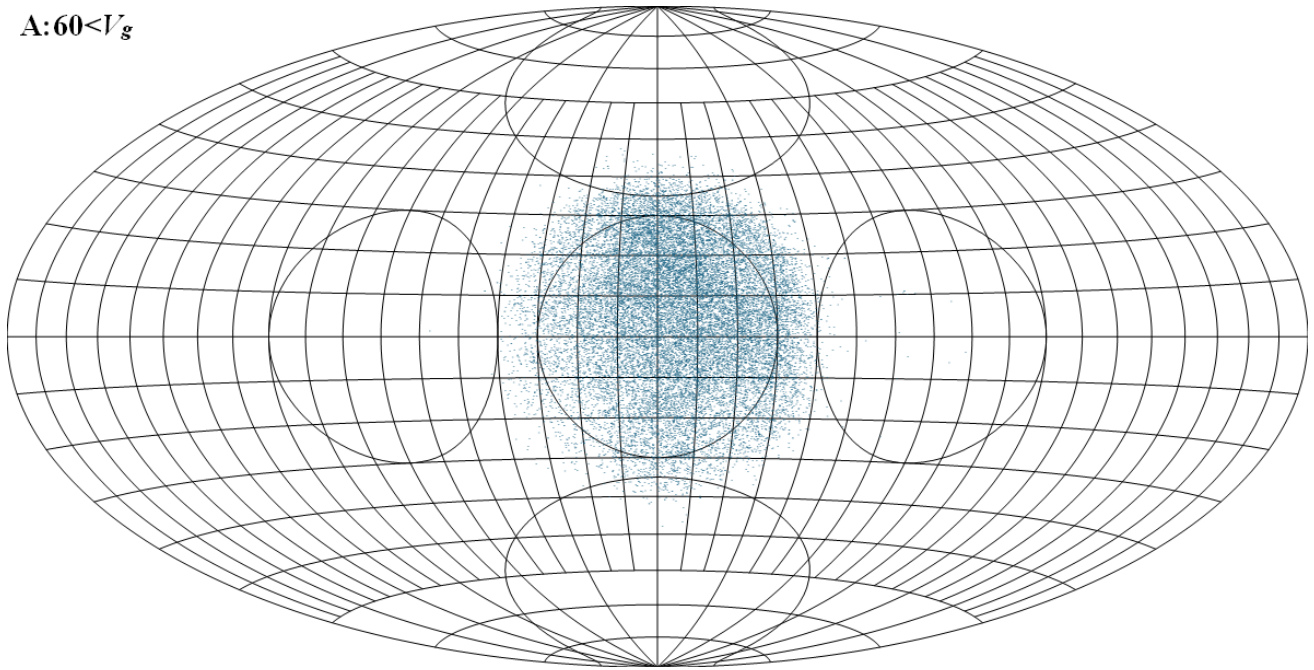


Figure 66 – Distribution map of meteors classified as group A in the geocentric velocity range $60 \text{ km/s} < v_g$ based on solar longitude, centered on $(\lambda - \lambda_0, \beta) = (270^\circ, 0^\circ)$. ANT, Helion, Toroidal (north and south), and Apex sources are indicated by circles with a radius of 30 degrees in the figure.

C: $60 < V_g$

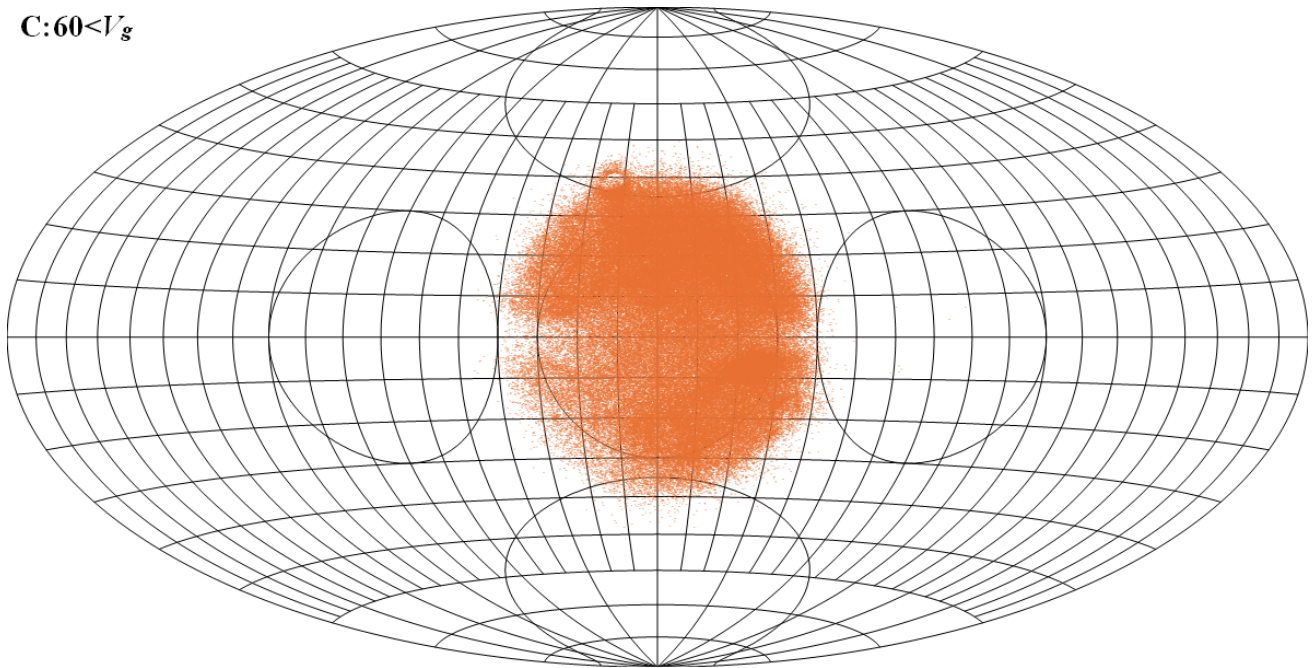


Figure 67 – Distribution map of meteors classified as group C in the geocentric velocity range $60 \text{ km/s} < v_g$ based on solar longitude, centered on $(\lambda - \lambda_0, \beta) = (270^\circ, 0^\circ)$. ANT, Helion, Toroidal (north and south), and Apex sources are indicated by circles with a radius of 30 degrees in the figure.

Regarding the distribution of perihelion distances q (Figure 71), the vast majority of objects in both groups A and C have $q = 1 \text{ AU}$. This is not a shared characteristic of groups A and C itself; rather, it is an artifact arising from the geometric conditions required for meteoroids to encounter Earth's orbit – a constraint that creates a misleading appearance. A notable feature of group A is the high number of meteors with $q < 0.3 \text{ AU}$., meaning they pass extremely close to the Sun. These correspond to the

objects distributed around $1/a = 0.5 \text{ AU}^{-1}$. within the group characterized by $0.8 < e < 1$ (“Ae”), a population previously mentioned in the discussion of eccentricity distribution.

In the distribution of orbital inclinations (Figure 72), both groups A and C contain many objects with inclinations of less than 30 degrees. However, this is not a shared characteristic inherent to groups A and C themselves; rather, it is an artifact – a consequence of the geometric

conditions required for meteoroids to encounter Earth's orbit. A distinctive feature of group C is the large number of objects with retrograde orbits (inclinations greater than 90 degrees). In terms of the “fish” analogy, this corresponds to the fact that the “head” section is vastly larger in group C than in group A. Comparing orbital inclinations by categorizing objects based on the reciprocal of the semi-major axis ($1/a$) – specifically into groups where $1/a > 0.2 \text{ AU}^{-1}$ (Figure 73) and $0 < 1/a < 0.2 \text{ AU}^{-1}$ (Figure 74) – reveals a stark contrast between groups A and C. For orbits where $1/a > 0.2 \text{ AU}^{-1}$ (corresponding to short-period comets and asteroids; Figure 73), the vast majority of both A and C have inclinations of $i < 30^\circ$. However, for orbits where $0 < 1/a < 0.2 \text{ AU}^{-1}$ (corresponding to long-period comets; Figure 74), the number of group A objects with higher inclinations decreases beyond a threshold of approximately $i = 50^\circ$, whereas the number of group C objects increases as the inclination rises, with many exhibiting retrograde orbits.

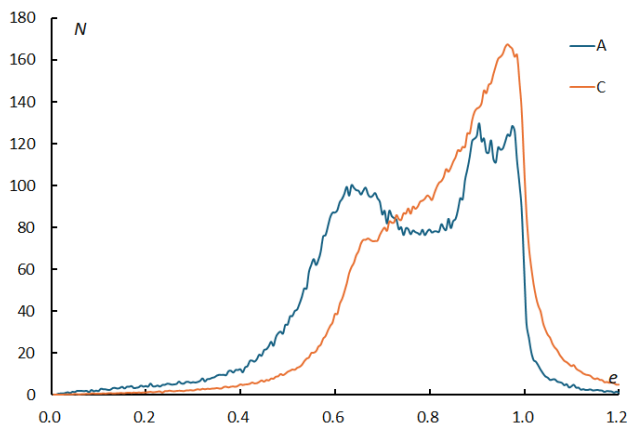


Figure 68 – Distribution of eccentricity for Group A and Group C, the meteor counts for groups A and C have been normalized to 10000.

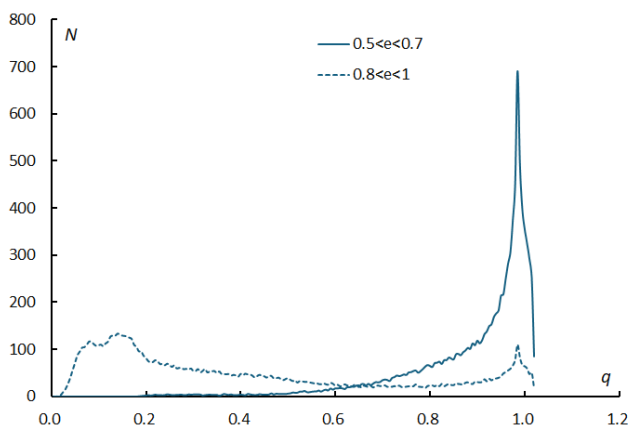


Figure 69 – Group A in Figure 68 is subdivided into two groups: “Ar” (rounded: $0.5 < e < 0.7$) and “Ae” (elongated: $0.8 < e < 1$). Perihelion distance distribution normalized to 10000 objects each for “Ar” and “Ae”.

In the distribution of the reciprocal of the semi-major axis ($1/a$) shown in Figure 75, both groups A and C exhibit a high concentration of values in the $0.5 < 1/a < 0.3 \text{ AU}^{-1}$ range – characteristic of the orbits of short-period comets and asteroids; however, the $1/a$ values for group C are slightly lower, placing them closer to short-period comets than to asteroids. Furthermore, group C is overwhelmingly

dominant in the region where $1/a < 0.1 \text{ AU}^{-1}$, which corresponds to long-period comets. Using the “fish” analogy, this corresponds to the difference in the ratio between the “head” and the “body”. For meteor ratios where $1/a < 0 \text{ AU}^{-1}$, category C significantly exceeds category A; this is because there are many meteors with high velocities and, consequently, large semi-major axes (a). However, one must also consider the possibility that meteor images in category C are more difficult to measure than those in category A, leading to larger errors in orbital elements. It is plausible that category C meteoroids are low-density and prone to disintegration – resulting in diffuse images – whereas category A meteoroids are robust, producing images that appear nearly point-like. While it has been noted that category C may have a higher detection rate than category A, the impact of differences in meteor video imagery on detection and measurement warrants further investigation.

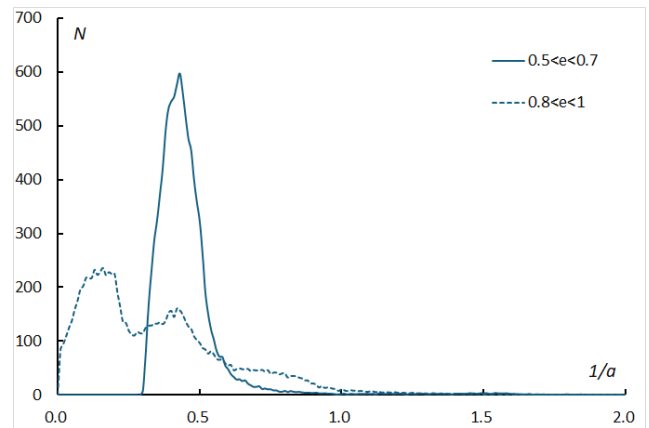


Figure 70 – Group A in Figure 68 is subdivided into two groups: “Ar” (rounded: $0.5 < e < 0.7$) and “Ae” (elongated: $0.8 < e < 1$). Reciprocal of the semi-major axis $1/a$ distribution normalized to 10000 objects each for “Ar” and “Ae”.

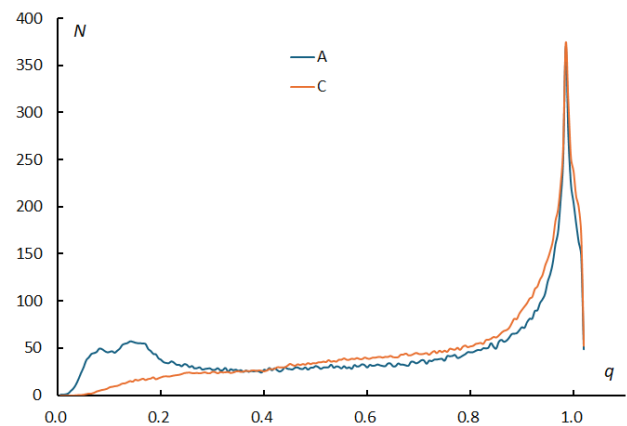


Figure 71 – Distribution of perihelion distances for Group A and Group C, the meteor counts for groups A and C have been normalized to 10000.

The division into “head” and “body” sections – using a fish analogy – corresponds to objects with retrograde orbits and those with prograde orbits, respectively. Consistent with this, both Group A and Group C can be broadly subdivided based on orbital elements, suggesting a possible link to their origins. However, determining the origin of the retrograde objects within Group A is not straightforward. Future

research must clarify whether these retrograde Group A objects are the rocky remnants of extremely old, weathered long-period comets, fragments of asteroids whose orbits were altered by perturbations, or something else entirely. Furthermore, the classifications proposed above – distinguishing between short-period comet/asteroid types and long-period comet types – will require thorough future verification.

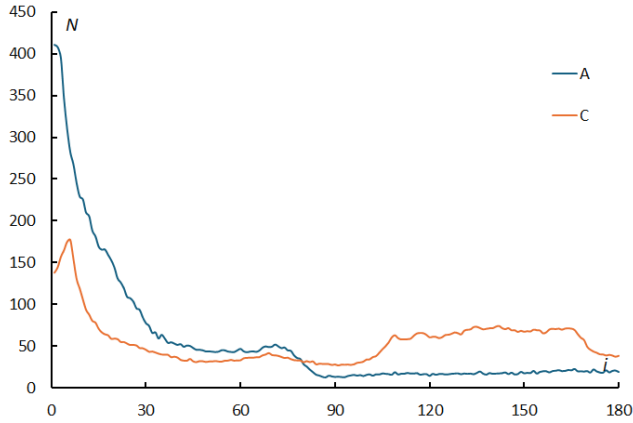


Figure 72 – Distributions of orbital inclinations for Group A and Group C, the meteor counts for groups A and C have been normalized to 10000.

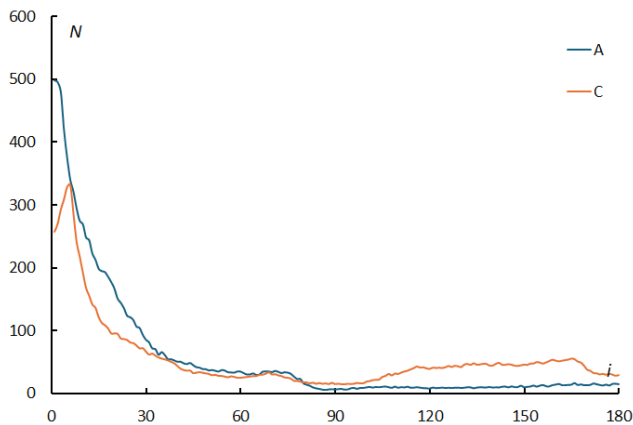


Figure 73 – Comparison of the orbital inclination distributions of Group A and Group C for meteors with $1/a > 0.2 \text{ AU}^{-1}$. Based on the reciprocal of the semi-major axis ($1/a$), meteors are classified into a group with $1/a > 0.2 \text{ AU}^{-1}$ and a group with $0 < 1/a < 0.2 \text{ AU}^{-1}$ (see Figure 75).

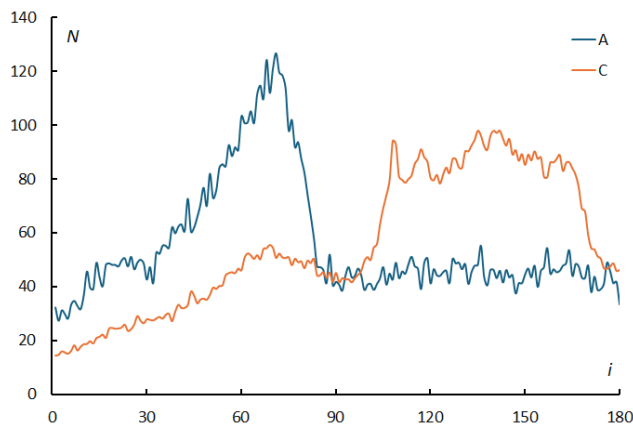


Figure 74 – Comparison of the orbital inclination distributions of Group A and Group C for meteors with $0 < 1/a < 0.2 \text{ AU}^{-1}$. Based on the reciprocal of the semi-major axis ($1/a$), meteors are classified into a group with $1/a > 0.2 \text{ AU}^{-1}$ and a group with $0 < 1/a < 0.2 \text{ AU}^{-1}$ (see Figure 75).

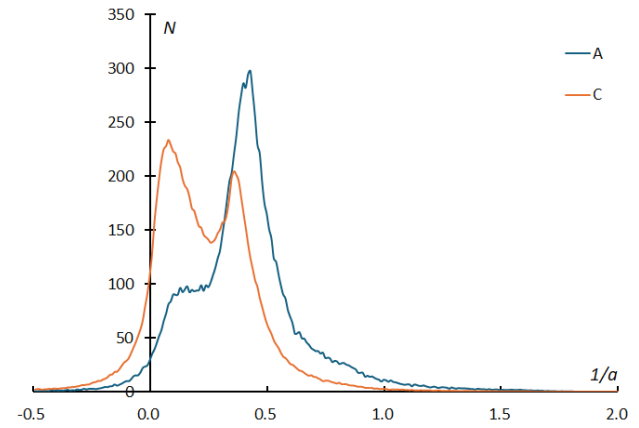


Figure 75 – Distribution of the reciprocal of the semi-major axis $1/a$ for Group A and Group C, the meteor counts for groups A and C have been normalized to 10000.

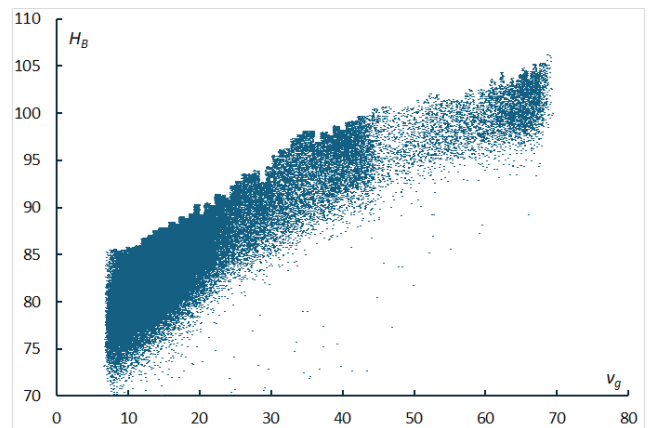


Figure 76 – v_g - H_B diagram for “Ar” (rounded: $0.5 < e < 0.7$) of Group A. Unlike Figures 11 and 12, this plot covers the full range of magnitude.

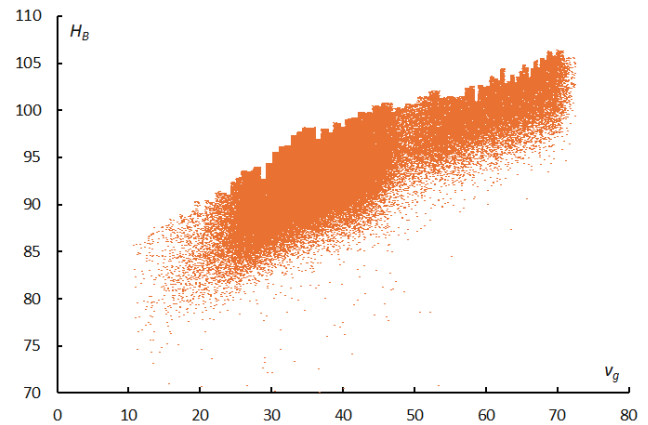


Figure 77 – v_g - H_B diagram for “Ae” (elongated: $0.8 < e < 1$) of Group A. Unlike Figures 11 and 12, this plot covers the full range of magnitude.

The distribution of orbital elements suggests that both Group A and Group C are further subdivided into smaller groups. However, these subgroups do not directly correspond to the distributional biases observed in the v_g - H_B diagrams. For instance, Group A can be divided into two populations – Ar ($0.5 < e < 0.7$) and Ae ($0.8 < e < 1$) – and Figures 76 and 77 show the v_g - H_B diagrams for “Ar” and “Ae”, respectively. At first glance, the beginning heights for “Ae” appear higher than those for “Ar”; however, the difference in eccentricity stems from the magnitude of the geocentric velocity, and it is natural for

the beginning height of “Ae” – which has a higher geocentric velocity – to be higher. Furthermore, when these two diagrams are superimposed, the distributions of “Ar” and “Ae” connect seamlessly; no differences in beginning height arise between “Ar” and “Ae” within the same geocentric velocity range.

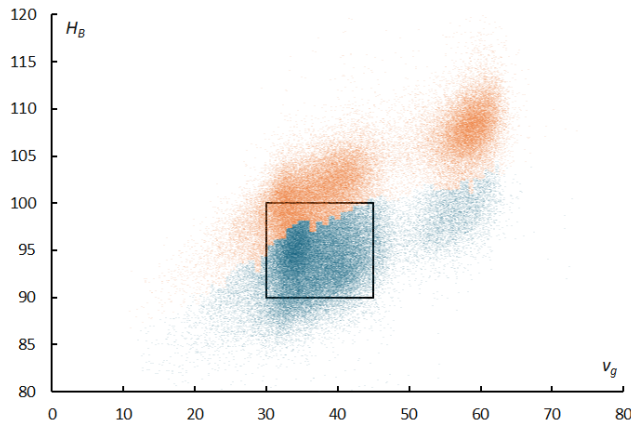


Figure 78 – v_g - H_B diagram for meteors with perihelion distance $q < 0.3$ AU. The upper distribution represents Group C, and the lower represents Group A. The area enclosed by the square frame indicates the range of possible Group B ($30 < v_g < 45$ km/s, $90 < H_B < 100$ km), as inferred from Figures 52 and 54.

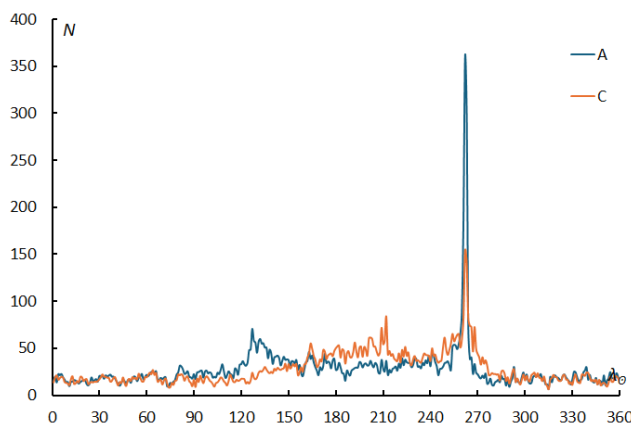


Figure 79 – Changes in the number of meteors for Groups A and C (with perihelion distance $q < 0.3$ AU) along with solar longitude.

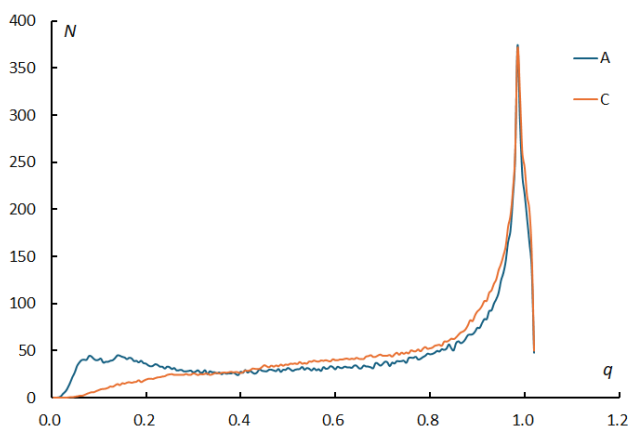


Figure 80 – Distribution of perihelion distances q for meteors, excluding those with solar longitudes (λ_O) in the ranges $120^\circ < \lambda_O < 134^\circ$ and $258^\circ < \lambda_O < 264^\circ$ to remove the influence of the Geminids and Southern delta-Aquariids.

Since Ceplecha characterizes Group B by a small perihelion distance, we examine the relationship between the

beginning height and the group defined by a perihelion distance of $q < 0.3$ AU. Figure 77 shows the distribution of beginning heights for meteors with $q < 0.3$ AU. Based on Figures 52 and 54, we have enclosed the region corresponding to Group B – defined by $30 < v_g < 45$ km/s and $90 < H_B < 100$ km – within a rectangle (Figure 78). Indeed, a large number of meteors are distributed inside this rectangle; however, it is evident that many meteors with $q < 0.3$ AU are also distributed outside this range. We previously noted that both Groups A and C split at a geocentric velocity of 50 km/s into two groups each, and the area enclosed by the rectangle appears to represent a portion of this split. Thus, the existence of Group B, as proposed by Ceplecha, cannot be definitively confirmed based on the distribution of orbital elements. In general, subdivisions made using v_g - H_B or mag - H_B diagrams do not correspond to distinct populations identified by orbital element distributions. Further subdivisions of Groups A and C, as well as the validity of Group B’s existence, remain subjects for future study.

Finally, while it was noted that the variation in meteor counts by solar longitude for group A reflects the influence of the Geminid meteor shower, we will now examine the extent to which this influence affects the analysis presented here.

A clear effect is observed in Group C, where there is an increase in the number of meteors with a perihelion distance $q < 0.3$ AU. Examining the variation in the number of meteors with $q < 0.3$ AU as a function of solar longitude (Figure 79) reveals a particularly distinct increase at $\lambda_O = 262^\circ$. Furthermore, another increase in the number of meteors is also evident near $\lambda_O = 125^\circ$. The former is attributed to the Geminids, while the latter is considered to originate from the Southern delta-Aquariids (#0005SDA). To eliminate the influence of both, we exclude meteors with solar longitudes in the ranges $120^\circ < \lambda_O < 134^\circ$ and $258^\circ < \lambda_O < 264^\circ$ and examine the distribution of the perihelion distance q (Figure 80). In this figure, too, an increase in the number of Group C meteors at $q < 0.3$ AU is evident. Thus, it can be concluded that the arguments presented in this paper remain valid, even if meteors belonging to specific meteor showers are present among the sporadic meteors.

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The Eccentrids of the Jupiter family in the minor bodies system

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This work is a continuation of our research on Eccentrids in the system of minor bodies. In this paper, we examine Eccentrids among asteroids and minor meteor streams in the Jupiter system. From the Lowell Observatory asteroid catalogue, which contained 1553303 asteroids as of June 30, 2026, we identified 1644 asteroids. The selection criteria were $e \geq 0.4$ and $4.70 \text{ AU} \leq Q \leq 5.70 \text{ AU}$. From the catalogue of 249 minor meteoroid streams (Terentjeva, 1966, 1967), 68 Eccentrid streams were identified, containing 100 meteoroid orbits. The distributions of asteroid Eccentrids and Eccentrids of minor meteor streams by eccentricity e and longitude of perihelion Π were studied. The dependence of eccentricity e on orbital period P was examined. Several conclusions were made from these distributions.

1 Introduction

This paper is a continuation of our research on Eccentrids (Terentjeva and Barabanov, 2016; Terentjeva and Bakanas, 2026, et al.), in which we examined the Eccentrids of the Earth group and the Mars family. In this paper, we focus on the Eccentrids of the Jupiter family. Jupiter is one of the large planets in the Solar System, with a significant sphere of influence (0.50 AU).

2 Research results

From the Lowell Observatory asteroid catalogue¹⁷, which contained 1553303 asteroid orbits as of June 30, 2026, 1644 asteroids belonging to the Eccentrids were selected. The selection criteria were $e \geq 0.4$ and $4.70 \text{ AU} \leq Q \leq 5.70 \text{ AU}$.

For the selection of the Eccentrids of the Jupiter Family among the meteoroid streams, we used the most comprehensive catalogue of 249 minor meteor streams (Terentjeva, 1966, 1967). The catalogue was compiled using photographic data, incorporating and analysing catalogues of radiants based on the best visual observations conducted by experienced observers, such as I. S. Astapovich and others. The minor meteor streams in this catalogue represent the smallest bodies in the Solar System's minor body population, which are the most susceptible to various disturbances and perturbations.

According to our selection criteria for the Eccentrids of the Jupiter family, out of 249 minor meteor streams, we identified 68 streams belonging to the Eccentrids,

accounting for 27%. This is a completely different situation from that of the Eccentrids of the Mars family, where, out of 670 orbits of meteoroid streams listed in several catalogues, only one Eccentrid stream of the Mars family was found (Terentjeva and Bakanas, 2026).

Let us examine the 68 Eccentrid streams that were found (they contain 100 meteoroid orbits). The distribution of these 100 values by eccentricity e is shown in Table 1.

Thus, the largest number of the Eccentrid streams of the Jupiter family (78%) have eccentricities of 0.7 and 0.8. The largest number of the Eccentrid asteroids of the Jupiter family have an eccentricity of about 0.6 (Figure 1).

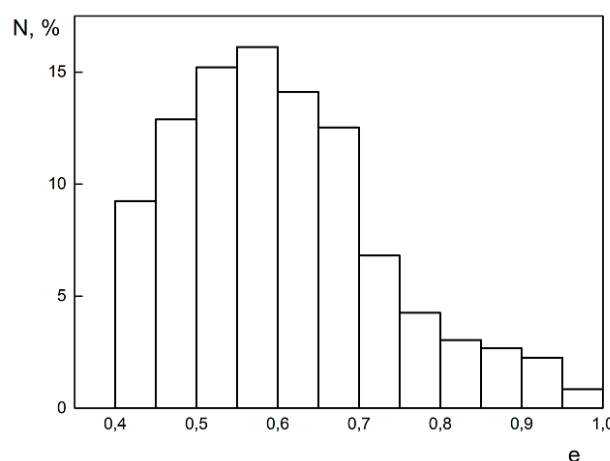


Figure 1 – Distribution by eccentricity e of the Eccentrid asteroids of the Jupiter family.

Table 1 – Distribution of the number of orbits in function of the eccentricity.

e	0.4	0.5	0.6	0.7	0.8	0.9	0.96	Total
Number of orbits, %	0	0	4	39	39	16	2	100

¹⁷ Lowell Observatory. The Asteroid Orbital Elements Database (astorb). Available at <https://asteroid.lowell.edu/astorb> (accessed 30.06.2026).

Figure 2 shows the dependence of eccentricity e on the orbital period P for the Eccentrid asteroids of the Jupiter family. As P decreases, e increases. This may be the effect of secular perturbations from inner planets.

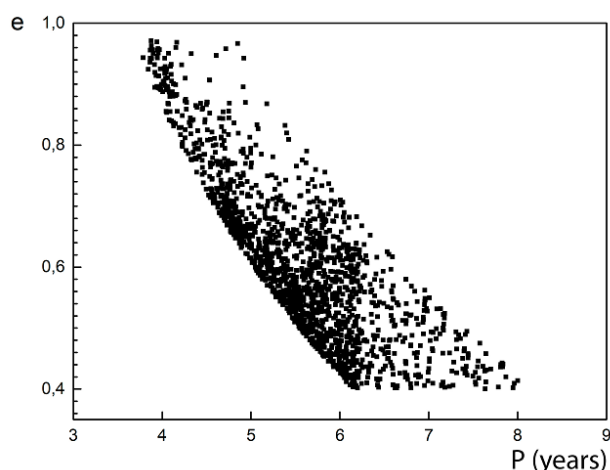


Figure 2 – Eccentricity as a function of orbital period P for the Eccentrid asteroids of the Jupiter family.

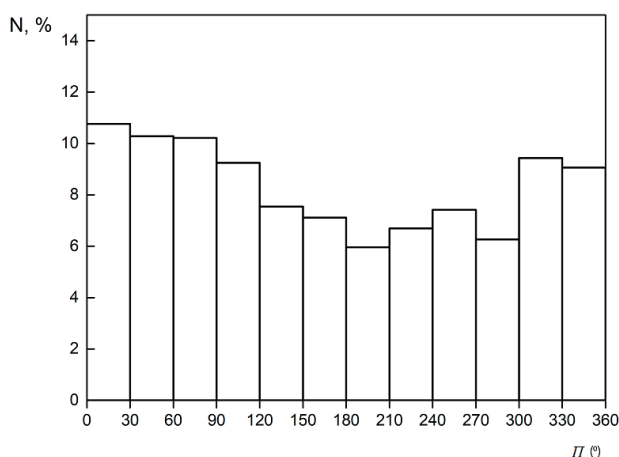


Figure 3 – Distribution of the longitudes of perihelion II of the Eccentrid asteroids of the Jupiter family.

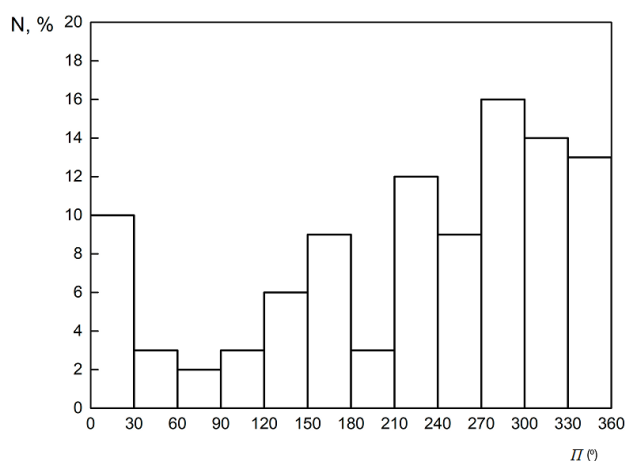


Figure 4 – Distribution of the longitudes of perihelion II for the Eccentrids of minor meteor streams of the Jupiter family.

Let us now examine the distribution of the longitudes of perihelion II of the Eccentrid asteroids (Figure 3) and the minor meteoroid streams of the Eccentrids (Figure 4) of the Jupiter family. The variation of II for asteroids is rather

smooth, with the main maximum in the interval of $II = 0^\circ\text{--}30^\circ$ and two minima at the intervals of $II = 180^\circ\text{--}210^\circ$ and $II = 270^\circ\text{--}300^\circ$. The main maximum includes the now well-known maximum of the Main Belt asteroids in the interval of $II = 0^\circ\text{--}20^\circ$, discovered by Putilin (1953). Jupiter falls within this interval, at $II = 15^\circ.4$. In Figure 3, a broader area of $II = 0^\circ\text{--}90^\circ$, adjoined by Saturn ($II = 91^\circ.1$), can be considered the maximum in the distribution by II .

Let us further examine the distribution of the longitudes of perihelion II of the minor meteor streams of the Eccentrids (Figure 4). It cannot be said that this distribution is particularly pronounced. This is evidently a feature of finely dispersed matter, which is easily subject to various perturbations. Nevertheless, we can identify the main maximum in the interval of $II = 270^\circ\text{--}300^\circ$, the second maximum in the interval of $II = 210^\circ\text{--}240^\circ$, the third peak in the interval of $II = 0^\circ\text{--}30^\circ$, and perhaps the fourth maximum in the interval of $II = 150^\circ\text{--}180^\circ$. The area of the second maximum includes Pluto ($II = 223^\circ.6$), and the area of the fourth maximum includes Uranus ($II = 169^\circ.0$). The area of the third maximum, $II = 0^\circ\text{--}30^\circ$, was discussed above.

It should be noted that the main maximum at $II = 270^\circ\text{--}300^\circ$, which none of the planets of the Solar System falls within, for minor meteor streams (Figure 4) coincides with the minimum for asteroids (Figure 3) and, at the same time, with one of the main maxima for the Eccentrid asteroids of the Mars family (Figure 1, Terentjeva and Bakanas, 2026).

The values of the Tisserand dynamical parameter T_J , with Jupiter as the perturbing planet, were calculated for 11 Eccentrid minor meteor streams. Ten of these fell within the range of $T_J = 2.55\text{--}2.89$, meaning that these streams are of cometary origin. Only one Eccentrid stream has $T_J = 3.55$, indicating asteroid origin. This result was not unexpected. Minor meteor streams had previously been studied in relation to comets, and links between both individual streams and their families and comets had been identified (Terentjeva, 1968, et al.).

3 Conclusion

Thus, in this paper and in the previously mentioned work, we have examined the Eccentrids of the Jupiter family and the Mars family. There are, of course, considerably more Eccentrids in the Jupiter family.

It would be valuable, for anyone engaged in programmes of calculating planetary perturbations to demonstrate how an almost circular orbit evolves into one with a high eccentricity of $e \geq 0.7\text{--}0.8$.

Over 30 years ago, Dr E.I. Kazimierzczak-Polonskaya, had an outstanding programme researching the evolution of comets under the influence of close encounters with planets. In her works, she provided examples of the catastrophic changes that the elements of a comet's orbit can undergo as a result of such close encounters. There is, for example, a

remarkable case in which the perihelion and aphelion can exchange positions. Her major works, which were extremely complex from a mathematical point of view, were published in the Proceedings of the ITA, St Petersburg, and other publications. The year 2027 will mark the 125th anniversary of the birth and the 35th anniversary of the death of this remarkable scientist and individual.

The authors would like to thank *Paul Roggemans* for contributing to our understanding of Eccentrids (Roggemans et al., 2026).

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September epsilon-Perseids outburst (SPE#208)

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The September epsilon-Perseids displayed a sharp peak during a few minutes with a maximum ZHR of 73 ± 33 at $\lambda_O = 167.206^\circ$, which corresponds to September 10, 2026, at 06^h22^m UT, close to the predicted peak times for three different ejection years.

1 Introduction

On Thursday, September 10, 2026, a brief outburst of the September ϵ Perseids (SPE#208) was observed from North America. Canadian observer Pierre Martin reported the following: “I believe I have seen a small outburst of SPEs last night near this predicted time (see Table 1). There was definitely a surge in especially bright meteors for several minutes (perhaps briefly reaching a ZHR around 30), then the rates quickly lowered to a weak level.

At 06^h10^m for a few minutes, my sky had an unexpected patch of cloud, and unfortunately had to wait for it to pass. By 06^h20^m when it cleared again, I think that was near the maximum with a lot of SPEs before the rates rapidly wound down. I'll decode my data after some needed sleep”.

Pierre was able to observe between 05^h00^m and 08^h15^m UT. He saw a total of 45 meteors, 29 of which were SPEs. Never before had Pierre seen so many SPEs during a single observing session. Later that night, observer Paul Jones was also active from Florida; he, too, saw a significant number of SPEs.



Figure 1 – Composite image of the September Epsilon Perseid outburst on September 10, 2026, observed from Stewartville, Ontario, Canada. Camera: Canon 6D with a 14mm f/2.8 lens, ISO 3200. The composite was created from continuous 20-second exposures taken between 05^h00^m and 08^h00^m UT. Most of the meteors in the image appeared between 06^h00^m and 07^h00^m UT. © Pierre Martin. The image is available for download in full resolution¹⁸.

¹⁸ <https://pmartin.smugmug.com/Astronomy/20260910-September-Epsilon-Perseids/i-RPkjGf/A>

Table 1 – Overview of expected peak times according to Mikiya Sato and Jeremy Vaubaillon (table taken from Rendtel, 2026). The assumed ejection years differ between calculations, but all three model calculations point to a possible encounter on September 10, 2026, around 06^h10^m UT.

Ejection Year	Earth Encounter 2026 UT	λ_o (°)	Author and remarks
1583	06 ^h 09 ^m	167.199	Sato; 450 yr orbital period
1085	06 ^h 10 ^m	167.200	Sato; 950 yr orbital period
1848	06 ^h 13 ^m	167.200	Vaubaillon

2 Population index r

Table 2 presents the magnitude distribution of the SPEs as observed by Pierre Martin. It is an unusual distribution, featuring many meteors of magnitude +2 or brighter, hardly any at +3, and a somewhat larger number of fainter ones.

Table 2 yielded the following population index $r[-2;+5]$: 2.01 ± 0.46 (see also Table 2). A population index r of 2.00 was used for the ZHR calculations. Normally, the population index r of the SPE is 2.50 (Rendtel, 2026). Thus, the SPE meteors were, on average, much brighter during the outburst.

Table 2 – Magnitude distribution of the SPEs observed by Pierre Martin.

−2	−1	0	+1	+2	+3	+4	+5	Lm
1	2	3	4	10	1	3	5	6.28

3 Zenital Hourly Rate (ZHR)

Subsequently, the ZHR was calculated based on data from both observers. Overlapping 12-minute counts were used for the most part. During the peak, 6-minute counts were employed, whereas counts of 0.3 or 0.4 hours were used at the beginning and end of Pierre Martin’s session. Paul Jones’s data were derived from overlapping 20-minute counts. *Figures 2 and 3* show the results.

Due to the relatively low altitude of the radiant (25 degrees at the start of Pierre’s observation session) and the small number of meteors, the error margins are quite large, an important point to note. After all, a difference of just one meteor during such a counting interval can lead to significant changes in the calculated ZHR values. Nevertheless, it is clearly evident that there was a peak in activity and that the activity increased more slowly than it decreased. The maximum, with a ZHR of 73 ± 32.7 , lasted a few minutes, while the phenomenon as a whole spanned approximately 1.5 hours. The maximum occurred around $\lambda_o = 167.206^\circ$, which corresponds to September 10, 2026, at 06^h22^m UT. This indicates that the predictions by both Sato and Vaubaillon in Rendtel (2026) were accurate (see *Figure 3*), with Vaubaillon’s timing coming closest to the observed result. Unfortunately, as of the time of writing this article (September 21, 2026), no further visual observations have been reported.

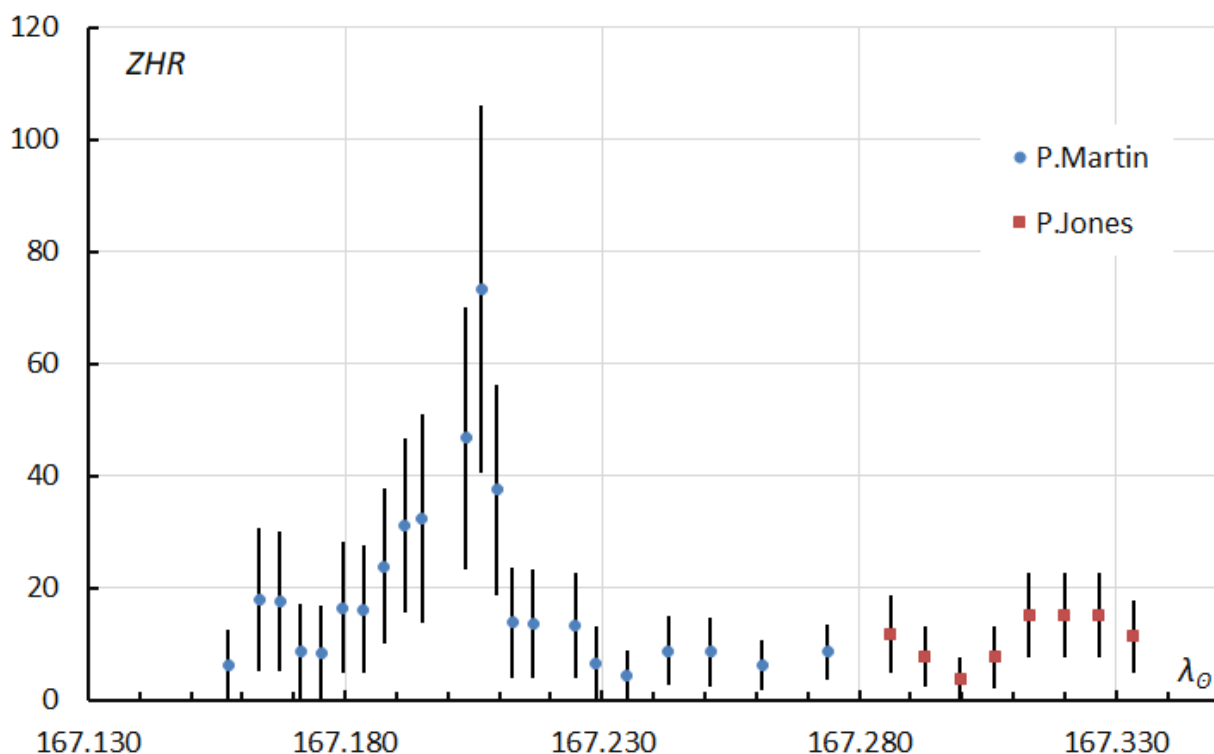


Figure 2 – ZHR graph of the September epsilon-Perseids on September 10, 2026, as a function of the solar longitude. Blue dots: Pierre Martins data, red dots: Paul Jones data.

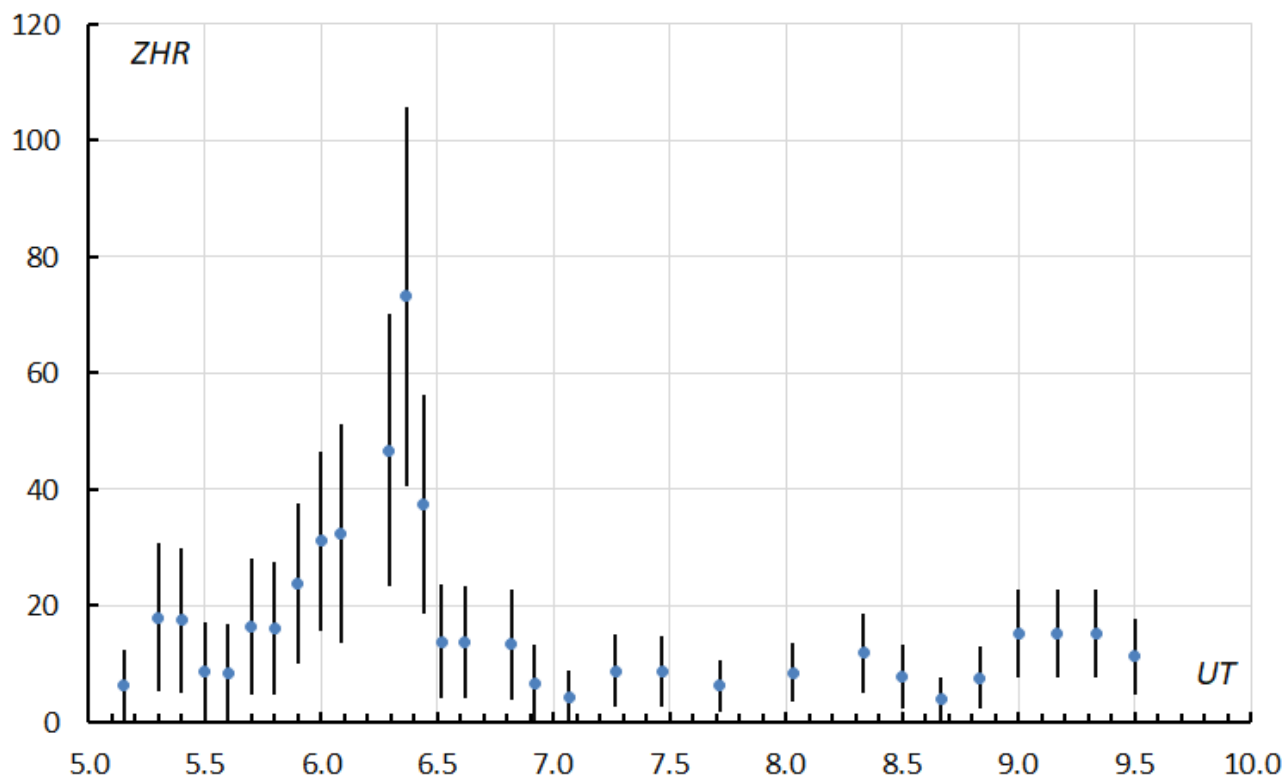


Figure 3 – ZHR graph of the September epsilon-Perseids on September 10, 2026, as a function of Universal Time (UT).

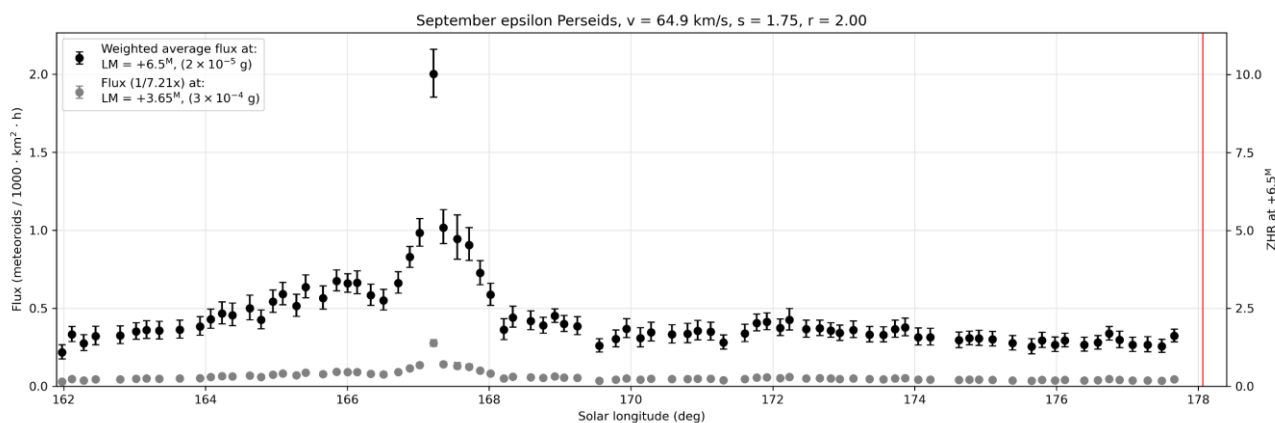


Figure 4 – Flux and ZHR data based on GMN observations.

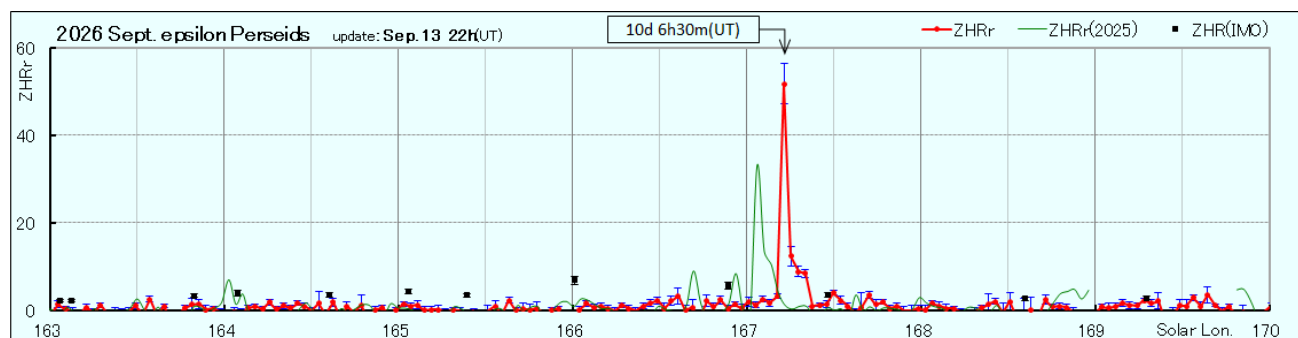


Figure 5 – ZHRr based on radio observations collected by RMOB.

4 Confirmation from other observation methods

On September 12, the Global Meteor Network reported via CBET 5736 that the outburst had also been recorded by the network. The GMN determined the time of the peak to be 06^h33^m UT (± 2 hours). The peak *ZHR* recorded by the GMN network was 9.4 (± 0.4). In a “normal” year, the GMN records an average *ZHR* of 4.5 (± 0.1). See *Figure 4*.

This is also confirmed by observations collected by RMOB, which are used by H. Sugimoto and H. Ogawa to determine a radio *ZHR*. They find a peak at 06^h30^m UT. See also *Figure 5* and H. Sugimoto’s website¹⁹.

It is interesting to note that all the peak times identified fall within 11 minutes of each other:

- Visual: 10 September 2026 at 06^h22^m UT
- Radio: 10 September 2026 at 06^h30^m UT
- GMN: 10 September 2026 at 06^h33^m UT (± 2 hours)

The annual peak was expected on 9 September 2026 at 18^h00^m UT (peak *ZHR* of 8), meaning the outburst occurred 12.5 hours after this peak.

5 Conclusions

Despite the limited amount of data, the results are excellent. This is also due to the quality of the data provided. While it is not possible to directly compare the results from the three observation methods mentioned, the peak times identified are close together, confirming the observations made by Pierre Martin and Paul Jones.

It cannot be entirely ruled out that the SPEs remained active above average levels for a longer period. Two SPE fireballs were recorded on the morning of 11 September by both Czech and BeNeLux all sky networks, and Jürgen Rendtel reported seeing more SPEs than usual during the night of 8–9 September, including ones with magnitudes of -2 and -3 . The author intends to investigate this further once the IMO website is back online.

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¹⁹ <https://mro.chips.jp/Flash/2026/SPE/index-e.htm>

Visual July meteor observations in the Netherlands: the first Perseids

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A summary is presented with the results of the visual observations by the author during July 2026.

1 Introduction

After a quiet period in the meteor hobby (though CAMS and All-Sky work continued), I decided to resume visual observing after the Full Moon in July. My last night of observing had been nearly three months earlier (April 22–23). The goal was to spot the first potential Perseids (PER), as well as the first Capricornids (CAP), Southern delta-Aquariids (SDA), July Pegasids (JPE), gamma-Draconids (GDR), and Antihelions (ANT). The weather forecast looked promising. Following the extreme heatwave in June, a second heatwave was expected in mid-July, though without such extreme temperatures and with much lower humidity. And, importantly, clear nights were predicted.

The first spell of clear weather lasted four consecutive nights. However, almost every night there was a threat of low-hanging clouds drifting inland from the Wadden Sea. Additionally, significant numbers of satellites were visible each night, some flaring brightly at times. Due to daytime work commitments, observations were conducted from the “meteor roof,” with the viewing direction always due south unless otherwise noted.

2 July 10–11, 2026

A fine 2.5-hour session under clear conditions. Transparency was good; the limiting magnitude reached 6.3 for an hour. A total of 23 meteors were counted, including 2 JPEs, 2 ANTs, and 1 SDA. The finest meteor was a white, magnitude -1 Sporadic (SPO) in Corona Borealis. The other meteors were faint. Additionally, two nice ISS passes were observed, the first at 22^h38^m UT. The space station moved from Boötes, through Hercules and Lyra, toward the eastern horizon. The second pass occurred between 00^h10^m and 00^h14^m UT, this time slightly lower in the sky.

3 July 11–12, 2026

Conditions were much the same as the previous night. This time, 22 meteors were spotted between 22^h19^m and 00^h47^m UT. These included 2 SDA, 1 CAP, 3 JPE, and 1 ANT. The finest meteors were two sporadic ones with a magnitude of $+1$.

There was another ISS pass at 23^h18^m UT, moving from Boötes toward Pisces. After 00^h30^m UT, a few small clouds drifted rapidly across the field of view. The session ended at 00^h47^m UT: the sky was becoming too bright for

observation, and more cloud cover was moving in from the northeast.

4 July 12–13, 2026

Another clear night, though the sky was a bit hazier than on previous nights. The limiting magnitude (L_m) was 6.2. Despite this, 24 meteors were observed, including 1 PER, 1 CAP, 1 SDA, 2 JPE, and 2 ANT. This night I observed the first possible Perseid of 2026: a magnitude $+4$ meteor in Cygnus. The first hour was quiet, with only 5 meteors, while the second hour was significantly better, yielding 12. The most impressive meteor was a slow-moving $+1$ ANT traveling from Delphinus to Pegasus. There were also two ISS passes, at 22^h49^m and 00^h14^m UT. During the second pass, the ISS dipped into Earth’s shadow in the southern part of Ophiuchus. During this second appearance, two magnitude 0 satellites were also visible flaring simultaneously.

5 July 13–14, 2026

This night was somewhat hazier than the previous one; conditions were significantly worse, especially at lower altitudes. I cut the observation session short due to a busy workday ahead. It was a dull session; only 14 meteors were counted. A bright flash occurred at 23^h04^m UT, followed by no further flashes, leading me to suspect a fireball. However, more flashes appeared from 23^h20^m UT onwards, indicating lightning. Later, weather radar showed thunderstorms active in the Münster/Bielefeld region in Germany, moving eastward. One ISS pass was also observed.

6 July 16–17 2026

After two nights with increased cloud cover, observations were possible again tonight. This was the best night in terms of numbers, largely because the atmospheric transparency was excellent. A total of 29 meteors were counted, comprising 2 PER, 2 SDA, 2 CAP, 1 JPE, and 3 ANT. There were also more bright meteors; notably, a magnitude 0 Perseid. It was dark orange, something I had seldom seen before with Perseids. The finest meteor, however, was a beautiful magnitude $+2$ ANT that moved slowly through Aquila. Later that night, I spotted another magnitude $+1$ Perseid.

Additionally, I observed another ISS pass at 22^h42^m UT, low in the southwestern sky. The current series of ISS passes over the Netherlands at night is coming to an end. While checking cloud cover in the northeast, I spotted a very bright satellite moving slowly through Perseus from east to west. For a long time, its brightness was magnitude –6. You don’t see that very often anymore, now that the well-known Iridium satellites are no longer visible; they could sometimes reach magnitude –8.

At 23^h39^m UT, there was a bright flash (the only one); I checked the all-sky recordings later, but nothing was visible. According to Buienradar (a Dutch weather app), there was a thunderstorm active in northwest Germany moving further north. That was likely the source of the flash.

7 July 20–21, 2026

A beautifully clear and transparent sky tonight. Between 22^h06^m and 00^h55^m UT, 29 meteors were counted. Two bright meteors.

At 23^h09^m50^s UT, a beautiful, fast, yellowish sporadic meteor appeared within the Summer Triangle, right in the middle of my field of view, displaying flares reaching magnitude –4 and a persistent train lasting 3 seconds. It was also beautifully captured by the all-sky camera (EN908). And at 00^h21^m UT, a lovely magnitude 0 Perseid appeared.



Figure 1 – The fireball of July 20, 2026 at 23^h09^m50^s UT, captured with my all-sky camera EN908.

Table 1 – Overview of the observations by the author in July 2026.

Date	Period UT		Teff.	Lm	F	Showers								Fireballs
Start	Start	End	h			PER	SDA	CAP	JPE	ANT	GDR	SPO	Tot	
10/07/2026	22:14	23:15	1.000	6.19	1.04	0	1	0	0	1		7	9	
10/07/2026	23:15	00:01	0.750	6.28	1.04	0	0	0	1	1		7	9	
11/07/2026	00:01	00:47	0.750	6.20	1.04	0	0	0	1	0		4	5	
12/07/2026	22:19	23:20	1.000	6.15	1.04	0	0	1	1	0		6	8	
12/07/2026	23:20	00:06	0.750	6.25	1.04	0	1	0	1	1		5	8	
13/07/2026	00:06	00:47	0.667	6.14	1.04	0	1	0	1	0		4	6	
12/07/2026	22:18	23:19	1.000	6.10	1.04	0	0	0	0	1		4	5	
12/07/2026	23:19	00:10	0.833	6.23	1.04	1	0	0	1	1		9	12	
13/07/2026	00:10	00:56	0.750	6.15	1.04	0	1	1	1	0		4	7	
13/07/2026	22:40	23:41	1.000	6.20	1.04	0	0	0	0	2		3	5	
13/07/2026	23:41	00:42	1.000	6.16	1.04	0	1	1	1	1		5	9	
16/07/2026	22:17	23:18	1.000	6.15	1.04	1	1	0	0	2		7	11	
16/07/2026	23:18	00:04	0.750	6.25	1.04	0	0	2	1	1		6	10	
17/07/2026	00:04	00:50	0.750	6.18	1.04	1	1	0	0	0		6	8	
20/07/2026	22:06	23:06	1.000	6.16	1.04	0	1	0	0	1		5	7	
20/07/2026	23:06	23:59	0.867	6.28	1.04	2	2	2	0	1		6	13	–4 SPO
21/07/2026	00:05	00:55	0.833	6.21	1.04	1	0	0	0	0		8	9	
24/07/2026	23:20	00:20	1.00	6.23	1.00	3	1	1	~	1	0	4	10	
25/07/2026	00:20	01:10	0.83	6.19	1.00	2	1	1	~	0	1	8	13	

8 July 24–25, 2026

Once again, a clear night, the last one before the Full Moon on July 28. Unfortunately, the air was slightly hazy. Cirrus clouds extended up to an altitude of 50 degrees in the south, so I shifted my FOV toward the north. Although the cirrus drifted slowly northward during the session and entered my field of view, it was simultaneously dissipating, so it barely hindered me. However, it did make classifying the southern summer showers somewhat more difficult.

Between 23^h20^m and 01^h10^m UT (1.833 hours of effective observation time), I spotted 23 meteors: 5 PER, 2 SDA, 2 CAP, 1 GDR, and 1 ANT. The GDR are the gamma-Draconids, which produced a brief outburst in 2016. The finest meteor was a slow +2 magnitude one that cut across Perseus and flared to magnitude +1 at the end; it also displayed a short wake. CAMS captured this meteor as well.

All in all, a successful July and good practice for—hopefully—a marathon session on Crete. See *Table 1* for the results.

Perseids 2026: visual meteor observations from Crete and the Netherlands

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A summary is presented with the results of the visual observations by the author during August 2026.

1 Introduction

After the first Perseids were spotted in July (Miskotte, 2026), I had to wait for the Full Moon on July 29th to pass. Back in January, my partner Lizzie and I had booked a holiday from August 9th to 21st at the Lenikos Resort near Agia Galini. We had visited this location before, in 2017; back then, the Cretan sky offered exceptionally clear conditions, thanks to the dry and strong Meltemi winds.

The plan was to enjoy a holiday but also to do some meteor gazing, attempting to gather data on every clear night. I always find it fascinating to see how a meteor shower evolves over time. This makes not only the peak interesting, but also the increasing and decreasing activity, something you can see changing night after night.

However, things got a bit tense as the holiday approached. In late July, three major wildfires were raging on Crete, two of which were just 5 and 10 kilometers away from Agia Galini. Fortunately, they were extinguished around August 4th. We drove through that area on August 10th: what a desolate sight. A valley where vast stretches of land were charred black, mostly grassland, but many olive trees had burned as well.

2 The observations

The first clear night following the Full Moon of July 29 was August 5–6.

August 5–6, 2026

A brief observing session in Ermelo under a sky with good transparency. This was due to the moon rising around 21^h20^m UT. Observations took place between 21^h00^m and 22^h00^m UT. A total of 12 meteors were counted, 3 of which were Perseids. The finest meteor was a fast, orange, magnitude –3 sporadic meteor in Bootes, leaving a persistent train lasting 2 seconds and captured with the all sky camera (EN908).

On the afternoon of August 8th, we set off for the CitizenM hotel at Amsterdam Schiphol Airport, as we had an early flight the next day. We arrived in Heraklion on August 9th, quickly sorted out our rental car, and began the 70 km drive to Agia Galini, heading for the coast of southern Crete to escape the busy, mass-tourism north. We stayed at the Lenikos Resort, a small-scale, luxury holiday complex featuring about twenty cottages and apartments (*Figure 1*). Everything was equipped with good Wi-Fi (essential for managing CAMS at home at Ermelo!) and air conditioning,



Figure 1 – Part of the Lenikos Resort near Agia Galini on Crete, viewed towards the east-southeast. The observation site was located more than 200 meters west of this small complex.

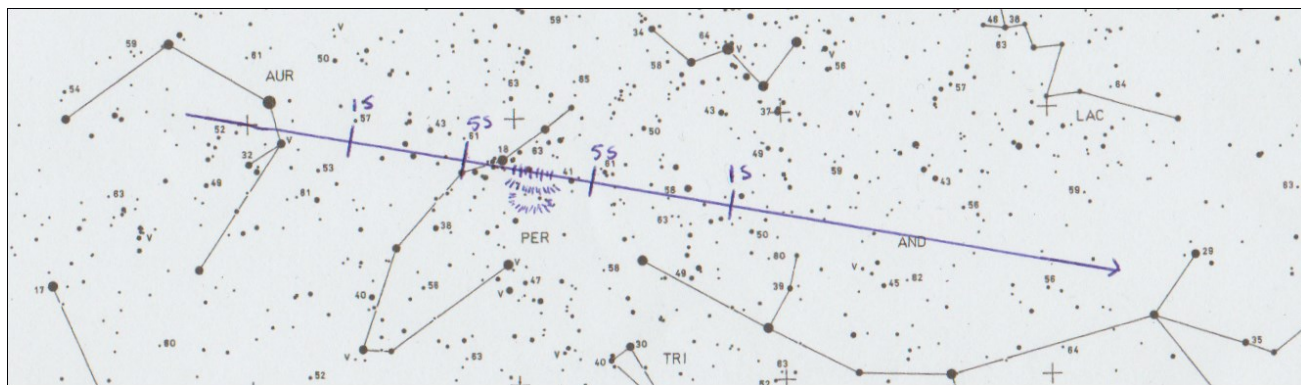


Figure 2 – The bright Earth-Grazing Fireball of August 11, 2026, at 00^h33^m UT. The labels “1 s” and “5 s” indicate the length of the persistent trail after 1 and 5 seconds, respectively. The drawing was made after the session, but it is reasonably accurate thanks to a trajectory passing near bright stars and easily identifiable reference points.

and there were four swimming pools that we made great use of. They also served fantastic, extensive Greek breakfasts, a must for the hungry visual observer :-).

The resort itself was well-lit, though most of the lights were switched off later in the night. My routine for the evening and night usually went like this: I would go to bed early in the evening, then get up around 1^h00^m AM local time, walk about 200 meters to my observing spot, and observe for three hours. The only exceptions were the Perseid peak nights of August 11–12 and 12–13, when I observed for about 5 hours. After that, I’d get a few more hours of sleep before breakfast was ready. This made the observing schedule sustainable without leaving me feeling groggy during the day. During the day, whenever holiday activities allowed, I would simply transcribe the data. I saved the tasks of creating tables and uploading them to the IMO website for after I got home. A stockpile of all-sky recordings and CAMS data processing awaited me there, too.

I was able to start observing the very first night after our arrival; that night, I set up my observing spot just 100 meters away from the resort. It was the same location where I had conducted observations in 2017. Although nighttime temperatures on Crete remain well above 20 degrees in August, I wore long trousers, socks, and a long-sleeved T-shirt while observing. I also used mosquito repellent, all necessary measures to ward off attacks by the pesky mosquitoes. Fortunately, this worked very well.

Over the course of several nights, Norwegian observer Kai Gaarder was also active on Crete near the village of Chora Sfakion, located about 60 km west of Agia Galini. We were in regular contact via Messenger to share our findings.

August 9–10, 2026

When I arrived at the observing site, a strong northerly Meltemi wind was blowing (Beaufort 4). The wind gradually subsided after two hours of observing. Even so, the sky clarity wasn’t “top-notch.” It was somewhat hazy, especially below an altitude of 10 degrees; consequently, the night lacked the exceptional clarity and high transparency of 2017. SQM readings ranged between 21.23 and 21.39. The limiting magnitude is between 6.4 and 6.5.

Nevertheless, the starry sky was quite beautiful, featuring a mottled Milky Way stretching from northeast to southwest. Observations took place between 22^h25^m and 02^h00^m UT (01^h25^m and 05^h00^m local time), focusing on the southern sky. A hill and some bushes partially obstructed my favorite viewing direction, the northeast, as well as the small amount of light pollution coming from the resort.

The Perseids were already clearly active, with hourly rates reaching up to 18 meteors, while the Southern delta-Aquariids also contributed 1 to 4 meteors per hour. A total of 107 meteors were spotted over 3.52 hours of actual observing time. See *Table 1* for the complete overview. The brightest meteor observed was a magnitude –2 Perseid.

Although the sky wasn’t perfectly clear, it is evident that light pollution low in the east has increased. While I could see the zodiacal light reasonably well in 2017, that was no longer the case. However, this also depends, of course, on the amount of moisture and dust in the air. Fortunately, the rest of the sky was nice and dark.

August 10–11, 2026

Once again, a somewhat hazy night at lower altitude. A total of 3.58 hours of effective observation time was logged between 22^h45^m and 02^h20^m UT. Quite a few bright Perseids were spotted, reminding me of 1980 and 2008, when many bright Perseids were also seen during the August 10–15 period. I had started observing at 22^h45^m UT, and eight minutes later, I caught my first Perseid fireball: a magnitude –4 meteor shooting through the “Great Square” of Pegasus. Later that night, at 02^h00^m and 02^h11^m UT, two more Perseids, magnitudes –4 and –3, respectively, were observed.

The highlight of the session, however, was a sporadic Earth-grazing fireball that appeared at 00^h33^m UT. It was a stroke of luck that I saw the fireball almost from the very beginning. I had just spotted a magnitude +2 Perseid and was verifying the radiant’s position, so I was looking toward Perseus. The fireball emerged from behind the hill in the northeast, making a long trail that passed Capella and cut through Perseus and Andromeda before fading out near the three stars Beta, Eta, and Mu Pegasi (see *Figure 2*). The fireball illuminated the surroundings significantly; I

estimated its brightness at a minimum of magnitude -6 . Its brightest section lay between Alpha Persei and Gamma Andromedae. A broad, long, white-blue persistent train of magnitude 1 lingered, though it rapidly shortened. A segment within Perseus remained visible for longer and clearly drifted in an east-southeast direction. I was able to track it for about 150 seconds! *Figure 2* provides an approximate indication of the length of the persistent train after 1 and 5 seconds. The section between Alpha and Theta Persei remained visible for 150 seconds. WOW, what a spectacular event. Kai Gaarder saw the fireball appear low in the east and also estimated it at magnitude -6 , with a persistent train lasting nearly 2 minutes.

A total of 173 meteors were counted over 3.58 hours; see *Table 1*. SQM values ranged from 21.30 to 21.39. The limiting magnitude increased from 6.4 to 6.5.

August 11–12, 2026: low activity but a relatively high number of bright meteors

Once again, a somewhat hazy night, though conditions improved, especially at lower altitudes. The limiting magnitude ranged from 6.4 to 6.6. SQM readings fluctuated between 21.08 and 21.41, with a single peak at 21.52. A Beaufort 4 Meltemi was blowing when I started, but it went down after an hour. The low-altitude haze dissipated as the night progressed; this made stars such as Tiaki and Al Nair in the constellation Grus (the Crane), low in the southern sky, more clearly visible than in previous nights.

Hourly Perseid counts ranged from 20 to 50. This seemed a bit meager for August 11–12. However, this was more than compensated for by a good number of bright Perseids. In addition to nearly 40 meteors with magnitudes between -2 and $+1$, several fireballs were also observed:

- 22^h55^m UT: -3 Perseid in Delphinus with a 5-second persistent train.
- 23^h36^m UT: -5 Perseid moving from Aries to Pisces with a 15-second persistent train.
- 00^h56^m UT: -4 sporadic fireball in Aquarius with a 1-second persistent train.
- 00^h57^m UT: -5 Perseid low in the west in Aquila; 12-second persistent train.
- 01^h01^m UT: -4 Perseid in Perseus/Auriga with a 4-second persistent train.
- 01^h35^m UT: -3 Perseid in Cetus; 4-second persistent train.
- 01^h48^m UT: -4 Perseid in Piscis Austrinus with an 8-second persistent train
- 02^h00^m UT: Flash! Wow... A very bright -7 to -8 magnitude Perseid lit up almost the entire sky. It moved from Perseus toward Cassiopeia. The persistent train remained visible for 25 seconds.
- 02^h08^m UT: -3 Perseid in Pegasus with a 2-second persistent train.

All in all, a distinctive observation session: somewhat lower activity, yet a relatively high number of bright meteors.

Incidentally, I had decided to look for a different observation site after this night. This spot was easily accessible in 2017, but perhaps due to heavy rainfall, the ground had become quite loose and covered in small stones. I took a nasty fall while leaving the site, resulting in two scraped knees and a torn pair of trousers.

August 12–13, 2026: filament active?

During the day, I walked along the path again to find a better observation spot. Overall, the path had deteriorated significantly since 2017. On the positive side, however, the two houses that were previously occupied, complete with free-roaming, barking dogs back in 2017, were now abandoned. This allowed me to walk further along the path undisturbed. Unfortunately, a lot of trash got dumped along roadsides in Greece; a bit further along, for instance, a tub of leftover concrete had been tipped out next to the path. Fortunately, the surface had been smoothed over. It was an ideal spot to set up a sleeping mat and observe. Given the poor condition of the path, I didn't expect any traffic.

I decided to look towards the south from this location, though I noticed the view to the northeast wasn't bad either. That night, I brought along my Sony Alpha A7 SII with the Sigma 20mm f/1.4 super-wide-angle lens. Although the camera didn't run flawlessly, it still managed to capture 42 meteors.

When I started at 20^h55^m UT (just before midnight local time), the sky background was still somewhat bright, but it improved quickly. The SQM reading rose from 21.10 to 21.45, and the limiting magnitude improved from 6.4 to nearly 6.6. The first hour revealed a number of bright Perseids: magnitudes -2 , -3 , and a -5 . The last one appeared in Aquarius at 21^h26^m UT and left a persistent train visible for 15 seconds. After that, the rate of bright Perseids dropped off noticeably, although overall activity remained good, with numbers trending upwards. Quarter-hourly counts ranged from 9 to 16 Perseids. Activity dipped slightly after 00^h00^m UT but then increased sharply and quite rapidly after 00^h30^m UT. I noticed this while in the field, but upon processing the data, it became clear that the numbers were higher than I had anticipated. Quarter-hourly counts were between 20 and 25. The number of bright meteors also increased, though there were no fireballs; most fell within the -3 to $+1$ magnitude range. This surge in activity aligns with Peter Jenniskens's prediction regarding the filament expected to pass Earth on August 13 around 01^h00^m UT (± 5 hours) (Jenniskens, 2006). Of course this must be confirmed by data from other European observers. Incidentally, I changed my viewing direction after 01^h08^m UT, shifting to the north-northeast. That remained the case for all the nights that followed.

While walking the 200 meters back to our rented apartment around 00^h40^m UT, I saw a bright flash, even though the sky was already beginning to brighten ($L_m \sim 4.0$). It was possibly a bright fireball. I immediately scanned the sky for a persistent train but found none. I also checked for thunderstorms on the weatherapp, but there was no active storm activity within a radius of at least 200 km.



Figure 3 – 12 August 2026, around 22^h00^m UT. Composite image of multiple Perseids near the southern Milky Way. The effect of the anti-radiant is clearly visible. Camera: Sony Alpha A7 with a Sigma 20mm f/1.4 wide-angle lens. Camera settings: ISO 1600, f/1.8, and 20-second exposure.



Figure 4 – 13 August 2026, around 01^h00^m UT. Composite image of 8 Perseids, the brightest of which was estimated at magnitude –3. Camera: Sony Alpha A7 with a Sigma 20mm f/1.4 wide-angle lens. Camera settings: ISO 1600, f/1.8, and a 20-second exposure.

All in all, it was a fantastic observing session! A total of 363 meteors were counted.

August 13–14, 2026

A strong south-westerly wind picked up during the day. Haze increased significantly, and later, cumulus clouds drifted inland. Cloud cover increased further towards the evening. I set an alarm anyway, recalling the 2018–2022 period when the Perseids displayed (sometimes major)

outbursts on this night. However, when the alarm went off, it was still largely cloudy. By morning, the sky had cleared, and the haze had vanished.

August 14–15, 2026

Starting this night, I returned to shorter sessions following the nights of peak activity. I started with a strong north-westerly Meltemi wind, estimated at Force 5. The transparency of the starry sky was excellent, though the

limiting magnitude lagged slightly behind. SQM readings also peaked at only 21.42. The sky background was somewhat light, suggesting the presence of a moist layer somewhere. As expected, Perseid activity was on the decline, with hourly counts ranging from 12 to 24 meteors. There were few bright meteors, unlike in 1980 and 2008, with only one Perseid of magnitude -3 observed.

I logged 3.68 hours of effective observation time, yielding 136 meteors, 73 of which were Perseids. The Capricornids were barely active by this point; I spotted just one. The kappa-Cygnids showed little activity as well, we are in a quiet year. The SDAs, however, remained active, with 5 meteors observed.

August 15–16, 2026

This night also started with a strong Meltemi wind: starting at Bf 5, but it quickly intensifies to Bf 7 or 8. It is blowing so hard that I strap the backpack containing my observing gear to my arm to prevent it from blowing down into the valley. After an hour, things gradually calm down, and by the end of the session, only a light breeze remains. The temperature is also lower than on previous nights, settling at 20 degrees Celsius by the end.

The sky background is now truly dark, resembling the dark skies of 2017 for the first time. Limiting magnitudes range between 6.6 and 6.7, and SQM readings are higher than on previous nights, between 21.45 and 21.55. Occasionally, tiny clouds form, only to be blown away and dissipate quickly.

I observed for just over three hours, counting 107 meteors. The Perseids showed hourly rates of between 12 and 18. The SDAs were somewhat more prominent now, with eight of them spotted. The brightest meteors were two Perseids with magnitudes of -2 and -4 . At 01^h45^m UT, I see a bright satellite moving past the bright stars Castor and Pollux. I suspect it is the ISS, though it appears slightly fainter than usual. A quick check in Stellarium afterwards reveals it to be the Chinese Tiangong space station. It is great to have seen that.

August 16–17, 2026

This turned out to be the clearest night, along with the following one. Limiting magnitude reached 6.7 and SQM readings up to 21.55. Over three hours of observing yielded 88 meteors, 37 of which were Perseids. Hourly Perseid counts ranged from 9 to 15. During this night, I also spotted my last Capricornid of the year, and what a spectacular one it was! A beautiful magnitude 0 meteor traced a long path from Sagitta toward Draco, moving almost parallel to the horizon and showing slight fragmentation. I also caught a glimpse of a magnitude -4 Perseid out of the corner of my eye near the eastern horizon. I initially thought it was a Perseid, but that turned out to be incorrect; the persistent train pointed toward Capella, so I reclassified it as a sporadic meteor. The first Aurigid of the season was also spotted that night. At 02^h10^m UT, another bright satellite appeared; this time, it was indeed the ISS.

August 17–18, 2026

This night observations were conducted for exactly three hours under excellent sky conditions once again. A notable feature was a persistent, light NW breeze throughout the night that carried the smell of smoke; indeed, the wind was blowing from the area affected by wildfires. Interestingly, there was no smell of smoke during stronger NW winds, but it was present when the wind was slow. The three-hour session yielded 78 meteors, including 29 Perseids, with hourly counts of 12, 6, and 11 meteors respectively. A greenish, late-appearing magnitude -2 SDA was the finest meteor of the night.

August 18–19, 2026

Weather conditions mirrored those of August 13–14. In the evening, the sky became very hazy and very humid, so no observations were made. The next day the sky was clear again with no haze.

August 19–20, 2026

Another three-hour session resulted in 67 meteors, 20 of which were Perseids. The brightest meteor was a magnitude -2 Perseid. Once again, there was a gentle NW breeze carrying the same smell of smoke. Another interesting fact from this night: it marked the 1400th night of visual observations since April 1980...

August 20–21, 2026

The final night from Agia Galini! Observations were again carried out for three hours, resulting in 50 meteors, 16 of which were Perseids. There were almost no spectacular meteors, with the exception of a very fine magnitude -3 sporadic meteor. This fast-moving meteor displayed rapid, very short successive flares and left a persistent train lasting 5 seconds. Despite SQM readings of 21.50, the limiting magnitude lagged slightly at 6.6.

August 23–24, 2026

For the first few nights after returning home, the moon did not yet interfere observations at night. This allowed for three hours of observation during the night August 23–24. A chance to get used to the light-polluted Dutch sky and to catch the last of the Perseids. Sky transparency was very good, though the conditions were very humid. The temperature dropped from 9 to 5 degrees Celsius. The maximum SQM reading was 20.32, and the limiting magnitude was 6.3. A total of 36 meteors were spotted, including 5 Perseids.

August 24–25, 2026

The final night of August, and thus the last Perseids of 2026. Once again, transparency was good. Over two hours of effective observation, 20 meteors were seen, including (the final) three Perseids.

3 Summary

All in all, a highly successful campaign: a total of over 42 hours of observation took place in August, yielding 1490 meteors. Notable highlights included the sporadic fireball on August 11 at 00^h33^m UT; the somewhat low Perseid

activity on the night of August 11–12, combined with a high number of bright Perseids; and the sudden burst of activity on August 13 after 00^h32^m UT. This last event might have been caused by the Perseid filament, or was it perhaps the annual peak? Analysis of data from other observers may provide the answer.

References

- Miskotte K. (2026). “July observations: the first Perseids”. *eMetN Meteor Journal*, **11**, 478–480.
- Jenniskens P. (2006). *Meteor Showers and their Parent Comets*, Cambridge University Press.

Table 1 – Overview of the authors observations in August 2026.

Date	Period UT		<i>T_{eff}</i>	Max		Meteor showers									Site
	Start	End		<i>L_m</i>	<i>F</i>	PER	SDA	CAP	KCG	ANT	ERI	AUR	SPO	Total	
05–06	21:00	22:00	1.00	6.30	1.00	3	0	0	0	0	~	~	9	12	ERM
09–10	22:25	02:00	3.52	6.50	1.00	49	10	5	0	7	1	~	35	107	AGI
10–11	22:45	02:20	3.58	6.50	1.00	94	9	3	4	8	4	~	51	173	AGI
11–12	21:23	02:30	5.12	6.60	1.00	173	6	5	3	9	1	~	56	253	AGI
12–13	20:55	02:15	5.10	6.60	1.00	282	4	3	3	7	3	~	61	363	AGI
14–15	22:34	02:15	3.68	6.60	1.00	73	5	1	5	7	2	~	43	136	AGI
15–16	23:05	02:15	3.12	6.70	1.00	47	8	0	3	6	4	~	39	107	AGI
16–17	23:10	02:20	3.12	6.70	1.00	37	4	1	3	4	2	1	36	88	AGI
17–18	23:19	02:22	3.00	6.70	1.00	29	5	0	1	7	2	2	32	78	AGI
19–20	23:17	02:25	3.10	6.60	1.00	20	5	0	2	8	2	1	29	67	AGI
20–21	23:08	02:21	3.20	6.60	1.00	16	5	~	2	3	3	0	21	50	AGI
23–24	23:47	02:50	3.00	6.30	1.00	5	2	~	2	3	1	1	22	36	ERM
24–25	00:30	02:30	2.00	6.20	1.00	3	0	~	0	2	1	1	13	20	ERM
13 sessions			42.54			831	63	18	28	71	26	6	447	1490	

August 2026 CARMELo report

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The CARMELo network (Cheap Amateur Radio Meteor Echoes LOGger) is a collaboration of SDR radio receivers aimed at detecting meteor echoes. This report presents the data for August 2026.

1 Introduction

August is the month of the Perseids. Although no particularly intense activity was recorded this year, a peak in activity was observed on the night of August 13.

2 Methods

The CARMELo network consists of SDR radio receivers. In them, a microprocessor (Raspberry) performs three functions simultaneously:

- By driving a dongle, it tunes the frequency on which the transmitter transmits and tunes like a radio, samples the radio signal and through the FFT (Fast Fourier Transform) measures frequency and received power.
- By analyzing the received data for each packet, it detects meteor echoes and discards false positives and interference.
- It compiles a file containing the event log and sends it to a server.

The data are all generated by the same standard, and are therefore homogeneous and comparable. A single receiver can be assembled with a few devices whose total current cost is about 210 euros.

To participate in the network read the instructions on this page²⁰.

3 August data

In the plots that follow, all available at this page²¹, the abscissae represent time, which is expressed in UT (Universal Time) or in solar longitude (Solar Long), and the ordinates represent the hourly rate, calculated as the total number of events recorded by the network in an hour divided by the number of operating receivers. The time resolution is 15 minutes.

In *Figure 1*, the trend of signals detected by the receivers is given for the month of August.

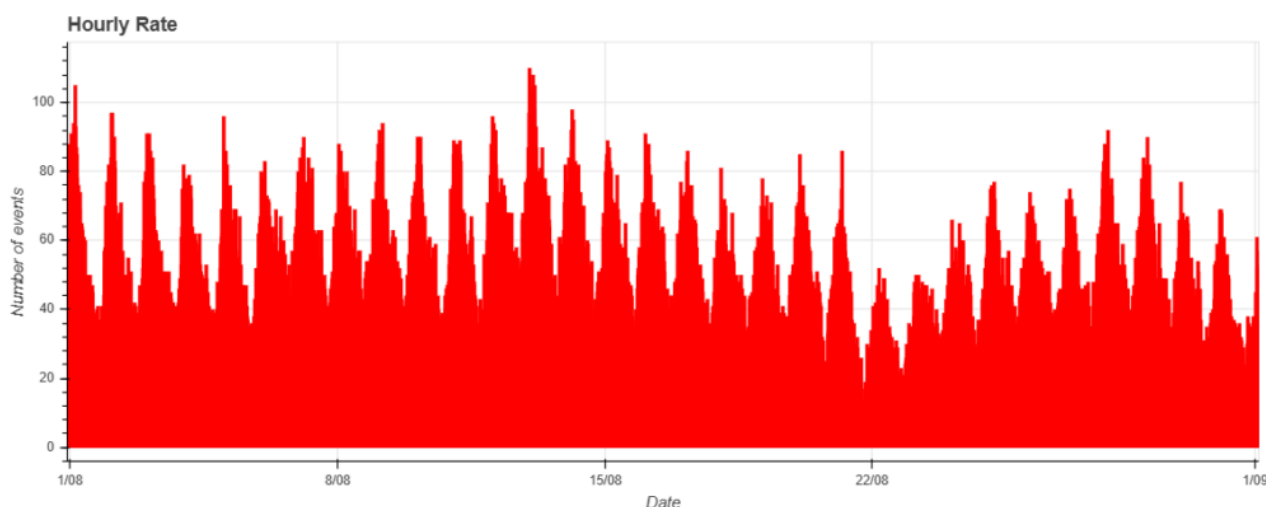


Figure 1 – August 2026 data trend.

²⁰ http://www.astrofiliabologna.it/about_carmelo

²¹ <http://www.astrofiliabologna.it/graficocarmelo>

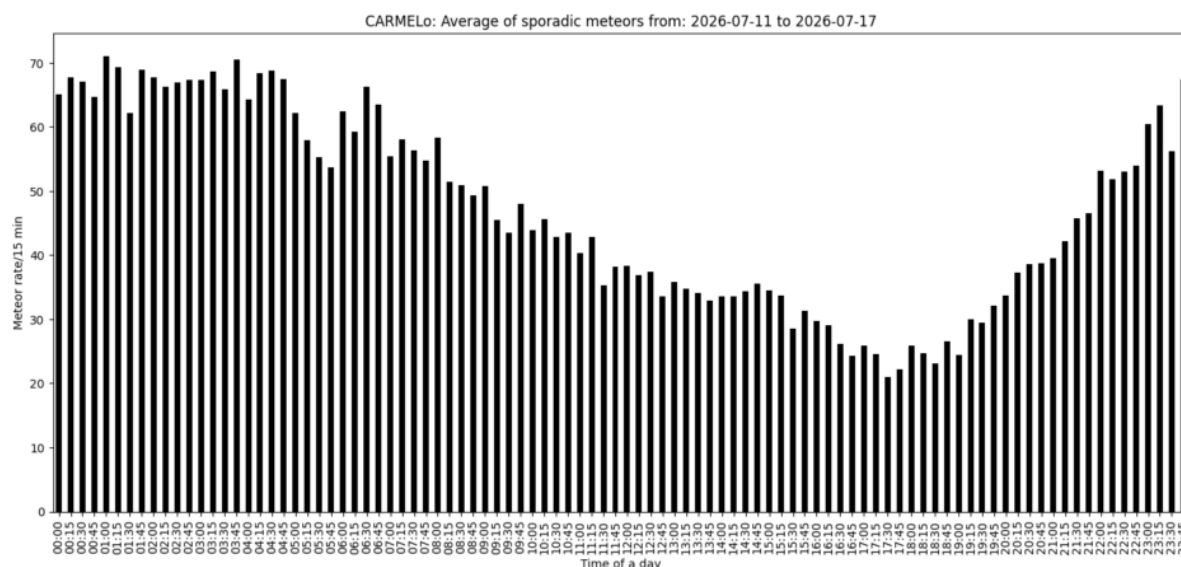


Figure 2 – A sample of sporadic meteors collected in July 2026 for analysis of the Perseids.

4 Perseids

The Perseids (PER) are one of the best-known and most spectacular meteor showers of the year, active from July 17 to August 24. Peak activity usually occurs around mid-August, on the night of August 12–13.

The Perseids originate from debris left behind by Comet Swift-Tuttle, which Earth encounters every year during this period. The radiant is located in the constellation Perseus, from which the shower takes its name. The meteors are particularly fast, with an atmospheric entry speed of about 61 km/s, and produce bright, persistent trails, often accompanied by ionization trails that are clearly detectable even through radio observations.

In 2026, despite the favorable conditions provided by the new moon, visual observations revealed activity that appeared less intense than in previous years, with a relatively small number of meteors and few fireballs. Radio data from the CARMELO network partially confirm this trend. The hourly rate recorded at the peak, however, is comparable to that observed in previous years.

5 The construction of RZHR

By RZHR (Radio Zenithal Hourly Rate), we mean the hourly rate of radio meteors in a shower, calculated by processing data from meteor scatter receivers.

This tool allows us to make a significant leap in quality, moving away from the qualitative analysis we have conducted so far (which relied exclusively on graphs) and transitioning to the direct processing of data from our database. To do this, we developed a Python script with the help of the “Cursor” tool, an AI-powered code editor created by Anysphere. This support proved crucial in developing a satisfactory script.

First, it should be clarified that, in calculating the RZHR, we make certain approximations, including:

- We do not take into account that the varying geographical distribution of receivers causes them to “see” meteors from slightly different angles.
- We disregard the fact that observations are not isotropic but are influenced by antenna pointing, which favors a specific sector of the sky over the entire sky.
- We define a contribution as “sporadic” even though it may also include meteors from small showers.

The algorithm for this calculation uses data from the database of all meteors recorded by the CARMELO network. First, it asks the user to identify certain days on which no significant meteor shower activity is expected. These days are selected as close as possible to the date being analyzed. This data is then averaged to form a second database called the “sporadic average.”

This database is then subtracted from the one for the days under examination, during which a meteor shower is presumed to be present. Any negative values are eliminated, and the profile is smoothed using a smoothing function.

The figure is then divided by the sine of the radiant’s altitude above the horizon, calculated for an average Italian location in the same way as the algorithm used to calculate the ZHR (Zenithal Hourly Rate), which, as we recall, is:

$$ZHR = \frac{N \cdot r^{6.5-lm}}{\sin h_R \cdot F \cdot T_{eff}}$$

Where:

- N : number of meteors counted.
- L_m : the limiting magnitude of a star that is visible to the observer.

- r : shower's density (the ratio indicating how many more meteors are visible for each magnitude; typically ranging from 2.0 to 3.5).
- h_r : angular height of the radiant above the horizon in degrees.
- T_{eff} : actual observation time (in hours).
- F : field-of-view correction factor.

The temporal resolution, which is 15 minutes in the original data, is retained at that value; therefore, the term H in RZHR should be considered as $H/4$.

To estimate the activity of the Perseids, the sample of sporadic meteors (in *Figure 2*) was collected in mid-July.

Figure 3 shows the trend in meteor activity recorded by the network, limited to the hours when the radiant was above the horizon for most of the observing stations between August 2 and August 21 (between solar longitudes of approximately 129° and 147.5°).

It can be seen that most of the events attributable to the meteor shower are observed in the early morning hours, when the radiant reaches its highest point in the sky.

Calculating the RZHR using the algorithm we developed (Barbieri and Maglione, 2026) yields the results shown in *Figure 4*.

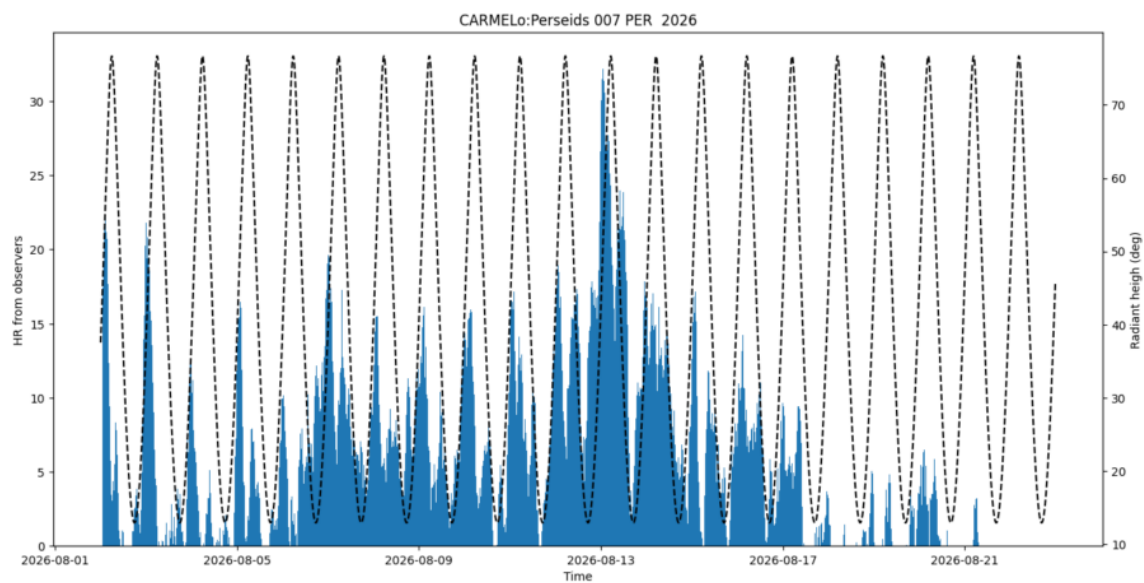


Figure 3 – Meteor activity trends between August 2 and August 21, 2026, limited to the hours when the radiant was at least 10° above the horizon, as a function of solar longitude, and the altitude of the Perseid radiant (dashed line).

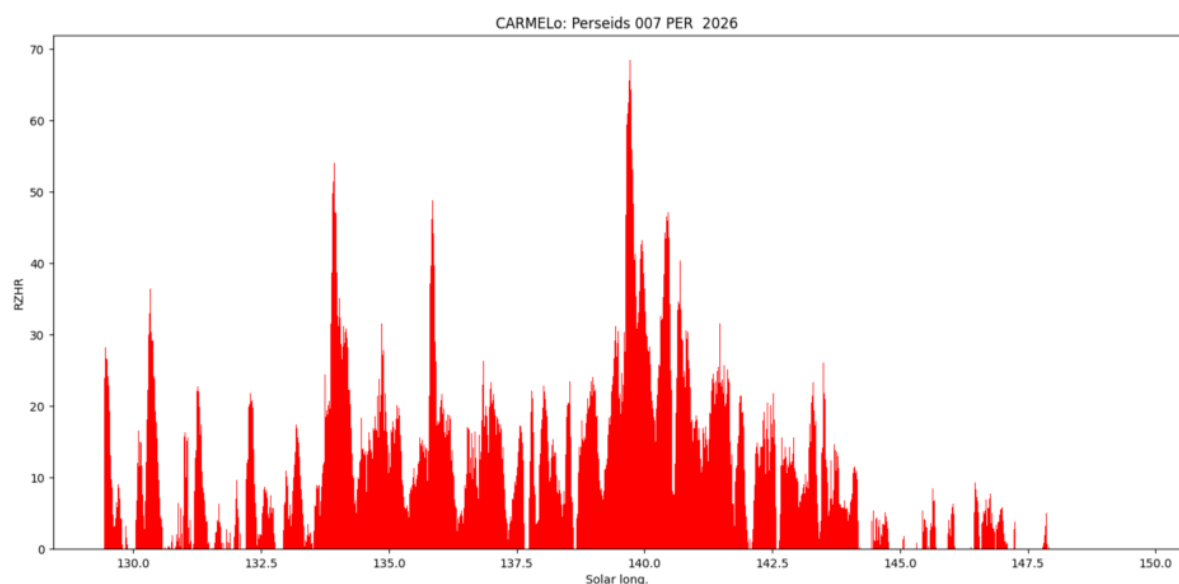


Figure 4 – Residual distribution of events.

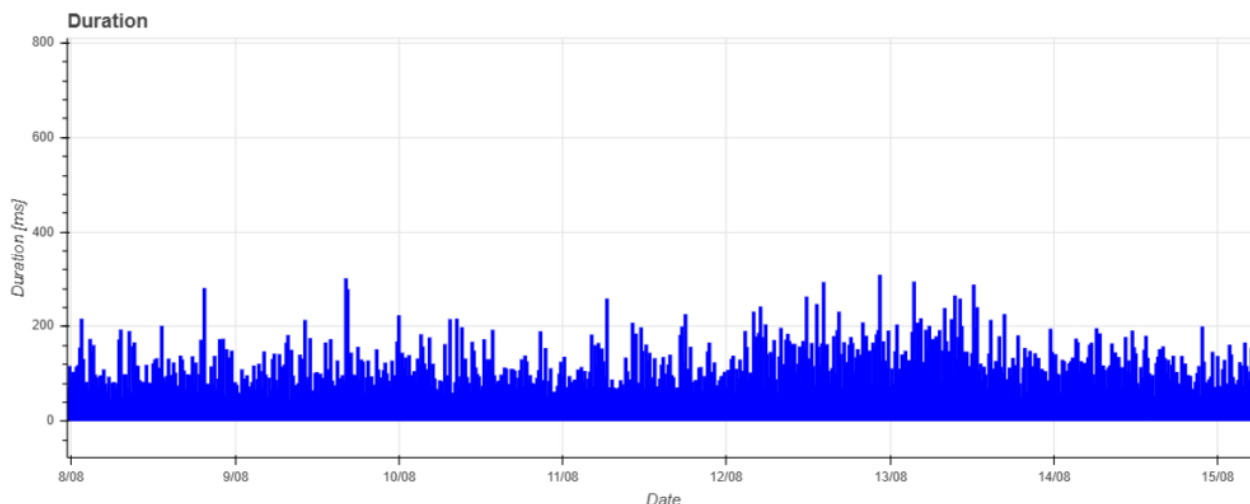


Figure 5 – Duration of the radio echoes detected by CARMELO between August 8 and August 15, 2026.

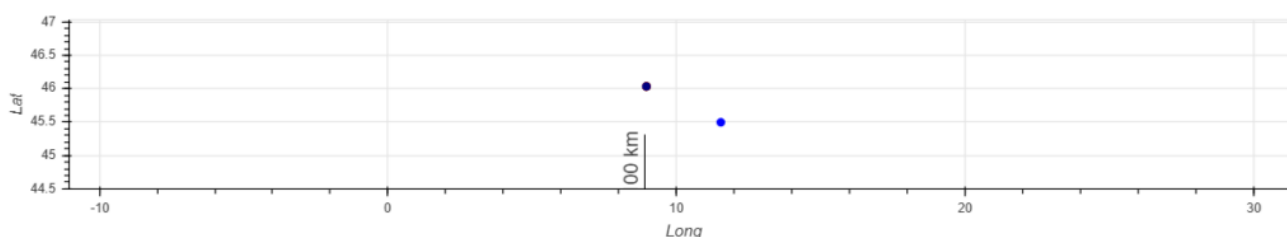


Figure 6 – The first two echoes detected by the fireball on August 13.

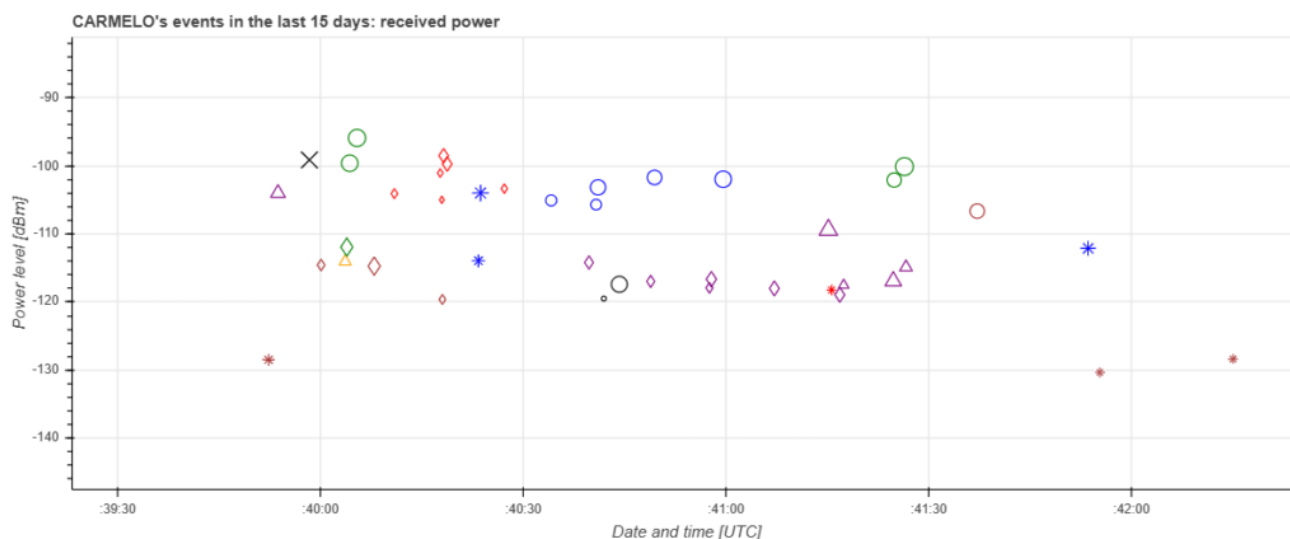


Figure 7 – A series of possible echoes following the breakup of the fireball on August 13.

6 More showers

Throughout August, other meteor showers are also active and may contribute to the recorded activity. Among these are the eta-Eridanids (ERI#191), active from July 31 to August 19 and peaking around August 7, at a solar longitude of approximately 135° . Their radiant is located at right ascension 41° and declination -11° , and the meteors have a high speed of about 64 km/s. However, this is a difficult shower to identify because the radiant remains very low on the horizon. The eta-Eridanids may have contributed to the increases in activity observed between August 7 and 8.

The kappa-Cygnids (KCG#012) are also active during the same period, observable from August 3 to 28 and peaking around August 17 at a solar longitude of approximately 144° . The radiant is located at right ascension 288° and declination $+55^\circ$, while the meteor velocity is significantly lower, at about 23 km/s. In this case as well, identifying them is challenging, both due to the significant overlap in timing with the Perseids and the lower kinetic energy of the meteors.

7 The fireball of August 13

On the evening of August 12, 2026, at $22^{\text{h}}39^{\text{m}}53^{\text{s}}$ UT ($00^{\text{h}}39^{\text{m}}53^{\text{s}}$ Italian time on August 13), a particularly bright fireball was sighted from Switzerland (magnitude

approximately $-7/-8$). The fireball was also photographed by two Swiss observation stations, which, through triangulation, confirmed that it was not a Perseid.

Although they did not detect the echo of the initial impact, the radio stations of the CARMELo network recorded echoes that were temporally consistent with that fireball. *Figures 6 and 7* show, respectively, the first echoes detected and a series of possible subsequent, fragmented echoes, which could be related to the progressive deformation and dispersion of the ionized trail produced by the meteor due to winds in the upper atmosphere.

8 The CARMELo network

The network currently consists of 18 receivers located in Italy, Spain, the UK, Switzerland and the USA. The European receivers are tuned to the Graves radar station frequency in France, which is 143.050 MHz. Participating in the network are:

- Lorenzo Barbieri, Budrio (BO) ITA;
- Associazione Astrofili Bolognesi, Bologna ITA;
- Associazione Astrofili Bolognesi, Medelana (BO) ITA;
- Paolo Fontana, Castenaso (BO) ITA;
- Associazione Astrofili Pisani, Orciatice (PI) ITA;

- Gruppo Astrofili Persicetani, San Giovanni in Persiceto (BO) ITA;
- Roberto Nesci, Foligno (PG) ITA;
- MarSEC, Marana di Crespadoro (VI) ITA;
- Gruppo Astrofili Vicentini, Arcugnano (VI) ITA;
- Associazione Ravennate Astrofili Rheyta, Ravenna (RA) ITA;
- Mike German a Hayfield, Derbyshire UK;
- Mike Otte, Pearl City, Illinois USA.
- Yuri Malagutti, Comano (TI) CH.
- Leslie Fry, Trawscoed Ceredigion, Wales UK
- Brian Coleman, Redenham Observatory, Andover, England UK
- Radio club La Salle University, Barcellona ESP
- Alberto Latini, Carona (TI) CH
- AstroCampania, Agerola (NA) ITA

The authors' hope is that the network can expand both quantitatively and geographically, thus allowing the production of better-quality data.

References

- Barbieri L., Maglione M. (2026). "May 2026 CARMELo report". *eMetN Meteor Journal*, **11**, 307–310.

September 2026 CARMELo report

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⁴ CARMELo network and MarSEC, Marana Space Exploration Center, Italy

The CARMELo network (Cheap Amateur Radio Meteor Echoes LOgger) is a collaboration of SDR radio receivers aimed at detecting meteor echoes. This report presents the data for September 2026.

1 Introduction

In September, the meteor activity recorded by the CARMELo network was moderate and did not reveal any activity peaks from specific meteor showers.

2 Methods

The CARMELo network consists of SDR radio receivers. In them, a microprocessor (Raspberry) performs three functions simultaneously:

- By driving a dongle, it tunes the frequency on which the transmitter transmits and tunes like a radio, samples the radio signal and through the FFT (Fast Fourier Transform) measures frequency and received power.
- By analyzing the received data for each packet, it detects meteor echoes and discards false positives and interference.
- It compiles a file containing the event log and sends it to a server.

The data are all generated by the same standard, and are therefore homogeneous and comparable. A single receiver can be assembled with a few devices whose total current cost is about 210 euros.

To participate in the network read the instructions on this page²².

3 September data

In the plots that follow, all available at this page²³, the abscissae represent time, which is expressed in UT (Universal Time) or in solar longitude (Solar Long), and the ordinates represent the hourly rate, calculated as the total number of events recorded by the network in an hour divided by the number of operating receivers. The time resolution is 15 minutes.

In *Figure 1*, the trend of signals detected by the receivers is given for the month of September.

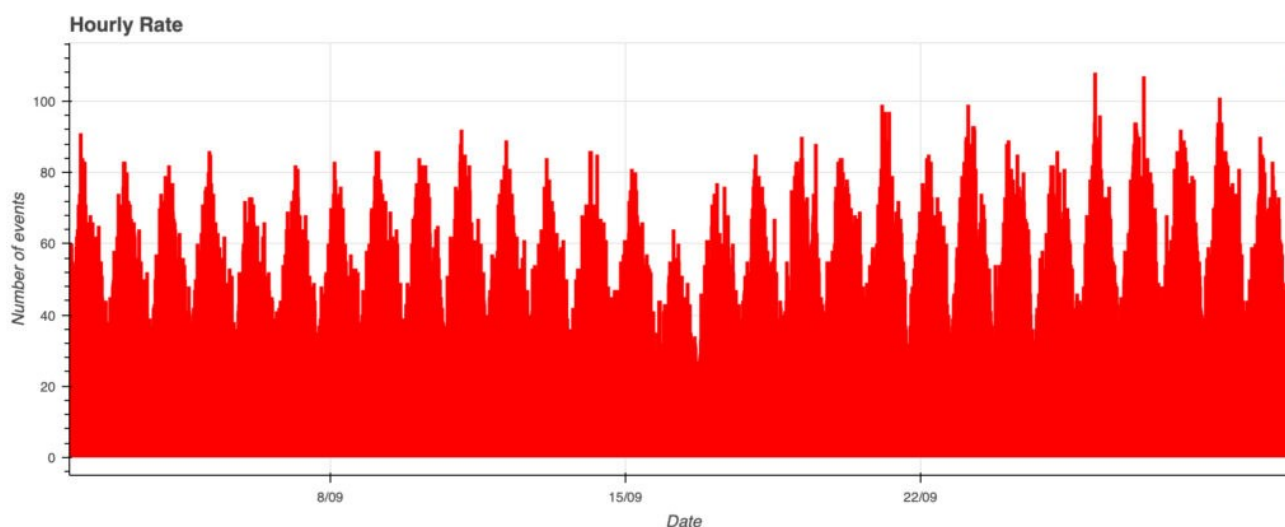


Figure 1 – September 2026 data trend.

²² http://www.astrofiliabologna.it/about_carmelo

²³ <http://www.astrofiliabologna.it/graficocarmelo>

4 The September epsilon-Perseids

The September epsilon-Perseids (SPE#208) are a meteor shower active during the first half of the month, with a peak that was predicted for September 10, 2026, at approximately 06^h33^m UT. The radiant is located in the constellation Perseus, with right ascension 48.6° and declination of +39.6°.

In 2026, observation of the meteor shower was hampered by the position of the radiant, which, at Italian latitudes, set in the early morning hours, significantly reducing the number of detectable meteors.

This made it particularly difficult to verify the sudden increase in activity (outburst) reported by the Central Bureau for Astronomical Telegrams (CBAT) in Circular No. 5736 (Vida et al., 2026), since only the initial phase of the phenomenon was observable from our latitudes.

The data collected by the CARMELo network did not clearly identify this increase in activity. Even a separate analysis of the observations made by the network's westernmost receiver did not yield any significant results.

5 The Daytime Sextantids

The Daytime Sextantids (DSX#221) are a meteor shower active between September and October, with a radiant located in the constellation Sextans, near the Sun. They are therefore unobservable visually and can only be detected using radio techniques.

In 2026, analysis of the data collected by the CARMELo network did not reveal an activity profile clearly attributable to this meteor shower. Even when the analysis was limited to observations from the network's westernmost receiver, no significant results emerged. It was therefore not possible to distinguish with sufficient certainty the contribution of the diurnal Sextantids from the background meteor activity.

6 The CARMELO network

The network currently consists of 18 receivers located in Italy, Spain, the UK, Switzerland and the USA. The European receivers are tuned to the Graves radar station frequency in France, which is 143.050 MHz. Participating in the network are:

- Lorenzo Barbieri, Budrio (BO) ITA;
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- Associazione Astrofili Bolognesi, Medelana (BO) ITA;
- Paolo Fontana, Castenaso (BO) ITA;
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- Gruppo Astrofili Persicetani, San Giovanni in Persiceto (BO) ITA;
- Roberto Nesci, Foligno (PG) ITA;
- MarSEC, Marana di Crespadoro (VI) ITA;
- Gruppo Astrofili Vicentini, Arcugnano (VI) ITA;
- Associazione Ravennate Astrofili Rheyta, Ravenna (RA) ITA;
- Mike German a Hayfield, Derbyshire UK;
- Mike Otte, Pearl City, Illinois USA.
- Yuri Malagutti, Comano (TI) CH.
- Leslie Fry, Trawscoed Ceredigion, Wales UK
- Brian Coleman, Redenham Observatory, Andover, England UK
- Radio club La Salle University, Barcellona ESP
- Alberto Latini, Carona (TI) CH
- AstroCampania, Agerola (NA) ITA

The authors' hope is that the network can expand both quantitatively and geographically, thus allowing the production of better-quality data.

References

- Vida D., Brown P., Cooke W.J. (2026). "September epsilon-Perseid meteor outburst 2026". CBET 5736, 2026 September 12, edited by Daniel W. E. Green.

Radio meteors August 2026

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An overview of the radio observations during August 2026 is given.

1 Introduction

The graphs show both the daily totals (*Figure 1 and 2*) and the hourly numbers (*Figure 3 and 4*) of “all” reflections counted automatically, and of manually counted “overdense” reflections, overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during the month of August 2026.

The hourly numbers, for echoes shorter than 1 minute, are weighted averages derived from:

$$N(h) = \frac{n(h-1)}{4} + \frac{n(h)}{2} + \frac{n(h+1)}{4}$$

Local interference and unidentified noise remained quite limited, and lightning activity was recorded on only 3 days. However, strong solar bursts occurred regularly, mostly of type III, though their number appears to be steadily decreasing.

The highlights of the month were, of course, the Perseids, featuring numerous long-duration reflections as they do every year. Following a lead-up period of increased activity during the first half of the month, the shower reached its expected peak on August 13, after which activity quickly declined.

Across the entire month, 52 reflections lasting longer than 1 minute were recorded here. A selection of these, along with several other interesting reflections, is shown in *Figures 5 to 28*. Many more are available upon request.

In addition to the usual graphs, you will also find the raw counts in cvs-format²⁴ from which the graphs are derived. The table contains the following columns: day of the month, hour of the day, day + decimals, solar longitude (epoch J2000), counts of “all” reflections, overdense reflections, reflections longer than 10 seconds and reflections longer than 1 minute, the numbers being the observed reflections of the past hour.

²⁴ https://www.emeteornews.net/wp-content/uploads/2026/09/202608_49990_FV_rawcounts.csv

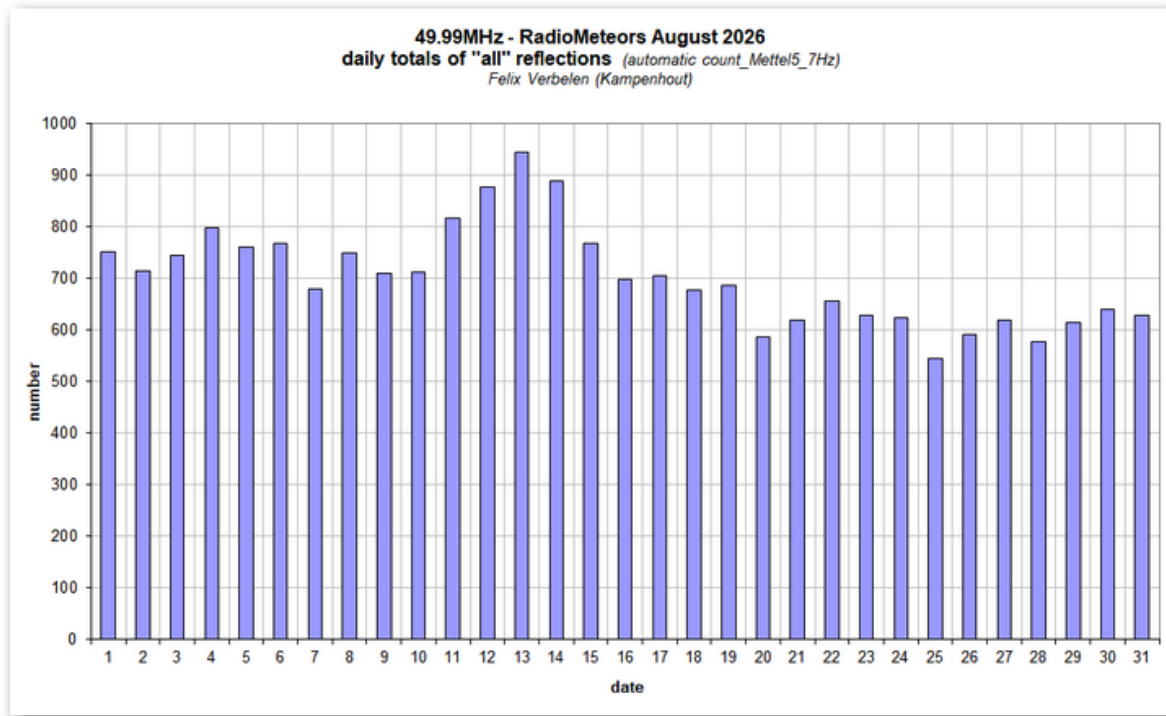
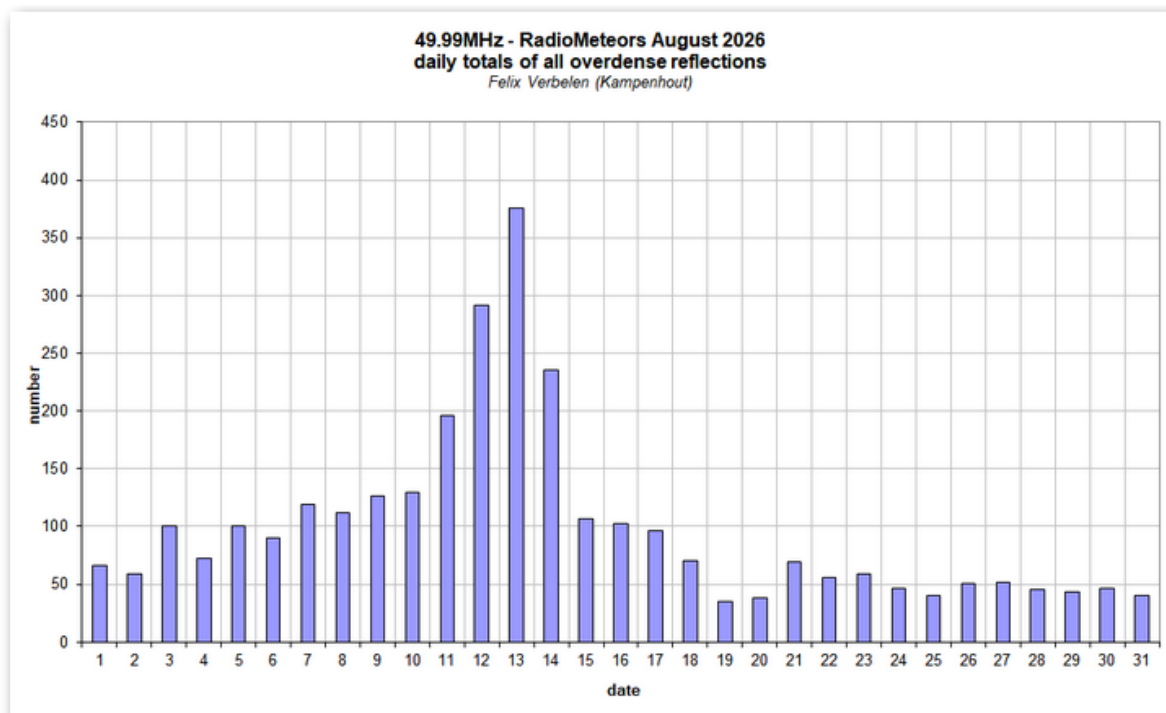


Figure 1 – The daily totals of “all” reflections counted automatically, and of manually counted “overdense” reflections, as observed here at Kamphenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during August 2026.

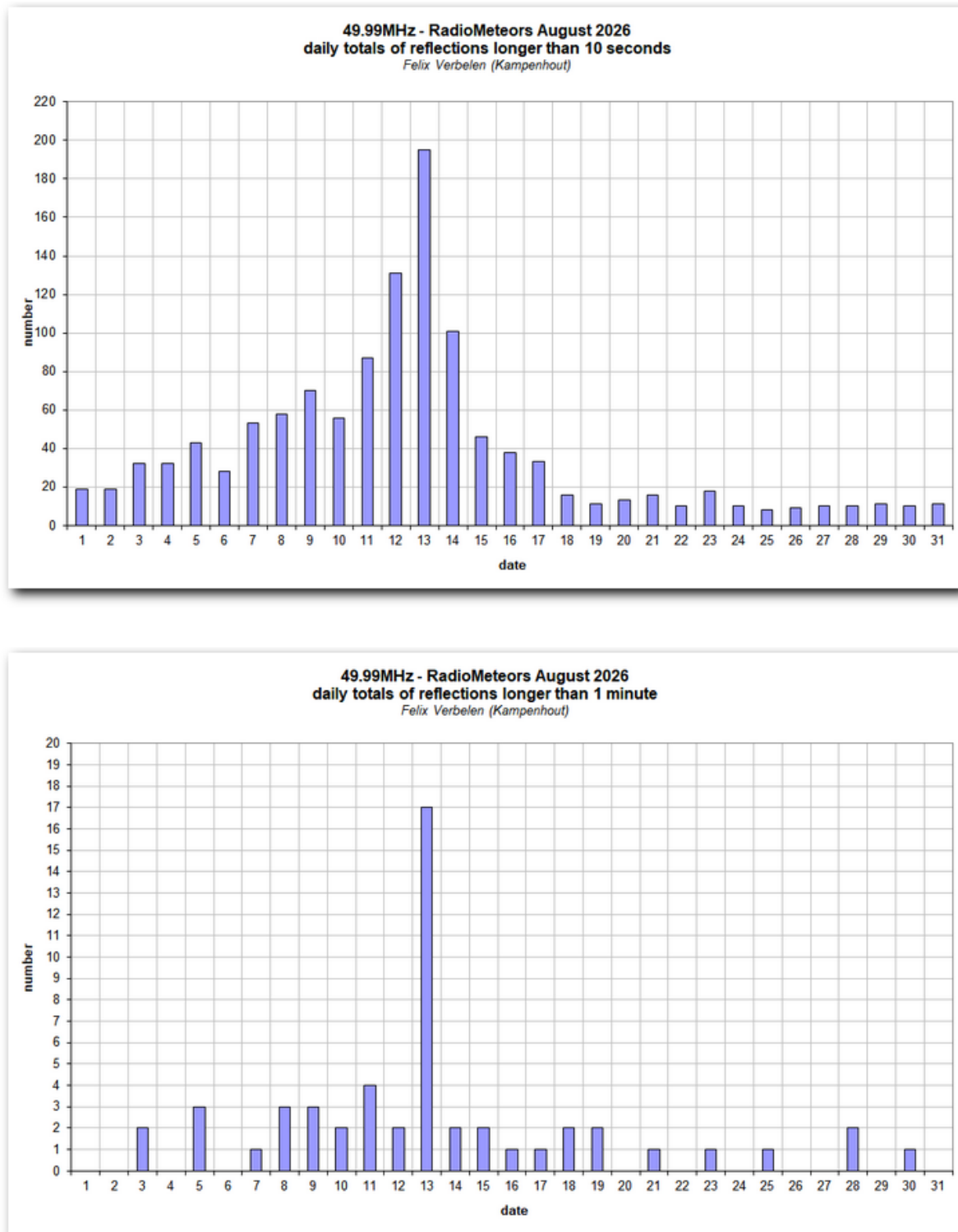


Figure 2 – The daily totals of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kamphenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during August 2026.

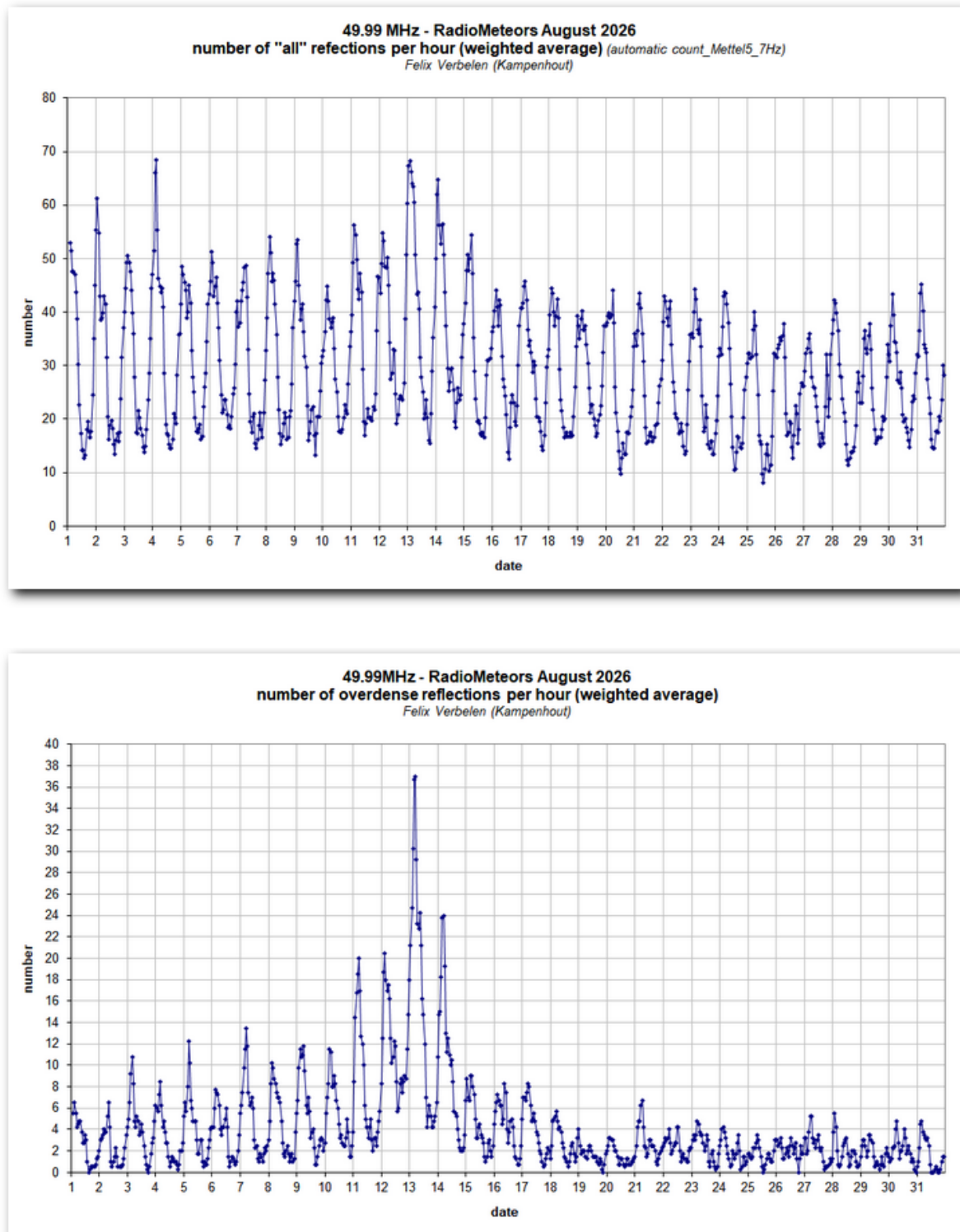


Figure 3 – The hourly numbers of “all” reflections counted automatically, and of manually counted “overdense” reflections, as observed here at Kamphenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during August 2026.

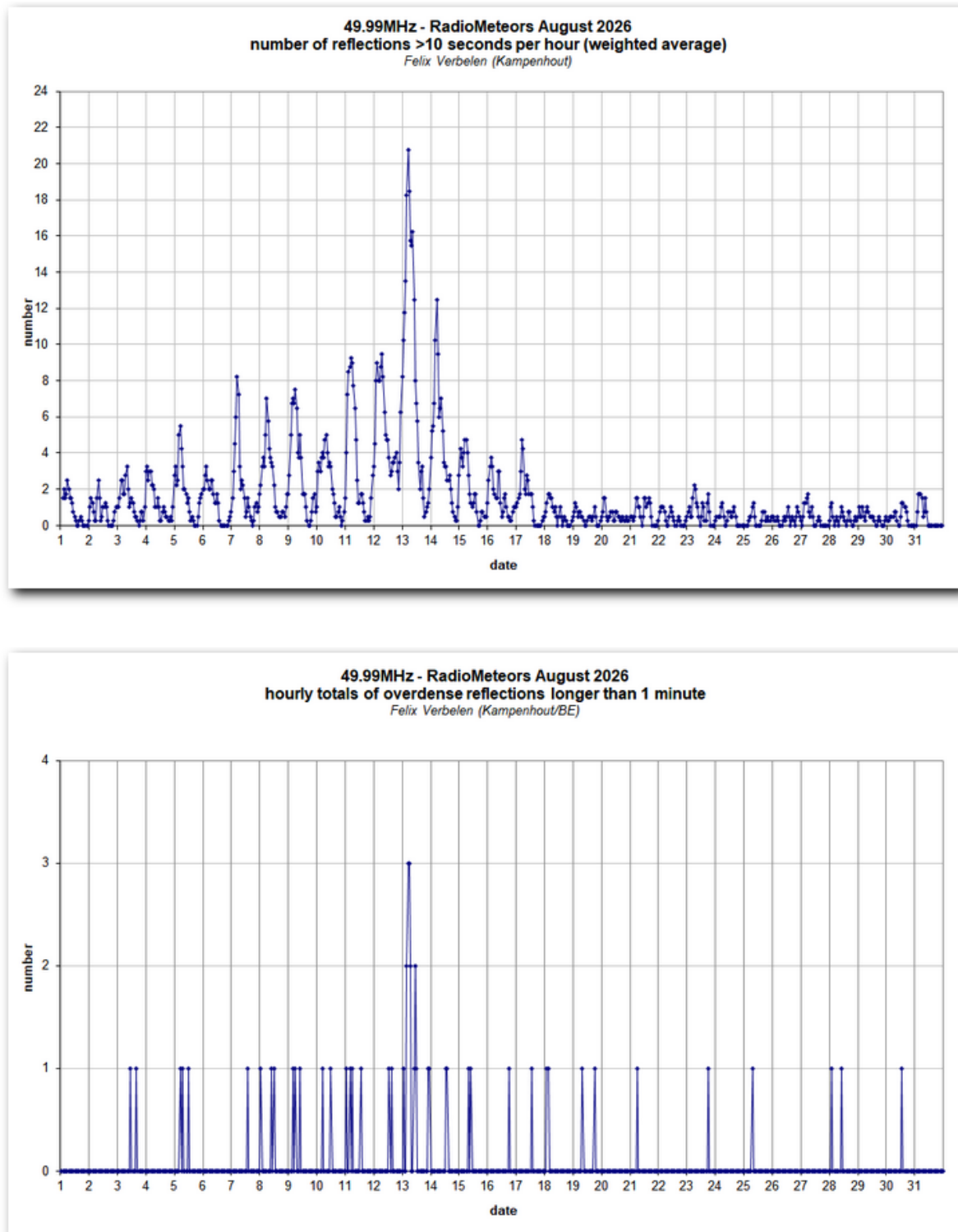


Figure 4 – The hourly numbers of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kamphenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during August 2026.

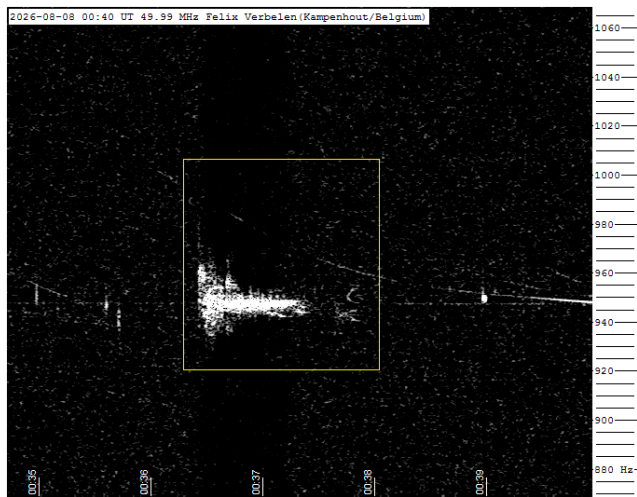


Figure 5 – Meteor echo August 8, 0^h40^m UT.

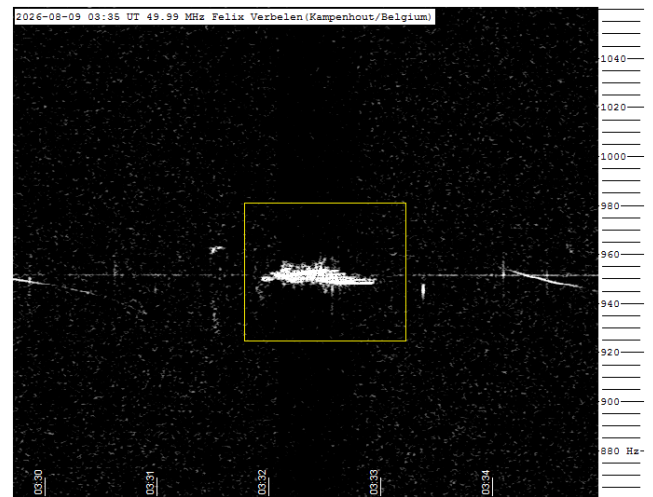


Figure 8 – Meteor echo August 9, 3^h35^m UT.

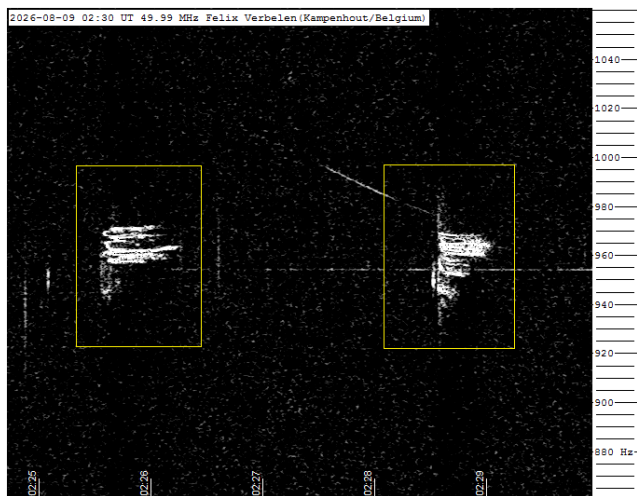


Figure 6 – Meteor echo August 9, 2^h30^m UT.

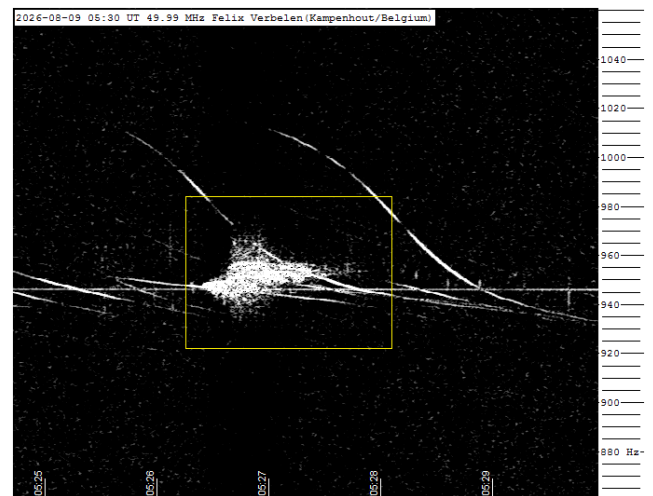


Figure 9 – Meteor echo August 9, 5^h30^m UT.

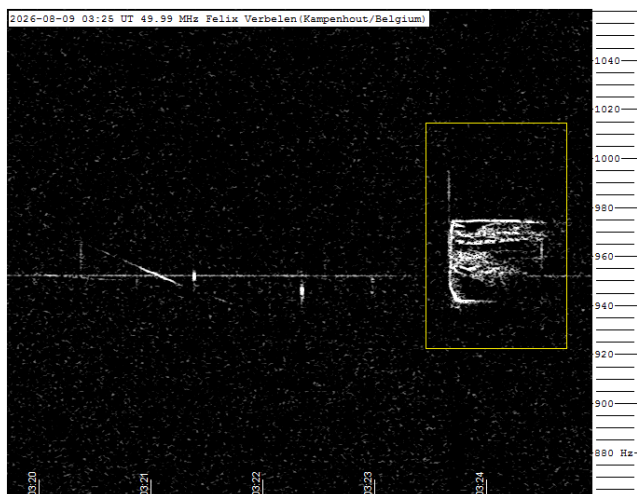


Figure 7 – Meteor echo August 9, 3^h25^m UT.

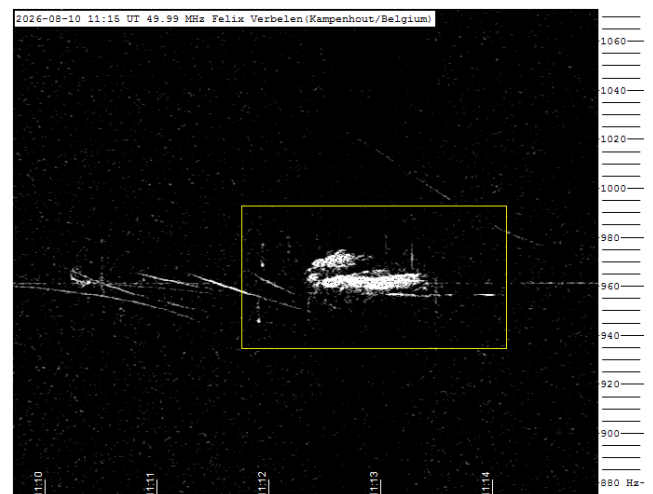


Figure 10 – Meteor echo August 10, 11^h15^m UT.

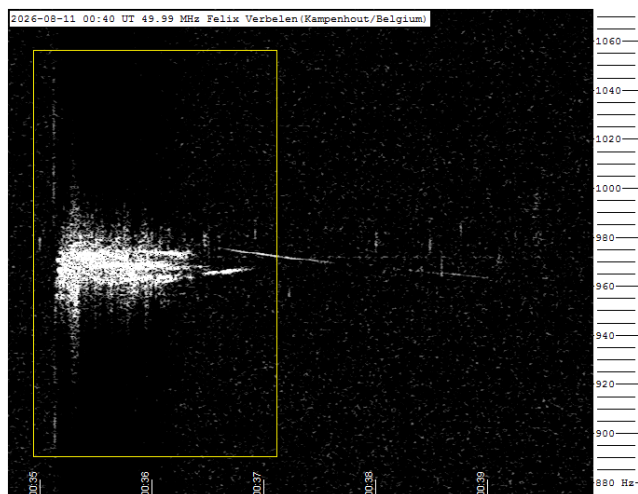


Figure 11 – Meteor echo August 11, 0^h40^m UT.

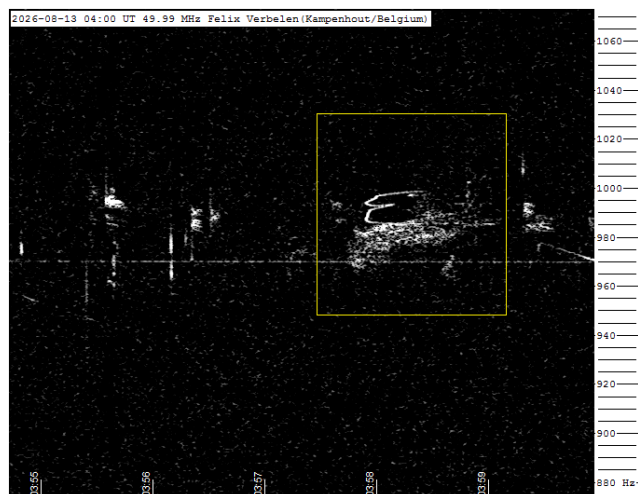


Figure 14 – Meteor echo August 13, 4^h00^m UT.

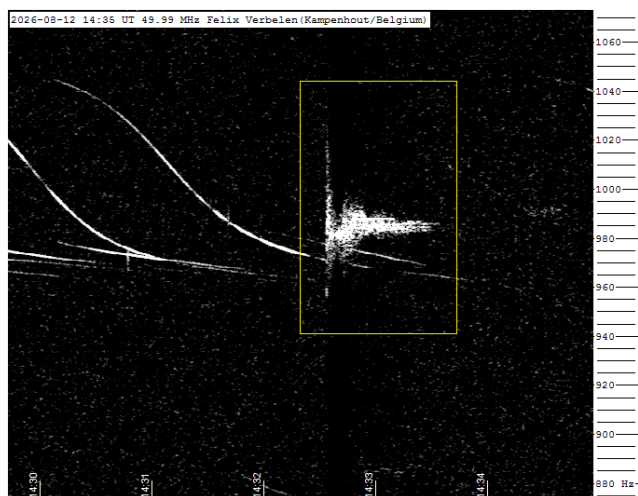


Figure 12 – Meteor echo August 12, 14^h35^m UT.

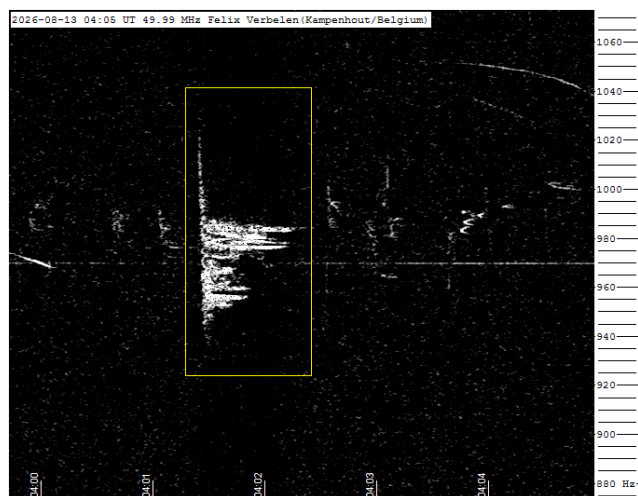


Figure 15 – Meteor echo August 13, 4^h05^m UT.



Figure 13 – Meteor echo August 13, 2^h10^m UT.

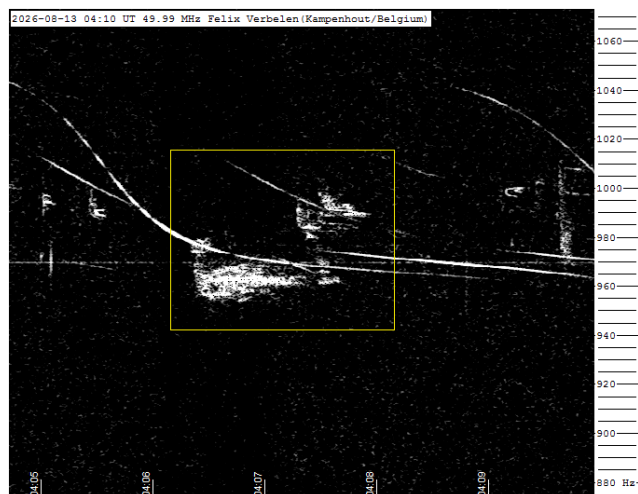


Figure 16 – Meteor echo August 13, 4^h10^m UT.

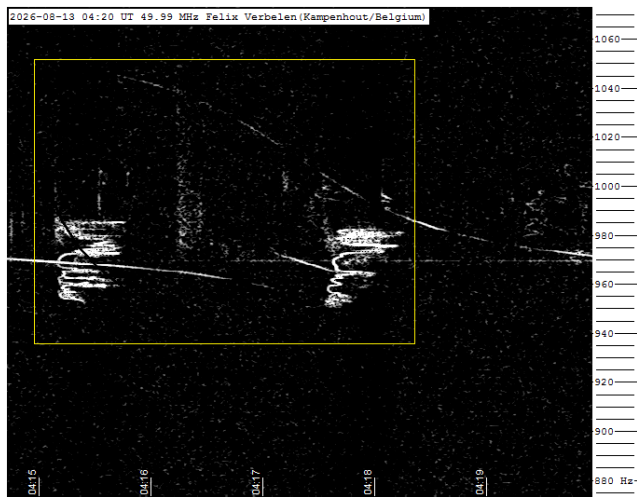


Figure 17 – Meteor echo August 13, 4^h20^m UT.

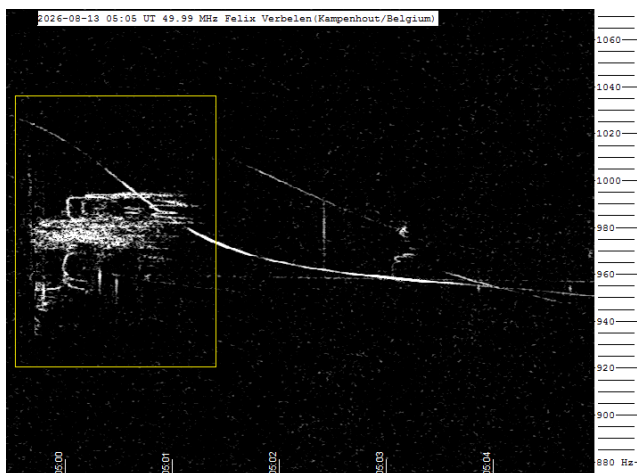


Figure 18 – Meteor echo August 13, 5^h05^m UT.

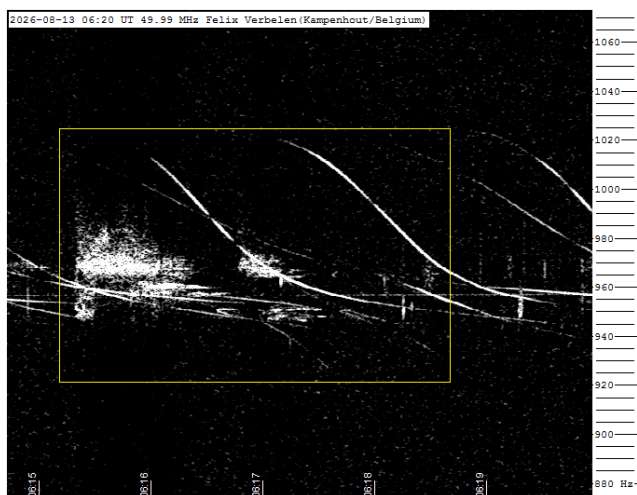


Figure 19 – Meteor echo August 13, 6^h20^m UT.

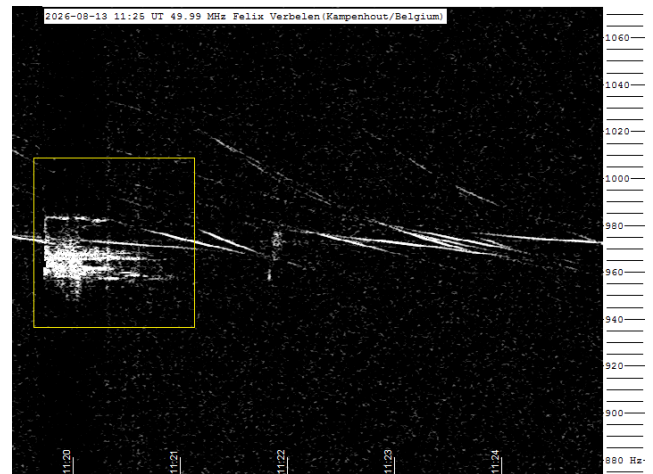


Figure 20 – Meteor echo August 13, 11^h25^m UT.

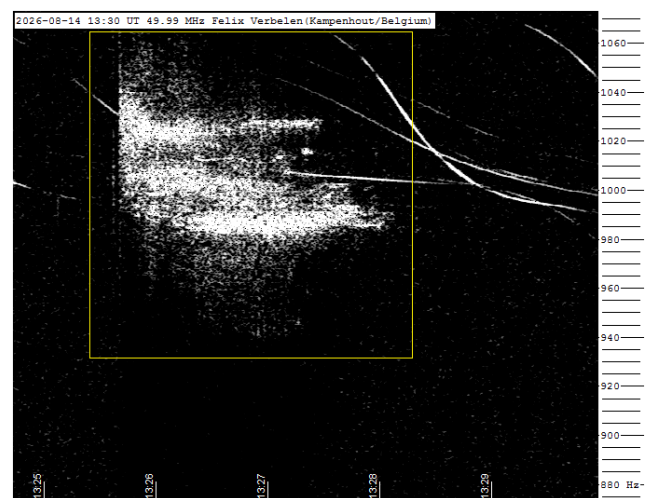


Figure 21 – Meteor echo August 14, 13^h30^m UT.

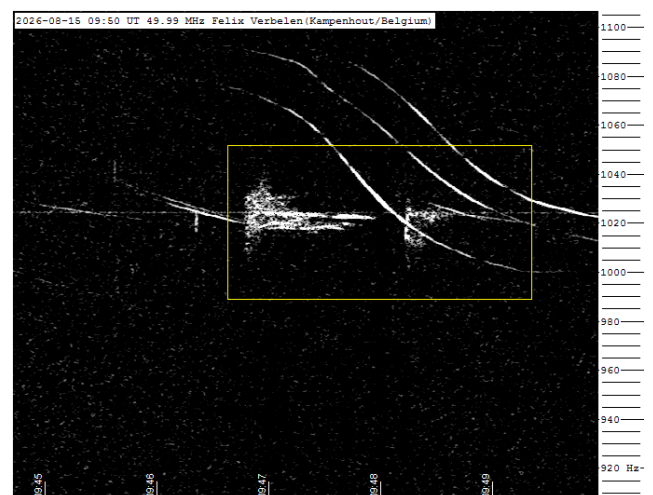


Figure 22 – Meteor echo August 15, 9^h50^m UT.

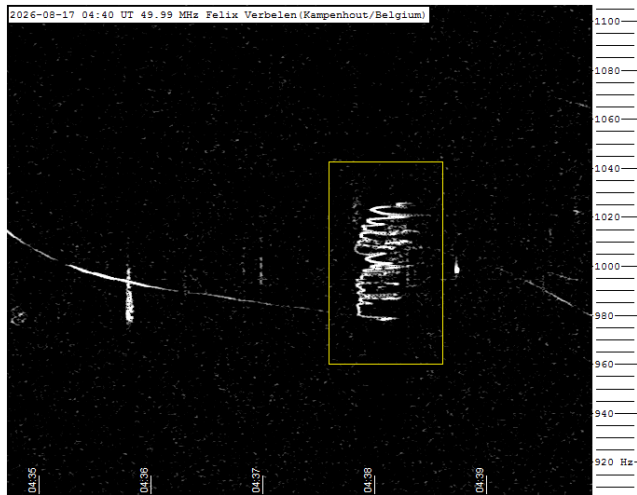


Figure 23 – Meteor echo August 17, 4^h40^m UT.

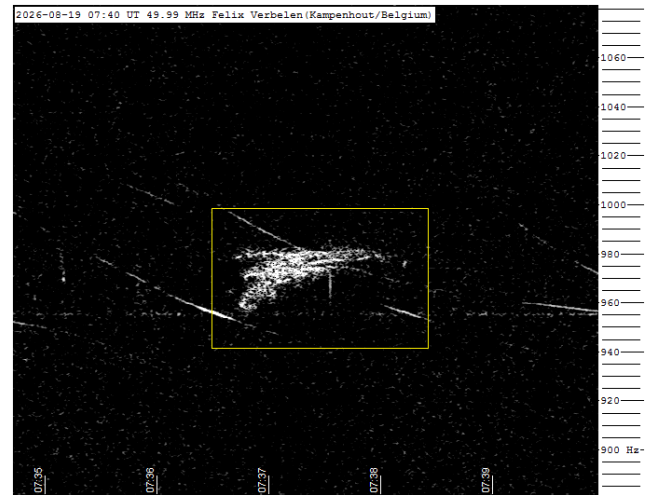


Figure 26 – Meteor echo August 19, 7^h40^m UT.

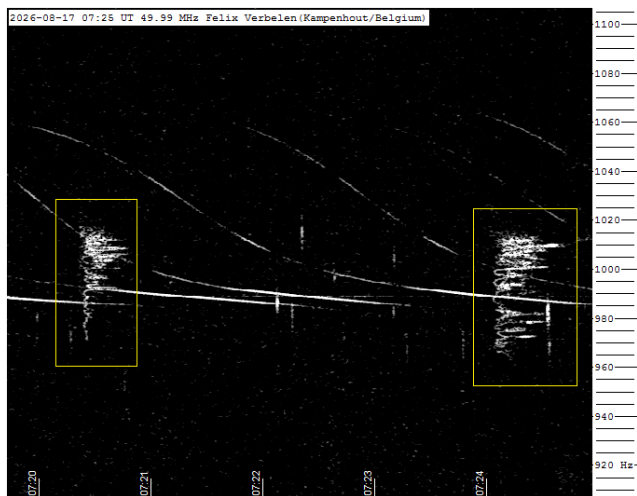


Figure 24 – Meteor echo August 17, 7^h25^m UT.

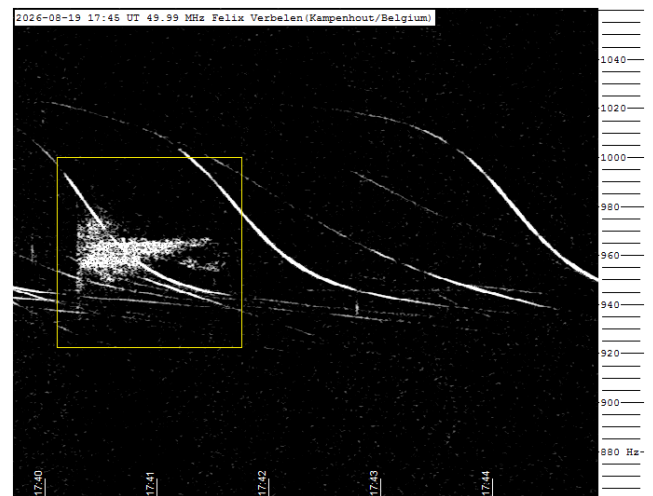


Figure 27 – Meteor echo August 19, 17^h45^m UT.

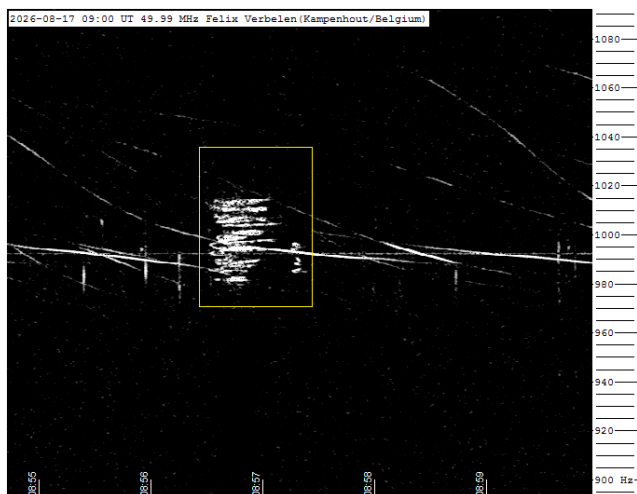


Figure 25 – Meteor echo August 17, 9^h00^m UT.

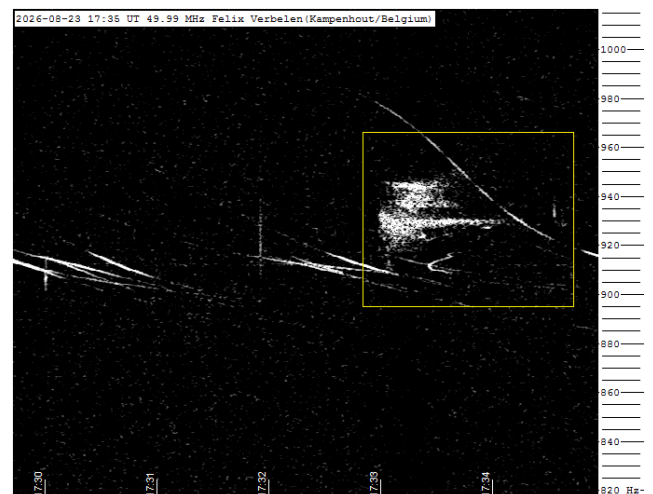


Figure 28 – Meteor echo August 23, 17^h35^m UT.

Radio meteors September 2026

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An overview of the radio observations during September 2026 is given.

1 Introduction

The graphs show both the daily totals (*Figure 1 and 2*) and the hourly numbers (*Figure 3 and 4*) of “all” reflections counted automatically, and of manually counted “overdense” reflections, overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during the month of September 2026.

The hourly numbers, for echoes shorter than 1 minute, are weighted averages derived from:

$$N(h) = \frac{n(h-1)}{4} + \frac{n(h)}{2} + \frac{n(h+1)}{4}$$

Local interference and unidentified noise remained very limited, and no lightning activity was recorded this month. The first few days of the month saw regular strong solar outbursts, mostly of type III, though their frequency decreased significantly during the second half of the month.

There were no truly striking meteor showers during this month except on September 10 (September epsilon Perseids), but activity nevertheless remained interesting, featuring both a number of minor showers and a fair number of long reflections on September 15 (solar longitude = 172°).

Over the course of the month, 20 reflections longer than 1 minute were recorded here. A selection of these, along with several other interesting reflections, is shown in *Figures 5 to 17*. Many more are available upon request.

In addition to the usual graphs, you will also find the raw counts in cvs-format²⁵ from which the graphs are derived. The table contains the following columns: day of the month, hour of the day, day + decimals, solar longitude (epoch J2000), counts of “all” reflections, overdense reflections, reflections longer than 10 seconds and reflections longer than 1 minute, the numbers being the observed reflections of the past hour.

²⁵ https://www.emeteornews.net/wp-content/uploads/2026/10/202609_49990_FV_rawcounts.csv

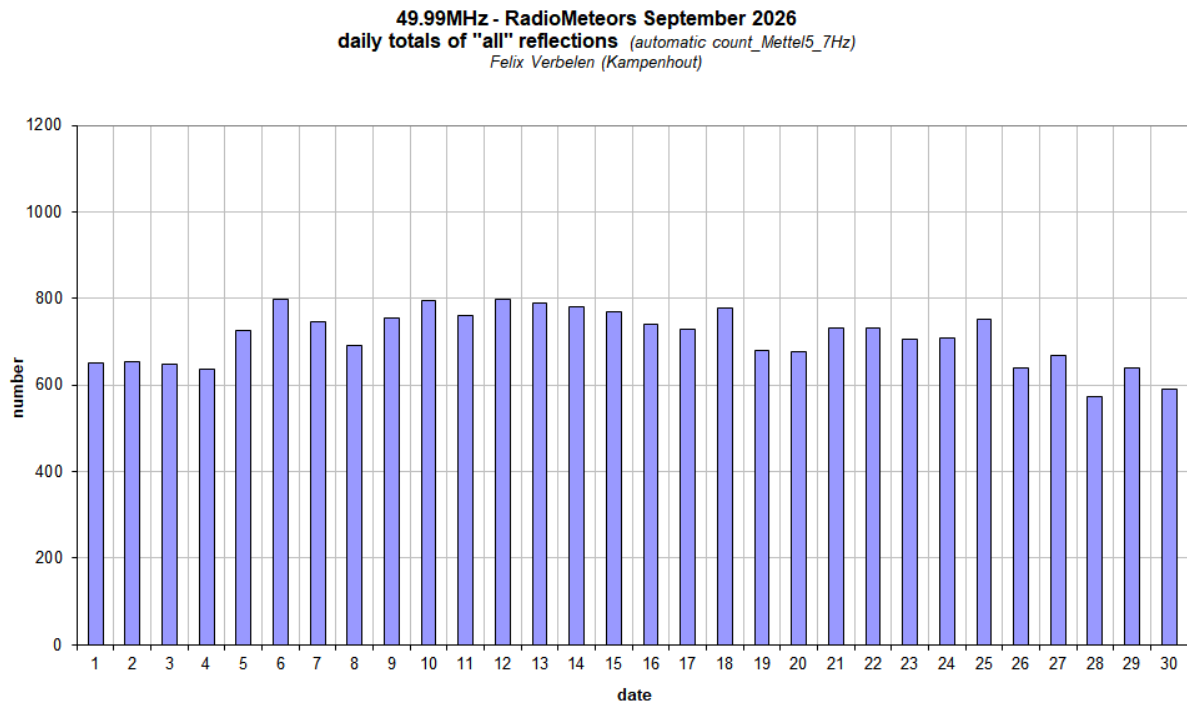
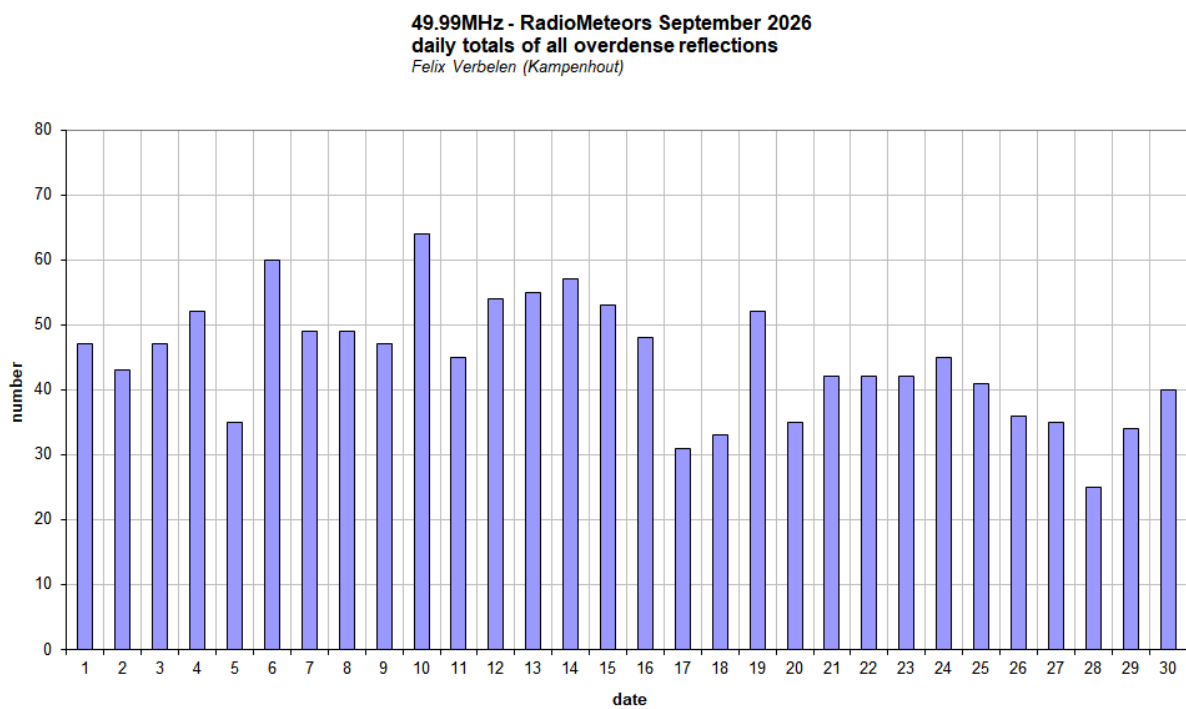


Figure 1 – The daily totals of “all” reflections counted automatically, and of manually counted “overdense” reflections, as observed here at Kamphenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during September 2026.

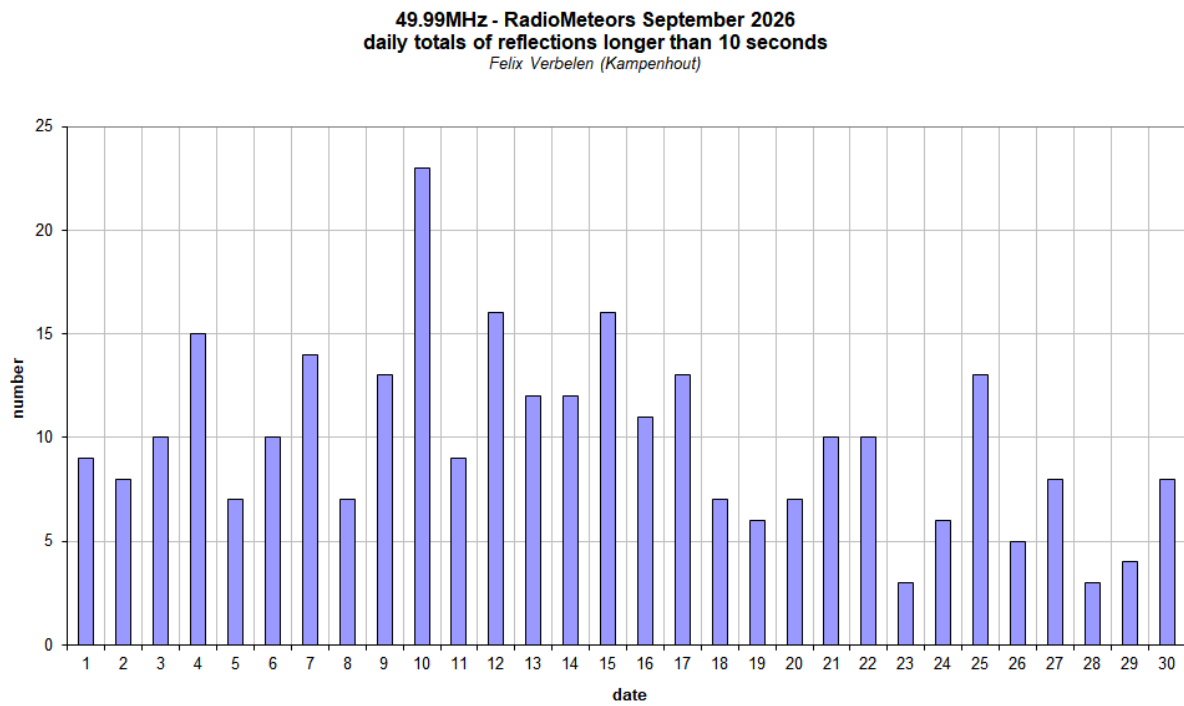
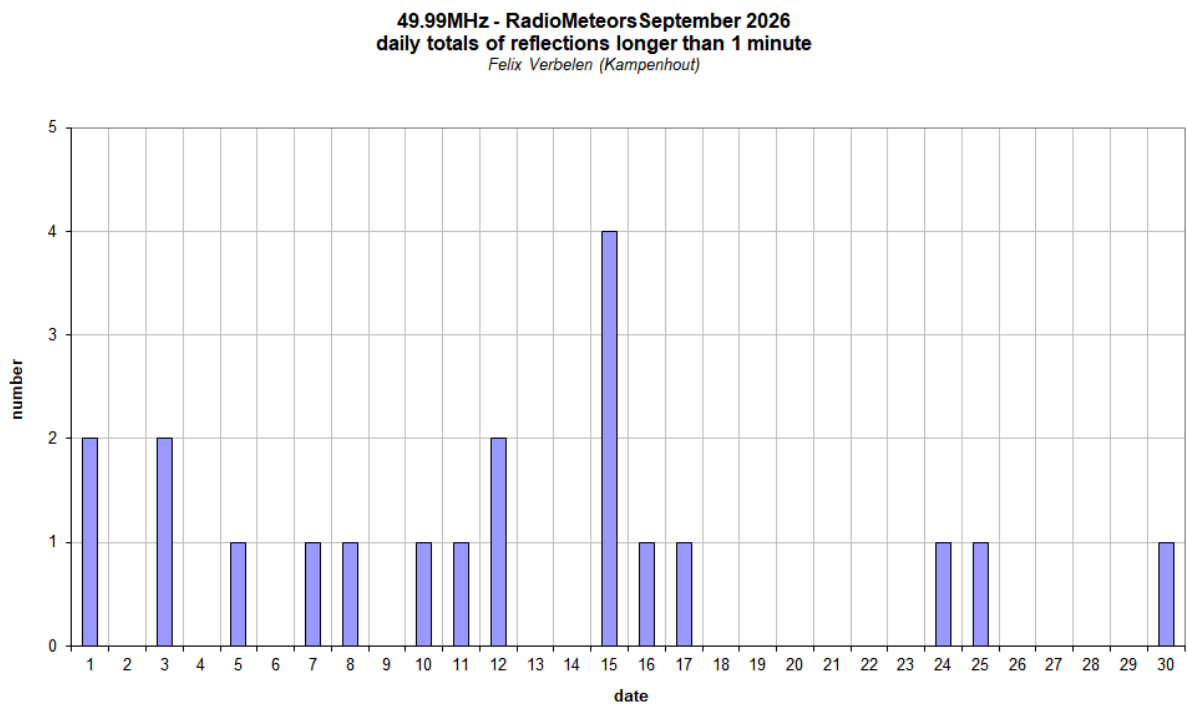


Figure 2 – The daily totals of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during September 2026.

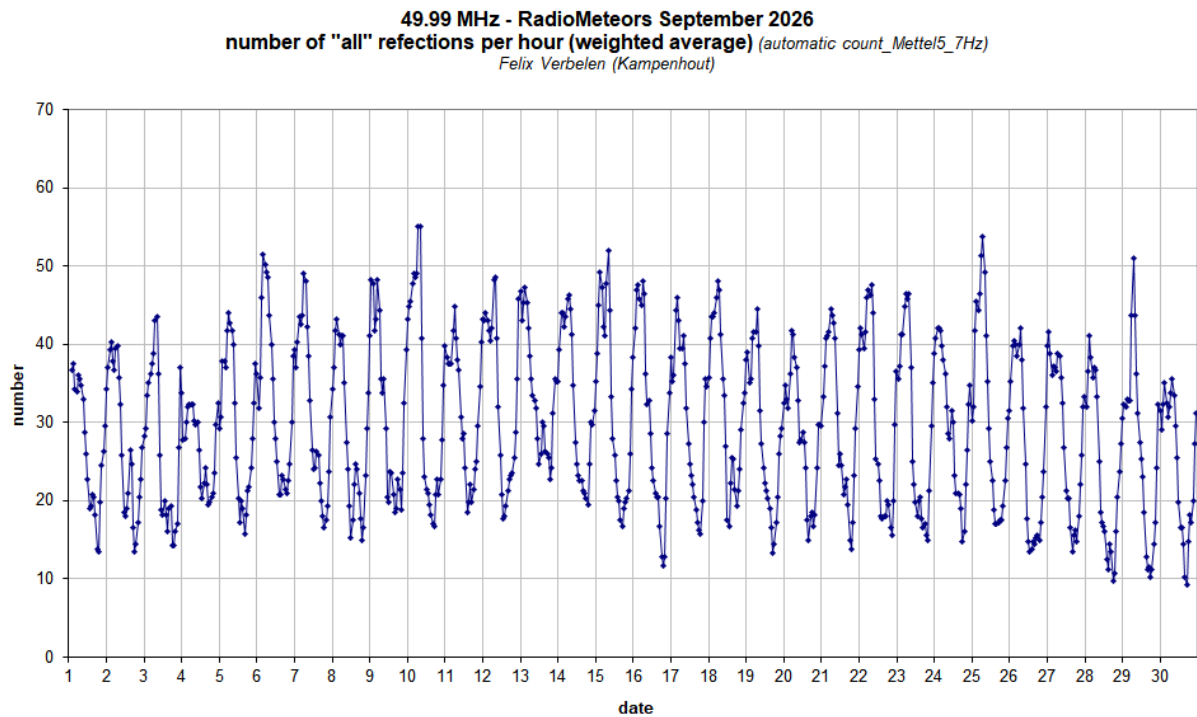
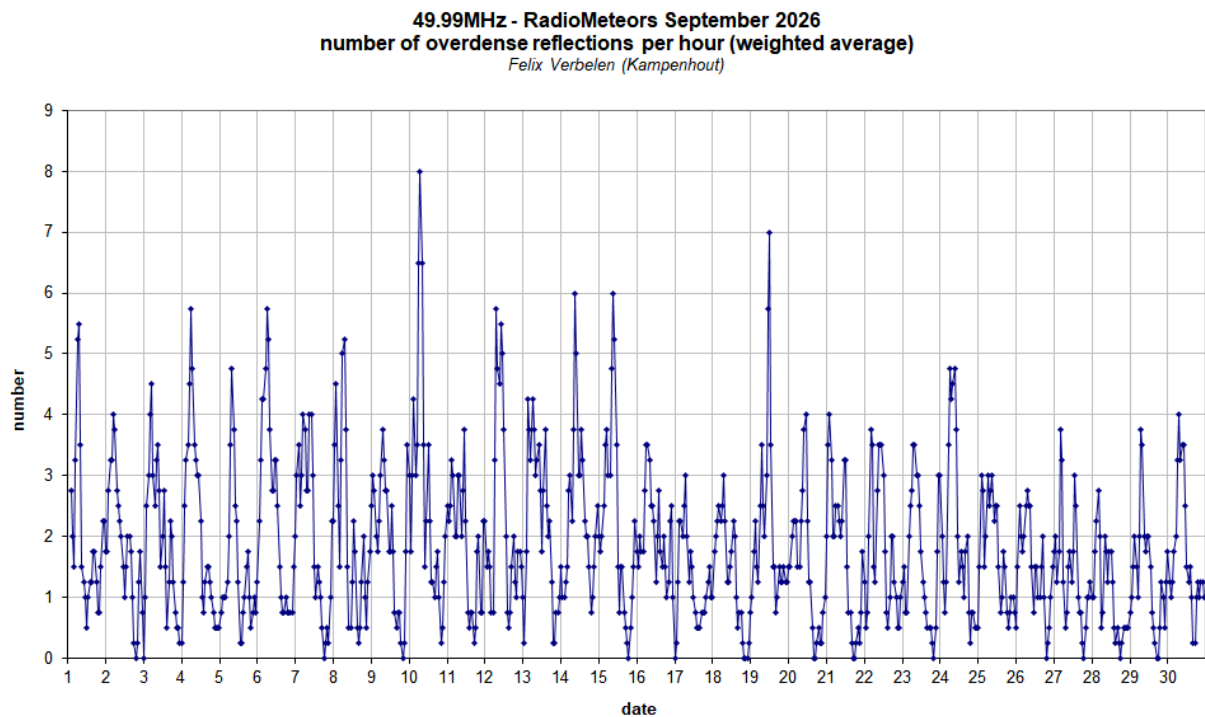


Figure 3 – The hourly numbers of “all” reflections counted automatically, and of manually counted “overdense” reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during September 2026.

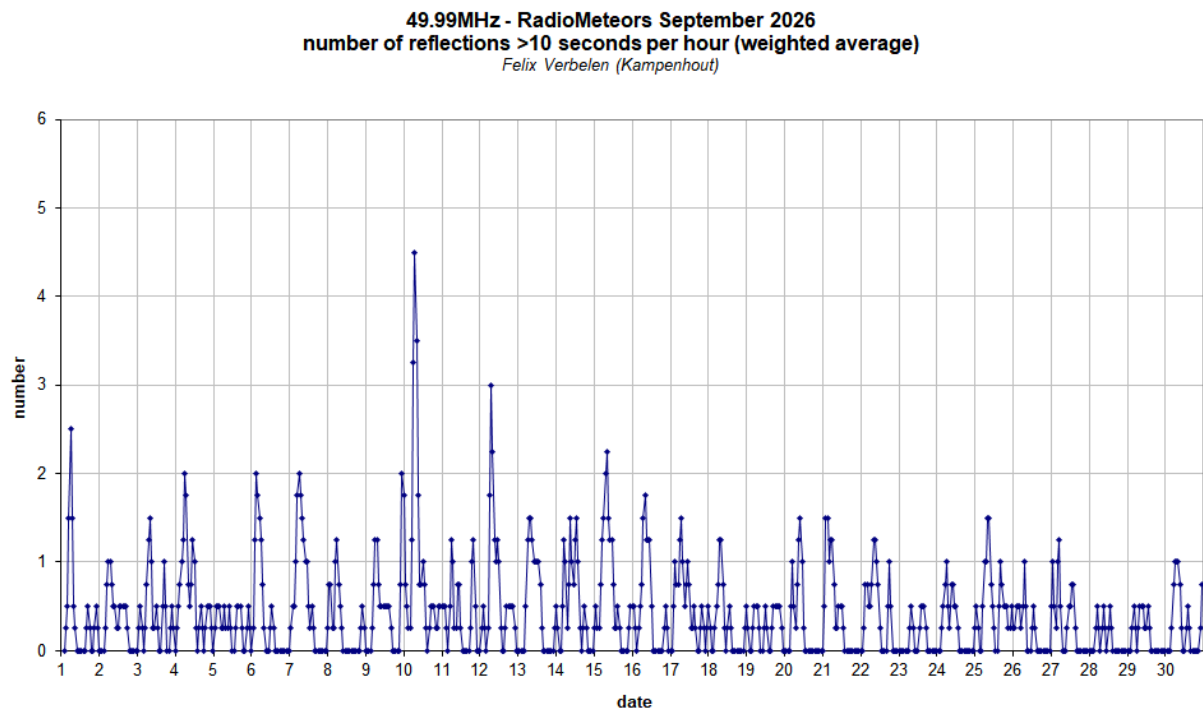
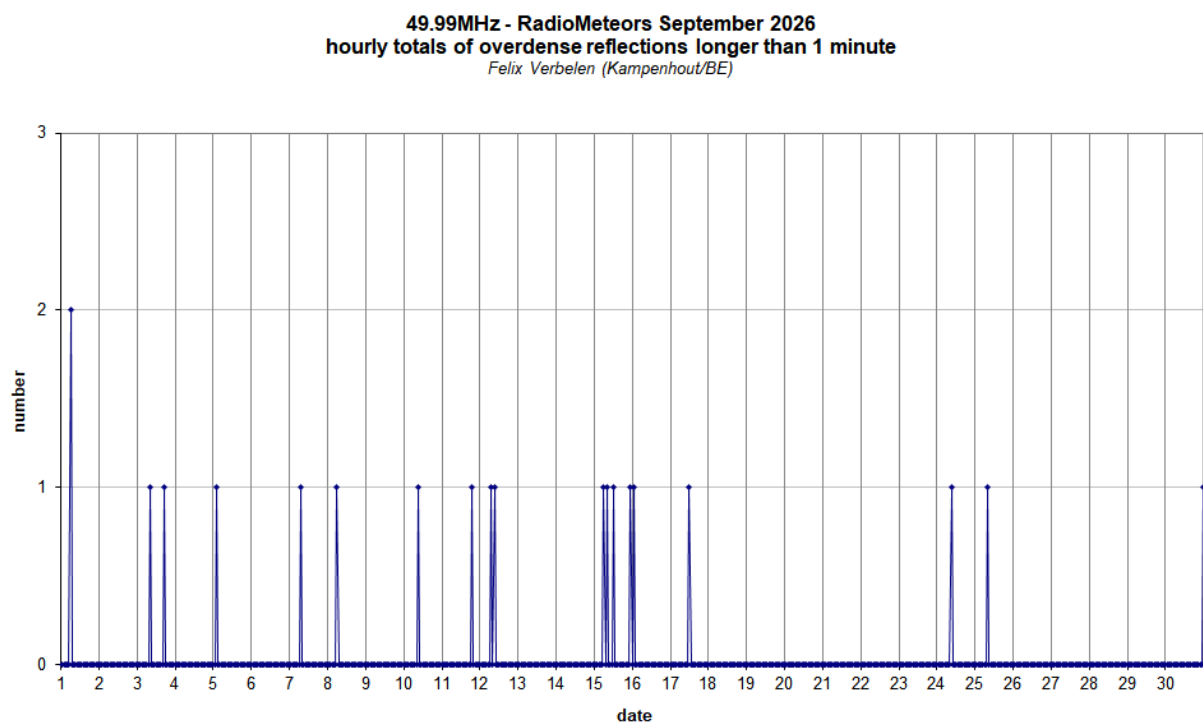


Figure 4 – The hourly numbers of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during September 2026.

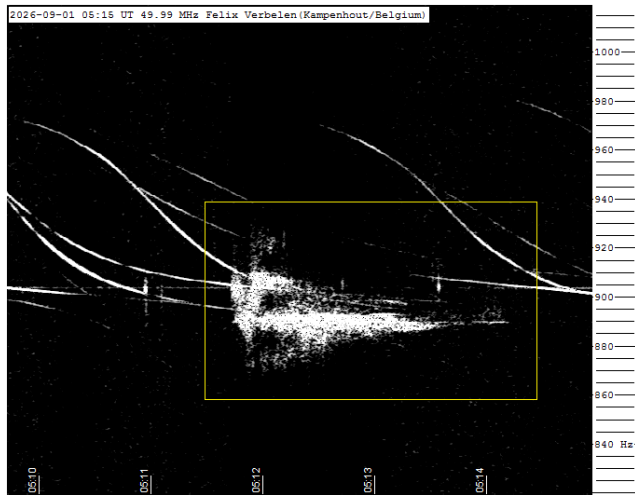


Figure 5 – Meteor echo September 1, 5^h15^m UT.

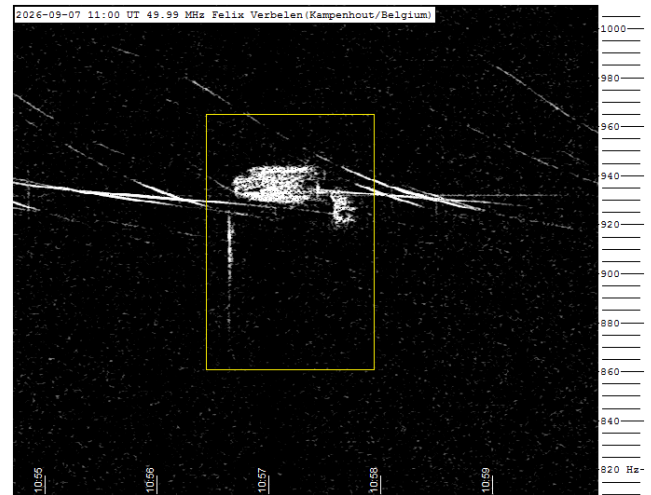


Figure 8 – Meteor echo September 7, 11^h00^m UT.

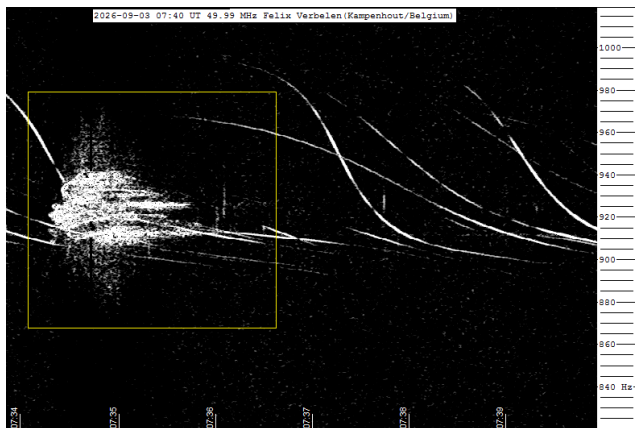


Figure 6 – Meteor echo September 3, 7^h40^m UT.

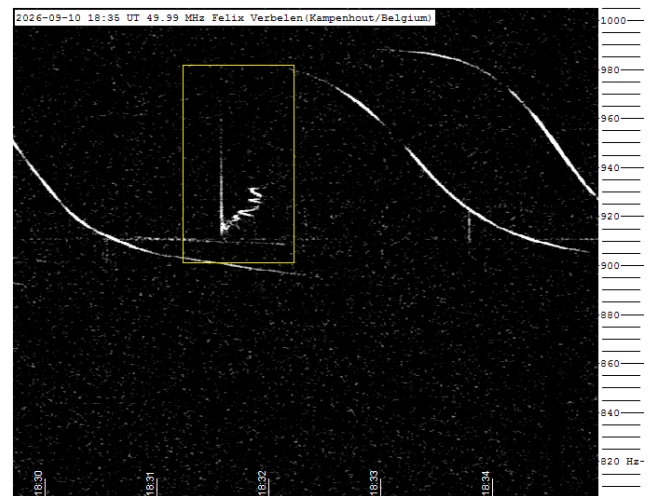


Figure 9 – Meteor echo September 10, 18^h35^m UT.

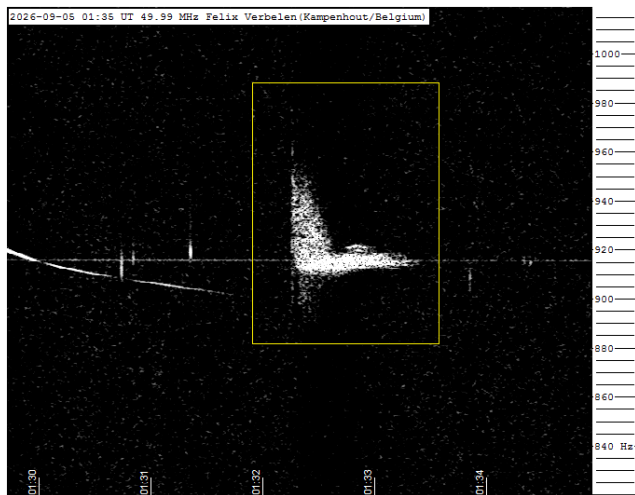


Figure 7 – Meteor echo September 5, 1^h35^m UT.

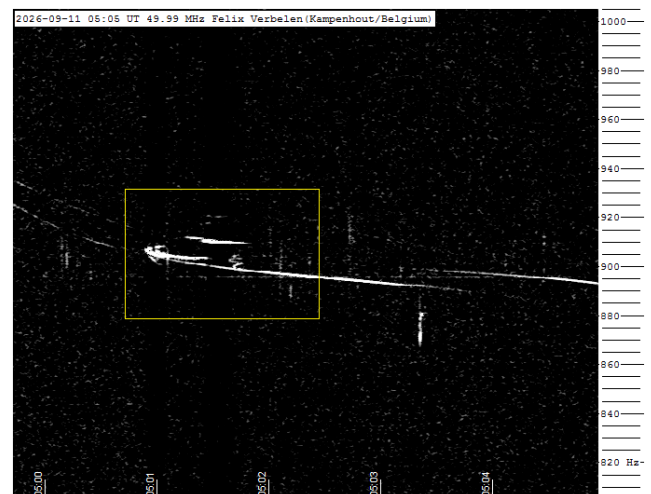


Figure 10 – Meteor echo September 11, 5^h05^m UT.

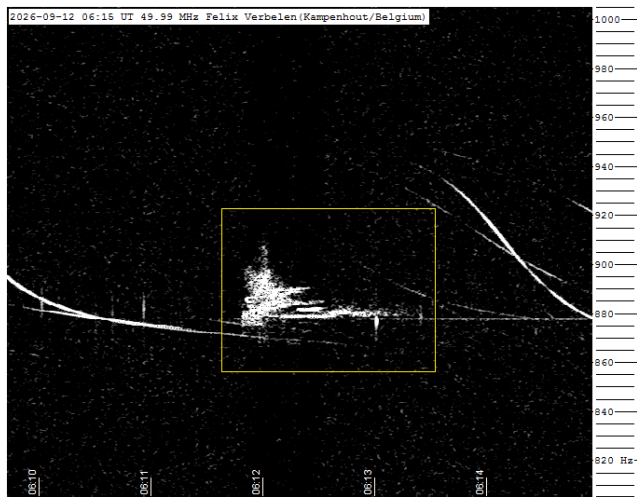


Figure 11 – Meteor echo September 12, 6^h15^m UT.

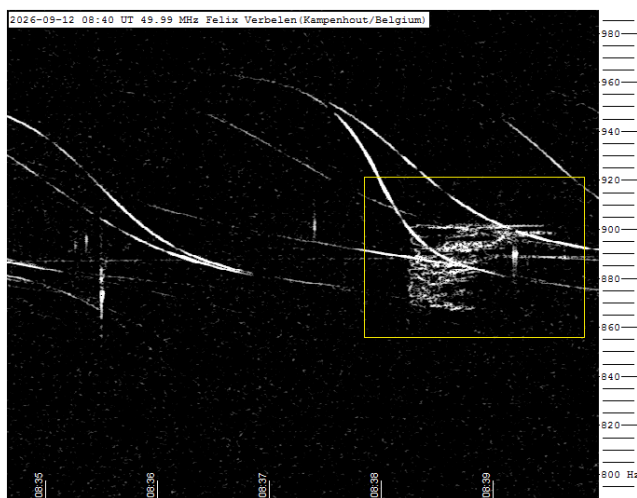


Figure 12 – Meteor echo September 12, 8^h40^m UT.

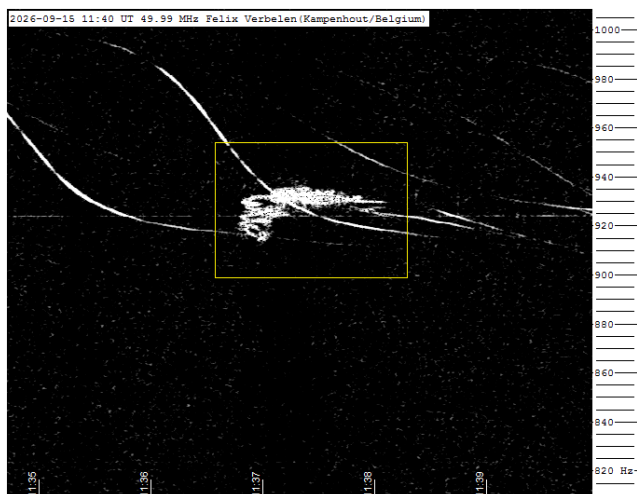


Figure 13 – Meteor echo September 15, 11^h40^m UT.

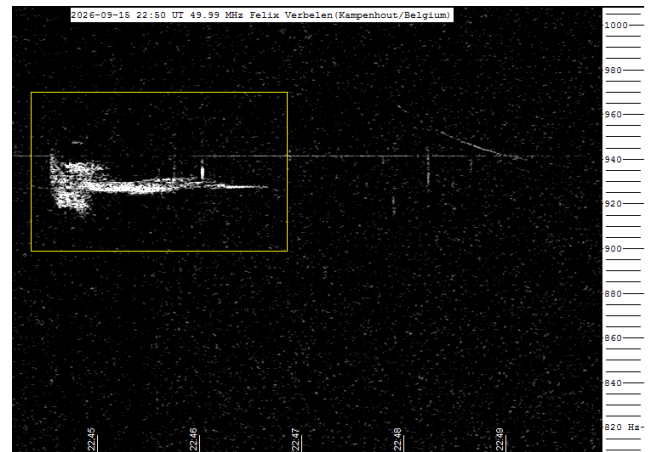


Figure 14 – Meteor echo September 15, 22^h50^m UT.

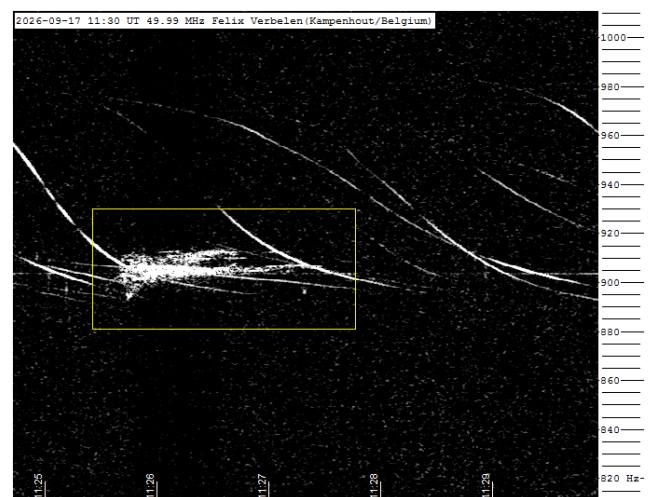


Figure 15 – Meteor echo September 17, 11^h30^m UT.

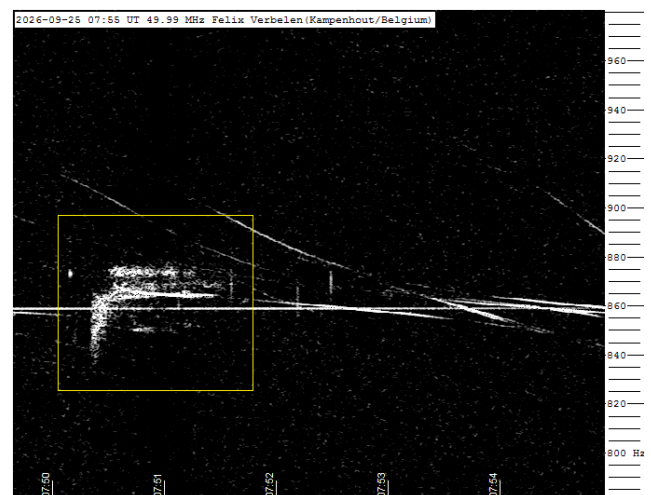


Figure 16 – Meteor echo September 25, 7^h55^m UT.

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