NASA METEOROID ENVIRONMENT OFFICE

The 2025 meteor shower activity forecast for low Earth orbit

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The purpose of this document is to provide a forecast of major meteor shower activity in low Earth orbit (LEO). Most annual showers are expected to display typical activity, but the October Draconids and possibly the Andromedids are forecast to exhibit significant outbursts in activity. The eta Aquariids are expected to return to normal this year, after two years of increased rates.

1   Overview

Multiple modelers are projecting a strong outburst of the October Draconids in 2025 [1, 2, 3, 4, 5]. This shower, which normally has a zenithal hourly rate (ZHR) of 5, is predicted to reach a peak ZHR of approximately 400. The models indicate that there will be a significant increase in the number of particles with kinetic energies up to 105 J (0.1 cm), but practically no activity for particles with greater energies. The duration of the Draconid outburst is expected to be brief, lasting no more than a few hours.

Less certain is the possible enhancement of the Andromedid shower in December, which consists of particles ejected from the now-extinct Comet 3D/Biela. This shower has proven extremely difficult to model, with predictions not matching at all well with observations. The current best prediction indicates a ZHR increase of up to 10 [1], elevating the maximum 105-J (0.1 cm) particle flux to approximately the same level as that of the annual Geminid shower. Like the Draconids, the Andromedid outburst is also expected to be just a few hours in duration.

We revised our shower parameters this year based on the current state of knowledge. The timing and shape parameters have been refined for almost every shower, with the exception of the Daytime zeta Perseids (ZPE) and Southern mu Sagittariids (SSG). We reduced the peak ZHR of four showers – the Quadrantids (QUA), Daytime Arietids (ARI), Southern delta Aquariids (SDA), and Geminids (GEM), while increasing the peak ZHR of the eta Aquariids (ETA), Perseids (PER), Daytime Sextantids (DSX), and Ursids (URS). The Quadrantids were updated to have a steeper mass distribution (that is, proportionally more small particles) than we have assumed in recent years; shallower mass distributions were adopted for the eta Aquariids, Perseids, and Ursids to represent proportionally more large particles. The Geminids and Southern delta Aquariids are now represented by dual profiles, which better match the shape of the observed activity curves. These changes are based on an analysis of a combination of data from the Canadian Meteor Orbit Radar [6], the Global Meteor Network [7], and the International Meteor Organization's Video Meteor Network [8] and Visual Meteor Database [9]. The Orionids (ORI), Southern Taurids (STA), and Northern Taurids (NTA) have been removed entirely, as they do not contribute significantly to the hazardous meteoroid flux in a typical year [10].

This document is designed to supplement spacecraft risk assessments that incorporate an annual averaged meteor shower flux (as is the case with all NASA meteoroid models). Results are presented relative to this baseline and are weighted to a constant kinetic energy. One shower – the Geminids – attains a flux

level exceeding that of the baseline meteoroid environment for 6.7-J (0.04-cm-equivalent) meteoroids. This energy corresponds to that capable of penetrating an EVA suit. Both the Geminids and Draconids attain a flux level matching or exceeding the baseline meteoroid environment for 105-J (0.1-cm-equivalent) meteoroids, a rough threshold for structural damage. The Geminids and Draconids, along with the Daytime Arietids, Quadrantids and Andromedids, match or exceed the baseline flux for 2.83-kJ (0.3-cm-equivalent) particles, which is near the limit for pressure vessel penetration.

Meteor shower fluxes drop dramatically with increasing particle size. Thus, a PNP (probability of no penetration) risk assessment should use the flux and flux enhancements corresponding to the smallest particle capable of penetrating a component because this size will be the dominant contributor to the risk.

2   Details

Our forecasting algorithm is presented in detail in ref. [11] and has not changed in the past year. Figure 1 gives the expected visual meteor rates (ZHR) for ground observers during calendar year 2025. The visual rate is dominated by the Quadrantids in early January, the eta Aquariids in May, the Geminids in mid-December, and, to a lesser extent, the Perseids in mid-August. Although meteor astronomers record and predict showers in terms of visual rates, ZHR does not directly correspond to meteoroid flux. The conversion from ZHR to flux must take into account the biases of the typical human observer, the speeds of the shower meteors, and the mass distributions of meteoroids belonging to these showers. The result is a flux profile that looks significantly different from the ZHR profile and in which high flux does not necessarily correspond to a visually spectacular meteor shower.

Showers typically contain proportionally more large particles than the sporadic background does; for this reason, showers are more significant at larger particle sizes, masses, or energies. Figure 2 gives the flux profiles for four limiting kinetic energy values, listed in Table 1. These are the same limiting kinetic energies for which we have been reporting fluxes, 7-hour fluences, and enhancement factors for many years; starting with the 2020 annual forecast, we began labeling these plots with the energy itself rather than with the diameter when such a particle has a speed of 20 km s^{-1} and a density of 1 g cm^{-3}. Equivalent masses and diameters are provided in Table 1.

Figure 2 also includes an estimate of the sporadic meteoroid flux for each of these limiting kinetic energies (horizontal lines). Note that for small particle sizes (low kinetic energies), shower fluxes are less significant when compared to the sporadic flux. Figure 2 also indicates that, depending on the energy threshold considered, a handful of showers produce the highest fluxes. The basic characteristics of five major or outbursting showers, including radiant position at the time of the shower's peak, are listed in Table 2 (the full list of included showers is provided at the end of this document in Table 3). For a spacecraft, the apparent directionality of a meteor shower (i.e., the aberrated radiant) will be shifted by the spacecraft's geocentric velocity.

In order to facilitate risk assessments, including Bumper PNP calculations, we provide flux enhancement factors for all of 2025 in 1-hour intervals (Figure 3). The larger flux enhancement factors in Figure 3 correspond to a kinetic energy of 105 J (0.1-cm-equivalent particles), which have lower absolute fluxes.

The fluxes and enhancement factors presented in this memo may or may not apply to individual spacecraft. For instance, we have not presented crater-limited fluxes; meteoroids incident on a surface at right angles penetrate deeper for many ballistic limit equations, and, for a surface directly facing the shower,

this can further boost the significance of a shower relative to the background by another factor of approximately 2. Conversely, a surface tilted away from a shower radiant will encounter a less significant flux enhancement, and it is possible for the Earth to shield the spacecraft from all or part of a shower at a particular point in time. This forecast is designed for spacecraft in LEO; it does not, for instance, cover spacecraft orbiting the Moon or near the Sun-Earth Lagrange points.

kinetic energy	equivalent mass at 20 km s^{-1}	equivalent diameter at 1 g cm^{-3}
6.7 J	3.35×10^{-5} g	0.04 cm
105 J	5.24×10^{-4} g	0.1 cm
2.83 kJ	1.41×10^{-2} g	0.3 cm
105 kJ	5.24×10^{-1} g	1.0 cm

Table 1: The limiting kinetic energies (and their equivalent masses and diameters at 20 km s^{-1} and 1 g cm^{-3}) to which we report fluxes, fluences, and enhancement factors.

shower name	radiant RA (°)	dec (°)	speed (km s^{-1})	date of maximum (UT)
Quadrantids	230	+49	41	2025-01-03 12:27
Daytime Arietids	42	+24	39	2025-06-09 19:49
October Draconids	263	+56	24	2025-10-08 15:46
Andromedids	20	+50	19	2025-12-03 09:16
Geminids	113	+32	35	2025-12-14 06:55

Table 2: Highly active (in terms of flux) meteor showers in 2025. The radiant is the geocentric, unaberrated radiant and speed is that at an altitude of 100 km.

3 Contact information

The Meteoroid Environment Office will update this forecast as necessary. Those with questions or special needs in the near future are encouraged to contact:

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References

[1] Moser, Moorhead, and Cooke. Forecast 2025 parameter choices. *MEO Internal Report*, 2024.

[2] Egal et al. Meteor shower modeling: Past and future Draconid outbursts. *Icarus*, 330:123–141, 2019.

[3] Jenniskens. Meteor showers and their parent comets. *Cambridge University Press*, 2006.

[4] Ye et al. The unexpected 2012 Draconid meteor storm. *Monthly Notices of the Royal Astronomical Society*, 437(4):3812–3823, 2014.

[5] Maslov. Future Draconid outbursts (2011 - 2100). *WGN, Journal of the International Meteor Organization*, 39(3):64–67, 2011.

[6] Jones et al. The Canadian Meteor Orbit Radar: System overview and preliminary results. *Planetary and Space Science*, 53(4):413–421, 2005.

[7] Vida et al. Computing optical meteor flux using Global Meteor Network data. *MNRAS*, 515(2):2322–2339, 2022.

[8] Molau and Rendtel. A comprehensive list of meteor showers obtained from 10 years of observations with the IMO Video Meteor Network. *WGN, Journal of the IMO*, 37(4):98–121, 2009.

[9] Roggemans. The Visual Meteor Database of the IMO. In *Proceedings of the International Meteor Conference, Balatonfüred, Hungary, 1989*, pages 78–81, 1990.

[10] Moorhead et al. The threshold at which a meteor shower becomes hazardous to spacecraft. *Advances in Space Research*, in press.

[11] Moorhead et al. Meteor shower forecasting in near-Earth space. *Journal of Spacecraft and Rockets*, 56(5):1531–1545, 2019.

[12] Moorhead, Kingery, and Ehlert. NASA's Meteoroid Engineering Model 3 and its ability to replicate spacecraft impact rates. *Journal of Spacecraft and Rockets*, 57:160–176, 2020.
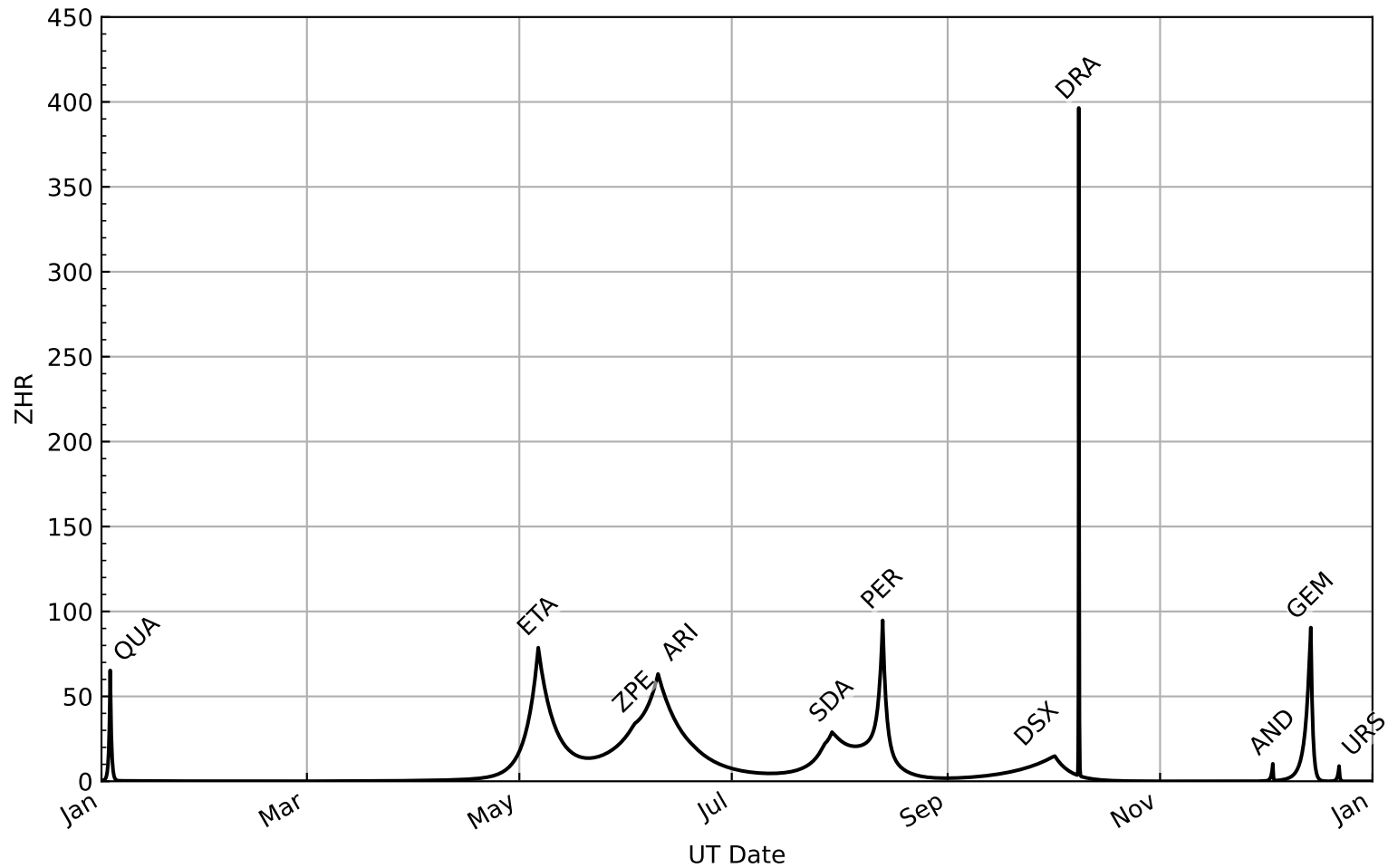
Figure 1: Meteor shower visual rates (zenithal hourly rate, or ZHR) over the course of 2025. Note how showers overlap; a large, broad shower such as the Daytime Arietids (ARI) can boost the cumulative shower ZHR and flux at the peak of an adjacent shower such as the Daytime zeta Perseids (ZPE).
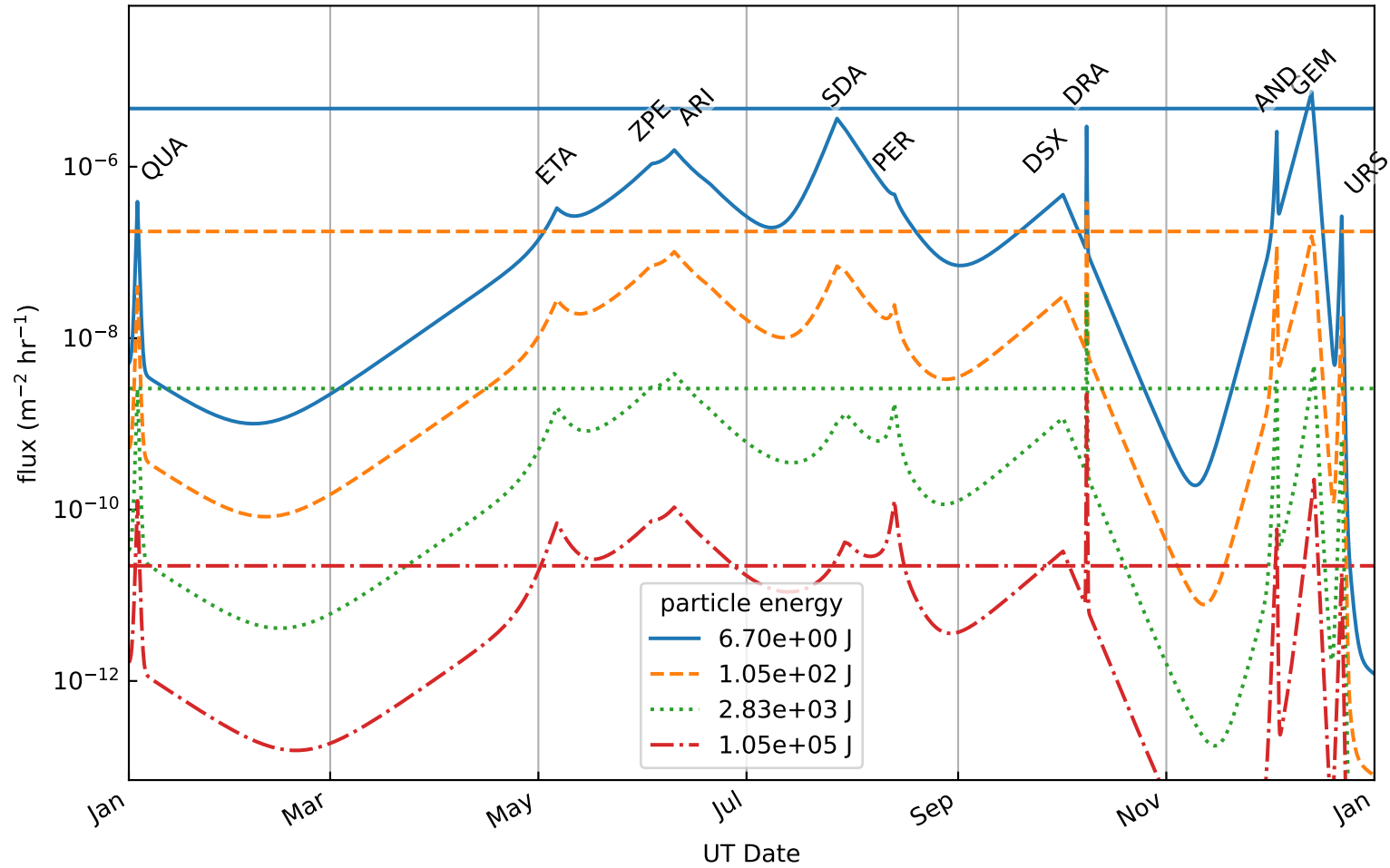
Figure 2: Meteor shower flux (variable lines) and sporadic meteoroid flux (horizontal lines) over the course of 2025. Fluxes have been weighted to a constant limiting kinetic energy. Fluxes are quoted for four particle kinetic energies; these kinetic energies correspond to particles with diameters of 0.04 cm, 0.1 cm, 0.3 cm, and 1 cm, assuming a density of 1 g cm^{-3} and a speed of 20 km s^{-1}. Some showers, such as the Perseids (PER) and Quadrantids (QUA), are more heavily weighted toward large particles and thus play a more significant role for 1-cm-equivalent particles than for 0.04-cm-equivalent particles.
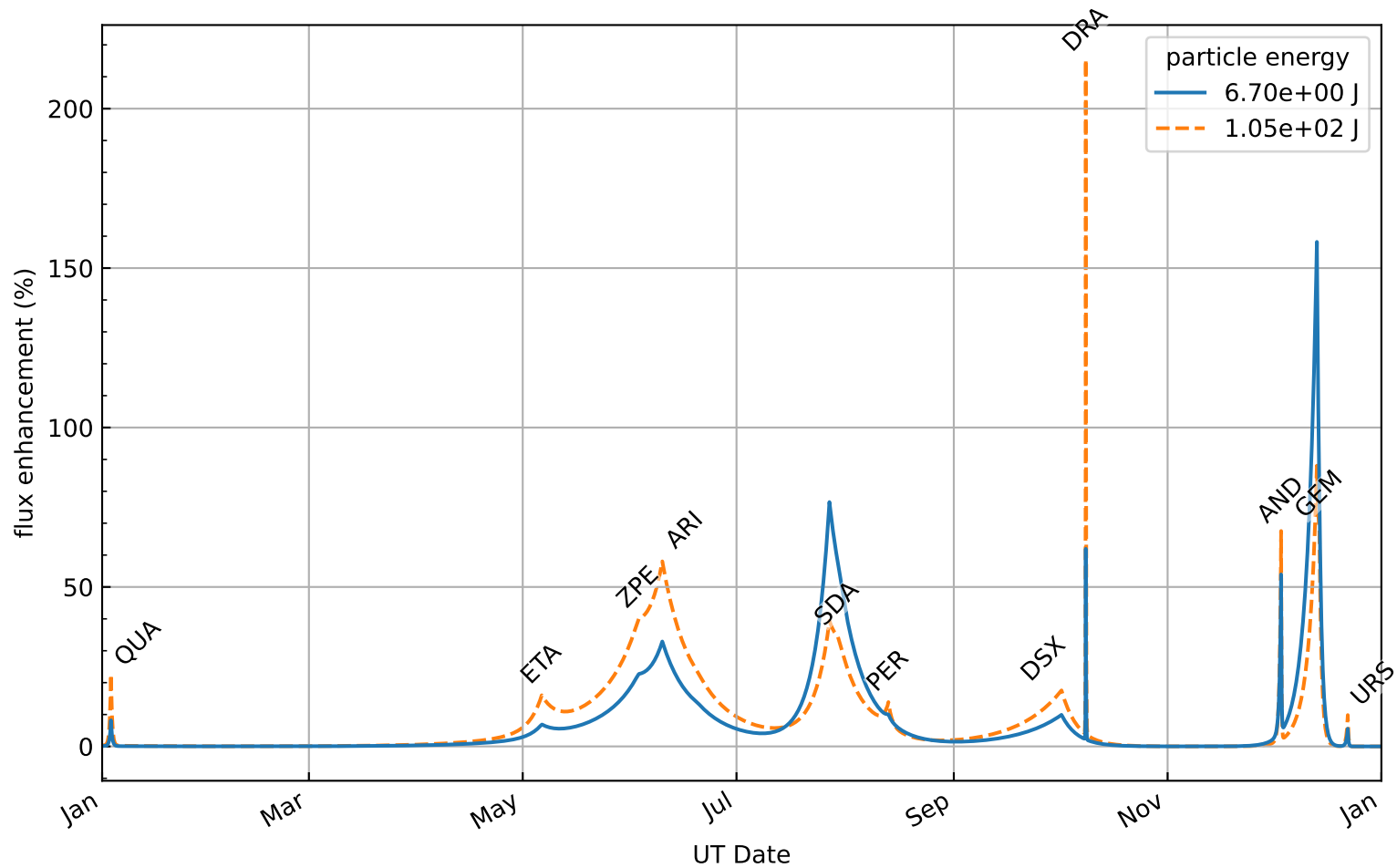
Figure 3: Meteor shower flux enhancement relative to the sporadic meteoroid flux over the course of 2025. These factors can be used in conjunction with a meteoroid model such as the Meteoroid Engineering Model (MEM) [12], to compute the flux at a particular time of year on a plate facing the unobscured shower radiant.

shower name	ID	date of maximum (UT)	max ZHR
Quadrantids	QUA	2025-01-03 12:27	65
eta Aquariids	ETA	2025-05-06 10:16	75
Daytime zeta Perseids	ZPE	2025-06-03 00:34	20
Daytime Arietids	ARI	2025-06-09 19:49	49
Southern mu Sagittariids	SSG	2025-06-19 21:50	2
Southern delta Aquariids	SDA	2025-07-29 18:26	20
alpha Capricornids	CAP	2025-07-30 22:16	3
Perseids	PER	2025-08-13 08:01	92
Daytime Sextantids	DSX	2025-10-01 17:25	15
October Draconids	DRA	2025-10-08 15:46	394
Andromedids	AND	2025-12-03 09:16	10
Geminids	GEM	2025-12-14 06:55	90
Ursids	URS	2025-12-22 09:44	9

Table 3: Meteor showers in 2025. Column 2 provides the 3-letter code for each shower, column 3 lists the date and time of maximum activity, and column 4 provides the shower's ZHR at the time of maximum activity.