NASA METEOROID ENVIRONMENT OFFICE

# The 2021 meteor shower activity forecast for low Earth orbit

Issued 9 October 2020

The purpose of this document is to provide a forecast of major meteor shower activity in low Earth orbit (LEO). Most major showers are expected to exhibit typical activity, but the Andromedids, Aurigids, and "Finlayids" (a possible new shower originating from comet 15P/Finlay) may produce outbursts.

## 1 Overview

Both the MSFC meteoroid stream model [1] and multiple external modelers have predicted a possible new meteor shower in 2021 originating from comet 15P/Finlay [2, 3, 4]. The orbit of this comet has evolved in recent decades such that its orbit now closely approaches that of the Earth. Furthermore, 15P/Finlay exhibited two periods of high activity in 2014 and 2015 [5]; if these outbursts produced significant material intersecting the Earth, a new meteor shower would result. Because this is new activity, it is not possible to estimate the activity level by calibrating models against past observations. We therefore caution that our predictions for the strength of this shower are highly uncertain. Furthermore, even if this comet does produce meteor activity in 2021, it will be difficult to confirm due to the brief window of activity, southern radiant, small particle size, and slow encounter speed (which corresponds to dim meteors).

Multiple modelers have also predicted a possible Aurigid outburst in 2021, with ZHR estimates ranging from 50 to 100 [3]. Once again, this result is corroborated by the MSFC stream model. However, the Aurigids intercept the Earth at a speed of 66 km $s^{-1}$; high speed meteors are brighter, and so even a fairly high ZHR corresponds to a modest particle flux.

The Andromedids may also outburst in 2021, according to MSFC stream model results. This model shows a record number of particles intersecting the Earth in 2021. On the other hand, the Wiegert et al. model [6] predicts no unusual activity at all in 2021. We tentatively predict a zenithal hourly rate (ZHR) of 10 for this shower, but caution that this shower is unpredictable; both of the above models have failed to predict past Andromedid activity in certain years.

We have also revised key parameters for two major showers in this year's forecast. Recent observations indicate that the size distributions of both the Perseids and the Southern delta Aquariids are less steeply skewed toward small particles than we have previously modeled. We have therefore corrected the size distributions of these two showers, making the corresponding flux enhancements less significant for small limiting sizes and energies.

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 (GEM) – attains a flux level exceeding that of the baseline meteoroid environment for 105-J (0.1-cm-equivalent) meteoroids. This size is a rough threshold for structural damage. The Geminids, along with the Daytime Arietids (ARI), Quadrantids (QUA), and "Finlayids" (FIN), 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 [7] and, for spacecraft in low Earth orbit, this algorithm has not changed in the past year. Figure 1 gives the expected visual meteor rates (ZHR) for ground observers during calendar year 2021. As is typical, the visual rate is dominated by the Quadrantids in early January, the Perseids in mid-August, and the Geminids in mid-December. 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 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, fluences, and enhancement factors for many years; starting with last year's 2020 forecast, we began labeling these plots with the energy itself rather than with the corresponding diameter at 20 km $s^{-1}$ and 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 eight major or possibly 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.

| **kinetic energy** | **equivalent mass** at 20 km $s^{-1}$ | **equivalent diameter** at 1 g $cm^{-3}$ |
|---|---|---|
| 6.7 J | $3.35 \times 10^{-5}$ g | 0.04 cm |
| 105 J | $5.24 \times 10^{-4}$ g | 0.1 cm |
| 2.83 kJ | $1.41 \times 10^{-2}$ g | 0.3 cm |
| 105 kJ | $5.24 \times 10^{-1}$ 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 | | speed | date of maximum |
|---|---|---|---|---|
| | RA (°) | dec (°) | (km $s^{-1}$) | (UT) |
| Quadrantids | 230 | +49 | 41 | 2021-01-04 00:38 |
| Daytime Arietids | 42 | +24 | 39 | 2021-06-10 16:31 |
| Southern delta Aquariids | 342 | -16 | 42 | 2021-07-28 01:42 |
| Perseids | 47 | +58 | 61 | 2021-08-12 20:33 |
| Aurigids | 91 | +39 | 66 | 2021-08-31 21:22 |
| "Finlayids" | 255 | -49 | 15 | 2021-10-07 00:58 |
| Andromedids | 23 | +30 | 20 | 2021-11-28 06:56 |
| Geminids | 113 | +32 | 35 | 2021-12-14 07:43 |

**Table 2: Highly active (in terms of flux) or outbursting meteor showers in 2021. The radiant is the geocentric, unaberrated radiant and speed is taken at the top of the atmosphere.**

In order to facilitate risk assessments, including BUMPER PNP calculations, we provide flux enhancement factors for all of 2021 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.

## 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:

**Althea Moorhead**
NASA Meteoroid Environment Office
EV44, Marshall Space Flight Center
althea.moorhead@nasa.gov

**Bill Cooke**
Lead, NASA Meteoroid Environment Office
EV44, Marshall Space Flight Center
(256) 544-9136
william.j.cooke@nasa.gov

Contributors:

**Danielle Moser** (Jacobs ESSCA, NASA MEO)

## References


[1] D. E. Moser and W. J. Cooke. Updates to the MSFC Meteoroid Stream Model. *Earth Moon and Planets*, 102:285–291, 2008.

[2] Q.-Z. Ye, P. G. Brown, C. Bell, X. Gao, M. Mašek, and M.-T. Hui. Bangs and Meteors from the Quiet Comet 15P/Finlay. *The Astrophysical Journal*, 814(1):79, 2015.

[3] J. Rendtel (ed.). 2021 Meteor Shower Calendar. *International Meteor Organization*, pages 1–28, 2020.

[4] J. Vaubaillon, A. Egal, J. Desmars, and K. Baillié. Meteor shower output caused by comet 15P/Finlay. *WGN, Journal of the International Meteor Organization*, 48:29–35, 2020.

[5] M. Ishiguro, D. Kuroda, H. Hanayama, et al. 2014-2015 Multiple Outbursts of 15P/Finlay. *The Astronomical Journal*, 152(6):169, 2016.

[6] P. A. Wiegert, P. G. Brown, R. J. Weryk, and D. K. Wong. The Return of the Andromedids Meteor Shower. *The Astronomical Journal*, 145(3):70, 2013.

[7] A. V. Moorhead, A. Egal, P. G. Brown, D. E. Moser, and W. J. Cooke. Meteor shower forecasting in near-Earth space. *Journal of Spacecraft and Rockets*, 56(5):1531–1545, 2019.

[8] A. V. Moorhead, A. Kingery, and S. Ehlert. NASA's Meteoroid Engineering Model 3 and its ability to replicate spacecraft impact rates. *Journal of Spacecraft and Rockets*, 57:160–176, 2020.

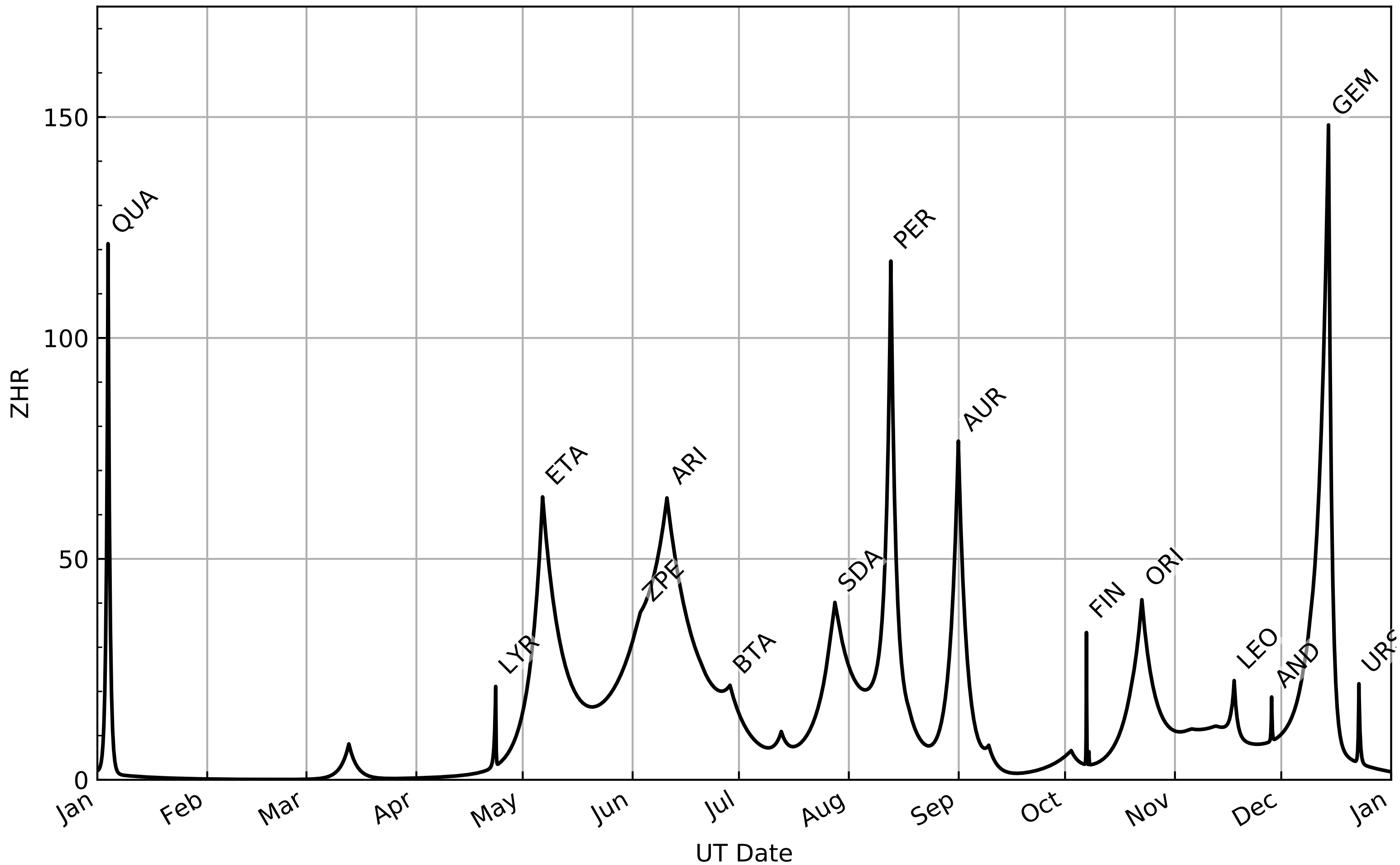


**Figure 1: Meteor shower visual rates (zenithal hourly rate, or ZHR) over the course of 2021. Note how showers overlap; a large, broad shower such as the Daytime Arietids (ARI) can boost the cumulative shower ZHR and flux at the peak of an adjacent shower.**

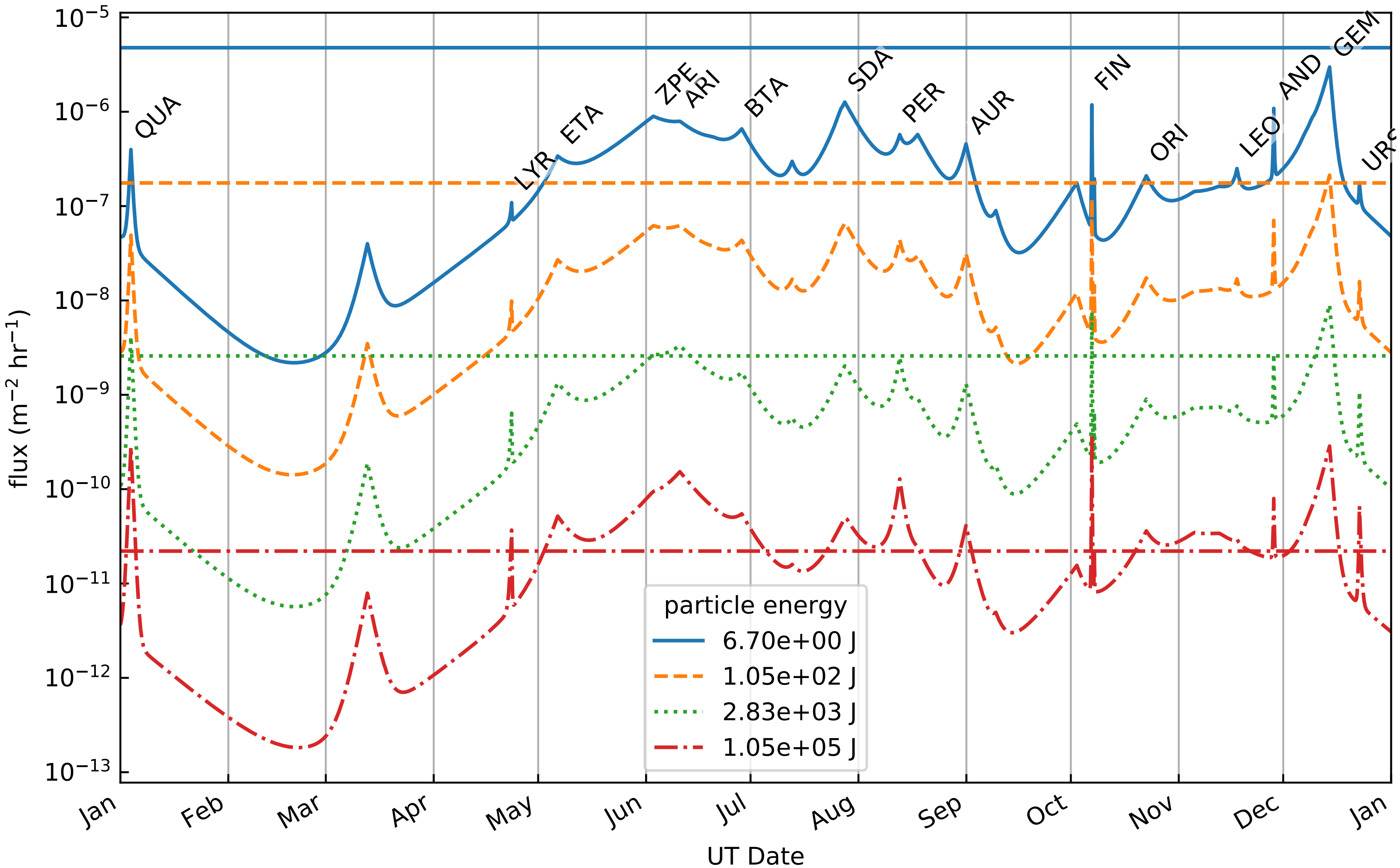


**Figure 2: Meteor shower flux (variable lines) and sporadic meteoroid flux (horizontal lines) over the course of 2021. Fluxes have been weighted to a constant limiting kinetic energy. Fluxes are quoted for four particle kinetic energies; these kinetic energies correspond to particles with diameters 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.**

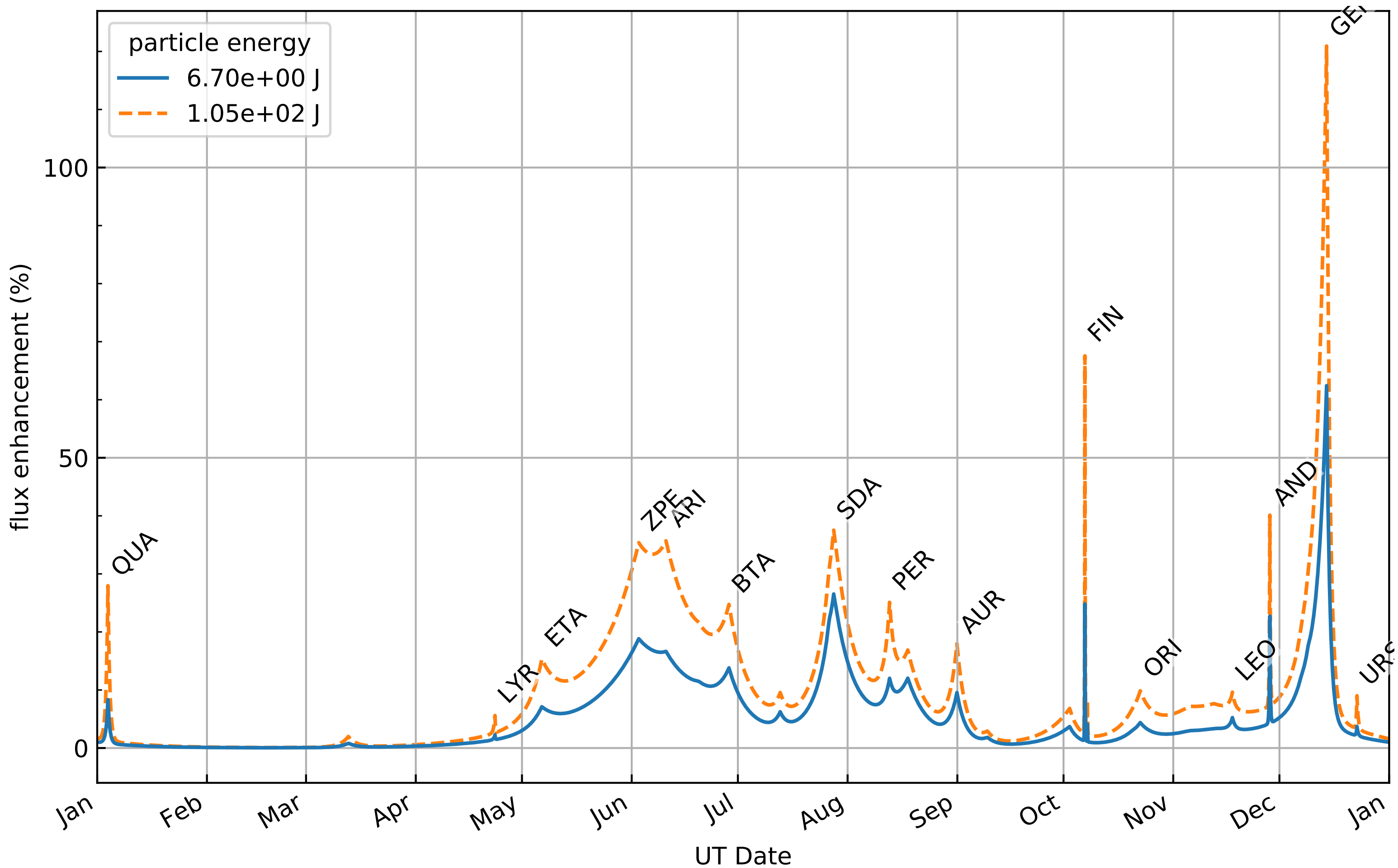


**Figure 3: Meteor shower flux enhancement relative to the sporadic meteoroid flux over the course of 2021. These factors can be used in conjunction with a meteoroid model such as the Meteoroid Engineering Model (MEM, [8]) to compute the flux at a particular point in the year on a plate facing the unobscured shower radiant.**

| **shower name** | **ID** | **max time** (UT) | **max ZHR** |
|---|---|---|---|
| Quadrantids | QUA | 2021-01-04 00:38 | 120 |
| gamma Normids | GNO | 2021-03-12 22:59 | 8 |
| April Lyrids | LYR | 2021-04-23 09:08 | 18 |
| eta Aquariids | ETA | 2021-05-06 14:43 | 60 |
| Daytime zeta Perseids | ZPE | 2021-06-02 23:58 | 20 |
| Daytime Arietids | ARI | 2021-06-10 16:31 | 50 |
| Southern mu Sagittariids | SSG | 2021-06-19 21:07 | 2 |
| beta Taurids | BTA | 2021-06-28 11:30 | 10 |
| July Phoenicids | PHE | 2021-07-12 22:49 | 5 |
| Piscis Austrinids | PAU | 2021-07-26 18:48 | 3 |
| Southern delta Aquariids | SDA | 2021-07-28 01:42 | 30 |
| alpha Capricornids | CAP | 2021-07-28 15:31 | 4 |
| Perseids | PER | 2021-08-12 20:33 | 112 |
| kappa Cygnids | KCG | 2021-08-18 00:12 | 5 |
| Aurigids | AUR | 2021-08-31 21:22 | 75 |
| September epsilon Perseids | SPE | 2021-09-09 11:09 | 5 |
| Daytime Sextantids | DSX | 2021-10-02 17:28 | 5 |
| Finlayids | FIN | 2021-10-07 00:58 | 30 |
| Draconids | DRA | 2021-10-07 18:06 | 3 |
| Leo Minorids | LMI | 2021-10-19 14:47 | 2 |
| Orionids | ORI | 2021-10-22 16:12 | 35 |
| Southern Taurids | STA | 2021-11-05 12:13 | 5 |
| Northern Taurids | NTA | 2021-11-12 11:28 | 5 |
| Leonids | LEO | 2021-11-17 17:05 | 14 |
| Andromedids | AND | 2021-11-28 06:56 | 10 |
| Puppid-Velid I complex | PUV | 2021-12-07 04:58 | 10 |
| December Monocerotids | MON | 2021-12-09 04:14 | 3 |
| sigma Hydrids | HYD | 2021-12-12 03:05 | 2 |
| Geminids | GEM | 2021-12-14 07:43 | 140 |
| Ursids | URS | 2021-12-22 21:39 | 18 |

**Table 3: Meteor showers in 2021. Column 2 provides the 3-letter code for each shower, Column 3 lists the date and time of peak activity, and Column 4 provides the shower's ZHR at the time of each shower's peak activity.**