



The NASA Meteoroid Environment Office

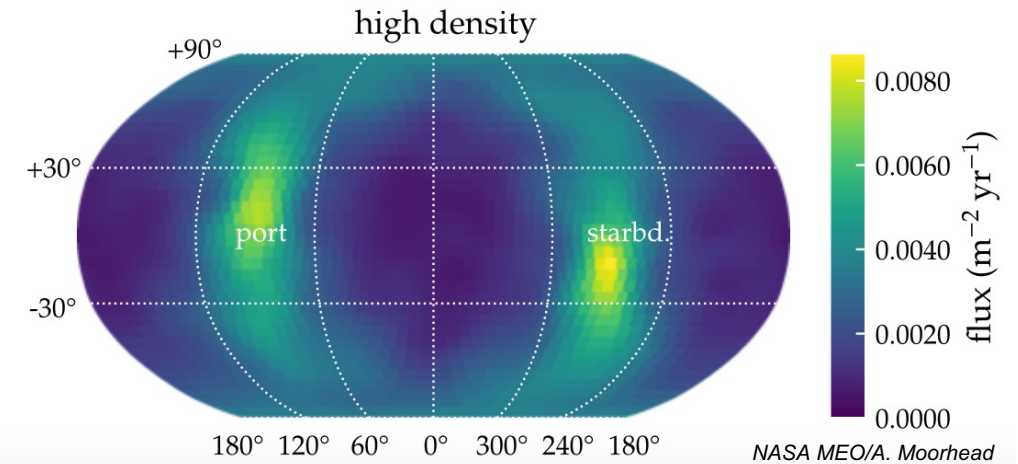
Workshop goals and MEO overview

Bill Cooke, Lead

Workshop goals

- To provide an overview of current meteor instrumentation, meteoroid models, and meteor shower forecasting techniques.
- Identify knowledge gaps and areas of focus for the *hazardous* meteoroid environment (0.1 to 1 cm).
- Foster collaborations and discussions among North American meteor researchers.

Meteoroid directionality in body-fixed frame



Why the MEO? *(and why OSMA?)*

First signs of a problem



- Meteor science died out in the United States during the early 1970's
 - NASA terminated its meteor office in 1970
 - NSF ceased to fund after 1974
 - No colleges/universities teaching meteor astronomy/physics
- STS-51 (Discovery) delayed by 8 days due to NASA's inability to predict the timing/intensity of the expected Perseid meteor outburst in August of 1993
 - Concern began to develop over the ISS and the Leonid meteor storms that could occur in the late 1990's-early 2000's



NASA

The Leonid meteor storms



NASA/Ames

- 1st meteor shower forecasts began to be produced in the late 1990's
 - Computers just fast enough to perform complex dynamical calculations for large numbers of particles
 - Modeling began outside U.S. (Canada, U.K.) and spread to MSFC/NASA
- NASA concerned about ISS (then in early phases)
 - Fairly large (millions of \$, battle exercise) effort on part of DoD to protect U.S. space assets
 - MSFC coordinated DoD/NASA efforts; data and information centralized at the LeOC (LEonid Operations Center) at MSFC
 - Meteor storms occurred in 1998, 1999, 2001 and 2002.
 - Forecasts enabled operators to "batten down the hatches"

Creation of the MEO



- Columbia accident in 2003
- MOD quickly eliminated as a possible cause; however, internal studies found that NASA had no meteoroid SMEs - only a couple folks at MSFC from the Leonids, and they had no funding to do meteor work
- Recommendations were made to create a meteor office similar to the ODPO to develop/maintain capability
 - Funding to be from "stable" source to prevent repeat of 1970 closure of JSC meteor office near end of Apollo
- MEO created by OSMA at MSFC using Leonid meteor people at beginning of FY05

- The MEO is an operational, applied science entity – we often cannot afford to operate on academic/SMD timeframes
 - Skyfall analyses have to be completed and reported within a news cycle (few hours)
 - Initial comparisons of meteor shower forecasts with observations have to be performed within a couple of days
 - If shower characterization appears in a CBET or something like MeteorNews before we have information, then we have failed
 - Anomaly resolutions/assessments cannot wait months or a year for journal publications (such things can be used to improve future forecasts)
 - Software must be as automated as possible to facilitate fast turn around



Who we are

- Bill Cooke, Office lead and relic from the Leonids (CS)
- Blane Craft – IT/system administrator (Contractor)
- Marcus Holden – Analyst/programmer (Contractor)
- Danielle Moser – Analyst/modeler (CS)
- Althea Moorhead, Chief modeler – MEM, meteor shower forecasts (CS)
- Arazi Pinhas – Analyst/Modeler (Contractor)
- Sierra Whitfield – Observer (Contractor)



What we do

- The MEO responsibilities are defined in NPR 8715.6B section 2.1.4.
- Primary mission is to define the hazardous meteoroid environment throughout the Solar System and assist in the protection of NASA/USG assets and crew from the associated risks.
- Starting in late 2013, the NPR was expanded to include the responsibility of notifying USG/media/public of significant bright meteor events over the U.S.
- We are the only meteoroid group in the USG. Everyone (including DoD, FAA, etc.) comes to us for meteoroid help.

Product overview

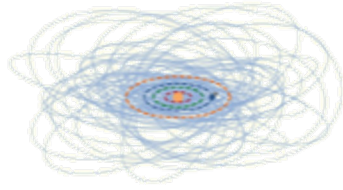


	Meteoroid Engineering Model (MEM)	shower forecasts	"sky falls"
what does it model?	sporadic complex	meteor showers	individual bright events
how important is it to spacecraft?	95-99% of risk	1-5% of risk	~ 0% of risk
what form does it take?	software at NASA	annual report and data files	individual emailed reports
what is it used for?	Also available as a cloud-based service	operational mitigation	keeping the public informed

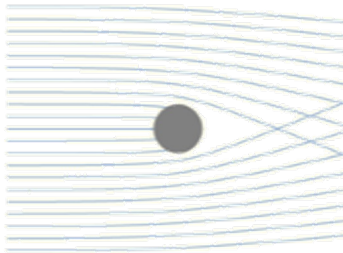
The Meteoroid Engineering Model (MEM)



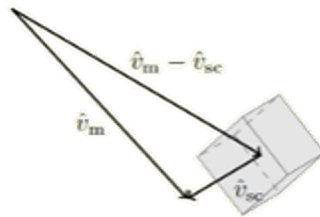
- The Meteoroid Engineering Model is used in the design of spacecraft and does the following:



models meteoroid orbits



determines the local environment



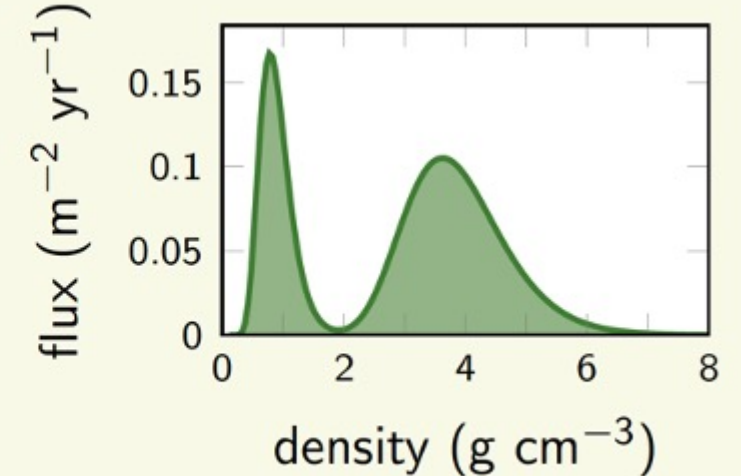
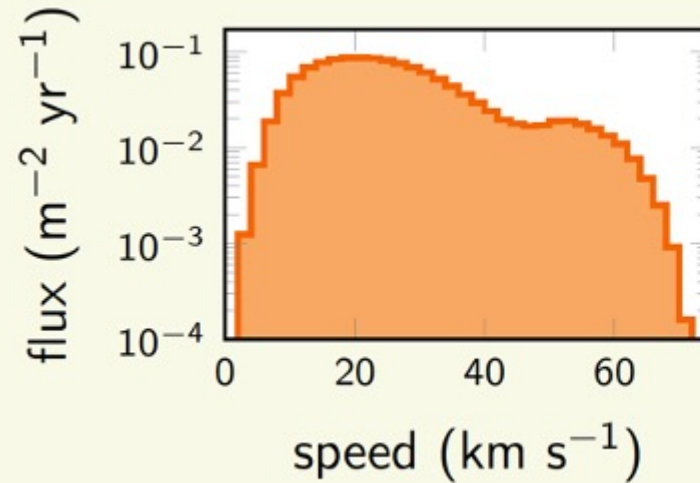
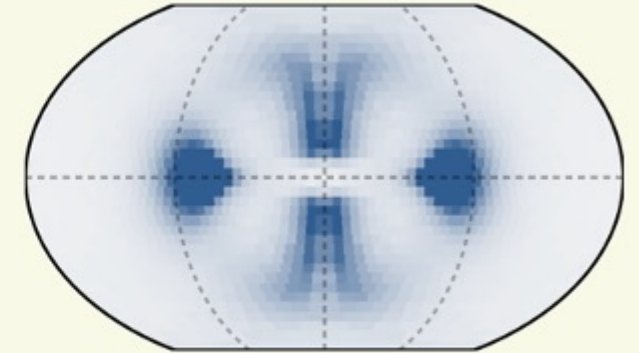
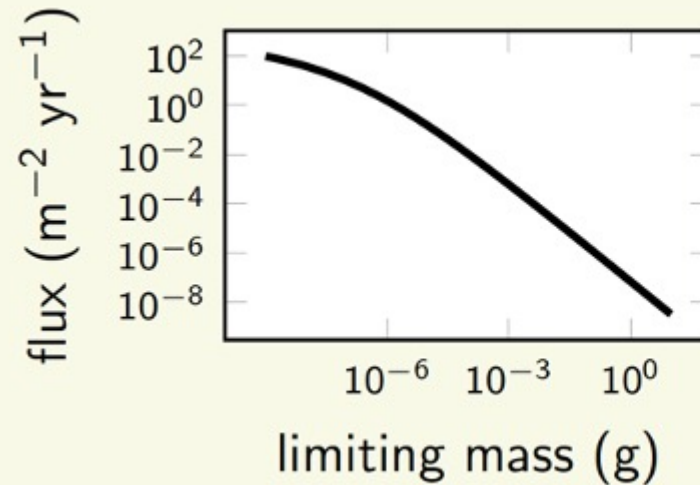
outputs the environment relative to a spacecraft

Graphics by NASA MEO/A. Moorhead

MEM provides:

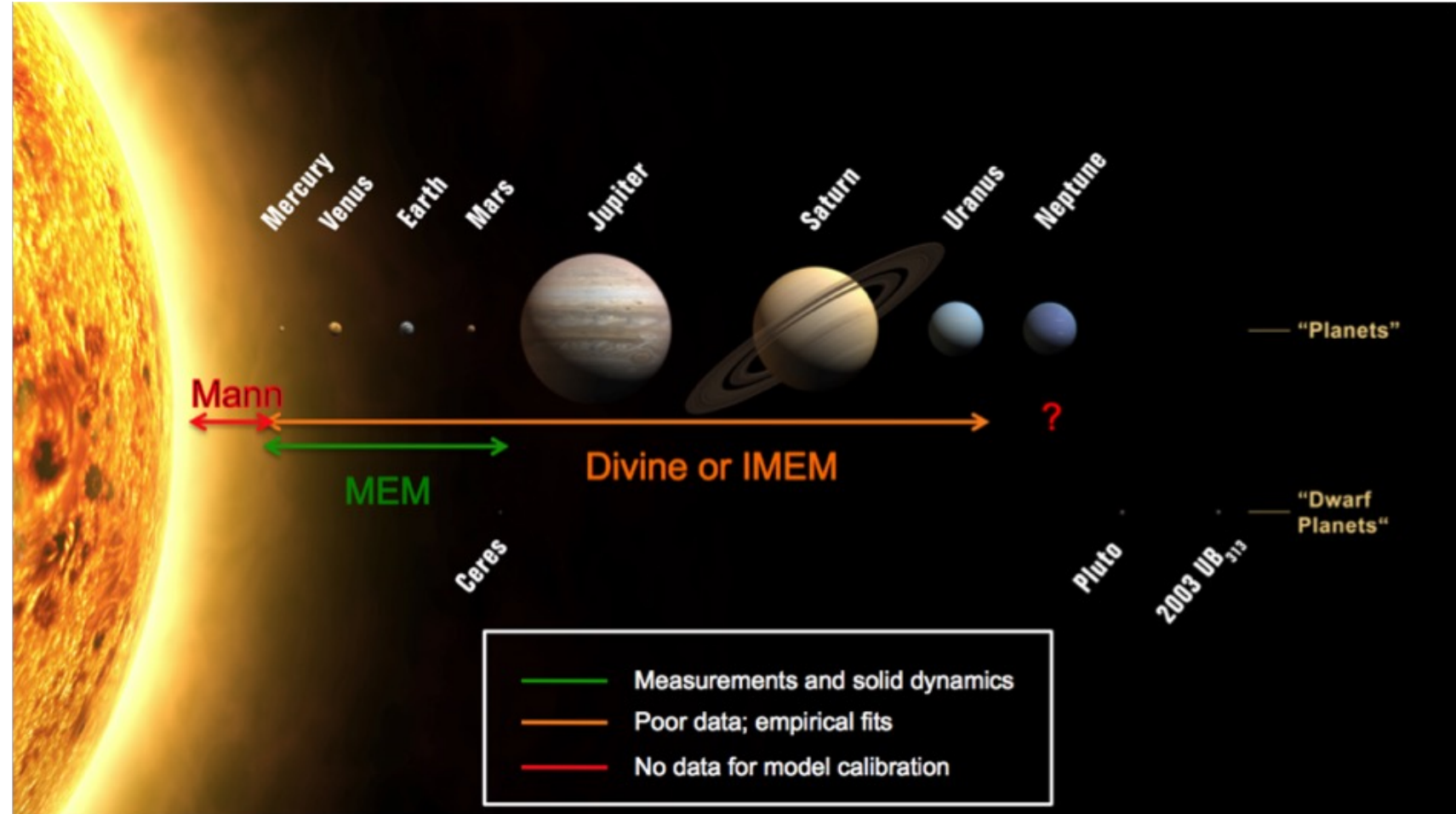
- Impactor mass (size)
- Angle
- Speed
- Density

Everything needed for risk assessments



Graphics by NASA MEO/A. Moorhead

- MEM has limitations that need to be removed:
 - Limited to inner solar system (0.2 to 2 au – Mercury to asteroid belt)
 - Mass range confined to vehicle threat sizes (approximately 0.1 mm to 10 cm)



NASA

Uncertainty in the meteoroid environment



- We have added a section on the uncertainty in the meteoroid environment to the Meteoroid Engineering Model user guide.
- Gives the 1st ever **quantitative** estimate of the uncertainty as a function of distance from Earth.
- Very important in helping programs place bounds on their risk assessments.

Uncertainty factor s can be calculated from

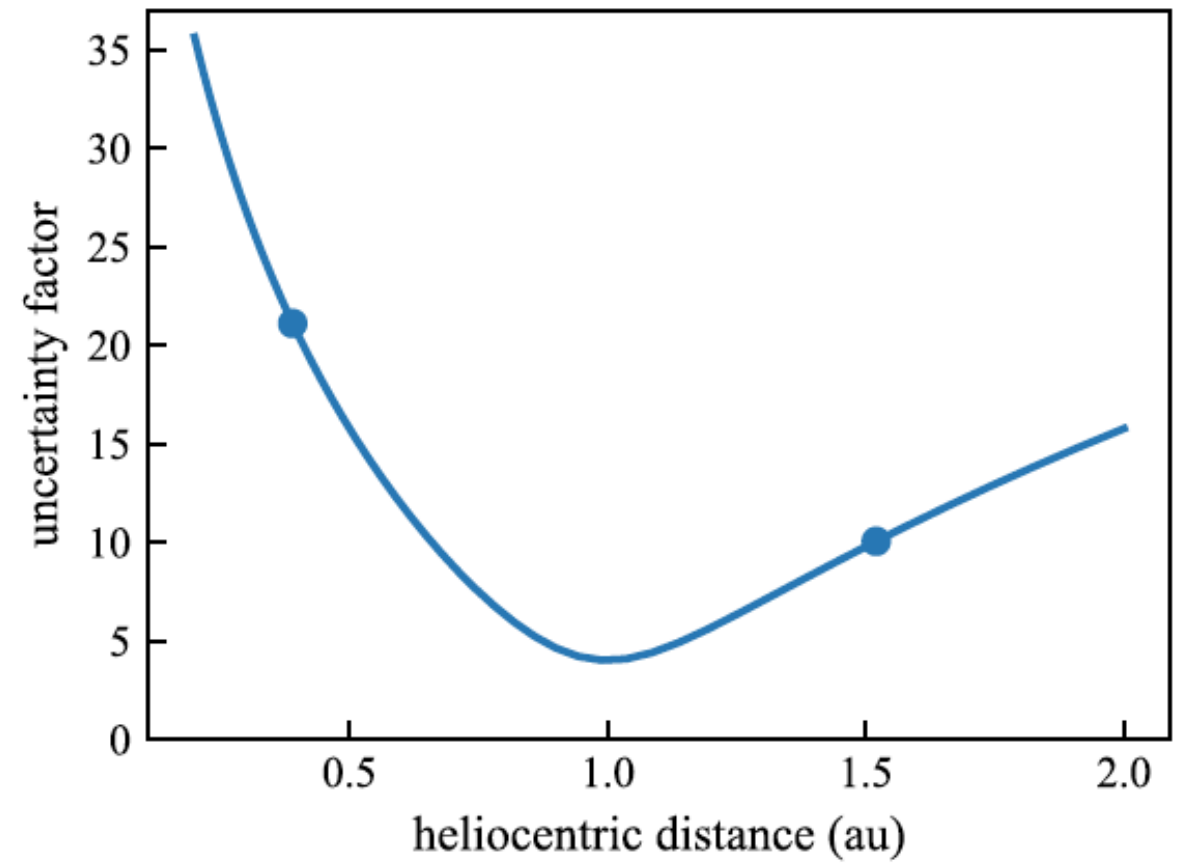
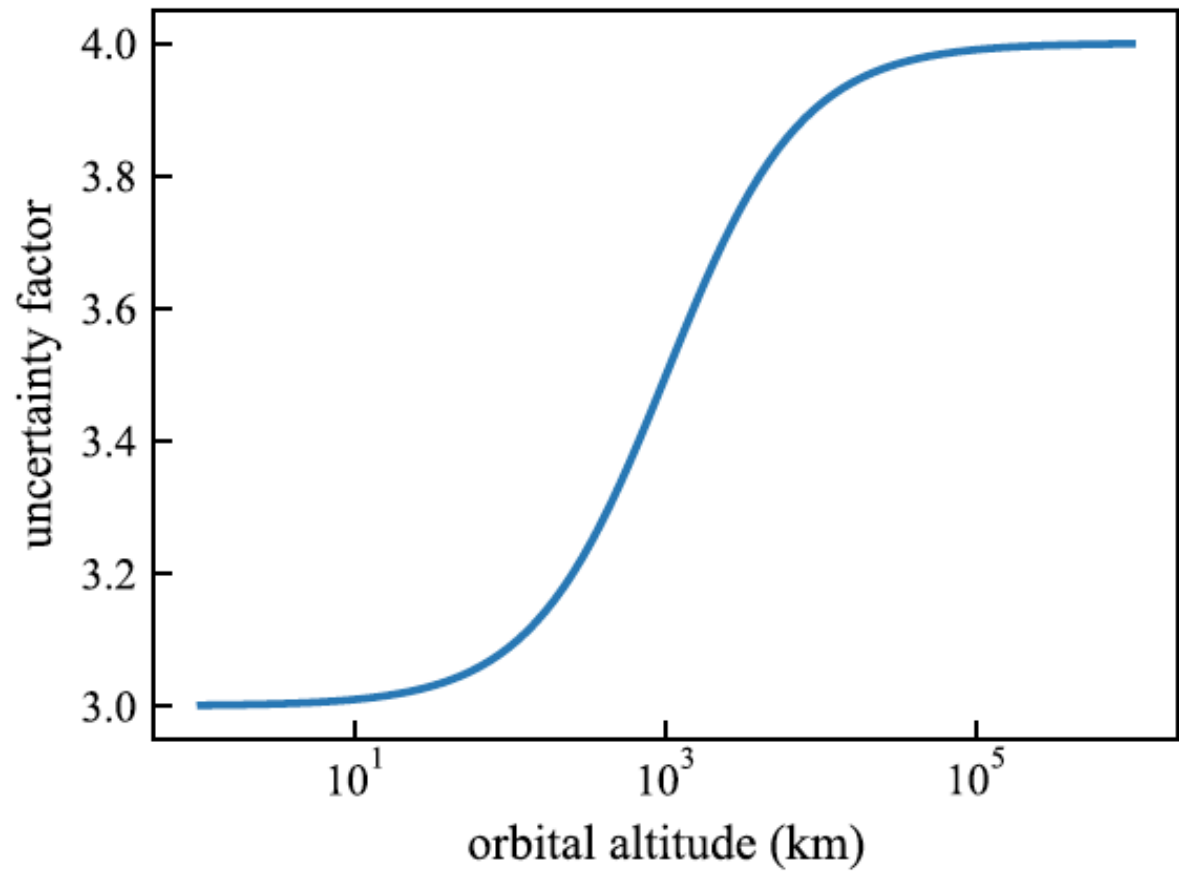
$$s^2(h, r_h) = \left(3 + \frac{h}{1000 \text{ km} + h}\right)^2 + \left(22 \ln \frac{r_h}{1 \text{ au}}\right)^2 \quad (5)$$

where h is distance of the spacecraft from Earth and r_h is its distance from the Sun. The probability distribution function is then

$$\text{PDF}(n) = \frac{1}{\sqrt{2\pi}\sigma} \frac{1}{n} \exp\left\{-\frac{(\ln n - \ln N)^2}{2\sigma^2}\right\} \quad (6)$$

$$\sigma = \frac{1}{2} \ln s \quad (7)$$

NASA MEO/A. Moorhead



NASA MEO/A. Moorhead

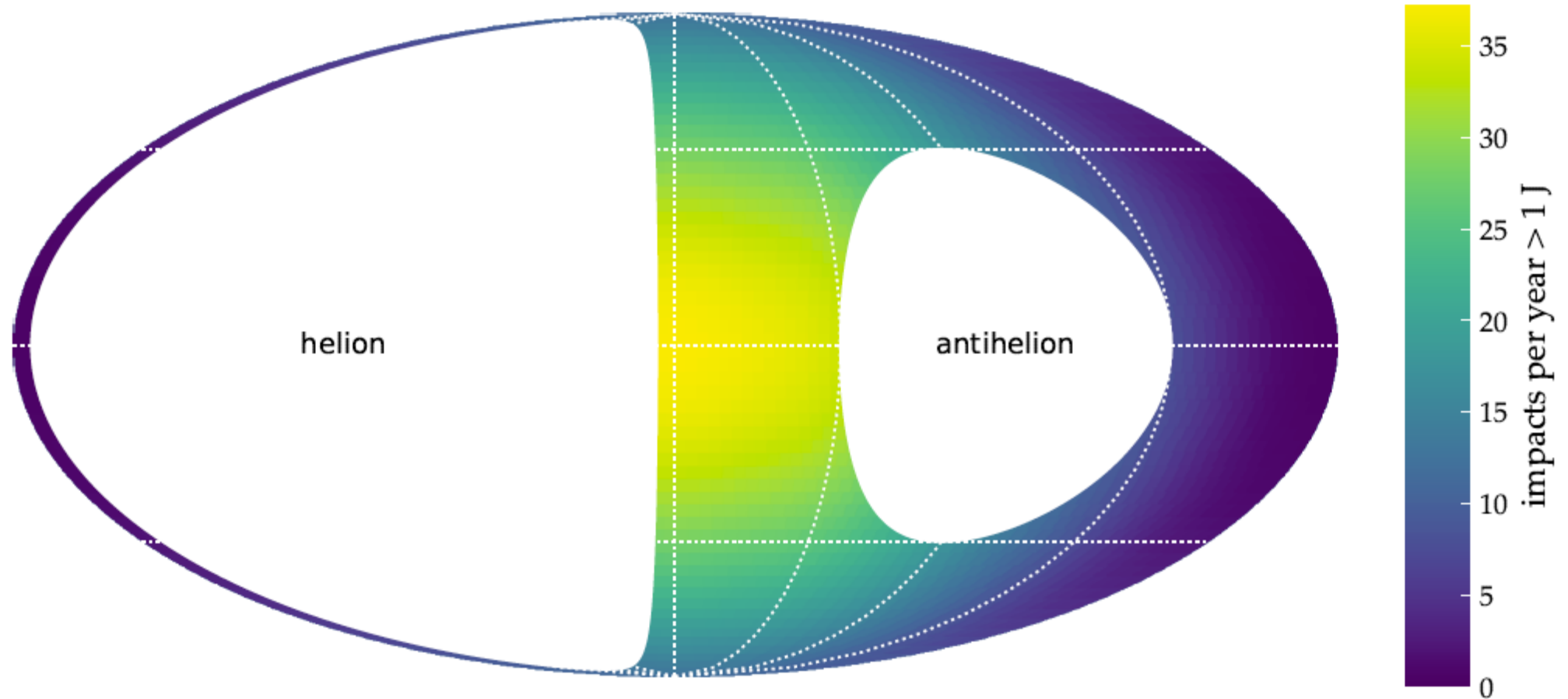
MEM application - JWST Micrometeoroid Avoidance Zone (MAZ)



NASA/GSFC

- JWST primary mirror is taking more impacts than expected. Only 1 “significant” hit so far
- MEM was used:
 - to establish probable energies of meteoroids producing detectable features on mirror
 - These energies were factored in the formulation of a hypervelocity test plan performed at the White Sands hypervelocity facility
 - to establish a Micrometeoroid Avoidance Zone (MAZ) for science observations in order to reduce number of impacts over vehicle lifetime
- The MAZ extends for 75° away from spacecraft direction of motion
 - Took effect for Cycle 2 science operations

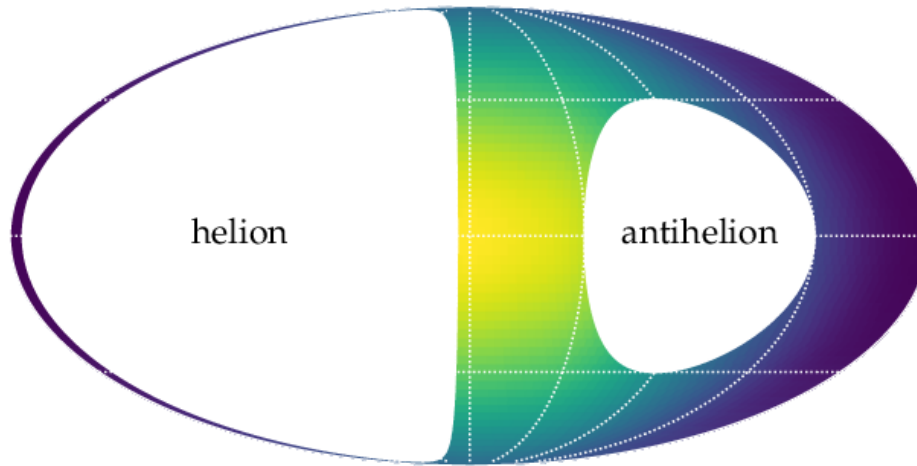
Spacecraft direction of motion is at center



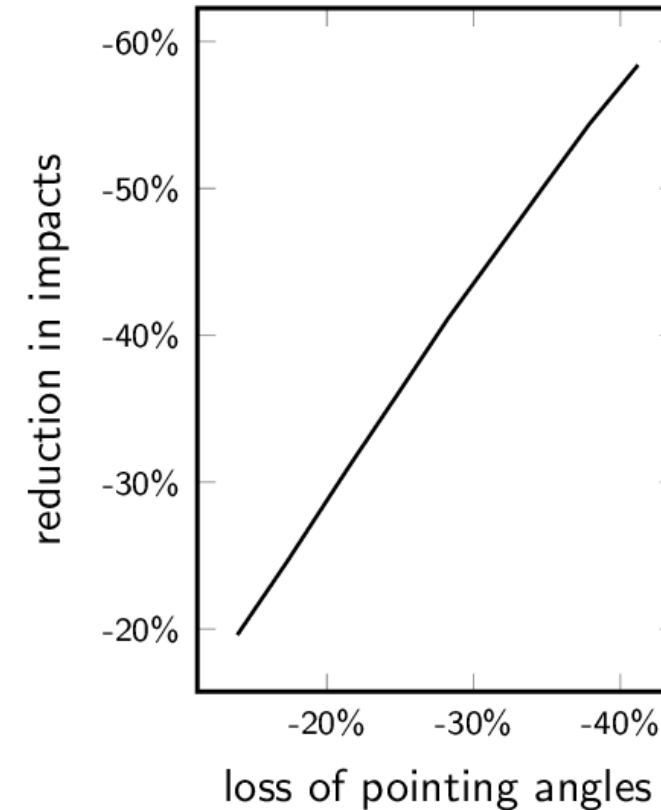
NASA MEO/A. Moorhead

Risk can be reduced by avoiding certain orientations.

Because the impact rate is higher when JWST points toward ram, the risk of future impacts can be reduced by minimizing the amount of time spent facing ram.



NASA MEO/A. Moorhead



Proposing Opportunities

- Opportunities and Policies
 - › Call for Proposals for Cycle 3
 - › Cycle 3 Guaranteed Time Observations Call for Proposals
- Cycle 3 Director's Discretionary (DD) Time Proposals
- ▼ General Science Policies
 - Guidelines for Proposals where JWST and HST Overlap in Capabilities
 - Observing Overheads and Time Accounting Policy
 - Duplicate Observations Policy
 - › Observation Duplication Checking
 - Science Parallel Observation Policies and Guidelines
 - The Single-Stream Proposal Process
 - **Micrometeoroid Avoidance Zone: Policies and Procedures**
 - Observing Program Modification Policy
 - Policies for the Telescope Time Review Board
 - How to Submit a Program Change Request (PCR)
 - Target of Opportunity Program

Home / JWST Opportunities and Policies / JWST General Science Policies / Micrometeoroid Avoidance Zone: Policies and Procedures

Micrometeoroid Avoidance Zone: Policies and Procedures

Micrometeoroid impacts on JWST optical components have the potential to degrade the image quality, leading to a reduction in the effective lifetime. NASA commissioned a Micrometeoroid Working Group (MmWG) to examine this issue and identify potential mitigations.

On this page

- [Context](#)
- [Documentation](#)
- [Proposal preparation](#)
- [Post-TAC procedures](#)
- [Protocols for scheduling in-cycle programs](#)

Context

The MmWG identified a Micrometeoroid Avoidance Zone (MAZ), a cone of diameter 75 degrees, centred on JWST's orbital direction of motion (the ram direction). This direction is expected to see the largest flux of higher-velocity micrometeoroids. The MmWG recommended minimizing observations within the MAZ, setting an implementation goal of <15% (by time) of the Cycle 2 program, with <10% as an aspirational goal. Meeting this goal is estimated to reduce major impacts by a factor of 2, with a corresponding reduction in the growth of the wavefront error.

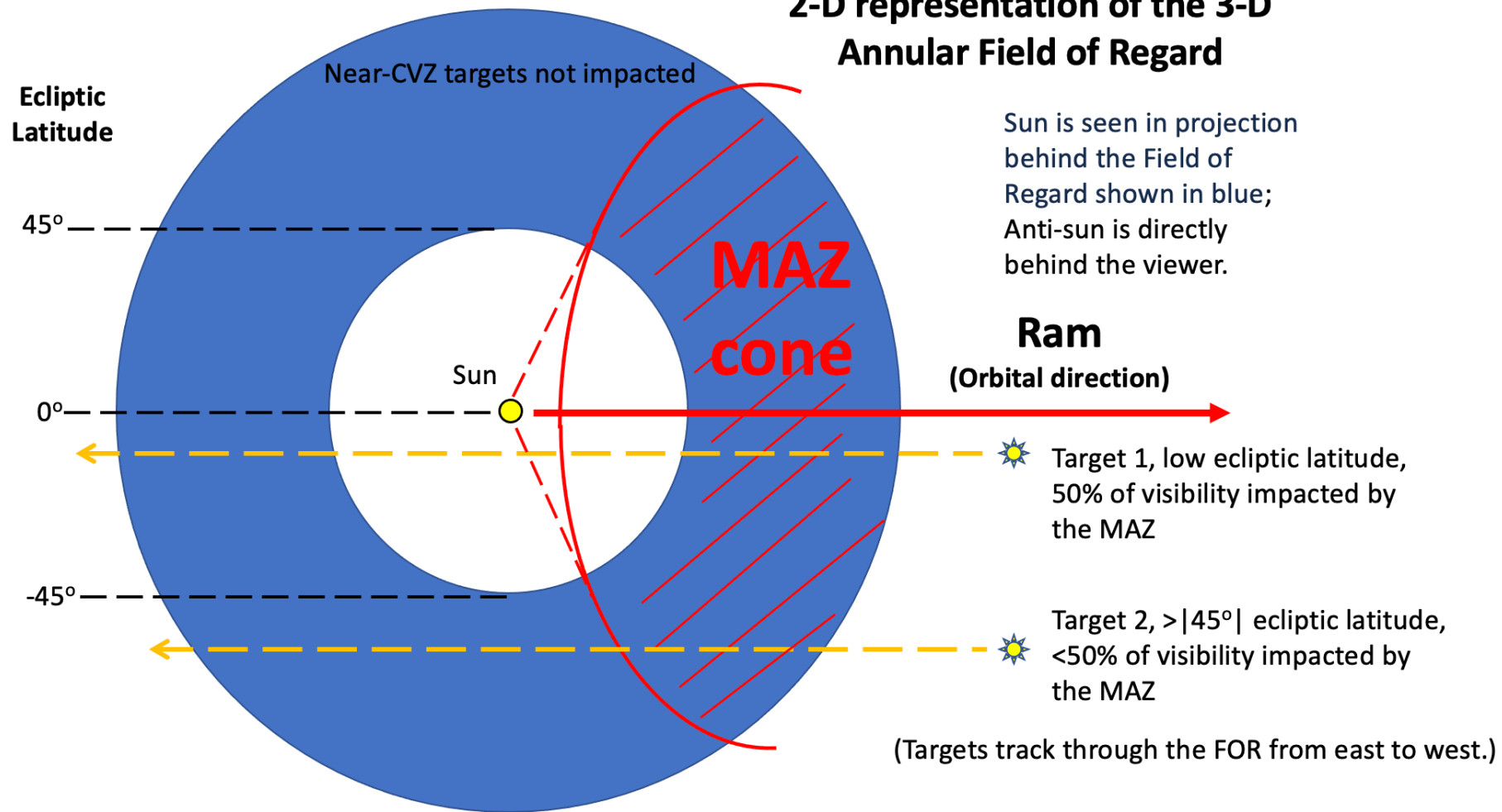
The MmWG also recommended that JWST should be scheduled to avoid pointing in the direction of major meteor showers, notably the Geminids and Quadrantids. These concerns will likely affect scheduling on 2-4 days during the year.

This article describes the steps being taken to help achieve the MAZ goals in Cycle 2.

Documentation

STScI has developed JDoc material that provide a description of the issue (see [JWST Micrometeoroid Avoidance Zone \(MAZ\)](#)) and a guide for proposers on how to reduce the MAZ exposure of their observations (see [APT Micrometeoroid Avoidance](#)).

2-D representation of the 3-D Annular Field of Regard



NASA/JWST [website](https://www.nasa.gov/jwst)

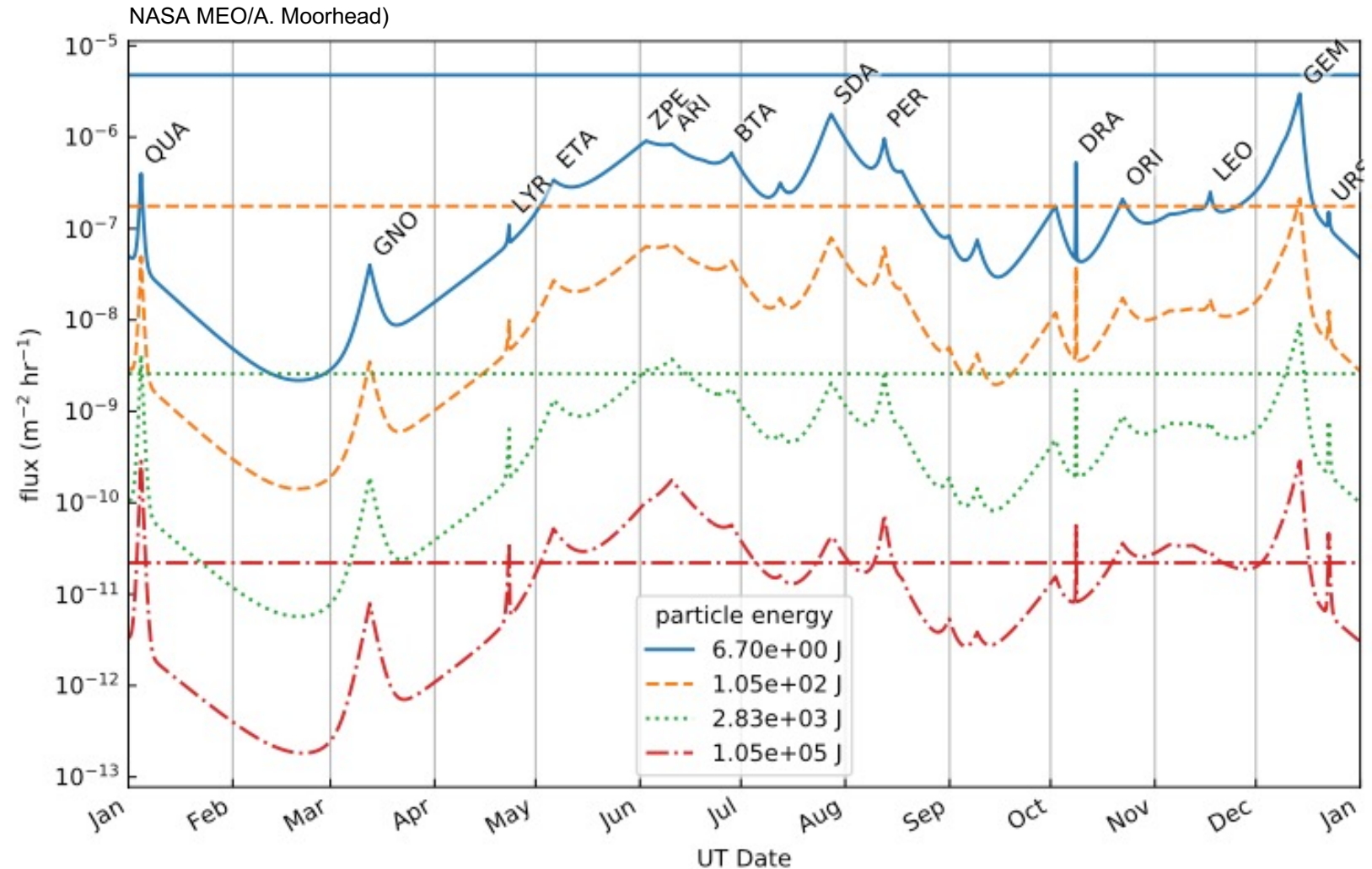
Meteor shower forecasting



- Meteor showers are a small but varying fraction of the environment
- Shower meteoroids constitute 1-5% of the risk for long term missions but this risk varies with time
- Problem is deterministic, rather than statistical – meteor streams move toward/away from Earth because of Jupiter/Saturn perturbations, etc.
 - Past provides model calibration points but does not establish bounds
- We generate annual meteor shower forecasts for LEO, the Moon, and specific spacecraft (Chandra, HST, JWST)
 - Forecasts are generated for each ISS EVA
- Meteor shower risk is mitigated through operational means (reorientation, shutting down instruments, etc.)

When we look at fluxes instead of rates, things are very different:

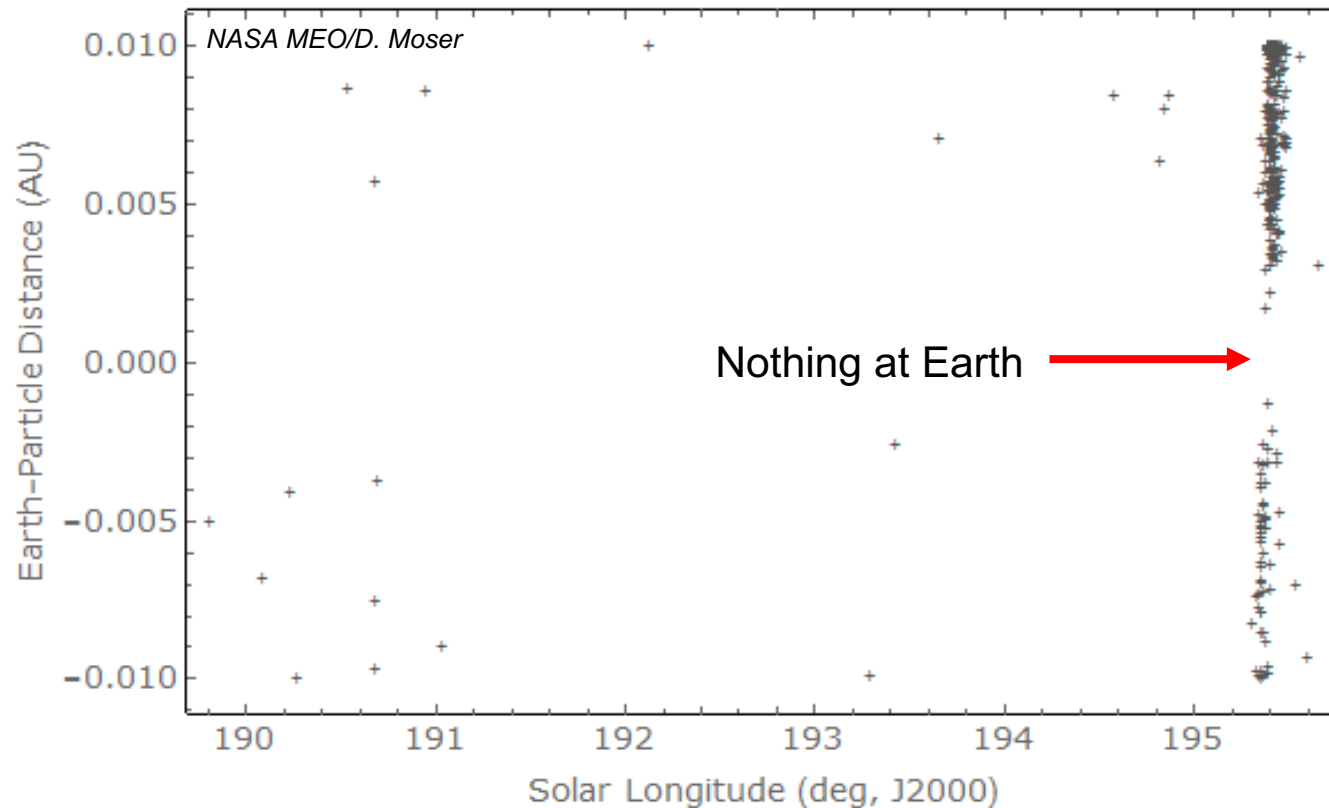
- At the energy capable of penetrating EVA suits (6.7 J), no shower exceeds the sporadic flux
- Only at higher energies (ISS wall penetrations) do a few showers exceed sporadic levels



Why?

- The sporadic background is richer in the more numerous mm and smaller particles (bulk of spacecraft risk); showers become important in the cm sizes, where the number and flux of meteoroids is much lower
- Showers with slower meteors have a higher flux than expected from the rates because we only see the high end of the size distribution (slow meteors have to be larger to be detected by optical instruments/radar)
- For more details, see Moorhead et al., “Meteor shower forecasting in near-Earth space”, Journal of Spacecraft and Rockets, Vol. 56, p. 1531-1545 (2019)

2018 Draconids

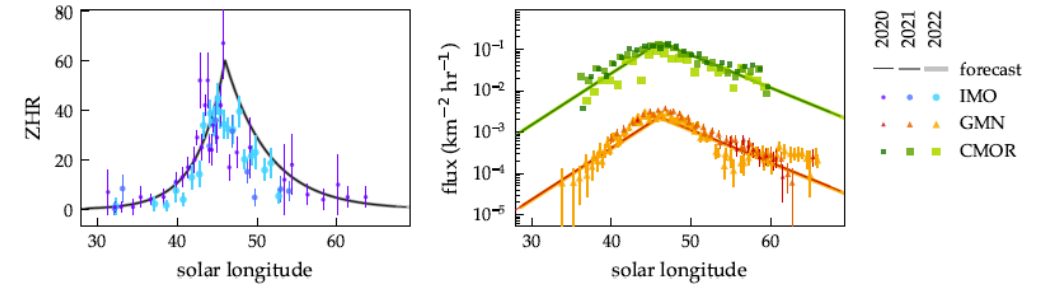


- We have known how to do meteor shower forecasting for over a century
 - Just had to wait for computers to get powerful enough to handle complex orbit propagation over hundreds (sometimes thousands) of years for millions of particles
 - This did not occur until the mid-1990's
- Unlike the diffuse sporadic background, dense meteor streams can be narrow enough to affect one location (Earth, L_1 , L_2) without impacting the others

- We compare our forecasts to observations of meteor showers and use this information to improve future forecasts
- Updates to the annual forecasts are issued as needed

2 eta Aquariids (ETA)

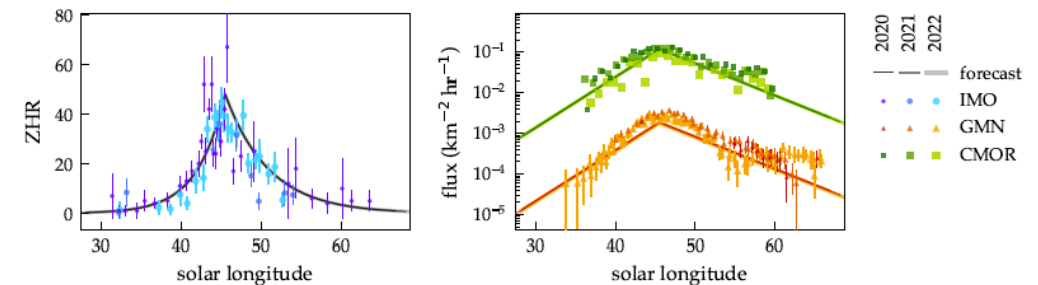
2.1 Nominal forecast



2.2 Adjusted profile

We can obtain a better fit to the data if we make the following changes:

- -0.5 day shift in peak solar longitude
- 20% reduction in peak ZHR

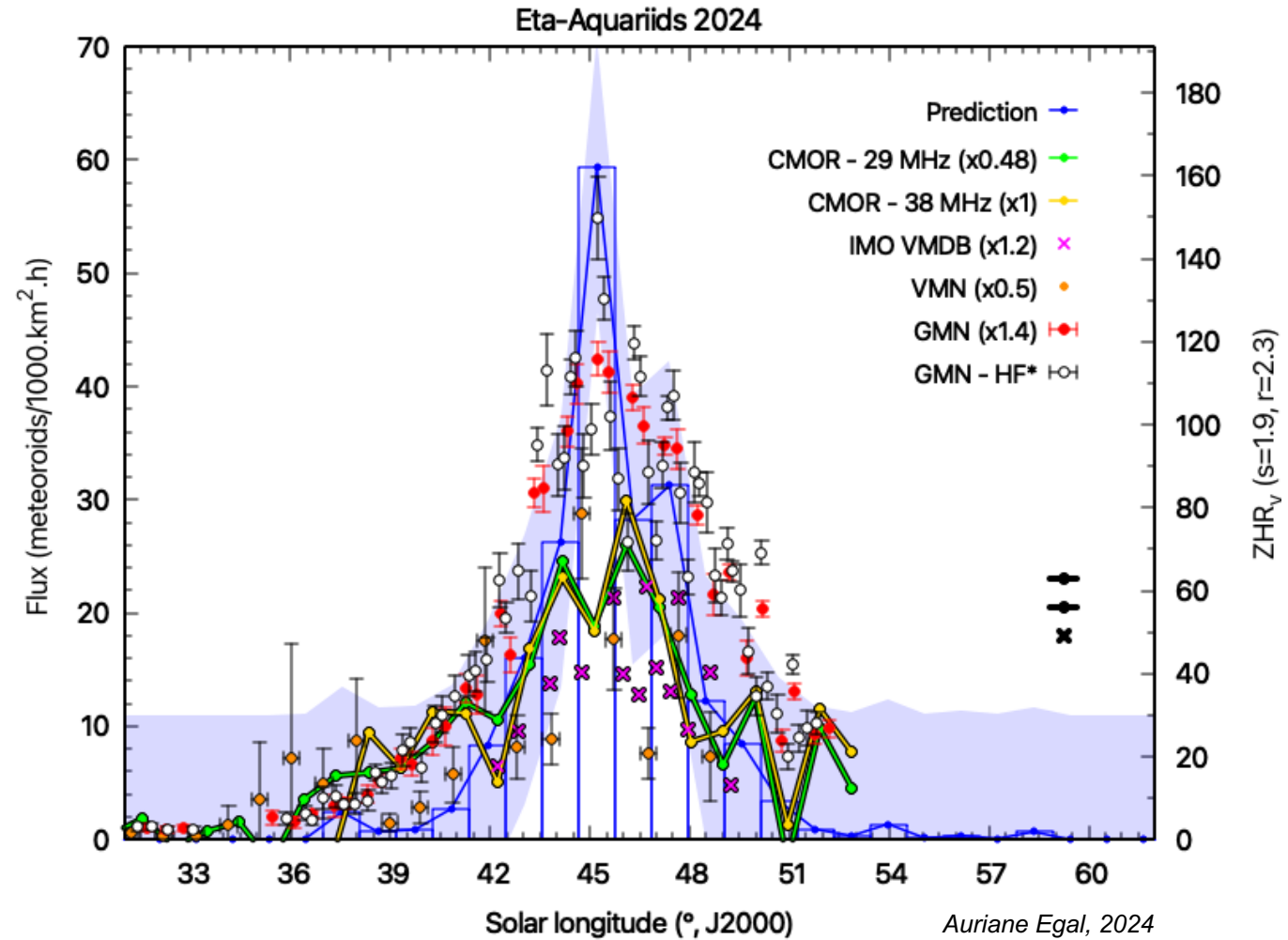


NASA MEO/A. Moorhead

2024 eta Aquariid outburst



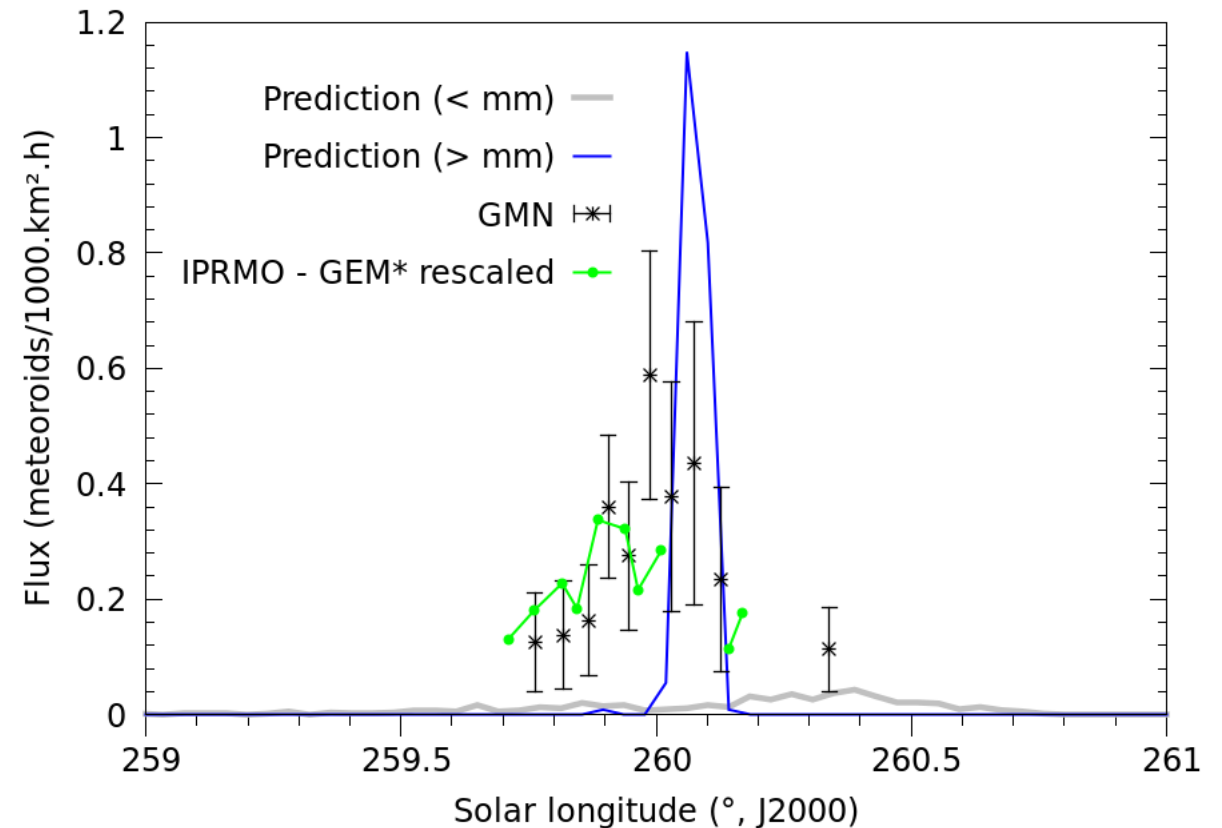
- Outburst forecast for May 5, 14 UTC (Solar Longitude 45.2)
- Peak ZHR of 130-160
- ~30% increase in meteoroid flux above sporadic levels



New shower – lambda Sculptorids



- Perturbations moved debris shed by Comet 46P/Wirtanen back in 1974 very close to Earth's orbit
- In agreement with predictions, low intensity shower observed to peak near 17 UTC on December 12 (Solar Longitude 260)

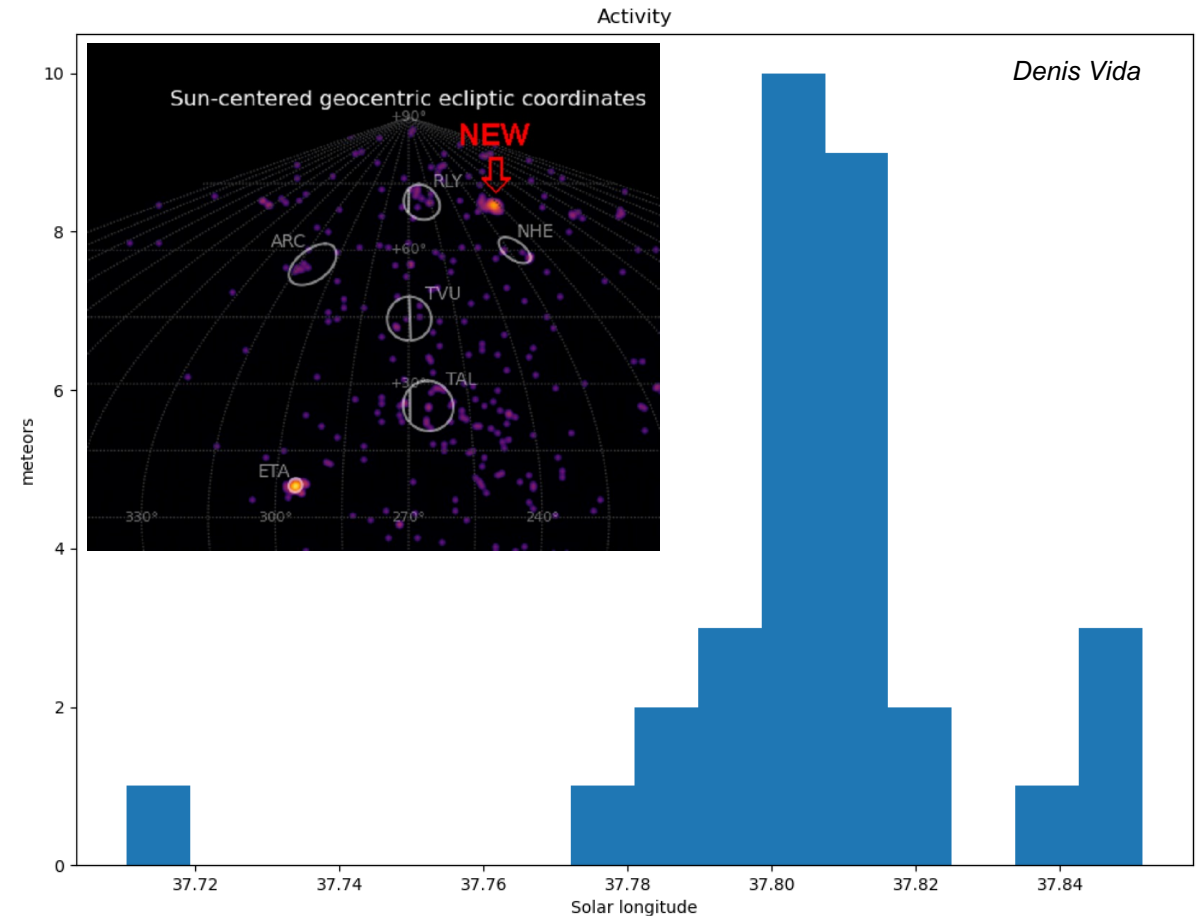


Auriane Egal, 2024

Outburst of iota Herculids



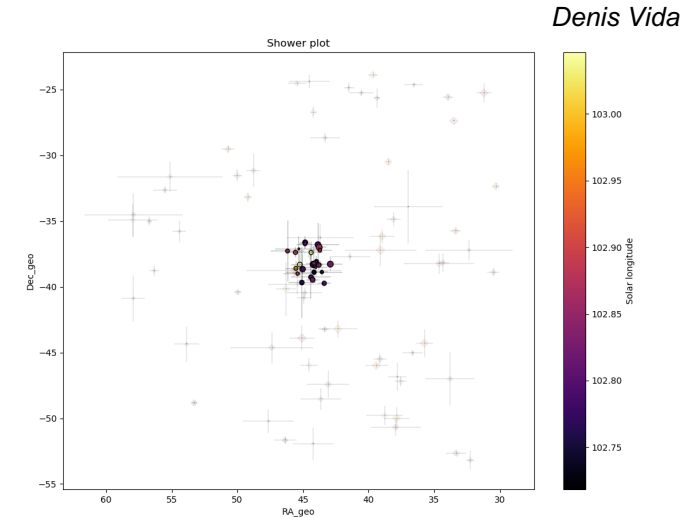
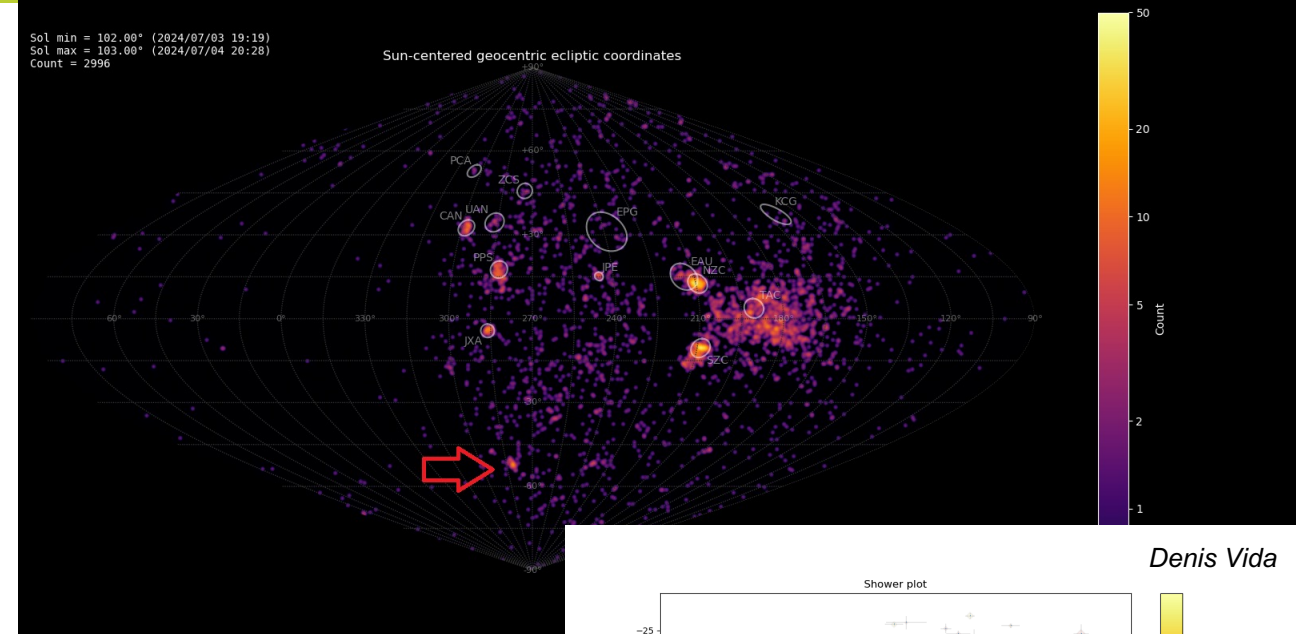
- Surprise outburst of the very weak iota Herculid meteor shower on April 27 between 20-23 UTC
- Product of debris from an unknown/uncorrelated Halley-type comet
- Orbits suggest another outburst is not likely until sometime in the 2030's



New meteor shower in Fornax



- Detected by GMN and CAMS.
- Low intensity shower peaking July 3-4 – approximately 50 meteor orbits.
- Appears to be caused by debris from a highly inclined (92.7°) long period comet.
- Meteor speed is about 51.7km s^{-1} .



- Meteoroid densities are important components of damage equations.
- Very few measurements – until recently equipment resolution was not adequate to measure small meteor decelerations.
 - Western’s CAMO observatory provides meteor trajectories at 1 meter resolution (50-100 times better than other instruments).
- Have about 80 sporadic (“background”) meteor densities. Working on obtaining more + determining values for major showers.

Quantifying the Bulk Density of Southern Delta Aquariid Meteoroids: Insights from the Canadian Automated Meteor Observatory

Arazi Pinhas,^{1*} Zbyszek Krzeminski,^{2,3} Denis Vida^{2,3} and Peter Brown^{2,3}

¹Columbus Technologies & Services Inc., Jacobs Space Exploration Group, NASA Marshall Space Flight Center, Huntsville, Alabama 35812, USA

²Department of Physics and Astronomy, University of Western Ontario, London, Ontario, N6A 3K7, Canada

³Western Institute for Earth and Space Exploration, University of Western Ontario, London, Ontario, N6A 5B7, Canada

Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT

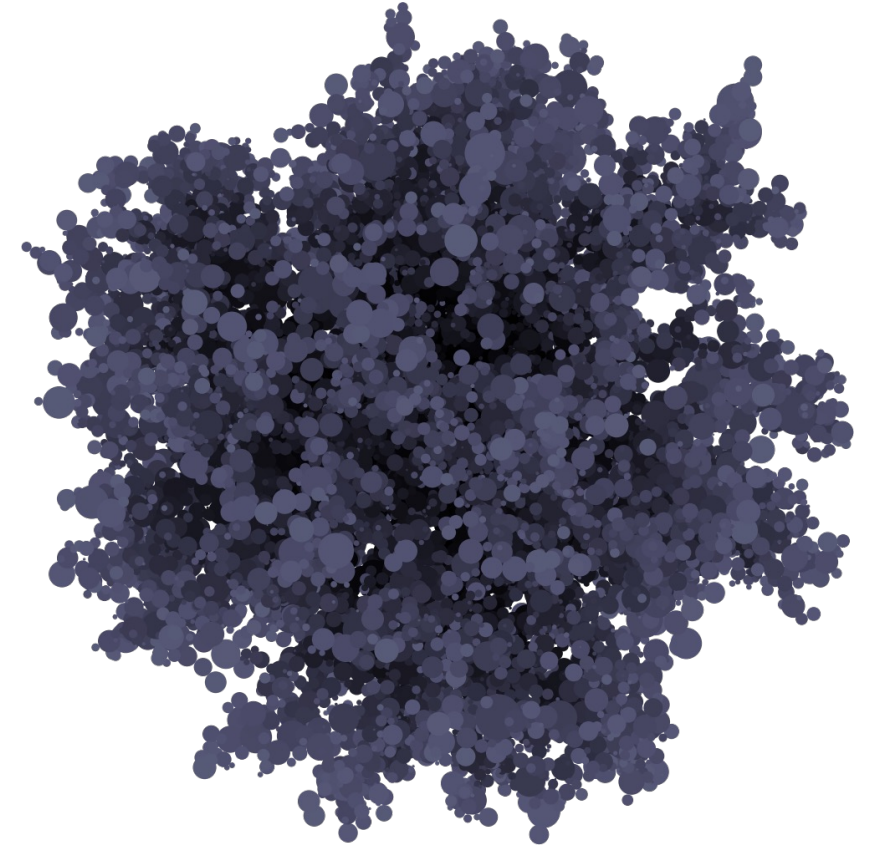
Physical properties of ten millimeter-sized meteoroids from the Southern Delta Aquariids (SDA) shower are derived using optical observations from the Canadian Automated Meteor Observatory between 2020 and 2023. The meteors are found to ablate in two distinct erosion stages, the second stage showing a single, bright leading fragment. Our modelling interprets these observations as evidence for equal masses of compact grains embedded in a porous, low density matrix. The average bulk density of SDA meteors is found to be $1,420 \pm 100 \text{ kg m}^{-3}$, with the compact component having a density of $2,310 \pm 160 \text{ kg m}^{-3}$ and the porous component a density of $700 \pm 110 \text{ kg m}^{-3}$. The high bulk density of SDA meteors is comparable to densities found for the Quadrantid and Geminid showers, both of which also have low perihelion distances. This suggests that thermal desorption may play a significant role in the processing of meteoroids.

Key words: meteors – meteoroids – comets: general – asteroids: general

Myth – Meteoroids are rocks



- The popular concept of meteoroids is that they are tiny rocks
- Most meteoroids (Nesvorny et al., 2011) are ejected from comets, which are “snowy dirt balls.” Asteroidal material accounts for a small fraction of meteoroids of hazardous size
- Rosetta (Langevin et al, 2016) and high precision meteor observations (Vida et al., 2022) indicate meteoroids are fragile, porous conglomerates with weak structural strengths (as low as kilopascals) and bulk densities less than that of water ice



NASA MEO/A. Moorhead

Skyfalls



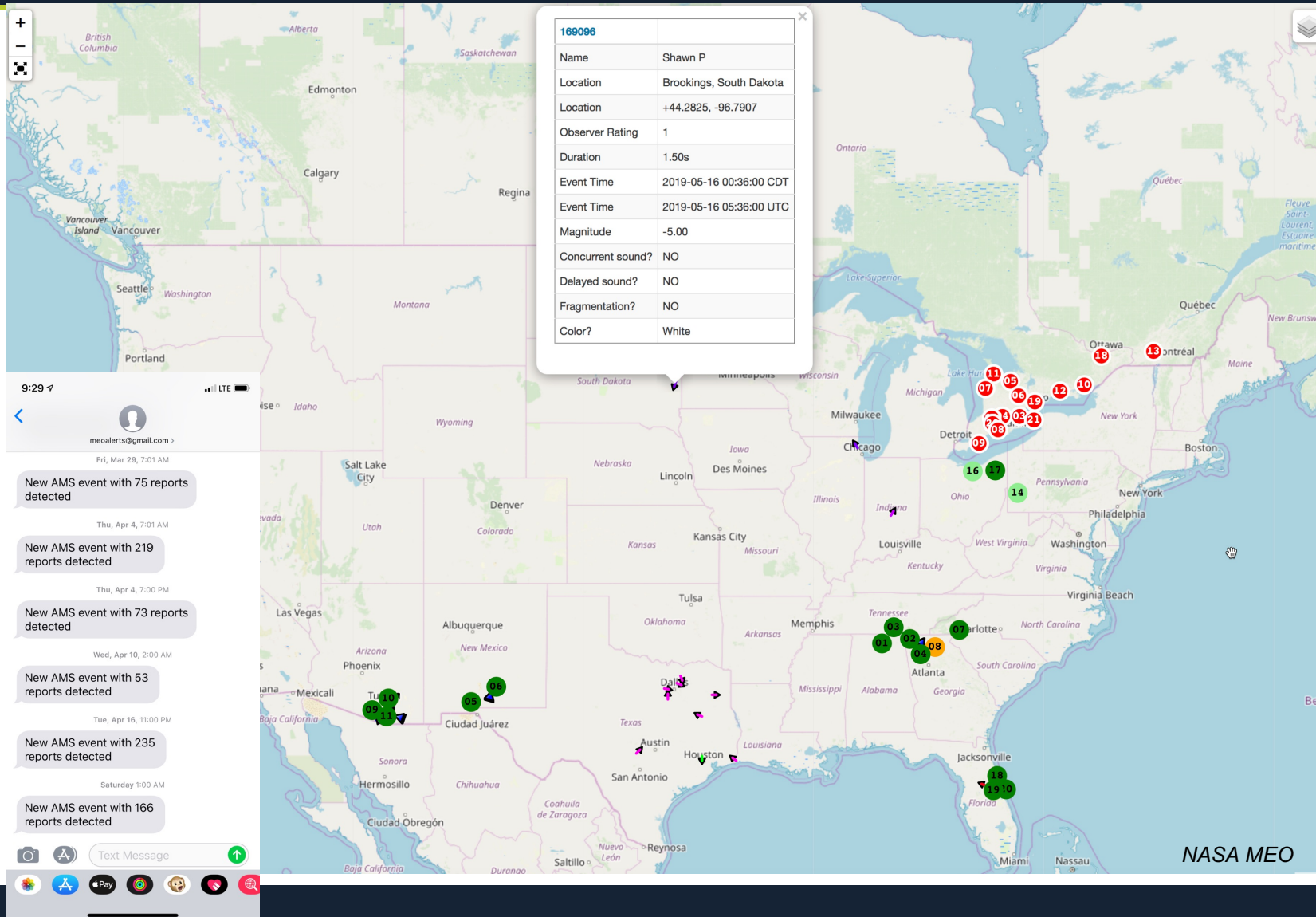
- The MEO has to prepare a quick response whenever there are "large" numbers of reports about a bright object in the night sky.
- We have software tools ("Chicken Little") that enable us to do a rapid analysis of the eyewitness accounts, establishing a crude trajectory that permits the searching of data from cameras, weather radar, etc. in the area.
- The summary is sent to HQ PAO within a few hours (typically by noon CST) for events that happened the previous night.



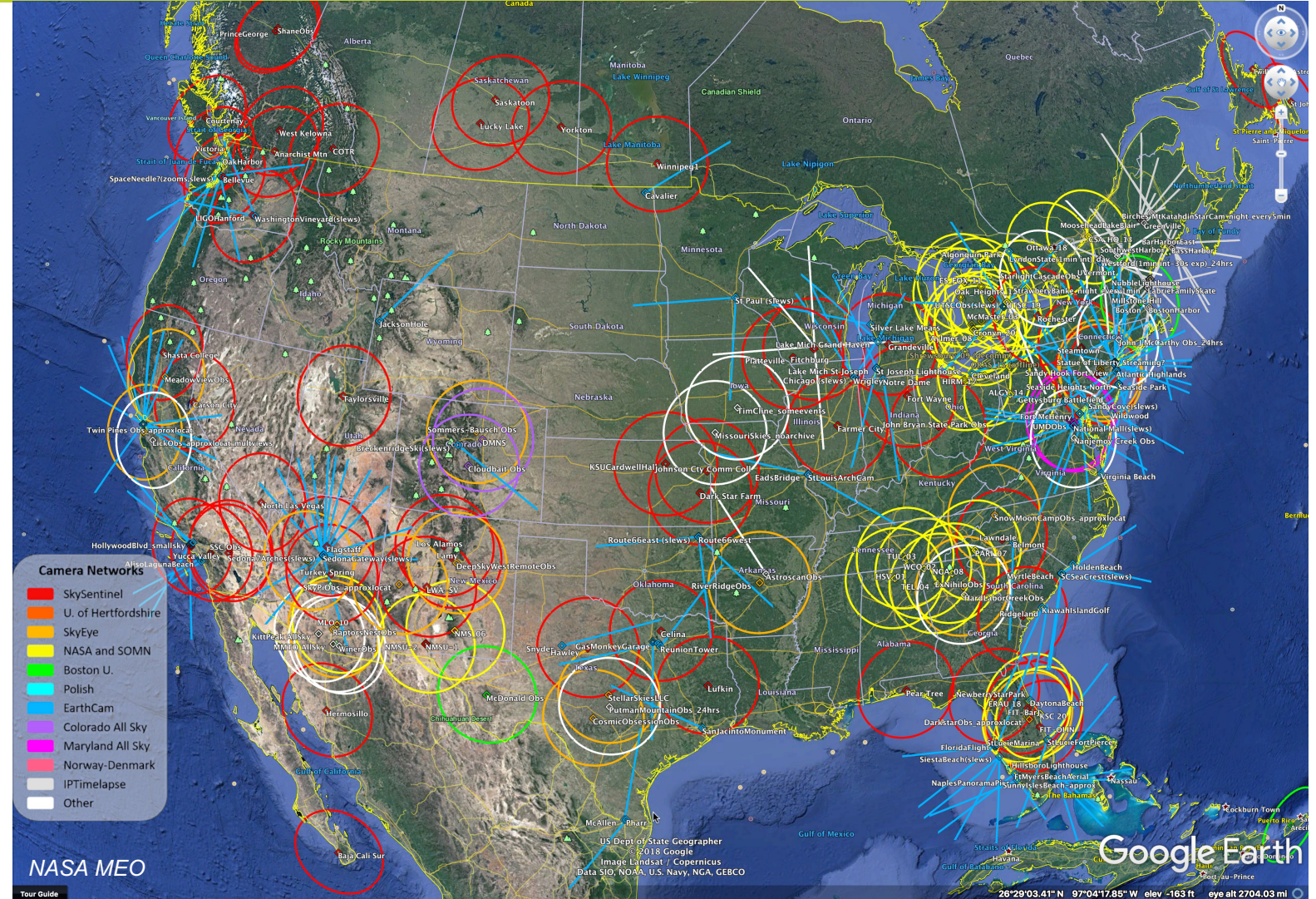
NASA MEO

The “Big Board”

- Updates regularly with eyewitness reports on the Internet
- Also includes NASA meteor camera status
- Text/email alerts automatically sent out whenever there are “significant” (50) numbers for an event



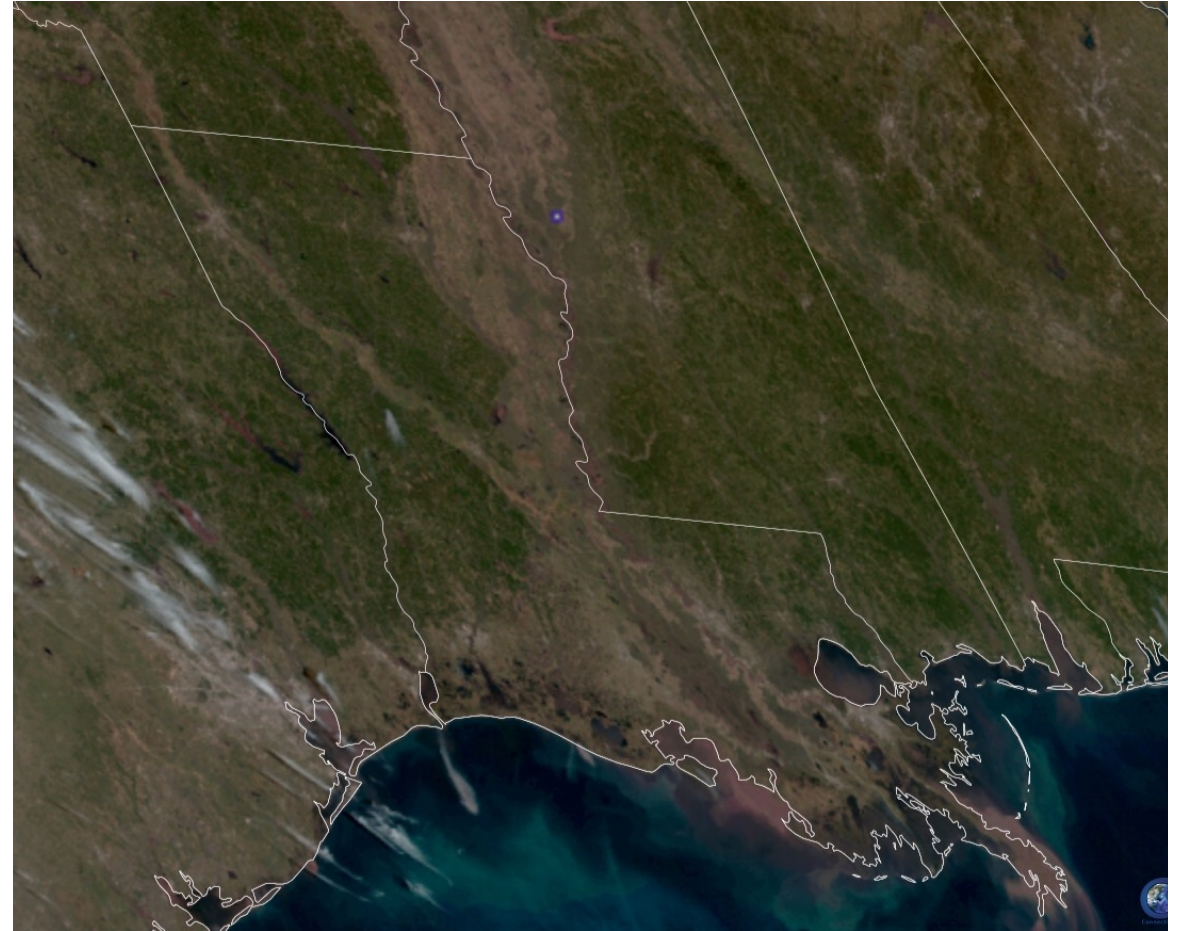
We have an
“database” of
internet
accessible
cameras that we
use to assist in
our analyses



Fireball Trajectories from the Geostationary Lightning Mapper



- Meteor cameras not on during the day
 - Bright sun damages chips
- The Geostationary Lightning Mappers (GLM) on GOES 16 and 18 do detect bright fireballs
- Can this data be used to construct fireball trajectories, especially for daytime events?



NOAA/NASA

Citations and permissions



- Graphics attributed to Auriane Egal and Denis Vida were produced under the joint NASA/University of Western Ontario cooperative agreement 80NSSC24M0060; used with permission of authors.