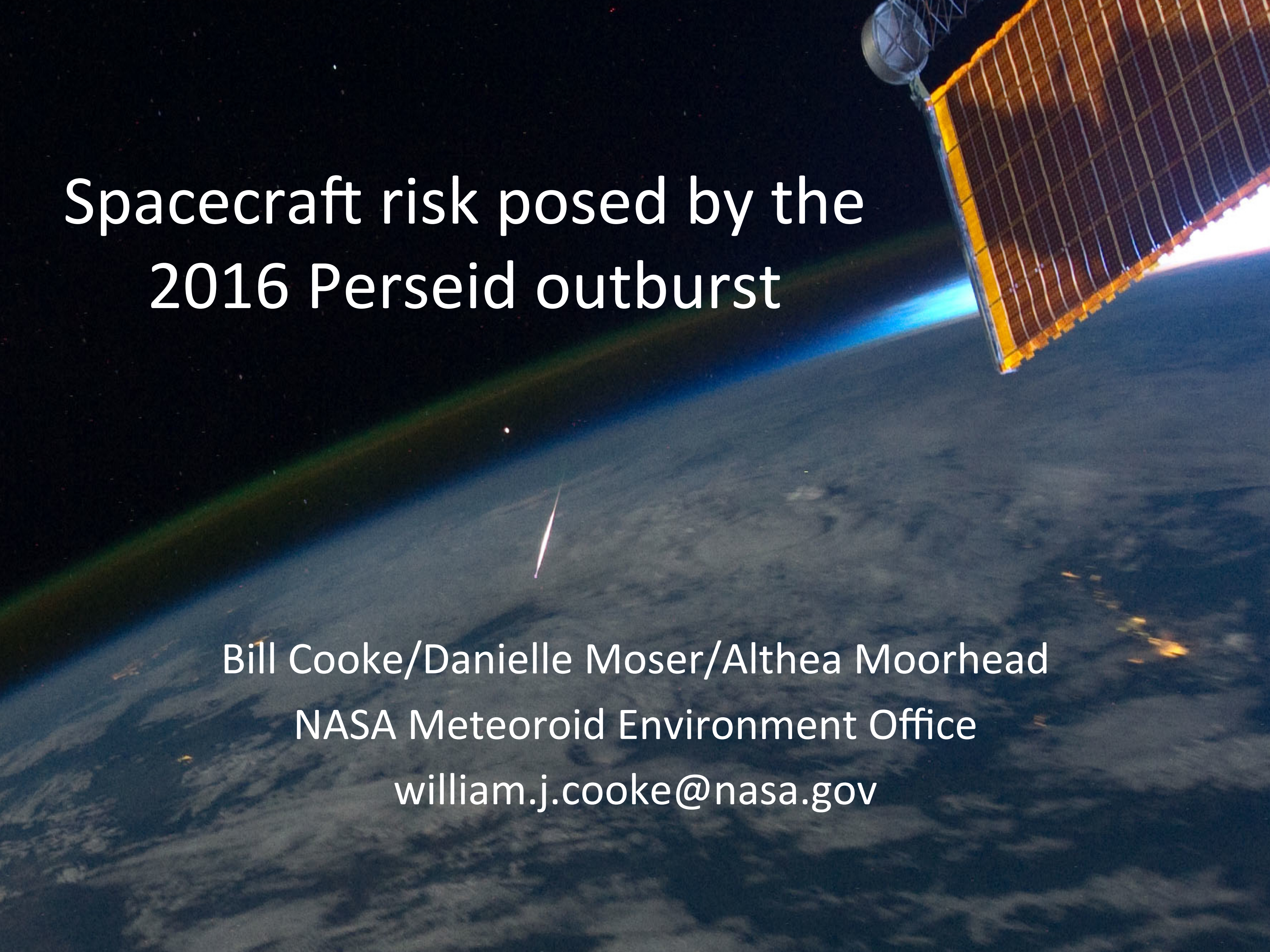

# Spacecraft risk posed by the 2016 Perseid outburst

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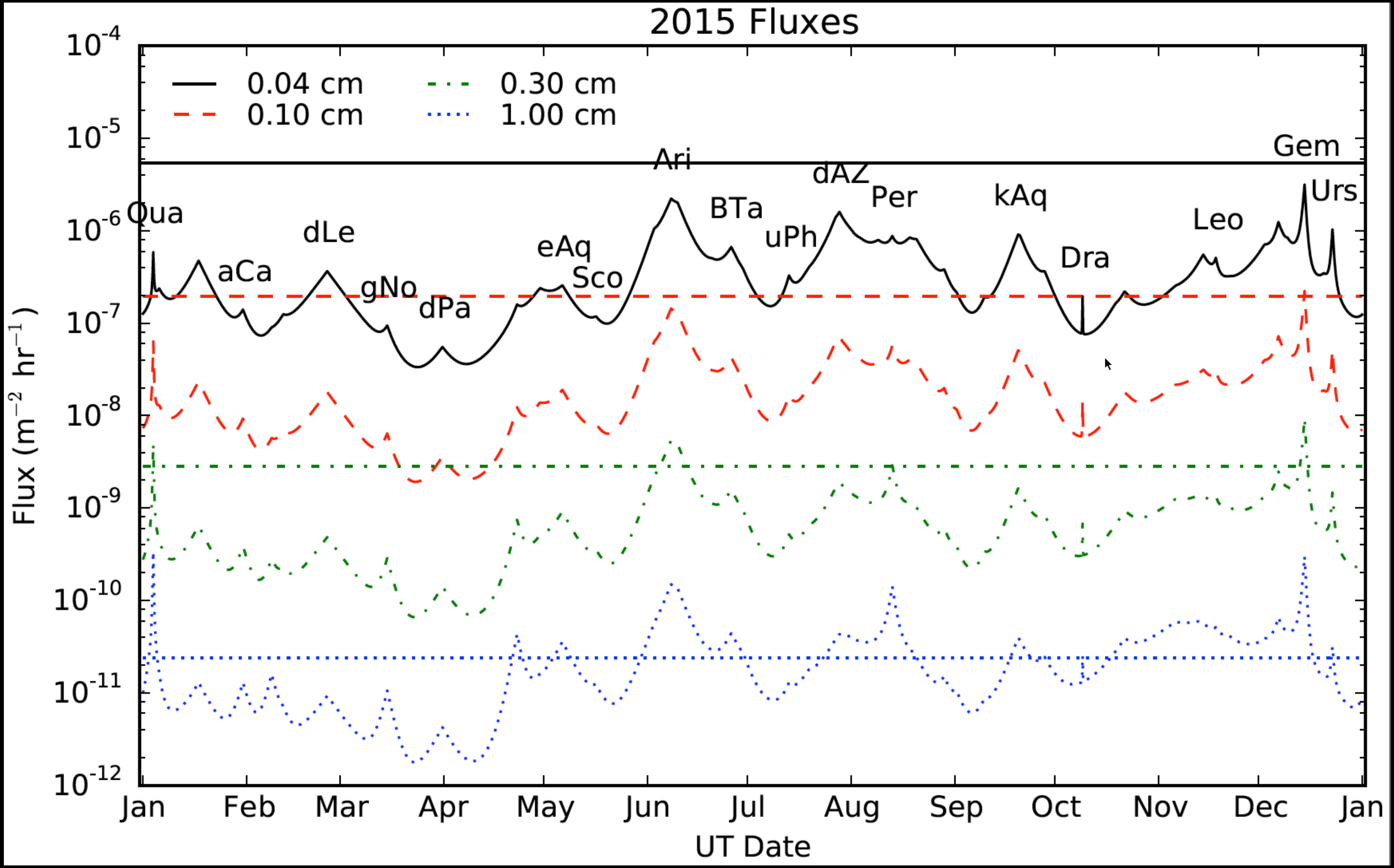
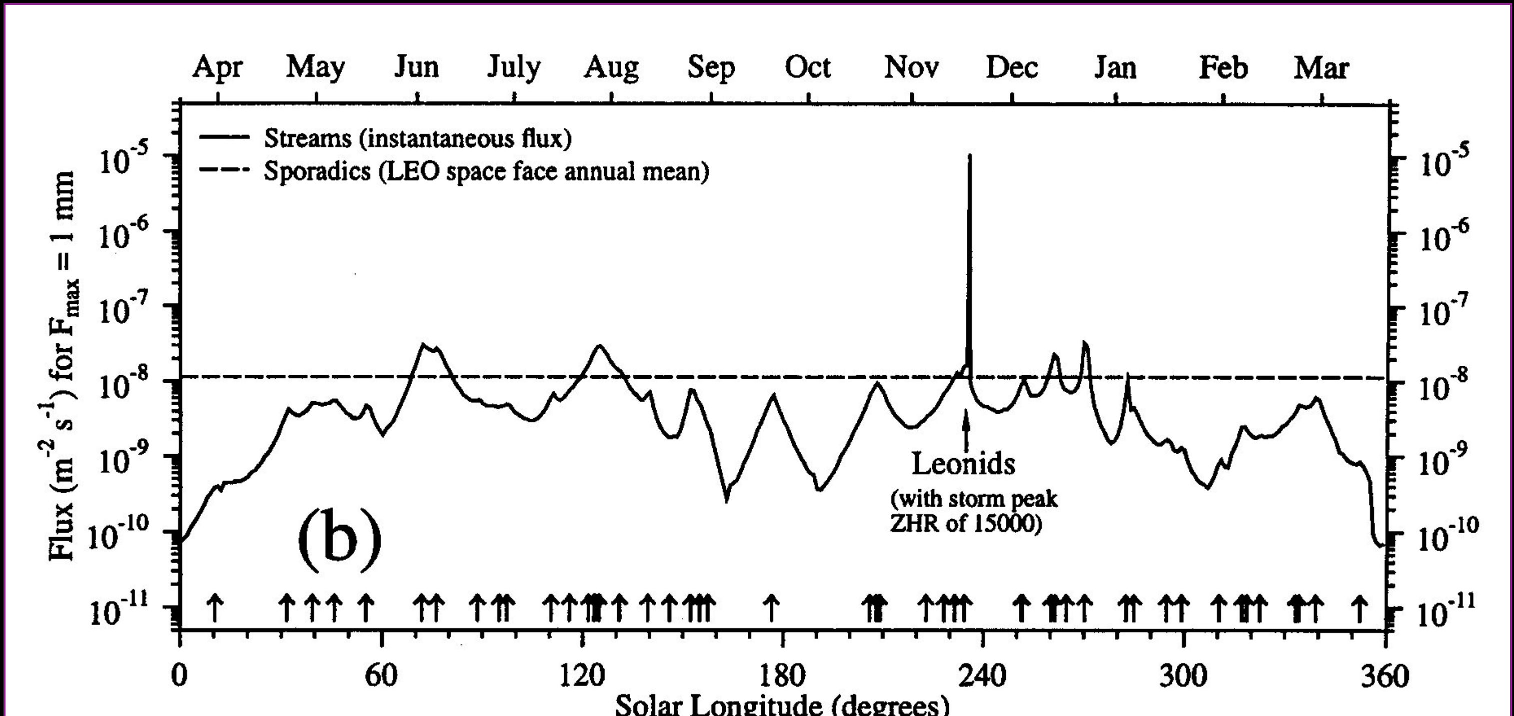
# Showers vs. Sporadics




At sub-mm & mm sizes, the average flux of meteor showers is an order of magnitude below the sporadic (background) flux

# Storms vs. Sporadics




McBride & McDonnell, 1999

- Instantaneous storm flux required to penetrate a surface can exceed the background by several orders of magnitude
- Penetrating fluence can range anywhere from a few days to a year's equivalent exposure to background meteors

# Notes on meteoroid risk

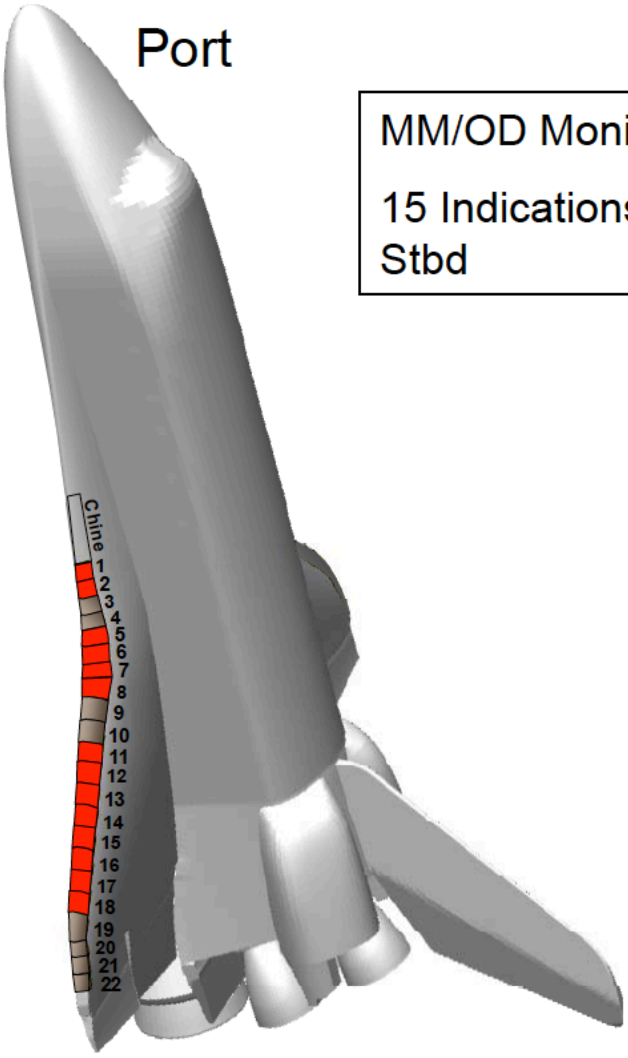
- Sporadic meteoroid background is directional (not isotropic) and accounts for 90% of the meteoroid risk to a typical spacecraft
- Meteor showers get all the press, but account for only ~10% of spacecraft risk
  – Bias towards assigning meteoroid cause to anomalies during meteor showers
- Design to sporadic background, mitigate outbursts/ storms by operational means
- Gun tests/damage equations focus on physical damage – hard to assess other anomaly causes, such as meteoroid generated plasma

# Could it be a meteoroid hit?

- Are the anomaly characteristics consistent with a particle impact?
  - Sudden change in attitude most common
- Was there a meteor outburst or storm at the time of the anomaly?
  - If yes, was the shower radiant visible from the spacecraft?
  - If yes, did the affected surface "see" the shower radiant?
  - If yes, shower impact possible
- Compare meteoroid (sporadic + shower) flux to orbital debris flux at spacecraft location to establish likelihood.
  - If affected surface is sun-fixed, must use a directional meteoroid model to compute flux

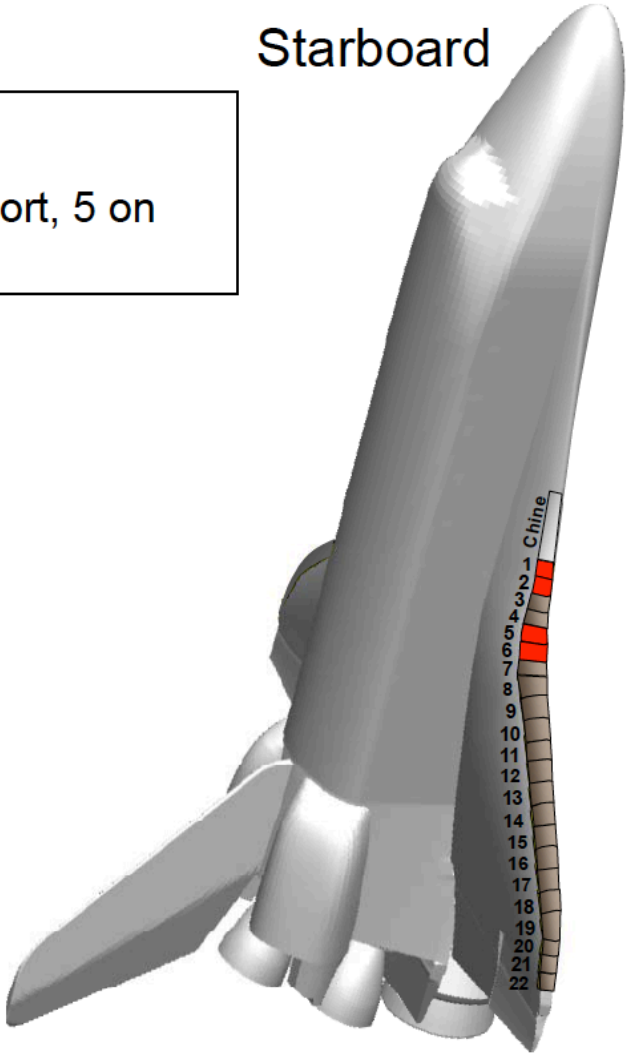
# Affected Panels






MM/OD Monitoring

15 Indications: 10 on Port, 5 on Stbd



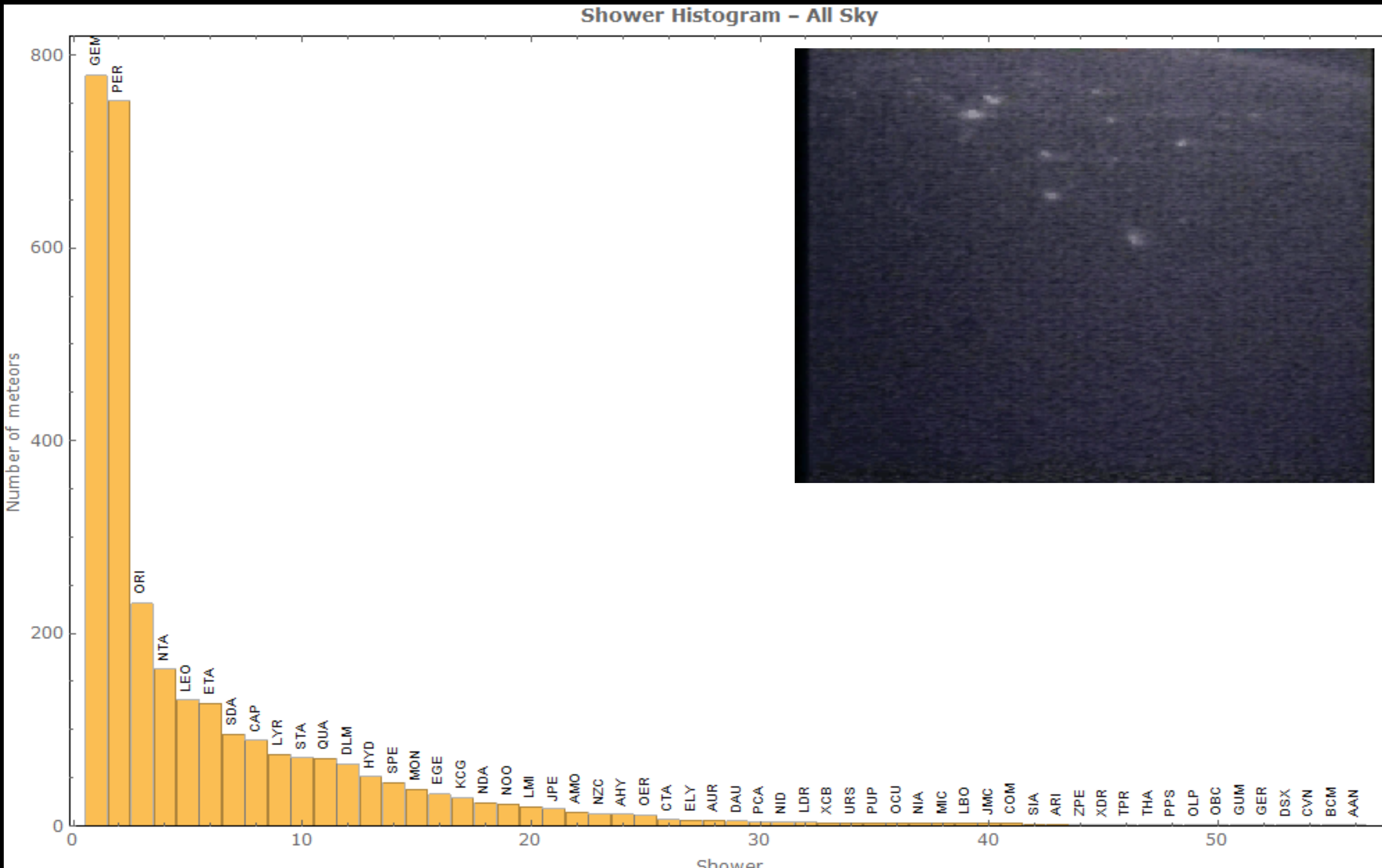
| Launch Time | MET | GMT | Possible Perseid? | Possible SDA? |
|---|---|---|---|---|
| 8/8/07 22:36 | 02 08:49:14 | 8/11/07 7:25 | Y | Y |
| | 02 06:17:53 | 8/11/07 4:54 | N | N |
| | 02 03:19:10 | 8/11/07 1:55 | N | N |
| | 02 21:46:13 | 8/11/07 20:22 | Y | N |
| | 02 22:51:46 | 8/11/07 21:28 | N | Y |
| | | | | |
| | 00 21:51:50 | 8/9/07 20:28 | Y | Y |
| | 00 20:46:20 | 8/9/07 19:22 | N | Y |
| | 00 20:32:48 | 8/9/07 19:09 | Y | Y |
| | 00 21:09:00 | 8/9/07 19:45 | Y | N |
| | 00 22:25:31 | 8/9/07 21:02 | N | N |
| | | | | |
| | 01 16:37:58 | 8/10/07 15:14 | N | N |
| | 01 12:03:15 | 8/10/07 10:39 | N | N |
| | 01 10:27:42 | 8/10/07 9:04 | N | N |
| | 01 15:53:58 | 8/10/07 14:30 | Y | Y |
| | 01 16:45:12 | 8/10/07 15:21 | N | N |

# Perseid Summary

- Parent comet: 109P/Swift-Tuttle
- Peak: Max. around Aug 11-13
- Activity range: Jul 17 – Aug 24
- Speed: 59 km/s (2.5-3x average sporadic speed)
- Radiant: $\alpha = 48°$, $\delta = +58°$ at peak
- Typical ZHR: 100/hr
- Recent major displays: 1991-1995, 2004, 2009


Perseid fireball recorded Aug 12, 2012

# Rich in bright meteors

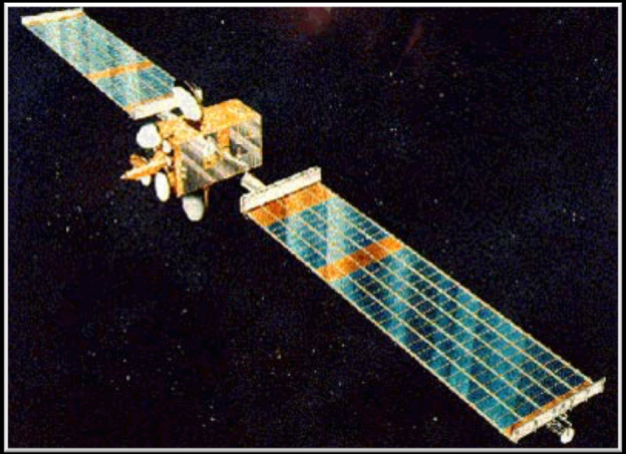


# The 1993 Perseids

- The Perseid parent, Comet Swift-Tuttle, reached perihelion in late 1992. High Perseid rates were also seen near the last perihelion passage of the comet, in the 1860’s
- Many astronomers postulated a dense concentration of dust near the comet’s orbit
- Perseids had never been observed to reach storm levels, but historical record showed outbursts of a few hundred per hour

- STS-51 launch, slated for late July delayed until after Perseid peak (August 12)
  - NASA unable to predict shower intensity
  - Head of astronaut office decided to delay launch
- Perseid outburst with ZHR of ~360 occurred, peaking at 03:30 UT on August 12.
- Cosmonauts aboard Mir space station reported hearing "pings" on outside of craft, and retreated to Soyuz (Science News, 1993)

# Spacecraft struck by Perseids



## Olympus

ESA communication satellite

Struck by a Perseid near the time of the shower peak in August 1993

Sent tumbling, fuel exhausted, end of mission

## Landsat-5

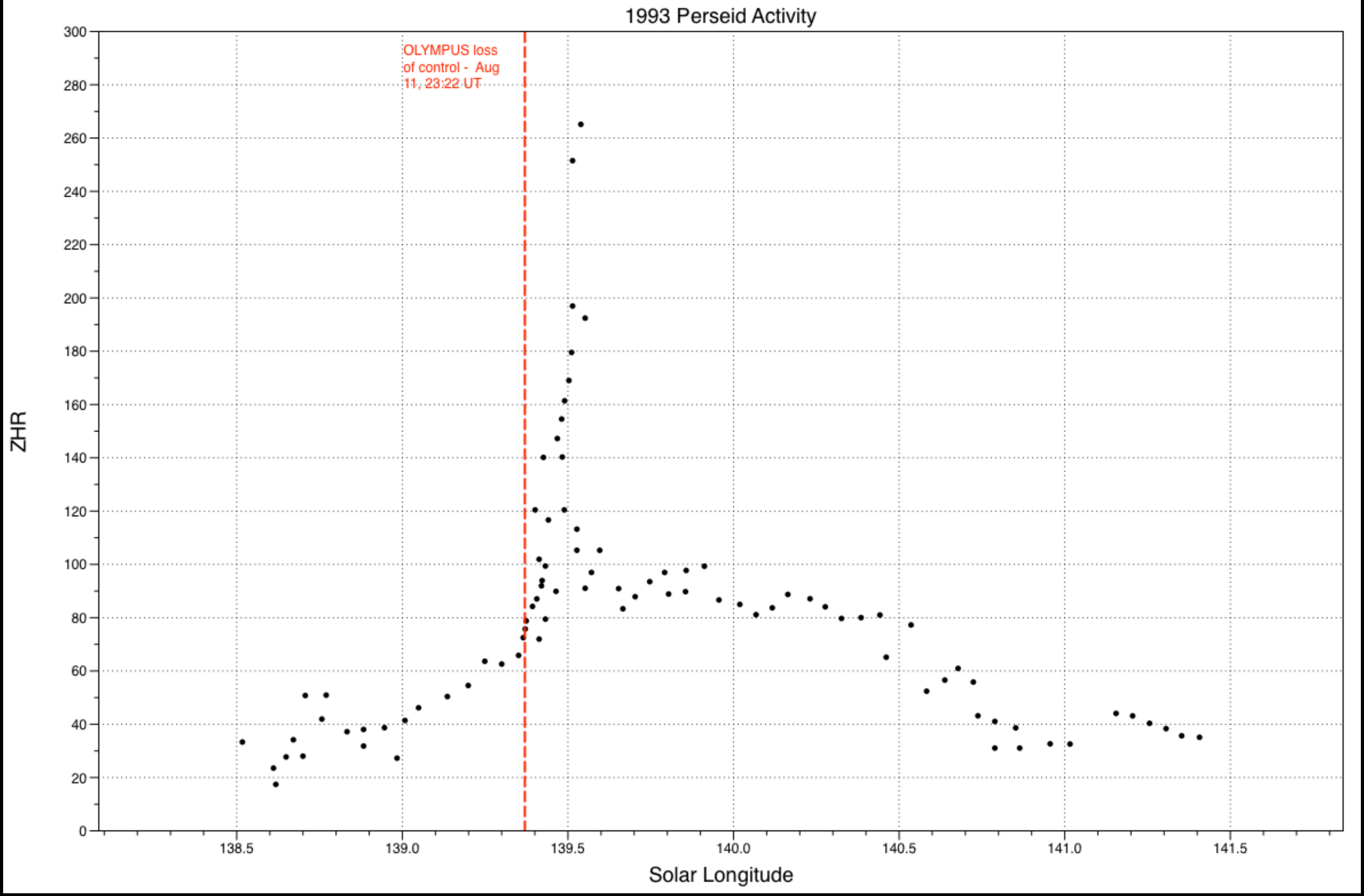
NASA/USGS imaging satellite

Struck by a Perseid near the time of the shower peak in August 2009

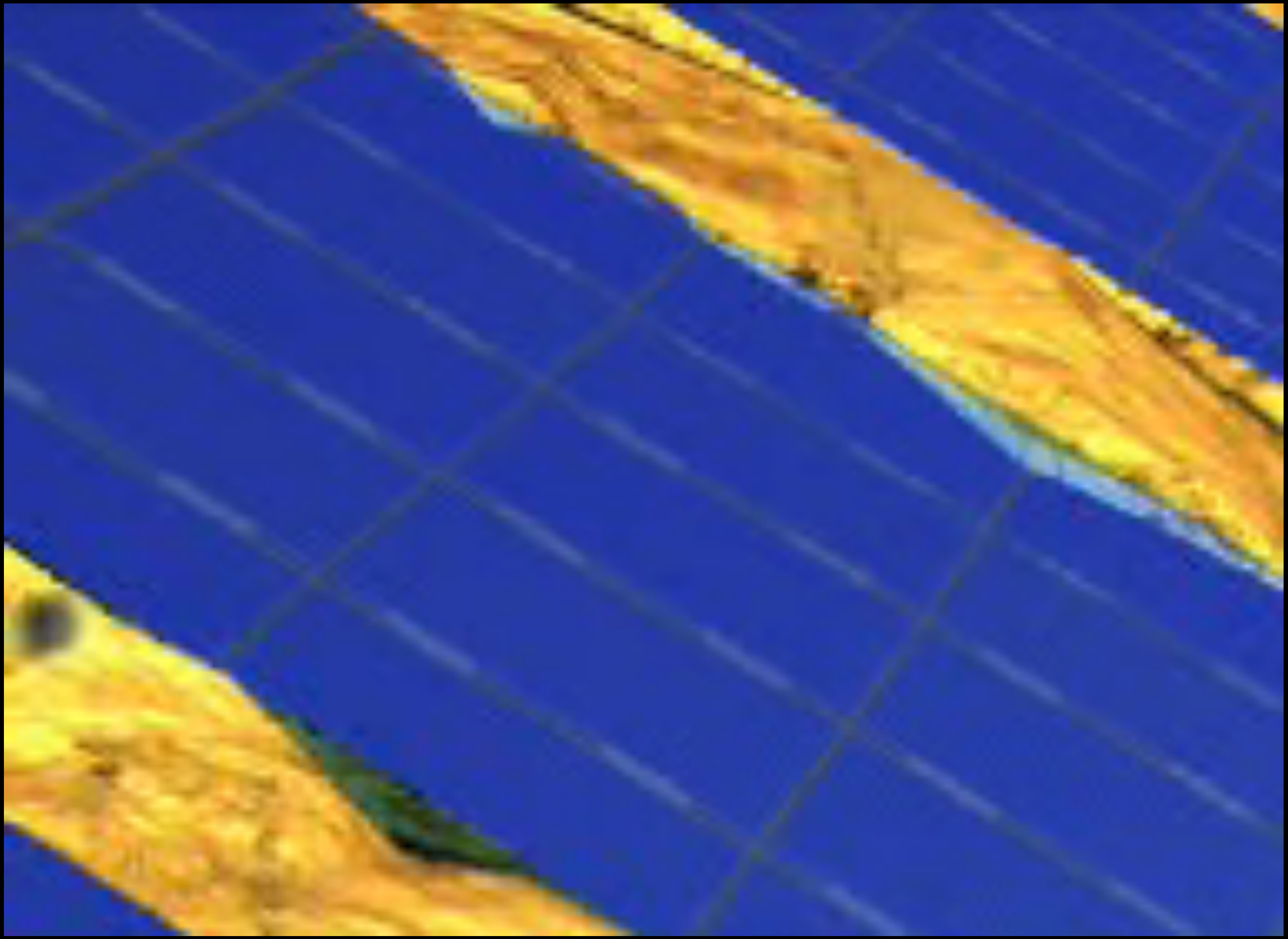
Sent tumbling, stabilized, returned to normal operations

# Olympus

- Technology demonstration satellite - launched 12 July 1989; largest civilian comm satellite built up to that time
- South solar panel stopped tracking the Sun in January 1991 (particle impact?)
- 19 June 1991– attitude control issue; incorrect commands uplinked from ground resulted in tumbling and drift off station. Vehicle recovered and put back into service at 19W on 7 August 1992
- Olympus roll gyro stops at 23:32 UTC August 11 during 1993 Perseid outburst. Spacecraft enters Emergency Sun Acquisition (ESA) mode and fails to acquire the Sun


1993 Perseid Activity
OLYMPUS loss of control - Aug 11, 23:22 UT
ZHR
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
138.5
139.0
139.5
140.0
140.5
141.0
141.5
Solar Longitude

- Attempts to recover spacecraft exhausted most of remaining fuel, making it impossible to return the vehicle to service. Mission was terminated August 12, and the spacecraft was moved into a disposal orbit 200 km below GEO
- ESA anomaly investigation attributed the failure to a Perseid strike on the south solar array
  - South array had 8.5 $m^{-2}$ of area exposed to the stream.
  - There was a possible conducting path to the gyro though the spacecraft umbilical
  - Ground hypervelocity tests showed plasma generated by a meteoroid strike to be proportional to $v^{3.5}$

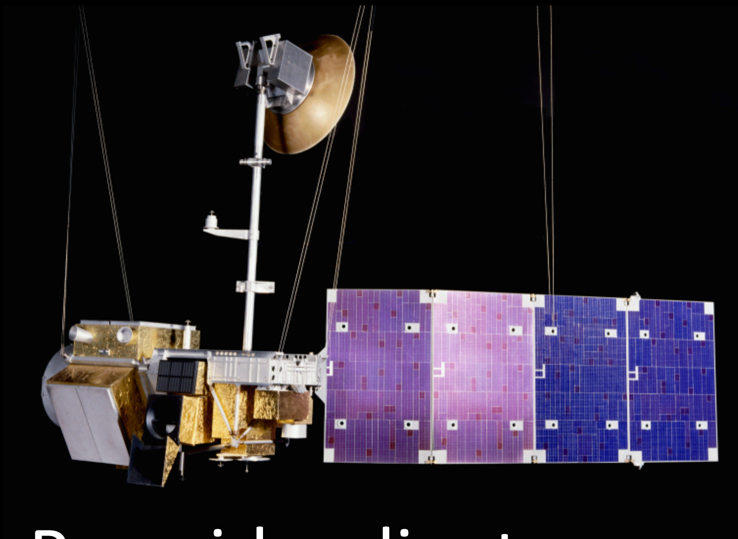


# Olympus conclusion and recommendations

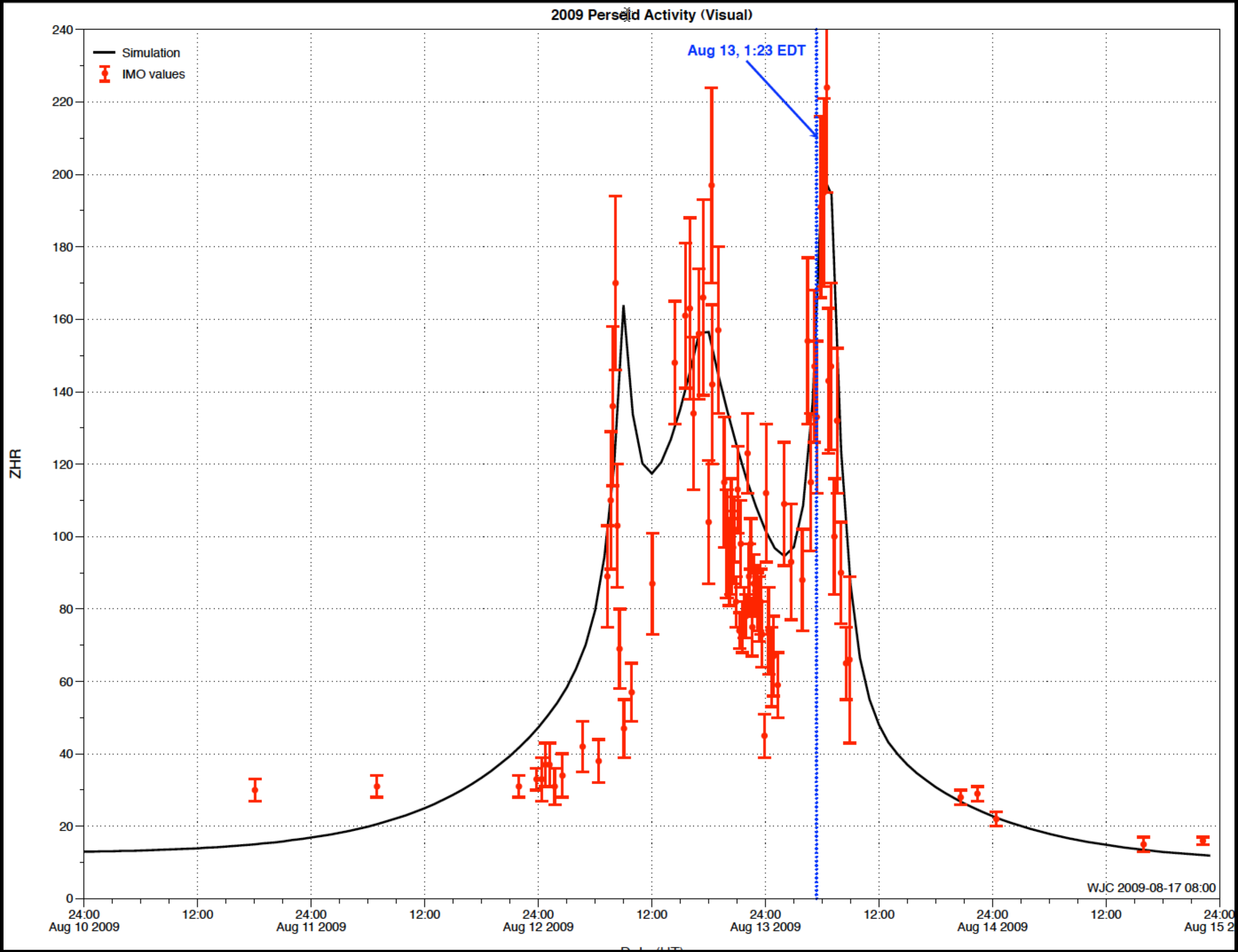
- Conclusion of investigation: "The impact by a small meteoroid may have generated a plasma triggering a discharge of charged surfaces entering the grounded spacecraft via the umbilical and an external sensor. Such a scenario is particularly interesting for other spacecraft since the Perseid shower is likely to be worse for the next few years."
- Recommendations:
  - Minimize the area cross-section as much as possible during the peak period of the shower.
  - Prepare operational contingency plans for recovery from and for observation of impacts/plasmas.
  - Provide total protection from plasmas through external electrical windows such as sun sensors.
  - Ground and cover all interface points such as spacecraft umbilical connections.

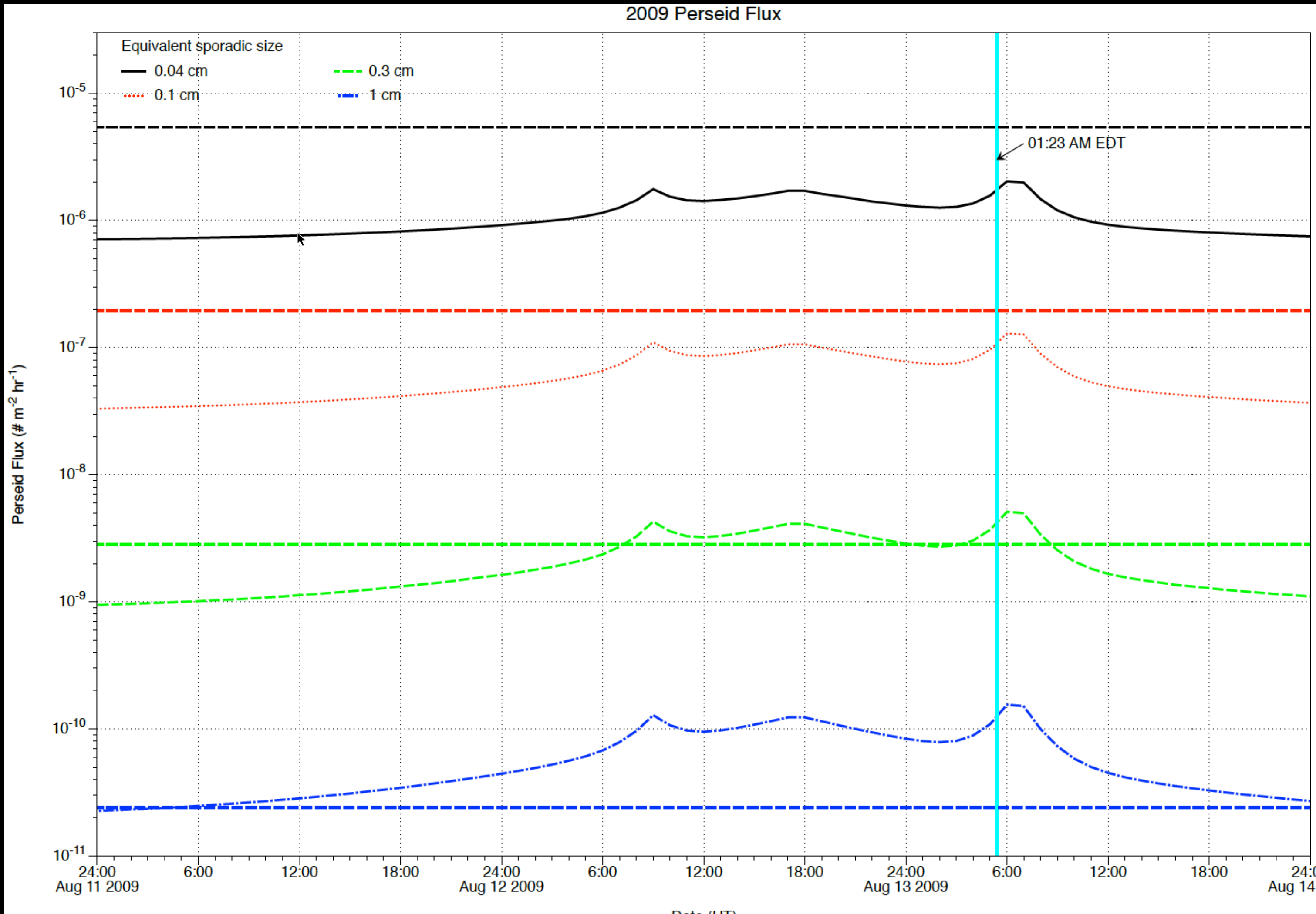
# Landsat-5

- USGS remote sensing satellite launched into sun-synchronous LEO orbit March, 1984
- Decommissioned June, 2013
- Began tumbling at 5:23 UTC on August 13 2009, just before 3rd and strongest peak of the Perseid shower



- Perseid radiant was 37° above Earth limb at time of anomaly
- Operations restored a week later (August 17)

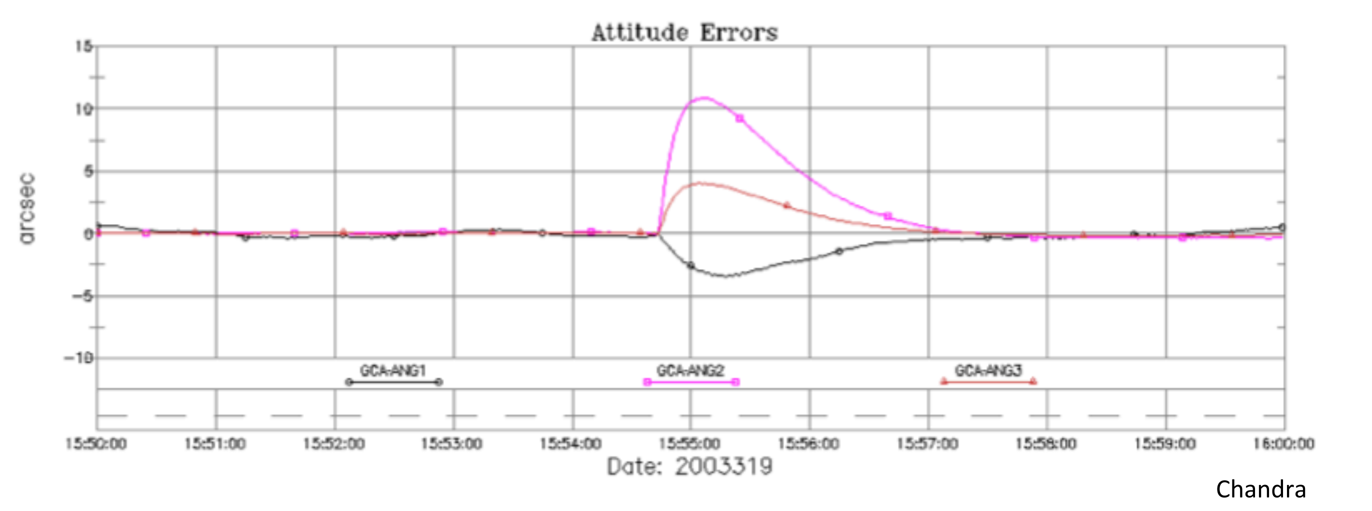

2009 Perseid Activity (Visual)
Simulation
IMO values
Aug 13, 1:23 EDT
ZHR
WJC 2009-08-17 08:00
24:00 Aug 10 2009
12:00
24:00 Aug 11 2009
12:00
24:00 Aug 12 2009
12:00
24:00 Aug 13 2009
12:00
24:00 Aug 14 2009
12:00
0
20
40
60
80
100
120
140
160
180
200
220
240



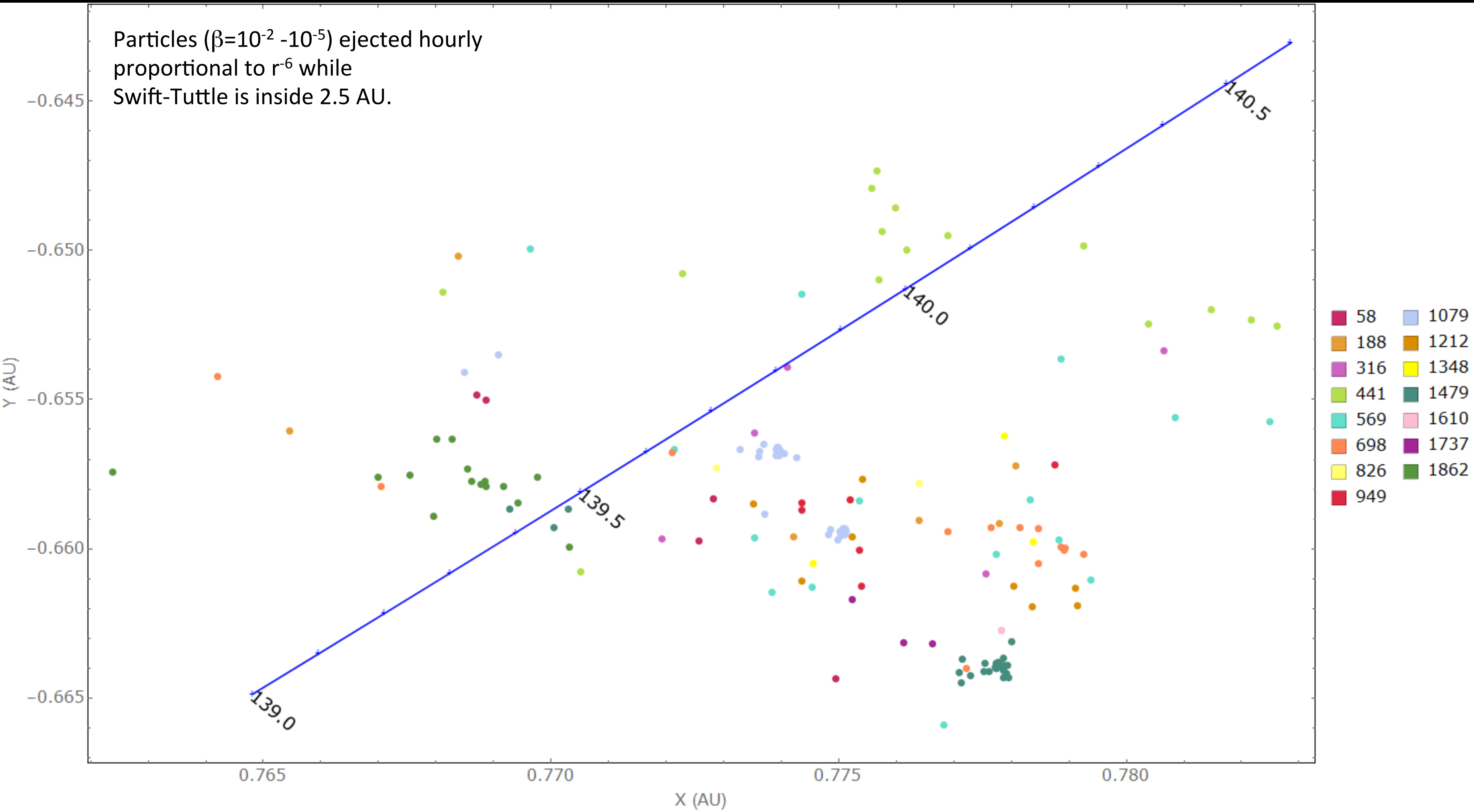
2009 Perseid Flux
Equivalent sporadic size
0.04 cm
0.1 cm
0.3 cm
1 cm
01:23 AM EDT
Perseid Flux (# m$^{-2}$ hr$^{-1}$)
$10^{-5}$
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
24:00
Aug 11 2009
6:00
12:00
18:00
24:00
Aug 12 2009
6:00
12:00
18:00
24:00
Aug 13 2009
6:00
12:00
18:00
24:00
Aug 14 2
Date (UT)

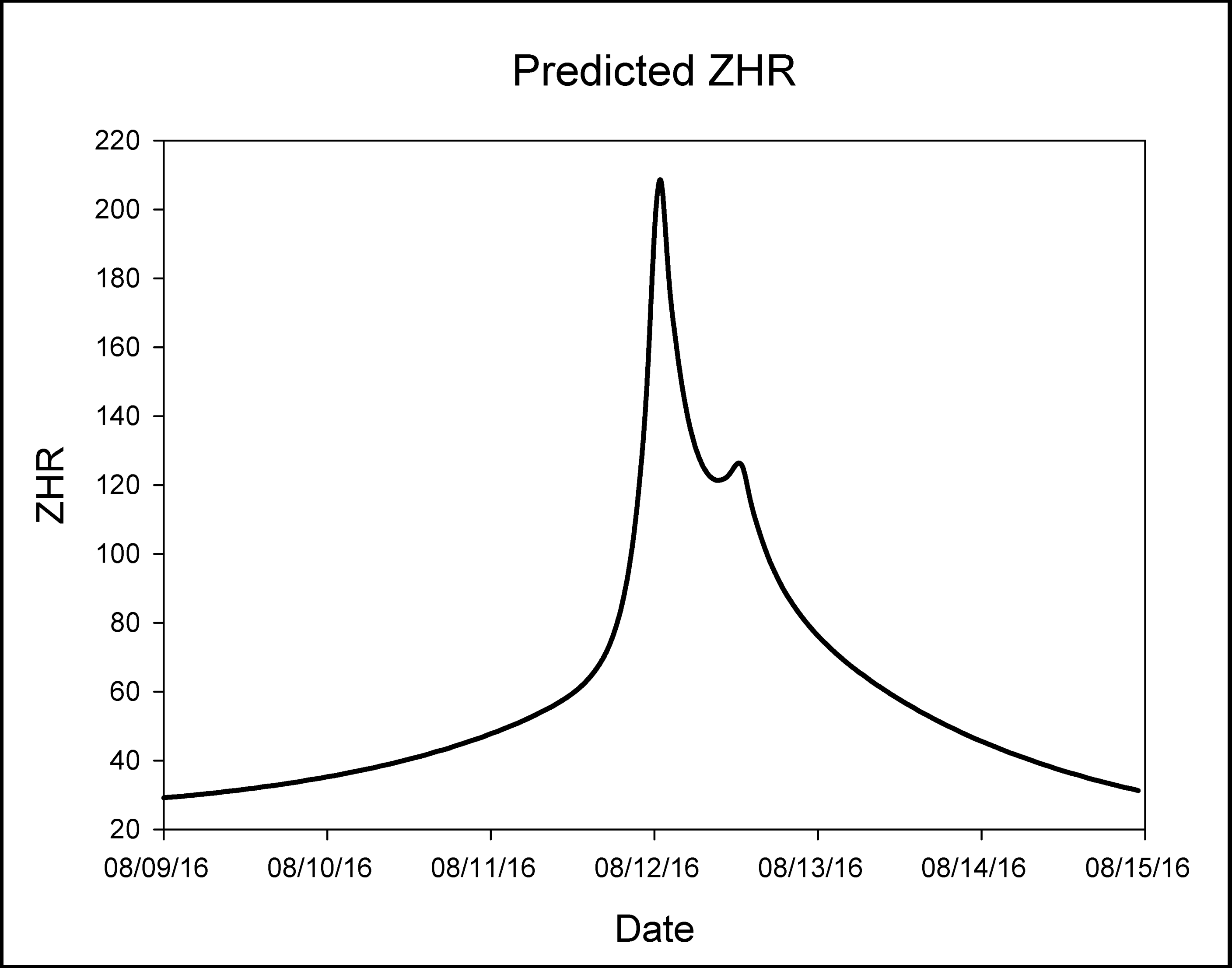
# Thoughts

- Plasma production ($v^{3.5}$) is >40x mass limited and 5x kinetic energy
- Drives affecting particle mass down the mass scale (e.g. 1 mg to $2.3 \times 10^{-5}$ g), with corresponding increase in flux
- Both satellites aging at time of anomalies
- Neither OLYMPUS or Landsat showed momentum disturbances at the times of the anomalies



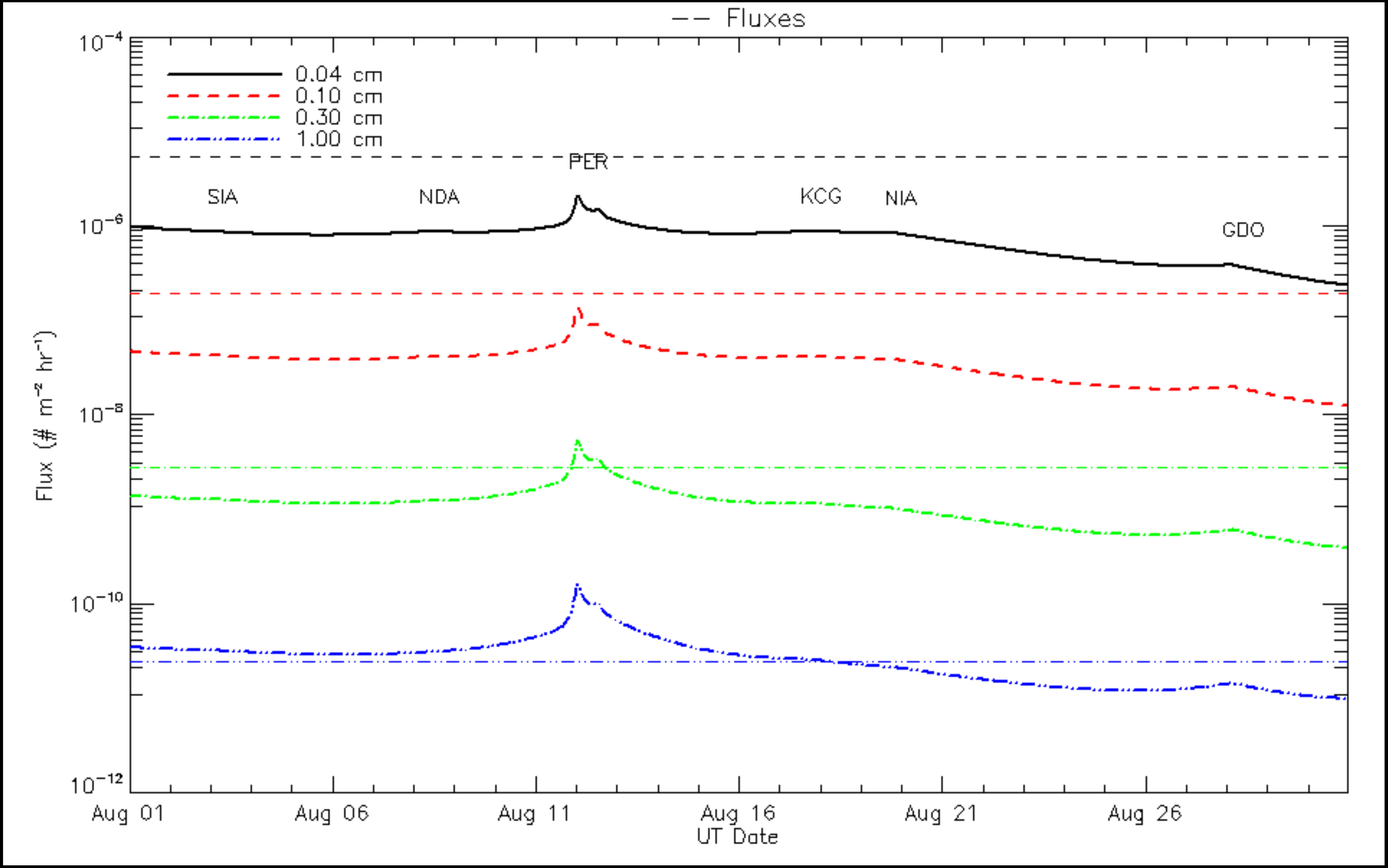
# 2016 Perseid model results: MSFC preliminary





Predicted ZHR
220
200
180
160
140
120
100
80
60
40
20
ZHR
08/09/16
08/10/16
08/11/16
08/12/16
08/13/16
08/14/16
08/15/16
Date

# Kinetic energy flux

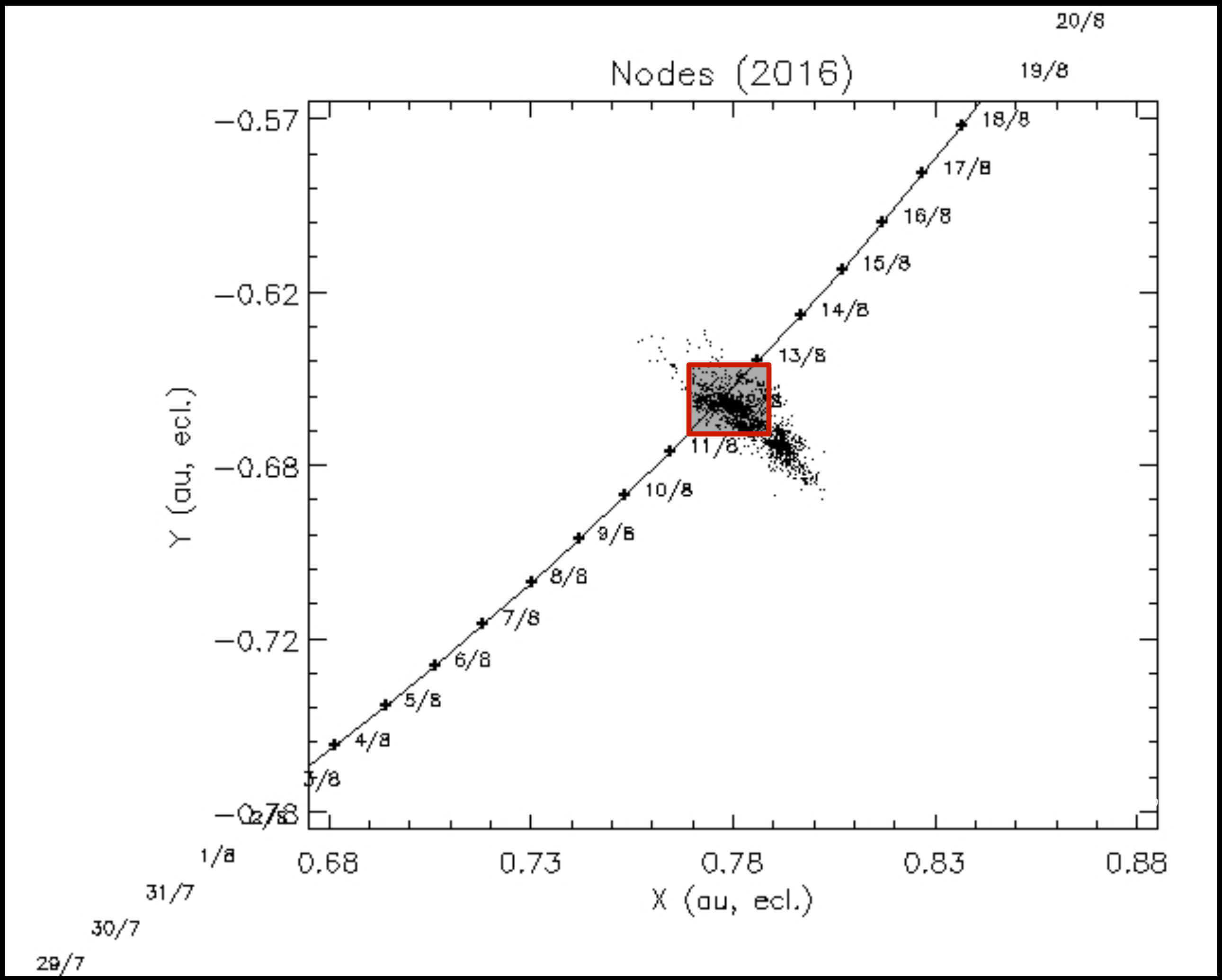


# 2016 Perseid model results
# - Summary -

| Modeler | Rev | Date | Time (UT) | $\lambda_s$ (°) | ZHR | $r_d$-$r_E$ (AU) |
|---|---|---|---|---|---|---|
| Maslov (web, undated) | 1862 | Aug 11 | 22:34 | 139.436 | ? | -0.00134 |
| Vaubaillon (Jenniskens, 2006) | 1862 | Aug 11 | 22:36 | 139.438 | 1 | -0.00327 |
| MSFC single rev (June 2015) | 1862 | Aug 11 | 22:47 | 139.445 | - | -0.00170 |
| Maslov (Rao, 2012) | - | Aug 11 | 23:23 | - | 160-180 | - |
| Maslov (web, undated) | 1479 | Aug 11 | 23:23 | 139.468 | ? | 0.00008 |
| Vaubaillon (Rao, 2012) | - | Aug 12 | ~00:00 | - | "Unusually high activity" | - |
| **Main MSFC (June 2015)** | **Combined 15 revs** | **Aug 12** | **00:32** | **139.515** | **210 ± 50** | **-** |
| MSFC single rev (June 2015) | 1079 | Aug 12 | 04:36 | 139.678 | - | 0.00194 |
| Vaubaillon (Jenniskens, 2006) | 1079 | Aug 12 | 04:43 | 139.683 | 580 | 0.00023 |
| MSFC single rev (June 2015) | 441 | Aug 12 | 13:03 | 140.016 | Comprises secondary peak? | -0.00046 |

Increased activity lasts about half a day, from late-Aug 11 to mid-Aug 12.

# 2016 Perseid model results: Vaubaillon




Approx. region covered by MSFC model

http://www.imcce.fr/langues/en/ephemerides/phenomenes/meteor/DATABASE/Perseids/BIN-tout/Noeuds-Earth2016.jpg

# Conclusion

- A Perseid outburst in 2016 is predicted by numerous forecasters, similar in intensity to 2009
- Increased activity predicted late Aug 11 – Aug 12, lasting ~half a day
- Peak rates predicted between 160 – 580 per hour
- Kinetic energy (physical damage) flux is elevated by a few 10's of % above sporadic background
- The outburst represents a time of increased potential for meteoroid-induced plasmas capable of causing spacecraft anomalies

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