MASS INDEX AND MASS OF THE GEMINID METEOROID STREAM

AS FOUND WITH RADAR, OPTICAL, AND LUNAR IMPACT DATA

June 6, 2016

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Introduction

- In 2015, Geminid fluxes were found in 3 size ranges
  - Lunar Impact
  - Wide-Field
  - CMOR

- These fluxes will be used to

  1) derive a Geminid mass index

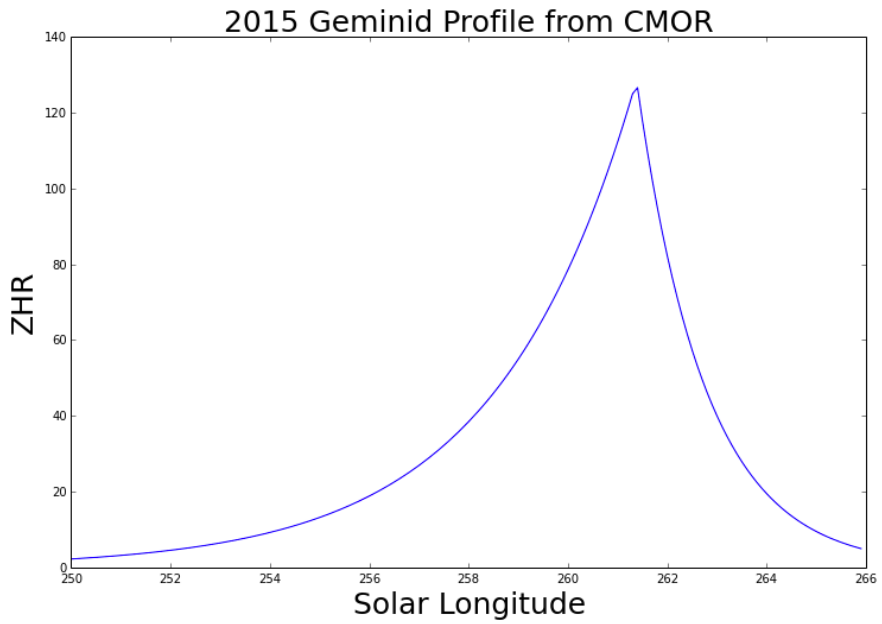
  2) derive a Geminid mass the Earth encountered in 2015

  3) derive a minimum total mass of the Geminid meteoroid stream

- Similar work shown for 2015 Perseids.

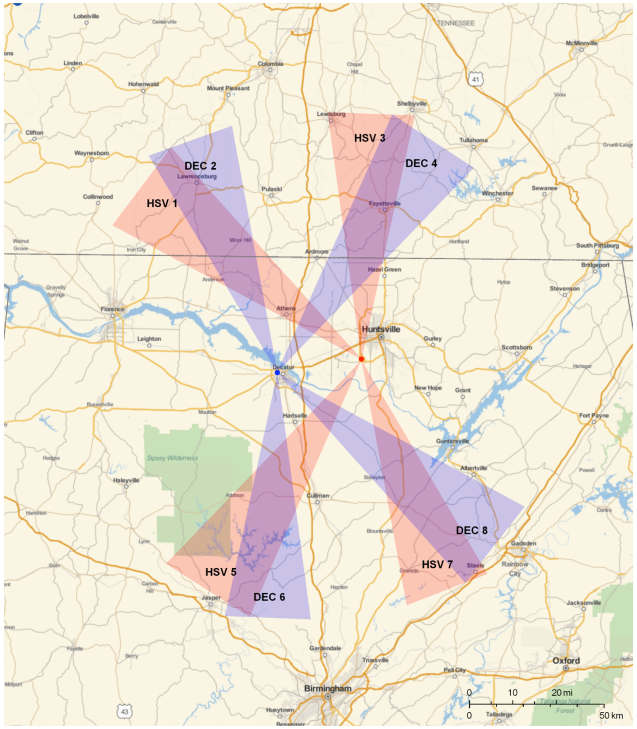
Geminid Fluxes - CMOR

Date (UTC)	Flux (gems/km^2/hr)	Limiting Mass (kg)	ZHR
00:00 -24:00 December 14	5.92e-02	1.8e-07	101.9
00:00-24:00 December 15	2.27e-02	1.8e-07	39.1



Geminid Fluxes – Wide Field

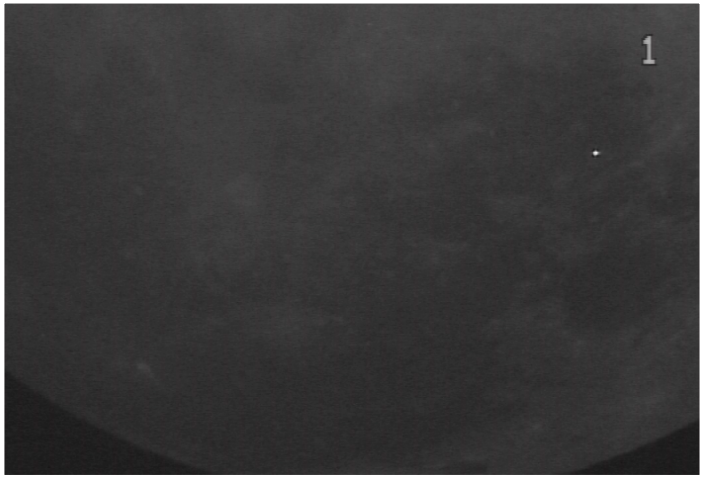
Date (UTC)	Flux (gems/km^2/hr)	Limiting Mass (kg)	ZHR
23:30-12:00 December 14/15	1.89e-03	2.01e-6	29.7



Geminid Fluxes – Lunar Impact

Date (UTC)	Flux (gems/km^2/ hr)	Limiting Mass (g)
23:30-02:00 December 14/15	3.7e-06	30

- 33 impacts were seen over the 2.5 hours on a collecting area of 4 million km^2
- The Geminid geometry: 89% of unlit portion of Moon exposed to radiant



Raw Fluxes

All Points

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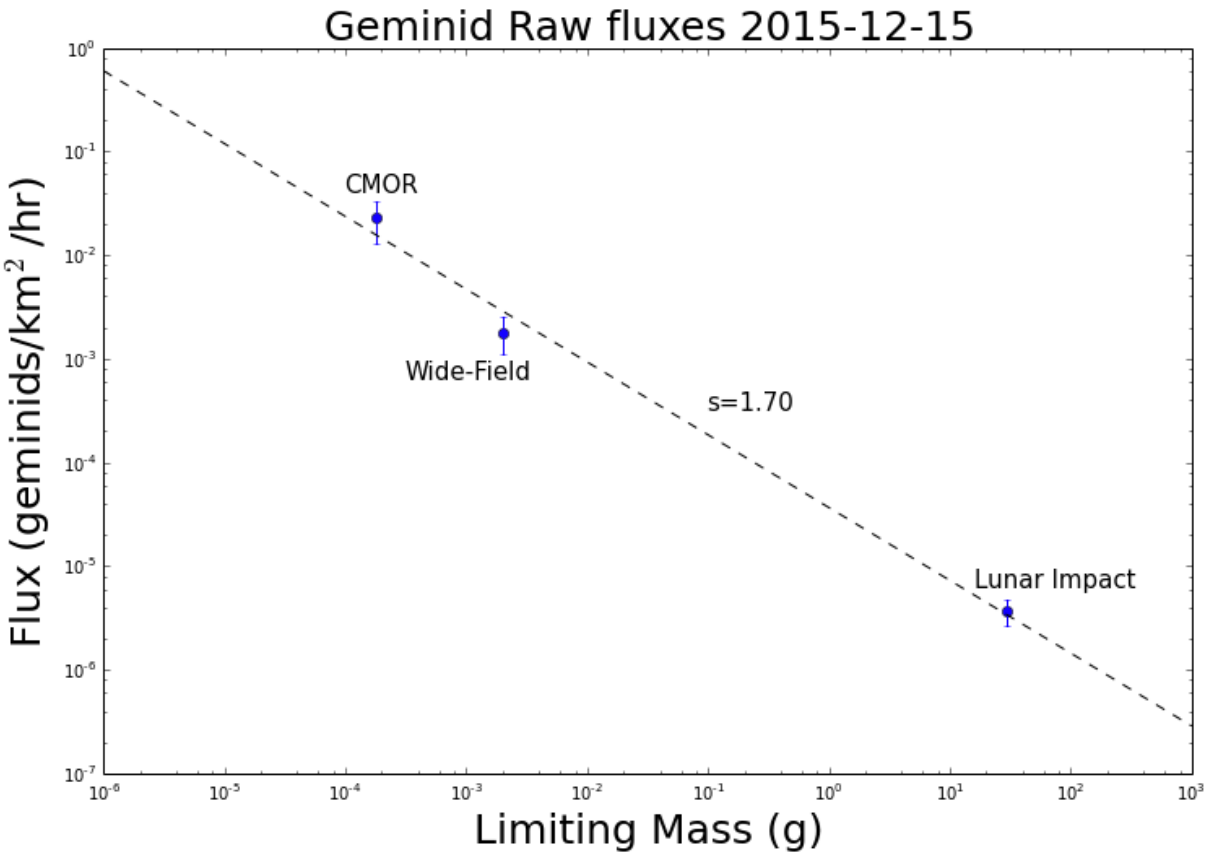
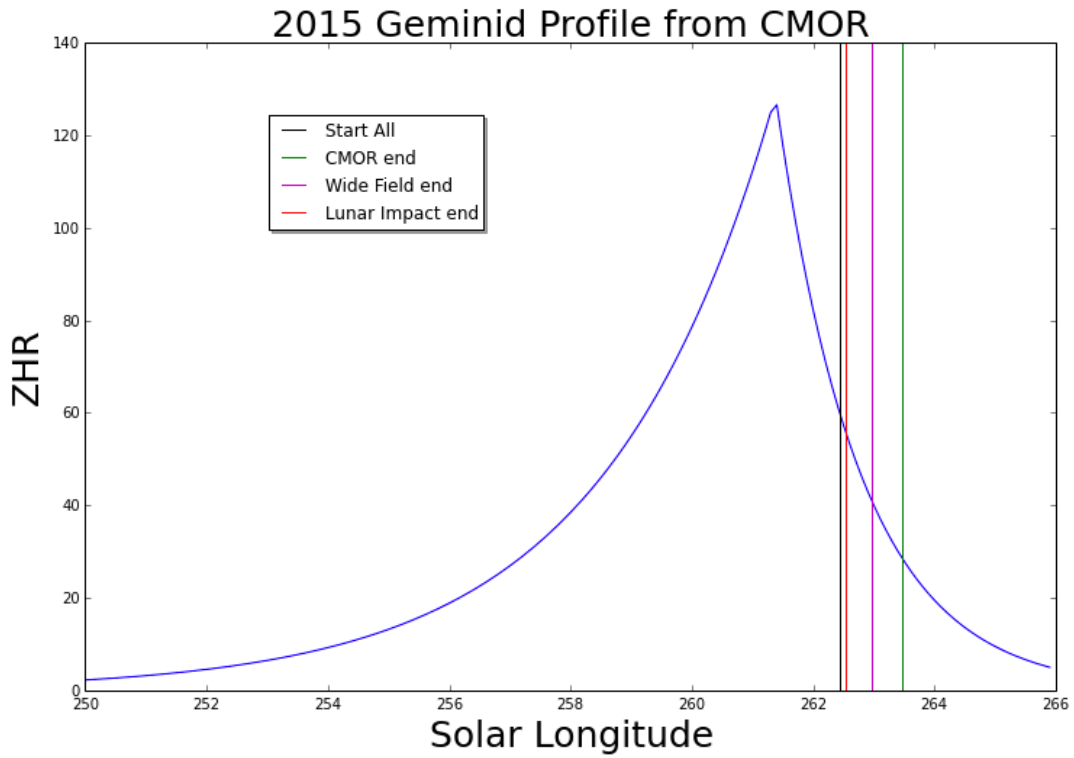
Finding a mass index with these 3 raw values:

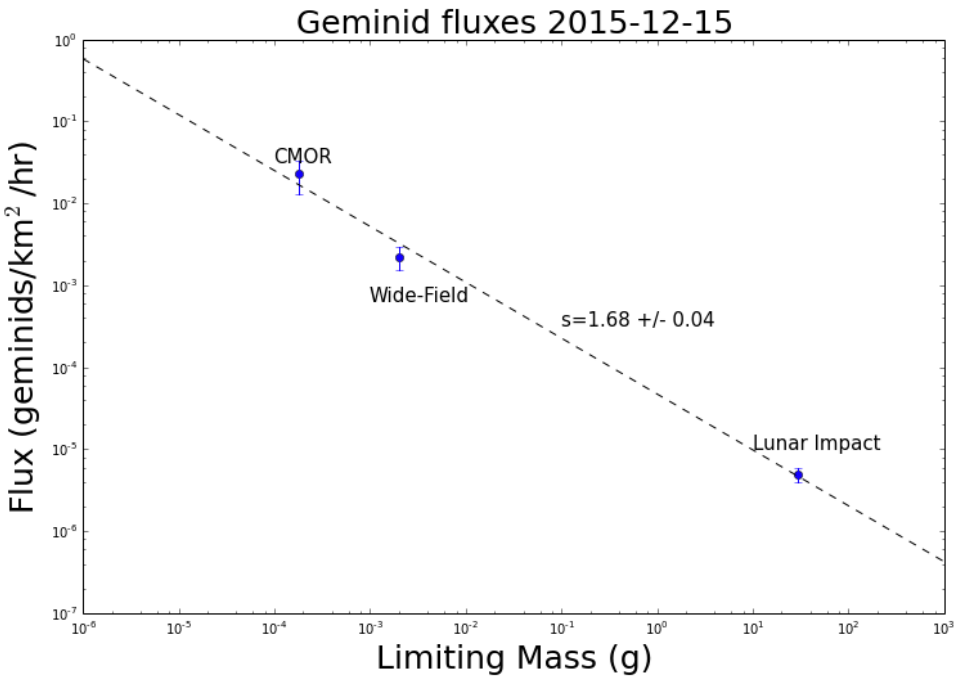


Scaled Fluxes

1) Need to scale all fluxes to the same time period.
2) Used a profile of the 2015 Geminids from CMOR



Scaled Fluxes



Study	Mass Index	Data
Blaauw et al (2011)	1.69	2007,2008,2009 radar data (CMOR)
Zigo et al (2009)	1.73	1996-2007 forward-scatter radar data
Jones & Morton (1982)	1.69 +/- 0.07	Radar, avg +8 magnitude
Babadzhanov et al (1992)	1.67	Radar observations from Tadjikistan
Chenna Reddy et al (2008)	1.65-1.75	2003 and 2005 Geminids from Gadanki Radar (+3.5 mag)
Chenna Reddy et al (2006)	1.75	2004 Visual Data
Arlt & Rendtel (2006)	1.7	2004 Visual Data

From this mass index, those flux values, and the activity profile of the Geminids, we can derive the total mass of Geminids the Earth encounters throughout the stream.

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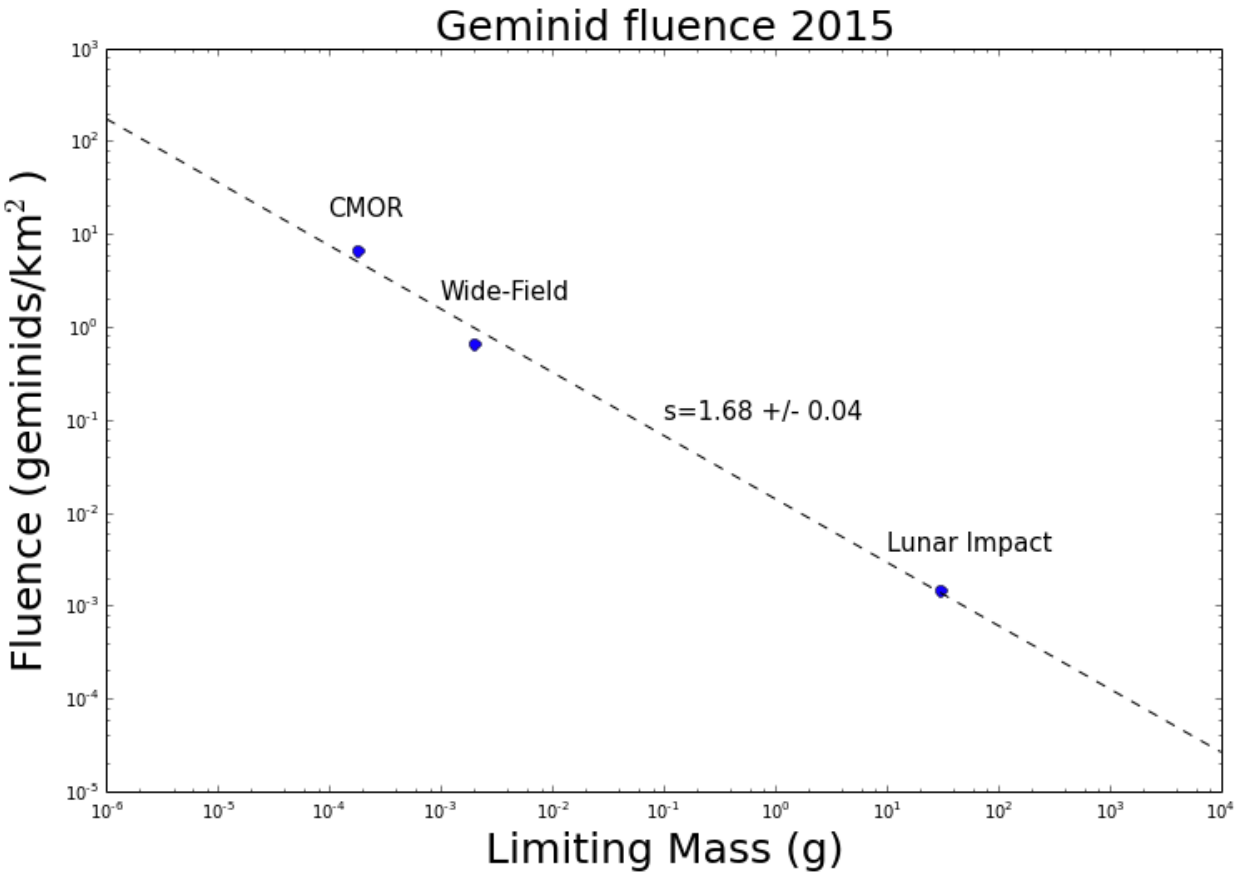
Used activity profile to find total Geminid Flux Earth encounters in 2015



Mass Limits

- Mass range to integrate over:
  - Lower Limit:
    - As the mass index is skewed toward more massive particles, a lower limit on the mass is chosen where decreasing the lower limit makes no sizable difference to the total mass. 10^{-6} grams was this lower limit.
  - Upper Limit:
    - From cross-section of Earth, can figure out what size Geminid this plot would predict 1 particle/year hitting Earth.
    - Claims each year a 10^{6} kg Geminid should hit. Slightly smaller than Chelyabinsk.
    - At some point, the power law mass index breaks down or Geminids that large don not exist
    - In last 3 years, the largest Geminid seen in the All-Sky cameras was ~600 grams. Currently the upper limit is set at 1 kg

Range: 10^{-6} to 10^{3} grams

Geminid Results

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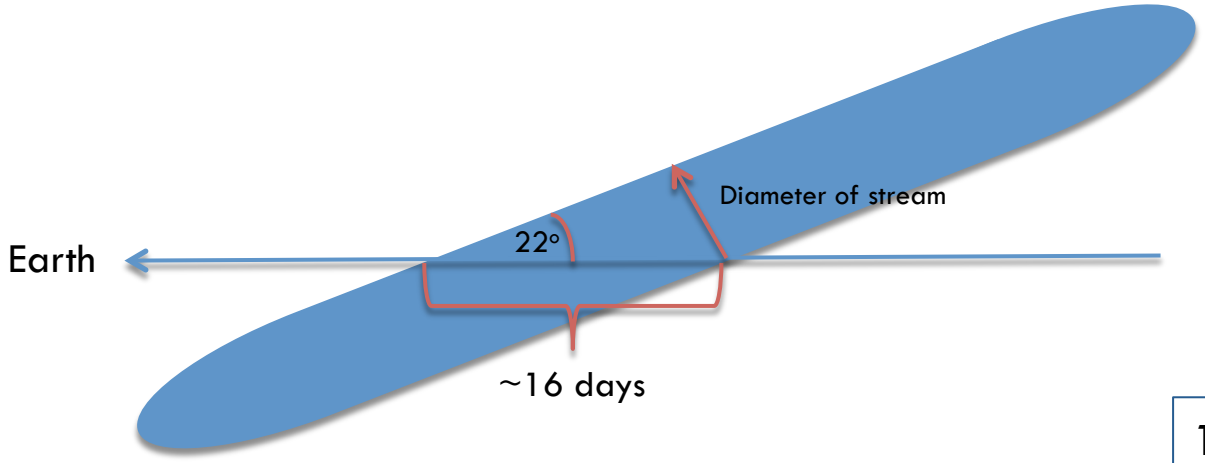
0.00091 grams/km^2/hr	Geminid mass flux at Earth just after the peak.
0.271 grams/km^2	Geminid mass fluence Earth encountered throughout the 2015 Geminids. • Accounts for the range of masses, the date range of activity, and the varying flux.
3.46*10^7 grams	Total amount of Geminid mass the whole Earth encountered during 2015 Geminids.

Geminid Results



Geminid
Meteoroid
Stream

$1.64*10^{15}$ grams

Minimum mass of the Geminid meteoroid stream.

$$= \frac{M_C t V_E^2 V_H \sin^2 \varepsilon}{R_E^2 4 V_G}$$

(Hughes & McBride, 1989)

$M_c = 3.5*10^7$ grams = total mass collected by the Earth during stream transit
t = 16 days = equivalent duration of shower
V_E= 30.28 km/s = Earth's heliocentric velocity
R_E = 6371 km = radius of Earth
ε = angle the Earth's path is inclined to the orbit of the stream – 22 degrees
V_G = 35 km/s =geocentric velocity of the meteoroids
V_H= 33 km/s = Meteoroid's heliocentric velocity
Period = 1.43 years
Diameter: 5.10 km * (estimated diameter from IRAS observations)

Geminid Results

All Points

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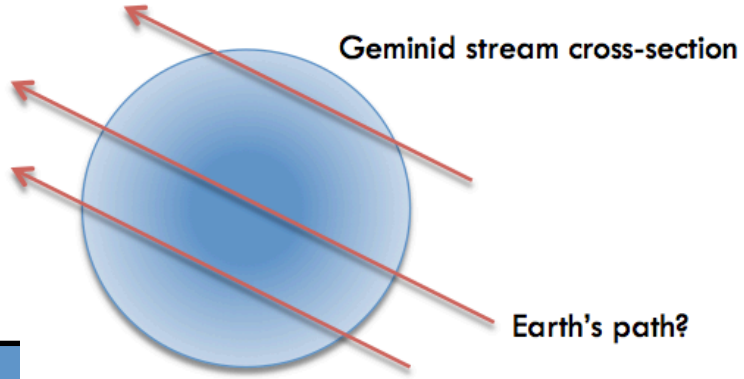
Total mass of the Geminid meteoroid stream. $= \frac{M_C t V_E^2 V_H \sin^2 \varepsilon}{R_E^2 4 V_G}$

BUT there is a factor, f, always included.
To account for Earth not travelling through the center of the stream.
Usually f=10.

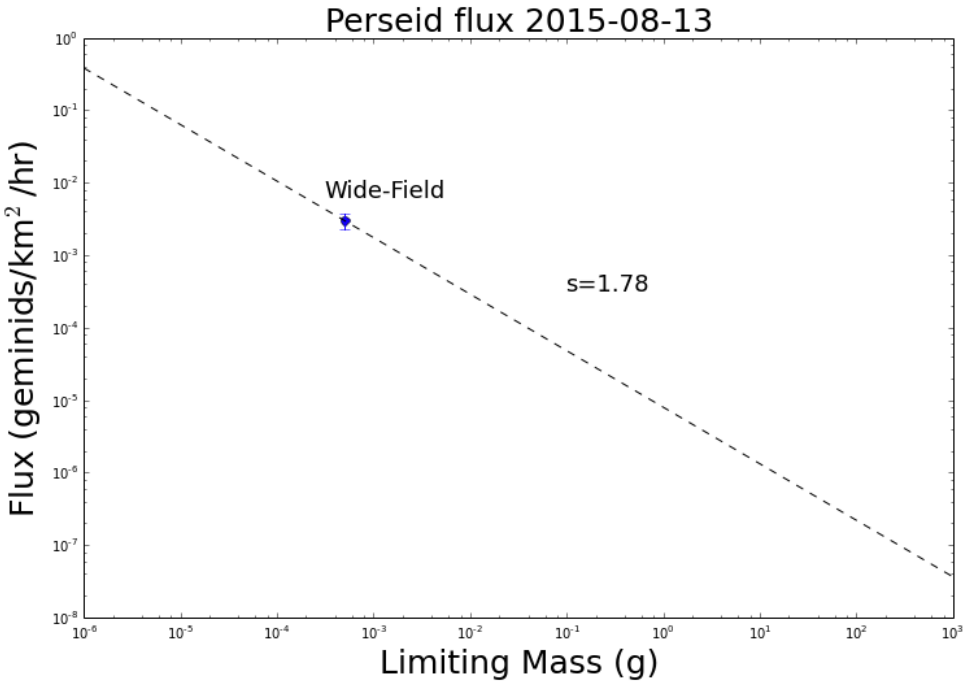
$1.64*10^{16}$ grams

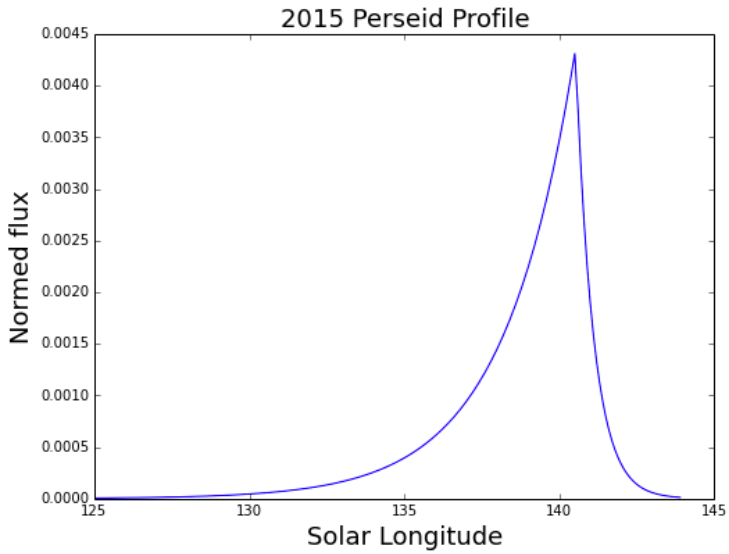


Study	Mass (grams)	Publication/Book
Lovell (1954)	$2.0*10^{15}$	Meteor Astronomy
Hughes & McBride (1989)	$1.6*10^{16}$	The Mass of Meteoroid Streams. Fluxes from Hughes (1973) radar.
Jenniskens (1994)	1.4 (+/- 0.5) $*10^{15}$	Meteor Stream Activity I. The annual stream.

Perseid stream mass:

- Same mass bounds (10^{-6} to 10^{3} grams)





0.000128 grams/km^2/hr:	Perseid mass rate Earth encounters during peak.
0.0113 grams/km^2:	Perseid mass/km^2 Earth encounters in 2015.
1.438e+6 grams:	Perseid mass Earth encountered during 2015.

3.30e+17 grams ← Perseid stream mass

Comparison

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Quantity	Perseids	Geminids	PER vs GEM	H & M 1989 Perseids	H & M 1989 Geminids	H & M 1989 PER vs GEM
Mass Rate at Peak (grams/km^2/hr)	1.28 e-4	9.10 e-4	0.14x	1.01 e-4	8.64 e-4	0.12x
Mass Fluence (grams/km^2)	1.1 e-2	27.1 e-2	0.041x			
Mass at Earth/year (grams)	1.44 e+6	34.6 e+6	0.042x			
Total mass of stream (grams)	33.0 e+16	1.64 e+16	20x	31 e+16	1.6 e+16	19x

*H & M = Hughes & McBride

Conclusions

All Points

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- Geminid mass index 1.68 +/- 0.04 over 5 orders of magnitude.
- Geminids: 5.1 km asteroid 3200 Phaethon.
- Perseids: 26 km comet Swift-Tuttle.

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- BUT Perseid stream size is much larger because the orbit size.

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- Geminids deposit much more material.
- We see similar ZHRs for Perseids because of their speed: seeing smaller Perseids.
- BUT Perseid stream size is much larger because the orbit size.
- Implies 3200 Phaethon has only shed ~ 1/10th of its mass, or shed a 70 meter shell of material.
- Implies Swift-Tuttle has shed about 3% of its mass, or 150 meter shell of material.