Investigation of meteor models with numerical simulation

Toying with models of meteor flight for a deeper understanding

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Overview

Motivation

All work and no play makes Jack a dull boy...

English proverb

What do we have?

- a (more-or-less) universal meteor simulator

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  - estimate meteor flux
  - validate physical models
  - investigate r and s indices
  - ...

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- with it we can
  - estimate meteor flux
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  - investigate r and s indices
  - ...
- let's go beyond statistics
- look at variations in meteors' properties

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   - how?

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   - position in the sky
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   - ...
   - **anything**
4. look at the dataset

Simulation

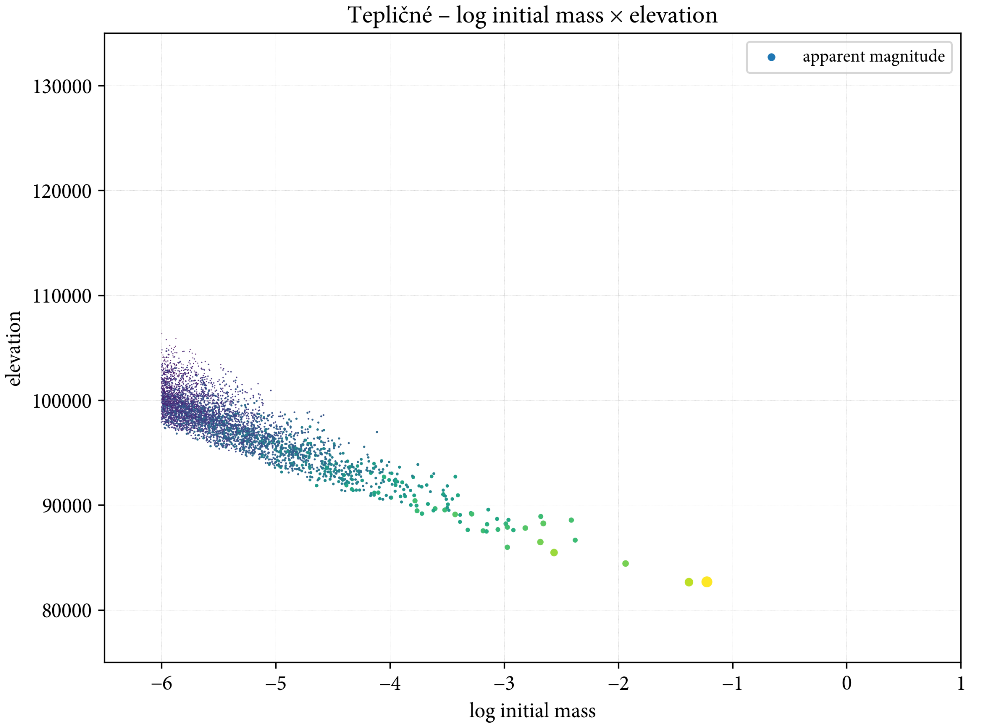
Simulation of flight

Standard model – **Öpik** (1955)

- single spherical body
- continuous thermal ablation
- no ionization or trail emission

3D simulation on spherical Earth

- Runge–Kutta integrator
- **snapshots** taken N times per second
- until complete ablation (or...)



Tepličné – log initial mass × elevation
apparent magnitude
elevation
130000
120000
110000
100000
90000
80000
−6
−5
−4
−3
−2
−1
0
1
log initial mass

Prerequisites

Grid generator

Plain old scientific method:

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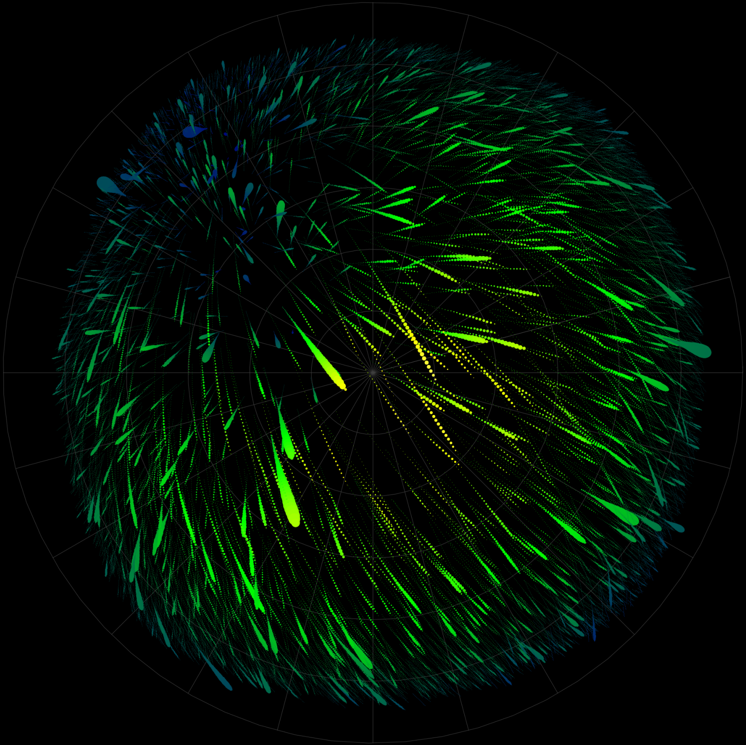
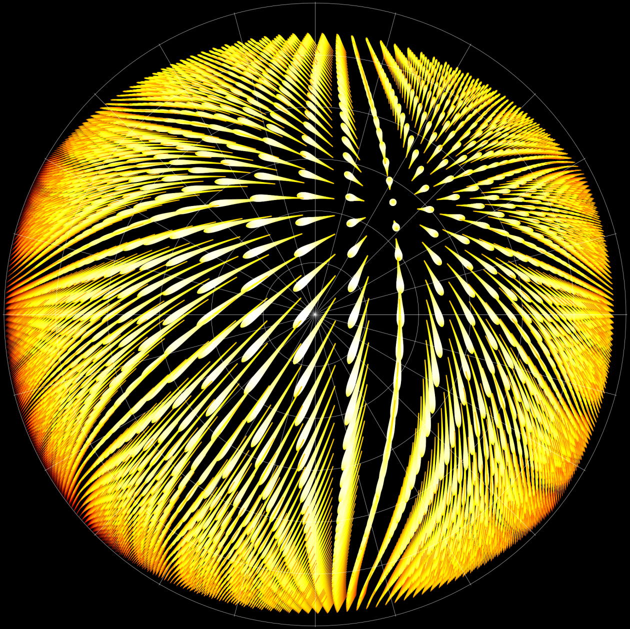
We may look at the **brightest frame** or **entire trail**





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- observer at North Pole
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- scatter plot
- colour by varied property
- emphasize **max-light frame**

What is it good for?

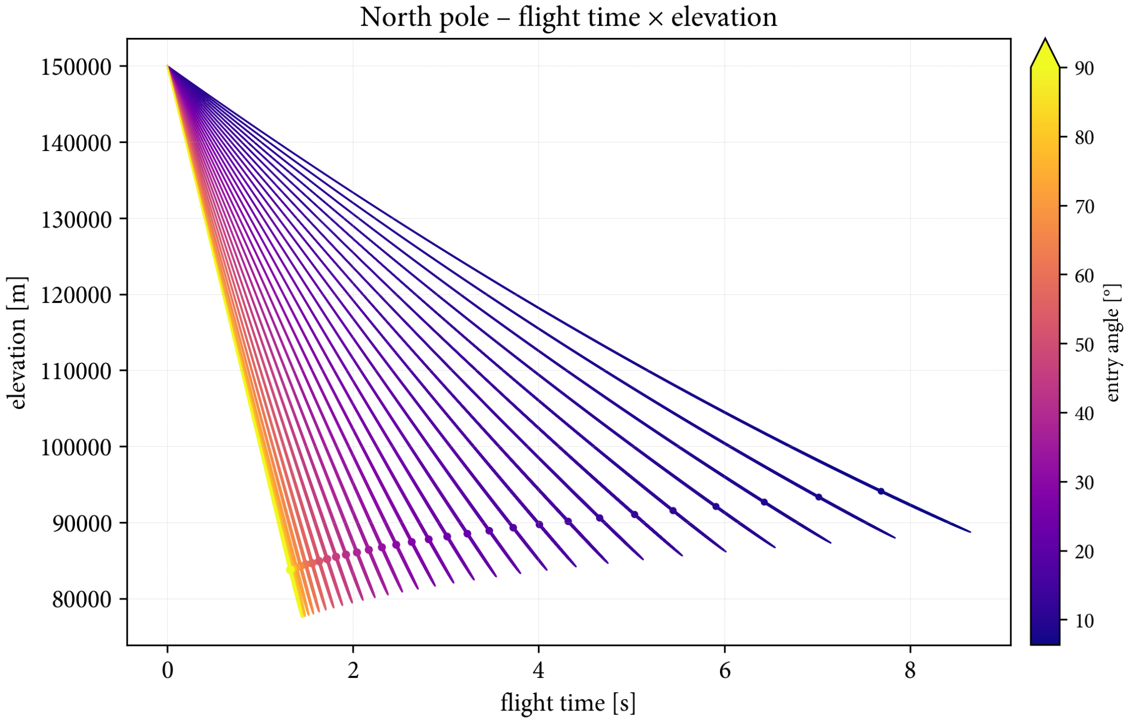
- predict properties of **any** incoming particle
- improve ablation and flight models
- try to find something interesting in the data

Entry angle

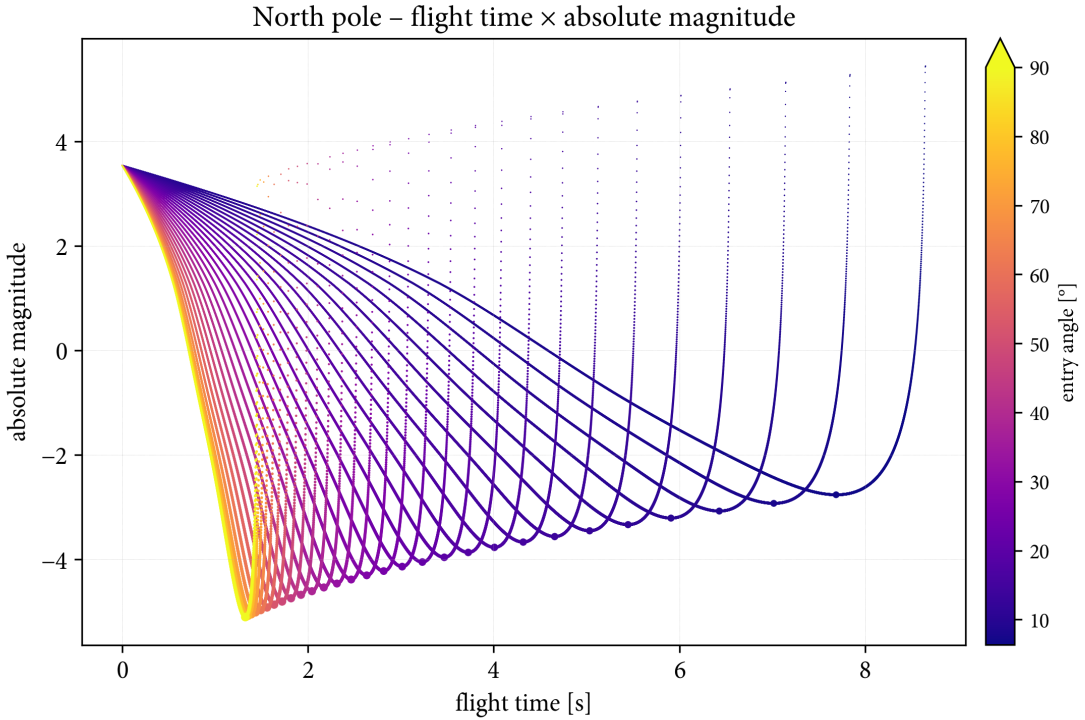
Entry angle

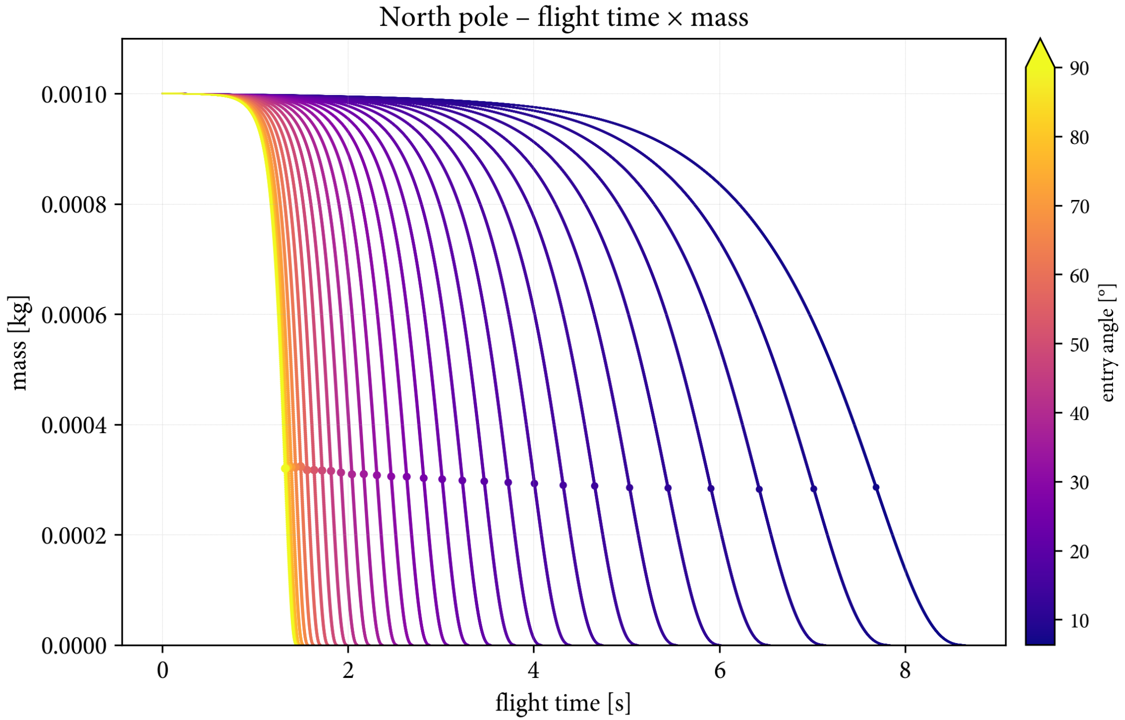
varying **entry angle**

- Perseids
  - material, velocity, ...
- mass 1 g
- θ between 10° and 90°



North pole – flight time × elevation
150000
140000
130000
120000
110000
100000
90000
80000
elevation [m]
0
2
4
6
8
flight time [s]
90
80
70
60
50
40
30
20
10
entry angle [°]


North pole – flight time × absolute magnitude
absolute magnitude
flight time [s]
entry angle [°]
4
2
0
−2
−4
0
2
4
6
8
90
80
70
60
50
40
30
20
10



North pole – flight time × mass
mass [kg]
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0
2
4
6
8
flight time [s]
entry angle [°]
90
80
70
60
50
40
30
20
10

Mass

Parameters

- Perseids
  - material, velocity, ...

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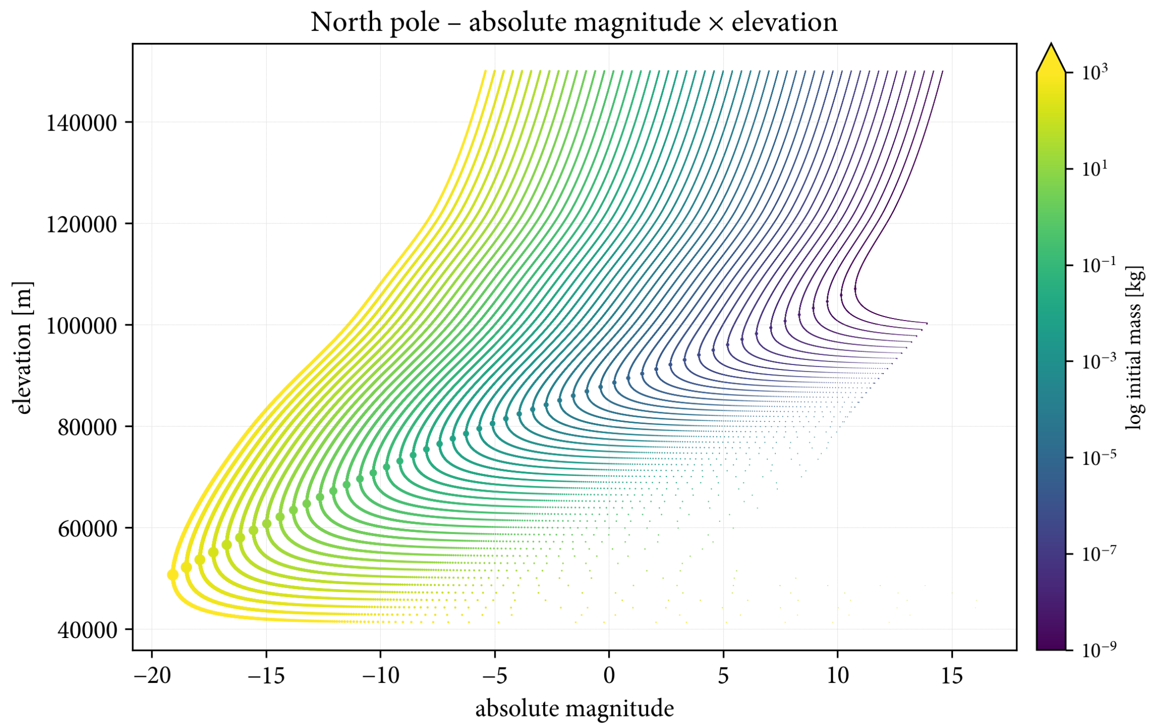
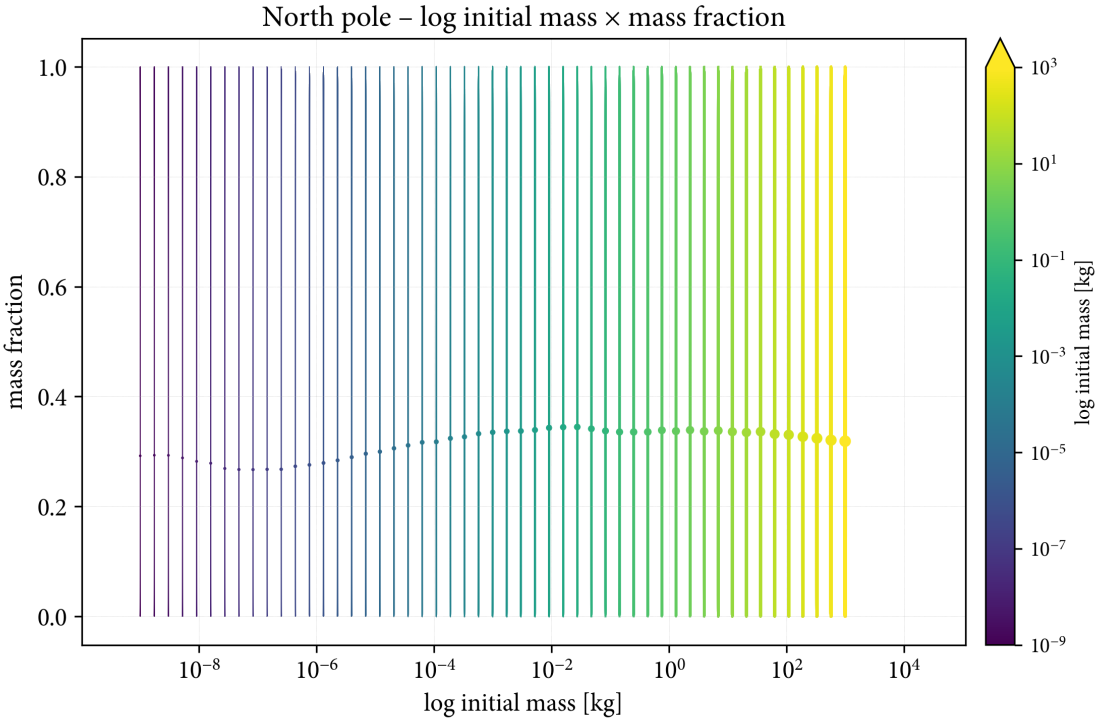
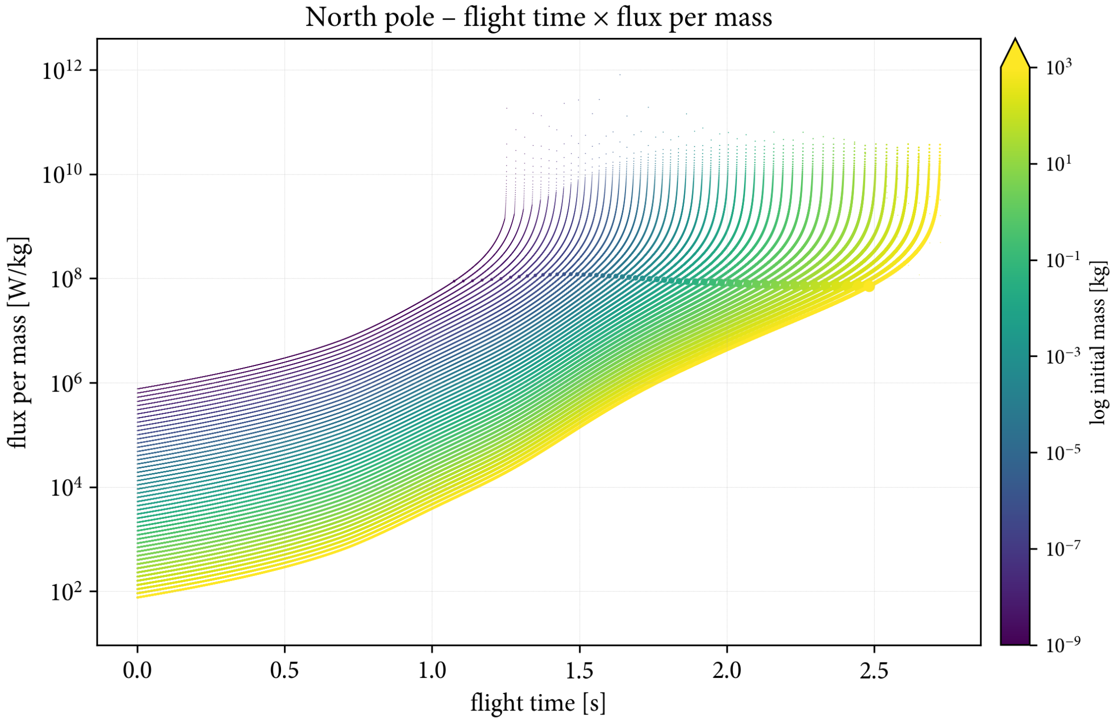
- Perseids
  - material, velocity, ...
- entering atmosphere at 45°
- m_∞ from 1 µg to 1000 kg
- log spacing

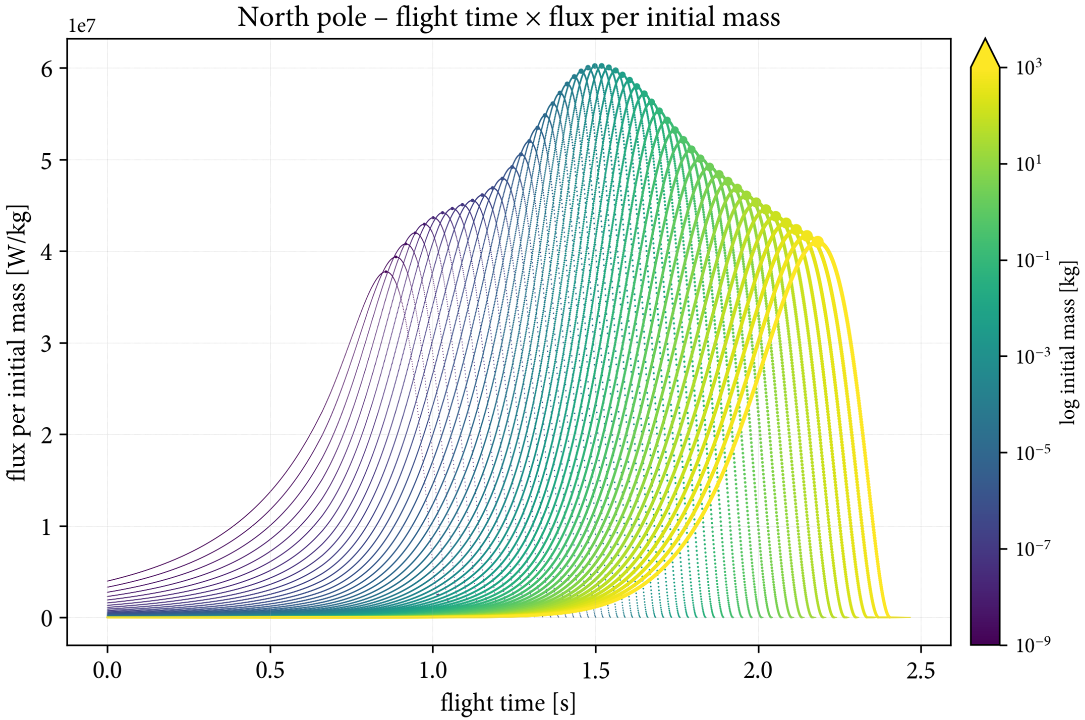

North pole – absolute magnitude × elevation
elevation [m]
140000
120000
100000
80000
60000
40000
−20
−15
−10
−5
0
5
10
15
absolute magnitude
log initial mass [kg]
10^3
10^1
10^{-1}
10^{-3}
10^{-5}
10^{-7}
10^{-9}


North pole – log initial mass × mass fraction
mass fraction
1.0
0.8
0.6
0.4
0.2
0.0
10^{-8}
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
log initial mass [kg]
10^{3}
10^{1}
10^{-1}
10^{-3}
10^{-5}
10^{-7}
10^{-9}
log initial mass [kg]

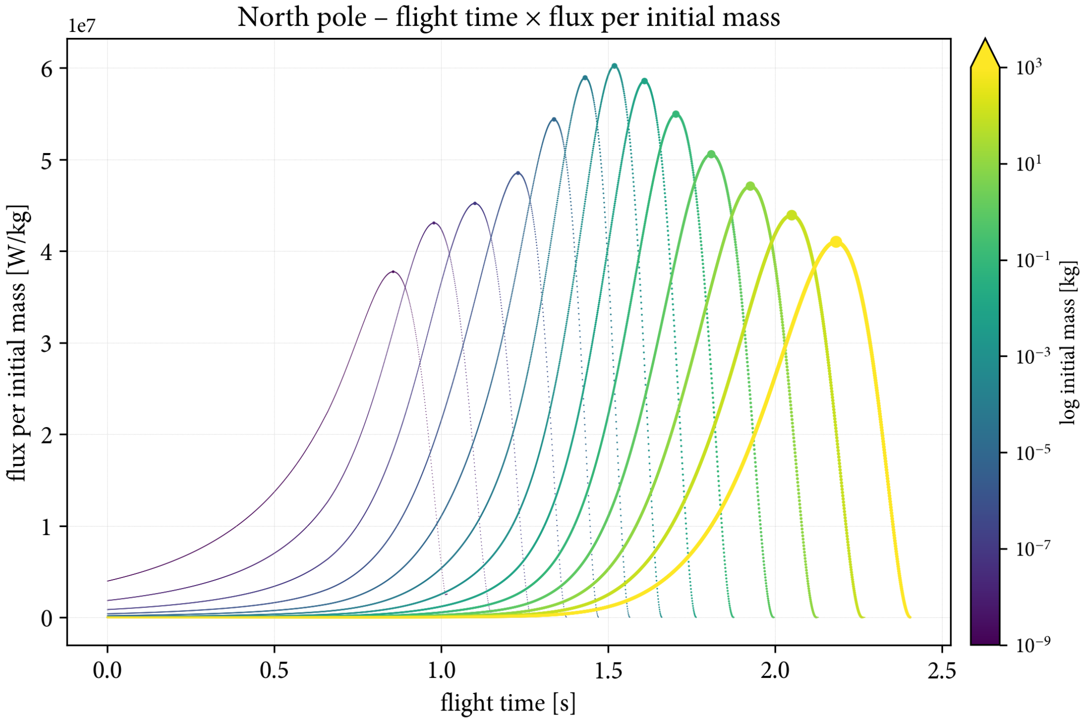
Mass fraction at maxlight

- maximum brightness at 1/3 initial mass
- non-linear behaviour


North pole – flight time × flux per mass
flux per mass [W/kg]
flight time [s]
log initial mass [kg]
10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
0.0
0.5
1.0
1.5
2.0
2.5
10^{3}
10^{1}
10^{-1}
10^{-3}
10^{-5}
10^{-7}
10^{-9}



North pole – flight time × flux per initial mass
1e7
flux per initial mass [W/kg]
0
1
2
3
4
5
6
0.0
0.5
1.0
1.5
2.0
2.5
flight time [s]
log initial mass [kg]
10^{3}
10^{1}
10^{-1}
10^{-3}
10^{-5}
10^{-7}
10^{-9}



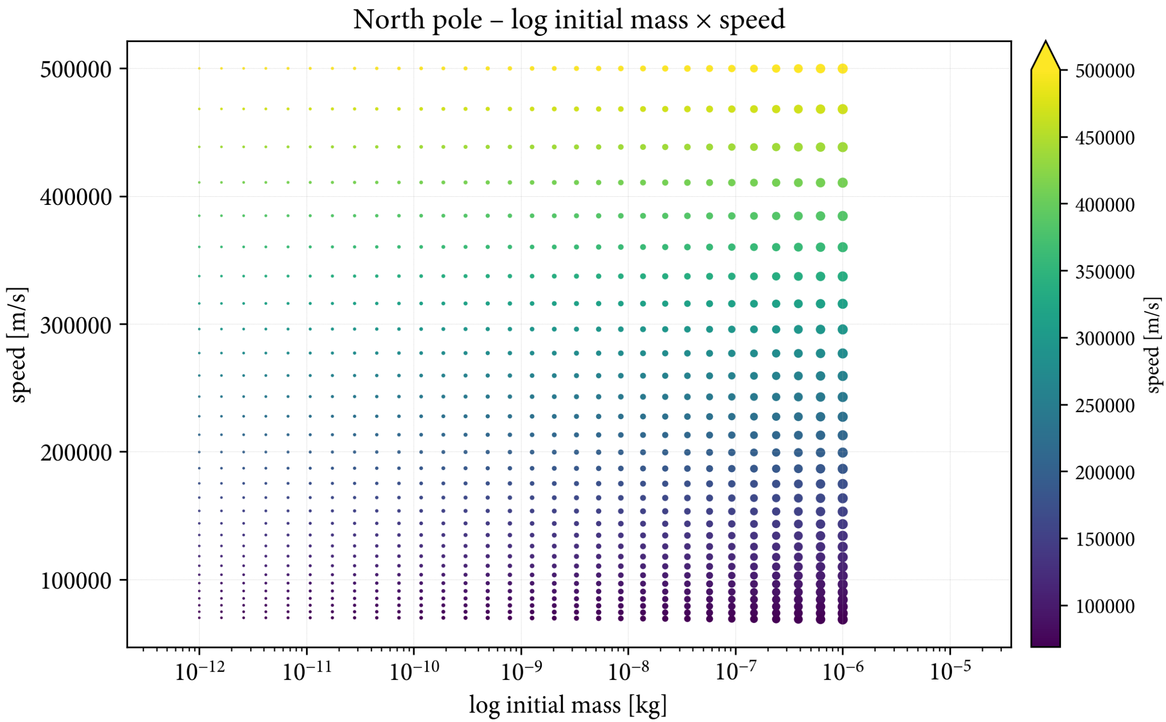
North pole – flight time × flux per initial mass
1e7
6
5
4
3
2
1
0
flux per initial mass [W/kg]
0.0
0.5
1.0
1.5
2.0
2.5
flight time [s]
10^{3}
10^{1}
10^{-1}
10^{-3}
10^{-5}
10^{-7}
10^{-9}
log initial mass [kg]

Hypervelocity

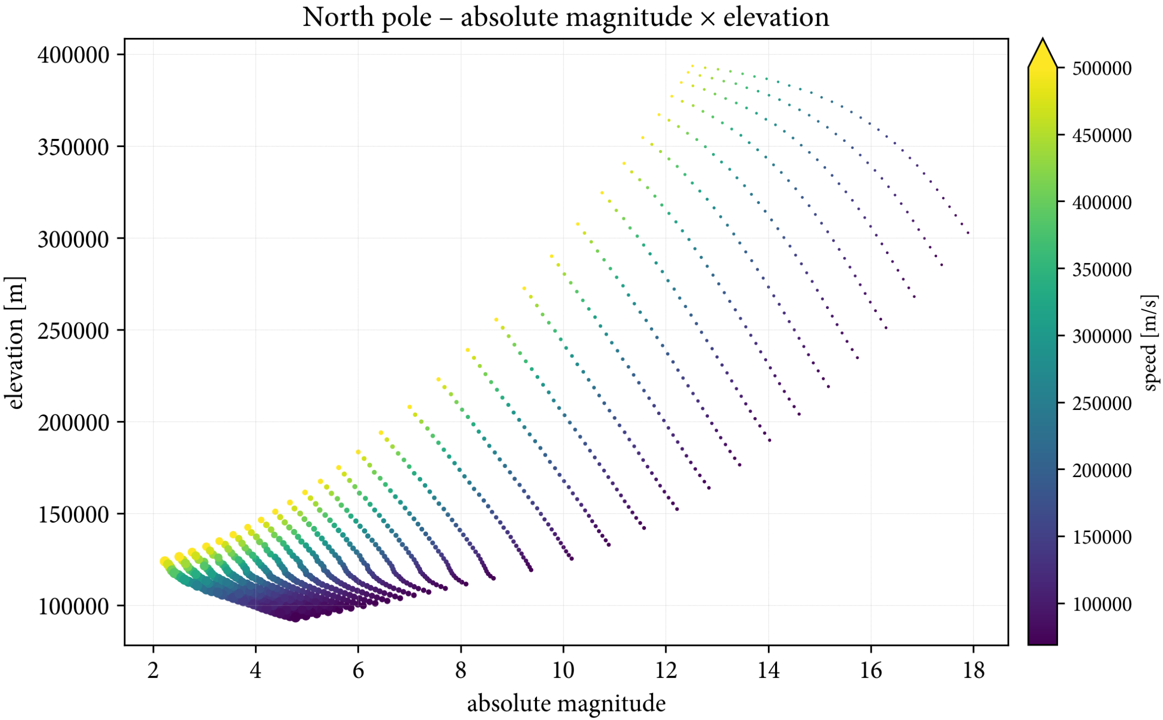
Hypervelocity

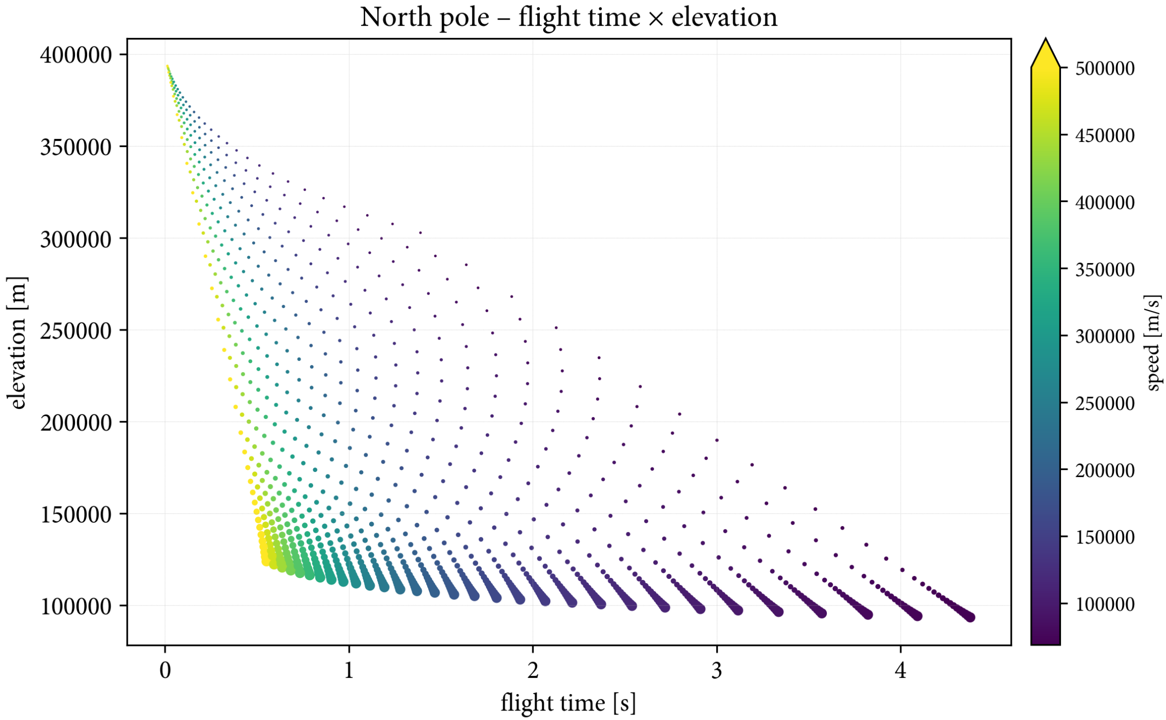
Revise **High geocentric velocity meteor ablation** (Hill et al., 2005)

- fluffy cometary material
- **speed** between 70 – 500 $\mathrm{km\,s^{-1}}$
- **mass** between $1 \cdot 10^{-12} - 1 \cdot 10^{-6}$ kg



North pole – log initial mass × speed
speed [m/s]
500000
400000
300000
200000
100000
log initial mass [kg]
10−12
10−11
10−10
10−9
10−8
10−7
10−6
10−5
speed [m/s]
500000
450000
400000
350000
300000
250000
200000
150000
100000


North pole – absolute magnitude × elevation
elevation [m]
400000
350000
300000
250000
200000
150000
100000
absolute magnitude
2
4
6
8
10
12
14
16
18
speed [m/s]
500000
450000
400000
350000
300000
250000
200000
150000
100000


North pole – flight time × elevation
elevation [m]
400000
350000
300000
250000
200000
150000
100000
0
1
2
3
4
flight time [s]
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400000
350000
300000
250000
200000
150000
100000

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- there are still no observations of such meteors

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- upper limit on flux
  - needs precise understanding of selection bias
- observation difficult
  - all-sky cameras
  - telescopes

Conclusion

Validation

- try to simulate real **individual meteors**
- revise the physics in the model
  - does not take body heating into account
  - very simple light emission model
  - not sensitive to Γ

Ultimate goal

- hopefully design a **better model** of meteor flight
  - compare with real meteors
  - use in flux estimations

Find motivation

...all play and no work makes Jack a mere toy.

Harry and Lucy Concluded
Maria Edgeworth (1825)

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- versatile, universal tool
- applicable to **almost any** meteor observing system

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- everything is **open-source**
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- available for anyone (Python required)
- suggestions or comments always welcome

References

- **Öpik, E. J.**: Physics of meteor flight in the atmosphere. Interscience Publishers, 1958.
- **Hill, K. A. – Rogers, L. A. – Hawkes, R. L.**: High geocentric velocity meteor ablation. Astronomy & Astrophysics 444, 615–624 (2005)
- **Jones, W. – Halliday, I.**: Effects of Excitation and Ionization in Meteor Trains. MNRAS vol. 321, 2001, pp417–423.