SIMULATION OF LIGHT PROFILES OF METEORS AND ITS APPLICATIONS TO THE JEM-EUSO PROJECT

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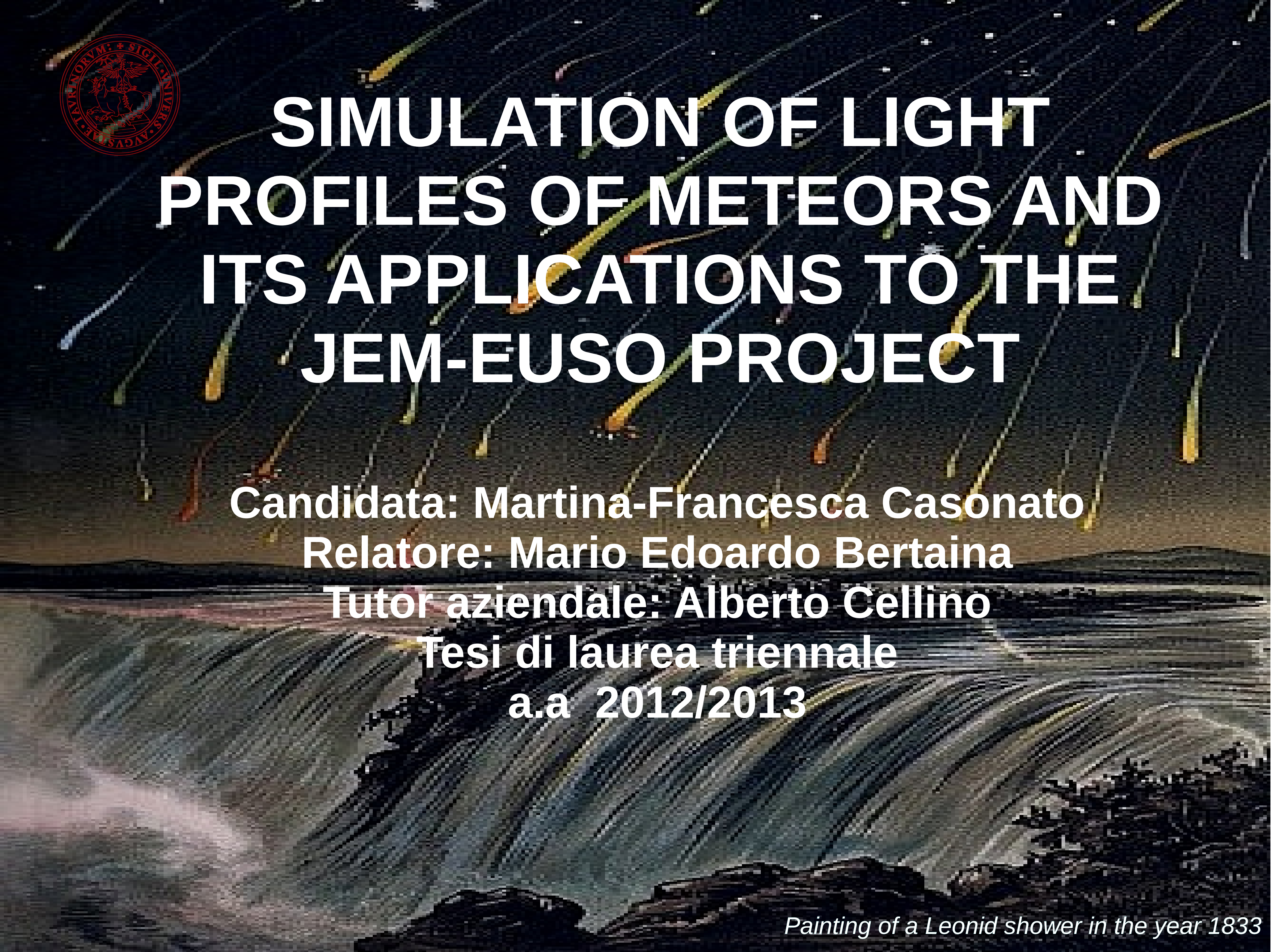
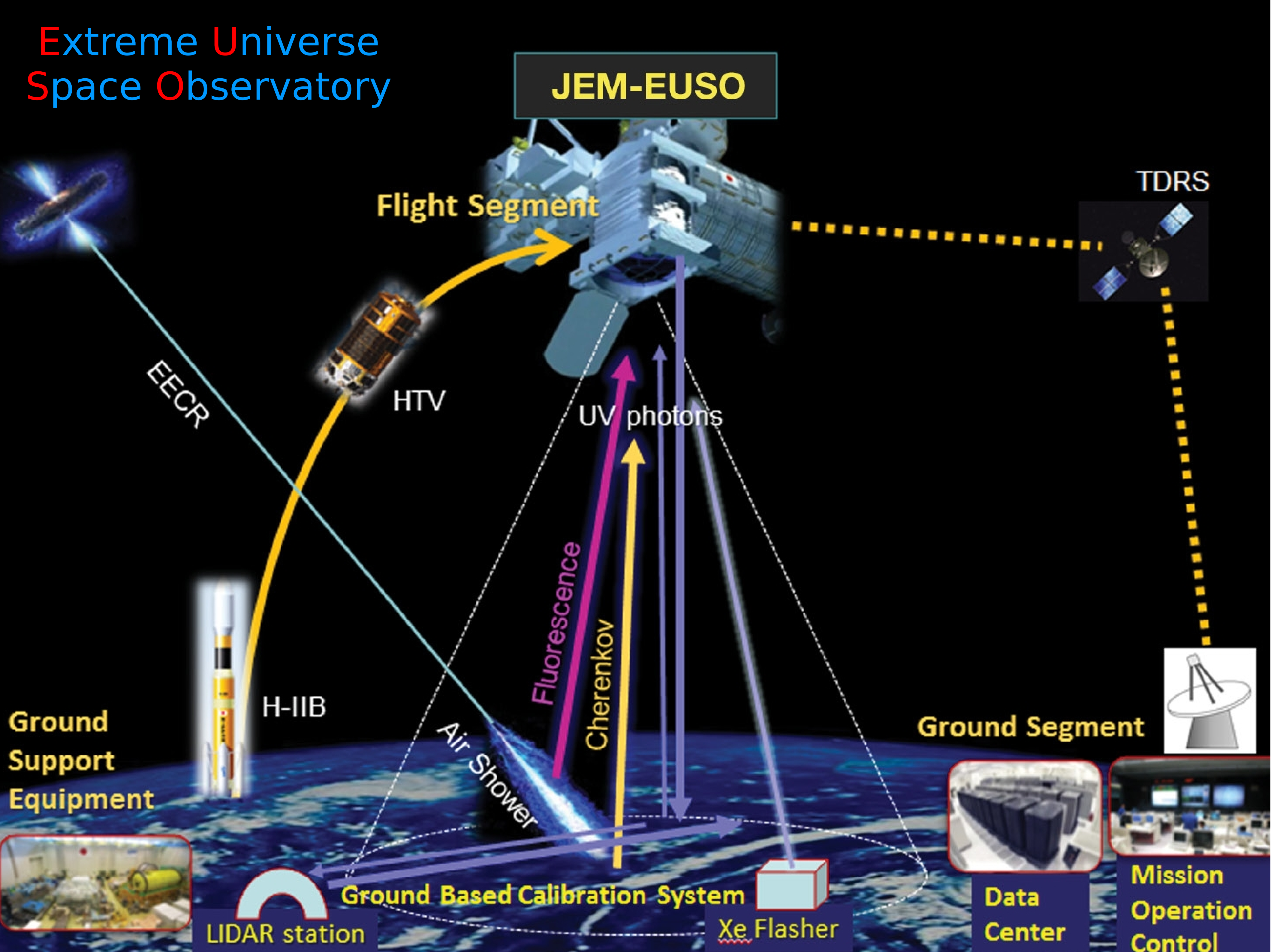
Tesi di laurea triennale
a.a 2012/2013

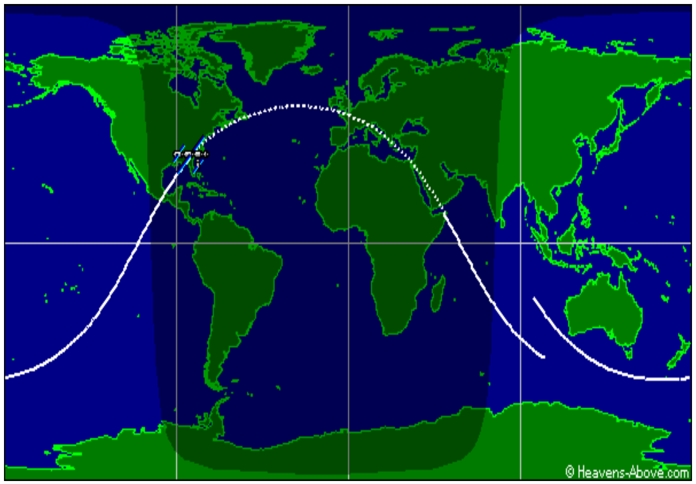


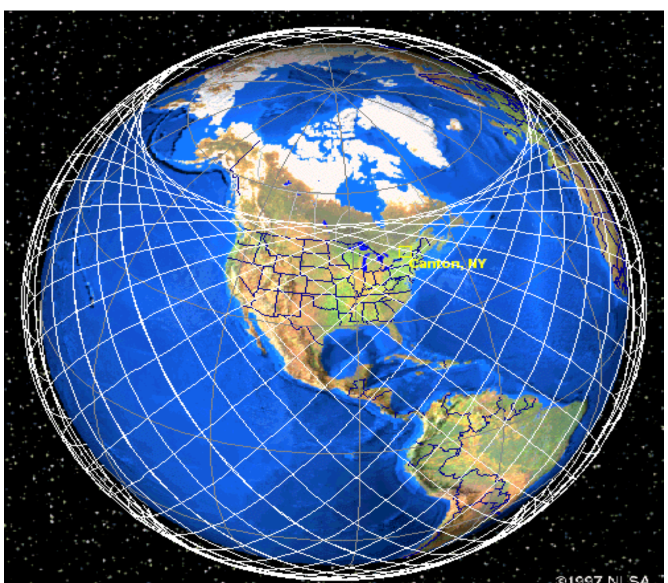
Painting of a Leonid shower in the year 1833


Extreme Universe
Space Observatory
JEM-EUSO
Flight Segment
TDRS
HTV
EECR
UV photons
Fluorescence
Cherenkov
H-IIB
Air Shower
Ground
Support
Equipment
Ground Segment
Ground Based Calibration System
LIDAR station
Xe Flasher
Data
Center
Mission
Operation
Control

What is JEM-EUSO

ISS orbit

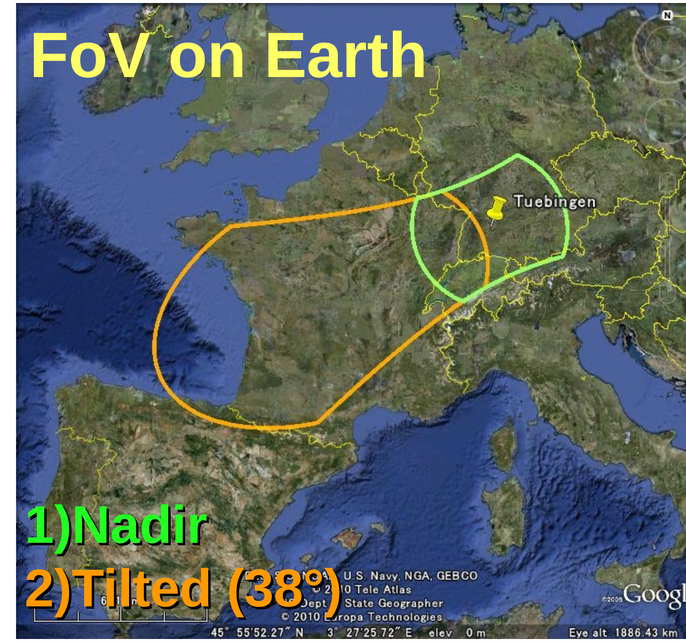


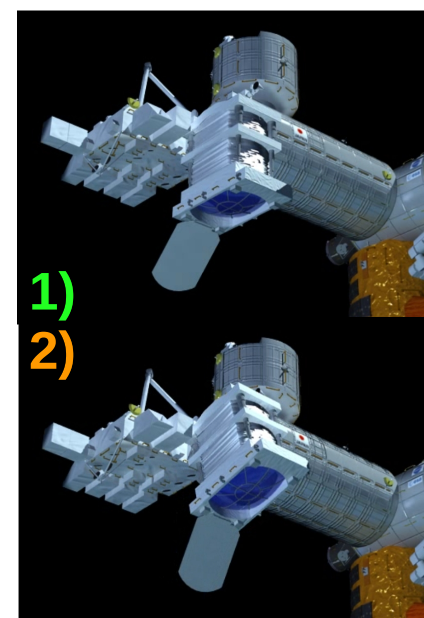


MISSION & INSTRUMENT PARAMETERS

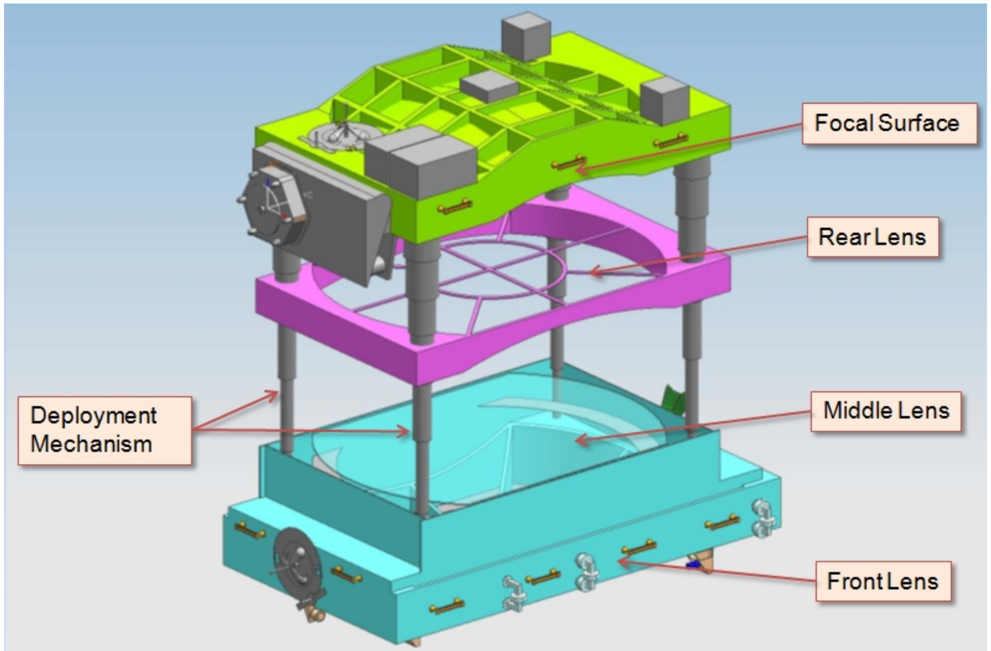
Time of launch: year 2017
Duration: 3 years (+2 years)
Height of the Orbit: ~ 400 km
Latitude & longitude: 51,6° N - 51,6° S (for all longitudes)
Period of the Orbit: 90 mins

Field of view: ± 30°
Observational aperture on the ground area: ~ circle of 250 km radius
Angular resolution: 0.07°
Pixel size at ground: 560 m
Pixel size: 2.9 mm
Number of pixels: ~ 3×10^5
Event time sampling: 2.5 μs = 1GTU
Focal surface area: 4.5 m^2





Optics and electronics



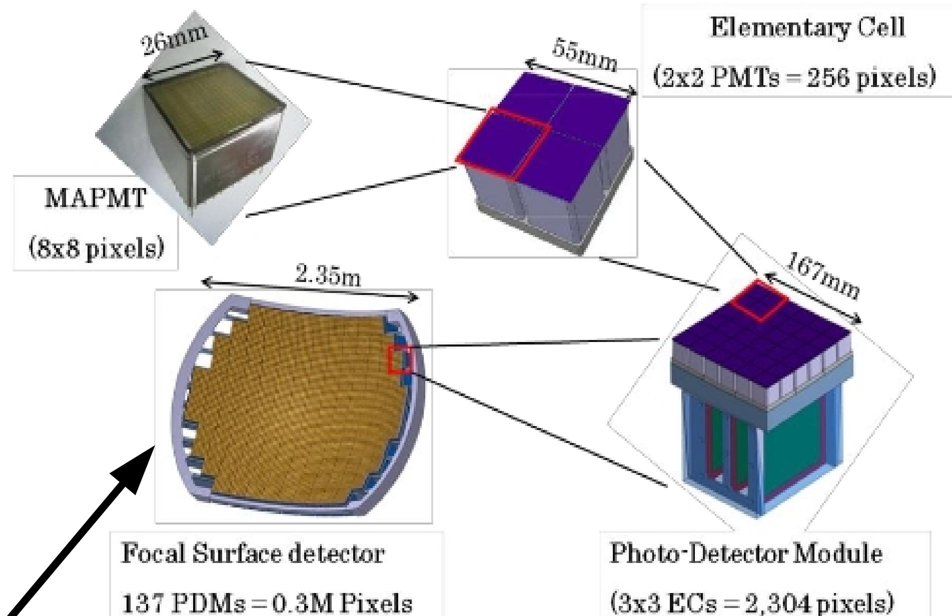
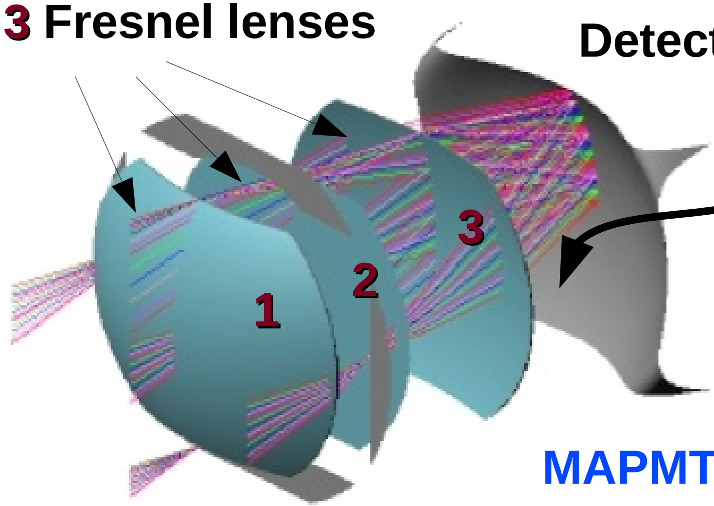


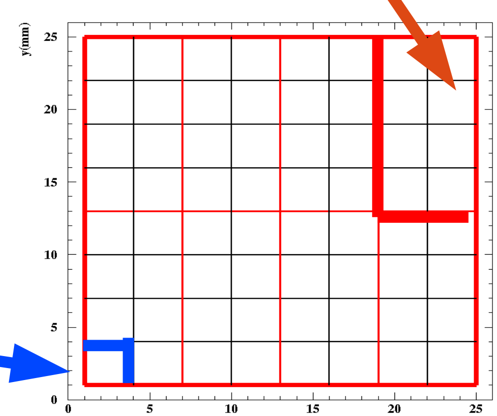
Figure 4.3.1-1. *Focal surface detector and its structure.*

3 Fresnel lenses



Detector Focal Surface

single KI pixel



MAPMTpixel

Working modes:

DIGITAL (MAPMT pixel)

1 – 30 phe/pix/GTU

ANALOG (charge integration)

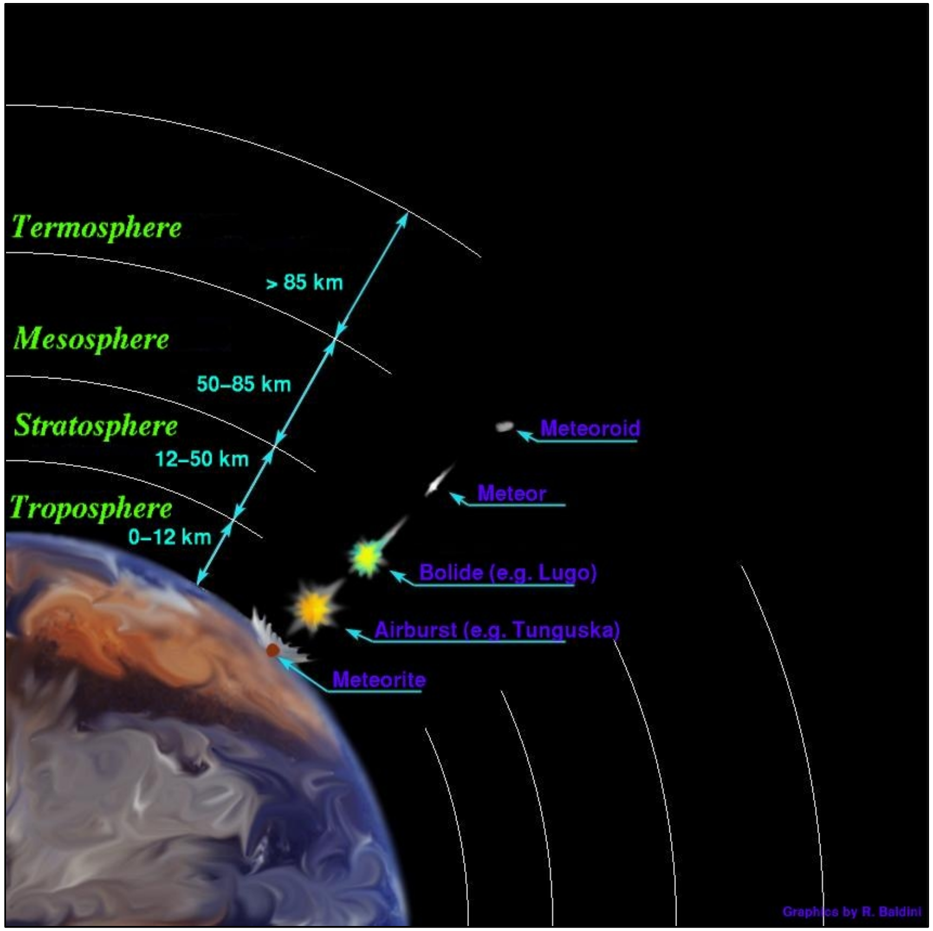
KI pixels = 4 X 2 MAPMT pixels

10 – 10^6 phe/pix/GTU

Gate Time Unit (GTU) = 2.5 µs

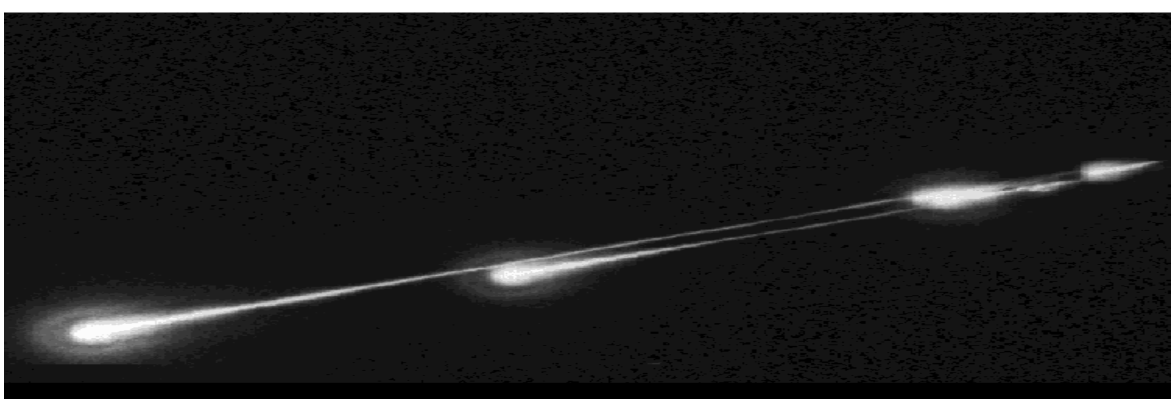
Meteor of the Perseids observed from ISS (Aug. 2011)

- **Beginning point:** ~ 75 ÷ 120 km
- **End point:** ~ 30 ÷ 70 km
- **Duration:** ~ 0.5 ÷ 3 s
- **Length:** ~ 10 ÷ 20 km
- **Type:** sporadic, showers (~ 25% obs. meteors)
- **Frequency:** ~ 5 ÷ 100 per hour
  (up to thousands during meteor storms)
- **Velocity: ~** 12 ÷ 70 km/s
- **Light spectrum**: violet to red



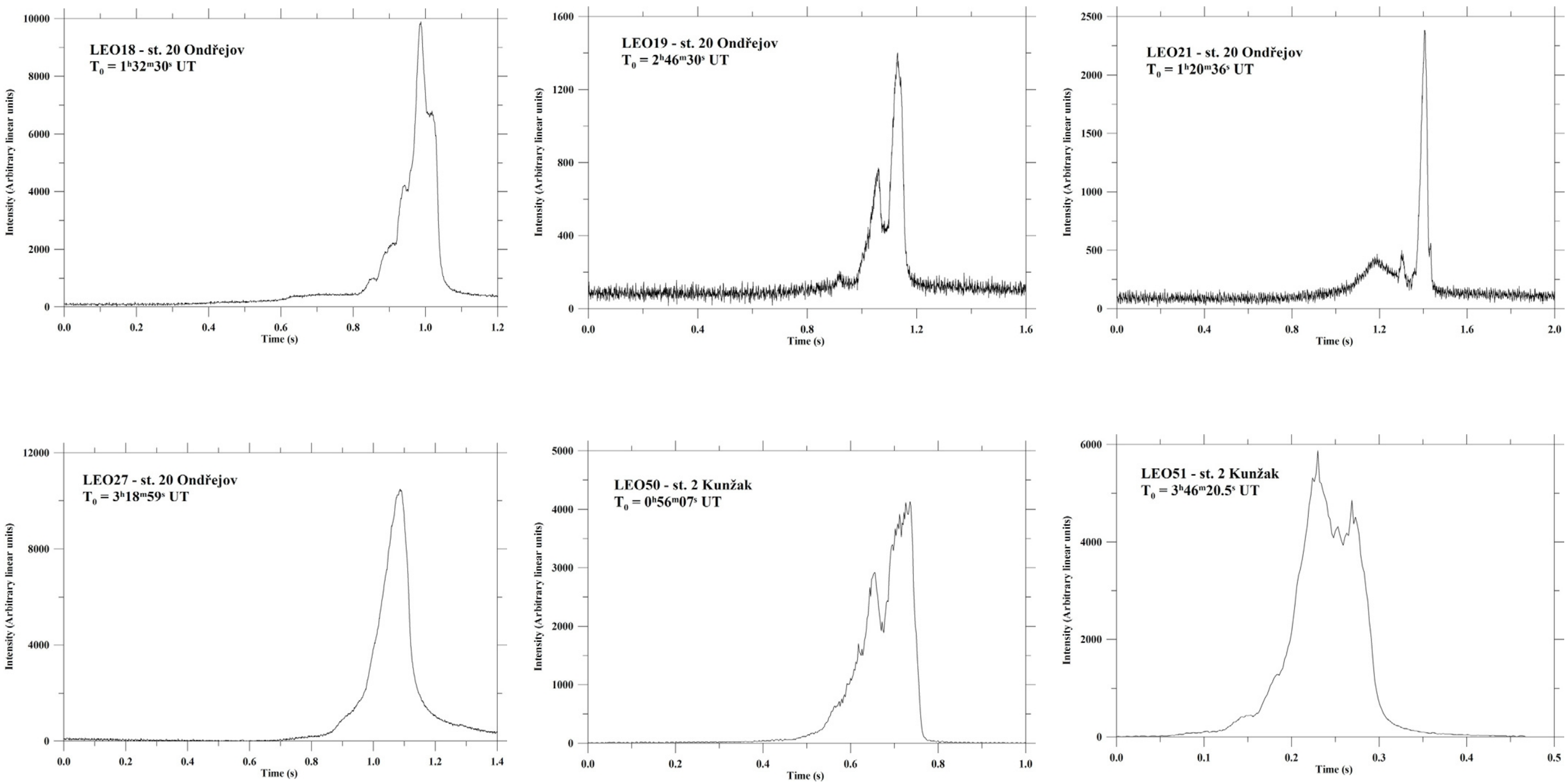
- **M = absolute magnitude**, in the zenith of the observer at a height of 100 km.
- **-5 < M < 7 meteor** (mass 100 g ÷ 2mg)
- **M < - 8 bolide or fireball** (meteoroid mass 10÷100 kg)
- **M < -17 superbolide** (meteoroid mass > 1000 kg)

The Peekskill fireball (Oct. 9, 1992)



Leonid meteor swarm in 2001 taken by Hivison camera

Meteor shower: the Leonids
(from Leo constellation)
Different types of lightcurves



From the article of L. Shrbeny' and P. Spurny', *“Precise data on Leonid fireballs from all-sky photographic records*”, Astronomy & Astrophysics, vol. 506, 1445-1454 (2009).

Meteor & Nuclearite simulation

INPUT

LIGHT CURVE

Meteor: yes/no secondary burst
polynomial coefficients

Nuclearite: M(mass) dependence (only)
emission for $h < h_{max}$

ISS

height of flight

velocity

METEOR
beginning height
yes/no random generation
duration
v_x, v_y, v_z
absolute magnitude
x_0,y_0 of ISS

NUCLEARITE
h_{max}
yes/no random generation
absolute magnitude (mass)
x0,y0 of ISS
v_x, v_y, v_z (any v_z possible)

METEOR / NUCLEARITE

SIMULATOR

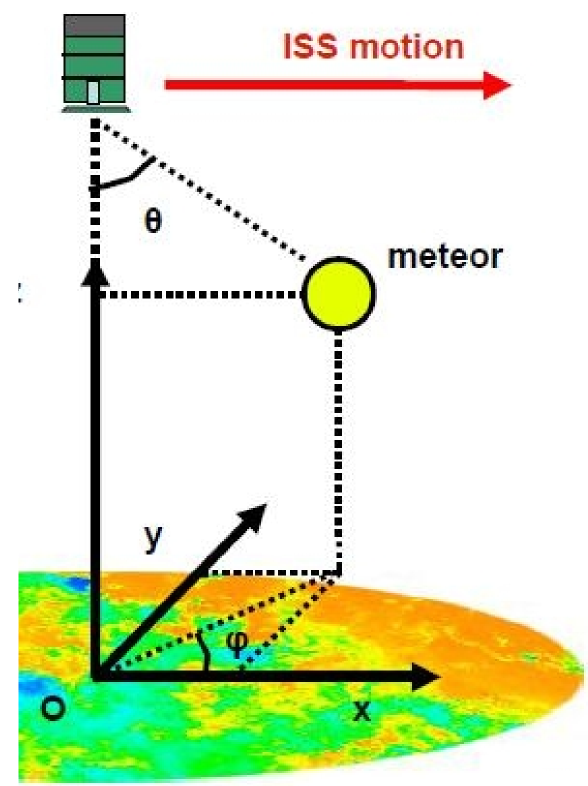
OUTPUT

METEOR/NUCLEARITE
FROM THE GROUND

timestep
x, y, z
flux
x, y, z of the ISS

METEOR/NUCLEARITE
FROM ISS

timestep
x, y, z
flux
zenith angle (θ)
azimutal angle (φ)
x, y (pix)



Computation of the flux

Absolute magnitude (M)	U-band flux (erg/s/cm^2/A)	photons (s^{-1})	photo-electrons (GTU=2.5 μs)$^{-1}$	mass (g)	collisions in JEM-EUSO FoV
7	$6.7 \cdot 10^{-12}$	$4.3 \cdot 10^{7}$	4	$2 \cdot 10^{-3}$	1/s
5	$4.2 \cdot 10^{-11}$	$2.7 \cdot 10^{8}$	23	10^{-2}	6/min
0	$4.2 \cdot 10^{-9}$	$2.7 \cdot 10^{10}$	2300	1	0.27/orbit
-5	$4.2 \cdot 10^{-7}$	$2.7 \cdot 10^{12}$	$2.3 \cdot 10^{5}$	100	6.3/year

Data for a meteor in the zenith, at a height of **100 km** from the ground (**300 km** from the ISS).
The flux of phe (ph) is **on the ISS**.

Absolute magnitude: $M = -2.5 \times \log_{10}[\mathrm{Flux}(h=100)] + C$

Apparent magnitude: $m = -2.5 \times \log_{10}(\mathrm{Flux}(h)) + C$

For **distance = 100 km** *(from the ground)* **:**

$$m = M = -2.5 \log_{10}[\mathrm{Flux}(h)/\mathrm{Flux}(h=100)]$$

$$\mathrm{Flux}(h) = \mathrm{Flux}(h=100) \times 10^{-0.4(m-M)}$$

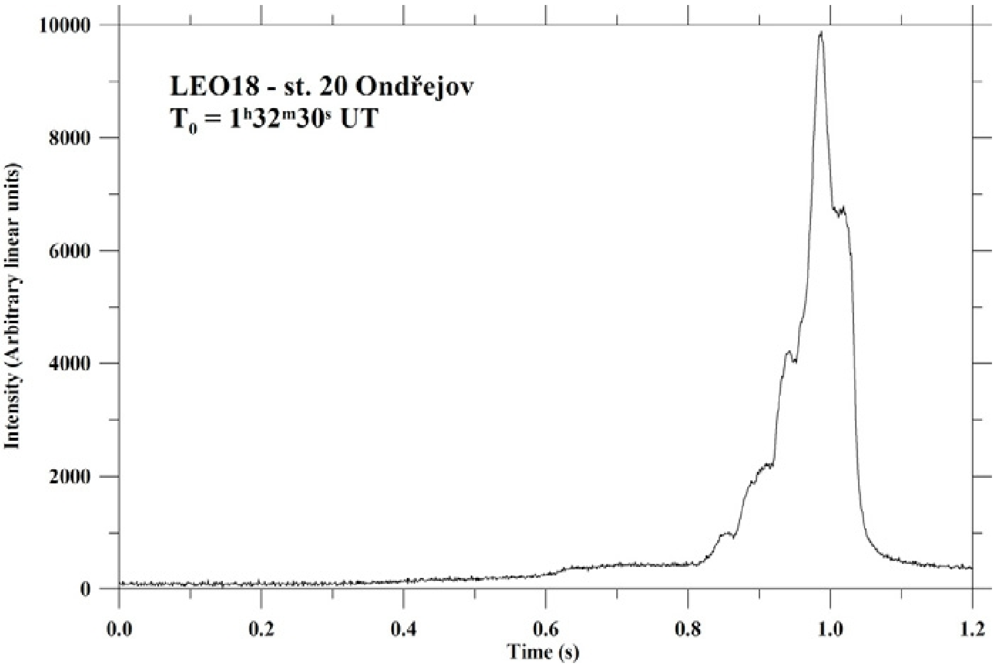
TABLE from "JEM-EUSO:Meteor and Nuclearite observations", submitted to experimental astronomy (JEM-EUSO collaborations).

Leonids Simulations

Physical data on the 1999,2001,2002 and 2006 Leonid fireballs.

Meteor No.	v_{in} *(km/s)*	M_{max}
LEO18	71.30	-11.9
LEO19	71.63	-11.8
LEO21	71.45	-11.5
LEO27	71.59	-13.8
LEO50	71.66	-10.1
LEO51	70	-12.9

$\mathbf{v_{in}}$ = initial velocity
$\mathbf{M_{max}}$ = maximum absolute magnitude



Equation of the light profile

Intensity = function of time:

$$\mathbf{I(t)} = p0 + p1\cdot t + p2\cdot t^2 + p3\cdot t^3 + \ldots$$

polinomy of degree 8

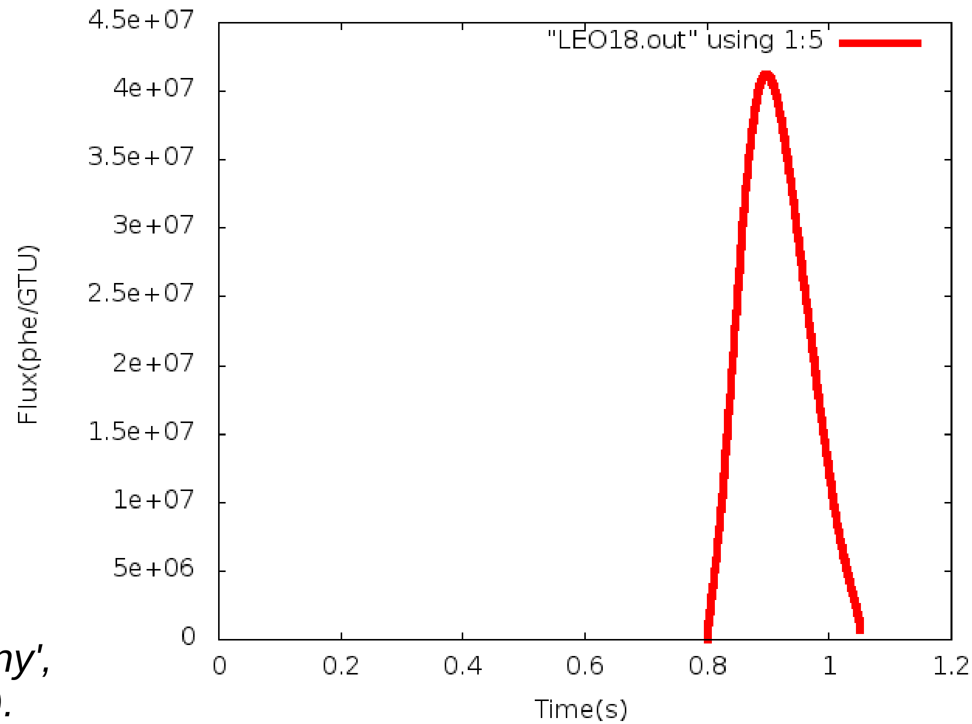
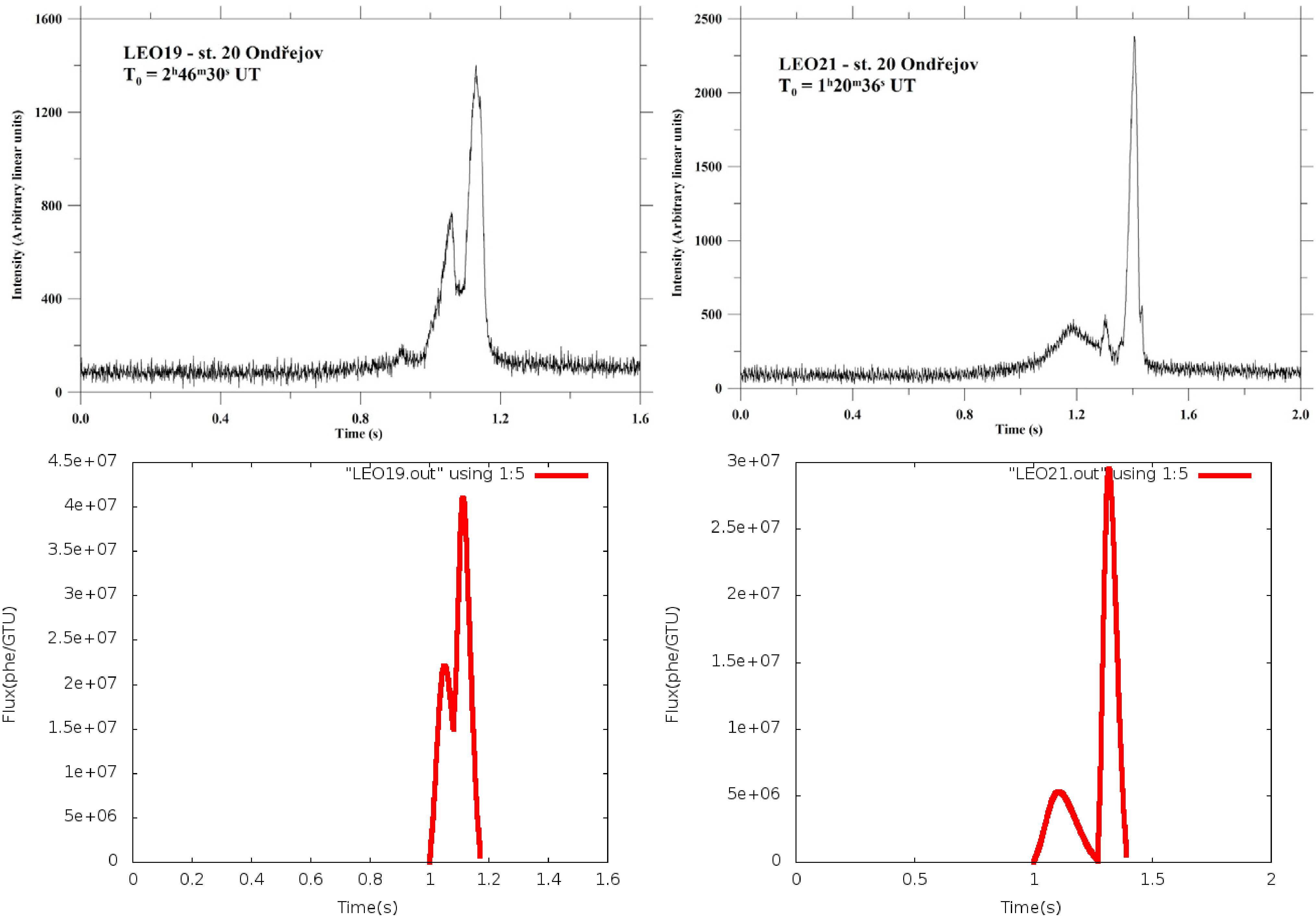
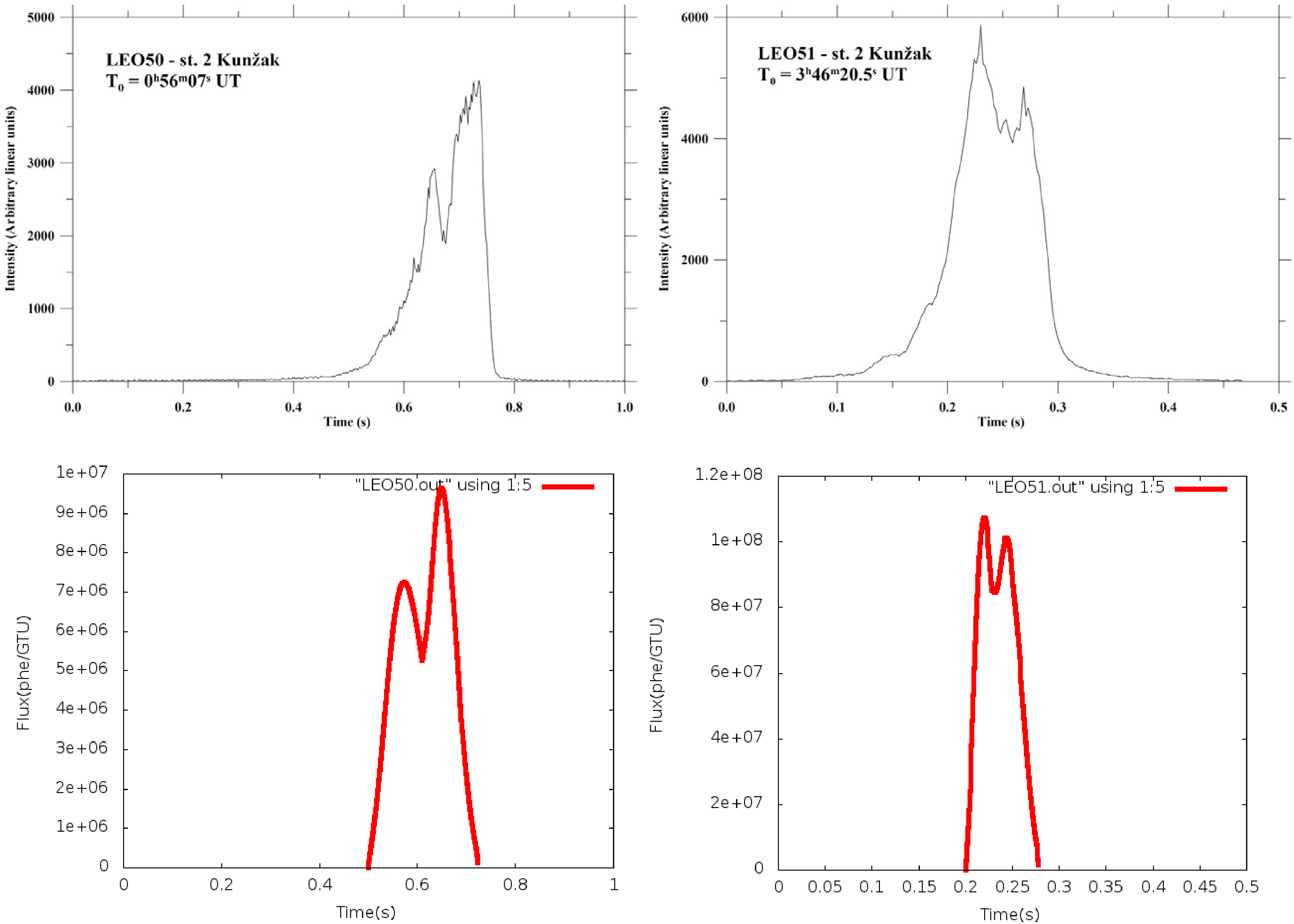


Table taken from the article of L. Shrbeny' and P. Spurny', Astronomy & Astrophysics, vol. 506, 1445-1454 (2009).


LEO19 - st. 20 Ondřejov
T0 = 2h46m30s UT
Intensity (Arbitrary linear units)
Time (s)
LEO21 - st. 20 Ondřejov
T0 = 1h20m36s UT
Intensity (Arbitrary linear units)
Time (s)
"LEO19.out" using 1:5
Flux(phe/GTU)
Time(s)
"LEO21.out" using 1:5
Flux(phe/GTU)
Time(s)



LEO50 - st. 2 Kunžak
T0 = 0h56m07s UT
Intensity (Arbitrary linear units)
Time (s)
LEO51 - st. 2 Kunžak
T0 = 3h46m20.5s UT
Intensity (Arbitrary linear units)
Time (s)
"LEO50.out" using 1:5
Flux(phe/GTU)
Time(s)
"LEO51.out" using 1:5
Flux(phe/GTU)
Time(s)

Meteors out of cone of visibility

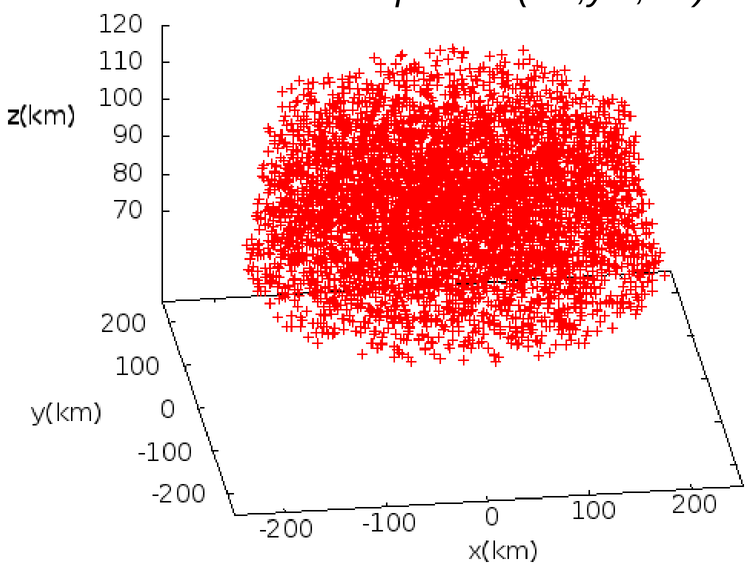
Random generator numerical program

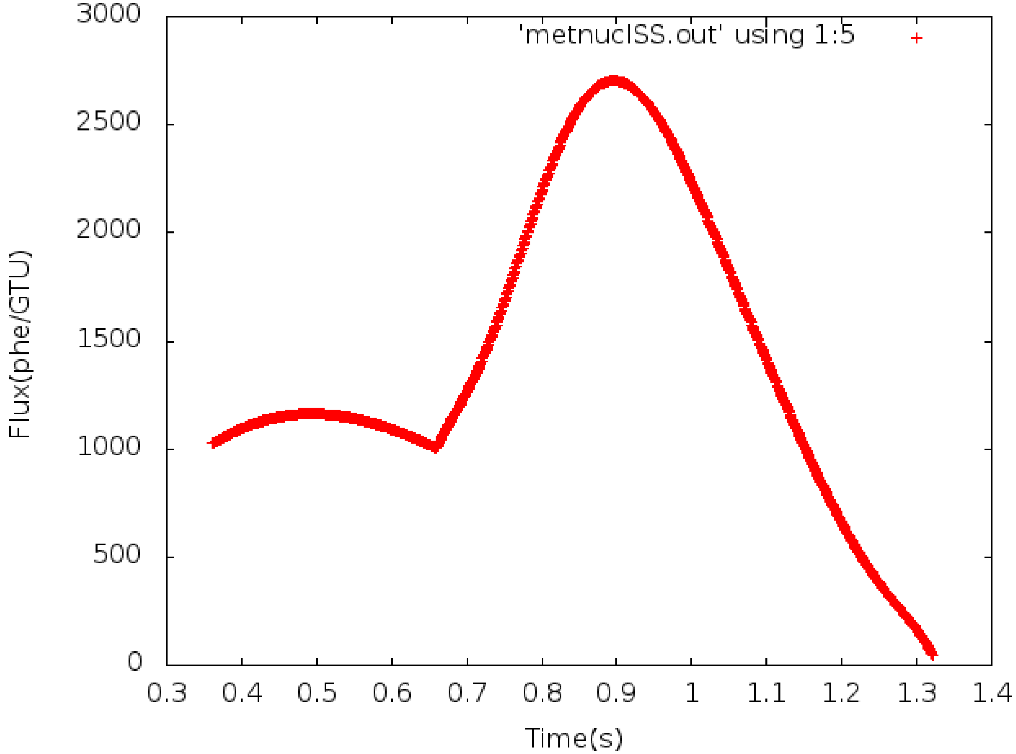
$75 < z_{in} < 120$ km
$30 < z_{fin} < 70$ km
$11 < v < 70$ km/s
$v_{iss} = 7.8$ km/s
duration < 4 s

(yellow) = random
(red) = from data

z_{in}, z_{fin} → $r_{in}(z_{in})$, $r_{fin}(z_{fin})$ (radius) → $x_{in}(r_{in})$, $y_{in}(r_{in})$ → θ,φ → $x_{fin}(x_{in},z_{in},z_{fin},\theta,\varphi)$, $y_{fin}(y_{in},z_{in},z_{fin},\theta,\varphi)$ → v (module), $v_x(\theta,\varphi)$, $v_y(\theta,\varphi)$, $v_z(\theta)$ → duration

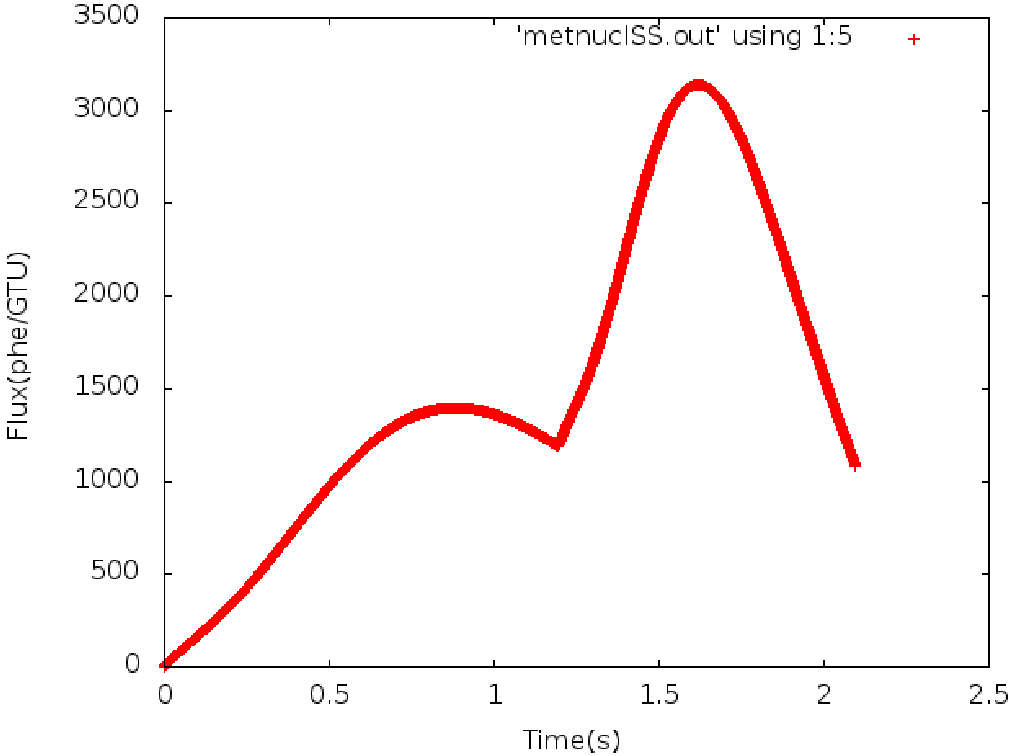
5443 samples of (xin,yin,zin).



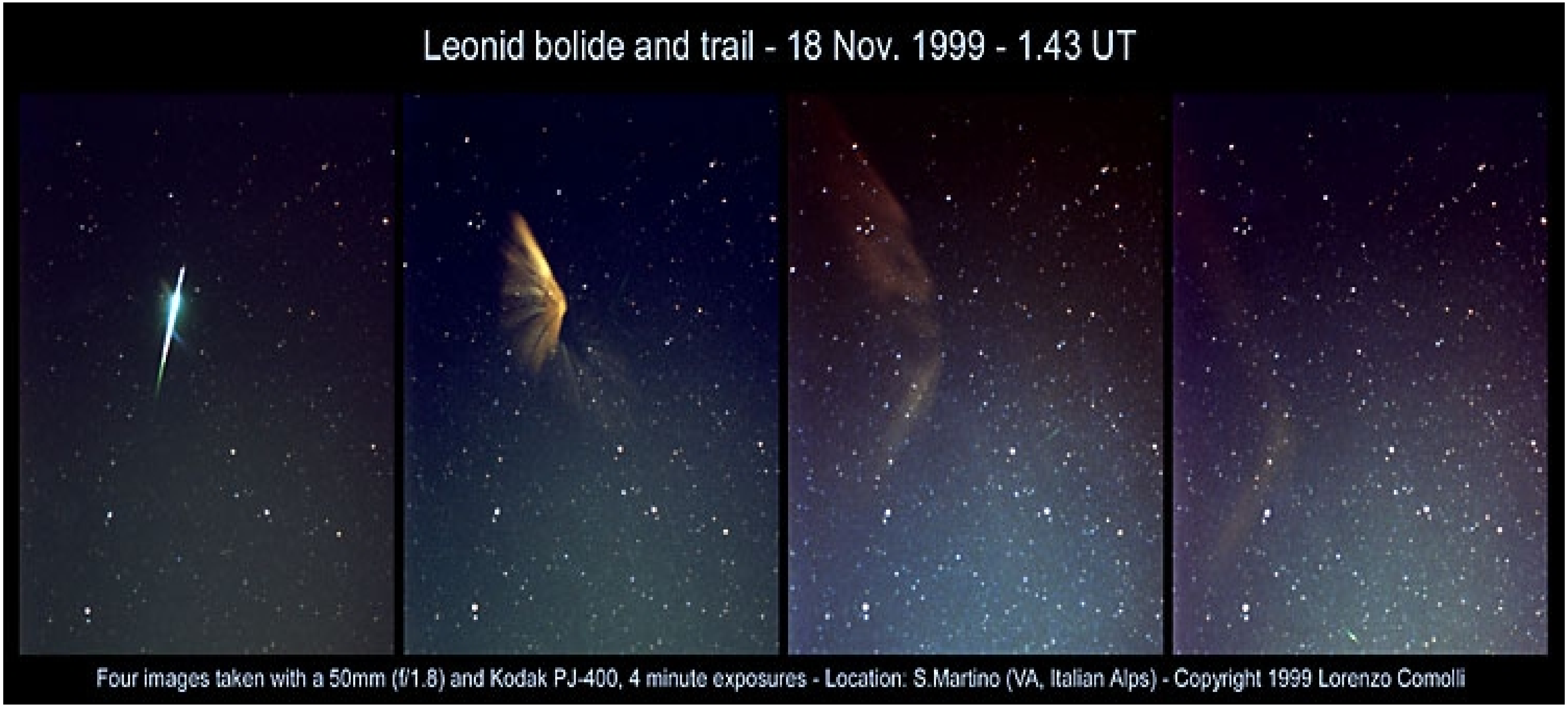


Meteor entering the cone of visibility

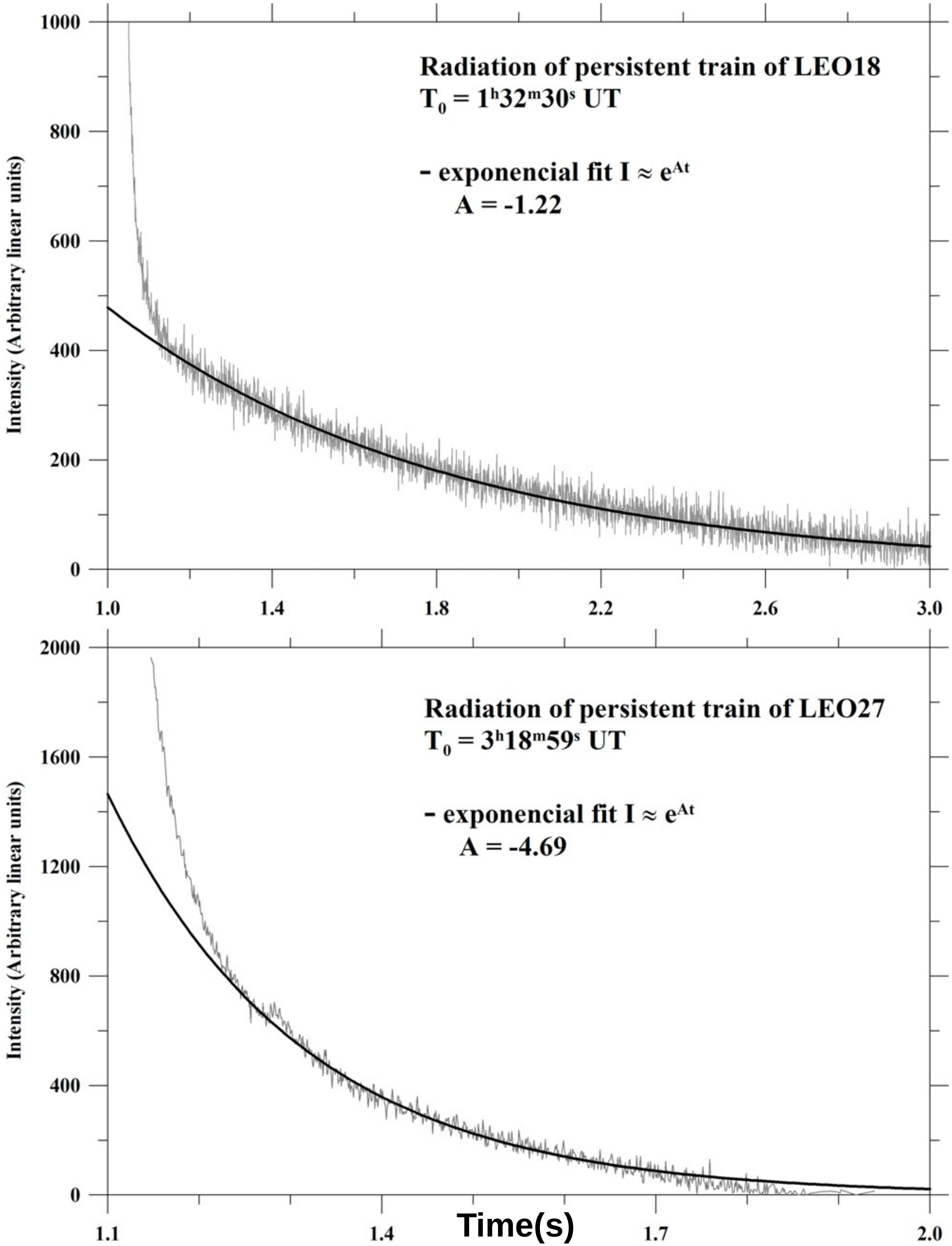
Meteor going out from the cone



THE LIGHT TRACK
persistence of the signal in the atmosphere



Sequence of a 1999 Leonid fireball captured from an observing site in the Italian Alps.
The meteor was brighter than the full moon and left a smoke trail that was visible for more than 20 minutes.
Features of this kind should be observable by the JEM-Euso IR camera.



From the article of L. Shrbeny' and P. Spurny', Astronomy & Astrophysics, vol. 506, 1445-1454 (2009).

- The decrease of intensity is an exponential function of time:

$$I \approx e^{At}$$

A = **negative** damping coefficient [counts/sec]

	A (counts/s)
LEO18	**-1.22**
LEO27	**-4.69**
LEO51	-19.52

- **Sky background**:

10 phe/GTU

no signal persistence for flux below this value(~*full moon*).

Before: only one moving point → **Now**: *"stripes"*, groups of fading points

INPUT = <u>output</u> files of the meteor/nuclearite simulator

Choice of the exponential coefficient A

METEOR/NUCLEARITE FROM ISS

timestep
x, y, z
flux
zenith angle (θ)
azimutal angle (φ)
x, y (pix)

METEOR/NUCLEARITE FROM THE GROUND

timestep
x, y, z
flux
x, y, z of the ISS

LIGHT TRACK SIMULATOR

OUTPUT

LIGHT TRACK FROM THE GROUND

***<u>STRIPES</u>* OF:**
timestep
x, y, z
flux
x, y, z of the ISS

LIGHT TRACK FROM ISS

***<u>STRIPES</u>* OF:**
timestep
x, y, z
flux
zenith angle (θ)
azimutal angle (φ)
x, y (pix)

- <u>First point,</u> **the most brightful**, OLD SIMULATOR DATA
- <u>Other points</u>: flux RECEIVED **ON THE GROUND**

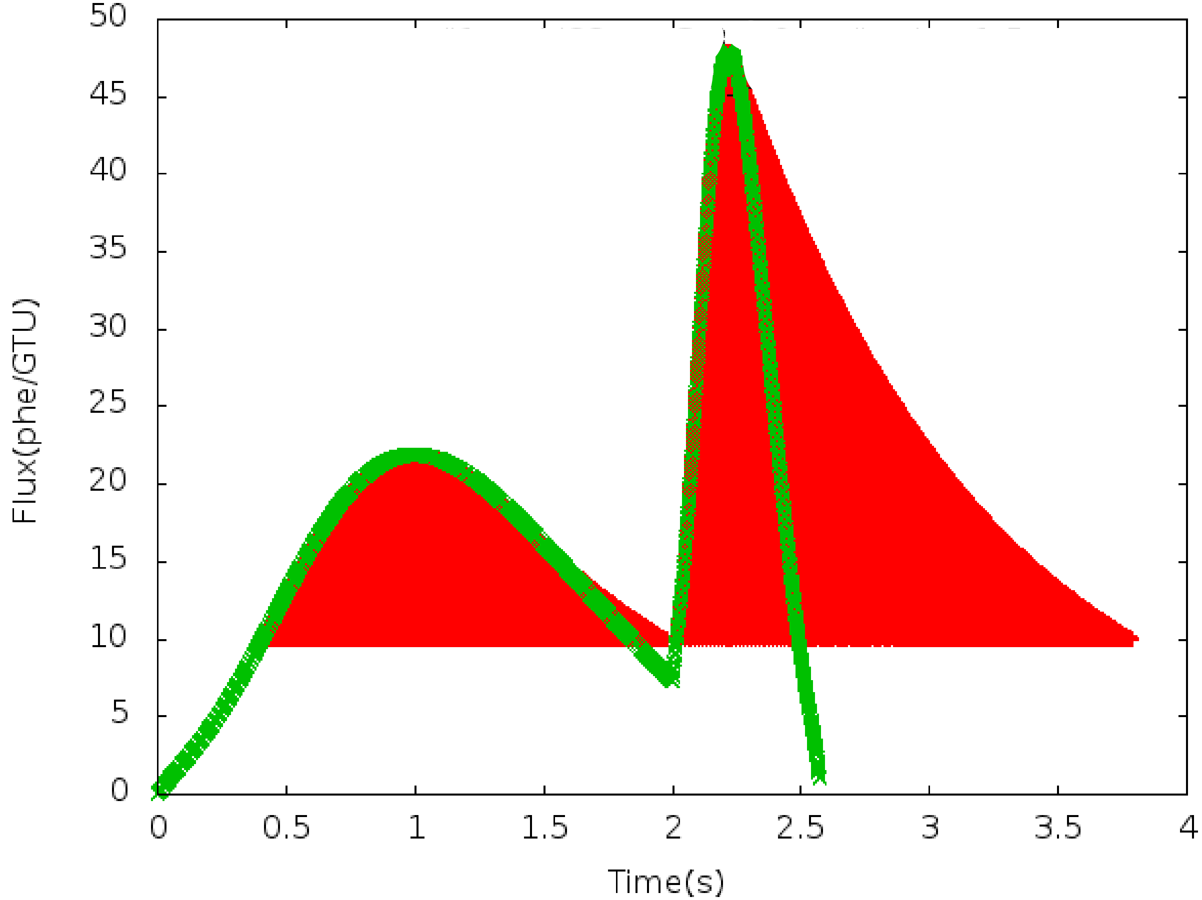
$$I \approx e^{At}$$

- **Flux(ISS)**=Flux(ground) x dist(ground)^2/dist(ISS)^2

Beginning of an output file from ISS: the data are not grouped in stripes

First 4 stripes →

Stripe	Time(s)	x(km)	y(km)	z(km)	Flux (phe/GTU)	Θ (arcsec)	Φ (deg)	x(pix)	y(pix)
1ª	0.028000	-10.064	-9.668	-300.132	10.09877	9584.1	-136.2	-25.60	-24.59
2ª	0.029000	-10.066	-9.656	-300.137	10.43528	9579.2	-136.2	-25.60	-24.56
	0.030000	-10.074	-9.656	-300.137	10.22863	9583.0	-136.2	-25.62	-24.56
	0.031000	-10.082	-9.656	-300.137	10.02608	9586.9	-136.2	-25.64	-24.56
3ª	0.030000	-10.069	-9.644	-300.142	10.77082	9574.7	-136.2	-25.61	-24.53
	0.031000	-10.077	-9.644	-300.142	10.55753	9578.6	-136.3	-25.63	-24.53
	0.032000	-10.085	-9.644	-300.142	10.34846	9582.4	-136.3	-25.65	-24.53
	0.033000	-10.092	-9.644	-300.142	10.14352	9586.3	-136.3	-25.67	-24.53
4ª	0.031000	-10.071	-9.633	-300.146	11.10570	9570.2	-136.3	-25.61	-24.50
	0.032000	-10.079	-9.633	-300.146	10.88578	9574.1	-136.3	-25.63	-24.50
	0.033000	-10.086	-9.633	-300.146	10.67021	9578.0	-136.3	-25.65	-24.50
	0.034000	-10.094	-9.633	-300.146	10.45890	9581.8	-136.3	-25.67	-24.50
	0.035000	-10.102	-9.633	-300.146	10.25179	9585.7	-136.4	-25.69	-24.50
	0.036000	-10.110	-9.633	-300.146	10.04877	9589.6	-136.4	-25.71	-24.50



$\sim e^{At}$

A= -1

Abs mag 3

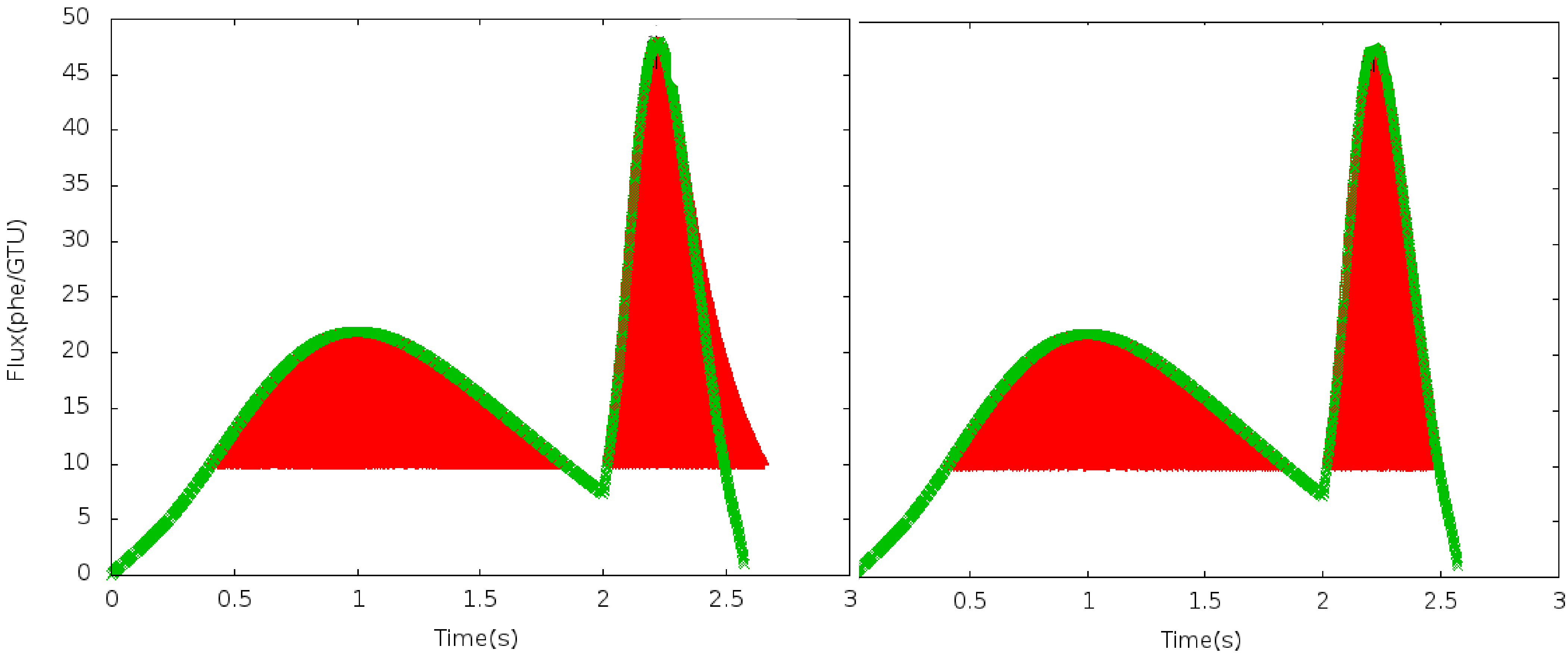
with persistence (train)

NO persistence (head)

with persistence

NO persistence

Abs mag
3



$\sim e^{At}$

A= - 4

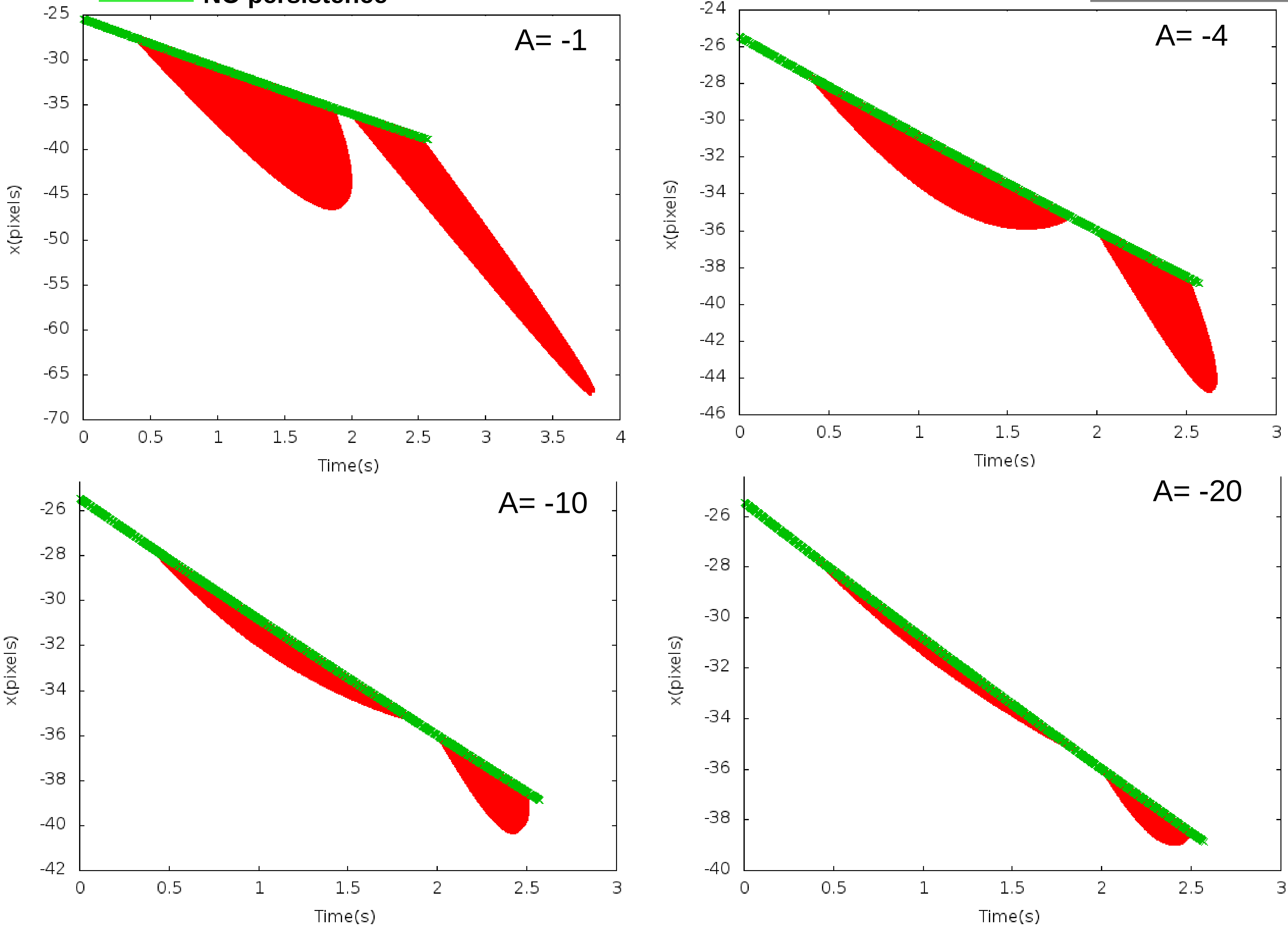
A= - 20

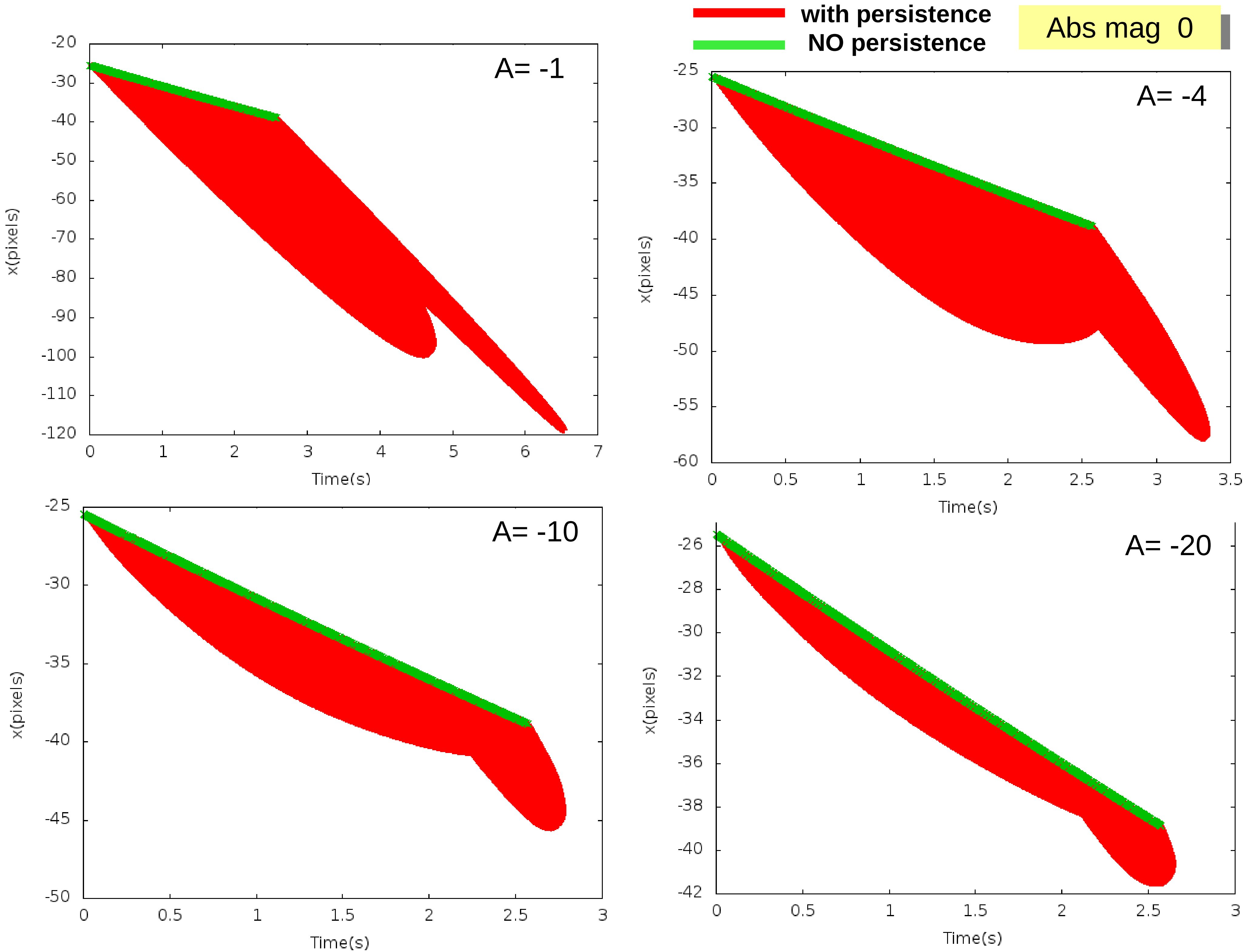
X (PIXELS) IN FUNCTION OF TIME

Abs mag 3

with persistence

NO persistence




with persistence
NO persistence
Abs mag 0
A= -1
A= -4
A= -10
A= -20
x(pixels)
Time(s)

How to determine a meteor trajectory and velocity from its persistence train in the atmosphere

Divide the output file into groups of stripes

↓

Find z for each stripes with this formula, using the first term ("1"), fixed, and changing the others("2")

↓

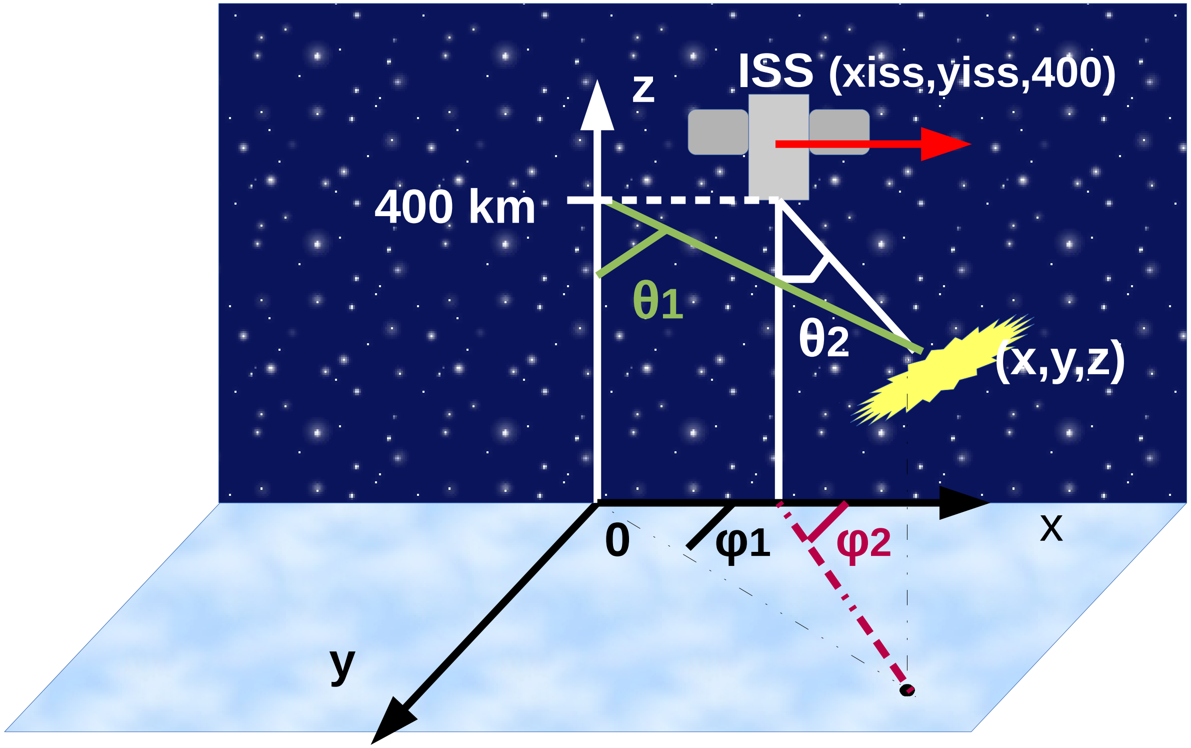
Find x , y
v_x , v_y , v_z
(with their errors)

Development of another numerical program

$$y = yiss(t_0)+\tan(\varphi)\cdot[x-xiss(t_0) - v\cdot t]$$

$$x = xiss+v\cdot t+(z-400)\cdot\tan(\theta)/\sqrt{1+\tan(\varphi)^2}$$

$$z = 400 - v\cdot t/ \{tg[\theta 2]/\sqrt{(1+\tan[\varphi 2]^2)} - \{tg[\theta 1]/\sqrt{(1+\tan[\varphi 1]^2)}\}$$



Results

- *Font: light track output file with* ***A= -1*** *and* ***abs mag = 3****.*
- *Total stripes:* ***4717***
- *There are selected* ***three samples*** *from three different stripes of the output file.*

N°	x (km)	$\pm\sigma_x$ (km)	x expected (km)	y (km)	$\pm\sigma_y$ (km)	y expected (km)	z (km)	$\pm\sigma_z$ (km)	z expected (km)
1	-1.2	1.5	-0.1	6.2	0.7	6.2	96.7	1.6	97.5
2	-3.5	1.0	-2.1	17.6	0.8	17.5	91.0	2.1	93.0
3	-6.0	0.9	-5.4	28.7	1.2	28.6	86.9	3.6	88.6

Expected value of x, y and z refers to the most brightful point of each stripe.

	km/s	$\pm\sigma_v$ (km/s)	Expected value (km/s)
vx	2.1	1.7	5.5
vy	10.5	1.0	11.9
vz	-5.2	2.4	-4.2

v module (km/s)	$\pm\sigma_v$ (km/s)	Expected value (km/s)
11.9	3.1	13.8

Expected value of velocity is given by the input file.

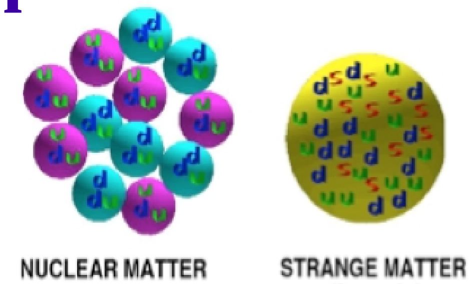
- Time error = **0.5 ms**
- Angle φ error: *given by the propagation formula, where* φ = arctan(y_{pix}/x_{pix})
- σx_{pix}, σy_{pix} = **± 1 pixel**
- Angle θ error = **0.075° = 270 arcsec = 1pixel**
- *The associate errors are all calculated using the propagation formula.*

Conclusions

- A simulation of different meteors light profiles as seen from JEM-EUSO has been performed, on the evidence coming from ground based photographic records.
- Starting from ISS measurements of θ & φ angles and taking profit of the persistence of the signal in the atmosphere, it is possible to find position and velocity vectors of a meteor during its passage in the JEM-EUSO field of view.
- A study of the answer in pixels of JEM-EUSO focal detector can be done in future using these data.


Thank you

Criteria to identify Nuclearites in Jem-Euso and differences with meteors



- **Speed**: **meteor** up to 70 km/sec, Dark Matter **nuclearites** ~ 300km/sec
 (nuclearite max velocity value→ 570 km/s meteor max value → 72 km/s)

- **Light profile**: in **meteors** the light starts immediately and then decreases due to the mass ablation; most of the meteors doesn't reach earth.

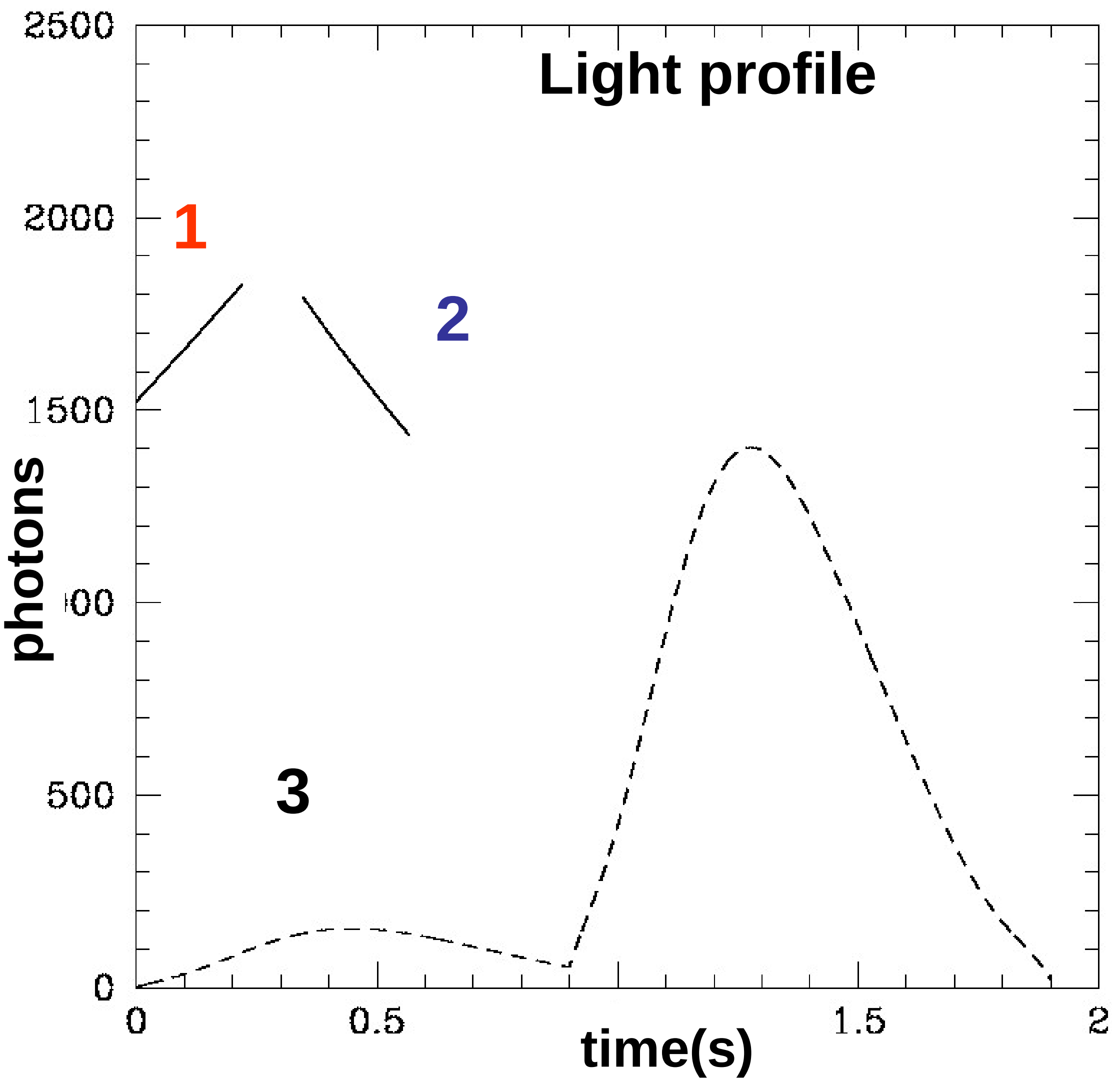
On the contrary **nuclearites** are very compact objects, the energy loss is similar to the one of an elementary particle.
No mass ablation.
The light emission is constant at $h \leq h_{max}$ (very low altitudes).

$h_{max} = 2.7 \cdot \ln (m / 1.2 \cdot 10^{-5}\ g)$ km (m: 0.1 – 100 g → h_{max}: 24 – 60 km)

$M = 15.8 - 1.67 \cdot \log_{10} (m / 1\ \mu g)$ (m: 0.1 – 100 g → M: 7.5 – 2.5)

A nuclearite of mass > 0.1 g should cross the entire earth and **can move upward.**
JEM-EUSO could detect also upward going nuclearites.

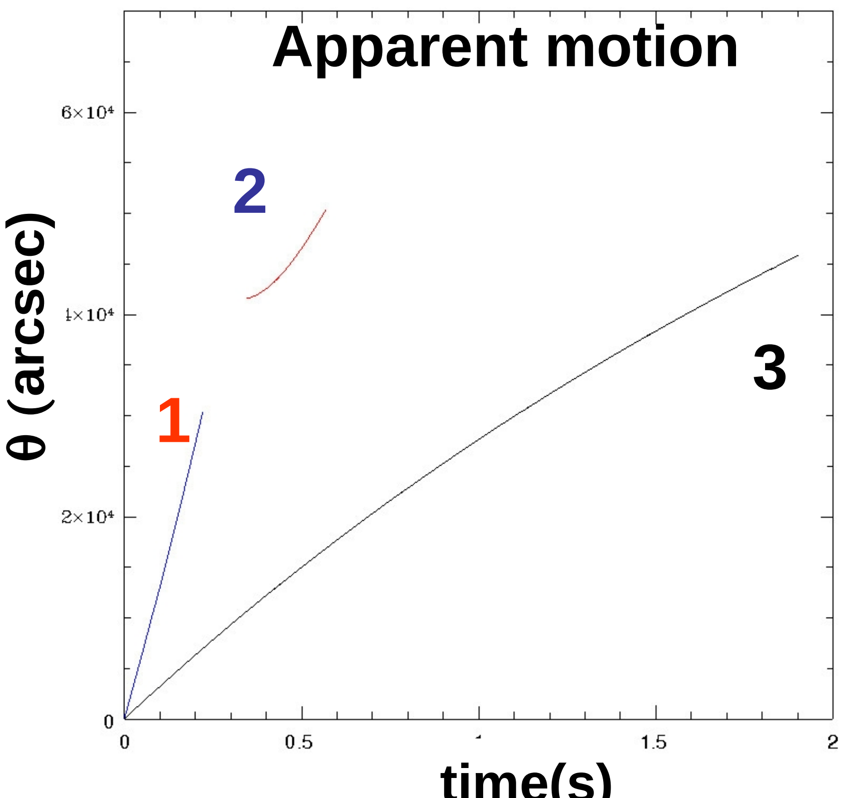
Nuclearites and meteors comparison



1) up-ward going nuclearite
m = 20 g, v = 250 km/s, θ = 45°
h = 40 km → 0.0001 km

2) down-ward going nuclearite
m = 20 g, v = 250 km/s, θ = 45°

3) Meteor
v = 70 km/s, θ = 45°, h = 100 km,
Abs mag = 1.7, Abs mag sec burst = -1



Nuclearites are much faster than meteors !!!

Graphics done in collaboration with Giulia Bruno.