Osservazione di meteore dal telescopio spaziale Mini-EUSO sulla ISS

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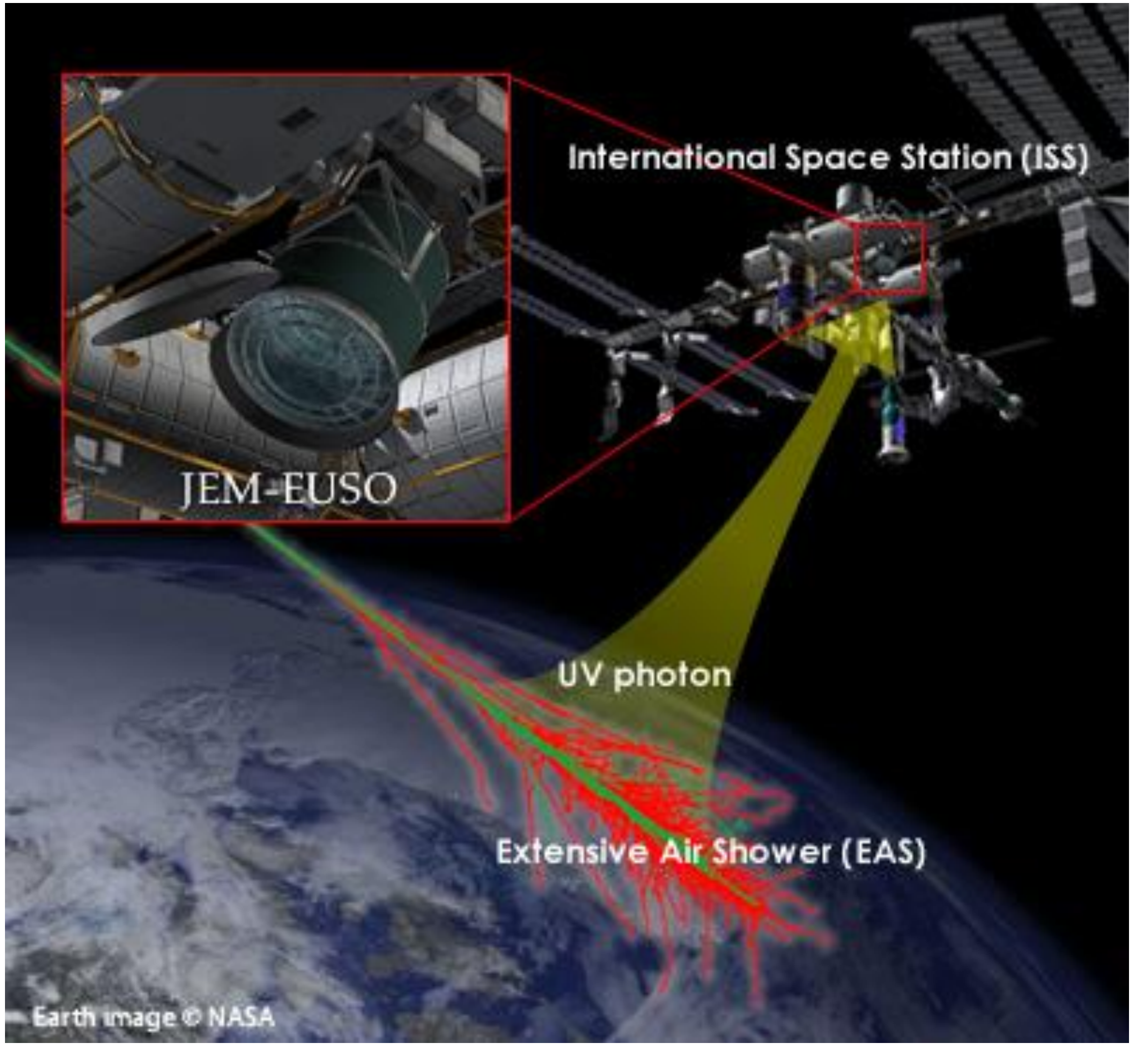
The JEM-EUSO program

Joint **E**xperiment **M**issions for
Extreme **U**niverse **S**pace **O**bservatory

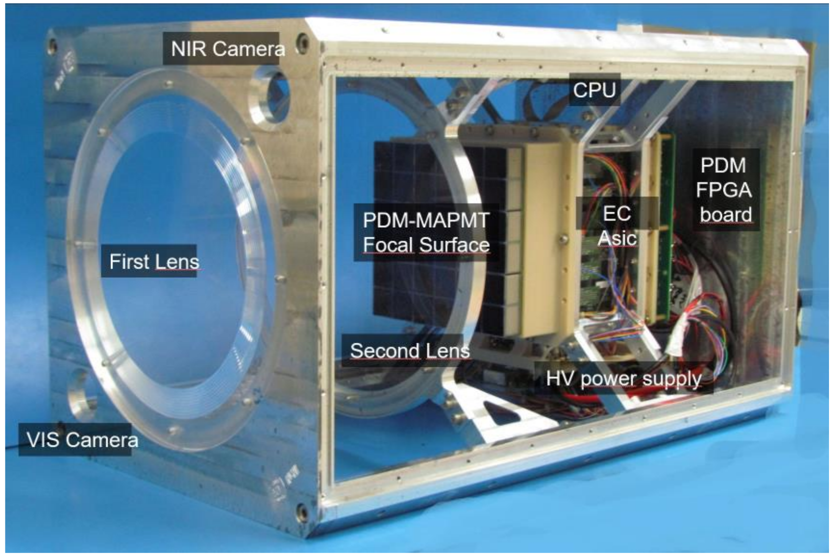
- **Main goal**: detection from space of UV fluorescence and Cherenkov light from Extensive Air Showers (EAS) produced by Ultra High Energy Cosmic Rays (UHECR, $E \geq 10^{19}$ eV)
- Other scientific objectives:
  - Night UV emission, airglow
  - Space debris
  - **Meteors**
  - Nuclearites (SQM)
  - Lightnings, TLEs



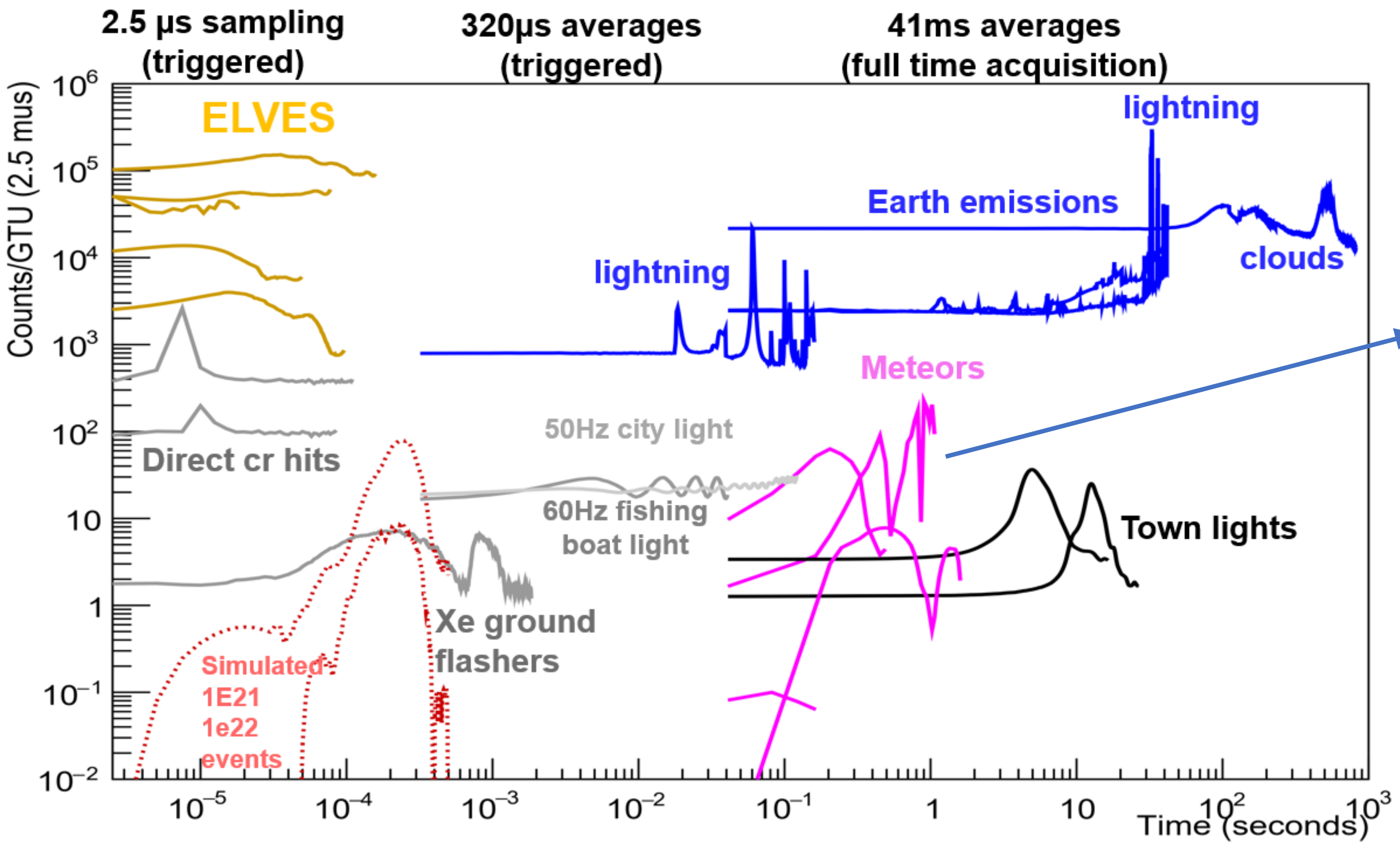
The Mini-EUSO telescope

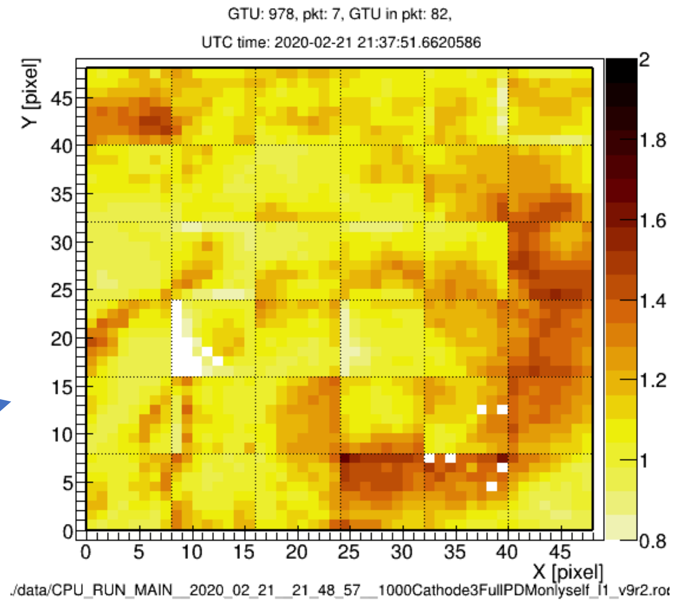
Multiwavelength **I**maging **N**ew **I**nstrument for **E**xtreme **U**niverse **S**pace **O**bservatory

- Installed on the nadir-facing UV transparent window in the Russian **Zvezda module of the ISS on 7 October 2019** (Beyond mission, Luca Parmitano)
- Small-size detector (37 x 37 x 62 cm^3) equipped with two Fresnel lenses, **Ø 25 cm**
- **UV range** (290 – 430 nm)
- 48 x 48 pixels in single photon counting mode for a 44° x 44° FOV (pixel res. on ground **~6.5 km**)
- Three timescales: D1 (2.5 µs), D2 (320 µs) and **D3 (40.96 ms)**



Mini-EUSO observations

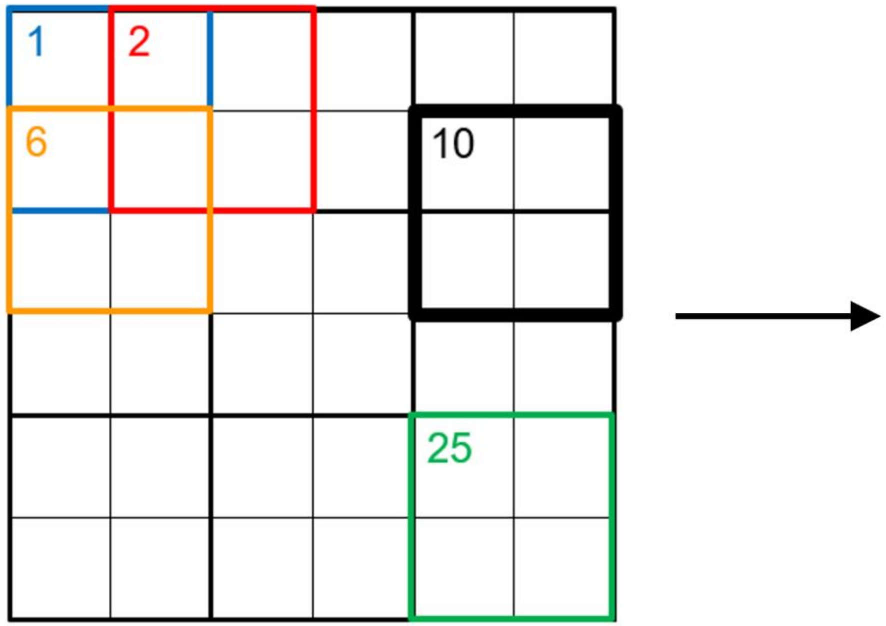




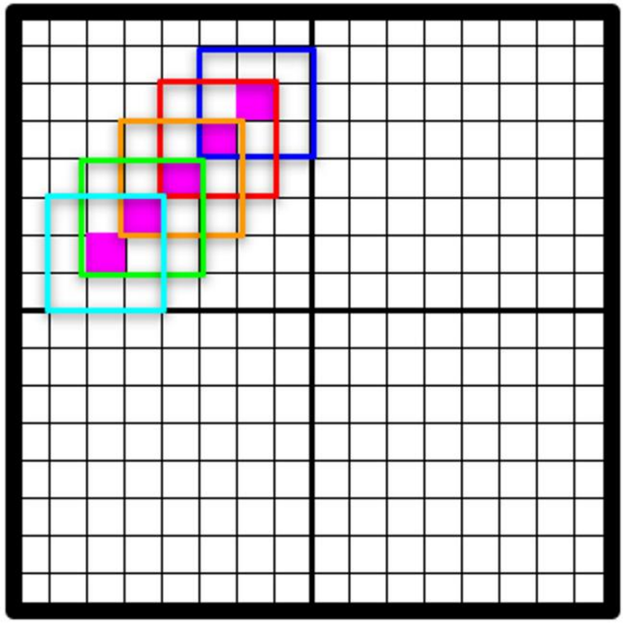
Meteor trigger

- Scanning D3 data for **tracks of over-threshold pixels over 4 consecutive GTUs**
- Threshold is computed at the pixel level as:

$$\begin{cases} \mu_{xy}(t) = \frac{1}{16}\sum_{k=t-16}^{t-1} C_{xy}(k) \\ \sigma_{xy}(t) = \sqrt{\frac{1}{16}\sum_{k=t-16}^{t-1}[C_{xy}(k) - \mu_{xy}(t)]^2} \end{cases} \rightarrow \quad T_{xy}(t) = \mu_{xy}(t) + 3\sigma_{xy}(t)$$

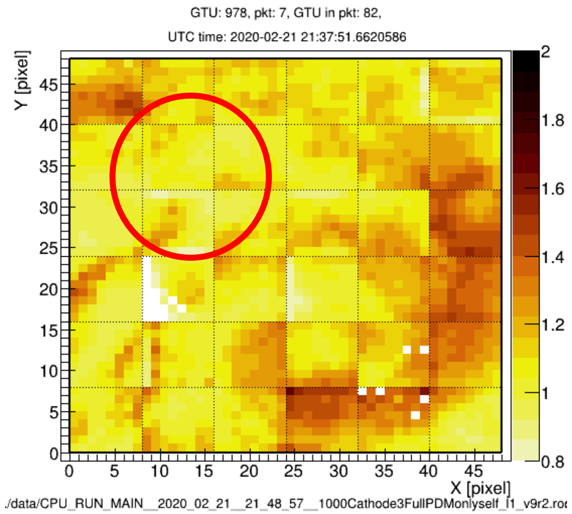


(a) Scan 25 «virtual» ECs (Elementary Cells) over 9 «physically existing» ECs

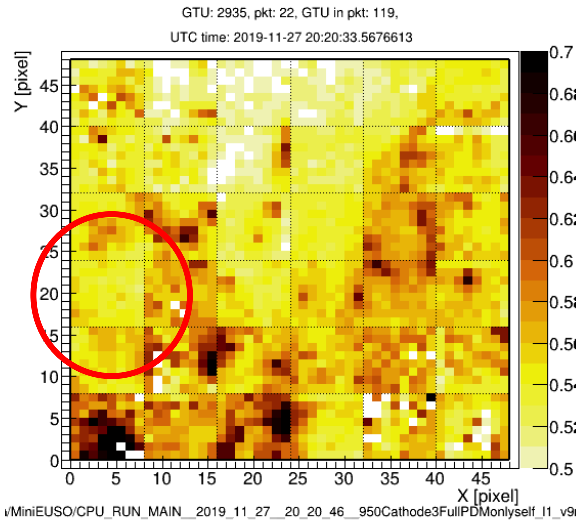


(b) Trigger: excess on the neighboring pixels lasting 4 consecutive GTUs

Examples of events

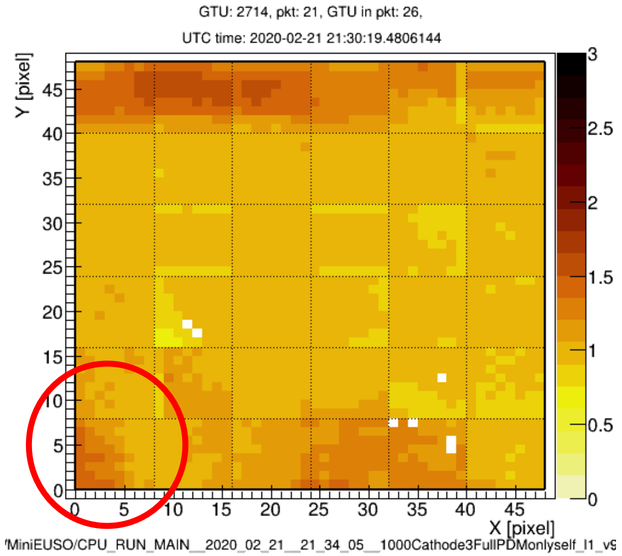


Meteors (M)

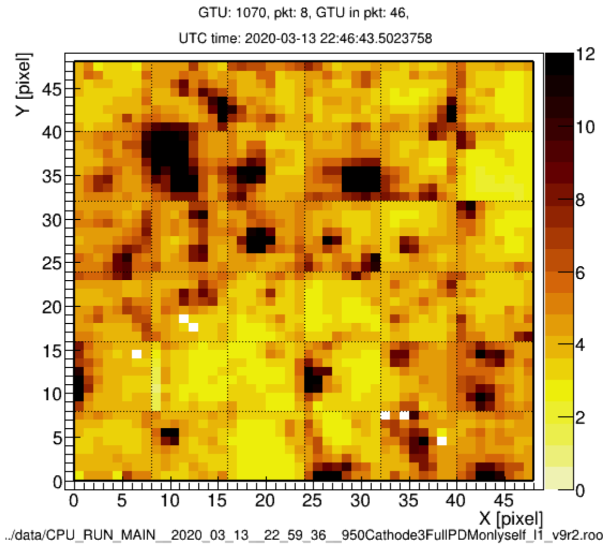


Meteor candidates (M?)

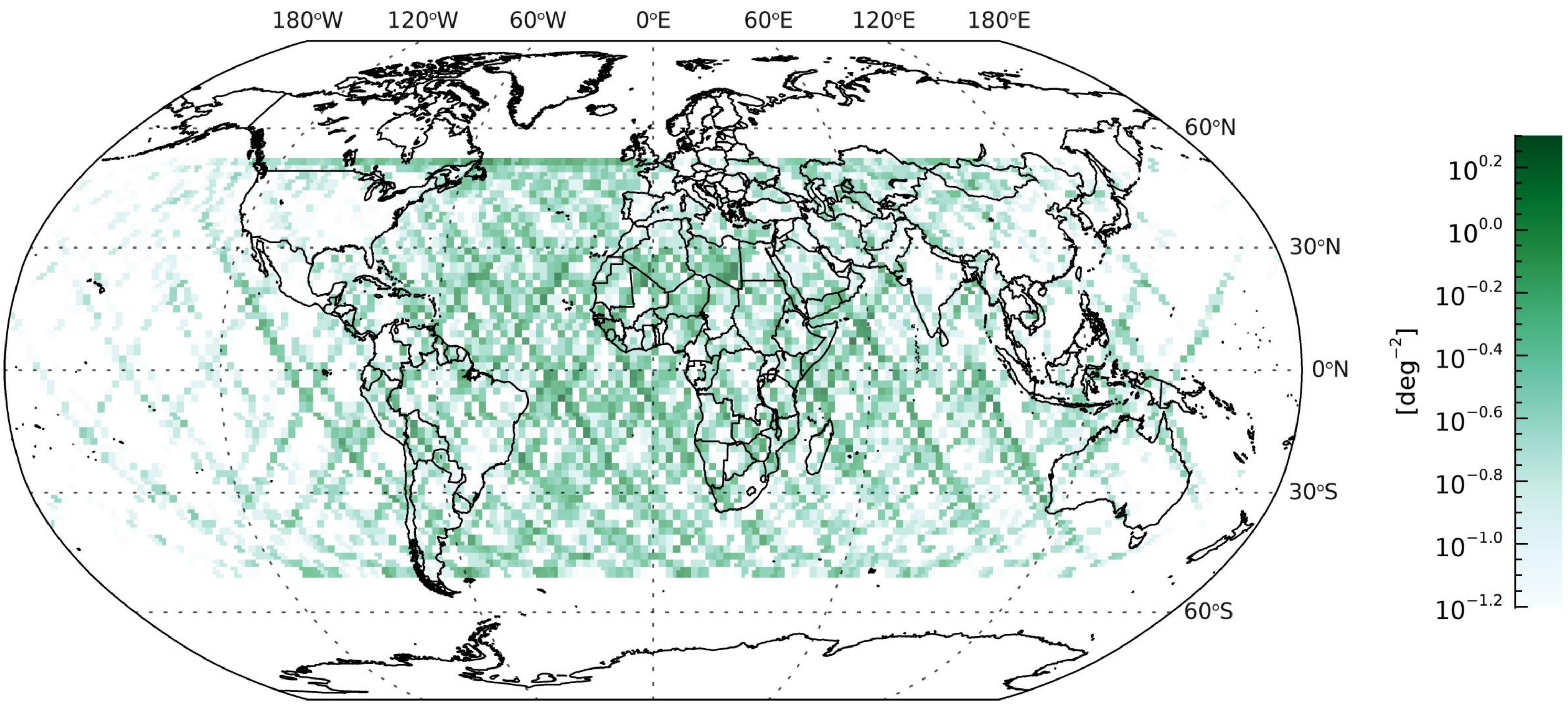
Other/Unidentified events (U)



False triggers (N)

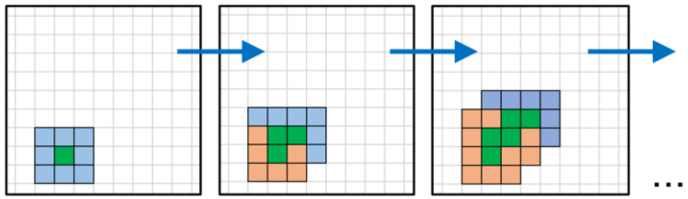


Resulting meteors database

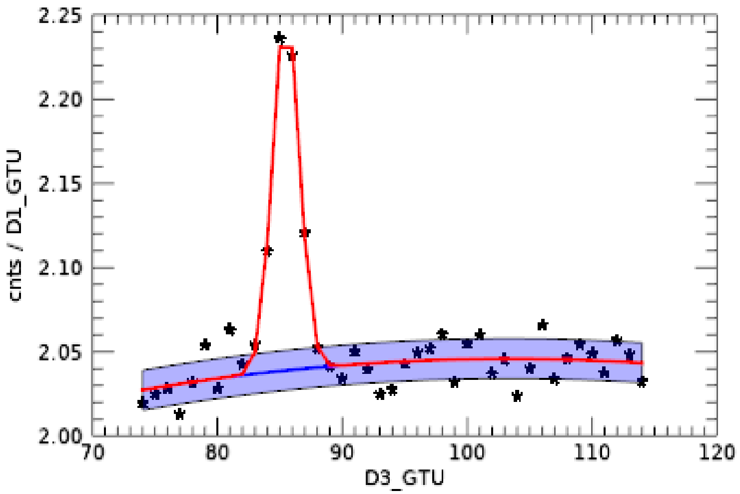


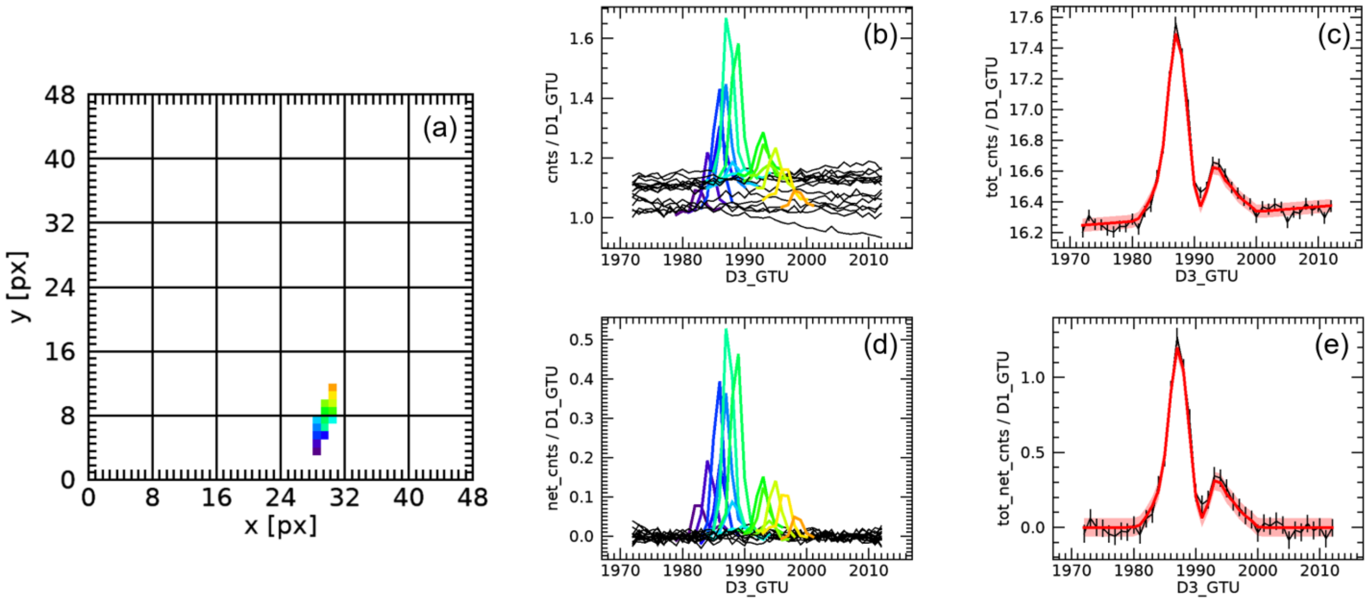
Meteor tracking algorithm (1)

- Starting from the trigger results (first triggered pixel and GTU), we **scan neighbouring pixels** to reconstruct the entire meteor track
- For each pixel, we perform an **automatic gaussian fit + polynomial background** on the lightcurve within ±30 GTUs



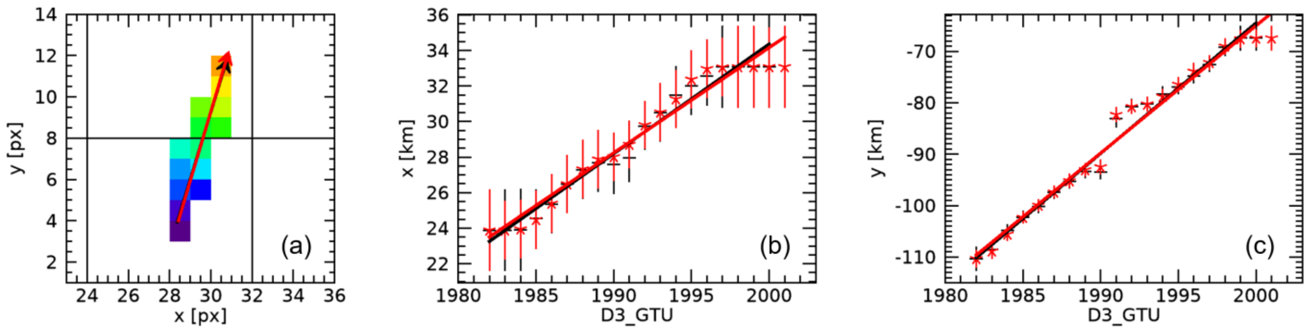
- If several criteria are matched (*e.g.*, is the gaussian height significant?) the pixel is added to the track and its first neighbourhood is added to the process. This procedure is iteratively repeated **until no more pixels are found** to be significant.

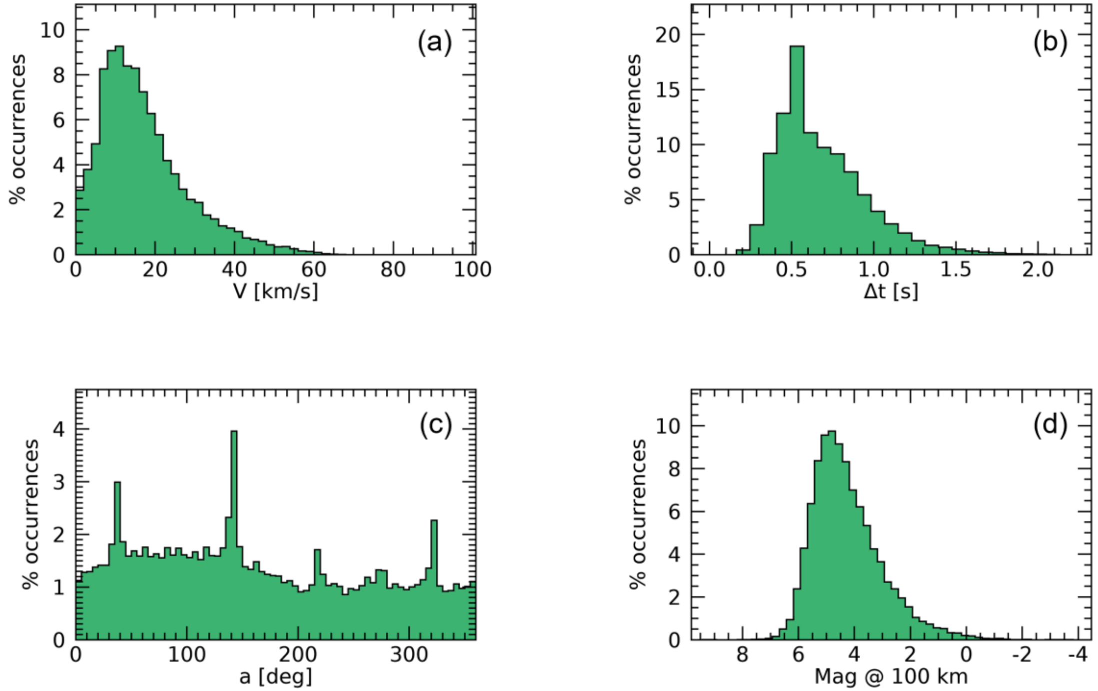




Meteor tracking algorithm (2)

- For each GTU with at least one significant pixel in the track, we then compute **barycentre and total flux**
- We can therefore retrieve **relevant physical parameters** of the observed meteor:
  - duration
  - azimuth
  - horizontal speed
  - magnitude
- Affected by the **assumed altitude** from ground, *i.e.*, the distance of the meteor from the ISS
- The classification between M, M?, U and N is performed based on the visual inspection of these results





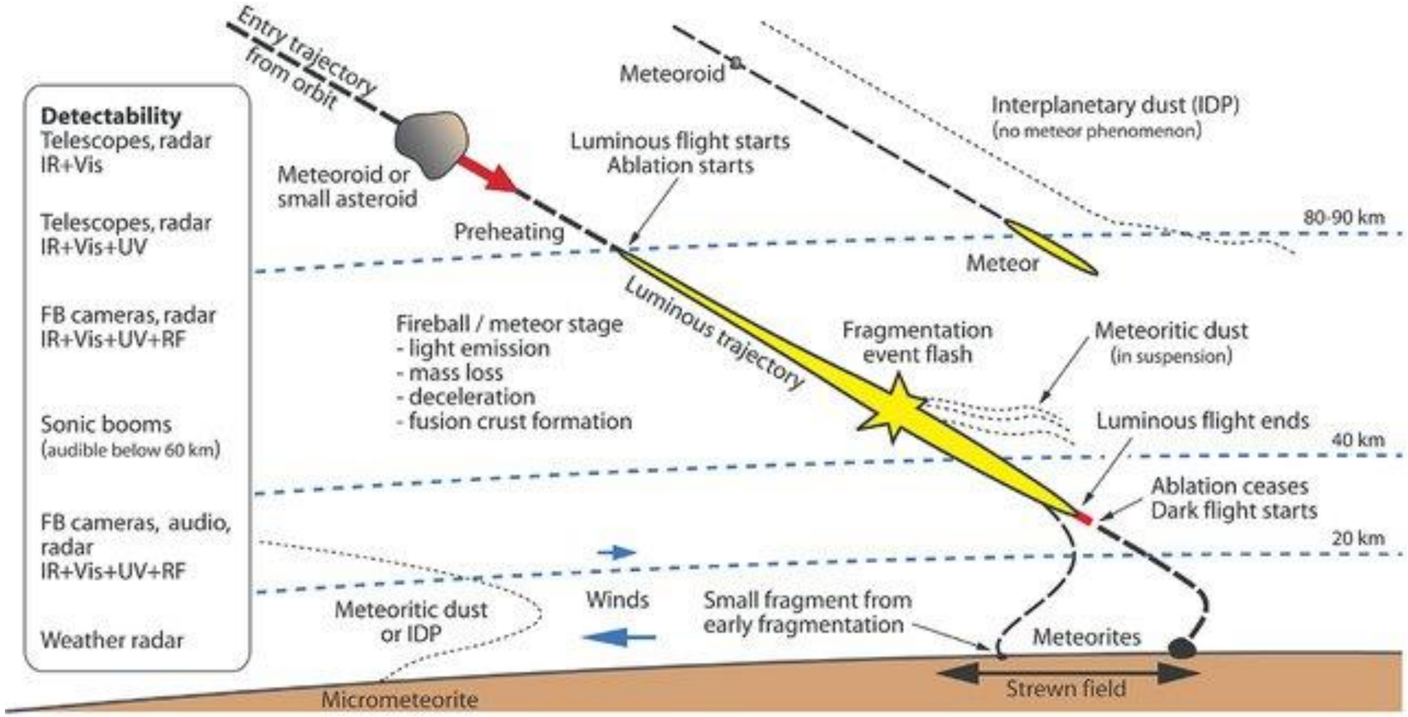
Trigger efficiency simulations

Goal: compute the **exposure of Mini-EUSO** for the observations of meteors at a varying absolute magnitude

- Implementation of the solution of the **dyanamic model** of the meteoroid within the Earth's atmosphere

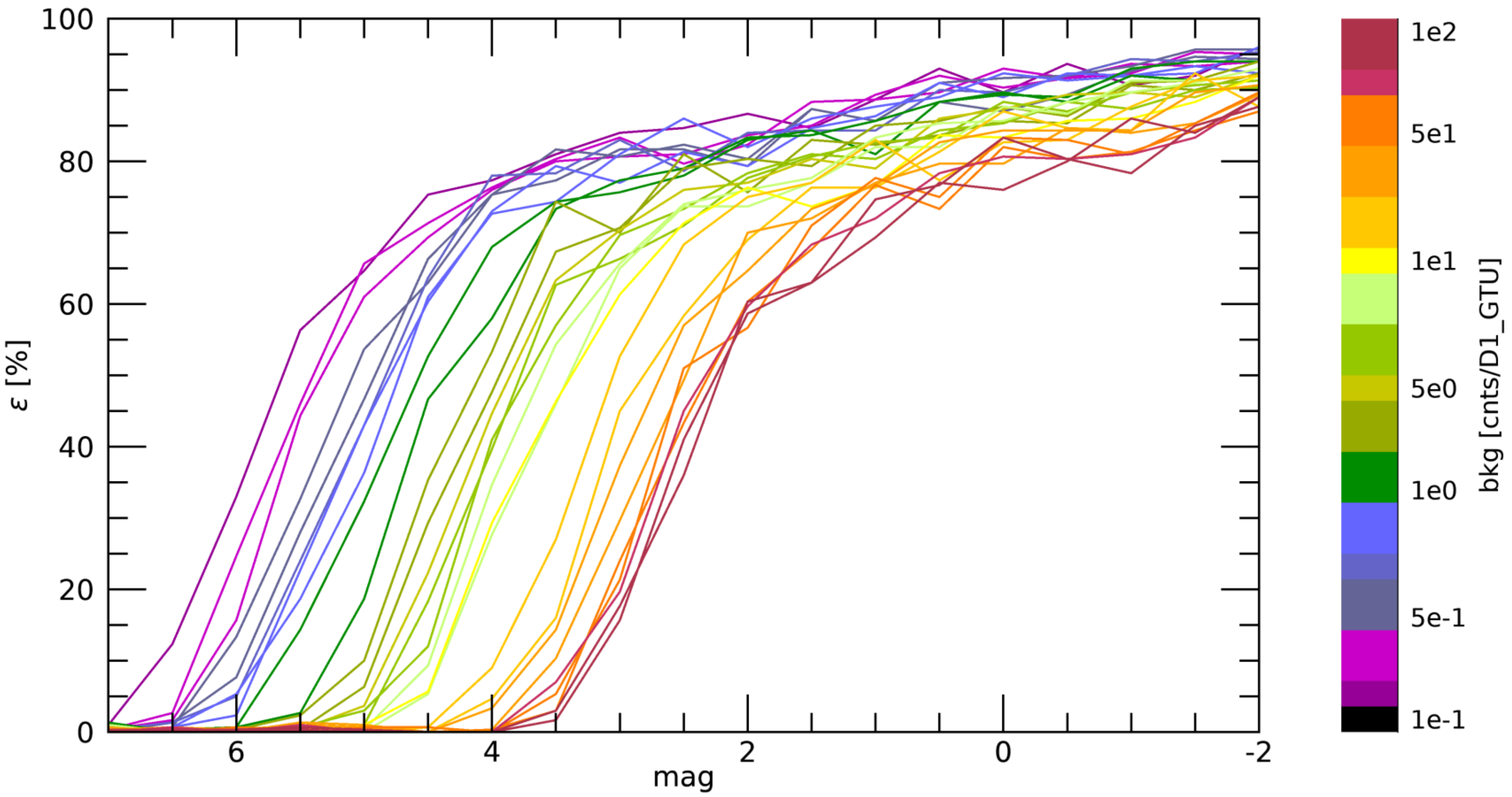
$$
\begin{cases}
\frac{\mathrm{d}H}{\mathrm{d}t} = -V \sin\gamma \\
M\frac{\mathrm{d}V}{\mathrm{d}t} = -\Gamma S \rho_a V^2 \\
M = M_\infty \exp\left\{\frac{1}{2}\sigma\left(V^2 - V_\infty^2\right)\right\} \\
I = -\tau M V \left(1 + \frac{\sigma V^2}{2}\right)\frac{\mathrm{d}V}{\mathrm{d}t}
\end{cases}
$$

- To solve this set of equations, we use the **quasi-analytical approach** by Gritsevich et al. (2009, 2011)
- Accounting for the **observative conditions** within the FoV of Mini-EUSO during the observation period (sessions n. 05-44)



Simulations over flat background (Trigger 1)

- Run the trigger over 300 events per $\mathcal{M} \in [-2, 8]$ at 0.5 mag step and **background value $b \in [10^{-1}, 10^2]$** cnts/GTU at 0.1 log steps
- Background fluctuations are generated with a Poissonian statistics accounting for flat-field normalization
- Even at the lowest background illumination values, we are limited to $\mathcal{M} \simeq +7$
- The efficiency curve shifts of 3 mag from 0.1 to 100 cnts/GTU of background value
- **Post-processing** to exclude false positives on real data filters **~10% of meteor events**

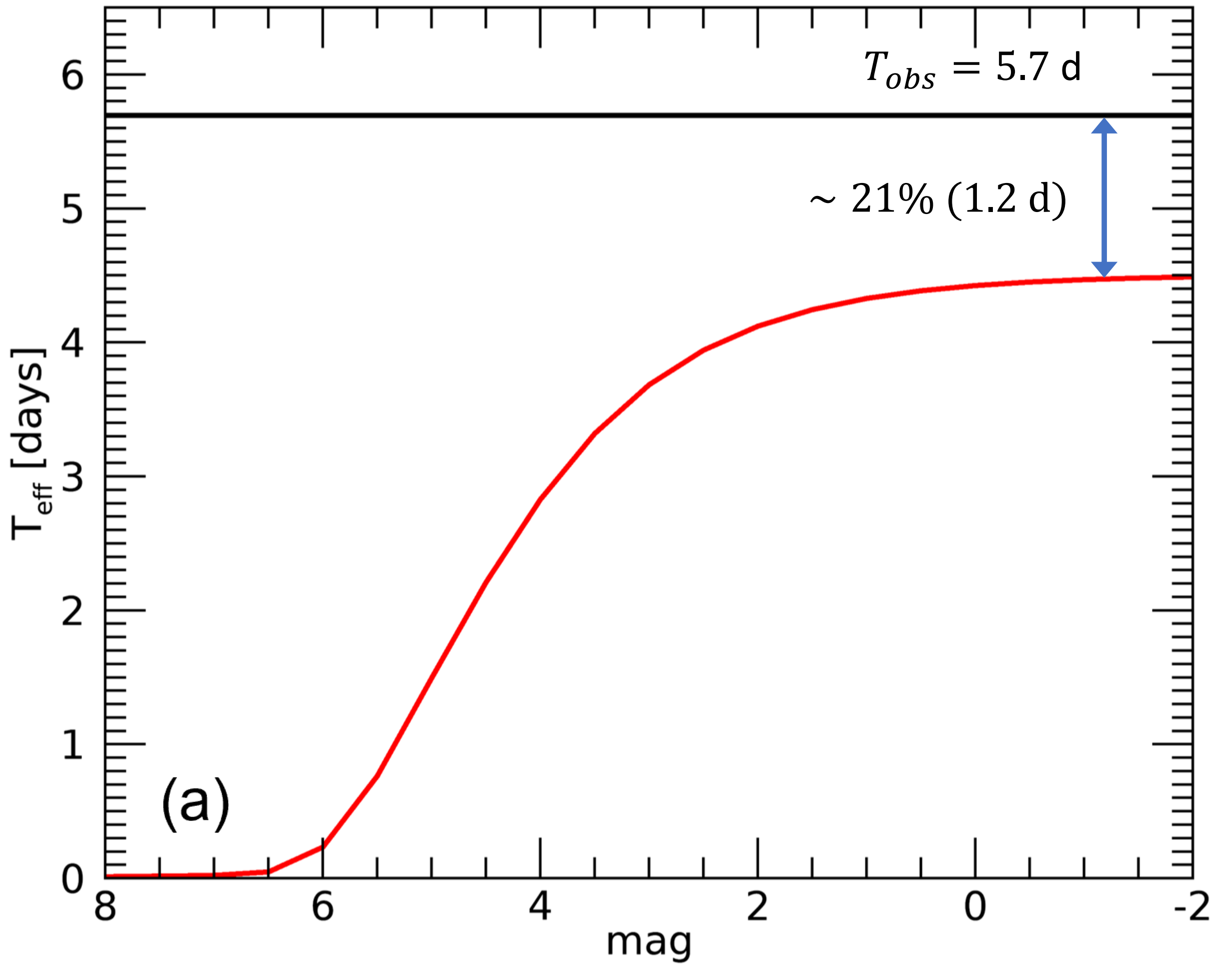


Exposure computation

- Total observing time of 5.7 days
- We scan Mini-EUSO data and compute pixel-wise **average background level each 25 GTUs (~1 s)**

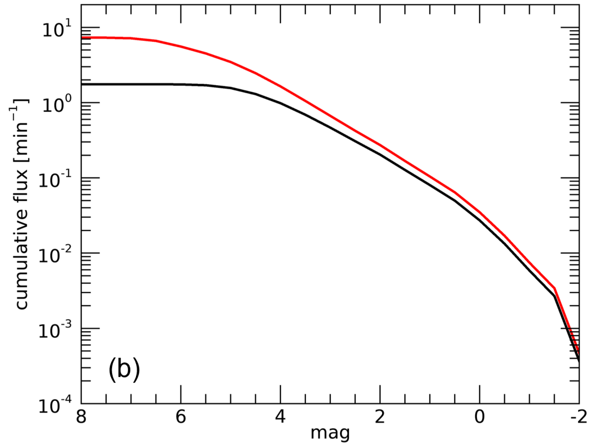
$$X(\mathcal{M}) = A_{px}\delta t \sum_{t_i=0}^{127} \sum_{x,y}^{\mathrm{PDM}} \Omega_{xy}(t_i)\epsilon\left[\mathcal{M}, \frac{b_{xy}(t_i)}{S_{xy}}\right]$$

- Maximum effective time is **79% of T_{obs} (~ 4.5 d)**. 21% difference is due to:
  - $\epsilon_M < 100\%$
  - Cathode-2 fraction time
- Steep decrease of the exposure:
  - **4.1 d at $\mathcal{M} = +2$**
  - 2.6 d at $\mathcal{M} = +4$
  - 5.6 h at $\mathcal{M} = +6$
  - 0.5 h at $\mathcal{M} = +7$



Estimation of the meteor flux

- Through the total exposure of sessions n. 05-44 we can estimate
  the **meteor flux as a function of the absolute magnitude**

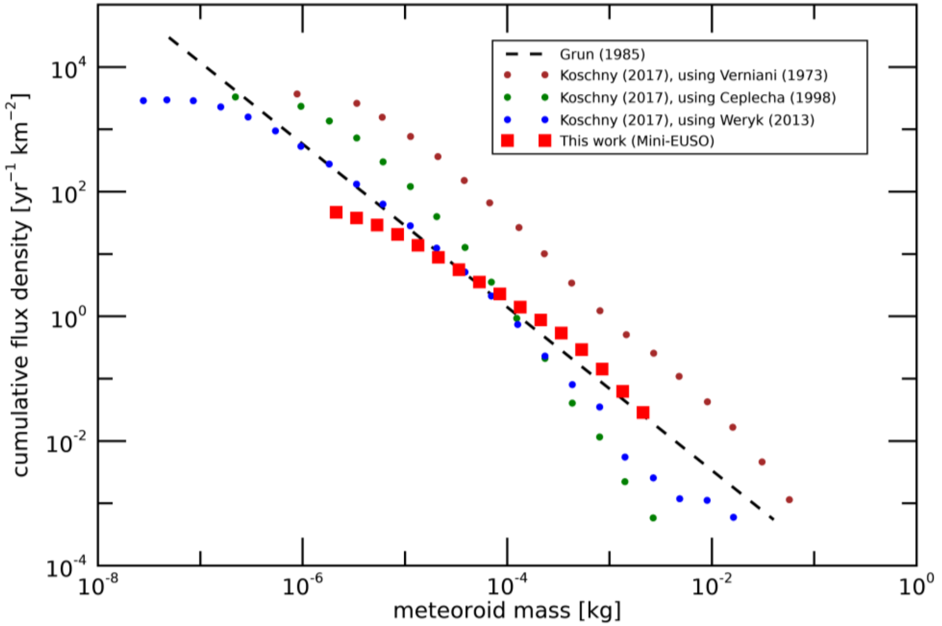


- To compare our result with other estimations available in literature, we considered the following **mass – mag conversion**:

$$\log_{10} M_\infty = -2.985 - 0.4\mathcal{M}$$

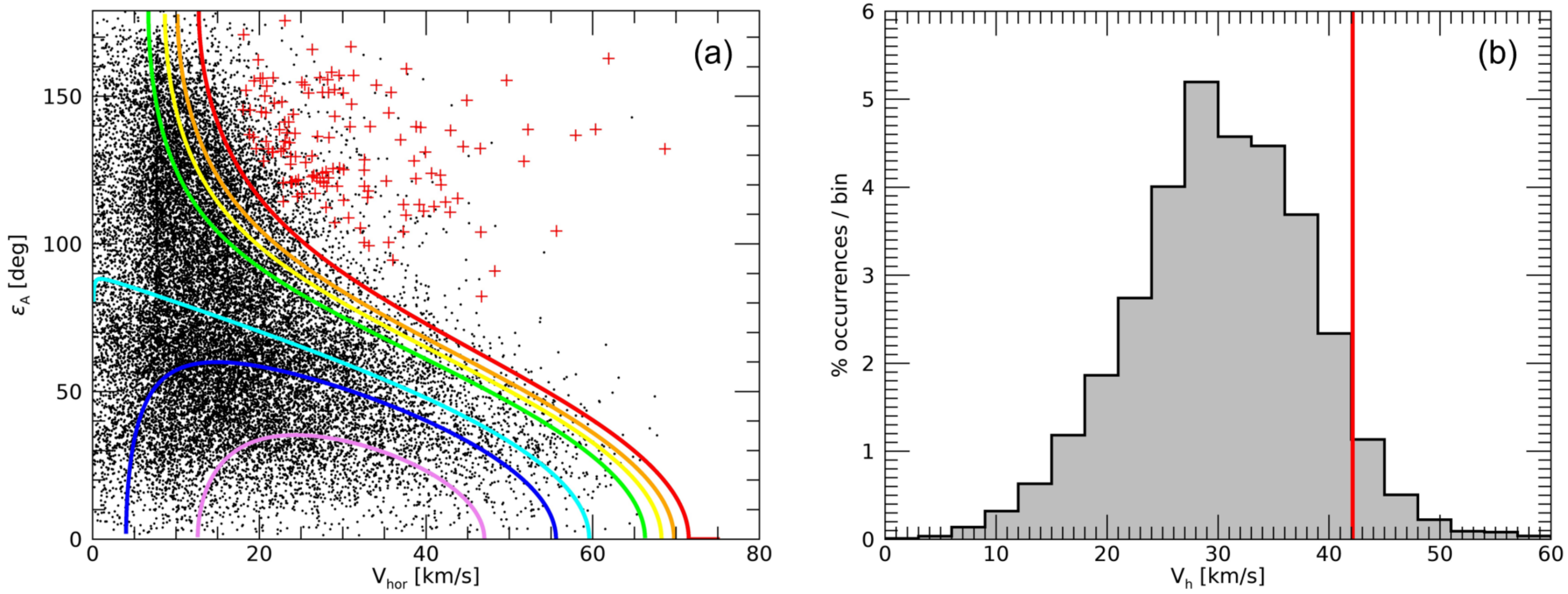
Overall compatibility with results by Koschny et al. (2017) within a similar mass range

- **Close match with the result of Grun (1985)** (micro-craters on returned lunar samples)
- Mass – mag conversion is the weak point



Kresak's diagram for Mini-EUSO ($\gamma = 0$)

- «Peculiar» distribution on the Kresak's diagram:
  high fraction of events at $a < 1$ AU (light blue curve, in the region of Atens and Atiras NEOs)
- **1397 (5.8%) events are geometrically hyperbolic**
- Only **135 survived the initial 3σ selection** criteria with $\gamma = 0$

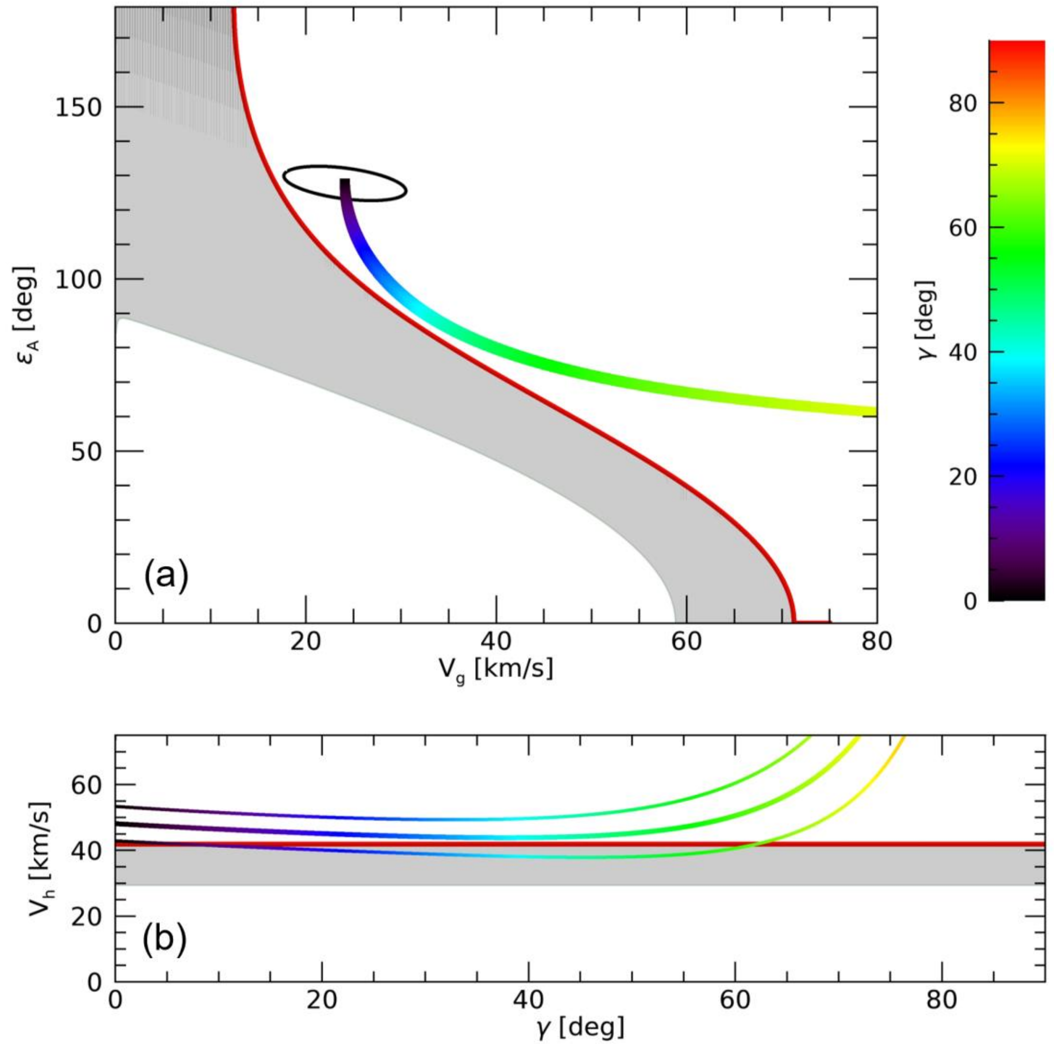


Exploring the (V_g, ϵ_A) space

IDEA: varying $\gamma \in [0{,}90]^\circ$ to check the position of the residual events on the Kresak's diagram

$$V_\infty(\gamma) = \frac{V_{hor}}{\cos\gamma}$$

- The point will **move in the (V_g, ϵ_A) space** towards higher V_g values, and the elongation of the radiant will vary accordingly to (a, γ) in horizontal coordinates
- Then, the 3σ confidence region can **enter to the region left of the parabolic limit**, being compatible with a Solar System origin for a range of γ
- Again, this is a **conservative approach** (we actually do not know γ)
- For the case of the figure, the event is compatible with a closed orbit for $\gamma \in [7{,}62]^\circ$



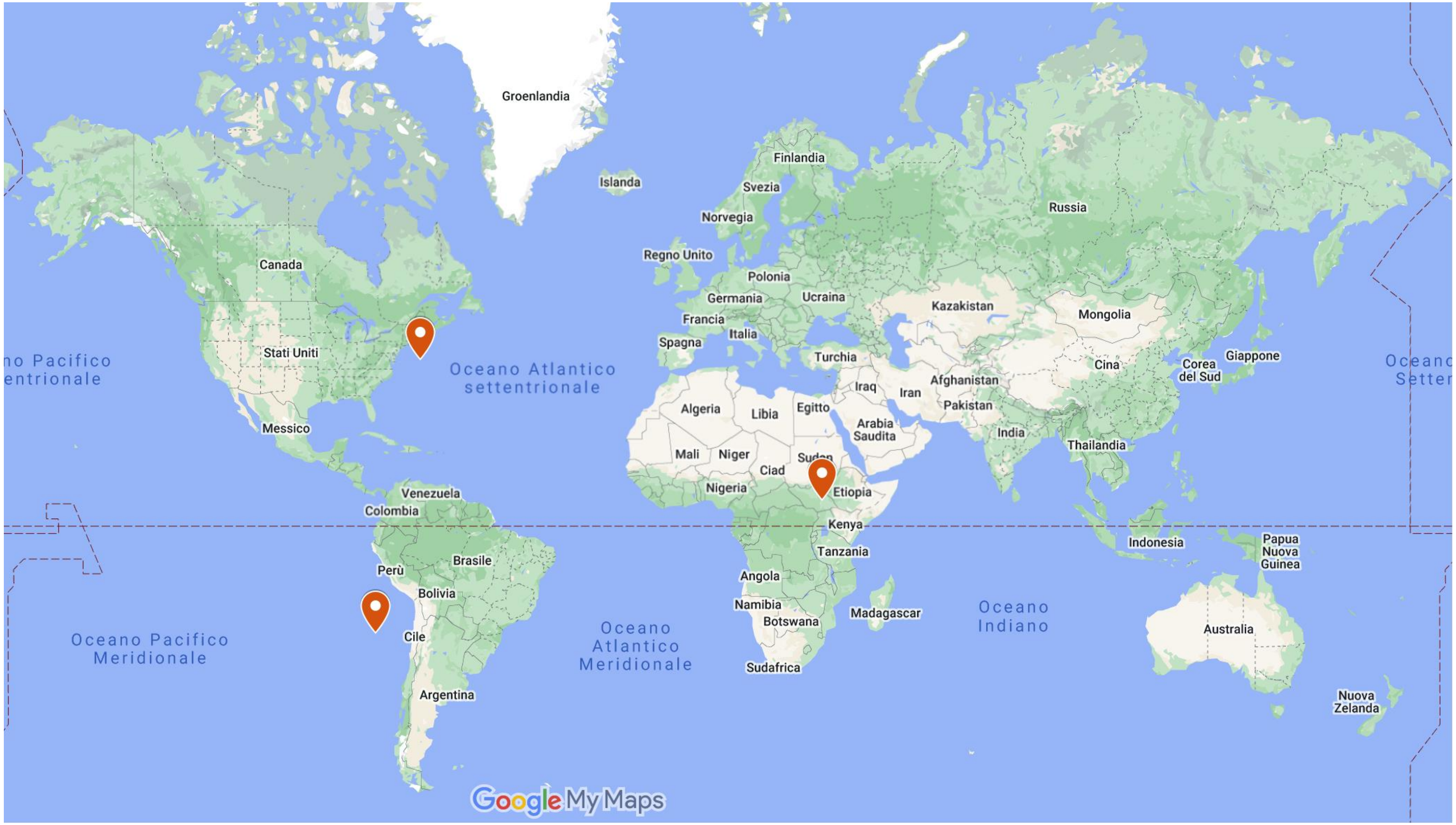
Mini-EUSO ISM candidates

- **9 events survived** this further selection, and we **excluded 6 of them being M?** (5 events with just 2 or 3 pixels, one event shows a peculiar lightcurve that is hardly linkable to a meteor event)
- We finally have **3 interstellar meteor (ISM) candidates**

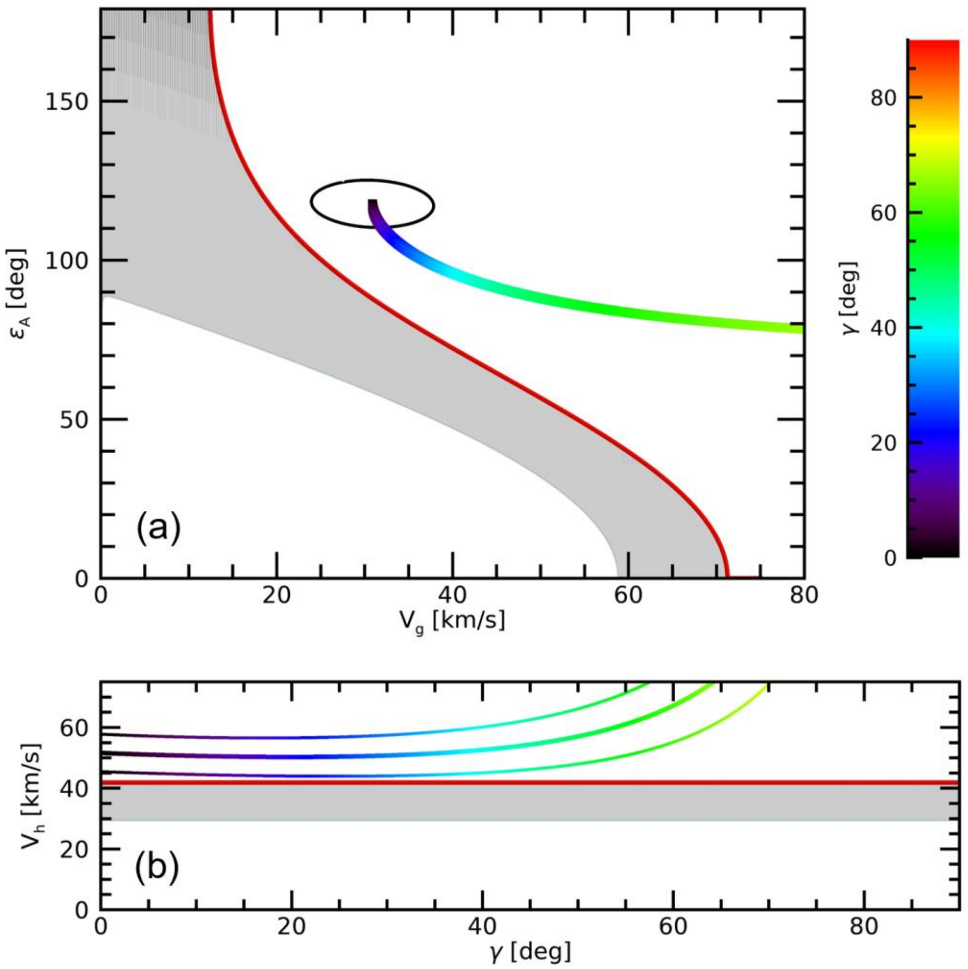
Date	Time UT	Lat. [deg]	Lon. [deg]	N_{px}	Δt [s]	V_{hor} [km/s]	a [deg]	$\mathcal{M}$ [mag]	$\overline{V}_h$ [km/s]
25/05/20	23:49:24.83	06°33'N	31°45'E	9	0.70	33 ± 2	223 ± 3	2.7 ± 0.1	50 ± 2
28/07/20	08:04:48.02	25°47'S	80°30'W	22	0.82	47 ± 4	292 ± 4	3.3 ± 0.1	64 ± 4
16/01/21	07:12:43.96	38°40'N	69°11'W	10	0.78	37 ± 3	231 ± 1	2.9 ± 0.1	51 ± 3

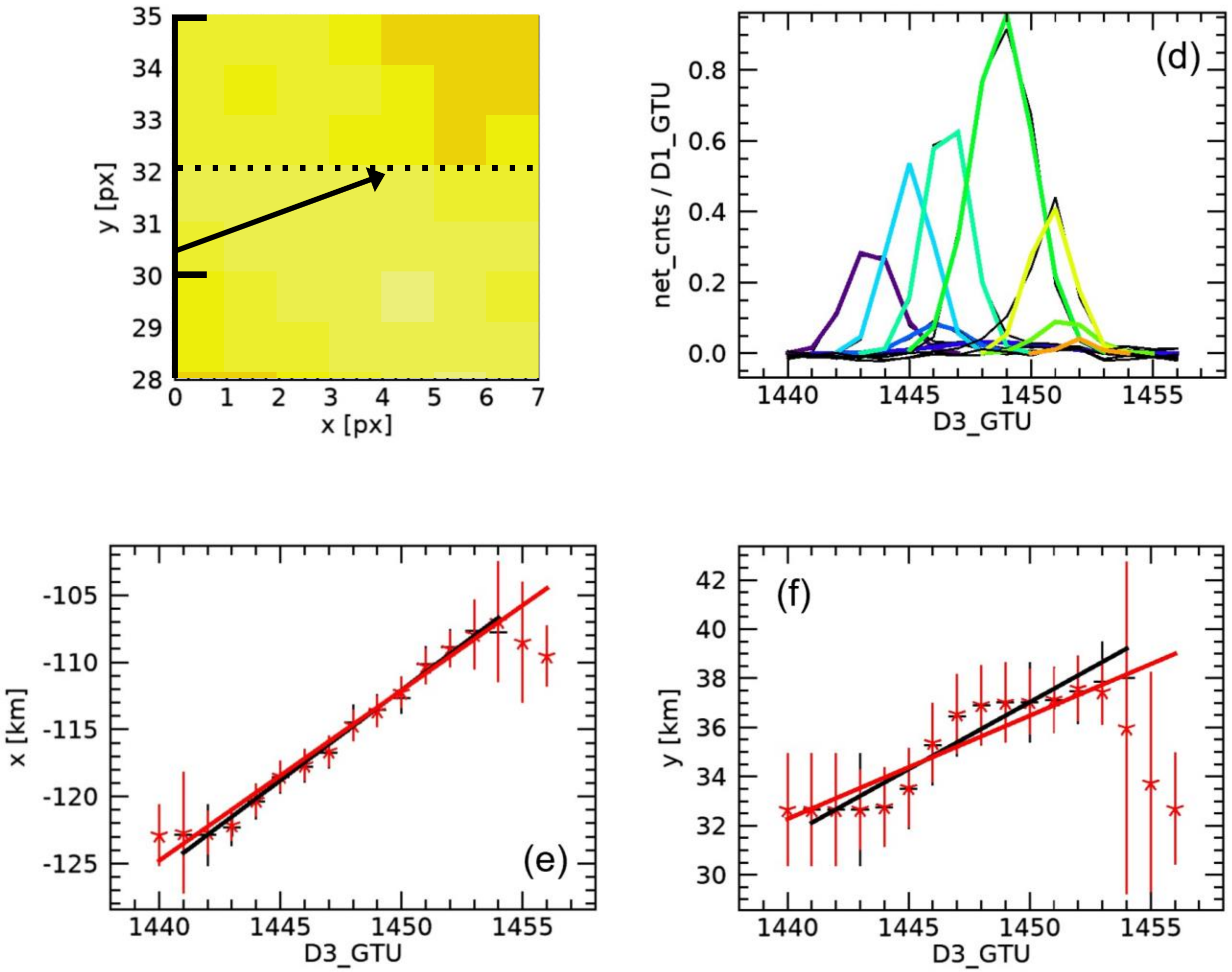
Tab. 7.1: Relevant data about the three interstellar meteor candidates identified in the Mini-EUSO database. From left to right: Date and time UT of the detection, latitude and longitude of the ISS at that time, number of pixels on the PDM that were interested by the meteor signal, duration of the event, horizontal speed module at a 100 km altitude, azimuth direction from the North, absolute magnitude and minimum heliocentric speed (Eq. 7.5).

Mini-EUSO ISM candidates

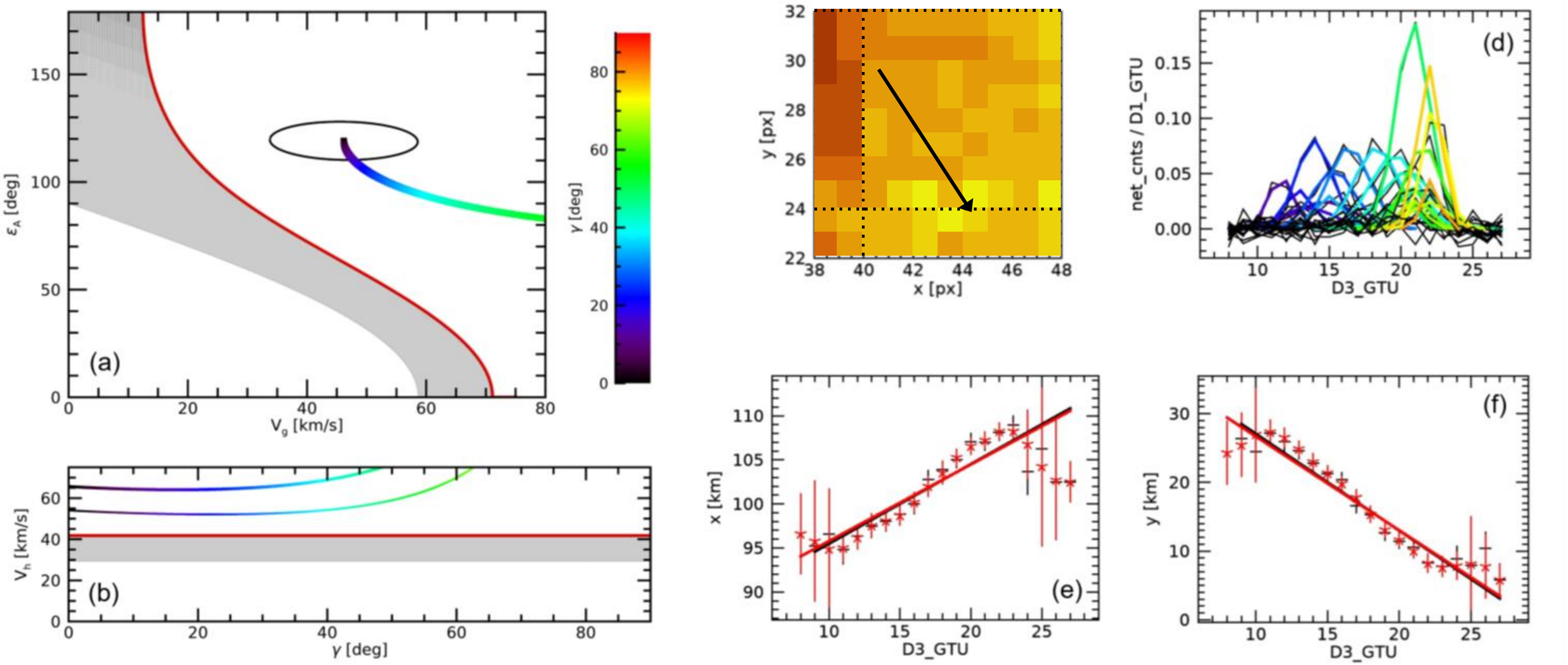


Mini-EUSO ISM candidates (1)

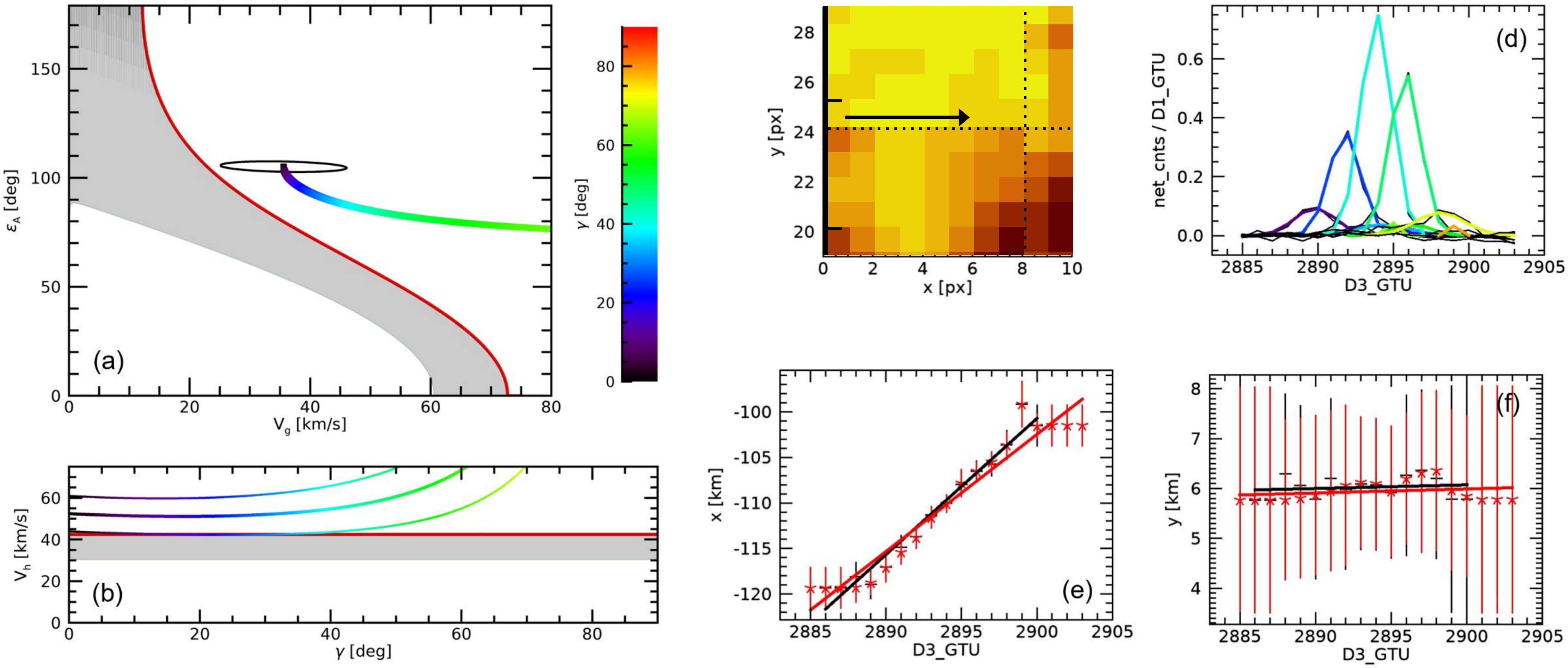




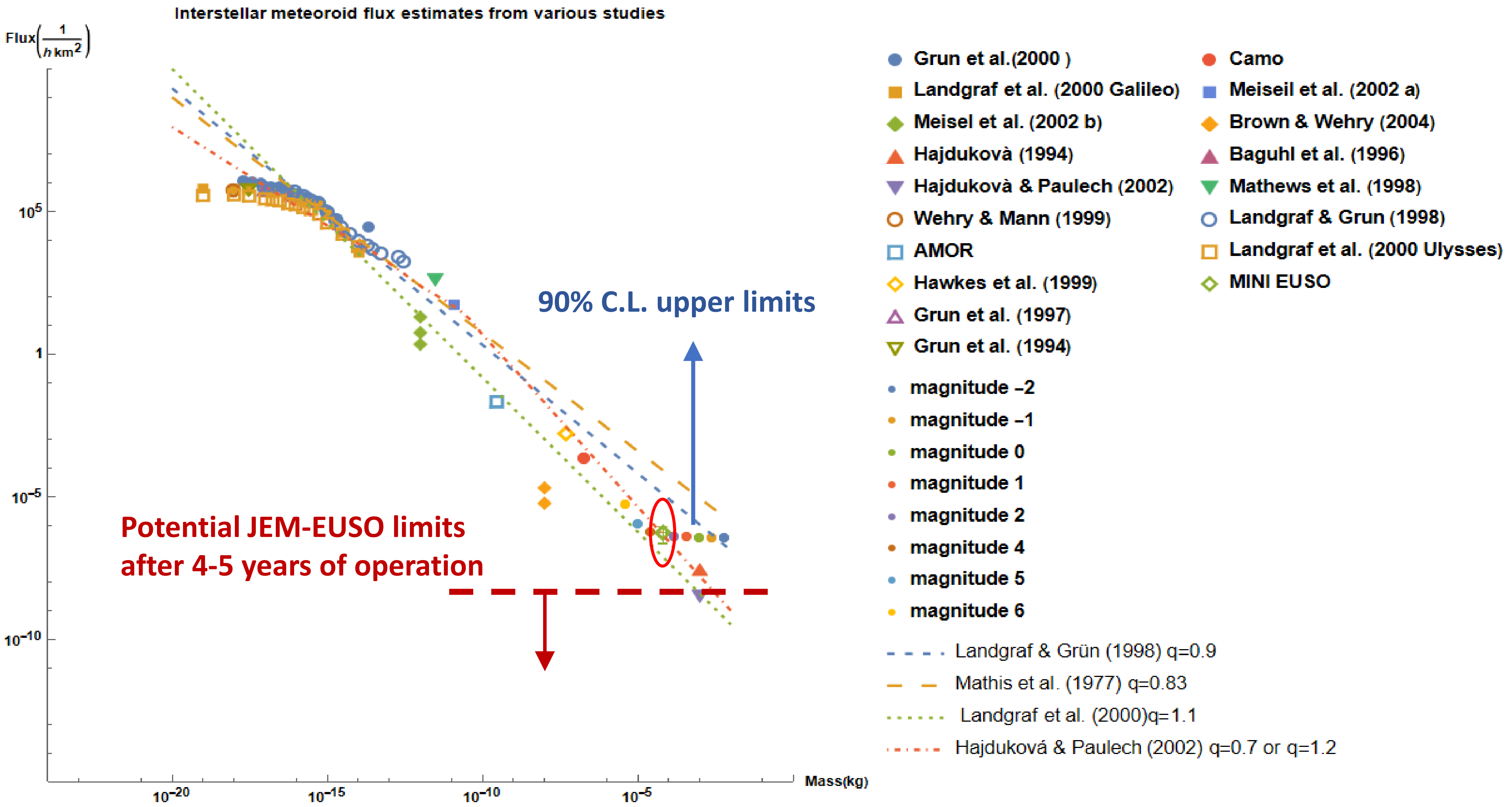
Mini-EUSO ISM candidates (2)



Mini-EUSO ISM candidates (3)



Estimation of the flux of interstellar meteors




Grazie per l’attenzione!