JEM-EUSO: Joint Experiment Missions for Extreme Universe Space Observatory

L’esperimento Mini-EUSO come osservatorio per meteore dallo spazio

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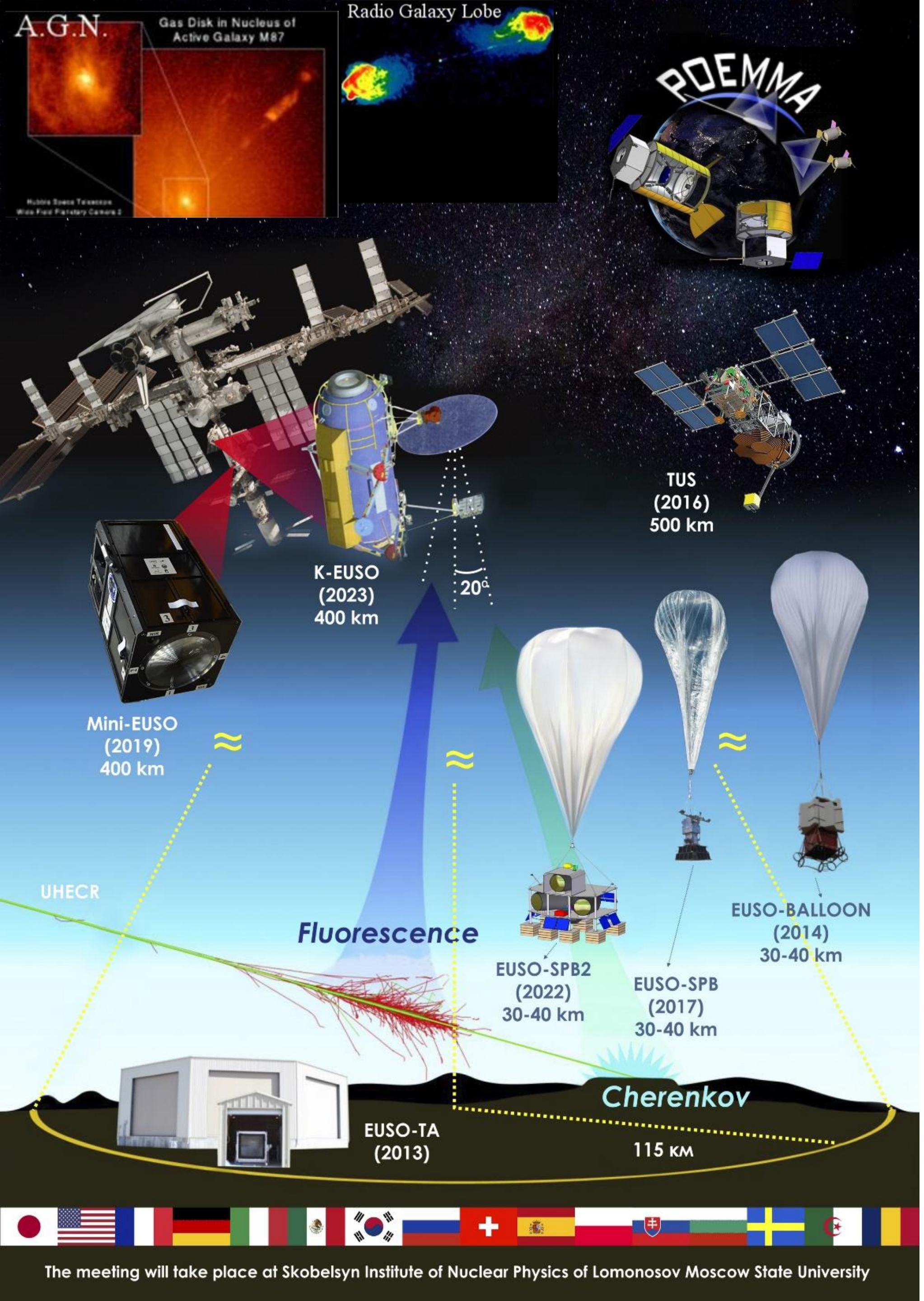
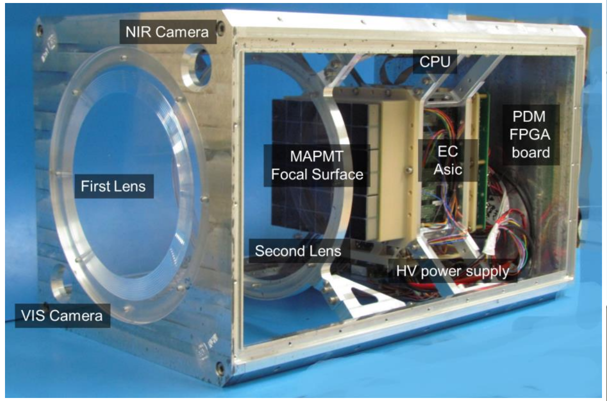
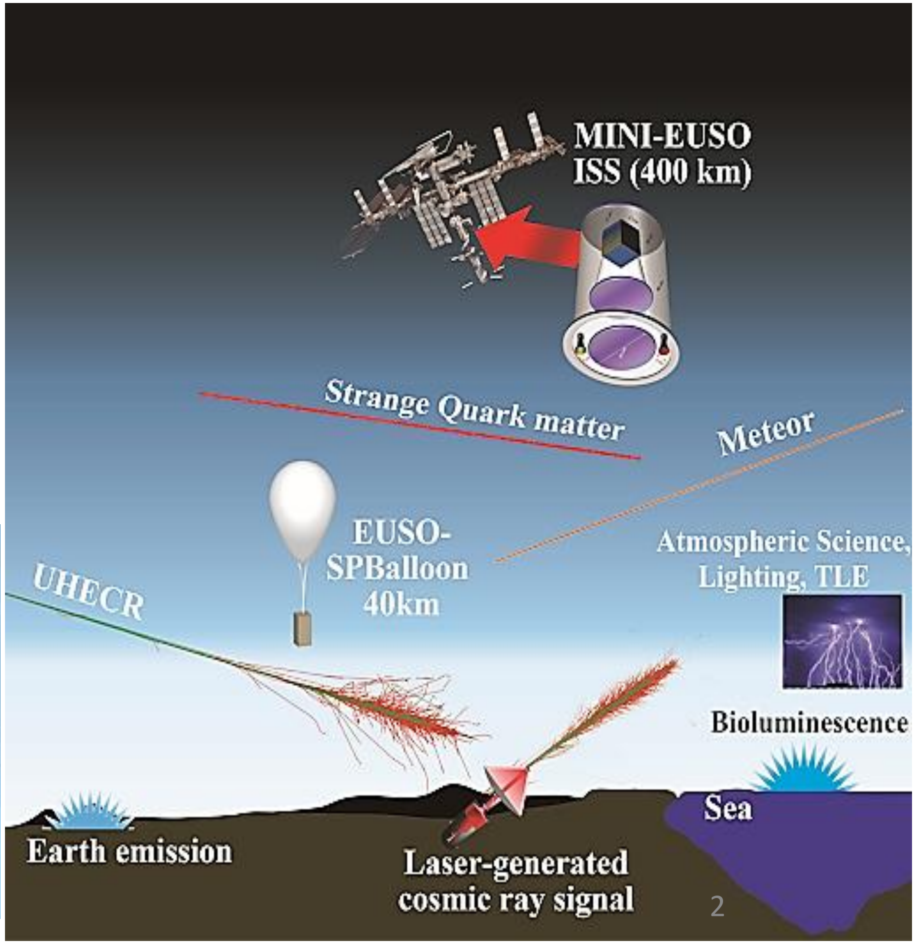
(Univ. Torino & INAF-OATo)
on behalf of the JEM-EUSO Collaboration
PRISMA day 25-26 Novembre 2022



JEM-EUSO Program: observation of Extreme Energy Cosmic Rays (E>5x10^{19} eV) from space

Mini-EUSO: precursor mission with several scientific objectives

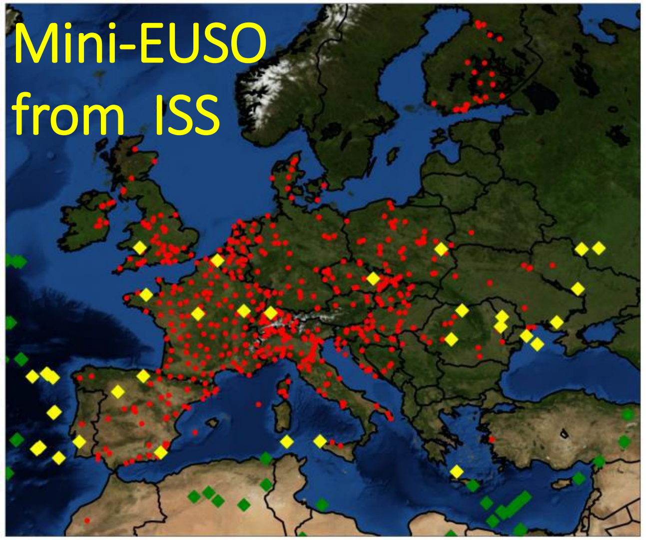




Mini-EUSO & PRISMA
a sinergy from the beginning

- PRISMA Day – Firenze 2016: M. Bertaina «Mini-EUSO e attivita’ correlate all’osservazione di Meteore e Space Debris in associazione con PRISMA»
- PRISMA Day – Bologna 2018: F. Bisconti «Osservazioni con l’Engineering model di Mini-EUSO e la camera PRISMA all’INAF-OATo»
- PRISMA Day – 2020: M. Bertaina «L’osservazione di meteore con l’esperimento Mini-EUSO a bordo della Stazione Spaziale Internazionale»
- PRISMA Day – 2022: M. Bertaina «L’esperimento Mini-EUSO per l’osservazione di meteore dallo spazio»

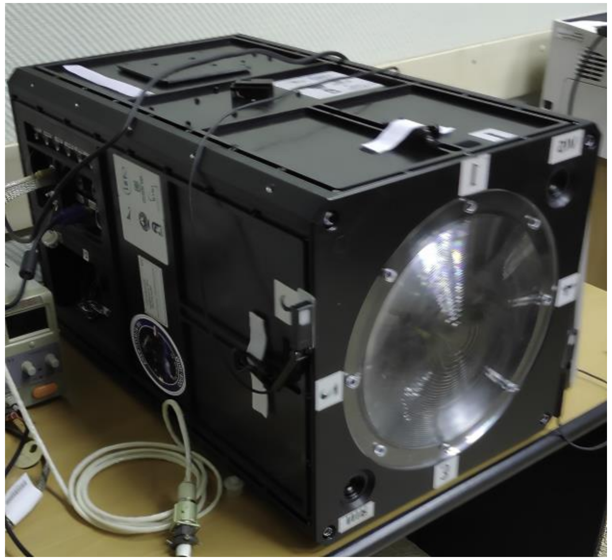
PRISMA camera
@INAF-OATo

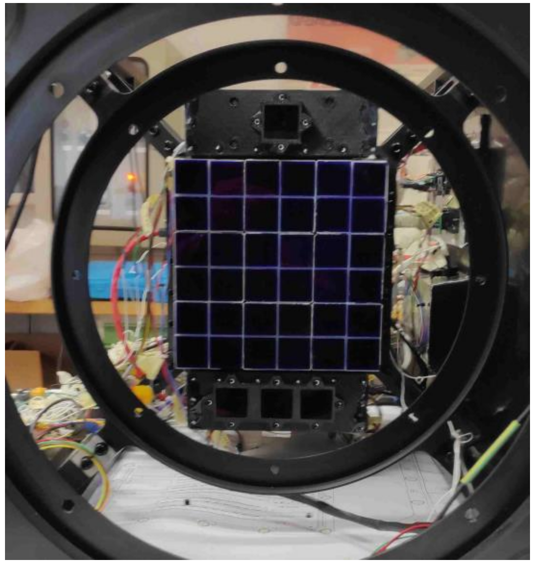


Mini-EUSO Flight & Engineering Models

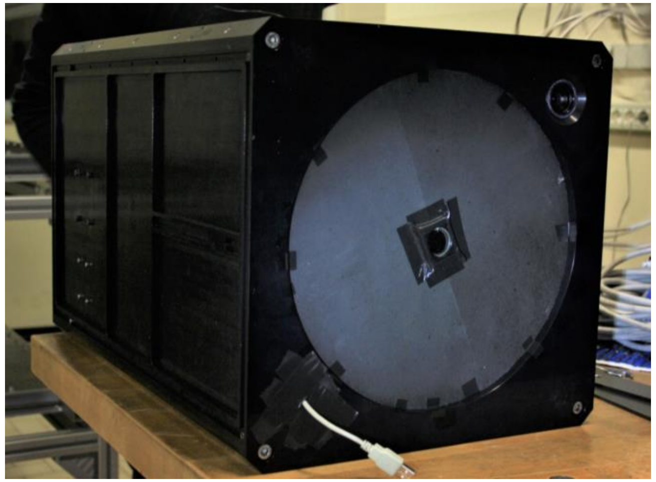
P. Barrillon et al.: Exp. Astron. https://doi.org/10.1007/s10686-022-09871-8

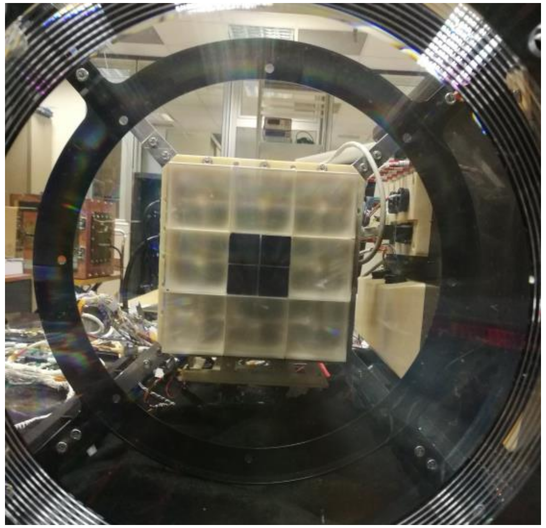
FM





EM





	Mini-EUSO *EM*	Mini-EUSO
Focal Surface	2×2 MAPMTs $16 \times 16 = 256$ pixels	6×6 MAPMTs $48 \times 48 = 2304$ pixels
Optical system	1 plano-convex lens	2 Fresnel lenses
Diameter lens(-es)	2.5 cm	25 cm
Focal length	30 cm	20.5 cm
Focal ratio	$f/12$	$f/1.2$
Field of view	square	square
Total	$\sim 10°$	$\sim 44°$
Per pixel (no gaps)	$\sim 0.6°$	$\sim 0.8°$

Table 1: Comparison of the key specifications of Mini-EUSO*EM* and Mini-EUSO.

Integration tests of Mini-EUSO EM in 2017 @ Univ. Torino to mimic ISS orbits & @ INAF-OATo for sky tests

TurLab @ UNITO

Tests at INAF-OATo

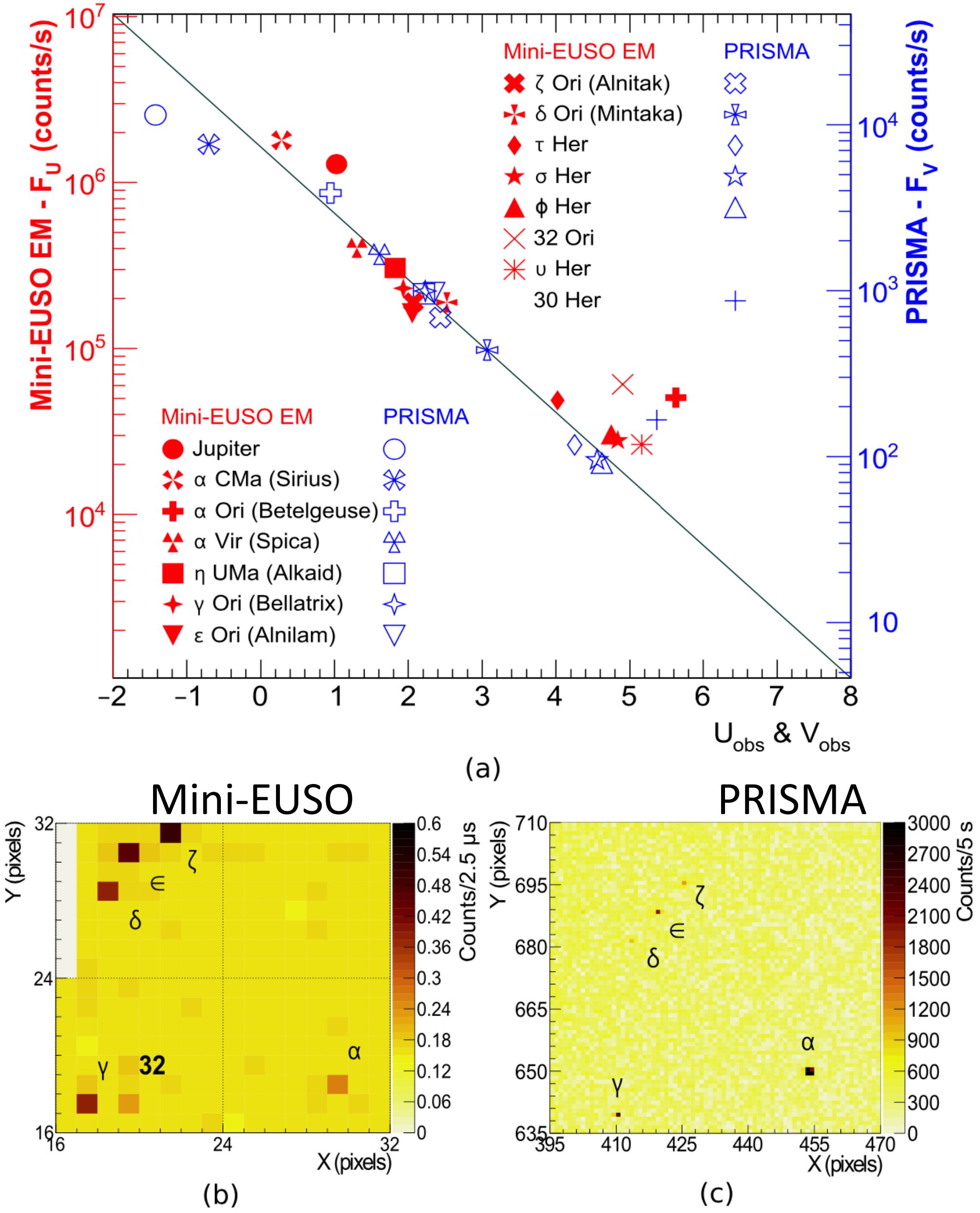


Fig. 10 (a) Count rates from stars and Jupiter for the Mini-EUSO *EM* and for the PRISMA camera, with respect to the observed U and V apparent magnitudes, respectively. (b) Some of the stars of the Orion constellation in a D3 frame of the Mini-EUSO *EM* integrated over 40.96 ms and (c) the same stars in a frame of the PRISMA camera integrated over 5 s, where the 32-Ori star is not recognizable. Image (b) has been mirrored to have the same orientation of image (c)

Meteors

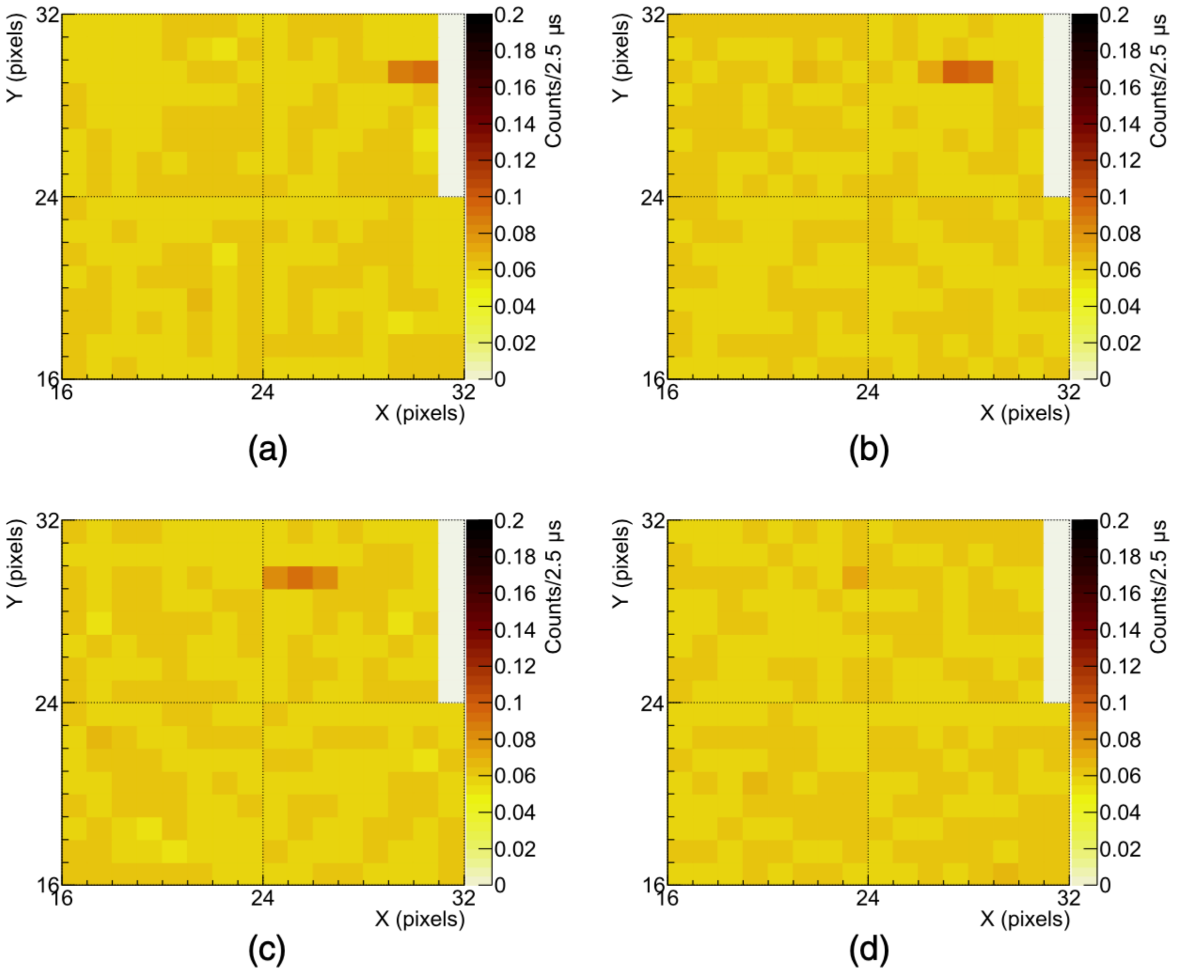
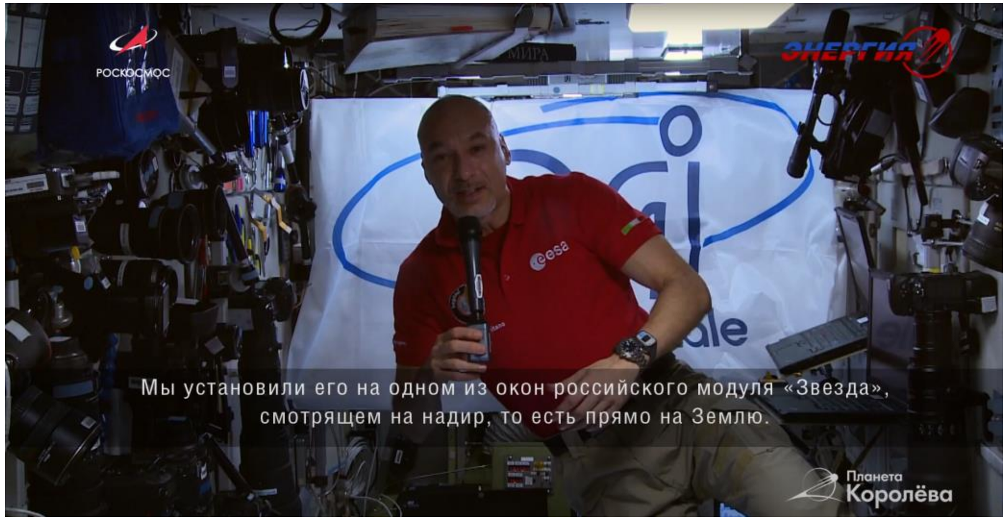


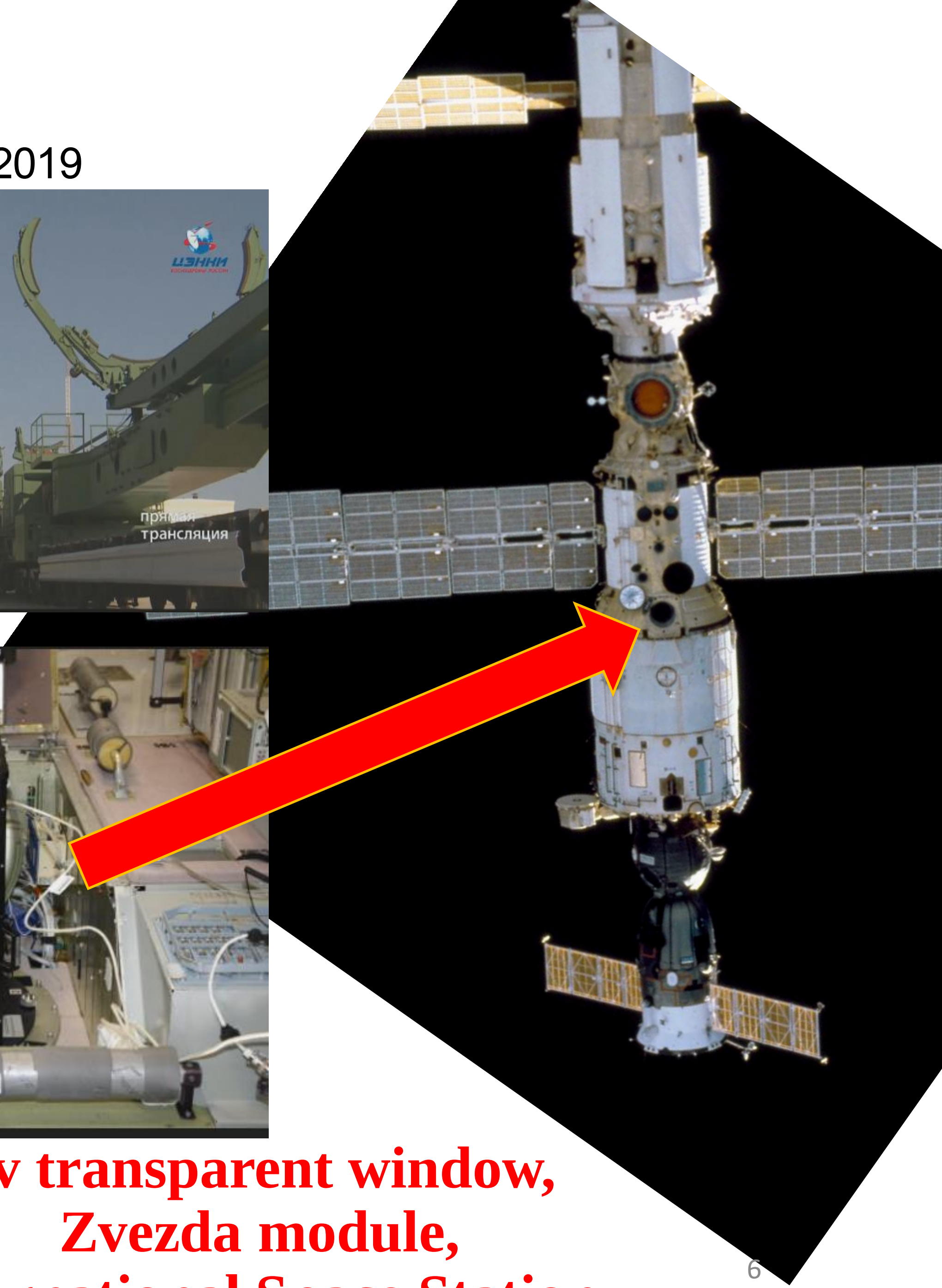
Fig. 11 Example of a meteor candidate shown in four consecutive D3 frames, each integrated over 40.96 ms. Figure adapted from [27]

F. Bisconti et al.: Exp. Astron. https://doi.org/10.1007/s10686-021-09805-w

Mini-EUSO on the ISS

Launch 22/08/2019





Mini-EUSO operated ~2/month for ~12h.
Data are transferred to ground with ISS crew **once/year.**
At the moment 71 sessions, ~1/2 available for analysis.

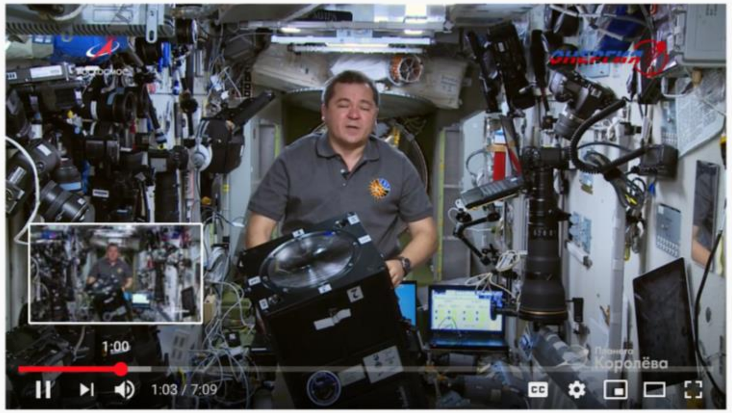
Uv transparent window,
Zvezda module,
International Space Station

Beyond mission & outreach

Also in Russia a certain success:

@ Tor Vergata with FM Mini-EUSO

Video of Outreach from ISS
https://www.youtube.com/watch?v=QincAp4V-SM&t=1s

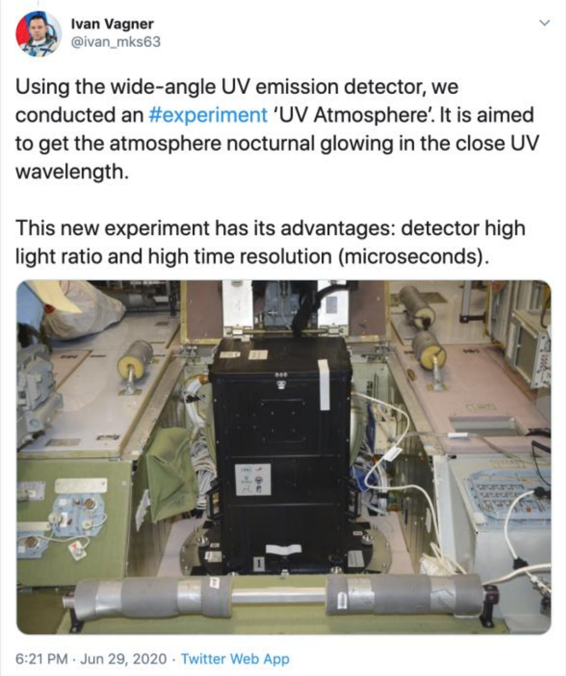


https://www.youtube.com/watch?v=lXedBGVHc4o&t=62s

Video ofioutreach on Corriere della sera

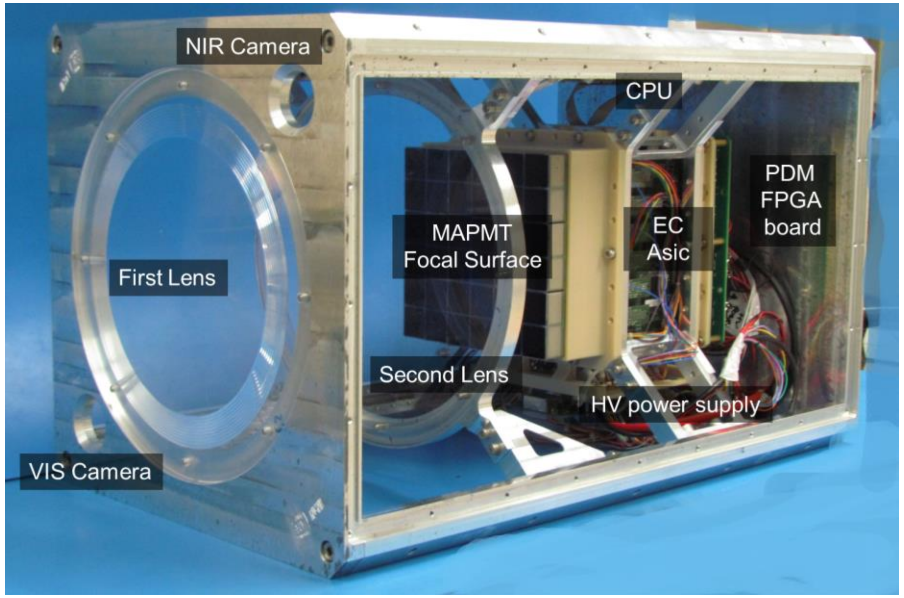
https://video.corriere.it/cronaca/mini-euso-luca-parmitano-protagonista-web-serie-beyond/2582bd90-aa06-11e9-a88c-fde1fa123548

Mentioned in the teleconference with Presid. Mattarella
https://www.youtube.com/watch?v=NMTTSB6BVaw (min 5:15-6:30)
and Prime Minister Conte:
https://www.youtube.com/watch?v=4GDgpyAsz94 (min 16:51 – 19:15)



MINI-EUSO / UV-Atmosfera

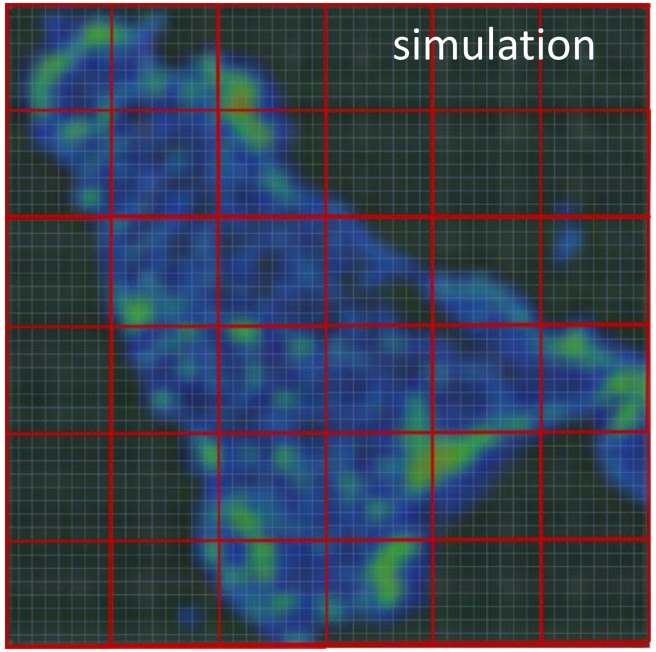
Multiwavelength Imaging New Instrument for the Extreme Universe Space Observatory



- Detector: dimensions of 36 x 36 x 62 cm^3, two Fresnel lenses (25 cm of diameter)
- The light focuses on 36 multi-anode photomultiplier tubes (MAPMTs)
- Focal surface of 2304 pixels
- Field of view of 44°x 44°
- Spatial resolution on ground ~ 6.3 km/pixel
- Bandwidth: 290 – 430 nm

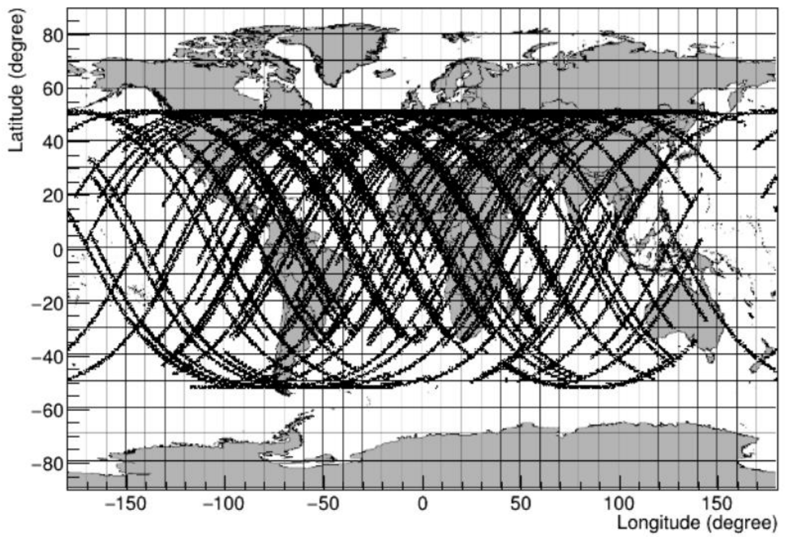
- **Acquisition logic with 3 times resolutions**:
- D1= 2.5 μs, D2=320 μs and D3 =41 ms ,
- 1 packet = 128 frames or Gate Time Unit (GTU)
- D1 and D2 are self triggered (4 packets/5.24s), D3 is a continuous video stream.

Instantaneous FoV



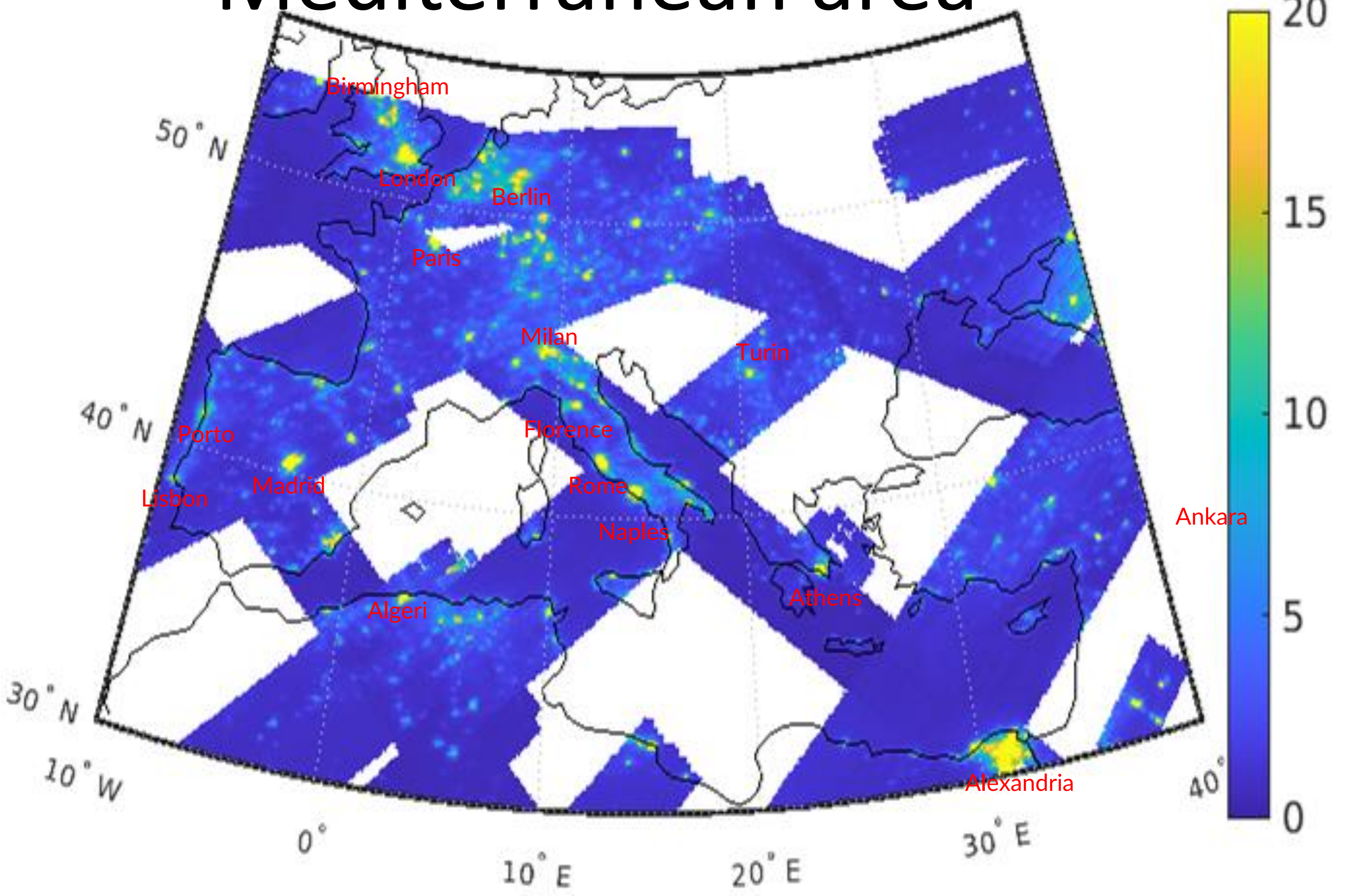
Mini-EUSO in orbit

Data transfer and Earth Coverage (up to Nov 2021)

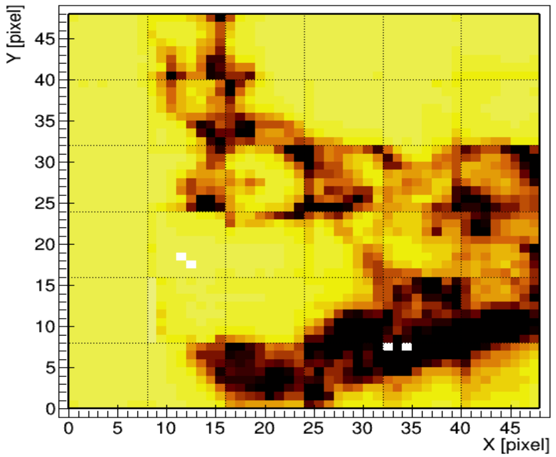


Data from sessions 4-41

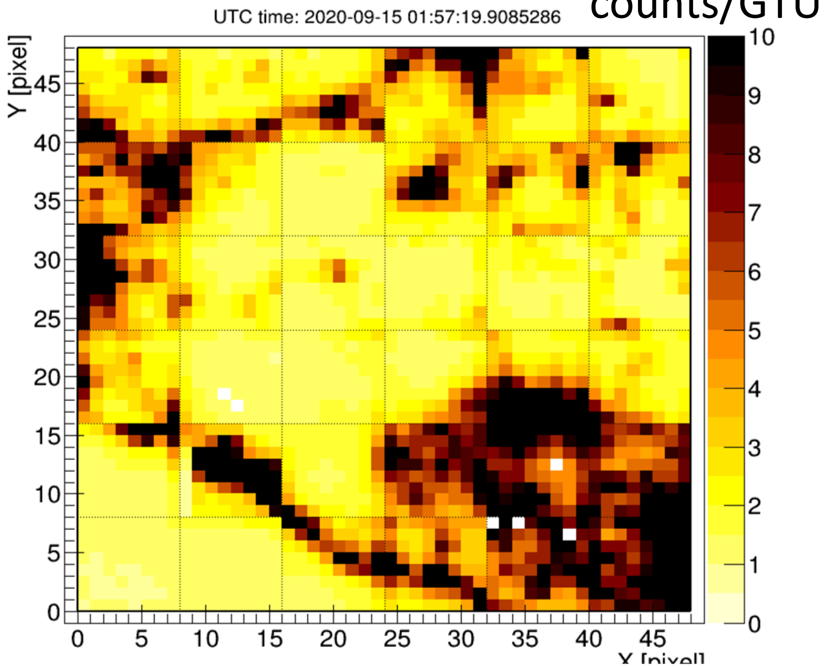
UV maps - Europe and Mediterranean area

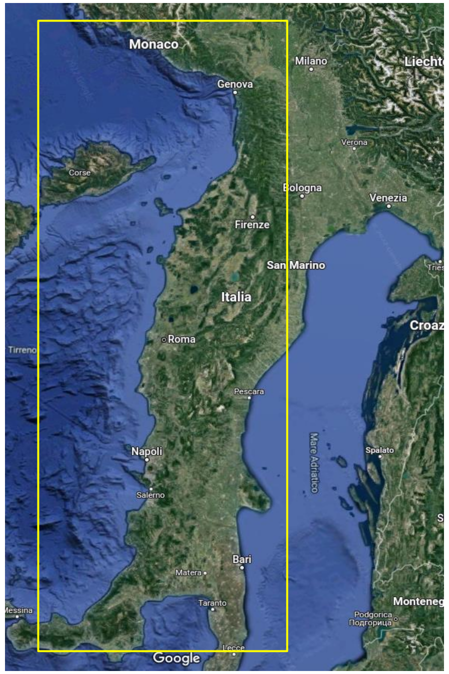


Diffused sources in Mini-EUSO

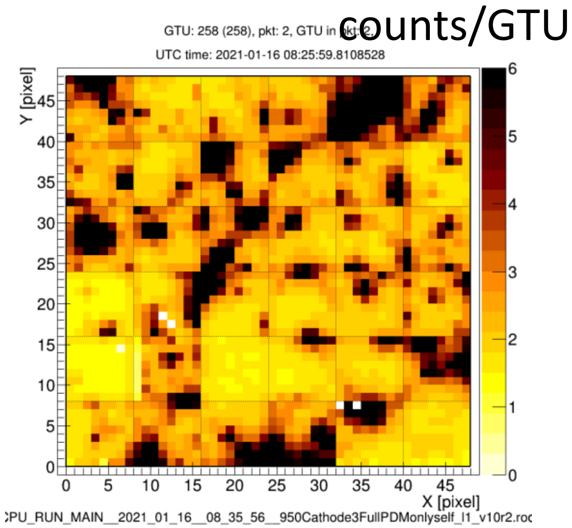


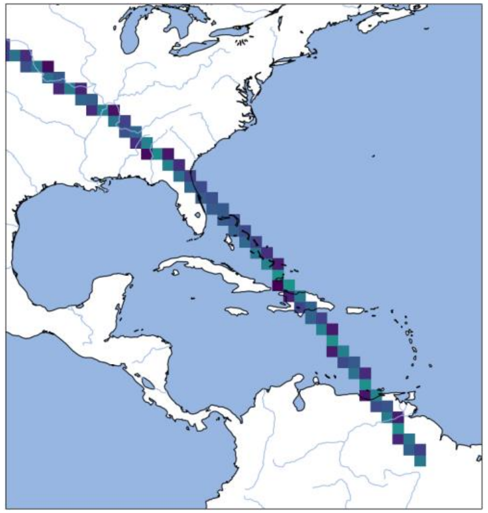
Southern Italy





Italy view from North to South



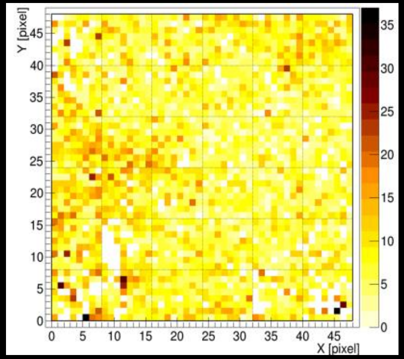


Florida and Haiti/Dominican Republic

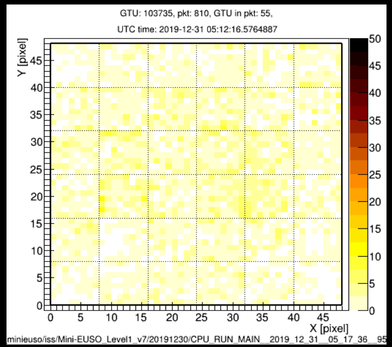
S. Bacholle et al. ApJS Vol. 253 (2021) 36

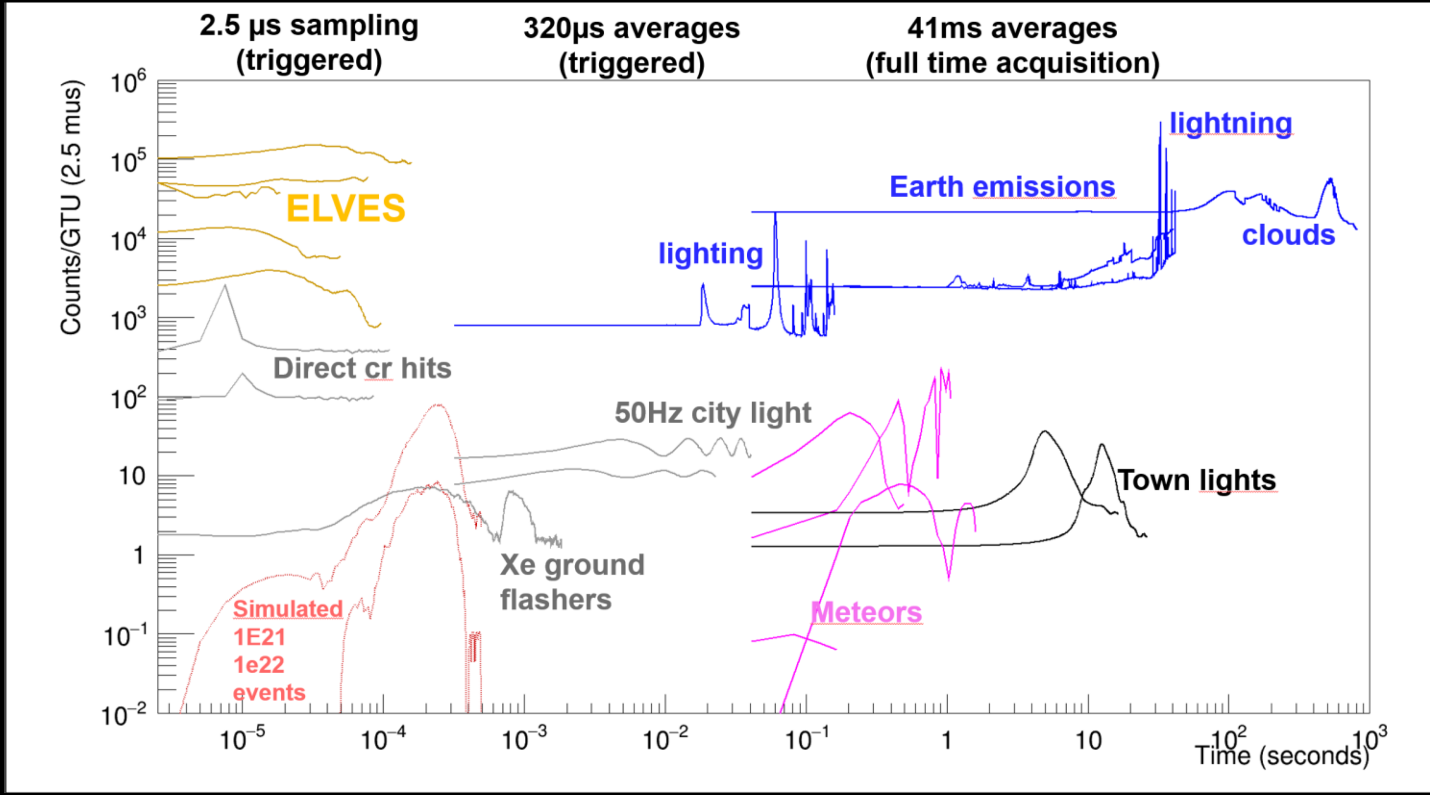
Mini-EUSO events zoo

TLEs

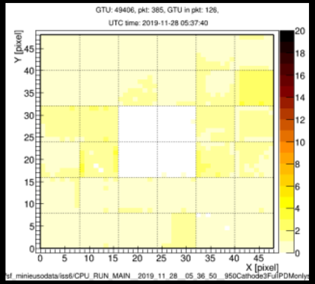


Direct CR

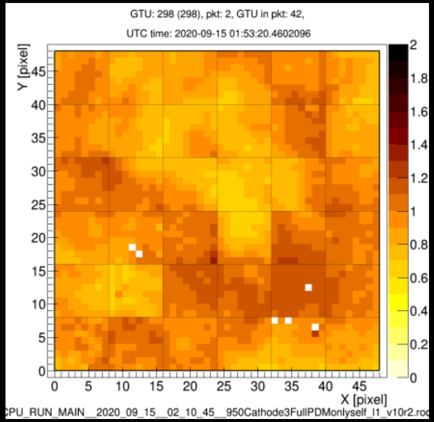




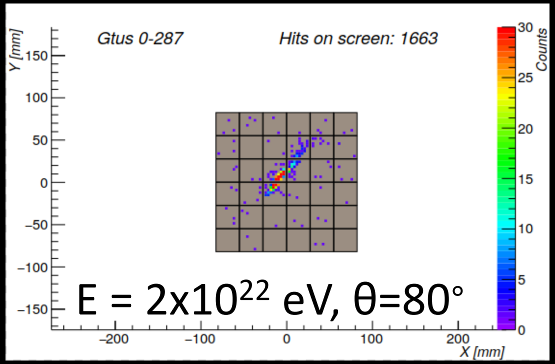
lightning



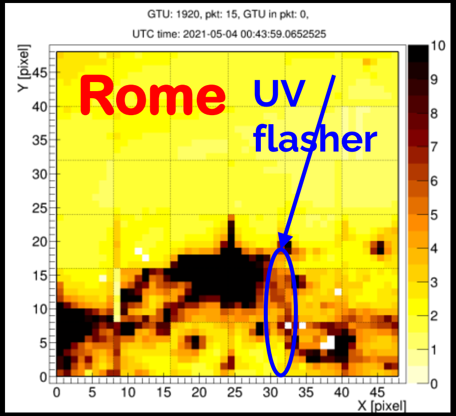
clouds



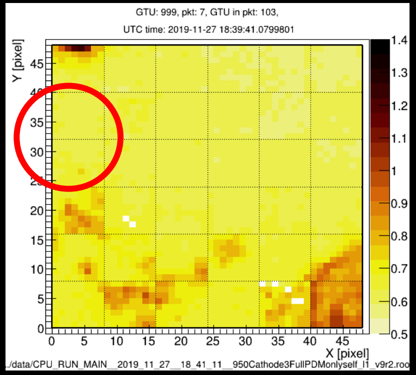
Simulated EAS



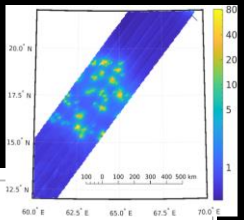
Artificial sources

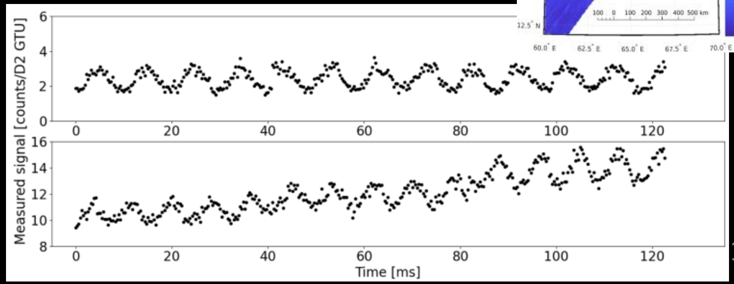


meteors

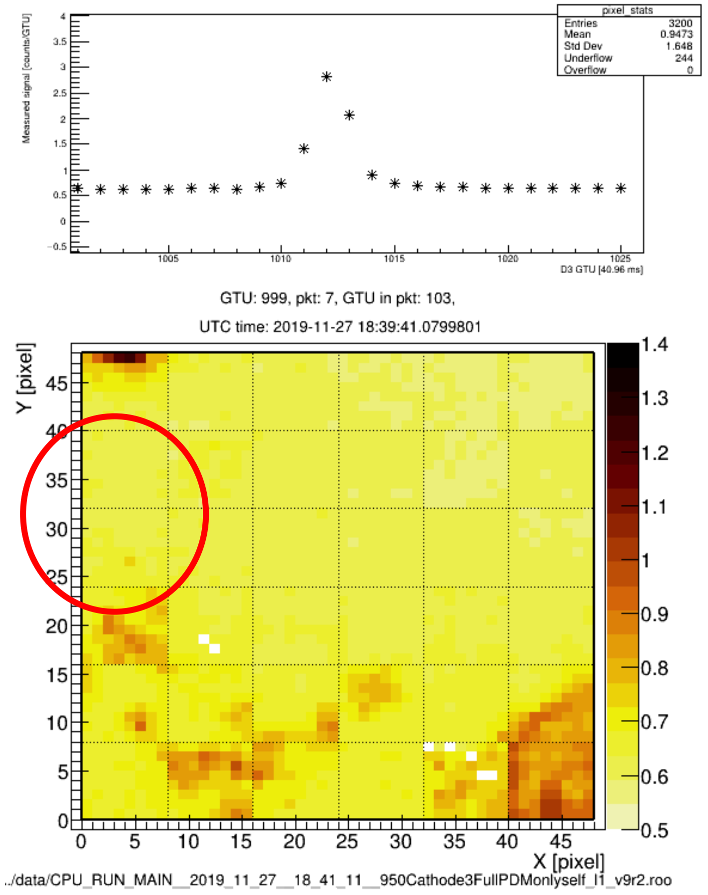


Artificial sources (50-60 Hz oscillations)

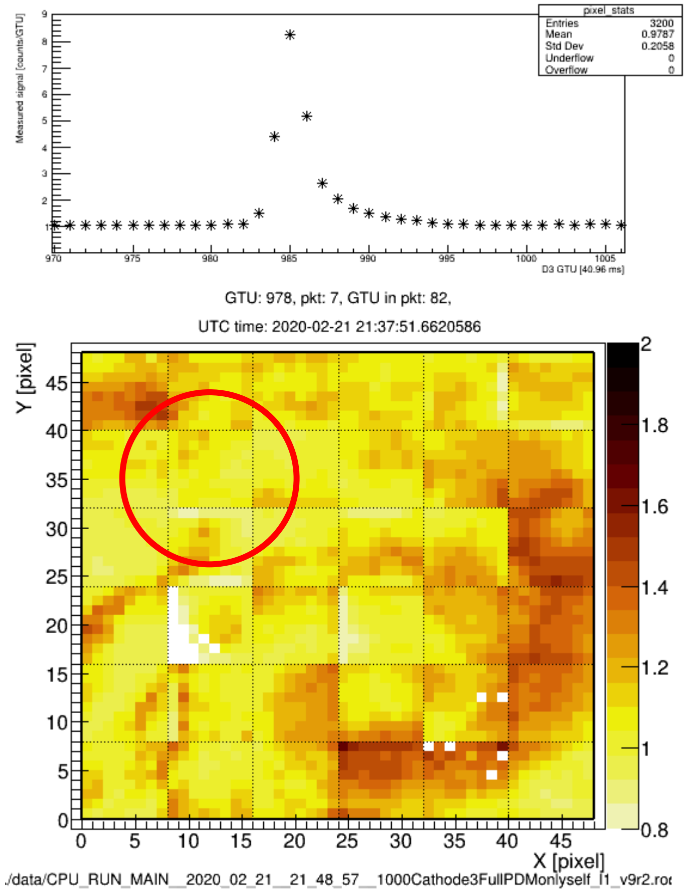




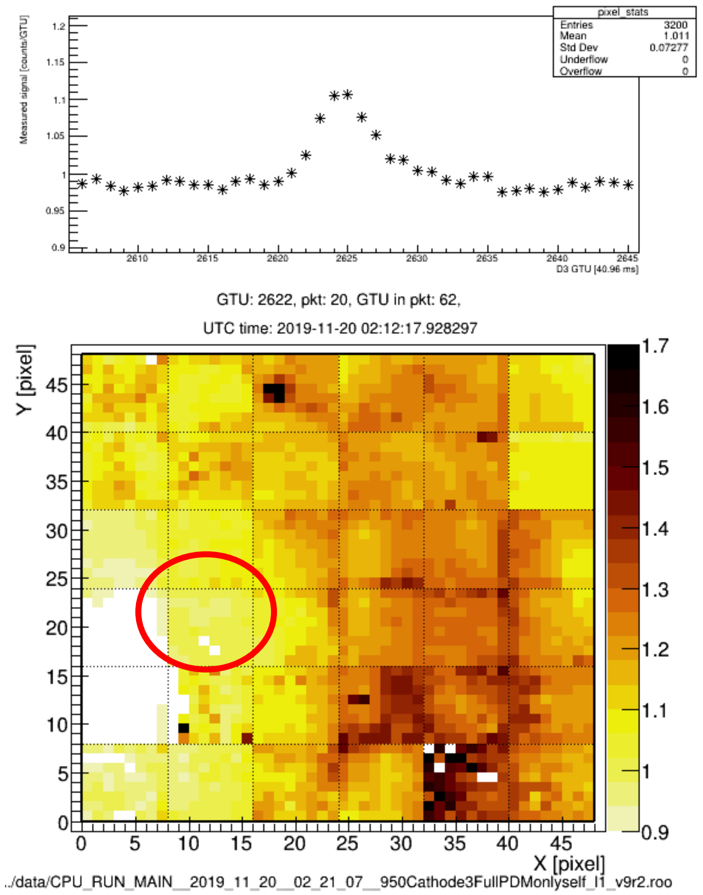
Meteors in Mini-EUSO from ISS



Session 06, 27/11/2019, 18:41:11 UTC
Andaman sea (near Thailand)

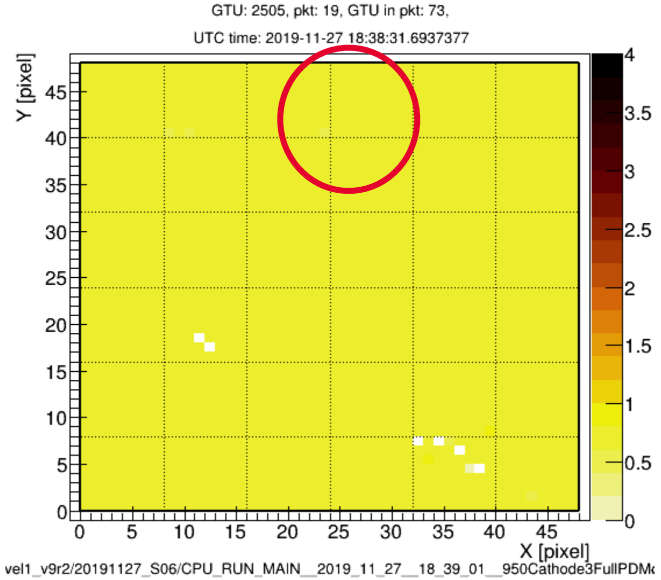


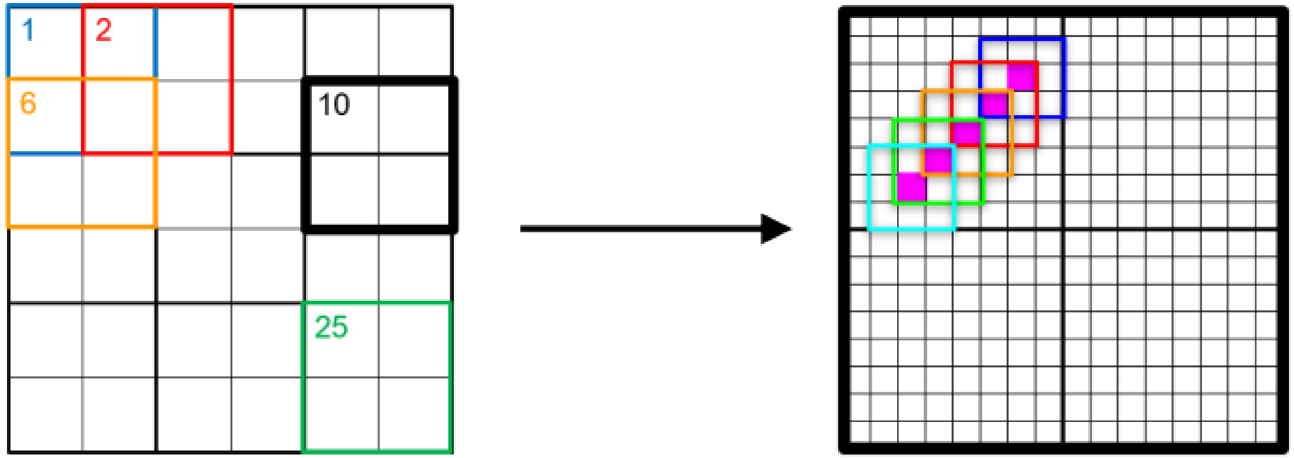
Session 11, 21/02/2020, 21:48:57 UTC
Indian Ocean



Session 05, 19/11/2019, 02:21:07 UTC
North Atlantic Ocean

Trigger Offline



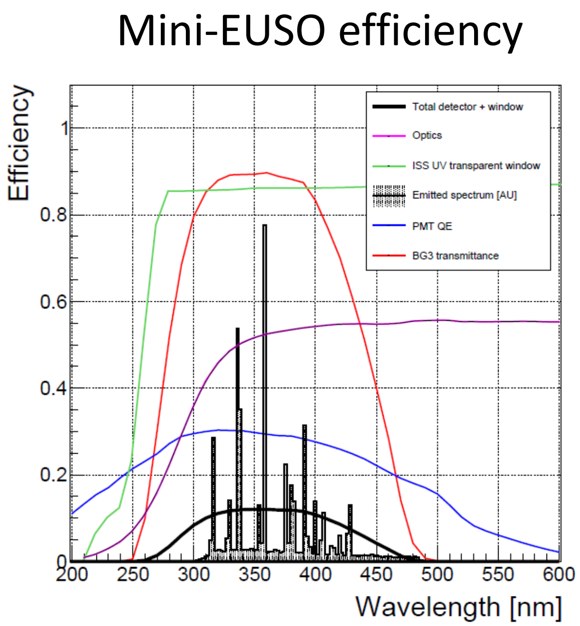


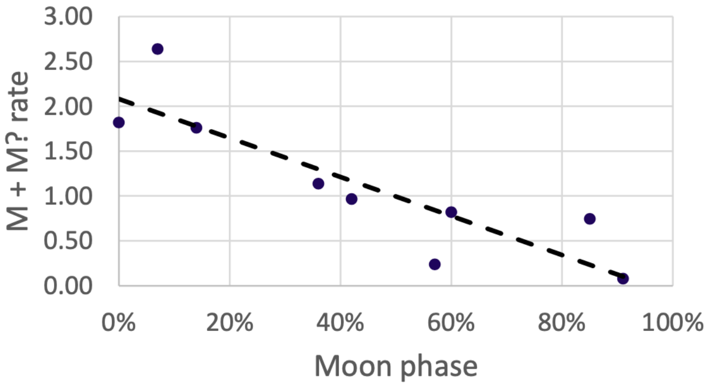
- Search for tracks above threshold on 4 consecutive GTUs (D3)
- Threshold is set at pixel level: $\mu_{pix} + 3\sigma_{noise}$, computed on the last 16 GTU
- An event is eliminated if 64 pixels are activated at the same time on the same EC
- After the trigger, a second selection is operated to exclude too faint or non meteor events
- One event is discarded if the excess $< 5.5\sigma$
- Events are then inspected and classified by eye

Events of sessions S05-14

Extrapolation on detected meteors → $O(10^4)$ in full data sample

			M			M?			U			N			TOT		
SESSION	**[min]**	**M_{ph}**	**count**	**rate**	**perc.**	**count**	**rate**	**perc.**	**count**	**rate**	**perc.**	**count**	**rate**	**perc.**	**count**	**rate**	**perc.**
20191119_S05	192	60%	100	0,52	25%	58	0,30	14%	49	0,25	12%	194	1,01	48%	401	2,09	100%
20191127_S06	282	0%	327	1,16	39%	186	0,66	22%	77	0,27	9%	240	0,85	29%	830	2,95	100%
20191205_S07	214	57%	20	0,09	5%	31	0,14	8%	74	0,35	19%	275	1,28	69%	400	1,87	100%
20191230_S08	232	14%	285	1,23	37%	123	0,53	16%	63	0,27	8%	295	1,27	39%	766	3,31	100%
20200108_S09	236	91%	5	0,02	2%	14	0,06	4%	127	0,54	40%	169	0,72	54%	315	1,34	100%
20200221_S11	168	7%	335	1,99	57%	109	0,65	18%	40	0,24	7%	108	0,64	18%	592	3,52	100%
20200302_S12	210	42%	135	0,64	30%	68	0,32	15%	60	0,29	13%	187	0,89	42%	450	2,15	100%
20200313_S13	208	85%	122	0,59	26%	33	0,16	7%	27	0,13	6%	283	1,36	61%	465	2,24	100%
20200331_S14	221	36%	173	0,78	35%	78	0,35	16%	83	0,38	17%	165	0,75	33%	499	2,26	100%
TOTAL	**1962**		**1502**	0,77	32%	**700**	0,36	15%	**600**	0,31	13%	**1916**	0,98	41%	**4718**	2,41	100%



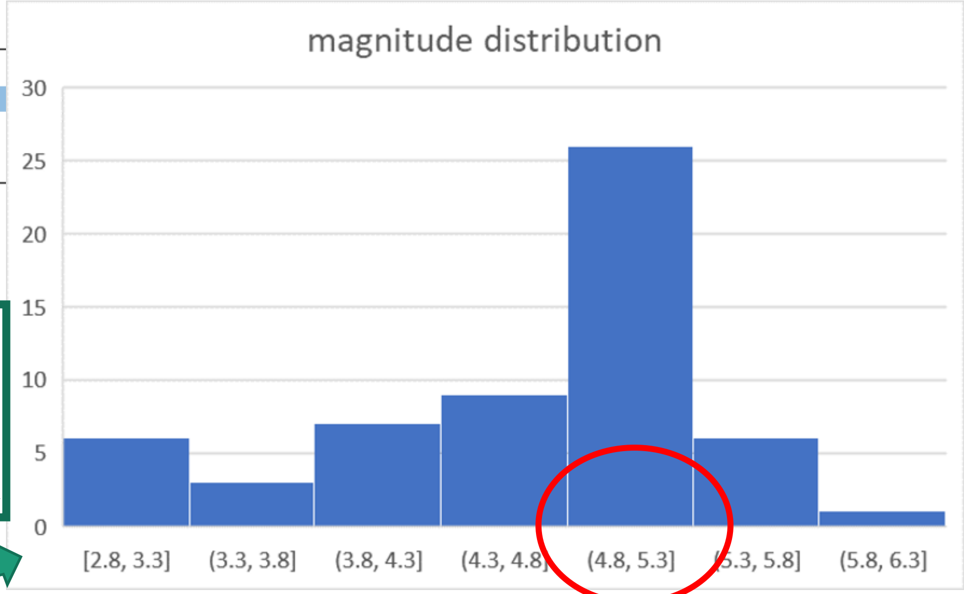


Observed event rate: 2.0 – 2.5 / min (in optimal conditions)

Predicted event rate at $+5^m$ (U) : 2.4 / min

Abs. mag	U-band flux (erg/s/cm²/A)	mass (g)	event rate (Mini)
+7	$6.7{\cdot}10^{-12}$	$2{\cdot}10^{-3}$	0.4/s
+5	$4.2{\cdot}10^{-11}$	10^{-2}	2.4/min
0	$4.2{\cdot}10^{-9}$	1	0.11/orbit
−5	$4.2{\cdot}10^{-7}$	100	2.5/year

Abdellaoui et al., *Planet. Space Sci.* 143, 245 (2017)



Zero-point flux in UV:

Energy flux U-band: $f_\lambda = 4.75{\cdot}10^{-8}$ erg cm^{-2} s^{-1} nm^{-1}

Mini-EUSO bandwidth: [250, 470] nm: $\Delta\lambda$ = 220 nm

Collection area: A = 490.6 cm2

Photon energy @ λ = 365 nm: $E_\gamma = 5.45 \cdot 10^{-12}$ erg

D1 GTU δt_{D1} = 2.5 μs , integral mean efficiency η= 8%

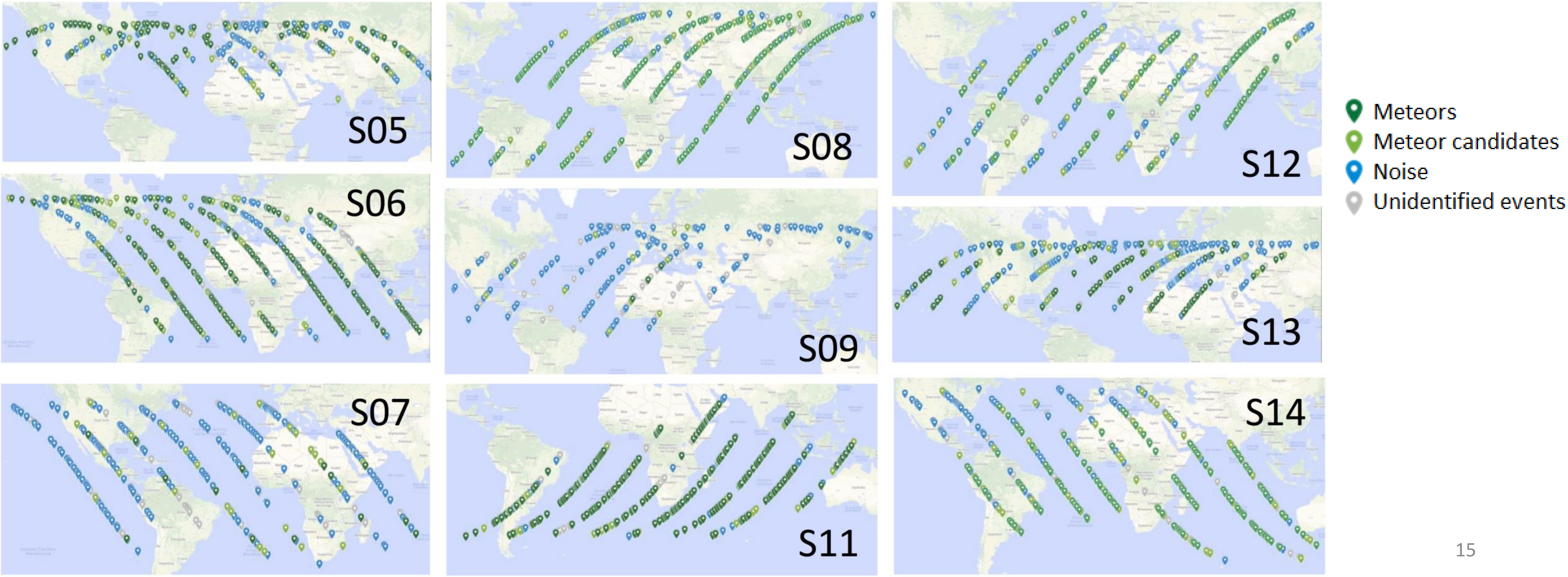
$$F_0 = \frac{f_\lambda \cdot \Delta\lambda \cdot A}{E_\gamma} \cdot \delta t_{D1} \cdot \eta \simeq 163 \text{ cnts}$$

$$\boldsymbol{F_0[d = 300\ km] \simeq 18 \text{ cnts}}$$

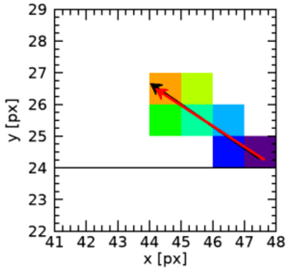
Maps:

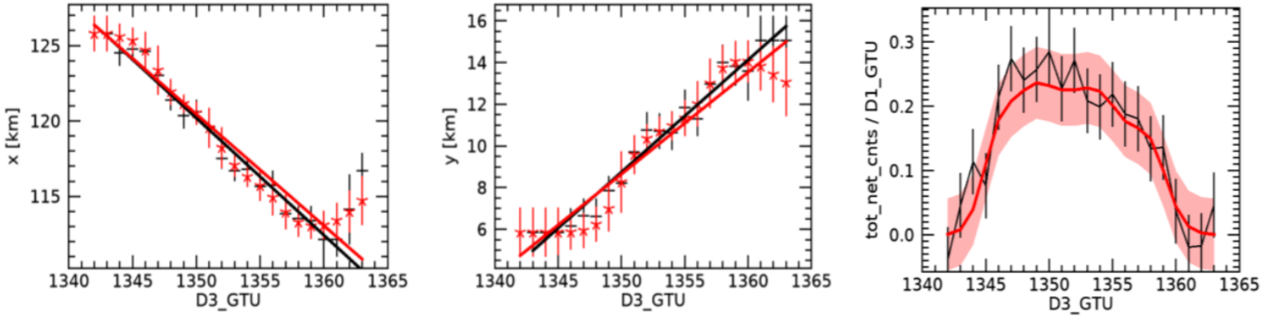
- Most of the meteors are detected where the background is lower
- The false positives rate is higher over continents

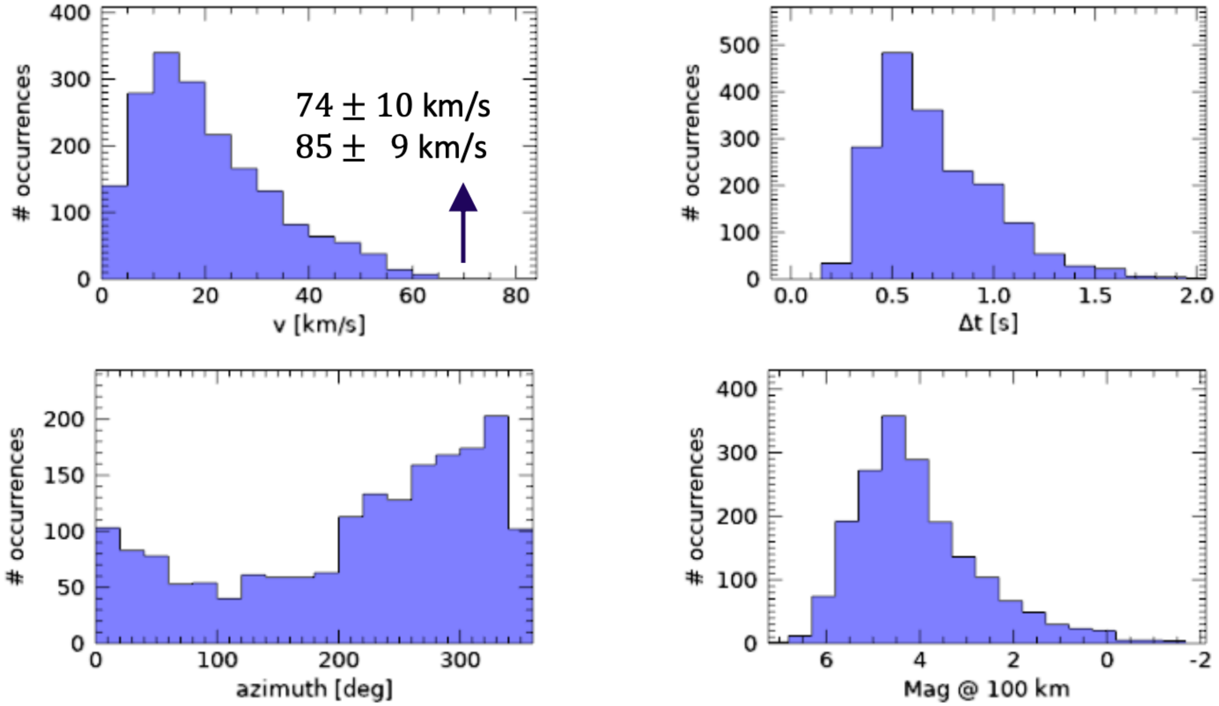
Maps of ISS ground projection for triggered events

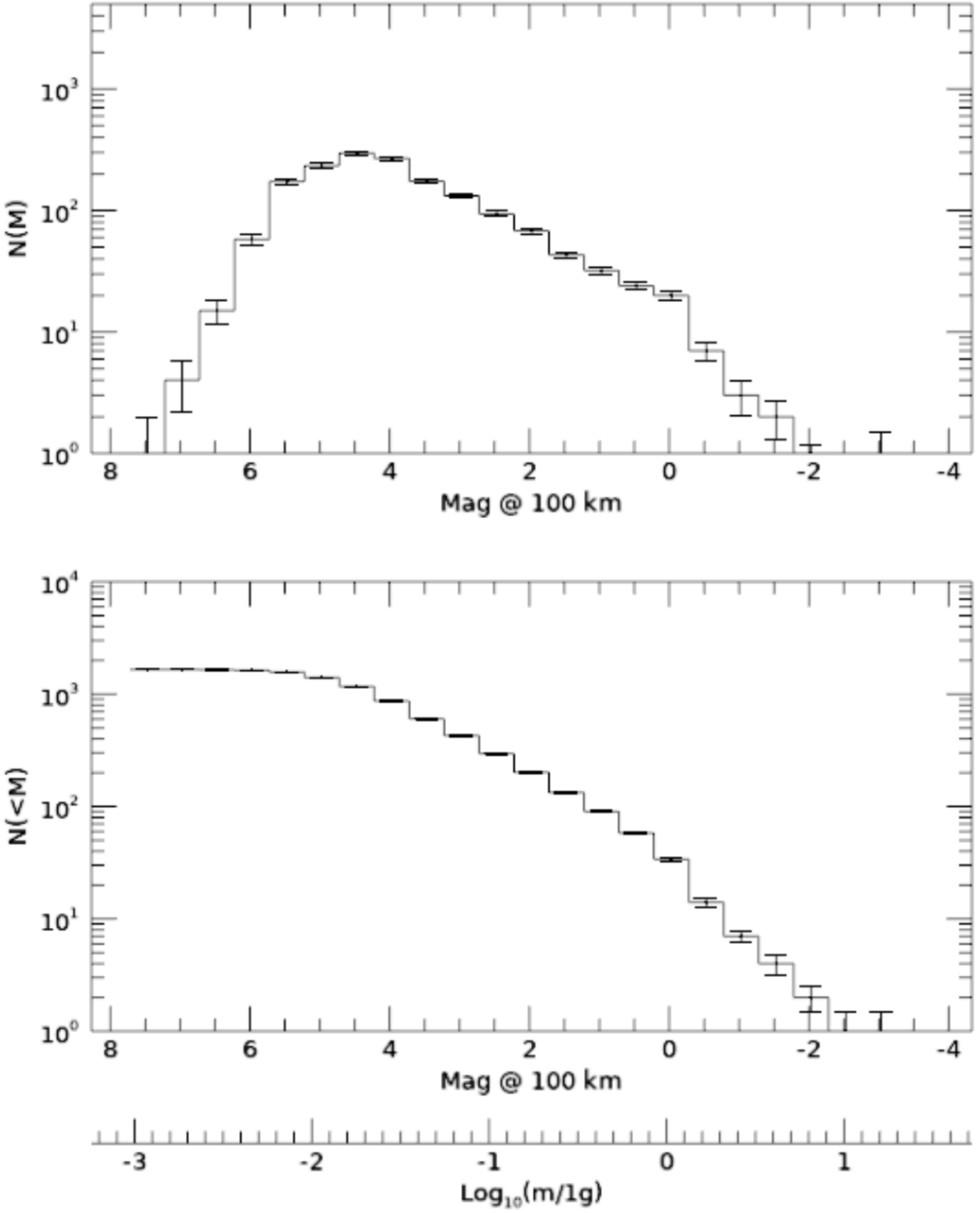


Meteor parameters and magnitude distribution









Simulations

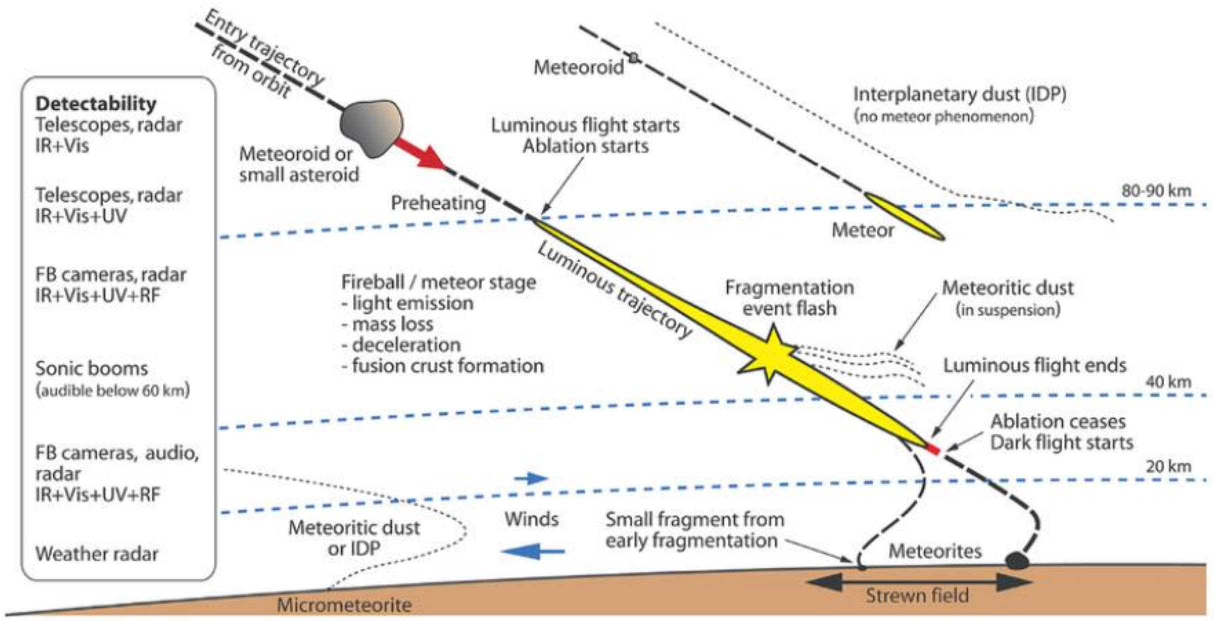
- Events are simulated in Mini-EUSO FoV to deduce detection efficiency and exposure as a function of magnitude M and background b

1. Random generation of meteor parameters.
   Input = (amag, bkg)
   - Speed (v_∞), Inclination (γ), Density (ρ)…
   - Height, speed and azimuth of ISS movement

2. Solve the dynamic model of meteors:
   $v = v(h), M = M(h), h = h(t)$

3. Add background map

4. Trigger + post processing



Meteor dynamic model

Gritsevich (2009), *Adv. Space Res.*, 44, 323
Gritsevich & Koschny (2011), *Icarus*, 212, 877

$$\begin{cases} \alpha = \dfrac{1}{2} c_d \dfrac{\rho_0 H_0 S_e}{\sin\gamma\, M_e} & \textbf{BALISTIC COEFFICIENT} \\ \beta = (1-\mu)\dfrac{c_h V_e^2}{2 c_d H^*} = \dfrac{1-\mu}{2}\sigma V_e^2 & \textbf{MASS-LOSS PARAMETER} \end{cases}$$

Adimensional quantities:

$$y = \frac{h}{M_e};\ v = \frac{V}{V_e};\ m = \frac{M}{M_e},\ s = \frac{S}{S_e}$$

$$\begin{cases} y = \ln 2\alpha + \beta - \ln\left[Ei(\beta) - Ei(\beta v^2)\right] \\ m = \exp\left\{-\beta \dfrac{1-v^2}{1-\mu}\right\} \\ I = \tau \dfrac{M_e V_e^3 \sin\gamma}{2H_0} v^3 \left[Ei(\beta) - Ei(\beta v^2)\right] \left(\dfrac{\beta v^2}{1-\mu} + 1\right) \exp\left\{-\beta \dfrac{1-\mu v^2}{1-\mu}\right\} \end{cases}$$

$$\mathcal{M} = -2.5(\log_{10} I - 3.185)$$

ATMOSPHERIC PARAMETERS

c_d = drag coefficient
ρ_0 = atmospheric pressure at sea level
H_0 = atmospheric scale height

METEOROIDS PARAMETERS

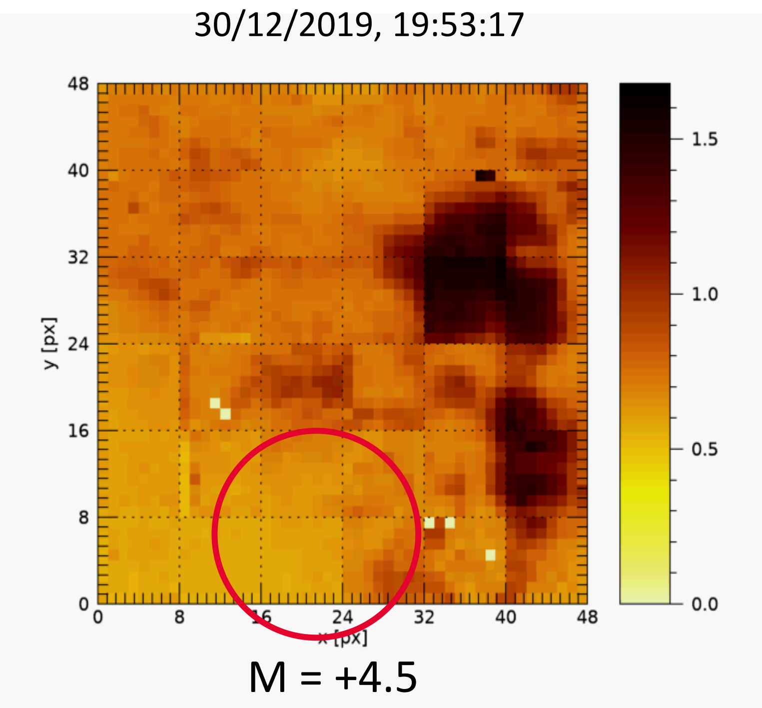
M_e = pre-atmospheric mass
S_e = pre-atmospheric cross-section
ρ_e = bulk density
V_e = pre-atmospheric speed
γ = trajectory inclination w.r.t. ground

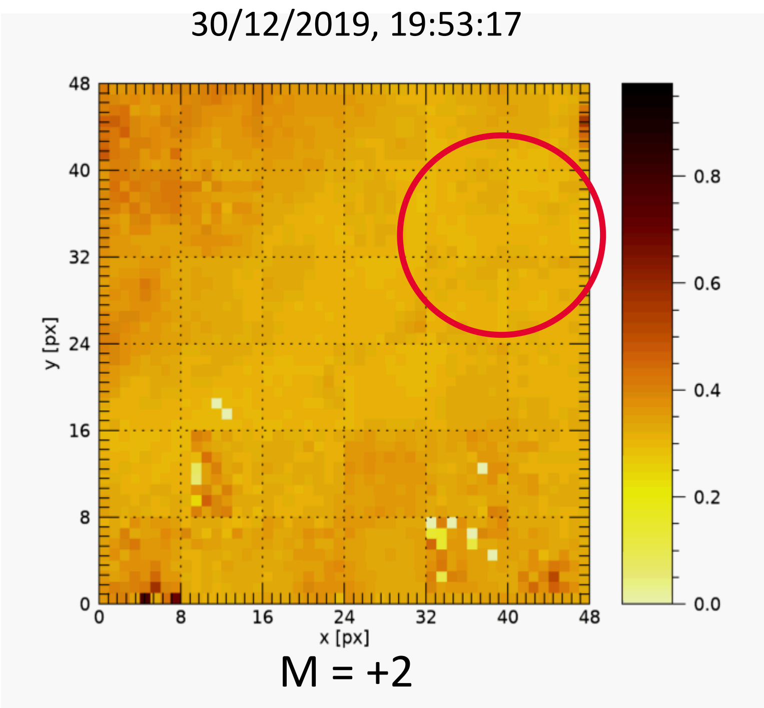
ABLATION PARAMETERS

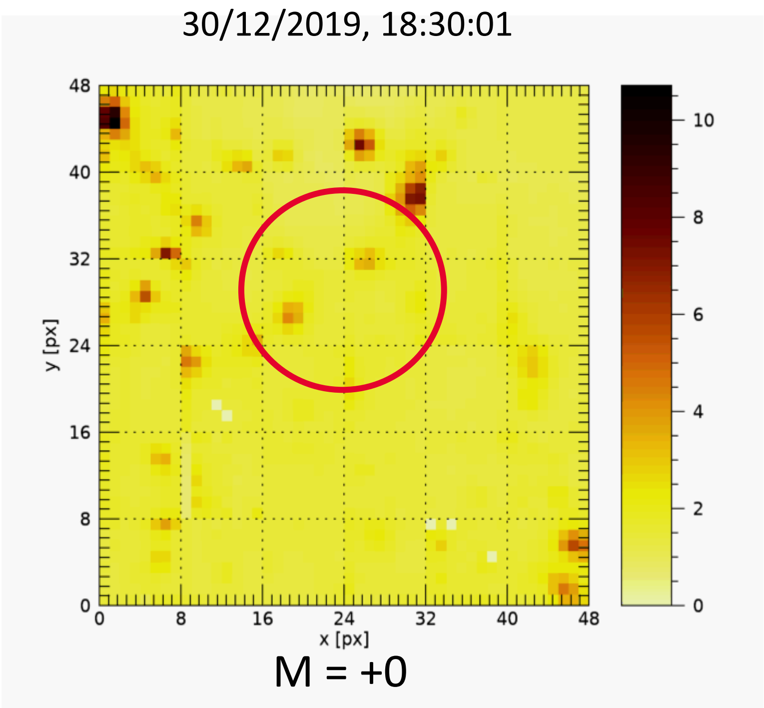
σ = ablation coefficient
μ = shape-change coefficient
τ = luminous efficiency

Simulated meteors on real background

Simulated meteors (100 x M), varying magnitudu added on background







Trigger → number of detected events

Computation of Efficiency and Exposure

Background implementation

Option 1: **Meteors simulated on Real Background**

- Select real data of Mini-EUSO
- Add simulated meteors, varying magnitude M
- Trigger
- Get exposure

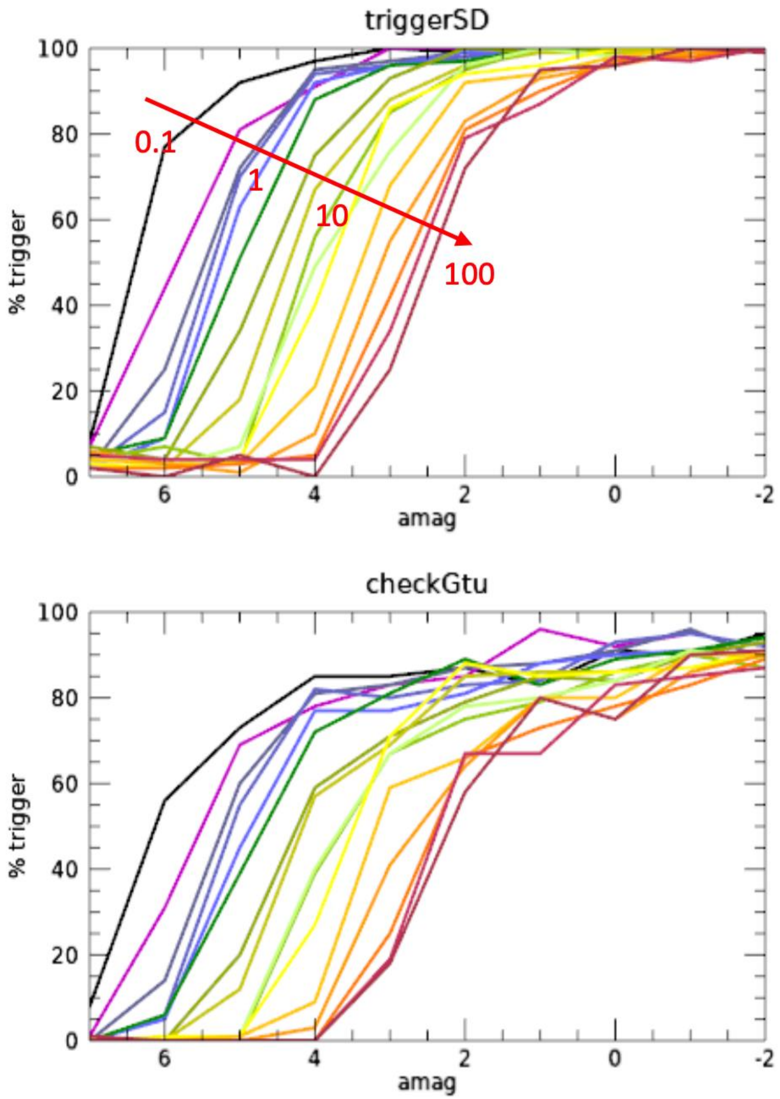
Limit! Require large computation time for

- 70 sessions with 5-8 orbits each

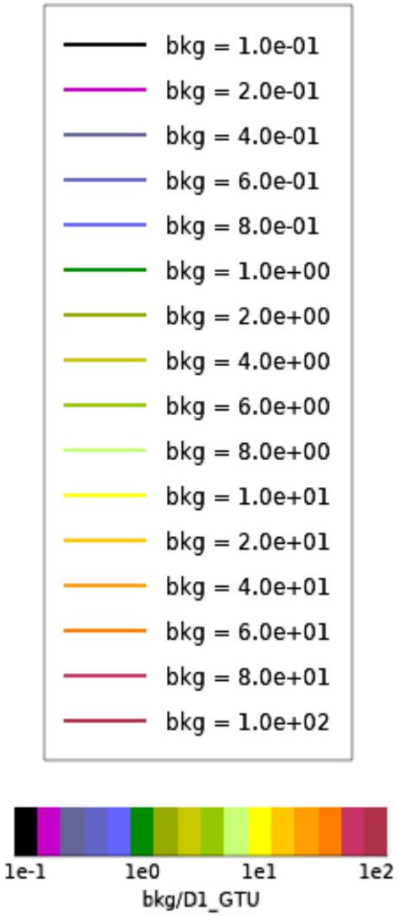
Option 2: **Meteors simulated on Simulated Background**

- Produce a constant simulated background, varying background level b
- Add simulated meteors, varying magnitude M
- Trigger
- Get a dependence for the efficiency $\eta(b, M)$
- Apply $\eta(b, M)$ to Mini-EUSO data, where b is calculated as average on 1 $pixel$

Trigger efficiency (Simulated background)



Background counts on D3 data (normalized to D1)
Typically in the range **[0.5 – 20] cnts/GTU**



Simulations over flat poissonian background maps

triggerSD: first trigger searching tracks in 4 consecutive GTUs
checkGtu: post-processing to tentatively exclude false triggers

- trigger efficiency **>80% for mag < +2**
- decay above $+2^m$ very depending on the background value
- **checkGtu discards ~10% of triggers** even for very bright events

Efficiency (1 session used)

- Data used in analysis, 30/12/2019 – 31/12/2019

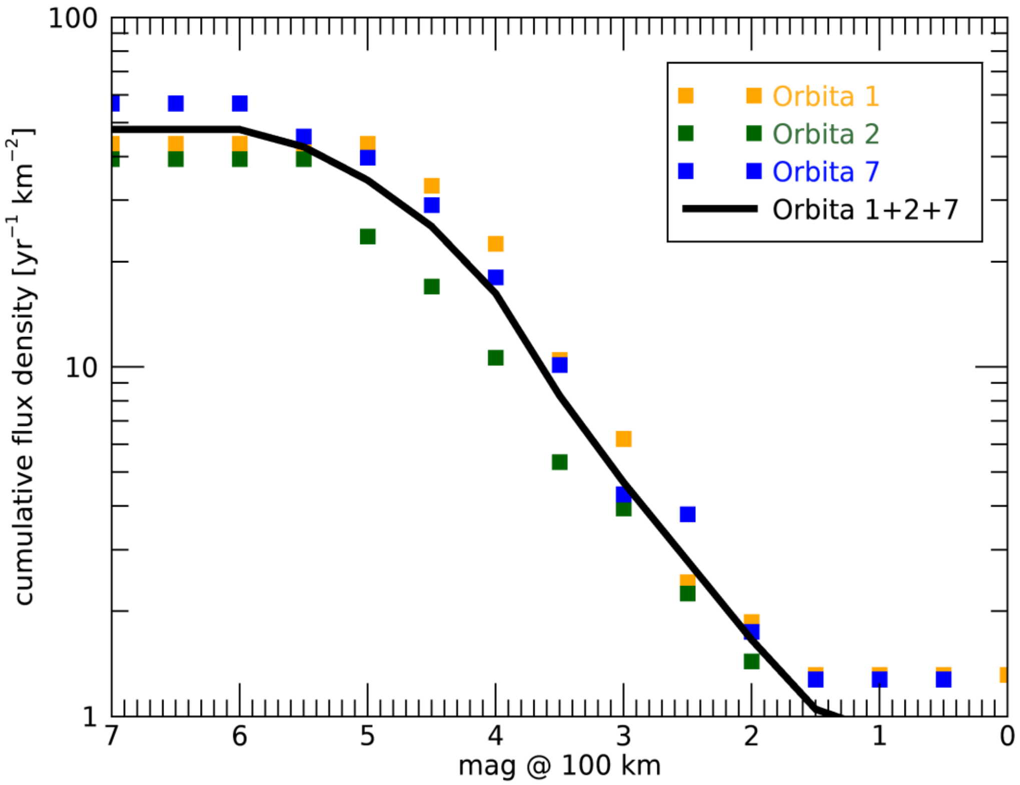
- Every orbit ≅ 15 files
- $File = 3200\ GTU = 131{,}07\ s$
- $Orbit \cong 2000\ s$

- $\eta(M) = \frac{n_{triggeredevents}}{n_{totalevents}}$

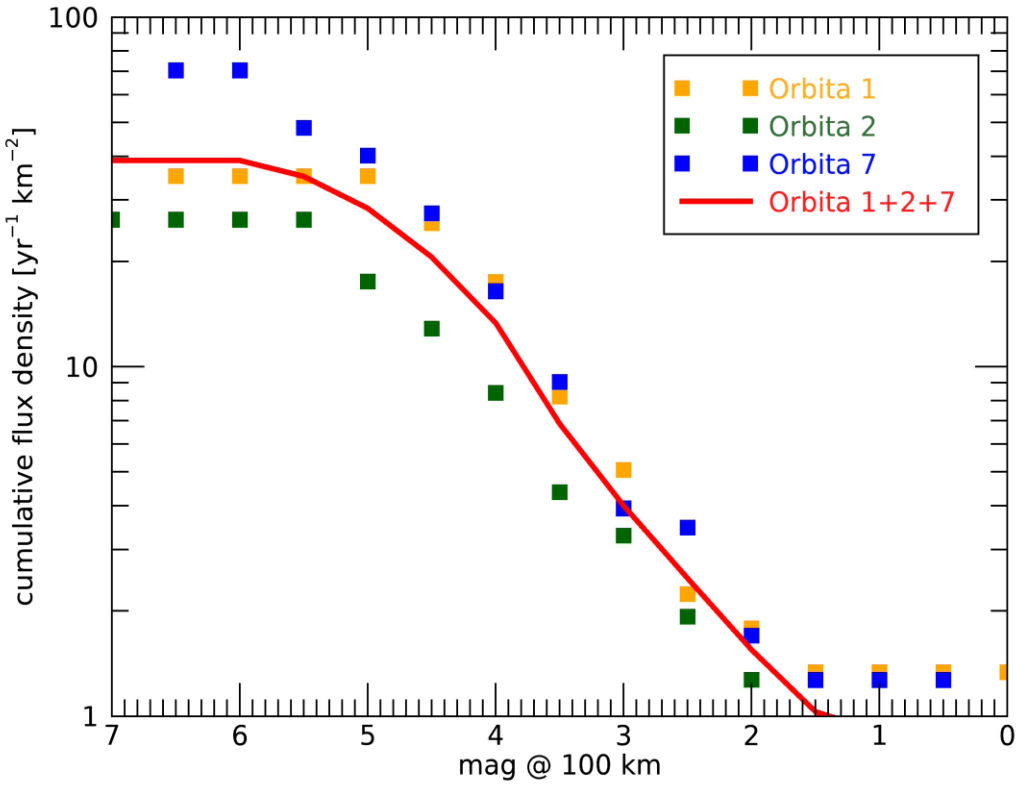
Cumulative flux density

PRELIMINARY

- On real background



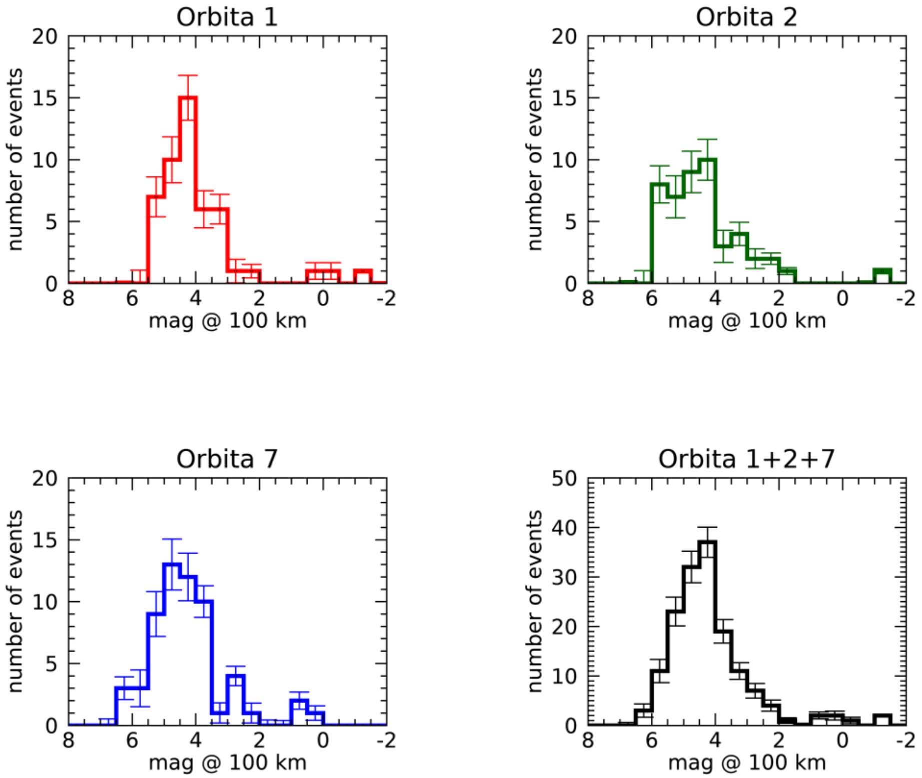
- On simulated background



Exposure and flux density

PRELIMINARY

- Distribution of real events as a function of magnitude



Range of Magnitudes (6,1)

- Exposure

$$Esp_{orbita} = Eff \frac{[n_{file} \times 3200GTU \times (40{,}96 \times 10^{-3} s)]}{60 \times 60 \times 24 \times 365} \times 250^2 km^2$$

Time

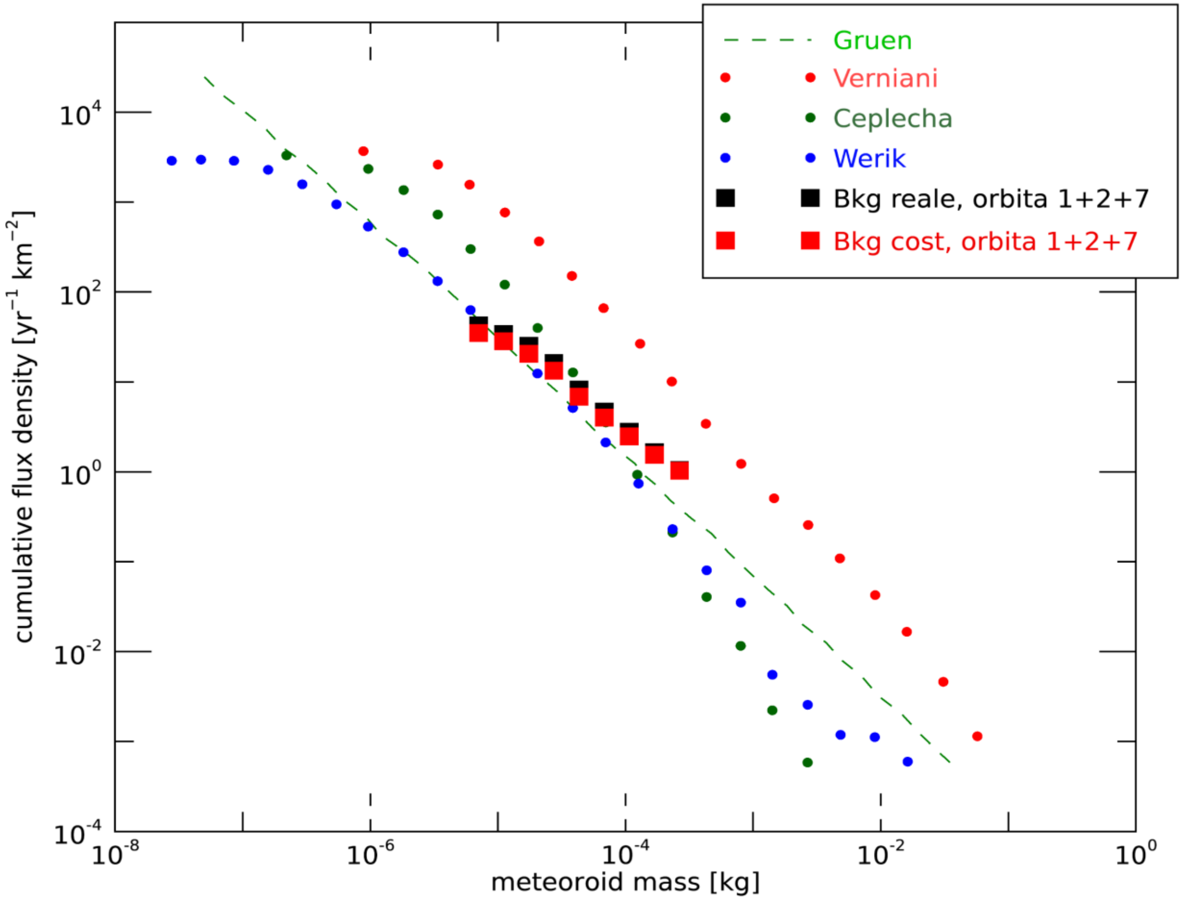
Area

$(@\ h = 100\ km)$

- $Cumulative\ flux\ density = \frac{Event\ Distribution}{Esp_{orbit}}$

Cumulative Flux Density

PRELIMINARY



Koschny and Drolshagen, 2016, *Flux densities of meteoroids derived from optical double-station observations*, Planetary and Space Science

- Magnitude – Mass Conversion

Magnitude	Mass (kg)
$+7$	$2 \cdot 10^{-6}$
$+5$	10^{-5}
0	10^{-3}
-5	10^{-1}

Abdellaoui et al., 2017, *Meteor studies in the framework of the JEM-EUSO program,* Planetary and Space Science

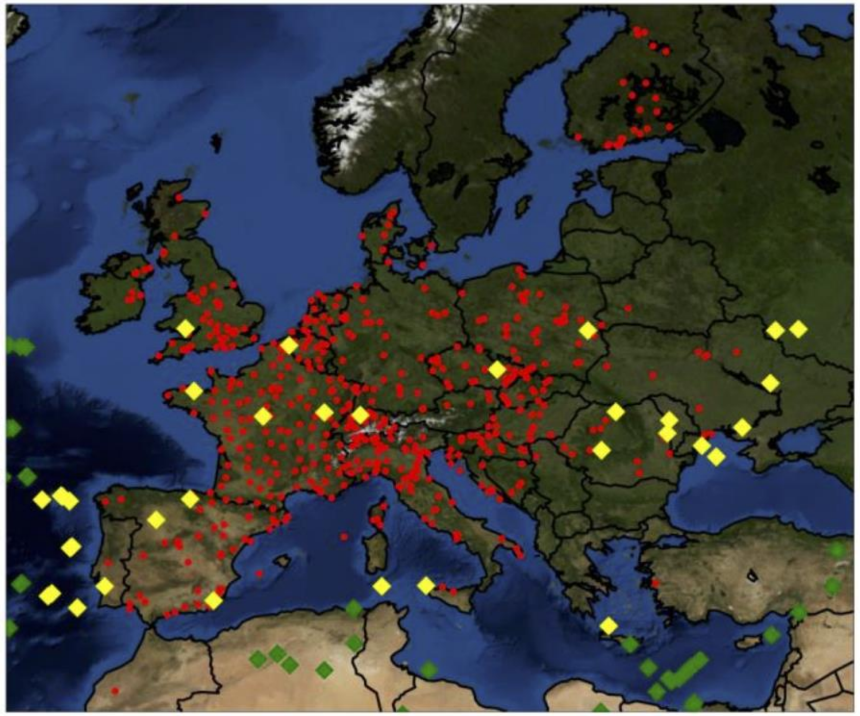
- Data used to get the trend $= 150$
- Data used for comparison $\cong 20000$
- The trend follows expected behaviour

Correlation with ground sources

(130 ev. with d < 400 km from a ground station around the world)

Detail from session 06

- Meteors
- Meteor candidates
- Noise
- Unidentified events



Red dots: ground networks
Yellow diamonds: ISS position at M event
Green diamonds: position of M event

- **2 M in FoV of Palermo PRISMA camera: NO counterpart**
- **3 M in FoV FRIPON network: still to be checked**

Conclusions:

- Mini-EUSO is on ISS and takes data twice per month.
- Mini-EUSO detects events of different nature according to expectations.
- Thousands of meteor events being analysed.
- Preliminary estimation of sensitivity to meteors in agreement with simulations as well as meteor flux.
- Detailed data analysis in process.
- We look forward to have events detected in correlation with PRISMA, we got close but not lucky yet.

THANK YOU