TUS (Tracking Ultraviolet Setup) METEOR mode operation

Reported by Kenji Shinozaki

National Centre for Nuclear Research, Łódź, Poland

2nd DIMS Workshop 2020-12-05

Outline

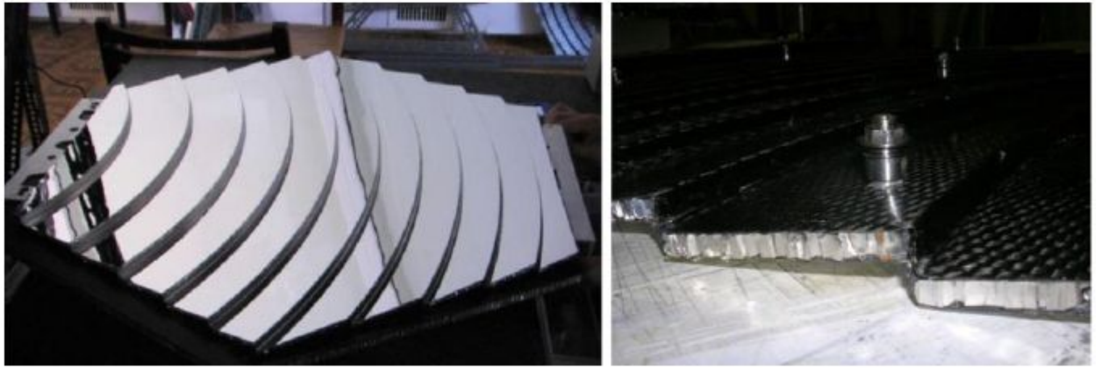
TUS (Tracking Ultraviolet Setup), the first orbital fluorescence detector for ultra-high energy cosmic ray air shower detections is a **JEM-EUSO** (Joint Experiment Missions for Extreme Universe Space Observatory) family project promoted by **Moscow State University** group from development to operation and data analysis . **University of Turin** group joined the data analysis effort.

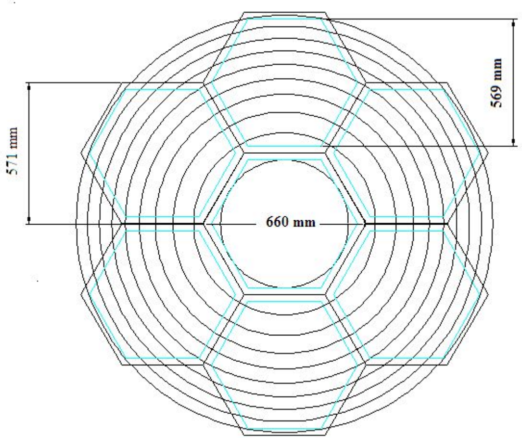
- TUS (Tracking Ultraviolet Setup) detector and operation
- Meteor mode operation and analysis by TUS
    - Meteor event
    - In-progress work for nuclearite search by TUS
- Summary

TUS on Lomonosov satellite

Left: an artist's view of Lomonosov, right: TUS with a packed hand on the Lomonosov frame

Primary mirror

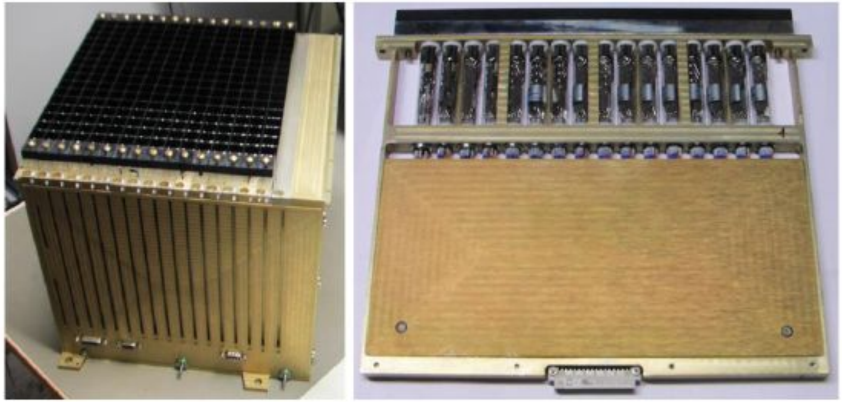




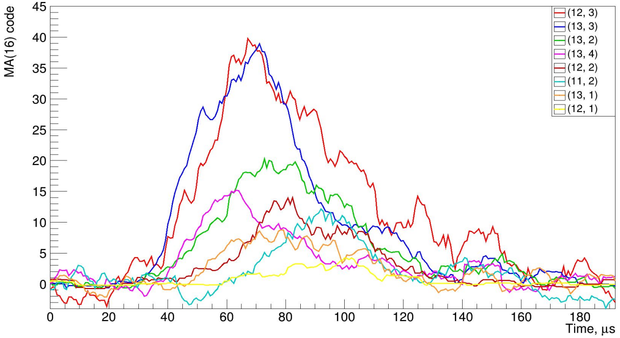
- Fresnel mirror: 2 m^2, focal distance 1.5 m:
  7 segments of equal size, 2 carbon plastic layers strengthened by a honeycomb aluminium structure; covered by an aluminium film, protected with a MgF_2 coat deposited through a vacuum evaporation process.
- Reflectivity @350 nm: $\sim 85\%$
- Field of view: $\pm 4.5°$
  ~ 80 km$\times$80 km at sea level at orbit height ~ 500 km

B.A. Khrenov *et al* JCAP03(2020)033

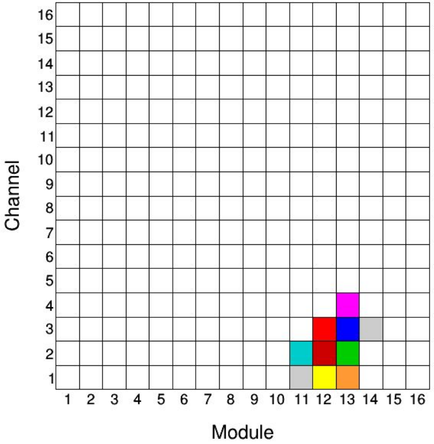
Camera on focus



- Photodetector: 256 Hamamatsu R1463 PMTs, ø13 mm cathode, combined in a block of 16 clusters
- Light guides with square entrance apertures (15 mm×15 mm) and circular output
- Black blends 1 cm above light guides
- 2.5 mm-thick UV filter in front of each PMT cathode
- Quantum efficiency of PMTs ∼ 20% @350 nm

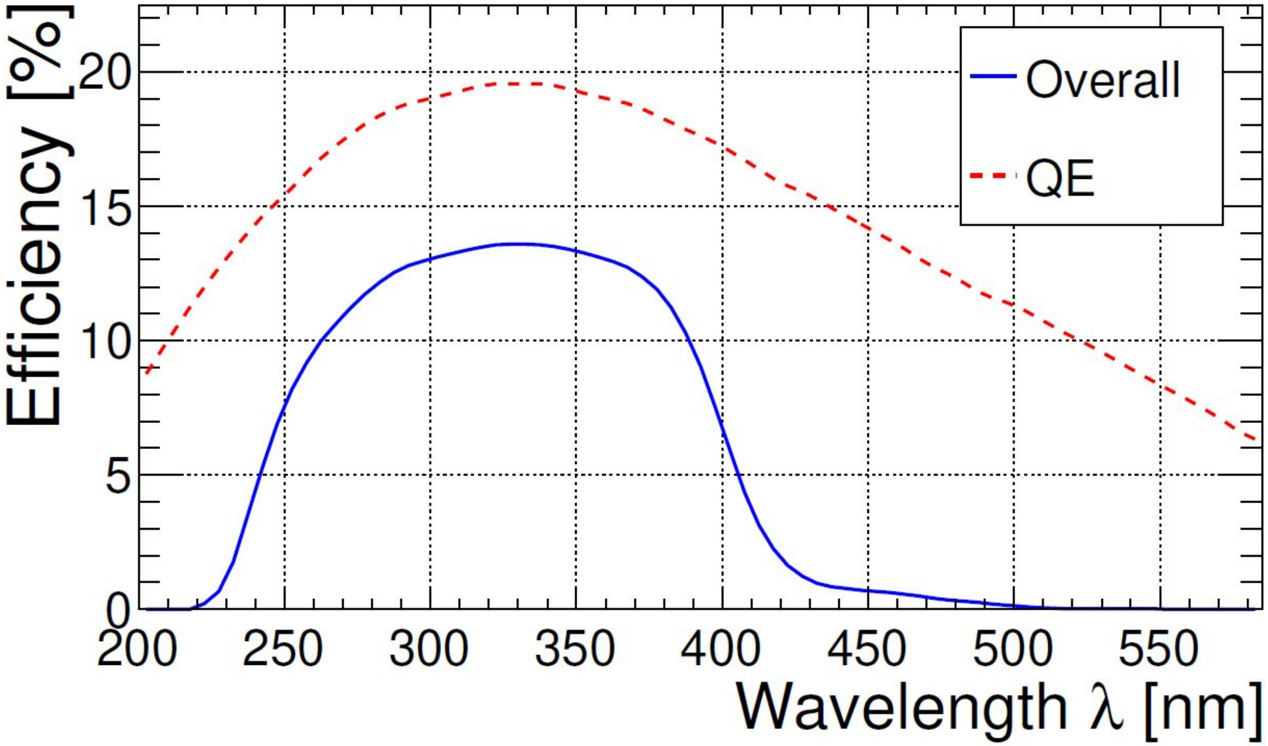


256 times steps for 256 PMTs



1 PMT ~5 km resolution from 500 km

Sensitive wavelength band



Operation overview

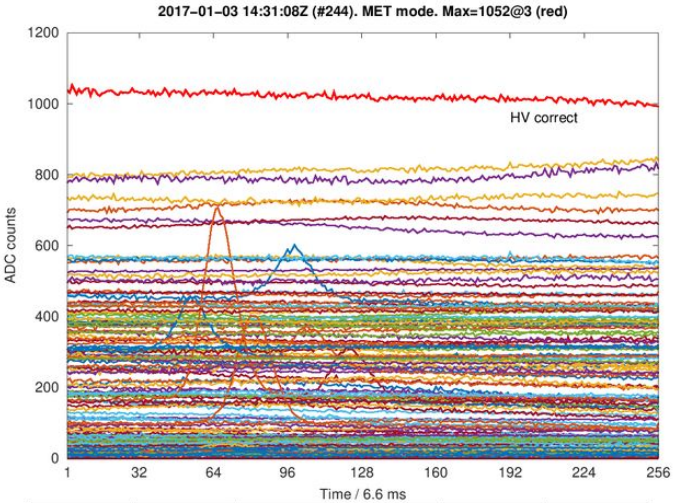
- Launch: 2016-04-28
- Orbit: 97.8° inclination at ~500 km (*P*=94 min) (sun-synchronous)
- First light (switch-on): 2016-05-19
- Regular operation start: 2016-08-16
- End of operation: 2017-11-30 (last data)
- Operation modes
  - EAS mode: time res. 0.8 μs for duration of ~205 μs
  - TLE "dust" mode: time res. 25.6 μs for duration of 6.6 ms
  - TLE mode: time res. 0.4 ms for duration of ~0.1s
  - **METEOR mode: time res. 6.6 ms for duration of 1.68 s**

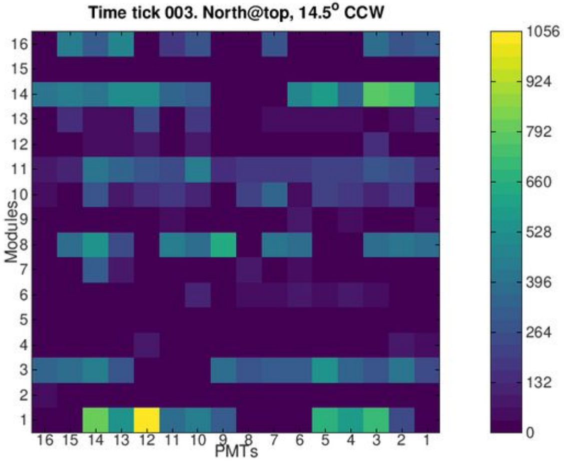
METEOR mode data

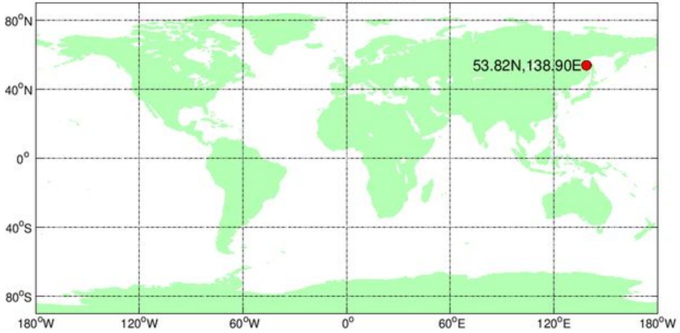
- Three campaigns delegated to METEOR mode performed
  - 2016-12 -- 2017-01
  - 2017-02 -- 2017-03
  - 2017-11
- Statistics
  - ~35,000 events in METEOR mode
  - ~9500 events in “Dark conditions” according to HV status
    - Can be used for generic analysis for meteors (~5 day obs. time)
  - ~1700 events under no moon effect (zenith angle < 90°)
    - Mainly used for nuclearite search (~2 day obs. time)

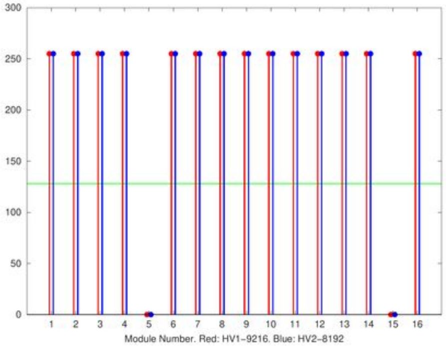
Observation time is preliminary

Example of METEOR mode event (170103)

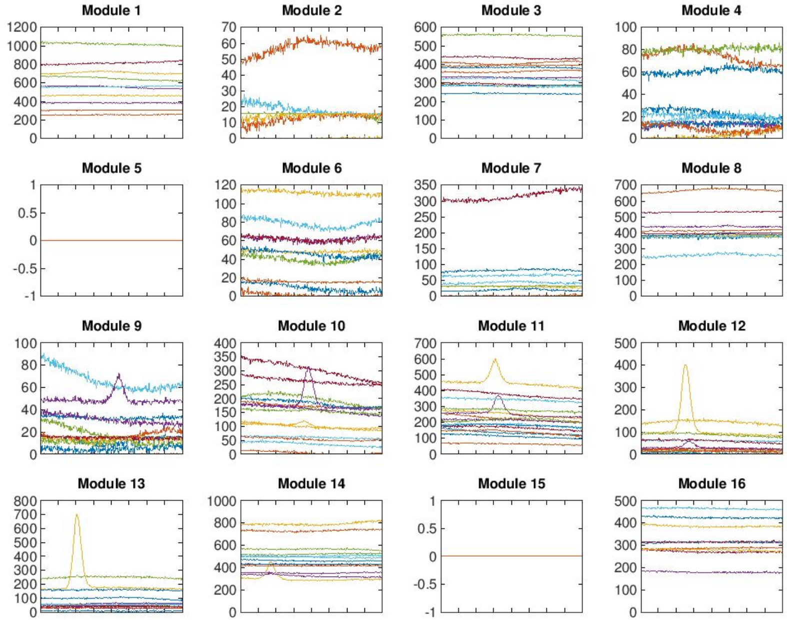


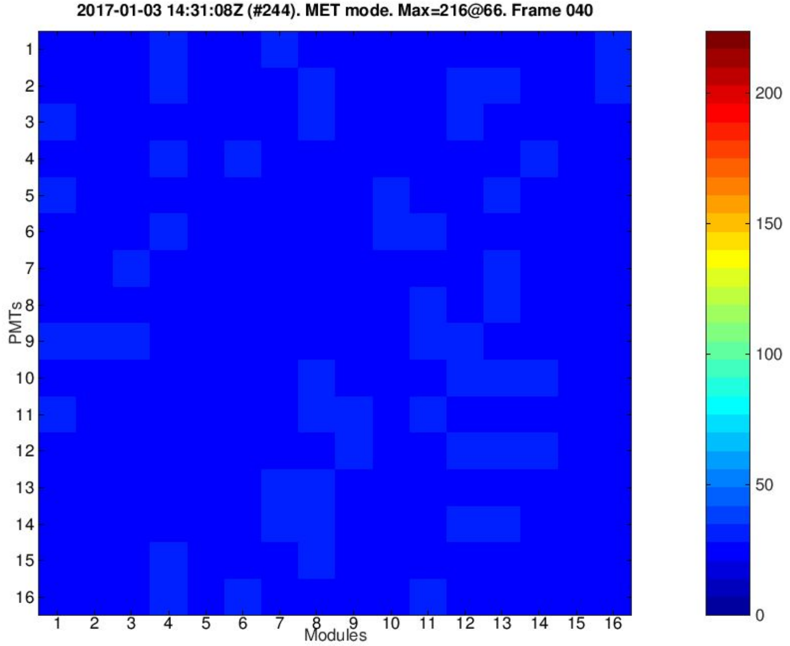




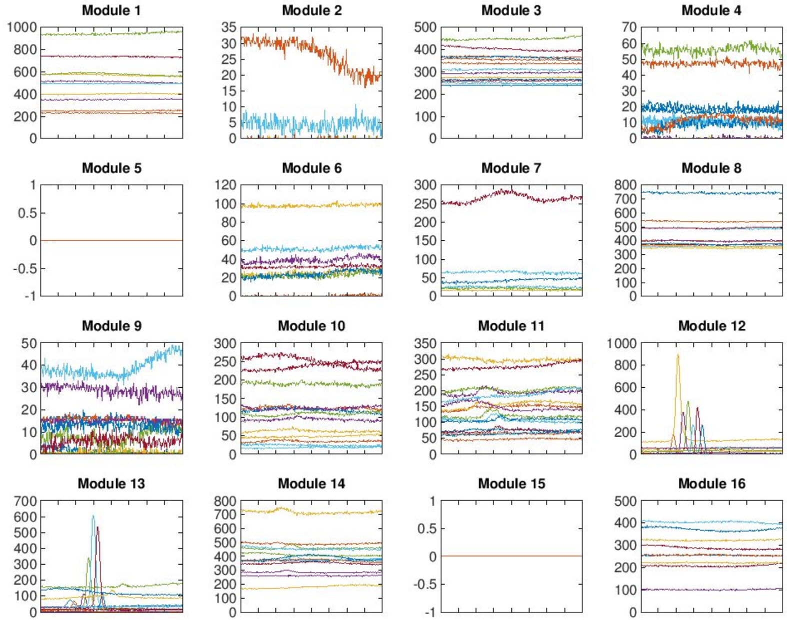


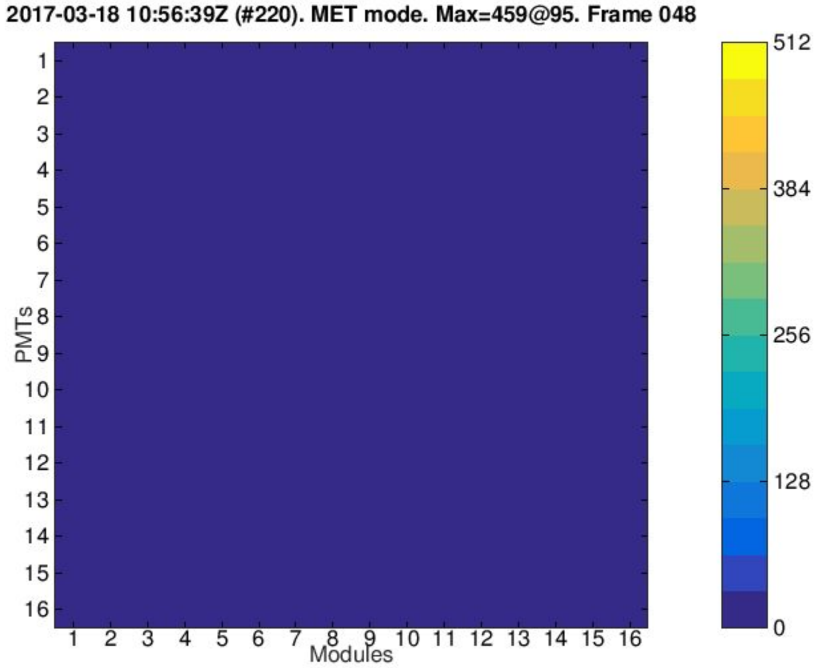
METEOR mode event (170103)





METEOR mode event (170318b)



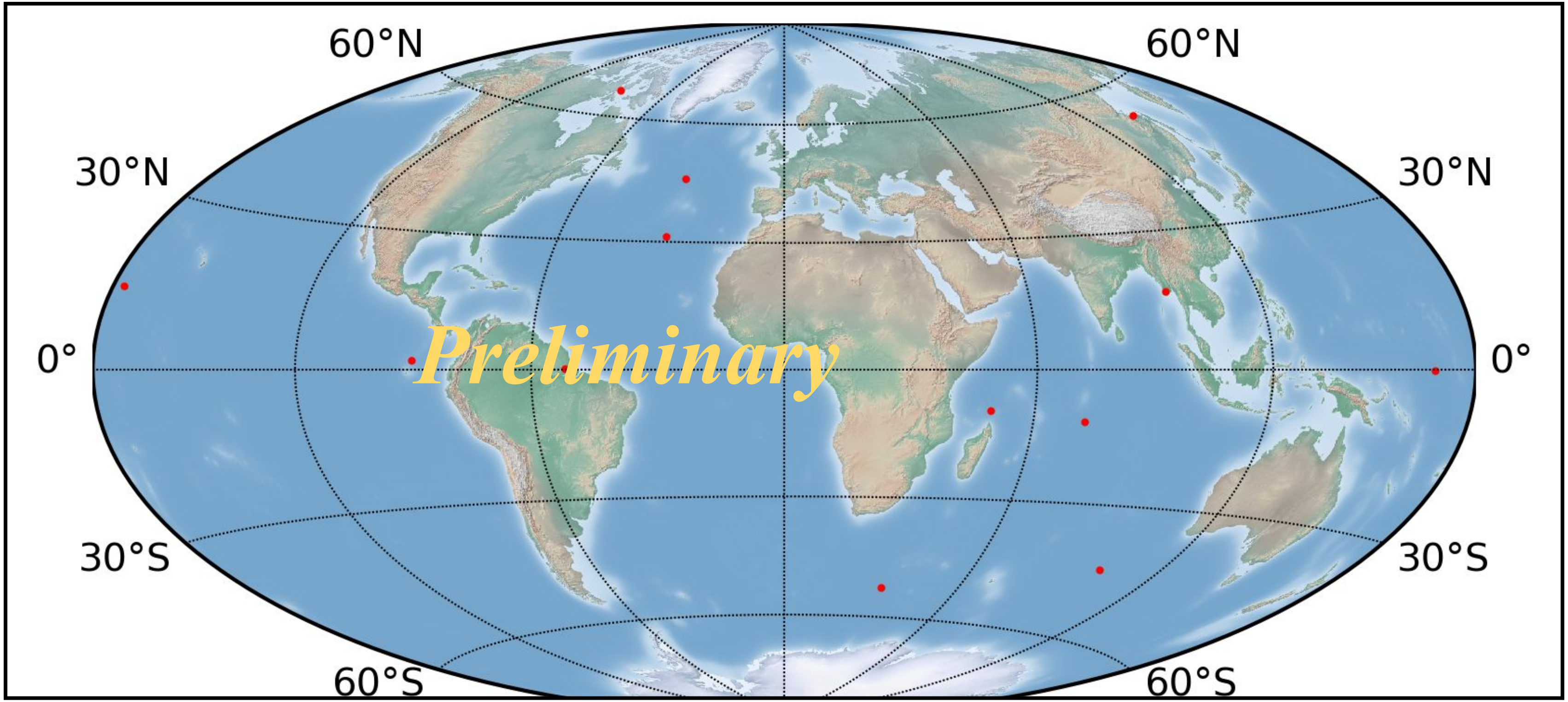


List of meteors detected by TUS

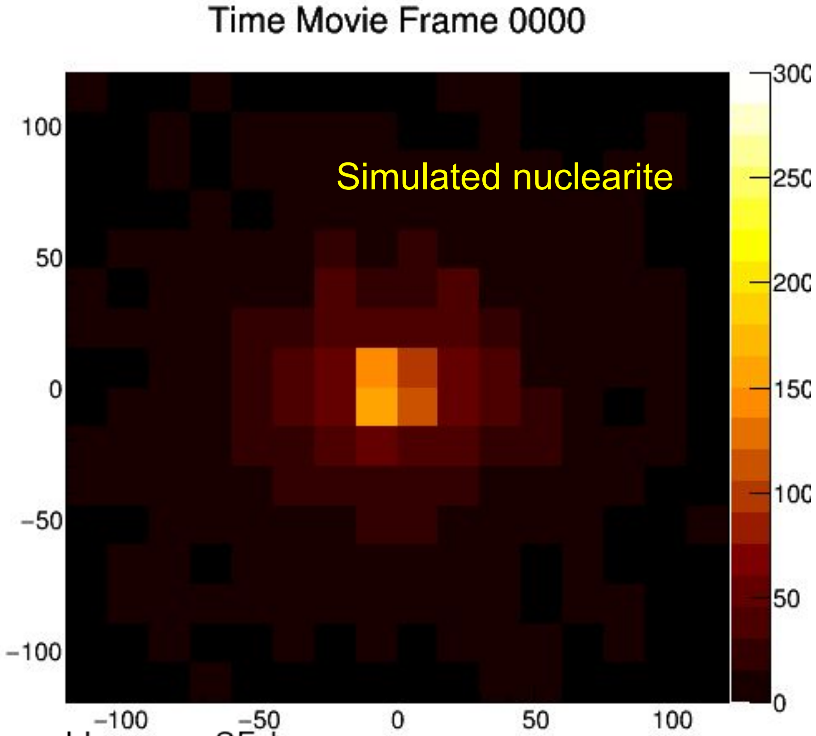
Event	Time (UTC)	Latitude	Longitude	Location	# hit pixels
TUS161230	19:44:46	9.38° S	49.34° E	North of Madagascar (Middle of the sea)	6
TUS161231	05:06:54	2.08° N	89.72° W	Northeast of Galapagos Islands (Middle of the sea)	5
TUS170103	14:31:08	53.77° N	138.88° E	Krai de Jabárovsk (Rusia, near zaliv Nikolaya)	13
TUS170105	16:54:56	16.84° N	95.15° E	Irawadi (Birmania)	7
TUS170106	18:09:26	11.66° S	72.82° E	Indian Ocean (Middle of the sea)	16
TUS170318a	01:27:04	3[illegible].31° N	31.26° W	North Atlantic Ocean (Middle of the sea)	3
TUS170318b	10:56:39	14.14° N	176.25° W	North Pacific Ocean (Middle of the sea)	29
TUS170318c	15:54:32	44.29° S	100.34° E	Indian Ocean (Middle of the sea)	32
TUS170319	20:11:56	52.37° S	33.62° E	South Atlantic Ocean (Middle of the sea)	12
TUS170321	01:35:37	45.51° N	30.43° W	North Atlantic Ocean (Middle of the sea)	60
TUS171110	05:40:44	66.45° N	84.6° W	West of Cuenca Foxe (Canada)	13
TUS171111a	02:22:15	0.17° N	51.8° W	Northwest of Amazonas River (Brazil)	26
TUS171111b	11:47:16	0.22° S	166.89° E	North of Nauru (Middle of the sea)	25

Names of TUS events correspond to their registration date.
For those events recorded on the same day, suffixes a, b, c are used.

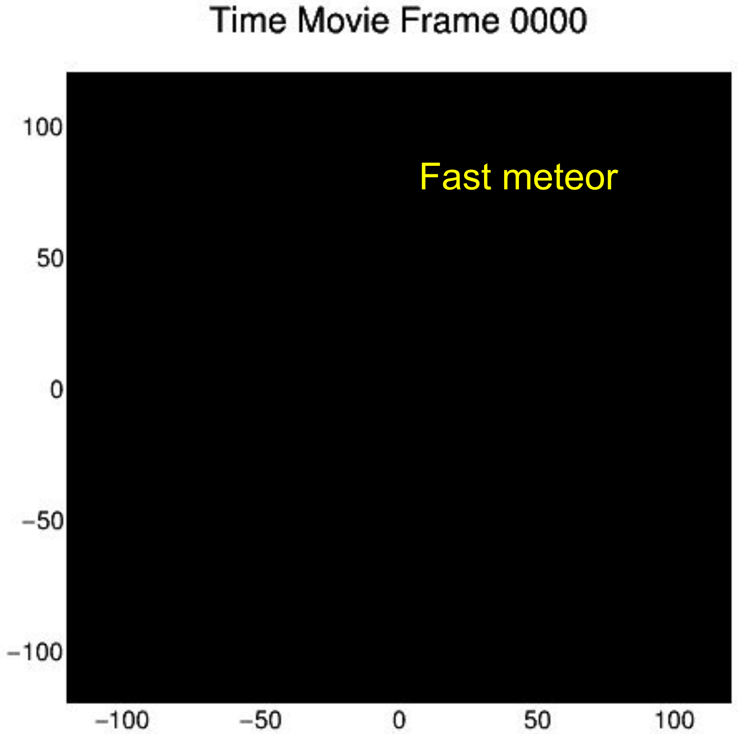
List of meteor measured by TUS



A few comments linking nuclearite search (Turin)

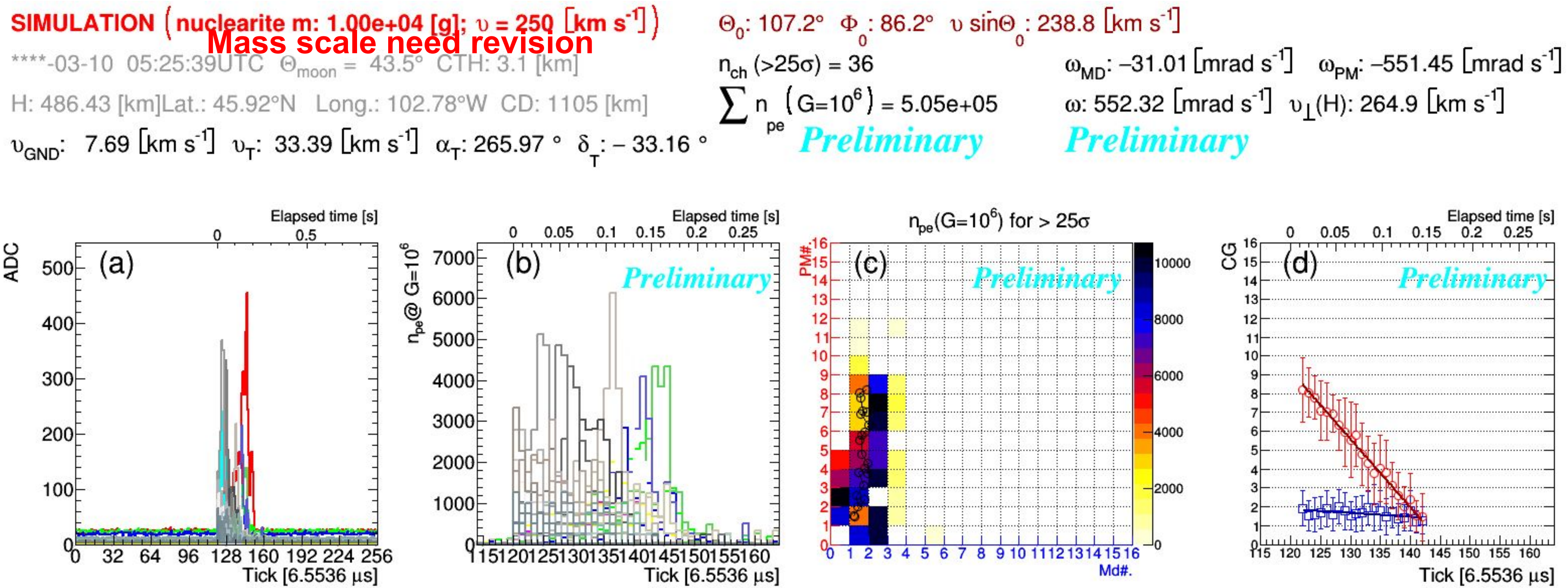


Hmax = 35 km
Zeith angle = 73.7 deg
V = 250 km/s, V_perp ~ 240 km/s

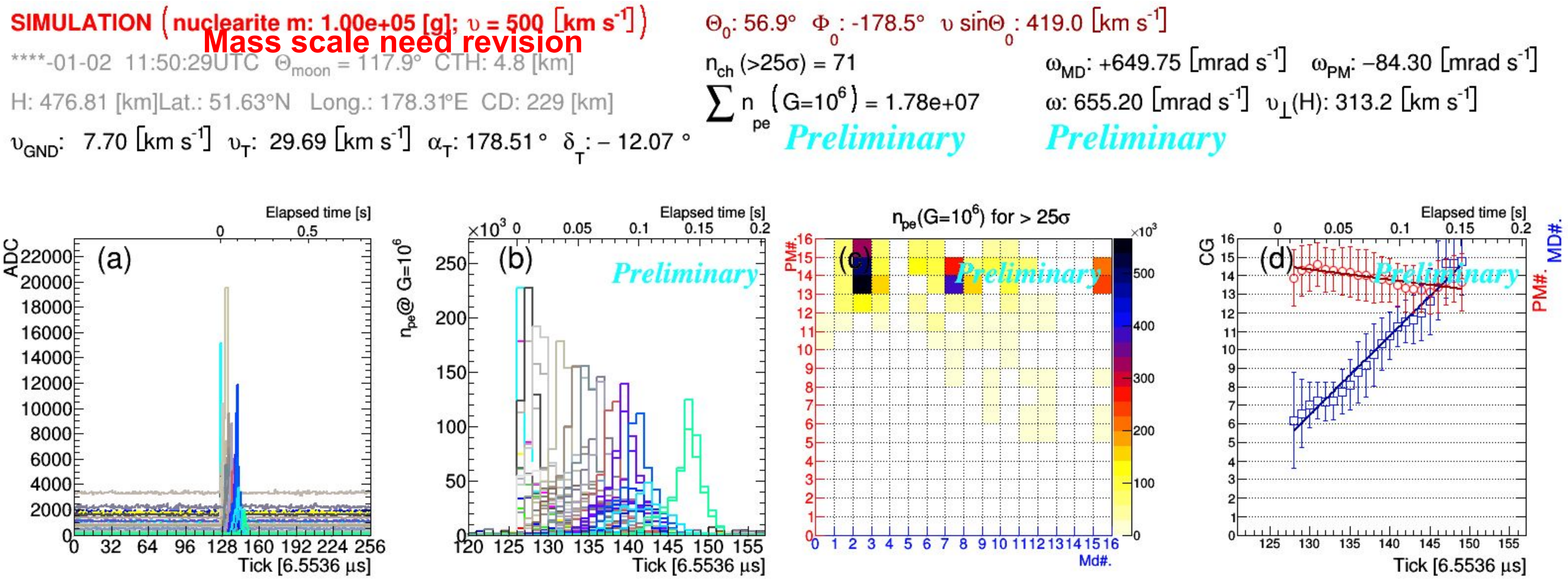


Hmax = 108 km – 49 km
Zeith angle = 48 deg
V = 72 km/s (at limit), V_perp ~ 54 km/s

Projected speed analysis



Projected speed analysis



Analysis applied to real data (Quadrantis event)

TUS DATA

2017-01-03 14:31:08 Θ_{moon} = 129.4° CTH: 2.0 [km]

H: 476.97 [km] α_T: 80.10° Lat.: 53.82°N Long.: 138.90°E

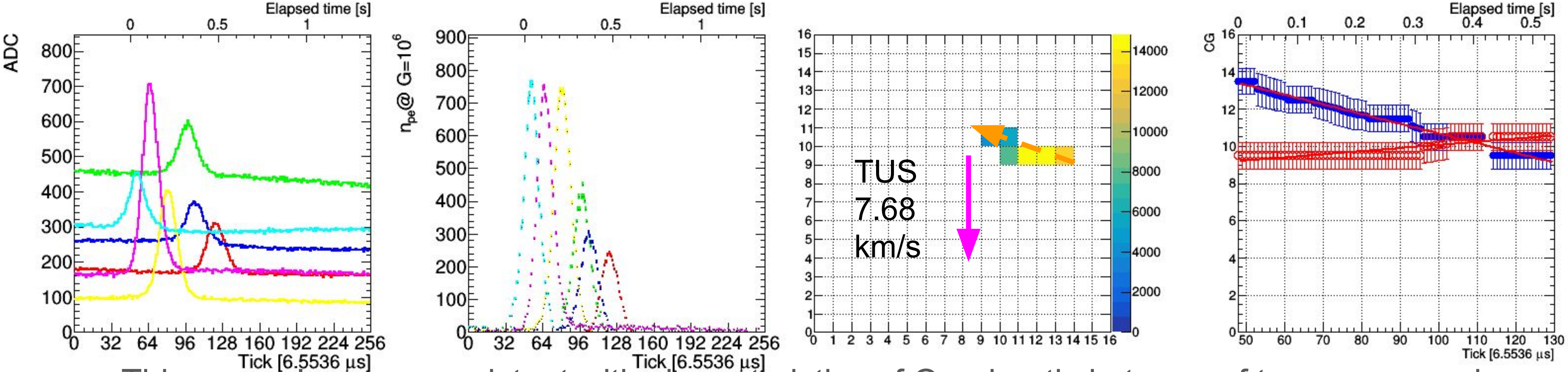
v_{GND}: 7.65 [km s^{-1}] v_T: 30.87 [km s^{-1}] α_T: 156.62 ° δ_T: + 3.35 °

n_hit (>25σ) = 6

$\sum n_{pe}$ (est.) = 429237.9

$\sum n_{pe}$ (G=10^6) = 59524.1

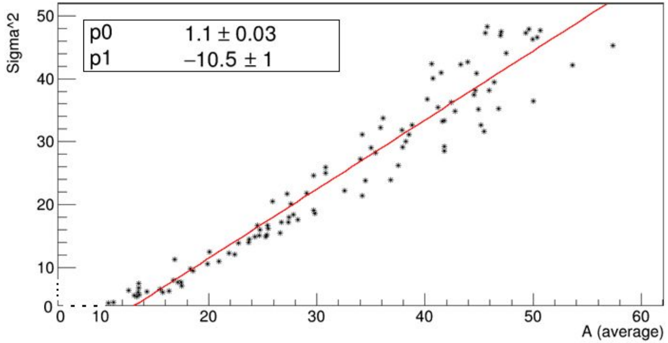
Projected seed at ~100 km height" ~40 km/s (preliminary)



- This example: very consistent with characteristics of Quadrantis in terms of traverse speed and directionality to the radiant (RA: ~15.5h Decl: +50°)
- Every selected METEOR data, the first 32 ticks are used to determine the average and fluctuation of background baseline for every PMT

Recent improvement for METEOR mode analysis

New inflight gain calibration scheme



The linear approximation $\sigma^2(A)$ for pixel 126

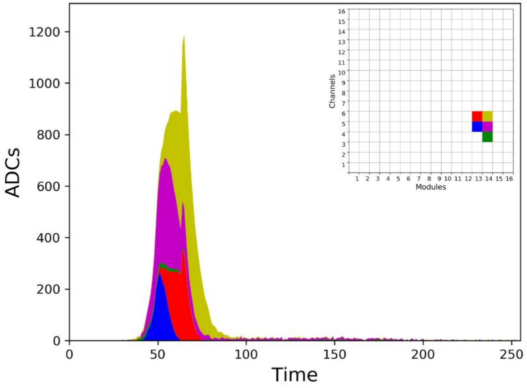
$$K = \frac{G_f}{G} \approx 2{,}7 \pm 0{,}9$$

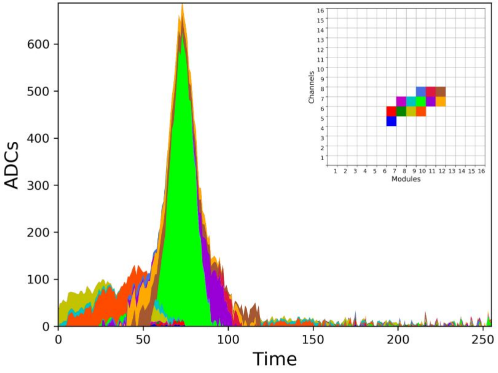
Gain value for pixel # 126

$$G \approx (0{,}29 \pm 0{,}10) * 10^6$$

Paper is to be published in 2021

General METEOR mode analysis





- ✔️ Track reconstruction algorithms
- ✔️ Light curves analyses
- ✔️ Simultaneous ground-based measurements?

Summary

- TUS observed more than a dozen of meteors in its limited METEOR mode campaigns among other science objectives
- Registered events are reasonably explained to be moving events consistent with meteors by measuring the light curve and angular speed from the orbit
    - This capability is essential for nuclearite search
- Recent improvement on the meteor analysis and inflight calibration also allows further investigation for meteor study and nuclearite search from the orbit