JEM-EUSO and pathfinders

Observation of ultra-high-energy cosmic rays from space

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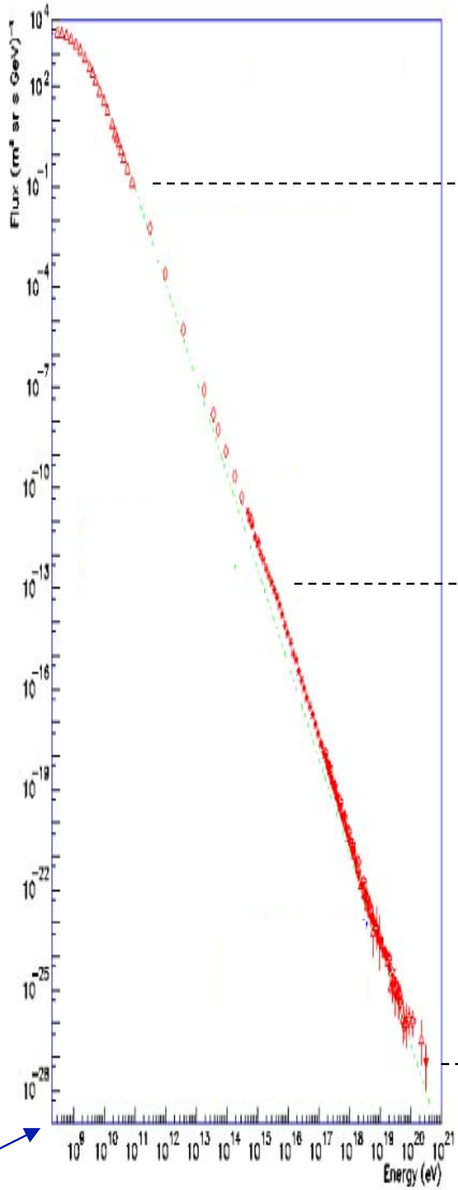
ONR-APC-IPGP meeting — 29th October 2014

The cosmic ray energy spectrum

Flux



~ 1 particle/m^2/second

~ 1 particle/m^2/year

10^{21} eV

~ 1 particle/m^2/billion year!

100 MeV

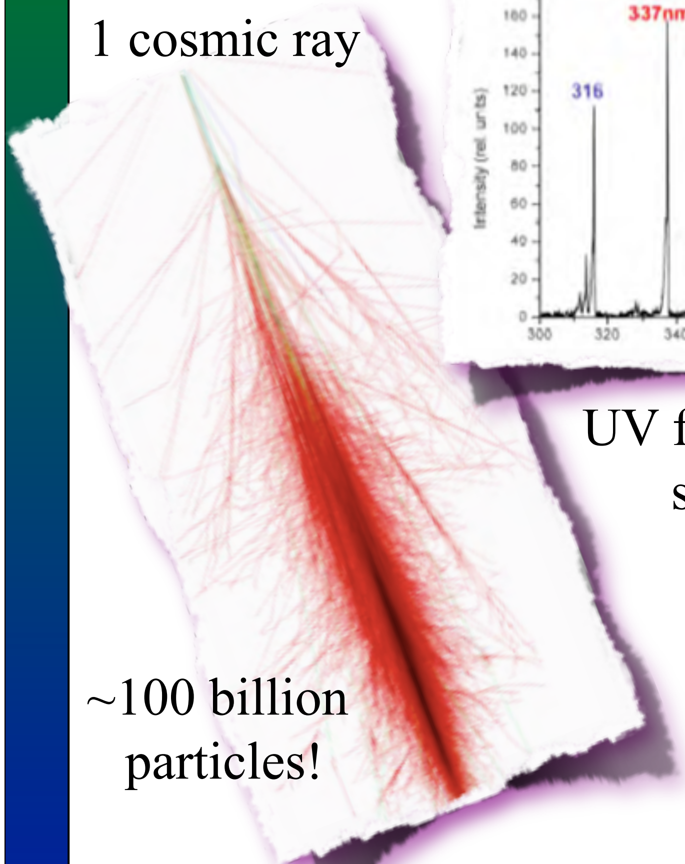
Energy

Ultra-high-energy cosmic rays (UHECRs)

How JEM-EUSO works

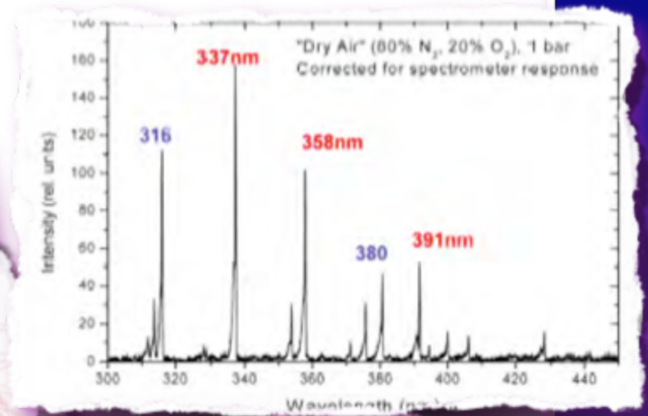
Detect UHECR-induced showers through the fluorescence light generated in the atmosphere

1 cosmic ray

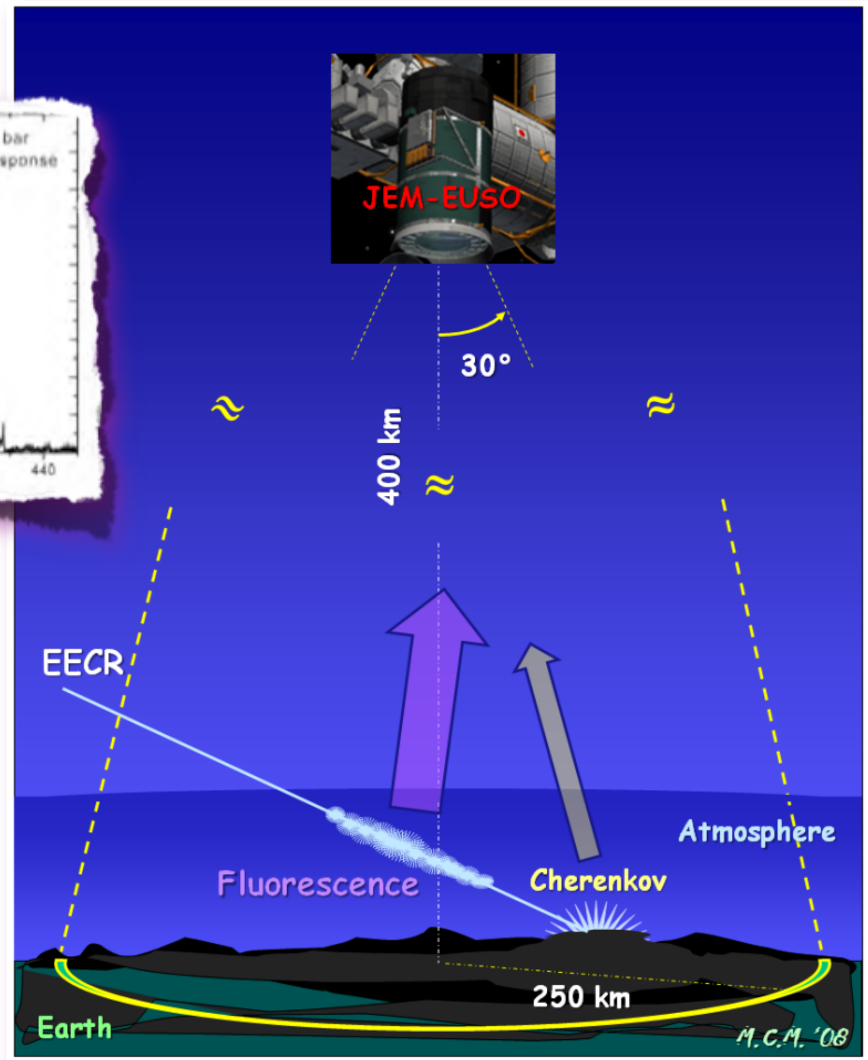


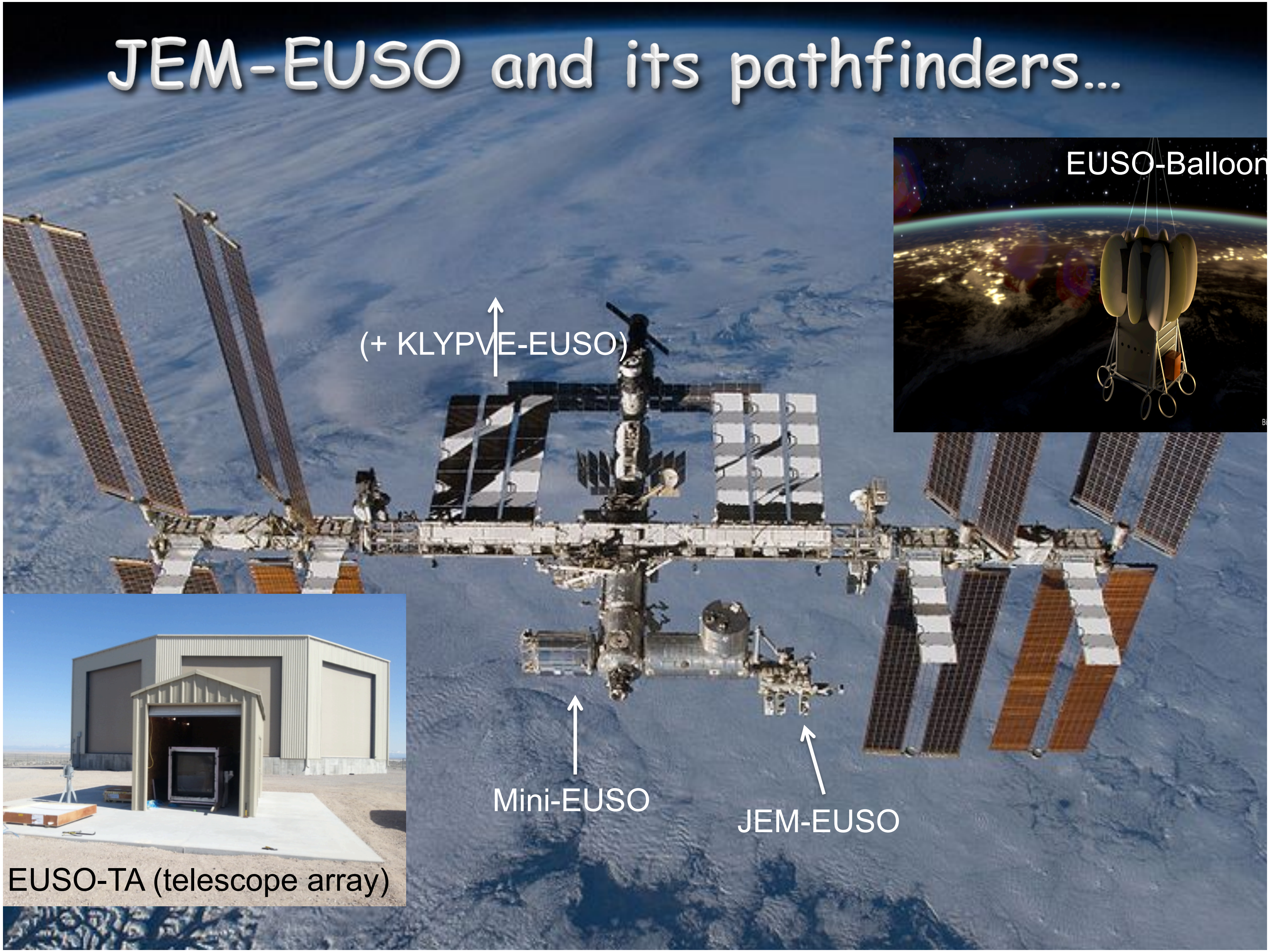
~100 billion particles!

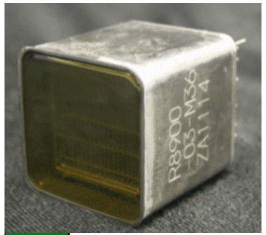
"extensive air shower"



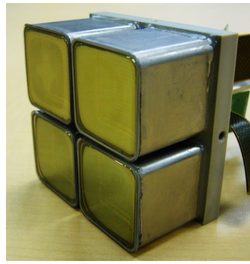
UV fluorescence spectrum

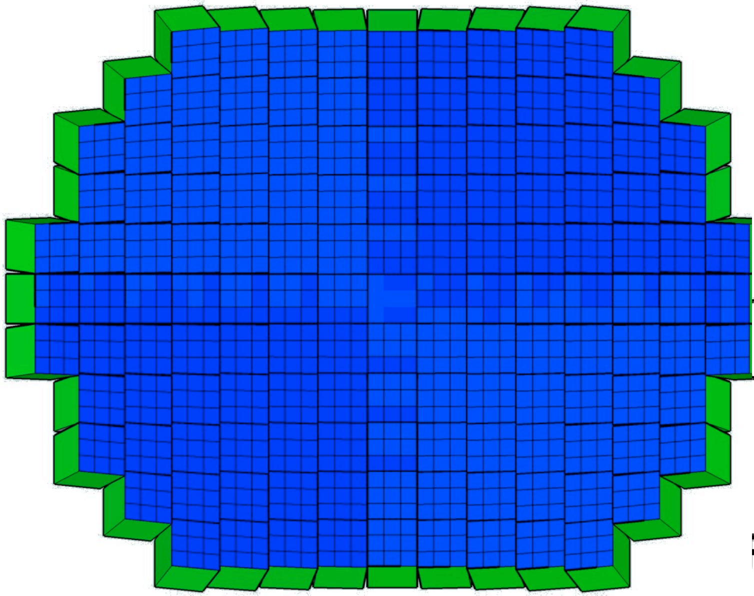


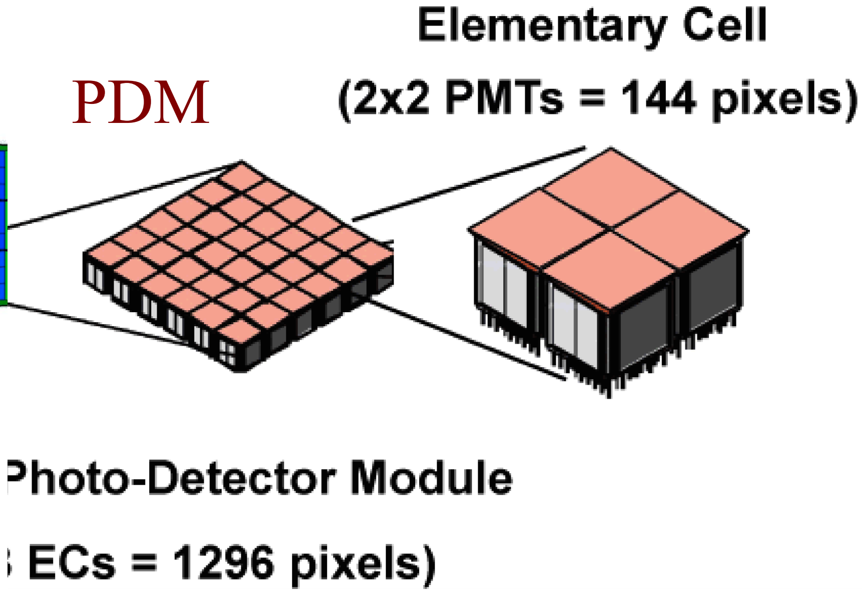

JEM-EUSO and its pathfinders…
EUSO-Balloon
(+ KLYPVE-EUSO)
Mini-EUSO
JEM-EUSO
EUSO-TA (telescope array)

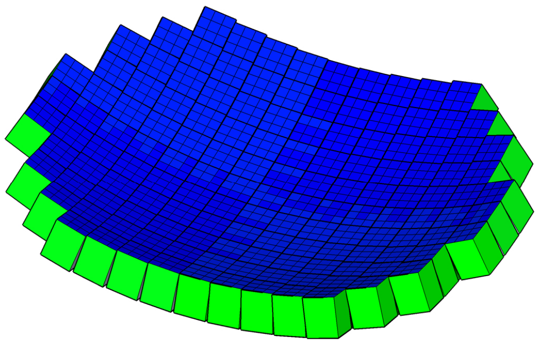


Focal surface





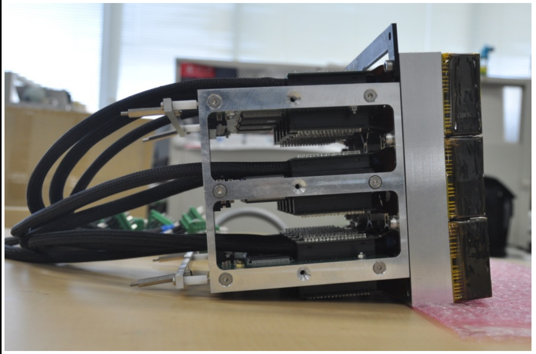


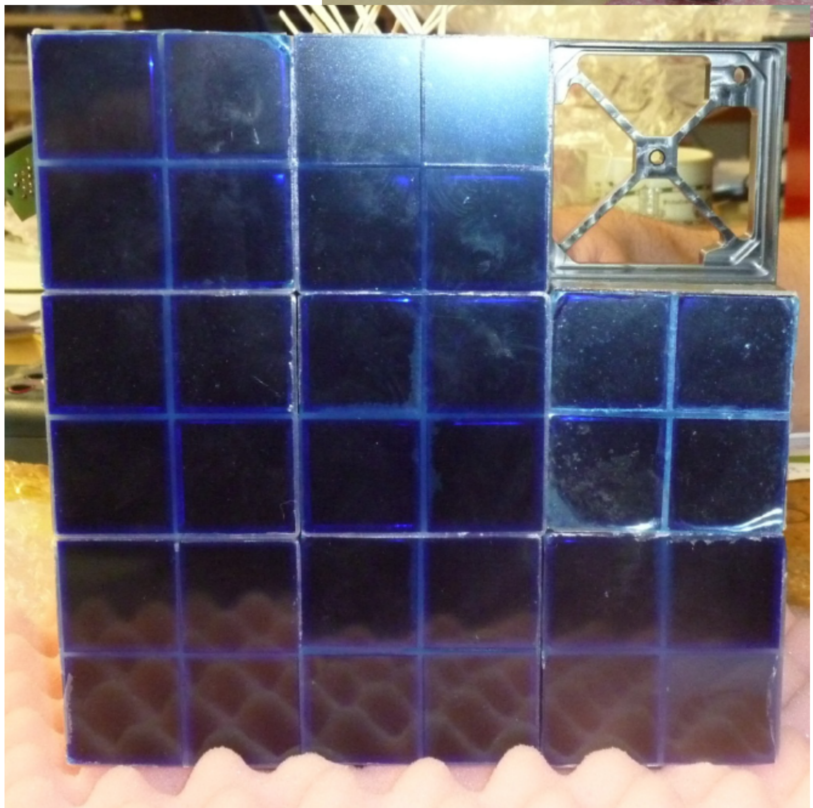


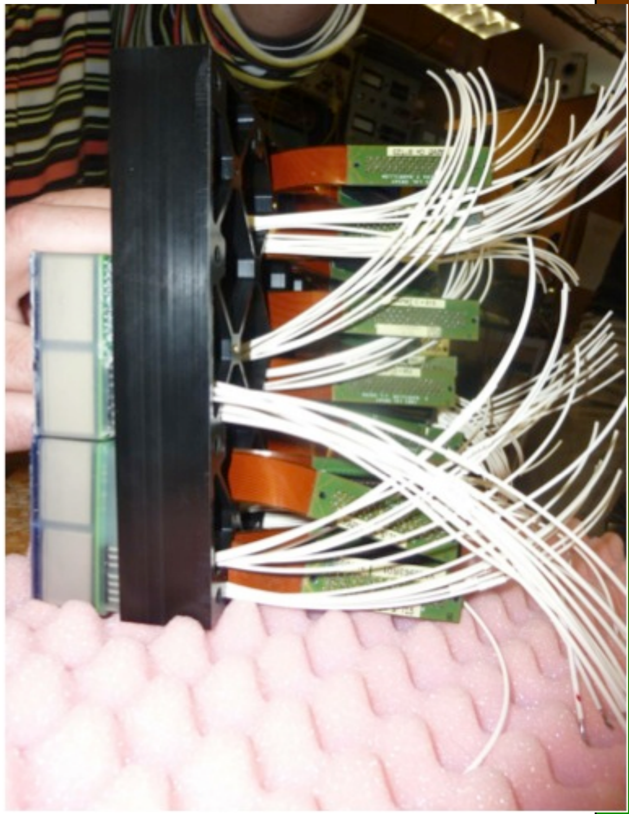
137 PDM of 9 EC, each EC has 4 PMT with 64 pixels each

4932 PMT and 0.3156 Megapixels

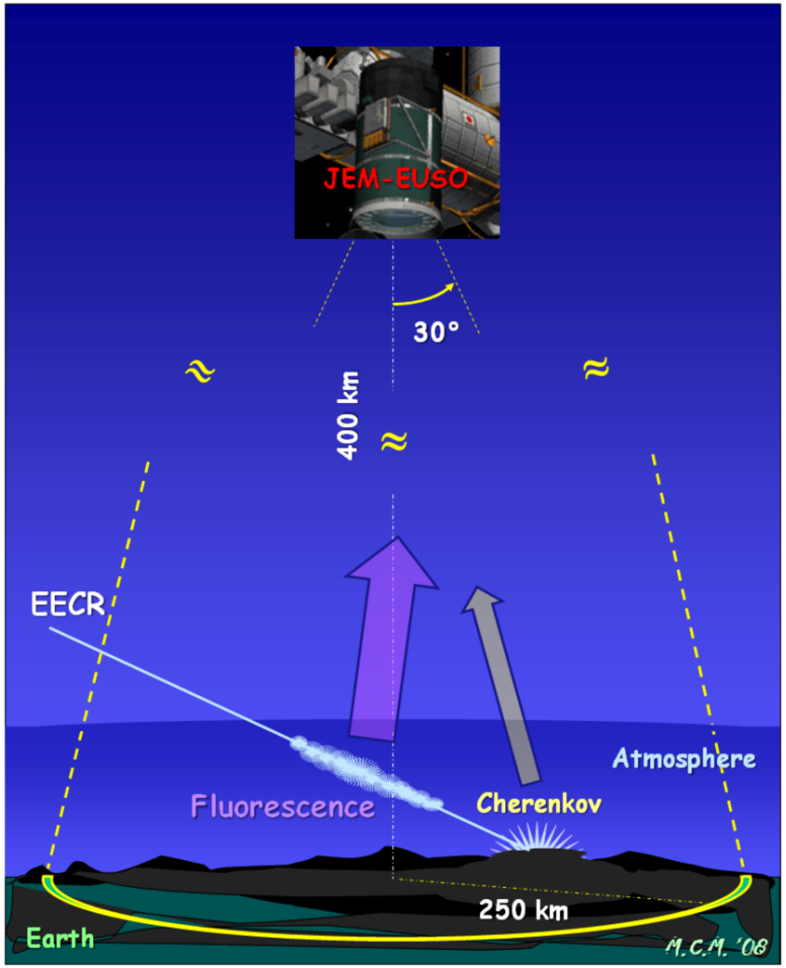
Photo-Detection Module (PDM)







Characteristics and advantages



- ✧ Huge field of view (60° aperture)
- ✧ Ultra-sensitive UV camera (single photon counting)
- ✧ Ultra-fast camera (2.5 μs → 400 000 images/second)
- ✧ Large dynamic range (automatic gain switches)
- ✧ Over 300 000 pixels
- ✧ Full-sky coverage, over several years
- ✧ + infrared camera + LIDAR

Many possible synergies

Atmospheric sciences

TLEs (sprites, jets, elves, halos…)

Cloud coverage

Links between cosmic rays and lightning

Airglow (nightglow) monitoring

Sciences of the ocean

Surface bioluminescence

Can a surface water temperature survey (3K accuracy) be useful?

LIDAR reflection → water level?

Meteorites sciences

Statistics, Trajectories, Recovery…

Space debris removal

identification, trajectory → laser shot

Others?

Plant fluorescence…

EUSO-Balloon

✧ Pathfinder to JEM-EUSO (CNES mission)

Successful flight on August 24th, 2014 (Timmins, Ontario)

EUSO-Balloon

✧ Pathfinder to JEM-EUSO (CNES mission)

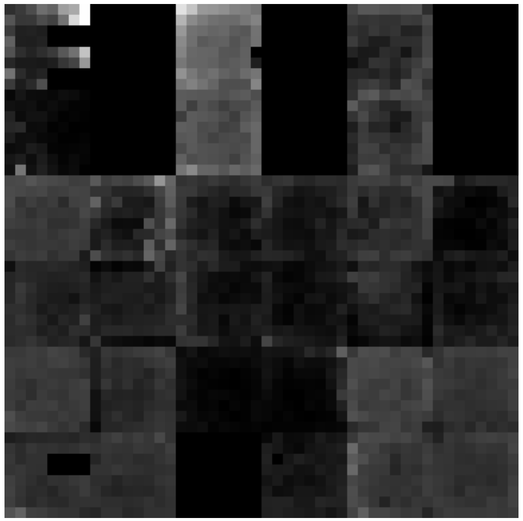
Technology demonstration

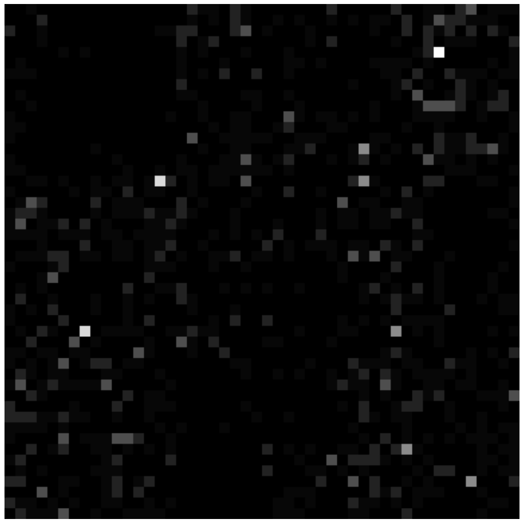
Data on the UV background and its space/time variability

- additional to the airglow
- investigation of different types of ground / albedos

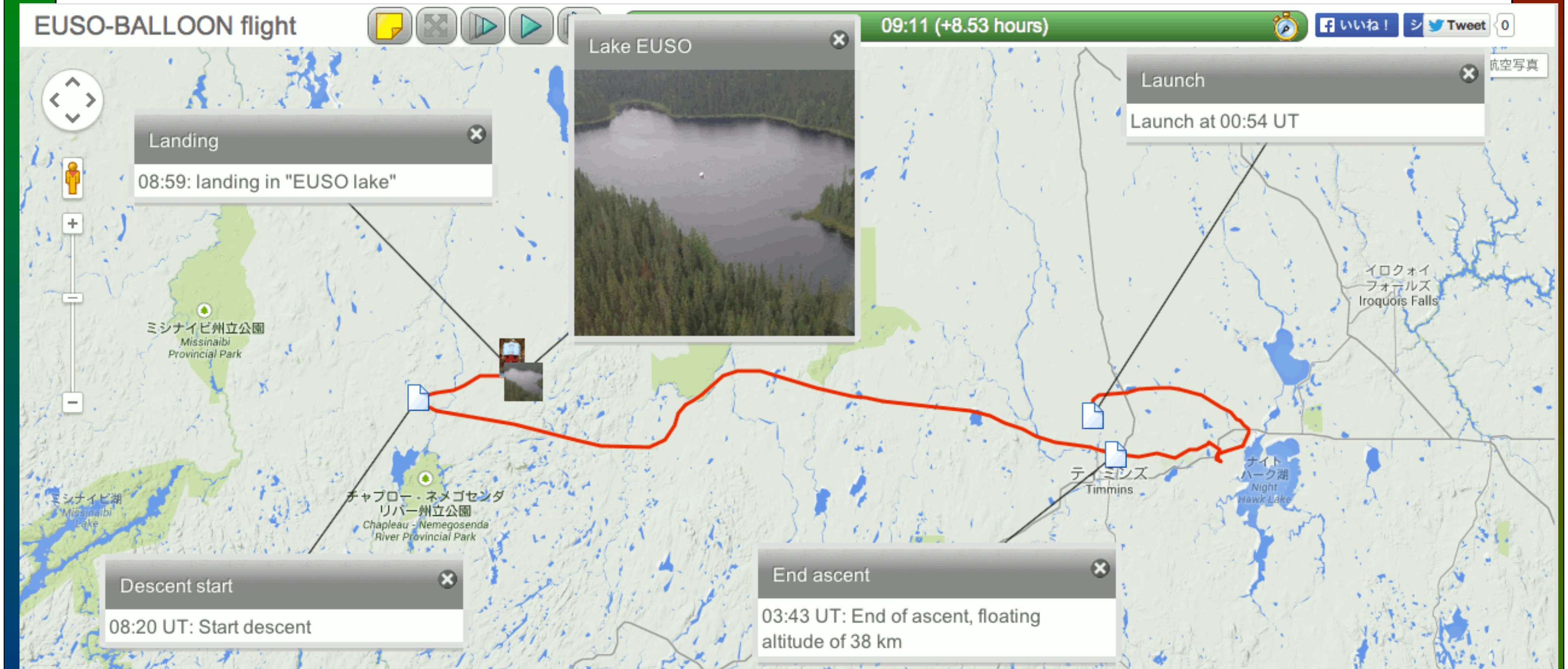
Observation of artificial transient events

laser shots + LED + Xenon flashers (US/NASA)



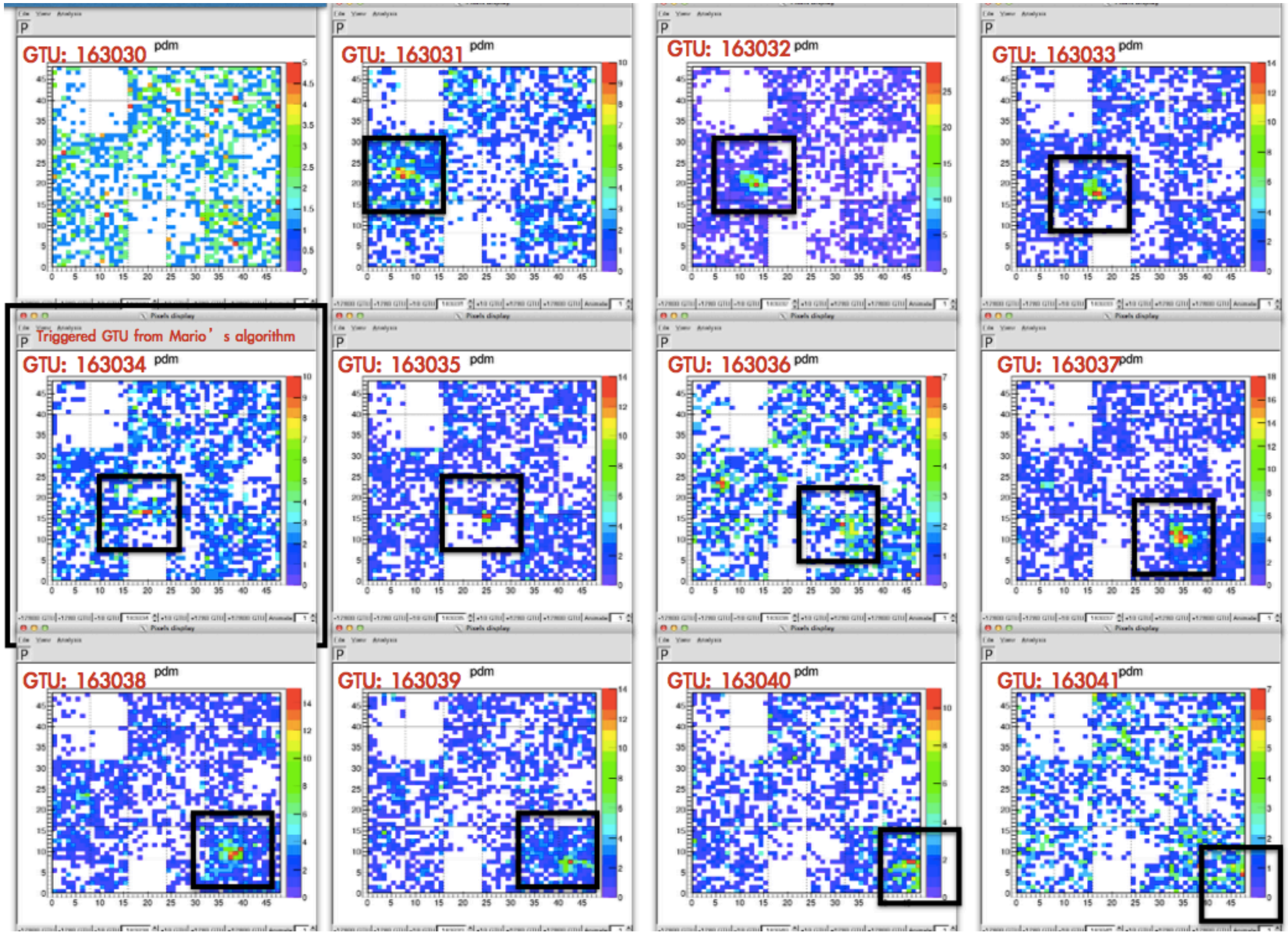


EUSO-Balloon + helicopter

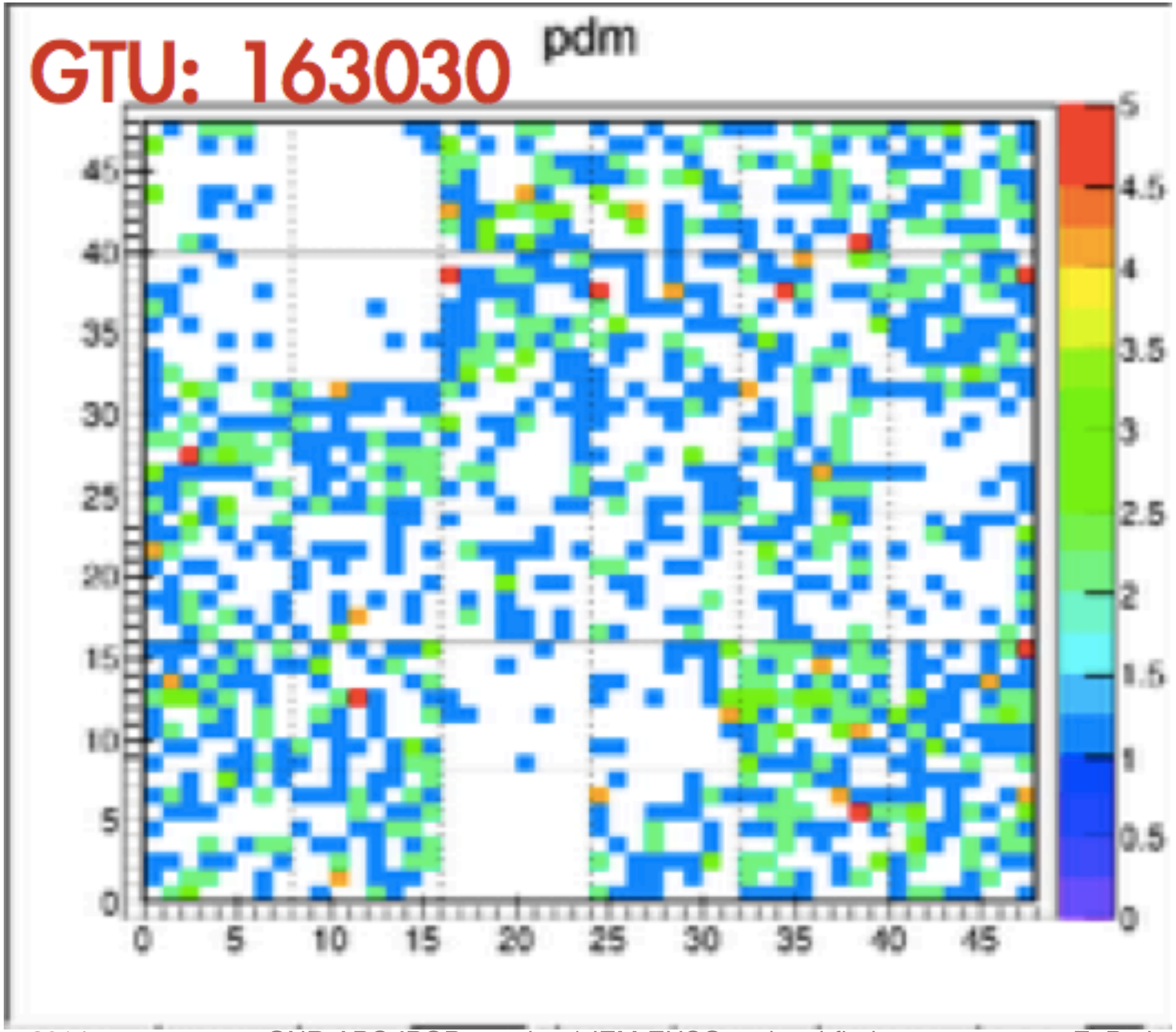


EUSO-Balloon

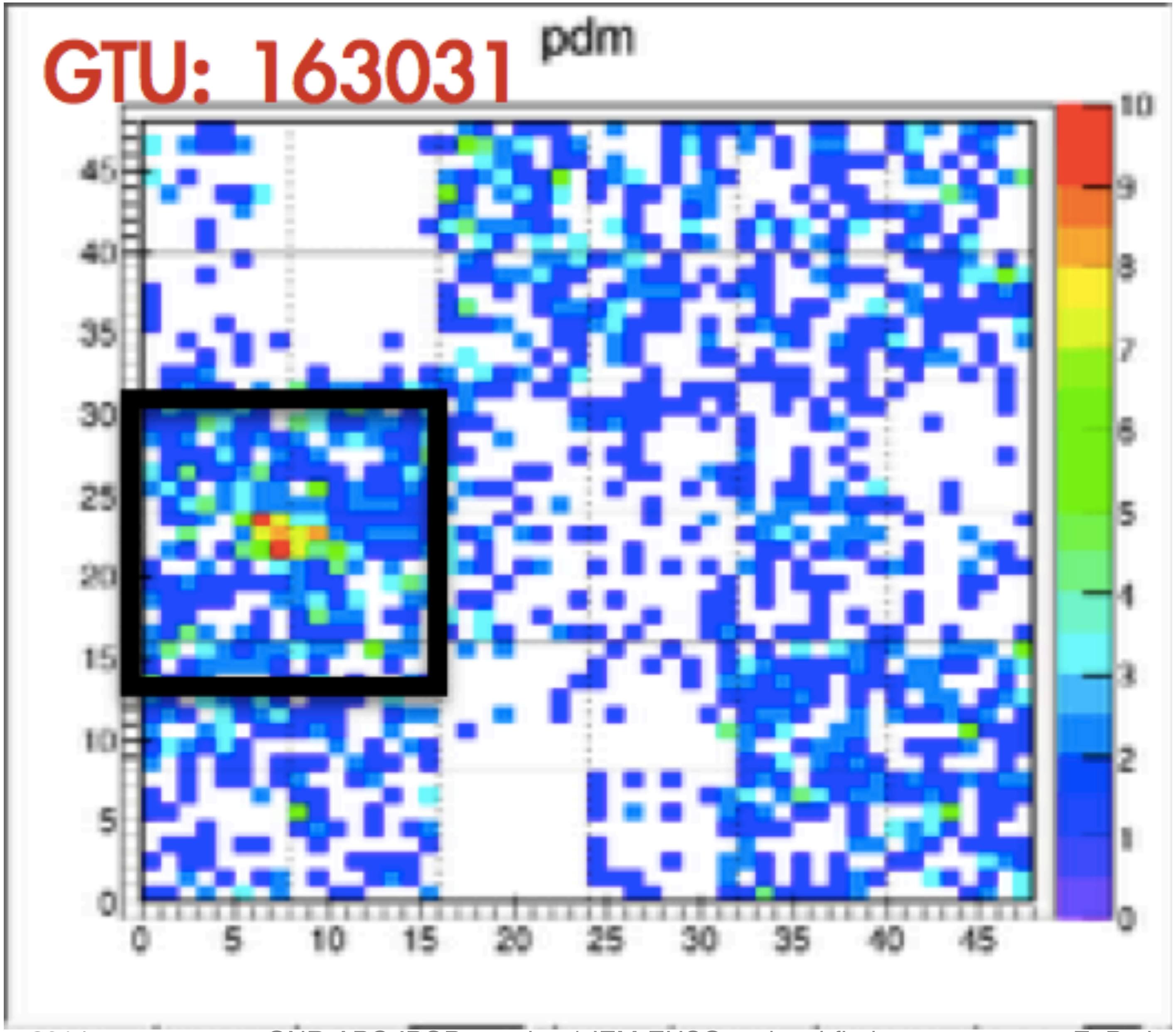
✧ The data are being analyzed right now!



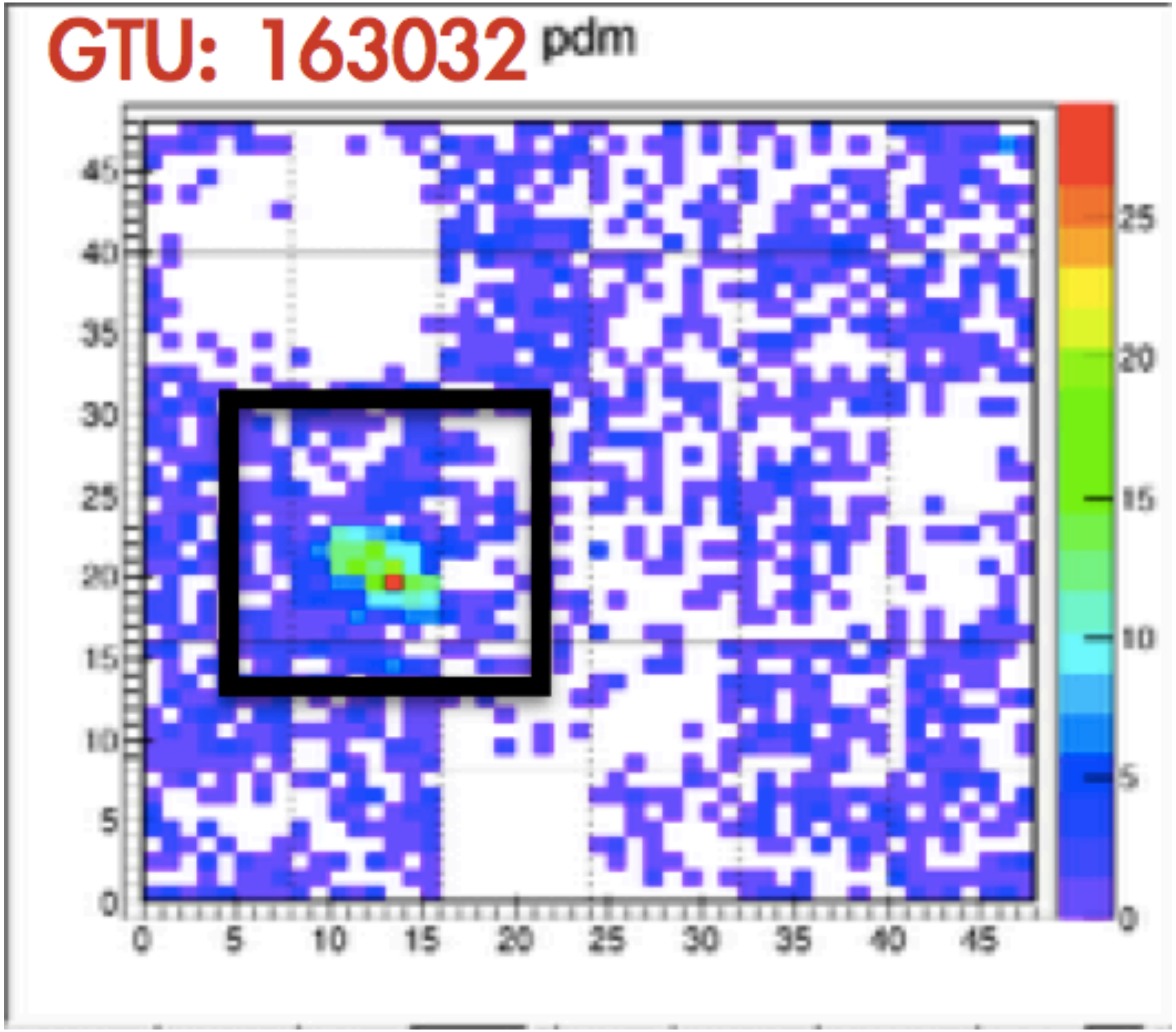
EUSO-Balloon



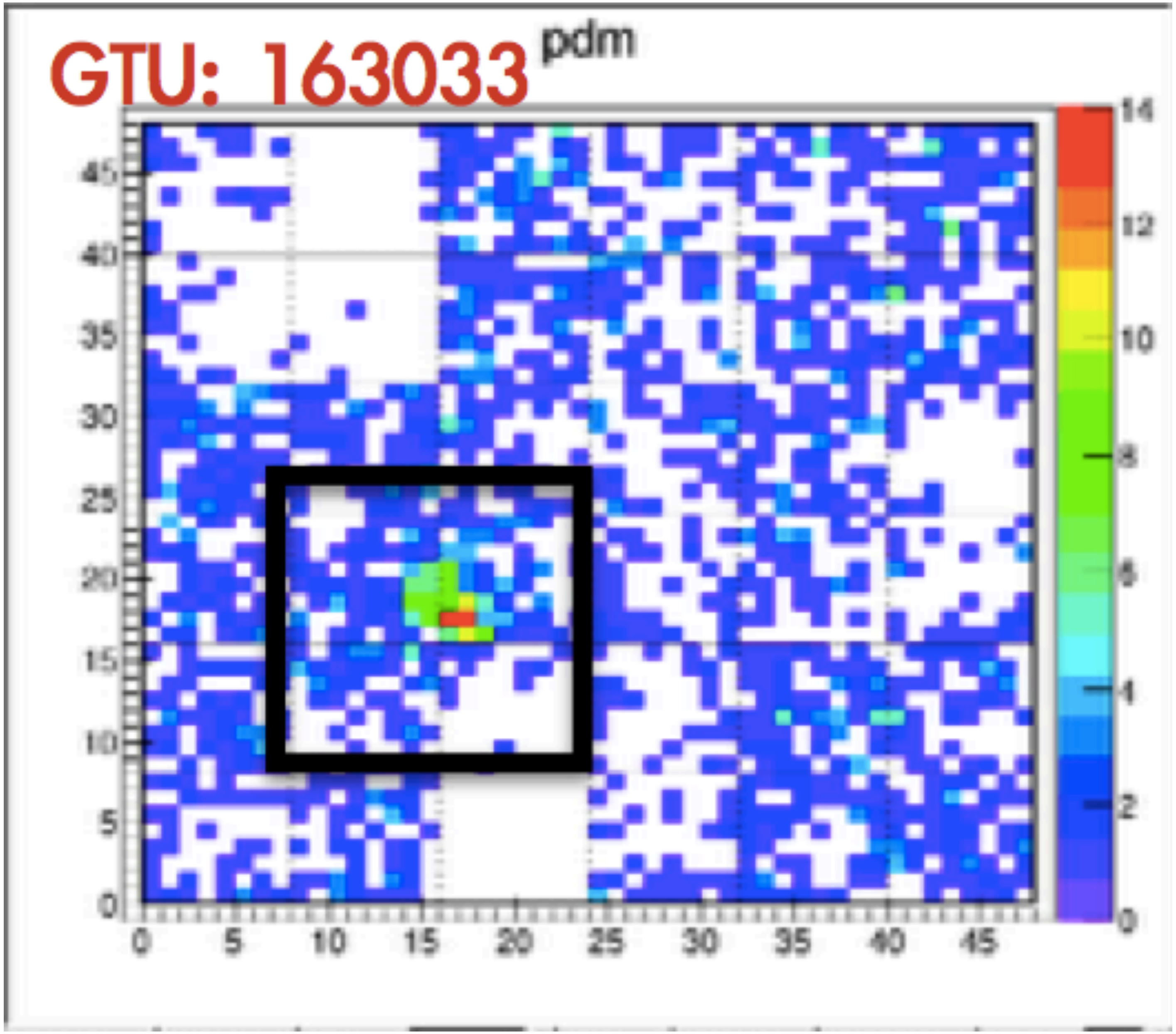
EUSO-Balloon



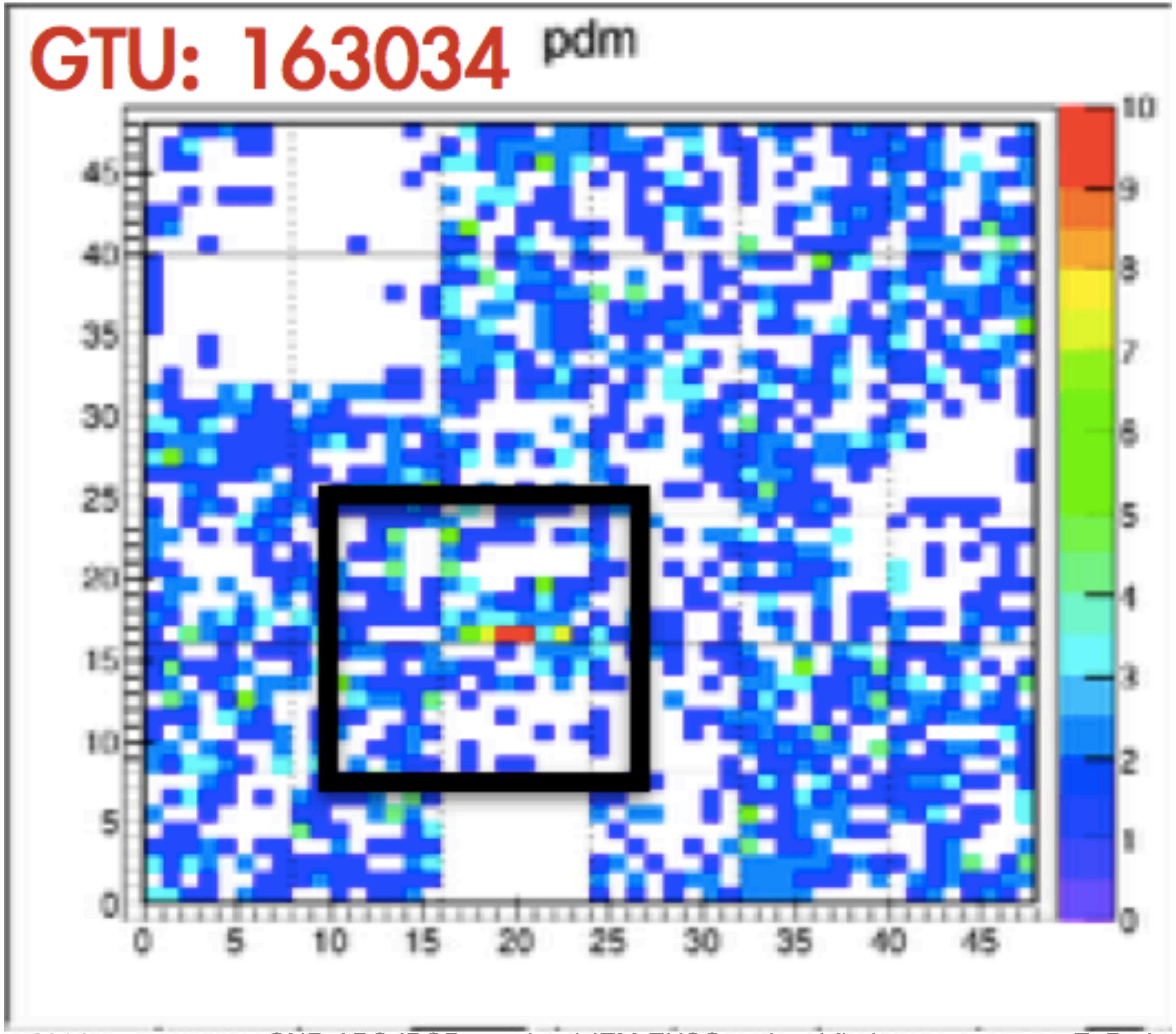
EUSO-Balloon



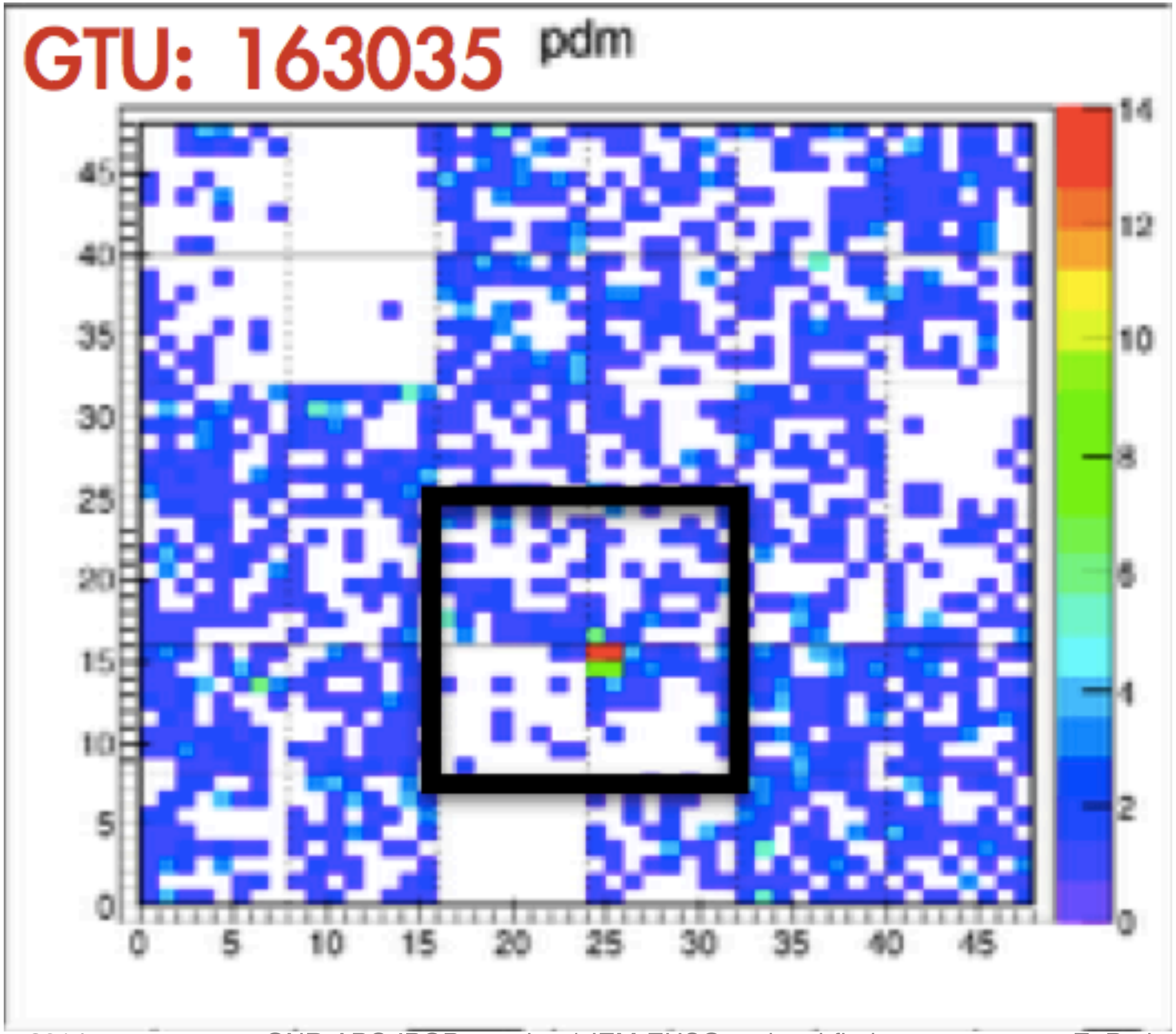
EUSO-Balloon



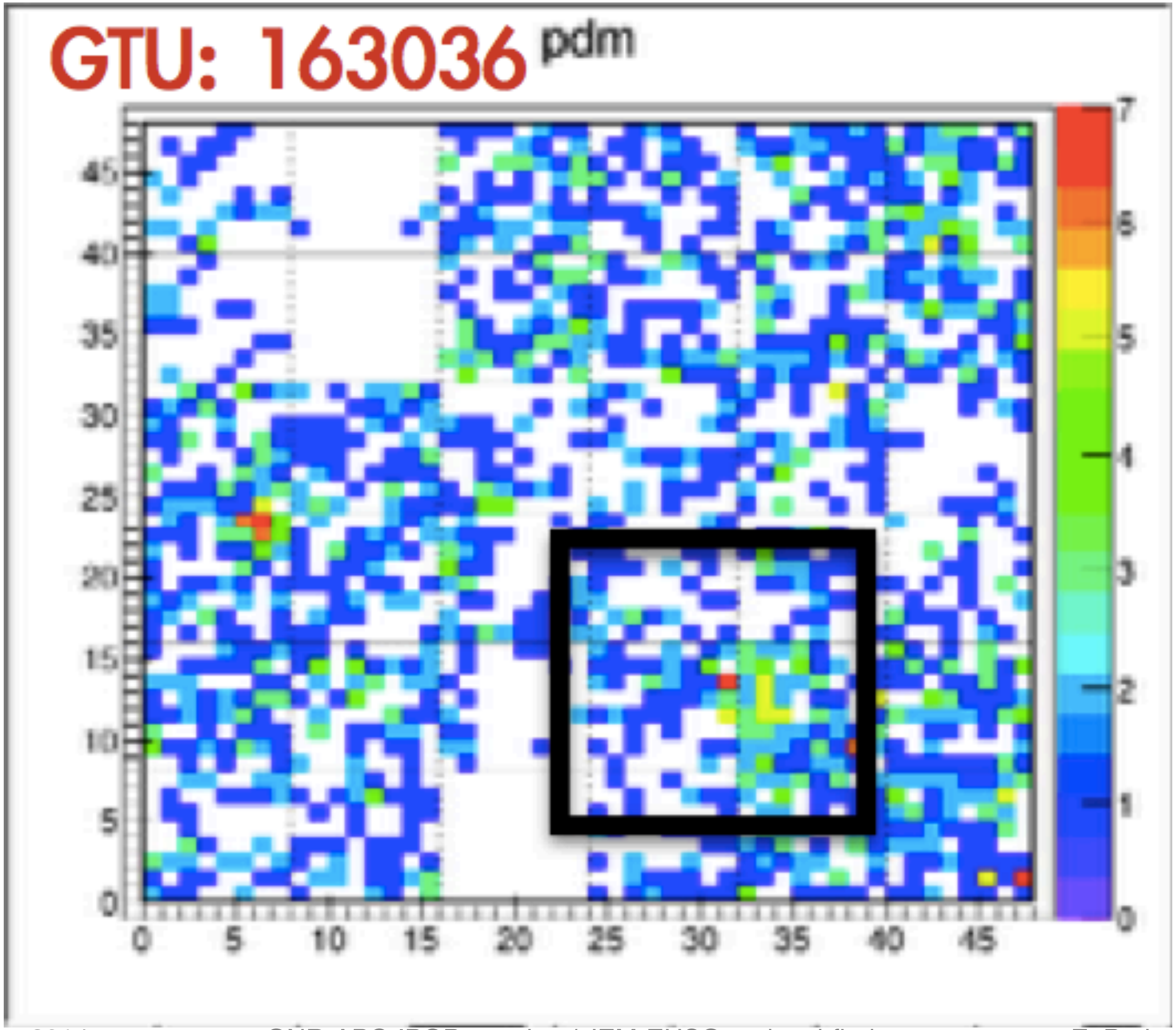
EUSO-Balloon



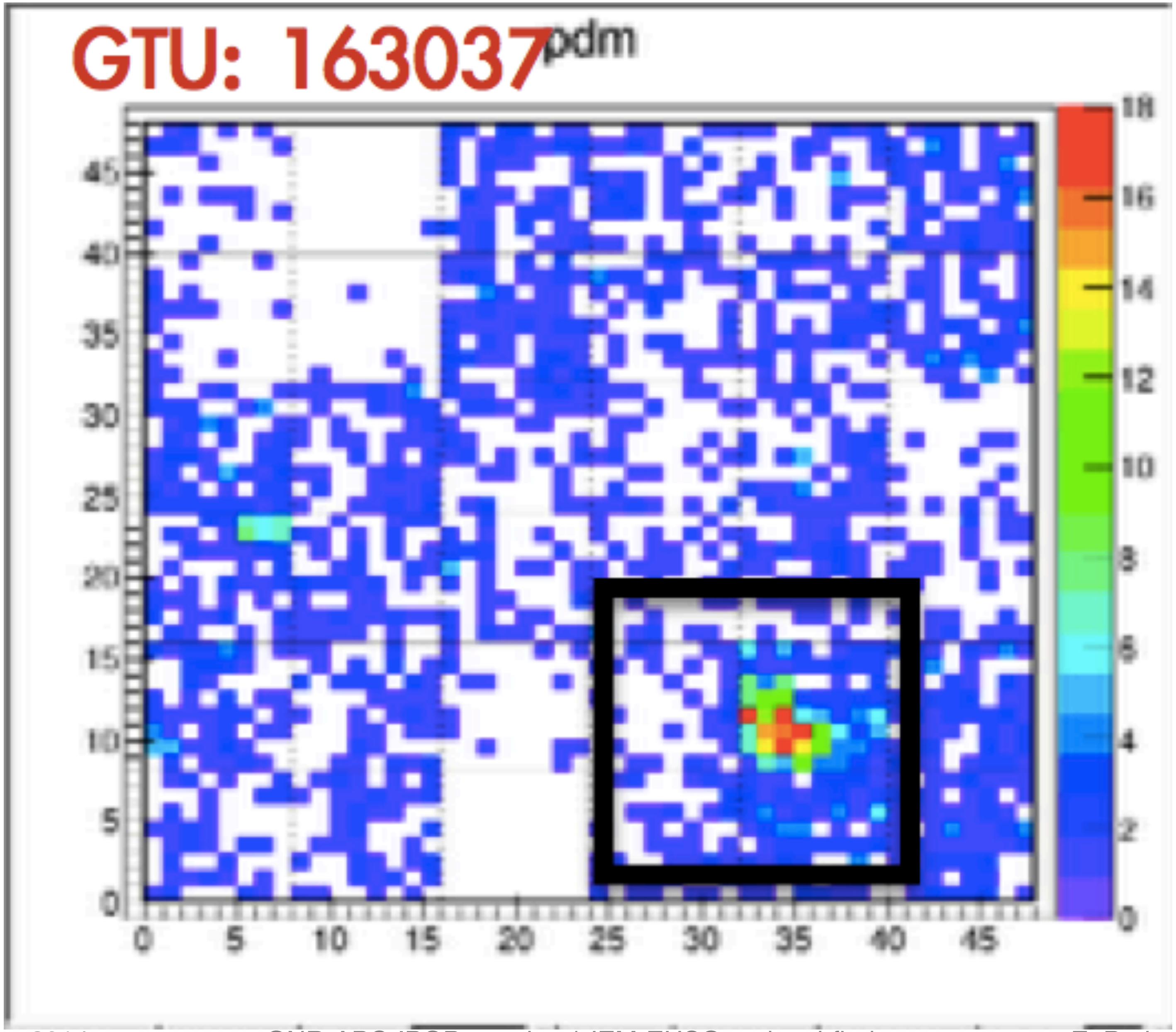
EUSO-Balloon



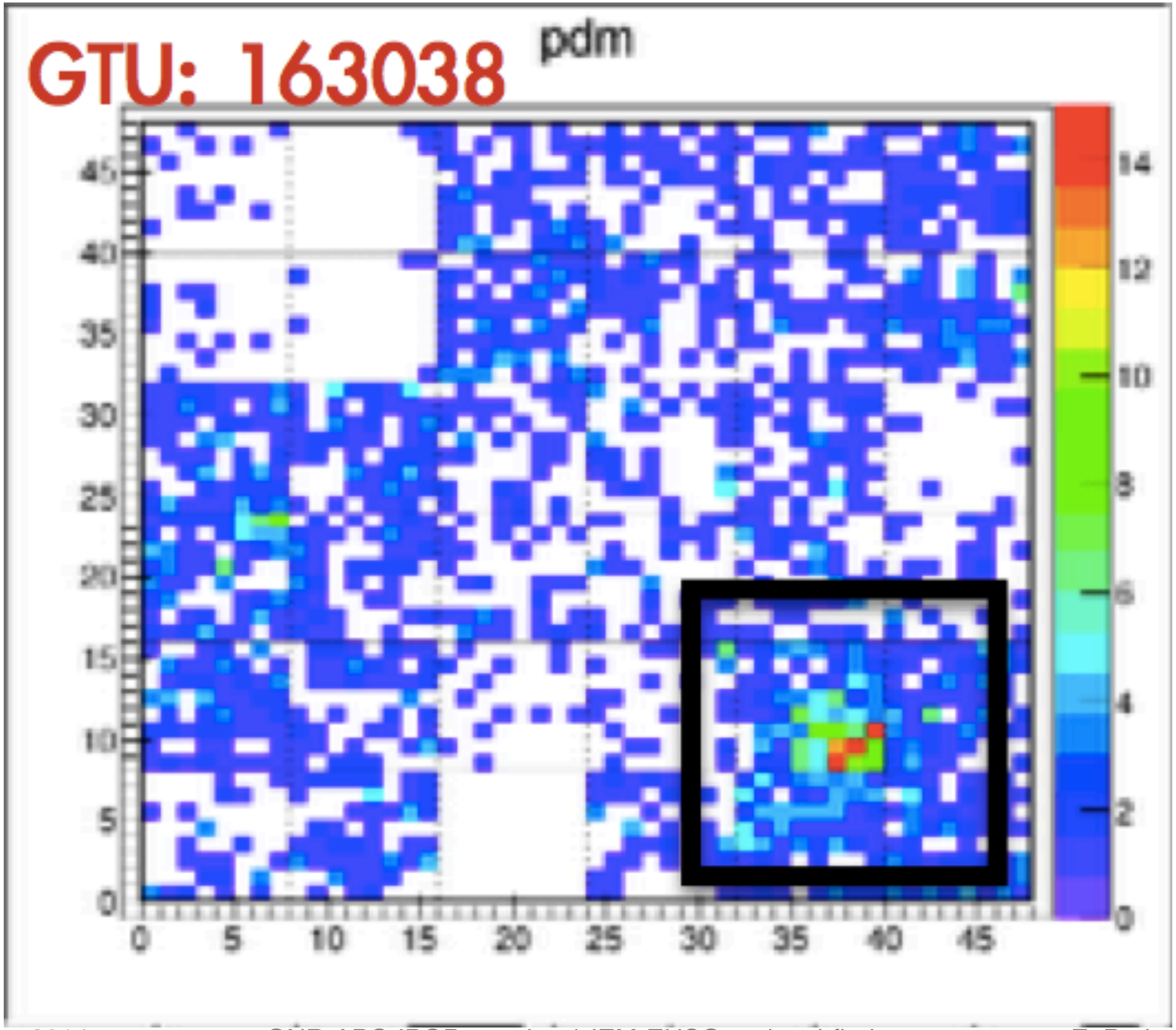
EUSO-Balloon



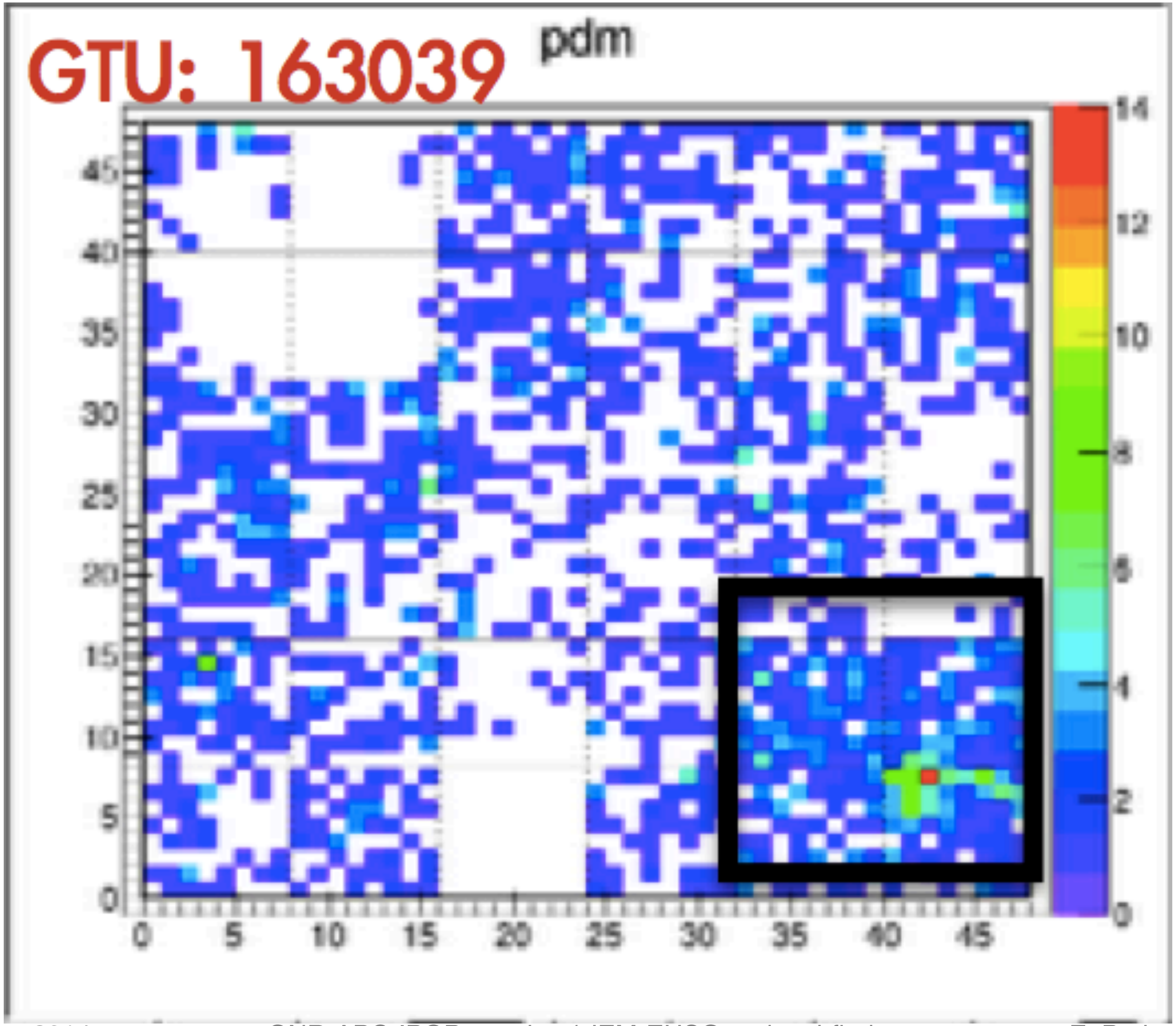
EUSO-Balloon



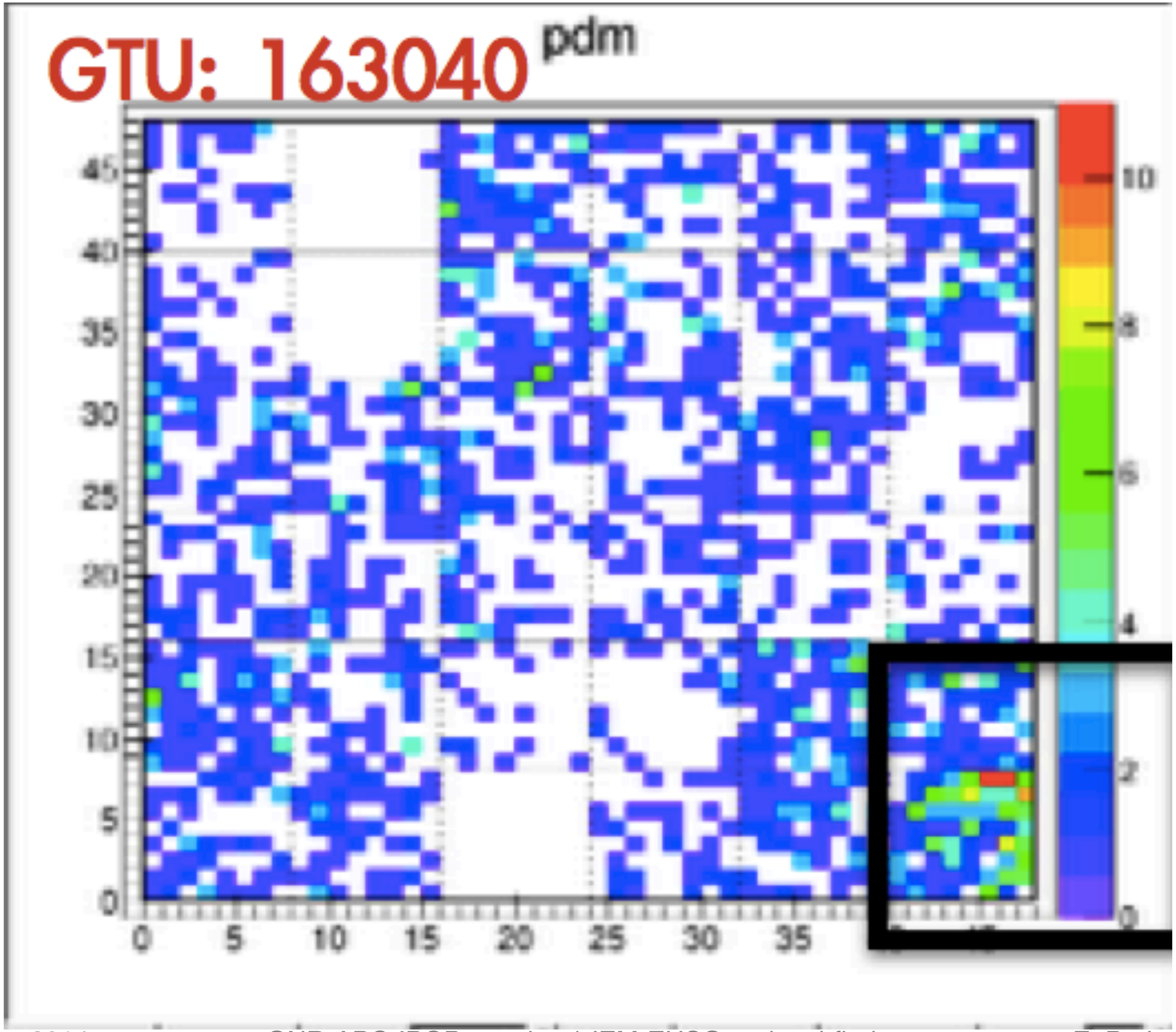
EUSO-Balloon



EUSO-Balloon

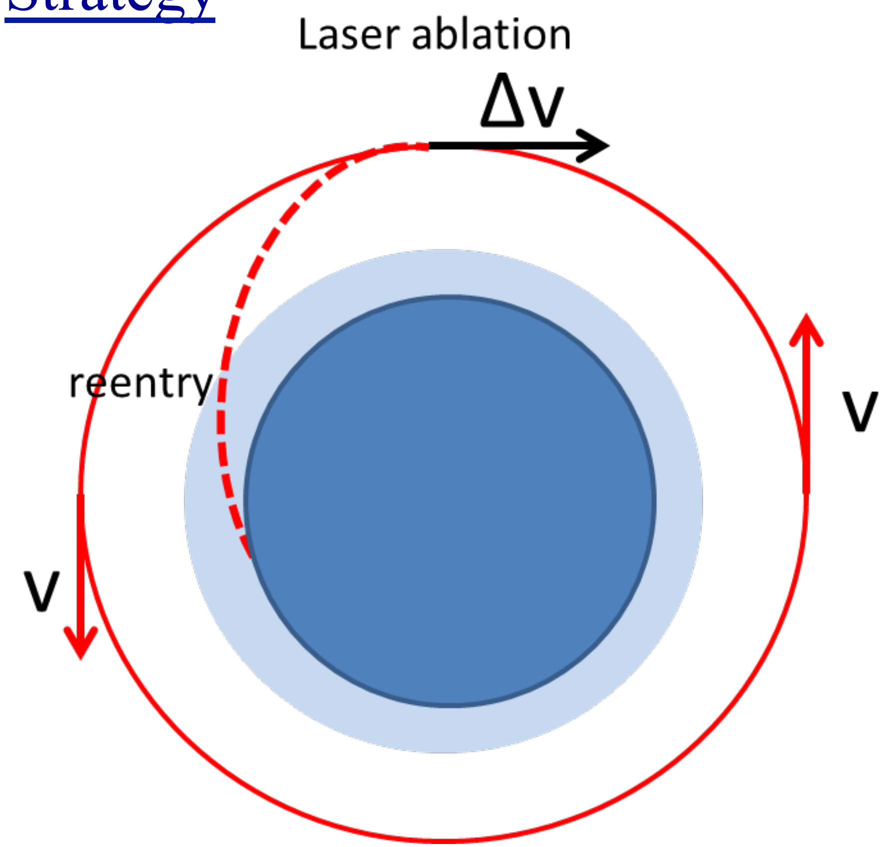


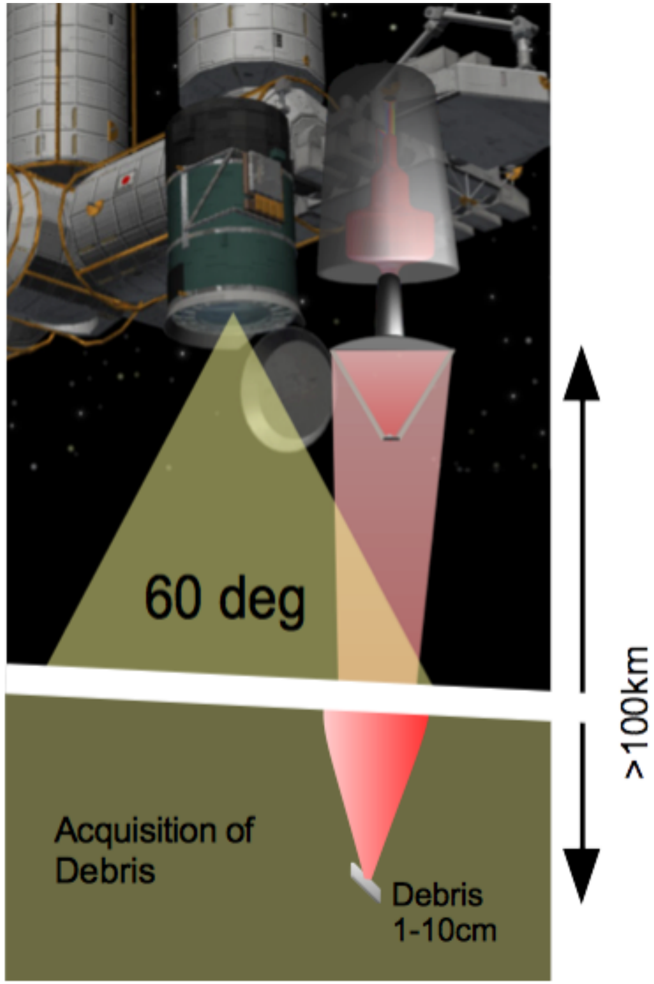
EUSO-Balloon



Space debris removal

Strategy





JEM-EUSO can detect and determine the trajectory of debris in the critical 1 cm – 10 cm range!

Next steps

Long duration balloon flight

Expected strong support from both CNES and NASA

Key milestone: detect the first UHECR showers from above (with the fluorescence technique, well established on ground)

Mini-EUSO

Approved mission ASI (Italian Space Agency) and ROSCOSMOS)

JEM-EUSO demonstrator onboard the ISS (inside, not outside)

Will include test SiPMT detectors

Will observe airglow from space

Will observe TLEs and meteors

Can demonstrate space debris removal strategy

(to be operated in the ISS in 2017)

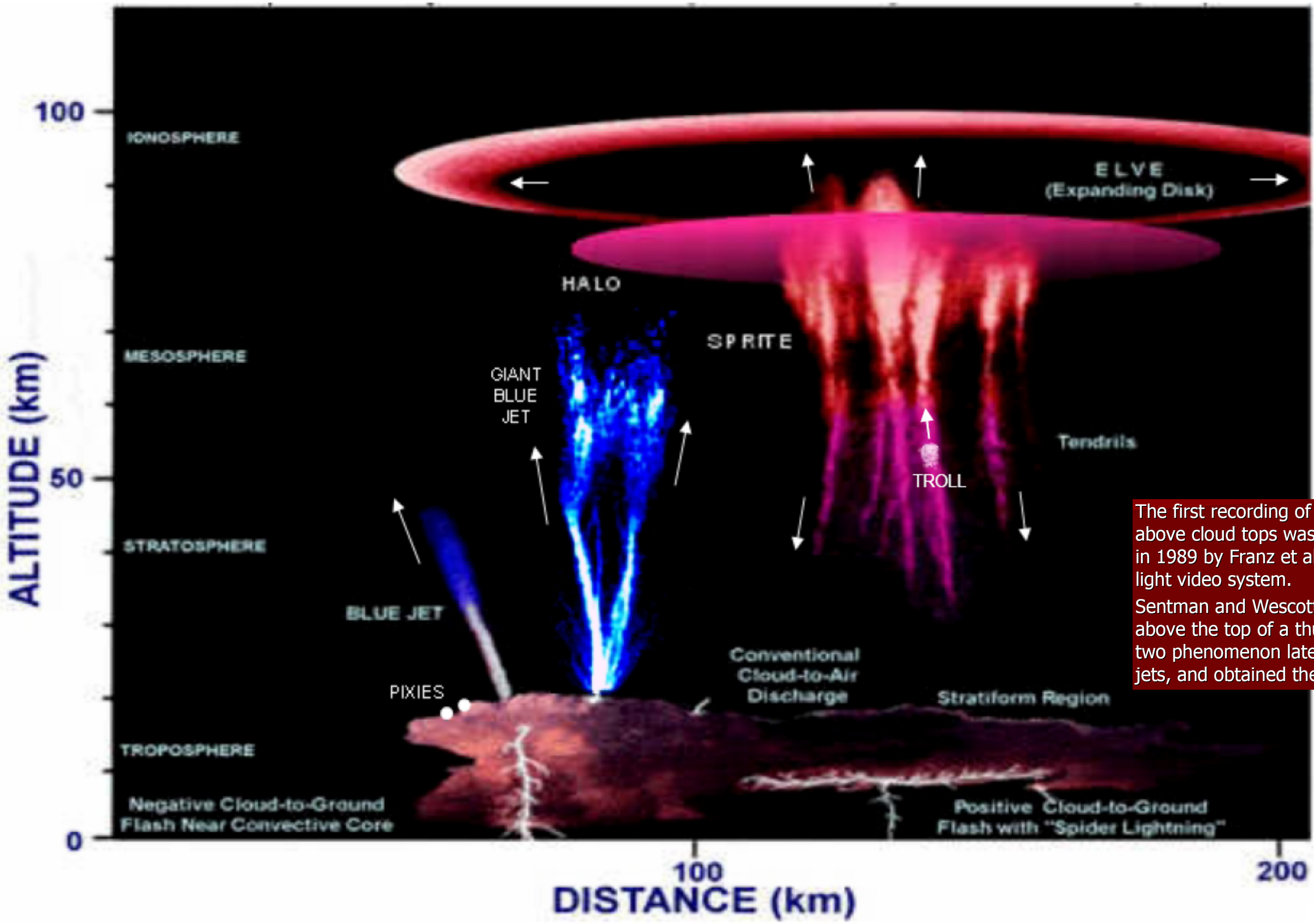

Thank you!

Back-up slides

- ✧ Transient luminous events
- ✧ Meteor(ite)s
- ✧ EUSO-Balloon
- ✧ Space debris removal strategy

Back up - I – Transient luminous events (TLEs)

TLEs (sprites, jets, elves, halos …) are the effects of intensive interaction between different regions in the space around Earth

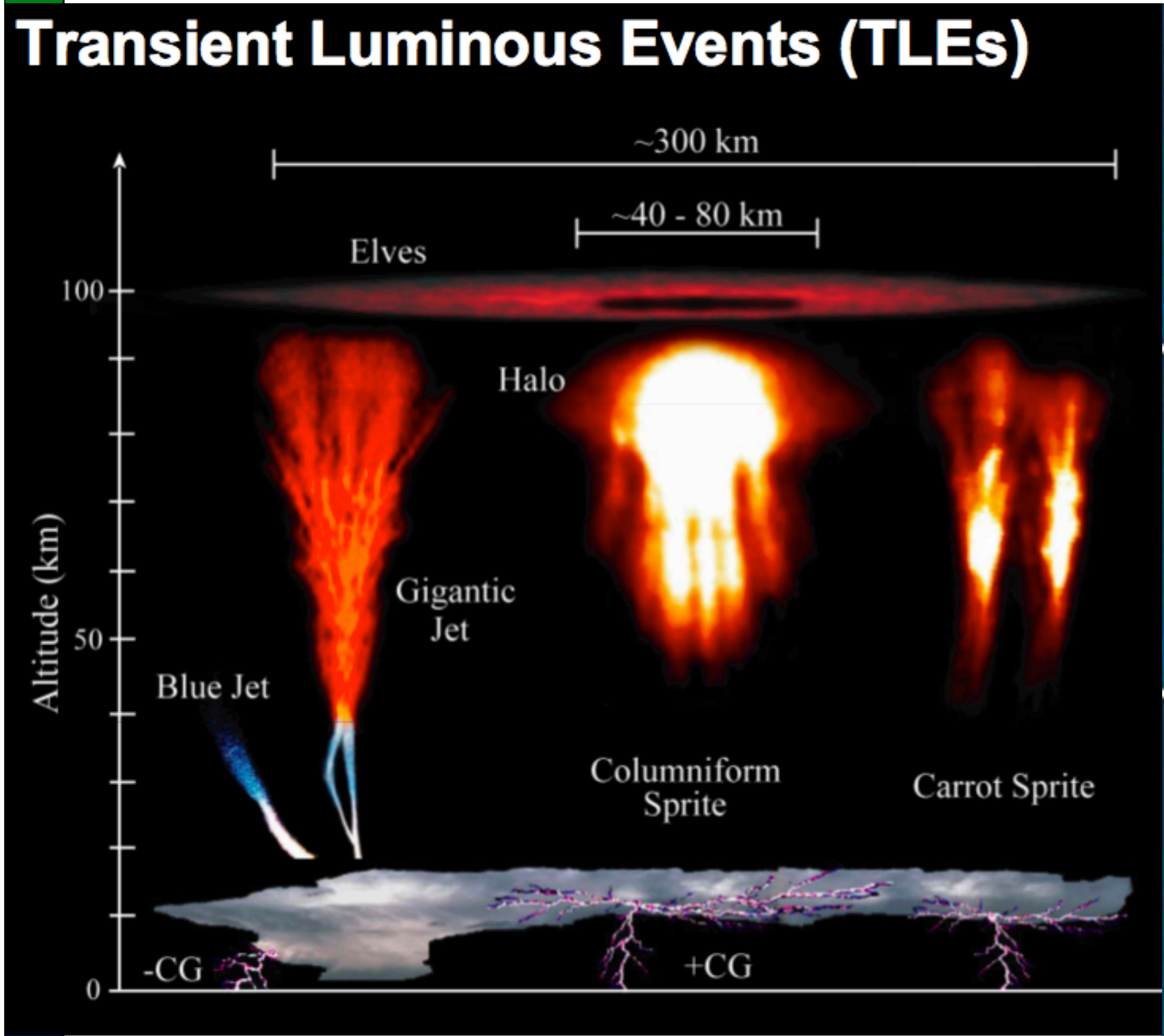


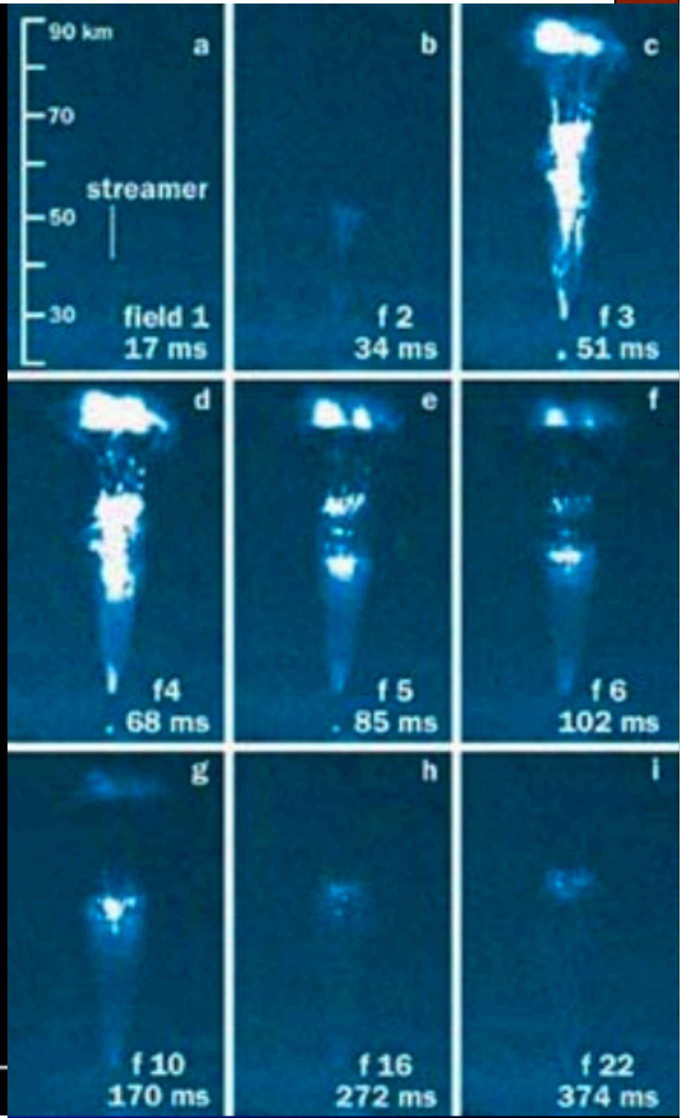
The first recording of luminous phenomena above cloud tops was serendipitously obtained in 1989 by Franz et al. while testing a new long-light video system.

Sentman and Wescott [1993] flue two jets above the top of a thundercloud. They recorded two phenomenon later termed as sprites and jets, and obtained their altitude.

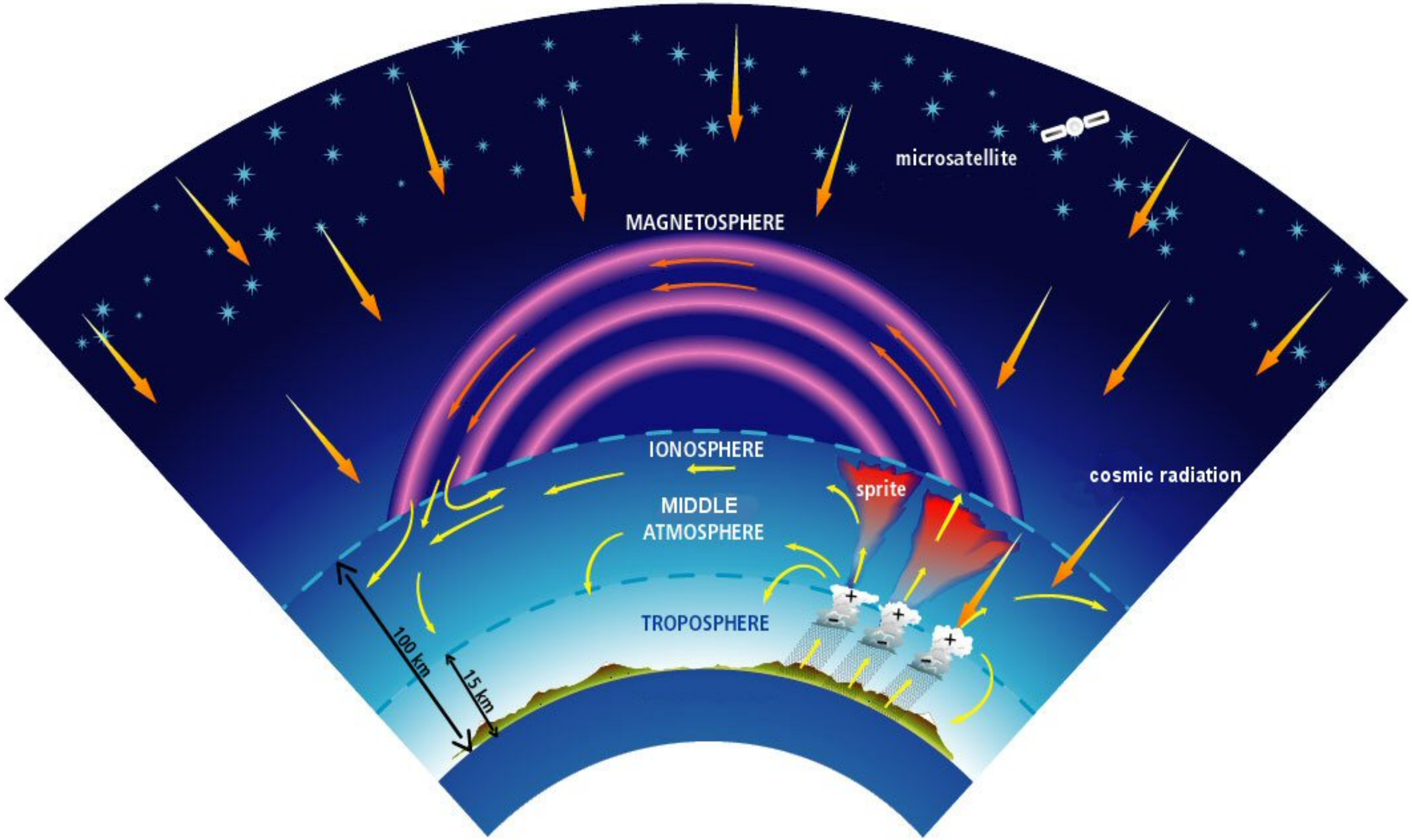
(Elaboration of figure by Lyons et al. 2000)

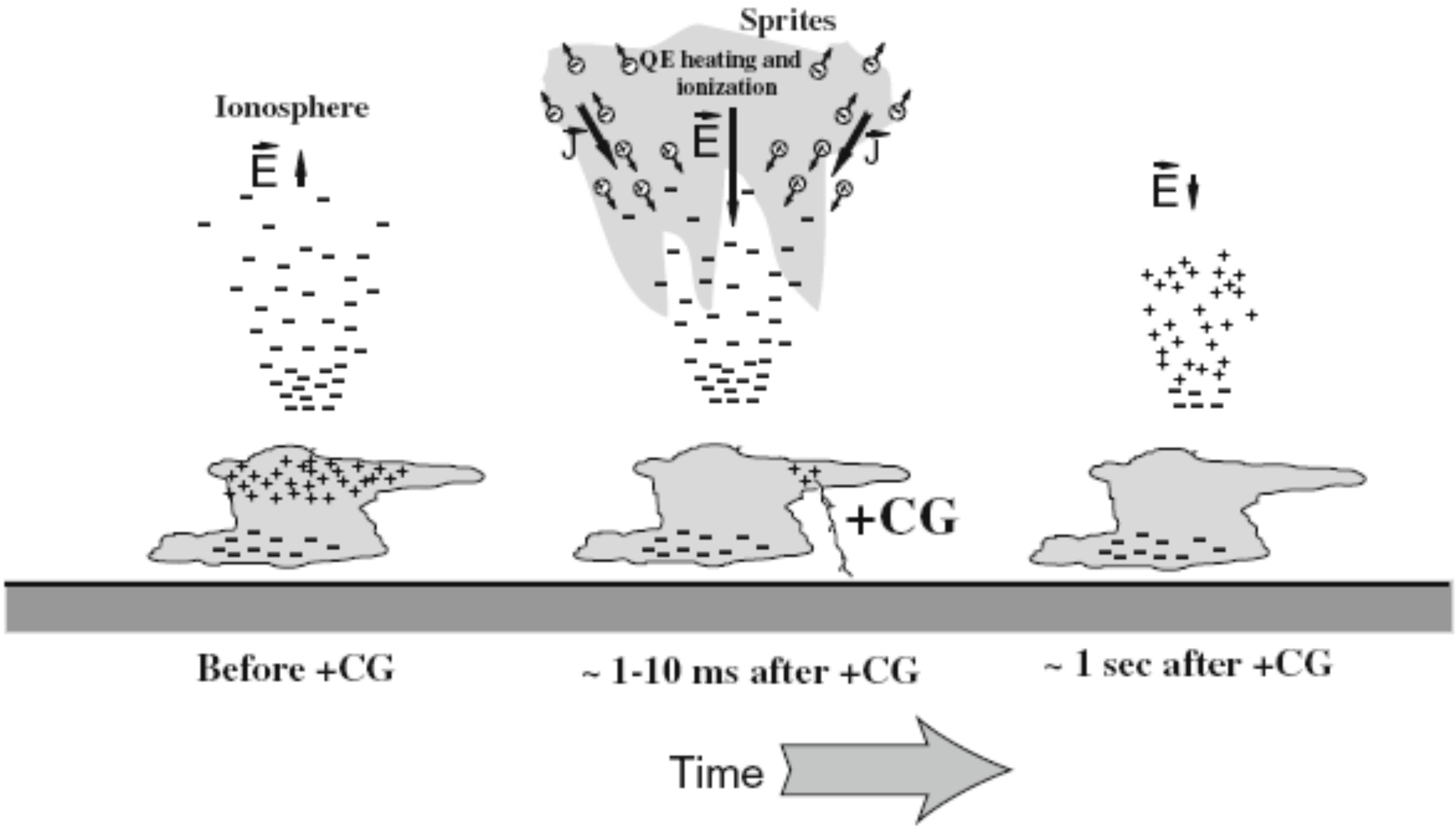
Ionosphere phenomena

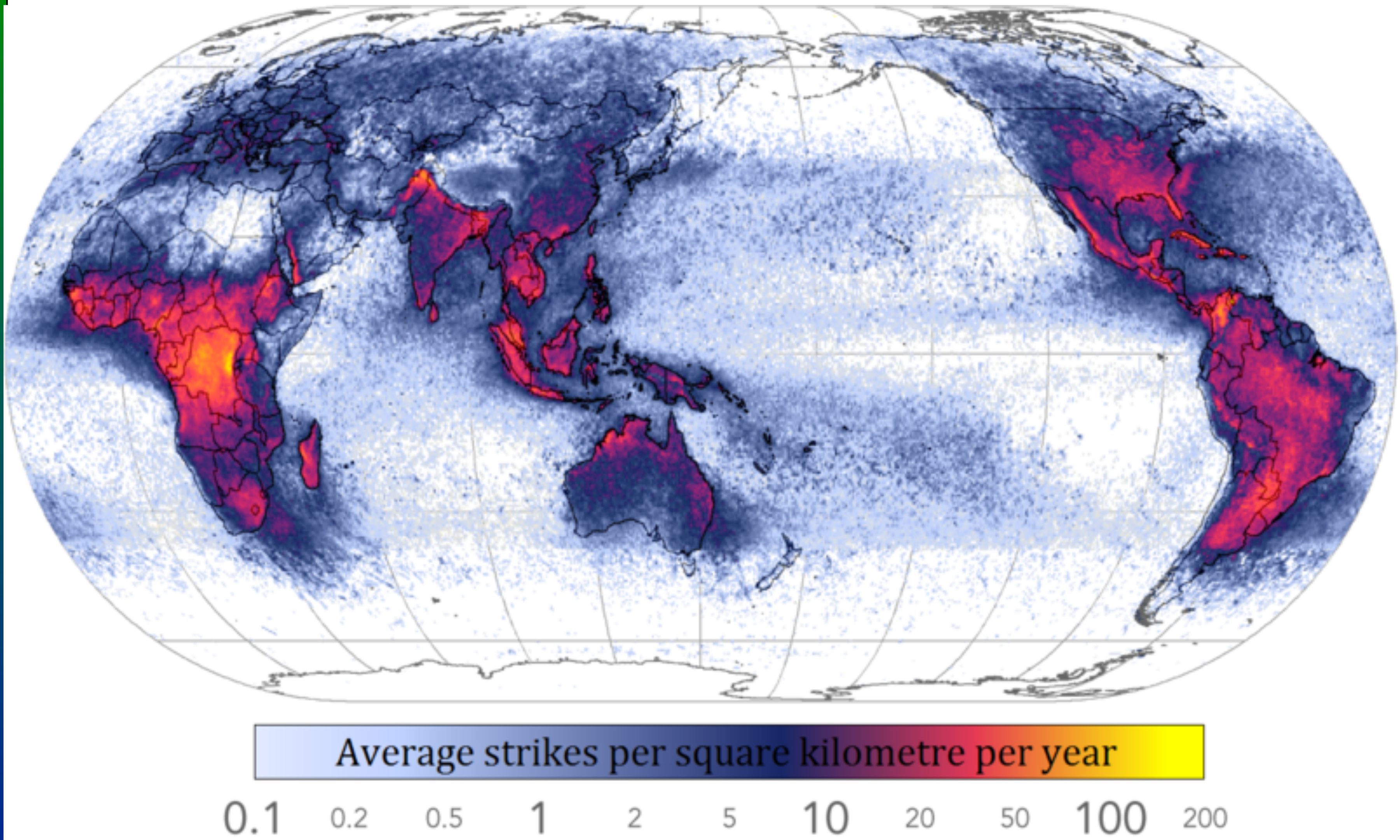


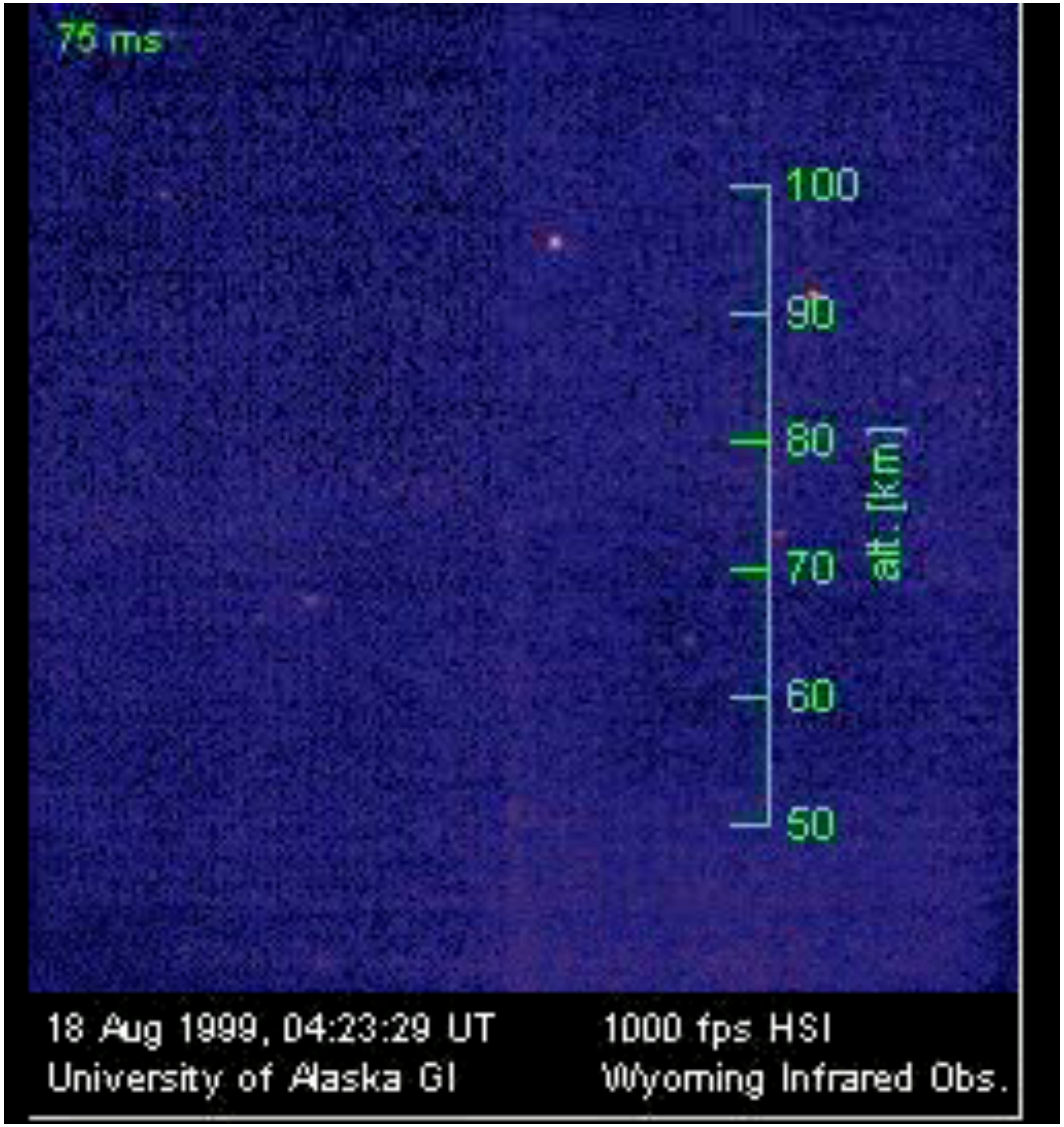


TLE are associated with the electromagnetic connections and interactions between atmosphere, ionosphere and magnetosphere and with strong thunderstorm activity

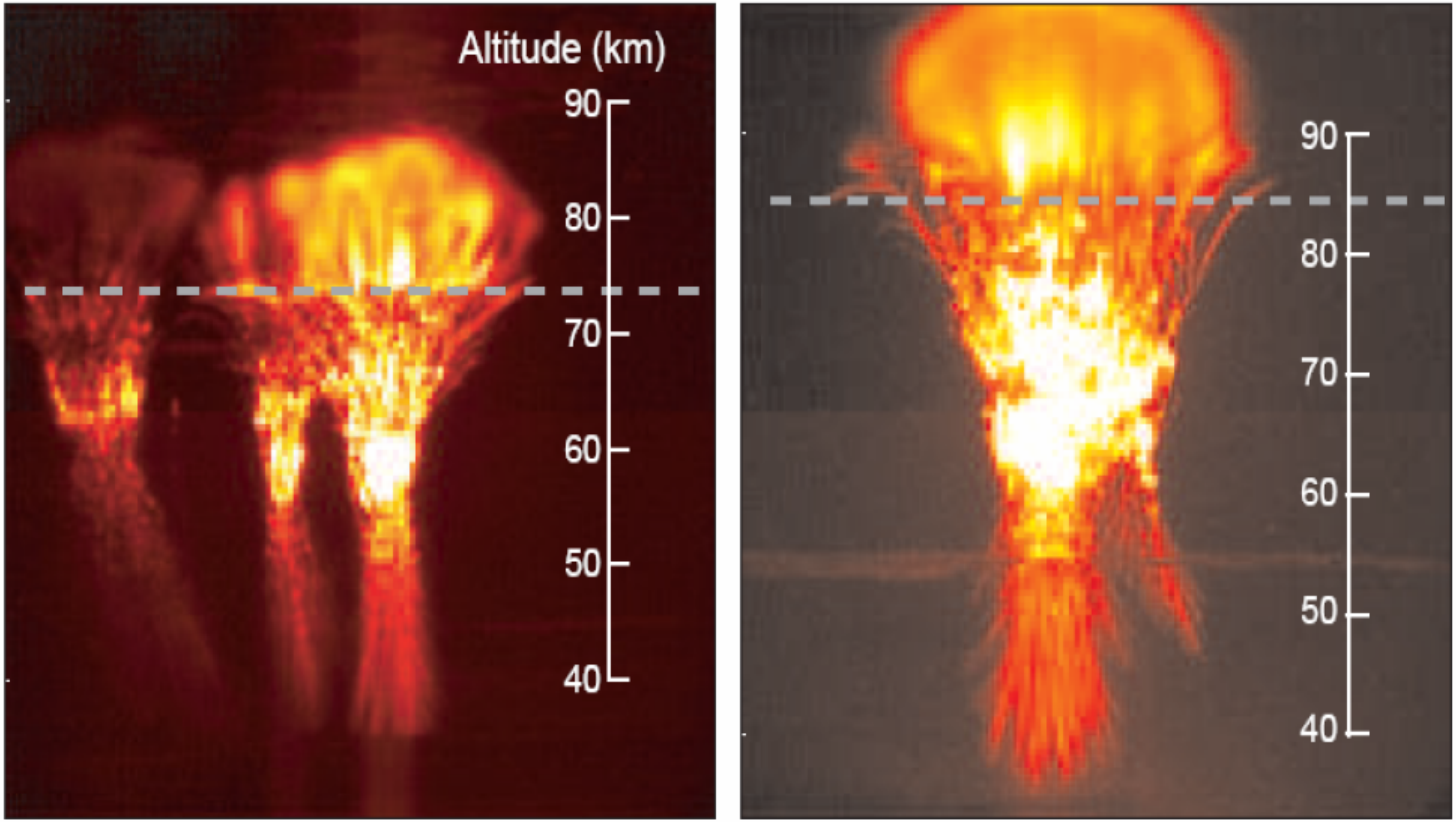



Sprites
QE heating and ionization
Ionosphere
E
J
J
E
E
+CG
Before +CG
~ 1-10 ms after +CG
~ 1 sec after +CG
Time

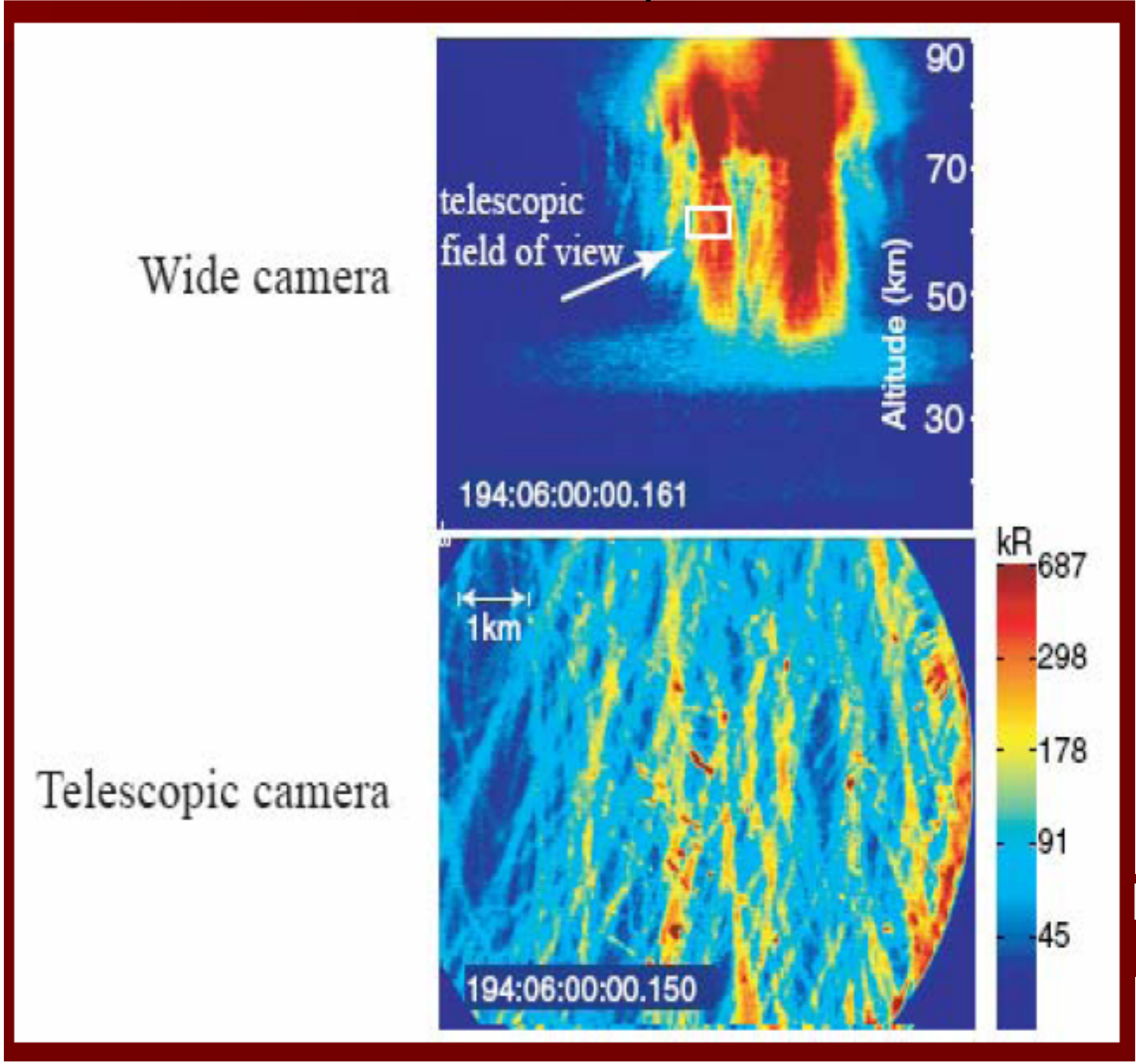

Average strikes per square kilometre per year
0.1
0.2
0.5
1
2
5
10
20
50
100
200


75 ms
100
90
80
70
60
50
alt. [km]
18 Aug 1999, 04:23:29 UT
University of Alaska GI
1000 fps HSI
Wyoming Infrared Obs.

- The images illustrating the altitude transition between diffuse and streamer regions in sprites [*Stenbaek-Nielsen et al.*, GRL, 27, 3827, 2000]:



Subtle structure of the sprite

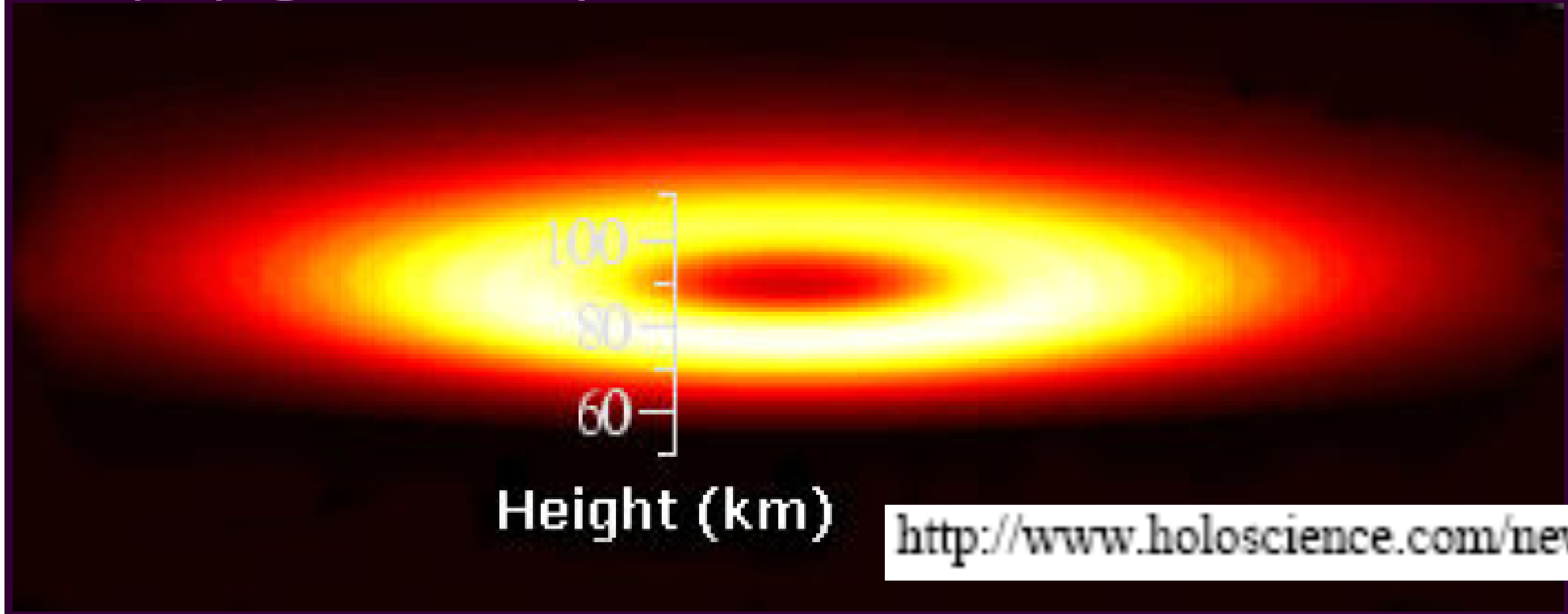


[Gerken and Inan, GRL, 2000]

Fig. 1 A typical sprite event with multiple elements, with tendrils and bright cores. A large sprite-halo is clearly observed at the upper part. The image was taken by Michal Ganot with a Watec 902H camera at regular video speed, as part of the Eurosprite 2007 campaign in France. Courtesy of the ILAN team

What is an elve?

Elves are shaped quite differently from sprites and were first identified in 1990 as brief brightenings of the airglow layer in space shuttle imagery. The ringlike elve in Figure 1 (not "elf": the acronym stands for "emissions of light and very low frequency perturbations from electromagnetically pulsed (EMP) sources") is centered on the vertical channel to ground. It is a rapidly expanding ring of luminosity in a narrow altitude range (85-95•m). For an observer on the ground, the flash appears to drop in altitude and spread outward with time. While the optical flash may last only tens of microseconds, light is emitted from different regions for 1•illisecond as the EMP propagates radially outward.



http://www.holoscience.com/news/balloon.html

Blue and giant blue jets


Orebound Images®

Blue Jet structure [Wescott,et al., JGR, 2001]

•At the base of the jet the diameter ~400m.

•The diameter does not vary till ~22 km.

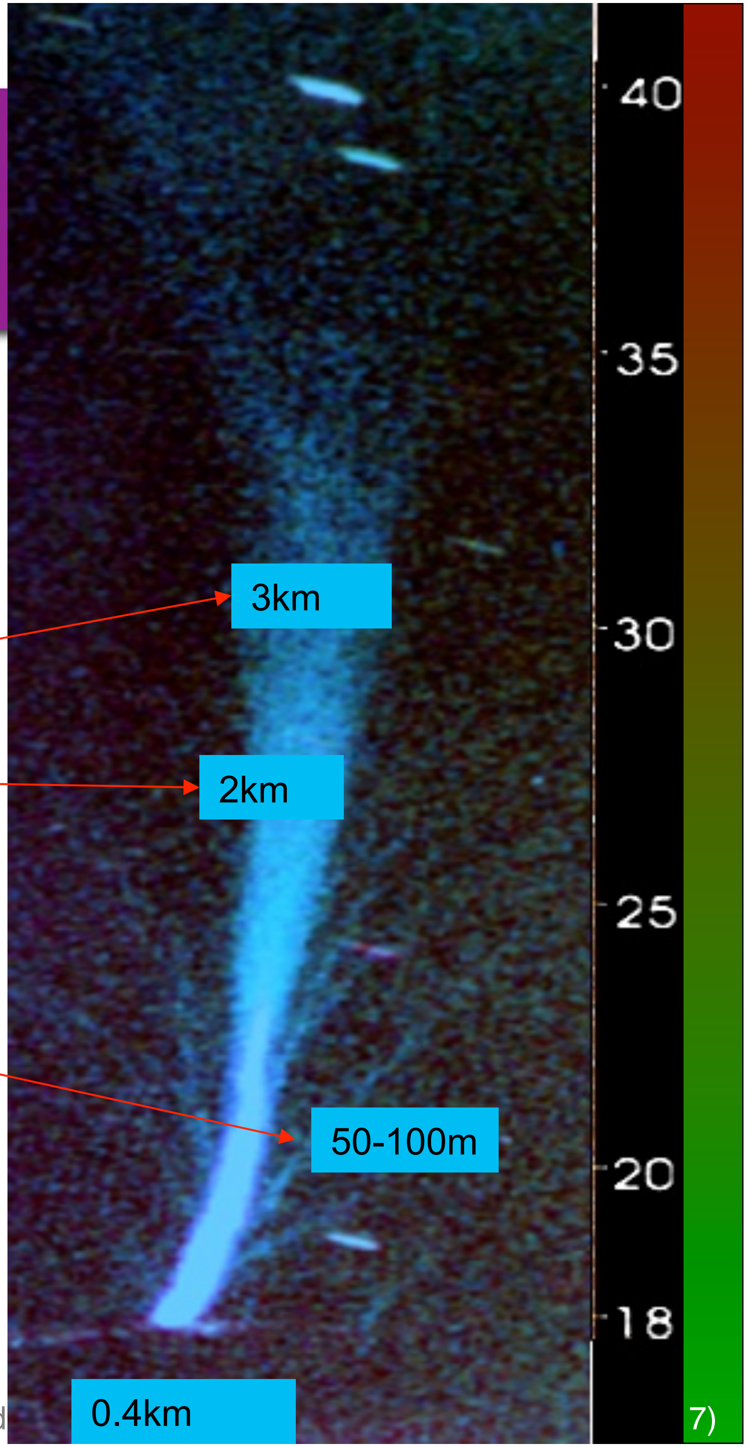
•At 27 km it broadens to ~2 km, and is ~3 km at 35 km.

•Eight smaller streamers with 50-100 m diameter detected.

•Lifetime of the event ~0.1 s.

•Was not associated with any particular CG lightning.

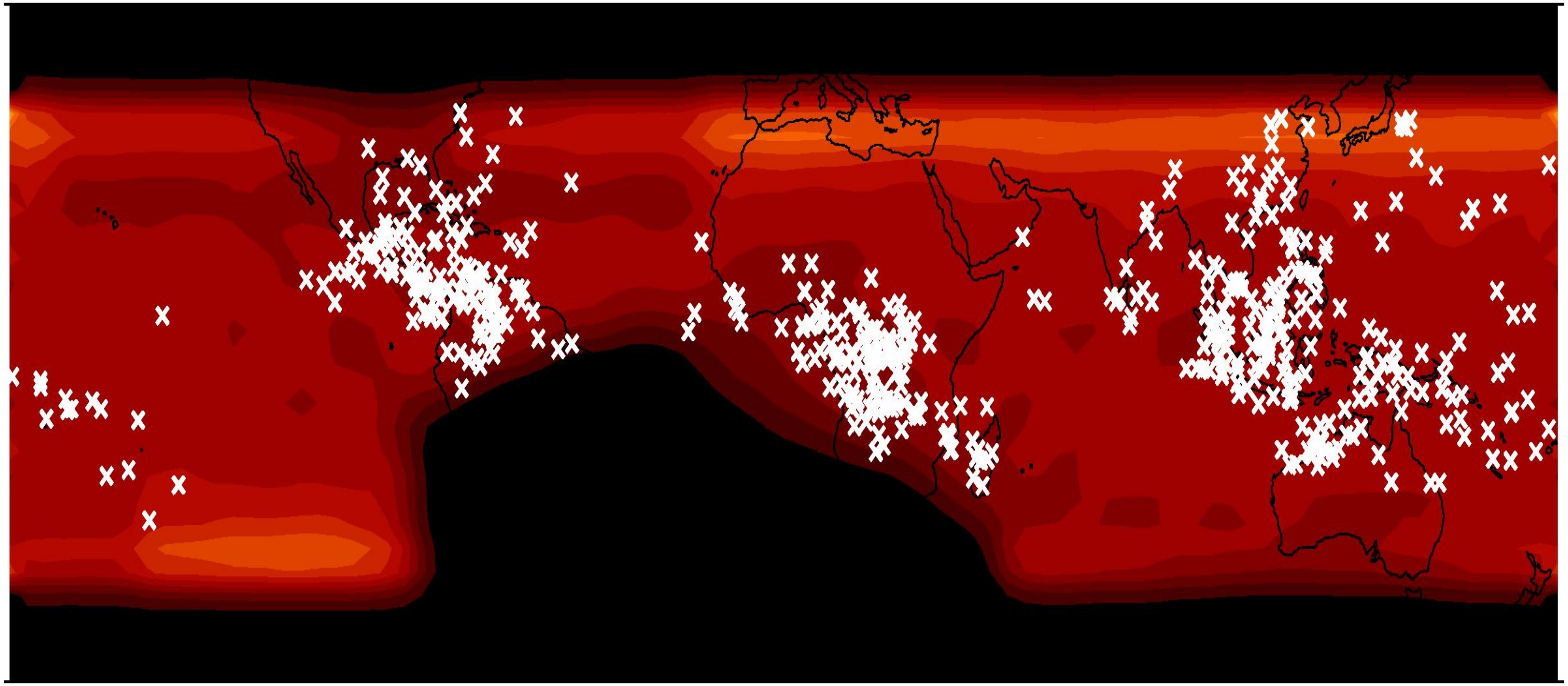
•The total optical brightness reached 6.7 MR (0.5 MJ of optical energy).



Principal Types of Transient Luminous Events in the Upper Atmosphere Associated with Thunderstorms/Lightning

Type of TLE	Altitude Regime	Transverse Dimensions	Spatial Characteristics	Apparent Motion	Duration	Inventory of Observations (est.)
Sprites	~ 50-90 km	~1-20 km	Top (>80 km) diffuse Bottom (<70 km) structured	Top-upward Bottom-downward	few ms	>10,000
Elves	~ 100 km	> 100 km	Diffuse	Lateral Expansion	few ms	>10,000
Blue Jets	~ 18-45 km	few km	Structured	Upward	100s ms	<100
Giant Blue Jets	~ 18-75 km	few km	Structured	Upward	100s ms	<10
Halos	~ 75 km	~ 50 km	Diffuse	Downward	~ ms	>10,000
Trolls	~ 60-70 km	~ kms	Structured	Upward (Within decaying sprite tendrils)	100s ms	100s

RHESSI : (Terrestrial Gamma Flashes TGFs)



498 events in 37 months

Smith et al., 2005

The most energetic electrons accelerate because the dynamic friction, which is due to collisions, at certain electron energies decreases with increasing energy and has a minimum around 1 MeV.

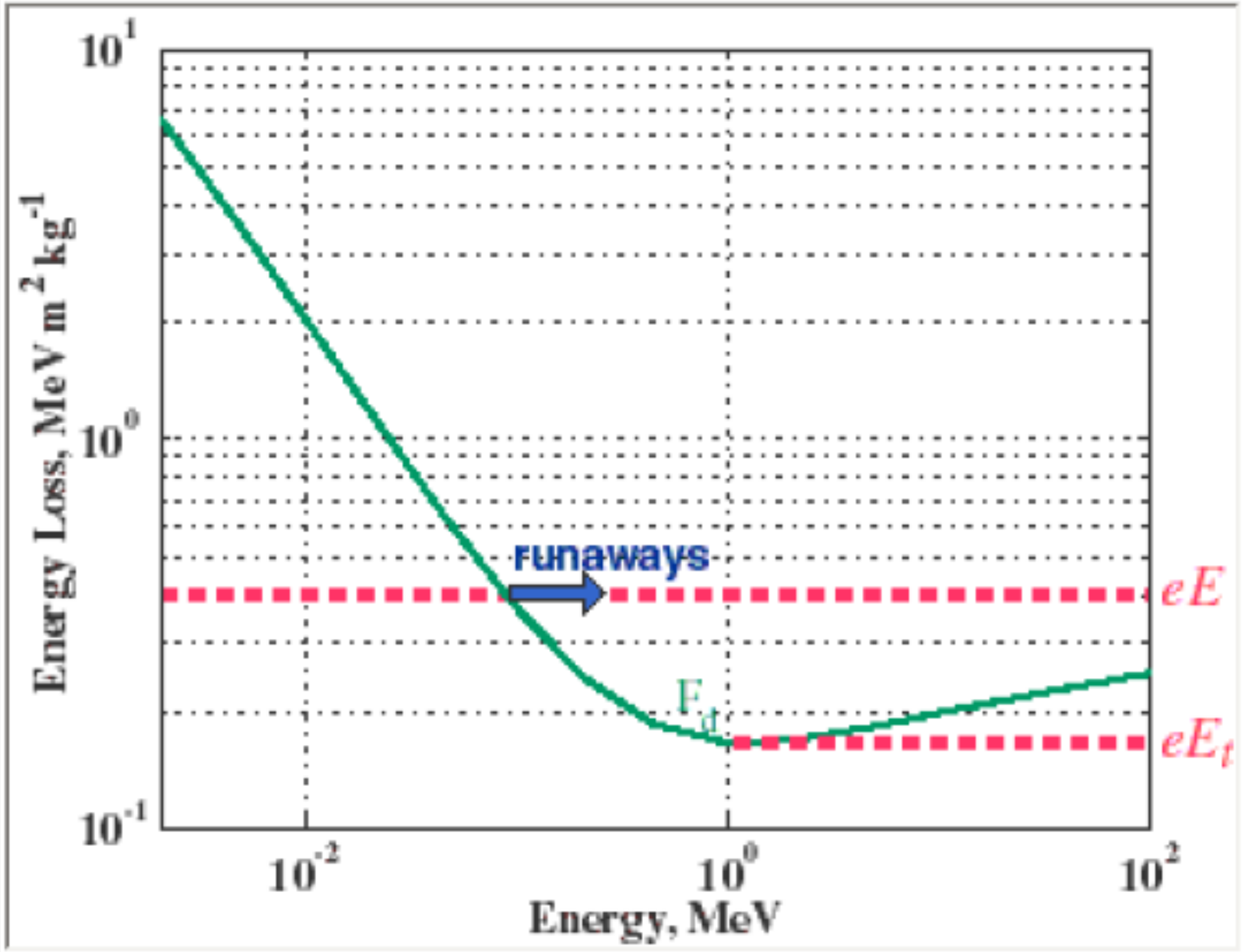
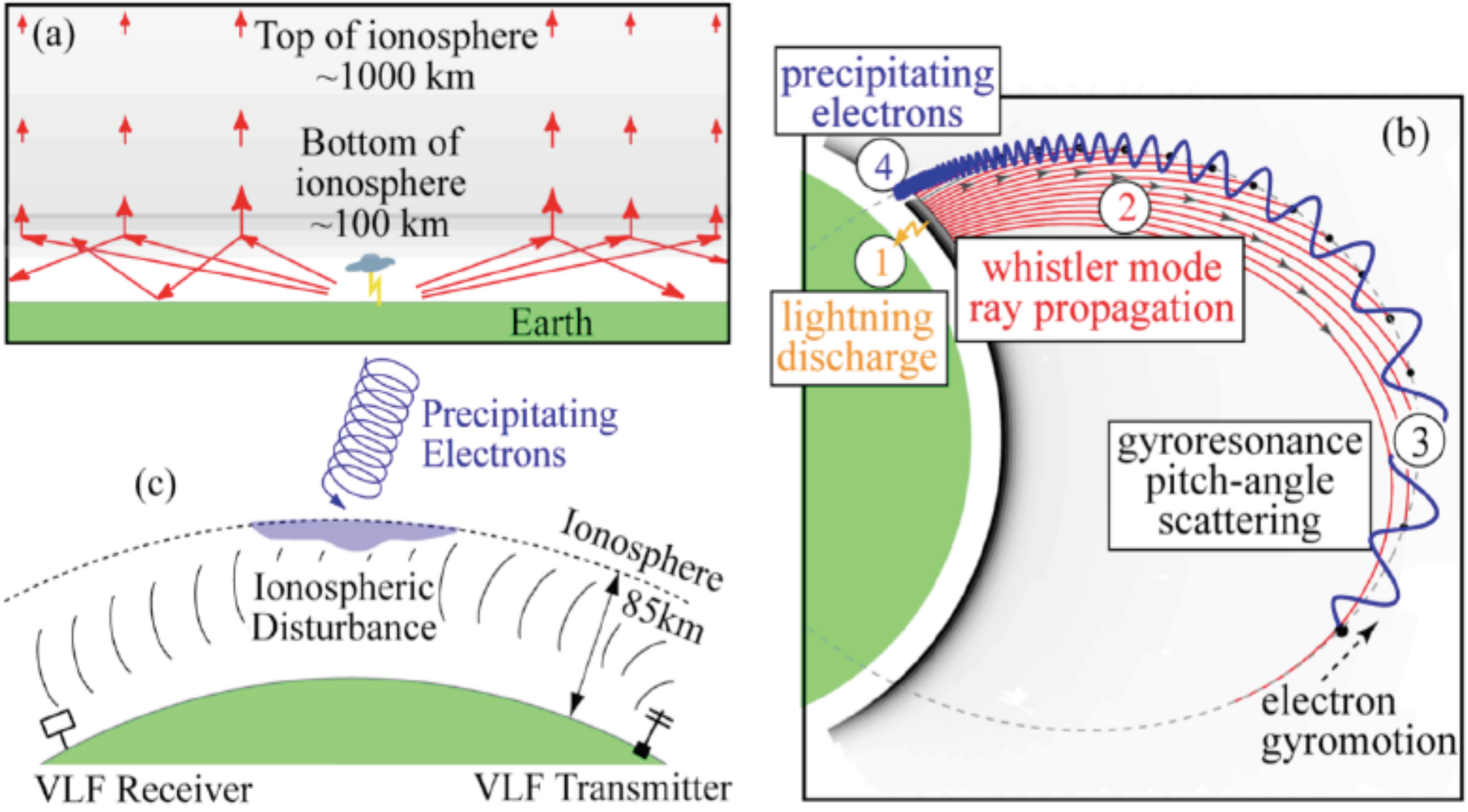


Figure 2. Dynamic friction function.

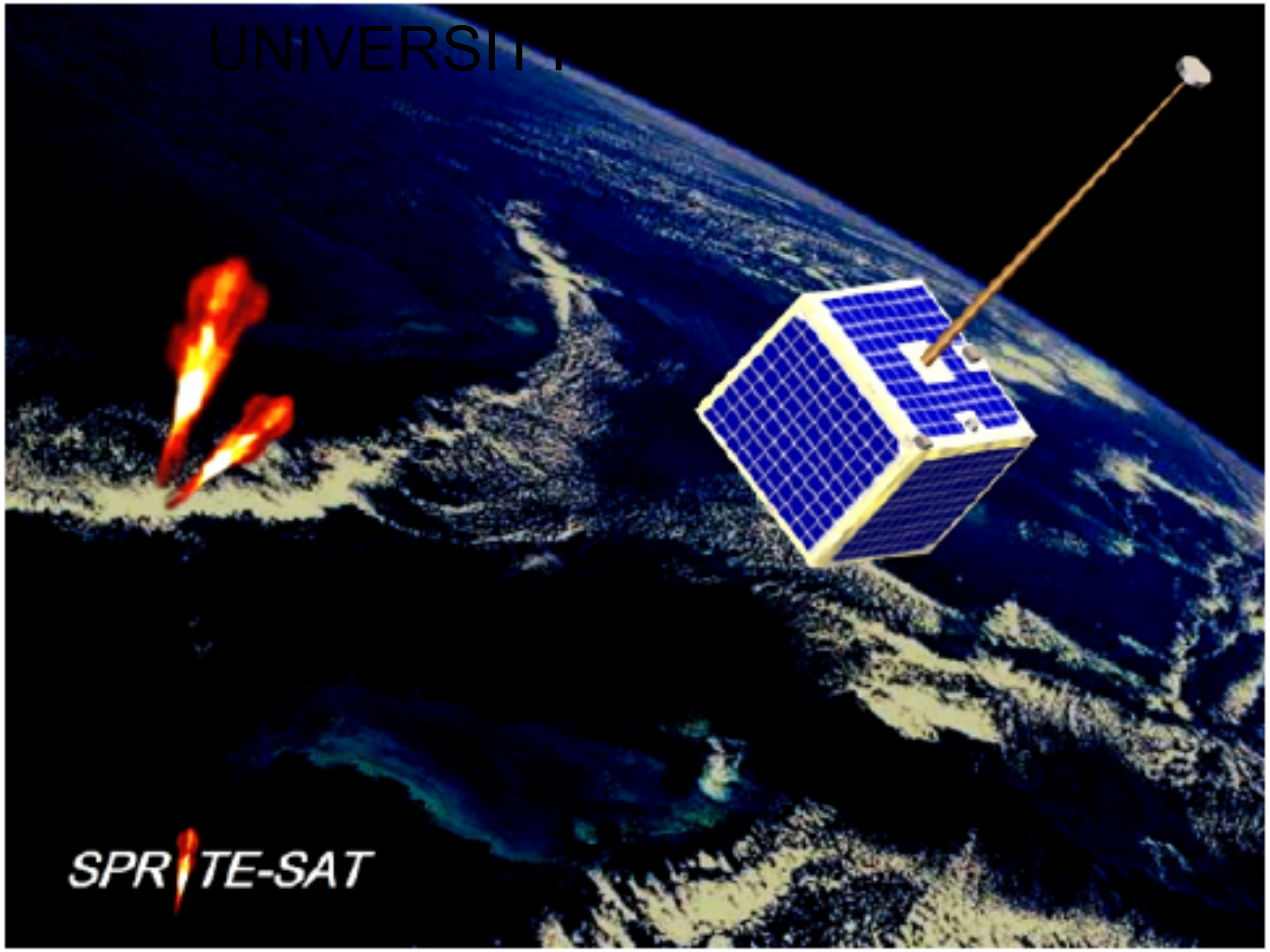
Interaction with radiation belt



SPRITE-SAT (RISING) Project

mission for sprites and TGFs studies

2009 TOHOKU UNIVERSITY

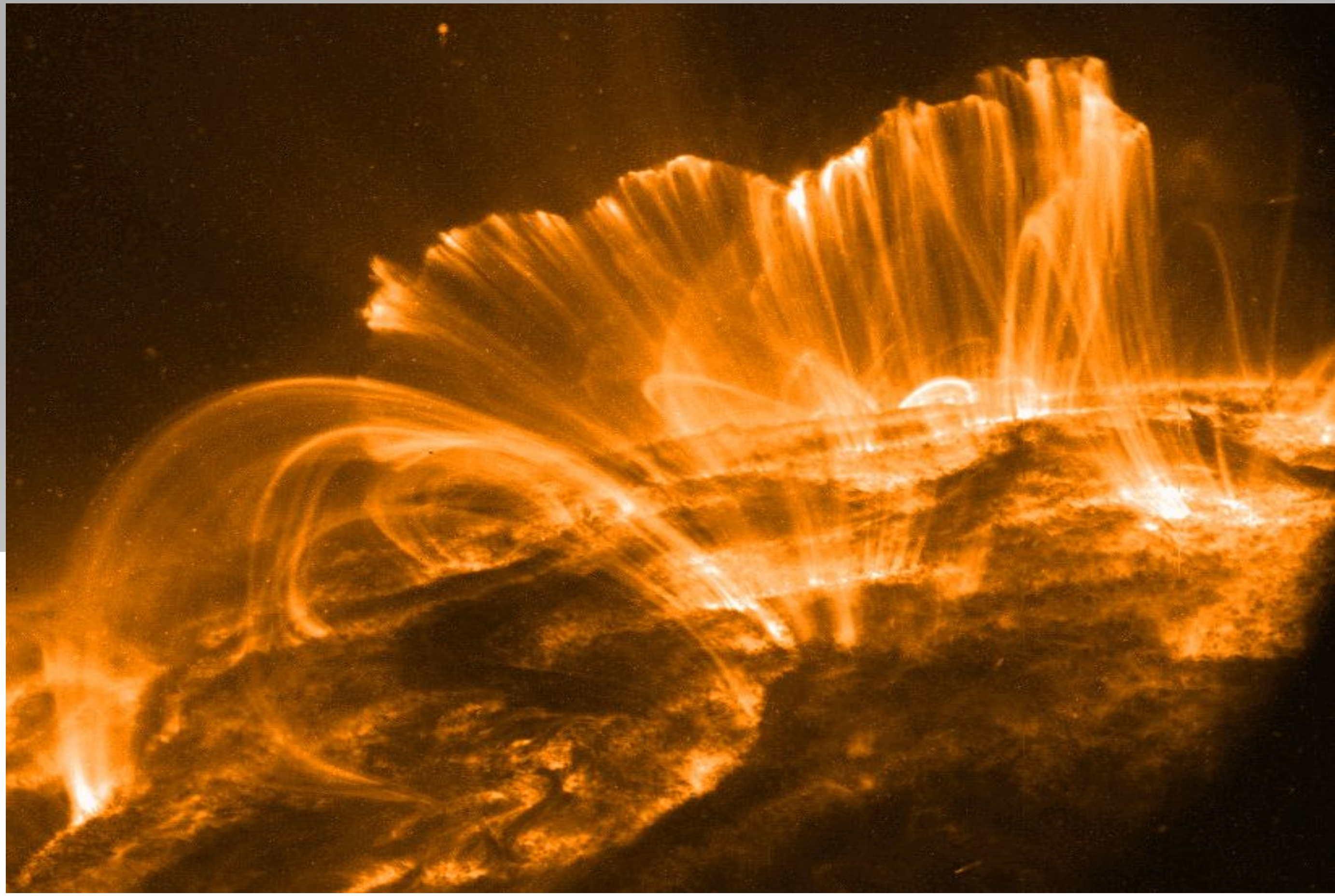


Tool for the Analysis of RAdiations from lightNIngs and Sprites =TARANIS

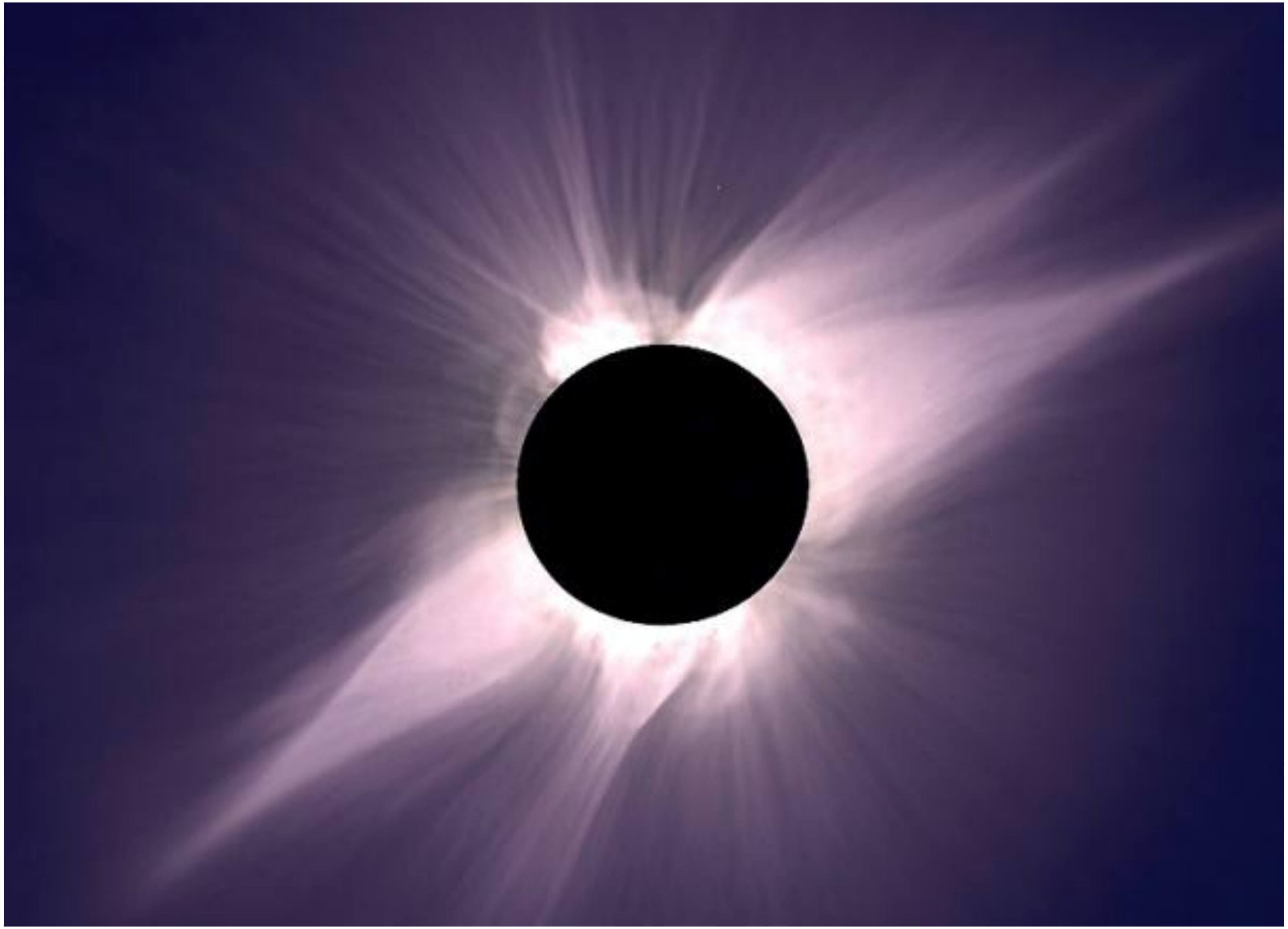
THE ATMOSPHERIC-SPACE INTERACTION MONITOR

Space Observations

- Spectral information
  - Study: Discharge mechanism
  - Needed: Electron energetics
  - Method: Simultaneous obs. in several spectral bands
- Spatial information
  - Study: structure, intensity, altitude dependence
  - Needed: Imaging
  - Method: Cameras
- Temporal information
  - Study: dynamics
  - Needed: high time-resolution measurements
  - Method: photometers



FILAMENTATION OF THE SPACE PLASMA



Field-Aligned Currents and Filaments in Space Plasmas

- Filamentary strucures are found in the following space plasmas, all of which are observed or are likely to be associated with electric currents:
- 1.In the aurora filaments parallel to the magnetic field are often observed. These can have dimensions down to 100m.
- 2. Inverted V events (10^5 -10^6 A) and in situ measurements of the electric currents in the magnetosphere demonstrate the existence of the filamentary structures
- 3. In the ionosphere of Venus „flux ropes” or „magnetic ropes”, whose filamentary diameter are typically 20km, are observed.

- 4.In the Sun, prominences (10^{11}A), spicules, coronal streamers, polar plumes etc. Show filamentary structure whose dimensions are in order 10^{7}-10^{8}m.
- 5.The cometary tails often have a pronounced filamentary structure.
- 6.In the interstelar medium and in the interstelar clouds there is a abundance of the filamentary structures.
- 7.The center of the Galaxy, where twisting plasma filaments, apparently held together by magnetic field possesing both azimutal and poloidal components, extend for nearly 60pc (10^{18} m.)

Physical Mechanisms of Filamentation

- There are two fundamental physical mechanisms trying to explain a creation of the filamentary structure in the space plasmas. Both are associated with currents and ambient magnetic field.
- 1.Pinch instability of the field aligned electric current (Galperin et al. 1986)
- 2.Filament instability of the dispersive Alfven waves (Shukla and Stenflo 1989, Lavader et al. 2001)

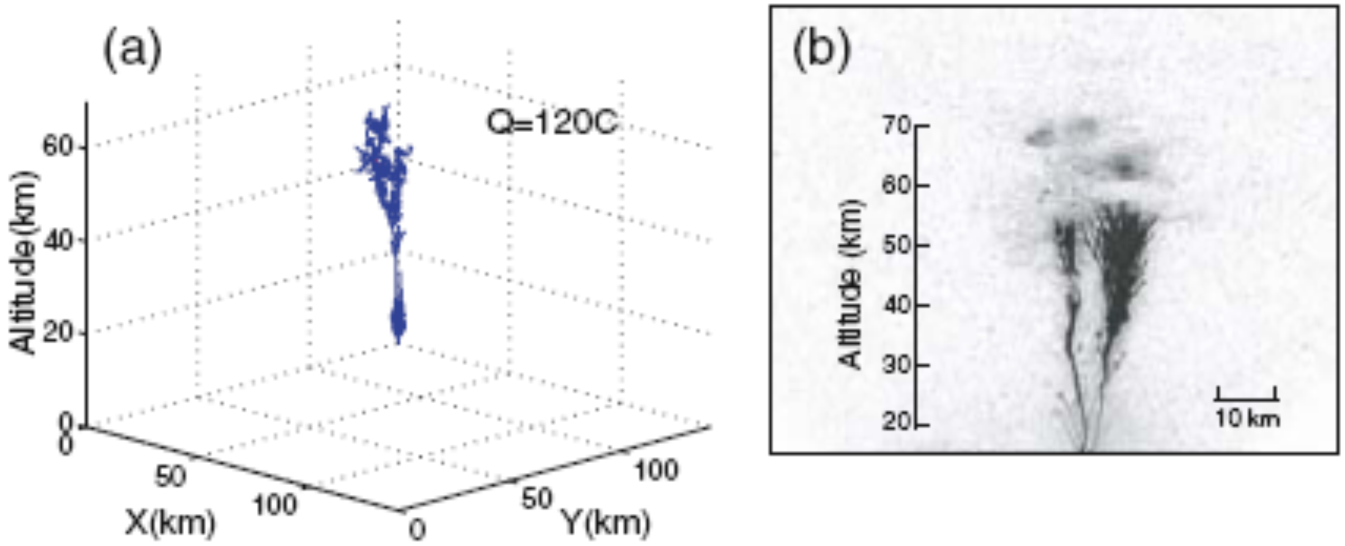


Figure 13. (a) Fractal model results for thundercloud charge Q=120 C at altitude h_Q=15 km and the upper simulation box boundary at 70 km (Pasko and George, 2002). Reprinted by permission from American Geophysical Union. (b) Image of a blue jet at the moment of attachment to the lower ionospheric boundary (Pasko et al., 2002a). Reprinted by permission from *Nature*.

SUMMARY

The characteristics of the TLE' s have been described by different groups working with detectors on the orbit and on ground detecting systems.

JEM EUSO is unique in that its time and spatial resolution is very high and it will allow to see evolution in time of the subtle structure (filamentation) of TLE' s.

There will be two more experiments dedicated to measuring the TLEs on the orbit soon ASIM and Taranis.

The set of data produced by all these experiments may create an exceptional chance to further investigate the physical nature of the TLEs.

Back up - II - Observation of meteor(ite)s with JEM-EUSO

JEM-EUSO: Meteor and nuclearite observations

The JEM-EUSO Collaboration

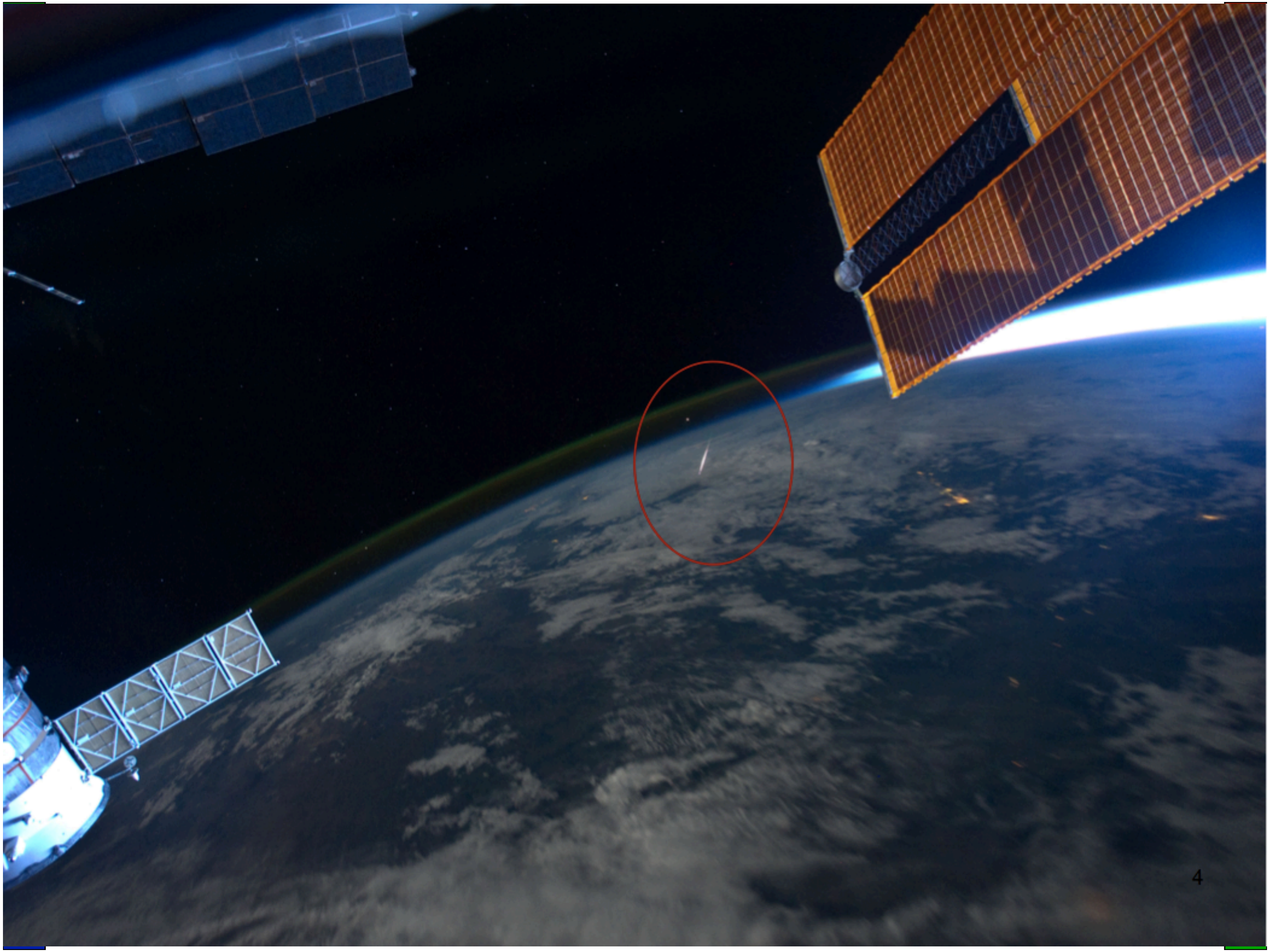
Received: date / Accepted: date

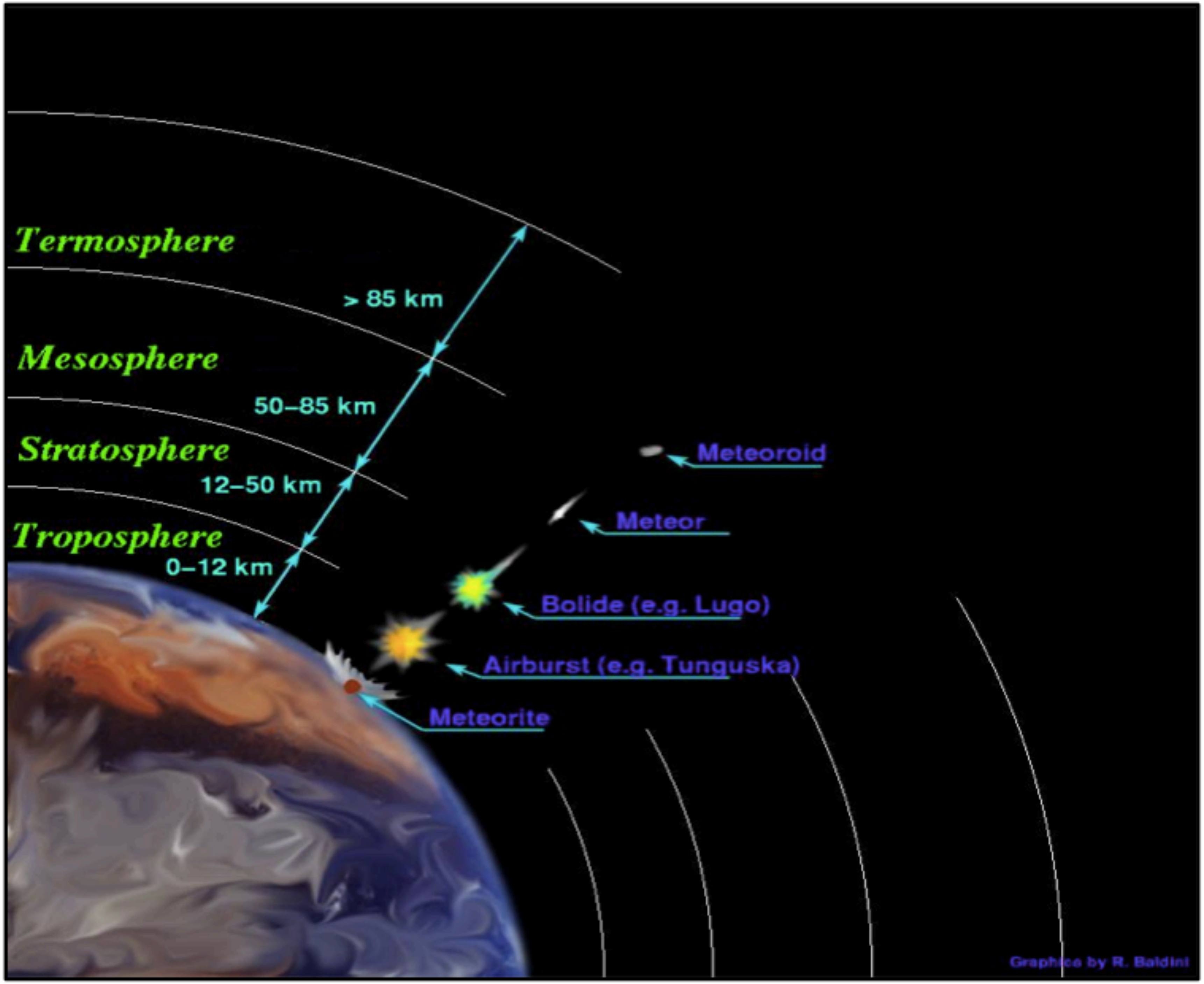
Abstract Meteor and fireball observations are key to the derivation of both the inventory and physical characterization of small solar system bodies orbiting in the vicinity of the Earth. For several decades, observation of these phenomena has only been possible via ground-based instruments. The proposed JEM-EUSO mission has the potential to become the first operational space-based platform to share this capability. In comparison to the observation of extremely energetic cosmic ray events, which is the primary objective of JEM-EUSO, these phenomena are relatively slow. The observing strategy developed to detect such cosmic rays may have application to the detection of nuclearites. This would greatly enhance the scientific rationale behind the JEM-EUSO mission.

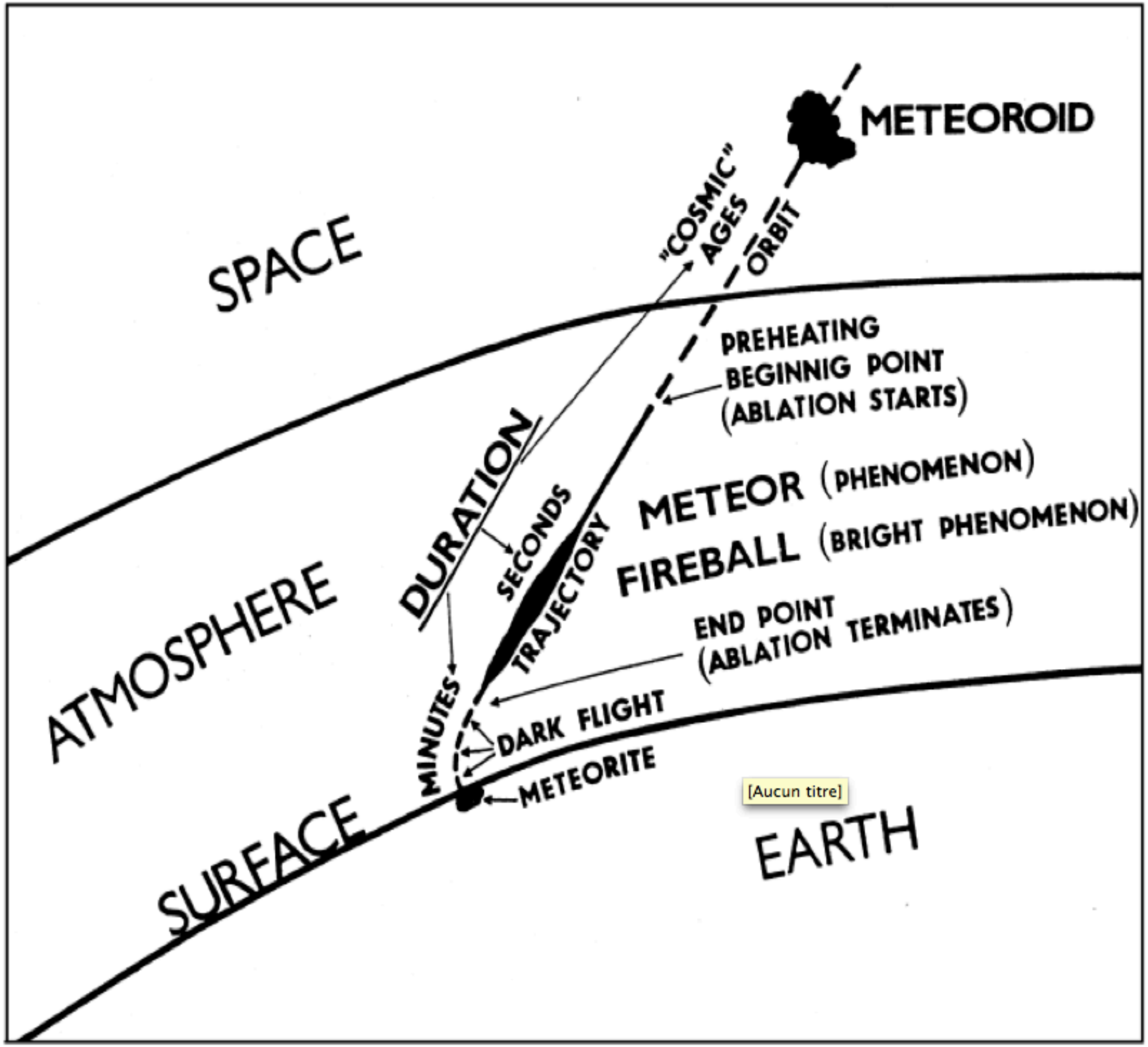
Keywords Meteors · Nuclearites · JEM-EUSO · Space Detectors

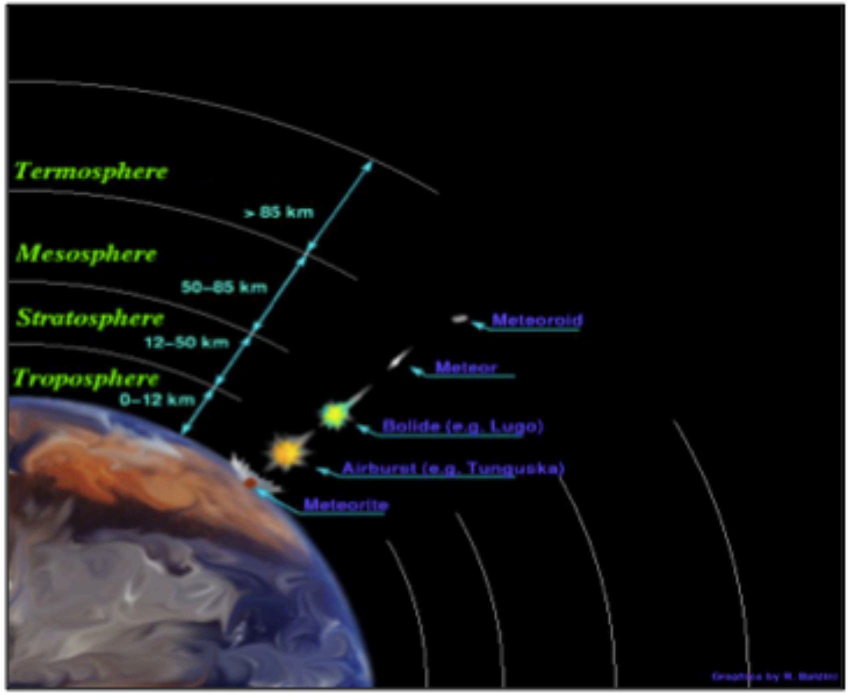
Conclusions

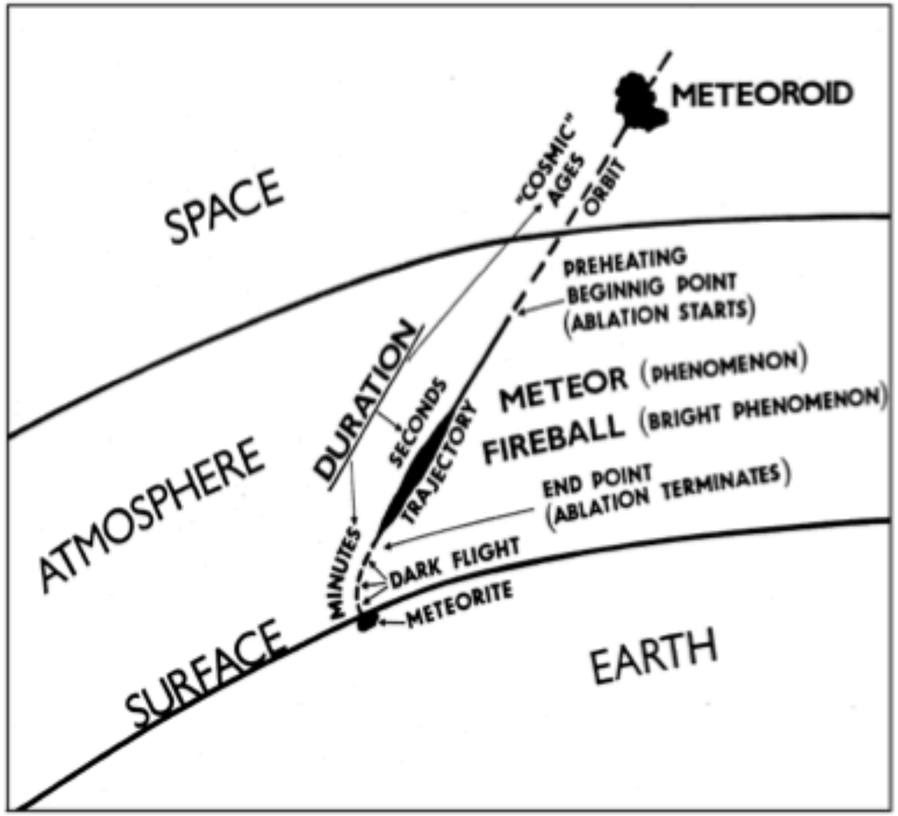
- We can adapt the first level trigger to meteors detection using KI and changing the rate at which we acquire data
- We can detect and reconstruct event up to:
  - *M = 3 for a 160 phe background*
  - *M = 4 for a 64 phe background*
  - *M = 5 for a 16 phe background*
- We have found a way to discriminate cities from meteors.




Termosphere
> 85 km
Mesosphere
50–85 km
Stratosphere
12–50 km
Troposphere
0–12 km
Meteoroid
Meteor
Bolide (e.g. Lugo)
Airburst (e.g. Tunguska)
Meteorite
Graphics by R. Baldini


METEOROID
"COSMIC" AGES
ORBIT
SPACE
PREHEATING
BEGINNIG POINT
(ABLATION STARTS)
DURATION
SECONDS
TRAJECTORY
METEOR (PHENOMENON)
FIREBALL (BRIGHT PHENOMENON)
ATMOSPHERE
END POINT
(ABLATION TERMINATES)
MINUTES
DARK FLIGHT
METEORITE
[Aucun titre]
SURFACE
EARTH





- **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)

Visual meteors → **meteoroids with D > 2 mm**

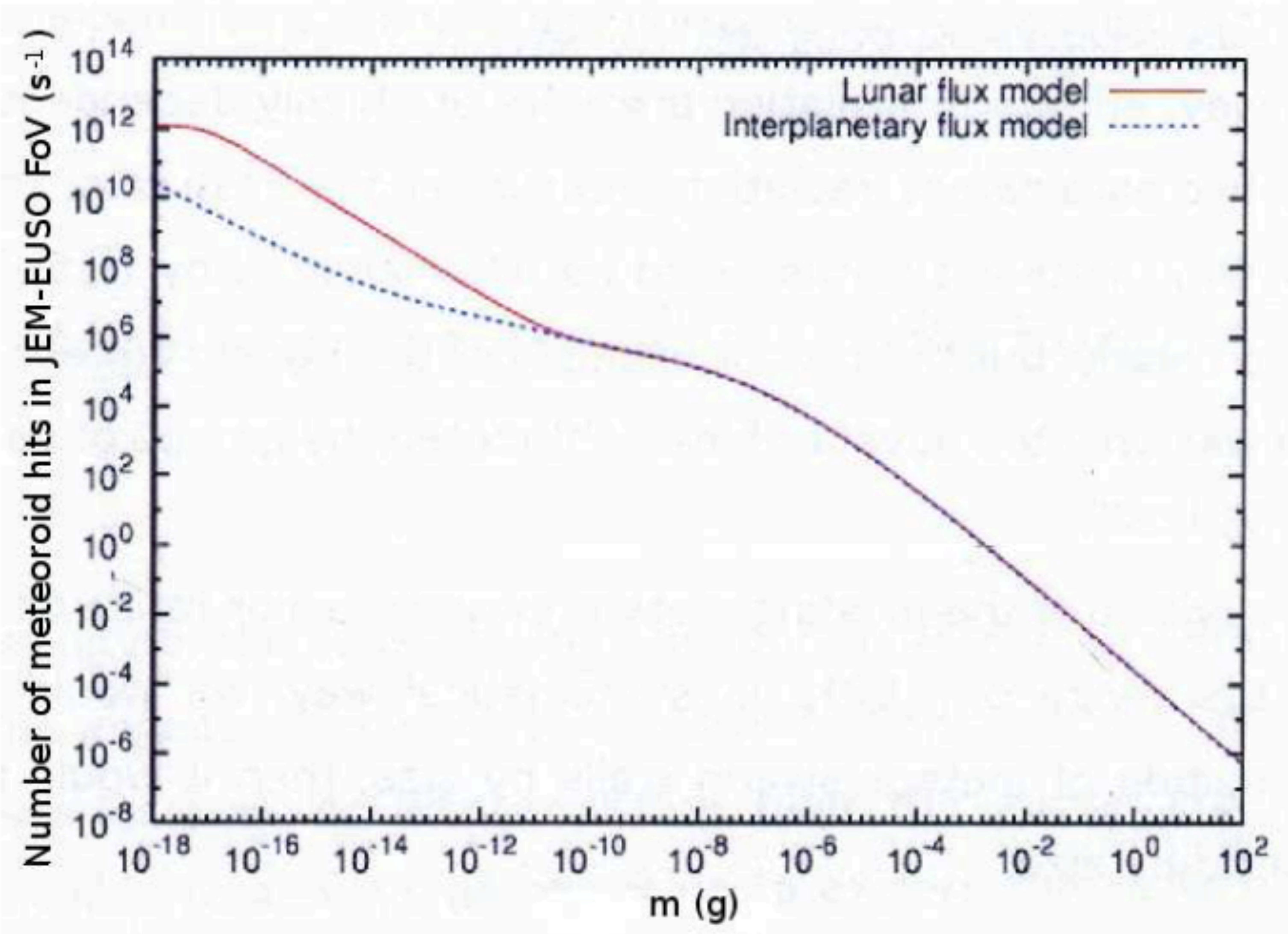


Fig. 2 Number of micro-meteoroid impacts expected per sec in the JEM-EUSO FoV as a function of impactor mass in grams. Figure adapted from [18]

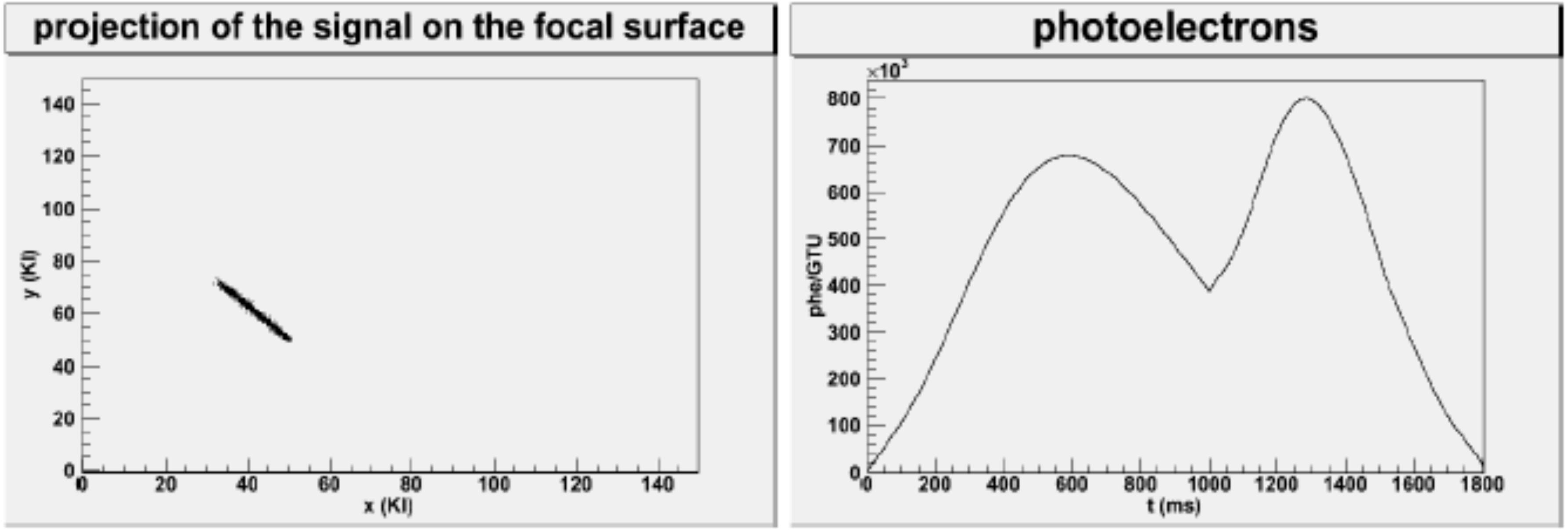


Fig. 3 Example of meteor signal computations carried out using the simulation described in the text. The top panel shows the resulting path of the signal in the focal plane, while the bottom panel shows the simulated lightcurve, including a secondary burst occurring at $t \simeq 1000$ msec.

Table 2 For different absolute magnitudes (M) of meteors in visible light, the corresponding flux in the *U*-band are shown (according to the Flux Density Converter of the Spitzer Science Center; details can be found at the web site http://ssc.spitzer.caltech.edu/warmmission/propkit/pet/magtojy/index.html). The corresponding number of photons per second, the number of photo-electrons per GTU, the typical mass of the meteor, and the number of events expected to be observed by JEM-EUSO (the latter is computed assuming a duty cycle of 0.2) are also shown.

magnitude (M)	U-band flux ($erg/s/cm^2/A$)	photons (s^{-1})	photo-electrons ($GTU=2.5\mu s)^{-1}$	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

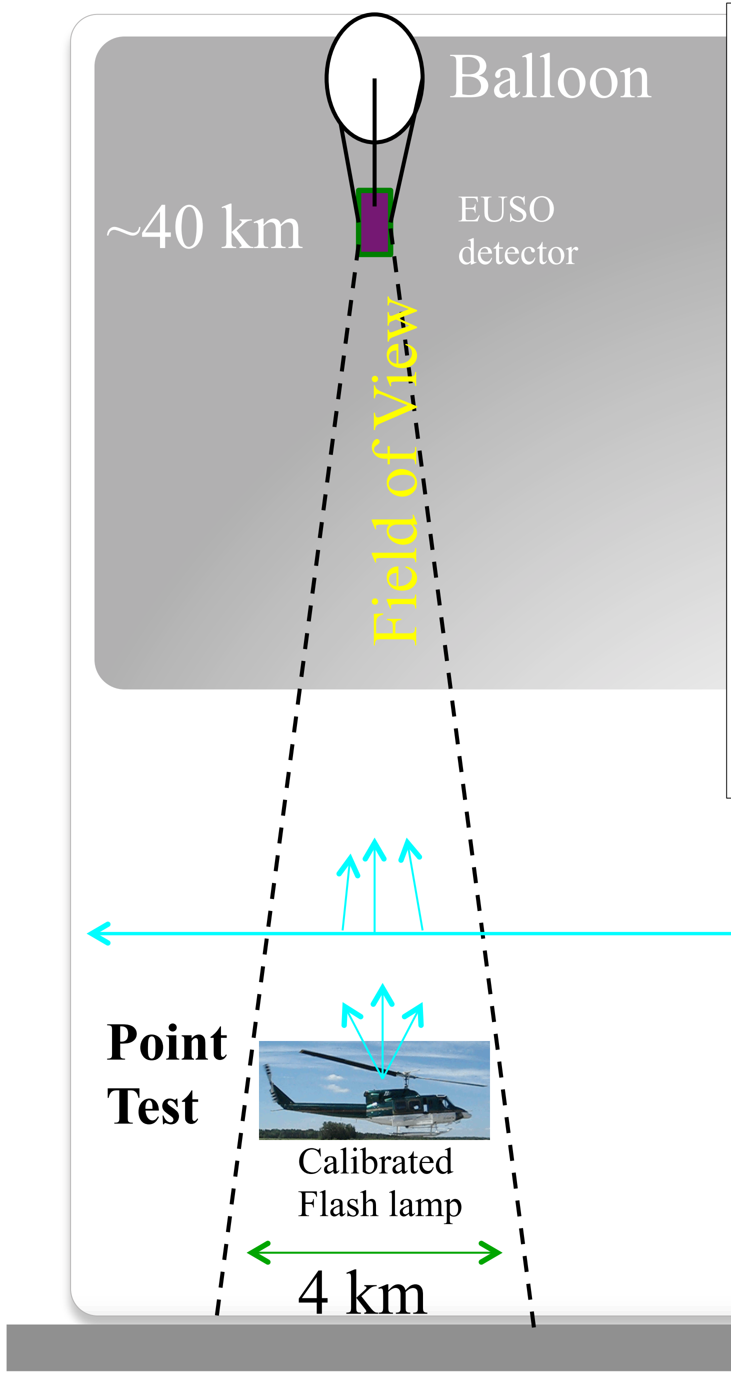
Back up – III – EUSO-Balloon

EUSO-BALLOON

- A balloon-borne fluorescence telescope, pathfinder of JEM-EUSO
- 1 PDM with electronics and mechanics as close as possible to JEM-EUSO
- DAQ & BG study
- Detection EAS > ~10^{18}eV from an altitude of 40km (expected 0.2-0.3 events with E>2×10^{18} eV during 10 hours night-flight)
- CNES project with IRAP, APC & LAL + support of the whole JEM-EUSO collaboration

1st launch was successfully carried out on August 24-25th 2014, Timmins (Canada)

	JEM-EUSO	EUSO-BALLOON
Height [km]	420	40
Diameter [m]	2.5	1
FoV/pixel [deg]	0.08	0.25
Pixel@ground [km]	0.058	0.175
FoV/PDM [deg]	3.8	12(8)
PDM@ground [km]	28.2	8.4
Signal Ratio	1	17.6
BG Ratio	1	0.9-1.8
S/√N	1	20-10
Eth [eV]	3×10^{19}	1.5-3×10^{18}
# of PDM	137	1



Testing EUSO-Balloon

Fly one aircraft equipped with
two types of calibrated pulsed UV light sources.

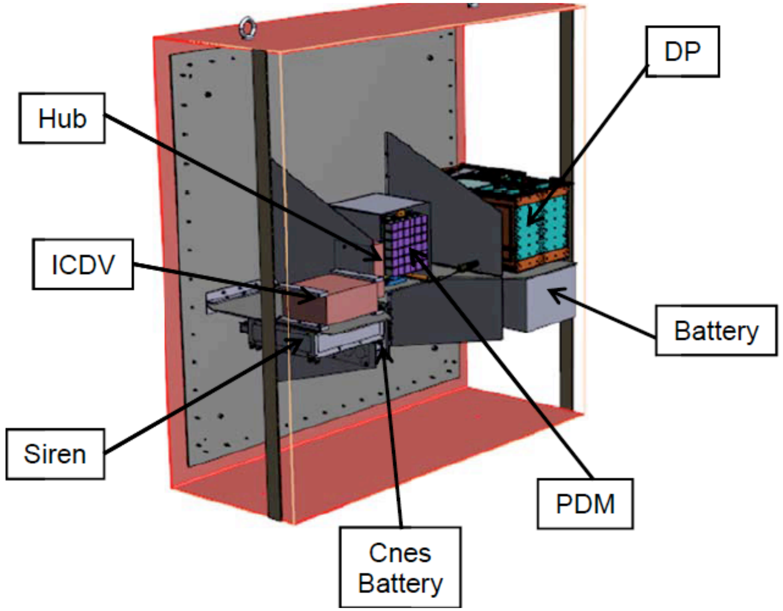
Point Test: Fly airplane in field of view and fire **flash lamp**. Light travels directly from lamp to detector

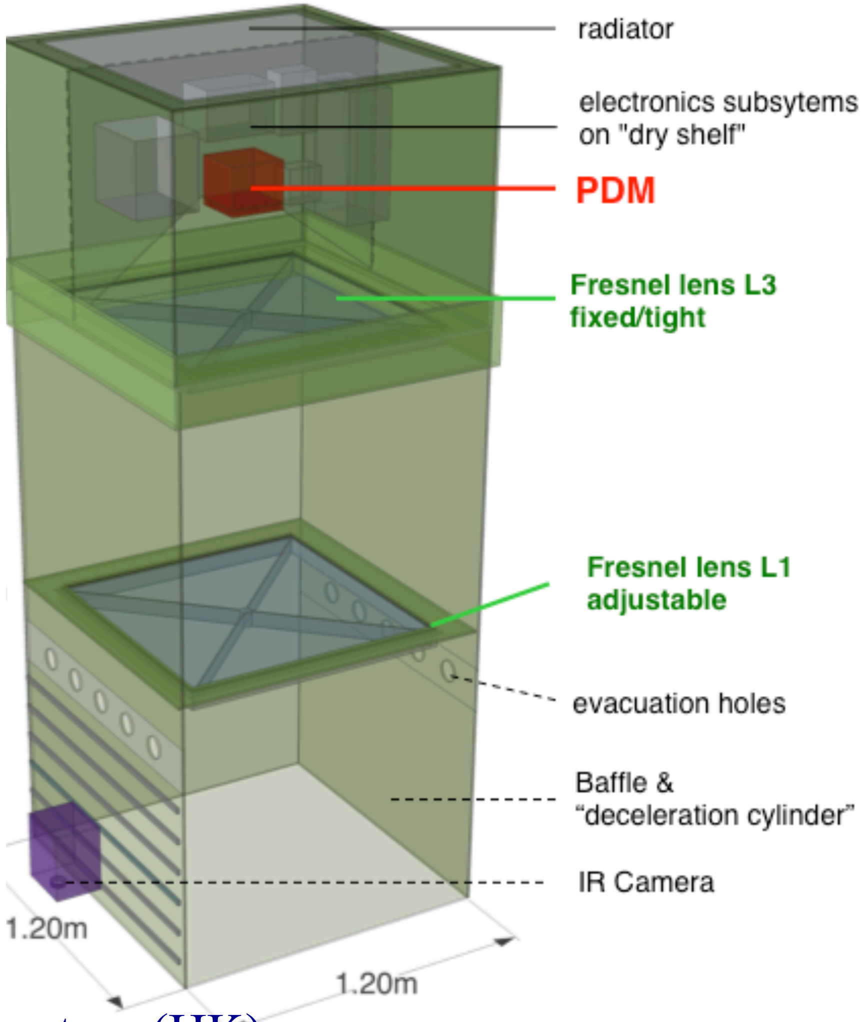
Track Test: Fly airplane outside field of view and shoot a UV pulsed **laser** across field of view. Light scatters out of the beam to the detector.
(5 mJ Laser ~100 EeV Cosmic Ray)

Fly aircraft at altitudes between 1-5 km.

Helicopter equiped with
laser and Xenon flasher

EUSO-BALLOON Instrument





Instrument

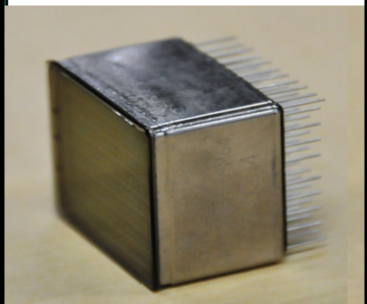
- Mechanical structure (gondola)
- Optics: 2 flat Fresnel lenses (L1&L3)
- 1 Photodetector Module (PDM)
- Data acquisition system (DAQ)
- Monitoring controlled by House Keeping system (HK)
- A set of power supplies (LVPS) powered by onboard batteries (Power Pack)
- An IR camera for atmospheric monitoring

EUSO-BALLOON
Data Acquisition (DAQ) Chain

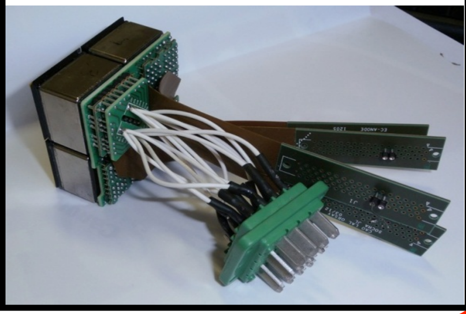
IR camer

Sensor (photodetector)

PMT
- Hmamatsu 64-ch MAPMT
- BG3 filter

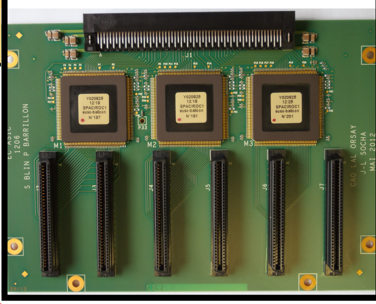


EC-Unit
- 4 PMTs (256-ch) readout cables
- HV board
- potting

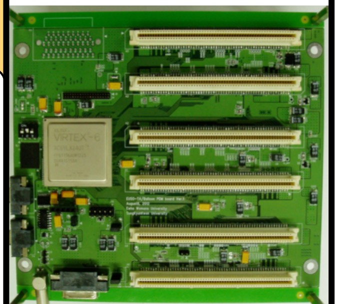


Front-end (FE) electronics

EC-ASIC
- 6 x ASICs
- readout
- counter

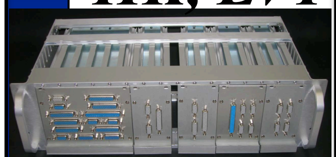


PDM-Board
- Slow control
- Level 1 (L1, track) trigger



Data Processing (DP)

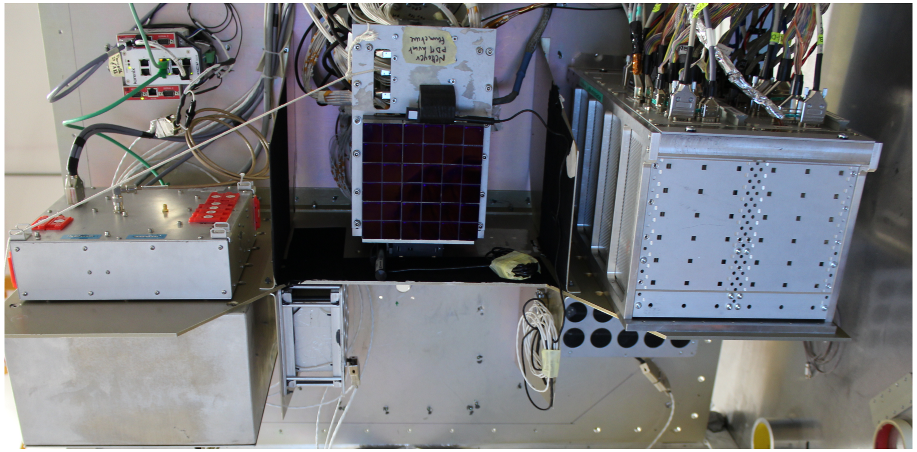
HK, LVPS

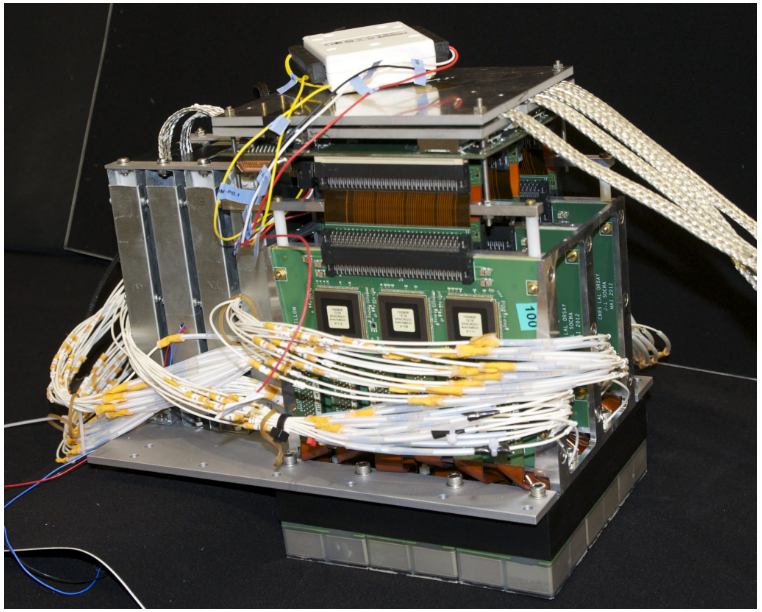


CPU
- Run control, config. FE electronics
- Console & GUI, remote access, etc.
- Data processing
- managing Mass Memory for data storage

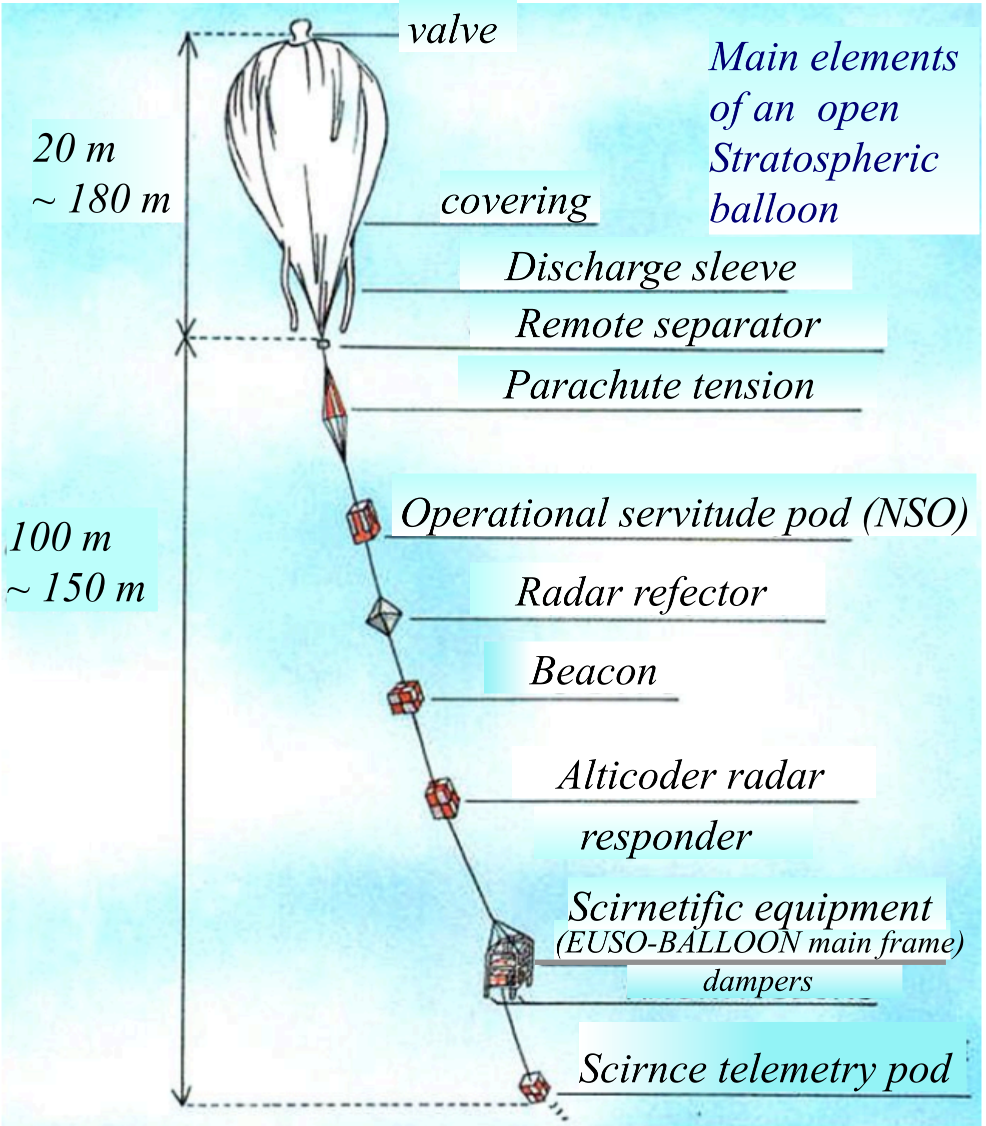
CCB
(Cluster Control Board)
- Receive data from 9 PDMs

EUSO-Balloon



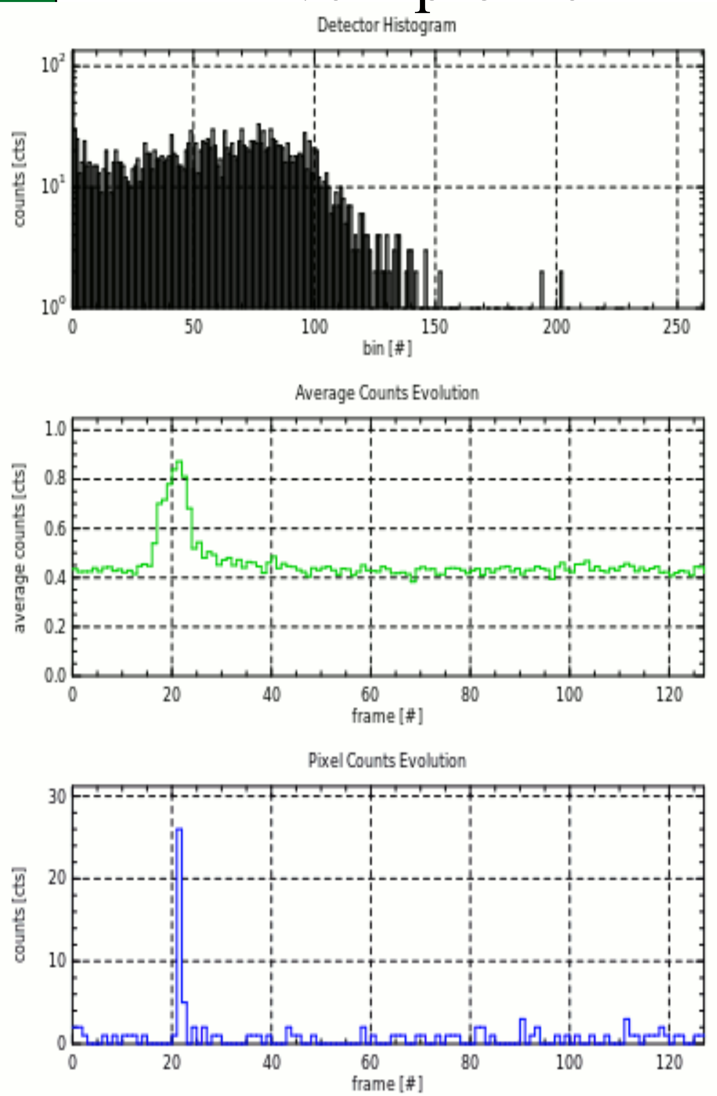


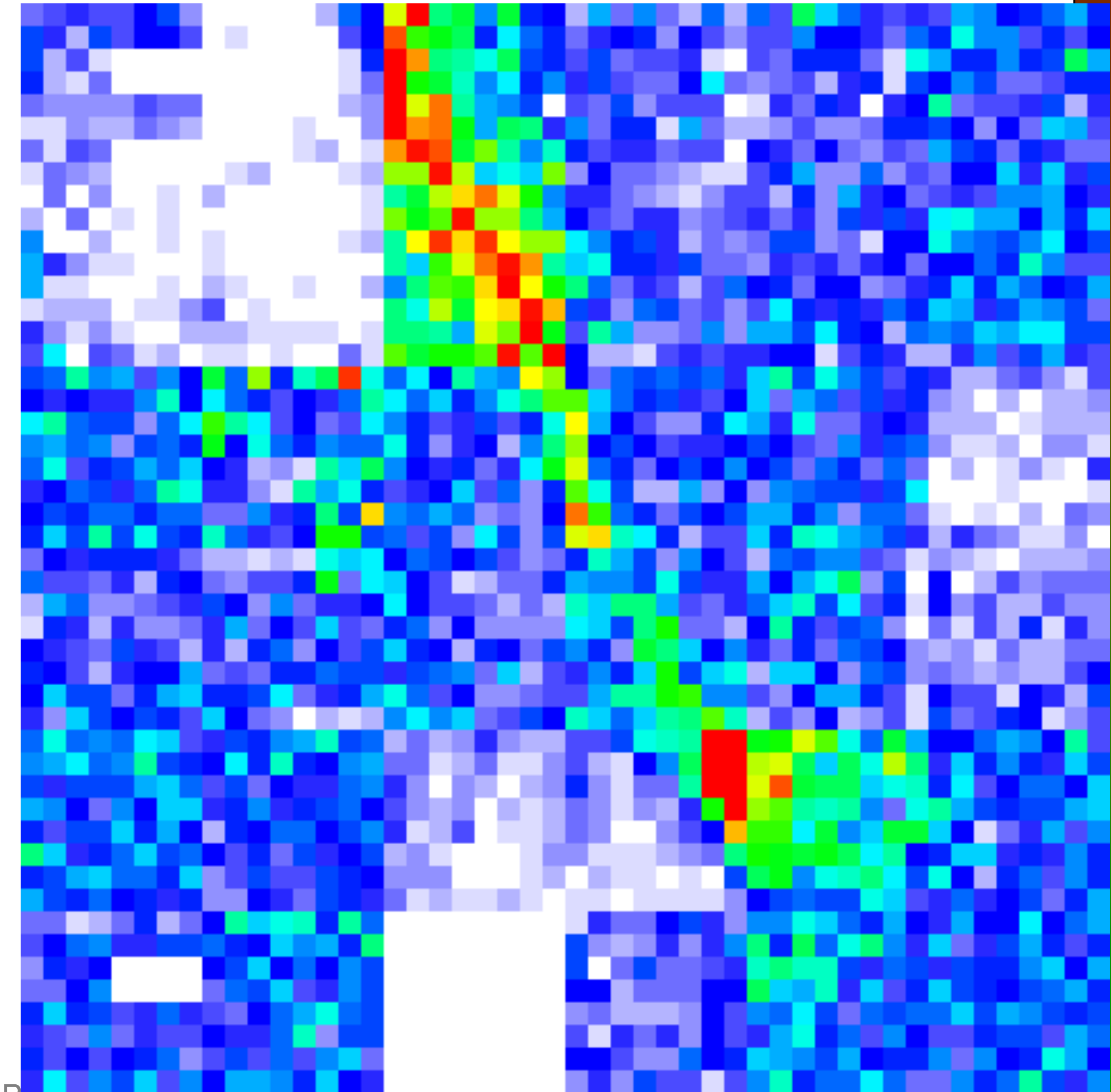
CNES Flight Chain



Laser track

Event profile





Other instruments onboard

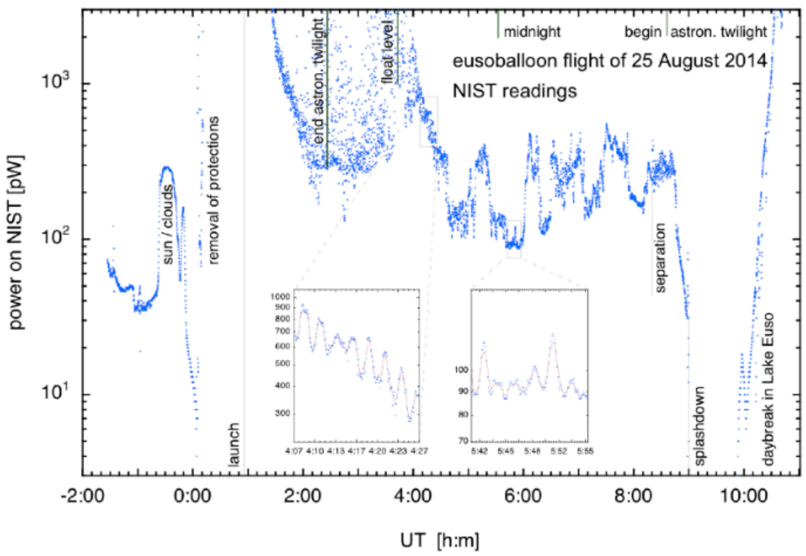
- Infrared Camera (IR Camera)
- NIST photodiode
- Gerger counter
- GPS
- Attitude sensor
- GoPro camera

Independent of data acquisition systems

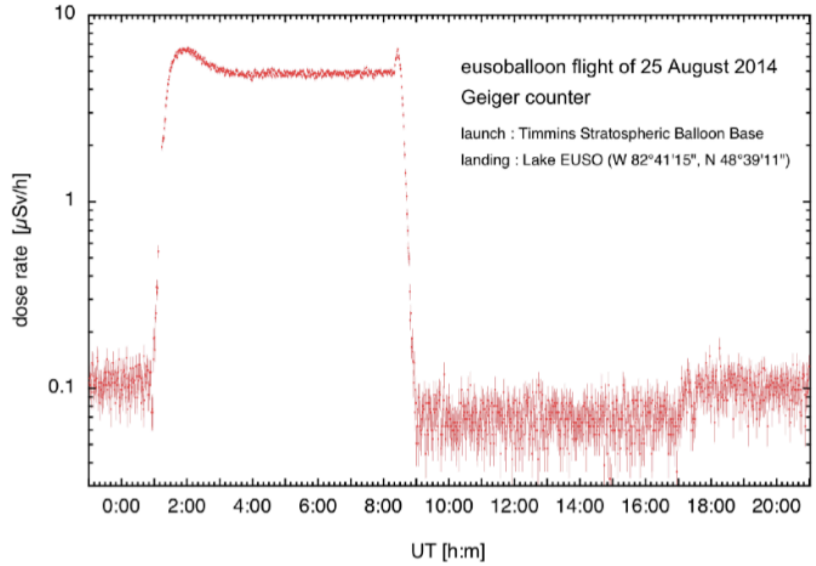
Offline synchronization (UTC time stamps)

Complementary and/or anecdotal data

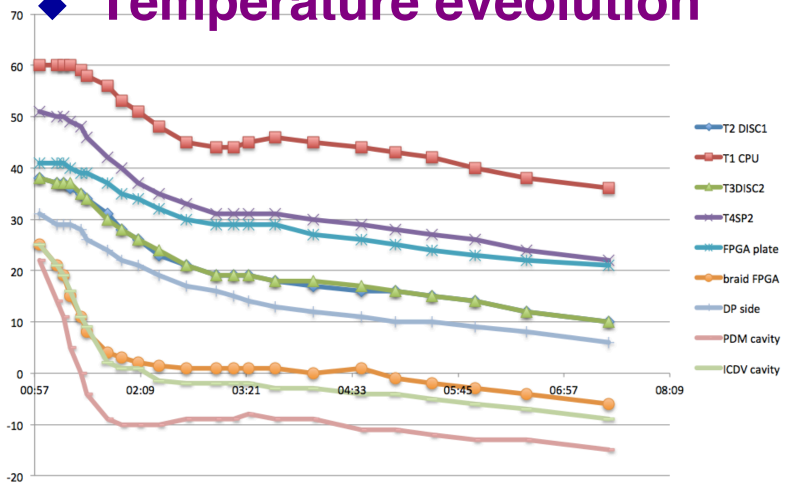
- **Light intensity (NIST)**



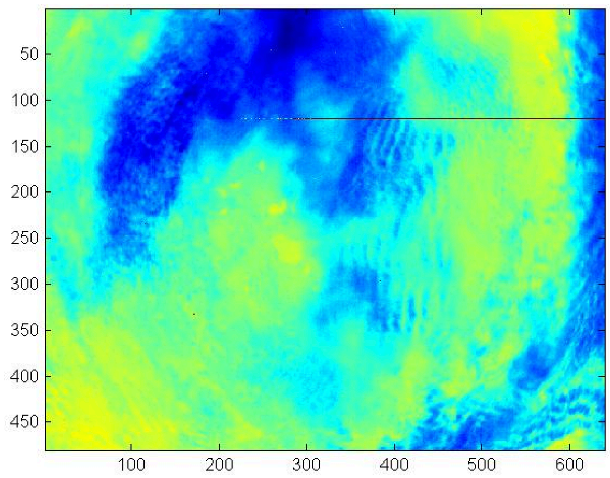
- **Cosmic ray intensity (Geiger)**



- **Temperature eveolution**



- **Infrared data**



Back up – IV – Space debris removal strategy

Quinn et al. (2014): Acta Astronautica 105, 192-200

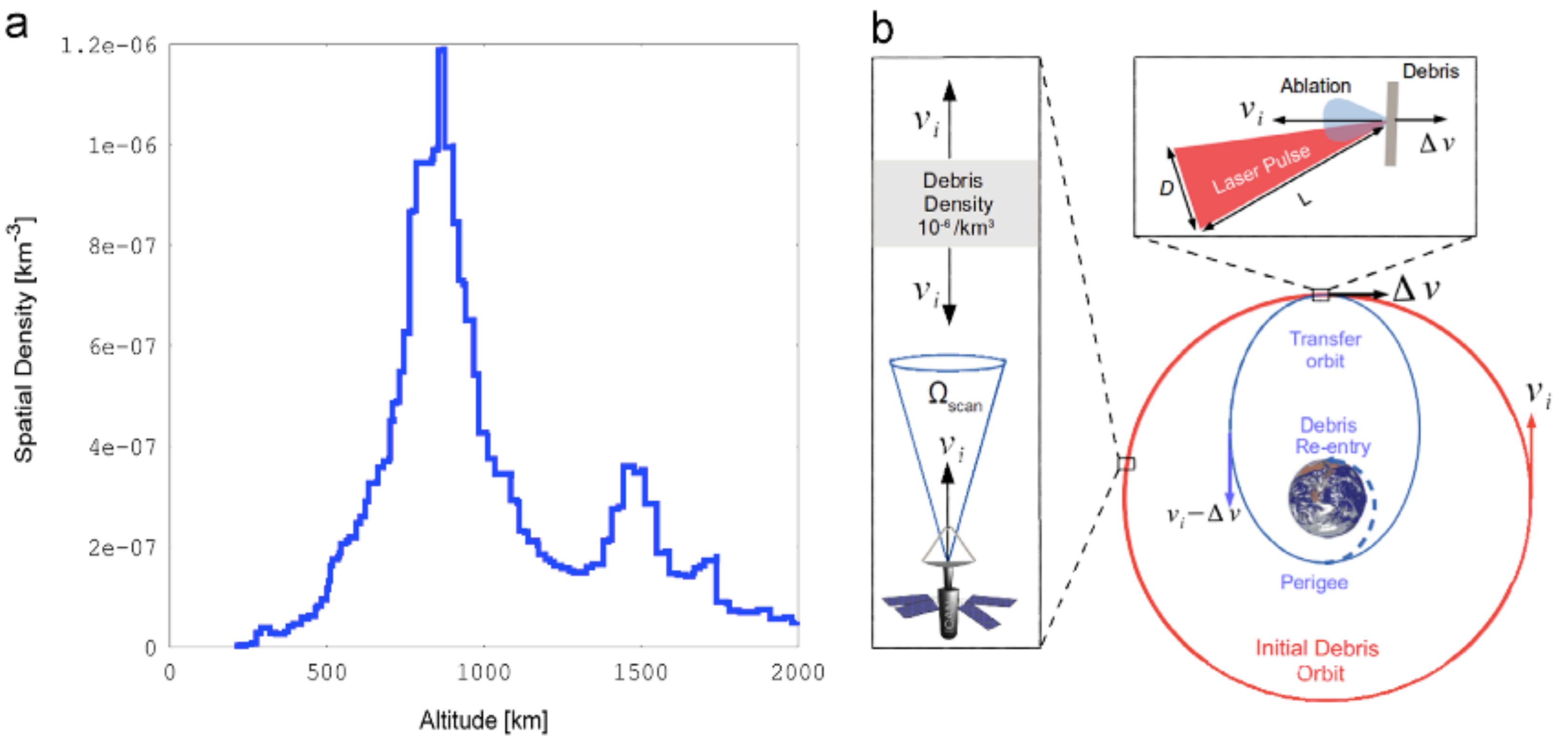


Fig. 1. (a) The predicted distribution of debris in low-Earth orbit for 1–10 cm debris according to MASTER-2009 [9]. The peak near 800 km is in large part the debris remaining from the Iridium, Cosmos and Fenhyun-1c satellites. (b) A schematic of the orbital adjustment required to re-entry debris. Here a laser pulse induces a recoil by surface ablation. This modifies the debris velocity from a circular to elliptical orbit with a perigee near 100 km altitude where rapid re-entry occurs.

Quinn et al. (2014): Acta Astronautica 105, 192-200

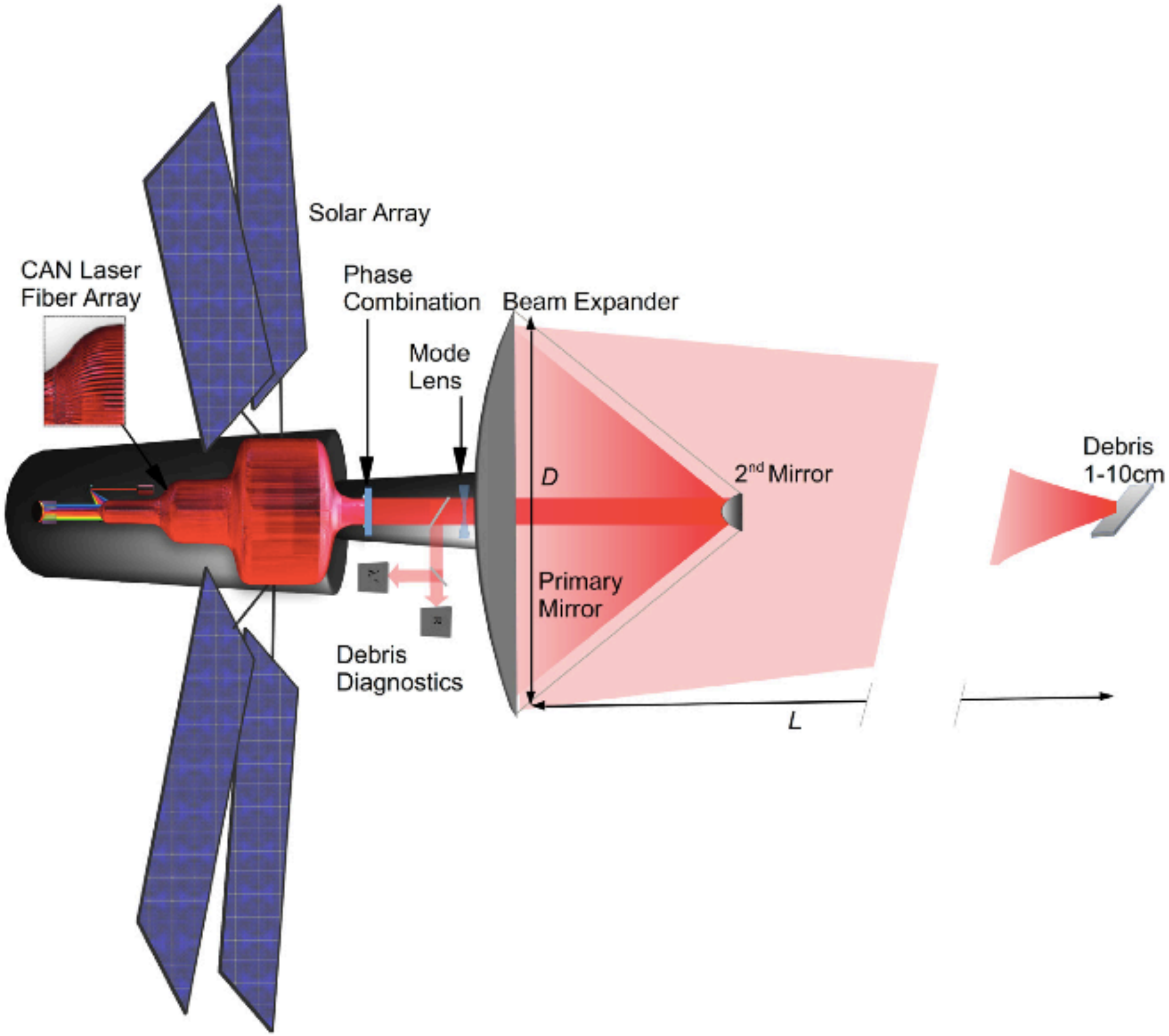


Fig. 3. The ICAN concept for orbital debris removal. Powered by the solar array, the amplified beam from the combined array of fibers is expanded via the telescope to aperture *D* which enables focusing to large distances, $L \gtrsim 100$ km, while the phase array controls wavefront and hence the focal distance of the beam. Reflected light from the debris is also collected by the telescope and enables precise diagnostics for its size and velocity.

Quinn et al. (2014): Acta Astronautica 105, 192-200

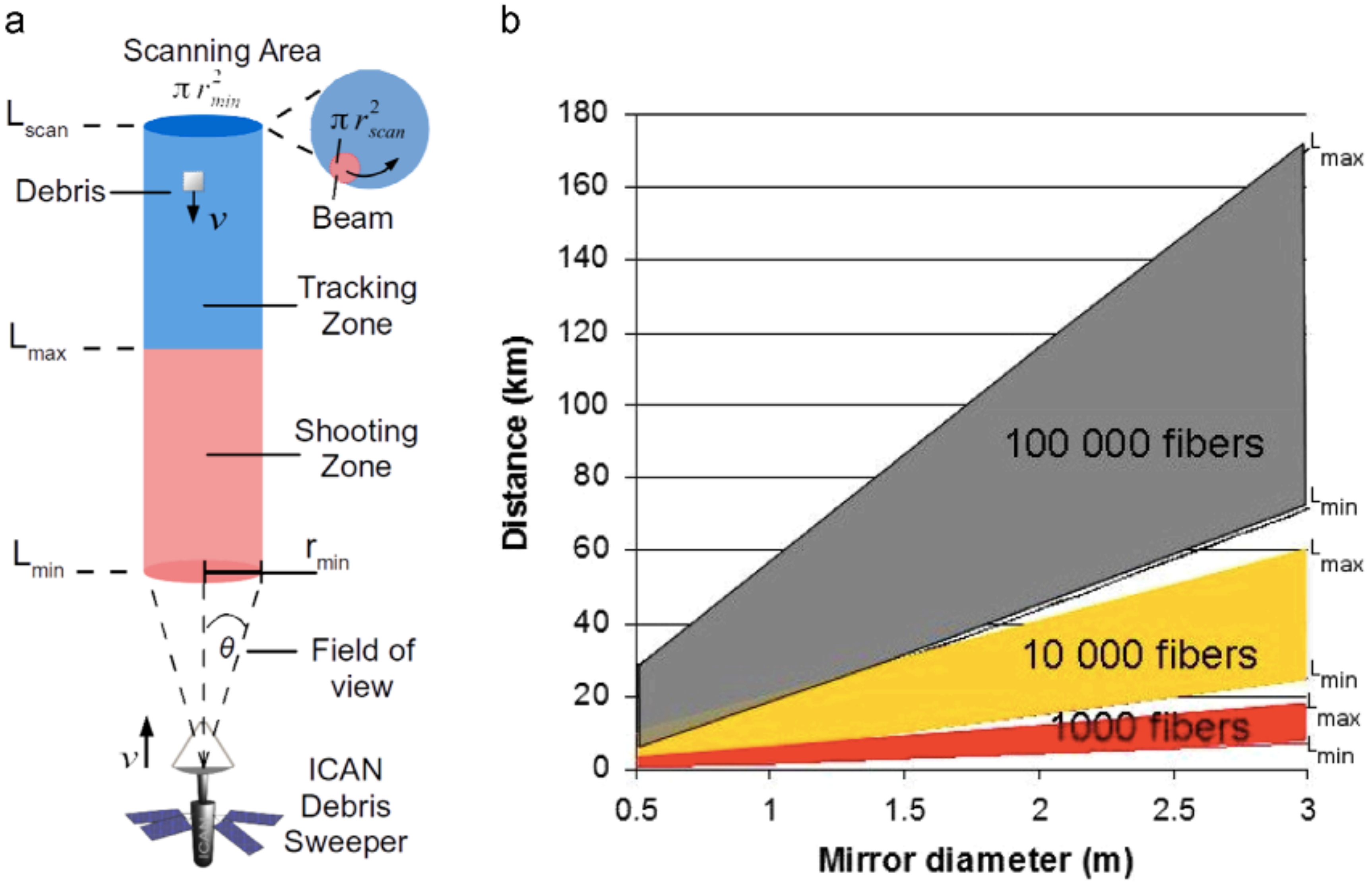


Fig. 4. (a) An operational schematic for the ICAN debris sweeper. The field of view half-angle, θ and the limiting distances are shown indicating the zones for tracking, scanning and shooting. (b) The beam-expanding mirror diameter required as a function of distance L. The upper and lower limit for shooting distances, L_{max}, L_{min}, are shown for different fiber array sizes. A mirror diameter of 3 m is used in calculations in the text.