EBERHARD KARLS UNIVERSITÄT TÜBINGEN

MATHEMATISCH-NATURWISSENSCHAFTLICHE FAKULTÄT

Institut f. Astronomie u. Astrophysik

EUSO

"Doing astronomy by looking downward"

Searching for UHE particles from space: The EUSO Program

A. Santangelo*

** Global Coordinator of the JEM-EUSO Collaboration*

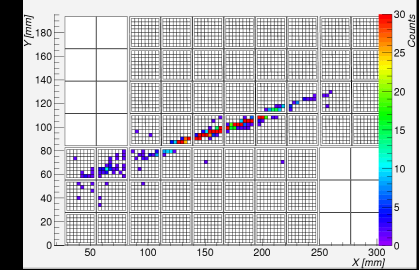
Speaker: F. Fenu
Università degli studi di Torino - INFN Torino

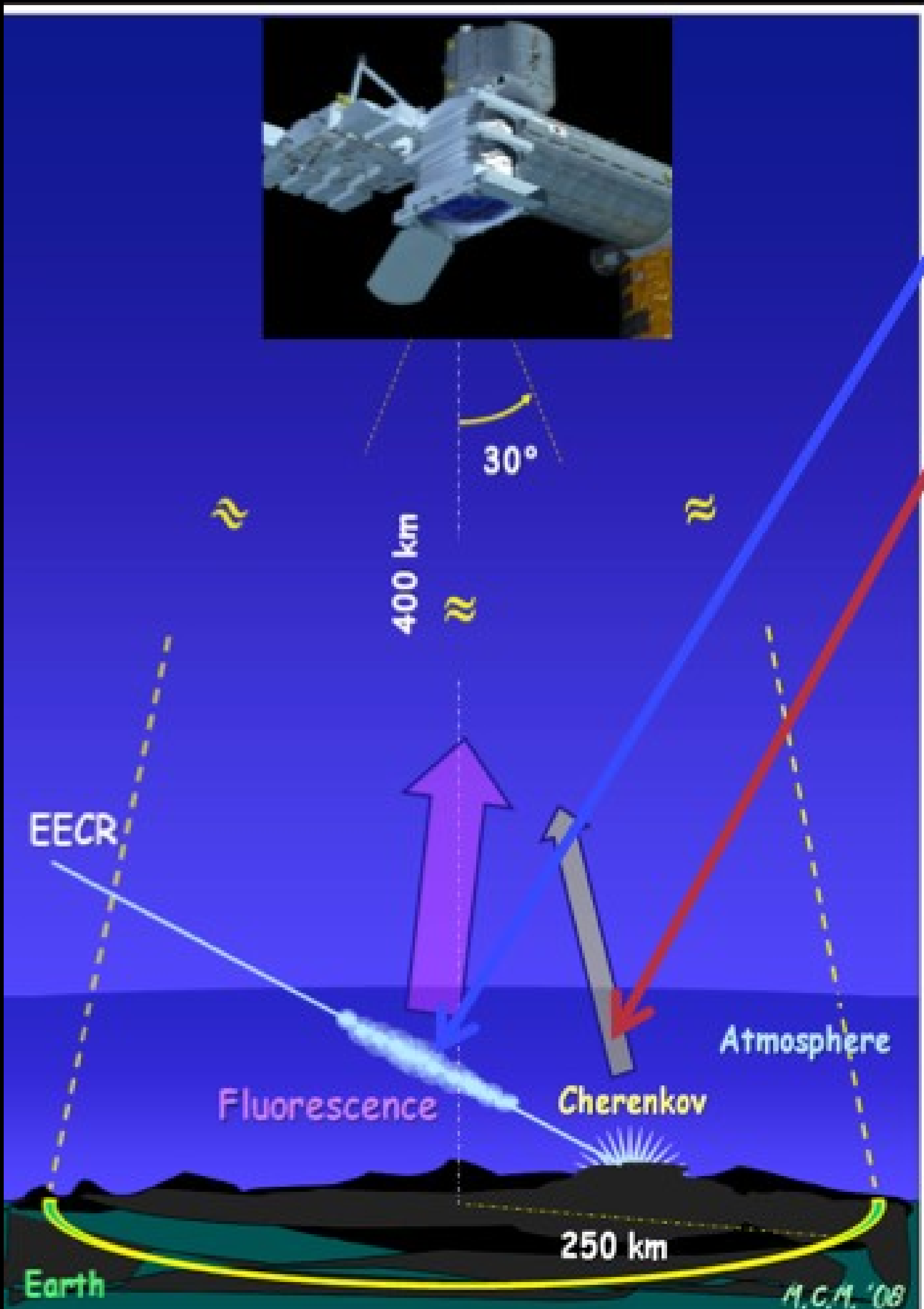
EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Part I

The EUSO concept: exploring the UHE Universe from space

Fluorescence from SPACE



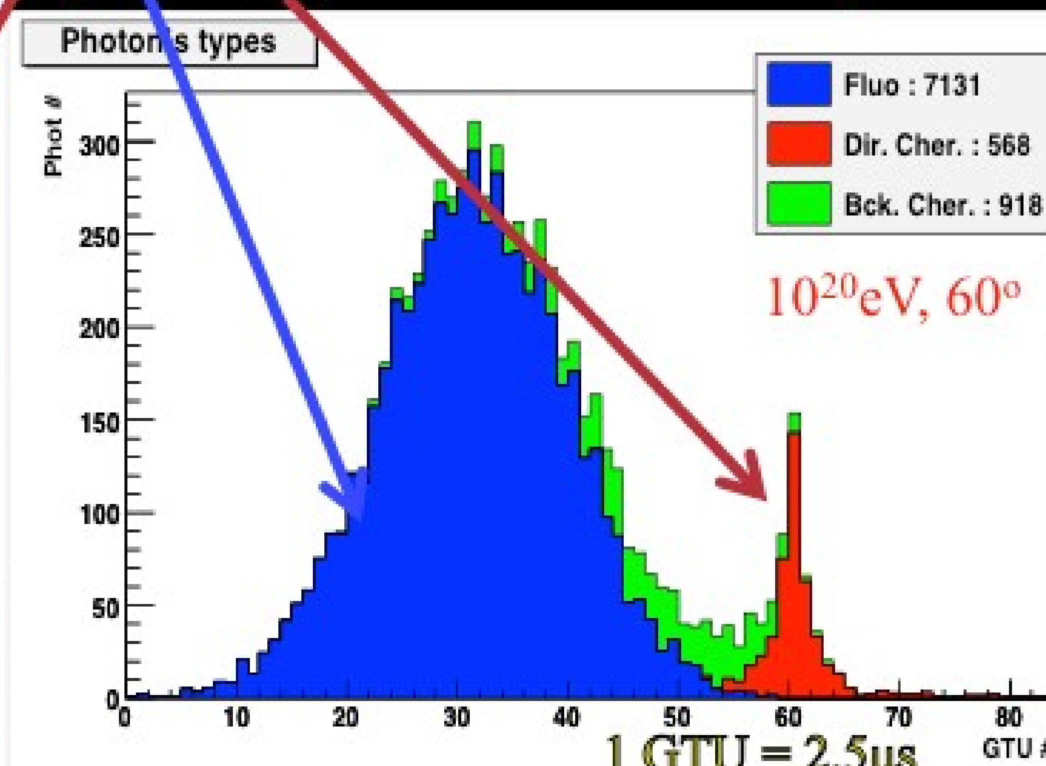


Fast Signal: 50 -150 μs

a) Fluorescence

b) Scattered Cherenkov

c) Direct (reflected Cherenkov)



Background: 500 /m^2 sr ns

EUSO Science case (1)

Astrophysics and Physics from $E>5.\times10^{19}$eV, focusing at $E \sim 10^{20}$ eV (and above!):

Main Science Objectives:

- Explore the sky at the highest energies ever, with unprecedented exposure and uniform coverage → *go above $2x10^{20}$ eV!*

- Perform key anisotropy studies with UHECRs, and study the evolution of anisotropies with energy→ *flux, cut-off, angular size…*

- Identify sources in the sky and study their spectra

- Constrain the composition of the UHECRs at the highest energies→*messengers discrimination, ln<A>*

EUSO Science (2)

Exploratory objectives:

- discovery of UHE neutrinos (or set limits on their flux)
- discovery of UHE Gamma-rays (or set limits on their flux)
- study of the galactic and local extragalactic magnetic field

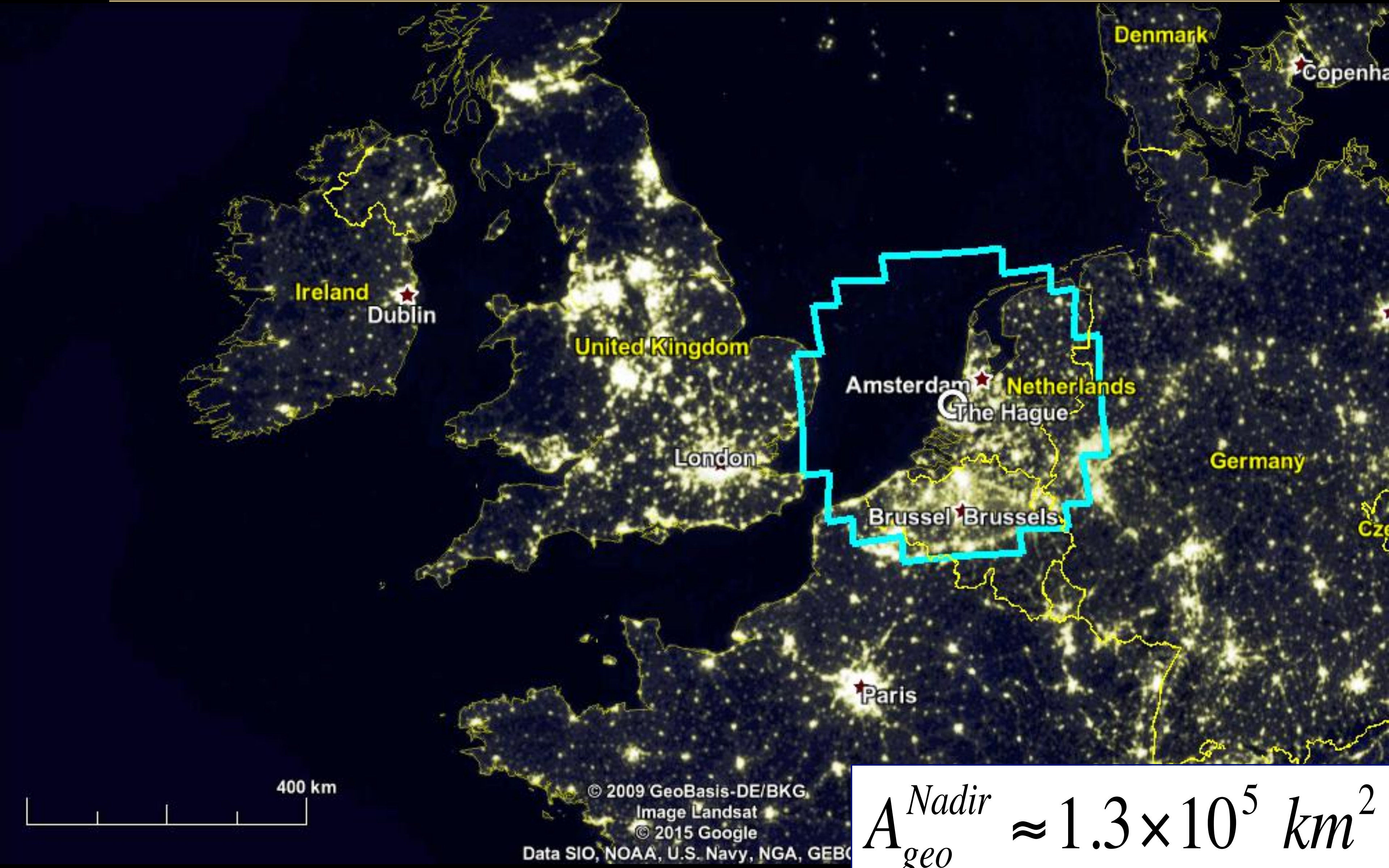
- Stringent limits on “Top-Down” mechanisms, on neutrino cross sections, on strangelets

- **Atmospheric Science and more**

  - Nightglow
  - the transient luminous events (TLEs)
  - meteors and meteoroids
  - Debris studies

Two advantages: 1. Monitored Area

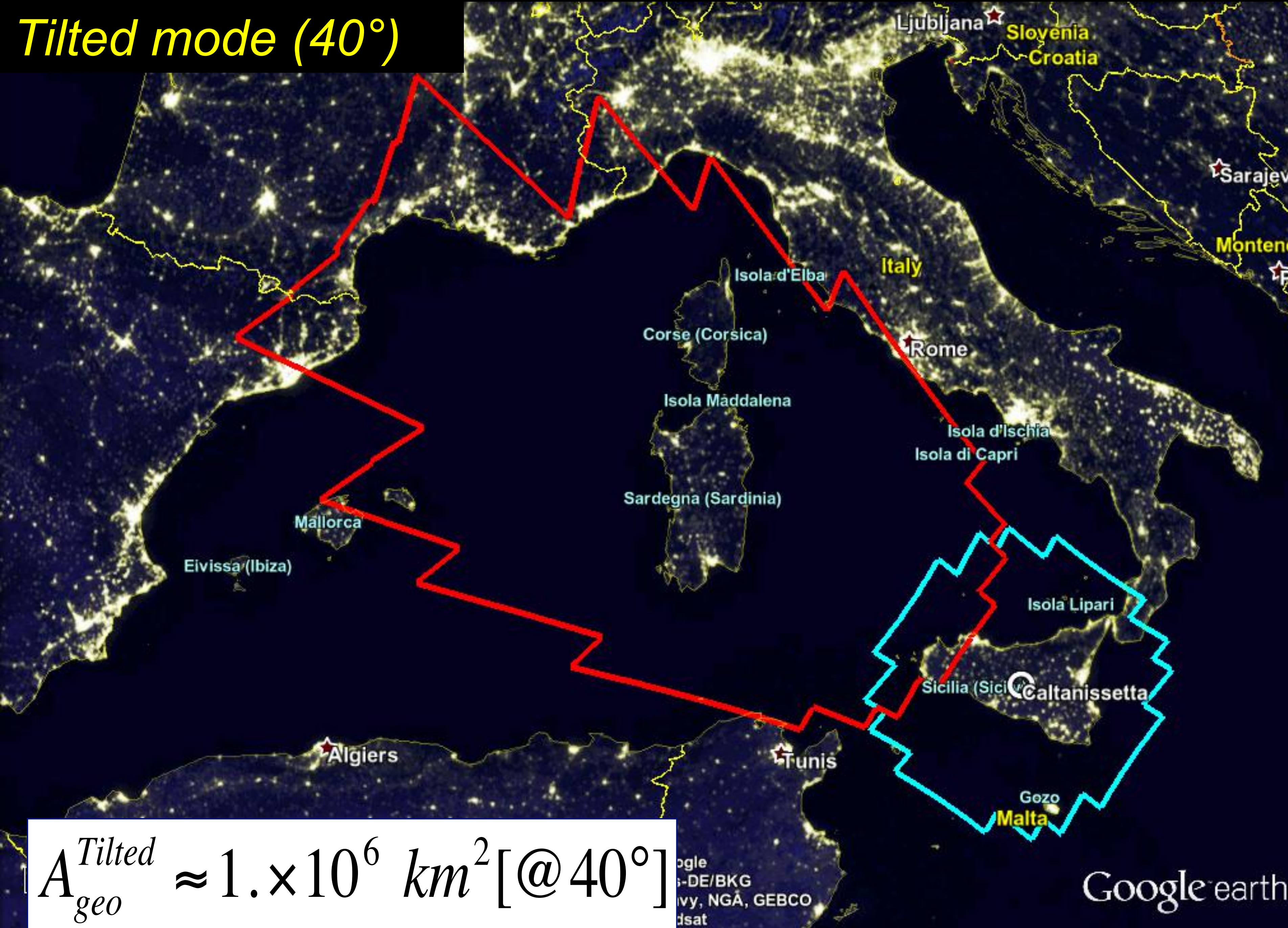
$\approx few \times 10^{12}\ tons$



$$A_{geo}^{Nadir} \approx 1.3 \times 10^5\ km^2$$

Adams et al. , Astr. Part. Phys. 2013

Tilted mode (40°)

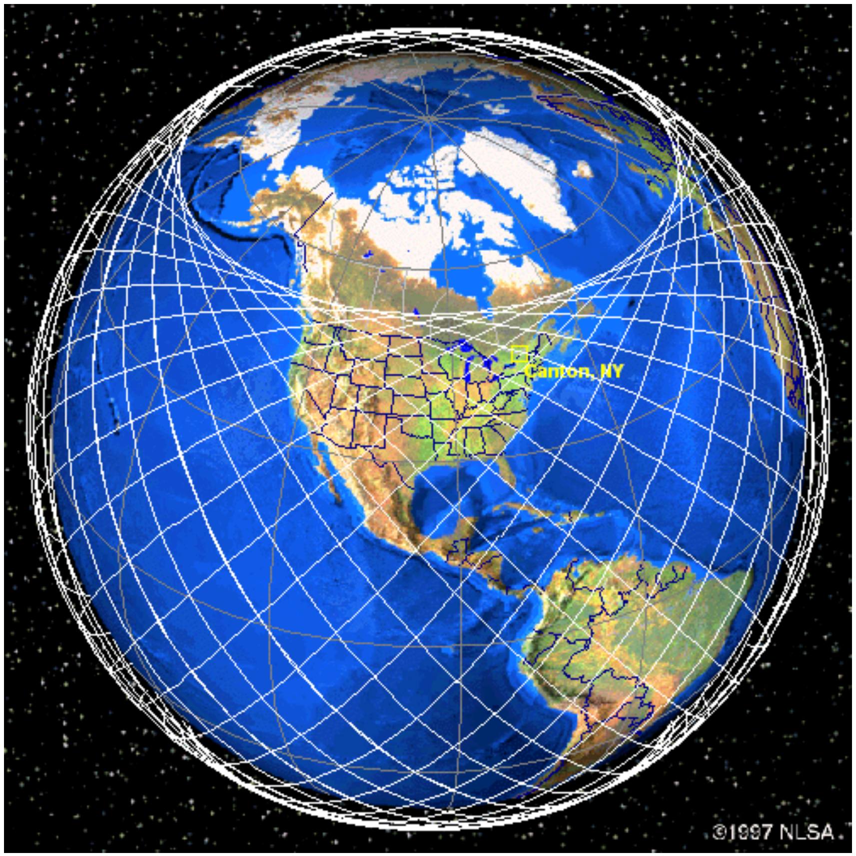


$$A_{geo}^{Tilted} \approx 1.\times 10^{6}\ km^{2}[@40°]$$

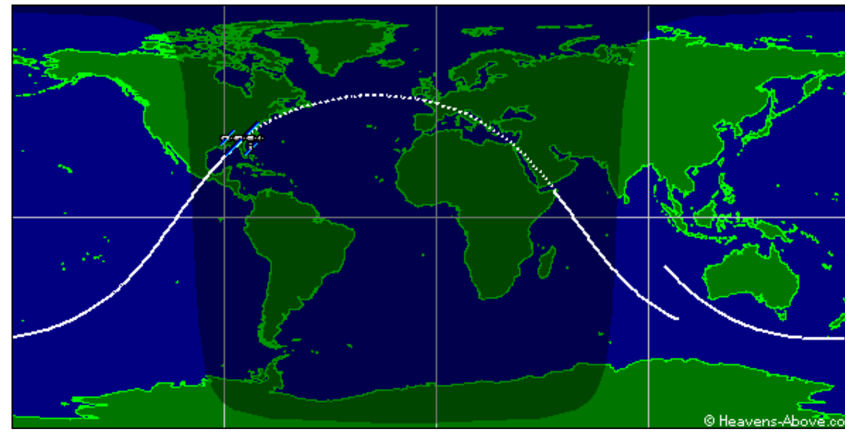
EBERHARD KARLS UNIVERSITÄT TÜBINGEN

2. ISS Orbit→ Full sky Coverage…

4π coverage



http://www.nlsa.com/



Inclination: 51.6°
Height: ~400km

JEM-EUSO can observe the arrival direction of EECR very uniformly owing to the nature of the ISS orbit.

EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

Part II

The near term JEM-EUSO, or better EUSO-program:

From paperwork to the real signal, the technique and technological pathfinders

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

The JEM-EUSO program (1)

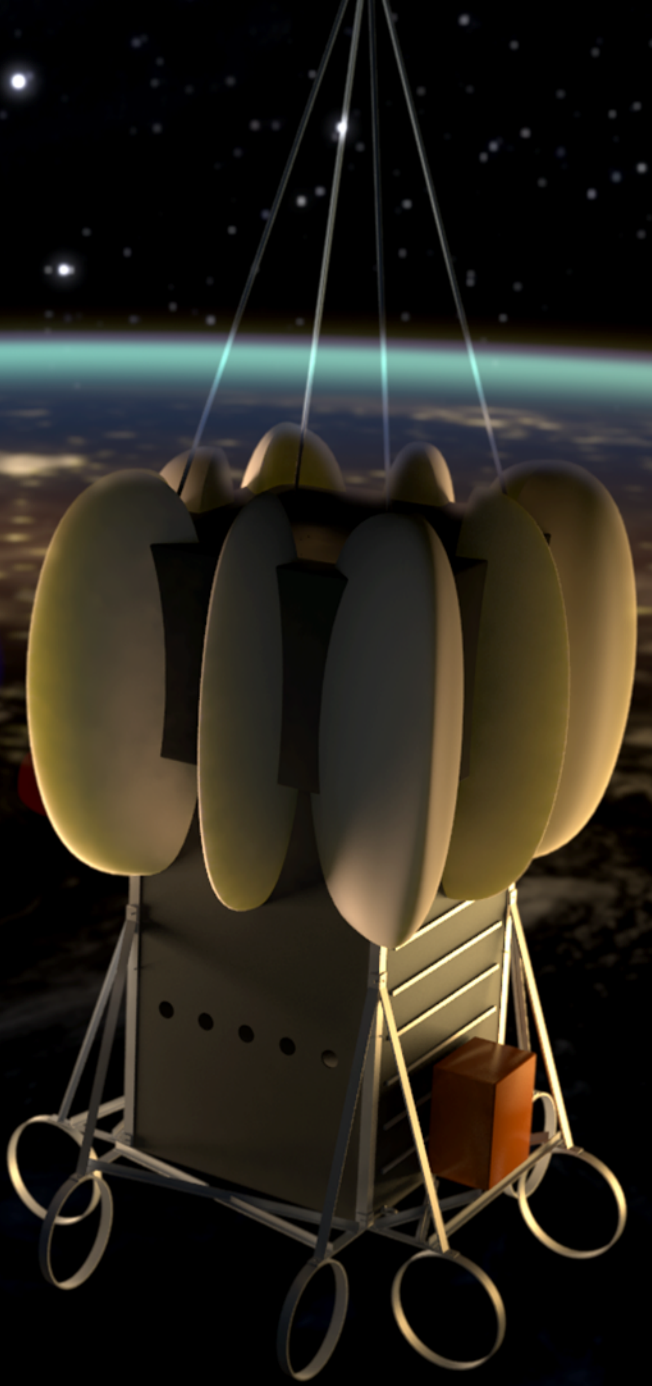
- **Near Term (or in operation): a series of scientific-technological steps →**
  1) *optimize our understanding of the observational technique, and*
  2) *develop engineering models that could later reduce the mission development schedule*

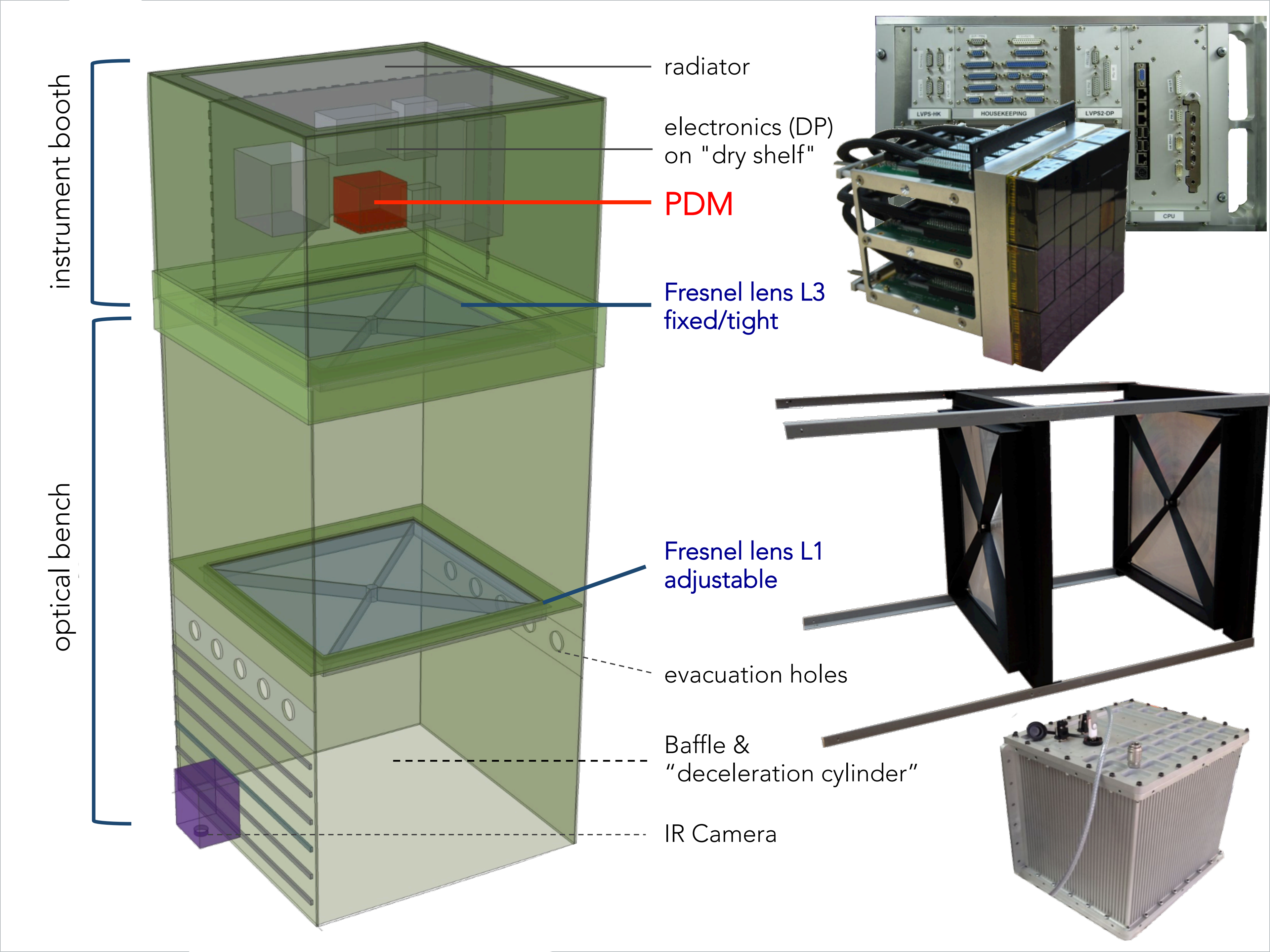
  - **EUSO Balloons** (First flight completed, New flights In preparation)
  - **MINI-EUSO** (on the ISS, approved by ROSCOSMOS and ASI)
  - **EUSO-TA** (On-ground, operating)
  - **TUS** (In space, operating)


EUSO-Balloon

EUSO-Balloon

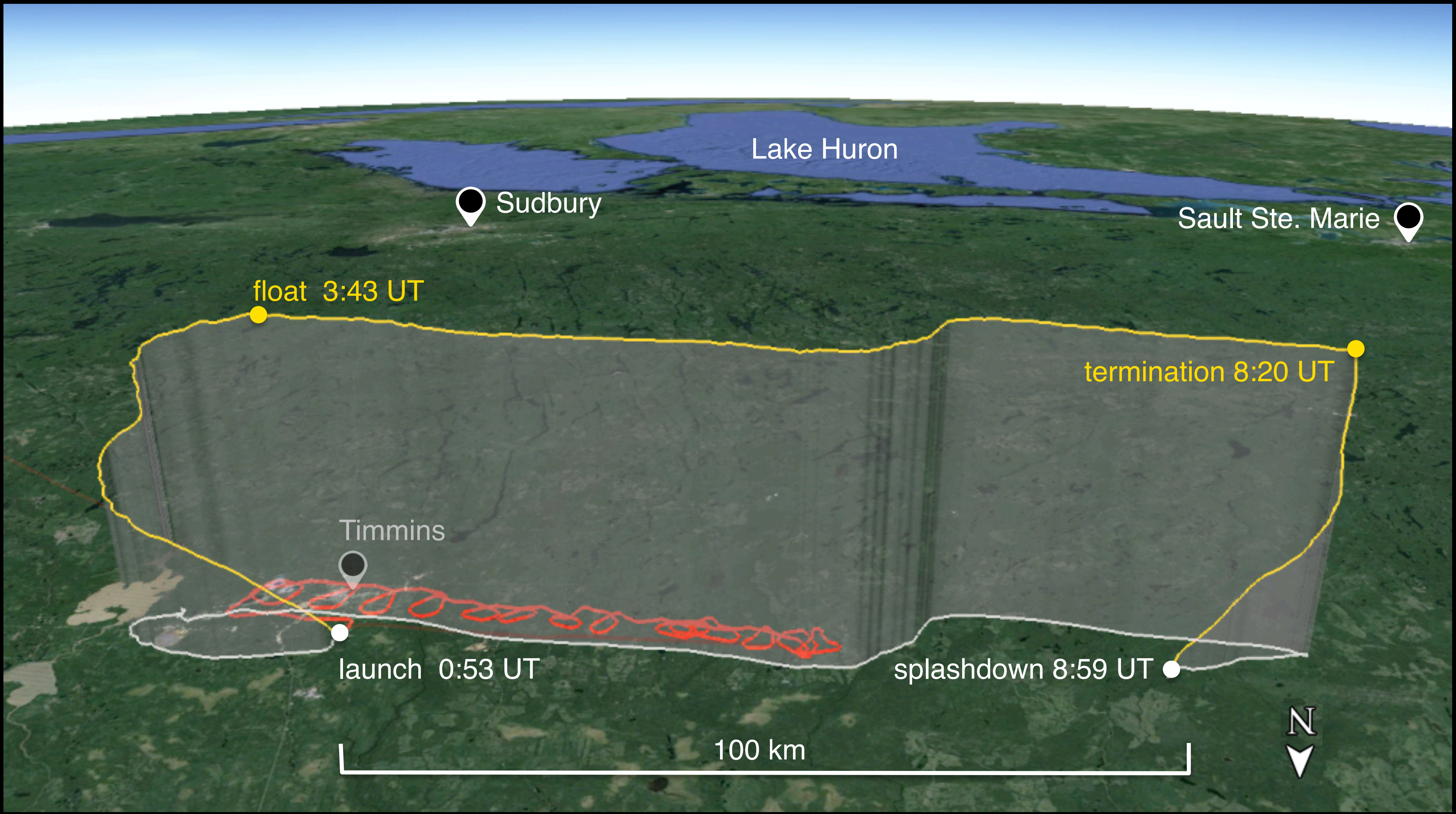
- Test the key technologies and techniques for EUSO
- Test the EUSO EM
- Measure the background UV levels
- Search for background events that mimic air showers
- Detect the fluorescent signals of air showers from near space for the first time





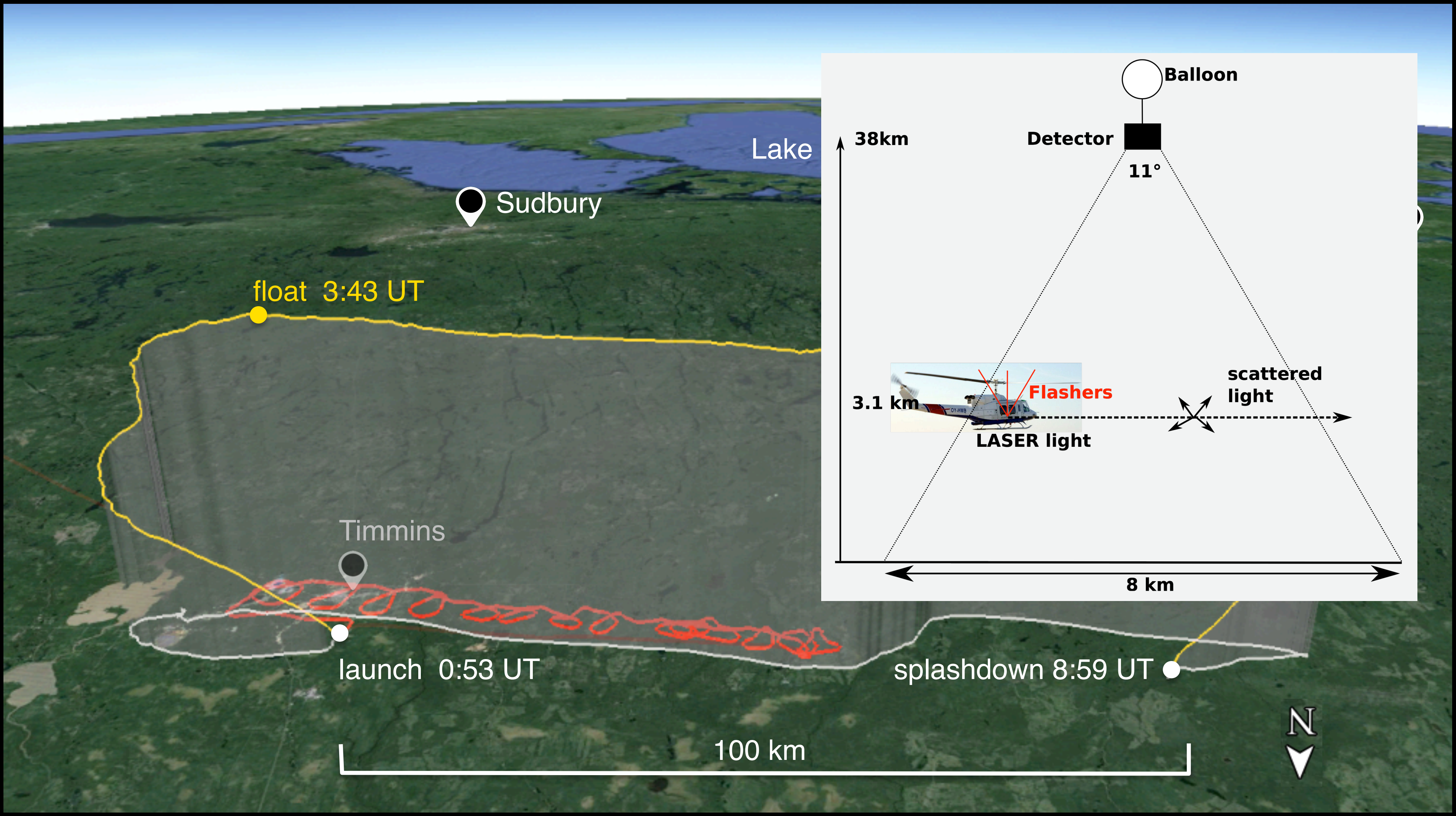
instrument booth
optical bench
radiator
electronics (DP)
on "dry shelf"
PDM
Fresnel lens L3
fixed/tight
Fresnel lens L1
adjustable
evacuation holes
Baffle &
“deceleration cylinder”
IR Camera
LVPS-HK
HOUSEKEEPING
LVPS2-DP
CPU

EUSO Balloon first flight (led by CNES)



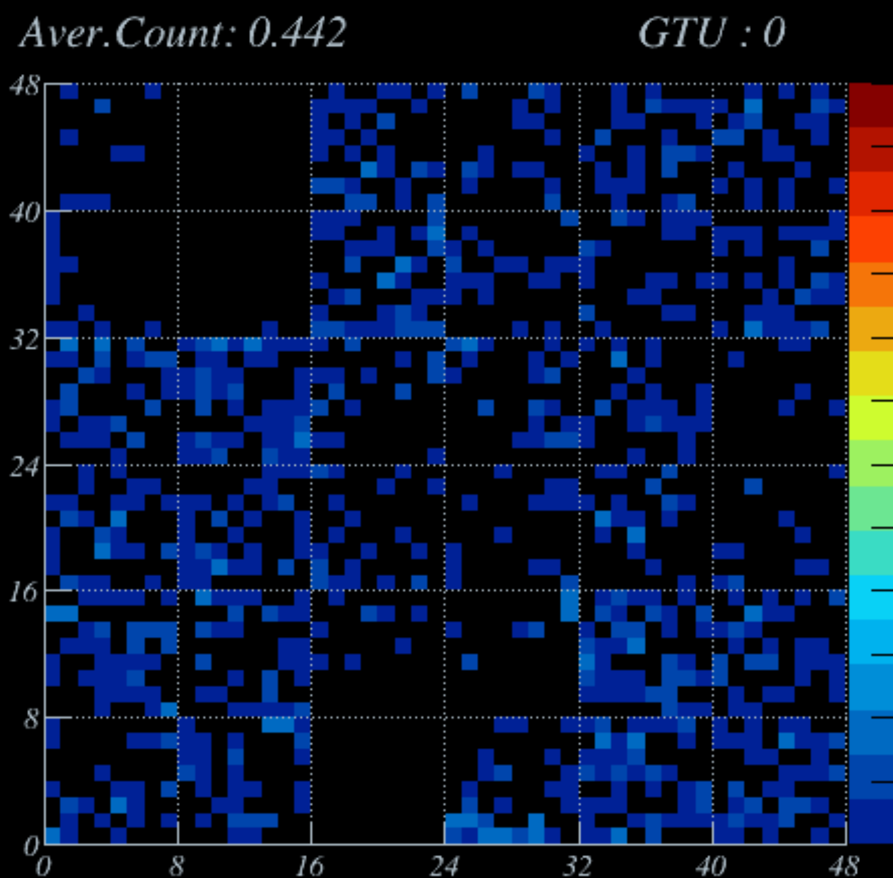
EUSO-Balloon: was *launched on August, 24 2014 from Timmins, (Canada)*

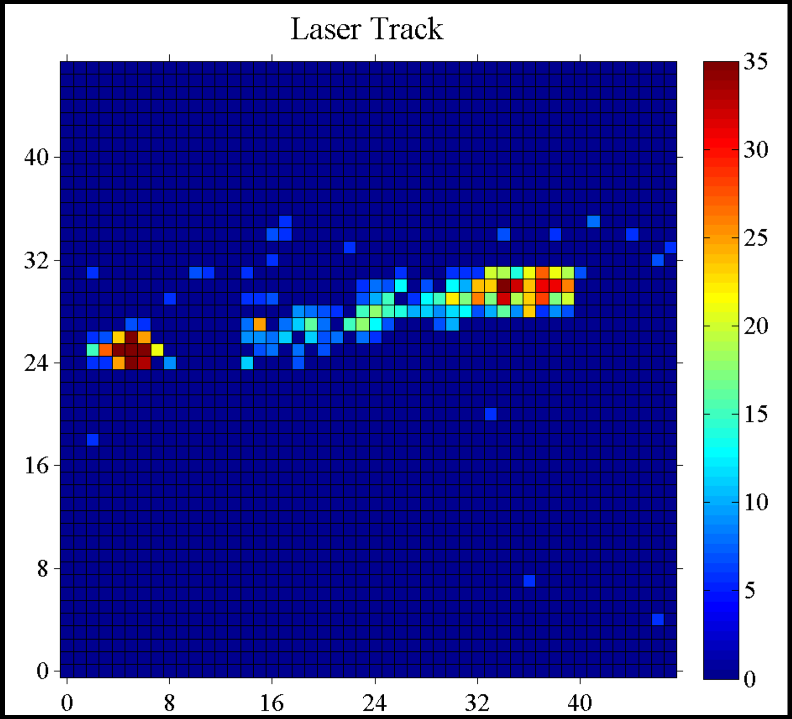
EUSO Balloon first flight



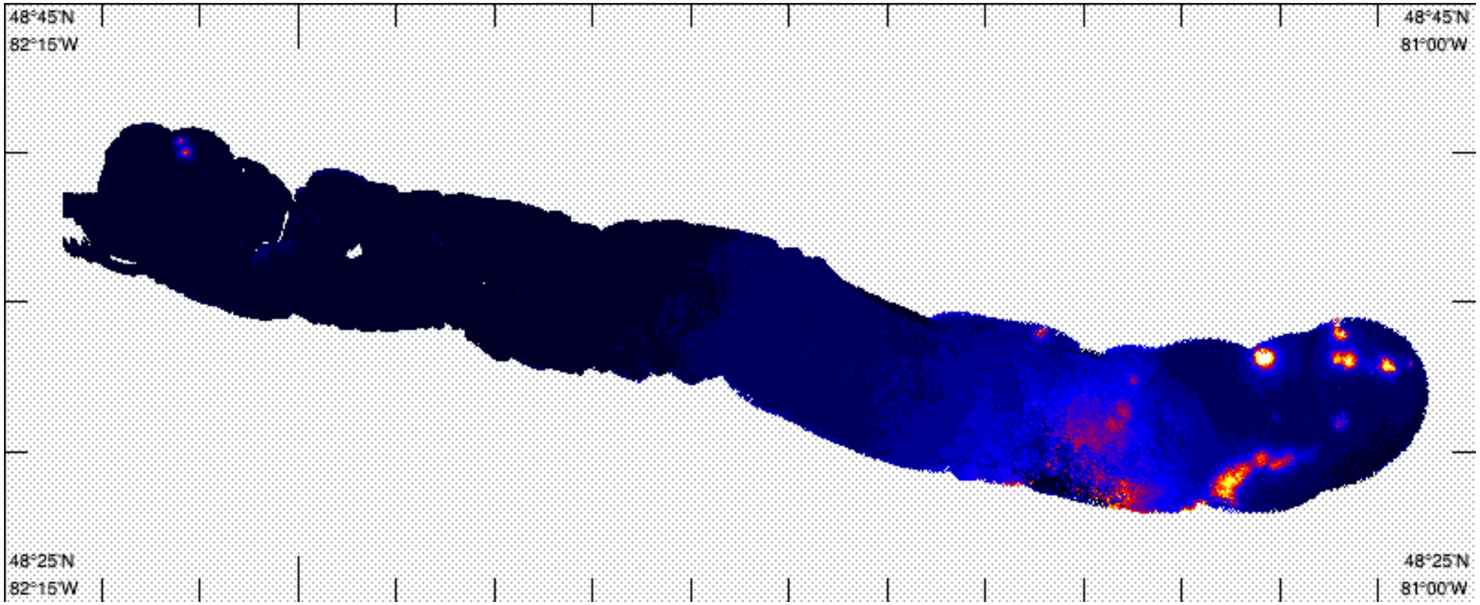
EUSO-Balloon: was *launched on August, 24 2014 from Timmins, (Canada)*

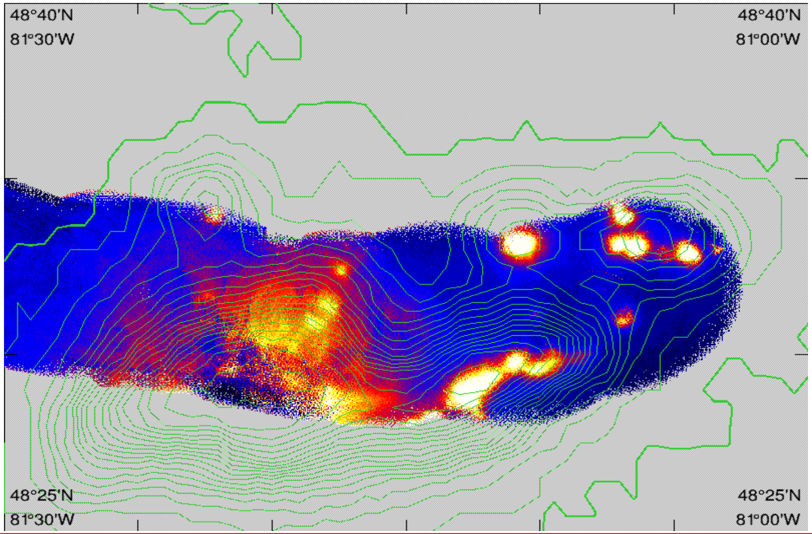
A typical detection





Mapping of the UV-nightglow intensity





Position of man-made lights matches lights observed by DMSP satellites

SPB Flight under NASA leadership *(2017)*

Super Pressure Balloon (SPB) Ultra Long Duration flight

First observations of UHECRs from near space: 20 nights

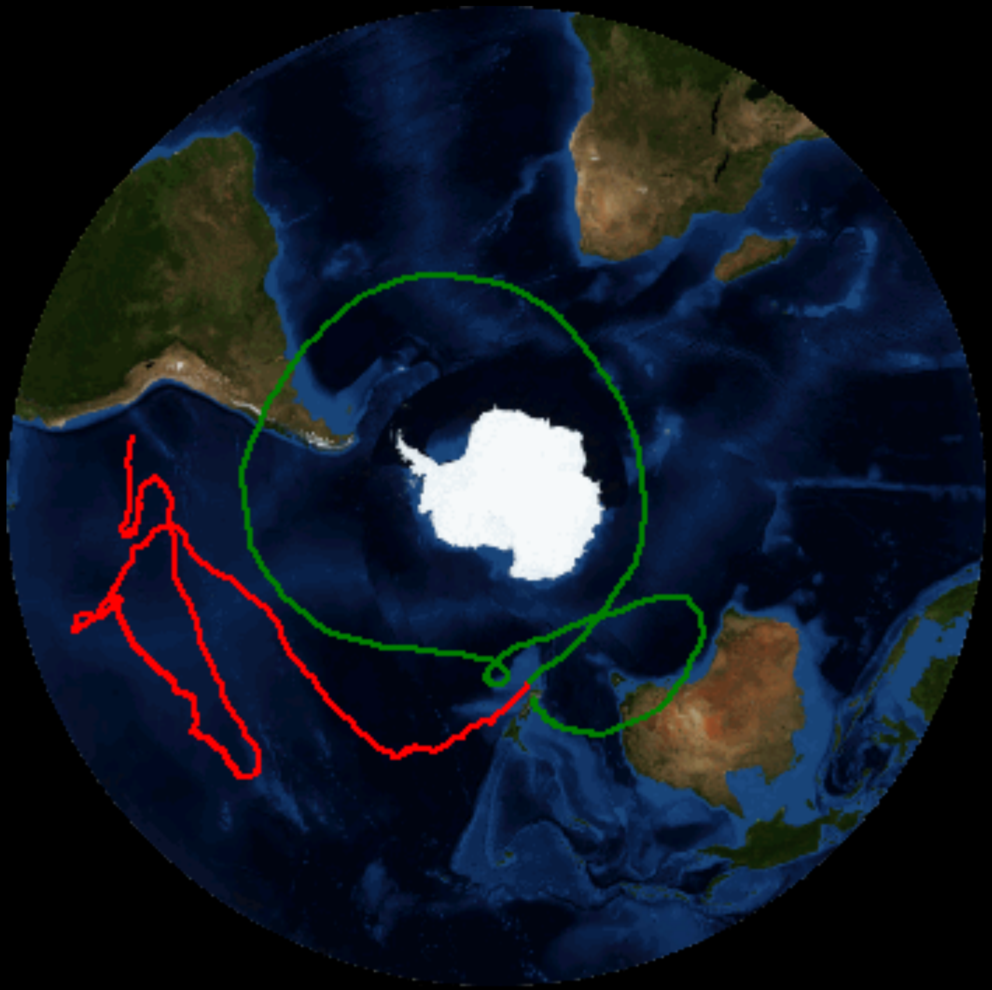
More than 10 events shall be observed

Columbia Scientific Balloon Facility
SPB 32 days, 5 hours, 51 minutes

$$A_{Exp.} \approx 10^3\, km^2 sr$$

Path of the successful 2015 flight by NASA, from Wanaka NZ

COSI SPB – Flight (a few weeks ago)



Test if different Background conditions: Ocean, Clouds, Twilight,

Transient atmospheric events

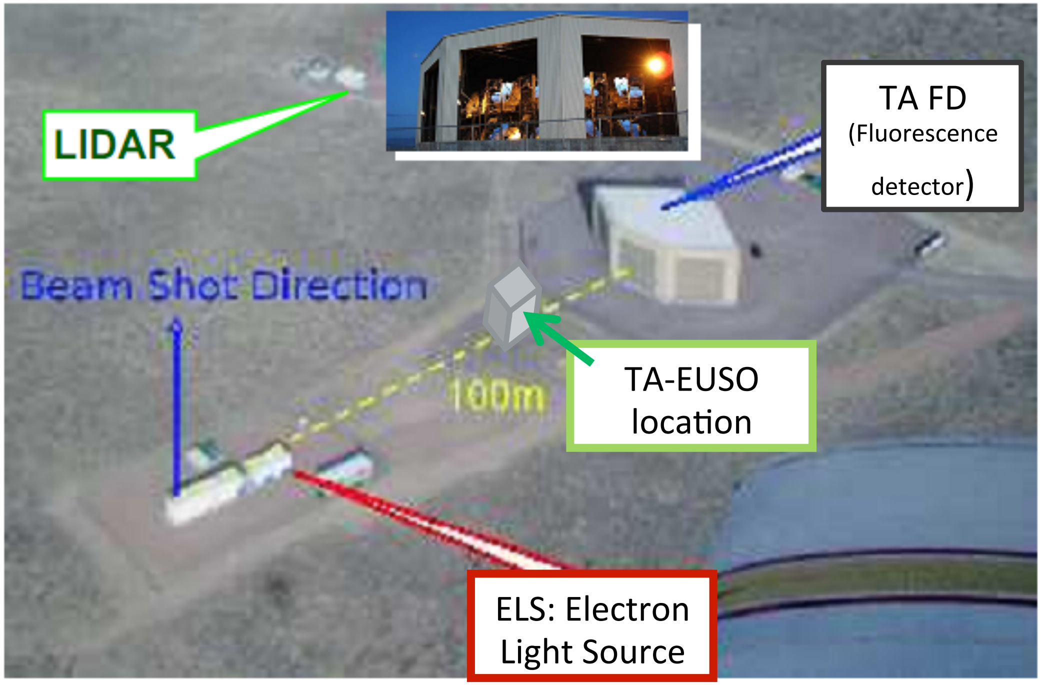

(C) Oscar Larsson

Pathfinders: EUSO-TA

TA site, UTAH, Black Mesa

EUSO-TA: *Cross-Calibration tests at the Telescope Array site* in Utah in collaboration with the ICRR in Tokyo and the TA collaboration

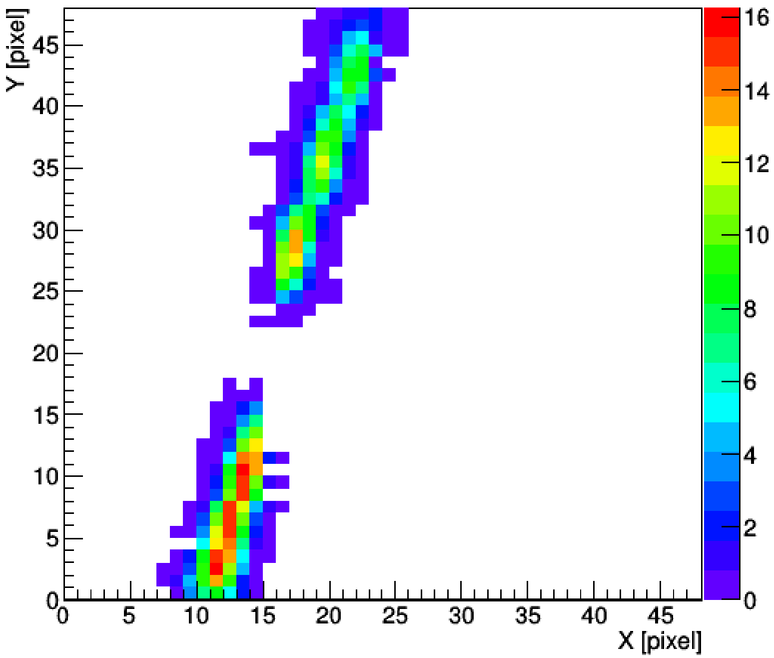
EUSO-TA is currently successfully operating taking a wealth of data



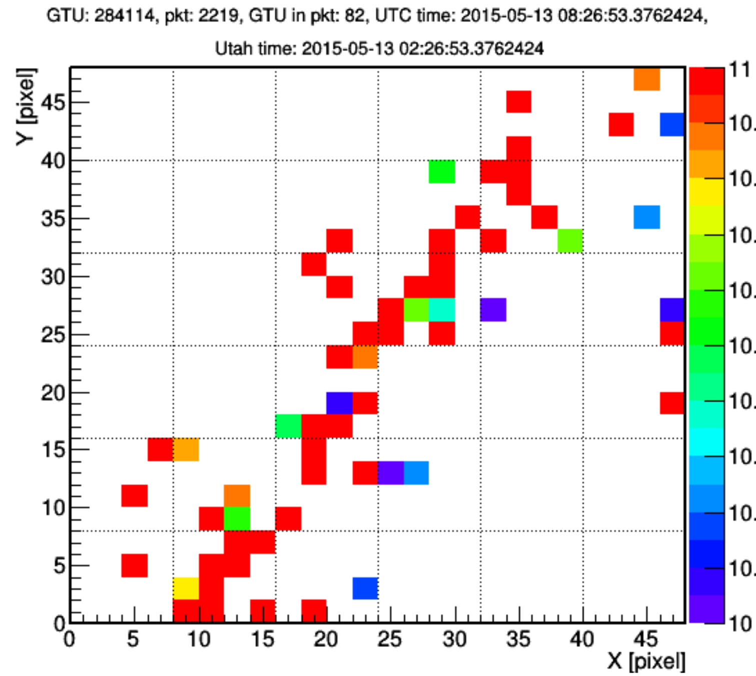
located at Black Rock Mesa FD Station

- *Electron Light Source at 100m*
- *Most nearby SD is at ~3.5 km*
- *Central Laser Facility ~21km*

EUSO-TA results

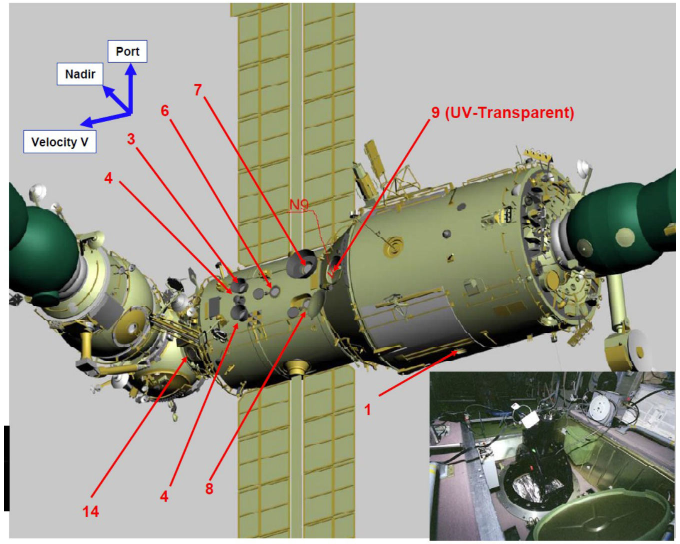


Average of ~ 150 inclined shots of the Colorado School of Mines laser, 40 km from EUSO-TA (≃ 62mJ). **Actually tracks are seen up to from 100 km!**



A real cosmic ray: An UHECR event of low **(~10^{18} eV) energy** traversing **at ~ 2.5 km distance from EUSO-TA** visible as a track on a single GTU.

Pathfinders: Mini-EUSO



It will be hosted in the **Zvezda Module of the ISS. UV transparent Nadir looking window.**

Based on a proposal approved by ASI- the Italian Space Agency

Mini-EUSO is included, with the name **UV Atmosphere,** into the Russian **"Stage program of scientific and applied research and experiments"**

Flight is scheduled in 2017

Science and technological objectives

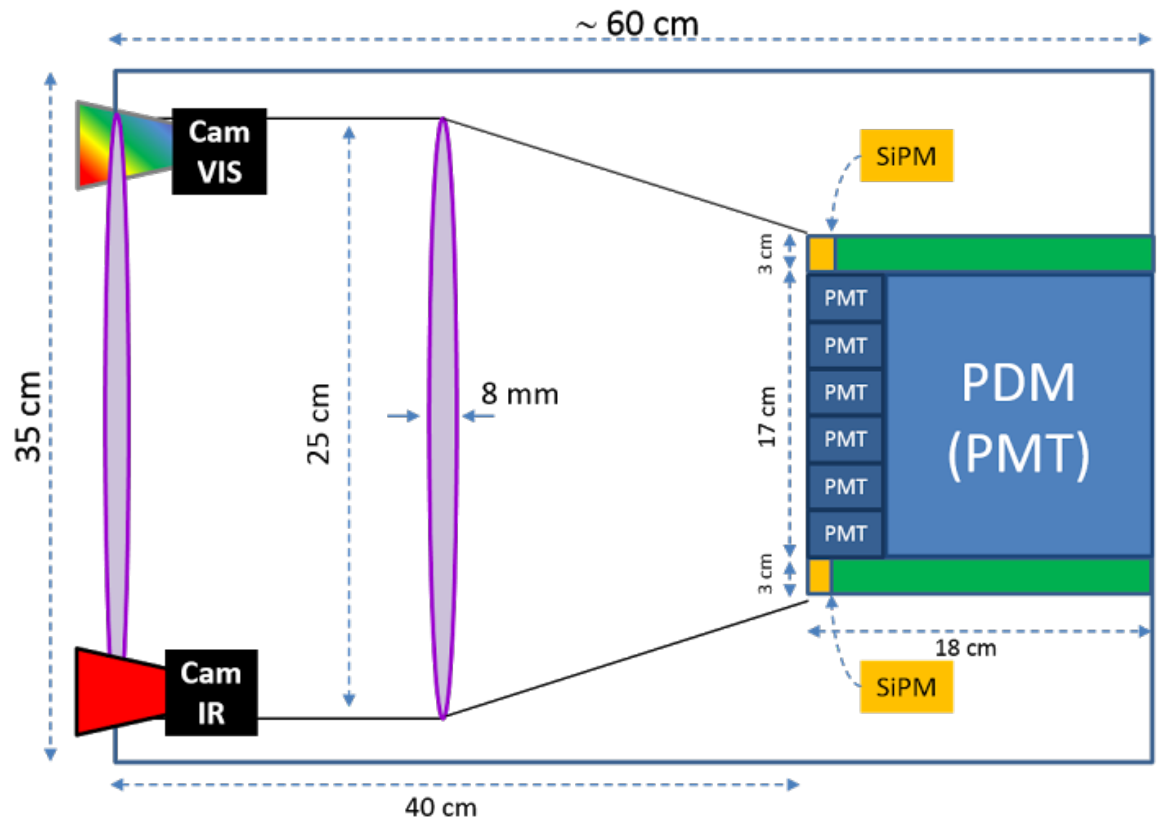
UV emissions from night-Earth

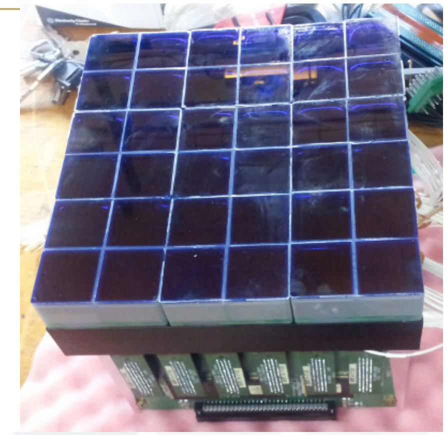
- Background from different lightning conditions, moon phases
- Background from different inclinations

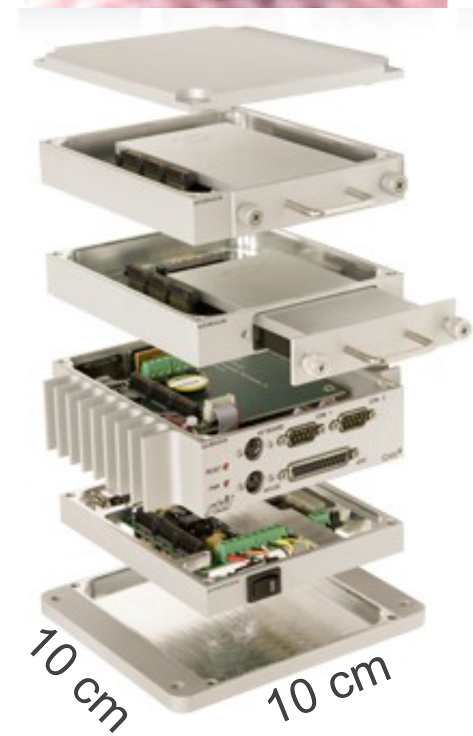
- *Map of the Earth in UV*
- ***Study of atmospheric phenomena***
- *Bioluminescence of Animal and vegetal*
- ***Study of meteors and Search for Strange quark matter***

Optimization of characteristics and performances of EUSO: obtain info on duty cycle, cloud coverage and UV background

Mini-EUSO (2)





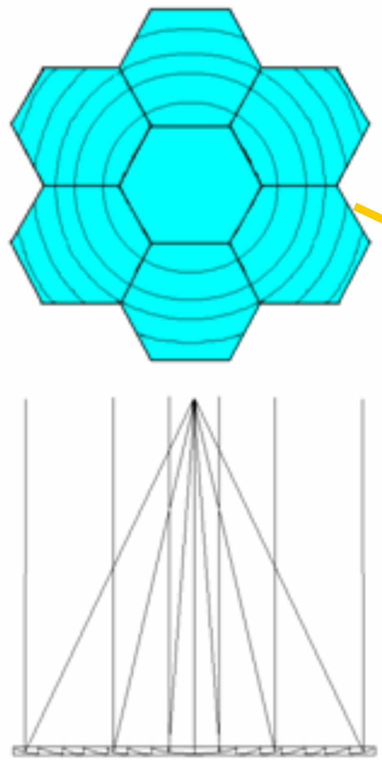


Mini-EUSO scheme: a refractive optics based on two Fresnel lenses images UV light on 1 PDM (36 MAPMTs). A SiPM module (italian ASTRI module) is an option.

Launch Summer 2017


КОСМОДРОМ
ВОСТОЧНЫЙ
ПОДНИМИ ГОЛОВУ!!

TUS detector on board Lomonosov satellite



Fresnel type mirror-concentrator

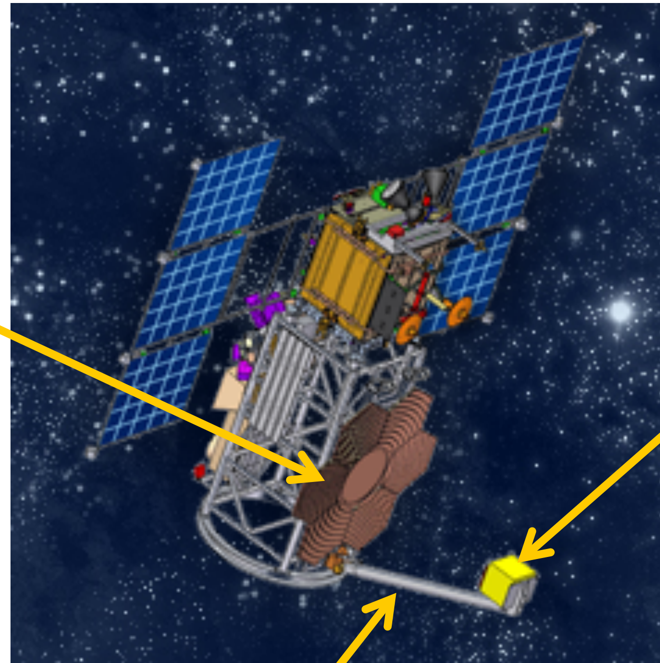
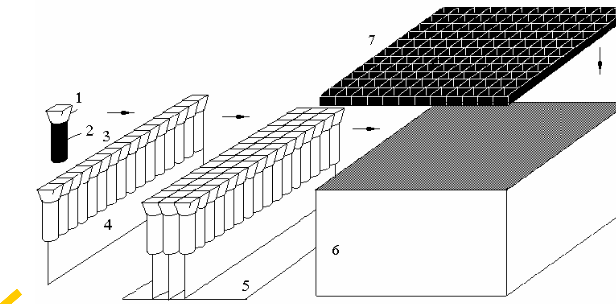
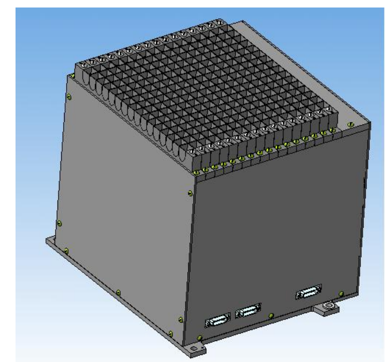


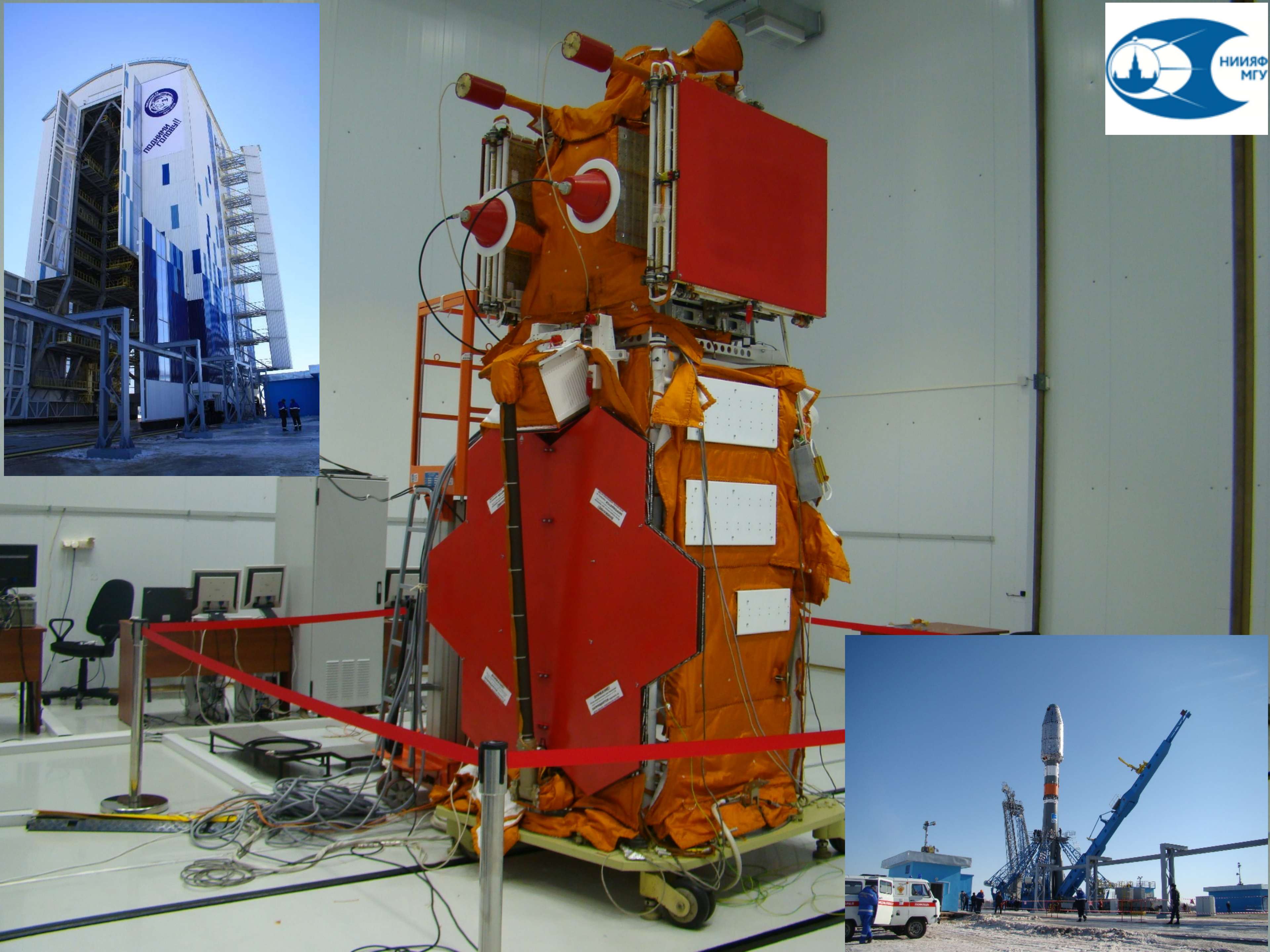
Photo receiver moving system

Photo receiver

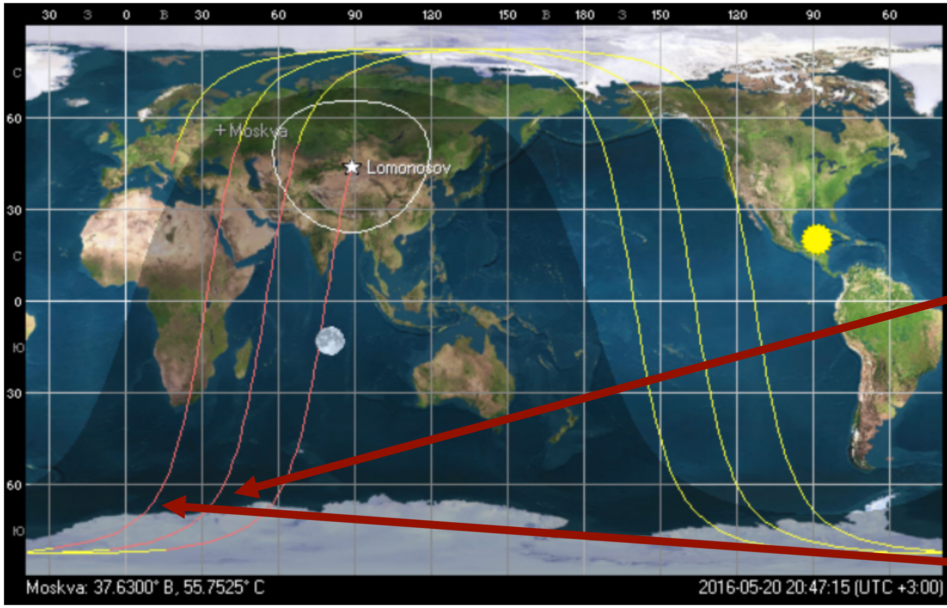


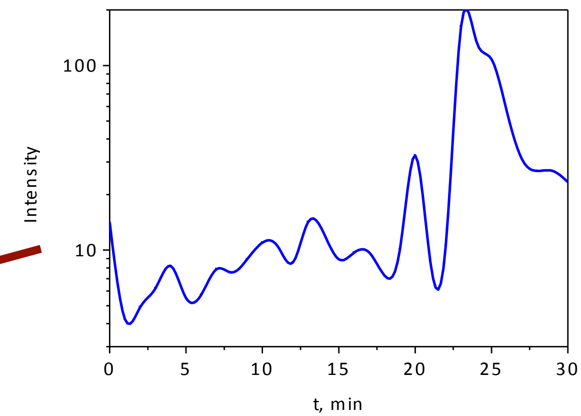


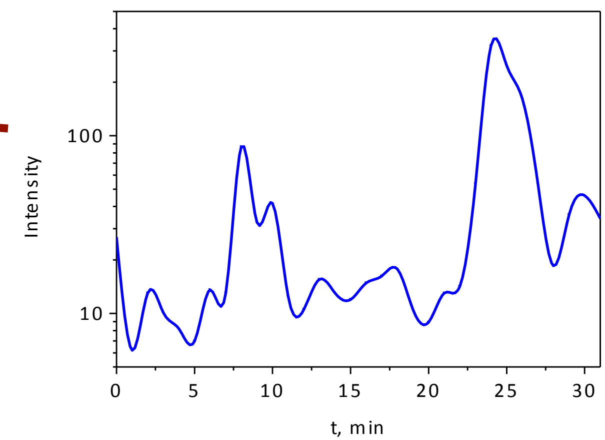
Launched on April 2016!

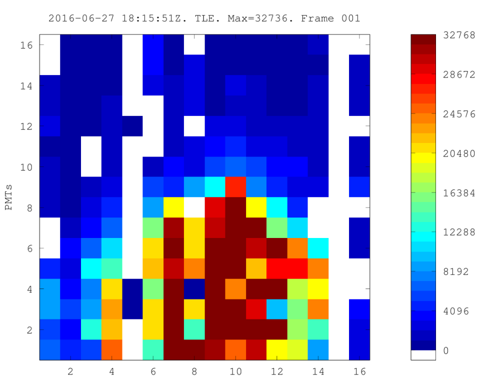

ПОДНИМИ ГОЛОВЫ!!
НИИЯФ МГУ

Aurora light measurements









Example of fast UV flash in atmosphere (0.4 ms temporal resolution)

TUS preliminary results

Part III

The long term EUSO-program:

K-EUSO and EUSO-FF

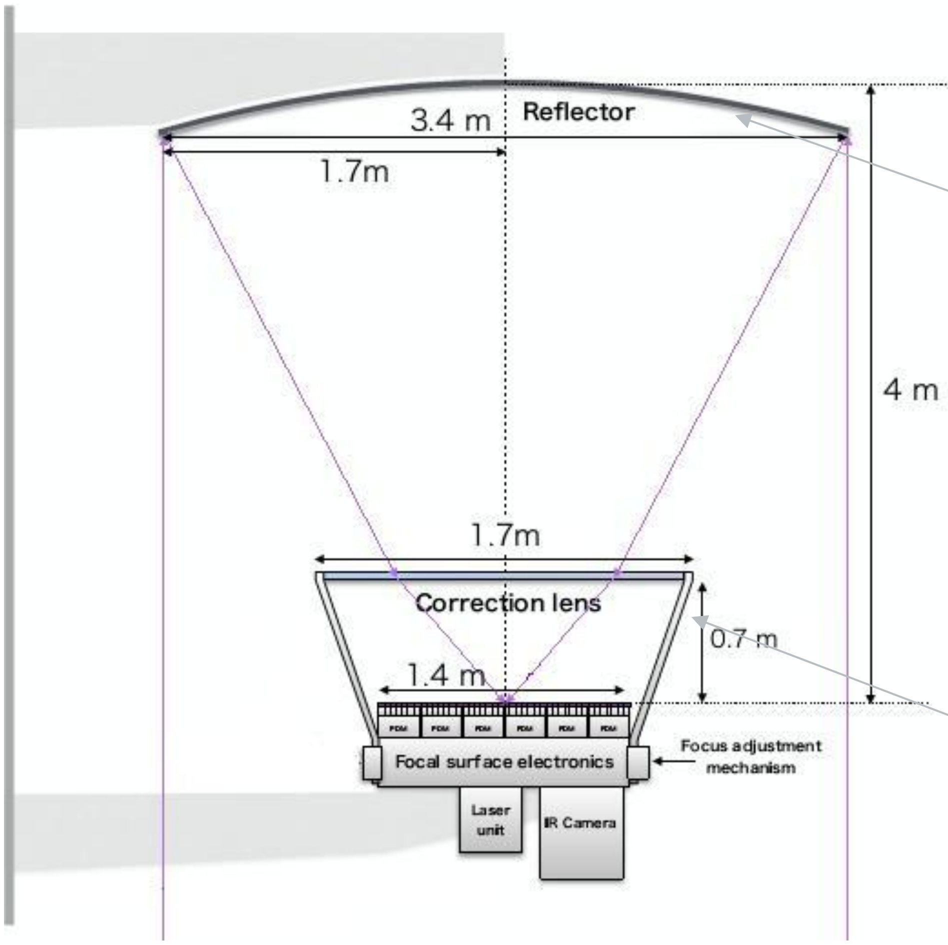
The JEM-EUSO program (1)

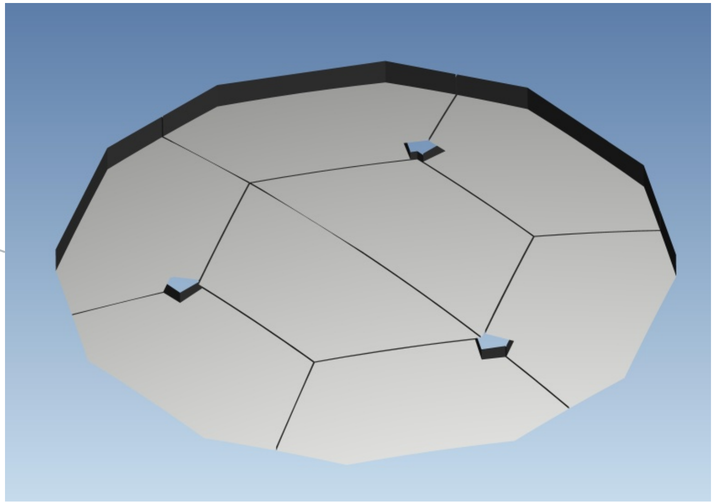
- **Long Term: two mission profiles are being actively studied.**

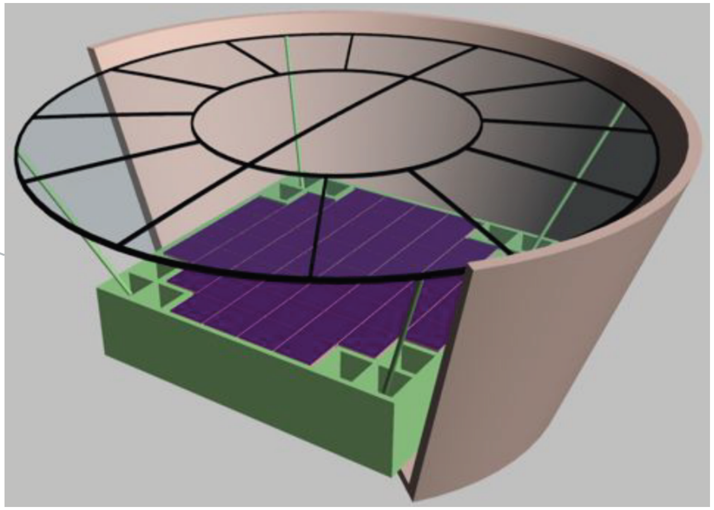
The driving idea is to open the field of the observation from space of UHE particles at the dawn of the new decade!

  - **K-EUSO mission** (Phase A passed, to be delivered to ROSCOSMOS in 2019)
  - **EUSO-FF** To be submitted to ESA M5 call (next 5th of October)

K-EUSO Baseline





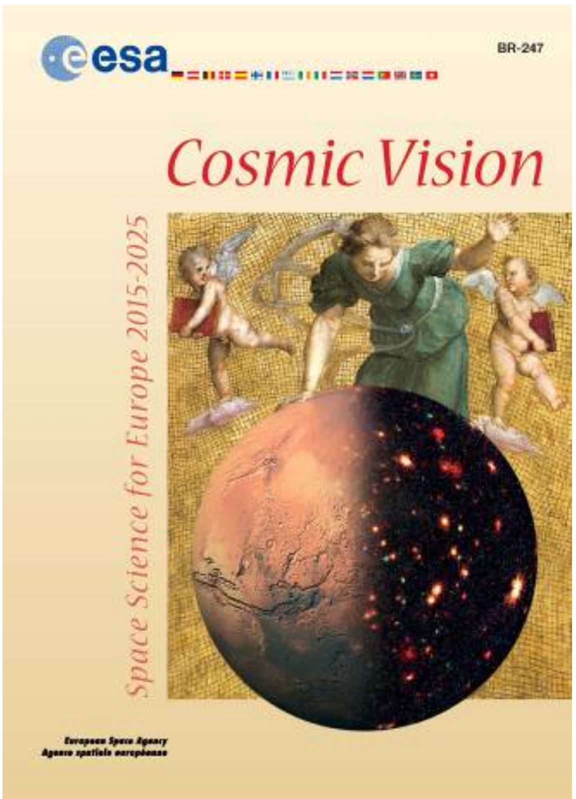


Status of KYPVE-EUSO

- K-EUSO is included into the Space program on the Russian segment of the ISS
- the contract (between RSC Energia and SINP MSU) is in process of signing
- JAXA approved corrective lens production for K-EUSO
- the scientific equipment is in the preliminary design stage: mirror technology and production development, new electronics design and tests

The new challenge: EUSO-FF

EUSO FF stands for EUSO Free Flyer



To be Submitted to ESA in response of the AO for *the fifth cycle (M5) of medium missions* of the Programme “Cosmic Vision 2015-2020”.

Submission is early October.

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

EUSO-FF Science Requirements

More challenging than EUSO or JEM-EUSO since it will fly 2029!

Parameter	Requirement value
Exposure at 100 EeV*	10^6 km^2 sr yr
at 50 EeV*	0.5×10^6 km^2 sr yr
Angular res. at 50 EeV	≤5°
at 200 EeV	≤2°
Energy res. at 50 EeV	≤30%
at 100 EeV	≤20%
$^{**}X_{max}$ res.	≤100 g/cm^2
***$\langle X_{max} \rangle$ **res.** at 50 EeV	≤20 g/cm^2
at 100 EeV	≤30 g/cm^2

← 1 ML

← 0.5 ML

*For events which can be used for anisotropy studies
**For photon and neutrino discriminations
*** Determination of the average logarithmic mass

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

EUSO-FF UV Instr. Requirements

Instrument requirements for the UV telescopes:

Parameter	Requirement value
Operational wavelength	300-400 nm
Field of View	±30°
Effective aperture	≈ 12 m^2
Pixel Field of View	≤ 0.06°
*Pixel size on the FS	≈3mm
Optics Throughput	>60%
Time Resolution	2.0 μs
Number of pixels	≈1.x10^6
Detection efficiency	≥40%
Dead Time	<3%

*it depends on the f number of the optics. The value here is for a refractive optics solution

Requirements are preliminary: *we are currently studying the case for the M5 proposal*

EUSO-FF Mission Requirements

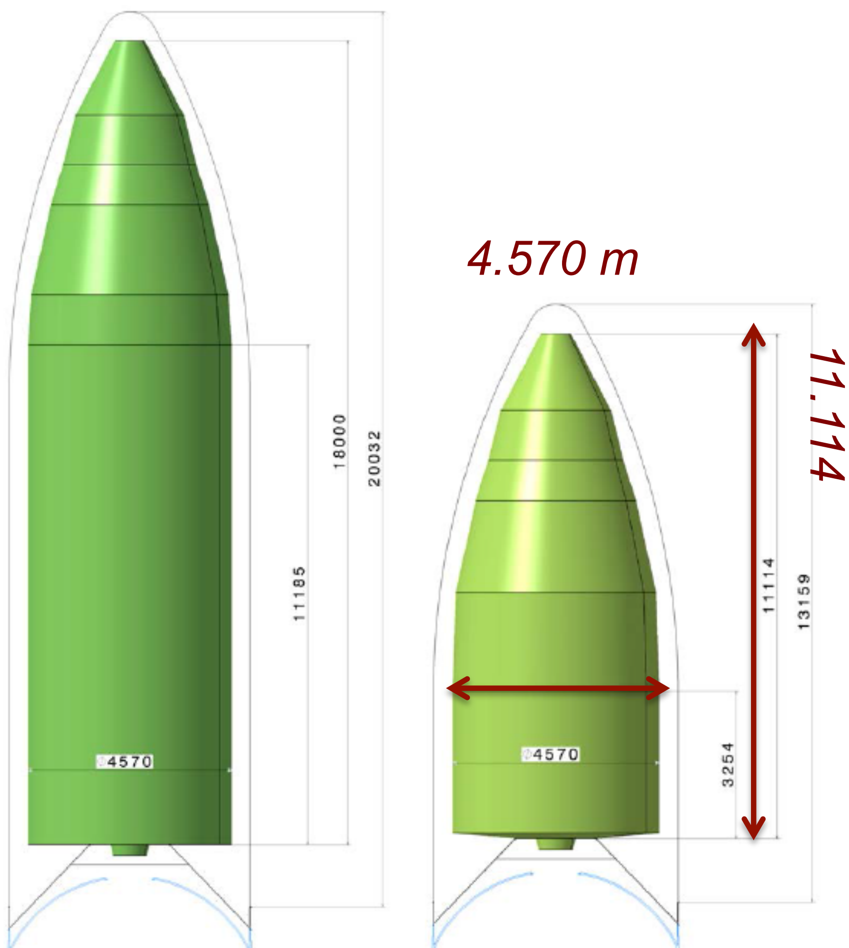
Mission requirements:

Parameter	Requirement value
*Orbit altitude	600÷700 km
Monitored Area	$2.8 \div 3.8 \times 10^5$ km^2
Pixel size on ground	< 700 m
Mission Lifetime	≥5 yr
Launcher	Arian 62
**Orbit Inclination	52° (TBC)
Duty cycle	≈20%

*Above 700 km the radiation dose strongly increases, at lower altitudes drag effect might become severe.
**The orbit inclination has not yet decided: a polar orbit will go through the auroras, an equatorial orbit will have a not ideal cloud coverage conditions

EUSO FF Launcher

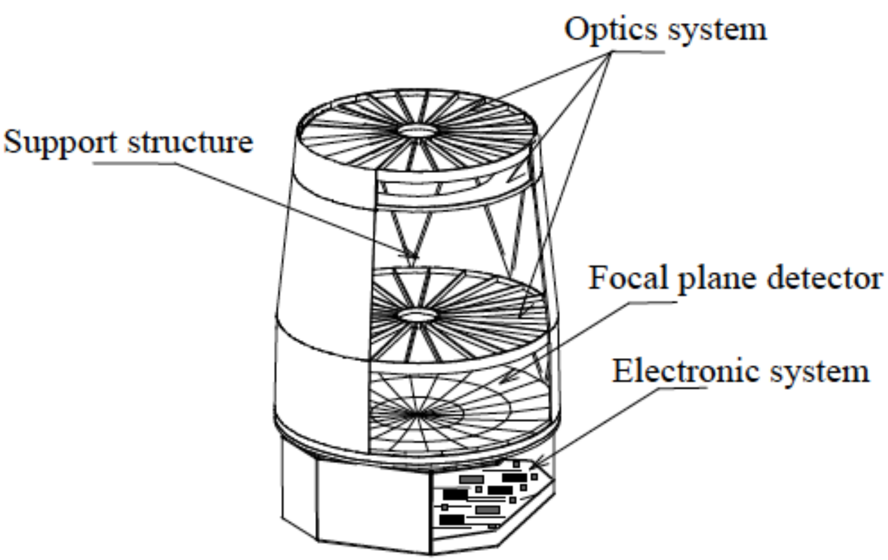
Ariane 6 Fairing limiting factor

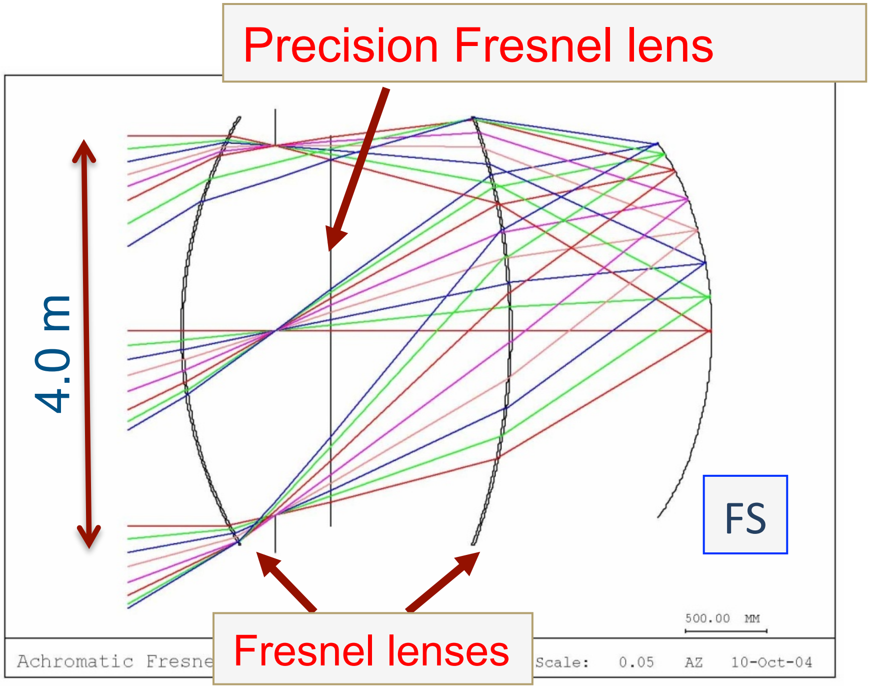


Allows mono-eye solution

Multi eyes difficult within the cost cap of the M5 budget.

Technical solutions: Optics (1)





Two Fresnel lenses, plus a central precision Fresnel lens to cancel chromatic aberration

Materials : PMMA + CYTOP (light)

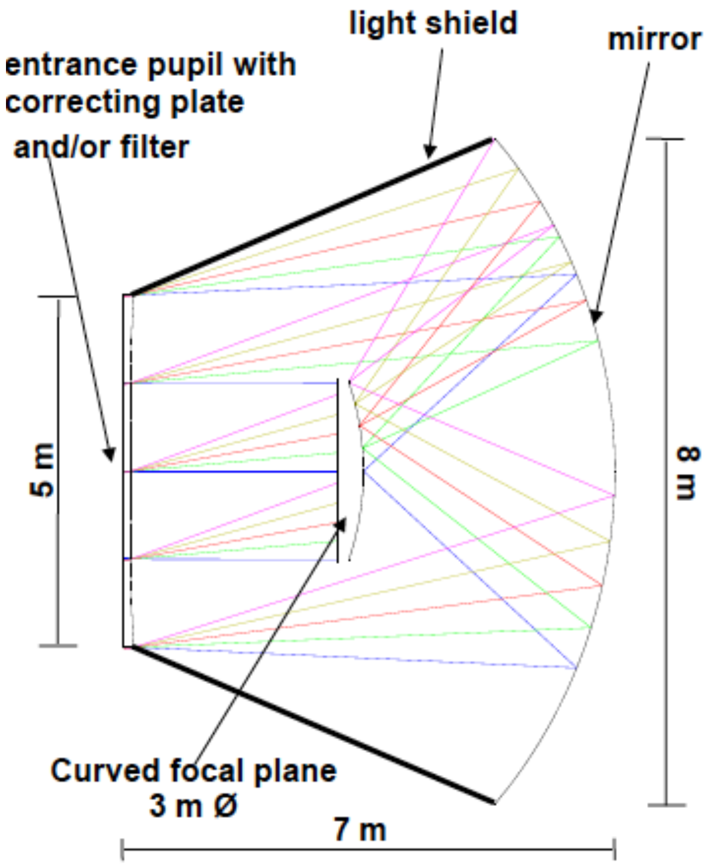
Large diameter (1.5 m diam.) Fresnel lenses manufactured in Japan by RIKEN

…tested at the University of Alabama (Huntsville) and at MSFC (NASA)

Technical solutions: Optics (2)

Design of a **mirror optics, based on the Schmidt camera** principle

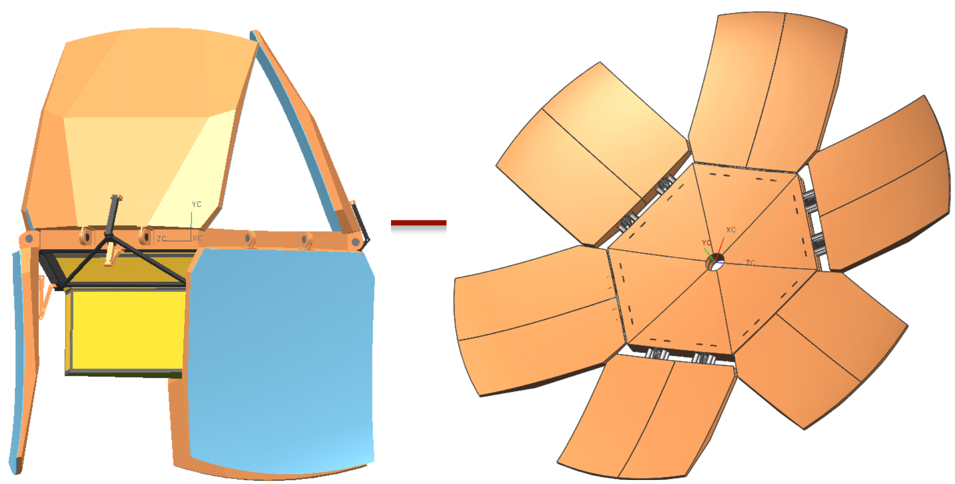
This is the only design allowing wide FOV, up to ≈ 50°, with just 2 optical elements



Smaller F# and therefore *smaller focal surface*

Higher throughput but obscuration

Key issue: deployability!



4 m ∅ deployable mirror for LIDAR application, studied for ESA

Courtesy of Carlo Gavazzi Space SpA

CARLO GAVAZZI SPACE SpA

Conclusions

- The EUSO program *is an essential element of the roadmap* of the UHE Community

- *Prototypes and Models of the major elements* (Lenses, PDM, DP Unit) have been *produced and are being tested* to increase the TRLs levels.

- The Pathfinders (EUSO-TA and EUSO-Balloon) are providing exciting technical and science data: *the transition from paper work to prototyping and measurements has been done.*

- Mission concepts are actively studied: *K-EUSO* will open the *scientific exploration of the field as a pathfinder,* and then

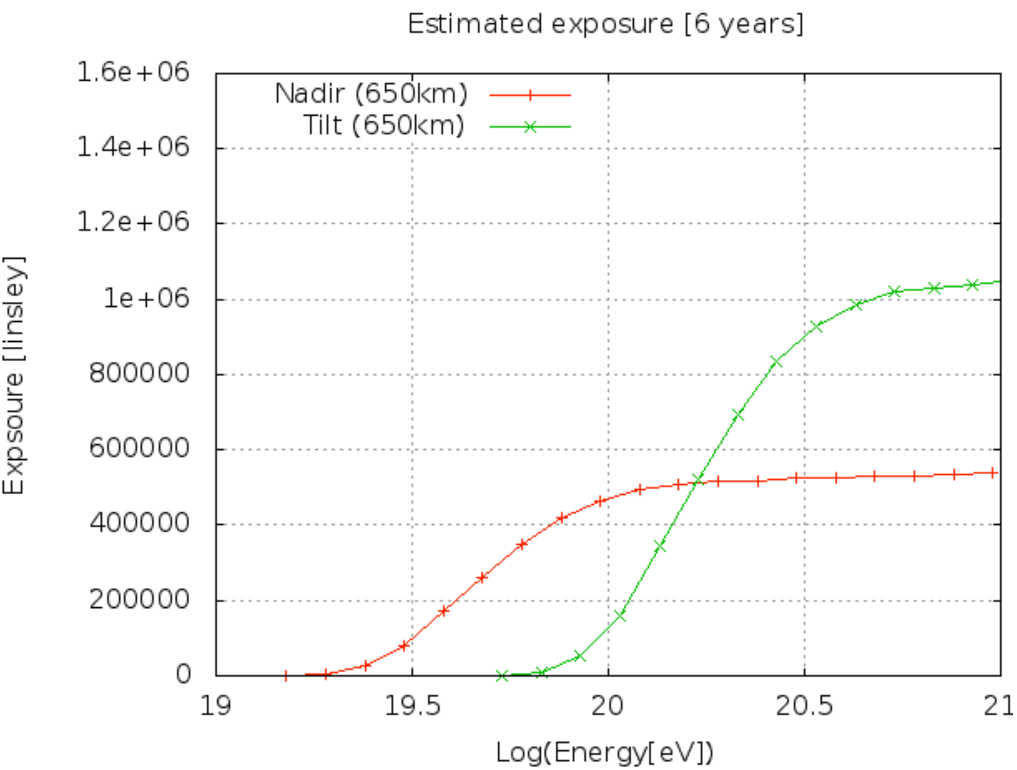
EUSO-FF is expected to unveil the highest energy sky ever explored.

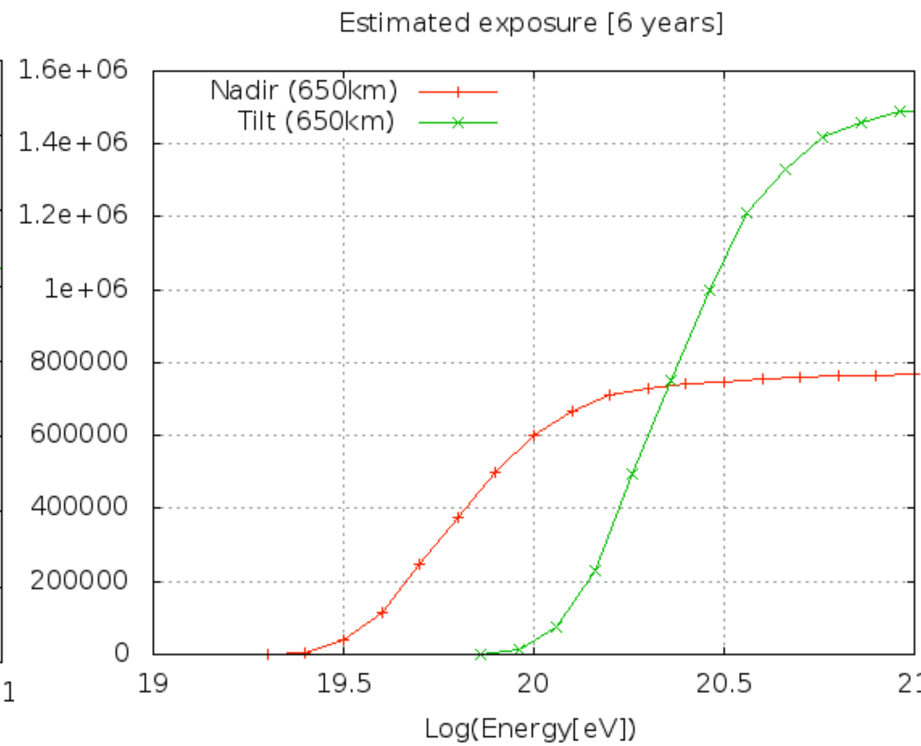
Thank you.

Contact:

Andrea Santangelo
Abteilung Hochenergieastrophysik
Sand 1, 72076 Tübingen · Germany
Phone: +49 7071 29-76128
Andrea.Santangelo@uni-tuebingen.de

Exposures: refractive and reflective



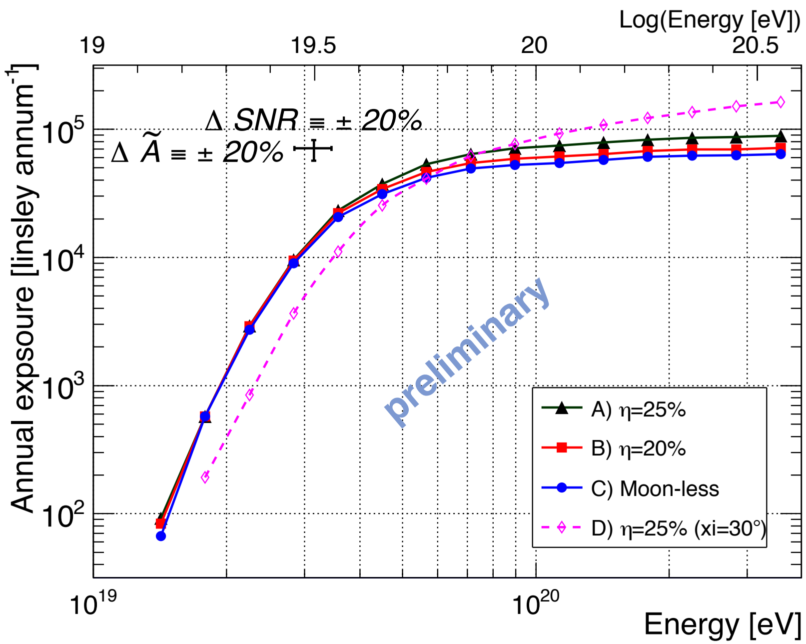


Reflective optics

Refractive optics

h=650 km, lifetime 6 years

JEM-EUSO with Dragon (Performance)



Expected annual exposure for different criteria (from Moonless to duty cycle η∼25%)

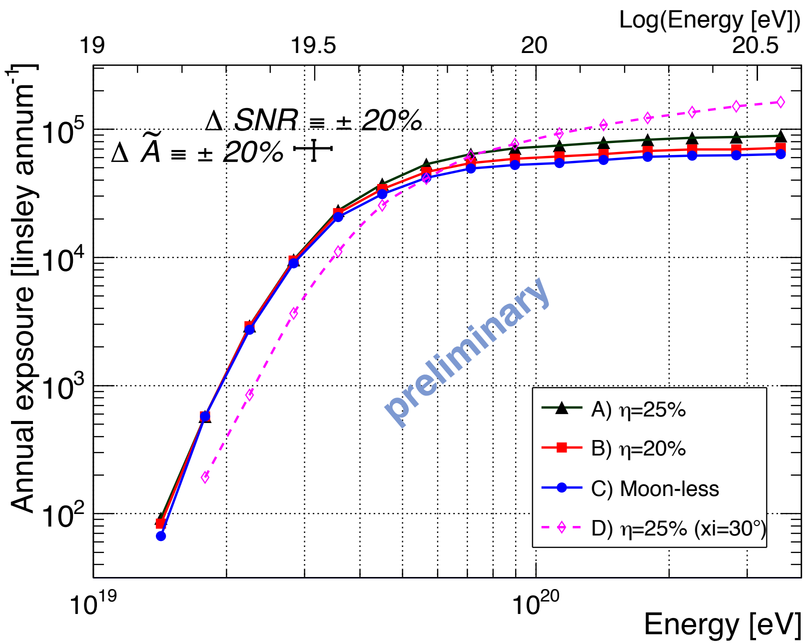
$$A_{Ann.Exp.} = (5-9)\times 10^4\, linsley$$

This corresponds to *(6-10) times what attainable by the Pierre Auger Observatory*

Details on the duty cycle and cloud coverage in *Adams et al., 2013 and Shinozaki ID0682*

T. Mernik ID0577, K. Shinozaki ID0682, A. Guzmán ID0570, F. Fenu ID0611

JEM-EUSO with Dragon (Performance)



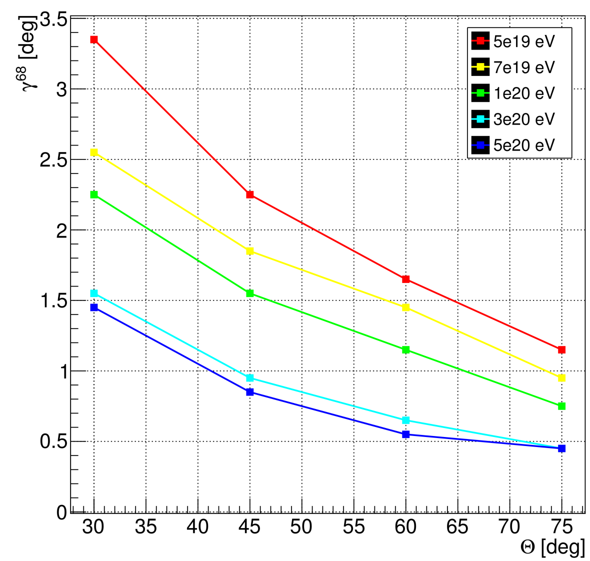
Expected annual exposure for different criteria (from Moonless to duty cycle η∼25%)

$$A_{Ann.Exp.} = (5-9)\times 10^4\, linsley$$

This corresponds to *(6-10) times what attainable by the Pierre Auger Observatory*

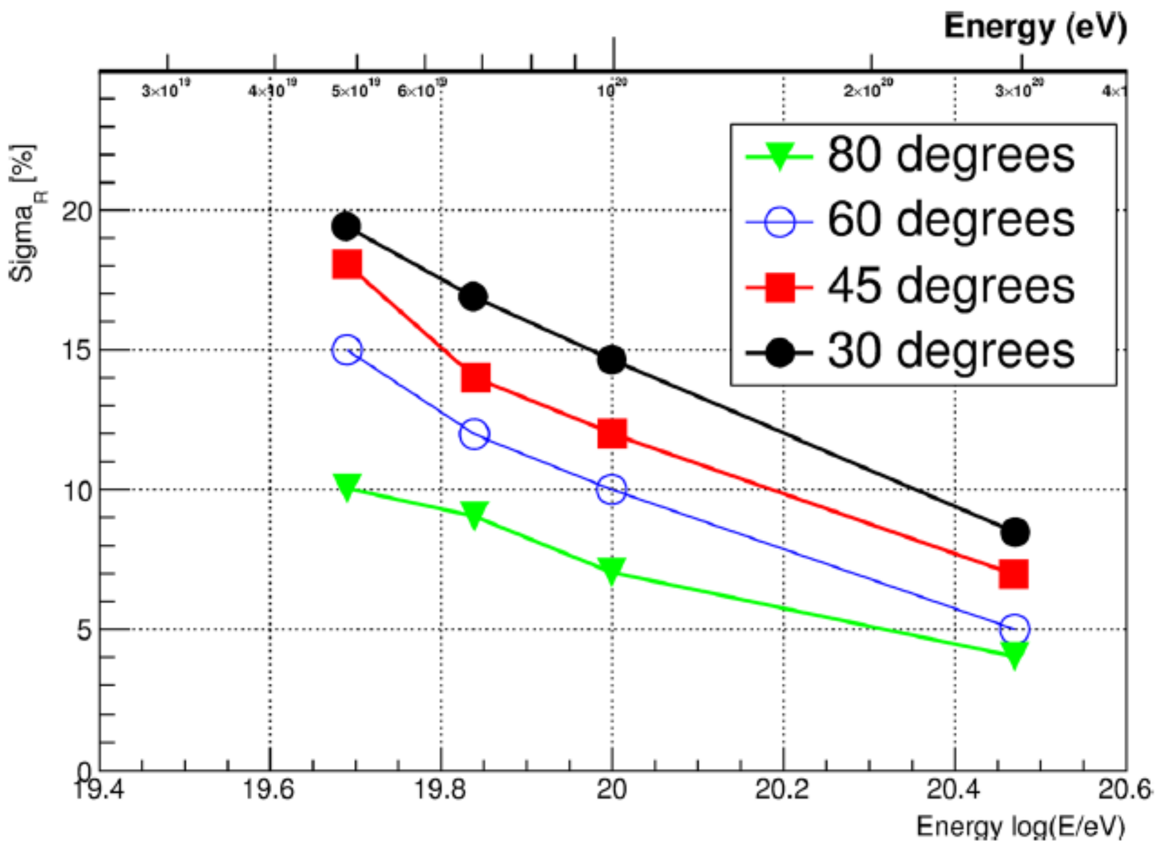
Details on the duty cycle and cloud coverage in *Adams et al., 2013 and Shinozaki ID0682*

Angular resolution: it's improved with respect to JEM-EUSO with HTV and meets the requirements.



T. Mernik ID0577, K. Shinozaki ID0682, A. Guzmán ID0570, F. Fenu ID0611

Energy resolution (HTV configuration)

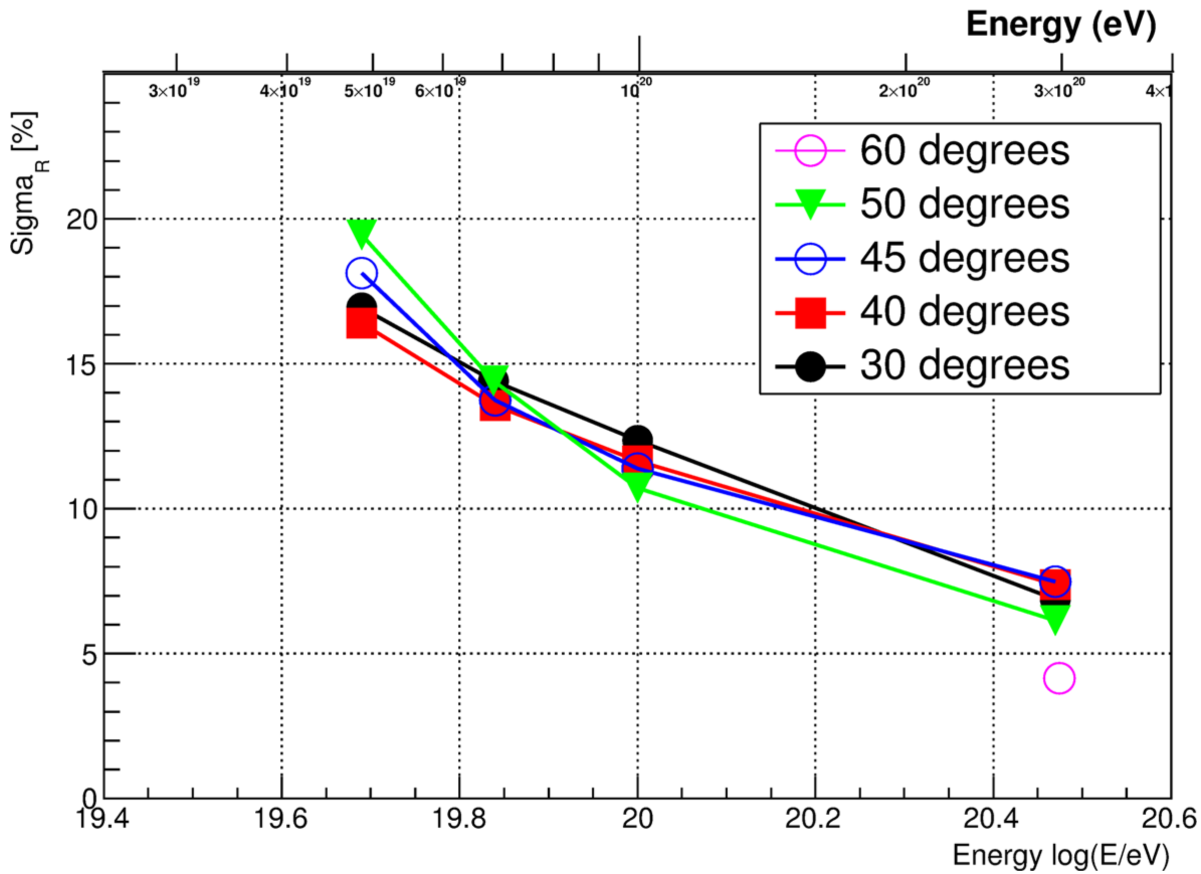


$$R = \frac{E_{reco} - E_{real}}{E_{real}}$$

Events impacting in the central
part of the field of view
namely in the inner
(+/-20,+/-20) km. The
geometry has been
reconstructed with
the slant depth method

The sigma of the R distribution

F. Fenu et al., Exp. Astron. 2014

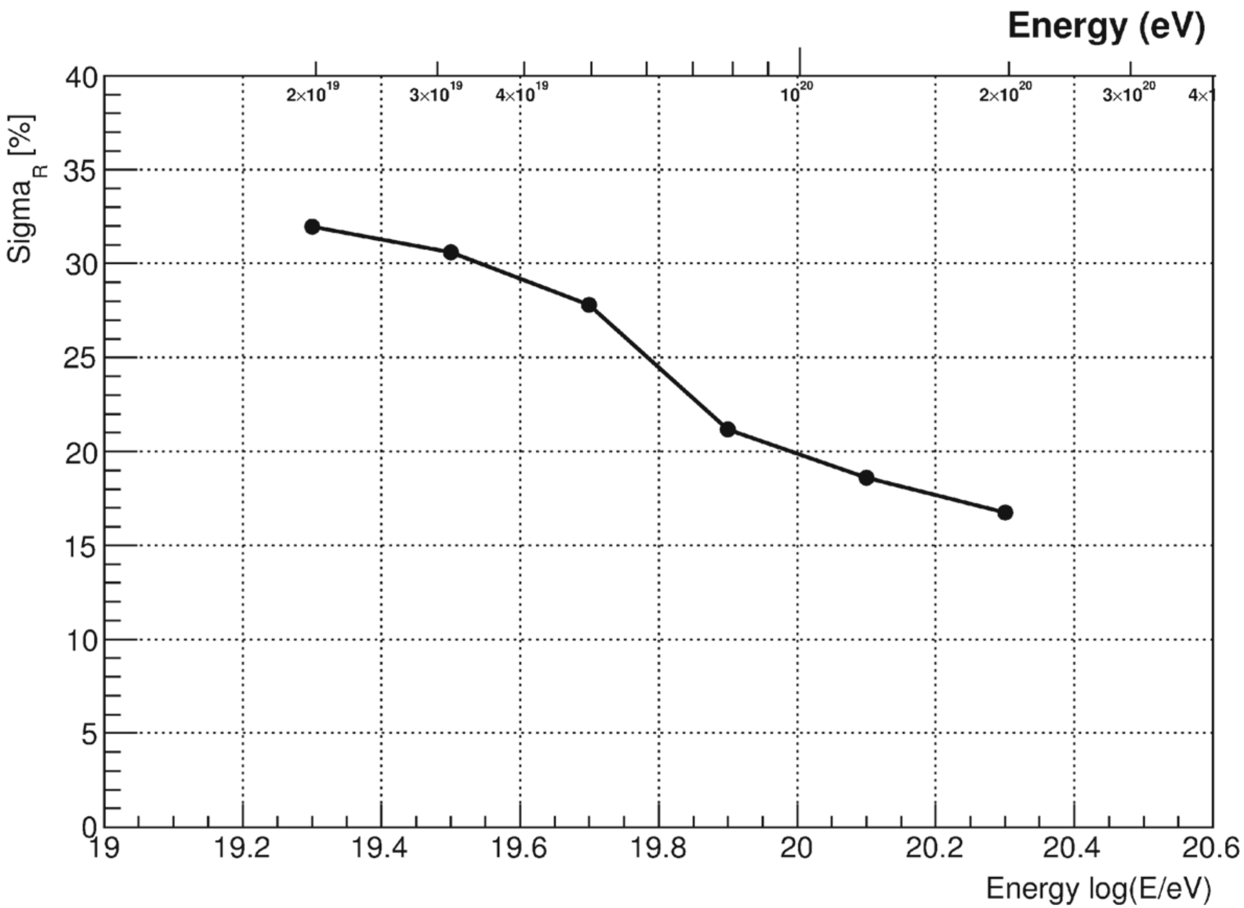


$$R = \frac{E_{reco} - E_{real}}{E_{real}}$$

Events impacting in the central part of the field of view namely in the inner (+/-20,+/-20) km. The geometry has been reconstructed with the Cherenkov Stamp method

The sigma of the R distribution

F. Fenu et al., Exp. Astron. 2014



$$R = \frac{E_{reco} - E_{real}}{E_{real}}$$

All events

The sigma of the R distribution

F. Fenu et al., Exp. Astron. 2014