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
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 /m² sr ns
Astrophysics and Physics from $E > 5 \times 10^{19}$ 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 $2 \times 10^{20}$ 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, $\ln<A>$
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

\[ A_{\text{Nadir}} \approx 1.3 \times 10^5 \text{ km}^2 \]

\[ \approx \text{few} \times 10^{12} \text{ tons} \]

Tilted mode (40°)

\[ A_{\text{geo}}^{\text{Tilted}} \approx 1. \times 10^6 \, \text{km}^2 \, [\text{@} \, 40°] \]
2. ISS Orbit → Full sky Coverage...

4π coverage

Inclination: 51.6°
Height: ~400km

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

http://www.nlsa.com/
Part II

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

From paperwork to the real signal, the technique and technological pathfinders
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)
• 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
EUSO-Balloon: was launched on August 24, 2014 from Timmins, (Canada)
EUSO-Balloon was launched on August 24, 2014 from Timmins, Canada. The balloon launched at 0:53 UT and floated for 3:43 UT before splashdown at 8:59 UT. The trajectory of the balloon is shown with a yellow line, and the path of the helicopter is shown with a red line.
A typical detection
Mapping of the UV-nightglow intensity

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

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

\[ A_{\text{Exp.}} \approx 10^3 \text{ km}^2 \text{ sr} \]
COSI SPB – Flight (a few weeks ago)

Test if different Background conditions: Ocean, Clouds, Twilight, Transient atmospheric events
Pathfinders: EUSO-TA

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
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

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.

It will be hosted in the Zvezda Module of the ISS. UV transparent Nadir looking window.
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 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
Fresnel type mirror–concentrator

TUS detector on board Lomonosov satellite

Photo receiver moving system

Launched on April 2016!
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)
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.
### EUSO-FF Science Requirements

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exposure</strong></td>
<td></td>
</tr>
<tr>
<td>at 100 EeV*</td>
<td>$10^6$ km$^2$ sr yr</td>
</tr>
<tr>
<td>at 50 EeV*</td>
<td>$0.5 \times 10^6$ km$^2$ sr yr</td>
</tr>
<tr>
<td><strong>Angular res.</strong></td>
<td></td>
</tr>
<tr>
<td>at 50 EeV</td>
<td>$\leq$ 5°</td>
</tr>
<tr>
<td>at 200 EeV</td>
<td>$\leq$ 2°</td>
</tr>
<tr>
<td><strong>Energy res.</strong></td>
<td></td>
</tr>
<tr>
<td>at 50 EeV</td>
<td>$\leq$ 30%</td>
</tr>
<tr>
<td>at 100 EeV</td>
<td>$\leq$ 20%</td>
</tr>
<tr>
<td><strong>$X_{max}$ res.</strong></td>
<td>$\leq$ 100 g/cm$^2$</td>
</tr>
<tr>
<td><strong>$&lt;X_{max}&gt;$ res.</strong></td>
<td></td>
</tr>
<tr>
<td>at 50 EeV</td>
<td>$\leq$ 20 g/cm$^2$</td>
</tr>
<tr>
<td>at 100 EeV</td>
<td>$\leq$ 30 g/cm$^2$</td>
</tr>
</tbody>
</table>

*For events which can be used for anisotropy studies

**For photon and neutrino discriminations

*** Determination of the average logarithmic mass
## EUSO-FF UV Instr. Requirements

**Instrument requirements for the UV telescopes:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational wavelength</td>
<td>300-400 nm</td>
</tr>
<tr>
<td>Field of View</td>
<td>±30°</td>
</tr>
<tr>
<td>Effective aperture</td>
<td>≈ 12 m²</td>
</tr>
<tr>
<td>Pixel Field of View</td>
<td>≤ 0.06°</td>
</tr>
<tr>
<td>*Pixel size on the FS</td>
<td>≈ 3 mm</td>
</tr>
<tr>
<td>Optics Throughput</td>
<td>&gt;60%</td>
</tr>
<tr>
<td>Time Resolution</td>
<td>2.0 µs</td>
</tr>
<tr>
<td>Number of pixels</td>
<td>≈ 1x10⁶</td>
</tr>
<tr>
<td>Detection efficiency</td>
<td>≥ 40%</td>
</tr>
<tr>
<td>Dead Time</td>
<td>&lt; 3%</td>
</tr>
</tbody>
</table>

*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
**Mission requirements:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement value</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Orbit altitude</em></td>
<td>600÷700 km</td>
</tr>
<tr>
<td>Monitored Area</td>
<td>2.8÷3.8 × 10⁵ km²</td>
</tr>
<tr>
<td>Pixel size on ground</td>
<td>&lt; 700 m</td>
</tr>
<tr>
<td>Mission Lifetime</td>
<td>≥5 yr</td>
</tr>
<tr>
<td>Launcher</td>
<td>Arian 62</td>
</tr>
<tr>
<td><strong>Orbit Inclination</strong></td>
<td>52° (TBC)</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>≈20%</td>
</tr>
</tbody>
</table>

*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**
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)
Design of a **mirror optics, based on the Schmidt camera principle**
This is the only design allowing wide FOV, up to $\approx 50^\circ$, with just 2 optical elements

*Smaller F# and therefore smaller focal surface*
*Higher throughput but obscuration*

**Key issue: deployability!**

4 m $\varnothing$ deployable mirror for LIDAR application, studied for ESA

Courtesy of 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

\( h=650 \text{ km, lifetime 6 years} \)
Expected annual exposure for different criteria (from Moonless to duty cycle $\eta \sim 25\%$)

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

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*
JEM-EUSO with Dragon (Performance)

**Expected annual exposure** for different criteria (from Moonless to duty cycle $\eta \sim 25\%$)

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

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

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

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*
Energy resolution (HTV configuration)

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.

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

The sigma of the R distribution

F. Fenu et al., Exp. Astron. 2014
The sigma of the $R$ distribution

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

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
The sigma of the R distribution

\[ R = \frac{E_{\text{reco}} - E_{\text{real}}}{E_{\text{real}}} \]

All events

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