

Extreme Universe Space Observatory

Results from the first missions of the JEM-EUSO program

M. Bertaina – Univ. & INFN Torino for the JEM-EUSO Collaboration

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JEM-EUSO

PROGRAM

EUSO-TA (2013-)



EUSO-TA & Balloons detector

instrument booth



Comparing Auger FD and EUSO-like telescopes

	Auger (1 FD site)	EUSO-Balloons/TA	JEM-EUSO
mirror size	6 x 11 m ²	1 m ² lens	4 m ²
FoV	6 x (30 x 30) deg ²	11 x 11 deg ²	4 x 4 deg ² /PDM
Ang. resolution	1.5 deg/pixel	0.2 deg/pixel	0.075 deg/pixel
Pixel size	5x5 cm ²	3x3 mm ²	3x3 mm²
Camera size	6 x 440 pixels	2304 pixel	2304 pixel/PDM
EAS distance	40 km	1- 30 km	400 km
light intensity (@40km=1)	1	>1	0.01
time resolution	100 ns	2.5 μs	2.5 μs
signal acquisition	charge integration	photon counting	photon counting

~1.2 m²

~1.0 m²





EUSO-SPB lens & camera

EUSO-SPB camera has ~100 times higher density of pixels

A significant difference in detectors, a technological challenge...



OffLine Simulation



Cosmic ray event, 13/5/2015

Telescope Array reconstruction Zenith = 35° Azimuth = 7° (clockwise from N) E = 10^{18} eV Rp = 2.5 km Core = (14.8 km, -10.9 km) respect CLF



EUSO, 2*2

TA signal (courtesy TA coll.)₆

EUSO, 1 frame, 2.5micros

icros

E_{equivalent} – Distance along tel. axis

Fit with second degree polynomial



Total of 9 events in ~130h detected in coincidence with TA

(8-9 events from ESAF simulations assuming a simplified trigger scheme)

G. Abdellaoui et al. (JEM-EUSO Coll.), Astroparticle Physics 102 (2018) 98–111

See poster by F. Bisconti on EUSO-TA results

CLF and laser tests





Laser direction reconstruction



- · 34km away from the detector
- Energy: 23mJ
- Sweep in azimuth with 2 different zenith angle (130°/140°)





- Telescope tilt 10°
- GLS zenith 90° (vertical)
- 2Hz
- Various energy settings
 4, 6, 9, 12, 13, 15, 16, 17, 19, 20mJ
- 500 shots were fired (50 each setting)

EUSO-TA under upgrade



2. EUSO Balloon flights

1st flight, Aug 2014 Timmins (CA) Flight Performance flight: 18900 s @ float data: 256,000 events equivalent to 80 s integrated time



Payload built by JEM-EUSO collaboration CNES (French Space Agency) mission

the balloon track and helicopter path



Very good matching with DMSP satellite images



Implications for UHECR observation



$$\begin{aligned} A(E_0) &\equiv \int_0^{T_0} \dot{A} \left(E_0, \bar{N}(T) \right) \, dT \\ &= \int_0^{\bar{N}_{\text{lim}}} \left[\dot{A}_0 \left(\sqrt{\frac{N_0}{\bar{N}}} \cdot E_0 \right) \cdot \left(\frac{\Delta T}{\Delta \bar{N}} \right) \right] \, d\bar{N}. \end{aligned}$$

 $\begin{array}{l} \mathsf{A} = \mathsf{Exposure} \\ \mathsf{E}_o = \mathsf{energy} \\ \mathsf{N}_o = \mathsf{reference} \ \mathsf{counts} \ \mathsf{in} \ \mathsf{dark} \ \mathsf{condition} \\ \overline{\mathsf{N}} = \mathsf{counts} \\ \mathsf{T} = \mathsf{time} \\ \mathsf{T}_o = \mathsf{measurement} \ \mathsf{time} \end{array}$

Variations in exposure due to light variation can be calculated directly from the data

EUSO-Balloon Airglow - Starlight models:

- $I_0 = 300 320$ photons m⁻² sr⁻¹ ns⁻¹ 300 - 500 nm band
- $I_0 = 260 170$ photons m⁻² sr⁻¹ ns⁻¹ 300 - 400 nm band

a factor ~ 2 increase with clouds

BaBy balloon (1998):

 $I_0 = 400 - 450$ photons m⁻² sr⁻¹ ns⁻¹ - (300 - 500) nm band

BaBy balloon (2002):

 $I_0 = 310$ photons m⁻² sr⁻¹ ns⁻¹ - (300 - 400) nm band

NIGHTGLOW balloon (2000): $I_0 = 300$ photons m⁻² sr⁻¹ ns⁻¹ - (300 - 400) nm band

Reasonable results considering variability of night glow and complexity of medsurement for EUSO-Balloon

Helicopter Events







Laser Track

N detected events: 275 N expected events: 261 <u>+</u> 16

 $N_{exp} = t_{ev} \cdot R_{CPU} \cdot N_{laser} \cdot \epsilon_{flight} \cdot \epsilon_{clouds} \cdot \epsilon_{inst} \cdot \epsilon_{detector}$

where: $t_{ev} = 427.5 \ \mu s$ and it includes the length of 1 packet (128 GTUs of 2.5 μs each), the duration of 1 helicopter event (45 GTUs) subtracted by the 2 GTU signal required by the trigger logic; $R_{CPU} = 20$ Hz; $N_{laser} = 1.5 \times 10^5$; $\epsilon_{flight} = 0.35$ and corresponds to the 48 minutes in which helicopter shots were detected of the 137 minutes in which the system was on; $\epsilon_{clouds} = 0.81$ is the fraction of time in which likely there were no clouds (see Fig. 3); $\epsilon_{inst} = 0.81$ corresponds to the relative live time of the instrument; and $\epsilon_{detector} = 0.86$ indicates the fraction of MAPMTs that could be used for the analysis.

G. Abdellaoui e¹⁴al. (JEM-EUSO Coll.), JINST 13 (2018) 98–111

TRACK RECONSTRUCTION



G. Abdellaoui et al. (JEM-EUSO⁵Coll.), JINST 13 (2018) 98–111

EUSO-SPB1: launch on 25th April 2017 from Wanaka, New Zealand

NASA Mission. 2nd Payload built by JEM-EUSO collaboration New lenses, Focal Surface, Improved Electronics

In principle up to 100 days flight!!!

Objective: First UV UHECR shower observation from above







- EUSO-SPB1 flew as a mission of opportunity on 3rd NASA super pressure balloon test flight April 25- May 6th 2017

- 12 day flight, early termination
- Preflight Ground tests of flight instrument in the desert lasers, LEDs, aircraft, stars, meteorite
- 40 hours flight data dark, moon down (28 hours downloaded)

Internal trigger boosts sensitivity to UHECRs

x10³ compared to EUSO-Balloon

NASA Super Pressure Balloon

2015: 32 d 5 h

2016: 46 d 20 h



2017: 12 d 4 h



NASA Engineering Flight

COSI

EUSO

Expected EAS events for EUSO-SPB (ESAF sim.)

6.3<u>+</u>0.9

10.6<u>+</u>2.3

NASA goal is to reach 100 days flight !



Tests in September 2016 Black rock mesa, Utah Photometric Calibration Counts (photoelectrons)/photons at aperture

<u>Piece Wise in Lab</u> — Camera 0.305

- Lenses 0.30
Result: 0.09 (+/- 0.01

End-to-End in Field Using Calibrated UV LED on a tower • Result: 0.08 (+/- 0.01)



EUSO-SPB (balloon)

TA FD

Photo by Malek Mastafa

EUSO-TA (ground)

Trigger Threshold Measurement with Laser



Test of Simulation Accuracy with OffLine



EUSO-SPB & EUSO-TA



Equivalent Energy 0.85 mJ (50% Trigger Threshold) ~ 3×10^{18} eV for EAS as viewed looking down from balloon height.

Scaling JEM-EUSO to EUSO-SPB

	JEM- EUSO	EUSO-SPB rescaled
Height(km)	400	33
Diameter(m)	2.4	1
FoV/pix(deg)	0.08	0.2
Pixel@ground (km)	0.580	120
FoV/ PDM(deg)	3.8	11
PDM@ground (km)	27	6.3
Signal Ratio	1	31.3
BG Ratio	1	3.1*
S/√N	1	17.8
E _{thr} (eV)	3.5x10 ¹⁹	2x10 ¹⁸
Number of PDM	137	1

* taking into account the ratio of background (1.8/1) and residence time in the 3x3 pixel box (1.7)

Experimentally: EUSO-SPB E_{thr} ~ 3x10¹⁸ eV \implies ~ 5x10¹⁹ eV JEM-EUSO Note: EUSO-SPB2 is expected to decrease threshold through improved optics, higher QE of MAPMTs, and shorter GTU



05/05

05/06 Date [UTC]



0



~1 Expected Event during EUSO-SPB1 flight

Reality: Altitude unstable



See poster by K. Shinozaki on EUSO-SPB



Cross shows the current balloon position

AHI (Advanced Himawari Imager) Geostationary 25-04-2017 12:00 UTC



05/01

05/02

05/03

3.41





Search for EAS candidates: no event found so far....





- After data reduction: 88824 events to analyse.
- Small sized events represent majority of detections 92%
- Most events are 5 px in size
- No EAS-like track identified



Category	Qty	%
Small blob	46041	51.8
Edge effect	33802	38.0
PSF blob	2995	3.4
Track	2194	2.5
Pixel	2136	2.4
Bog blob	946	1.1
unknown	710	0.8

- **Based on the Hough transform** – searching for lines in X-Y, GTU-X, GTU-Y projections

-Precision of estimation (area of a peak in Hough space) is considered as likelihood of single line in the image



<u>Utah laser events</u>: >98% efficiency, also in the raising part of trigger efficiency curve



simulated EAS injected in EUSO-SPB1
experimental data: > 80% efficiency

CONCLUSIONS

- The JEM-EUSO program is an essential element of the roadmap of the UHECR Community
- Prototypes and Models of the major elements (Lenses, PDM, DP Unit) have been produced and are being tested. TRLs levels have been increased up to TRL=7.
- The first pathfinder missions (EUSO-TA, EUSO-Balloon & EUSO-SPB) are providing exciting technical and science-oriented data: the transition from paper work and design to prototyping and measurements has been successfully performed.
- The second series of missions (TUS, Mini-EUSO and EUSO-SPB2) are expected to provide further TRL upgrades as well as interesting scientific results.

THANK YOU



- Launched 2016
- 60kg 65W 2m² fs
- 256 channels (13 mm pixels)

TUS: developing methodologies for K-EUSO and POEMMA







ſ	md/ah	4	4	T un	T
ļ	ma/cn	Abg	-rimax	$I_{\rm max}, \mu s$	$I_{1/2}, \mu s$
	13/4	5.7	15	63	36
	12/3	7.2	40	67.5	47
	13/3	0.9	38	71.5	41
	13/2	1.7	20	73.0	49
	13/1	4.5	8.6	78	42
	12/2	0.8	14	81	41
	11/2	10.8	12.2	92	29
	12/1	0.2	4.2	100	27

See talk by P. Klimov & poster by M. Bertaina

TUS event occurred in a region excluded by JEM-EUSO exposure calculation









All 9 detected events



logE = 18.69logE = 18.06logE = 18.20logE = 18.05logE = 18.51Rp = 8.3, D = 8.67Rp = 2.5, D = 2.88Rp = 0.8, D = 1.04Rp = 5.0, D = 5.12Rp = 9.1, D = 19.81Zen = 56.9, Azi = 15.7Zen = 34.5, Azi = 82.8Zen = 62.9, Azi = 27Zen = 29.5, Azi = 254.9Zen = 60.4, Azi = 169.3



Expected triggered events using ESAF simulations: dark hours during SPB flights 2015 & 2016

l flight (2015)		detector height	detector height
Non-uniform detector		38 km	30 km
138 h (March-April 2015)	weighted sum	3,7 ± 0,8	6,3 ± 0,9

- 138 hours: time without sunlight and moonlight during the balloon flight 2015;

- comparison between the triggered events with the detector at two different heights;

ll flight (2016)		detector height	detector height
Non-uniform detector		38 km	30 km
211 h (May-July 2016)	weighted sum	5,9 ± 1,3	10,6 ± 2,3

- 211 hours: time without sunlight and moonlight during the balloon flight 2016;
- comparison between the triggered events with the detector at two different heights;

In both estimations the role of clouds was taken into account based on climatological data along the trajectory of the two balloon flights (ISCCP cloud atlas)

Expected detected events N(E) for 2 different cases



Internal L1 trigger tested



~1 Expected Event during EUSO-SPB1 flight



See poster by K. Shinozaki on EUSO-SPB

MINI-EUSO/UV-ATMOSPHERE

Launch 2019





MINI-EUSO

ISS (400 km)

Scientific challenges:

- » Energy threshold below GZK cutoff (a factor of 2 higher energies means very few statistics and no inter calibration with ground experiments).
- » Light conditions continuously varying (ISS speed 7.5 km/s —> night/day change every 45 minutes).
- » Atmospheric conditions (clear sky, clouds, lightning, cities and anthropic light) continuously changing.
- » We need to test the capability of the instrument to adapt its working conditions to the different situations.
- » We need to record and recognise the different atmospheric and anthropogenic conditions.

Technological challenges:

- » Low power consumption (<1kW for JEM-EUSO 3x10⁵ pixels)
- » Low mass (~1-2 tons for JEM-EUSO)
- » Low telemetry (300 kbit/s for JEM-EUSO on ISS)
- » Radiation hard instrumentation
- » Space-qualified instrumentation (need to increase TRL)

From JEM-EUSO mission to JEM-EUSO program

JEM-EUSO mission: Extreme Universe Space Observatory on Japan Experiment Module

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





See JEM-EUSO roadmap talk of E. Parizot + P. Klimov (TUS/κ-ευso) & J. Krizmanic (POEMMA/spb2)

Note: Both definitions will be used in the forthcoming slides





EUSO-SPB2

CHERENKOV EMISSION FROM UHECRS TAU NEUTRINO BACKGROUND FLUORESCENCE FROM UHECRS





Tests of Mini EUSO engineering model



Airplane crossing the FoV (frame duration 40.96 ms)

PDM summed counts lightcurve





D1 lightcurve in self trigger mode. The system detects the two peaks coming from plane flashers. The same event was triggered by the L2 as well <u>Mini-EUSO DATA:</u> D1 : 2.5 μs resolution D2: 320 μs resolution D3: 40.96 ms resolution













Parameter	Requirement value
Operational wavelength	300-400 nm
Field of View	±30°
Effective aperture	≈ 4 m²
Pixel Field of View	≤ 0.06°
Pixel size on the FS	≈3mm
Optics Throughput	>50%
Time Resolution	2.5 µs
Number of pixels	≈3.x10⁵
Detection efficiency	≥30%
Dead Time	<3%









