Calibration of photo sensors for the space-based cosmic ray telescope JEM-EUSO

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Extreme Universe Space Observatory onboard Japanese Experiment Module
Outline

- The JEM-EUSO mission
- Pathfinders
  - EUSO-Balloon
  - EUSO-TA
- JEM-EUSO readout electronics
- Calibration
  - MAPMTs & SiPMs
- Outlook
Science Objectives

- Measurement of the cosmic ray spectrum at highest energies
- Identification of sources and source regions

**Exploratory Objectives:**

- Multi-messenger approach ($\nu$, $\gamma$-rays)
- Galactic magnetic fields
- Atmospheric science (lightning, night glow, …)
- Meteors and meteoroids

![Graph showing cosmic ray spectrum and energy thresholds](image)

- Equivalent c.m. energy $s_{pp}$ (GeV)
- Scaled flux $E^{-2.5} J(E)$ (m$^{-2} s^{-1} sr^{-1} eV^{-1.5}$)
- Measured fluxes at various energies and experiments:
  - RHIC (p-p)
  - HERA ($\gamma$-p)
  - Tevatron (p-p)
  - 7 TeV 14 TeV
  - LHC (p-p)
  - HiRes-MIA
  - HiRes I
  - HiRes II
  - Auger 2011
  - TA 2011 (prelim.)

- Thresholds:
  - Knee: $10^{15}$ eV
  - Ankle: $10^{18}$ eV
  - GZK-suppression: $10^{19}$ eV
  - E $> 5 \times 10^{19}$ eV

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JEM-EUSO – Overview

Detection principle

- UV-photons
  - Fluorescence light
  - Cherenkov light

Field of view

- 60° opening angle
- three Fresnel lenses

Observation area

- $1.4 \cdot 10^5$ km$^2$ (nadir mode)
- $\sim 1 \cdot 10^6$ km$^2$ (tilt mode)

Start planned for 2017
JEM-EUSO – Observation area

Nadir mode

Tilt mode
JEM-EUSO – Full sky coverage

- Very uniform observation of the arrival direction of EECR

4π coverage

Inclination: 51.6°
Altitude: ~400 km

Relative exposure (Isotropic = 1)

Declination [°]

per year

-90–60
-30
0
+30
+60+90

sin(Declination)

-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

JEM-EUSO (ISS) /64,000 km²-sr
Auger (φ = 35.5°S) / 7,000 km²-sr
TA (φ = 39.1°N) / 1,800 km²-sr
JEM-EUSO – Detector

Multi-Anode Photomultiplier Tube - MAPMT
8x8 Pixels

Focal Surface Detector
137 PDMs = 0.3 M Pixels

Photodetector Module - PDM
3x3 ECs = 2,304 Pixels

Elementary Cell - EC & UV-Filter
2x2 MAPMTs = 256 Pixels
EUSO-Balloon

Look down from a balloon with an UV-telescope
- 1 PDM + 1 IR-camera + Optics
- Support Equipment
  - Helicopter + UV-Laser
  - UV-Flashers on ground

Goals:
- Engineering test
- Background light test
- Air shower from 40 km altitude

Organized by CNES
- Whole instrument assembled
- First flight in August 2014 from Timmins (Canada)
EUSO-TA

EUSO-TA installed at
Black Rock Mesa FD Station
- Electron Light Source at 100m
- Most nearby SD is at ~3.5 km
- Central Laser Facility ~21 km

Background test
Calibration test
EUSO-TA

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JEM-EUSO Readout Electronics

- **SPACIROC** (Spatial Photomultiplier Array Counting and Integrating Chip)

- ASICs developed by Omega Micro group (CNRS-IN2P3 Paris)

64 Channels
- Preamplifier & Q-to-T converter
- Photon counting & charge measurement
- Low power consumption (1mW/Channel)
- Mounted on ASIC-Boards
JEM-EUSO Readout Electronics

- Production of 12 ASIC-boards for both pathfinders by KIT
  - Test of these boards
- Production of elementary cells by KIT
  - HV-, Anode-, Dynode-board, connectors
JEM-EUSO Readout Electronics

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Designed to save space
JEM-EUSO Data Acquisition

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Calibration principle

Photon Shielding

Photon-Efficiency = \( \frac{N_{PMT}}{N} \)

N / N_{PMT}

N_{Sphere}
Set-up

- Photon shielding
- Motorized x- and y-stages
  - Mounted on breadboard
- Reference light Source
  - Integrating sphere
  - LED-array
  - NIST-photodiode
  - Collimator
- Multiplexer
  - 64 channels $\rightarrow$ 16 Channels

In progress:
- Mount for MAPMTs/ECs
- Connector board
- Software
Set-up

- Calibration stand designed to fit one whole PDM (2,0 x 1,0 x 1,0 m³)
Reference light source

- Uniform Lambertian light source
- Known output via NIST-Photodiode
SiPMs for JEM-EUSO

Advantages:
- High gain
- Small depth
- Low mass
- Insensitive to magnetic fields
- Low voltage
- Scalability
  - Large arrays possible

Open problems to solve:
- Wavelength dependent efficiency
  - Efficiency drops at wavelengths smaller than 350nm
    - Strong fluorescence signal from 300nm upwards
    - For Cherenkov light no problem
- Radiation hardness
- Temperature stability in space
- Fast readout necessary
  - *SiPM integrated on top of ASIC*
The latest status of JEM-EUSO

2014

TA-EUSO

2015

EUSO-Balloon

2017

JEM-EUSO

AO from NASA in 2014?

2020

Collaboration with Russian project, KLYPVE

2024

“K-EUSO”

2024

two opportunities
Outlook

- Calibration of MAPMTs/SiPMs
  - Single pixel scan
  - Illumination of whole MAPMT/EC/PDM

- Inflight calibration
  - Smaller light source

- SiPM for JEM-EUSO
  - Swap MAPMT-PDMs with SiPM-PDMs?
  - Possible pathfinder experiment

- In development (Omega Micro):
  - Integrated SiPM-array on top of ASICs
    - Fast readout
    - Compact & low mass
Backup Slides
BACKUP - Reference light source

Measurement of light fluxes at both exit ports

- Multi_02_38top1_39side2_allnight
  - Start: 11/09/2013 at 13:42:32.74 h
  - 1 hour masked
  - avg: 1.89441 mW
  - std-dev: 0.00301 mW

- avg. difference: 0.08671 mW
- std-dev: 0.00343 mW

Graph showing optical output (mW) over time (h) with data points for different calibration error.

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Measurement of collimator ratio with different light levels

Calculated Coll-Ratio (Geometry):
\[ 1.23 \cdot 10^{-6} \]

Coll-Ratio
\[ 2.032 \cdot 10^{-5} \pm 1.770 \cdot 10^{-7} \]

Ratio
\[ 1.886 \cdot 10^{-5} \pm 1.231 \cdot 10^{-7} \]

Light level after collimator is one order of magnitude to big.
Measurement of light emission spectrum from integrating sphere
Comparison of NIST-calibrated photodiode with our Ophir photodiode

Light level after collimator is one order of magnitude too big.

Avg. ratio: 1.00106
Std. dev.: 0.00489
≈ 0.1% deviation
BACKUP - Single photoelectron spectrum

Poisson distribution

\[ N_1 < 1\% N_0 \]

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<td>Entries</td>
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