EUSO-TA, a JEM-EUSO pathfinder at the Telescope Array site

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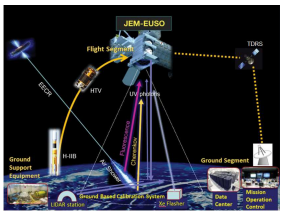
ABSTRACT: EUSO-TA is one of the prototypes of the JEM-EUSO space telescope, realized in the framework of the EUSO project. Its aims are to calibrate the detector response, test its performance in air and space, raise the technological readiness level of some of the components and improve our knowledge of the various detector systems.
EUSO-TA is located at the Telescope Array (TA) site in Black Rock Mesa, Utah, USA and is mainly devoted to study the detector response in conjunction with the TA fluorescence detector. The telescope is housed in a shed located in front of one of the fluorescence detectors of the Telescope Array experiment, pointing in the direction of the ELS (Electron Light Source) and CLF (Central Laser Facility), i.e. the artificial light sources at the Telescope Array site.
The detector consists of two Fresnel lenses, 1x1 m2 each, with a field of view of 11° x 11°, able to focus the ultraviolet light generated by cosmic-ray showers as well as from artificial sources, on a focal surface identical to the ones that will be employed in JEM-EUSO .

JEM-EUSO

The **E**xtreme **U**niverse **S**pace **O**bservatory onboard the International Space Station **J**apanese **E**xperiment **M**odule is a new type of observatory which observes transient luminous phenomena occurring in the Earth's atmosphere.

The instrument is planned to be attached to JEM/EF of ISS for a 3 years long mission.

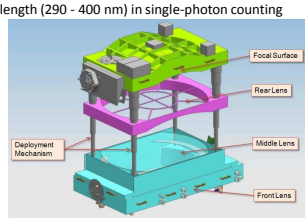
The main objective of JEM-EUSO is to study the Extreme Energy Cosmic Rays, EECR (E > 5×10[19] eV), which are the most energetic component of the cosmic radiation.

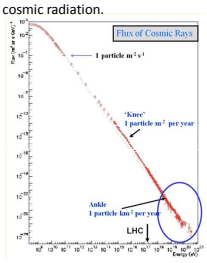


The telescope is an extremely-fast and highly-pixelized (~3·10[5] pixels) digital camera with a large diameter (2.35 m) and a wide-Field of View (FoV, ±30°). It works in near-UV wavelength (290 - 400 nm) in single-photon counting mode. The telescope consists basically of four parts:

- **Optics**: 3 high transmittance optical Fresnel lenses focusing the arriving UV photons onto the Focal Surface
- **Focal Surface detector:** - 5000 Multi Anodic PhotoMultipliers Tubes of 64 pixels
- **Focal Surface electronics**: trigger, data acquisition and controls
- **Mechanical structure**

The apparatus is completed by an atmosphere monitoring system (Infra-Red camera and Lidar) and a calibration system.



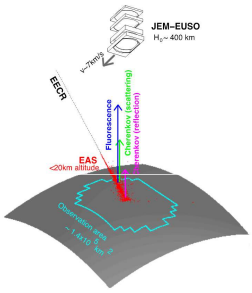


Physics and Astrophysics from E > 5×10[19] eV, focusing at E~10[20] eV (and above):

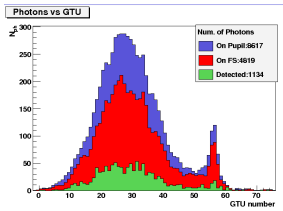
- Identification of EECR sources by high-statistics arrival direction analysis
- Measurement of the energy spectra of individual sources (spectral shape, flux, power)
- Understand and constrain acceleration and emission mechanisms

Observation from space has two main advantages:

1. The target volume is far greater than possible from the ground
2. Full sky coverage



JEM-EUSO telescope will observe fluorescence and Cherenkov UV photons generated by Extensive Air Showers (EAS) created by EECR.



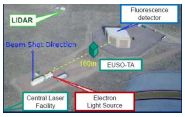
EAS development time ~ 50 - 150 μs

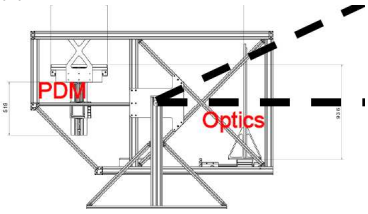
Simulation of the light profile observed at the entrance pupil and through the instrument

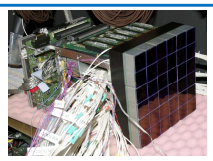
EUSO-TA

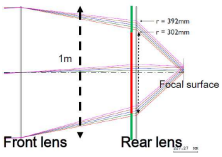
Main objective: bring to maturity the technologies for the JEM-EUSO telescope

- Calibration with Central Laser Facility (CLF), Electron Light Source of TA and portable laser (CSOM)
- Cross-calibration with TA Fluorescence Detector through comparison of noise and signal
- Observation observations of UV light generated by cosmic-ray Extensive Air Showers triggered by TA
- Tests/modifications of electronics for other EUSO experiments
- Gathering data (CR and artificial) for testing algorithms/software
- Measurement of the UV night background



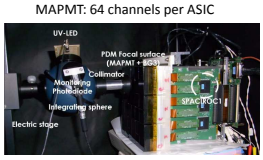






The prototype:

- 2 Φ1m Fresnel lenses
- 1 Photo Detector Module = 36 Multi-Anode PMT (MAPMTs)
- Concave focal surface
- UV transmitting filter (330-400 nm)
- Axis elevation: 26°
- FoV: ±5.5°
- Readout performed by one ASIC per MAPMT: 64 channels per ASIC



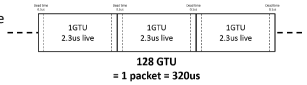
2015 campaign

February/March	- Detector installation, focusing, initial calibration - Initial CLF and CSOM laser observations
May	- Cosmic ray observations – one UHECR detected - CLF and CSOM laser observations - Flat screen and LED calibration
September	- Cosmic ray observations – analysis ongoing - CLF and CSOM laser observations
October	- Cosmic ray observations – analysis ongoing - Tests on the balloon PDM board triggering on laser - CLF and CSOM laser observations
November	- Cosmic ray observations - CLF laser observations

Data structure of EUSO-TA:

- Basic data storage unit is called a "packet"
- A packet has 128 of consecutive GTUs of Photoelectron counting data of all pixels (1byte * 2304 * 128 = 288kb)
- A GTU has 2.5us of length with 2.3us of live time

1 Packet = Data storage basic unit
2.5us(1GTU) –0.2us(dead time) = 2.3us (live time)

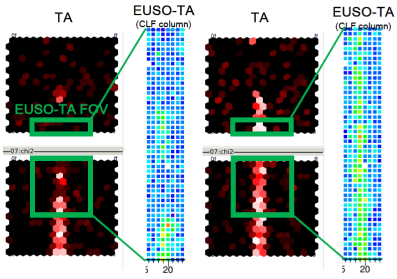


Artificial light

- Central Laser Facility (CLS) of TA
- LEDs
- Portable lasers (CSOM)
- Airplanes crossing the Field of View

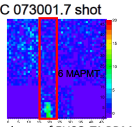
Laser shot from the CLF

- 21 km away from EUSO-TA
- Shoots a 355nm laser vertically
- Shots with energy of 4-6 mJ (2.2 mJ pulse corresponds to 1019.2 eV shower seen from 21 km)
- 300 shots per single set, 10Hz
- Twice in an hour: hh:00, hh:30
- Time evolution of the laser shot in GTUs (1 GTU = 2.5 μs)
- PDM dead time of 60 ms after data acquisition of 128 GTUs



CLF events analysis

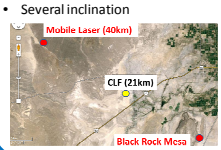
- Using 12k events, the photometric characteristics of CLF is compared
- Linear correlation between two telescopes is confirmed despite of pile-up
- Different linear coefficient for different angles (10 to 15 degrees)
- It is still not clear why correlation could be seen under pile-up condition
- Need to understand cluster structure, probably from atmospheric condition

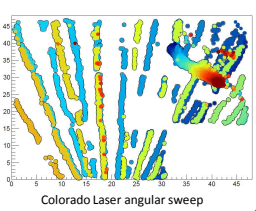


CLF column of EUSO-TA PDM

Colorado School of Mines movable laser

- 17 nights
- Distances: 24, 34, 40, 60, 100 km
- Power: 0.5mJ up to 90mJ
- Several inclination





Colorado Laser angular sweep

Cosmic Rays

3 working modes:

1. Internal trigger (undergoing testing) (not optimized for ground observations)
2. External (i.e. TA) trigger
3. Untriggered data taking

3 software triggered EAS events with TA reconstruction result

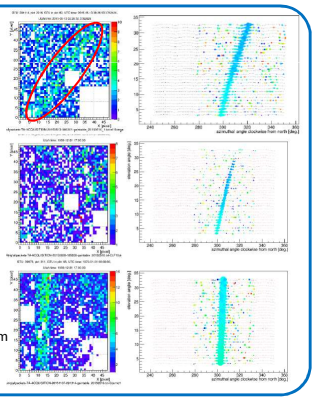
CR events analysis by Shin Hengsu,

- 3 events were distinguished as CR induced EAS events so far
- This number is low when compared to initial approximation, by using TA data, we are currently searching for CR events not seen by EUSO-TA
- Useful for estimating trigger efficiency

20150513-08:26:50.356
E = 10[17.99] eV
Distance core-telescope = 2.5km

20150920-10:59:19.309
E = 10[18.63] eV
Distance core-telescope = 6.7 km

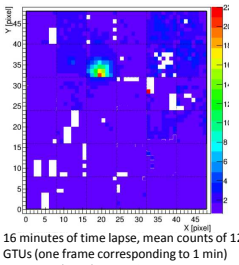
20151107-09:15:06.732
E = 10[18,37] eV
Distance core-telescope = 2.65 km



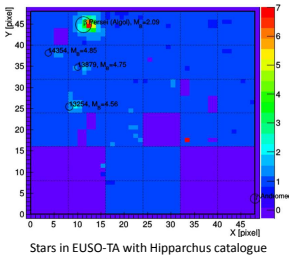
Stars and meteors

EUSO-TA has DC level (Poisson) background so it is able to see stars. Preliminary analysis shows that EUSO-TA can observe stars up to M_B = 6.5 on sums of 1280 frames (about 3.2 ms observation time). While very bright stars can be seen on single frames, such stacking allows us to get a good signal to noise ratio, with negligible star movement on the sky compared to the angular size of our pixel.

Meteors and moving of cloud possibly have been found, and are now under analysis. So far, we have 5 meteors candidates and more searching are needed. All the candidates cross the FoV in a time comprised between 1 and 2 seconds .



16 minutes of time lapse, mean counts of 128 GTUs (one frame corresponding to 1 min)
Star: Vega (α Lyr), U-V color index Mag = 0.00



Stars in EUSO-TA with Hipparchus catalogue superimposed