IL NUOVO CIMENTO Vol. 32 C, N. 3-4 Maggio-Agosto 2009
DOI 10.1393/ncc/i2009-10506-5

Colloquia: IFAE 2009

The JEM-EUSO experiment

M. Casolino(*) on behalf of the JEM-EUSO Collaboration
INFN, Sezione di Roma Tor Vergata - Rome, Italy

(ricevuto il 19 Settembre 2009; pubblicato online il 17 Dicembre 2009)

Summary. — JEM-EUSO is a space-borne cosmic ray experiment devoted to the study of Ultra-High Energy Cosmic Rays (UHECR). It will be placed with H2 transfer vehicle on the Japanese Experiment Module/Exposure Facility (JEM/EF) of the International Space Station in the mid-2010. The principle of operation is the observation in the dark side of the Earth of fluorescence and Cherenkov light emitted by UHECR showers in the atmosphere. During its 5 years of planned operation it is expected to detect at least 1000 events with energy above 7×10^{19} eV assuming Greisen Zatsepin Kuzmin (GZK) suppression spectrum, localizing possible sources and the relative spectrum.

PACS 98.70.Sa – Cosmic rays (including sources, origin, acceleration, and interactions).
PACS 43.20.Ye – Measurement methods and instrumentation.

1. – Historical overview

Charged cosmic ray flux is characterized by an almost uniform power law, from $\simeq 10^9$ eV to $\simeq 10^{20}$ eV. There are however various features which give hints on the acceleration and propagation processes: At the low end of the spectrum solar modulation effects take place and distort the power law, believed to continue below 1 GeV in interstellar space. At $\simeq 3 \times 10^{15}$ eV *(the knee)*, the power law index steepens, changing from 2.7 to 3.0 [1] changing again only at $\simeq 10^{19}$ eV. This structure, believed to arise from the stochastic process of acceleration at magnetohydrodynamic shock, results in an extremely low flux, requiring huge ground experiments to gather the statistics needed. An alternative approach to achieve large geometrical factors is to have a space-based detector, observing the fluorescence and Cherenkov light of particle showers in the atmosphere and hitting the ground.

A single wide-field telescope in space can detect a number of extreme-energy particles with $E > 10^{19}$ eV, using the dark side of Earth as a detector (fig. 1). This concept originated in various studies of a free-flyer mission concepts of the late 1990s at NASA and

(*) E-mail: casolino@roma2.infn.it

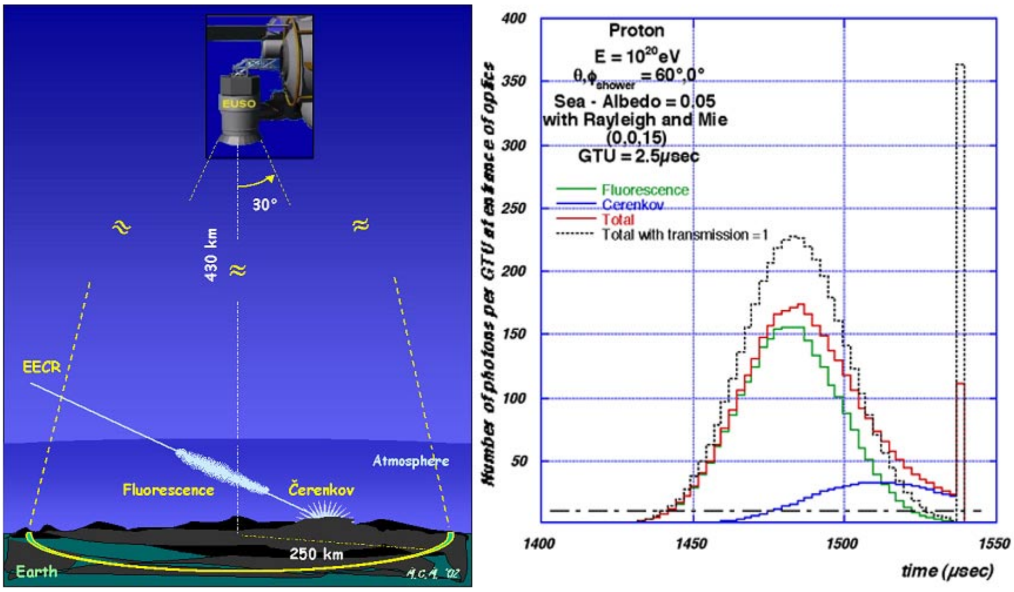

Fig. 1. – Left: principle of operation of UHECR observation from space. The fluorescent and Cherenkov light emitted by CR shower in the atmosphere is detected by a wide field lens located at $\simeq 400$ km. Right: temporal profile of the UV light emission. UV light emission grows with the shower development, reaching a maximum about $50\,\mu$s from the start. As the shower end and reach the Earth, UV emission decreases and Cherenkov light reflected from the Earth component increases. After $10\,\mu$s from the start a strong Cherenkov mark is emitted. The light emission is sampled every $2.5\,\mu$s (= 1 GTU).

in Italy, the Orbiting Wide-angle Light-collector (OWL) and Airwatch. The European Space Agency (ESA) originally selected EUSO as a mission attached to the European Columbus module of the ISS. The phase-A study was successfully completed in June 2004 under ESA contract. However, because of the financial problems in ESA and European countries, together with the logistic uncertainty caused by the Columbia accident of NASAs Space Shuttle, the start of phase-B was postponed. The JEM-EUSO (Extreme Universe Space Observatory on Japanese Experiment Module) [2] Collaboration began in 2007 with the aim to adapt the EUSO/ESA [3] concept to the JEM external facility. The experiment was selected by the Japan Aerospace Exploration Agency (JAXA) in 2007 as one of the mission candidates of the second phase utilization of JEM/EF. Phase A/B was recently completed in 2009, adapting and improving many of the concepts of EUSO/ESA.

2. – Science objectives

JEM-EUSO scientific objectives range from the observation of UHECR and identification of possible sources to the study of luminous atmospheric phenomena in space. In detail they are:

- *Astronomy and astrophysics through particle channel with extreme energies* $> 10^{20}$ eV
  - Identification of sources by the high-statistics arrival direction analysis.

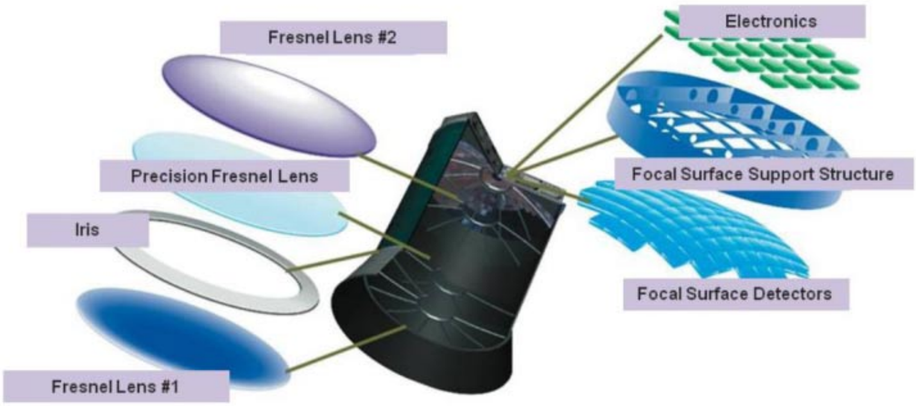

Fig. 2. – Exploded view of the JEM-EUSO experiment, showing the various parts of the optics and the focal surface.

  - Measurement of the energy spectra from individual sources to constrain acceleration or emission mechanisms.
  - Study of the Galactic magnetic field
- Search for new physics and unknown phenomena
  - Search of extreme energy gamma-rays
  - Search of extreme energy neutrinos
  - Verification of the relativity and the quantum gravity effect in extreme energy
- Atmospheric physics
  - Study of nightglows
  - Study and classification of plasma discharges
  - Study of lightning

For a detailed description of the scientific objectives of JEM-EUSO see [4, 5].

3. – JEM-EUSO telescope

The JEM-EUSO telescope is a fast, high-pixelized, large-aperture and large field-of-view digital camera, working in the near-UV wavelength range (330–400 nm) with single photon counting capability. The main components of the telescope are the collecting optics, the focal surface detector, the electronics and the structure, as shown in fig. 2. The optics system is composed of two Fresnel lenses and one diffractive precision lens. With an aperture of $\simeq 30^\circ$ field of view (FoV), the optics focuses the UV light incident onto the front lens (lens 1) toward the focal surface with a spatial resolution of 0.1°. The focal surface detector is composed by a grid of $\simeq 6000$ multi-anode photomultipliers (MAPMT) which convert the energy of the incoming photons into electric pulses with duration of

10 ns. The electronics counts-up the number of the electric pulses in time periods of 2.5 μs and records them to the memory; when a signal pattern coming from extreme energy particle events is found, the electronics issues a trigger signal and transmits all the useful data to the ground operation centre, tracking back the image information stored in the memory. For what concerns the atmosphere monitoring, JEM-EUSO will use an infrared (IR) camera and a Lidar (LIght Detection and Ranging) with ultraviolet laser to observe the conditions of the atmosphere in the FoV of the EECR telescope, with the objective of determining effective observation time, and of increasing the reliability of the events around the energy threshold. With respect to ESA-EUSO(min), JEM-EUSO reduces the role of the Lidar to the following: to observe the condition of clouds in several points of the JEM-EUSO field of view, and to calibrate with high accuracy the transformation table between altitude of cloud tops and their temperature, obtained by the analysis of the IR camera images. Being the wavelength of the laser (355 nm) in the range of interest for JEM-EUSO, the focal surface (FS) detector of the EECR telescope will be used as Lidar receiver unit.

4. – Electronics and data handling

The FS Electronics of JEM-EUSO consists of proximity electronics for the signal from the high-resolution camera. Also it has driving circuits of the camera, LIDAR and IR camera assembly, interface between JEM-EUSO and the ISS via the Japanese External Module (JEM) platform, Thermal control and Calibration, Direction, and Lid mechanism of the telescope. JEM-EUSO DAQ System is designed to maximize detector observation capabilities to meet various scientific goals, to monitor system status, autonomously taking all actions to maintain optimal acquisition capabilities and handle off-nominal situation. The DAQ system discriminates event-like signatures against various background noises based on a system trigger algorithm described in [6]. The fluorescence and Cherenkov photons coming from EAS are converted to electric charge by 36 pixel MAPMT [7]. About 5000 PMTs, *i.e.* $\sim 2\times10^5$ pixels, are mounted on the FS which has a curved surface of about 2.3 m in diameter. The signals from the MAPMT are digitalized by front-end ASIC and FPGA for the First Level Trigger. This front-end ASICs discriminate the signals from electrical noise and the FPGAs count number of photo-electrons every 2.5 μs. These digital data are delivered to the Second Level Trigger board. When the second level trigger is issued, data are delivered to higher hierarchy for the third level trigger which extract air-shower like events.

REFERENCES

[1] Gaisser T. K., *Cosmic Rays at the Knee*, in Sato K. and Hisano J. (Editors), *Energy Budget in the High Energy Universe* (World Scientific Publishing Co.) 2007.
[2] Kajino F., *The JEM-EUSO Mission to Explore the Extreme Universe, ICRC 2009 proceedings.*
[3] EUSO Collaboration, *EUSO Red Book Report on the Phase A Study*, EUSO-PI-REP-005, 2004.
[4] Takahashi Y. (The JEM-EUSO Collaboration), *New J. Phys.*, **11** (2009) 065009.
[5] Olinto A. V., Adams J. H., Dermer C. D., Krizmanic J. F., Mitchell J. W., Sommers P., Stanev T., Stecker F. W. and Takahashi Y., *Astronomy*, **2010** (2009) 293.
[6] Kawasaki Y. *et al.*, *Int. J. Mod. Phys. A*, **20** (2005) 6890.
[7] Bertaina M. *et al.*, *Int. J. Mod. Phys. A*, **20** (2005) 6872.