Overview of the JEM-EUSO Instruments

F. Kajino*, T. Ebisuzaki†, Y. Takahashi‡†, H. Mase†, A. Santangelo§, M. Teshima¶, E. Parizot||, P. Gorodetzky||, O. Catalano, P. Picozza††, I.H. Park‡‡, V. Mitev[x], G. Medina-Tanco[xi], M.I. Panasyuk[xii], B.A. Khrenov[xii], M.D. Rodriguez-Frias[xiii], J. Szabelski[xiv] and P. Bobik[xv]**
for the JEM-EUSO collaboration

*Department of Physics, Konan University, Okamoto 8-9-1, Higashinada, Kobe 658-8501, Japan
†Computational Astrophysics Lab. , RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan
‡Department of Physics, The University of Alabama in Huntsville, Huntsville, AL35899, USA
§Institut für Astronomie und Astrophysik, Universität Tübingen, Sand 1, 72076 Tübingen, Deutschland
¶Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 Munich, Germany
||APC, Univ. of Paris Diderot, CNRS/IN2P3, 10, rue A. Domon et L. Duquet, 75205 Paris Cedex 13, France
**Istituto di Astrofisica Spaziale e Fisica Cosmica di Palermo, INAF, Via Ugo La Malfa 153, 90146 Palermo, Italy
††Department of Physics, University of Rome Tor Vergata, Via della Ricerca Scientifica 1, 00133 Rome, Italy
‡‡Department of Physics, Ewha Womans University, Seoul 120-750, Korea
[x] CSEM Rue de l'Observatoire 58, Neuchâtel 2000, Switzerland
[xi] Inst. de Ciencias Nucleares, UNAM, AP 70-543 / CP 04510, Mexico D.F.
[xii] SINP, Lomonosov Moscow State Univ., Leninskie Gory 1 str. 2, Moscow, 119991, Russia
[xiii] University of Alcalá Ctra. Madrid-Barcelona, km. 33.6, E-28871, Alcalá de Henares, Madrid. Spain.
[xiv] A. Soltan Institute for Nuclear Studies, 90-950 Lodz, Box 447, Poland
[xv] Institute of Experimental Physics SAS, Watsonova 47, 040 01 Kosice, Slovakia

***Abstract*. The space mission JEM-EUSO with a large and wide-angle telescope mounted on the International Space Station has been planned to open up "particle astronomy" through the investigation of extreme-energy cosmic rays by detecting fluorescent and Cherenkov photons which accompany air showers developed in the earth's atmosphere. The telescope consists of high transmittance optical Fresnel lenses with a diameter of about 2.5m, 200k channels of multianode-photomultiplier tubes, front-end readout, trigger, and system electronics. An infrared camera and a LIDAR system will be also used to monitor the earth's atmosphere.**

***Keywords*: Extreme Energy Cosmic Rays, ISS, JEM**

I. JEM-EUSO Mission

JEM-EUSO (Extreme Universe Space Observatory on Japanese Experiment Module) on board the International Space Station (ISS) is a new type of observatory which uses the whole Earth as a detector. Extreme energy cosmic rays (EECR) coming to the earth's atmosphere collide with atmospheric nuclei and produce many secondary particles which form extensive air showers (EAS). The number of the particles reaches roughly 10^{11} for 10^{20} eV primary particles. The charged particles in EAS excite nitrogen molecules to emit near ultra-violet (UV) photons. They also produce Cherenkov photons in the cone of about 1.3°. The JEM-EUSO mission observes such fluorescent and Cherenkov photons from the ISS orbit at an altitude of about 400 km. JEM-EUSO observes a light spot moving with nearly light velocity. When it meets the ground or cloud, reflected Cherenkov photons are observed as a strong Cherenkov mark. Viewing from the ISS orbit, the Field-of-View of the telescope (±30°) corresponds to the observational area at the ground of $> 1.9 \times 10^5$ km^2[1],[2],[3],[4].

Threshold energy to detect EECRs is as low as several$\times 10^{19}$ eV. Increase in exposure is realized by inclining the telescope from nadir to tilted mode. In the tilted mode, the threshold energy becomes higher since the mean distance to the EAS and atmospheric absorption both increase. The first half of the mission lifetime is devoted to observe lower energy cosmic rays with the nadir mode and the second half of the mission to observe higher energies by the tilted mode.

JEM-EUSO will be launched by H2B rocket and conveyed by H-II Transfer Vehicle (HTV) to ISS. It will be attached to one of the ports of the Exposure Facility (EF) of the Japanese Experiment Module (JEM).

II. Instrument General

The JEM-EUSO instrument basically consists of the following systems:
- Large diameter EECR observation telescope
- Atmosphere monitoring system
- Calibration system

The JEM-EUSO telescope is an extremely-fast, highly-pixelized, large-aperture and large-FoV digital

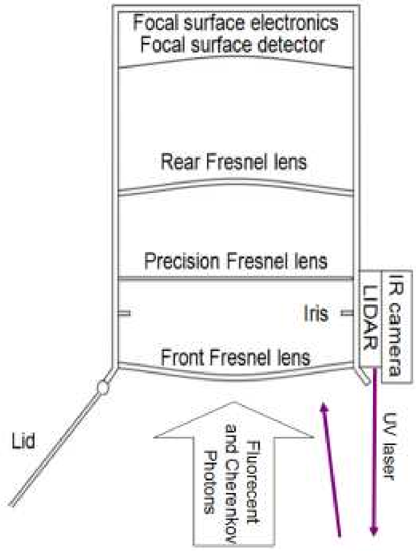

Fig. 1. Concept design of JEM-EUSO telescope.

camera, working in near-UV wavelength range (330400 nm) with single photon counting capability.

The telescope mainly consists of four parts: collecting optics, focal surface detector, electronics, and structure (Fig.1).

The optics focuses the incident UV photons onto the focal surface with an angular resolution of 0.1°. The focal surface detector converts the incident photons to photoelectrons and to electric pulses. The electronics counts the number of the pulses in a period less than 2.5 μs and records it as a brightness data. When it finds a signal pattern of EAS, it issues trigger signal. It starts a sequence to send the brightness data around the triggered pixels stored in the memory and sends them to the ground operation center. The structure encloses all the parts of the instruments and keeps them out from the outer harmful environment in space. It also keeps the lenses and the focal surface detector to the preset place.

Main parameters of the JEM-EUSO telescope are summarized in TABLE I.

TABLE I
PARAMETERS OF JEM-EUSO TELESCOPE

Field of View	$\pm 30°$
Observational area	$> 1.9 \times 10^5$ km^2
Optical bandwidth	$330 \div 400$ nm
Focal Surface area	4.5 m^2
Number of pixels	$\sim 2.0 \times 10^5$
Pixel size	4.5 mm
Pixel size at ground	750 m
spatial resolution	0.1°
Event time sampling	≤ 2.5 μs
Duty cycle	~ 20 %

Total mass of the instruments is 1983 kg and electric power is suppressed less than 1kW in operation mode. Overview of each part of the instrument is described in the following sections.

Fig. 2. Experimental manufacture of the central part of the rear Fresnel lens with a diameter of 1.5 m [6].

III. OPTICS

Two curved double sided Fresnel lenses with 2.65m external diameter, an intermediate curved precision Fresnel lens and a pupil constitute a ”baseline” optics of the JEM-EUSO telescope.

The Fresnel lenses can provide a large-aperture, wide FoV optics with low mass and high UV light transmittance. Combination of 3 Fresnel lenses realized a full angle FoV of 60° and an angular resolution of 0.1°. This resolution corresponds approximately to (0.75 - 0.87) km on the earth, depending on the location inside the FoV.

The material of the lens is UV transmitting PMMA which has high UV transparency in the wavelength from 330nm to 400nm. Prototype sample is shown in Fig. 2.

A precision Fresnel optics adopting a diffractive optics technology is used to suppress the color aberration.

Details of the optics are described in [5].

IV. FOCAL SURFACE DETECTOR

The focal surface (FS) of JEM-EUSO has a spherical surface of about 2.3 m in diameter with about 2.5 m curvature radius, and it is covered with about 5,000 multi-anode photomultiplier tubes. The FS detector consists of Photo-Detector Modules (PDMs), each of which consists of 9 Elementary Cells (ECs). The EC contains 4 units of the MAPMTs. About 150 PDMs are arranged in FS (Fig. 3). Owing to a recent technological progress, the quantum efficiency of the MAPMT will be improved to about 40%.

High-voltage divider including a protection circuit to protect the MAPMT from an instantaneous large amount of light like lightning will be used. We can operate it safely by intercepting the photoelectron multiplication at the initial stage of the dynodes.

SiPM (MPPC) with better quantum efficiency was developed for FS detector as an ”advanced option”.

See details in [7], [8].

V. FOCAL SURFACE ELECTRONICS SYSTEM

The FS electronics system records the signals of UV photons generated by EECRs at FS successively in time.

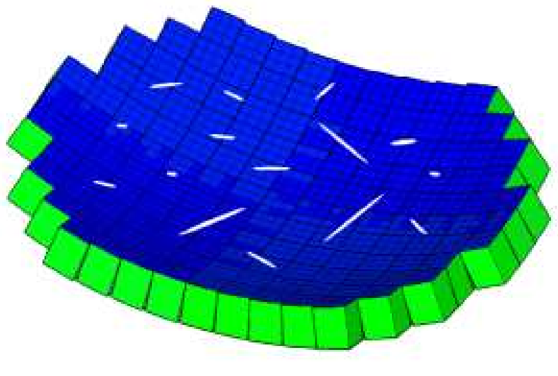

Fig. 3. Illustrated images of air showers with 10^{20} eV and various incident angles on the focal surface detector

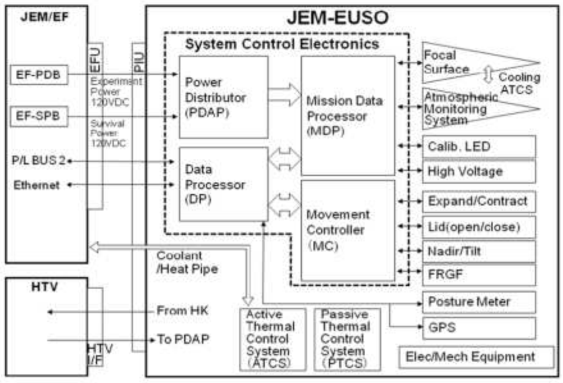

Fig. 4. Block diagram of the JEM-EUSO system functions

The system is required to keep high trigger efficiency with a flexible trigger algorithm as well as a reasonable linearity over 10^{19}-10^{21}eV range. The requirements of power consumption within 2.5mV/ch must be fulfilled to manage 2 10^5 signal channels in an available power budget. Available volume for the instruments is limited and radiation tolerance of the electronic circuits in the space environment during a scheduled operation period is also required.

The FS electronics is configured in three levels corresponding to the hierarchy of the FS detector system: front-end electronics at an EC level, PDM electronics common to 9 EC units, and FS electronics to control 150 units of PDM electronics.

Anode signals of the MAPMT are digitized and recorded in ring memories for each GTU (=2.5 μs) to wait for a trigger assertion, then, the data are read and are sent to control boards.

JEM-EUSO uses hierarchical trigger method to reduce huge original data rate of ~10GB/s/FS to 297 kbps for sending data from ISS to ground operation center

We are designing the following 3 trigger modes. a) Normal mode with a GTU of 2.5 μs for routine data taking of EAS. b) Slow mode with a programmable GTU up to a few ms, for the study of meteorites and other atmospheric luminous phenomena. c) Detector calibration mode with a GTU value suitable for the calibration runs.

See details in [9], [10], [11].

VI. Monitoring/Control Electronics System

System functions of JEM-EUSO mission is shown in Fig. 4. System control electronics consists of Data Processor (DP), Mission Data Processor (MDP) and Movement Controller (MC).

Main functions of DP are: a) Communication with MDP, MC and JEM/EF, b) House Keeping (HK) data acquisition related to mission system, c) Interface function which distributes clock signal from GPS to MDP.

MDP acquires observation data from FS detector, atmospheric monitor and HK data, and then sends data to DP.

MC accepts signals from DP and controls movable mechanisms.

VII. Atmosphere Monitoring System

Atmosphere Monitoring System (AMS) monitors the earth's atmosphere continuously inside the FoV of the JEM-EUSO telescope. Intensity of the fluorescent and Cherenkov light emitted from EAS at JEM-EUSO depends on the transparency of the atmosphere, the cloud coverage and the height of cloud top, etc...

These must be determined by AMS of JEM-EUSO. In case of events above 10^{20} eV, the existence of clouds can be directly detected by the signals from the EAS. However, the monitoring of the cloud coverage by AMS is important to estimate the effective observing time with high accuracy and to increase the confidence level in the events just above the energy threshold of the telescope.

The AMS and its specifications are as follows. (Fig. 5)

- Infrared (IR) camera : 11-13 μm, FoV=60°, 7.7×10^4 pixels
- Lidar : 355 nm, 50 Hz, 20 mJ/pulse
- Slow data of the JEM-EUSO telescope

These elements are planned to measure the height of cloud top with an accuracy better than 500 m at least.

See details in [12].

VIII. Calibration System

The calibration system measures the efficiencies of the optics, the focal surface detector and the data acquisition electronics with a precision necessary to determine energy and arrival direction of the EECRs.

The calibration system consists of the following categories (Fig. 5) :

- Pre-flight calibration
- On-board calibration
- Calibration in flight with on-ground instruments
- Atmospheric monitor calibration

The pre-flight calibration of the detector will be done by measuring detection efficiency, uniformity, gain etc. with UV LED's for several kinds of wavelength.

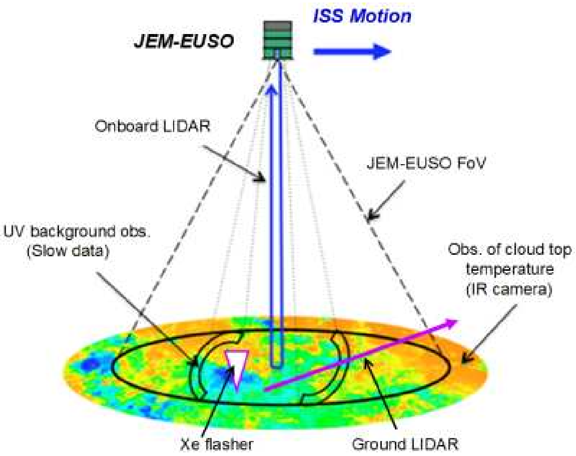

Fig. 5. Concept of the atmosphere monitor and the calibration.

To measure efficiencies of FS detector, several diffuse light source of LEDs with different wavelengths in the near UV region, are placed at the support of the rear lens before FS, and illuminate FS. To measure efficiencies of the lenses similar light source is placed at the center of FS. Reflected light at the inner surface of the lid is observed with FS. In this way, the gain and the detection efficiency of the detector will be calibrated on board.

The system can be calibrated with 10-20 ground light sources when JEM-EUSO passes over them. The amount of UV absorption in the atmosphere is measured with Xe flasher lamps. The systematic error in energy and direction determination will be empirically estimated, by observing emulated EAS images with a UV laser by the JEM-EUSO telescope. The transmittance of the atmosphere as a function of height will be also obtained.

The IR camera as a FoV monitoring system takes pictures periodically in observation and the effective area will be estimated.

See details in [13].

IX. Structure Analysis

To accommodate JEM-EUSO into a volume of the HTV transfer vehicle, a contractible/extensible structure is adopted. The structure is stowed at launch by H2B rocket and it is extended at JEM/EF of ISS as shown in Fig. 6. Structure analysis for vibration showed that the minimum natural frequency for launch mode was 25.6 Hz and that for the observation mode it was as high as 1.7 Hz. Both of them satisfied the requirements.

X. Thermal Analysis

Thermal analysis has been done for two cases of MAPMT and SiPM as the FS detector. Special cooling device is not necessarily for the MAPMT detector for the operation. To operate SiPM lower temperature than 0° is required to reduce background noises. We continue the analysis for this case.

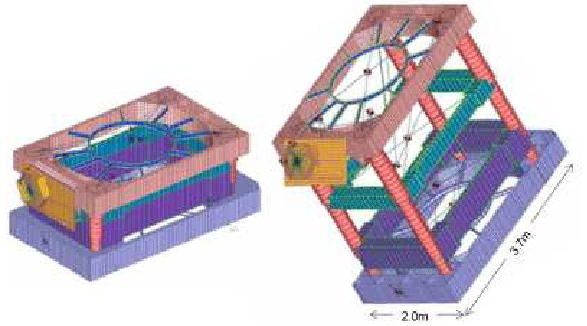

Fig. 6. Structure simulation model for stowed launch mode (left) and for tilted observation mode (right).

XI. Expected Performance

JEM-EUSO will observe the fluorescence light from EAS together with the background light emitted from the surface of earth and airglow sources. Therefore, optimized EAS triggering method will be required to acquire the EAS events efficiently with the best S/N avoiding fake triggers by background light components.

The threshold energy of JEM-EUSO in nadir mode (50% trigger efficiency) is 5×10^{19}eV, and the trigger efficiency at 10^{20}eV is 86%. The threshold energy for showers observed in a FoV of 15 degrees can be lowered down to 3.7×10^{19}eV because of a better efficiency of the optis in the center of view, and due to the smaller distance of the EAS axis to the detector.

The threshold energies rises by the tilt mode observation due to longer distance to EAS axis. However, the increase of the acceptance by the tilt mode observation has an important advantage over it.

See details in [14].

XII. Conclusions

JEM-EUSO is a new type of space mission and many new technological items have been developed to realize the mission by inheriting ESA-EUSO. Phase A study of JEM-EUSO mission (feasibility study and conceptual design) started in September 2007 and the study is now successfully in progress.

References

[1] T. Ebisuzaki et al., Nucl. Phys. B (Proc. Suppl.) Vol. 175-176 p. 237 (2008).
[2] JEM-EUSO homepage: http://jemeuso.riken.jp/
[3] T. Ebisuzaki et al. (JEM-EUSO collab.) , Proc. 31st ICRC, 2009.
[4] G. Medina-Tanco et al. (JEM-EUSO collab.), Proc. 31st ICRC, 2009.
[5] Y. Takizawa et al., (JEM-EUSO collab.), Proc. 31st ICRC, 2009.
[6] K. Maekawa et al., (JEM-EUSO collab.), Proc. 31st ICRC, 2009.
[7] Y. Kawasaki et al., (JEM-EUSO collab.), Proc. 31st ICRC, 2009.
[8] H. Miyamoto et al., (JEM-EUSO collab.), Proc. 31st ICRC, 2009.
[9] F. Kajino et al., (JEM-EUSO collab.), Proc. 31st ICRC, 2009.
[10] O. Catalano et al., (JEM-EUSO collab.), Proc. 31st ICRC, 2009.
[11] M. Casolino et al., (JEM-EUSO collab.), Proc. 31st ICRC, 2009.
[12] S. Wada et al., (JEM-EUSO collab.), Proc. 31st ICRC, 2009.
[13] P. Gorodetzky et al., (JEM-EUSO collab.), Proc. 31st ICRC, 2009.
[14] N. Inoue et al., (JEM-EUSO collab.), Proc. 31st ICRC, 2009.