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Instrument Overview of the JEM-EUSO Mission

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Abstract: JEM-EUSO with a large and wide-angle telescope mounted on the International Space Station (ISS) has been planned as a space mission to explore extremes of the universe through the investigation of extreme energy cosmic rays by detecting photons which accompany air showers developed in the earth's atmosphere. JEM-EUSO will be launched by Japanese H-II Transfer Vehicle (HTV) and mounted at the Exposed Facility of Japanese Experiment Module (JEM/EF) of the ISS in the second phase of utilization plan. The telescope consists of high transmittance optical Fresnel lenses with a diameter of 2.5m, 200k channels of multianode-photomultiplier tubes, focal surface front-end, readout, trigger and system electronics. An infrared camera and a LIDAR system will be also used to monitor the earth's atmosphere.

1. Overview of the Instruments of the JEM-EUSO mission

Extreme energy cosmic rays (EECR) coming to the earth's atmosphere collides with nucleus and produces many secondary particles to form an extensive air shower. The number of the particles reaches roughly 10^{11} for 10^{20}eV primary particles. This number is proportional to the energy of the primary particles. The charged particles in EAS excite the nitrogen molecules to emit near UV photons. They also produce Cherenkov light in the cone of about 1.3 degree. JEM-EUSO mission observes such near UV fluorescent and Cherenkov photons from the ISS orbit at an altitude of about 400 km. JEM-EUSO observes such light spot moving in nearly light velocity. When it meets the ground or cloud, the Cherenkov light reflected at them is observed as strong Cherenkov mark. [1],[2]

JEM-EUSO instrument is divided into four parts; optics, focal surface detector, electronics, and structure. Optics focuses the UV light (330nm-400nm) incident to the front lens onto the focal surface with an angular resolution of 0.1 degree. Focal Surface detector converts the incident photons to photoelectrons and to an electric pulse. The electronics counts the number of photons in the period of 2.5 microseconds and records as a brightness of a pixel. When it finds a signal pattern came from EAS, it issues trigger signal. It starts a sequence to send the all the brightness data close to the triggered pixels stored in the memory and send to the ground operation center. Structure encloses all the parts of the instruments and keeps them out from the outer harmful environment in the space. It also keeps the lenses and focal surface to the preset place.
JEM-EUSO plans to reduce the threshold energy of EAS down to as low as 10^{19}eV and increase the exposure. The reduction of threshold energy may realize 1) new material and improved optics design, 2) higher quantum efficiency detector, and 3) improved trigger algorisms. The increase in exposure is realized by inclining the telescope from nadir (tilted mode). In this tilted mode, the threshold energy gets higher since the mean distance to EAS and atmospheric absorption both increase. First half of the mission lifetime is devoted to lower energy in the nadir mode and second half of the mission to high energy by the tilted mode.

Overview of the instruments is mentioned in the following sections.

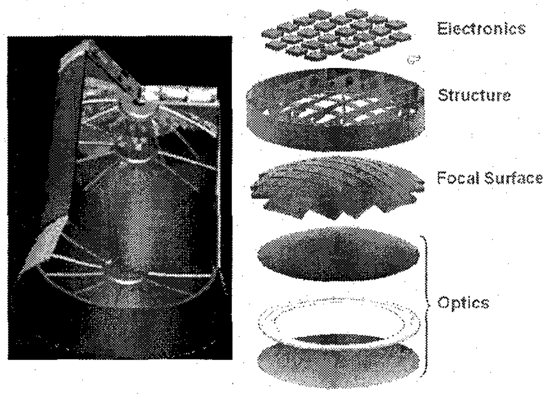

Fig. 1 Configuration of the JEM-EUSO telescope

2. Optics

A double Fresnel lens module with 2.5m external diameter is the baseline optics for the JEM-EUSO Telescope, which observes the 330nm - 400nm optical bandwidth. Fresnel lenses can provide a large-aperture, wide Field of View (FoV) system with reduced mass and low absorption. Its telescope has a full angle FoV of 60° and a 6 arcmin (=0.1°) angular resolution. This resolution corresponds approximately to (0.75 - 0.87) km on the earth, depending on the location inside the FoV.

JEM-EUSO (min) optics design is described as follows.
1) Material of the lens is UV transmitting fluoropolymer (CYTOP, ASAHI GLASS CO., LTD. JAPAN), which has high UV transparency of 99% (15mm thickness) in the wavelength from 330nm to 400nm.
2) Mass of the optics is 480kg. The density of CYTOP is about twice as much as the UV-PMMA.
3) CYTOP has ~50% smaller dispersion than the commercial UV-PMMA. Furthermore, we use the diffractive optics technology to suppress the color aberration. A diffractive plane is arranged between the iris and the rear lens. This arrangement copes with an easy construction of the telescope as well as its performance.
Overall light-collecting power of JEM-EUSO is about 1.5 times better than ESA-EUSO (min).

Details of the optics are shown elsewhere [3].

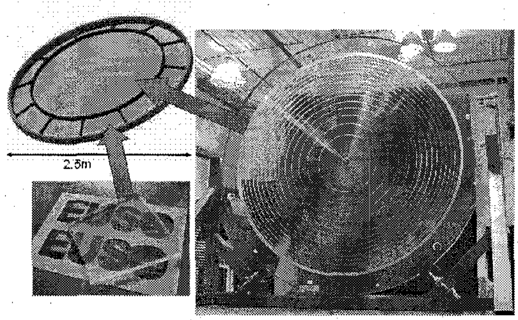

Fig. 2 Fresnel lenses of the JEM-EUSO consisting of a central lens and peripheral petal segments

3. Focal Surface Detector

The focal surface of JEM-EUSO has a curved surface of about 2.5m in diameter, and it is covered with about 6,000 multi-anode photomultiplier tubes (Hamamatsu R8900-M36: MAPMT). The focal surface detector consists of Photo-Detector Modules (PDMs), each of which consists of 9 Elementary Cells (ECs). The EC contains 4 units of the MAPMTs. Therefore, about 150 PDMs are arranged on the whole of the focal surface (Fig. 3).

A high voltage power supply for the MAPMT is set one unit on each PDM. A photoelectron is multiplied to about $3x10^5$ electrons in the MAPMT. The output pulse signals of the MAPMT are fed into ASICs (Application Specific Integrated Circuit) which are included in the front-end electronic circuits.

Fundamental design of the JEM-EUSO focal surface succeeds the design of ESA-EUSO. Owing to the recent technological progress, the quantum efficiency of the MAPMT will be improved to about 30-40%.
We are developing a high-voltage divider including a protection circuit. It protects the MAPMT from an instantaneous large amount of light like the lightning. We can operate it safely by intercepting the photoelectron multiplication at the initial stage of the dynodes using a Photo-MOS relay.

Details of the focal surface detector are shown elsewhere [4].

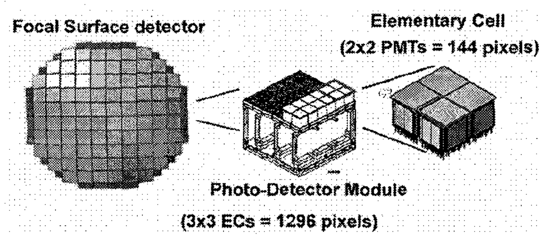

Fig. 3 Focal surface detector

4. Electronics

The electronics system of JEM-EUSO consists of focal-surface electronics subsystem and monitoring/control subsystem of the detector instruments.

The focal-surface electronics subsystem records the signals of UV photons generated by EECRs at the focal surface successively in time. 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 a power consumption within 2-3mV/ch must be fulfilled to manage 200k 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 focal-surface electronics is configured in three levels corresponding to the hierarchy of the focal-surface detector system : front-end electronics at an EC level, nine of which are consolidated to a PDM level. An FS level electronics controls about 150 PDM level electronics.

Photoelectrons in the MAPMT are multiplied and output signals are fed into a front-end ASIC. The ASIC provides pulses with a width proportional to the input charge.

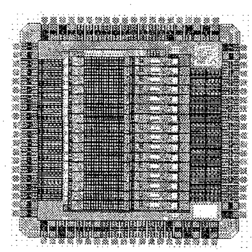

Fig. 4 Layout of the front-end ASIC based on a new method using a submicron CMOS process

Output signals are discriminated by a comparator and the pulse widths are digitized. In order to compensate for channel-to-channel gain variation the threshold voltage of the comparator is adjustable for each pixel, which covers from a fraction of a single-photon-level to several-photon level. The digitized signals of the comparator in a 2.5μs interval (GTU) count up with a 10-bit scalar. The scalar counts are recorded in a ring memory for each GTU to wait for a trigger assertion, then, the data are readout and are sent to a readout-and-control (ROC) board. The depth of the ring memory is designed to compensate for the trigger latency, which is tentatively 128.

The dynode signal is utilized to supplement the anode signal; the dynode signal is integrated and recorded in an analog memory. Once the trigger condition is met, the signals stored in the analog memory are digitized by an analog-to-digital converter, then, transmitted to the ROC board of the photo-detector module via a serial transmission line.

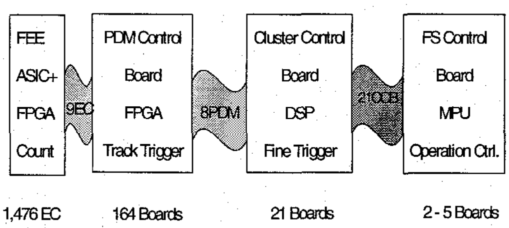

Fig. 5 Outline of the data processing system

JEM-EUSO uses "Truck trigger method", which searches the light point moving with the light speed at 400km ahead. This method reduces the threshold energy. [5]

We are designing three trigger modes:
A) Normal mode with a GTU of 2.5μs 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. [6]

Calibration of JEM-EUSO instrument will be performed by many methods.[6]

5. Atmospheric Monitoring

Atmospheric monitoring system of JEM-EUSO observes the earth's atmosphere continuously inside the FOV of the JEM-EUSO telescope. This observation provides key parameters for the energy estimation of an extreme energy particle, since the intensity and the atmospheric transmittance of the fluorescence and Cherenkov emissions strongly depend on the atmospheric conditions, especially on the cloud amount and cloud-top altitude. The atmospheric monitoring onboard the JEM-EUSO telescope would permit to correct the JEM-EUSO acceptance due to cloud interference and to introduce correcting factors in the observed EAS parameters. Thus, the present concept for the atmospheric monitoring of JEM-EUSO is based on the use of a complex of sensors in synergy with each other, which have a small impact on the overall budget: (A) Infrared camera, (B) Lidar, and (C) JEM-EUSO slow-data.[7]

6. Conclusions

JEM-EUSO had inherited ESA-EUSO and developed many new items to improve the observation feasibility of EECR. As a result collection efficiency of photons from EECR has been remarkably increased and the observable energy threshold decreased. One year long phase A study under JAXA will be carried out this year.

7. Acknowledgements

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