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Instrument Overview of the JEM-EUSO Mission

JEM-EUSO COLLABORATION
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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.

Overview 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 (EAS). 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 nitrogen molecules to emit near UV photons. They also produce Cherenkov photons in the cone of about 1.3 degree. The 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 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. [1], [2]

The JEM-EUSO telescope consists of four parts; 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 degree. The focal surface detector converts the incident photons to photoelectrons and to electric pulses. The electronics counts the number of photons in the period of 2.5 μs and records 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 the space. It also keeps the lenses and the focal surface detector to the preset place.

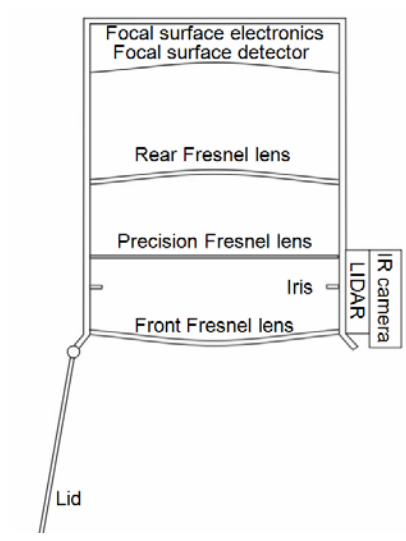

Figure 1: Configuration of the JEM-EUSO telescope

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 the threshold energy is realized by 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 to tilted mode. In the tilted mode, the threshold energy becomes higher since the mean distance to the EAS and atmospheric absorption both increase. First half of the mission lifetime is devoted to observe lower energy cosmic rays with the nadir mode and second half of the mission to higher energy by the tilted mode.

Overview of the instruments is mentioned in the following sections.

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 wavelength. 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.
Material of the lens is UV transmitting fluoropolymer (CYTOP) which has high UV transparency of 99% with 15mm thickness in the wavelength from 330nm to 400nm. CYTOP has ~50% smaller dispersion than the commercial UV-PMMA.

Figure 2: A prototype model of the Fresnel lens of the JEM-EUSO telescope with a diameter of 1m.

A precision Fresnel optics utilized a diffractive optics technology is used to suppress the color aberration. This arrangement copes with an easy construction of the telescope as well as its performance. Details of the optics are shown in [3].

Focal Surface Detector

The focal surface (FS) 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. 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 30-40%.

High-voltage divider including a protection circuit has been developed. 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. Details of the focal surface detector are shown in [4].

Electronics

The electronics system of JEM-EUSO consists of FS electronics subsystem and monitoring/control subsystem of the detector instruments (Fig. 4).

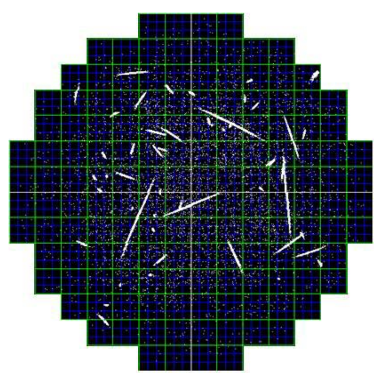

Figure 3: Images of simulated air shower events on the focal surface with 1020eV and various incident angles. Fifty events are super imposed. (EC : blue line, PDM : green line)

The FS electronics subsystem records the signals of UV photons generated by EECRs at FS 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 power consumption within 2-3mV/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, nine of which are consolidated to a PDM level. An FS level electronics controls about 150 PDM level electronics.

Anode signals of the MAPMT are digitized and recorded in ring memories for each GTU to wait for a trigger assertion, then, the data are readout and are to control boards.

Dynode signals are utilized to supplement the anode signals which are integrated and recorded in analog memories. Once the trigger condition is met, the signals stored in the memories are digitized and sent the control board.

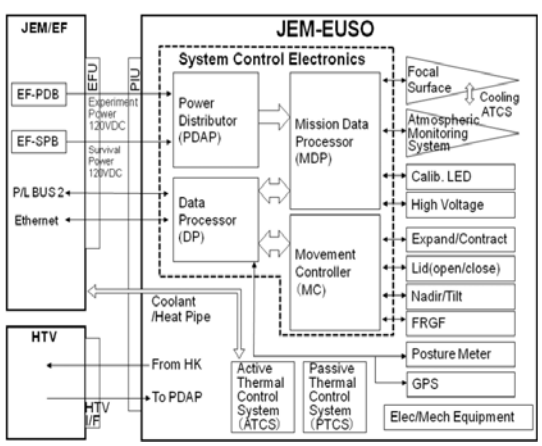

Figure 4: Block diagram of the JEM-EUSO system functions

JEM-EUSO uses “Truck trigger method”, which searches the light point moving with nearly the light speed at 400 km ahead. This method is effective to reduce the threshold energy. [5]

We are designing following 3 trigger modes. [6]
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.

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) (Fig. 4).

- 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 control movable mechanisms.

Atmospheric Monitoring

Atmospheric monitoring system monitors the earth’s atmosphere continuously inside the FoV of the JEM-EUSO telescope. This observation provides key parameters for the energy estimation of EECR, 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 acceptance due to cloud interference and to introduce correcting factors in the observed EAS parameters. Thus, the present concept for the atmospheric monitoring 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. See details in [7]

Calibration

Instrument calibration is one of the most important issues in order to discuss the reliable absolute energy of extreme energy particles. The following calibration methods are proposed.
a) 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.
b) A diffuse light source of 3 LED's with different wavelengths in near UV region is placed at the center of FS, and the reflected LED 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.
c) An IR camera (11-13μm) as a FoV monitoring system takes pictures periodically on observation and the effective area will be estimated.
d) The system can be calibrated with 10-20 ground light sources when JEM-EUSO passes over them. 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.

Expected Performance

Air fluorescence light from EAS has to be observed in a 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. Fig. 5 shows trigger efficiencies vs. energy for JEM-EUSO with an assumption of background intensity of 300 photons/m^2/sr/ns. EAS threshold energies in JEM-EUSO have been estimated to be 2.2×10^{19}eV at 50% detection efficiency. The threshold energies of EAS observed within the FoV of 15 degrees could be lowered by 50% because of smaller distance to EAS axis and a better optical efficiency at the center of view. The tilt mode observation with a tilt angle of 45º shows that the threshold energies rises by 70% due to longer distance to EAS axis. However, the increase of the acceptance by the tilt mode observation has an important advantage over it. Conclusive estimations on threshold energies will be derived from the current end-to-end simulation.

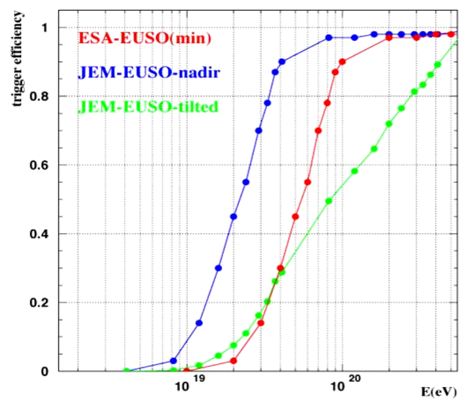

Figure 5: Trigger efficiencies vs. energy for ESA-EUSO(min) (red line) and JEM-EUSO (vertical mode: blue line and tilt mode: green line)

Conclusions

JEM-EUSO had inherited ESA-EUSO and developed many new technological 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 fairly decreased. One year long phase-A study under JAXA will be carried out this year.

Acknowledgements

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