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Atmospheric Monitoring System of JEM-EUSO Mission

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Abstract: The Extreme Universe Space Observatory on JEM/EF (JEM-EUSO) will study extreme energy cosmic rays by their optical yield in the atmosphere. To evaluate this yield it is important to monitor the atmosphere inside the field-of-view (FOV) of JEM-EUSO receiver. This monitoring shall permit the correction of the JEM-EUSO signal, where the critical parameters are the cloud presence and cloud top altitude. The Atmospheric Monitoring System will be based on a complex of sensors, containing infrared (IR) camera, Lidar, and JEM-EUSO "slow-data". The IR camera will acquire images of the cloud top temperature covering the JEM-EUSO FOV, with relatively low precision of cloud-top determination. High-precision (approx 30m) cloud-top altitude measurements will be performed by Lidar. The Lidar will probe in three fixed directions. The optical background signal in the UV, detected by JEM-EUSO will allow imaging of the cloud field inside its FOV (EUSO "slow-data" operation). The "stereoscope" processing of this image will provide additional low-resolution evaluation of the cloud top altitude.

Introduction

The Extreme Universe Space Observatory on JEM/EF (JEM-EUSO) observes the night side of the earth to detect fluorescence and Čerenkov emissions from extensive air showers generated by the Extreme Energy Cosmic Rays (EECR) (over 5×10^{19} eV) with a time resolution of 2.5 μs and a spatial resolution of 800×800 m at the ground surface. In order to evaluate the optical yield in the atmosphere, JEM-EUSO will equip the atmospheric monitoring system which consists of a complex of instruments.

The objective of the atmospheric monitoring system is to observe 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 Čerenkov emissions strongly depend on the atmospheric conditions, especially on the cloud amount and cloud-top altitude. In the Phase A study of ESA-EUSO it was planned to employ a Lidar (Light Detection and Ranging) system with capabilities to scan the laser beam in the Lidar receiver field of view (FOV), so it covers completely the FOV of the EUSO telescope. This was planned via the use of a large aperture and complicated scanning device. In addition, the Lidar was supposed to use a separate telescope. As the Lidar telescope size shall be kept small in comparison to the EUSO telescope. This implied increased requirements on the laser power. Such Lidar proved to have a significant impact on the overall mass and power budget. Moreover, recent results of numerical simulations revealed that the existence of clouds is easily identified using the backscatter fluorescence and Čerenkov emissions of extensive air showers (EAS) generated by EECR.

However, the existence of instruments for the atmospheric monitoring 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) Elastic backscatter Lidar,

(C) UV background detection or ”slow-data”.

The Infrared Camera

The objective of the infrared (IR) camera is to obtain IR images of the cloud-top temperature inside FOV of the JEM-EUSO telescope. Using these images and the Lidar data, contour maps of the clout-top altitude and the derivative cloud coverage can be estimated. These parameters will be used to correct the JEM-EUSO acceptance.

One IR camera which detects middle-IR intensities is installed at the JEM-EUSO telescope. As shown in Figure 1, the IR camera consists of Ge dioptric lenses, a band-pass filter and an uncooled micro-bolometer array detector. The bandwidth of the interference filter is 11-13 μm. The FOV and the angular resolution of the IR cameras are 60° and 0.25° (at the FOV center), respectively. By calibrating the sensor background and gain homogeneity using the onboard shutter and mirror and the sea surface temperature data, it is possible to estimate the absolute cloud-top temperature with the absolute temperature accuracy of 3 K. Though the IR images are continuously acquired with the video frame rate (= 1/30 sec), the actual data storage will be performed every 30 sec which corresponds to the time interval that ISS travels the $\sim$1/2 of JEM-EUSO FOV. The specifications for the IR camera are summarized in Table 1.

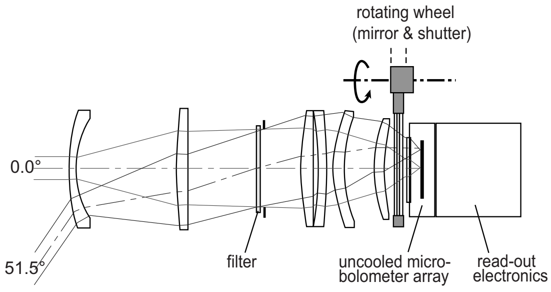

Figure 1: Schematic illustration of IR camera design.

Table 1: Specifications for IR camera.

Parameter	Target value
Temperature range	220-300 K
Wavelength	11-13 μm
FOV	60°
Spatial resolution	0.25°
Absolute temp. res.	3 K
Exposure time	33 ms/image
Mass	7 kg
Dimensions	200 × 280 × 320mm
Power (operative)	20 W

It is the most advanced point for the micro-bolometer array that the detector works stably without using an active cooling system, though the conventional semi-conducting IR detectors (HgCdTe, CaAs, InGaAs, etc.) need such systems. This enables us to develop more light, compact and low power-consuming instruments easily. Recently, numerous IR sensors equipped with the uncooled micro-bolometer array detector were developed and launched by the Space Shuttle (STS-58 mission) and Mars Odyssey spacecraft. In the Planet-C/VCO (Venus Climate Orbiter) mission scheduled to be launched in 2009 by JAXA same micro-bolometer array sensor is adopted as a detector of a middle-IR camera. In addition, the Ge dioptric system with wide FOV for a middle-IR camera has been developed in the SPF (Stratospheric Platform) project led by JAXA. We develop the IR camera for the JEM-EUSO mission in collaboration with the PIs of the IR cameras of VCO mission and SPF project.

The Backscatter Lidar

The objectives of the Lidar as part of the JEM-EUSO atmospheric monitoring system are as follows:

(A) To provide absolute measurements of the range to the top of the opaque clouds in three directions into the FOV of the JEM-EUSO telescope. These measurements will be used to calibrate the assessment of the cloud top altitude provided by the IR camera via the evaluated cloud top temperature.

(B) To provide a tool for calibration of the JEM-EUSO efficiency, using the molecular backscatter

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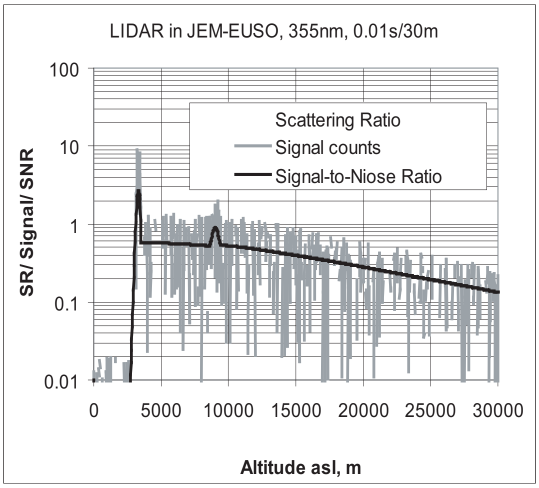

Figure 2: Backscatter signal and signal-to-noise ratio for the proposed Lidar, with integration time of 0.01 sec (one laser shot). See the text for explanations.

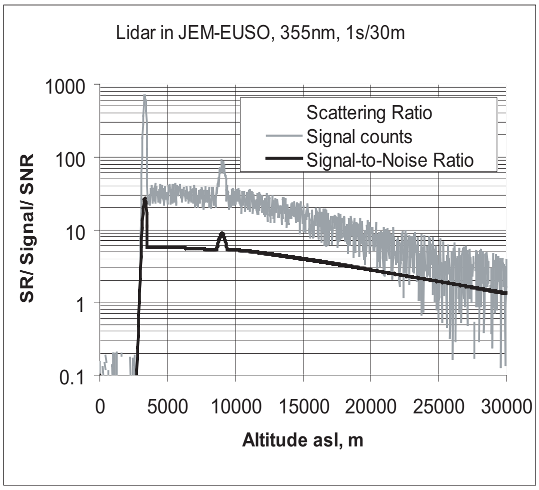

Figure 3: Backscatter signal and signal-to-noise ratio for the proposed Lidar, with integration time of 1 sec. See the text for explanations.

Table 2: Specifications of the proposed Lidar subsystems.

Parameter	Target value
Wavelength	355 nm
Pulse repetition rate	100 Hz
Pulse energy	10 mJ
Laser beam divergence	0.5 mrad
Range resolution	30 m
Probing directions	nadir, ±15°
Mass (total/only laser)	17 kg / 15 kg
Dimensions (one laser)	450 × 350 × 250 mm
Power (operative)	< 75 W

signal (from the laser beam) and/or the signal scattered from cloud top and surface.

(C) To provide evaluation of the albedo of the sea and land-mass surface.

The proposed Lidar will be a backscatter type using wavelength in the UV spectral range, *i.e.*, coinciding with the wavelength of the atmospheric trace of the EECR. In this way it is possible to use the JEM-EUSO telescope as Lidar receiver, by this achieving two targets:

(a) Operation with large size receiver decreases the requirements to the laser power, what decreases the power budget.

(b) The necessity to have a separate telescope is cancelled what saves mass and volume.

The Lidar will use three laser diode (LD) pumped Nd:YAG lasers with third harmonic conversion, having pulse repetition rate of 100 pps. Each laser will cover one of the probed directions. The baseline pulse energy is 10 mJ. The optical filters and the PMT will be of the same or similar types as in the JEM-EUSO receiver. The specifications and an evaluation of the mass, size and power budget for such Lidar are given in Table 2. Figures 2 and 3 preset results from numerical performance simulations of the Lidar (one probing direction only).

The results in Fig. 2 show that the detection of the cloud-top is possible with SNR$>$2 with this Lidar configuration. This makes possible to have 10 measurements in one detection pixel of the JEM-EUSO receiver. The results in Fig. 3 demonstrates that a detection of even sub-visible cloud is achievable with integration time of 1 sec. Also, the detection of the molecular backscatter signal above and below the subvisible cloud is also possible, allowing both the evaluation of the cloud attenuation and using the molecular backscatter signal for calibration of selected JEM-EUSO detectors.

The proposed Lidar is similar in its concept to already operating space Lidars as GLAS [1] and CALIOP-CALIPSO [2].

JEM-EUSO Background Measurements ("slow-data")

The objectives of the "slow-data" are as follows:

(A) To measure background UV emissions continuously. These measurements will be used to estimate clout top altitude by a stereo image analysis, presently applied in processing of IR images [3], [4].

(B) To detect atmospheric luminous phenomena such as lightning-associated transient luminous events (sprites, elves, blue jet), nightglow and meteors.

All of the Photo-Detector Modules (PDMs) locating at the JEM-EUSO focal surface will be equipped with the "slow-data". Usually, photoelectron signals are converted into digital signals and counted by the front-end ASIC. The scaler counts are recorded in a ring memory for each GTU (2.5 μs). In addition to this, the scaler counts for the time interval of 20 GTU (50 μs) are also recorded every 3.5 sec without using trigger. Thus, the background UV images are continuously obtained by these PDMs. Since the two lines of PDMs would look spatially separated area, the cloud top altitude can be estimated by a stereo image analysis.

In addition to the UV background reflected from the surface the "slow-data" will detect also the night glow in the wavelength between 330-400 nm, where stripes (width of ~40 km) of the emission are associated with the propagation of gravity waves. Above the thunderclouds many transient luminous events whose optical emission typically lasts several milliseconds can be also observed by the JEM-EUSO "slow-data".

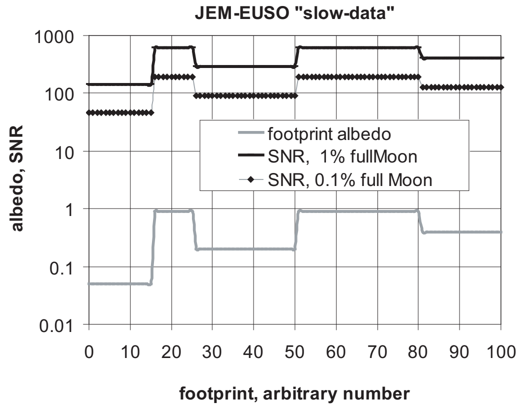

Figure 4: Signal-to-noise ration for JEM-EUSO detection of the UV back reflected from surface with different albedo.

Figure 4 presents results of simulations, showing the SNR of detection of the UV background respectively at illumination level of 1% and 0.1% of the full Moon. The horizontal axis presents an arbitrary model of the observed surface. The number of observed footprint of JEM-EUSO pixel on the surface is arbitrary. The numbers from 15 to 25 and from 50 to 80% clouds with albedo 0.9, shown on the vertical axis. The other numbers present sea-surface and various land surface. The vertical axis presents the model surface albedo, as well as the SNR of back-reflected UV background for the different illuminations. As we may see from the figure, the SNR is sufficient to distinguish between the cloud top and the sea or land surface, *i.e.*, providing the possibility to apply the "stereoscopic vision" method.

References

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