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EUSO Instrument: Concept and Solutions

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The EUSO (Extreme Universe Space Observatory) telescope is a compact instrument assisted by an Atmospheric Sounding device. The telescope is basically a large-aperture and large Field of View digital camera working on the near UV wavelength (330-400 nm) with high pixelization and fast Multi-Anode detectors operating in single counting mode and charge integration.
EUSO phase A study has been successfully completed on July 2004. The project is waiting for a formal decision by the Space Agencies (ESA, NASA, JAXA, ASI) involved to proceed with the phase B study. An overview of the up-to-date configuration of the telescope is reported, with the related description of all the various parts of the Instrument.

1. Introduction

This paper reports on the Instrument EUSO (Extreme Universe Space Observatory) configuration as resulting from the Phase A study successfully completed on July 2004. The EUSO scientific case, goals and detailed technological solutions are described in several contributions to this Conference [1]. A more completed and detailed description of EUSO is available in "The EUSO RedBook – Report on the Phase A study" [2]. We will describe the concept and adopted solutions for the Instrument coming out from a joint study of the members of the EUSO collaboration and ESA-NASA-JAXA Space Agencies. It should be noted that the simplicity and reliability of a system is very important in Space experiments. The payload, normally, has a limited budget for mass, volume, power and funding. It is necessary to make the best possible use of these budgets in the contest of the mission requirements. The approach used in designing the EUSO Instrument takes into account such limitations offering a possible solution in term of feasibility to the stringent requirements for such intriguing enterprise. Technical and operative feasibility as well as components Space-qualified availability has been checked and discussed with the Industries and Space Agencies involved in the project all the time during the phase A study.

2. Observational approach

The idea of EUSO is based on the property that charged particles interacting with air molecules produce light in the UV range (330-400 nm). This property has been used successfully for ground observation of EAS (Extensive Air Showers) by previous experiments such as Fly's Eye and currently by Hi-Res and Auger. The limitation of ground observation of the fluorescence light is severe if the energy of the particle producing the shower is of the order of 10^{20} eV. In that case the frequency of such events is so small that to succeed to observe, in average, one event per year, 1000 km^2 of territory has to be monitored (assuming a duty cycle of 10%). The goal of EUSO is to extend, as much as possible the target area making use of an Instrument accommodated in a Space platform, in our case the ISS (International Space Station), equipped with a wide-angle optics looking down toward the Earth from a distance of order of 400 km.. Figure 1 shows an artistic view of the EUSO-Earth system.

Larger target area implies, naturally, a larger active detection area and consequently a larger number of UV sensor elements. The demanding requirements imposed by the project, the very high pixelization together with the detection of faint signals, have been the starting point for designing an Instrument consisting basically of a UV high sensitivity telescope assisted by an Atmosphere Sounding device (AS). An Instrument with a sufficiently fast time response allows determining the direction of the primary extremely high energy Cosmic Ray by means of one single observation point [3]. In fact any EAS will be seen as a point moving inside the Instrument field of view (FoV) with a direction and an angular velocity depending on the EAS direction with respect to the Instrument. The EAS direction (i.e. the EAS velocity vector) can be decomposed into its parallel and perpendicular components with respect to the line joining the EUSO observation point to any suitable point of the EAS (EUSO-EAS line of sight). As the speed of the EAS is known (equal to the speed of light) the former depends on the observed angular velocity of the EAS inside the FoV, while the latter is given by the observed EAS direction on the focal Surface (FS) of the Instrument. The peculiar characteristics of the EAS, in particular the kinematical ones, allow one to distinguish them from the various backgrounds, due to a typically different space-time development.

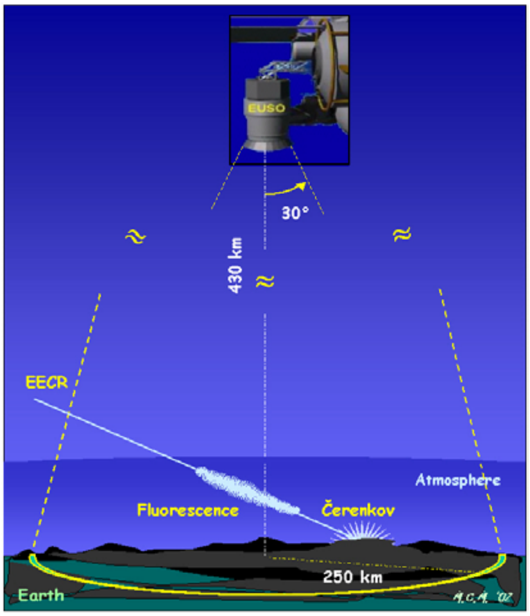

Figure 1. The EUSO-Earth system. EUSO looks downward the night side of Earth atmosphere from ISS looking for faint UV light produced by EECR (Extreme Energy Cosmic Ray) crossing the atmosphere.

2. Instrument concept and solutions

The Telescope is basically a fast, high-granularity, large-aperture and large Field-of-View digital camera, working in the near-UV wavelength range (330 nm ÷ 400 nm) with single photon counting capability. It allows observation of the Earth atmosphere, making possible, during the night-time of the ISS orbit, the detection of Extreme Energy Cosmic Rays (EECR) and Neutrinos (EEν) of energy exceeding ~5×10^{19} eV through the fluorescence signal, produced in air by the Extended Air Shower, and the diffusely reflected Čerenkov light beam associated with the EAS. The atmospheric sounding device is based on a LIDAR system. A preliminary schematic view of the EUSO Instrument is shown in Figure 2 while an exploded view of the EUSO Instrument outlining the major parts of the Instrument is shown in Figure 3.

The following sub-systems presently constitute the EUSO Instrument:

Optical Module
A double Fresnel lenses module with 2.5 m external diameter is the baseline optics for the EUSO Telescope. Fresnel lenses (made of radiation hard light-weight plastic material) can provide a large-aperture, wide FoV system with reduced mass and low absorption. The EUSO mission has an unusual set of requirements to be met by an optical system. The large aperture, the wide FoV, and the low f/# requirements, coupled with the

mass and size constraints are major challenges. On the contrary the resolution of the EUSO Telescope is three orders of magnitude less stringent than a diffraction-limited astronomical Telescope.

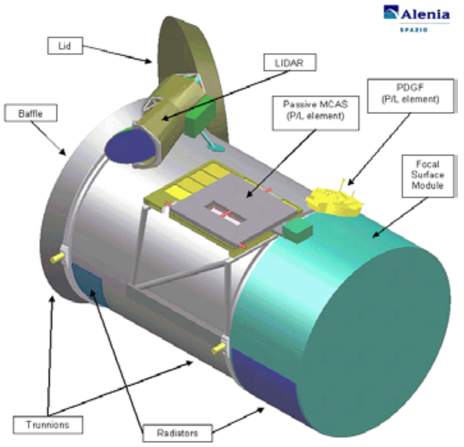

Figure 2. EUSO schematic view.

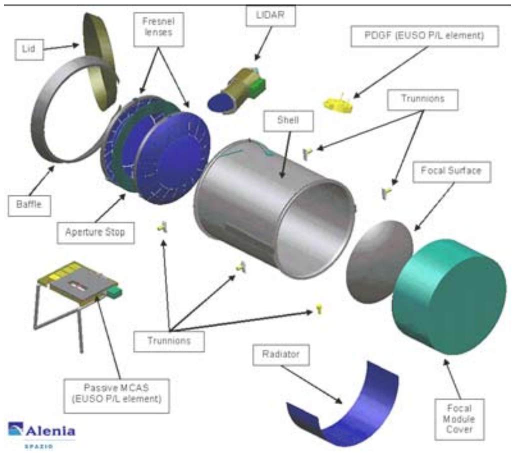

Figure 3. Exploded view of the EUSO Instrument.

The Photo-Detector on the FS

The UV light, focused by the large collecting area of the optics, is imaged onto the Focal Surface, FS. The FS photo-detector is made of highly pixelized single photon sensitive sensors and it is based on a modular structure made of modules with a geometrical shape that allows a good fitting to the FS while reducing the complexity of assembly and testing. The Photo-Detector must detect near-UV photons in the 330 nm ÷ 400 nm wavelength range with single photon counting capability; it must be capable of acquiring time-resolved images of EAS with the frame rate of ~2.5 μs (the GTU: Gate Time Unit); it should resolve single photon signals with a double-hit resolution of about 10 ns; it should also reliably and stably operate in the space environment with the limited available resources and for the required EUSO Instrument lifetime.

System (Trigger and Control) Electronics

The basic method of measurement and triggering exploits the single photon counting technique. A charge integration approach is also implemented to handle signals at high energy and from strong Čerenkov light. By using both analogue and digital electronics, the detection is possible with a threshold as low as a fraction of the mean amplitude of the single photo-electron signal up to about four thousands photo-electrons. The Trigger part of this subsystem provides all the functions required for trigger, read-out and storing of the scientific observational data, whereas the Control part is in charge of managing the operations of the Instrument, including data telemetry preparation and transmission and thermal control.

Atmosphere Sounding Device

The real time knowledge of the scattering and light absorption properties of the local atmosphere where the EAS occurred is provided by means of a LIDAR. The LIDAR essentially provides accurate profiles of the atmosphere, sounding the presence and nature of clouds and aerosol and evaluating the transparency and scattering properties. The LIDAR baseline is based on a space qualified Nd-YAG laser operating as a stand-alone device on the third harmonics.

Structure and Thermal Control

The structure holds together all subsystems, providing the necessary stiffness for the relative alignment among subsystems and the strength to withstand all mechanical environments (on ground and on orbit).

It protects the Instrument from debris and meteoroids, ensures light tightness in daylight orbit phases and provides the connection with the P/L (on ground and on orbit). The Thermal Control system maintains all Instrument parts within their operating temperature ranges, in all mission conditions, by means of proper thermal hardware and control.

Monitoring, Alignment and Calibration subsystem
It is devoted to the on-board monitoring of all the parameters and to the alignment and calibration of all the items of the EUSO Instrument (Optics, Photo-Detector and Electronics) affecting the Scientific Observation results. The resources in flight are very limited. Hence the calibration system on-board must be very simple and stable. We need to get enough information of EUSO detector for data analysis and adjustment of gain, HV and discrimination level. The major concern for the calibration system is to produce a stable illumination on the FS. This stability must be continuously monitored during the Instrument lifetime. The completely uniform illumination on the FS should be ideal; however, small geometrical non-uniformity within 20% level on the FS is acceptable. But this non-uniform light distribution must be well calibrated on the ground before the flight.

4. Conclusions

The EUSO Instrument is made of a collecting Optics, focusing the EAS image onto a Photo-Detector assembly located at the FS of the Optics. The EECR signal is extracted from the background and processed on-board, before raw data are sent to ground-stations. The Atmospheric Sounding device provides useful information on the atmosphere profile, helping the EECR events reconstruction.
Though an Instrument aiming to watch from Space the EAS produced in the atmosphere by EECR is conceptually simple, its design is a challenging task, mainly because the EECR flux reaching the Earth is very small, the observable signal is very faint and the apparatus has to operate in Space within all the constraints and resource limitations imposed by a Space Mission.
EUSO basically operates as a Time Projection Chamber to measure the properties of EECR induced EAS. EUSO measures both the fluorescence and the Čerenkov photons generated by the EAS. A two dimensional projection of an EAS is reconstructed from the distribution of the light signals imaged onto the FS. The third projection, the distance along the line of sight, is measured from time delays of the arriving photons. The absolute altitude of the EAS can be further evaluated from the diffusely reflected Čerenkov signal.
Although the scientific merit and technological feasibility has been successfully demonstrated with the Phase A study, the EUSO project is in a hold status, due to the economical difficulties in this period of the European Space Agency.

References

[1] EUSO Collaboration, several contributions to this 29th ICRC, Pune (2005).
[2] L. Scarsi and EUSO Collaboration, www.euso-mission.org/docs/RedBookEUSO_21apr04.pdf (2004).
[3] O. Catalano, Il Nuovo Cimento, 24-C, 3, 445 (2001).