EUSO - IDD

Instrument Definition Document (Phase A Study)

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Reference Documents

1 L. Scarsi, et al., "EUSO – Extreme Universe Space Observatory", Proposal for the ESA F2/F3 Mission, January 2000, http://www.ifcai.pa.cnr.it/~EUSO/docs/OrigProp_jan00.pdf and references therein.

2 "Report on the Accommodation of EUSO on the Columbus Exposed Payload Facility", ESA/MSM-GU/2000.462/AP/RDA, December 2000, http://www.ifcai.pa.cnr.it/~EUSO/docs/AccRep_dec00.pdf

3 M. Cacciani, G. Cevolani, G. Fiocco, G. Giovanelli, I. Kostadinov, R. Matthey, V. Mitev, G. Pace, E. Plagnol, "EUSO: Atmosphere Sounding and The Detection of High Energy Cosmic Rays. A working document", Doc. Ver. 3.0, 10 May 2001 (internal).

4 "Minutes of the Meeting EUSO-ESA (8-9 May 2001)", ESA/ESTEC, Noordwijk, The Netherlands, EUSO/MOM/08-09MAY01, Issue 1, June 11, 2001.

5 "Minutes of the Meeting EUSO-ESA (29 August 2001)", ASI, Roma, Italy, EUSO/MOM/29AUG01, September 6, 2001.

Contents

1. Foreword and Executive Summary

This Technical Note is produced in the framework of the EUSO Payload Phase A Study, and deals with the understanding and the definition of the requirements for the accommodation of the EUSO Instrument. The document is mainly focused on the Instrument Definition. In the following the term "Instrument" defines the scientific instrumentation that shall allow the implementation of the science objectives of the mission. While the term "Payload" defines the ground segment and the Integrated Flight segment including robotics, flight transportation (including all the necessary items), collocation on the ISS (including all the necessary items and activities on ISS).

The mission "***E****xtreme* ***U****niverse* ***S****pace* ***O****bservatory* – ***EUSO***" is devoted to the exploration from space of the highest energy processes present and accessible in the Universe; they are directly related to the extreme boundaries of the physical world. The results obtained will extend our knowledge about the basic problems still open in the present situation, with a big impact on Fundamental Physics, Cosmology, and Astrophysics.

The milestones of the mission can be outlined as:

- Extension of the measurement of the energy spectrum of the Cosmic Radiation beyond the GZK conventional limit ($E_{GZK} \approx 5x10^{19}$ eV) to identify possible structural features characterizing the GZK effect in the spectral shape. The observational goal is the increase of the available dataset for $E>10^{20}$ eV from less than 40 events available today and the hundreds/year from the major ground experiments now planned or under construction (Auger) to the several thousands expected from the operational three year lifetime foreseen for ***EUSO*** on the ISS.
- Detailed map of the arrival distribution for the EECRs extended to entire sky (north and south hemispheres).
- Observation of a possible flux of High Energy Cosmic Neutrinos and opening of the field of high-energy Neutrino Astronomy.
- Detection of "Atmospheric Phenomena" such as meteoroids and electrical discharges

The corresponding specific goals for science:

- Nature and source distribution of EECRs at universal scale
- Information on dark matter distribution
- Probing of the far/extreme regions of the Universe
- Information about the validity of the theory of relativity at values of the Lorentz factor $\gamma \approx 10^{11}$, far beyond the domain reached by the particle man-made accelerators

EUSO will detect the Extreme Energy Cosmic Rays (EECRs with $E > 3\times10^{19}$ eV) and the High Energy Cosmic Neutrino flux looking at the streak of fluorescence light produced when the particles interact with the Earth's atmosphere, and the Čerenkov signal diffused when the shower hits the ground or the top of a cloud.

Initially ***EUSO*** was submitted to ESA as a Free-Flyer mission in answer to the Announcement of Opportunity for the F2/F3 missions on January 2000. The instrument was based on a telescope sized in volume and mass by the capacity of the launcher Delta-III, with a Fresnel lens diameter of 3.5 m. ***EUSO*** was approved to proceed to an Accommodation Study for the ISS: present version results from the positive outcome on this Accommodation Study (see Ref. 2, "Report on the Accommodation of EUSO on the Columbus Exposed Payload Facility", ESA/MSM-GU/2000.462/AP/RDA, December 2000, http://www.ifcai.pa.cnr.it/~EUSO/docs/AccRep_dec00.pdf). The positive result of this report is the basis for the Phase A Study to which the present document is referred. The limiting value of 2.5 m for the external diameter of the Fresnel lens system derives from the boundary condition imposed, in the Accommodation Study, by the consideration of the ICC (Integrated Cargo Carrier) as the system assumed for the transportation via Shuttle.

EUSO will observe the fluorescence signal looking to Nadir at the dark Earth's atmosphere from its location on the CEPF (Columbus External Payload Facility) under a 60° full field-of-view. Fluorescence light will be imaged by a large Fresnel lens optics onto a finely segmented focal plane detector. The segmentation and the time resolution adopted will enable the reconstruction of the arrival direction and shower energy with acceptable precision: $\Delta E/E \approx 30\%$ and angular resolution for the reconstruction of direction of arrival for the EECR/ν from a fraction of a degree to a few degrees depending on the energy and on the inclination to the vertical.

Basic ***EUSO*** Instrument Observational characteristics for the EECR/ν telescope are:

Field of View	± 30° around Nadir
Lens Diameter	2.5 m
Entrance Pupil Diameter	≥ 2.0 m
F/#	< 1.25
Operating wavelengths	300-400 nm
Angular resolution (for event direction of arrival)	~ 1°
Pixel diameter (and spot size)	~ 5 mm
Pixel size on ground	$\sim 0.8 \times 0.8\ \mathrm{km}^2$
Number of pixels	$\sim 2.5 \times 10^5$
Track time sampling (Gate Time Unit)	833 ns (programmable)
Operational Lifetime	3 years

The atmosphere acts as the active signal generator for the EECR/ν telescope; the lower boundary of this natural detector is depending from the cloud coverage on Earth and the signal is affected by the atmospheric basic parameters such as the transparency to UV. The necessity of assessing the detector performance characteristics for each event imposes the coupling of the EUSO UV cosmic ray telescope with a Lidar monitoring in real/quasi-real time the status of the atmosphere.

The following table refers to the baseline configuration of the EUSO instrument to be located on the Columbus External Payload Facility of the ISS.

Item Description	**Characteristic Quantity or Parametric Value**
EECR/ν Telescope	
Mass	1000-1500 kg (*)
Power	750 Watt (heaters included)
External Geometry	cylindrical/polygonal (pointing to Nadir)
Dimension	∅ 2.5 m × 4.2 m
Telemetry (scientific data)	2 kbit/s continuous
Housekeeping Telemetry	100 kbit/s
LIDAR for Atmosphere characterization	
Mass	100-200 kg (*)
Power	300 Watt
External Geometry	Cylindrical/polygonal (co-axial to Main Telescope)
Dimension	∅ 1 m × 3 m
Telemetry	25 kbit/s (per event)
(*) The mass value quoted for the EUSO Instrument (1700 kg as combination of the EECR/ν telescope and of the Lidar) is derived from a first evaluation of the general requirements: it is in apparent conflict with the nominal mass capability (1000 kg) quoted for the Columbus CEPF hosting the EUSO Instrument. A fundamental objective of the Phase A studies is the optimisation of the two values with the aim to converge on a common acceptable target.	

Summary of the baseline requirements for EUSO.

Item	**Min (kg)**	**Max (kg)**	**Notes**
Optics	200	400	Choice of material
Focal Surface	250	250	
FEE	200	350	
Trigger Electronics	50	50	
Structure	100	200	
LIDAR	* 100	200	* Laser in internal of ISS pressurized module
Total	900	1450	
Contingency ~20%	200	250	
Grand Total	1100	1700	

Instrument mass distribution.

No major technological development is required for ***EUSO*** which is based on currently available hardware/software. Optimisation will be carried out during Phase A.

EUSO will detect about 10^3 EECR events per year, and will open a window to the High Energy Neutrino Astronomy: as demonstrated in Figures 2.3, 2.4, and 2.5, the ISS configuration satisfies the requirement set by the initial Free-Flyer EUSO proposal.

EUSO is a collaborative effort of research groups from Europe, Japan, and U.S..

2. Science Objectives

“ ***EUSO*** - ***E****xtreme* ***U****niverse* ***S****pace* ***O****bservatory* ” is unique in its class as astroparticle space observatory.
EUSO has as a main objective the exploration of the domain of the highest energy processes occurring in the Universe and the probing of its accessible boundaries. The scenario is directly related to the frontiers of the physical world and involves the early history of the Big Bang and the framework of Grand Unified Theories (GUTs).
For these purposes the **Extreme Energy Cosmic Radiation (EECR)** component with energy $E>10^{19}$ eV can be considered as the appropriate "Particle" channel to complement the "Electromagnetic" one, specific of conventional Astronomy. EECRs present us with the challenge of understanding their origin in connection with problems in Fundamental Physics, Cosmology and Astrophysics.

At high energies focal points are represented by:

- The change in the spectral index at the “Ankle” (the break in the C.R. energy spectrum occurring at $\sim 5x10^{18}$ eV). This could correspond to: a change in the production mechanism in the original sources; a change in the primary elemental composition connected with a different confinement region , intervention of a new component of extragalactic origin superimposing to the general Galactic component .

- How far the Cosmic Ray energy spectrum extends and what is the maximum value observable, if there is any limit? The existence of cosmic rays with $E >10^{20}$ eV is itself problematic: indeed, in this range the production mechanisms and propagation of primary quanta involve processes that are poorly understood. The energy loss mechanism related to the interaction of C.R. particles with the 2.7 K universal background radiation, (the Greisen-Zatsepin-Kuzmin GZK effect with photoproduction at energy $E \sim 5x10^{19}$ eV), constrains the mean free path of high energy hadrons to be <50-100 Mpc, a short distance on cosmological scales.

- The energy range investigated allows us to test the Theory of Relativity in an extreme domain orders of magnitude above the limit reached with man made particle accelerators: the observation of the occurrence of the GZK effect at $5x10^{19}$ eV constitutes in itself a crucial test for the Lorentz transformations at $\gamma \sim 10^{11}$ for protons.

Cosmic neutrinos with high enough energy produce detectable Extensive Air Showers (EAS). Not suffering of the GZK effect and being immune from magnetic field deflection or from an appreciable time delay caused by Lorentz factors, these particles are ideal for disentangling source related mechanisms from propagation induced effects. The opening of the High Energy Neutrino Astronomy as a new branch of Science will allow to probe the extreme boundaries of the Universe. Astronomy at the highest energies must be performed by neutrinos rather than by photons, because the Universe is opaque to photons at these energies. Astrophysical neutrinos, however, demand a very large detector for observation. The orbiting night-sky watcher, ***EUSO***, with the large area and target mass of Earth’s atmosphere observed will possibly allow the exploration of the cosmic neutrinos flux.

2.1 Observational approach

The very low event rate of EECRs (1 particle / 100 km^2 sr / y) requires extremely large sensitive areas. In spite of the big efforts lavished in the last 40 years, no more than a handful of events in this category has been reported by the ground based experiments. The Earth atmosphere, viewed from space with acceptance area which can reach $5x10^5$ km^2 sr and 10^{12} tons target mass for a field of view ±30° from the 400 km of the ISS orbit, constitutes an ideal absorber/detector for the EECRs and for Cosmic Neutrinos. EECRs and EE Gamma Rays and Neutrinos, colliding with air nuclei, produce secondaries that in turn collide with the air atoms giving rise to a propagating cascade of particles (Extensive Air Showers, EAS). In the complex hadron-electromagnetic cascade represented by the EAS the most numerous particles are electrons; their number at “shower maximum development“ is proportional to the energy of the Primary. Electrons moving through the atmosphere ionise the air and excite metastable energy levels in its atoms and molecules. With a short relaxation time, electrons from those levels return to ground state emitting a characteristic fluorescence light. In air the fluorescence extends from Infrared (IR) to Ultraviolet (UV), with peaks at wavelengths from 330 nm to 450 nm. The emitted light is isotopic and proportional to the shower energy at any given depth in the atmosphere.

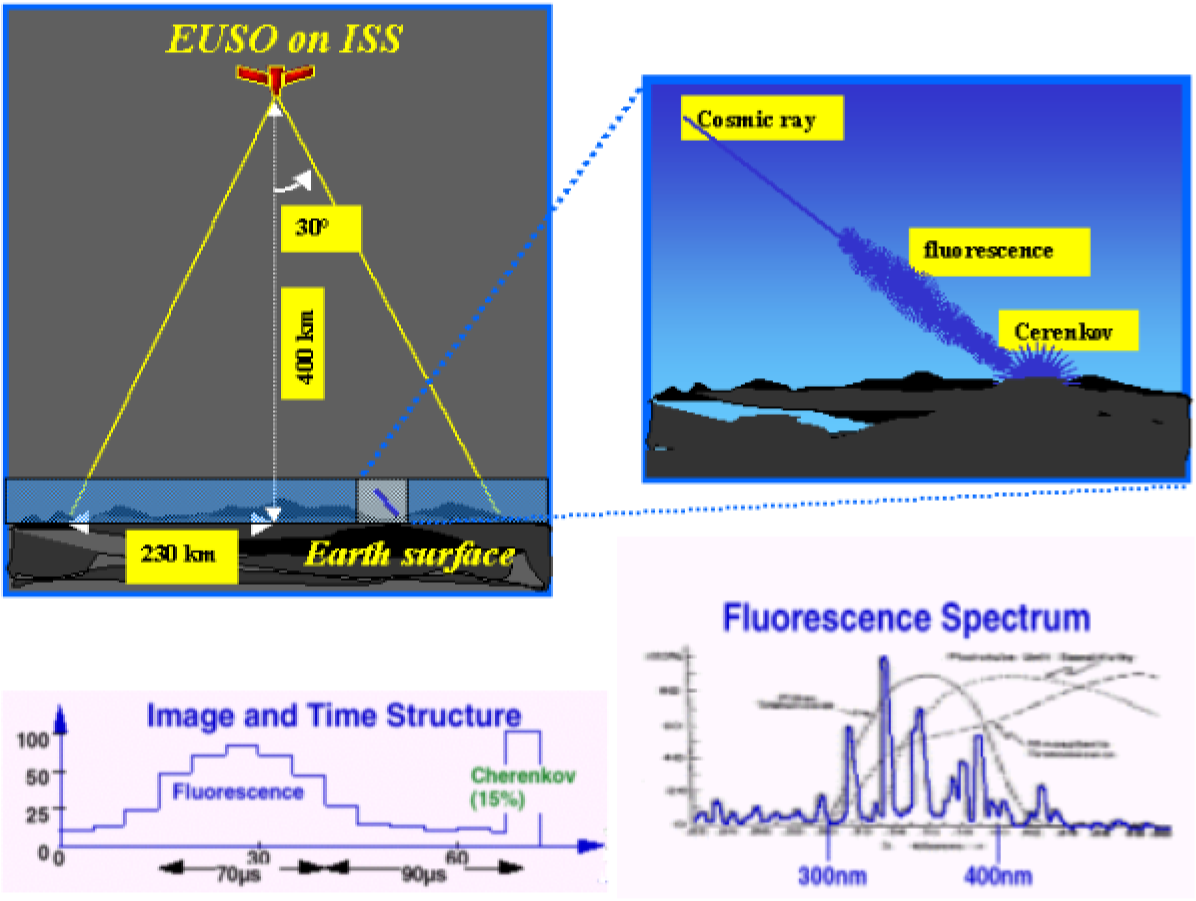


Fig. 2.1 – Artist view of the ***EUSO*** concept. The shower development occurs in the atmosphere layers below 30-40 km a.s.l.; the isotopic fluorescence emission is proportional at any depth to the number of charged particles (mainly electrons) present in the shower front: $N_e \approx E_{eV} / (1.4x10^{9})$. The UV yield is ≈4 photons per meter of electron track, almost independent from air pressure and temperature. The Čerenkov light, beamed along the shower axis, when the shower hits the Earth surface or the top of a cloud, diffuses and becomes isotropic and it will be detected by the EUSO telescope. The signal at the ***EUSO*** altitude is practically free from the “proximity” effect ($1/r^2$).

A high energy EAS forms a significant streak of scintillation light over 10-100 km in length along its passage in the atmosphere, depending on the energy of the Primary and the angle with the vertical axis. Observation of this fluorescence light with a detector at distance from the shower axis is the best way to control the cascade profile of the EAS. The shower appears as a relatively small disc-shaped luminous object emitting a power of 100 kW; when viewed continuously, the object moves on a straight path with the speed of light. As it does so, the disc luminosity changes from so faint to be undetectable up to a maximum followed by a gradual fading. The resulting event seen by the detector looks like a narrow track in which the recorded amount of light is proportional to the shower size at the various penetration depth in the atmosphere. The integral of light recorded in the track (as well as the light signal at the shower maximum) is proportional to the Primary energy. The cascade shape (especially the position of the shower maximum as a function of the penetration depth) gives an indication about the nature of the Primary. A different shape for the cascade curve is expected for different particles initiating the EAS. Showers initiated after the traversal of a very deep layer of atmosphere indicate an origin by neutrinos because the neutrino-air nuclei interaction cross-section is several orders of magnitude lower than the cross section for hadrons or photons.

The fluorescence method has been successfully implemented at operational level by the "Fly's Eye" in the past and presently by “HiRes“ in Utah; it is planned, in combination with an array of Water Čerenkov particle detectors, as baseline for the Auger project. Fig. 2.1 shows an artist view of the ***EUSO*** concept.

From the ISS low Earth orbit the UV fluorescence induced in the atmospheric nitrogen by the incoming radiation can be monitored and studied; the luminescence coming from EAS produced by the Cosmic Ray quanta (protons, nuclei, gamma rays, neutrinos,...) can be disentangled from the general background and measured exploiting, as a discriminating factor, the “ fast (nanosecond level) “ timing characteristics. Other phenomena such as meteoroids, space-debris, lightning, atmospheric flashes, distribution of minor components in the atmosphere, can also be observed.

2.2 Payload concept and mission requirements

The coverage from a Low Earth Orbit (LEO) of the observable atmosphere surface at the scale of hundred thousands square kilometres and the measurement of very fast and faint UV-optical phenomena, requires:

- optical systems with large collecting areas and wide equivalent Field-of-View (FoV);
- high segmentation and high speed (well below the microsecond level) of the focal plane detector;
- a sophisticated on-board image processor acting as a trigger.

The requirement of an “in situ / real time” knowledge of the properties of the atmosphere at the EAS occurrence (presence of clouds and their nature, transparency of the atmospheric layer, ..) to correct for systematic errors in the measurement of the EAS parameters is fulfilled by a “Lidar sounding” carried out with appropriate instrumentation on ***EUSO***.

The status of the atmosphere as “active” detector is monitored by Lidar sounding.

Mission requirements and technology development are not very stringent and do not need a long time of development. The payload foreseen for the ***EUSO*** mission, although based on current technology, presents innovative aspects for what concerns the optical system (wide angle and large aperture) and the electronics system governing the imaging technique. The payload design criteria are based on the following basic requirements:

Looking Nadir from CEPF (*) on the ISS	**Pixel size at ground**: 0.8 km × 0.8 km	**Event energy threshold**: 3×10^{19} eV
Optics FoV: ± 30°	**Total pixels at focal plane**: $\sim2.5\times10^{5}$	**Mission lifetime**: 3 years
Area covered at ground: $\sim5\text{x}10^{5}$ km^2 sr	**Target mass covered:** $\sim10^{12}$ tons	**Duty cycle for operation: (**)** (10 - 15) % (depending on EAS energy)

(*) to increase the area coverage at the highest energies (> 10^{20} eV) a "tilted mode" (30°-40° from Nadir) is envisaged for a part of the mission lifetime.
(**) determined by daytime background luminosity and the moon cycle.

2.3 Main goals for *EUSO*

EECR statistics. About 10^3 events/year (7 times those expected by the presently planned ground based experiments) will be available with ***EUSO*** to allow a quantitative energy spectral definition above 10^{20} eV, together with the evidence of possible anisotropy effects and clustering (if any) for the directions of arrival; one year of operation in the "tilted mode" will increase the expected statistics to 10^4 events/year for $E>10^{20}$ eV and about 100 events/year for $E>10^{21}$ eV.

Neutrino induced EAS. Neutrinos are elusive low interacting objects that can be hardly observed as EAS initiators for all ground-based detectors, present or in the planning. Even for the largest ground observatories under construction, the expected rate hardly reaches few events/year. With its effective area and target mass, ***EUSO*** will be sensitive to this class of events: the expected event rate ranges from several events/year to several events/day according to the effectiveness of the "topological defects" hypothesis or of other mechanisms suggested by theory. From the observational point of view, the neutrino induced EAS can be distinguished from other EECR EAS by triggering on horizontal (or upward showers) initiating deep inside the atmosphere (or Earth).

Physics of the Atmosphere. The optical effects of the fluorescence produced by EAS and by GRBs must be confidently distinguished from the other optical atmospheric phenomena (like lightning, meteor tracks, blue jets, elves) that represent a very interesting field of research for themselves. Balloon and micro-sat programs to measure the night sky UV background have been initiated. A balloon flight (BaBy) has been carried out in 1999 from the ASI base of Trapani-Milo, Italy. A value of UV background corresponding to 450 photons sr^{-1} ns^{-1} m^{-2} has been measured over sea in a moonless night. A second flight has been carried out in July 2001 (BaBy 2001); a quick look analysis substantially confirms the data obtained with the1999 flight.

Table 2.1 and Fig.2.2 show how ***EUSO*** compares with the present and future ground experiments.

	AGASA	**HiRes**	**Auger**	***EUSO (Nadir mode)***	***EUSO (tilted mode)***
	Presently in operation		**Under construction**	**Year 1 and 2**	**Year 3**
Effective km^2 sr	150	500 *	$\sim3500\longrightarrow7000$ (particle array)**	**~ 50 000 ***	**~ 500 000 ***

* *reduction for 10% duty cycle has been considered.*
** *becoming 700 km^2 sr if operating in the combined mode with the fluorescence detectors (10% duty cycle assumed)*

Volcano Ranch, Haverah Park, Yakutsk, Fly's Eye operated for a total of ~1700 km^2 sr yr providing 7 EECR events with $E>10^{20}$ eV. AGASA has provided 6 events for a total exposure of 1050 km^2 sr; HiRes 7 events for an equivalent exposure

Estimated flux for EECR with $E>10^{20}$ eV: ~ 1 event per 100 km^2 per year

Table 2.1 - Effective area size of observation in unit of km^2 sr.

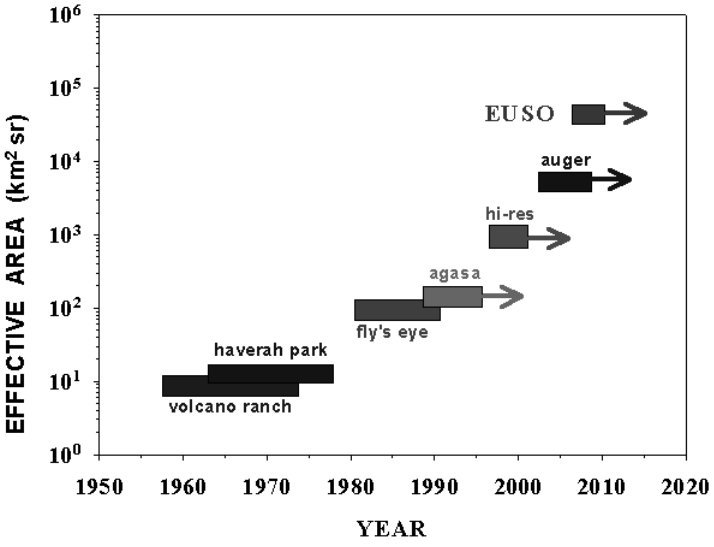


Fig.2.2 – ***EUSO*** (Nadir mode) compared with previous and future ground-based

Figures 2.3 and 2.4 show the predicted number of EECR and neutrino events per year as a function of energy detected by ***EUSO*** in the original free-flyer and ISS Nadir mode configurations. The simulations were adopting the following reference values for the optics: f/# = 1.15; pupil diameter = 2 m; aging effect, vignetting, reflection, .. = 80% transparency. A conservative value of 10% has been used for the duty cycle. Both configurations give comparable results within a small factor with the lower observational altitude of the ISS (380 km) counterbalancing somewhat the sensitivity afforded by the larger optics diameter of the free-flyer. The integral number of counts above an energy E for the two configurations is shown in Fig. 2.5 assuming the 2-year operational life of the free-flyer and the 3-year lifetime for the Nadir mode version on board the ISS.

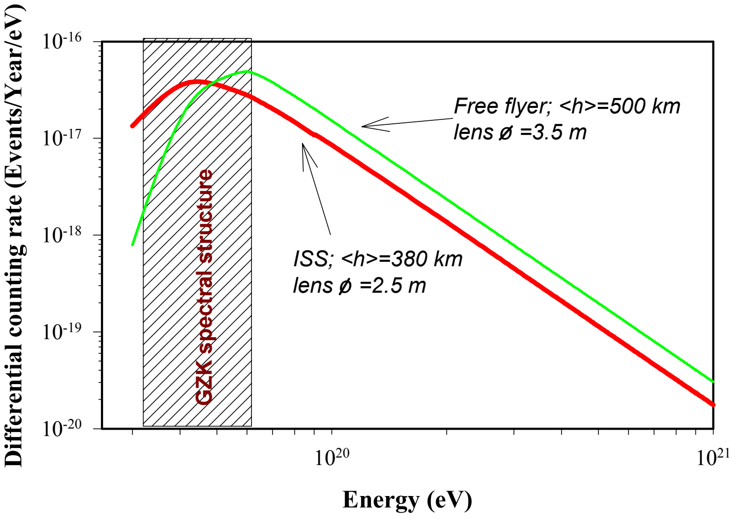


Fig. 2.3 - Differential EECR counting rate comparison between the ISS version (Nadir mode) of the EUSO and the original free flyer. The dashed zone shows the spectral region where structure induced by the GZK cutoff is expected. The lens diameter is the maximum external diameter allowed in each configuration.

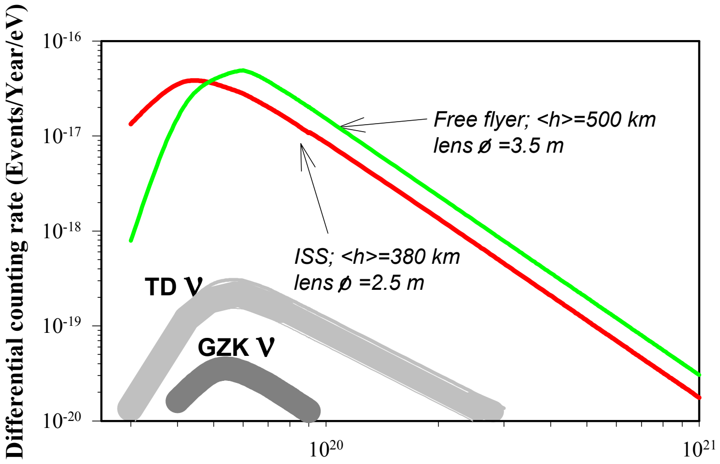


Fig. 2.4 - The differential flux of neutrinos predicted using the Topological Defects model of Sigl et al. (1998) and the GZK model of Stecker et al. (1991). The energy dependence of the neutrino cross section ($\sigma \propto E^{0.5}$) is applied to the calculations (Quigg et al., 1986; Gandhi et al., 1996).

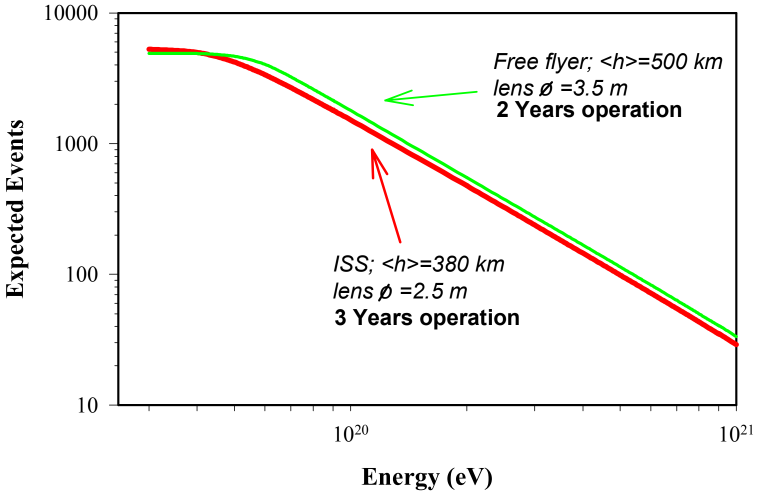


Fig. 2.5 - The integral count rates above an energy E predicted for the original free flyer proposal with 2 years of operations and the ISS configuration with 3 years operations in Nadir mode.

3. Scientific Payload

As a baseline, a compact instrument with an external lens diameter of 2.5 meters is required to be accommodated on the CEPF of the Columbus module together with an auxiliary instrument devoted to contemporary atmosphere sounding (cylindrical structure coaxial to the main telescope).

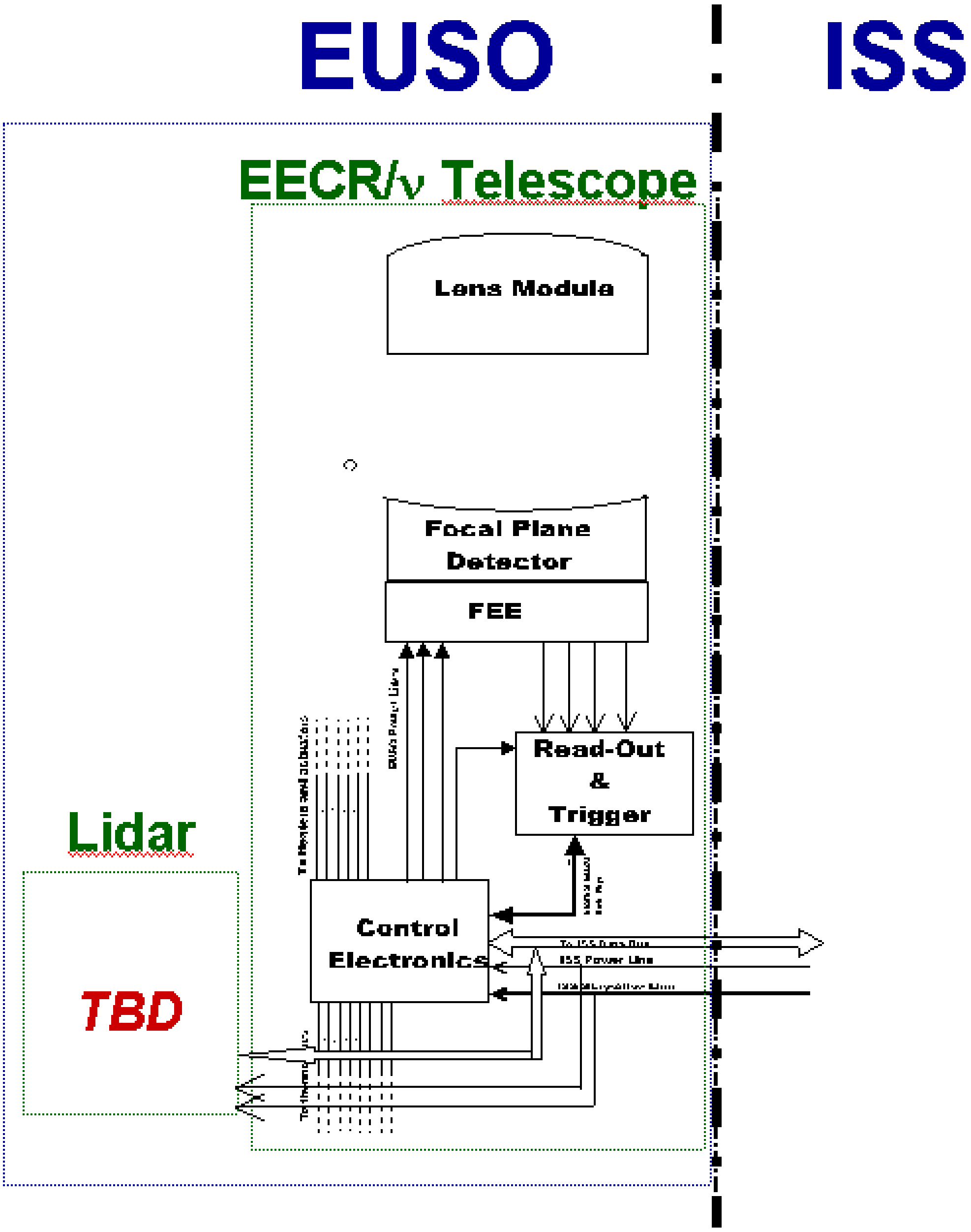


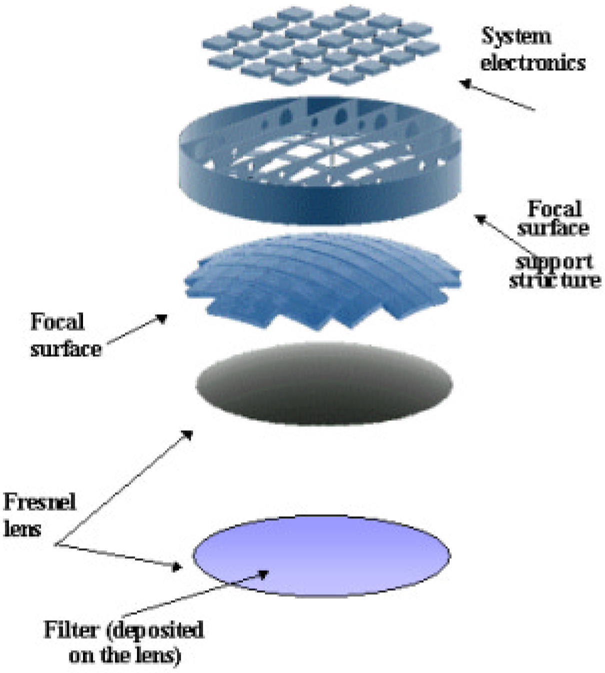
Fig. 3.1 - General functional block diagram of the EUSO Instrument

3.1 The Main Instrument

The EUSO Main Instrument is shown schematically in the exploded artistic view here below. The instrument consists of three main parts: optics, focal surface detector, and trigger and electronics system. The optics, detector elements, system and trigger electronics all have to be matched and interfaced coherently to obtain a correct response from the instrument. The scientific requirements have driven the conceptual design of the apparatus and the choice of various technical solutions. The design criteria are based on the following assumptions:

- 380 km orbit
- FOV of ±30°
- Planned pixel size at ground: 0.8×0.8 km^2
- Event energy threshold: 3×10^{19} eV

Observation from space calls for an approach different from that of the conventional ground based fluorescence experiments. For space applications the instrument has to be compact as much as possible, highly efficient, and with a built-in modularity of the detection and electronics parts. For the detection method, a single photon counting technique is preferred to the charge integration alternative, because of a better response in the presence of the very few photoelectrons produced by the faint UV fluorescence signal.



3.1.1 Optics

The resolution requirements of 10^4 times more forgiving than the diffraction limit suggest the consideration of unconventional solutions for EUSO, identified in the multiple Fresnel lens technology. Fresnel lenses provide large-aperture, wide-field systems with drastically reduced mass and absorption. The use of a broader range of optical materials (including lightweight polymers) is possible for reducing the overall weight. A two Fresnel lenses system has been designed to meet the EUSO specifications (Fig. 3.2). Each lens is cut on a spherical substrate and has grooves in both sides. All of the elements are 2.5 m in diameter and will fit, without folding, into a “to be defined” envelope.

Achromatic corrections are feasible with the existing technology by using two lens materials that differ in Abbe number or by applying a diffractive surfacing at least on one of four Fresnel lens surfaces. The system optics has initially been optimised for λ=391 nm. Chromatic aberration of refractive system limits the performance but more than 85% of energy in the 337 nm and 391 nm bands is contained within a single pixel on either side of the central pixel. This allows sufficient image quality to yield a reliable trigger.

Prototype Fresnel lenses were manufactured at the University of Alabama in Huntsville by directly diamond turning acrylic blanks with no post-polishing; test for radiation damage and vacuum effects have been carried out at large dosage. The test results were less than 3% transmission loss for 3-year equivalence of orbital operation, which validated the material for use in space. The EUSO-scale optics will most likely be "pie-slice" segmented and molded rather than directly turned. The diamond turned metal mold will have an inherently smoother surface than a turned polymer, and a mold can easily be polished. Surface scattering is readily controlled in large scale Fresnel lenses.

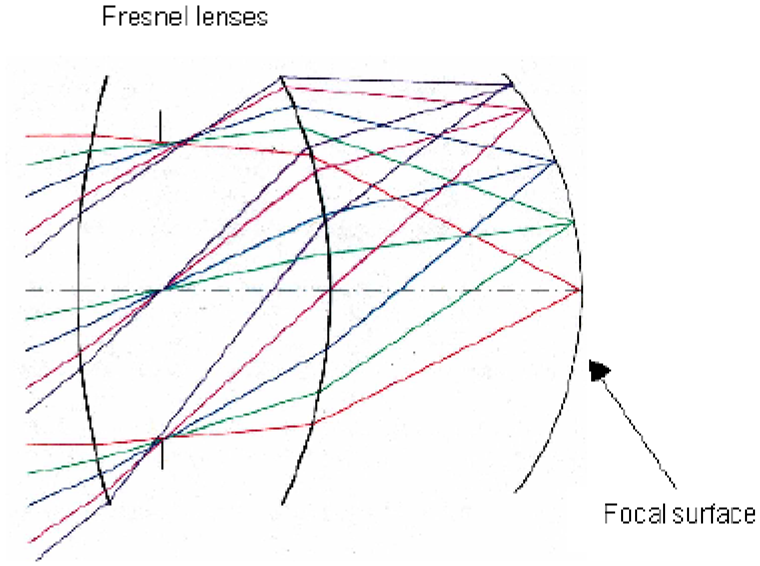


Fig. 3.2 - The EUSO optics design consisting of two 2.5 m diameter plastic Fresnel lenses which focus light on a curved focal surface (right).

Candidate materials are relatively free from radiation damage, solarization, and UV photochemistry. Basic preference of materials emphasizes molecular-structural and radiation hardness. The EUSO optics has to be however protected against daylight and direct atomic oxygen flux in the ISS environment. The shielding walls of the camera case and the iris/shutter will provide natural solution.

Candidate materials for EUSO wide-angle Fresnel optics are Polymethyl-Pentene (TPX), Amorphous Cyclo-Olefin (ZEONEX), Amorphous Perfluoro Alkenylvinylether (CYTOP), Optical-grade polymethyl-metha-acrylate (PMMA), and other conventional lens materails (Fused Silica, Quarz). Among others, Zeonex and TPX have appropriate properties for use in space. Identified candidate materials have efficient transmission of 86 – 93% for Near-UV lights with the thickness of a several mm to cm. Surface reflection can be reduced to 4% (transmissivity, 90 ~ 96%) by anti-reflection coating on most of the candidates except CYTOP that may also be subject to radiation damage.

The lens surface directly exposed to the external environment shall be protected for the external environment with appropriate coating or layer. Moreover, in order to guarantee the light trasmissitivity and the electrical conducibility of the lens front surface, the more external layer shall be based on material like Tin-oxide. No UV effect on the lens material is envisaged because during the operative condition the amount of UV light is negligible.

For the handling of the instrument in all phases prior to the accommodation on the ISS appropriate cleanliness requirements shall be adopted to avoid optical degradation .

3.1.2 Filters

An optical filter will be needed to limit the band-pass of the optics in the 330÷400 nm band where most of N2 fluorescence lines and Čerenkov radiation are emitted. Bulk absorption filters (Shott BG-3), dielectric coatings or combinations can be used for this purpose. The preferred solution is related to the overall optical design. An interference filter is an option and it has been designed transmitting 90% of the desired flux over a large range of incidence angles. It also blocks more than 80% of the flux in the ranges 200÷300 nm and 425÷800 nm.

3.1.3 Focal Surface

Due to the large FOV and the large collecting area of the optics, the focal surface detector must allocate $\sim 2.5 \times 10^5$ pixels. The demanding detector requirements of low power consumption and weight, small dimensions, fast response time, high detection efficiency in the near UV region (300–400 nm), and single photoelectron sensitivity, limit the possible choices to a few devices.

A suitable off-the-shelf device is the multi-anode photomultiplier Hamamatsu R7600 series. The pixel size, the gain, the fast response time, the low weight and dimensions of this MAPMT, and its single photoelectron resolution are well suited to the EUSO focal surface detector.

The physical dimension of the MAPMT section is 25.7 x 25.7 mm^2 while the length is about 35 mm and the weight is about 30 g. The tube is equipped with a bi-alkali photocathode and a UV-transmitting window 0.8 mm thick. The device has a Metal Channel dynode structure with 12 stages, providing a gain of the order of 10^6 for a 0.9 kV applied voltage, using a standard tapered voltage divider. This large gain allows to use a simple front-end electronics, without the need for sophisticated fast, low noise and low power preamplifiers. The availability of different pixel sizes proves to be extremely useful to match the desired space resolution of the photon detector. The device with the largest number of pixels (R7600-M64) has 8x8 square pixels of 2 mm side and 2.3 mm pitch. This configuration leads to ~4000 MAPMTs on the focal plane. Devices with a larger pixel size are also available: the R7600-M16 has 4x4 square pixels of 4 mm side and 4.5 mm pitch. In both cases the sensitive area is about 0.45 of the total area of the device with the sensitive area located at the centre of the device.

The low overall geometrical acceptance appears to be the main limiting factor to the use of this MAPMT in EUSO. The main problem is not the low overall acceptance but the fact that the acceptance would be highly non-uniform on the focal surface by using only the bare devices. A detail study has to be carried on to identify possible solutions to this problem. The large dead area at the border of the device could be recovered by means of a suitable light collector system, to be placed in front of each device, and performing the required demagnification onto the MAPMT sensitive area. This might be either a lens system, or a system made of a bundle of tapered light pipes, working either by total internal reflection inside plastic pipes or by normal reflection inside empty pipes. The lens could be one single thick plane-convex hemispherical lens, with the curved surface facing the incident light and whose flat surface is placed in contact with the input window of the multi-anode photomultiplier and coincident with the focal surface of the optics. The three systems preliminarily studied, must be evaluated and some prototypes built. Preliminary results show that the overall geometrical acceptance could be improved up to about 0.7 becoming, what is most important, rather uniform on the focal surface. The optimisation of the design and the evaluation of the global impact of the light collection system on the overall detector design will be object of the Phase A study.

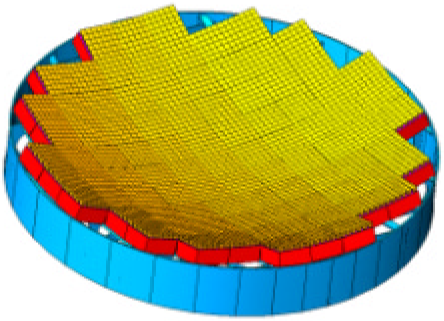


Fig. 3.3 - Schematic example of the EUSO focal surface assembly showing how the individual macrocells could be mounted to approximate the curve focal surface of the optics. The shape of the focal surface shown in the figure does not correspond to the "real geometry" but it is meant to give an overall artistic vision of the assembly philosophy.

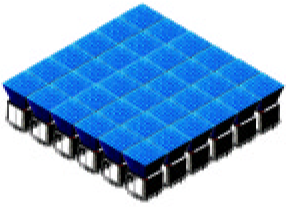


Fig. 3.4 - Each macrocell consists of 6x6 Photomuliplier Tube assemblies, associated light guides and electronics and is a modular unit.

Fig. 3.5 - Each PMT is a commercially available 8x8 anode device; here it is shown with a possible light guide used to match the active area to the focal surface.

The focal surface detector will be based on plane modules with a geometrical shape that allows a good fitting to the focal surface while reducing the complexity of assembly and testing. The organization in "macrocells" of the focal surface (a macrocell is a bi–dimensional array of n×n MAPMTs) is shown in Fig. 3.3. This configuration of the focal surface offers many advantages such as an easy planning, implementation and flexibility. Moreover, modularity is ideal for space application. Preliminary layouts of the focal surface have been studied, based on square macrocells.

3.1.4 Front End Electronics

A prerogative of the front-end pixel electronics is the reduction of the background when, as in our case, "single photoelectron counting" techniques with a fast response detector is used. The functions of the front-end module are:

- to convert the analog detector signal into a logic signal,
- to count the logic pulses and enable the output at a programmable counts threshold (binary set),
- to split the logic signal for the X-Y positions and for the macrocell timing channel,
- to convert grouped detector analog signals, and transfer them to a FADC.

Very Large Scale Integration (VLSI) chips using ASIC (Application Specific Integrated Circuit) technology are foreseen for the front-end electronics.

3.1.5 Read-Out and Trigger Electronics

Special attention has been given to the trigger scheme where the implementation of hardware/firmware special functions is foreseen.

The trigger module named OUST (On-board Unit System Trigger) has been studied to provide different levels of triggers such that the physics phenomena in terms of fast, normal and slow in time-scale events can be detected. Particular emphasis has been introduced in the possibility of triggering upward showers (emerging from the Earth, "neutrino candidate") by means of dedicated trigger logic.

The FIRE (Fluorescence Image Read-out Electronics) system has been designed to obtain an effective reduction of channels and data to read-out, developing a method that reduces the number of the channels without penalizing the performance of the detection system. Rows wired-or and columns wired-or routing connections have been adopted inside every single macrocell (of the order of 100 macrocells constitute the focal surface detector) for diminishing the number of channels that need to be read-out.

A "free running" method has been adopted to store temporarily the information, coming from the detector, in cyclic memories and recuperate them at the time that a trigger signal occurs. The front-end pixel electronics design has been formalised and computer simulations have proven the validity of the approach we propose.

The organisation in macrocells is directly applicable to the system electronics. The advantage of such a scheme is to treat macrocells as independent units from one another thus simplifying the design of the entire system, making it simply consisting of a repetition of equal blocks.

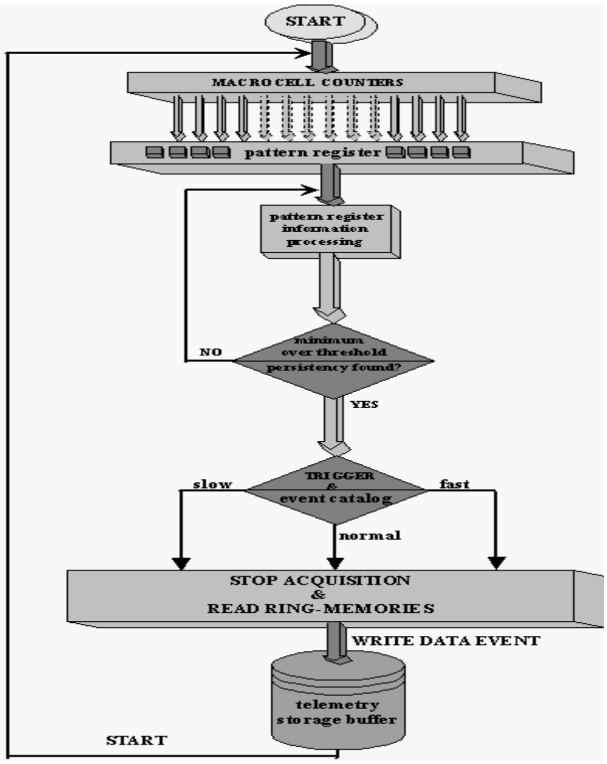


Fig.3.6 – Flow-chart of the trigger logic

3.1.6 Control Electronics

The Control Electronics is in charge of managing the operations of the instrument. In particular its main functions are:

- The collection of scientific data coming from the detector arrays (macrocells) consisting of the position and arrival time of detected photoelectrons.
- The collection of the housekeeping monitors to check the correct configuration and operation of the instrument.
- The preparation of telemetry source packets (scientific, housekeeping, etc.) and their transmission to the ISS.
- The reception, validation and distribution of telecommands coming from the ISS.
- The control of instrument operative modes during observations, diagnostic and calibration intervals. These modes include also the autonomous maintenance of the detector in safe conditions.
- The active thermal control, by means of the management of the heaters (part of the passive thermal control).
- The provision of data patches and dump capability for on-board software programming.
- The management of time information.
- The conversion of the primary bus provided by the ISS into the secondary regulated voltages necessary for instrument operation.

This unit can be configured as a classical electronics box based on microprocessor architecture with an internal standard bus. A Payload (P/L) Data Handling Unit connected via a standard data bus to the Spacecraft Module On-Board Computer will manage the P/L module functions, the scientific and housekeeping telemetry and the command from ground.

A statistically significant number of EECR and neutrino events (~3500 /year) will be collected in about 10-15% of the orbital time. In these conditions no pile-up is present and the transmission peak will be of the order of 10 events/day for E $>3\times10^{19}$ eV, or other neutrino events. On the focal surface detector, each cosmic ray event is seen as a track in an X-Y-time structure, where the spatial scale corresponds to $\sim2\times10^{5}$ pixels, while the timescale depends on the persistence of the track in the detection area. Other classes of events (meteoroids, lightning, etc.) have to be also considered to evaluate the correct telemetry as well as atmosphere sounding data (only tentative values are listed in Table 4.5.1).

3.1.7 Mechanical Structure

The EUSO mechanical structure shall keep all the EUSO EECR observatory modules (optics, surface detector…). EUSO mechanical structure shall guarantee the stability of the optics/detector at the launch condition and at the ISS environment. The EUSO mechanical structure shall also guarantee the protection of the modules from the on-orbit environments (i.e. molecular contamination, out of FOV light impingement on PMTs, debris. ..) and it shall include a baffle that shall be closed the optics aperture during the Sun-light period. A possible shutter/baffle arrangement (to be evaluated during the Instrument Phase A) is based on a Teflon membrane and flexible Cu-Be ribs (technology developed by ESA for the multipurpose deployable membrane reflector).

The mechanical structure shall not include all the items for the mechanical, electrical and thermal interface connection to STS and ISS. These items shall be identified during the Payload Phase A study.

3.1.8 Thermal Control

EUSO allowable temperature shall be guaranteed by the means of the passive Thermal Controls, composed by:

- heat radiators,
- electrical heaters,
- heat piping (if necessary),
- thermal blanket,
- special paints or surface coating for the determination of the external thermo-optic properties,
- thermal baffle (if necessary).

The heaters necessary for the Optics/Filter thermal control shall be accommodated along the lens frame and spider arms.

The Control Electronics, by the means of a temperature control law, shall drive the heaters that keep the various EUSO Modules temperature, identified in the following table.

EUSO Item	Min. Op. °C	Max. Op. °C	Min. Non-Op. °C	Max. Non-Op. °C
Optics/Filter	-40	+40	-50	+60
Focal Surface	0	+40	-10	+50
FEE	0	+40	-10	+50
OBDH & Trigger Electronics	-40	+60	-50	+70
Control Electronics	-40	+60	-50	+70

Table 3.6 – Operative and non-Operative Temperature Range

In order to guarantee the respect of the Non-Op. temperature range with in a no power condition it is supposed the availability of a keep-alive power line for the survival heaters. Moreover, during the flight and the EUSO handling before the docking on the ISS a power line for the maintenance of the temperature at the minimum Non-Operational level shall be provided (if necessary).

3.2 Atmosphere Sounding

(for more detail, see Ref.3)

The detection and identification (direction of arrival, nature and energy of the primary particle) of an EECR or EE Cosmic Neutrino result from the observation of two phenomena:

- When an EECR traverses the atmosphere it will deposit its energy through the creation of a "Shower" of secondary particles. Because of the fluorescence of N2 molecules excited by this shower, a line of isotropic light sources will be created close to the axis of the shower. This fluorescence light corresponds to wavelengths in the range between 300 nm and 400 nm.

- Accompanying this process, a wave front of Čerenkov light is also created. It is beamed along the Shower axis, but it will be partially diffused (and reflected) either by the Earth surface or by the cloud top that it may encounter before reaching the Earth surface.

Both these phenomena are detected by the EUSO telescope. The sequence of the shower development along the depth of air traversed can be analysed for the spatial and temporal transition of the fluorescence intensity, as well by using the landmark Čerenkov signal, as shown in Fig.2.1.

Three important parameters will be extracted by the measurement: the direction of arrival of the incoming EECR or Neutrino, and the energy of the primary particle and its nature (proton, heavy ion or neutrino/gamma, …).

The precision with which these parameters can be measured will be influenced by the absorption, scattering and reflection processes of the light (fluorescence and Čerenkov) on its flight path to the EUSO detector. These effects will depend on the presence of relatively variable atmospheric constituents, namely gases, aerosol, clouds.

The following atmospheric factors are of importance:

A. The attenuation of the fluorescence light in its path to the receiver of EUSO, caused by absorption and scattering by the above mentioned air constituents, will result in a biased measurement of the amount of total light created by the EAS and hence of the initial energy of the primary particle inducing the EAS.

B. For the detection of the Čerenkov light the presence of a well-defined scattering layer, such as the ground, the sea or other water surface or a sharply defined cloud top is critical. An incorrect evaluation of the altitude at which the Čerenkov light is reflected will bias the identification of the identity of the primary particle and its energy.

C. The amount of Čerenkov light detected by EUSO can also be used as an independent measure of the energy of the primary particle. The precision with which the reflection properties (albedo) of the reflective medium as well as the extinction properties of the intermediate medium will be known, shall determine the quality of the measurement.

A quantitative estimate of these effects requires a precise evaluation of the above processes coupled to the response of the EUSO detector. Such simulations will be one of the goals of Phase A studies. An estimation of the error associated to the EUSO measurements, not taking into account the atmosphere processes, yields a value of the order of 15%. As a working hypothesis, it is assumed that the maximum uncertainty allowed for the radiative transfer processes should be kept at the level of 5 to 10%.

3.2.1 Scattering by the molecular atmosphere and absorption due to trace gases in the atmosphere

It is presently assumed as not necessary to consider a dedicated instrument for these measurements. But it is necessary to assess the error reduction by models based on the presently available data and the expected one by the time of EUSO operation. Depending on the result of this assessment a final decision will be taken.

3.2.2 Aerosol and Cloud Structures: attenuation and diffuse reflection

Aerosol layers. While clouds in the generally accepted sense, consist of condensed water particles, aerosols may have a varied composition: in the Earth' atmosphere dust particles are frequent and can produce values of the optical thickness well above one. The presence of dust is a frequent feature in desertic areas and can be detected downwind for thousand of kilometers, as for instance west of the Sahara, east of Gobi. Thick aerosol layer are generally a regional phenomenon, often related to pollution. In the case of volcanic eruptions of explosive type the aerosol layers that form in the stratosphere have a global character that lasts for a few years.

Thin clouds. Through these semi-transparent or even subvisible cloud the Čerenkov radiation and the fluorescence may penetrate at the cost of some attenuation. They will also produce relatively weak scattering of the Čerenkov beam, but will not substantially limit the visibility of the region where the interaction of the particle with the atmosphere takes place. They act as a semi-transparent screen, which will attenuate the fluorescence from the atmosphere below, as well as the Čerenkov radiation scattering either from the underlying Earth surface or from an opaque cloud. In addition, such cloud may produce a small peak in the Čerenkov radiation in addition to the high peak due to the scattering from the underlying Earth surface or an opaque cloud. The magnitude of such peak and the attenuation depends on the cloud scattering properties. As for the case of opaque clouds, the top altitude and the scattering properties for an individual sub-visible cloud structure cannot be evaluated from model values and shall be individually measured.

Thick clouds. Clouds characterized by optical thickness of the order of 10, will scatter completely the Čerenkov radiation. The Čerenkov radiation generated in the atmosphere below such clouds and scattered by the Earth surface or by underlying layers, as well as the fluorescence generated in the atmosphere below the cloud will be practically estinguished before reaching the EUSO detector. The EUSO detector cannot assess the atmosphere below thick clouds. The cloud top acts as an irregular "surface" and the type of the particle shall be determined from its interaction with the atmosphere above the top of the cloud. The altitude of the top for such clouds may be very important: being typically several km high at mid latitudes, in tropical convection they may reach 20-22 km. The cores of such cloud fields are also very dynamic in their development. Due to the limited resolution of synoptic scale models used in weather forecasting, the evolution of individual cloud structures cannot be evaluated from models and should be measured for each EECR event at the place of its occurrence. On the other hand, large cloud that are common in the tropical regions, may extend over hundreds of kilometers and their main features can be retrieved through successive passages and additional observations from space. In the periphery the cloud cover they produce becomes progressively thinner and give rise to extensive cloud fields that can be observed at the same location for days.

3.2.3 LIDAR devices

The LIDAR (LIght Detection And Ranging) application to the study of the Earth's atmosphere dates back to the early sixties. The lidar detects echoes due to a laser beam in its propagation through the atmosphere. The echoes are due to scattering by the molecules and by the aerosol suspended in air; in thick clouds the extinction is large and only the external aspect of the cloud can be obtained. The lidar essentially provides profiles of the atmospheric backscattering. It is in general possible to separate the echoes from the molecular atmosphere from those due to aerosol and clouds. The characteristics of a lidar relevant to this application are the power, the antenna aperture, and frequency of operation. Integration time is an important factor in enhancing the signal-to-noise ratio.

Three possible types of lidar devices are being considered:

- **Pulsed LIDAR.** Pulsed radar provides range of the target in a simple way and has advantages in detection in the presence of noise. In the configuration proposed the lidar will utilize a narrow field of view (of the order of millirad or less), a narrow band (of the order of 1 nm or less), a telescope with aperture up to 1 meter: its dimensions will be the object of trading compromise with laser power, in view also of the inevitable deterioration with time of its performance. In general most of the lidar systems operating on the ground at present are based on Nd YAG laser; a few use excimer lasers and other varieties. To our knowledge all lidars operating or planned to operate from aerospace platforms (OLEX, ABLE, LITE, PICASSO-CENA etc.) are of the Nd-YAG type. In a pulsed laser the output power can be easily converted to harmonics: for a Nd YAG the fundamental is at 1064 nm, the second harmonic is at 532 nm and the third at 355 nm. Since the third harmonic is in the center of the EUSO band, it could directly provide a measure of the extinction. Also important is the consideration, already mentioned, that lidar molecular backscattering will automatically provide a calibration of the lidar sensitivity, since the molecular cross section is known and the molecular number density should be obtainable from the meteorology. A feature common to all lasers is the requirement that in order to achieve proper operational regime some time length is required (of the order of 10 minutes) to obtain condition of equilibrium. This leads to the conclusion that in order to be operational within seconds the system has to be kept running continuously. However, data scientifically valuable may be gathered even though they will not be immediately relevant to EUSO: the cloud cover, although variable and moving with respect to the surface, maintains a certain amount of coherence over time periods of days. The data collected in past and subsequent passages will permit a better characterization of the phenomena of interest to EUSO. Another problem is related to the pointing the lidar beam: pointing should be achieved within seconds after the occurrence of the shower and such capability should minimize moving parts of different acceptance in the ISS ambient.

- **Continuous Wave LIDAR.** The Pseudo-Random Noise Continuous Wave backscatter Lidar (PRN-cw) performs range-resolved measurements with a modulated continuous wave laser beam. The modulation of the transmitted power follows the pattern of a PRN sequence. Respectively the recovery of the atmospheric response function is done by cross-correlation of the detected signal and the initial PRN code. The advantage of the PRN-cw lidars is in the possibility of using diode lasers in the near infrared spectral region. The operating wavelengths are in the intervals 780 nm- 850 nm and around 980 nm. The diode laser is the most compact laser source. Its plug-in efficiency is 30-35%. Its operational lifetime exceeds uninterrupted operation during the planned period of EUSO mission. Both PRN modulation and demodulation technology, and the CW-diode lasers technology in near IR are well developed because of their use in the communication technique. This makes the PRN cw lidar a technologically feasible and reliable lidar instrument. Its advantages are in making lidar measurements possible when the available power and mass in the space mission are limited. A feasibility study and advanced breadboarding of PRN-cw lidar has been done in Observatory of Neuchâtel (ESTEC Contract 9099/90/NL/PB: Advanced Breadboard of Pseudo Random Noise - continuous wave total backscatter lidar). This included also a test of the realized lidar for target and cloud detection. PRN principle allows the realization of a lidar for EUSO, dedicated to cloud detection during night time, i.e., when the EECR EUSO measurements will be performed. The use of compact and efficient cw diode lasers makes possible to consider multiplication of the transmitter, what will increase the transmitted power and will make the atmospheric package less sensitive to failure. Due to the long-life of the diode lasers, the lidar may be operational during all the mission, what gives a possibility for collection of a large data base what will be also a benefit for the atmospheric science community.

- **Lidar utilizing EUSO as a receptor.** The possibility of utilizing the optics and the detectors of EUSO as the receiver section for a Lidar device will be considered. At this time this has to be considered as an additional, complementary mode of operation of the basic pulsed lidar considered before. The main feature of the EUSO system in this regard relates to its being essentially an imager. If utilized as a wide-angle lidar receiver, the problem of steering the lidar system will be simplified. The larger aperture will provide strong signals, but the signal to noise will probably decrease, due to the wide spectral acceptance of the filter and to a possible increase of the background/sterad expected due to a lack of screening. Compared with a conventional Lidar as previously described, the overall sensitivity will probably deteriorate. Advantages may result from the release in alignment accuracy between the transmitter and the receiver, since the echoed signal will always be detected in view of the wide-angle capacity of the Main Telescope. As a further, and profound, consequence this may made possible to position the transmitter at some distance from the receiver since retrieval of the alignment will not be difficult. In such a case the laser, and an appreciate fraction of the Lidar system configured may be housed in a inhabited part of the ISS where suitable optical windows exist. The housing of the laser “inside” may make its maintenance an easier problem and assure a longer operational lifetime.

Additional instrumentation. Complementary to the Lidar, analysis of the existing passive technologies will be performed as an attempt to deploy smart and low power consumption IR camera with FoV equal or larger than that of EUSO for overall observing of the cloud systems during the night, assisting the lidar detection.

3.2.4 Mode of Operations

In order to determine the characteristics of the devices suggested, it is important to outline some important features of the EECR detection by EUSO:

1. The duration of an EECR, at the level of EUSO, is of the order of 100-200 microseconds.
2. A typical EECR has a longitudinal extension of 10-50 km and a transversal extension of the order of 1 km. An EECR event covers therefore a very limited portion of the total surface covered by the wide-angle optics (150000 km^2).
3. The speed of the ISS is 7 km/sec. The average time that can be allowed for a measurement of the cloud structure is estimated to be around 30 sec.
4. For each EECR events, EUSO will be able to locate, almost instantaneously and with a precision of the order of few km, the geographical location of the EECR shower trajectory.

These numbers do not allow, and do not call for, a systematic inspection of the cloud structure over the whole area covered by EUSO. It is therefore recommended that the LIDAR be coupled to a pointing device of the desired precision and with a time response of the order of 1 sec. The remaining time (30 sec) will allow for a reasonable scanning of the EECR shower trajectory, particularly at the footprint of the shower where the Čerenkov light is reflected to verify the possible cloud field properties.

Although the first priority of such a system is to inspect the region of interest at the instant of EECR detection, the continuous functioning of the apparatus can also be considered. Indeed, an average and statistical study of the regions covered by EUSO can also be of interest, particularly for cases where a proper pointing of the LIDAR will not have been possible. An example of such a case would be an event on the external border of the EUSO geographic range.

Surveying the stability of the EUSO detector: EUSO as a receptor of the backscattered LIDAR beam.

The continuous control of the stability of the EUSO detector is a necessity for the reliability and quality of the measurements. A number of internal procedures will be established for the control. The devices suggested for atmosphere sounding could elegantly complement those procedures if it can be arranged for the LIDAR beam to be within the EUSO sensitive wavelength range (350-500 nm). In such a situation the EUSO detector could be able to detect the backscattering of the LIDAR beams. Phase A will study this option.

3.2.5 Simulation of EECR detection: the radiative transfer process

During the period of Phase A, the EUSO collaboration will construct a sophisticated “computer simulator” of the physical process (EECR fluorescence and Čerenkov light production) and of the detector response function (electronics, trigger, …): in between these two steps, the radiative transfer processes are of primary importance.

The retrieving of the brightness B of the EECR fluorescence event could be performed in several ways. It is planned to be tested two methods. According to the first one an appropriate atmosphere model should be adopted in order to calculate the atmospheric transmittance: from known equations it is possible to calculate B. The second method is based on Monte Carlo simulations of the of the photons optical path trough the atmosphere: by varying B it is possible to match the model output with the measured signal. These model simulations will perform under different atmospheric scenarios: presence of a variety of cloud structures, minor gases absorption, aerosol loading, ground albedo, etc.

In the both cases representative information about the actual atmospheric conditions in the region of EECR event is essential. It requires representative information about the vertical distribution of the temperature, pressure, aerosol content, minor gases, cloud field and etc. The best approach will be to have information about aforementioned parameters in the same time and for the same space location where EECR event is detected. However, such requirement is very strong and some approximations should be done. For this purpose the output results form other space, aircraft, balloon, and ground-based experiments will be also exploited.

3.2.6 Estimation of the technical budgets

In view of the overall budget of the EUSO project, a very preliminary estimate of the main technical budgets, compatible with the solutions mentioned above, could be the following:

- **Mass: 100-200 kg**
- **Dimension: Cylindrical/polygonal, ∅ 1 m × 3 m**
- **Power: 300 Watts**
- **Telemetry: 25 kbit/s**

The EUSO mission is planned for a 3-years timelength; therefore the LIDAR device should have an equivalent lifetime, rather demanding for these devices. Different options can be considered: either a duplication (or more) of the suggested device, or, taking advantage of the ISS, a periodic replacement.

Note that the lidar data could be stored on the ISS, and only a minimum amount needs to be transmitted. The data to be stored could be of the order of 1 Gbyte/month/channel. The number of detection channels may amount to six (3 wavelengths, 2 polarizations).

3.2.7 Possible extension of the LIDAR activity in EUSO project

An EECR (or a EE neutrino) is a rare event: over a three-year period, a total of 3000-5000 events is expected. This rate will not exhaust the possibilities of the LIDAR. Within the limitations of the different technical budgets of the EUSO project, it would therefore be possible to consider an extension of its use and the definition of a specific program in the interest of the general “Atmospheric Physics Community”.

3.2.8 Existing projects, Expressed Interest and Concerned Communities for spaceborne atmospheric sounding, in particular Clouds and aerosol layers study

There exist today well developed experimental methods for obtaining the necessary information needed for calculating the atmospheric transmittance. Various Remote Sensing Satellites instruments, operating in space or foreseen for launch, give global distribution of the ozone and other minor gases, the temperature, aerosol distribution, etc. (GOME, MIPAS, GOMOS, OSIRIS, MISIR, PICASSO-CENA, QuickTOMS).

The following space missions with a scheduled launch date, targeting range resolved cloud and aerosol fields measurements with backscatter lidar are of relevance to EUSO:

- **PICASSO-CENA** (http://essp.gsfc.nasa.gov/picasso-cena/index.html ; scheduled launch date August 2004) is a joint NASA-CNES mission. The mission is based on the use of lidar to detect clouds and subvisible aerosol layers. The mission target: aerosol and cloud vertical distributions, aerosol extinction, optical depth, and single scattering albedo; cloud extinction and optical depth.

- **ICESAT**(http://icesat.gsfc.nasa.gov; scheduled launch date May 2003) scheduled launch date May 2003) is a NASA mission. A component of ICESAT is GLAS (Geoscience Laser Altimeter System), a Lidar for precise measurements of the variation of the thickness of the ice shield and profiles of the vegetative canopies. In addition it will contain an atmospheric channel to measure cloud heights and the vertical structure of clouds and aerosols in the atmosphere. Its laser and receiver hardware are similar to the one used in PICASSO-CENA.

3.2.9 Meteoroids studies

UV observations of meteor streams yield rich astrobiology research results. A great deal of organic matter is thought to survive the rapid heating of Earth' atmosphere caused by meteor streams (P.Jenniskens, Earth, Moon and Planets, November 2000). The fingerprint of complex organic matter, identical to space-borne cometary’s dust, was discovered in the path of bright Leonid fireballs. Further investigation (mainly in the near-UV) is requested to ensure that trace-air compounds are not contributing to the detection. A confirmation could have important implications for the existence and survival of life's precursors in cometary and/or asteroidal materials that reach Earth.

4. Instrument Requirement Specifications

The following Tables refer to the baseline configuration given in Chapter 3.

Item Description	**Characteristic Quantity or Parametric Value**
EECR/ν Telescope	
Mass	1000-1500 kg (*)
Power	750 Watt (heaters included)
External Geometry	cylindrical/polygonal (pointing to Nadir)
Dimension	∅ 2.5 m × 4.2 m
Telemetry (scientific data)	2 kbit/s continuous
Housekeeping Telemetry	100 kbit/s
LIDAR for Atmosphere characterization	
Mass	100-200 kg (*)
Power	300 Watt
External Geometry	Cylindrical/polygonal (co-axial to Main Telescope)
Dimension	∅ 1 m × 3 m
Telemetry	25 kbit/s (per event)
(*) The mass value quoted for the EUSO Instrument (1700 kg as combination of the EECR/ν telescope and of the Lidar) is derived from a first evaluation of the general requirements: it is in apparent conflict with the nominal mass capability (1000 kg) quoted for the Columbus CEPF hosting the EUSO Instrument. A fundamental objective of the Phase A studies is the optimisation of the two values with the aim to converge on a common acceptable target.	

Table 4.1 – Summary of the baseline requirements for EUSO.

4.1 Optics

The “Optics” system includes lenses, filters, and optics support structure.

Item Description	**Characteristic Quantity or Parametric Value**	**Notes**
Lens Material (see Table 4.1.2)	PMMA / ZEONEX / TPX / CYTOP	Trade Off during Phase A
Number of lenses	2	
Lens Diameter	2500 mm	Minimum mandatory requirement
Lens Element Axial Thickness	20 mm	Average value
Mass per lens	from 100 kg to 200 kg, material dependent	Trade Off during Phase A
Filters (interference / Shot BG-3)		Define in Phase A
Optics Support Structure		Light structure to be interfaced with the main telescope structure.

Table 4.1.1 – Baseline requirements for the EUSO optics.

Property	**ZEONEX**	**TPX**	**CYTOP**	**PMMA**
Refractive index	1.525	1.463	1.346	1.49
Abbe’s number	56		90	55
Transmittance (400 nm) 3 mm	92 %	92 – 93 %	92 %	86 %
Linear expansion coefficient /°C	6.0 e-5	1.17 e-4	7.45 e-5	8.0 e-5
Water absorption rate (%) 60°C	< 0.01	< 0.01	< 0.01	0.3
Density g/cm^3	1.01	0.833	2.03	1.19 – 1.20
Tensile strength kg/cm^2	600	> 235 (at yield)	400	490 – 770
Transmission loss on orbit in vacuum	TBD	< 3 %	TBD	TBD
Transmission loss on orbit by orbital radiation (3 years)	TBD	< 1 %	TBD	TBD

Table 4.1.2 – Characteristics of candidate materials for EUSO wide-angle Fresnel optical system.

4.2 Focal Surface

The “Focal Surface” refers to detectors, optical adapters, and focal surface support structure.

Item Description	**Characteristic Quantity or Parametric Value**	**Notes**
Detector baseline	MAPMT Hamamatsu R7600-M64 / M16	Trade Off during Phase A
Detector total mass (including PCB, protection frames, …)	250 kg	Estimated value both for R7600-M64 and R7600-M16
Detector power budget	250 W	TBC during Phase A
Optical adapters	Lens / Empty tapered light pipes / Solid tapered light pipes	Trade Off during Phase A
Focal Surface Support Structure		Common for detectors and optical adapters. To be interfaced with the main telescope structure.

Table 4.2.1 – Baseline requirements for the EUSO focal surface.

4.3 Front End Electronics

The “Front End Electronics” refers to front-end module, analog macrocells, and FEE support structure.

Item Description	**Characteristic Quantity or Parametric Value**	**Notes**
FEE Total mass (including analog macrocells, sockets, harness)	200-350 kg	TBC during Phase A
FEE Power budget (including analog macrocells)	400 W (350 W + 50 W for the analog macrocell)	TBC during Phase A
FEE Support Structure		Shared with that of the focal surface .To be interfaced with the main telescope structure.

Table 4.3.1 – Baseline requirements for the EUSO front end electronics.

4.4 Read-Out and Trigger Electronics

The “Read-Out and Trigger Electronics” refers to read-out and trigger modules.

Item Description	**Characteristic Quantity or Parametric Value**	**Notes**
Total mass (including harness)	50 kg	TBC during Phase A
Power budget (Read-Out & Trigger)	50 W	TBC during Phase A

Table 4.4.1 – Baseline requirements for the EUSO read-out and trigger electronics.

4.5 Atmosphere Sounding

Item Description	**Characteristic Quantity or Parametric Value**	**Notes**
Dimensions	∅ 1 m × 3 m	Cylindrical/polygonal (co-axial to Main Telesc.)
Total mass	100-200 kg	TBC during Phase A Study
Power budget (Transmitter & Receiver)	300 W	TBC during Phase A Study

Table 4.5.1 – Baseline requirements for the EUSO Atmosphere Sounding instrument.

5. Science Operations

5.1 The EUSO Ground Segment

Telemetry from EUSO would be received at the ISS Payload Operation Center located at the NASA/MSFC in Huntsville, Alabama, and then forwarded to the European EUSO Operation Center, which will constitute essential part of the EUSO Ground Segment (GS).

A Mission Operations Center (MOC), a Science Operations Center (SOC) and a Science Data Center (SDC) shall compose the EUSO-GS.

The MOC, as a data-receiver/command-trasmitter, will act as the interface to ISS operations and it may be located at MSFC. The SOC should have the main role to generate EUSO specific commands (to be sent to MOC), to monitor instrument health, its functional status, performance and trend, and to notify any relevant scientific/monitoring event. The SDC will be responsible for the calibration of the EUSO instrument, establishing the EUSO archive, and providing data to users together with a dedicated EUSO data analysis system. Together with the SDC, the SOC should be located with the Principle Investigator’s institution or elsewhere in Europe.

It is expected that during a Phase A study the nature and locations of the ground segment components will be further defined.

6. Management

A general outline of the management is given in the following.

For the EUSO-P/L Phase A Study

ESA side		EUSO Collaboration side
Payload level activities		**Instrument level activities**
<u>Scientific Aspects:</u> **Resp. Study Scientist** **A. Parmar (D/SCI)**	← →	**<u>Scientific Program:</u>** **Resp. EUSO Principal Investigator** **L. Scarsi**
<u>Technical and Managerial Aspects:</u> **Resp. Study Manager** **G. Gianfiglio (D/MSM)**		**<u>Technical Program:</u>** **Resp. EUSO Instrument Manager** **O. Catalano**

<u>Payload:</u> Integrated Flight Segment (as defined by D/MSM), including robotics, transportation, plus Overall Ground Segment, …

For the EUSO P/L Phase A Study

ESA side

Science Study Team

(SST)

Chair: ESA Study Scientist

(A. Parmar)

MSM Representative: ESA Study Manager

(G. Gianfiglio)

Members:

- EUSO PI (L. Scarsi)
- EUSO Instr.Manager (O. Catalano)
- + others

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EUSO Collaboration side

EUSO Instrument Working Group

(EUSO-IWG)

Chair: EUSO Instrument Manager

(O. Catalano)

Members:

Specialists from each of the major EUSO components:

- Optics
- Focal plane detector & optical adapters
- Trigger & OBDF
- System, inc.Thermal, Structure, Shutter
- Atmosphere Sounding
- Simulations
- Science Operations: Ground Segment, …

SST: acts as "advisory body" for ESA and assists the "Study Scientist" in all aspects of the EUSO Mission.

IWG: provides technical support to the EUSO Mission.

List of Acronyms and Abbreviations

ADM	The Atmospheric Dynamics Mission
ASIC	Application Specific Integrated Circuit
ATLID	Atmospheric Lidar
CEPF	Columbus External Payload Facility
CYTOP	Amorphous Peffluoro Alkenylvinylether
CW	Continuous Wave
EE	Extreme Energy
EECR	Extreme Energy Cosmic Ray
EAS	Extended Air Shower
ESA	European Space Agency
EUSO	Extreme Universe Space Observatory
FADC	Fast Analog-to-Digital Converter
FEE	Front End Electronics
FIRE	Fluorescence Image Read-out Electronics
FITS	Flexible Image Transfer System
FOV	Field Of View
GLAS	Geoscience Laser Altimeter System
GS	Ground Segment
GUT	Grand Unified Theories
GTU	Gate Time Unit
GZK	Greisen - Zatsepin – Kuzmin (effect)
IDL	Interactive Data Language
IIDD	Instrument Interface Definition Document
IR	InfraRed
ISS	International Space Station
I2D2	(as IIDD)
LEO	Low Earth Orbit
LIDAR	LIght Detection And Ranging
MAPMT	Multi Anode Photo Multiplier Tube
MOC	Mission Operation Centre
OBDH	On Board Data Handling
OUST	On-board Unit System Trigger
PCB	Printed Circuit Board
PI	Principal Investigator
P/L	Payload
PMMA	Poly Methyl Metha Acrylate
PRN	Pseudo-Random Noise
ROOT	An Object-Oriented Data Analysis Framework developed at CERN
SC	Steering Committee
SDC	Science Data Centre
SOC	Science Operations Centre
S/W	Software
TBC	To Be Confirmed
TBD	To Be Defined
TPX	Polymethyl-pentene
UV	Ultra Violet
VLSI	Very Large Scale Integration
ZEONEX	Amorphous Cycle-Olefin