EUSO: USING HIGH ENERGY COSMIC RAYS AND NEUTRINOS AS MESSENGERS FROM THE UNKNOWN UNIVERSE (°)

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ABSTRACT

Exploiting the Earth Atmosphere as a giant detector for the incoming extraterrestrial flux of High Energy Cosmic Rays and Cosmic Neutrinos , the mission " EUSO - Extreme Universe Space Observatory " is devoted to the exploration of the domain of the highest energy processes occurring in the Universe up to its accessible boundaries. The observable is provided by the Air Nitrogen fluorescence light emitted in the UV band 300 – 400 nm by the Extensive Air Showers produced by the cascading processes of the Primary C.R. Particles interacting with the Atmosphere. The EUSO telescope is based on a double Fresnel lens optics (diameter 2.5 m) coupled to an highly pixelized focal surface composed by multianode PMTs ; the image at the Earth surface is detailed at 1 Km^2 over a total of several hundred thousand of Km^2. EUSO will fly on the International Space Station accommodated as External Payload of the European Space Agency Columbus module . The mission is scheduled to last 3 years , with the start of operations foreseen for 2007/8 . The expectations are of a collection rate of a thousand events / year for Cosmic Rays at $E > 10^{20}$ eV together with tens / hundreds Cosmic Neutrinos at energy above about 4×10^{19} eV. EUSO is the result of the collaborative effort of several Institutions in Europe, Japan and USA and it is conceived within the science program sponsored by various Space Agencies coordinated by ESA.

(°-This text is largely derived from contributions made by the Author in 2000/2001 to other Workshops and Conferences and from documentation submitted by the EUSO Consortium to the European Space Agency as a part of the proposal EUSO.

1 Introduction

The Cosmic Radiation can be considered the "Particle channel" complementing the "Electromagnetic Channel" proper of the conventional Astronomy.

A classic presentation of the Cosmic Ray Energy Spectrum is shown in Fig.1; an unconventional view (which I borrowed from a colleague of Karlsruhe, where it was first shown at the Cerimonial organized in honor of Dr. Shatz) is given in Fig.2 to illustrate in an anthropomorphic perspective the features conventionally nominated "knee" (around 10^{15} eV) and "ankle" (above 5×10^{18} eV). The remarkable "feminine leg" in the figure is that of the famous German movie Star Marlene Dietrich.

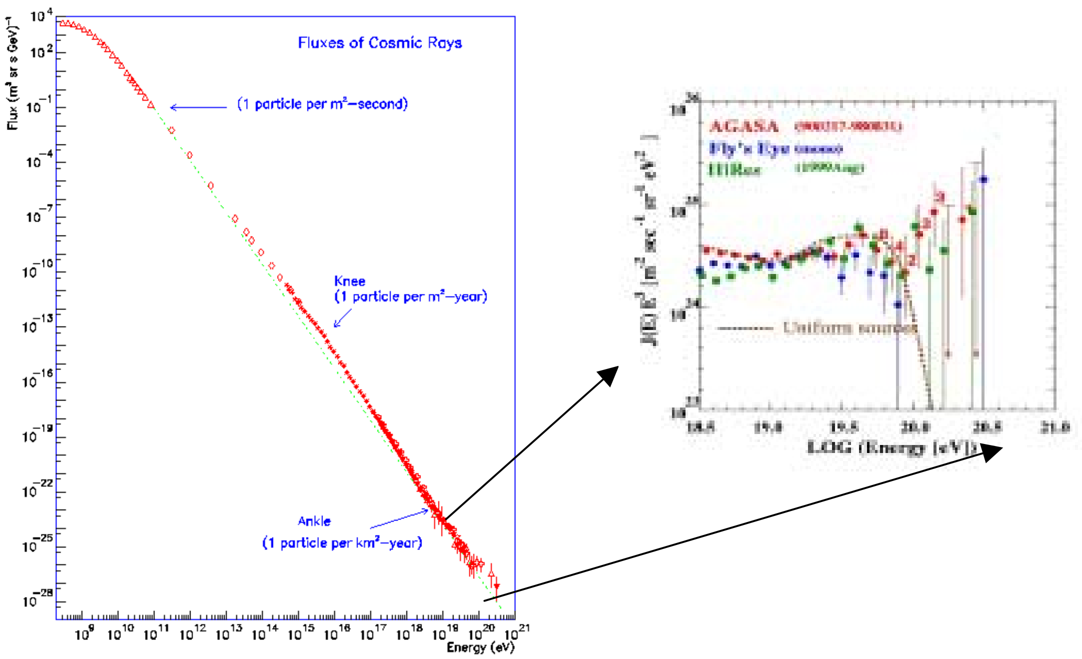


Figure 1. The observed cosmic ray spectrum for E >10^8 eV showing the principle features. The inset shows the high-energy part with the overall E-3 dependence removed as observed by AGASA (Takeda et al. 1998), Fly's Eye and HIRes (Teshima 2000). The dashed line shows the effect of the GZK cutoff assuming a homogenous source population filling the Universe. The numbers are the actual number of events in each bin.

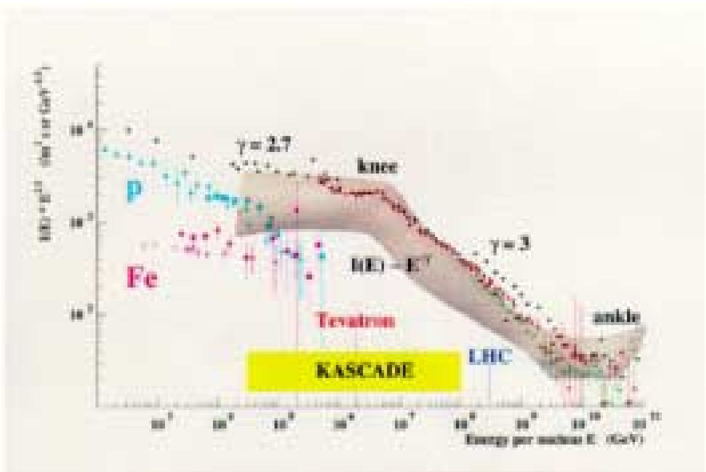


Figure 2. The Cosmic Ray energy spectrum: anthropomorphic presentation.

Today substantial progresses have been made in the knowledge of the nature of Cosmic Rays of the relatively modest energies (up to the "knee" at 10^{14}-10^{15} eV); the Cosmic Radiation on the higher energy side on the other hand presents us with the challenge of understanding its origin and its connection with fundamental problems in Cosmology and Astroparticle Physics.
Focal points are represented by:

i) The change in the spectral index at $\sim 5\times10^{18}$ eV ("Ankle ")

ii) Existence of "Cosmic Rays" with energy $E>10^{20}$ eV: (EECR) (Fig.1).

A direct question arising is: what is the maximum Cosmic Ray energy, if there is any limit? Addressing the theoretical issue concerning the production and propagation of 10^{20} eV Primary quanta is problematic and it involves processes still little known.

2 The Universe and the probing depth of the Extreme Energy Cosmic Radiation.

(From the document "Report on the Accommodation of EUSO on the Columbus Exposed Payload Facility: ESA/MSM-GU/2000.462/AP/RDA. December 2000).

Soon after the discovery of the cosmic microwave background radiation (CMB) by Penzias and Wilson in 1965, Greisen, and, independently, Zatsepin and Kuzmin pointed out that this radiation would make the universe opaque to cosmic rays of sufficiently high energy. For protons, e.g., this occurs when the pion production threshold is reached (about 5×10^{19} eV , if the Lorentz tranformations of Relativity still hold at $\gamma \geq 10^{11}$). The reaction $p + \gamma \rightarrow \Delta^{+} \rightarrow p + \pi^{\circ}$ or $n + \pi^{+}$ will lead to an effective attenuation length of 50 Mpc for a proton of 10^{20} eV. This is about the size of the Virgo cluster to which our galaxy belongs, and is just a small fraction of the size of the Universe .Table 1 summarizes the effects introduced on the primary EECR components, including gamma rays, by the interaction with the CMB. To a much lesser extent, neutrinos decay above 10^{21}-10^{22} eV by Z_0-resonance with cosmic neutrino background (CNB).

Table 1. Extreme energy processes that cutoff the energy spectrum of particles in Universe.

	Process	Cutoff Energy	Mean free path
Protons	$p + \gamma_{2.7K} \rightarrow \pi^{\circ} + X$	eV	50 Mpc
Nuclei	$A + \gamma_{2.7K} \rightarrow \Delta^{++} + X$	$\geq 5 \times 10^{18}$ eV/n	100 Mpc
Gamma-rays	$\gamma + \gamma_{2.7K}$	$\geq 10^{14}$ eV (at 10^{20} eV)	10 Mpc (at 10^{20} eV)
Neutrinos	$\nu + \nu_{1.95K} \rightarrow (W/Z_0) + X$	$\geq 4 \times 10^{22}$ eV	40 Gpc

The Greisen-Zatsepin-Kuzmin effect shapes in a complicate way the form of the observed energy spectrum of the EECR as a function of the distribution of the extragalactic sources in the Universe (see Figure 3).

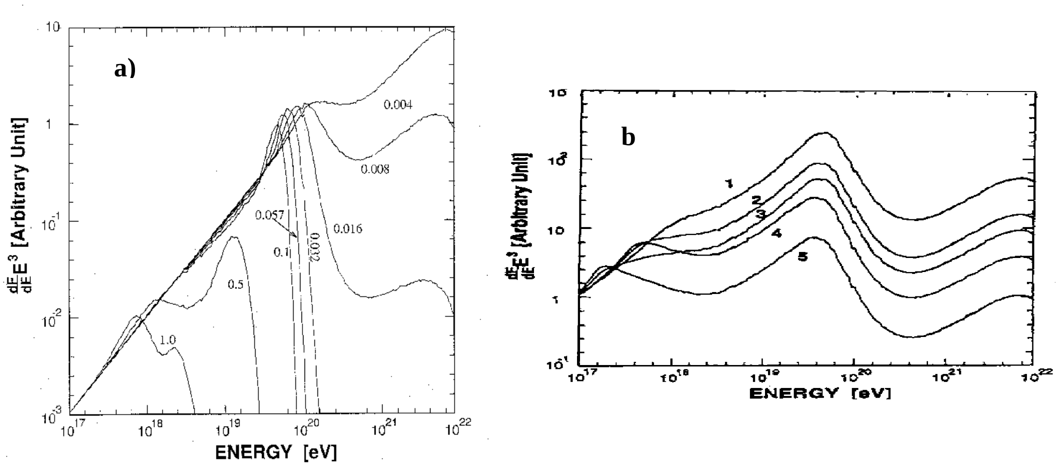


Figure 3. Left: Energy spectra from a single source of protons with an E^{-2} spectrum, for various source distances between z = 0:004 and 1 (i.e. between 2 and 5000 Mpc). **Right:** The nucleon spectrum at the trans-GZK and super-GZK energies predicted from different models of the cosmic evolution, including the hypothetical component at EE up to 10^{23} eV. The curve 1 is for the case of homogeneous evolution for the redshifts $0 \leq z \leq 2$. The curve 5 shows non-homogeneous distribution up to z = 4 in which early cosmological era has more active EE sources. Curves 2-4 are for intermediate models. Cosmological neutrinos and their secondaries are not included in this figure.

2.1 Sources of Extreme Energy Cosmic Rays

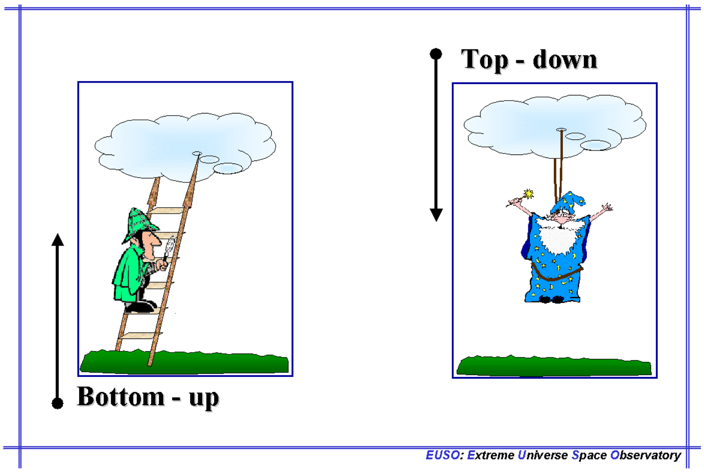
Many sources of high-energy particles could exist in the Universe at distances beyond the GZK length of 50 Mpc. The predicted sharp cutoff of energy spectrum above $5x10^{19}$ eV may not be present if a possible high abundance of cosmological neutrino events, or others from nearby sources, are dominant. A significant bump should exist at 10^{19}-10^{20} eV due to the GZK effect for protons, because cosmological protons that were accelerated to the super-GZK energies decay down to the trans-GZK energies, and pile up at sub-GZK energies. The details of the energy spectrum in the trans-GZK energy regime (10^{19}– $2x10^{20}$ eV) depend on the model of the evolution of Universe from about 10 billion years ago (or z~5). High event statistics can provide information on the evolution of the highest energy Universe. This information on the evolution of Universe may be distorted by the probable existence of super-GZK neutrinos. However, using EUSO the neutrino energy spectrum can be identified and directly measured, and the non-neutrino spectrum can be statistically corrected by subtracting relevant neutrinos and their secondaries. The evolution of energetic sources in universe will be examined by such statistical means.

The current summary of the data from AGASA, Fly's Eye and Hi-Res is shown in the insert of Fig. 1 and suggests that the observed cosmic ray spectrum is not necessarily cut off following the predicted GZK process for protons and nuclei. It suggests that either the majority of cosmic rays originated within the GZK length (< 50 Mpc), or the relativity principle fails at extreme energies, or some other unknown sources exists.

Concerning the distribution of arrival directions , AGASA and world wide data summary of cosmic rays above about the GZK cutoff energy shows a quasi-isotropic distribution in the sky clearly suggesting an extragalactic origin. Among them, 6 pairs and 1 triple set of spatially correlated events within 2 years from 58 events were recognized by AGASA only, while the world-wide data show 9 pairs and two triples. The chance coincidence probability for these "clusters" of events is less than 0.07%, and therefore, the particles of a "cluster" possibly had the same sources

Although the existence of the highest energy cosmic rays is proven, their origin is still an enigma despite the efforts of many theorists and experimentalists. One is led to the conclusion that they have an entirely different origin than the lower energy cosmic rays. The present data raise questions of great importance for astrophysics, cosmology, and fundamental physics.

Focusing the attention on the primary sources, the general production mechanisms proposed for the EECRs can be classified as:



- BOTTOM-UP, with acceleration in rapidly evolving processes occurring in Astrophysical Objects. The scenario involves astrophysical objects such as, e.g. AGNs and AGN radio lobes. The study of these objects is, besides radio observations, a main goal of X-ray and Gamma-ray astrophysics of the late 90`s. An extreme case in this class is represented by the Gamma Ray Bursts, found to be located at cosmological distances. The observation of “direction of arrival and time” coincidences of GRBs and Extreme Energy Neutrinos ($E \geq 10^{19}$ eV) in the EUSO mission could provide a crucial test for the identification of the observed GRBs as EECR sources in spite of their location at distances well above the GZK limit.

- TOP-DOWN Processes. This scenario arises from the cascading of ultrahigh energy particles from the decay of topological defects. Cosmic Strings would play an essential role for releasing the X-bosons emitting the highest energy quarks and leptons. This process could occur in the nearby Universe. The relics of an early inflationary phase in the history of the Universe may survive to the present as a part of dark matter and account for those unidentified EECR sources active within the GZK boundary limit. Their decays can give origin to the highest energy cosmic rays, either by emission of hadrons and photons, as through production of EE neutrinos.

From the Astroparticle Physics point of view, the EECRs have energies only a few decades below the Grand Unification Energy (10^{24}-10^{25} eV), although still far from the Plank Mass of 10^{28} eV.

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2.2 Neutrino induced Air Showers

Neutrinos with high enough energy can produce detectable EAS observable by EUSO. This will provide precious information about their origin together with that of the EECR. Not suffering the GZK effect and being immune from magnetic field deflections, or from a delay caused by the quantum relativity effects, neutrinos are ideal for disentangling source related mechanisms from propagation related effects. The opening of the neutrino astronomy channel will allow the extreme boundaries of the Universe to be probed.

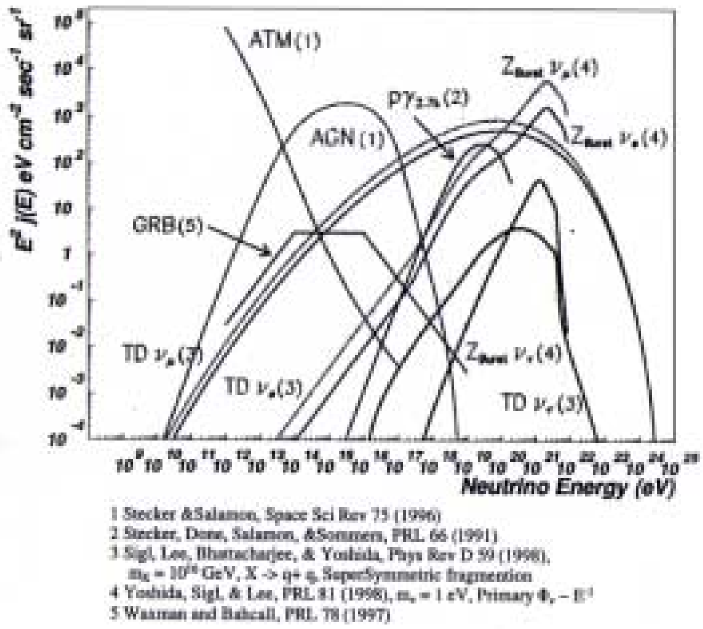

Figure 4. Predicted neutrino fluxes for various models. The large range of predicted fluxes should be noted as should the number of models which exceeds the number of events with energies $>10^{20}$ eV !

However, neutrinos are elusive objects with a low interaction probability, to such an extent that they can be neglected as observable EAS initiators for all ground based detectors, present or planned. Even for the largest planned ground based cosmic ray detector (the Auger project), in the most optimistic case, the expected rate is only a few events per year. EUSO, with its large sensitive area and accessible mass target of the order of 10^{13} tons of atmosphere, will be sensitive to this class of events.

The expected neutrino event rate ranges from a few events per year (GZK processes, AGN, GRB sources etc) to 150 per year according to the effectiveness of the "topological defects" hypothesis (see Fig. 4). Observationally, neutrino induced EAS can be distinguished from background events and from other EECR EAS by selecting events with large zenith angles which initiate deep in the atmosphere (Fig. 5). A nearly horizontal τ-neutrino event with an energy $>10^{19}$ eV can be identified by a “double bang” structure. Both the initial shower in the $\nu_\tau \rightarrow \tau$ interaction, and another, by the τ-decay, can be seen because of the long path length (~1000 [E/10^{20} eV] km) for τ-decays.

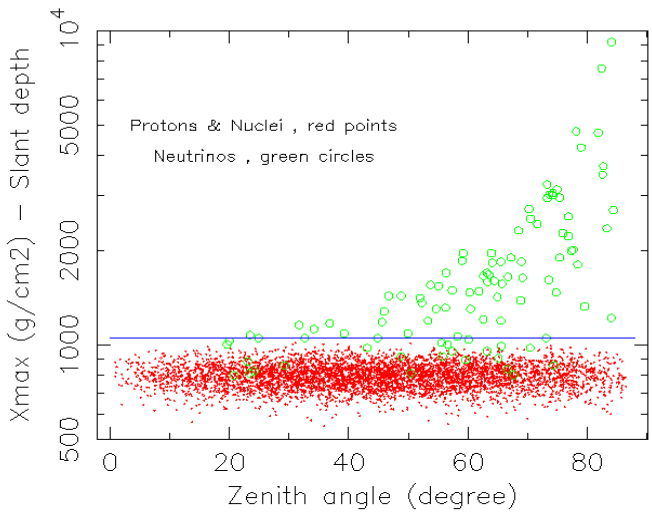

Figure 5. Shower depth distribution from Monte Carlo simulations showing how neutrino and proton and nuclei induced events can be distinguished.

3 Observational problems

The extremely low value for the EECR flux, corresponding to about 1 event per km^2 and century at E > 10^{20} eV, and the extremely low value for the interaction cross section of neutrinos, make these components difficult to observe if not by using a detector with exceptionally high values for the effective area and target mass. The integrated exposure (~ 2×10^3 km^2 yr sr) available today for the ground based arrays operational over the world is sufficient only to show the "ankle" feature at ~5×10^{18} eV in the Cosmic Ray energy spectrum and the existence of about ten events exceeding 10^{20} eV; the limited statistics excludes the possibility of observing significant structures in the energy spectrum at higher energies. Experiments carried out by means of the new generation ground-based observatories, HiRes (fluorescence) and Auger (hybrid), will still be limited by practical difficulties connected to a relatively small collecting area (<10^4 km^2 sr) and by a modest target mass value for neutrino detection.

To overcome these difficulties, a solution is provided by observing from space (Fig.6) the atmosphere UV fluorescence induced by the incoming extraterrestrial radiation, which allows to exploit up to millions km^2 sr for the acceptance area and up to 10^{13} tons as target for neutrino interaction. This is the philosophy of the “AirWatch Programme” and “*EUSO*” is a space mission developed in the AirWatch framework.

The Earth atmosphere in fact constitutes the ideal detector for the Extreme Energy Cosmic Rays and the companion Cosmic Neutrinos. The EECR particles, interacting with the air nuclei, give rise to propagating Extensive Air Showers (EAS) accompanied by the isotropic emission of UltraViolet fluorescence (300-400 nm) induced in Nitrogen by the secondary charged particles in the EAS as result of a complex relativistic cascade process; an isotropically diffuse optical-UV signal is also emitted following the impact on clouds, land or sea of the Cherenkov beam accompanying the EAS. A Shower corresponding to a Primary with $E>10^{19}$ eV forms a significant streak of fluorescence light over 10-100 km along its passage in the atmosphere, depending on the nature of the Primary, and on the pitch angle with the vertical.

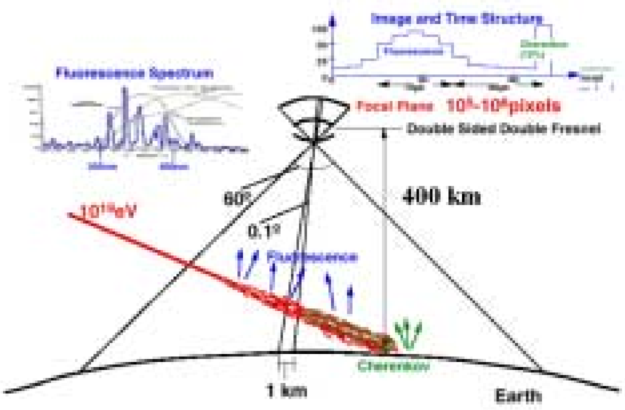

Figure 6 . Observation of EAS from Space.

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. When viewed continuously, the object moves on a straight path with the speed of light. The resulting picture of the 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. From a Low Earth Orbit (LEO) space platform, the UV fluorescence induced in atmospheric Nitrogen by the incoming radiation can be monitored and studied. Other phenomena such as meteors, space debris, lightning, atmospheric flashes, can also be observed; the luminescence coming from the EAS produced by the Cosmic Ray quanta can be on the other hand disentangled from the general background exploiting its fast timing characteristic feature.

EUSO observes at Nadir from an orbital height of about 400 km. It is equipped with a wide angle Fresnel optics telescope (60° full FoV) and the focal plane segmentation corresponding to about 1 km^2 pixel size on the Earth surface. The area covered on Earth is of about 160000 km^2. Exploiting the high speed of the focal plane detector (10 ns class), EUSO is able to reconstruct the inclination of the shower track by the speed of progression of the projected image on the focal surface and to provide the tri-dimensional reconstruction of the EAS axis with a precision of a degree (or better) depending on the inclination. By measuring the EAS front luminosity with the photoelectrons (PE) detected by the MAPTs covering the focal surface, EUSO registers the longitudinal development of the EAS.

3.1 EUSO General Requirements and Main Goals

For a significant observation from a space mission the assumed values are: a) Geometrical exposure of $(5\times10^4$-$10^5)$ km^2 sr considering a duty cycle of 0.1-0.15; b) EAS energy threshold at about 5×10^{19} eV.

EECR statistics. About 10^3 events/year (an order of magnitude above those expected by the presently planned ground based experiments) 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.

Neutrino events. The expected event rate ranges from several events/year (AGN, GRB source) to several events/day according to the effectiveness of the "topological defects" hypothesis. From the observational point of view, the neutrino induced EAS can be distinguished from background and from other EECR EAS by triggering on horizontal showers initiating deep inside the atmosphere. Moreover neutrinos with energy of about 10^{15}- 10^{16} eV interacting in the solid earth and emerging upward in the atmosphere create showers which can be detected by EUSO by means of the Cherenkov beamed signal induced in the atmosphere, extending the capability of EUSO to this lower neutrino astronomy energy band. A horizontal tau-neutrino event at energies greater than 10^{19}eV can be identified by a “double bang” structure. Both the initial shower at the $\nu_\tau \rightarrow \tau$ interaction, and another, by the τ-decay, can be seen because of the long enough path-length (~ 1000 [$E/10^{20}$ eV] km) for τ-decays observable by EUSO. Tau-neutrinos above 10^{15} eV, on the other hand, will be observed and identified as Earth-penetrating “upward” showers (by Cherenkov). High ν_τ flux by the $\nu_\mu \rightarrow \nu_\tau$ oscillation and the low detection threshold energy for them allow EUSO to make oscillation experiments in space as well as ν_τ astrophysics of AGN above 10^{15} eV.

3.2 EUSO Schematic Outline

EUSO, originally proposed to ESA in January 2000 for a free-flyer LEO mission, has been approved in March 2000 for an “Accommodation study” on the ISS International Space Station. As a result, EUSO is now undergoing a “bridging phase” to enter “Phase A design” carried out by Industry under an ESA contract (transportation and transfer to the ISS/Columbus EPF (Fig.12)).

Under the assumption of both a LEO (~ 500 km altitude) free-flyer mission or the ISS accommodation (400 km average altitude), the coverage of the observable atmosphere surface at the scale of thousand kilometers across and the measurement of very fast and faint phenomena like those EUSO is interested in, requires:

- optical system with large collecting area (because of the faint fluorescence signal) and wide equivalent field of view covering a sizable half opening angle around the local Nadir (to reach geometrical factor of the order of 10^6 km^2 sr) ,
- focal plane detector with high segmentation (single photon counting and high pixelization), high resolving time (~10 ns), contained values for weight and power,
- trigger and read-out electronics prompt, simple, efficient, modular, capable to handle hundreds of thousands of channels, and comprehensive of a sophisticated on-board image processor acting as a trigger.

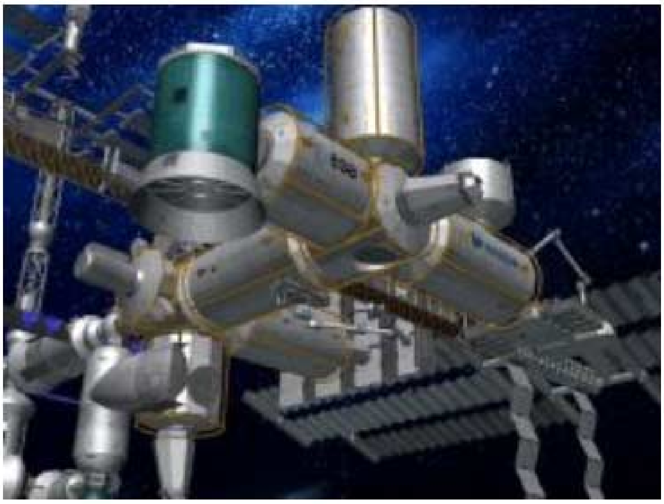

Figure 7. EUSO at the COF-EPF.

3.3 EUSO Payload: The "Main Telescope"

The EUSO Main telescope is presented schematically in the artistic view of Fig.14. The instrument consists of three main parts: Optics, Focal surface detector, Trigger and Electronics System. An effective synergy between the parts constituting the instrument is of fundamental importance for achieving the EUSO scientific objectives. Optics, detector elements, system and trigger electronics have to be matched and interfaced coherently to obtain a correct response from the instrument. Scientific requirements have been of guidance for the conceptual design of the apparatus and in the choice among various possible technical solutions.

The observation from space calls for an approach different from that of the conventional ground based fluorescence experiments. For space application the instrument has to be compact as much as possible, highly efficient, and with a built-in modularity in its detection and electronics parts.

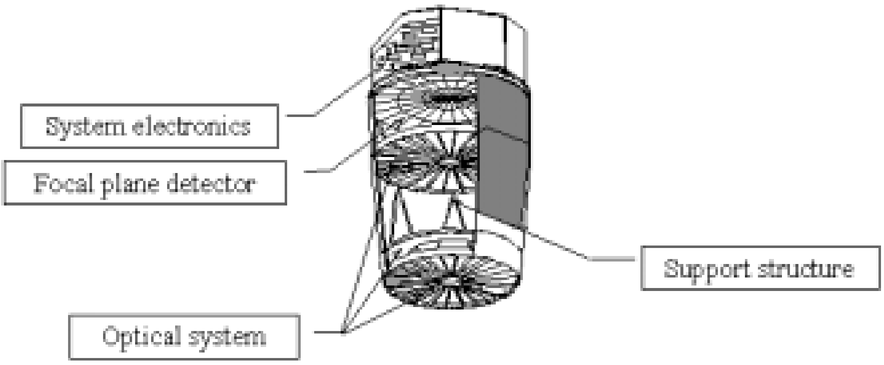

Figure 8 . View of the EUSO Main Telescope.

3.3.1 The Optics

The optical system required for EUSO aims at finding the best compromise in the optical design, taking into account the suitability for space application in terms of weight, dimensions and resistance to the strains in launch and orbital conditions.

The optical system views a circle of radius ~220 km on the Earth and resolves 0.8×0.8 km^2 ground pixels: this determines the detector size to be adopted to observe the events. The forgiving resolution requirements of EUSO suggest the consideration of unconventional solutions, identified in the Fresnel lens technology. Fresnel lenses provide large-aperture and wide-field 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.

The present Fresnel optical camera configuration study (FoV 60°) considers two plastic Fresnel lenses with diameter 2.5 m and iris diaphragm 2.0 m diameter.

3.3.2 The Focal Surface Detector

Due to the large FOV and large collecting area of the optics, the focal surface detector is constituted by several hundreds of thousands of active sensors ($\approx2\times10^5$ pixels). The detector requirements of low power consumption, low weight, small dimension, fast response time, high quantum efficiency in UV wavelength (300–400 nm), single photoelectron sensitivity, limit the field of the possible choices to a very few devices. A suitable off-the-shelf device is the Multi-Anode Photomultiplier Hamamatsu R5900 series. These commercial photomultipliers meet closely the requirements imposed by the project. Pixel size, weight, fast time response and single photoelectron resolution are well adaptable to the EUSO focal surface detector. The organization in "macrocells" of the focal surface (a macrocell is a bi–dimensional array of n×n pixels) offers many advantages as easy planning and implementation, flexibility and redundancy. Moreover, modularity is ideal for space application. The Multi–Anode Photomultipliers represent, in this contest, a workable solution.

3.3.3 Trigger and Electronics System

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 a 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" (n×n pixels unit, ≈100 macrocells constitute the focal surface detector) for diminishing the number of channels to read-out.

4 EUSO Duty Cycle

The EUSO duty cycle has been estimated taking into account the following factors affecting the level of background:

The ISS night time; ground locations with significant light output, natural or anthropomorphic ; Lunar cycle ; Clouds in the FOV strongly affecting the detection or interpretation of the EAS ; ISS activities or contingencies that do not allow the operation of EUSO .

The likely EUSO duty cycle is resulting to be in the range 0.1-0.15; a more precise evaluation requires a detailed assessment of the various elements, in particular of the cloud related effects: we, in a conservative approach, use a value of 0.1 throughout this report.

5 Expected Results

The slope of the CR energy spectrum in the region of the GZK limit and above is poorly known because of the reduced statistics available (see Fig. 1, insert). The expected counting rates for energies e.g. above 10^{20} eV, are therefore difficult to define and are strongly dependent from the assumed extrapolation for the energy spectrum. As an example, we show Fig. 9 where the integral count rates are given respectively for a spectral index –2.7 and –2.3: the counts per year above 10^{20} eV varies from 500 to 1300, accordingly. In the following, a spectral index of –2.7 is assumed (in a conservative way).

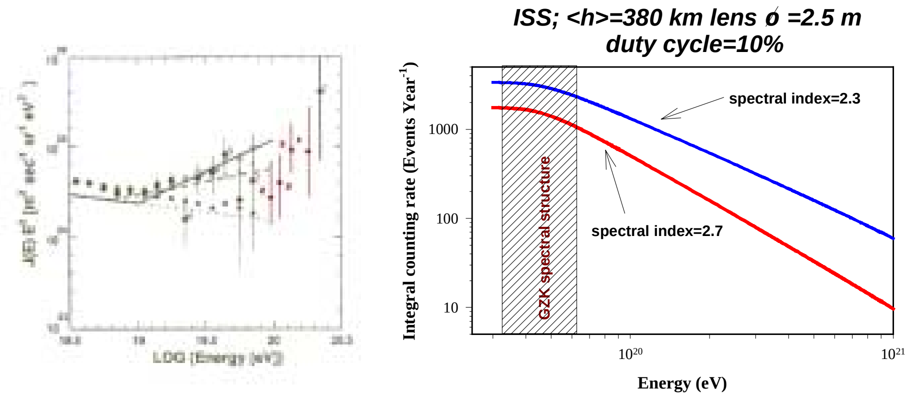

Figure 9. left)- This is Fig.10 from Yoshida et al., AstroParticle Physics 3, 1995, pp. 114: "Derived primary energy spectra expressed by Eqs. (11a) (solid line) and (11b) (dashed line) and the expected values in each bin simulated under the assumptions of these spectra with the energy resolution of the present experiment open squares and crosses). Black dots with error bars are the raw data. The case of a single power up to the highest energy is also shown by a dotted line and shaded circles." The slope of the continuous line above 1019 eV is 2.3; for the dashed line the slope is 2.7. The superimposed red points are from Takeda et al., Phys. Rev. Lett. 1998, 81, pp.1163. **right)-** EUSO counting rates under the hypothesis of the two different spectral index assumed (see Fig.1 left).

Figures 10 and 11 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 configurations. 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. 12 assuming the 2 year operational life of the free-flyer and a requested 3 year lifetime.

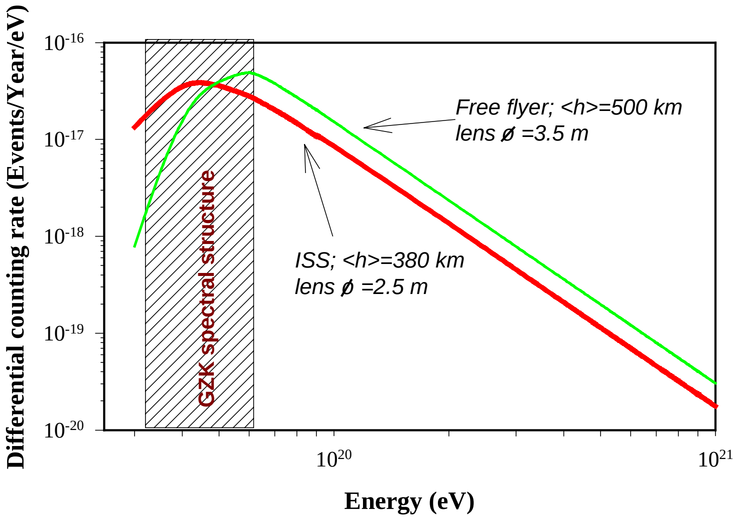

Figure 10. Differential EECR counting rate comparison between the ISS version of the EUSO and the original free flyer. The dashed zone shows the spectral region where structure induced by the GZK cutoff is expected. The lens diameter is the maximum external diameter allowed in each configuration.

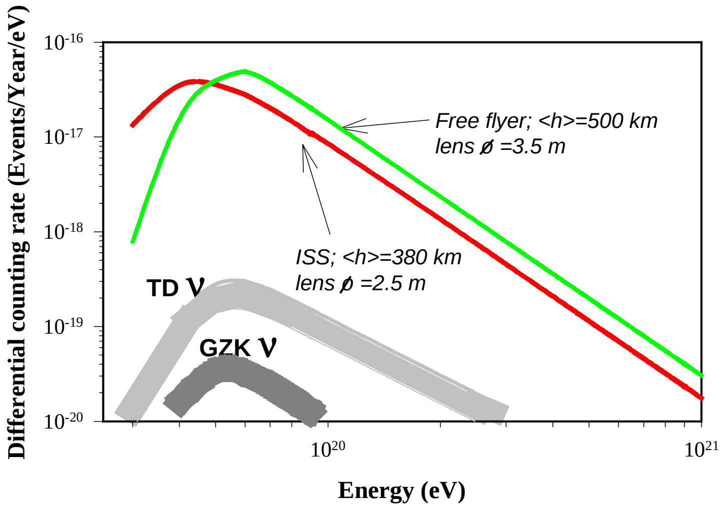

Figure 11. The differential flux of neutrinos predicted using the Topological Defects model of Sigl et al. (1998) and the GZK model of Stecker et al. (1991).

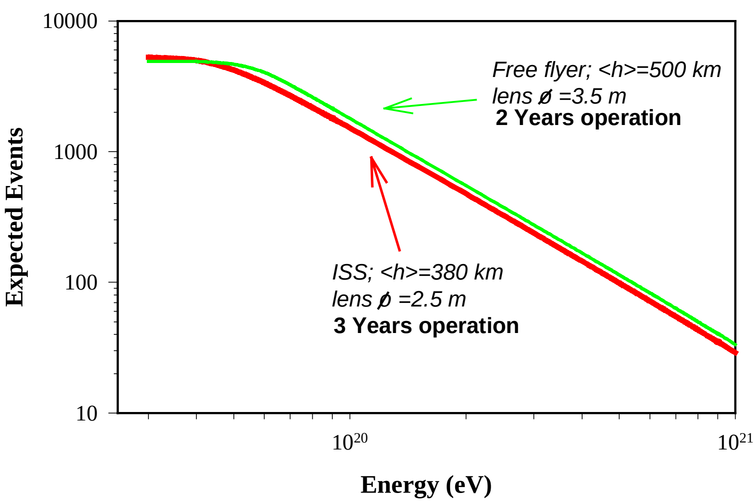

Figure 12. The integral count rates above an energy E predicted for the original free flyer proposal with 2 years of operations and the ISS configuration with 3 years operations.

5.1 Comparison with ground based observations

In the following, a spectral index of –2.7 is assumed whenever absolute values are quoted for the counting rates above 5×10^{19} eV. Currently only the AGASA and HiRes instruments are operational. The AGASA experiment near Tokyo, with coverage of about 100 km^2 (about 300 km^2 sr), comprises a scintillator array for electromagnetic shower particles and an array of muon detectors. The HiRes experiment in Utah consists of two fluorescence detectors at a distance of 12.6 km and, in a first stage, just came online. Its aperture is energy dependent and rises from 340 km^2 sr at 10^{19} eV to 1000 km^2 sr at 10^{20} eV. The largest planned ground-base experiment is the Pierre Auger Observatory, presently under construction in Argentina. This will consist of an array of 1600 particle detectors covering 3000 km^2 and 4 fluorescence light detectors, similar to the ones used in the HIRES experiment. The hybrid detector allows cross calibration and a check of the systematic uncertainties inherent in each of the techniques. The construction is expected to be completed in 2004. By then the Auger observatory will have an aperture of 7000 km^2 sr, leading to about 30 events per year with energies $>10^{20}$ eV. Though a second Auger observatory is planned in the northern hemisphere, it is not clear whether, and when, there will be funding for it. Auger will produce a comparable number of events to all previously observed above 10^{20} eV in only 4 months. Nevertheless, a rate of 30 events per year is too small to follow the CR spectrum to such energies, or to obtain the detailed form of the spectrum with small statistical errors. At 10^{21} eV only about 5 events are expected in 10 years of operation. At least an order of magnitude more statistics is desirable. By the year 2006, provided Auger is completed on schedule, the world data set will comprise about 100 events above 10^{20} eV and perhaps one or two events above 10^{21} eV, if the spectrum continues without a GZK cutoff. The existence or non-existence of the GZK cutoff will most likely be established by then. However, a definite answer concerning the origin and possible identification of sources will certainly rely on the precise spectral form and on the arrival direction distribution. In both cases good statistics are vital to distinguish between different competing scenarios.

For EUSO an effective geometrical factor of 5×10^5 km^2 sr and an observing efficiency of 0.1 gives an expected event rate of ~500 per year for EECR with energies $\geq10^{20}$ eV (no GZK suppression and spectral index of 2.7), or some hundreds per year with GZK suppression. The total number of events per year with the low-energy threshold of $>3\times10^{19}$ eV is >1700. For EECR neutrinos the expected rates vary from a few per year (GZK processes, AGN, GRB sources, etc) to ~150 per year if top-down processes dominate.

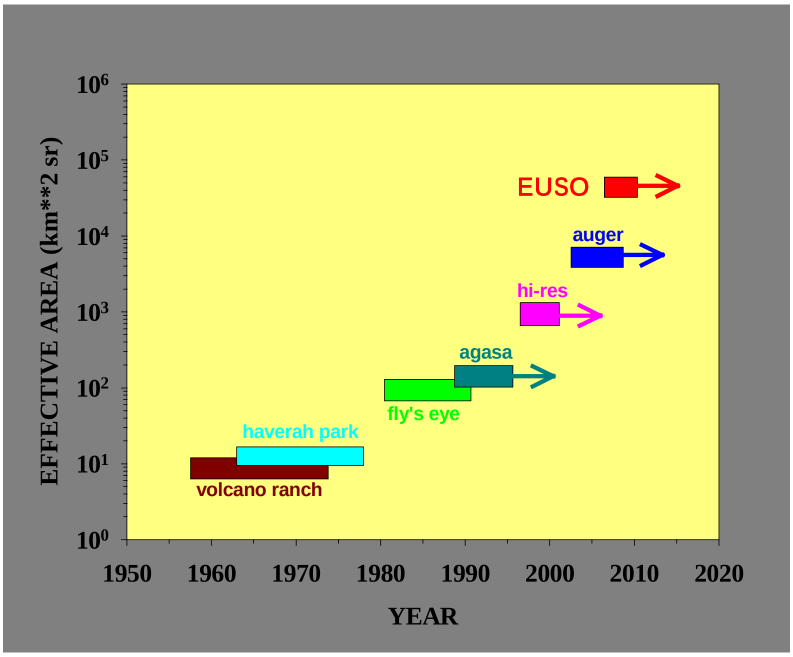

Figure 13. A Comparison of the EUSO effective area with ground based facilities.

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References

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