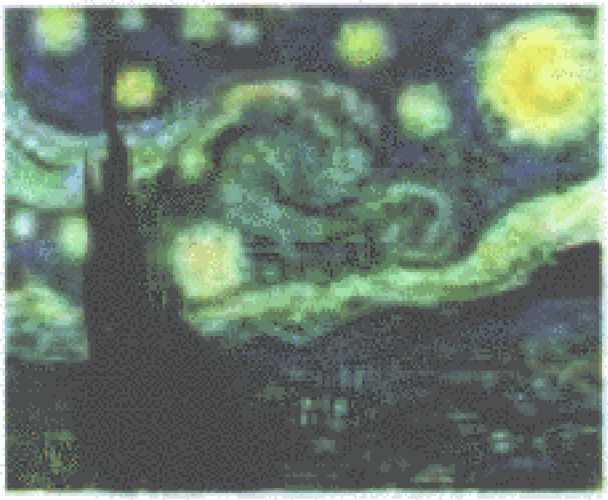
EUSO



Extreme Universe Space Observatory

An Innovative Space Mission
doing Astronomy
by looking downward
from the Space Station
at the Earth Atmosphere

EUSO Science

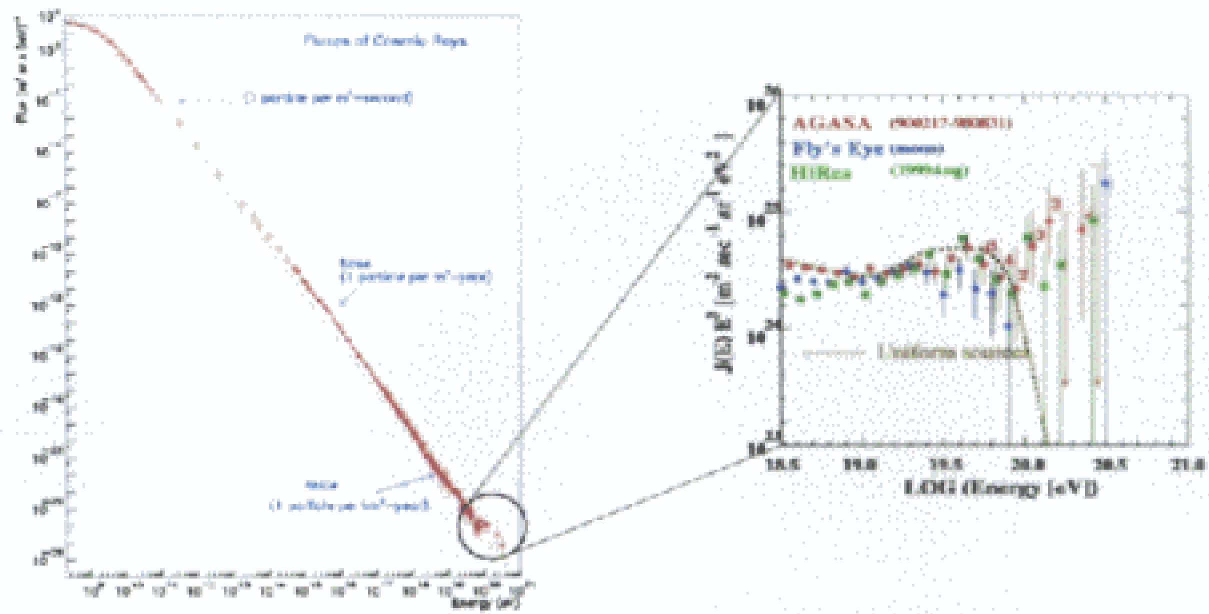
Objectives:

- Investigation of the Highest Energy processes present and accessible in the Universe, through the detection and analysis of the Extreme Energy component of the Cosmic Radiation (EECRs with $E \geq 5\times10^{19}$ eV).

- Open the channel of High Energy Neutrino Astronomy to investigate the nature and distribution of the EECR sources and to probe the boundaries of the extreme Universe.

The Cosmic Radiation

Observed Energy Spectrum



The observed cosmic ray spectrum (E>10^8 eV) showing the principal 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 cut-off assuming a homogenous source population filling the Universe. The numbers are the actual number of events in each bin.

Extreme Energy Cosmic Radiation

Extreme Energy Cosmic Radiation (EECR): $E>10^{20}$ eV.

- 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 rather far from the Planck Mass of 10^{28} eV.
- If protons, they show the highest value for the Lorentz factor observed in nature ($\gamma \sim 10^{11}$).
- What is the maximum Cosmic Ray energy, if there is any limit?
- There is no compelling evidence for identification of EECR sources with objects known in any astronomical channel.

EECRs present us with the challenge of understanding their origin in connection with problems in Fundamental Physics, Cosmology and Astrophysics.

The Extreme Energy Cosmic Radiation with energy greater than 10^{20} eV can be considered as the "Particle" channel complementing the "Electromagnetic" channel, specific of conventional Astronomy.

The Cosmic Radiation

The observed energy spectrum extends from 10^9 eV to > 10^{20} eV.

Up to ~ 10^{15} eV (the "knee"):

- direction of arrival
- energy
- elemental composition

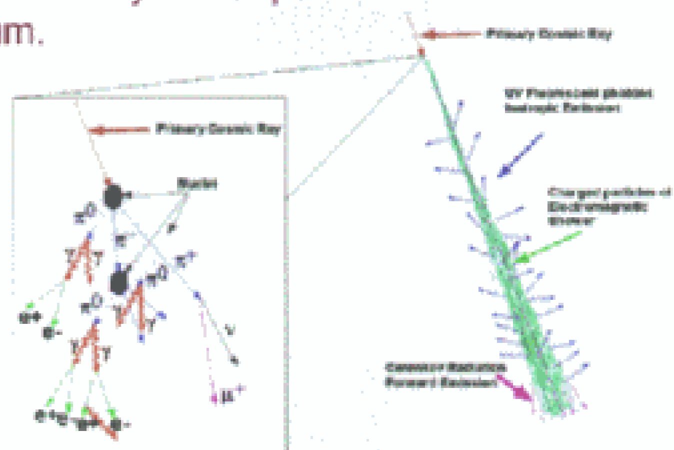
} through direct detection of the primaries

Above 10^{15} eV:

measurements are made by observation of the cascades of particles (Extensive Air Showers, EAS) that result from the interaction of a high energy Cosmic Ray with the Earth's atmosphere.

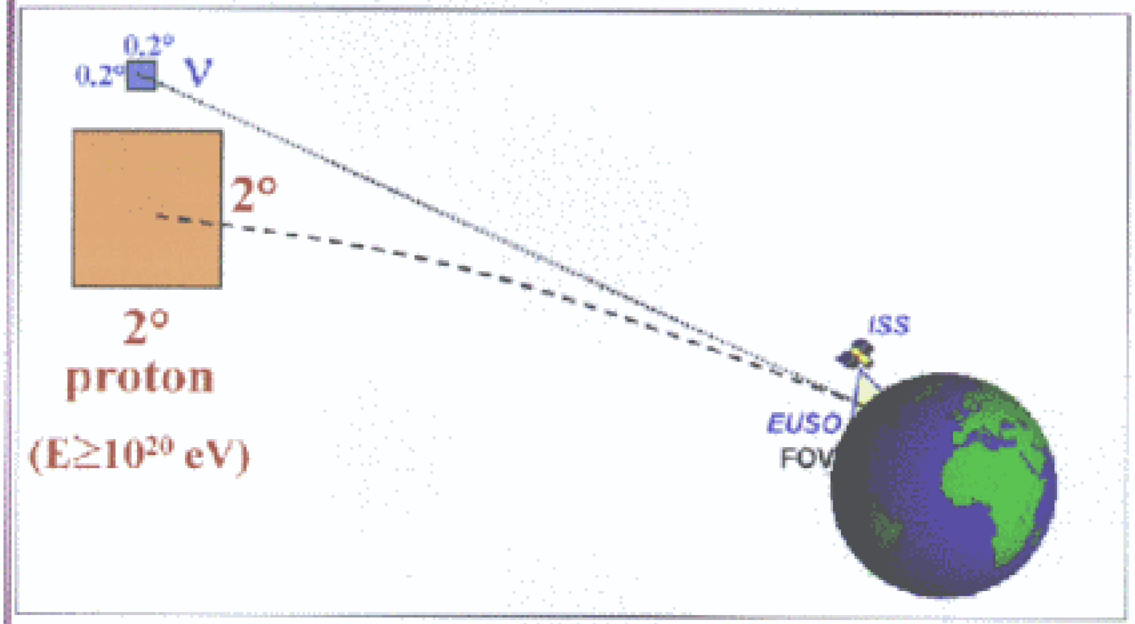
For the Primary Particles:

- direction of arrival: through the EAS axis;
- energy: by calorimetry through the EAS process;
- elemental composition: indications through the longitudinal development of the EAS. Neutrinos are discriminated by the depth distribution of the shower maximum.



The Cosmic Radiation

Direction of arrival.
Neutrino and hadron error boxes.



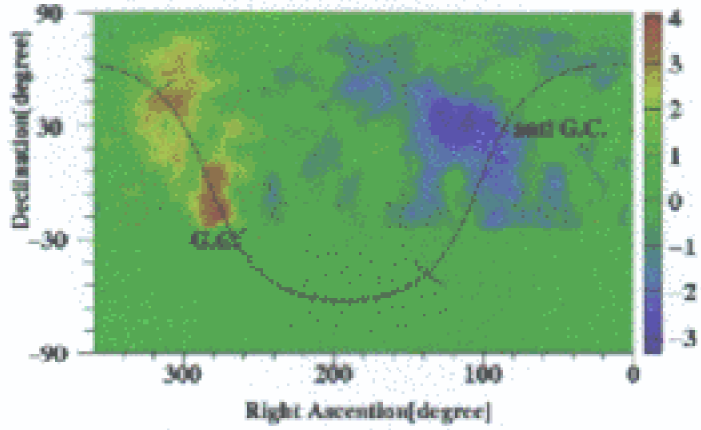
The neutrino error box is limited only by the EUSO angular resolution while the proton error box is dominated by the intergalactic magnetic fields.

Assumptions:

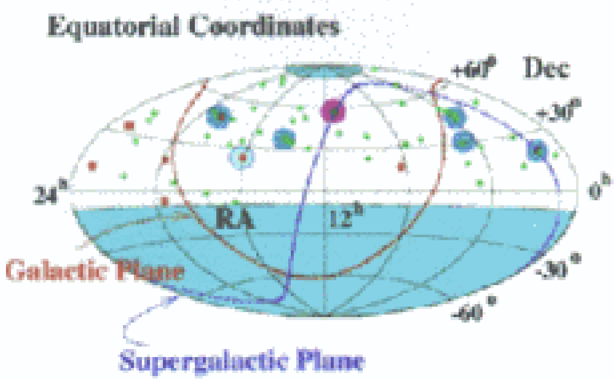
<B> = 1 nGauss
<d> = 30 Mpc

The Cosmic Radiation

Arrival distribution



Significance map of events at energies between 8×10^{17} and 2×10^{18} eV in equatorial co-ordinates observed by AGASA. Direction of galactic centre (GC) and anti-centre (anti-GC) are shown.



Cosmic Ray arrival distribution for $E > 10^{19}$ eV.

The Challenge

For EECRs with energy > 10^{20} eV:

Only 20 events detected up to now.
Energy spectrum trend is unclear.

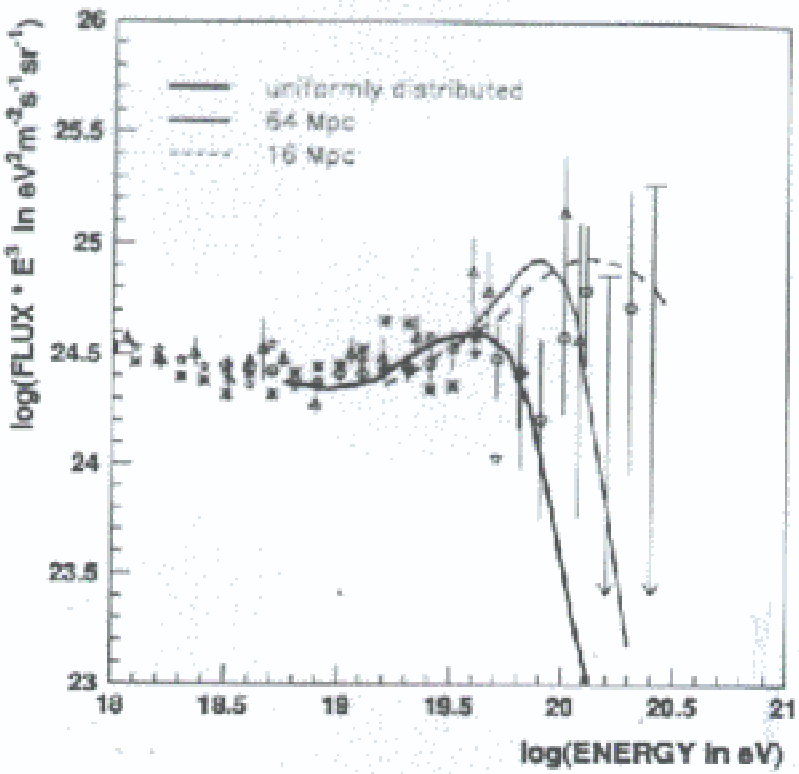
Cosmography:

Arrival directions: isotropic ?
At optical or radio-astronomy wavelength:
no counterparts

Cluster of events: (Takeda et al. 1999)

Doublets and triplets for $E>4\times10^{19}$ eV
(<2.5° and 1% chance) could indicate:
Long Lived Sources or Clumpiness or Focusing

EECR Energy Spectrum



Expected energy spectrum (in presence of the GZK effect) from extragalactic sources distributed uniformly in the universe (Takeda et al., 1998) and from sources at 64 and 16 Mpc, compared with the experimental results. An experimental energy resolution of 30% is convolved into the expected curves. Expected curves are from Hayashida et al., 1996.

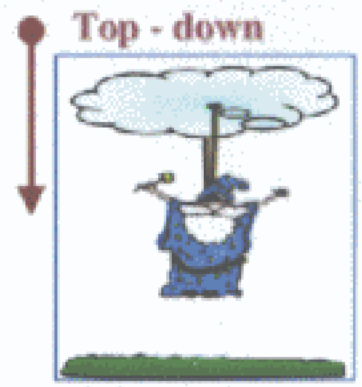
(from M.Nagano and A.A. Watson, 2000)

EECR production mechanism

Two general production mechanisms proposed for the EECR:

"Bottom-up": with acceleration in rapidly evolving processes occurring in Astrophysical Objects with an extreme case in this class being represented by the Gamma Ray Bursts (GRBs). The observation of "direction of arrival and time coincidences" between the optical-radio transient and Extreme Energy Neutrinos could provide a crucial identification of the EECR sources.

"Top-down" processes with the cascading of ultrahigh energy particles from the decay of Topological Defects; these are predicted to be the fossil remnants of the Grand Unification phase in the vacuum of space. They go by designations, such as cosmic strings, monopoles, walls, necklaces and textures. Inside a topological defect the vestiges of the early Universe may be preserved to the present day.



EECR production mechanism

Topological defects are expected to produce very heavy particles (X-particles).

As relics of an early inflationary phase in the history of the Universe, these particles may survive to the present as a part of dark matter. Their decay can give origin to the highest-energy cosmic rays, either by emission of hadrons and photons, or through production of Extreme Energy neutrinos.

Observation of these neutrinos may teach us about the dark matter of the Universe as well as its inflationary history.

EECR production mechanism

Observations/Experiments are needed to answer to the questions remaining open.

Bottom-up signatures:

- protons/nuclei
- power law spectrum
- counterparts

Top-down signatures:

- photons/neutrinos
- non-power law spectrum
- no counterparts/repeats
- halo distribution

EAS Detectors - EUSO approach

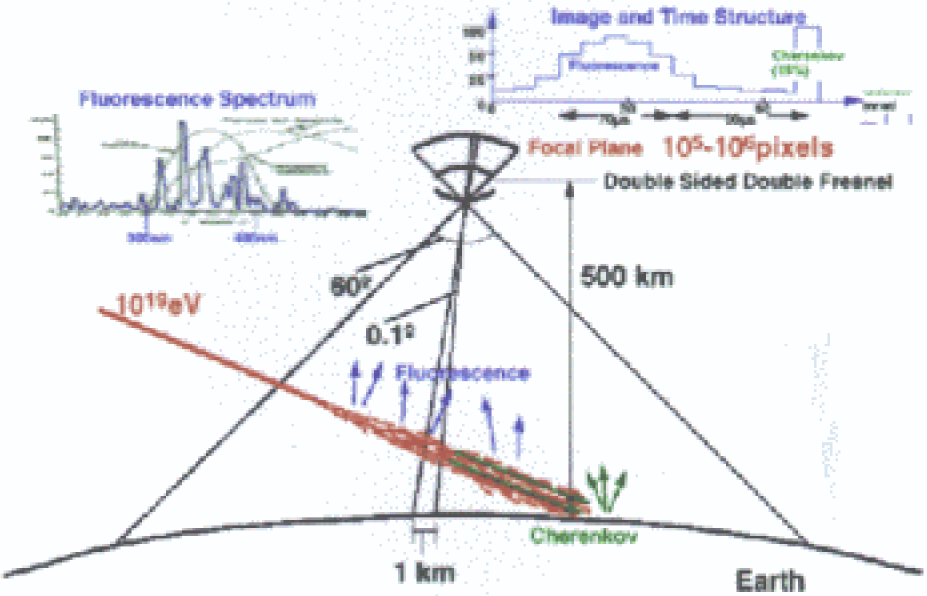
To obtain a statistically significant sample of EECR events at $E>10^{20}$ eV, with flux values at the level of

1 particle/100km^2/year,

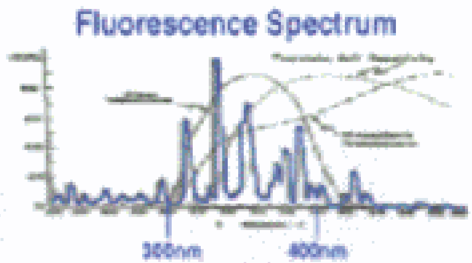
or with very low interaction cross section (high energy neutrinos), a gigantic detector of planetary scale is required.

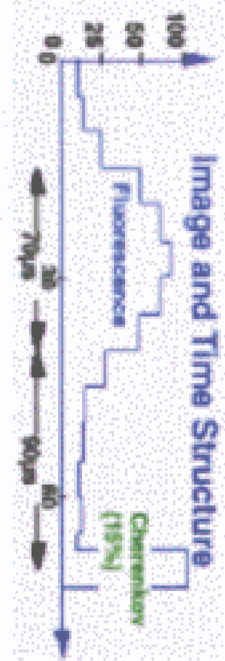
The Earth atmosphere, viewed from space with an acceptance area of the order of **10^6 km^2** sr and target mass of the order of **10^{13} tons**, constitutes an ideal absorber/converter for the EECRs and for Cosmic Neutrinos.

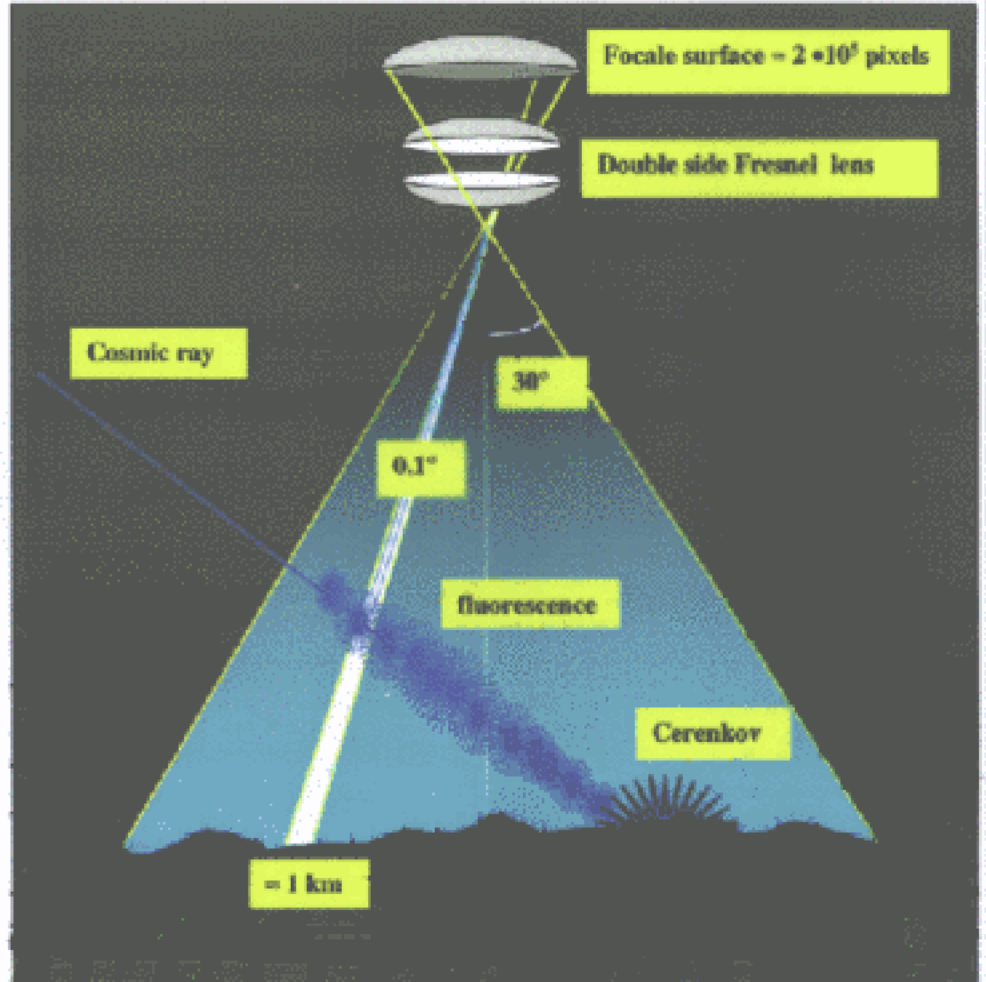
EUSO Concept



EUSO Approach



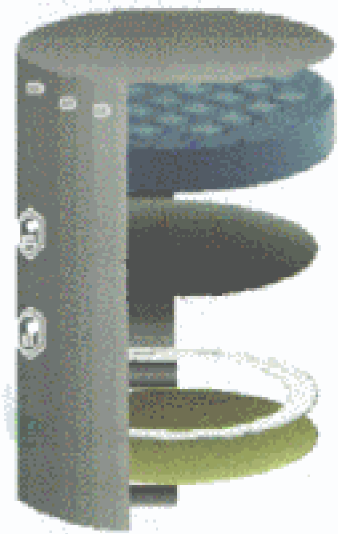


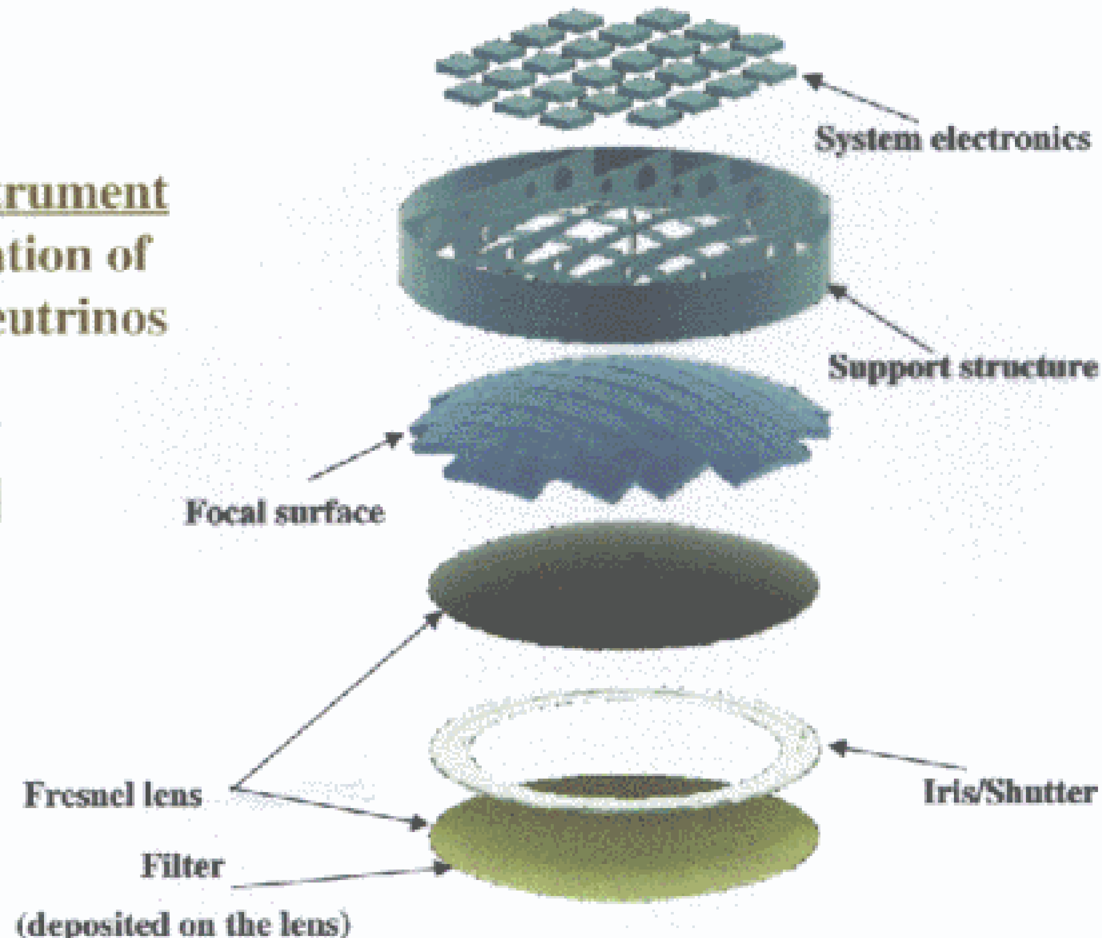


THE EUSO TELESCOPE

OVERVIEW

A compact instrument
for the observation of
EECRs and Neutrinos

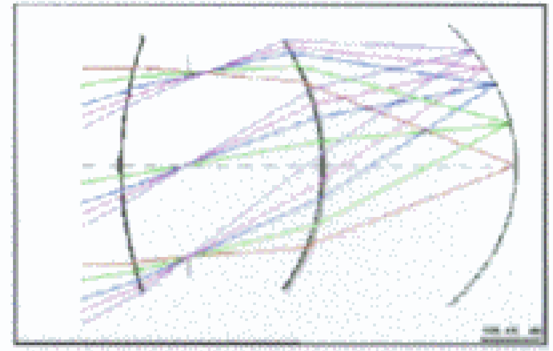




THE EUSO TELESCOPE

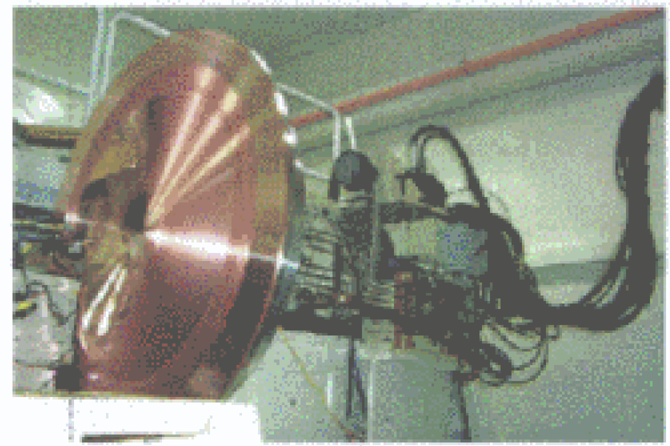
OPTICS DESIGN SPECIFICATION

- 2 meter entrance pupil diameter (EPD)
- f number ratio close to 1 (f/1.1 ~ 1.3)
- total field of view of 60°
- radiation-hard plastics
- filters like BG-3 or custom made deposited on the plastics



Double lens Fresnel configuration

Diamond turning of 1.3 m
Fresnel mandrel at
NASA/MSFC



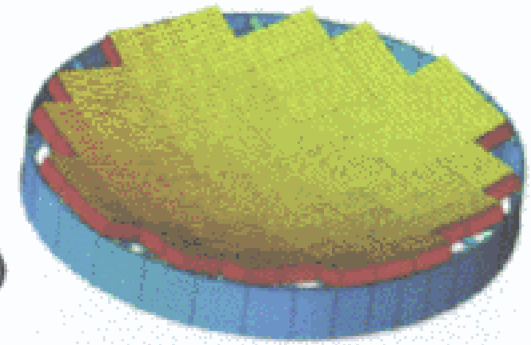
OPTICS CURRENT STATUS

- ⊗ Computer models have been developed indicating Fresnel lens system are optically feasible to achieve the EUSO requirements.
- ⊗ Candidate materials have been identified considering the manufacturability, space environmental endurance, optical quality and suitability for chromatic cancellation in a multiple Fresnel system.
- ⊗ Radiation and vacuum tests of the selected material assure no degradation for a period of 3 years. Further tests are in progress.

THE FOCAL SURFACE DETECTOR HIERARCHICAL VIEW

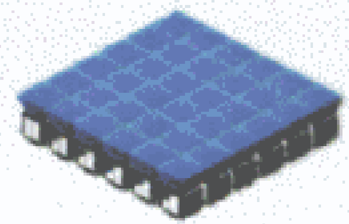
Focal surface detector

(89 macrocells = 205056 pixels)



Macrocell

(6x6 basic units = 2304 pixels)

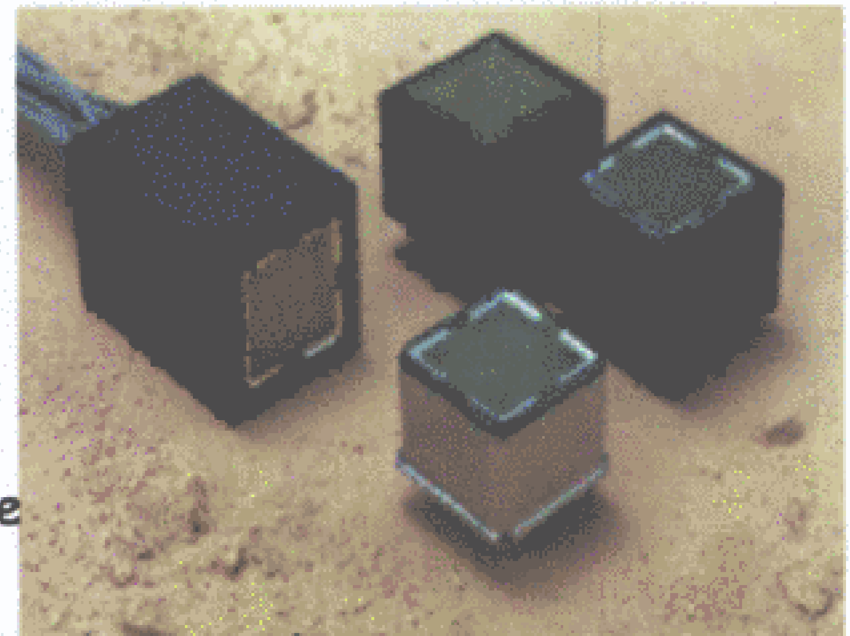


Basic unit

(8x8 pixels)

THE FOCAL SURFACE DETECTOR

Hamamatsu
R5900-M64



- FEATURES
  - 8 x 8 Multianode
  - High Speed Response
  - Low cross-talk
  - Newly Developed "metal channel dynode"

SYSTEM ELECTRONICS HIERARCHICAL ORGANIZATION

PFE
Pixel Front End

In order to minimize the background "single photoelectron counting" techniques with a fast response detector (~10 ns) are used. Pixel Front End electronics to be integrated into a custom ASIC (Application Specific Integrated Circuit) device.

FIRE
Fluorescence Image Read-out Electronics

The **FIRE** 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.

OUST
On-board Unit System Trigger

The trigger module OUST has been designed 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.

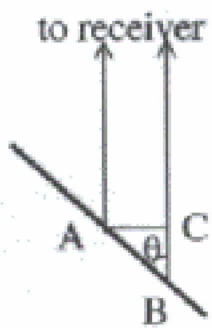
SYSTEM ELECTRONICS OPERATION

Trigger condition occurs when in a macrocell the level of the accumulated signal per Time Unit (TU) is greater than a predetermined level above the averaged macrocell signals.

The persistency of this condition for n TU determines the acquisition of the event.

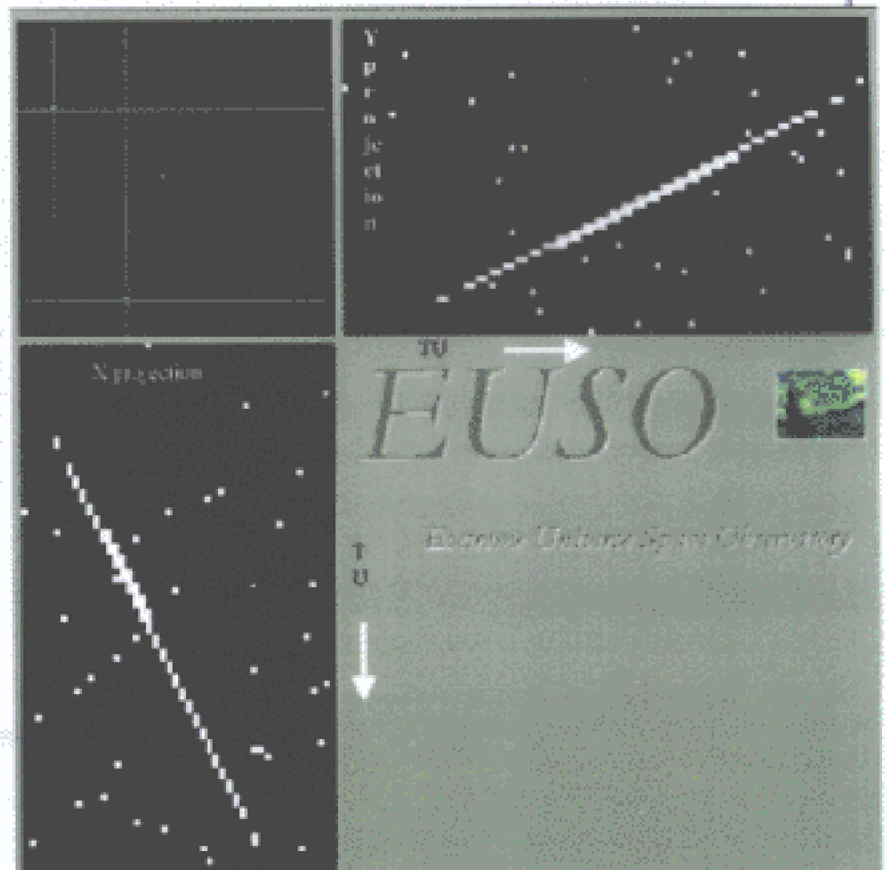
THE EUSO TELESCOPE

Direction and Energy reconstruction



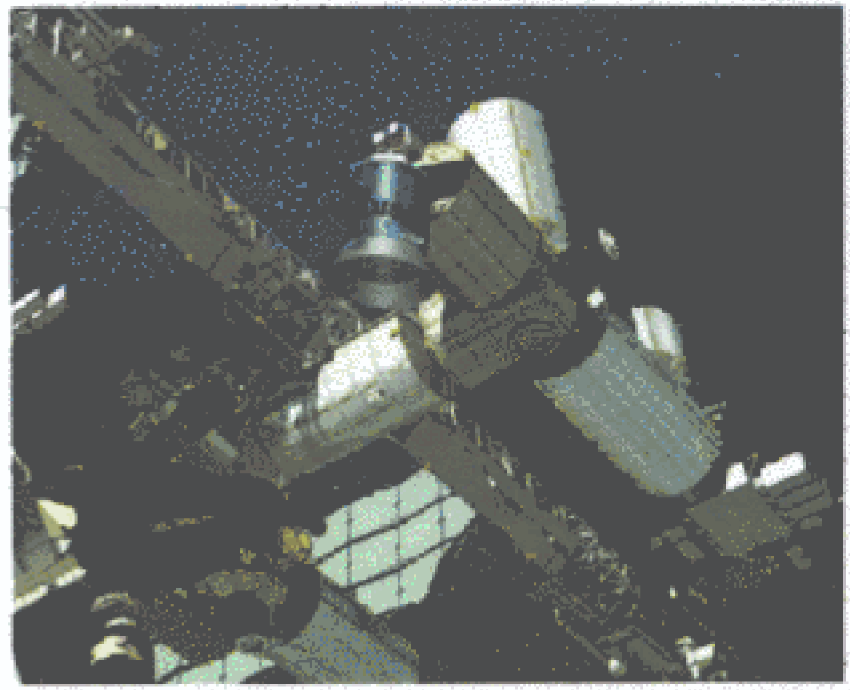
$$\varphi = \tan^{-1} \Delta Y/\Delta X$$

$$\theta = 2 \bullet \tan^{-1} \frac{(\Delta Y^2 + \Delta X^2)^{1/2}}{c \bullet \Delta t}$$



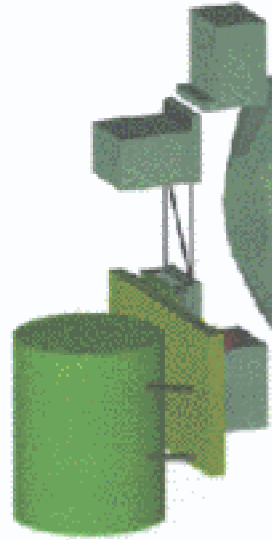
Extreme Universe Space Observatory - EUSO

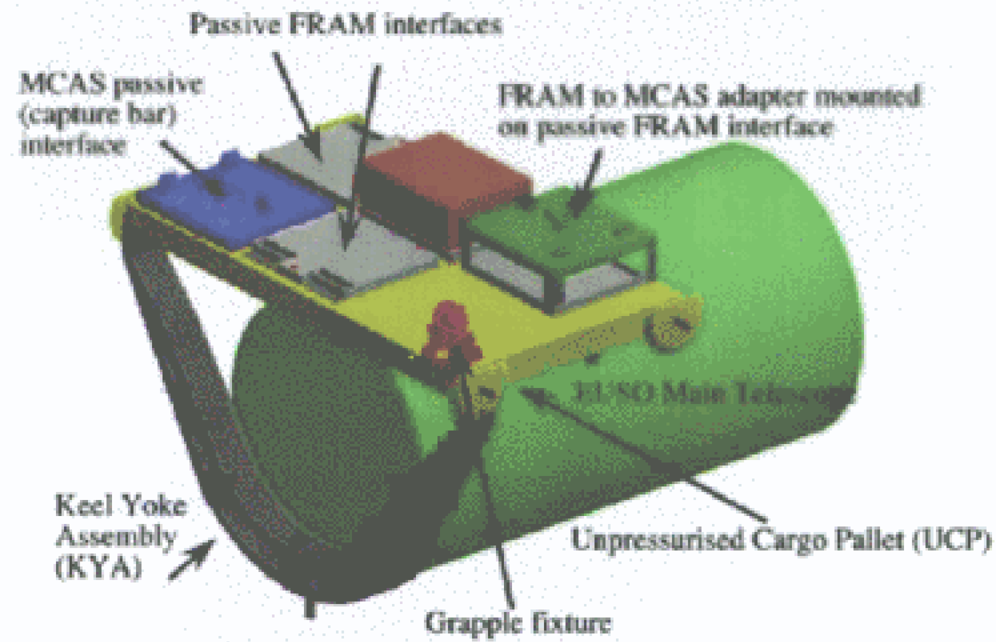
A Mission to Explore the Extremes of the Universe using the Highest Energy Cosmic Rays and Neutrinos



Report on the accommodation of EUSO on the Columbus Exposed Payload Facility

ACCOMMODATION STUDY



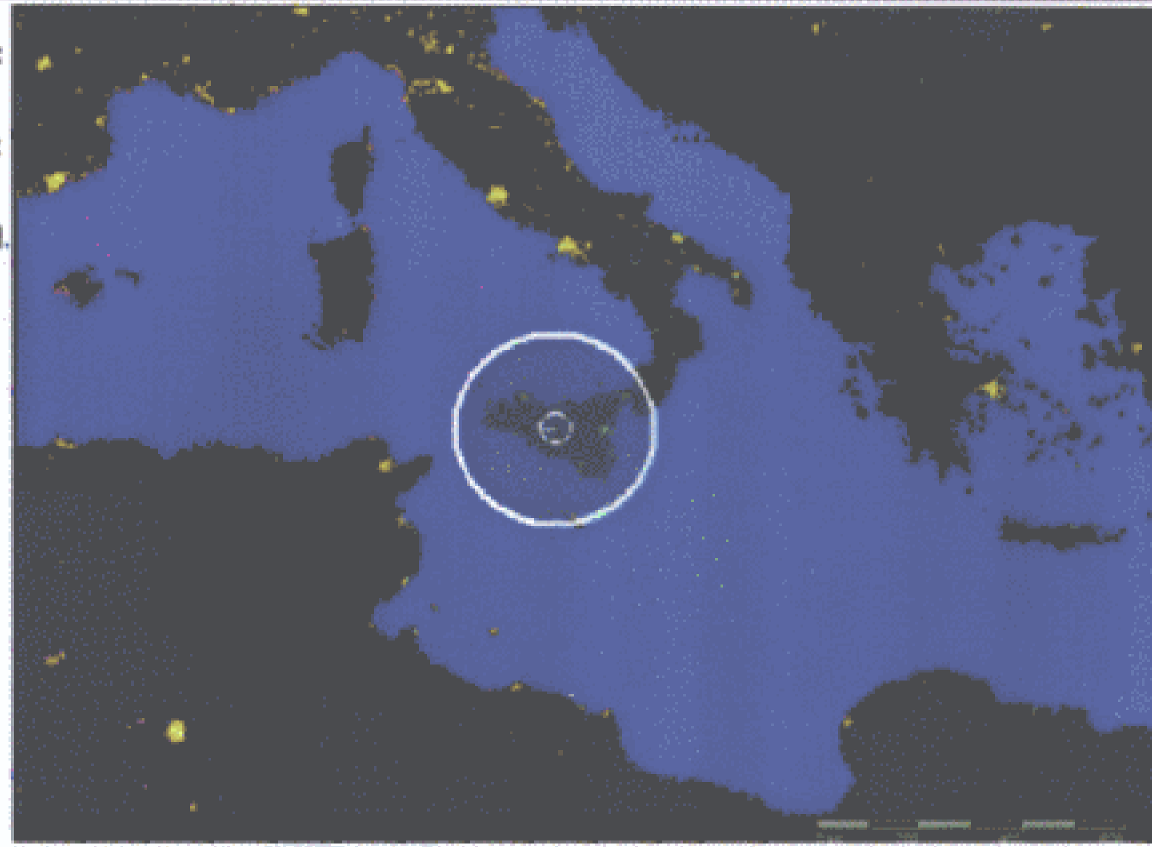


Comparison of UHECR Experiments

Large encircled area: EUSO

Small encircled area: AUGER.

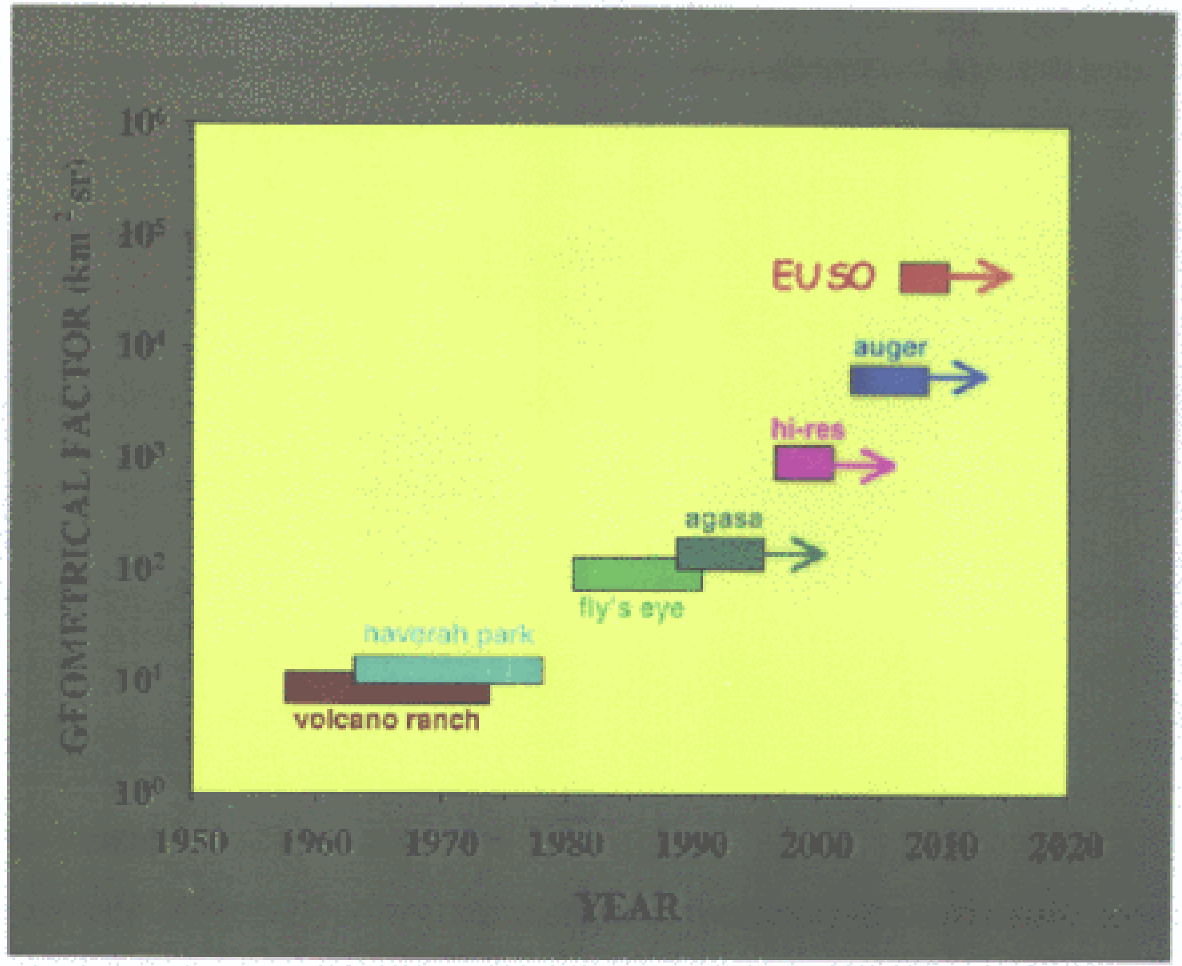
No duty cycle included.



Ratio of effective geometrical factor (EUSO/AUGER):

- including duty cycle (10% for both arrays): ~ 70
- with duty cycle (10%) only for EUSO: ~ 7

Comparison of UHECR Experiments

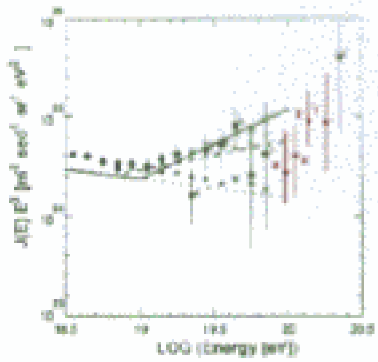


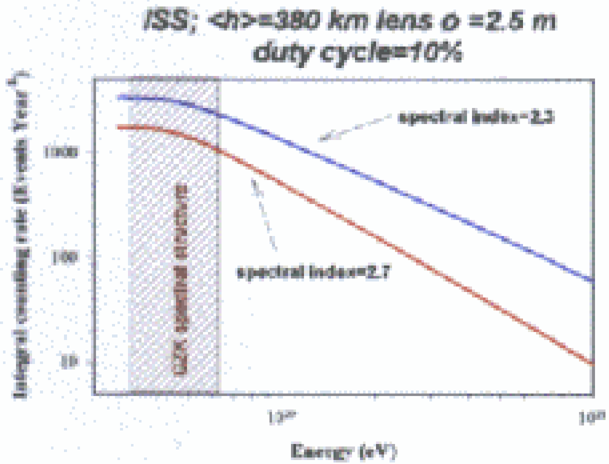
Comparison of UHECR Experiments

	Fly's Eye (stereo)	AGASA	HiRes	Auger (hybrid)	EUSO ISS
Status	Completed	Running	Running	Under construction	
Energy[(1)] range (eV)	$0.1 \rightarrow 60 \times 10^{18}$	$3 \rightarrow 150 \times 10^{18}$	$10^{17} \rightarrow 4 \times 10^{20}$	10^{18} - 10^{21}	$> 4 \times 10^{19}$
Incident θ resolution	3.2° (90% CL)	1.6° ($E > 4 \times 10^{19}$ eV)	0.6° ($E = 10^{19}$ eV)	1.3° (0.3°) ($E = 10^{20}$ eV)	0.3° (θ>70°) 3° (θ<30°) ($E = 10^{20}$ eV)
Energy resolution	20% ($E > 2 \times 10^{18}$ eV)	30%	< 20% ($E = 10^{19}$ eV)	25% (10%) ($E = 10^{20}$ eV)	20% ($E = 10^{20}$ eV)
Instantaneous aperture (km^2 ster)	400 @ 10^{20} eV	200	10^4	7 000	5×10^5
Duty cycle	10%	100%	10%	100% (hybrid 10%)	10%
Effective aperture (km^2 ster)	40 @ 10^{20} eV	200	1 000	7 000	50 000
Events/year $E > 10^{20}$ eV	0.4	2	10	70	500

(1) The upper limit is defined as the energy where 1 event/year is observed as determined by the experiment's aperture and assuming a differential spectral index of −2.75.

EUSO Expected Results

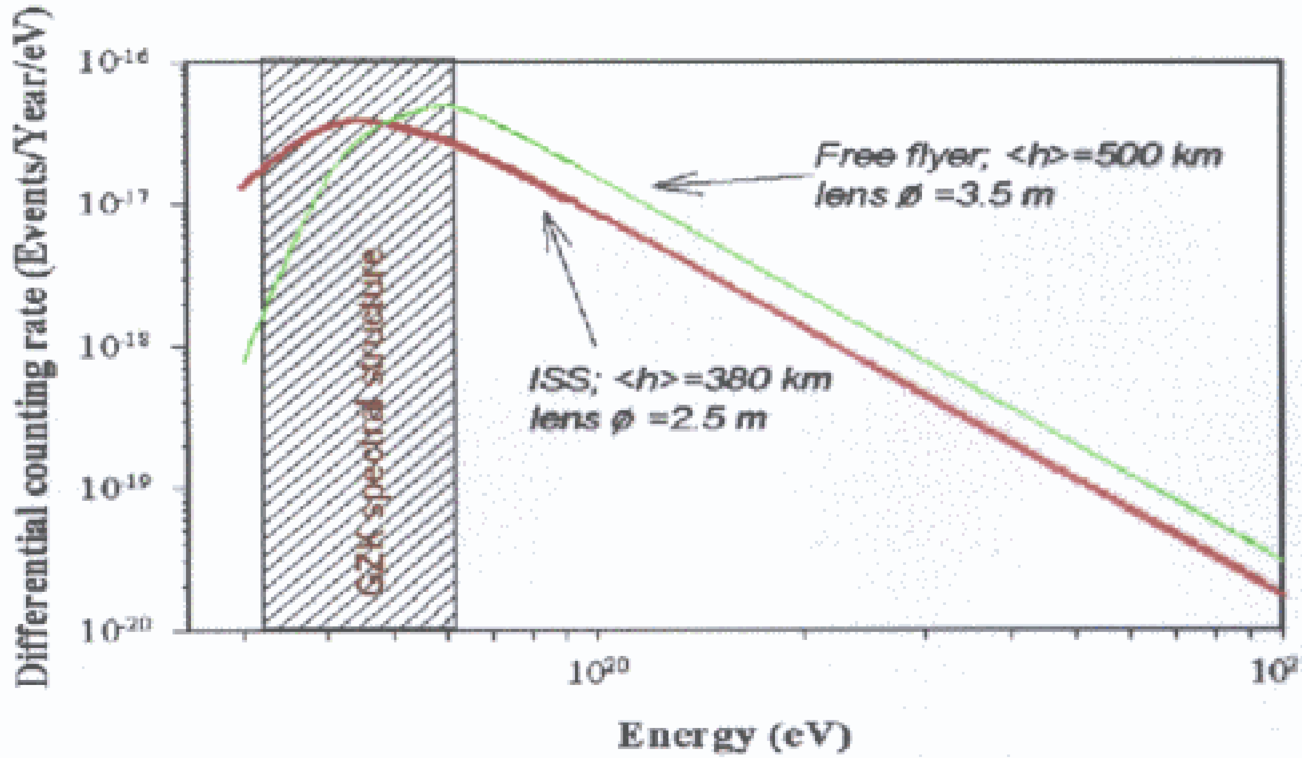




Left) - This is Fig.10 from Yoshida et al., AstroParticle Physics 3, 1995, pp. 114: "Derived primary energy spectra expressed by Eqs. (11a) (solid line) and (11b) (dashed line) and the expected values in each bin simulated under the assumptions of these spectra with the energy resolution of the present 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 10^{19} 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 .

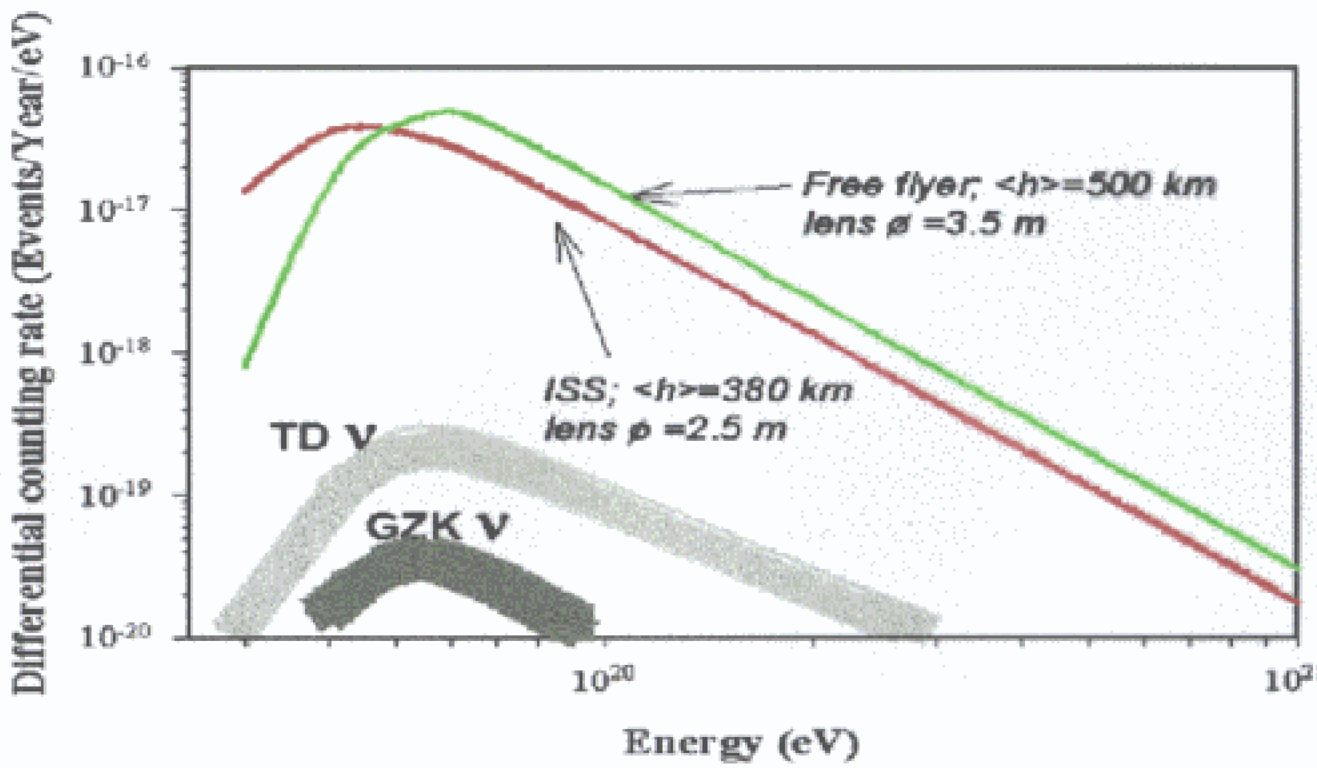
Right) - EUSO counting rates under the hypothesis of the two different spectral index (2.3 and 2.7) assumed.

EUSO Expected Results



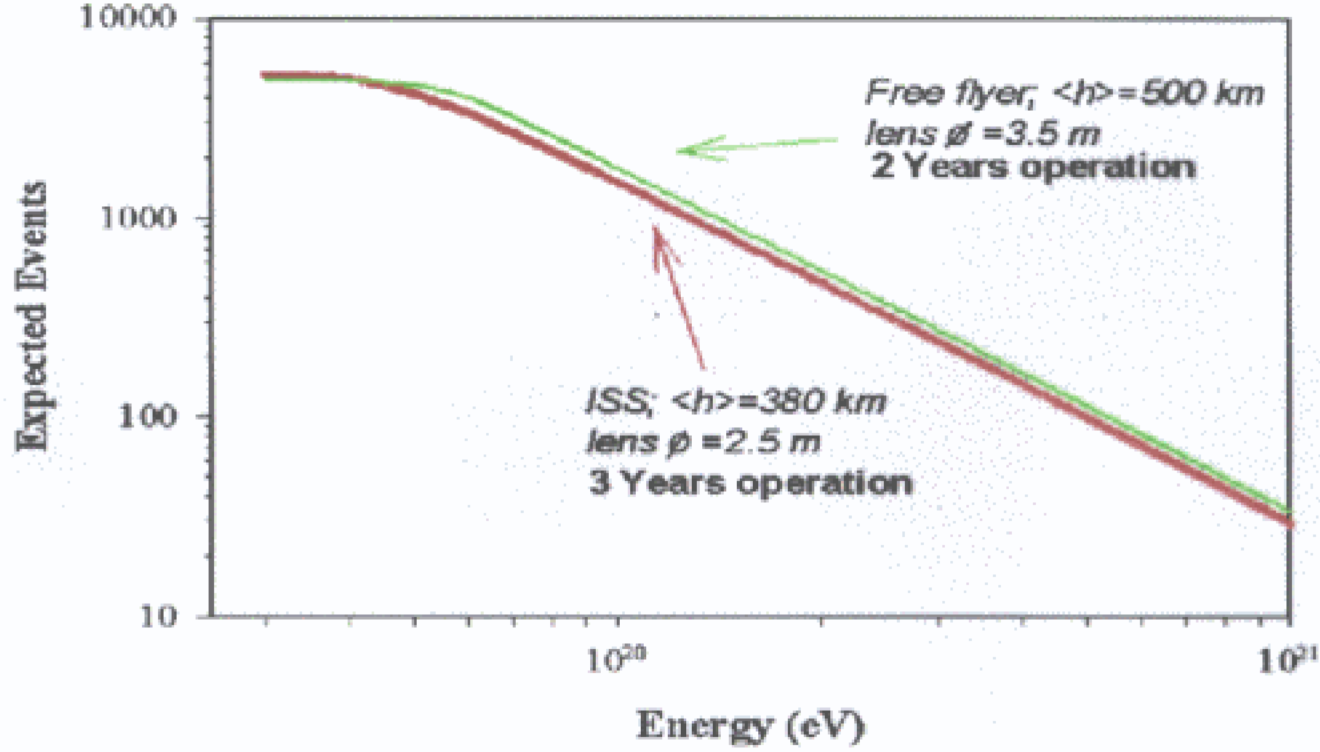
Differential EECR counting rate comparison between the ISS version of the EUSO and the original free flyer (spectral index assumed 2.7). The dashed zone shows the spectral region where structure induced by the GZK cut-off is expected. The lens diameter is the maximum external diameter allowed in each configuration.

EUSO Expected Results



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).

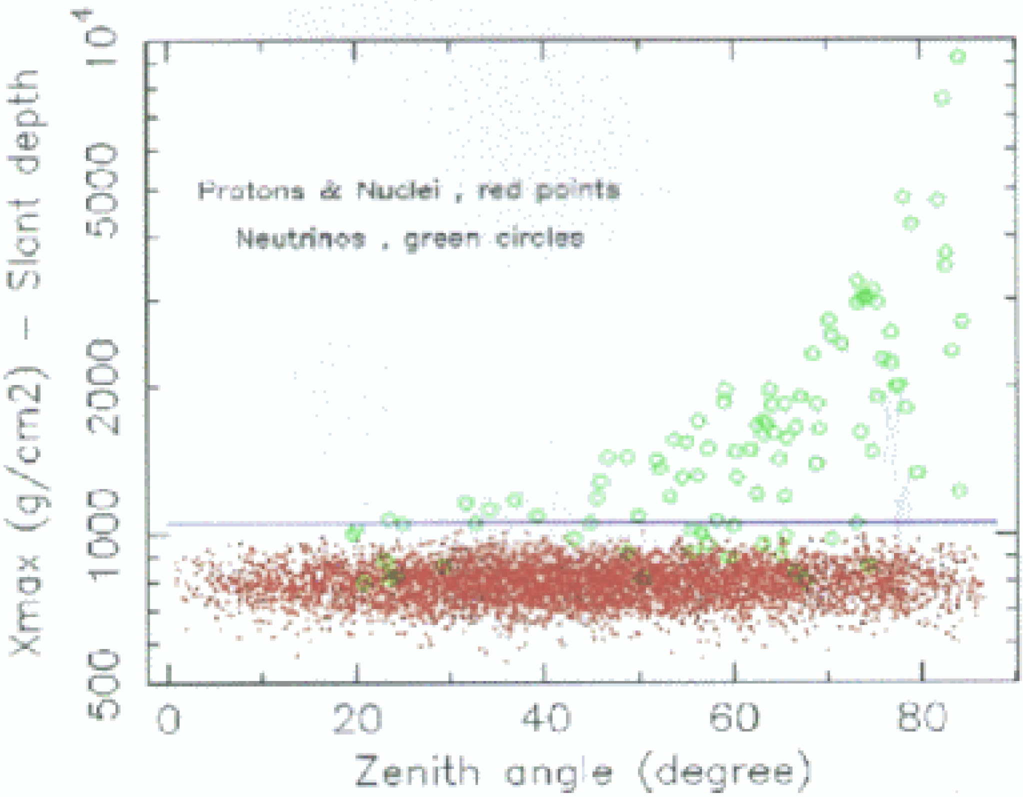
EUSO Expected Results



Expected number of events above an energy E for the original free flyer proposal with 2 years of operation and for the ISS configuration with 3 year operations.

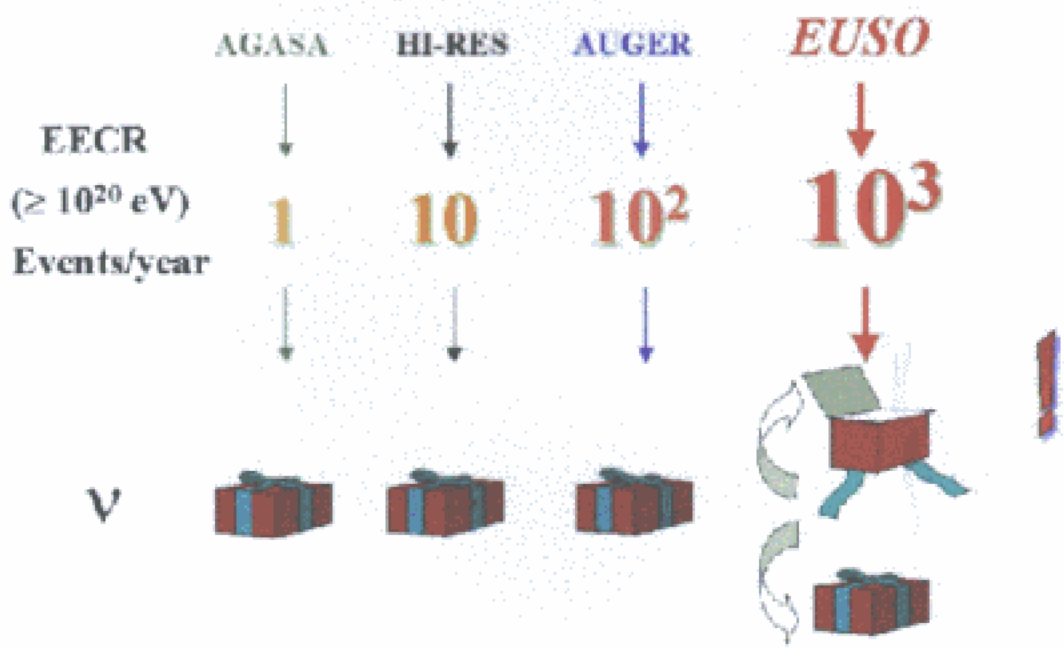
Neutrinos versus Protons and Nuclei

Showers initiated very deep in the atmosphere indicate an origin by neutrinos because of neutrino-air nuclei interaction cross section hundreds times lower than the cross sections for protons, nuclei, or photons.



Shower depth distribution from Monte Carlo simulations: neutrino events can be distinguished from protons and nuclei.

EUSO Expectations



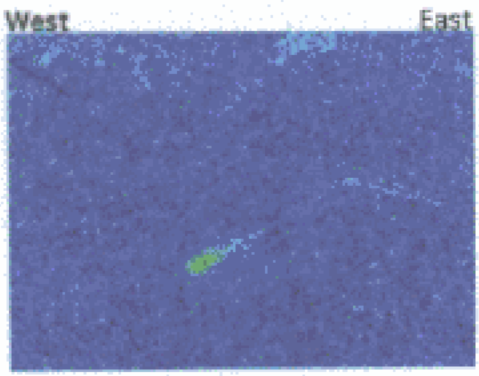
EUSO Science II

Atmosphere sounding.

As a main fall-out of the astrophysics oriented mission, EUSO will produce a wealth of systematic data concerning the clouds as physics systems and the atmospheric structure.

Meteoroids.

The observation of the UV track of meteoroids contextually to the EAS fluorescence "watch" will consent a complete and systematic monitoring and investigation of the physical properties of the infalling meteoroids and their interaction with the atmospheric layers.



View is toward North, 26° down from the horizontal, along the ARGOS orbit

The Naval Research Laboratory GIMI Instruments first UV observation of a meteor in space from the ARGOS satellite. In the lower portion of the image, a diffuse blob of apparent brightness comparable to that of the upper-atmospheric UV airglow toward the top of the image, was observed (the splotches in the upper part of the image are fixed-pattern image artefacts, which can be corrected in later image processing).

SYSTEM ELECTRONICS OPERATION

Nightglow background measurement have been carried out using Balloon flight.