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EUSO: Preliminary stray light analysis (DRAFT)

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1. Introduction

Euso aims to detect the fluorescence produced in the atmosphere by ultrahigh energy cosmic ray particles impacting the Earth atmosphere. The cosmic ray produces an electromagnetic shower that moves through the atmosphere, which induces nitrogen fluorescence in bands around 337 nm, 357 nm, and 391 nm. Other processes that produce emission in this wavelength range will contribute to the background against which the signal must be seen. The detection of the signal is triggered by the beginning of the event and is marked by a count rate that exceeds a fixed threshold, and the resulting event looks like a narrow track in which the recorded amount of light is proportional to the energy of the cosmic ray. As long as the background stays below this threshold, no matter whether it varies, EUSO will be able to detect all the cosmic rays above a threshold energy.

The source of background in the wavelength band from 300 nm to 400 nm are of natural origin, and manmade origin. The antropic sources are city lights and lights from ships and planes. The natural sources are transient phenomena like the aurorae and the lightnings and constant phenomena, like the nightglow produced by atom-atom collisional excitations and ionic recombination from O₂ bands, or moonshine reflections by clouds or by the Earth surface.

Some of these sources are localized but they can be so intense that the stray light produced inside the telescope will hinder the measurements.

Aim of this report is to show what is the maximum tolerable level of background stray light using a simplified optical configuration, although this preliminary draft explains the procedure to estimate the stray light but does not give quantitative results.

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2. Preliminary notes on the optical design

Optical ray tracing. Using the ray tracing code ZEMAX (Version 9.0), I have reconstructed the optical design of EUSO (see Fig.1), which has similar optical performances as the one in the proposal, described also in a recent report by Zuccaro and Takahashi.

The optics consist of two Fresnel lenses (F1 and F2) molded on both faces of a spherical substrate.

I have used the same distances between the optical components: Fresnel lenses, entrance pupil, and image surface, and the same curvatures of the lens substrate and of the image surface.

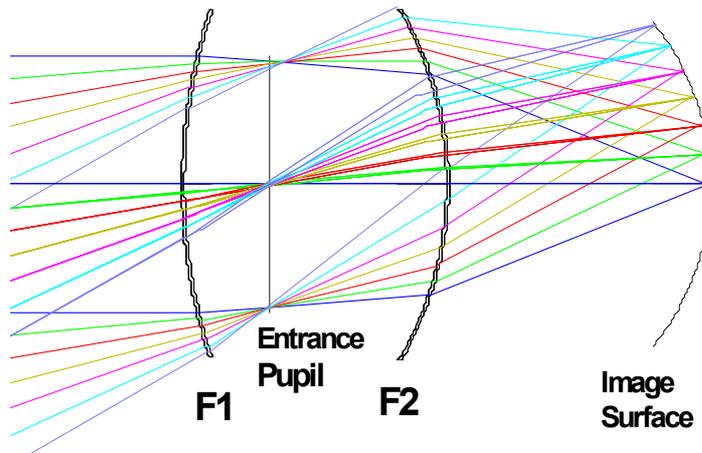


Figure 1 - EUSO optical layout.

Table 1 – EUSO optical layout parameters

EUSO Effective focal length	2650 mm
EUSO F#	1.32
F1 substrate radius (spherical)	4427 mm
F1 front Fresnel lens curvature (1/R), conic constant, 1 st and 2 nd aspheric coefficients	0.0081 mm^{-1} , -1, -0.0041 mm^{-1} , $-8 \cdot 10^{-11} \text{ mm}^{-3}$
F1 back Fresnel lens curvature (1/R), conic constant, 1 st and 2 nd aspheric coefficients	-0.1076 mm^{-1} , -1, -0.0536 mm^{-1} , $-5.85 \cdot 10^{-11} \text{ mm}^{-3}$
F1 thickness	20 mm
Distance F1 - Entrance pupil	666 mm
Entrance pupil aperture	2 m
Distance Entrance pupil – F2	1357 mm
F2 substrate radius (spherical)	2737 mm
F2 front Fresnel lens curvature (1/R), conic constant, 1 st and 2 nd aspheric coefficients	0.0126 mm^{-1} , -1 -0.0059 mm^{-1} , $-4.8 \cdot 10^{-11} \text{ mm}^{-3}$
F2 back Fresnel lens curvature (1/R), conic	0.0011 mm^{-1} , -1

constant, 1 st and 2 nd aspheric coefficients	-0.00064 mm ⁻¹ , -2.65 10 ⁻¹² mm ⁻³
F2 thickness	20 mm
Distance F2 – Image surface	2023 mm
Image surface radius (spherical)	2023 mm

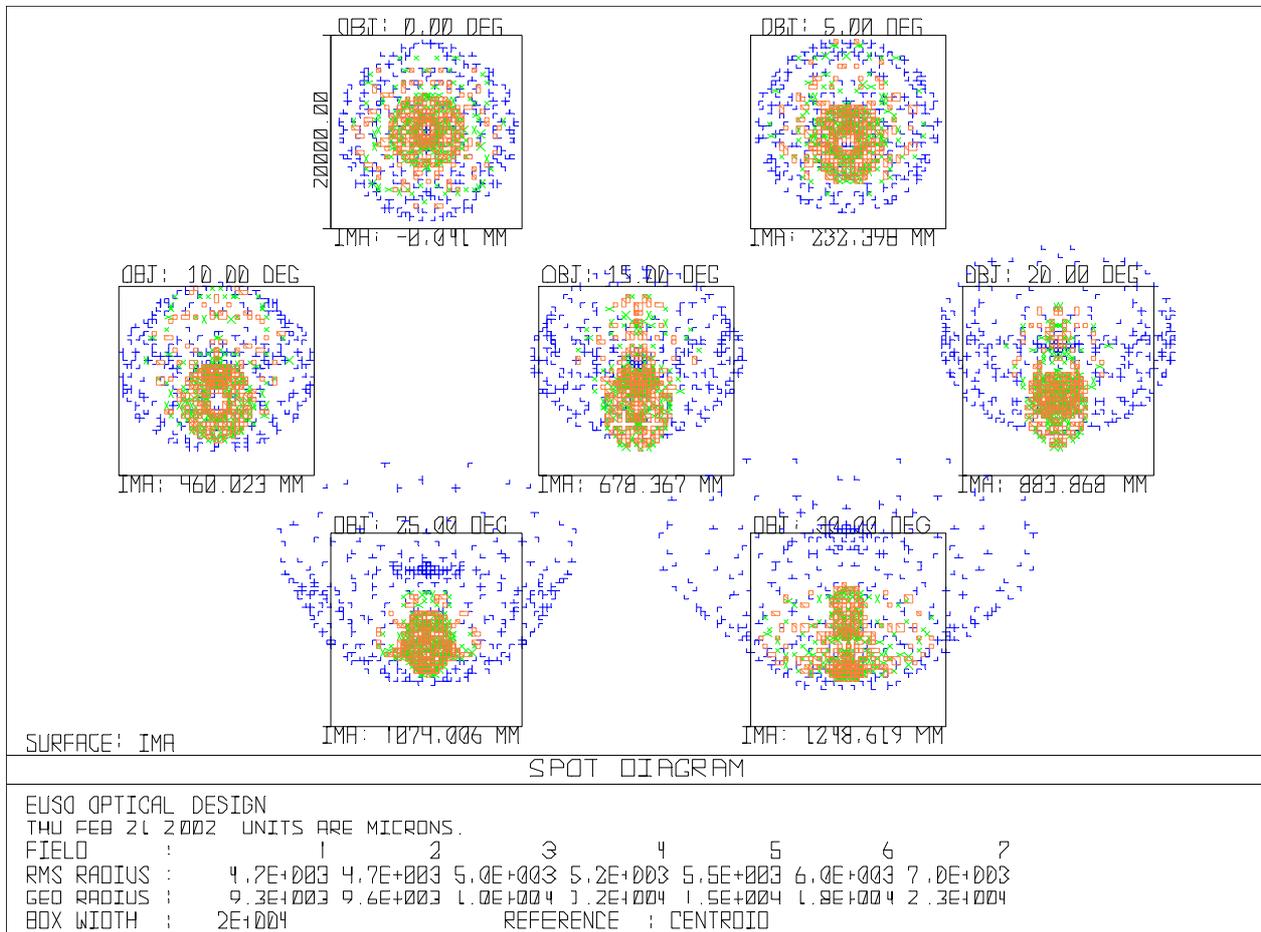


Figure 2 - Spot size for fields from 0 to 30 degrees. In color three wavelengths (blue 337 nm, green 357 nm, orange 391 nm).

Lens material. The material I used for the lens substrate is Cyclic Olefin Copolymer (COC) whose optical parameters are provided by ZEMAX down to 334 nm (its properties should be similar to those of ZEONEX which is mentioned in the proposal).

Optimization of optical design. I optimized the Fresnel lenses parameters in order to get a good spot size for a wavelength band from 335 nm to 400 nm. Table 1 reports the optical parameters where the Fresnel lenses are even aspheric surfaces with two coefficients. Figure 2 shows the spot diagram at three different wavelengths (superposed on the spot): 337 nm, 357 nm, 391 nm, for 8 fields: 0, 5, 10, 15, 20, 25, 30 degrees. Figure 3 reports the encircled energy for each field and for all three wavelengths combined. The encircled energy reaches 90% of the total within a radius of 6 mm from the center of the centroid.

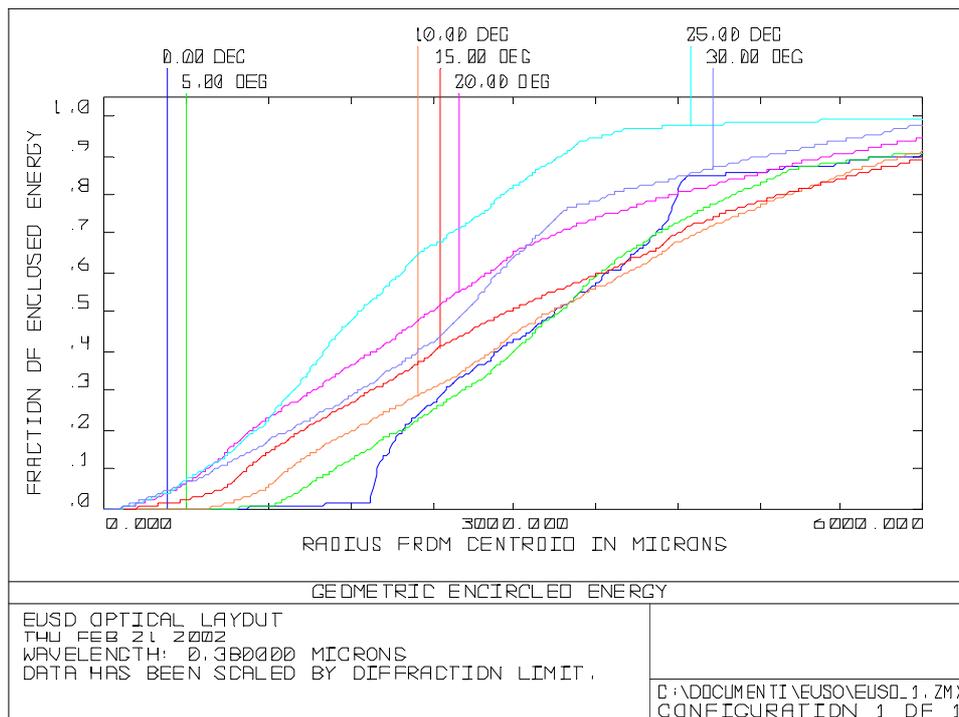


Figure 3 - Fraction of encircled energy for different fields.

Chromatism. The optimization of the optical design depends critically on the optical properties of the substrate material of the Fresnel lenses. Particular care is needed in the choice of the material since the optical properties are a function of wavelength, especially near the transmission cutoff, which is very close in this spectral band.

Ageing. Tests are also needed, in order to characterize the ageing of these plastic materials when irradiated with UV light. The ageing deteriorates the transmissivity and can increase chromatism.

3. Background estimate

Existing measurements. Only a few measurements of the NUV background exist and were obtained during a spacecraft flight (COSMOS, Lebedinski, 1965), rocket flights (Hennes, 1966; ETON, Greer, 1986) and a balloon flight (BABY, La Rosa, 2001). A new balloon experiment, NIGHTGLOW (<http://heawww.gsfc.nasa.gov/docs/gamcosray/hecr/NightGlow/ng.html>), had its test flight in February 2001, but no data have been published yet. Interesting reviews on the UV radiation from the atmosphere are given by Barbier, 1999, and Meier, 1991.

Background sources. The NUV background sources are of natural and antropic origin. City lights, ships, and planes are very localized sources with a strong emission in the NUV. Transient and less localized sources are lightnings, generated in the troposphere, and aurorae, bright from 100 km down. A more constant background is given by reflection of moonshine, particularly bright above cloud coverage, and by ionic recombinations of O_2 , the nightglow, produced between 80 km and

120 km. In addition, there is absorption in the ozone layer at 30 km that reduces both the fluorescence signal produced by the cosmic ray and the background coming from the lower layers of the atmosphere. The transmittance of the ozone layer goes from 35% at 330 nm to 55% at 390 nm (Barbier, 1999).

Instrumental parameters for the estimate. The following instrumental parameters for the estimate are used: telescope aperture (2m diameter), 3.14 m^2 , transmissivity of the telescope + bandpass filter, 50%, detector quantum efficiency, 18%, pixel size, 6 mm x 6 mm, that corresponds to 0.8 km x 0.8 km field of view on the ground at a distance of 380 km.

Detectable signal. It has been estimated that the threshold signal from a typical event produced by a ultrahigh energy cosmic ray is of the order of **10 counts/ μs** .

Nightglow estimate. I have estimated the nightglow background using data from Hennes, 1966. Hennes' measurements provide a radiance of the atmosphere of $32 \text{ photon cm}^{-2} \mu\text{s}^{-1} \text{ sr}^{-1}$ in the 300-400 nm range emitted from an average height of 100 km. The total count rate on the pixel will be **0.5 counts/ μs** .

Ozone layer. The ozone layer at roughly 30 km is responsible of the absorption of the NUV background emitted from the ground. A curve of the transmittance of the ozone layer as a function of wavelength is shown in Barbier, 1999. An average of the **ozone transmittance** in the wavelength band 300-400 is about **40%**.

Tropospheric background over sea and over city. The balloon flight BABY has provided a measurement of nadir background from about 27 km in the atmosphere. The flight performed above western Sicily and the Mediterranean Sea has given radiances that range from about $40 \text{ photon cm}^{-2} \mu\text{s}^{-1} \text{ sr}^{-1}$, above the sea, to $30000 \text{ photon cm}^{-2} \mu\text{s}^{-1} \text{ sr}^{-1}$, above Mazara, the brightest town below the balloon trajectory. The count rate on the pixel, that takes into account the telescope parameters and the ozone layer absorption will range from **0.2 to 150 counts/ μs** .

Other contributions. No data are available regarding aurorae emission and lightnings, although auroral light should not affect observations performed on an equatorial orbit, because aurorae occur at high latitudes. Moonshine reflected by the atmosphere has not been considered.

4. Stray light

The ray tracing code ZEMAX has the capability of performing non sequential surface ray tracing. This allow us to perform stray light analysis. Fresnel lenses with planar substrate can be simulated and the stray light produced by an incident beam of light on the focal plane is determined.

A preliminary stray light computation has been performed on a single Fresnel lens molded on both sides with an F# equal to that of EUSO. **Data on stray light presented in this draft are preliminary and do not represent the stray light behavior of EUSO telescope.**

Light beam for four different fields: 0, 10, 20, 30 degrees have been analysed. Figure 4 shows the result of one simulation: in false colors on a logarithmic scale the light pattern on a plane surface

produced by the 4 fields that are imaged and scattered by the Fresnel lens. In Table 2 the results of the simulation are reported. In the first column, the fraction of the beam that falls on the geometrical spot image; in the second column, the maximum stray light to signal ratio per pixel.

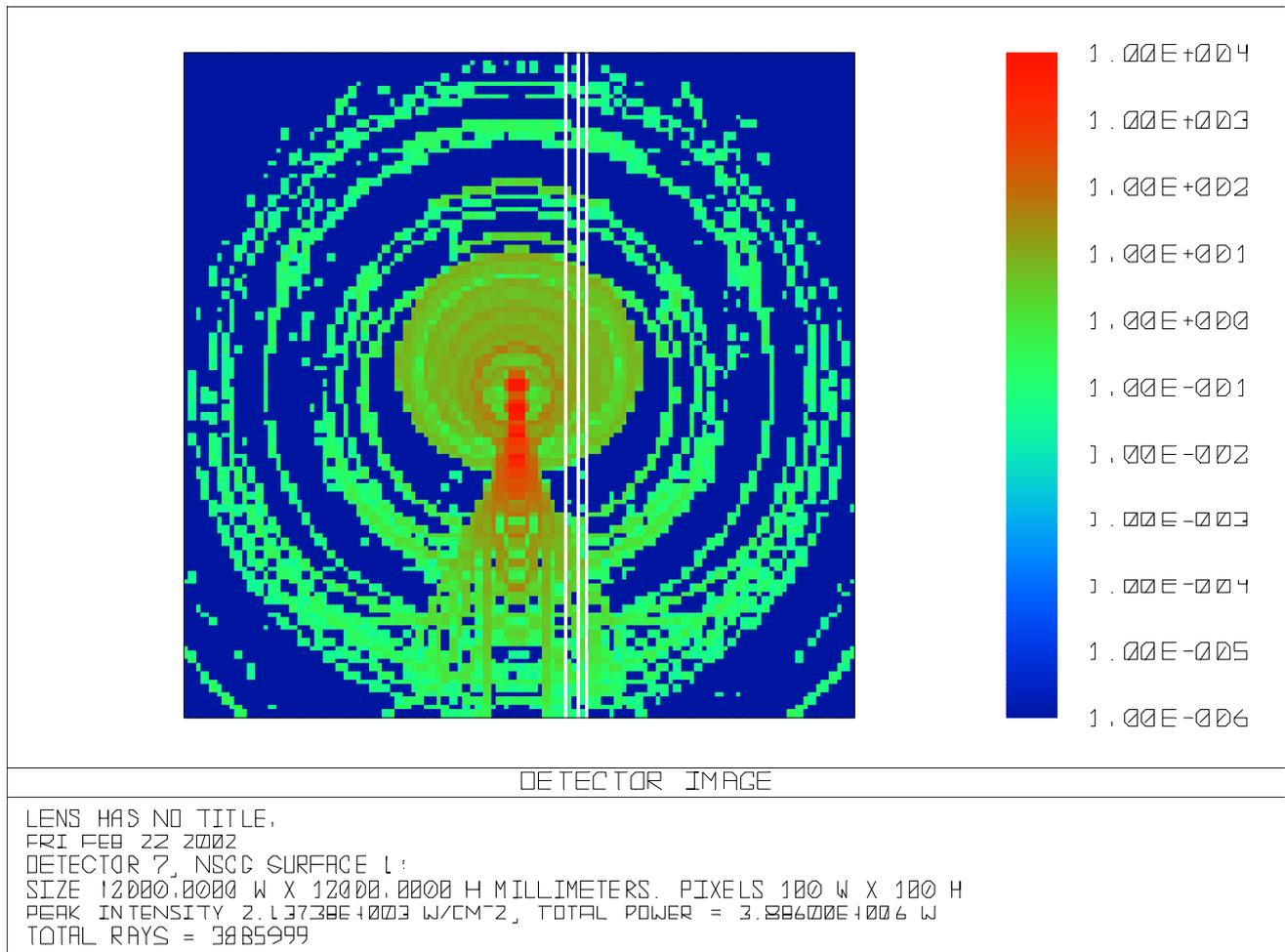


Table 2 – Stray light characteristics.

	Fraction of beam in the geometrical spot image	Stray light fraction per pixel
Field: 0°	91.5%	4 10 ⁻⁶
Field: 10°	86%	3 10 ⁻⁵
Field: 20°	77%	3 10 ⁻⁵
Field: 30°	62%	3 10 ⁻⁵

The future plan is to improve the stray light analysis by introducing in the non sequential ray tracing the actual EUSO optical layout.

4. Conclusions

The above analysis shows that the background radiation does not trigger the signal threshold when city lights are not in the field of view. A way of distinguishing between a trigger induced by a point

source of light, like a town, which is fixed in the field of view relative to the considered time frame of microseconds, can be envisioned. Stray light is produced by the optics and rather omogeneously scattered on the image plane. Nevertheless, the stray light produced by a source of light with intensity above 100000 counts/ μ s can go above the threshold, and observations performed during the pass of this source across the field of view must be avoided.

The telescope model that has been used in the simulation is just a simplified model, and the stray light computation described in this draft is qualitative. More analysis with a more realistic optical design is needed to derive the actual stray light of EUSO.

An **external baffle** is needed to prevent light from the Earth surface, especially from the bright horizon, from hitting the objective surface. Considering the aperture of the field, a conic baffle that extends out in front of the first Fresnel lens by about the size of the diameter of the lens itself will reduce the field of view from the external lens to about 1400 km diameter on the Earth surface.

As a comparison EUSO field of view is about 400 km projected on the ground.

5. Bibliography

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