



S-EUSO: a proposal for  
a space-based observatory  
of Ultra High-Energy Cosmic Particles.

Tuesday, 26 June 2007

Preliminary version

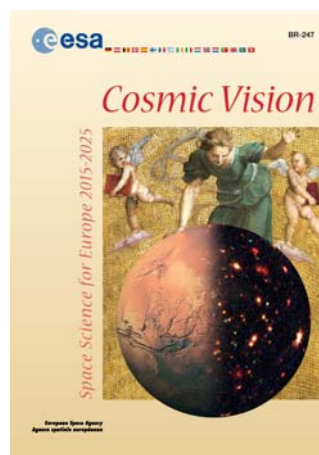
To be submitted to ESA  
in response in response to the  
Call for proposals for the first  
planning cycle of the new  
Cosmic Vision 2015-2025.

---

# Super-EUSO

---

Opening Particle-Astronomy:  
a Space Observatory for next-generation studies  
of the Universe at Ultra High-Energies  
via the observation of Ultra High Energy Cosmic  
Particles (UHECP).





<b>1</b>	<b>LIST OF PROPONENTS AND LETTERS OF ENDORSEMENT FROM THE AGENCIES.....</b>	<b>3</b>
<b>2</b>	<b>EXECUTIVE SUMMARY .....</b>	<b>4</b>
<b>3</b>	<b>THE S-EUSO SCIENCE CASE.....</b>	<b>6</b>
<b>4</b>	<b>SCIENTIFIC OBJECTIVES AND REQUIREMENTS.....</b>	<b>7</b>
4.1	SCIENTIFIC OBJECTIVES AND REQUIREMENTS .....	7
<b>5</b>	<b>THE OBSERVATIONAL TECHNIQUE.....</b>	<b>8</b>
<b>6</b>	<b>THE MISSION PROFILE AND REQUIREMENTS.....</b>	<b>9</b>
<b>7</b>	<b>THE INSTRUMENT CONCEPT AND ITS EXPECTED PERFORMANCE .....</b>	<b>10</b>
7.1	ARCHITECTURE OF THE INSTRUMENT .....	10
7.2	FROM SCIENTIFIC TO INSTRUMENTAL REQUIREMENTS AND THE EXPECTED PERFORMANCE.....	10
7.3	THE MAIN BASELINE PARAMETERS .....	11
7.4	INSTRUMENT DESCRIPTION.....	12
7.4.1	<i>Optics .....</i>	<i>12</i>
7.4.2	<i>The Photo-Detector: sensors .....</i>	<i>13</i>
7.4.3	<i>The Photo-Detector: f/e, trigger and OBDH electronics .....</i>	<i>15</i>
7.4.4	<i>The Atmospheric Monitoring .....</i>	<i>17</i>
7.4.5	<i>The Radio Pulse Detector (RPD) .....</i>	<i>17</i>
7.4.6	<i>Preflight and on-board calibration .....</i>	<i>18</i>
7.4.7	<i>The Central Control Unit (CCU).....</i>	<i>19</i>
7.5	OPERATING MODES .....	19
7.6	SUMMARY OF BUDGETS.....	19
7.7	POTENTIALLY CRITICAL ISSUES AFFECTING THE PERFORMANCE .....	20
7.8	THE TRADE-OFF ON THE INSTRUMENT DESIGN .....	20
7.9	R&D ON ALTERNATIVE SOLUTIONS .....	20
7.9.1	<i>R&amp;D on segmented detector modules for S-EUSO .....</i>	<i>20</i>
7.10	A ROAD-MAP .....	21
7.10.1	<i>Background measurement via micro-satellite.....</i>	<i>21</i>
7.10.2	<i>Path-finders .....</i>	<i>21</i>
<b>8</b>	<b>BASIC SPACECRAFT KEY FACTORS.....</b>	<b>22</b>
8.1	REQUIREMENTS .....	22
8.2	THE ORBIT .....	22
8.3	SYSTEM DESIGN APPROACH.....	22
8.4	MISSION CHARACTERISTICS DRIVEN BY THE LAUNCHER .....	23
8.5	SPACECRAFT SERVICE MODULE .....	23
8.6	OVERVIEW OF THE SATELLITE CONCEPT.....	24
8.7	CONFIGURATION PRELIMINARY CONCEPT .....	24
8.8	OBSERVATIONAL STRATEGY (ORBIT AND ON-GROUND MANAGEMENT) .....	26
8.9	CRITICALITIES AND CONCEPTS .....	26
<b>9</b>	<b>SCIENCE OPERATIONS AND ARCHIVING.....</b>	<b>27</b>
<b>10</b>	<b>KEY TECHNOLOGY AREAS AND TECHNOLOGY READINESS LEVEL.....</b>	<b>28</b>
<b>11</b>	<b>PRELIMINARY PROGRAMMATIC AND COSTS.....</b>	<b>29</b>
<b>12</b>	<b>COMMUNICATIONS AND OUTREACH .....</b>	<b>30</b>
<b>13</b>	<b>REFERENCES.....</b>	<b>31</b>



26-JUN-07

## 1 List of Proponents and Letters of Endorsement from the Agencies



## 2 Executive Summary

S-EUSO, the Super-(**Extreme Universe Space Observatory**) aims to be an international multi-agency mission, led by ESA, opening **Particle Astronomy**, a new window to the Universe, through the study of Ultra High Energy Cosmic Particles (UHECP) after the ground-based Pierre Auger Observatory (PAO). UHECP are particles, with energies in excess of  $E \approx 10^{19}$  eV, reaching the Earth from space with a very low flux of less than one particle per ( $\text{km}^2$  sr century), for energies  $E \geq 10^{20}$  eV.

S-EUSO will observe from space the Extensive Air Showers (EAS) induced by UHECP interacting with the Earth atmosphere. It will make accurate measurements of the nature, energy and arrival direction of the primary particles using a target far greater than possible from ground. Such data will shed light on the origin of UHE particles, on the sources that are producing them, on the propagation environment from the source to the Earth, and, possibly, on particle physics at energies well beyond the ones achievable in man-made accelerators.

Three are the major goals of the proposed mission:

- to develop Particle Astronomy, that is to probe and understand the evolving Universe via the investigation of the highest energy processes present and accessible in the Universe, through the detection and analysis of the Ultra Energy Component of the Cosmic Radiation;
- to open the Channel of Ultra High Energy Neutrino Astronomy, to probe the boundaries of the Extreme Universe and to investigate the nature and distribution of the UHE $\nu$  sources;
- to test high energy physics beyond the limits of existing and next generation particle accelerators.

These major goals can provide invaluable science to two out of the four main themes included in the ESA road-map, namely:

- What are the fundamental physical laws of the Universe?
- How did the Universe originate and what is it made of?

A scientific fall-out of S-EUSO is also represented by the systematic surveillance of Atmospheric Phenomena.

The possibility of conducting UV-sky observations will be also explored.

Although the ground-based Pierre Auger Observatory (both South and North sites) will provide in the near future more and more solid bases for the beginning of Particle Astronomy only an innovative and challenging space-based next-generation experiment can increase the event statistics aiming at an instantaneous geometrical aperture of the order of  $\approx 10^6$   $\text{km}^2$  sr. Exceeding the PAO performance requires a highly optimized L-class experiment, with a significant amount of preliminary R&D required. The apparatus will be basically a large aperture, large field-of-view, fast and highly pixelized digital camera detecting with high efficiency near-UV single photons. It will look downward the Earth at night to observe the EAS produced by the interaction of the primary cosmic particle with the atmosphere and detecting, in the near-UV, both the isotropic atmospheric scintillation light and the Cherenkov light diffusely reflected by ground, sea or clouds. Moreover the possibility of using a high-frequency radio system capable of detecting radio pulses produced by the EAS will be explored. The continuously changing field-of-view will be monitored by a suitable LIDAR plus an infrared camera, to gather all the information required for reconstructing the information on the primary particle.

The present proposal builds on the technological and mission studies already conducted in the framework of the EUSO phase A. However major improvements are expected by exploiting both novel technologies and the resources of a large free-flyer mission, as in the original EUSO proposal. Most of the novel technologies are already under development, as they all are of wide interest.

Moreover the scientific scenario which is becoming available thanks to PAO will help to tune the scientific objectives, driving the unavoidable trade-offs on the performance and the design choices that such a challenging space mission will require.

The demanding requirements have a strong impact on resources. Therefore a careful experiment optimisation is required which implies collecting as much as possible preliminary information, useful for the experimental design. To reach this goal a road-map with intermediate preparatory steps and an experimental program for auxiliary measurements has been already singled out, which includes:

- improving the current knowledge on basic parameters: fluorescence yield and Cherenkov albedo measurements continuing several dedicated experiments;
- long duration balloon flights and stratospheric airplane flights to perform functional and technological tests and measure some low-energy particles, both in the optical and in the radio range;
- small missions on a technological micro-satellite for:
  - background characterisation;
  - test of the capabilities to control the most critical issues;
  - test of most critical technological items;
- the Russian TUS precursor, which will soon test the approach and basic technologies;
- the Japanese JEM-EUSO path-finder currently under study by JAXA.

The importance of a space-based experiment, for the post-PAO era, is widely recognized by the whole High-Energy Astro-Particle Physics community, as revealed by the APPEC (Astro-Particle Physics European Coordination) road-



26-JUN-07

map [2]. To define future infrastructures for such kind of projects requires a close collaboration between the Astro-Particle and Space scientific communities, in view of their interdisciplinary character. The inclusion of UHECP into the **ESA Cosmic Vision 2015-2025** program provides a frame to study future space missions.



26-JUN-07

### 3 The S-EUSO science case



## 4 Scientific Objectives and Requirements

### 4.1 Scientific Objectives and Requirements

In this document, the term requirement indicates a figure or condition that must be met in order to not compromise the scientific case of the S-EUSO Mission/Experiment. A goal, in contrast, indicates a figure or condition which seems to be technically feasible which enhances the capabilities of the instrument significantly in a way to strengthen the scientific outcome of the mission. In order to reach the Science goals described in the previous sections, the S-EUSO mission shall address the following specific Scientific Objectives (SO) that is the following crucial observational lines.

- SO1→ Extension of the measurement of the UHECP energy spectrum beyond  $10^{20}$  eV, reaching  $E > 10^{21}$  eV.**
- SO2→ Detailed map of the arrival distribution for the UHECP extended to the entire sky; identification and localization of “compact” sources.**
- SO3→ Study of the spectra of individual sources of UHECP.**
- SO4→ Composition study of the UHECP flux ( $E > 10^{19} - 10^{20}$  eV).**
- SO5→ Measurement of the flux of compact and diffuse sources of Ultra-High Energy Neutrinos; search for horizontal and skimming showers induced by tau neutrinos; estimate of neutrinos cross sections at UHE.**
- SO6→ Systematic surveillance of the Atmosphere to map the cloud and aerosol features and distribution. “Slow” phenomena related to the Atmosphere system itself ( meteors, electrical discharges, ...) will also be observed.**

The Scientific Objectives summarized above convert into the following Scientific Requirements.

- SR1→ Low Energy Threshold (defined as the energy where the total EAS detection efficiency reaches a plateau) of  $E_{TH} \approx 10^{19}$  eV (goal: XXX) (SO5, SO3).**
- SR2→ Statistical Uncertainty on the energy resolution of  $\Delta E/E \approx 0.1$  @  $E \approx 10^{19}$  eV (SO3, SO5).**
- SR3→ An Instantaneous geometrical aperture average on one orbit of  $A_G \approx 10^6$  km<sup>2</sup> sr. The duty cycle  $\eta$  is not included: the current estimates, based on the EUSO study give  $\eta \approx (0.1 \div 0.2)$ . (SO1, SO2, SO5).**
- SR4→ An angular granularity corresponding to  $\Delta \ell \approx$  one km at the Earth.**
- SR5→ An average angular resolution on the reconstructed primary particle direction of about  $\Delta \chi \approx 3^\circ$  @  $E \approx 10^{20}$  eV; the angular resolution strongly depends on the EAS zenith angle: inclined EAS will have a better than average angular resolution.**



## 5 The observational technique

An EAS can be detected by observing the air scintillation light, isotropically produced during the EAS development, and proportional, at any point along the EAS development, to the number of charged particles in the EAS. The additional observation of the diffusely reflected Cherenkov light (reflected either by land, sea or clouds) provides additional information. Therefore it is possible to estimate the energy and arrival direction of the primary UHECP, and to gather information about its nature. The atmosphere serves as the detector medium, a passive, continuously changing and outside human control huge calorimeter. Any given EAS will be seen as a point moving with a direction and angular velocity depending on the EAS direction. The peculiar characteristics of the EAS, including the kinematical ones, allow one to distinguish them from the various backgrounds, because those have a typically different space-time development.

Key points of the observational technique are the following.

- A large instantaneous geometrical aperture can be obtained, depending on the distance and FoV. A large mass of atmosphere can therefore be observed.
- Detection of EAS produced by weakly interacting primary particles, starting to shower deeply in the atmosphere, is possible, by the direct observation of the EAS development and starting point.
- All sky coverage is possible with one single apparatus.

The approach is complementary to the ground-based one. In fact the space experiments are best suited for the observation of higher energy cosmic rays with respect to ground-based experiments. However an overlap of the observed energy spectrum with the one known from ground based experiments is required for a better comparison. A larger geometrical aperture is obtained from Space experiments with respect to ground-based experiments. The systematic effects are different in the two approaches.

**TO BE FINISHED (1 page maximum)**



## 6 The mission profile and requirements

### **Orbit**

A free-flyer can give many degrees of freedom in the choice of an optimized orbit and the orbit strongly affects both the performance and the operations. A careful orbit optimization is a complex task requiring a full phase-A study. However it is not considered to be a critical issue at this stage as the orbital parameters can be varied to a large extent. Therefore the following rough indications are sufficient at this stage.

The satellite orbit shall be elliptical with apogee at about  $r_A \approx (800 \div 1200)$  km (or higher) and perigee as low as possible, compatibly with constraints, including atmospheric drag. The perigee is currently assumed to be in the range  $r_P \approx (500 \div 1000)$  km, following the requirements discussed in section 7.2. An orbital inclination of about  $50^\circ \div 60^\circ$  is preferred.

The ground-track of the satellite orbit needs to be optimized according to the following parameters.

- Minimization of natural and man-made light entering the FoV (Sun, Moon and any other light source).
- Maximization of the rate of passages above a few fixed points at the Earth surface, for both exploiting ground calibration sources and hybrid observations and cross-calibrations with ground-based experiments.

### **Mechanical**

Dimensions after deploying shall be dictated by the optics, including the optical baffle and the optical shutter (see Table 1).

### **Light-tightness**

The interior of the instrument shall be light tight such that the parasitic lights impinging onto the Photo-Detector will be two orders of magnitude less than the expected night-glow background rate, namely: less than one GHz on the whole Photo-Detector.

### **Thermal**

Thermal control shall be provided to stabilize the large surfaces of the instrument with large power consumption: the optical elements and the Photo-Detector. The operational temperature of the main mirror shall be kept at  $T = (20 \pm 5)^\circ\text{C}$ . The active control of the mirror surface will be used to compensate for thermally induced distortions. The operational temperature of the sensors shall be kept at  $T = (-20 \pm 5)^\circ\text{C}$ , to reduce dark counts. However the long term goal is that improved sensors will not require such a cooling.

### **Electrical**

The scientific operations will have a low duty cycle. It is envisaged that during 2/3 of the orbit the Instrument will be in a standby status of low-power consumption. The power consumption quoted for operations is thus required during roughly 1/3 of the orbit only.

### **ACS**

Attitude: nadir pointing (approximate). Pointing accuracy: not a critical factor provided the absolute direction of the optical axis is known/measured for off-line use. It is assumed nadir pointing to within  $\Delta\zeta = 3^\circ$  with pointing direction known offline to  $\Delta\zeta = 0.5^\circ$ , well below the expected angular resolution of the instrument.

### **Telemetry and telecommanding**

The expected event rate will be high and depends on the final orbit, affecting the event rates. A precise estimation is currently lacking.

### **Programmatic**

Required lifetime: five years minimum, ten years goal.



## 7 The instrument concept and its expected performance

### 7.1 Architecture of the Instrument

The payload instrument will consist of the following parts (see section 10 for the Technology Readiness Level).

- The main digital camera operating in the near-UV, a large aperture, large FoV, fast and pixelized single photon detector, to detect the EAS generated in the Earth atmosphere by UHECP. This is made of:
  - the main reflective deployable optics; it consists of:
    - the main mirror: a large, lightweight, segmented, nearly spherical, deployable mirror;
    - the corrector plate on the entrance pupil which needs to be deployable as well;
    - the optical filters;
    - active control mechanism for both the mirror and the corrector plate;
  - the Photo-Detector (PD) on the focal surface (FS) of the optics; it consists of:
    - the sensors, arrays of GAPD;
    - the light-collection system on the sensor;
    - the f/e electronics chip and ancillary electronics;
    - the housing.
    - the back-end, trigger and onboard data-handling electronics.
- The Atmospheric Monitoring System (AM):
  - a dedicated LIDAR;
  - an infrared camera.
- The Monitoring, Alignment and Self-Calibration system (MAC).
- A Radio Pulse Detection system (RPD) for detection of radio signals from the EAS.
- The Central Control Unit (CCU).
- The system and other ancillary parts including:
  - the mechanical structure including the external protection;
  - the thermal control system;
  - the power system, including solar panels and batteries;
  - the system electronics;
  - the shutter
  - the optical baffle.
- The ground-support equipment.

### 7.2 From Scientific to Instrumental Requirements and the expected performance

The S-EUSO mission is an enlarged and improved free-flyer version of the former EUSO mission [3], improving on the performance of the latter both by modifying several aspects, including its size, and by exploiting novel technologies. The design of the experimental apparatus exploits the results of the detailed studies carried on during the phase A of EUSO [2] to redesign the apparatus in such a way to fully satisfy the Scientific Requirements. The estimation of the performance of S-EUSO and all the other arguments in this section will be relative to EUSO.

The improved scientific objectives, with respect to EUSO, imply modified mission and instrument requirements. It should be emphasized again that the detailed optimization of the experiment is a complex task which can be carried on only in the context of a full phase-A study and therefore only preliminary, but typically conservative, estimates are given here.

The current scientific scenario calls for an experiment with an order of magnitude lower energy threshold and a very large instantaneous geometrical aperture operating long enough to get an exposure providing samples of UHECP larger than it is possible from the Earth, and detect weakly interacting particles.

In order to increase the instantaneous geometrical aperture one needs to put the apparatus farther away from the Earth surface. This makes the signal fainter thus requiring a larger photon collection capability. Changing the orbit height actually extends the observational energy range. The orbital parameters need to be tuned to optimize the expected performance. An elliptical orbit height actually extends the observational energy range.

The current estimates of the performance safely rely on the detailed EUSO phase-A studies, based on full simulations, including the signal generation and transport, the instrument response as well as data analysis [3,4]. The EUSO performance are rescaled to the new apparatus on the basis of simple, but reasonably accurate, approximate scaling laws and/or consolidated expectations based on new technologies/techniques developments.

The main physics performance parameters are:

- the instantaneous geometrical aperture;
- lower threshold energy for EAS detection;
- the energy resolution;
- the angular resolution;



➤ the duty cycle.

The basic performance parameter is the photon collection capability, whose improvement positively affects all the other performances. It depends on the optics entrance pupil size (optics aperture) and the total photon collection efficiency. The latter is mainly affected by the Optics Efficiency (OE) and Photo-Detector Efficiency (PDE), whose values are typically significantly smaller than one and therefore capable to provide a significant improvement. In fact a lot of other factors affect the overall efficiency, but all of them are typically already close to one, and therefore it is not worth investing efforts on them.

The OE can be improved with respect to EUSO, by using a different, catadioptric, optical system with a slightly reduced FoV [**Errore. L'origine riferimento non è stata trovata.**], to get a better average optical efficacy:  $\gamma_M = (20^\circ \div 25^\circ)$ . The gain is an average factor of  $f_{OE} \approx 1.5$  by requiring  $\epsilon_{OE} \geq 0.7$ . The instantaneous geometrical aperture is recovered by means of higher orbits.

The PDE can realistically improve by a factor  $f_{PDE} \approx 3$ , thanks to the newly developed GAPD sensors which feature a much larger quantum efficiency and a much better flexibility in the design, which will allow to improve the filling factor of the FS.

The optics aperture is the only sizeable parameter, to within the external constraints. As the entrance pupil size is the only parameter affecting the performance which can be dimensioned the instrument is designed to have the largest possible dimensions compatible with a non-deployable PD. In fact while large deployable optical systems are under development for many applications [18,19,16] at the moment a deployable PD appears to be a too much challenging option.

In order to cope with the very large optics required it is planned to use a reflective deployable optical system; this has also the additional advantage to be capable of a smaller f/# than refractive optics, thus helping to limit the size of the FS. It is assumed:  $f/\# = 0.7$ , with a goal of  $f/\# = 0.6$ . Using this assumption the optics entrance pupil size increase can give a factor  $f_A \approx 10$  improvement.

Even without accounting for possible improvements in other efficiency factors these improvements alone give a factor  $f \approx 45$  improvement in the total photon collection capability. If one accounts for a perigee height twice larger than EUSO one still has a factor ten with respect to EUSO, allowing to bring the total EAS detection efficiency down to  $E_{th} \approx 10^{19}$  eV, as the EUSO efficiency plateau was reached at about  $E \approx (1 \div 2) \cdot 10^{20}$  eV.

Moreover the EAS triggering and reconstruction efficiency is another factor which will be improved by exploiting the increased number of photons, but this is not, conservatively taken into account at this stage.

It is assumed that the satellite orbit shall be elliptical with apogee in the range  $r_A \approx (800 \div 1200)$  km and perigee as low as possible, compatibly with constraints, including atmospheric drag. The perigee is currently assumed to be in the range  $r_P \approx (600 \div 1000)$  km. The current baseline is:  $r_P \approx 800$  km and  $r_A \approx 1100$  km.

The goal is to achieve an angular granularity of  $0.04^\circ$  ( $\approx$  one mrad), corresponding to  $\Delta l \approx 0.7$  km when observing at half FoV from an orbital height  $(r_P + r_A)/2$ .

The resulting Photo-Detector pixel size is  $d = 4$  mm and the resulting number of channels is 1.2 million.

The resulting orbit averaged instantaneous geometrical aperture is  $A_G = 2.0 \cdot 10^6$  km<sup>2</sup> sr. This might be increased further by choosing a higher apogee, if advantageous.

The outline of the estimations leading to the above instrumental requirements from the scientific requirement are summarized in [2,3]. The consequences of this assumption lead to the Instrument parameters summarized in Table 1.

### 7.3 The main baseline parameters

The following Table 1 summarizes the main experiment parameters. A detailed experiment/mission optimization as well as a detailed optimization of all the subsystems will require a detailed phase-A study. The following parameters are based on the current knowledge and the presently perceived constraints and might therefore change after a deeper study.

General Parameters		
Operating wavelength range (WR)	330 nm < $\lambda$ < 400 nm	
Night-Glow Background (NGB)	(300 $\div$ 1500) photons / (m <sup>2</sup> sr ns)	Improved measurements required
Satellite orbit parameters		
Orbit perigee	$r_P = 800$ km	To be optimized: [ $r_P \approx (500 \div 1000)$ km]
Orbit apogee	$r_A = 1100$ km	To be optimized: [ $r_A \approx (800 \div 1200)$ km]
Orbit inclination	$i \approx 50^\circ \div 60^\circ$	Preferred
Orbital period	$T \approx 100$ min	
Velocity of the ground track	$v_{GT} \approx 7.5$ km/s	
Pointing and pointing accuracy	Nadir to within $\Delta\zeta = 3^\circ$	Must be known offline to within $\Delta\zeta = 0.5^\circ$
Satellite parameters		
Satellite envelope	Frustum of a cone	Excluding baffle and shutter



	$D_{MAX} \approx 11 \text{ m}$ and $D_{MIN} \approx 8 \text{ m}$	Base diameters
	$L \approx 10 \text{ m}$	Cylinder height
Lifetime	Five years minimum ten years goal	
<b>Main Instrument parameters</b>		
Type	Deployable catadioptric system	
Main mirror	$D_M = 11 \text{ m}$	Diameter
Entrance pupil and corrector plate	$D = 7 \text{ m}$	Diameter
Field Of View	$\gamma = \pm 25^\circ$	Half-angle FoV
Angular granularity	$\Delta l \approx 0.7 \text{ km}$ at the Earth	Average
Optics throughput	$\epsilon > 0.7$	Average requirement
f/#	$\approx 0.6$	Current design has f/# = 0.7
Total length of the optics	$\approx 9 \text{ m}$	
FS	$\approx 4 \text{ m}$	Diameter
PDE	$\epsilon_{PDE} > 0.25$	Average requirement
Number of channels	$\approx 1.2 \text{ M}$	
Size of the pixels of the PD	$\approx 4 \text{ mm}$	To be optimized
Power consumption	$< 2 \text{ mW}$ per channel	Total
Sensors	GAPD	Modular array of sensors on the FS
<b>Main Performance parameters</b>		
Energy threshold	$E_{th} \approx 10^{19} \text{ eV}$	
Instantaneous geometrical aperture	$A_G \approx 2.0 \cdot 10^6 \text{ km}^2 \text{ sr.}$	
Statistical error on the energy	$\Delta E/E \approx 0.1 @ E \approx 10^{19} \text{ eV}$	
Angular resolution	$\Delta \chi \approx (1^\circ \pm 5^\circ)$	Depends on the EAS direction
Duty Cycle	$\eta \approx (0.1 \pm 0.2)$	Dedicated measurements required

• Table 1: Main baseline parameters

## 7.4 Instrument description

### 7.4.1 Optics

The proposed optics is based on the following concepts: the most versatile configuration is a catadioptric one; the required dimensions and the use in space require the optics to be lightweight and deployable.

Single or multi-pupil layouts might be taken into account. During the study, we will consider several catadioptric designs. As an example of a catadioptric system that might be chosen, we present a Schmidt design which meets the requirements. Thanks to the experience gained via an ESA contract for the study of an Earth-looking LIDAR telescope [15,16,17], an extended trade-off was developed, highlighting positive and negative aspects solution. A similar solution was studied by NASA for OWL [10]. A Schmidt telescope with a suitably shaped plane corrector was chosen, as shown in Figure 1.

The main advantage of this design is to reach the goals only through a single spherical mirror, with the off-axis performances greatly improved by the front correcting plate, with almost no chromatic aberrations and with UV transmission enhanced with respect to a refractive optics. Being an f/# 0.7, the (spherical) detector is small, meaning overall mass saving. The design developed has a 5m diameter Entrance Pupil, but it is easily scaled to any wanted dimension. The FoV is  $\pm 25^\circ$ , and the obscuration is limited.

The influence of stray light is a crucial issue. Baffles are required to reduce the propagation of this unwanted flux, through an appropriate dimensioning. Beside the light shield covering the lateral side, a front baffle may be needed but it must be cleverly designed. Because our ability to baffle stray light in such wide-angle optics is limited, observations can only be conducted when the spacecraft is in umbra and well beyond the terminator to eliminate increased background from civil twilight near the terminator. Operations may also be limited when the moon, even at a small phase, is near the horizon. The telescope must necessarily be a lightweight and deployable structure. It will be necessary to launch with both the primary mirror and the corrector plate folded. These must be deployed once on orbit. Because of the size of this optical system and the difficulty of controlling the temperature and temperature gradients in such a system, the optical surfaces (both the primary mirror and the corrector plate) must be actively controlled. The coupling between the thin optical surface of

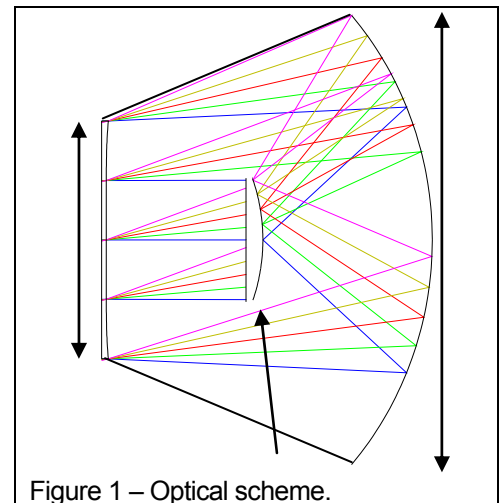
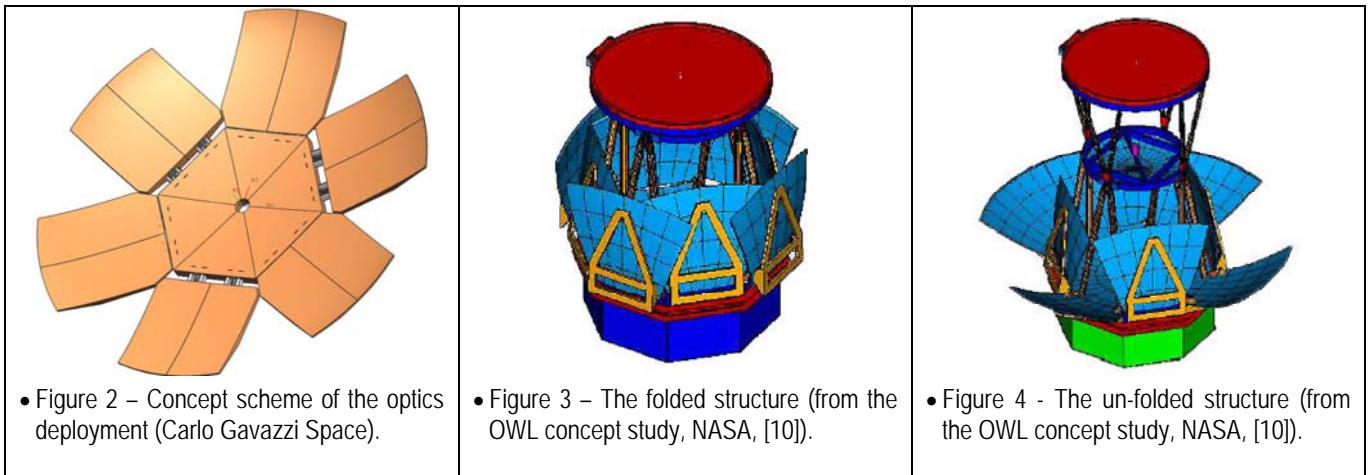


Figure 1 – Optical scheme.

Because of the size of this optical system and the difficulty of controlling the temperature and temperature gradients in such a system, the optical surfaces (both the primary mirror and the corrector plate) must be actively controlled. The coupling between the thin optical surface of



the primary and the stiff lightweight support structure is made through an array of actuators for the adjustment of the optical surface via active control: this is necessary for improving the optical performance (controlled through a wavefront sensing system that measures the aberration of the collected wavefront), for in-orbit alignment but also for compensating any deformation (i.e. thermo-elastic ones) of the support. This concept is already in use for the thin-glass secondary mirrors of ground-based telescopes, using many electromechanical actuators to instantaneously correct the atmospheric turbulence effect. For space application, however, the disturbances characteristic time is lower,  $\sim$ Hz. Furthermore, the tolerances in the mechanical deployment system are not so stringent, since the spot dimensions are relatively large and the active control can compensate fairly well. Active control of the corrector plate will focus on correcting the tilt of the segments because the optical performance is relatively insensitive to small relative translations of the segments of the corrector plate. The mirror is deployed with a series of petals around a central structure (Figure 2, Figure 3 and Figure 4). It is possible to scale the design to use the biggest monolithic FS that will fit within the rocket's fairing. The mirror and the corrector plate will be designed to fold with appropriate petals' dimensions to also fit in the fairing. The corrector plate will be made in segments and folded to fit in the fairing also. The proposed technology for space applications is already under way: a 4 m  $\varnothing$  deployable mirror for LIDAR application is under development. The current mirror is made of 15 kg/m<sup>2</sup>, 1-mm thick Zerodur and the supporting back plane is made of Carbon Fiber Reinforced Plastic (CFRP). In addition, a 6.5 meter deployable mirror has been developed for the James Webb Space Telescope. This is the primary mirror of a diffraction-limited optical telescope. It's design, deployment and alignment are much more critical than the primary mirror.



#### 7.4.2 The Photo-Detector: sensors

##### 7.4.2.1 The architecture

One of the main driving points of the PD design is to combine different functions as much as possible, in order to save on resources. The packing of the devices has to be optimised to reduce losses in the geometrical acceptance, due to dead regions between the close packed devices, and defocusing effects, originating from a positioning of the sensor at some distance from the ideal FS. The overall structure shall be modular and consist of small autonomous functional units (elementary-cells, EC) assembled in larger modules (Photo-Detector Modules, PDM). The EC consists of a limited number of devices sharing some common resources. Several EC form a PDM. PDM are independent structures tied to each other by a common support structure and having a shape determined by the layout of the FS. The EC concept is useful because it implements the desired modular structure allowing the sharing of many resources among a few sensors, such as the supporting structure power lines, cables, connectors and electronic chips. This sharing improves the economy of the architecture and makes design, production and testing easier.

##### 7.4.2.2 The photo-sensors

The performance of S-EUSO very much depends on the sensor characteristics. The requirements for the PD are as follows.

- Capability to measure the light at the single photoelectron level.
- Good charge resolution (excess noise factor <1.4)
- High PDE in WR ( $\epsilon_{\text{PDE}} > 0.6$ ).
- Good time resolution (two-pulse separation of 2+3 ns).
- Pixel size is  $\approx$ 5mm.
- Total power consumption shall be as low as possible (less than 10mW/cm<sup>2</sup>).
- Low dark current (much less than NGB).
- Life-time of more than ten years against Total Average Background and radiation effects.



We can consider the candidates of sensors, Photo-Multiplier (PMT), Hybrid Photo Detector (HPD) and Geiger-mode Avalanche Photo Diode (GAPD), also called Silicon Photo-Multipliers (SPM). There are a long experience and many varieties in PMT, for example, Multi-Anode PMT (MAPMT) and Flat Panel PMT from Hamamatsu are good candidates of sensors. Potential problems of PMT are the limited PDE, in-homogeneity of the response of pixels, and relatively high power consumption of the bleeder circuit as well as the use of high-voltages, poor flexibility in the design and a rather weak and relatively heavy mechanical structure. In case of HPD, there are not so many varieties and HPD suffer most of the other problems of PMT in addition to being a relatively young technology with little experience on its long-term behavior.

GAPD, are large array of Geiger-mode Avalanche PhotoDiodes (typically consists of about one thousand APD pixels), which was invented in Russia more than ten years ago and currently available from Sens-L, Hamamatsu and FBK-Irst companies. The variety of GAPD is rapidly growing, but the basic principles are well established and its advanced and excellent characteristics fascinated many scientists and industries and initiated rapid technological developments in many places in the world. We assume large size GAPD as the baseline sensor.

The GAPD is a solid state sensor developed for applications in High Energy Physics, Astro-Particle Physics and Medical Science. For Astro-Particle Physics applications, the most attractive feature of the GAPD is its potentially high PDE ( $>0.5$ , depending on the wavelength) and the capability of single photon counting. Further, there are many other advantages, such as the compactness of its size and volume, the low bias voltages, the very high gain of  $10^6$ - $10^7$ , the insensitivity to the magnetic field and the low power consumption. At present major issues of GAPD are the small size, the cross talk between micro-pixels in the and the high dark-count rate.

The larger size GAPD of  $5 \times 5 \text{mm}^2$  or even  $10 \times 10 \text{mm}^2$ , with high PDE, low dark-counts, low crosstalk and enhanced sensitivity in UV and blue light is necessary. Silicon itself has the nice feature of nearly 1, internal quantum efficiency. The increase of the filling factor of the sensitive area on the device surface and the increase of the Geiger efficiency will give us the very high PDE.

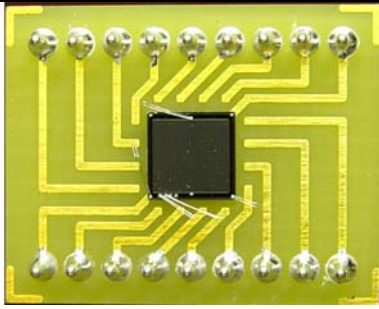
MPI and MEPhI have developed GAPD with a size of  $5 \times 5 \text{mm}^2$  for Astro-Particle Physics applications as shown in Figure 7 [11]. The micro-pixel size is enlarged to  $100 \times 100 \mu\text{m}^2$  to get a higher filling factor of the sensitive region. The PDE of 50% was achieved at around 500nm. The dark rate of GAPD is about  $0.5 \pm 2.0 \text{ MHz/mm}^2$  at room temperature ( $\sim 20^\circ\text{C}$ ). The dark current is produced by two mechanisms: the electric field assisted tunneling effect and the thermal effect. The dark current can be reduced by one or two orders of magnitude by cooling the temperature down to  $T \approx -7^\circ\text{C}$  or  $T \approx -35^\circ\text{C}$  in MPI/MEPhI GAPD, respectively. The sensitivity to UV light and blue light must be improved.

Hamamatsu Photonics LTD delivers three types of  $1 \times 1 \text{mm}^2$  GAPD, they call MPPC. The structure is quite similar with the MPI/MEPhI GAPD, but Hamamatsu employs the inverse polarity for GAPD (p-on-n structure). This inverse structure and thin structure in depletion layers enhance the sensitivity to UV and blue light. Drawbacks of Hamamatsu MPPC are the narrow range of operational bias voltages and high optical crosstalk between micro-pixels. Larger size GAPD  $3 \times 3 \text{mm}^2$  and  $5 \times 5 \text{mm}^2$  will be delivered in the near future with the same technology.

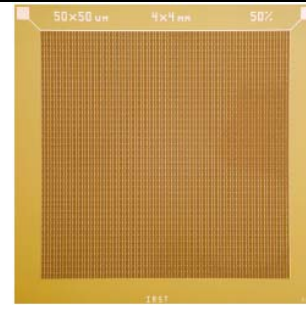
FBK-IRST and INFN have developed Multi-GAPD ( $\mu\text{GAPD}$ ), arrays of n-on-p GAPD from  $1 \text{mm}^2$  to  $16 \text{mm}^2$  sizes to match applications requiring multiple GAPD channels with high packing-factor (Figure 8). The current devices are optimized for blue light, with a 50% geometrical factor on  $50 \times 50$  micro-pixel. Cross talk below 1% and excellent timing resolution (50 ps for single photon counting) have been obtained. Developments to improve UV sensitivity and to reduce the dark counting rate to match S-EUSO needs are planned.

MPI-HLL is developing the Back-Illumination-Drift GAPD. Concerning the PDE, the ultimate performance will be achieved in the PDE (85% or more between 330nm and 400nm range). Due to the large volume of drift volume, the dark current and cross talk is expected to be relatively higher compared with other GAPDs.

UV sensitive large size GAPD, with low optical crosstalk are required for the photodetectors of Super EUSO. Unfortunately such device does not exist currently in the market. However, these GAPD will be delivered within a few years from most of groups mentioned above.



• Figure 5 - MPI and MEPhl 5x5mm<sup>2</sup> GAPD.



• Figure 6 - FBK-IRST 4x4 mm<sup>2</sup> GAPD.

### 7.4.2.3 The filter/light-collection system on the sensors

A filter/light-collection system made of a simple lens plus the optical filter will be provided on the sensors which will recover the losses of the geometrical acceptance due to tiling of the different sensor modules while filtering the incoming light. This kind of devices was already studied in EUSO [3].

#### 7.4.3 The Photo-Detector: f/e, trigger and OBDH electronics

The expected signal from an EAS is a **track**, that is a list of space-time correlated **hits** on the FS. Each hit is a fast bunch of photons in a pixel (about ten photons/ $\mu$ s near the energy threshold; up to a few thousands photons/ $\mu$ s at UHE). The expected background is several photons/ $\mu$ s, with significant variations that depend on many factors. Typical EAS has a useful length on the FS of (10÷20) pixels.

The electronics and the trigger system must be capable to sustain the high rate due to nightglow background and be tolerant to the huge signals generated by lightnings and human activities. As the background is variable in space and time along the orbit, the system must have both a on-board threshold setting system and a background subtraction system.

Moreover all the parts of the electronic system must be radiation tolerant, SEU free (or at least tolerant with suitable redundancies), latch free and low power demanding.

#### 7.4.3.1 The Front End electronics

As GAPD will be adopted, the f/e electronics will be definitely a custom ASIC highly integrated with the sensors. The ASIC will have to accomplish the following tasks.

- Provide the basic pre-amplification to collect the signal and shape it with suitable filters.
- Provide single photon counting capability, with a programmable and self-adjusting threshold, background subtraction and zero suppression.
- Provide charge integration and charge threshold, with self-adjusting thresholds, digitization and background subtraction. The use of analogue multiplexed memories is highly probable, in order to reduce the number of ADC on board.
- Include a track finding logic, in order to search for EAS like events.

Due to the very large span of the energy range (almost three order of magnitudes for EAS, but maybe four including other phenomena) two complementary approaches are required: the single photon counting technique and the charge measurement technique.

At very low energy near,  $E_{th}$ , the expected signal is of the same order of magnitude of the RNB, and is of the order of ten photons/ $\mu$ s or less. With these small numbers, it is possible and advisable to count the photons with a suitable preamplifier-discriminator-counter chain and identify the signal by putting a threshold on the counter, which should be periodically reset by a system clock. In this way, with a suitable on-chip logic, the system could have a self-adjusting threshold and subtract the expected background from each hit. Here and below we call the periodic reset clock a Gate Time Unit (GTU). Typical value of this gate will be 500ns÷2 $\mu$ s, depending on the operating conditions. This clock must be of course programmable on board. The single photon counting technique will finally provide the number of collected photons for each GTU and for each pixel, allowing full reconstruction of energy and direction of the EAS.

This approach, although simple, solid, easy to implement, and low power demanding, is not enough because it cannot work at high energies. Indeed, the single photon counting technique cannot be efficient when the rate of photons is of the order of 100photons/ $\mu$ s or more, because the resolving power of the discriminator cannot easily be pushed below 10ns. For this reason, the front end electronics should also provide a parallel system based on charge integration and charge discrimination that with suitable amplifiers can be used at any energies. Of course this will be more demanding in term of power and space, but it is probably unavoidable with a very large instrument.

#### 7.4.3.2 The principle of measurement and triggering

The trigger system has to provide a fast trigger capable to manage several hundreds of thousands of channels. It has to be selective in order to tag the EAS signal while rejecting the background in an efficient way. The system must be



modular, based on an assembly of sensors, physically grouped into many sub-arrays of defined size with each sub-array logically working as a single entity.

#### **Low energy (digital) trigger**

The basic method of measurement and triggering at low energy exploits the single photon counting technique. A charge integration approach is also implemented to handle signals at high energy and from strong reflected/diffused Čerenkov light. The subtraction of the fluctuated background signal will be implemented in real time, making use of the Poisson property of systems based on counting and briefly summarized below.

A fast discriminator recognizes the arrival of a single photo-electron event. The pulse is counted by a pixel-level 10-bit counter with double hit resolution of 10 ns or better.

When a pre-set counter value is reached within a given GTU (Gate Time Unit, the programmable basic time unit), a pixel-level trigger is issued, the pixel are marked into the (X,Y) memory and the pulse counting output is enabled during the remaining GTU time. Also, regardless of the threshold, for each GTU the number of collected photons in a given pixel is stored into a memory. The memory should be deep enough to keep several hundreds GTU for all pixels. When a pre-set counter value at the sub-array level is reached within a given GTU, due to the pulses coming from the enabled pixels, a sub-array level trigger is then issued. A hard wired (X,Y) proximity device for adjacent GTU at the sub-array level further rejects fake triggers in presence of large photon background. This proximity logic acts as first level trigger.

When a first level trigger is issued, the relevant memories must be read and a complete track finding algorithm must be performed. This most likely will require two levels of custom ASICs, the first being the front end one with internal memories, the second being the track finding one. The necessity of using a first level hard wired first level trigger is justified by the requirement to limit the power consumption and avoid the read out of Gbytes/s of data, which is unlikely to be feasible in space (although future electronics developments might allow it).

#### **High energy (analogue) trigger**

At relatively high energies, or whenever the signal is too large to be measured by single photon counting, the charge measurement should be used. Each channel should be equipped with a gated charge integrator followed by a discriminator with programmable threshold and by an analogue memory. The triggering logic can be designed in a very similar way with respect to the digital one, using the single bit output of this discriminator instead of the bit coming from the digital comparator that is used in the single photon counting trigger. The analogue memory allows storing the charge information, and to activate the time and power consuming ADC conversion only when a trigger is fired and the channels are relevant for the trigger. As for the digital case, the threshold must be continuously adjusted on board by means of the information coming from the digital comparators or specializing a few channels to do so.

The analogue trigger information might also be used to detect the Čerenkov pulse at the end of a shower.

An auto-level-trigger function within the system trigger is also foreseen. This would allow the Instrument to be set dynamically at the optimum trigger levels in case of varying background conditions due to slowly transient phenomena (moon phases, varying cloud coverage, large urban areas, ...) specializing few sub-arrays of the focal surface.

#### **Special trigger modes**

In addition to the fast triggers discussed in the preceding paragraphs, S-EUSO will have two special trigger modes, slow trigger and calibration trigger. The slow trigger will be used to trigger on atmospheric phenomena such as upward lightening effects like sprites and dwarves. The calibration trigger will be invoked when S-EUSO is calibrated using a ground light source (GLS). These passes will last only a few minutes. Invocation of this mode will be scheduled based on when S-EUSO will be over a GLS, whether weather conditions permit a useful calibration to be made and the need to take advantage of the calibration pass. Since the ephemeris of the S-EUSO spacecraft will be well known, these periods of calibration mode operation can be scheduled days in advance and uploaded to the instrument.

#### **7.4.3.3 On-Board Data Handling**

The On-Board Data Handling (OBDH) sub-system carries and stores data between the various electronics units and the ground segment, via the Telemetry, Tracking and Command (TTC) subsystem. The task of the OBDH will be very challenging, since it will have to deal with fast analysis of large amounts of data, compliant with the usually limited telemetry resources. S-EUSO will detect roughly (???) events per day, for a total amount of daily data of about (???). According to the number of download sessions that will be available, the duration of the sessions and their speed, an algorithm for on-board data reduction might be necessary. More specifically, the tasks of the OBDH will be:

- reception, error correction and decoding of telecommands (TC) from the TTC, and forwarding to the CCU for execution;

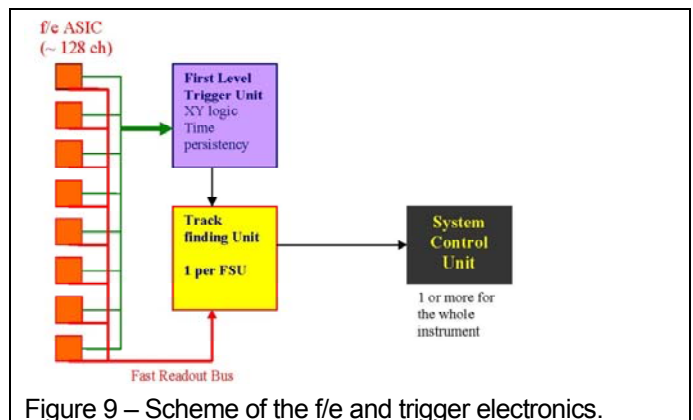


Figure 9 – Scheme of the f/e and trigger electronics.



- measurement of discrete values such as voltages, temperatures, binary statuses, to monitor the correct functioning of the apparatus (monitoring data);
- collection of scientific information coming from the detector, namely time and position of the detected photons;
- preparation, collation and encoding of both scientific and monitoring data in pre-defined telemetry frames, ready for transmission to Ground through a standard OBDH bus (such as MIL-STD-1553);
- storage of telemetry frames in a Mass Memory.

#### 7.4.4 The Atmospheric Monitoring

The main purpose of the Atmospheric Monitoring System (AMS) is to observe the Earth's atmosphere inside the FoV of the instrument. This observation shall provide key parameters for the reconstruction of the EAS, allowing a precise estimation of the optical yield from UHECP. The measurement objectives are:

- mapping of the opaque clouds and determination of the cloud-top altitude;
- mapping of the sub-visible clouds and determination of their attenuation.

The AMS will also substantially contribute to the Earth Observation. The horizontal size and the top altitude of the clouds cover and altitude are critical inputs in the evaluation of the Earth radiation balance and models forecast of the climate changes. The capability to detect low-level range resolved UV signals allows gathering statistics of the atmospheric electrical phenomena, strongly linked to the chemistry and the balance of critical atmospheric constituents such as ozone, nitrogen oxides and others.

The present concept for the AMS is based on the use of a complex of sensors in synergy with each other. The **slow-mode** and the IR camera will ensure mapping of the horizontal cloud coverage in the FoV as well as the inputs for estimation of the cloud top with bias. The LIDAR measurements of the cloud-top altitude will be performed in several selected directions with high-precision and will be used to correct the bias in the IR camera and **slow-mode** mapping. This synergy will ensure the fulfilment of the objectives of the corrections, use of the AMS measurements in EO, where all this will be fulfilled with an affordable impact on the overall budget.

##### 7.4.4.1 Composition of the Atmospheric Monitoring System

###### **Elastic backscatter LIDAR**

The proposed LIDAR will be a back-scatter type using wavelength in the UV spectral range, coinciding with the wavelength EAS scintillation light. In this way it is possible to use the telescope as LIDAR receiver, where only several of the detectors will be used for back-scatter signal detection. Two objectives are achieved:

- the large size receiver decreases the required laser power, resulting in a decrease of the power budget;
- there is no need to have a separate receiver and complicated scanning mechanism, saving on the budgets.

The objectives of the LIDAR are as follows.

- To provide absolute measurements of the range to the top of the opaque clouds in several directions into the FoV with vertical resolution of  $L \approx 30\text{m}$ . These measurements will be used to calibrate the assessment of the cloud top altitude provided by the IR camera via the evaluated cloud top temperature, and via the evaluation provided by the slow-mode.
- A calibration of the efficiency of the Instrument, using the molecular back-scatter signal and/or the signal scattered from cloud top and surface.
- To provide evaluation of the albedo of the sea and land-mass surface.

###### **Infrared Camera**

The objective of the infrared (IR) camera is to obtain IR images of the cloud-top relevant to the cloud-top temperature inside the FoV. Using these images will make possible the following:

- map of the clouds cover inside the FoV;
- rough estimate of the cloud-cover top altitude.

The first objective might be reached by means of image processing and statistical learning techniques. The latter exploiting the parallax between two images acquired from close positions of the satellite within a temporal interval opportunely chosen in order to optimize the overlap between the two images.

###### **Space-resolved detection of the UV background (slow-mode)**

The objectives of the **slow-mode** is to determine the background UV reflection from the Moon, stars etc., with a resolution sufficient to estimate cloud top altitude by a stereo image analysis. Additional objective, with respect to EO tasks is to detect atmospheric luminous phenomena such as lightning-associated transient luminous events (sprites, elves, blue jet), nightglow and meteors.

##### 7.4.4.2 Technological readiness

AMS is based on secure and proven technologies [12,13,14]. There are already two operational space lidars for EO (GLAS, CALIPSO-CALIOP), one planned for near future by ESA (ALADIN), as well as a number of IR cameras.

#### 7.4.5 The Radio Pulse Detector (RPD)



Radio detection of UHECP was first demonstrated by the LOPES experiment in 2005 [5] (Figure 10) by recording the radio-pulse emitted when a UHECP hits the atmosphere. The detected radio transients were the brightest and fastest ever seen on the sky, being a thousand times brighter than the sun and a million times faster than normal lightning. A similar detector would be very useful as a complement to the digital camera. The Radio Pulse Detector is an array of tri-axial electric field vector sensing antennas, each consisting of three orthogonal, 300 mm long and 5 mm diameter, monopole tubes made of 0.05 mm thick CuBe foil. The foil is pre-tensioned and stored on a reel and the tube is formed when the foil is rolled out. A drawing of the antenna is shown in Figure 11.

Every vector antenna has its own sampling unit, using three 8bits@3GHz analog-to-digital converters (ADC) with 4 kB on-chip buffer memories connected to a FPGA. A first stage software trigger is implemented in the FPGA, which also handles communication with an high performance on board computer (HPOBC). The power consumption of one RPD module is 5 W. The HPOBC has advanced high level coincidence trigger functions implemented; it controls the RPD experiment and communicates with the spacecraft bus. A performance of 200 GFlops at a power consumption of 20 W has been estimated using the Cell Broadband Engine CPU [9]. A 32Gbit mass memory is used to store radio pulse data. The RPD mass, power, and telemetry requirements are listed in Table 2. The RPD modules are small, light-weight, and easy to accommodate. Six modules could be mounted on the rim of the primary mirror and six on the rim of the entrance pupil, forming two concentric circular arrays. The main task for the HPOBC trigger system is to sort candidate events received from the RPD modules, taking the temporal shape of the pulses as well as their polarization into account. Full polarization characterization [6] is guaranteed since vector antennas are used. The possibility to use other properties of radio frequency electromagnetic fields [7, **Error. L'origine riferimento non è stata trovata.**] for pulse discrimination will be investigated further.

#### 7.4.5.1 Technology readiness

The RPD has its heritage in scientific instruments designed and built by the Swedish Institute of Space Physics in Uppsala, Sweden, currently in operation on board Cluster, Rosetta, Cassini, and Compass-2. The vector antenna with a high-frequency radio pulse detector will be flown in 2007. The mass memory will be space qualified in 2008 on a flight where the silicon multi chip module electronics packaging technology intended for the RPD will also be tested. Discussions with IBM Research to design and build an HPOBC based on the Cell BE have been started, with a projected test flight in 2009–2010. All components needed for the RPD are commercially available now albeit their performance is likely to increase significantly before the technology freeze, which we estimate to be in the 2010–2012 timeframe.

#### 7.4.6 Preflight and on-board calibration

It is devoted to the absolute measurement of the parameters characterizing the performance of: the telescope optics, the PD, the optical coupling parts (filters, and light adapters) and the triggering system.

A specific instrument based on lamps and optical systems is required to ensure calibration on the long term. Therefore a known and long-term stable light source is required, self-monitoring and radiation hardness of the components.

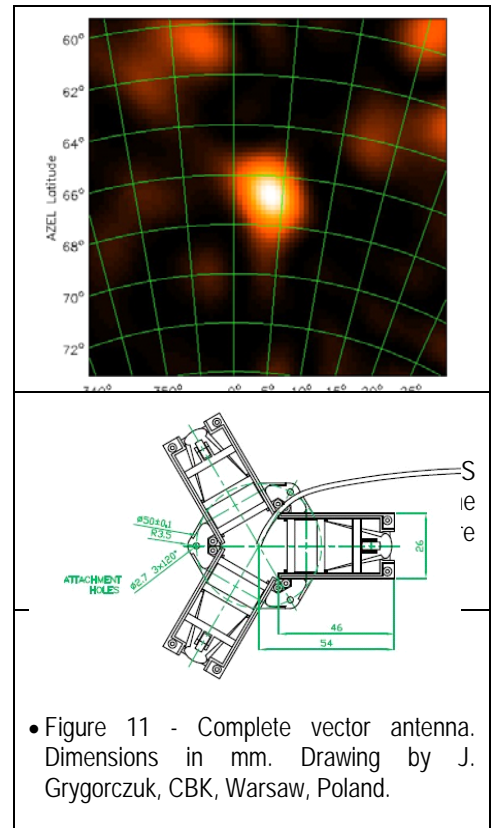
To achieve an effective instrument calibration the following parts require a deep investigation and development: the pre-flight calibration system, the on-board calibration system, the ground-source and the data archive.

The data archive must be conceived and developed in order to make easily accessible rough and processed data both from pre-flight calibration and on-board calibration.

#### 7.4.6.1 Pre-flight calibration

Pre-flight calibration is a crucial aspect of a telescope AIV phase because ground-based calibration of sub-systems and the integrated instrument provide the basic information on the instrument performance. The capability to discriminate signals against the background and the system noise is the main issue of the instrument.

This means that the ground support equipment have to be developed in order to ensure the precise measurement of the optical performance. In particular a facility using a photon source emitting in the whole spectral range of interest, producing wide-band collimated beam light to illuminate large optical systems. Synchrotron radiation could be used for such purposes for its optical and time characteristics. Producing UV tracks against wide-band backgrounds could simulate the measurement conditions to verify the optical performance of the whole telescope and detection system, the discrimination capability, the time response and all the operation conditions. Such facility can be developed at the exit of a synchrotron beam-line and R&D activities are: track production with the expected size, photon flux and time evolution; UV tracks and UV+VIS background illuminating the optical system at the same time and reproducing the real conditions; illuminate large telescopes, up to 4-5 meters, with a collimated beam starting from the synchrotron beam



• Figure 11 - Complete vector antenna. Dimensions in mm. Drawing by J. Grygorczuk, CBK, Warsaw, Poland.



light; characterization of large focal surface detector arrays and readout and trigger electronics. This facility could be used also during the R&D phases of experiment subsystems, such as detector arrays, trigger electronics, mirrors, adapters and filters. No lamp-based system can provide the same performances and accuracy as a synchrotron source.

#### 7.4.6.2 The onboard calibration

The onboard calibration system for future UHECR space experiments require the development of compact, lightweight and low-power optical arrangement based on lamps. The main issues are:

- calibrate the total throughput of the optical system;
- calibrate the performance of the PD;
- monitor the global and local optical performance of the optical system.

The required R&D activities concerns:

- the compact, lightweight and low-power optical arrangement of the calibration system;
- the light source (pulsed or continuous UV LED, lamps);
- the detectors of the monitoring system that must be reliable and stable over a long term program;
- the uniform and collimated illumination of the telescope optical assembly.

#### 7.4.6.3 Calibration via a ground-source

The energy measurements depend on accurately reconstructing the strength of the signal.

To measure how accurately the fluorescence signal is being reconstructed, we propose to deploy ground light sources (GLS) of precisely known luminosity. These sources will employ calibrated xenon flash lamps. We propose to use Hamamatsu L6604 flash lamps that produce  $\mu\text{s}$  flashes with flash-to-flash relative variations of less than 0.03 at flash rates up to 30Hz. The intensity is uniform to within 0.05 over a viewing angle of  $60^\circ$ . An internal photodiode monitors the actual light output of the GLS unit during operation to ensure that the absolute strength of the flashes is known.

The signals from these sources will be measured by S-EUSO. This will provide a direct and independent verification of the accuracy of the reconstructed luminosity of the EAS.

We propose to operate a few GLS units: one airborne unit and some ground-based units, deployed at host stations in different geographical locations to sample a variety of atmospheric conditions and terrestrial backgrounds. A careful orbit optimization will be carried on at a later stage. This will provide a detailed sampling of the accuracy of the signal reconstruction. When S-EUSO flies over one of the GLS sites, the unit will be activated to flash repeatedly. The GLS site will remain in the S-EUSO FOV for typically two minutes, observing as many as a few thousands light flashes. A special trigger mode in S-EUSO will be activated at the times of scheduled over-flights of these sources to record the flashes. The captured GLS flashes will be recorded by the S-EUSO flight-data system for transmission to the Earth where they will be analyzed to determine the accuracy of the fluorescence measurements. The pixels seeing the track will be absolutely calibrated and their relative calibration with the other pixels will be used to perform an absolute calibration of all the pixels.

An advanced variant might be to use a suitable laser shoot to simulate an EAS. A suitable LIDAR system located near the GLS will be used to measure the atmospheric transmission during the over-fly.

#### 7.4.7 The Central Control Unit (CCU)

The CCU is in charge of managing all the operations of the Instrument. A nominal and a redundant (cold) CCU are foreseen. The CCU will include a suitable micro-processor with dedicated SW running on it for both common services and for science data processing.

## 7.5 Operating Modes

The following observation operating modes are foreseen:

- EAS detection mode: triggering on candidate EAS and continuous background measurement and subtraction;
- Calibration mode: the apparatus is setup to perform self-calibration using its on-boards MAC system;
- GLS mode: the apparatus is setup to perform self-calibration based on the GLS;
- Other modes will be studied, if needed.

The instrument will switch between a non-observation operating mode and an observation operating mode based on ephemerides and/or upon signals received from its light sensors measuring the amount of light entering the FoV.

## 7.6 Summary of budgets

An overview of the payload budget requirements, based on current estimates and knowledge, is given in Table 2.

The budgets are strongly dependent on the final instrument design and, therefore, are subject to change following the instrument optimization. Volumes are not easily summarized in a table but they are written in the descriptive section of each sub-system.

All the values are worst-cases, that is, typically, in operating conditions. During non-operating modes the power, OBDH and Telemetry requirements might be much lower.

Telemetry requirements strongly depend on the final Mission/Instrument optimized design (as this will affect the event rate, among other things) and therefore can be only estimated with a large uncertainty now.



Safety margins are not included.

	Current best-estimates			
	Mass (kg)	Power (W)	OBDH (GFlops)	Telemetry (Mbit/orbit)
<b>Main Optics</b>	1800	300	0	0
<b>PhotoDetector on the focal surface</b>	1600	500	0	0
<b>Electronics: f/e, b/e, trigger and data-handling</b>	600	2500	TBD	3000
<b>Monitoring, Alignment, Self-Calibration</b>	50	200	TBD	30
<b>Atmospheric Monitoring</b>	70	600	450	7000
<b>Radio Pulse Detector (12 units + HPOBC)</b>	5	100	200	2000
<b>Structure</b>	500	TBD	0	30
<b>Thermal Control HW</b>	100	TBD	0	0
<b>Total</b>	4720	4200		

• Table 2: Current budgets estimates

## 7.7 Potentially critical issues affecting the performance

The following critical issues are identified; their solutions require a full phase-A study.

- Random (night-glow) background and other backgrounds. The total background is large: an online subtraction, required for triggering purposes, must be implemented, possibly in hardware.
- The observed FoV is continuously changing: a continuous monitoring and parameter recording is required.
- Optimal stray-light control of the large FoV and highly sensitive apparatus (large baffle).
- PD protection from intense light: shutter and/or attitude control.
- Orbit optimization: man-made background, atmospheric phenomena, day-night...
- Atmospheric monitoring.
- Detector calibration for  $\approx$  one million channels on orbit.
- Ageing of some of the components (sensors, light sources).
- Protection from orbital debris.
- Thermal control of the large surfaces.
- Optimization of the placement of the different parts.

The demanding requirements have an impact on resources (including power, OBDH and telemetry). Careful experiment optimization is then required which needs to collect as much as possible information during the phase of mission conception and design. A well defined road-map with intermediate steps is required (section 7.10).

## 7.8 The trade-off on the instrument design

A number of trade-off need to be carried on which require a full phase-A study.

- Lower orbit (better energy threshold and angular resolution) versus a higher orbit (better instantaneous geometrical aperture and longer lifetime).
- Monocular apparatus, a single satellite, (better energy threshold) versus stereo, two smaller satellites (better angular resolution). In fact two spacecrafts might be used to provide redundant measurements of the EAS along two different paths through the atmosphere. Consistent measurements between the two spacecrafts would help to confirm the atmospheric corrections used to reconstruct the EAS.
- Monolithic versus modular concept of the instrument.
- A binocular concept versus a monocular concept to reduce the instrument noise looking for coincidences.

## 7.9 R&D on alternative solutions

### 7.9.1 R&D on segmented detector modules for S-EUSO

The request of increasing the light is a formidable task which requires the development of a complex system. Although challenging, this design is based on the extrapolation of known and understood technologies to a new level of complexity and sophistication and to sizes much larger than before.



Given the relevance of this issue, one of our R&D goals is also to consider the feasibility and the merits of alternative designs, based on a number of smaller detector elements, each of them equipped with its own PD and readout system but operating coherently in order to allow for triggering on the EAS signals.

Such a segmented design could be made feasible by the advent of the  $\mu$ GAPD or SPMA, multiple GAPD assemblies being developed at FBK-irst and Sensl, where the individual micro-cell of a GAPD array are readout independently, allowing an extremely fine segmentation ( $50 \times 50 \mu\text{m}^2$ ) while maintaining a high PDE. Using these devices it would be possible to equip many optical units with similar optics parameters as the monolithic one, but scaled-down sizes, ensuring the same segmentation to ground of the FS of each unit. Such a reduction in size for the individual optical elements, would also allow for the usage of higher quality optics, with better imaging properties. A segmented design would impose, however, challenging requests on the readout and trigger electronics, which would have to be designed in a way to guarantee fast and coherent readout of the light collected by the subunits.

For these reasons a dedicate R&D is needed to understand the feasibility of such an option, before it could be seriously considered.

## 7.10 A road-map

The proposed space mission is challenging. The demanding requirements have a strong impact on resources. Therefore a careful experiment optimisation is required which implies collecting as much as possible preliminary information, useful for the experimental design. To reach this goal a road-map with intermediate preparatory steps has been developed, which includes:

- improving the current knowledge on basic parameters: fluorescence yield and Cherenkov albedo measurements;
- long duration balloon flights and stratospheric airplane flights to perform functional and technological tests and measure some low-energy particles, both in the optical and in the radio range;
- small missions on a technological micro-satellite for:
  - background characterisation;
  - test of the capabilities to control the most critical issues;
  - test of most critical technological items;
- the Russian TUS precursor, which will soon test the approach and basic technologies;
- the Japanese JEM-EUSO path-finder, an improved version of EUSO currently under study by JAXA.

### 7.10.1 Background measurement via micro-satellite

Various experiments have been carried on to measure the expected background. However a detailed measurement and characterization of the background, on the space-time scales characteristics of the EAS development, is required to improve our knowledge and to design background rejection; measuring far-off nadir is another important issue. This task can be easily accomplished via a technological micro-satellite [20]. It will help to: estimate the duty cycle; to verify the stray light control by measuring far-off nadir and, possibly, do tests for the radio-detection. The design will be tuned to the S-EUSO mission preparation but interesting measurements for geo-physics might be carried on.

#### 7.10.1.1 A technological model on micro-satellite

A dedicated technological small mission on a micro-satellite, for validation of the chosen technologies, is also foreseen in order to:

- perform functional tests on critical parts of the apparatus such as: optics deployment (not-to-scale); measurement of the optics performance in place via a small not-to-scale optical system; test of the atmosphere control methods; test of the apparatus calibration via GLS.
- qualify the observational approach (watching, for instance, suitable laser shoots at the Earth);
- test technological items.

### 7.10.2 Path-finders

The community is already working on the preparation of future missions via the Russian-led TUS precursor mission and the Japan-led JEM-EUSO pathfinder mission, which will be of invaluable value for the S-EUSO mission.



## 8 Basic spacecraft key factors

### 8.1 Requirements

The main Payload to be accommodated on the SVM is a very large dimension, digital camera, as described in section [7.1]. Moreover, there are some ancillary instruments to be accommodated: a LIDAR; an IR camera; a Radio-Detector (TBC). The set of instruments is Earth-pointed at nadir, while orbiting on a LEO orbit (see Table 1).

The reduction of both in-field and out-of-field stray-light is very important, so countermeasures have to be implemented. A baffling system has to be included for the off-field stray-light, while the **in field** stray-light is mainly a matter of optical quality of the optical elements.

Given the very large dimensions and the deployable character of the optical system, a baffling concept against background requires an ad-hoc study.

The S/C attitude will be three-axis stabilized, the pointing accuracy is not very demanding, only a few degrees are required. A GPS system is sufficient to this end.

The main observation constraint is the night-time nadir observation, which drives the operations and the performance of ad hoc maneuvers.

No observation is possible during daylight and the instrument must be protected from intense illumination.

To avoid too intense illumination two options are considered, which require a dedicated study:

- sky pointing, for which the S/C will have to undergo an attitude maneuver;
- use of a shutter, which also helps to protect the exposed optical surface from contamination and debris.

Lifetime required is: 5 years minimum, 10 years goal.

Ground Station(s) have not yet been identified but this is not deemed critical for the time being.

### 8.2 The orbit

The LEO orbit will be largely affected by atmospheric drag, due to the large dimensions of the main mirror, which, in deployed conditions has a surface of about  $100 \text{ m}^2$ , that is large drag coefficient affecting the atmospheric drag to a critical extent. Moreover it is likely that the Center of Mass (CM) will not be close to the geometrical center of the apparatus, giving rise to torques around the CM.

The magnitude of the effect is proportional to atmospheric density, which in turn, depends on the solar activity. The launch date foreseen now for a Large mission (>2018), is close to the Sunspot Maximum 25 (2023), and this has to be taken into account in designing the mission.

For this orbit, the ballistic coefficient is calculated by STK to be about  $0.04 \text{ m}^2/\text{kg}$ . The orbit shall be chosen in order to avoid the need for a thruster for orbit maintenance. If, for instance, a circular orbit with  $r=1000\text{km}$  is used, with the same inclination, the decay is a totally acceptable  $0.5\text{km}/\text{year}$ , approximately.

Moreover the problem of atomic oxygen (the prevalent atmospheric species at those orbital altitudes) will have to be considered too. The atomic oxygen problem is most severe at those times when the Sun reaches maximum elongation above or below the spacecraft orbital plane.

The orbit includes passages through the South Atlantic Anomaly (SAA) and the northern and southern radiation belts. In these regions a significantly enhanced charged particle density is encountered which might preclude. On average 27% of the time during an orbit might not be available for scientific observations.

NOTE: the data above refer to ROSAT, with proportional counter detectors!!! Our case might be totally different...

Solar Radiation Pressure action and radiation hardening aspects will require a careful analysis too.

### 8.3 System design approach

From a system-design point of view, satellite design will be driven by:

- the very large payload dimensions;
- the orbit selection;
- the required operations conditions.

The very large payload dimensions are relevant to:

- the launcher selection, which shall be of the class of ARIANE V;
- the atmospheric drag the satellite is subject to.

The orbit selection is relevant to (other than scientific motivations):

- the need to reduce the atmospheric drag to a value which allows to operate all the required lifetime with a small orbit decay and avoiding heavy orbit maintenance needs;
- the atomic oxygen effects to be taken into account;
- the scientific mission operations.

The operations conditions are relevant to:

- the attitude and orbital control system of the S/C;
- the implementation of a stray-light protection system.



The latter is an issue for the payload, as the PD can be damaged by an intense light flux, such as the light diffusion by the Earth during the daily portion of the orbit. A shutter can be considered, but it requires the related mechanisms, which decrease the mission reliability during the daily period. As an alternative, the satellite may swap from a nadir pointing to a sky pointing attitude, depending on illuminations conditions.

So, the options (not necessarily exclusive) are either to implement a shutter system or to implement an adequate ACS system for S/C pointing changes along orbit.

The guidelines for the identification of the space segment characteristics, to be considered for the understanding of the satellite dimension and mission profile, are listed in the following. The satellite main characteristics are summarized in Table 1. The choice of an orbit as high as  $\approx 1000\text{km}$  would not require the implementation of a thruster system for periodical height recovery.

The Spacecraft bus to accommodate the P/L shall satisfy the following requirements and shall provide:

- three axis stabilization;
- Earth pointing (nadir) during night-time portion of the orbit;
- sky pointing (in general, away from intense illumination) during some portion of the orbit (TBC);
- support for the large payload sizing: (4+5) ton;
- accommodation of the P/L folded configuration at launch, to be deployed on-orbit;
- accommodation of the ancillary instruments;
- electrical power;
- OBDH;
- thermal control;
- TT&C.

The spacecraft bus concept providing all the servicing functions has been singled out at a very preliminary level. The SVM can be considered as a recurrent from the HERSCHEL SVM, which is about to be launched next year (2008).

#### 8.4 Mission characteristics driven by the launcher

The considerable P/L dimensions drive the choice of an ARIANE V-class launcher. When suitably folded, three out of the six mirror petals of the main optics stick out from the static usable volume under the Ariane V fairing, considering a fairing diameter of 4570 mm. From the Ariane V User's manual issue 4 it is known that, if needed, the compatibility of the S/C critical dimensions with the usable volume could be studied in greater depth by coupled load analysis, based on detailed information provided by the Customer.

All the configuration aspects have to be dealt more carefully in order to obtain a scientifically meaningful P/L, while satisfying the requirement of the launcher authority.

#### 8.5 Spacecraft service module

The spacecraft service module concept considered in this study is directly derived from ESA HERSCHEL-PLANCK mission. These missions are characterized by a very high modularity, that is spacecraft and payload are two separate modules that can be developed tested and manufactured in parallel, by different industries/agencies. This kind of modularity has to be considered also for the EUSO satellite mission.

The mission has the following main requirements:

- low elliptic (LEO) orbit (TBD);
- scientific payload of about 4.5 ton;
- GPS in substitution of star trackers (accuracy of 0.5 degrees per second);
- power requirement: about 5 kW;
- the thermal dissipation requires a large radiator surface: about  $12\text{m}^2$  surface;
- ACS system for attitude modification (TBC);
- no thrusters and propellant (if the orbit is high enough);
- mechanical I/F adapter between service module and payload module;
- battery capability has to be increased in order to have power during night-time orbit period;
- autonomy from the ground-control.

The estimated spacecraft service module, Herschel-based, mass is about 600 kg.

The power generation requirement drives the Solar Array dimension. A preliminary estimate indicates a SA surface of about  $28\text{m}^2$ , as batteries have to be charged also for power provision during night-time operations. Moreover, this large SA surface has to be positioned far from the optics for stray-light and FoV clearance reasons and have to be rotated for the correct position of the panels surface towards the Sun direction. This means that Solar Arrays Drive Motors have to be accommodated.

The requirement of large power dissipation will require the study of options which could take the advantage of the large retro-surface of the mirrors other than parts of the lateral surface of the SVM for the location of radiators ( $12\text{m}^2$  are preliminarily estimated).



## 8.6 Overview of the satellite concept

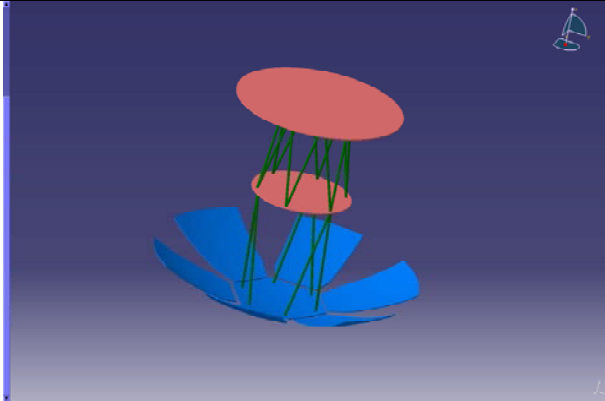
The table reports a summary of the identified characteristics.

<b>ORBITAL PARAMETERS</b>		See Table 1
<b>GROUND STATION</b>		TBD
<b>MASS (estimated)</b>	PAYLOAD MODULE SERVICE MODULE SATELLITE MASS	4500 kg 600 kg <b>5100 kg</b>
<b>POWER (estimated)</b>	PAYLOAD MODULE SERVICE MODULE SATELLITE POWER	4000 Watt 600 Watt 4600 Watt
<b>TELEMETRY</b>	TBD	TBD
<b>ATTITUDE &amp; POINTING</b>	3 AXIS STABILISED	1°-3° pointing accuracy
<b>MASS MEMORY</b>	TBD	TBD
<b>POSITION POINTING KNOWLEDGE</b>	FROM GPS (each second)	POSITION: 50 m POINTING: 0.5°
<b>TIME</b>	ON BOARD CLOCK FRAME TIMING	1 μsec 100 sec
<b>OPERATIVE LIFE</b>		> 5 YEARS; 10 YEARS goal

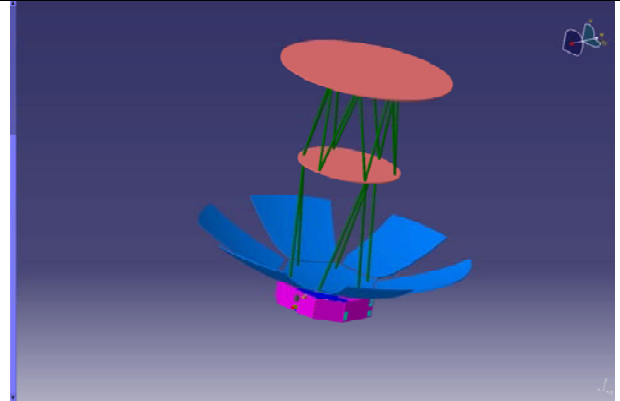
• Table 3: Identified characteristics

## 8.7 Configuration preliminary concept

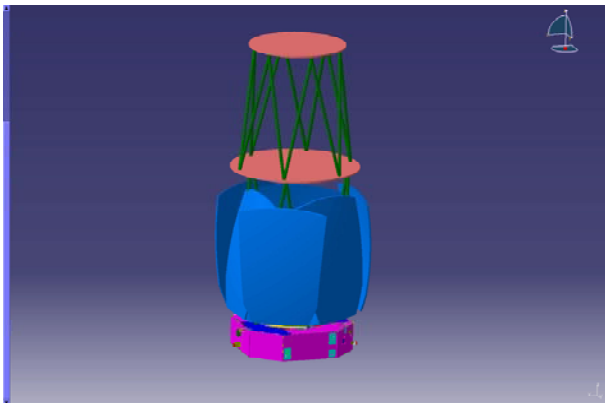
The following pictures are meant to give a very preliminary indication of the S/C concept and by no means are the result of a meaningful system configuration analysis.



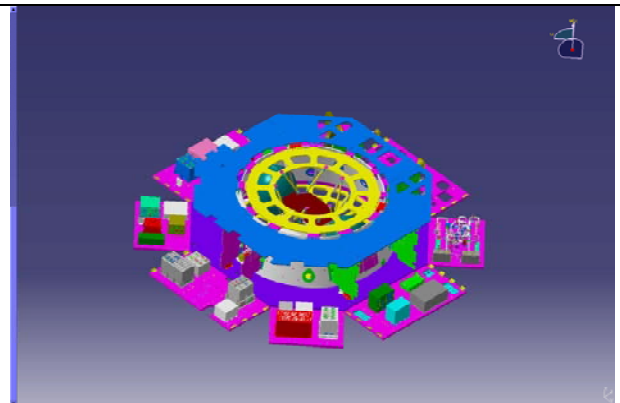
• Figure 12 – P/L schematics configuration.



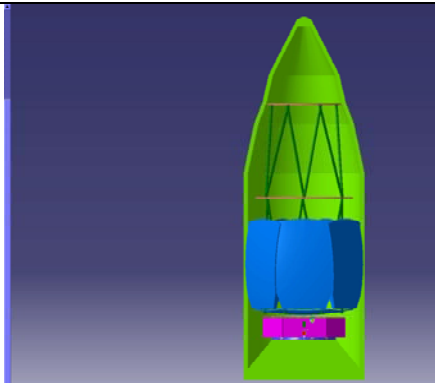
• Figure 13 – In-flight configuration.



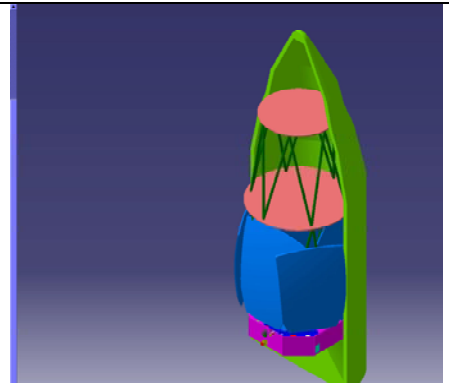
• Figure 14 - S/C in the closed configuration.



• Figure 15 – SVM: open lateral panels showing the accommodation of various equipments. The central thrust cone allows room for an eventual Thruster system and /or Mirror Module Adapter and/or SADM. Heritage from HERSCHEL S/C.



• Figure 16 – In stowed conditions at launch UNDER ARIANE V GENERIC FAIRING (static envelope showed only).



• Figure 17 - In stowed conditions at launch UNDER ARIANE V GENERIC FAIRING (static envelope showed only).



As can be seen from the two pictures above, the standard fairing of ARIANE V is not sufficient for the accommodation of the preliminary configuration of the S-EUSO P/L. A possibility may come from the use of a larger volume under ARIANE V provided launcher authority permission. In this configuration, both the main mirror and the corrector are folded (though the corrector folding is not visible, it has to be reduced, by folding over, up to 3 m diameter in order to fit fairing dimensions).

This configuration does not consider a cover to protect the payload from intense light flux. So, during a single orbital period (about 100 minutes) the mission shall be managed in the following way:

- during the full-night period (about 10 minutes) the satellite is:
  - earth pointing;
  - the instrument is configured to either detect candidate EAS events or calibration;
- during the rest of the orbital period (about 90 minutes) the satellite is:
  - sky pointing, far from any intense light source or nadir point with the shutter closed (TBD);
  - solar arrays viewing the Sun within  $40^\circ$  (in order to guarantee a good power figure from solar arrays);
  - the instrument is configured to is either configured to detect UV transient from the sky (TBC) or off.

Naturally, multiple and redounded Sun, Earth and sky optical sensor monitor the position of Sun, earth and Moon in such a way to maintain the satellite pointing direction far from intense light flux sources and/or close the shutter.

### 8.8 Observational strategy (orbit and on-ground management)

EUSO basically is a Nadir pointing satellite but light as may reduce the mission efficiency. An improvement of the mission efficiency can be obtained planning a pointing strategy for each orbit that allows observing direction with a lower diffuse light. An operative observation plan based on the above-identified strategy shall be transmitted to the satellite during each contact with the ground-station.

The management of the EUSO mission is very simple because:

- EUSO is an earth pointing observatory that does not need a new pointing planning at each ground-based contact period (about 10 minutes);
- The commands for the scientific payload configuration are very few and it is not envisaged the necessity to change the payload configuration each orbit.

The detailed orbit and on-ground management need the definition of the orbit.

### 8.9 Criticalities and concepts

Further important evaluations have to be performed on the optical system design in order to:

- improve the satellite compactness;
- decrease the complexity.

From a mission point of view, the main aspects which deserve important evaluations deal with:

- Orbit selection;
- Resources requirements tailoring (TT&C needs, Thermal stability, EPS analysis, Data Handling);
- Identification of the ground station(s);
- Launchability Analysis.
- 

Accommodation aspects of the ancillary instruments for the atmospheric monitoring (Radio Pulses Detector, LIDAR and IR Camera) have not been implemented in this short note due basically to lack of information.

For AIV aspects, it is important to note that the P/L is dedicated to the observation of UV light. Radiation Detection of UV wavelengths require special attention to the particles and molecular contamination. This means that, at integration and verification level, special rules, special tools and procedures have to be carried out which are complex and will have mainly a cost impact.

Radiation hardness qualification of the materials used needs to be assured.

As for the approach to the study we also recommend a very intensive collaboration between industry and scientists. The best way is to have a program organization based on a "Integrated Team" concept, extended also to the scientists. In this team organization the scientific mission goals shall be reviewed and adapted on the basis of time and cost constraints.

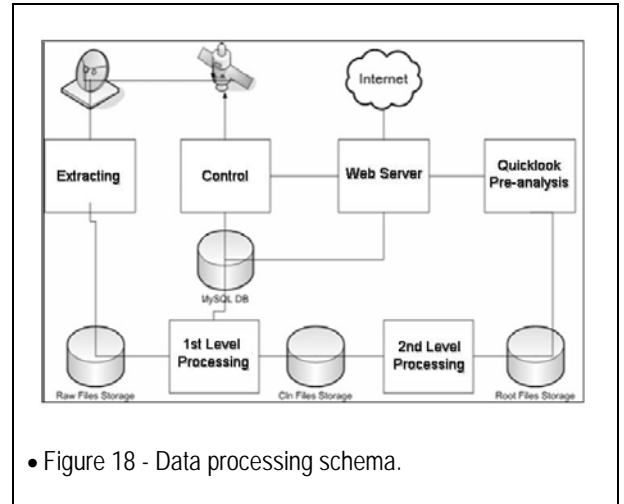
In order to identify a first area of cost benefit and identify a preliminary S-EUSO satellite system the spacecraft service module considered in this study is derived from ESA (European Space Agency) HERSCHEL mission.



## 9 Science operations and archiving

Data received from S-EUSO are collected by a data-set archive server, dedicated to data processing for instrument monitoring and control, and are also written to suitable media for long-term storage.

A possible data processing scheme is shown in Figure 18. A first Level Processing software calculates the downlink session quality (the error probability per bit). In addition, it removes from the files all headers and footers added by the telemetry frame and prepares data for unpacking. Information about down-linked files are meanwhile stored in a data base structure, accessible by a web interface to give the possibility to operators to check up data and faulty downlink sessions and possibly to ask for a retransmission of the data in a future downlink. Data are then processed by a second Level Processing software, which unpacks the data coming from the different instrument sections stored in the common file, and prepares them for the physics analysis. In parallel a “QuickLook Pre-analysis” program monitors the status of the instrument housekeeping and physics data in order to assess the status of the mission. Data coming from the QuickLook analysis must be available both locally in the Ground Segment and remotely (web based). Short term programming of telecommands or macro-commands (commands that go directly to the S-EUSO CCU and not through the satellite) issuing from Ground to the instrument is determined on the basis of the QuickLook analysis. Both raw and preliminary processed data are finally moved by a fast internet line or by the GRID infrastructure to the main storage centre of the S-EUSO Collaboration, so to be accessible to all institutions.





## 10 Key technology areas and Technology Readiness Level

The following key technologies developments are identified.

- (TRL=2) Optics with large area and large field of view suitable for a space mission. Large deployable optical system.
- (TRL=3) Develop fast (tens of ns) f/e electronics ASIC for the photo-sensors, featuring low-power, radiation hardness and hardness to other space-specific environmental conditions.
- (TRL=3) The required electronics is most likely to lead to the use of microelectronics technologies which require space-qualification, with possible use in other applications (low-power, radiation hardness).
- (TRL=4) Develop fast (tens of ns), pixelized (pixel size: 1 mm to 1 cm) photo-sensors, which can be packaged into vary large arrays (meters), with high total photon detection efficiency (order of 0.5) capable of single-photon sensitivity in the near-UV. Additional requirements: lightweight, reliable, flexible design, hardness with respect to space-specific environmental conditions.
- (TRL=7) Develop a LIDAR system for atmospheric monitoring from space with low budget requirements.



## 11 Preliminary programmatic and costs

<b>Sub-system</b>	<b>Partners</b>	<b>Preliminary Estimated cost (MEuro)</b>
Optics	Italy, US.	75
Photo-Detector: sensors	France, Germany, Italy, Russia.	20
Photo-Detector: electronics	France, Germany, Italy, Russia	20
Photo-Detector: housing and ancillary parts	France, Germany, Italy, Russia.	10
Atmospheric Monitoring	Switzerland.	8
Radio Detection	Sweden.	12
Calibration system	Germany, Italy, US.	2
HERSCHEL SVM		60

• Table 4: Preliminary sharing of responsibilities among the international partners and cost estimates



26-JUN-07

## 12 Communications and Outreach



## 13 References

1. C. Piemonte, NIM A, 568, 224 (2006); A Claverie et al., NIM B 147, 1 (1999); S. Whelan et al., J. Vac. Sci. Technol. B 20, 644 (2002); G. Fortunato et al., Appl. Phys. Lett. 89, 253502 (2006).
2. The ApPEC road-map: <https://ptweb.desy.de/appec/roadmap.html>
3. L. Scarsi et al., *EUSO: report on the Phase A study*, 21 April 2004.
4. R. Pesce, A. Thea, A. Petrolini and M. Pallavicini, *Space-based observation of UHECP*, to be published.
5. H. Falcke et al., Nature, 435 (2005) 313.
6. T. D. Carozzi et al., Phys. Rev. E, 61 (2000) 2024.
7. T. D. Carozzi and J. E. S. Bergman, J. Math. Phys., 47, (2006) 032903 (2006).
8. B. Thidé et al. On the utilization of photon orbital angular momentum in the low-frequency radio regime. Phys. Rev. Lett., in press, 26 June 2007.
9. J. A. Kahle et al., IBM J. Res. & Dev., 49(4/5):589-604, 2005. <http://www.research.ibm.com/journal/rd/494/kahle.pdf>
10. F. W. Stecker et al., Nucl. Phys. Proc. Suppl., 136C (2004) 433.
11. J. Ninković et al., Nucl. Instr. Meth. A572 (2007) 454.
12. Winker D. M., J. Pelon, M. P. McCormick, 2006, Initial results from CALIPSO, in Reviewed and Revised Papers Presented at the 23rd International Laser Radar Conference (ILRC 2006), Nara, Japan, 24-28 July 2006, Editors Chikao Nagasawa, Nobuo Sugimoto, Part II, pp. 991-994.
13. <http://www.esa.int/esaLP/LPadmaeolus.html>
14. Dubock P., M. Endmann, P. Ingmann, 2006, Progress with ADM-Aeolus, the Spaceborne Doppler Wind Lidar ADM, 2006, in Reviewed and Revised Papers Presented at the 23rd International Laser Radar Conference (ILRC 2006), Nara, Japan, 24-28 July 2006, Editors Chikao Nagasawa, Nobuo Sugimoto, Part II, pp. 1011-1014.
15. P. Mazzinghi, V. Bratina, D. Ferruzzi, L. Gambicorti, F. Simonetti, A. Zuccaro Marchi, P. Salinari, F. Lisi, M. Olivier, A. Bursi, J. Pereira do Carmo, "An ultra-lightweight, large aperture, deployable telescope for advanced LIDAR applications", Proc. '6th Internat. Conf. on Space Optics', ESTEC, Noordwijk, The Netherlands, 27-30 June 2006 (ESA SP-621, June 2006)
16. Francesca Simonetti; Andrea Romoli; Piero Mazzinghi; Vojko Bratina, Reflecting telescopes for an orbiting high-resolution camera for Earth observation (Journal Paper), Optical Engineering 45(05), May 2006
17. LIDAR-TN-CGS-002, LIDAR PRELIMINARY TELESCOPE DESIGN REPORT, P. Mazzinghi, V. Bratina, D. Ferruzzi, L. Gambicorti, F. Simonetti, A. Zuccaro Marchi, P. Salinari, F. Lisi, M. Olivier, A. Bursi, December 2005.
18. <http://www.jwst.nasa.gov/>
19. Christopher Folley and Allen Bronowicki, "Optical performance assessment under environmental and mechanical perturbations in large, deployable telescopes", Proc. SPIE Vol. 5867, 586700 (2005).
20. A. Thea et al. Nuc.Phys. B Proc. Suppl. 166 (2007) 223.



26-JUN-07