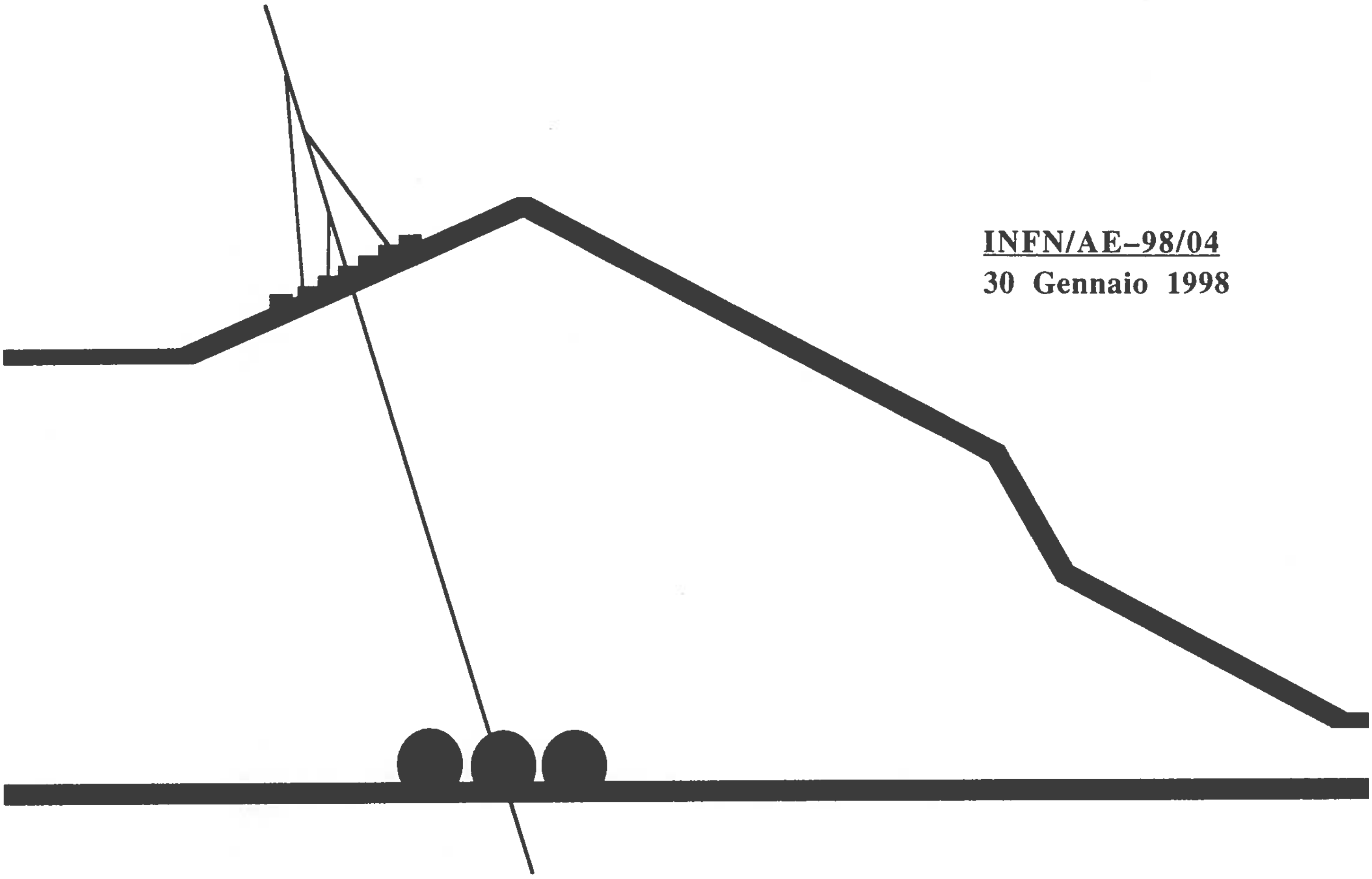

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Extreme Energy Cosmic Rays Observation (EECR) Capabilities of an "Airwatch from Space" Mission

The Airwatch Collaboration:

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Abstract

The longitudinal development of the Extreme Energy Cosmic Rays (EECR), along with other important characteristics of their atmospheric showers, can be studied by detecting the fluorescence light induced in the atmospheric nitrogen. In recent years it has been proposed to detect this fluorescence light from space. According to the Airwatch concept a single fast detector can be used for measuring both the intensity and the time development of the streak of flurorescence light produced by the atmospheric shower induced by an EECR. At present the technical aspects of an Airwatch mission, and particularly its detection system, are actively researched and developed. Because imaging of the events is mandatory, a highly sophisticated photon detector having high pixel granularity is under design. An optical system of large aperture and collection angle, minimum absorption and weight, will focus the fluorescence light on the photon detector. Also because the fundamental information concerning the direction of the shower axis must be obtained by measuring the velocity of the streak of light in the focal plane, fast electronics, at nanosecond level, is considered for data acquisition. Sophisticated image processing procedures, both for triggering and maximum information detection are also required. In the present communication the detection capabilities of the EECR observation from space are discussed.

1 Introduction

The origin of the Extreme Energy Cosmic Rays (EECR) — i.e. those having energy around and above 10^{20} eV — is one of the most challenging issues in High Energy Astrophysics. These particles are detected through the giant showers they produce in the Earth atmosphere [1]. Observable quantities are longitudinal shower profile, depth of shower maximum, size and arrival direction, that must be measured in order to study this phenomenon. The very existence of EECR raises fundamental scientific questions in connection with their origin and propagation.

One of the most important points to investigate is the role of the 'Greisen-Zatsepin-Kuzmin' cutoff in the energy spectrum of EECR's [2]. This cutoff is due to the 2.7 K microwave background and it is expected to show at around 6×10^{19} eV. Its existence has fundamental consequences in order to clarify the EECR origin. Because of the very high energy, EECR should be only marginally affected by the interstellar and intergalattic magnetic fields. If it is found out that they point to definite sources, this would favour an explanation in terms of "bottom-up" acceleration; while if they indicate broader or structured regions a "top-down" model considering EECR as decay products of topological defects should be taken into account [3]. It is also interesting to investigate possible connections with Gamma Ray Bursts.

The EECR shower development is accompanied by UV emission, in particular by the fluorescence light induced in the atmospheric nitrogen which has characteristic spectral lines in the near UV. The possibility to study high energy air showers through detection of the fluorescence light they produce has been proven by detectors like Fly's Eye [4] whose operation has given information on flux, incoming direction and composition of the primary particles.

In more than thirty years of data taking, about 20 EECR events with energy $\geq 10^{20}$ eV have been collected by all the ground detectors active all over the world, so that all the scientific speculations about their origin are severely hindered by the reduced information. Even one of the most important datum, the role of the Greisen-Zatsepin-Kuzmin cutoff cannot be investigated because of the lack of statistics. Taking the rough — and somewhat optimistic — parametrization:

$$\Phi(> E) = \frac{100}{E^2} \;\; (\Phi \equiv \mathrm{part.\,km^{-2}sr^{-1}y^{-1}}\,,\ \mathrm{E\,given\,in\,EeV,\,namely\,10^{18}eV}) \qquad (1)$$

we have that, per every new decade in energy to be explored, an increase of a factor 100 in exposure factor is needed for the detector. As a consequence: the general requirement for studying this physics is to monitor the largest possible atmospheric area and mass. This requirement can be fulfilled by detecting the fluorescence light induced in the atmosphere by EECR's from a space platform [5].

The proposed "Airwatch" Mission appears to have the capability to measure the EECR spectrum above 10^{20} eV, determining the distribution of the arrival direction, the energy and the X_{max} of single shower. The primary species: hadron, photon or neutrino can be identified on an event by event basis as well. This capability appears to provide a complemental approach to very large ground arrays and promises the possibility of extending EECR measurements beyond 10^{21} eV [6, 7].

2 The Airwatch from space mission

The amount of atmospheric area and mass that can be brought under observation from a space platform with reasonable design parameters - orbit height and field of view (FOV) — is given in Table 1. As a reference one can consider that the atmospheric mass observed by a ground based detector like Flye's Eye is of the order of 10^9 tons.

Orbit height (km)	FOV (degrees)		
	60°	90°	120°
400	0.17×10^6 km^2 1.7×10^{12} ton	0.50×10^6 km^2 5×10^{12} ton	1.5×10^6 km^2 15×10^{12} ton
500	0.26×10^6 km^2 2.6×10^{12} ton	0.80×10^6 km^2 8×10^{12} ton	2.4×10^6 km^2 24×10^{12} ton
600	0.38×10^6 km^2 3.8×10^{12} ton	1.1×10^6 km^2 11×10^{12} ton	3.4×10^6 km^2 34×10^{12} ton

Table 1: Observed area and amount of atmospheric mass observable as a function of orbit height and field of view (FOV).

The fluorescence light produced by an atmospheric shower of extreme energy is mainly emitted in the near UV molecular nitrogen lines 337, 357 and 391 nm. As seen from space, in these spectral bands the shower appears as a spot of light travelling with speed near to that of light and with changing intensity. The fluorescence light is accompanied by Cherenkov light having directional emission that possibly may be reflected on clouds or ocean surface ('end point flash'). It is also accompanied by Rayleigh scattered and Mie scattered Cherenkov light. All these optical phenomena bring further information on the shower development, helping on its X_{max} determination.

The spot velocity, projected on the horizontal plane, equals the velocity of light times the cosine of the angle of its direction with the horizontal plane itself. This fact provides one possible approach to measure the direction of the shower axis: i.e. by measuring position and time of the pixels fired in the focal plane detector by the shower development. In this approach single detector is required, but electronics and data acquisition capabilities are very demanding. Several images of each event need to be collected at very high speed , i.e. order of 1 μs per image — by one single focal plane detector. A single free-flyer is required, but electronics and data acquisition capabilities are very demanding.

In an alternative approach two focal plane detectors on two separate platforms, orbiting 600 kilometers apart, are used for stereoscopic view - *OWL concept* [7].

3 The detector requirements

Assuming that the shower streak of light is long 10 to 100 km in the atmosphere, the Airwatch focal plane detector segmentation must have an order of 1000×1000 pixels for monitoring one million km^2 of atmosphere with sufficient resolution and counts per year. Assuming a 5 m^2 light collector (1.3 m radius) and resonable values for its optical efficiency; considering that fluorescence light yield, in the 300–400 nm spectral interval, is $\sim 4\ photon/(particle \cdot \mathrm{m})$ and that a 10^{20} eV shower has 6×10^{10} particles at its maximum development, the detector has to work with sensitivity at a level of 10–100 photons per pixel on integration times of about 3 μs. These requirements rule out charged coupled devices (CCD) and ask for a detector technology based on photon–electron conversion on a photocathode and subsequent electron multiplication.

Pushing the detector sensitivity as far as possible results both in the possibility of a more complete measurement of the shower development and in the lowering of the energy threshold. R&D's along these lines are in progress by the Airwatch collaboration.

4 Counting rate

Counting rate depends primarily on the shape of the spectrum, which has to be found out by observation. Because detection difficulty lessens with energy, on the higher energy side counting rate is just limited by EECR flux. On the lower energy side detection efficiency depends on trigger sensitivity and feature extraction from data which put a threshold in detection capability.

The trigger electronics of an Airwatch from Space Mission can take advantage of the unique feature of the showers: there is no possible background looking like a luminous spot moving at light speed through the atmosphere over tens of kilometers. The Airwatch detector and its trigger need to be smart in detecting showers on the lower energy side. At present stage of the project an energy threshold something below 10^{20} eV appears reachable, allowing the comparison with measurements of ground based detectors and arrays. It is one of the ojectives of the R&D effort to push the energy threshold as low as possible.

Operations with an $10 \div 20$ % duty cycle are predicted for an Airwatch Space Mission, having taken into account sunlight, moonlight, civilization ground lights, high clouds and average weather patterns. An equatorial orbit will maximize observation time over oceans and deserted areas. Radiation degradation of the optics is also minimized. Conversely, one drawback of an equatorial orbit is the higher cloud coverage.

A thorough knowledge of all the optical phenomena accompanying the shower development — Cherenkov light, Rayleigh scattered and Mie scattered Cherenkov light, reflection of the same lights on clouds or ocean surface — and of all the sources of background is mandatory in order to exploit at best the scientific potentialities of the mission. To pursue a complete study of the various kinds of background — meteors, aurorae, lightining etc. — foreseen for an Airwatch from space, a precursor measurement of the light phenomena in the atmosphere (EAGLE Mission) has been proposed [8].

The effective counting rate for an Airwatch Mission depends on the amount of watched atmosphere and on the shape of the energy spectrum. In general in can be stated that for an atmospheric mass $\sim 10^{12}$ tons, an order of 100 events per year would be collected above 10^{20} eV.

5 On neutrino detection

Under "top-down" hypothesis, where EECR are decay products of topological defects, a sensible flux of neutrinos is expected on the Earth up to EECR energies. Airwatch from Space can detect these neutrinos at all angles because of most of the huge and transparent target ($\sim 10^{12}$ tons) available for interaction and detection. Moreover, it has been shown that the cross section for neutrino interaction will increase with energy up to order of 10^2 nb at 10^{20} eV [9]. Because atmospheric thickness rises of about a factor 40 as shower direction goes from vertical to horizontal angle, EECR showers initiated by neutrinos can be identified by their appearance at large zenith angles and large atmospheric depths where no hadron or photon initiated showers can be present.

6 On GRB detection

While EECR showering in the atmosphere will appear as UV tracks spatially well defined and short in time, a Gamma Ray Burst (GRB) will arrive as a plane wave investing the entire atmosphere and exciting by Compton electrons a diffuse fluorescence emission having a peculiar space-time function. As seen by a space observatory, like Airwatch, the diffuse fluorescence emission will last as much as the GRB signal remains above threshold and it will fluctuate in intensity according to the superposition of the GRB luminosity with the varying background luminosity, as the satellite moves during detection [10]. It appears that the interest of this way of measuring GRB's may be mainly in studying possible correlations with EECR's.

7 Discussion and prospects

The main design parameter for an Airwatch experiment is the height of the orbit. At fixed FOV, on one hand the monitored atmospheric mass increases with the orbit altitude; on the other hand the signal strength decreases. The optimum solution must be decided through an effective simulation of the detector performance as a function of the orbit height and other design parameters.

In the OWL Proposal [7] spacecrafts in the range ≈ 1 ton and ≈ 1 kW each are forseen. A different approach could be based on the segmentation of the mission in a certain number of small satellites. This scenario would in general be cheaper and have a faster schedule than the traditional single or double observatory, presenting the possibility to be implemented with the methodology used in manufacturing large number of satellites for telecommunication purposes. A further cost reduction due to launch of the whole system is to be considered also.

The 'costellation of small satellite' solution presents some sensible advantages. By distributing the spacecrafts along the orbit the atmosphere at night can be continuosly monitored. Moreover both higher mission reliability and reduced problems with the focal plane detector are achieved. This solution can be approached through an exploratory mission on a single small satellite that will be very useful both from the engineering and the physical point of view. A spacecraft in the range of 400 kg and 400 W can have a collection capability of some tens of events per year, still providing very interesting results for the EECR study. Finally, the possibility to locate an Airwatch from Space Mission on the Space Station cannot be neglected as one having several technical advantages; not least the opportunity to use a 9 m diameter collecting mirror whose technology is available by the russian colleagues of this collaboration [11].

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