THE OWL - AIRWATCH Experiment : Overview

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Abstract

The OWL-AirWatch space mission, jointly supported by an Italian Consortium (Air Watch) and a US Consortium (OWL) with a possible extension to Groups from Japan, is devoted to the imaging analysis of the UV atmospheric fluorescence induced by the Extreme Energy Cosmic Radiation ($E > 10^{19}$ eV). The objective is to obtain a detailed description of the CR energy spectrum beyond the GZK limit, together with a map of the arrival direction and to possibly open the channel of Cosmic Neutrino Astronomy in this energy range. The mission foresees a Midex class Free Flyer with a low (h~500 Km) circular near equatorial orbit and a target launch date around 2005.

1 Introduction.

The Earth Atmosphere by absorbing partially or in toto the incoming Cosmic Radiation, acts as an imaging calorimeter providing information on the energy of the Primaries , their nature and arrival direction ; the process exploitable for the detection is the UV fluorescence induced in the air by the secondary charged particles produced by the interaction of the Primaries with the air target nuclei (EAS). The light emitted is isotropic and proportional to the particle shower size at any depth in the atmosphere. An EAS corresponding to a Primary with $E>10^{17}$ eV forms a significant streak of fluorescence light over 10-100 km along its passage in the atmosphere ("Greisen-Bonner-Suga (GBS) signal") (1), depending on the nature and energy of the Primary, and the pitch angle with the vertical. Observation of this fluorescence light with a detector at a distance from the shower axis is the best way to control the cascade curve of the EAS. The detector will record the shower front moving with velocity c and emitting the fluorescence light characteristic of the air. The resulting event seen by the detector looks like a narrow track in which the recorded amount of light is proportional to the shower size Ne at the various penetration depth in the atmosphere. The integral of light recorded in the track (as well as the light signal at Shower maximum) is proportional to the Primary energy. The cascade shape (especially the position of the shower maximum as a function of the penetration depth) gives an indication about the nature of the Primary; a different shape for the cascade curve is expected for different particles initiating the EAS. Showers initiated very deep in the atmosphere indicate an origin by neutrinos because of neutrino-air nuclei interaction cross section hundreds times lower than the cross section for hadrons or photons. For high enough Primary energy ($E>10^{17}$ eV) the GBS fluorescence signal from EAS consents detection at a level sufficient for a quantitative analysis. An experimental approach has been practically implemented at operational level at a ground based site by "Utah Fly's Eye" which has operated from 1981 to 1992 (2) competing with the Arrays based on conventional scintillation or water-Cerenkov detectors in extending the exploration of the high energy tail of the Cosmic Ray spectrum up to 10^{20} eV (the highest energy known today, at $3x10^{20}$ eV, has been recorded by Fly`s Eye). The signal strength dependence from the varying distance "detector-progressing shower front" imposes the use of a multiocular approach (although Fly's Eye I has successfully operated as a monocular), which consents a stereoscopic reconstruction of the EAS and a better energy resolution. Along this lines have been planned and are under construction or in the advanced phase of design the HIRES expected to be fully operational in 1999 and Telescope Array experiments always in Utah. The effective exposed area rivals that of the largest conventional EAS array (Auger in the 3000 Km^2 range), devoted to the exploration of the "beyond the GZK cut-off at 5 x 10^{19} eV" C.R. energy spectrum.

2 Experiments from space based platforms. OWL - Air Watch.

The ground based experiments planned for the foreseeable future are limited in the effective aperture ($\varepsilon A\Omega$) (duty cycle e~0.1 for the experiments based on the atmospheric fluorescence and ~1 for the conventional scintillation / water Cerenkov arrays; $A\Omega$ is the geometric aperture in Km^2 sr) to values around 3000 Km^2 sr for Auger and somewhat under 10.000 Km^2 sr for "Snake" (derived by joining HiRes and Telescope Array). These values are however marginal to obtain a satisfactory quantitative analysis for which values higher of at least one order of magnitude are needed (See 3 Science objectives). J.Linsley in 1979 (3) suggested to apply the method of observing the EAS fluorescent track from space with detectors on board of Earth satellites orbiting at 400-600 km. There are several advantages in the observation from a LEO satellite: a) The EAS fluorescence signal shows no dependence on the distance from the shower track to the detector, as is the case for the ground based experiments; the use of very fast detectors in the focal plane of the observing optics consents the stereo reconstruction of the EAS axis by recording the speed of progression of the shower front in the projected image; b) a wide angle optics with FOV of 30° half angle from an orbit of 500 km height can observe an area of Earth Atmosphere of the order of 1 million square kilometers and correspondingly an air mass target of 10^{13} tons; c) near horizontal EAS tracks are effectively observed at different depths in the atmosphere; d) the air transparency for those tracks is very high and constant and observations are possible in low altitude cloudy sky; e) the duty cycle in observations from space can be 2 to 3 times higher than from ground (normally limited to 10%). A "quantum leap" has been made in these last years in imaging technology, high density data transfer and efficient detector devices and the possibility to observe EAS showers from space has become realistic and promising with the recent developments of wide field of view optics for space applications and fast detectors with high segmentation. Project proposals based on the exploitation of the Earth Atmosphere as "Radiation Detector" have already been made (4) and submitted to, and eventually been considered by Space Agencies like NASA (OWL – Orbiting Wide angle Light collector) (5) and ASI (Air Watch from Space) (6). The two proposals have recently converged to a joint project "OWL–AIRWATCH" submitted as a bilateral program to NASA/ASI. OA represents presently the more advanced proposal in the field. Specific literature is becoming available (4) (5) (6) (7) (8) (9).

3 OWL-Air Watch Science objectives.

Cosmology-Astroparticle Physics. The High Energy Cosmic Radiation. The Cosmic Radiation can be considered the "Particle channel" complementing the "Electromagnetic" proper of conventional Astronomy. The Cosmic Radiation on the high energy side (10^{18}-10^{19} eV) presents the challenge of understanding its origin and its connection with fundamental problems in Cosmology and Astroparticle Physics. Focal points are represented by the existence of "Cosmic Rays" with energy >10^{20} eV (Extreme Energy Cosmic Rays - EECR). The energy loss mechanism related to the interaction of hadronic particles with the 2.7 Kelvin universal radiation background, sets at ~ 5×10^{19} eV the upper energy limit for the EECR flux at Earth and constrains the mean free path of Cosmic Radiation, limiting the distance of the sources of Primary EECRs to less than 50-100 Mpc, a short distance on a cosmological scale.

Neutrino induced EAS. High Energy neutrinos, with energy high enough (E>~10^{19} eV) to produce a detectable EAS in the OA experiment, can provide precious information about their origin together with that of the EECR. On the other hand, according to model predictions, the "Topological Defects decay" should be by far the most effective source of very high energy (E=10^{18} eV) neutrinos, making the detection of" neutrino initiated EAS" a possible signature of the "TD" scenario and hence of the Top-Down mechanism as EECR source. Not suffering of the GZK effect and being immune from magnetic field deflections or from delay caused by Lorentz mass factor, neutrinos are ideal for disentangling source related mechanisms from propagation related effects. Neutrinos, on the other hand, are elusive low interacting objects, to such an extent that they can be neglected as observable EAS initiators for all ground based detectors, present or in the planning. Even for the Auger project, in the most optimistic case, the expected rate hardly reaches few events/year. OWL-AirWatch, with its effective area reaching values of the order of 1 million square kilometers and mass target of 10^{13} tons, will be sensitive to this class of events. The expected event rate ranges from several events/year (GZK collisions and GRB sources) to several events/day according to the effectiveness of the "TD" hypothesis. The assumed cross section value in air is of the order of 0.01

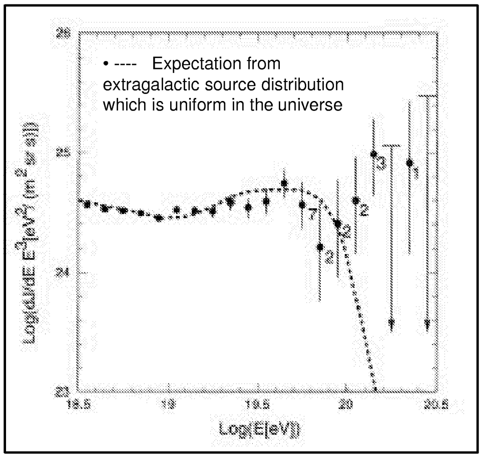

Fig. 1 GZK Cutoff; Akeno Data 1998

Takeda et al., Phys. Rev. Lett. 81, #6, 1163 (1998) microbarn at 10^{19} eV and 0.1 microbarn at 10^{20} eV with a factor of 4 model dependent uncertainty. From the observational point of view, the neutrino induced EAS can be distinguished from background and from other EECR EAs by triggering on horizontal showers initiating deep inside the atmosphere (see Sacco, this Conf. 1999).

Observational capabilities required from OWL-Air-Watch: Astrophysica1 aspects. The integrated exposure (~$2x10^3$) km^2 yr sr available today for the ground based arrays over the world is only sufficient to show the existence of the "ankle" fracture at ~$5x10^{18}$ eV in the CR energy spectrum. The limited statistical power for the available data excludes the possibility of observing significant structures in the energy spectrum at higher energies; with the current total exposure the subset of available data is of only 7 events exceeding 10^{20} eV. For a significant OA space mission the assumed values are: a) Effective aperture of (5 x 10^5) km^2 sr considering a duty cycle of 0.2; b) EAS energy threshold at ~10^{19} eV. With such parameter values, the expected event rate is: 5000/year for EECR with E>10^{20} eV (no GZK suppression) or 50-100 with GZK suppression; EECR neutrinos: from 150 to 1500/year.

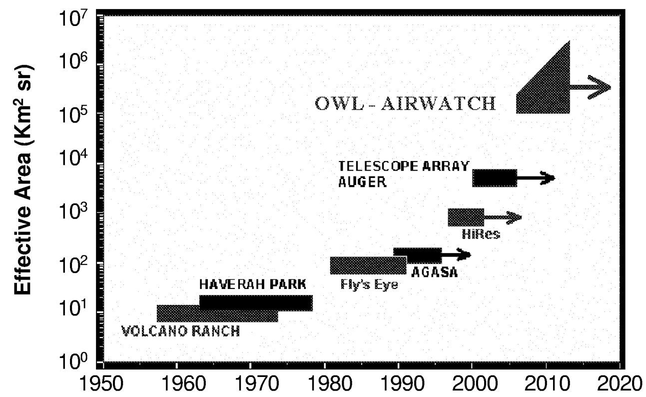

Fig.2. OA in historical perspective

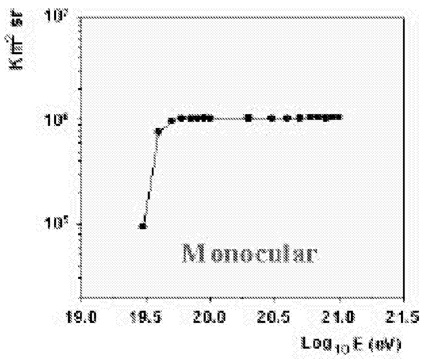

Fig.3. Geom. apert. of OA vs. EAS energy

4 Proposal rationale.

The luminescence produced by the Cosmic Ray quanta (protons, nuclei, gamma rays, neutrinos,...) can be disentangled from the general background and measured. Other phenomena such as Gamma Ray Bursts, meteors, lightning, atmospheric flashes, can also be observed and studied. The coverage from a LEO of the observable atmosphere surface at the scale of thousands km across and the measurement of very fast and faint phenomena of those described above, require: a) optical systems with large collecting areas and wide FOV around the local Nadir; b) high segmentation and high speed (well below the microsecond level) for the focal plane detector; c) a sophisticated on-board image processing acting as a trigger. In addition, it also could serve, when turned to the zenith, as a wide field, low spatial resolution, imaging system for astrophysical targets of opportunity like comets, supernovae, optical counterparts of Gamma ray bursts. In this phase the research is organized in the following way: a general coordination by a Project leader heading a Steering Committee, and research operations by Working Groups structured as sub-projects. The science Working Group is formed by scientists and representatives of the other groups; the technology WGs regard: Optics, Detectors, Read-out electronics and on board data analysis/trigger, Physical process simulations. The Mission WGs cover Mission requirement and Overall system validation.

Optics. The design criteria, based on the assumption of a 500 km orbit, lead to the following specifications: a) A large aperture, in excess of several m^2, and a high transmission efficiency, for the collection of a sufficient quantity of fluorescent light onto the detector. b) A wide field of view (FOV), about +/-30°. c) A low F# to keep the detector size within technological and practical limits, even at extreme FOVs. Such specifications are nearly impossible to achieve for high image quality optics; however the required resolution for OWL-AirWatch is much lower: about 10^4 times the diffraction limit. The chromatic aberration is also not stringent. Two solutions are currently investigated, namely a catadioptric system and a single, or double, plastic molded Fresnel lenses. The Fresnel lens approach is being currently investigated by a group of the University of Huntsville, Center for Applied Optics.

Detectors (Stalio, this Conf. 1999). The goal is to develop, build and test a demonstration model and subsequently a prototype of a detector for OA. The detector should satisfy the following requirements:

1) single light quantum sensitivity, 2) very high speed of the signal read-out, 3) low intrinsic noise, and 4) adaptability to a curved surface to fit the optical design (for this last requirement more than one detector elements in a mosaic design will be used). The choice of the detector type is not unique: in parallel to a commercial solution (multianod PMT Hamamatsu R5900 variant), is in progress a GSFC in-house development of detectors based on MCP or MSP.

Read-out electronics and on-board data processing/trigger (Catalano, this Conf. 1999). *FIRE: read-out electronics and trigger.* A preliminary study has driven to the identification of the "FIRE" system which is based on the modulation of the focal plane detector and implement the read-out and triggering systems in digital logic. FIRE is formed by three subsystems: pixel interface (time and position channels), time and position channel read-out and triggering system formed by more than one level to identify the event online. *Off-line event reconstruction* (Maccarone, this Conf. 1999). This activity refers to the event reconstruction from the raw data as selected and recorded by the read-out electronics. The goals are to extract the track from the residual background, the description of its geometrical characteristics and the classification of the event itself. The offline reconstruction uses techniques of cluster analysis and computation geometry for the identification and classification of the significant tracks.

Physical processes simulations (Krizmanic, this Conf. 1999). A code simulating the shower development initiated by Cosmic Radiation at very high energy (hadrons, gammas and neutrinos) as seen by OWL-Airwatch detectors is developed. It will be used to evaluate the performances of the mission under different hypothesis related to its fundamental parameters.

Measurement of fluorescence induced by X-Rays and charged particles in laboratory (Giarrusso, this Conf. 1999). Fluorescence measurements in laboratory allow to determine the yield of UV photons when the air, used as a target, undergoes an irradiation by X-Rays of energy in the range 10-30 KeV. These measurements are performed in the LAX laboratory in Palermo; the main goal is to measure the absolute efficiency of the atmospheric conversion into fluorescence for up to the MeV gamma region and for relativistic electrons.

Evaluation of atmosphere signal/noise ratio in fluorescence atmosphere measurement by using earth or balloon observations (Barbier, this Conf. 1999). The correct working of the proposed system in space can be verified by using a prototype on reduced scale for fluorescence light observations performed from Earth or from a stratospheric balloon. From a project point of view this system could allow also a better comprehension of the signal to noise ratio to improve the detection and triggering techniques.

Mission requirements. The goal is to identify the problems related to the realization of an OWL-AirWatch satellite as a function of the scientific requirements of the mission, of the target cost and working duration, of the type of satellite platform, mass, space and volume required by the launch. Preliminary evaluation of the Payload and Service modules indicates a Midex class satellite with ~2000Kg mass, 1500W power and ~200 million US$ cost. **Overall system validation.** This activity addresses the testing at system level and the characterization of the complete configuration.

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