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OWL – AIRWATCH Experiment: The Instrument.

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Abstract

Fluorescence light from EECR (Extreme Energy Cosmic Rays) can be detected at a distance of several hundreds of Km. The possibility to observe EAS (Extensive Air Showers) from space has become realistic and promising with, as a result of recent technical developments: 1) wide field of view optics for space applications, 2) fast detectors with high segmentation, and 3) a trigger and read-out electronics capable to handle millions of pixels. We present the OA (OWL-AIRWATCH) Instrument, a satellite payload composed of: optics, detector and trigger + read-out electronics.

1 Introduction:

The OA project is going to represent a unique explorative mission aiming to open interesting perspectives in the astrophysics and cosmology research fields. An overview of the OA project is presented by L. Scarsi (this conference 1999). The scientific goals of the project are presented by J. Linsley (this conference 1999) whereas OA performance, via Monte Carlo simulation, is presented by J. Krizmanic (this conference 1999). In this paper the instrument is presented with a discussion of the problem of designing its parts.

The ability of detecting, from space, fluorescence light produced in the Earth's atmosphere by EECR and neutrinos is related and strictly linked to the technical characteristics and capability of the instrument, which constitutes the payload of the OA mission space vehicle. In the last years the conceptual design of the OA instrument has taken shape and, supported by detailed calculations, many parameters have been set taking into account both scientific and space demands. Although it is planned to use current and established technology, compromises between technical and scientific requirements are common when an experiment is designed to work in space environment and OA project is certainly not an exception. Scientific expectation must be balanced, moreover, with mission requirements. Weight, volume, power consumption, can not be ignored in space devoted missions. All these assumptions are well considered in devising and designing the OA instrument.

The detection of faint signals from an orbit of 400-600 km together with a geometrical factor of 10^6 Km^2 · steradian (observed area on the Earth · solid angle) characterizes the challenge in designing the instrument. Fig. 1 shows the FOV (Field of View) and the resulting earth target volume observed by the instrument orbiting at an altitude of 500 km.

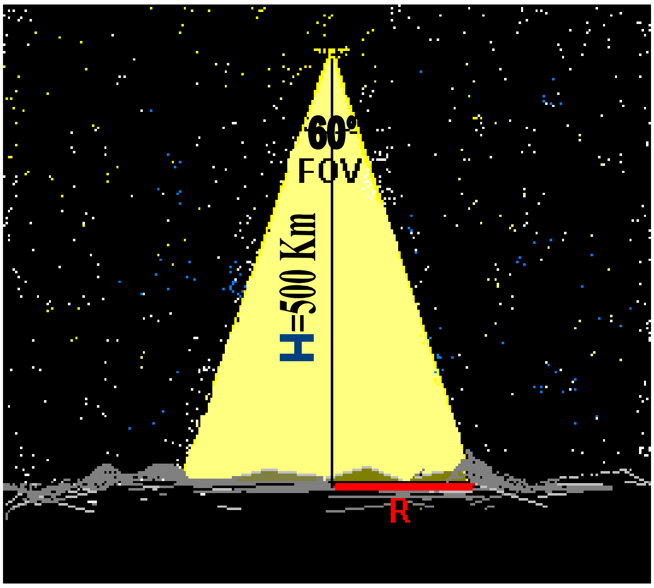

Figure 1: Important parameters that contribute to the huge geometrical factor of the OA experiment are: observation altitude and instrument FOV.

2 The OA Instrument:

The OA instrument is presented schematically, in the artistic view of fig. 2. The instrument consists of three main parts: optics, focal plane detector, trigger and electronics system.

A great synergy between the parts constituting the instrument is of fundamental importance for achieving the OA scientific objectives. Optics, detector elements, system and trigger electronics have to be matched and interfaced coherently to obtain a correct response from the instrument. Scientific requirements have been of guidance for the conceptual design of the apparatus and in the choice among various possible technical solutions. Still today, however, the final selections for many parts of the instrument have yet to be made. Nevertheless progress has been rapid in the past few years and detailed system architecture is available for the instrument. The design criteria, is based on following assumption:

- 500 Km orbit
- FOV of ±30°
- Pixel size at ground of 1 Km · 1 Km
- Event energy threshold $\geq 10^{19}$ eV

This calls for a completely different approach that the conventional one used for ground based fluorescence experiments. For space application the instrument has to be ***compact*** as much as possible, highly efficient, and with a built-in modularity in its detection and electronics parts. For what concerns the detection method, the single photon counting technique has been preferred to the charge integration alternative, because of better statistical response in presence of the very few photoelectrons expected by the faint UV fluorescence signal.

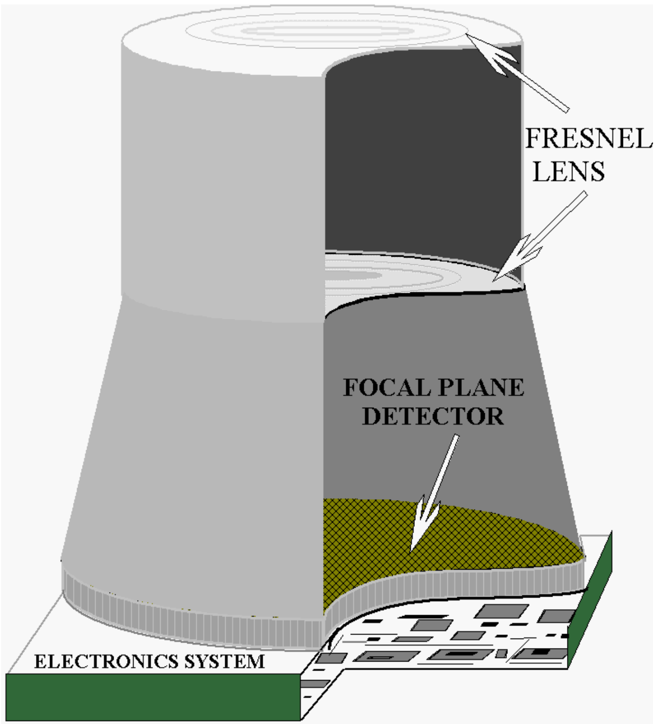

Figure 2: The OA instrument in its main parts. A configuration using Fresnel lens here

2.1 The Optics: The optical system required for OA project aims to find the best compromise in the optical design, taking into account the suitability for space application in terms of weight, dimensions and resistance to the strains in launch and orbital conditions. Two solutions are currently investigated by the international groups involved; namely, a catadioptric system and a single, or double, plastic molded Fresnel lens. The first solution is the most conservative approach, consisting in a spherical or aspherical mirror,

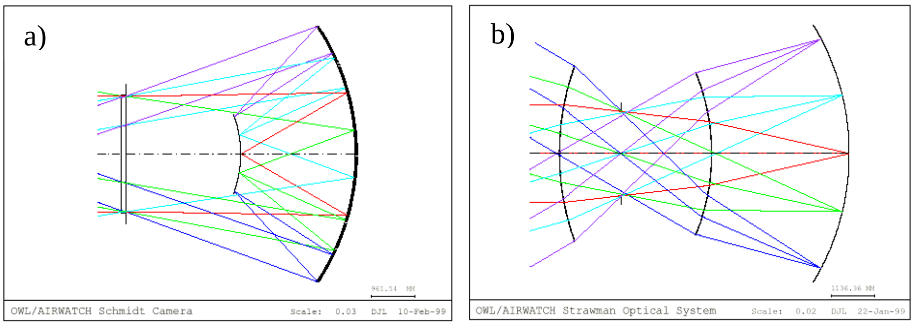

Figure 3: a) Optics using Schmidt lens configuration. b) Optics using double Fresnel lens configuration.

with an additional transmission plate for the reduction of transverse spherical aberration, known as of the Schmidt camera, or variations. Preliminary design shows that a FOV of ±20°, with transmission of about 70% can be achieved with this solution, close to the project requirements.

The Fresnel lens approach is being currently investigated by a group of the University of Huntsville, Center for Applied Optics (Lamb, 1998). Modeling of the optimized structure and the optical characterization of sample materials and prototypes are currently in progress. Fig. 3 shows a Schmidt and Fresnel optics configuration. Computer modeling of such optics requires a completely different approach with respect to the conventional ones, for the correct evaluation of the effect of the back-cuts of the Fresnel grooves. A non-sequential ray tracing procedure is required in order to correctly take into account the surface and total internal reflections. The Fresnel approach is quite appealing in terms of weight and payload integration and it represents the more promising solution.

2.2 The Focal Plane Detector: Due to the large FOV and large collecting area of the optics the focal plane detector is constituted by several hundreds of thousand of active sensors ($\approx 5\cdot 10^5$ pixels) (Stalio, 1998, this conference 1999). The demanding detector requirements as low power consumption, low weight, small dimension, fast response time, high quantum efficiency in UV wavelength (300–400 nm), single photoelectron sensitivity, and so on, limit the field of the possible choices to a very few devices. A suitable off-the-shelf device is the Multi-Anode Photomultiplier (Hamamatsu R5900 series). This commercial photomultiplier meets closely the requirements imposed by the project. Pixel size, weight, fast time response and single photoelectron resolution are well adaptable to the OA focal plane detector. The organization in "macrocells" of the focal plane (a macrocell is a bi–dimensional array of n·n pixels) is shown in fig. 4. This configuration of the focal plane offers many advantages as easy planning and implementation, flexibility and redundancy.

Moreover, modularity is ideal for space application. The Multi–Anode Photomultipliers represent, in this contest, a workable solution.

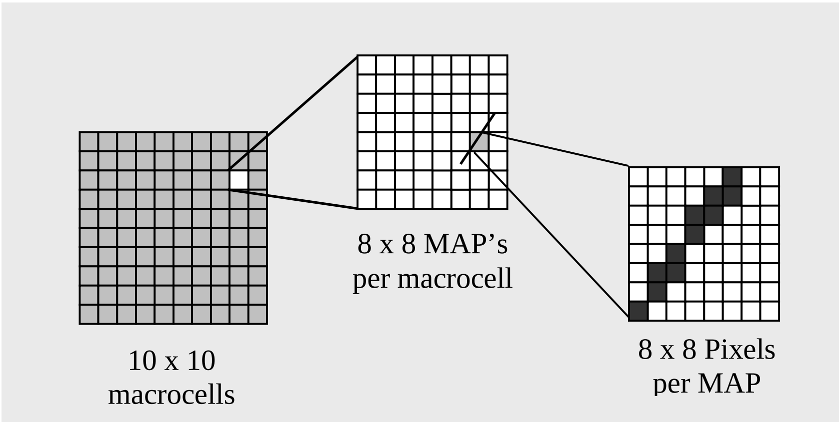

Figure 4: Schematic view of the modular focal plane. A Solution using 64 pixels Multi–Anode Photomultiplier R5900-64 (8 X 8 pixels) is shown. The focal plane macrocells are 100 with 64 MAP's per macrocell.

Other detectors as the Multi Anode Microchannel Array (MAMA) detectors are being evaluated as an alternative to the Multi–Anode Photomultipliers. A custom solution using MCPs (Microchannel Plates) or MSPs (Microsphere Plates) devices packed in a suitable structure is also considered (Mitchell, 1998). It is expected, in the coming year, the final decision for the detector technology to be used.

2.3 Trigger and Electronics System: Special attention has been given to the trigger scheme where the implementations of hardware/firmware special functions are foreseen.

The trigger module named **OUST** (On-board Unit System Trigger) has been studied to provide different levels of triggers such that the physical phenomena in terms of fast, normal and slow in time-scale events can be detected. Particular emphasis has been given to the possibility of triggering upward showers (emerging from the earth, "neutrino candidate") by means of dedicated trigger logic. Study has been undertaken for triggering the transient phenomenon using the wide-angle aperture of the instrument looking up the sky in the UV region.

The **FIRE** (Fluorescence Image Read-out Electronics) system has been designed to obtain an effective reduction of channels and data to read-out, developing a method that reduces the number of the channels without penalizing the performance of the detection system itself. Rows, columns routing connections has been adopted inside every single “macrocell” (n x n pixels unit, ≈100 macrocells constitute the focal plane detector) for diminishing the number of channels to read-out (Catalano, 1998, this conference 1999).

A “free running” method has been adopted to store temporarily the information, coming from the detector, in cyclic memories and recuperate them at the time that a trigger signal occurs. The front-end pixel electronics design has been formalized and computer simulations have proven the validity of the approach we are going to use. Fig. 5 shows the basic configuration of the pixel front-end electronics. A prerogative of the front-end pixel electronics is the reduction of the background when, as in our case, “single photoelectron counting” technique with fast response detector is used. The modularity concept, that is a common baseline of the project, is applied to the **OUST** and the **FIRE** systems too. The organization in macrocells is directly applicable to the system electronics. The advantages of such a scheme are to treat each macrocell as a unit independent on the other macrocells, thus simplifying the design of the entire system, making it simply consisting of a repetition of the same block.

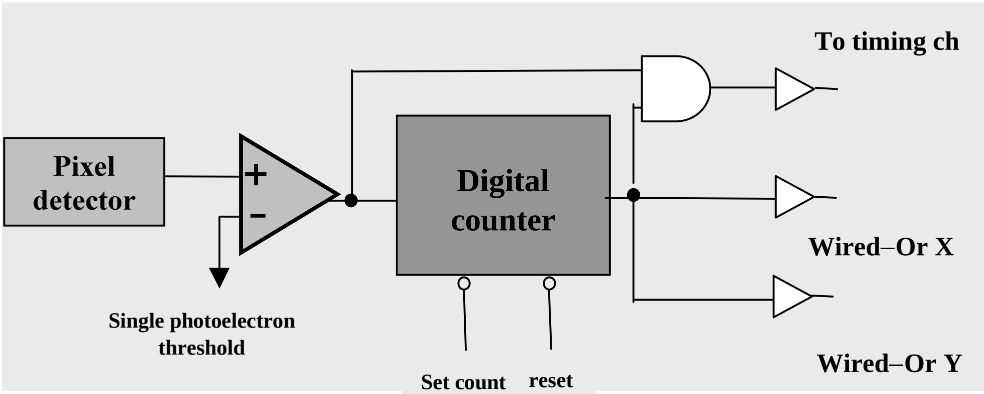

Figure 5: Block diagram of the pixel front–end electronics.

3 CONCLUSIONS:

The main conclusion of this paper is that it is possible to use current and established technology to fulfill the required performances of an ambitious project as OWL−AIRWATCH is. Naturally a lot of work remains to be done to complete the optimization and feasibility study, but we are confident that the OA collaboration will continue to work with a will to succeed in this revolutionary and fantastic enterprise.

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