Air Fluorescence efficiency measurements for AIRWATCH based mission: Experimental set–up

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Abstract. In the framework of the AIRWATCH project we present an experimental set–up to measure the efficiency of the UV fluorescence production of the air using hard X–ray stimulus. The measures will be carried out at different pressure and temperature to emulate the same condition of the upper layers of the atmosphere where X–ray and gamma ray photons of Gamma Ray Bursts are absorbed.

THE ATMOSPHERE AS TARGET AND SIGNAL GENERATOR FOR EXTRATERRESTRIAL RADIATION.

A very interesting technique to study the Extreme Energy Cosmic Rays (EECR) with E> 10^{19} eV (including primary Gamma Rays and Neutrinos) is the use of the atmosphere as a giant absorber scintillator. The method suggested several years ago by Linsley [1] and others consists in observing from space (let's say from 300–500 km) the physical phenomenon of the emission of the UltraViolet fluorescence radiation (or UV scintillation light) induced in the atmosphere during the passage of the EECR particles.

EECR particles in the collision with air nuclei produce hadrons that in turn collide with air nuclei giving rise to a propagating cascade of particle (Shower). In the complex hadron–electromagnetic cascade the more numerous particles are electrons. The number of electrons (size Ne of the Shower) at the cascade maximum is proportional to the primary energy Eo(eV):$Ne_{max} \sim Eo/1.3 \cdot 10^9$.

The basis of the observation is the UV fluorescent light emission from atmosphere (Nitrogen) excited by the Air Shower electrons. Shower electrons (and other charged particles) moving through atmosphere are ionising the air atoms and also exciting the methastable electron levels in the Nitrogen atoms and molecules. In a short relaxation time, the excited atoms (molecules) decay to the ground level emitting the characteristic UV fluorescence light with peaks at wavelengths from 330 nm up to 400 nm (narrow lines at 337, 357, 391 nm).

The emitted light is isotropic and proportional to the shower size at the given depth in atmosphere. An estimate of the UV fluorescence signal in a shower track can be done following the relation between primary energy and the light flux in the wavelengths 330–400 nm from the shower maximum: $Q \sim (Eo/1.3 \cdot 10^9) \cdot F \cdot \Delta L/4\pi R^2$ (photons m^{-2}). ΔL is the observed track length in meters, F is the fluorescence luminosity of the track in photons/meters and R is the distance in meters between the detector and the track. For electrons F ~4 photons/meter constant at different depth in the atmosphere.

GAMMA RAY BURST DETECTION BY UV ATMOSPHERIC FLUORESCENCE

The detection of the UV atmospheric fluorescence radiation induced by X and Gamma rays is important to catch the Gamma Ray Bursts (GRB) that represent one of the most intriguing phenomena in Astrophysics. Search for coincidence between GRB and Extreme Energy Cosmic Rays and Neutrinos is, moreover, the future challenge to advance in the GRB phenomenon knowledge as well as in the EECR origin. In fact, If the suggested association of the GRB with cosmological (extragalactic) origin is confirmed, the high energy release involved ($10^{51} - 10^{52}$ ergs) could involve the probable contemporary emission of high energy neutrinos or EECR, associated with the low energy gamma burst normally observed. The GRB are characterised by flat spectra from few keV up to several hundreds keV (up to the GeV, in some cases of particularly flat and intense GRB). The entire energy of an intense GRB ($10^{19} - 10^{21}$ eV) impacting with the atmosphere is absorbed by the upper atmospheric layers (30–50 km heights). A fraction of the absorbed energy is released in an UV flash of the same GRB duration (from few msec up to tens seconds) and of intensity proportional to the total GRB energy.

UV AIR FLUORESCENCE EFFICIENCY

As mentioned above an EECR particle (including neutrinos) or a Gamma ray photon produce in air a cascade of secondary particles (mainly electrons) as well as photons of moderately high energies. The interaction of these secondary through air results in the ionisation and excitation of its molecules. The electronic excitation energy of the molecules is either dissipated non–radiatively or emitted as visible or ultraviolet photons. It has been shown experimentally that, down to very low pressure, the fluorescence radiation from air results almost entirely from electronic transitions in the N_2 molecule and N_2^+ molecular ion. The radiative emission from these electronic transitions is detected as very narrow lines in the near UV band (main lines at 337, 357 and 391 nm). Due to the highly competitive non–radiative process, it is crucial to estimate the quality of air as a scintillator finding the efficiency of the fluorescence, that is, the fraction of the energy lost by ionisation and excitation that goes into UV fluorescence photons. Some experimental measurements and theoretical studies have been carried out in the past to determine the efficiency of the fluorescence process. In all experiments, included the recent measurements made by a Japanese team of the ICRR [2], the fluorescence was induced by high energy particles (electrons) with energies above 1 MeV up to few GeV. In the framework of the AIRWATCH project, in which the detection of GRBs in coincidence with EECRs or neutrinos is an important task, it is of interest to determine the air fluorescence yield at low energies by using electrons or directly photons of energies below 100 keV. Measurements of fluorescence efficiency as a function of pressure, temperature and chemical composition of the air, to reproduce the same condition in the upper layers of the atmosphere (where Gamma Ray photons are absorbed), are crucial.

THE EXPERIMENTAL SET–UP

The measurement of the fluorescence efficiency induced by low energy photons (X–ray) is in charge of the experimental team of AIRWATCH collaboration and it will carried out by IFCAI in Palermo. As starting point we are reusing a device designed, in the past, for the measurement of the fluorescence yield of pure Xenon excited by X–ray photons of 22 keV coming from a collimated radioactive source of Cd_{109}.

This apparatus, shown in Figure 1, is very simple and it consists of a cylindrical gas cell of ceramic closed at top and bottom by quartz windows. Two photomultipliers (pmt's) looking through the quartz windows detect the UV light produced inside the cell when a X–ray is absorbed (see Figure 2).

The coincidence technique eliminates the uncorrelated noise of the pmt's permitting to detect the very few UV photons produced. Random coincidence as well as coincidence induced by cosmic rays are cancelled by background subtraction. If the efficiency of the UV production is very low (as in our case where the expected value for air at the pressure of tens of mbar is of the order of 0.1%) the rate of coincidence due to UV photons is a key parameter to determine the efficiency. We have planned to use the 22 keV X–ray source because this is a trade–off with to have as much UV photons as possible and low X–ray Compton diffusion. The measurements are in course. Due to the very low photoelectric cross section and UV yield of air a high flux of X–ray photons is mandatory. This implies the use of an intense X–ray source. For this purpose, in Palermo, is installed an X–ray beam of adequate flux available for this experiment: the LAX [3] (LAboratory for X–ray experiment). This facility managed in collaboration between IFCAI–CNR and DEAF (University of Palermo), consists of a beam 12 m long with available lines at 5.4, 6.4, 8, 22 keV. The maximum flux of photons at the end of the beam line on axis is of the order of $10^4 - 10^5$ ph mm^{-2} s^{-1}. The vacuum inside the chamber is in the range of (2–4)$\cdot 10^{-6}$ mbar.

FUTURE PLANS

We are also planning to repeat the measurements of UV air efficiency at higher energies both with photons and high energy particles with an appropriate redesign of the shown above detector. These measurements will be carried out at a Synchrotron Facility and at a Particle Accelerator.

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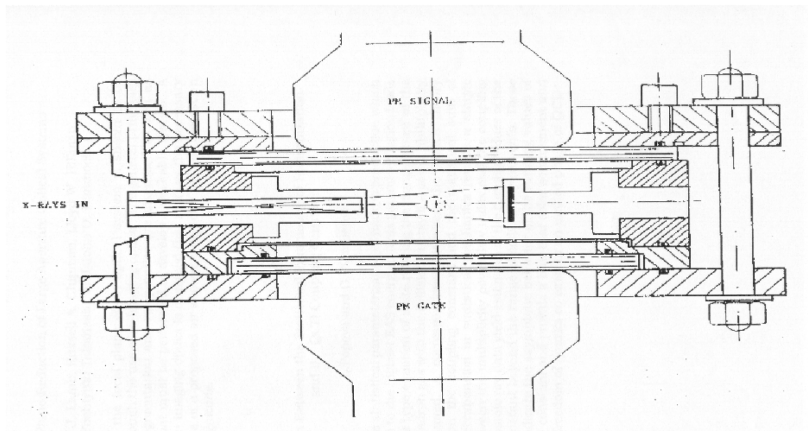

FIGURE 1. Schematic of gas cell.

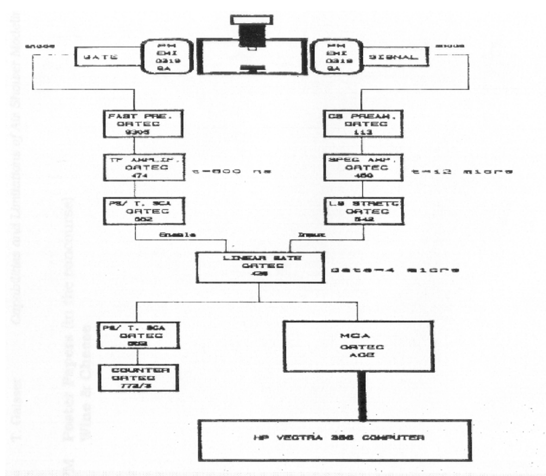

FIGURE 2. The coincidence electronic chain.

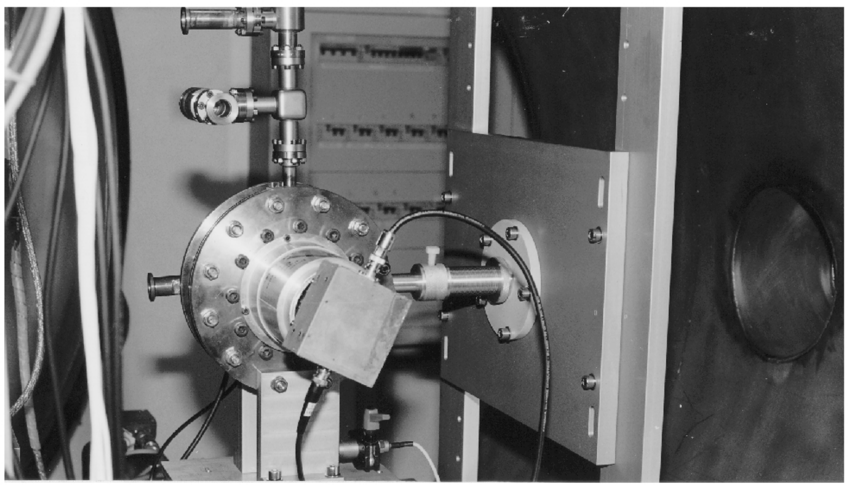

FIGURE 3. A picture of the apparatus.