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Laboratory measurements of Air UV fluorescence Light Yield induced by X-ray photons.

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Abstract

In the framework of the **OWL-AIRWATCH** space mission, we present an experimental set-up to measure the air UV fluorescence Light Yield induced by hard X-ray photons. We also report preliminary results in air and for comparison in pure Nitrogen. The experimental results indicate that the UV Light Yield is inversely proportional to the filling pressure and that, at pressure below 30 mbar, more than 0.1 % of the X-ray energy is transformed in UV photons.

1 Introduction:

The general goal of the **OWL-AIRWATCH** (**OA**) space mission (Scarsi et al., 1998) is to acquire the image of the EASs (Extensive Air Showers) that occur when the EECRs (Extreme Energy Cosmic Rays) strike the Earth atmosphere producing UV (UltraViolet) fluorescence light as the end-result of a complex cascade process. EECR particles (protons, nuclei or neutrinos) in the collision with air nuclei produce hadrons that in turn collide with air nuclei giving rise to a propagating cascade of particles (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. Shower electrons (as well as other charged particles) moving through atmosphere are ionizing the air atoms and also exciting the methastable electron levels in the Nitrogen molecules. In a short relaxation time, the excited molecules decay to the ground level emitting the characteristic UV fluorescence light with peaks at wavelengths of 337, 357 and 391 nm.

The **OA** space mission is also devoted to investigate the connection between GRBs (Gamma Ray Bursts) and EECRs (Catalano et al., 1998, Sacco et al., 1999). The GRBs represent another important phenomenon interesting the interaction between the Earth Atmosphere and the electromagnetic radiation (X and Gamma rays). The total energy of a GRB interacting with the Earth atmosphere is absorbed by the upper atmospheric layers below 30 mbar residual pressure (30-50 Km height). As for the EECRs, a fraction of the absorbed energy is released in an UV flash. In this case gamma ray photons are absorbed via photoelectric effect by the molecules of the air producing primary electrons with energy equal to the gamma photons. These in turn produce secondary electrons with lower energy (from few to hundreds eV) that excite (or ionize) the Nitrogen molecule whose de-excitation is followed by UV fluorescence light.

Due to the highly competitive non-radiative processes, the UV fluorescence Light Yield, defined as the fraction of the energy of the gamma photon that goes into UV fluorescence photons, is expected to be very low. So, in the framework of **OA** space mission, measurements of the UV fluorescence Light Yield induced by X and gamma ray photons or by the relativistic electrons are mandatory.

In this paper we report the technique and the experimental set-up to measure the UV fluorescence Light Yield of the air induced by X-ray. Preliminary results obtained in air and for comparison in pure Nitrogen are also reported.

2 The UV fluorescence Light Yield Experimental set-up:

To measure the UV fluorescence Light Yield of the air, induced by X-ray photons, we have chosen to make use of the technique of the counting of events seen by two photomultipliers (Pmts) operated in coincidence mode (Giarrusso, Manzo and Re, 1985).

The experimental set-up including the detection system and the electronic chain is reported in figures 1 and 2.

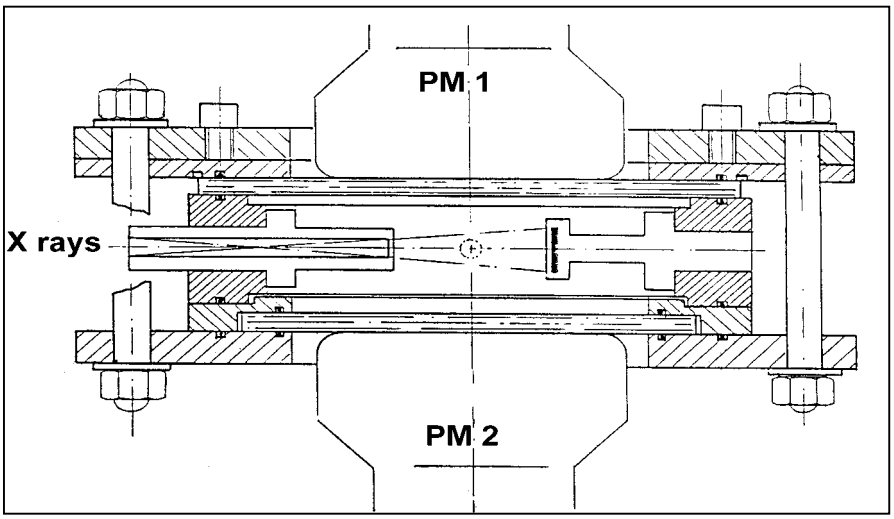

Figure 1: Schematic of the gas cell.

The apparatus of measurements is very simple and it consists of a cylindrical gas cell of ceramic closed at top and bottom by quartz windows. Two Pmts of 3 inches diameters operated at 2 kV detect the UV photons produced inside the cell. The X-ray photons are well collimated inside the cell in a small absorption region (4 cm) centered on the Pmts. This minimize the variations of the solid angle subtended by the Pmts at the point production of the UV photons. The two Pmts are used in coincidence mode thus eliminating spurious trigger signals due to the uncorrelated noise of the Pmts. To minimize the random coincidence, the coincidence gate time was settled at 500 nsec, ten times longer than the fluorescence decay time of the excited Nitrogen molecule (about 50 nsec).

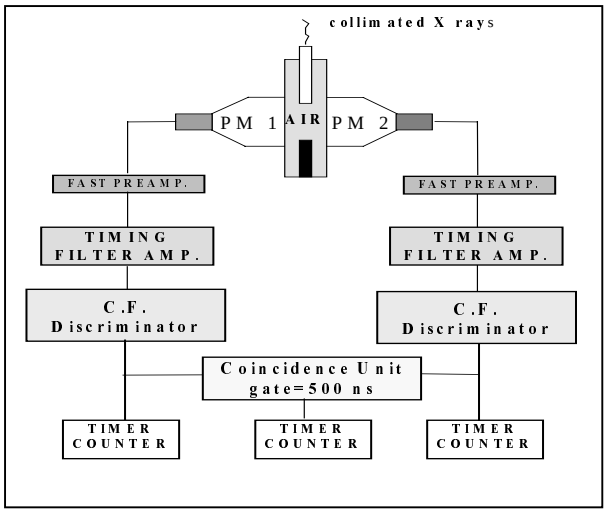

Figure 2: Schematic of the coincidence electronic chain.

All measurements have been carried out at the LAX X-ray Beam Facility in Palermo (Celi et al., 1996) where an intense X-ray source, covering an energy range from few keV to 25 keV and a flux range from 10^{10} to 10^{12} photons / (sr * sec), is available. This huge flux is necessary to overcome the low photoelectric cross section of the air and the small absorption region in which the very well collimated X-ray photons are absorbed. The measured collimated flux inside the gas cell was about $3 * 10^6$ photons / sec. We used the 22.1 keV fluorescence line of the Silver target anode, in the X-ray generator, with a trade-off between to produce in the gas cell as much UV photons as possible and minimize the X-ray Compton diffusion.

The estimate of the UV fluorescence Light Yield follows a statistical approach as described in (Giarrusso et al., 1998). Following this approach we found a formula that lies directly the experimental measured detection efficiency D_{eff} with the UV fluorescence Light Yield. D_{eff} is defined as the ratio of the measured coincidence rate of the X-ray events detected as UV fluorescence photons (R_{coinc}) to the measured rate of the total X-ray photons absorbed in the gas cell ($R_{x\text{-}abs}$).

$$D_{eff} = \frac{R_{coinc}}{R_{x-abs}}$$

3 Experimental results:

The energy spectrum of the absorbed X-ray photons inside the gas cell is shown in fig.3. This is the energy spectrum, as measured by a Silicium detector, normalized by the absorption efficiency of the air in the gas cell. The Silver kα fluorescence line at 22.1 keV is superimposed to a bremsstrahlung continuum which effective energy range is width only 20 % of the Silver kα line.

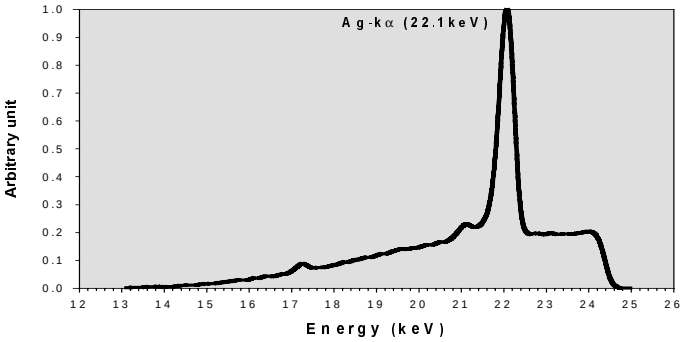

Figure 3: The X-rays input spectrum.

In fig. 4 is reported the measured coincidence rate of the X-ray events detected via UV fluorescence photons (R_{coinc}) as a function of the pressure, in air and in pure nitrogen. The coincidence rate was obtained by measuring the rate of coincidence signal of the two Pmts and by subtracting the background measured under the same conditions when no gas was present in the gas cell. A contribution to the measured coincidence rate comes from the random coincidences between the events detected by the two Pmts. This contribution has been evaluated and subtracted from the measured coincidence rate. As the rate of the signals detected by the two Pmts were in the range from 1000 to few thousands events per second and the time of the coincidence gate was 500 nsec, the random coincidences were about 20 % of the total count-rate. For each pressure we have evaluated the error by repeating several times the measurements. Any measurements was 100 sec long. A systematic error of about 5-10 % was found. The statistical error was less than few percent. The difference of the counting rate of Nitrogen and air, difference that increases by increasing the pressure, is due to the increasing non-radiative de-excitation of the Nitrogen molecules by collision with the Oxygen molecules.

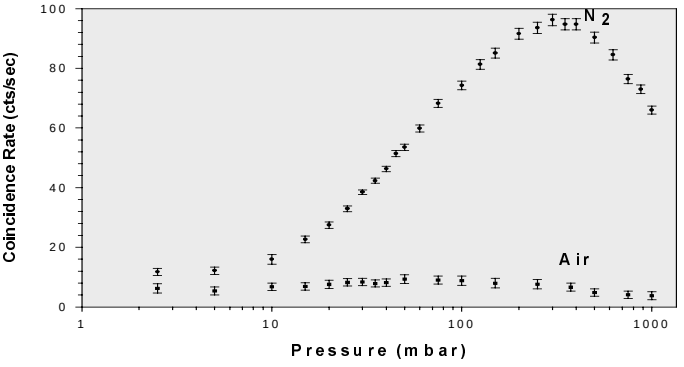

Figure 4: The coincidence count-rate (R_{coinc}) as function of the gas pressure.

The detection efficiency D_{eff} was derived estimating the rate of the X-ray photons absorbed in the gas cell ($R_{x\text{-}abs}$), by measuring the X-ray collimated flux with a fast scintillator. We found a flux of $2.7*10^6$ photons / sec with an uncertainty of about 10 %.

Finally we derived the number of the UV fluorescence photons (n_{uv}) produced inside the cell, and therefore the UV fluorescence Light Yield, using the statistical formulas (Giarrusso et al., 1998):

$$D_{eff} = (1 - e^{2 \cdot p_e \cdot n_{uv}} \cdot (1 + \frac{2 \cdot \sum_{k=1}^{n_{uv}} (p_e \cdot n_{uv})^k}{k!})) \cdot P_{ce}$$

$$Light\ Yield = \frac{n_{uv} \cdot \varepsilon_{uv}}{\varepsilon_x}$$

where p_e is the product of the quantum efficiency of the photocatode times the transmission of the quartz window times the solid angle subtended by the Pmt at the UV light point production, P_{ce} is the collection efficiency of the Pmts, ε_{uv} and ε_x are the energies of the UV and X-ray photons, respectively.

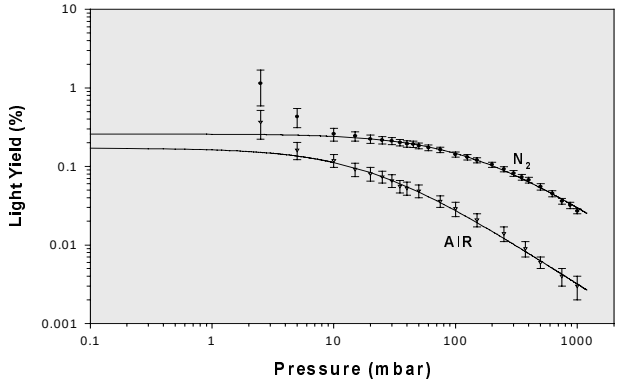

Figure 5: The UV fluorescence Light Yield as a function of pressure.

The UV fluorescence Light Yield as a function of the filling pressure for air and pure nitrogen is shown in fig. 5. The measured UV yield follows a proportional inverse law with the pressure, both for air and for pure Nitrogen, in accord with the kinetic theory taking into account that the non radiative collision de-excitations increase as the increasing pressure.

4 Conclusion:

The UV fluorescence Light Yield measurements have been made in pure dry air and, for comparison, in pure Nitrogen. As shown in fig. 5, the air UV yield for X-ray excitation is ranging from 0.18 % to 0.07 % for the air pressure varying from 1 mbar to 30 mbar, that is the pressure range in which the gamma rays of the GRBs are absorbed in the Earth atmosphere.

References

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