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OWL-AIRWATCH: Search for correlation between Gamma Ray Bursts and Extreme Energy Neutrinos

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Abstract

Particles and neutrinos with energy $E > 10^{19}$ eV can be detected through the Earth's atmosphere induced UV fluorescence light accompanying the Giant Showers production. With its wide angle optics and large collecting surface, OWL-AIRWATCH (OA) space mission (Scarsi, 1999) can monitor an atmosphere surface up to 1 million km^2 with a target mass above 10^{13} tons. This allows to detect very small flux values typical of Extreme Energy Cosmic Radiation. High energy showers initiated by neutrinos would appear to start at large depths in the atmosphere where a vanishing number of hadron-initiated showers should exist. We expect that neutrinos associated with cosmic rays with energy above OA energy threshold ($E \cong 3*10^{19}$ eV) should be detected in time coincidence with Gamma Ray Bursts. Due to the OA directional resolution for neutrino detection (< 2°), the occurrence rate of casual association for time coincidence is marginal.

1 Introduction:

One of the fascinating challenges of the OA space mission is its capability to explore the neutrino sky emission at extremely high energy $E > 3*10^{19}$eV (EHENs). Various physical and astrophysical processes can contribute to the EHEN emission : Top-Down (TD) processes with the decay of Topological Defects (Sigl et al., 1995) or of extremely-massive relic particles (Berezinsky, 1998) generated during the inflationary epoch of early universe; Bottom-Up (BU) processes taking into account the celestial engines that can accelerate cosmic ray particles up to $10^{20\text{-}22}$ eV (EHECRs) such as blazer relativistic jets or Gamma Ray Bursts (GRBs). Cosmological EHECRs produced by such engines can generate EHENs in situ or, if they survive to the local environment, by interacting with the microwave relic background (GZK effect). The observation of EHENs, the study of their spatial distribution and of their temporal and directional correlation with astrophysical events are an important way to probe extremely high energy processes beyond the GZK limit. In this paper we test the possibility of OA to search for correlation between GRBs and EHENs for which the time signature can offer a unique condition to identify the neutrino sources.

The BeppoSAX capability to locate GRBs (Costa, 1998) with residual error-boxes of few arc minutes and the X, optics and radio follow-on activity on the GRB afterglow (Costa et al, 1997; van Paradijs, et al., 1997; Frail et al, 1997) have allowed the discovery that these events originate in extremely distant Galaxies ($Z \cong 1$). The amount of energy involved in these events (order of 10^{52} erg) and the power law decay during the afterglow can be justified by a class of models (fireball models, Piran, 1995 and references therein): GRBs could be produced by collision of ultra relativistic shock waves generated in the impact of two collapsed objects (neutron stars and/or black holes) or a collapsed object with a super massive star. In this scenario very strong magnetic fields (10^{15} G) extract and accelerate electrons producing by synchrotron or inverse Compton the electromagnetic component of the burst; the same mechanism accelerates protons at energies up to $10^{21\text{-}22}$ eV. Due to the interaction with the dense photon field in the burst, these protons should efficiently produce neutrinos at energy of 0.05*Ep where Ep is the energy of the parent proton (Vietri, 1995).

Due to the poor knowledge about the number of objects existing in the various parent classes and of their distribution in distance, and due to the lack of information on the nature of the EHECR engines, quantitative estimates of the flux of neutrinos produced by GRBs and by the other astrophysical (BU and TD) processes are difficult. The OA Science Working Group (Cline et al. 1999) made a prevision of few hundred EHENs/year observable by this mission. The detection of an EHEN is, also in the most optimistic perspective, a rare event among a large number of detected EHECRs.

The arising question is: how an EHEN can be distinguished by an EHECR ?

2 Observational differences between an EHEN and EHECR:

OA has the capability to measure the angular direction and the maximum intensity height (X_{max}) of the EAS with energy $E > 3*10^{19}$eV (the experiment is described in: Barbier, Catalano, Giarrusso, Krizmanic, Maccarone, Scarsi, Stalio, 1999, proc. of this conference).

The measurement of the angular direction of each event is based on the imaging capability (1 km

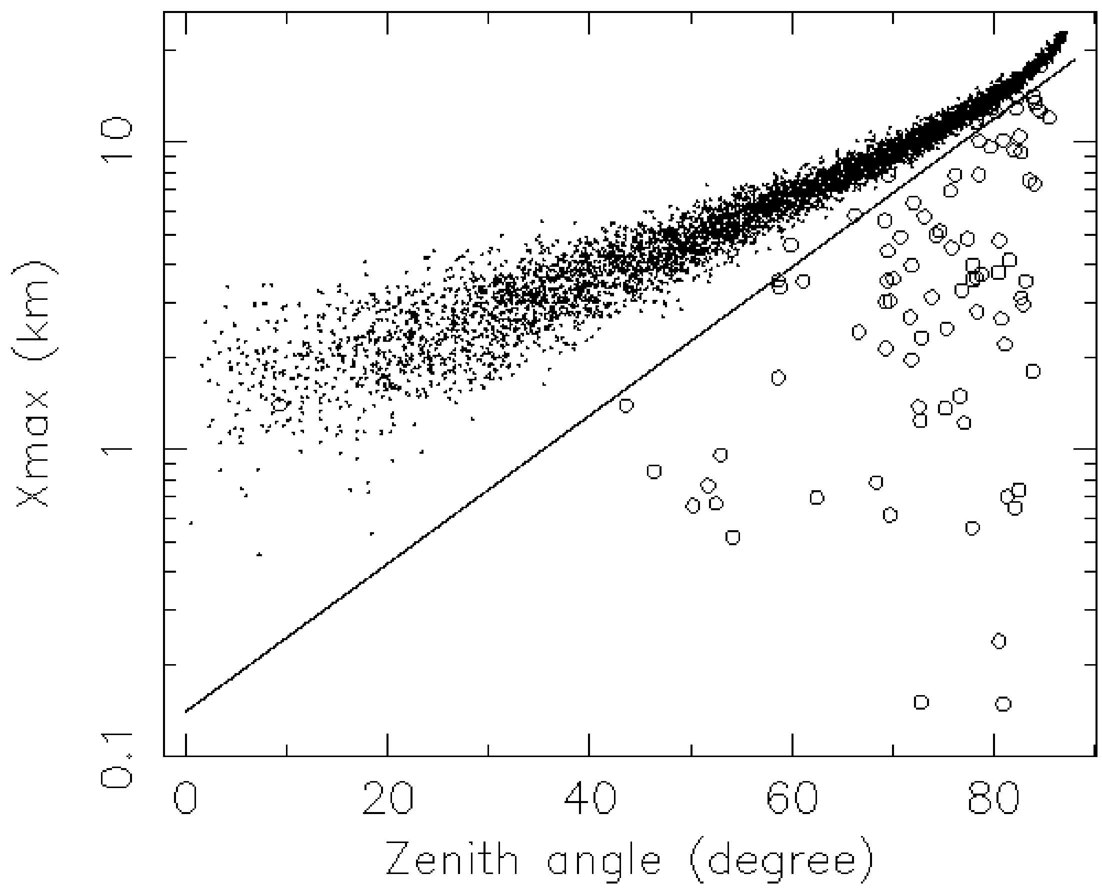

Figure 1: Plot of the results of a simulation of 5000 hadrons initiated EAS (dots) and 100 neutrino initiated EAS (circles). The area below the continuos line, where no hadrons are present, contains more than 80% of simulated neutrinos.

resolution) together with the fast detector response ($< 10^{-8}$ s) which allow to achieve a kinematic view of the observed fluorescence track. The measurement of X_{max} is based on the Cerenkov light, back reflected by the see surface or by clouds: the time difference between the arrival of the fluorescence light from the primary track and the back reflected Cerenkov flash localizes the height of the event.

Due to the very low cross section of the neutrinos they will generate EAS uniformly at all depths (gr/cm^2) in the atmosphere while other EAS initiated by protons, nuclei and gamma will occur essentially in the upper layers with a rapid exponential decrease with depth. For the same reason, from high zenith angle we expect a relative increment in the yield of neutrinos EAS respect to the other events.

To perform a quantitative evaluation we simulated this phenomenon by taking into account the geometrical OA parameters (height of the satellite = 500 km, field of view = 30° semi-aperture). Neutrinos and other cosmic rays are supposed isotropic in arrival direction; due to the very low cross section (Halzen & Saltzberg, 1998) neutrinos are linearly absorbed during the path expressed in g/cm^2 while for the hadron component we used an exponential law with the canonical decay constant, $\lambda_0 = 70$ g/cm^2; the contribution of the gamma initiated EAS ($\lambda_0 = 37$ g/cm^2) has been disregarded to obtain a conservative result. We have selected a simple geometry in which the earth curvature isn't taken into account: the choice could affect the computation only in a 2nd order approximation. We simulated 5000 hadrons, corresponding to the number of events expected for one year observation of OA; this number is computed starting from the AGASA spectrum (Nagano & Teshima, 1992) scaled for the OA sensitivity and 100 neutrinos initiated EAS (Cline et al., 1999) .

Figure 1 shows X_{max} of the simulated events as a function of the zenith angle for the two components (dots represent hadrons initiated EAS, empty circles represent neutrino initiated EAS which have interacted with the terrestrial atmosphere). The possibility of discriminating neutrinos from hadrons is function of the height and of the zenith angle of the EAS. As example of the method, we can consider the bottom area of figure 1, delimited by the continuos line: no one of the 5000 simulated hadrons appears below this line, where we find more than 80% of the 100 interacting neutrinos.

3 Correlation between EHENs and GRBs:

The rate of GRB events is of the order of 1/day on 4π sr above the fluence threshold of the BATSE experiment (Fishman & Meegan, 1995). Assuming for OA a life time of two years, a duty cycle of 0.12 and a field of view of 0.84 sr, we expect to have about a hundred of GRBs with an arrival direction within the OA field of view occurring in coincidence with the OA Earth atmosphere observation. The alert of the presence of a GRB can be given or by detecting a sudden increase of the UV atmospheric background using directly OA data (Catalano et al., 1996) or by using external information from space missions specialized for GRBs.

The chance occurrence rate of detecting a neutrino contemporary and in same direction of a GRB is:

$$r = Nu * \delta t * \delta o ,$$

where Nu is the average number of Neutrinos/(s sr) detected by OA , δt is the GRB time duration, and δo is the union of the GRB and OA error boxes.

The GRB light curves are dominated by a primary gamma-ray emission for a time variable between 0.1 and 100 s followed by a power law decay of about a week (afterglow): due to the fact that emission of EHEN from GRBs could occur also during the afterglow, we set $\delta t = 5*10^5$ s, neglecting the delay introduced by a possible neutrino mass because at energies greater than 10^{19} eV also a relevant mass and a so large distance ($\cong$ 5 Gparsec at Z=1) can't introduce any appreciable time delay between neutral particles and photons.

The new generation of space missions dedicated to GRB observations and the optical follow on will allow to measure GRB positions with few arc second resolution; δo is only dominated by the OA angular resolution (Maccarone et al., 1999) which is a function of the energy and the zenith angle: at energy of 5 10^{19} eV and zenith angle of 60°, the OA angular resolution is about 2° (at 2 standard deviations), and δo is $4*10^{-3}$ sr.

The EHEN rate foreseen for OA is of the order of 100 events/year corresponding to Nu $\cong 3.5*10^{-6}$ events/(s sr). Using these values we find $r < 10^{-2}$ if the coincidence occurs during the afterglow and $r < 10^{-5}$ if it occurs during the primary burst emission.

The observation of the UV atmosphere fluorescence with Space experiments of the OA class opens real perspectives of probing the neutrino sky emission at extreme energy. The sensitivity and the characteristics of the OA experiment are suitable for distinguishing neutrinos from hadrons and looking for coincidence between neutrinos and GRBs with low values of chance coincidence.

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