Astrophysics and Space Science manuscript No.
(will be inserted by the editor)

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Search for correlations of GRB and cosmic rays

September 2, 2006

Abstract It is possible that violent processes resulting in Gamma Ray Bursts produce also high energy photons and cosmic rays. The possible correlations of very short GRB with, e.g., CMB, cosmic rays is briefly discussed. We have also begun preparation of the experiment correlating in real time data from Maze cosmic ray detector and *Pi of the Sky* robotic telescope.

1 Introduction

The absence of an anisotropy of directions of Gamma Ray Bursts (GRB) was rather unexpected when the GRB were discovered and draw to them the attention of physicists as to the most powerful events in the Universe (since the Big Bang). Since that time - the discovery not the Big Bang - the question of the GRB origin was a mystery up to almost now, when progenitors of some of them have just been seen. Since about 1997 as a result of BeppoSAX satellite observations it is believed that the GRB of duration longer than about 2 seconds originate the results of the explosive collapse of the cores of young massive stars in star-forming galaxies at redshifts exceeding $z = 1$. Quite recently the shorter bursts were identified with something closer ($z \approx 0.2$), thus less energetic which is consistent with the hypothesis of the merger of two neutron stars, or of a neutron star with a black hole. Both classes of GRB agree very well with the isotropic distribution of their directions and therefore the isotropy seems to be an attribute of GRB. However a third class of GRB was found - the very short burst (vsGRB). The confusion was stronger when it was found that this, not very numerous class seems to be anisotropic on the sky [1] as is shown in the Fig. 1.

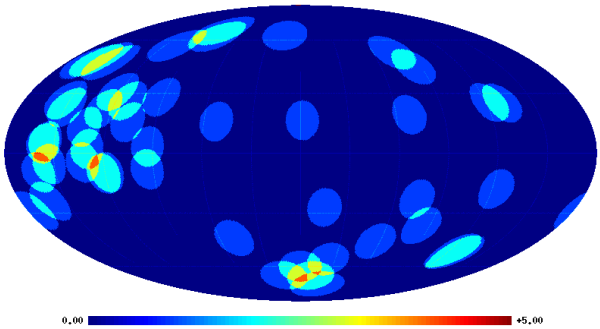

Fig. 1 Very short gamma ray burst counting within 10° radius cone around each vsGRB.

In order to proceed with understanding the nature of gamma ray bursts one needs to observe them systematically in full electromagnetic wave spectra. Especially optical observations are important. It is connected with high spatial resolution that allows for unambiguous object identification and with the distance estimation by red-shift. On the other hand, high-energy ($\sim$ GeV$\div$TeV) photon observation is important for particle physics. Understanding the creation mechanism of high-energy photons could help with understanding the origin of cosmic rays, and test new hypotheses about quantum-gravitational effects (i.e. vacuum dispersion), evidence of extra-dimension, etc.

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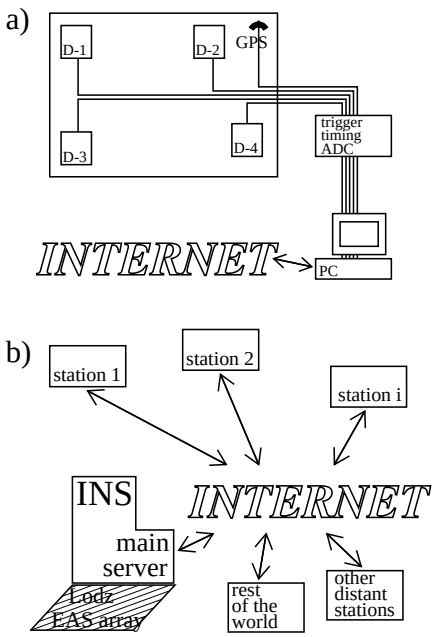

Fig. 2 Schematic view of a single station (a) and the idea of the whole Maze network (b).

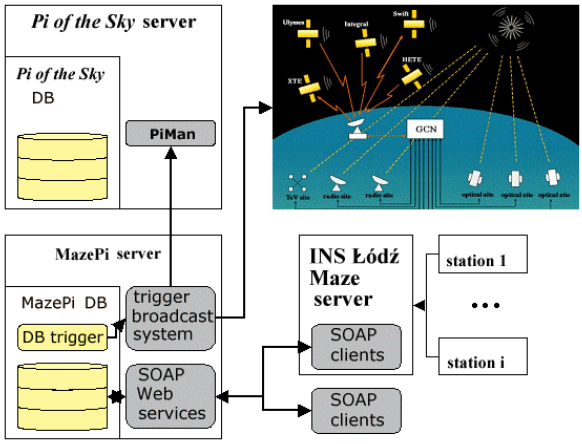

Fig. 3 Schematic view of the MazePi system.

2 The MazePi Experiment

The MazePi is a "multiwavelenght" project to study GRB. The 'optical wavelengths' part will be covered by the *Pi of the Sky* experiment [2] and the network of cosmic ray detectors of the Roland Maze Project [3], under construction at present, will be used to search for TeV photon emission.

2.1 The Roland Maze Project

The Maze detection points will be placed on the roofs of Łódź high schools over an area of $\sim 100\,\mathrm{km}^2$. Each school will be equipped with 4 scintillation counters of area of 1 m^2 separated by about 10 m distance. The electronic system should enable measurement of relative times and measurement of signal amplitudes from all the detectors (Fig. 2a).

The system of converters and master elaboration would be connected to a PC-class computer, on which preliminary data analysis and storing would be performed. For the purposes of GRB searches the system is equipped with the buffer able to store ~100 hours of detail information about each detector counting rates. Occasionally data will be sent via internet to the central server. The Global Positioning System (GPS) will be used for time synchronization. (Fig. 2b)

The main scientific goal of the project is studies of extensive air showers of energies above 10^{18} eV. The single detector counting rate (i.e. registration of muon flux) is related to cosmic rays in the GeV energy range, thus, e.g., with the activity of the Sun and geomagnetic events, the state of atmosphere, and atmospheric effects. The same data, however, could be used to look for GRB related signals of photons of TeV energies.

2.2 *Pi of the Sky* Project

The *Pi of the Sky* project [2] is conducted by The Soltan Institute for Nuclear Studies in collaboration with The Center of Theoretical Physics, Warsaw University and Warsaw University of Technology. Its main goal is the continuous observation and real-time analysis of the sky in a search for optical flashes, which are connected with gamma ray burst (GRB).

Because systematic search for phenomena responsible for GRB with classic astronomical equipment are rather difficult, we have designed a system [4], which consists of two sets of CCD cameras installed in two locations separated by about 100 km and working in coincidence. Each set contains 16 cameras covering a large fraction of the visible sky. A prototype system has been already built and it operated since June 2004 at Las Campanas Observatory in Chile. Recently it has been equipped with a new lenses of $f = 85\,\mathrm{mm}$ $d = f/1.4$ giving $20° \times 20°$ field. Exposure time of 10 s gives a limiting magnitude $12\text{-}13^m$.

The *Pi of the Sky* apparatus is controlled by a PC located inside the dome. The system is fully autonomous, but also fully controllable via Internet.

For most of the time, the cameras follow a field of view (FOV) of the HETE satellite. The system is also listening to the Gamma ray burst Coordinates Network (GCN) alerts received directly and through a backup server in Warsaw. Should an alert located outside the current FOV arrive, the mount automatically moves towards the target and exposures are taken for 30 minutes.

In addition to using GCN alerts, custom flash detection algorithms have been developed [4], which are being used as internal triggers for the apparatus. Moreover, twice a night a scan of the whole visible celestial hemisphere is performed. 16 fields are visited and three images are taken by both cameras. A single scan lasts about 20 minutes.

For data acquisition and analysis the MazePi system is being prepared. It consist of PostgreSQL Databases (it could be easily changed into another system like IBM DB2 or Oracle), object-oriented database API, SOAP web services and clients, and Trigger Broadcast System. The schematic view of the MazePi system is shown in Fig. 3

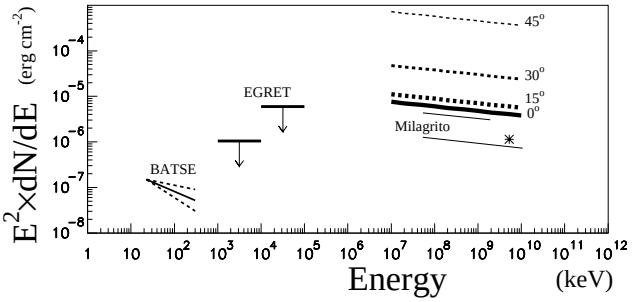

Fig. 4 Angular dependence of the registration sensitivity of Maze network and the GRB 970417a registration by BATSE and Milagrito.

2.3 Observations of TeV gammas from GRB by the MazePi Experiment

The EGRET experiment during its lifetime observed few photons of energies above 10 GeV from the GRB direction.Ground base observations in two cases a significant excess of events correlated with GRB reported in: Milagrito (the prototype of the Milagro experiment) saw an excess during the GRB970417a. 18 events were observed during 18 sec, while the expected background was 3.46±0.11. The photon energy threshold was estimated as 650 GeV. (Ref. [5]). The HEGRA-AIROBICC, air shower Cerenkov experiment found a significant excess during GRB020925c. Within 4 minutes (9° from the direction reported by WATCH) 11 events were registered with the background estimated as 0.93. The energy of photons was in all these cases greater than 16 TeV. (Ref. [6])

We have performed respective Monte Carlo calculations to estimate the sensitivity of the MazePi experiment. We used the CORSIKA program (v.6.200 (Oct. 5, 2004) [7] to check the possibility of registering high energy GRB tails in the Maze array detectors.

The exact electromagnetic cascade development in the atmosphere was followed and the charged particles were counted on ground level. A power-law (above 10 GeV) energy spectrum of GRB photons was assumed. The GRB is assumed to be detected if the Maze detectors single particle counting rate exceeded the background at the 2σ level. We are particularly interested in very short GRB, so the burst duration of 0.1 sec was assumed.

The background was measured with the prototype Maze detector [8].

The short GRB registration efficiency of the Maze array depends strongly on the zenith angle of the GRB direction as shown in Fig. 4. The gamma ray flux above the respective line will be seen by the MazePi experiment on the level higher than "2σ". The two thin lines and the black dot shows results of the Milagrito observation of GRB970417a [5]. The spectral index used there is -2.1. and the cutoff is fixed at 50 TeV. The comparison with GRB 970417a observed by BATSE and Milagrito is shown as well as the upper limits from the EGRET experiment.

The zenith angle acceptance of the MazePi experiment makes it a kind of a telescope looking up with an opening angle of about 20 deg.

The Roland Maze Project is a member of the European network of school CR experiments Eurocosmics. The limitted angular acceptance of the Maze network shown in Fig. 4 is, from other point of view, its advantage. The collaboration of a few similar experiments could obviously increase the abilities of observing high energy gammas, and could give important crosschecks due to overlapping 'FOV' of different arrays. The network of five similar experiments Poland and Portugal, Holland, Finland, and Greece (for example) can cover the sky over the Europe quite uniformly (with the additional array in Italy the coverage will be almost complete).

3 Possible correlations with CR related phenomena

3.1 Correlation of Cosmic Rays (EGRET γ-rays) and Cosmic Microwave Background temperature

The GRB are believed to be extragalactic, as is cosmic microwave background (CMB). A correlation is found [9] between the CMB [10] temperature and gamma ray intensities [11] and other cosmic ray indicators. For example, regions of the Galaxy having (line of sight) steep cosmic ray energy spectra have low mean CMB temperatures and the important Loop I edge region, where the cosmic ray intensity is high, has a high mean temperature.

Fig. 5 shows a map of the correlation coefficient between 3-years CMB temperature WMAP results [10] and the intensity of diffuse gamma rays of energies greater 1 GeV measured by EGRET [11]. The correlation coefficient was calculated within a cone centered at each point and the angular radius of 40°.

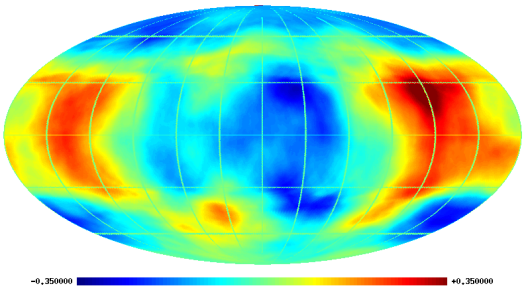

Fig. 5 Correlation coefficient of EGRET ($E_\gamma > 1$ GeV) vs. CMB temperature measured by WMAP calculated within the cone of the width of 40° around each pixel.

The significant positive correlation for outer Quadrants close to the Galactic plane is seen clearly. The positive correlation in the II Quadrant is where the very short GRB cluster exists, however for the III Quadrant the excess of vsGRB is absent.

3.2 Polars

There is a class of a type of cataclysmic variable binary star system with a white dwarf having magnetic field of order one hundred millions Gauss. They are called Polars. The number of known polars used to make a map shown in Fig. 6 is 66. It is seen by eye that their distribution is far from uniform and it is quite similar to the distribution of vsGRB (Fig. 1).

The calculation of the chance probability of such similar distributions on the sphere can be done with the help of factorial moments. Obtained value obtained is of the order of 10^{-4}.

3.3 The CMB observations

A useful map of the sky showing a big contribution from synchrotron radiation (and thereby cosmic ray electron sources) is that from the WMAP group [12]. This map, shown in Figure 7, is for the K-band (23 GHz) and shows considerable emission near the Galactic Plane at l approximately equal to 120 degrees, i.e., the region occupied by many of the vsGRB. The region in question includes the well known Cepheus clouds.

4 Conclusions

The *Pi of the Sky* project developed an autonomic system for detection and analysis of optical flashes connected with GRB and the Roland Maze Project ground level detector array used to look for high energy particles associated with gamma ray burst (GRB) can work together as the MazePi system.

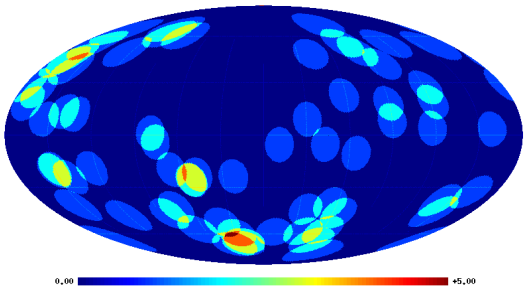

Fig. 6 Polars distribution shown as in Fig 1.

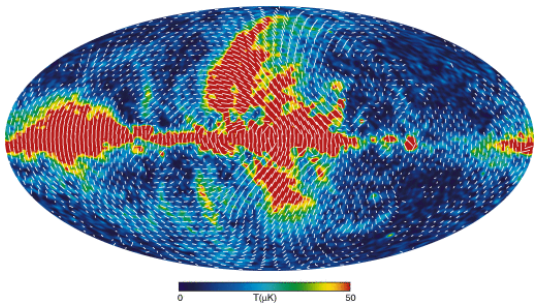

Fig. 7 3-year WMAP K-Band (23 GHz) polarization map [12].

The possible correlations of very short GRB with, CMB, cosmic rays or particular kind of astronomical objects is shown.

Acknowledgements This work was financed by Polish Ministry of Science in 2006-2007 as a research project. We would like to thank the Authorities of City of Lodz for the financial support.

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