A Cerenkov Imaging Telescope for High Energy Gamma Rays

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Abstract

A large area gamma ray telescope based on the gas Cerenkov imaging technique is presented. The performances of the instrument for the observation of high energy gamma ray point sources are discussed.

1 - Introduction

A new field in high energy astrophysics was opened with the discovery by SAS-2 and COS-B of some 25 gamma ray sources above 30 MeV (see /1/ for a review). After the publication of the COS-B catalog the situation is as follows: (i) sources are located with error radii of a fraction of a degree at best, (ii) detailed energy spectra up to a few GeV could be extracted for only a few sources (Crab, Vela and Geminga), (iii) reliable data on periodicity are available only for the Crab and Vela pulsars. The main limitation in these experiments was the restricted sensitive area of the telescopes which prevented from accumulating a sufficient statistics of photons to provide detailed results for the fainter sources.

On the upper energy side air shower arrays were also successful at identifying gamma ray sources from a few hundreds of GeV up to 10^{16} eV (a review is given in /2/). Hampered by a copious cosmic proton background these experiments typically locate gamma ray sources within a few degrees.

More accurate data will be collected by the GRO /3/ and GAMMA-1 /4/ instruments with sensitive areas of 2000cm² and 500 cm² respectively. However it is anticipated that the range 1-100 GeV, where the best angular resolution can be reached, will remain essentially unexplored calling for still larger instruments able to bridge the gap between orbiting telescopes and ground based detectors.

A promising technique to reach this goal is to use the Cerenkov light radiated in a gas by the pair electrons. The idea, originally developed by K. Greisen, led to the design of a large balloon borne telescope which was first to detect the Crab pulsar at several hundreds MeV /5/. More recently the concept was revived with two proposals for a gas Cerenkov gamma ray telescope for the Space Station /6/,/7/. In this paper we discuss in more details the expected performances of the large area Cerenkov imaging telescope for high energy gamma rays as proposed in /7/.

2 - The Gamma Ray Imaging Telescope (GRIMTEL)

A preliminary description of a gas Cerenkov imaging telescope was given in /7/ and a more detailed account was presented in /8/. A sketch of the telescope is shown in Figure 1. Briefly the incident gamma ray is converted into a e+/e- pair in the lead target. Both electrons emit Cerenkov light in the radiator gas at a well defined angle to the particle's trajectories. After being reflected by the mirror the Cerenkov photons are detected by a 2-dimensional position sensitive detector at the focal plane. The image pattern consists of 2 circles with fixed radius whose centers give the direction of propagation of each electron in the gas. The incident gamma ray direction is approximated from the bissector of the two electron directions. The physical characteristics of the envisioned GRIMTEL instrument are summarized in Table 1. The electronic signature of a gamma ray is the 4-fold coincidence S1 x S2 x S3 x F with S3 and F being delayed compared to S2 by 16ns and 33 ns respectively. The directionality and high energy threshold of the Cerenkov effect makes the telescope naturally immune to cosmic ray induced background. The difference between the present proposal and the one described by D. Koch in /6/ lies in the granularity of the focal detector. The latter instrument detects individual Cerenkov photons with an angular uncertainty of 0.21 degree compared to 0.017 for the GRIMTEL. We believe that the improved angular resolution will result in a more reliable gamma ray signature and a better angular resolution to individual gamma rays. In addition it opens the possibility to estimate the energy by the amount of Coulomb scattering in the radiator gas.In the next section we present the expected performances of the GRIMTEL instrument.

3 - Performances of the GRIMTEL

The physical effects ultimately shaping the Cerenkov images of high energy gamma rays are as follows:

- the angle at which converted electrons are emitted
- the Coulomb scattering in the remaining target material
- the Coulomb scattering in the radiator gas
- the chromatic dispersion of the Cerenkov effect

Since we are using a thick target (0.5 r.l.) the 1st effect may be neglected compared to the 2nd one. The 4th effect is minute compared to the 3rd one and may also be ignored.

A Monte-Carlo simulation was performed to evaluate the performances of the instrument. Images of gamma ray events are first generated with the above mentioned 2nd and 3rd effects taken into account. We assume that each electron gives 15 Cerenkov photoelectrons on average in the 5 meters long radiator. In a second step each image are searched for 2 Cerenkov circles whose center coordinates are determined. A typical image of a 2 GeV gamma ray is shown in figure 2 together with the fitted circles. In some cases, especially at very high energy, the circles are so close they cannot be disentangled. For those events the gamma ray signature is a number of photoelectrons along a single circle being twice that for singly charged particles. The effective sensitive area of the GRIMTEL as a function of the aspect of the source to the telescope axis is shown in figure 3. It is seen that a figure of 28000 cm^2 at 0° above 1GeV is reached i.e. 14 times larger than in the GRO instrument. The GRIMTEL with a field of view of about 5° is best suited to the observation of gamma ray point sources. The r.m.s. angular resolution to individual gamma rays is estimated as 0.45° at 2 GeV, 0.18° at 5 GeV and 0.10° at 10 GeV. The improvement brought up by the GRIMTEL over the GRO experiment is not with the intrinsic angular resolution which is similar for both instruments. Rather it is that the larger area enables statistically significant observations to be performed at higher energies where the angular accuracy is significantly better.

The energy measurement could be best achieved with using a shower calorimeter. However if restrictions on weight would rule out this possibility an estimate of the energy could still be obtained from a measurement of the Coulomb scattering in the radiator gas. Investigations of the energy resolution attainable with this method are in progress.

4 - Final comments

The feasability of the proposed experiment depends critically on the availability of a photon detector with fine spatial resolution and sensitive areas of several thousands of cm². In addition the device should deliver a fast linear response to Cerenkov light in order to take part in the trigger generation. The latter requirement is essential for minimizing the telescope dead time so that the readout of the focal detector, with its large number of cells, be triggered only on those events with an appropriate number of Cerenkov photoelectrons. Gaseous detectors sensitive to VUV light have been used successfully to record the Cerenkov rings of charged particles in accelerator beams (see /9/ for a review). An experiment, using a multineedle detector to record the Cerenkov images of 500 MeV gamma rays, is in preparation at Saclay. Development of multianode photomultipliers with a 3x3 mm² pixel size are also currently in progress at Saclay. With these devices a new generation of very large gamma ray telescopes can be envisioned for long exposures on the Space Station. These instruments, with a sensitivity higher by more than one order of magnitude over present day experiments, will undoubtedly increase our present knowledge of the astrophysics associated with celestial gamma ray sources.

References

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Converter:
  0.5 r.l. lead
Mirror:
  spherical f/1.7
  Ø = 3 meters
  f = 5 meters
Radiator gas:
  N2 at STP
  Cerenkov angle = 1.5°
Focal detector:
  Ø = 60 cm
  cell size = 3x3 mm²
  # of cells = 31,400

Table 1 - Physical characteristics of the GRIMTEL.

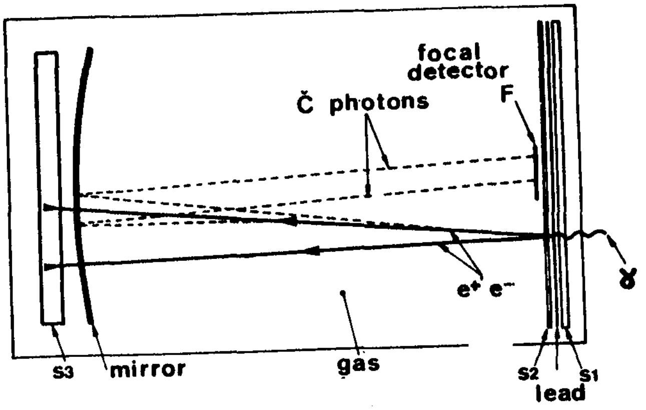

Figure 1 - Sketch of the GRIMTEL.

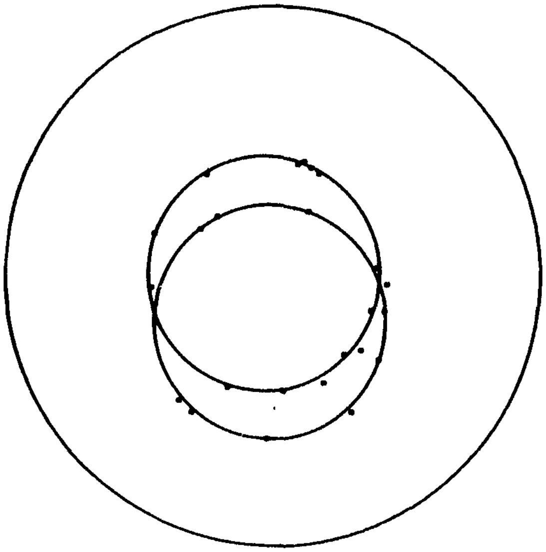

Figure 2 - A simulated Cerenkov image of a 2 GeV gamma ray with fitted circles. Each dot represents a cell lit up by a Cerenkov photon.

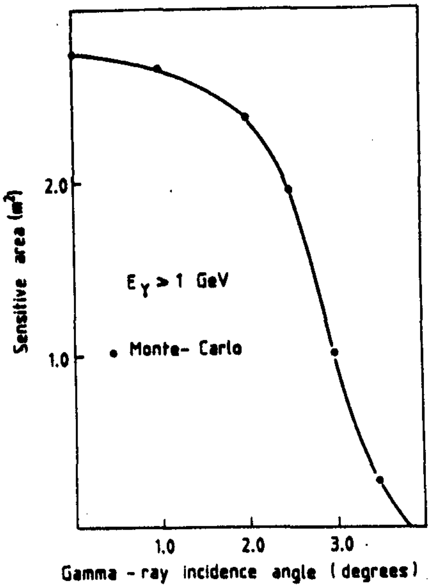

Figure 3 -The effective area of the GRIMTEL as a function of the aspect of the source to the telescope axis.