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FIGARO IV: Large-Area Balloon-Borne Telescope to Study Rapid Time Variabilities in the Gamma-Ray Sources at Energies Above 50 MeV (*).

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Summary. – We present a new γ-ray telescope based on the Limited Streamer Tube technology, used as tracking chambers to detect photons above 100 MeV. This technique allows to obtain very large sensitive areas (16 m^2 in our experiment), together with a good angular resolution for payloads embarcable in high-altitude balloon flights. The capability to collect a large signal in a short exposure time makes the telescope particularly suitable and competitive with respect to satellite-based detectors for studying both periodic and random time variabilities on galactic and extragalactic γ-ray sources.

PACS 98.70.Rz – γ-ray sources.

1. – Introduction.

The results of the observations of EGRET, operating since April 1991 on board the Compton Observatory, point out the relevant role played by random and periodic time variabilities in the celestial γ-ray sources emitting at energies above 100MeV.

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On the side of the galactic γ-ray astronomy, in addition to Crab and Vela, other two sources of the 2CG catalogue [1] are now firmly identified as Pulsars: 2CG195 + 04 (Geminga), pulsating with a period of 237ms [2], and 2CG342-02 identified with PSR1706-44 [3]. The nature of the remaining observed pointlike galactic γ-ray sources is unknown, but a well-founded hypothesis is that they too, or at least a large subset of them, are young pulsars. Data collected by satellite detectors, few hundreds or thousands of photons dispersed in a large-exposure time interval (week to month), are however not suitable for providing an answer in the absence of a known input by observations at other wavelengths because of the difficulty of taking into account the presence of the first derivative on the Pulsar period. Large-effective-area γ-ray telescopes are needed to reduce the exposure time to a scale of hours, to consent the independent search for the existence of a periodicity in the pulsar range (ms to s).

The same applies to the extragalactic sources ($E_\gamma \geqslant 100$MeV), if we want to investigate the short time variability. Sixteen AGNs have been discovered as γ-ray emitters [4]. The variability of their emission, well known at radio, visible and X-ray wavelengths, has been found also at high energies: the flux of 3C279 [5], for example, varies by a factor of 5 in few days, reaching and exceeding values of intensity of strong sources like Geminga or Crab.

2. – Search for γ-ray pulsars above 100 MeV.

The four known γ-ray pulsars have all been identified on the basis of the input provided by findings at longer wavelength: radio in the case of Vela, Crab, and PSR1706-44, soft X-ray in the case of Geminga [6].

On the other hand, it is not given for granted that all gamma-ray sources have an observable counterpart at lower energy: The radio-counterpart of Geminga is up to now unknown, in spite of the deep search in its error box [7-10] and the source is very weak in X-ray or visible light. The observation by ROSAT [6] was possible because the source is located near the Solar System ($d < 0.5$kpc); a Geminga-like source, few kpc far, would be visible only at gamma-ray energies $\geqslant 100$MeV.

To check the hypothesis that Geminga is not unique but it is representative of an entire class of γ-ray sources, it is necessary to perform searches for time periodicity in the other sources of the 2CG catalogue or the future EGRET catalogue, without any *a priori* knowledge (unbiased search) of the pulsar parameters.

A periodic phenomenon like that of a pulsar is characterised by two parameters: the frequency (F) and its first derivative ($\dot{F}$). The value of F ranges from 0.1 Hz (old radio pulsars) up to 1000 Hz (millisecond pulsars), and $\dot{F}$ reaches 10^{-9} Hz/s in the Crab Pulsar.

The condition for having phase coherence in the search gives the number of steps necessary to scan the entire parameter space: $N_{\rm step} = \Delta F * \Delta \dot{F} * T^3/2$, where ΔF and $\Delta \dot{F}$ are the scanning intervals and T is the total observation time.

The order of magnitude of $N_{\rm step}$ to test all the frequency and frequency derivative space for the data collected in the past by the COS-B satellite or presently by EGRET is:

$N_{\rm step} \approx 10^{13}$ COS-B (one month observation time),

$N_{\rm step} \approx 10^{10} \div 10^{12}$ EGRET (strong-weak sources), The minimum detectable flux is limited by the presence of the white-noise fluctuation whose value, proportional to N_{step} or to T^3, can reach or even overwhelm the expected periodic signal.

A typical example is, once more, the case of Geminga: the COS-B satellite observed the source 5 times from 1975 to 1982, in a month exposure time slots, but, in spite of the deep searches, no periodic signal showed up from the γ-ray data. When the ROSAT finding [6] was published, a small CPU time has been sufficient to identify the gamma-ray pulsar [11, 12]. In the following, we propose a new γ-ray telescope able to collect in few hours(4-6) an amount of γ-ray photons from the gamma sources sufficient to perform unbiased searches for periodicities (pulsar range) at high-sensitivity limits. This experiment, designed to search for periodic phenomena, is, also, suitable for studying random time variability in extragalactic gamma sources.

3. – Telescope layout.

The telescope, named FIGARO IV, is based on Limited Streamer Tubes LST [13] as tracking detectors to identify the arrival direction of gamma-ray photons at energy above 100MeV, after their pair conversion in a thin layer of lead.

Large system of LST are used at present, in several cosmic-ray experiments, either in underground laboratories of in surface layout [14, 15]. The tubes are industrially built using extruded PVC or policarbonate profiles.

Basically, the FIGARO IV telescope is composed of seven planes of LST, $16m^2$ each with a guard ring around the first three planes. A scheme of the arrangement of the configuration is shown in fig. 1.

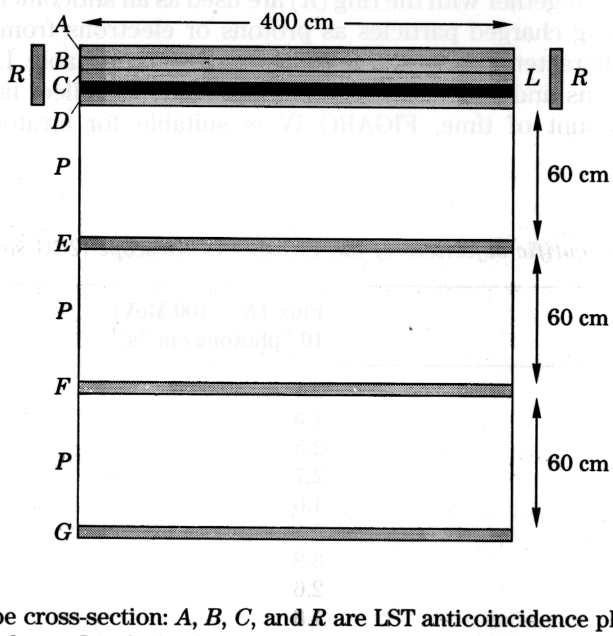

Fig. 1. – Telescope cross-section: *A*, *B*, *C*, and *R* are LST anticoincidence planes; *D*, *E*, *F*, and *G* are LST Stracking planes; *L* is the lead converter; *P* are Styrofoam honeycomb boxes. The figure is not in scale.

TABLE I. – *Technical characteristics of* FIGARO IV.

Detector type	LST (1cm^2 cell)
Number of LST plane	7
Gamma-ray converter	Lead (2 mm thick)
Geometric area	160 000 cm^2
Pick-up	Strips (1 cm pitch)
Read-out channels	4800
Intrinsic spatial resolution	0.5 cm
Telescope height	2 m
Telescope weight	1.5 ton

Each plane consists of 50 units of dimensions (8×400)cm^2, with the basic unit constituted by 8 square tubes of 1 cm^2 in section, 4 m long.

These first three planes (called *A*, *B* and *C* in the figure) are close to each other, spaced few centimetres apart, with a guard ring (*R*) placed around.

A 2mm thick layer of lead (*L*) is placed between the planes *C* and *D*; the *E*, *F* and *G* planes are spaced 60cm apart.

The LST planes are supported by an honeycomb Styrofoam structure (*P*), assuring the parallelism.

The read-out of the LST is performed by strips with 1cm pitch, parallel to the tubes (*X*-direction) and by strips hortogonal to them (*Y*-direction).

A chain of read-out electronics boards placed on both the *X* and *Y* sides of each plane transfers the digitalized position information into the data acquisition system.

Seven separate HV channels (1 for each plane) feed the LST, through a distribution bus.

A, *B*, and *C* planes together with the ring (*R*) are used as an anticoincidence system to discriminate incoming charged particles as protons or electrons from photons.

The technical characteristics of the telescope are given in table I.

For his dimensions and weight and for his capability to collect large signals in a relatively short amount of time, FIGARO IV is suitable for stratospheric balloon flights.

TABLE II. – *List of scientific objectives of the* FIGARO IV *telescope* (2CG *sources*).

Source name	Flux ($E>100$ MeV) 10^{-6} photons cm^{-2}s^{-1}
2CG006 – 00	2.4
2CG036 + 01	1.9
2CG078 + 01	2.5
2CG284 – 00	2.7
2CG288 – 00	1.6
2CG311 – 01	2.1
2CG333 + 01	3.8
2CG356 + 00	2.6
2CG359 – 00	1.8

4. – Telescope scientific performance.

We compute the effective area and resolution of the telescope, as a function of energy, by using a Monte Carlo based on GEANT of CERN. The work is still in progress, but the first results indicate an effective area of the order of 30 000 cm^2 or more at energy above 100MeV. The angular resolution is few degrees at low energy and improves until 1.5° at 1GeV.

The main component of the telescope background is due to the atmospheric γ-ray flux at the balloon altitude coming from all the acceptance solid angle. It is a complex function of energy, angle to zenith, altitude, cut-off rigidity. By using experimental results [16-20] we obtain for the flux normalized at 1 GV rigidity and 1 g/cm^2 of residual atmosphere:

$$\Phi = 5.6 \cdot 10^{-3} E^{-1.0} (\text{photons MeV}^{-1} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1} (\text{g/cm}^2)^{-1});$$

$$10 < E(\text{MeV}) < 100, \text{ and}$$

$$\Phi = 2.2 \cdot 10^{-1} E^{-1.8} (\text{photons MeV}^{-1} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1} (\text{g/cm}^2)^{-1});$$

$$E(\text{MeV}) > 100 .$$

Assuming a typical balloon altitude of 4 g/cm^2 and a cut-off rigidity of 8.2 GV (transmediterranean flight), we compute that about 400 counts s^{-1} will be collected in the telescope field of view (≈ 2sr).

To evaluate the sensitivity of FIGARO IV, we take into consideration a source observation time of $2 \cdot 10^4$ s, achievable in a typical balloon flight. The values of effective area, angular resolution and background foreseen for FIGARO IV indicate its capability to detect a time periodicity in gamma-ray sources which have a flux higher than $\Phi_{min} = (1.5 \div 2) 10^{-6}$ photons $cm^{-2} s^{-1}$ for energy above 100MeV.

Nine unidentified galactic sources of the 2CG catalogue (see table II) have fluxes above this limit. Two medium-latitude balloon flights, 24 hour long, one in the northern and the other in the southern Emisphere are sufficient to investigate all these objects.

5. – Conclusion.

The FIGARO IV telescope has been designed to provide high sensitivity in the search for time periodicities. Its main characteristics, given by the very large effective area, make it suitable, on the other hand, for other interesting fields of application: one is the study of random variabilities at the level of $(10^3 \div 10^4)$s in the γ-ray sources and, in particular, in the AGNs; a second is the observation of γ-ray bursts above 50MeV, as the one of May 3, 1991 detected by the EGRET spark chamber [21].

The study of these two items is limited in the one-day balloon flights because of the randomness of the phenomena, which requires extended observations. The possibility however of long-duration balloon flights or the use of the future Space Stations increase the scientific interest for telescopes like FIGARO IV and the importance of the space qualification of light detectors like the LST assembled in very large areas.

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