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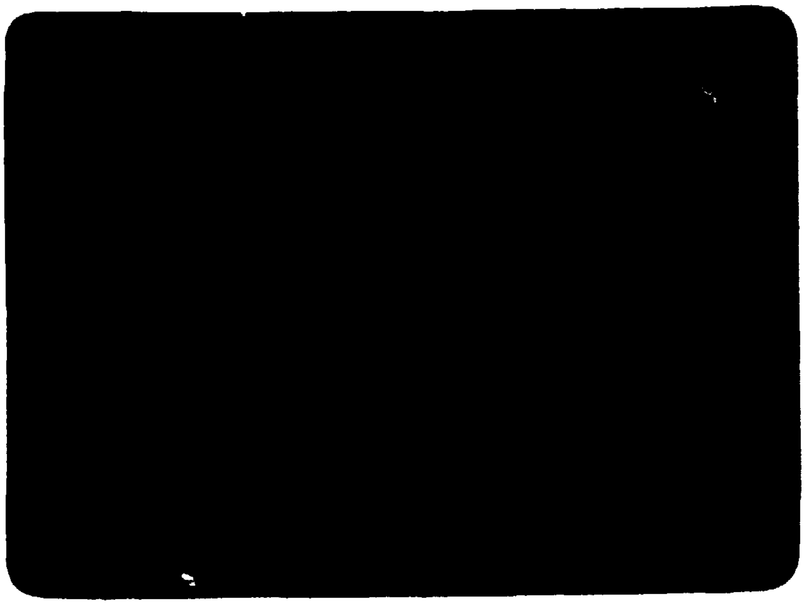

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14. Abstract/Notes The main goal of the balloon-borne "PULSAR" experiment is to observe γ-ray photons of variable sources and pulsars in the energy range 0.1-5.0 MeV. The geometrical arrangement of the telescope has been designed according to detector sensitivity estimations for the pulsed radiation, which have been made by empirical and analytical methods. From the obtained results we expect to achieve a detection sensitivity of 3.7×10^{-7} photons cm^{-2} s^{-1} KeV^{-1} (0.1-0.5 MeV) and 4.5×10^{-8} photons cm^{-2} s^{-1} KeV^{-1} (1.0-5.0 MeV), for 5 hours integration time at 5 g cm^{-2} atmospheric depth, with 3σ statistical significance. It was developed an on-board eletronics, compatible with the available telemetry capacity, that is able to process the data with a time resolution of ∿ 4 miliseconds.

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PULSAR: A BALLOON-BORNE EXPERIMENT TO DETECT VARIABLE LOW ENERGY GAMMA-RAY EMISSIONS.

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RESUMO

O principal objetivo da experiência "PULSAR", a ser lançada em balão estratosférico, consiste em observar raios gama oriundos de fontes variáveis e pulsares no intervalo de energia de 0.1 a 5.0 MeV. A configuração geométrica do telescópio foi projetada de acordo com estimativas da sensitividade do detetor para observar radiação pulsada. A partir destas estimativas, realizadas por métodos analíticos e empíricos, espera-se obter uma sensitividade de 3.7 X 10^{-7} fótons cm^{-2} s^{-1} KeV^{-1} para o intervalo de 0.1 a 0.5 MeV e de 4.5 X 10^{-8} fótons cm^{-2} s^{-1} KeV^{-1} para o intervalo de 1.0 a 5.0 MeV, para um tempo de integração de 5 horas a uma atmosfera residual de 5 g cm^{-2}, com um nível de confiabilidade estatística de 3σ. Foi desenvolvida uma eletrônica de bordo, compatível com a capacidade da telemetria disponível, capaz de analisar os dados com uma resolução temporal de 4 milissegundos.

ABSTRACT

The main goal of the balloon-borne "PULSAR" experiment is to observe γ-ray photons of variable sources and pulsars in the energy range 0.1-5.0 MeV. The geometrical arrangement of the telescope has been designed according to detector sensitivity estimations for the pulsed radiation, which have been made by empirical and analytical methods. From the obtained results we expect to achieve a detection sensitivity of 3.7 x 10^{-7} photons cm^{-2} s^{-1} KeV^{-1} (0.1 - 0.5 MeV) and 4.5 X 10^{-8} photons cm^{-2} s^{-1} KeV^{-1}(1.0 - 5.0 MeV), for 5 hours integration time at 5 g cm^{-2} atmospheric depth, with 3σ statistical significance. It was developed an on-board eletronics, compatible with the available telemetry capacity, that is able to process the data with a time resolution of $\sim$ 4 miliseconds.

Key words: PULSARS-GAMMA-RAYS.

I. INTRODUCTION

Some of the several γ-ray sources recently revealed by the COS-B satellite observations (Bennett et al., 1977; Masnou et al., 1977) have not been identified as X-ray emitting objects. Theoretical predictions concerning the pulsars among these sources suggest that they are in fact only γ-ray emitters (Massaro and Salvati, 1977; Lamb, 1978) although the results obtained so far at energies $E\gamma \gtrsim 10$ MeV indicate only upper limit fluxes.

In general the detectors utilized for these measurements have not large detection areas despite their high angular resolutions. The large field-of-view and large surface detectors, like our "PULSAR" telescope presented in this paper, allow to carry out simultaneous observations of different periodical sources. The fact that each of these sources is identified by its own period allows a separation of each one from the others and from the ever present background by using temporal analysis.

The most intense pulsar γ-radiation arriving at the Earth comes from nearby sources that loose large amounts of rotational energy by spinning rapidly (so that corresponding to short periods) in the presence of a large star magnetic field. Among these objects, the Crab (PSR 0531 + 21) and Vela (PSR 0833-45) pulsars are well known as short-period radio-pulsars that emit high-energy γ-rays (Kanbach et al., 1977; Kniffen et al., 1977). Their periods are 0.033 s and 0.089 s respectively. Hence it is very important to reach time accuracy of the order of miliseconds in the temporal analysis of the radiation coming from these objects. Such accuracy can only be achieved in a balloon-borne experiment by processing the data on board. The "PULSAR" telescope and its associated eletronics, described in this paper, have been projected in order to fulfil the above requirements.

II. DETECTION ASSEMBLY AND ASSOCIATED ELECTRONICS

A sketch of the detection assembly is shown in Figure 1. The main detector (A) is a 6"-diameter X 1"-thickness NaI(Tℓ) crystal, corresponding to a geometrical surface of ∿ 182 cm^2. The crystal is optically coupled to a RCA 8060 photomultiplier tube. The energy resolution (Full Width at Half Maximum) of the system is 23% at 611 KeV. The crystal is protected at the bottom by a 8"x4" NaI(Tℓ) scintillator (B) and is surrounded by a 14"x5" NE102 plastic scintillator ring shielding (W). The charged particles that would penetrate in the ring upper aperture are eliminated by a 5 mm-thick plastic scintillator (P).

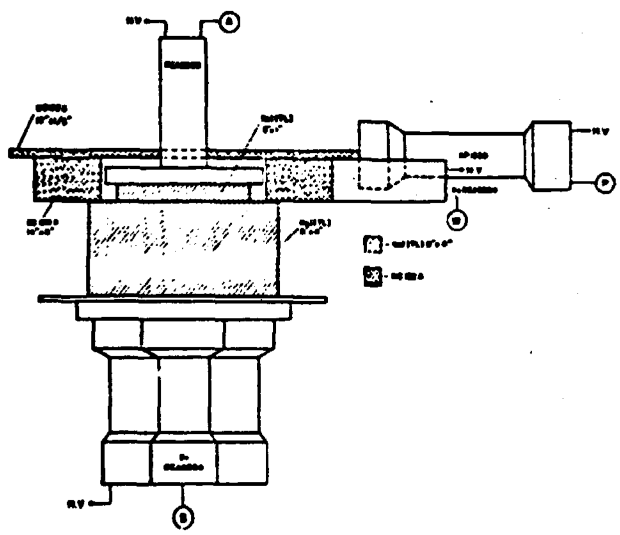

FIG. 1. Sketch of the detection assembly.

The output pulses of the photomultipliers associated with (B) and (W) are passively added, and then amplified and formatted (Fig. 2). After that, the lower level discriminators are triggered by the amplified signals. The discrimination levels for the anticoincidence are set at an equivalent energy of ∿ 100 KeV. The output pulses of the (A) detector, without any anticoincidence from the "nor" circuit, will be analysed by a 128- channels and a 5-channels encoders. The first one defines a 10-bits word of 4-miliseconds total width, randomly transmitted according to the arrival of the events at the telemetry E channel. The contents of each channel of the second encoder, which are registred in the respective counting scalers (Ci), will be loaded in the shift registrer in a 16f rate, f being the clock frequency fixed at 5 KHz. The shift registrer word is defined by 18 bits while the counter contents have 3 bits (C1-C4) and 2 bits (C5). Under these conditions, the observed counts for each energy band will be defined within 3.6 miliseconds time resolution.

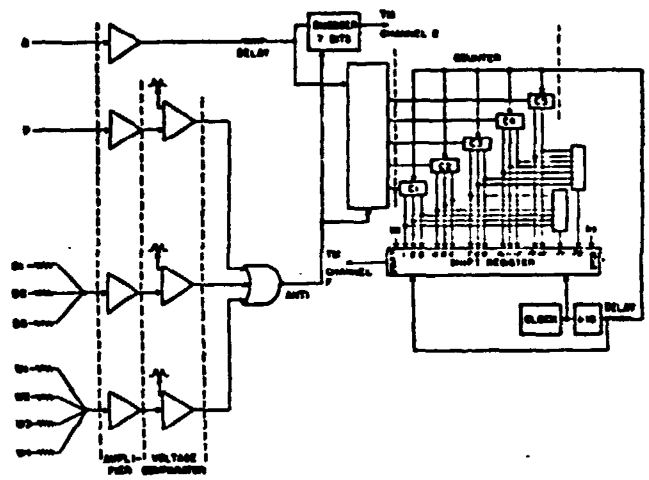

FIG. 2. Block diagram of the electronics associated to the detection assembly.

III. FLUX ESTIMATION AT BALLOON ALTITUDES

The spectra obtained with the 8"x4" NaI (Tℓ) crystal during a balloon flight and from ground calibrations are shown in Figure 3 (Jayanthi et al., 1983). The similitarity between the features of these spectra and those obtained on the ground using the 6"x1" NaI(Tℓ) detector in anticoincidence with the 8"x4", has allowed the inference of an empirical relation between the photon production at the ground and at balloon altitudes ($\sim$ 5 g/cm²), irrespective of detector dimensions. Using this assumption and the 8"x4" crystal results we can extrapolate our 6"x1" ground values to a background estimation at $\sim$ 5 g/cm² (Fig. 4).

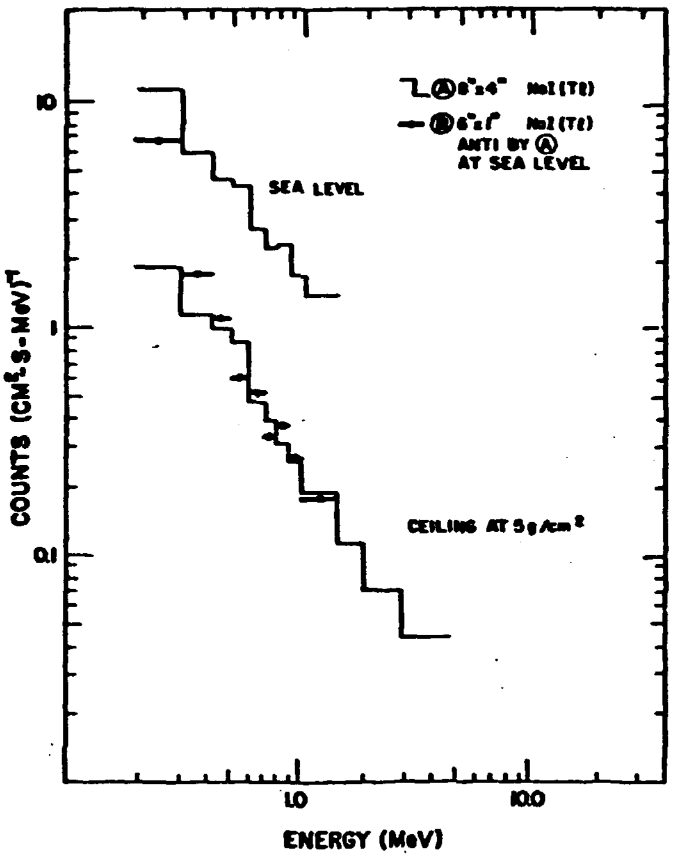

FIG. 3. Comparison between the background spectra observed at sea level and at balloon altitudes with different detectors.

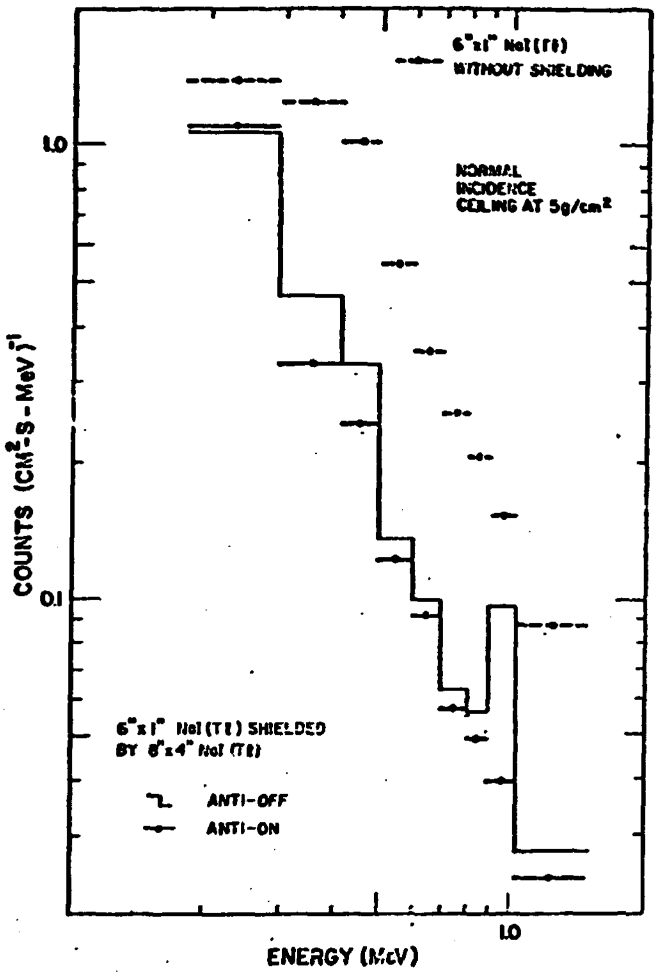

FIG. 4. 8"x4" NaI(Tℓ) shielding effect on the background spectra extrapolated to balloon altitudes.

The 8"x4" crystal performs as an almost perfect shield for energies below 300 KeV, whether it is activated or not. Besides that, a better lateral protection is achieved due to the small thickness of the 6"x1" detector. This effect is shown in Figure 5. It is noteworthy that when the detector's axis is inclined 45° and 90° with respect to the vertical, the estimated balloon-altitude spectra at energies around 1 MeV provide the same counting than those obtained at 0°.

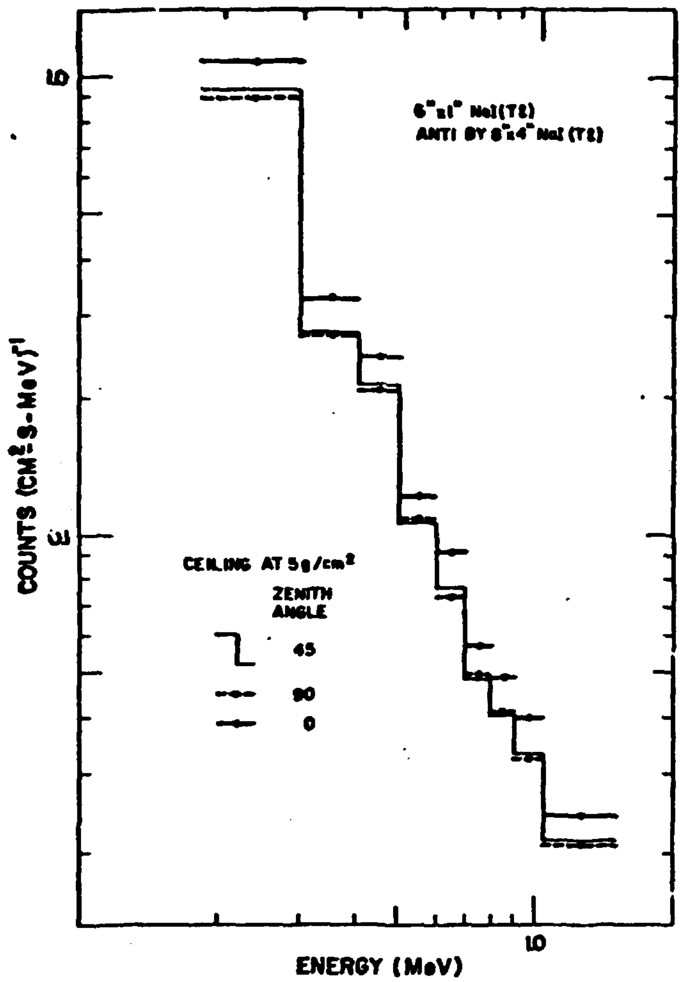

FIG. 5. 8"x4" NaI(Tℓ) shielding effect estimated for balloon altitudes at various zenith angles.

In order to confirm the validity of this empirical method, the results have been compared with the calculation made by a numerical simulation computer program (Mandrou, 1979), (Fig. 6), which have taken into account the contribution of the cosmic and atmospheric photons as well as the induced photon production in the NaI(Tℓ) crystals due to neutrons and charged particles. In fact, the calculated fluxes using both methods agree well at low energies (E $\lesssim$ 300 KeV), but at higher energies the induced reactions are no more negligible, so that the analytical calculations becames nearer to the expected real conditions than the empirical estimations.

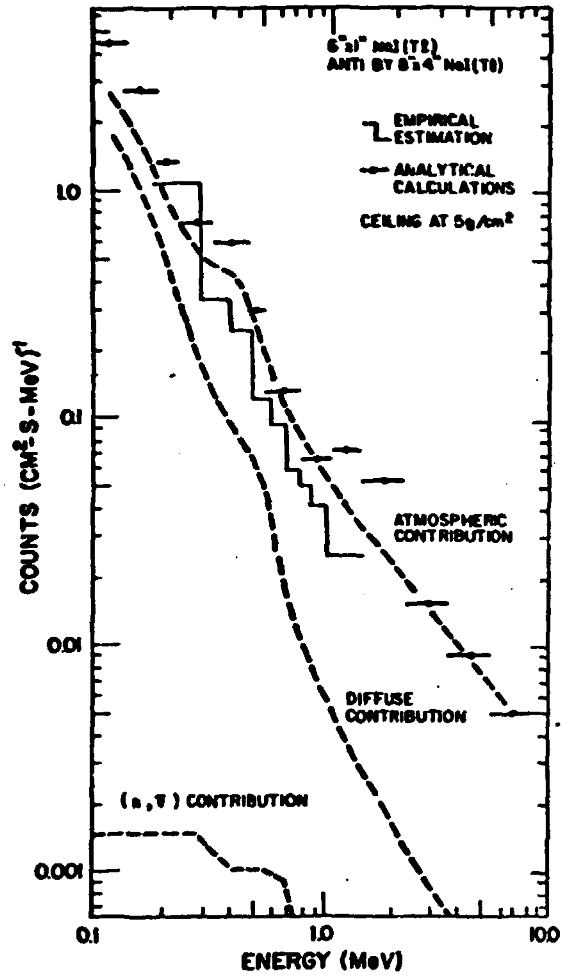

FIG. 6. Comparison between background spectra at balloon altitudes obtained with empirical and analytical calculations.

IV. SENSITIVITY ESTIMATIONS FOR THE DETECTION ASSEMBLY

The detection assembly sensitivity is defined as the minimum detectable flux F_m (photons cm^{-2} s^{-1} KeV^{-1}), which can be approximated by (Willett et al., 1978):

$$F_m \approx \frac{K^2 + K\sqrt{K^2 + B.T_s.\Delta E.\delta}}{2.A_e.T_s.\Delta E}$$

where

K - statistical significance (standard deviations above background)

A_e - effective area (cm^2)

B - background counting rate (counts s^{-1} KeV^{-1})

T_s - integration time (s)

ΔE - energy range of the measurements (KeV)

δ - duty cycle

The F_m values calculated using the B values obtained from the two methods, at different energy ranges, are shown in Figure 7. The results were obtained for K=3, T_s=18000 s (5 hours) and δ=0.2.

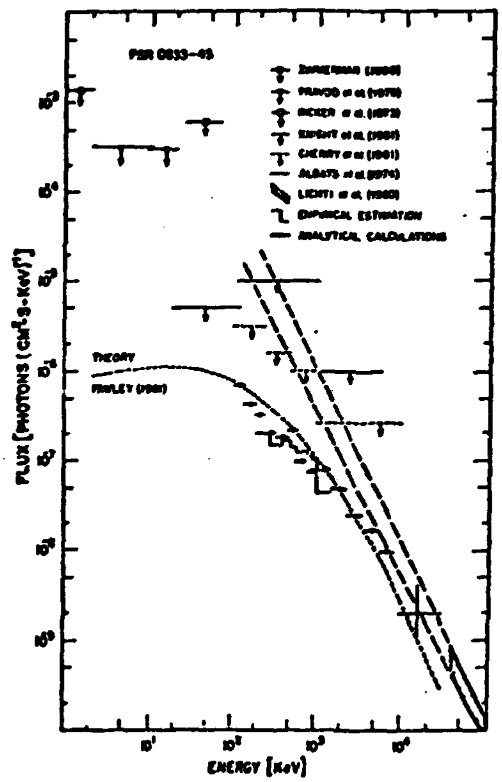

FIG. 7. Comparison between the sensivities of the detection assembly and the upper limit fluxes observed by several authors for the PSR 0833-45 (Vela) pulsar.

A comparison between these results and the flux upper limits of the PSR 0833-45 (Vela) pulsar reported by several authors (Pravdo & Serlemitsos, 1981; Zimmerman, 1980; Ricker et al., 1973; Knight, 1981; Cherry et al., 1981; Albats et al., 1974; Lichti et al., 1980) shows that the "PULSAR" experience is 10 times more sensitive than the presently known instruments in the energy range 0.1-1.0 MeV.

This sensitivity improvement will allow a verification of the theoretical predictions (Fawley, 1978) that foresee an extinction of the source emission in the X-ray energy domain.

V. CONCLUSIONS

Among the 350 known radio-pulsars (Manchester & Taylor, 1977 and 1981), only PSR 0531 + 21 (Crab) and PSR 0833-45 (Vela) have been identified as γ-ray emitter pulsars (Kanbach et al., 1977; Kniffen et al., 1977). The Vela observations in the energy range 0.1-1.0 MeV are limited by the relatively low sensitivities of the available detectors. The main goal of the "PULSAR" project is to improve the γ-ray observations (0.1-1.0 MeV) of the pulsed emissions of these objects. For this purpose, it has been developed an on-board electronics to achieve better time resolutions in the data analysis. We shall be able to achieve a detection sensitivity of 3.7×10^{-7} photons $cm^{-2}\ s^{-1}\ KeV^{-1}$ in the energy range 0.1-0.5 MeV and 4.5×10^{-8} photons $cm^{-1}\ s^{-1}\ KeV^{-1}$ in the energy range 1.0-5.0 MeV, for 5 hours integration time at 5 g cm^{-2} atmospheric depth, with 3σ statistical significance.

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