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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 configuraçao 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 3.7×10^{-7} fótons cm^{-2} s^{-1} keV^{-1} para o intervalo de 0.1 a 0.5 MeV e de 4.5×10^{-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 are carried out 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), in 5 hours integration time at 5 g cm^{-2} atmospheric depth, with 3σ statistical significance. On-board electronics was developed compatible with the available telemetry capacity, 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 limits of the fluxes.

In general the detectors utilized for these measurements do not have large detection areas despite their high angular resolution. 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 the Earth comes from nearby sources that lose large amounts of rotational energy by spinning rapidly (so that corresponding to short periods) in the presence of a strong stellar magnetic field. Among these objects, the Crab (PSR 0531+21) and Vela (PSR 0833–45) pulsars are well known as shsort-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 milliseconds 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 electronics, described in this paper, have been designed in order to fulfill 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 × 1″-thickness NaI(Tℓ) crystal, corresponding to a geometrical surface of $\sim$ 182 cm^2. The crystal is optically coupled to an 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 8″ × 4″ NaI(Tℓ) scintillator (B) and is surrounded by a 14″ × 5″ NE102 plastic scintillator ring shielding (W). Charged particles penetrating the ring upper aperture are eliminated by a 5 mm-thick plastic scintillator (P).

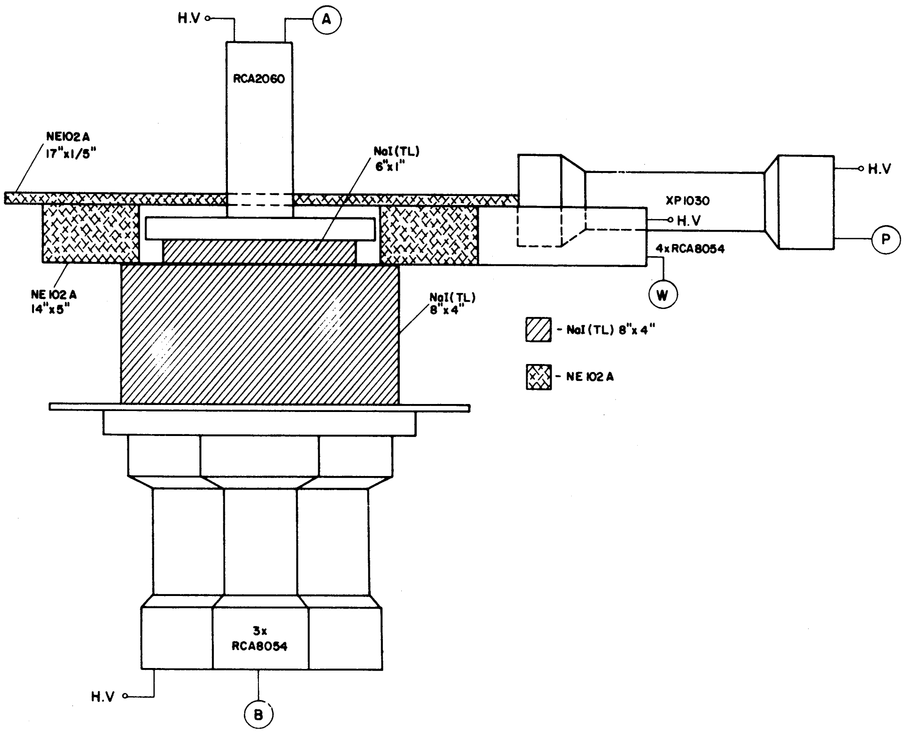

Fig. 1. Sketch of the detection assembly.

The output pulses of the photomultipliers associated with (B) and (W) are passively added, and then amplified and formatted (Figure 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 $\sim$ 100 keV. The output pulses of

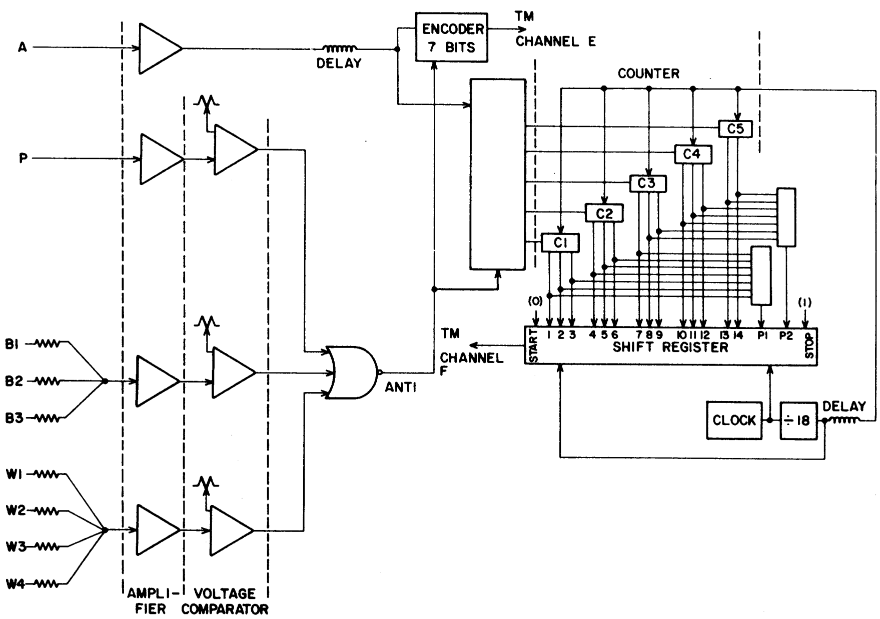

Fig. 2. Block diagram of the electronics associated to the detection assembly.

the (A) detector, without any anticoincidence from the "nor" circuit, will be analyzed by a 128-channels and a 5-channels encoders. The first one defines a 10-bit word of 4-milliseconds 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 registered in the respective counting scalers (Ci) will be loaded in the shift register in a 16 f rate, f being the clock frequency fixed at 5 kHz. The shift registered 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 milliseconds time resolution.

III. FLUX ESTIMATION AT BALLOON ALTITUDES

The spectra obtained with the 8″ X 4″ NaI (Tℓ) crystal during a balloon flight and from ground calibration are shown in Figure 3 (Jayanthi *et al.* 1983). The similarity between the features of these spectra and those obtained on the ground using the 6″ X 1″ NaI (Tℓ) detector in anticoincidence with the 8″ X 4″ crystal, has allowed the inference of an empirical relation between the photon production at the ground and at balloon altitudes (~ 5 g/cm^2), irrespective of detector dimensions. Using this assumption and the 8″ X 4″ crystal results we can extrapolate our 6″ X 1″ ground values to a background estimation at ~ 5 g/cm^2 (Figure 4).

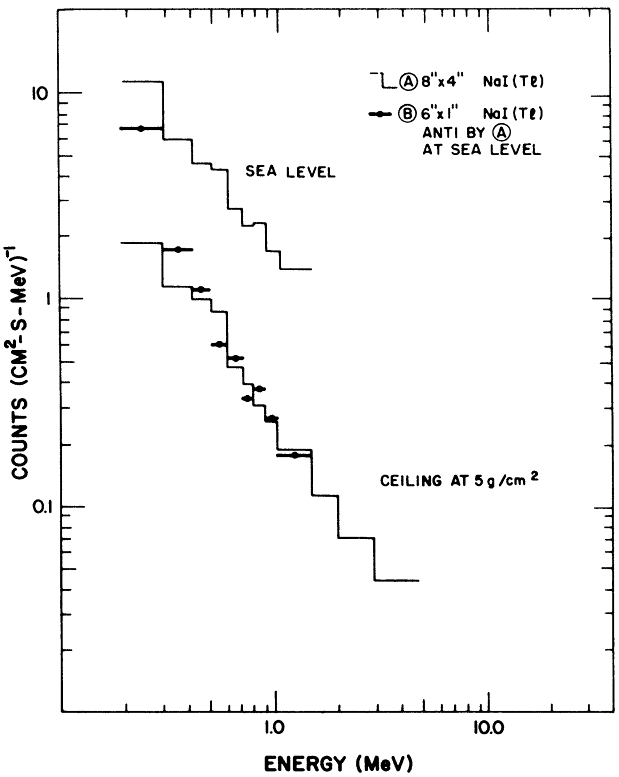

Fig. 3. Comparison between the background spectra observed at sea level at balloon altitudes with different detectors.

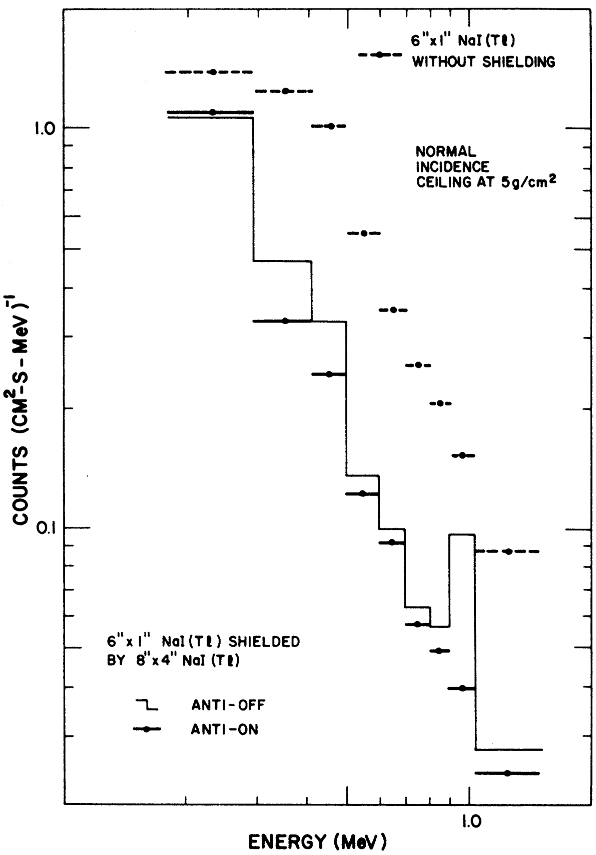

Fig. 4. 8″ X 4″ NaI(Tℓ) shielding effect on the background spectra extrapolated to balloon altitudes.

The 8″ X 4″ 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″ X 1″ detector. This effect is shown in Figure 5. It is noteworthy that when the detector's axis is inclined by 45° and 90° with respect to the vertical, the estimated balloon-altitude spectra at energies around 1 MeV provide the same counting rate as those obtained at 0°.

In order to confirm the validity of this empirical method, the results have been compared with the calculations made by a numerical simulation computer program (Mandrou 1979), (Figure 6), which takes 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 ($E < 300$ keV), but at higher ener-

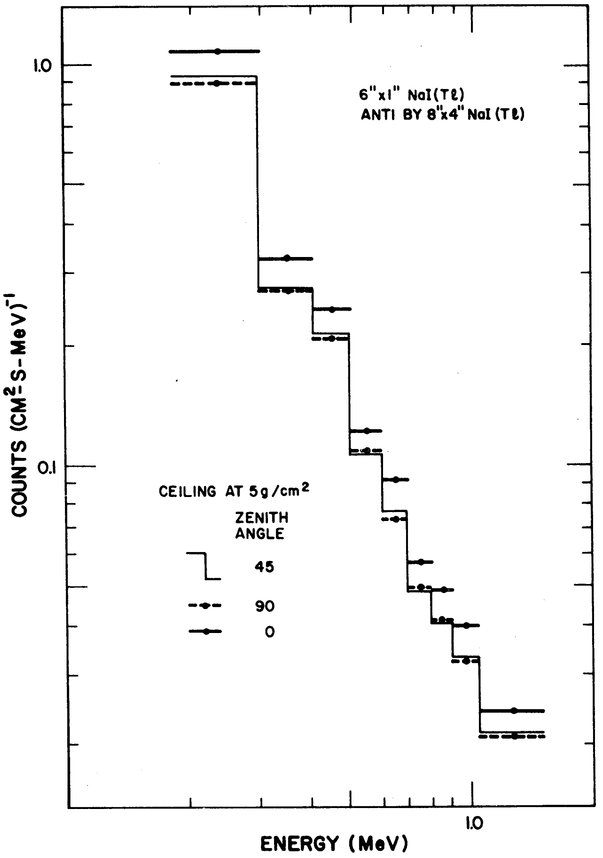

Fig. 5. 8" × 4" NaI(Tℓ) shielding effect estimated for balloon altitudes at various zenith angles.

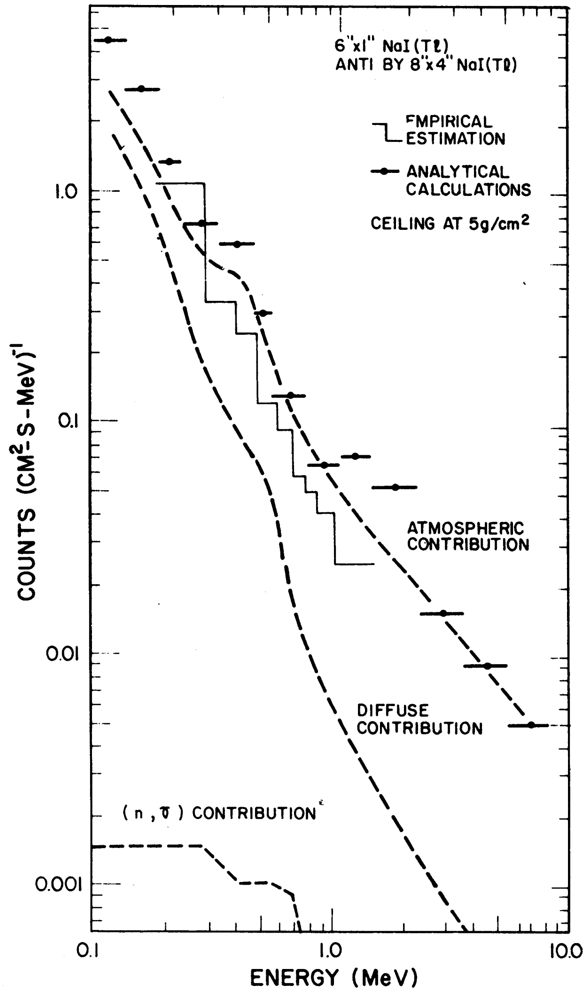

Fig. 6. Comparison between background spectra at ballooon altitudes obtained with empirical and analytical calculations.

gies the induced reactions are no more negligible, so that the analytical calculations became closer to the expected real conditions than the empirical estimations.

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):

$$F_m \approx \frac{K^2 + K\,(K^2 + B\,T_s\,\Delta E\,\delta)^{1/2}}{2\,A_e T_s\,\Delta E}$$

where: K is the statistical significance (in units of standard deviations above background), A_e is the effective area (cm^2), B is the background counting rate (counts s^{-1} keV^{-1}), T_s is the integration time (s), ΔE is the energy range of the measurements (keV), and δ is the 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 $\delta = 0.2$.

A comparison between these results and the flux upper limits of the PSR 0833−45 (Vela) pulsar reported by several authors (Pravdo *et al.* 1976, Zimmerman 1980; Ricker *et al.* 1973; Knight 1981; Cherry *et al.* 1981; Albats, Frye, and Thomson 1974; Lichti *et al.* 1980) shows that the "PULSAR" experience is 10 times more sensitive than the presently existing 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 and Taylor 1977, 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

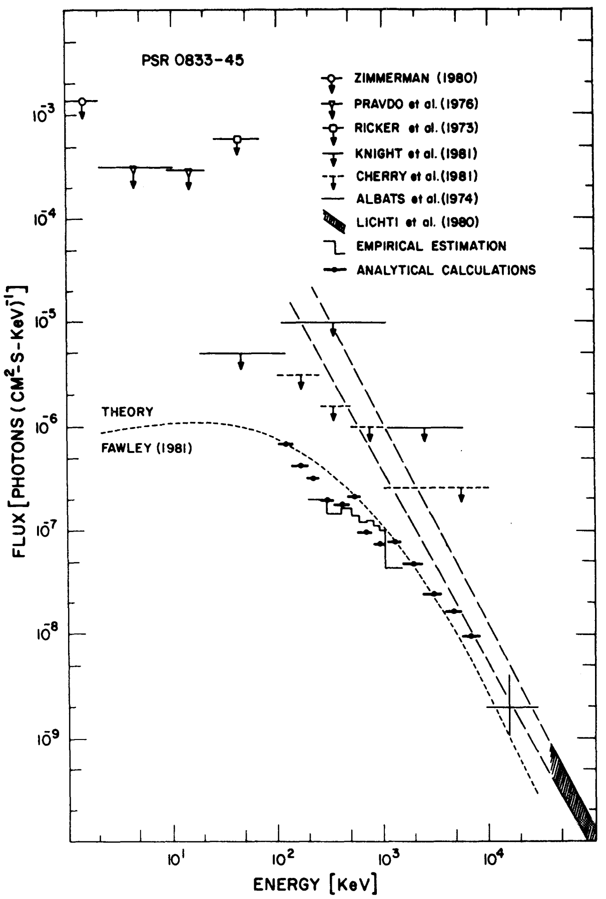

Fig. 7. Comparison between the sensitivities of the detection assembly and the upper limit fluxes observed by several authors for the PSR 0833−45 (Vela) pulsar.

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, onboard electronics has been developed to achieve better time resolution 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, in 5 hours integration time at 5 g cm^{-2} atmospheric depth, with 3σ statistical significance.

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