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ANGULAR SENSITIVITIES OF SCINTILLATOR  
SLAB CONFIGURATIONS FOR LOCATION OF  
GAMMA RAY BURSTS

by

John C. Gregory

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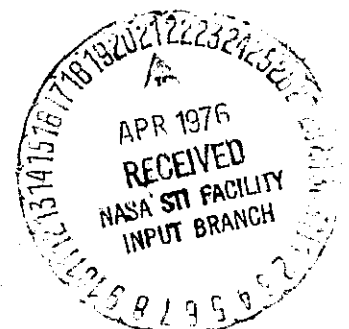
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National Aeronautics and Space Administration  
George C. Marshall Space Flight Center  
Marshall Space Flight Center, Alabama 35894

Submitted by

The University of Alabama in Huntsville  
School of Graduate Studies and Research  
P.O. Box 1247  
Huntsville, Alabama 35807

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## SUMMARY

Thin flat slabs of scintillator are a useful means of measuring angular location of gamma-ray fluxes of astronomical interest. A statistical estimate of position error has been made of two scintillator systems suitable for gamma-ray burst location from a balloon or satellite platform. A single rotating scintillator with associated flux monitor is compared with a pair of stationary orthogonal scintillators. Position error for a strong burst is of the order of a few arcmin if systematic errors are ignored.

## INTRODUCTION

Slabs of scintillator may be used as directional gamma ray detectors for a number of studies in astronomy including measurement of cosmological gamma ray anisotropy, location of discrete sources, measurement of atmospheric anisotropy, and location of gamma ray bursts.

We examine here only the last of these, and attempt to estimate the position error of scintillator systems of reasonable dimensions used to locate these transient phenomena.

Five years ago the gamma ray bursts were discovered by detectors on Vela spacecraft. Since then some 40 bursts have been detected by at least 9 spacecraft in addition to several Vela satellites. The bursts are a unique phenomenon with no parallels in other energy regions or time scales of astronomy. Compared to other astronomical sources of gamma rays the bursts have large flux, a hard spectrum and duration of less than one second to some tens of seconds. They have not yet been identified with any optical or x-ray object. Crude position measurements with uncertainties of  $5^{\circ}$ - $10^{\circ}$  are available for less than a dozen bursts and so far indicate an apparently random distribution.

The next major step in the understanding of these extremely energetic processes requires their position location to a degree of accuracy which allows identification with an object previously observed in some other spectral region. Candidate instruments and techniques which have been proposed for this purpose, include long baseline timing,<sup>1</sup> the x-ray shadowgraph,<sup>2</sup> an array of one dimensional Dicke cameras,<sup>3</sup> and

an active anti-collimator.<sup>4</sup> We examine here an alternative experimental arrangement using the directional sensitivity exhibited by a thin flat scintillator to a parallel beam of gamma rays. The general case of response of such shaped scintillators has been treated in detail by a number of authors, most recently Trombka et. al.<sup>5</sup> (1975). We have selected here a scintillator of dimensions suited to the purpose of locating the direction of the gamma ray bursts from a small satellite.

We have examined two configurations in detail. The first consists of a planar scintillator rotating rapidly about an axis in its own plane. A single rotating scintillator would locate gamma ray bursts on an arc. Because of the rapid temporal variability of the burst flux, a second stationary scintillator is required to normalize the flux. The second configuration considered is an orthogonal pair of stationary scintillators of similar dimensions. Both two-detector systems give a line position and require a third scintillator to obtain a point position for the burst origin.

A thin flat detector rotating about an axis perpendicular to the flux vector will respond to that flux according to a rectified cosine function,  $|\cos \theta|$ . If the position of the flux source is not known, the function may be fitted to obtain the offset of the source from some reference direction. We have performed this fitting for some simulated bursts allowing for (a) counting statistics of the quantized flux (b) high local and diffuse background (c) intense variation in flux with time over very short periods.

Photon count rates in the detectors were estimated from published burst spectra<sup>6</sup> and from natural background and used to estimate the location position resolution for various burst strengths. This lution was compared with that obtained by fixed orthogonal detectors of similar size.

ROTATING SCINTILLATOR

For a thin flat scintillator of arbitrary shape, area  $A \text{ cm}^2$  and thickness  $d \text{ cm}$ , the number of counts registered is given by

$$N(E, \theta, t) = \iiint A |\cos \theta| \{1 - \exp(-\alpha(E)d \sec \theta)\} \cdot I(E, t) dE d\theta dt \dots (1),$$

where  $\theta$  is the angle between the flux direction and the detector slab-normal,  $I$  is the flux intensity in photons  $\text{cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1}$  and  $\alpha$  is the absorption coefficient for the detector material. The spin rate was chosen to be 2 revolutions  $\text{s}^{-1}$  with counts stored in 1024 bins/ $\pi$  radians. Dwell time per angular bin is 0.244 ms. Counts per angular bin are summed throughout the burst, e.g. for a burst length of 20s, the count rate in a particular angular segment is sampled 80 times. Each sum of samples for each angular position is stored in one of 1024 bins. A similar set of 1024 sums is stored in a corresponding register for the stationary detector. Thus the  $i^{\text{th}}$  bin in the register of one detector covers exactly the same set of time periods as the  $i^{\text{th}}$  bin in the second register.

The burst count  $SP$  summed over the burst period for each bin is calculated from equation (1). To each of these is added the mean background  $\bar{B}$  for the same period, which has been previously determined. To simulate experimental reality, this set of numbers ( $SP + \bar{B}$ ) is randomized according to Poisson statistics and is called  $SP(R)$ . The

same process is performed for the stationary detector using a different set of random numbers to give  $ST(R)$ .

To remove the effect of temporal variation of burst flux, the normalized flux (AA) is calculated from

$$AA = \frac{SP(R) - \bar{B}}{ST(R) - B}$$

AA still retains the form of  $|\cos \theta|$ , see figure 1, and is fitted to the trial function  $K|\cos \theta|$  where K is a constant of normalization (figure 2). The least squares method then gives the burst direction,  $\theta$ . This was determined ten times using different random number sets and the standard deviation of  $\theta$  determined for several burst strengths.

Calculations were performed for a 23 cm x 23 cm x 1 cm CsI(Tl) crystal at a representative energy of 100 keV. In practice a 1 cm CsI slab is rather efficient at this energy and the deviation from the cosine function is not great. Edge effects were ignored.

Several burst strengths were tried and the results of this least-squares fit is shown in Table 1. The strongest bursts have a total energy of  $\sim 4 \times 10^{-4}$  erg  $\text{cm}^{-2}$  and a total of  $\sim 400$  photons  $\text{cm}^{-2}$  burst $^{-1}$  in the energy interval 40-200 keV are received at the Earth. The burst time profile of the April 27, 1972 burst as recorded<sup>7</sup> by the Apollo 16, shown in figure 3, was used as a model and the count rates scaled up or down as required.

A total estimated background count of 1 photon  $\text{cm}^{-2}$   $\text{sec}^{-1}$  between 40 and 200 keV for the local (albedo plus charged-particle-produced) and diffuse components was used. This is assumed isotropic and interacts



with both front and back surfaces of the detector. This flux is typical for a low inclination, low altitude orbit.

## STATIONARY SCINTILLATOR PAIR

Consider the response of two stationary orthogonal thin flat scintillators to a  $\gamma$ -ray flux from a direction perpendicular to the line of intersection of their planes. If  $\theta$  is the angle between the flux vector and the normal to one of the scintillators,

$$\theta + \tan^{-1} \frac{N_2}{N_1} = \tan^{-1} \frac{R_2 - B_2}{R_1 - B_1},$$

where  $R_1$  and  $R_2$  are the actual count ratios measured for each scintillator, and  $N_{1,2}$  and  $B_{1,2}$  are the respective number of burst and background photons respectively for each detector.

The statistical error in  $\theta$ , measured over part or all of the burst is given by

$$\sigma^2(\theta) = \left( \frac{1}{N_1^2 + N_2^2} \right)^2 \left[ N_1^2 \sigma_{R_2}^2 + N_2^2 \sigma_{R_1}^2 + N_2^2 \sigma_{B_1}^2 + N_1^2 \sigma_{B_2}^2 \right].$$

The position error was calculated for the same burst parameters used for the rotating system and is shown in the table. Two cases were considered for each burst type; the burst flux vector in the plane of one detector, and the flux vector at  $45^\circ$  to both detectors.

### CONCLUSION

The estimates of angular position errors made here indicate that the location uncertainties for gamma-ray bursts could be as low as a few minutes of arc for strong bursts and the sizes of scintillators considered if systematic errors in measured rates can be kept below statistical errors. It is noted that statistical errors fall below 1% for the "medium" bursts and these sizes of detector. With respect to systematic errors, the rotating scintillator will have an advantage over two stationary planar detectors. A direct comparison of two detector responses and efficiencies is required for the two fixed scintillators whereas for the rotating scintillator a comparison is only required to correct for temporal fluctuations in the burst flux.

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TABLE 1

Burst Strengths and Angular Resolution

Burst Size	Energy (erg cm <sup>-2</sup> )	Total Burst photons cm <sup>-2</sup> (40-200 keV)	Burst Duration (s)	$\sigma(\theta)$ (arc min) Rotating Slab	$\sigma(\theta)$ (arc min) Orthogonal Slabs	
					0°/90°	45°/45°
Strong	$4 \times 10^{-4}$	400	20	6.0	3.3	6.9
Medium	$5 \times 10^{-5}$	50	7	19.0	16.2	24.5
Weak	$5 \times 10^{-6}$	5	1	1.5 deg.	1.0 deg.	2.0 de <sub>o</sub> .

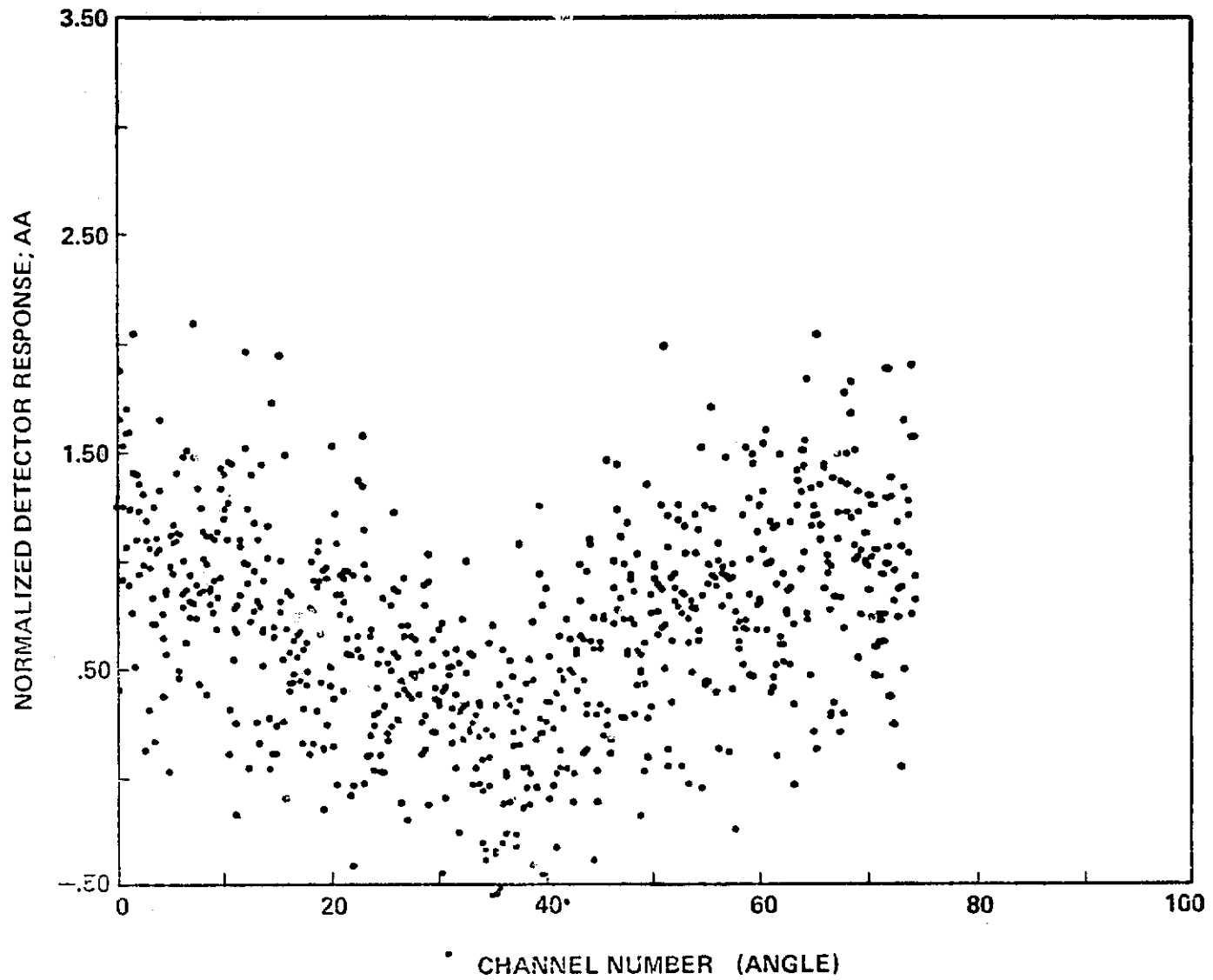


Figure 1: Simulated Detector Response Normalized for  
Flux Variation ;  $AA = \frac{SP(R) - B}{ST(R) - B}$

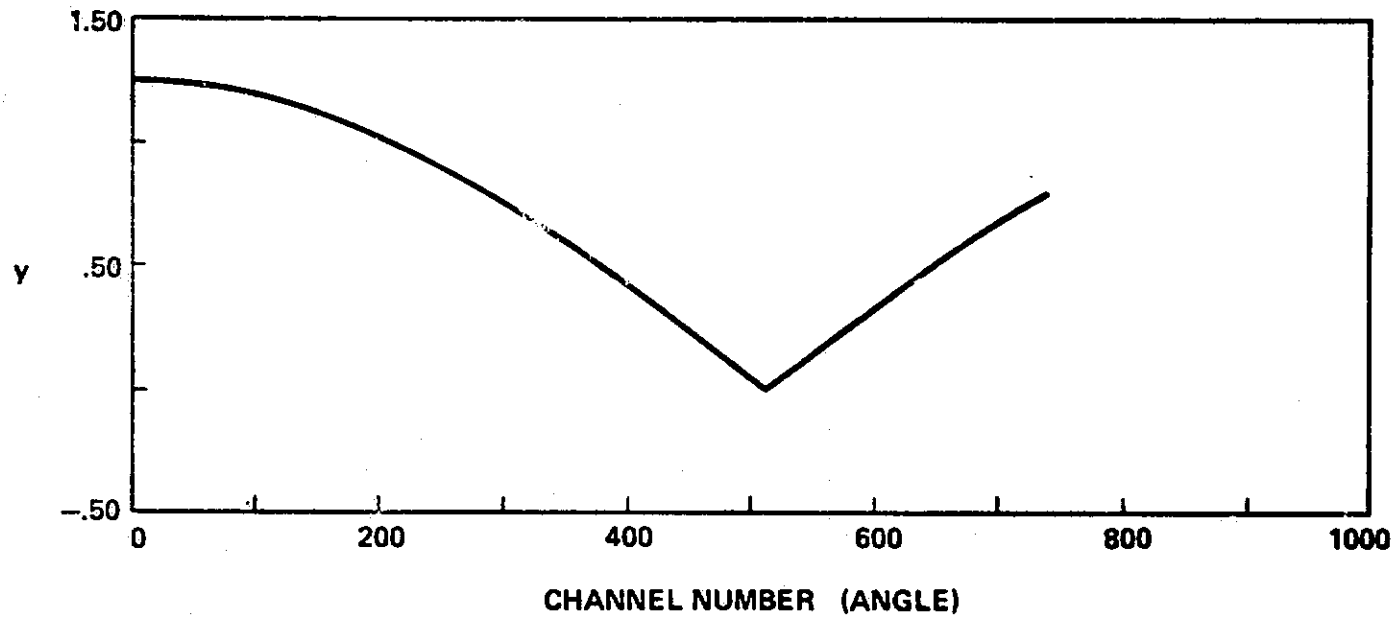


Figure 2: Trial Function (  $y = -kz / (c \omega t)$  )

FINANCIAL STATUS REPORT

Contract No. NAS8-24953

- I. Expenditures to date as of December 31, 1975 beginning with UAH fiscal year October 1, 1975, and each previous year, if any. \$341,742.69
  
- II. Forecast of funds required for completion: 20,109.31
  
- III. Problem areas: none