

A REVIEW OF IMAGING OBSERVATIONS OBTAINED WITH THE UNIVERSITY OF NEW HAMPSHIRE GAMMA-RAY TELESCOPE (DGT)

M. L. McConnell, E. L. Chupp, P. P. Dunphy,
D. J. Forrest, and A. Owens

Physics Department, University of New Hampshire, Durham, New Hampshire 03824, USA

Abstract

The University of New Hampshire Directional Gamma-Ray Telescope (DGT) was successfully flown on a balloon over Palestine, Texas on 1-2 October 1984. This instrument employs the coded aperture technique to image celestial photons in the energy range 160 keV to 9.3 MeV with an intrinsic angular resolution of 3.8° . Here we present the principal results from this balloon flight. In particular, observations of the Crab and Cygnus regions will be reviewed. These results represent the first in-flight demonstration of coded aperture imaging at energies above 160 keV.

1. Instrument and Observations. The DGT [1,2] primarily consists of a coded aperture mask placed above, and parallel to, a position sensitive photon detection plane. The detection plane consists of a 35 element array of BGO scintillation crystals, each 5.1 cm in diameter by 2 cm thick. The coded mask is based on a 7×5 URA pattern [3]. The opaque elements of the mask are composed of lead and measure 1.9 cm thick and 5.6 cm square. Located 84 cm in front of the detection plane, the mask provides an imaging resolution of 3.8° within a fully-coded field-of-view of 22.8° by 15.2° .

A major problem with any coded aperture imaging system is the image noise that results from a nonuniform distribution of background rates within the detection plane. This problem is sometimes referred to as "background systematics" and has been dealt with in the present experiment by directly evaluating the relative background rates within the detector array using a long accumulation of data (~ 6 hours). This accumulation is made without correcting for changes in the detector aspect. The knowledge of these relative background rates can then be used to correct the detector response prior to the image decoding process. The inflight results demonstrate that such a procedure is a viable one for dealing effectively with this problem [4,5].

A composite image of a given sky region is created by superimposing a large number of corrected short-exposure (~ 60 s) images, each of which have been subdivided into 0.95° elements and transformed into some common coordinate frame. Such a procedure is necessary in order to account for the relative motion of the source and the payload during the course of the observation.

The observations reported here were obtained during a balloon flight over Palestine, Texas on 1-2 October 1984. The payload reached float altitude at $\sim 17:00$ UT (October 1) and remained at a mean atmospheric depth of 3 g cm^{-2} for about 30 hours. Observations of a number of sky regions were obtained. The results from the observations of the Crab and Cygnus regions are summarized below.

2. Results. The composite image of the Crab region, integrated over the energy range 200 to 600 keV, is shown in Figure 1. This contour map represents the number of reproduced γ -ray events per 0.95° image element. The total livetime accumulation for this image was 12842 seconds, corresponding to a total exposure of $3.41 \times 10^6 \text{ cm}^2 \text{ s}$ at 511 keV. The strong response near the center of the image is due to the Crab Nebula/pulsar. The total significance of the response (in the 160-1000 keV range) is 12.0σ (S/B of 0.9%). The point-spread-function of the imaging system is well-represented by

a Gaussian of FWHM 4.8° . The source is located to an accuracy of ± 19 arc minutes at the 90% confidence level. The measured offset of the source from the true location is consistent with the estimated pointing error in the orientation system of ± 30 arc minutes.

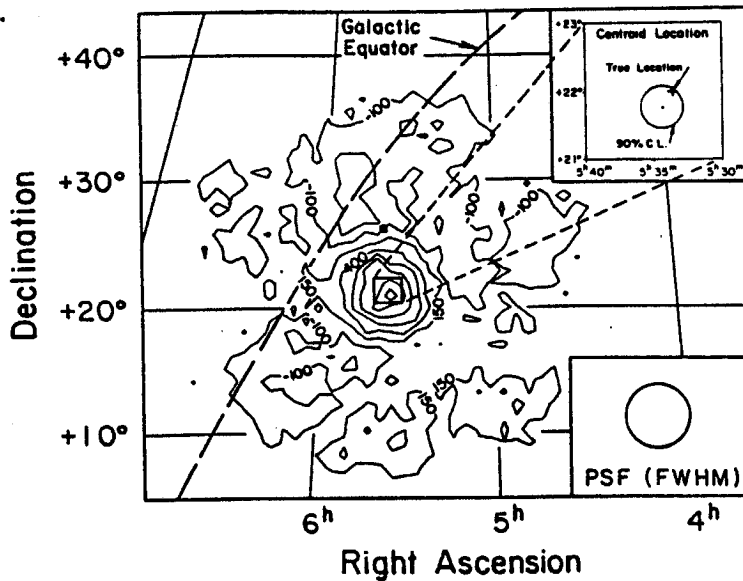


Figure 1

The energy-loss spectrum of the Crab has been determined from the response of seven different images, each covering a different energy range. The known response function of the DGT is used to determine, via an iterative procedure, the best-fit photon spectrum of the source. The photon spectrum of the Crab, determined in this fashion, is shown in Figure 2 along with other representative measurements. The spectrum is well-described by a power-law with a best-fit form of $5.1 \times 10^{-3} E_{\text{MeV}}^{-1.88}$ photons $\text{cm}^{-2} \text{s}^{-1} \text{MeV}^{-1}$ (corresponding to a reduced χ^2 of 1.5 for 5 degrees of freedom). We have also placed 3σ upper limits of 3.2×10^{-3} and 1.9×10^{-3} photons $\text{cm}^{-2} \text{s}^{-1}$ on line emission at 400 keV and 1049 keV, respectively.

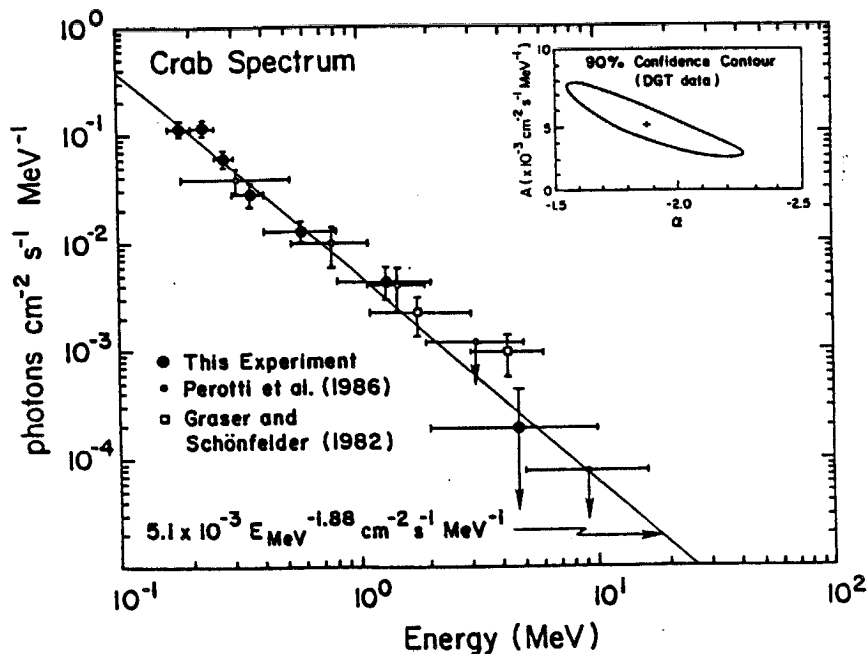


Figure 2

In addition to the Crab, we have searched this data for evidence of two other sources. The first source is the X-ray binary A0535+26, whose position is denoted by a small square in Figure 1. We find no evidence for this source and have placed upper limits on its emission (see Table 1). We also find no evidence for diffuse emission along the

galactic plane, as reported by Graser and Schönfelder [7]. The DGT upper limits for the diffuse emission, given in Table 1, lie above the positive measurements of Graser and Schönfelder [7].

The composite image of the Cygnus region is shown in Figure 3. The total integrated livetime for this image is 13039 seconds, corresponding to an exposure of $3.46 \times 10^6 \text{ cm}^2 \text{ s}$ at 511 keV. This image is dominated by the response to Cyg X-1. In the 160-1000 keV energy range, the source appears at the 11.2σ level ($S/B = 1.1\%$). In this case, the source is located to an accuracy of ± 16 arc minutes at the 90% confidence level. Again the measured offset of the source from the true location is consistent with the estimated pointing error.

The derived spectrum of Cyg X-1 is found to be consistent with previous measurements at energies below 1 MeV. We also find, however, a positive response from the source in the energy range 2-9.3 MeV with a statistical significance of 2.9σ . The positive measurements above 2 MeV may imply a second emission mechanism, in addition to the inverse Compton process. We have fit the measured energy loss spectrum using a composite model which incorporates an inverse Compton spectrum and a power-law spectrum. The Compton spectrum is consistent with an electron temperature, kT_e , of 80 keV and an optical depth (τ) of 2.0. The power-law component is given by $1.8 \times 10^{-3} E_{\text{MeV}}^{-0.6} \text{ photons cm}^{-2} \text{ s}^{-1} \text{ MeV}^{-1}$. The photon spectrum corresponding to this composite model is shown in Figure 4. (For further discussion regarding the spectral results, see reference [8].)

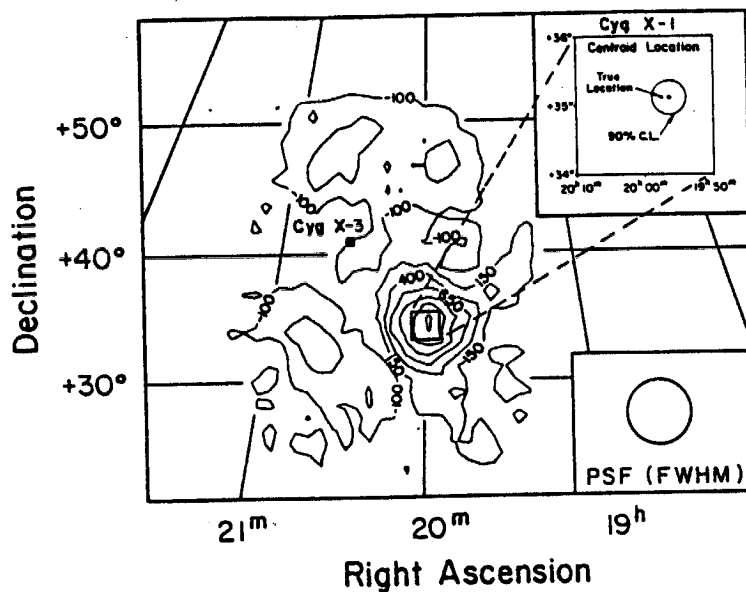


Figure 3

There is no evidence in the DGT imaging data for emission from Cyg X-3, whose location is denoted by a small square in Figure 3. The upper limits for this source are given in Table 2.

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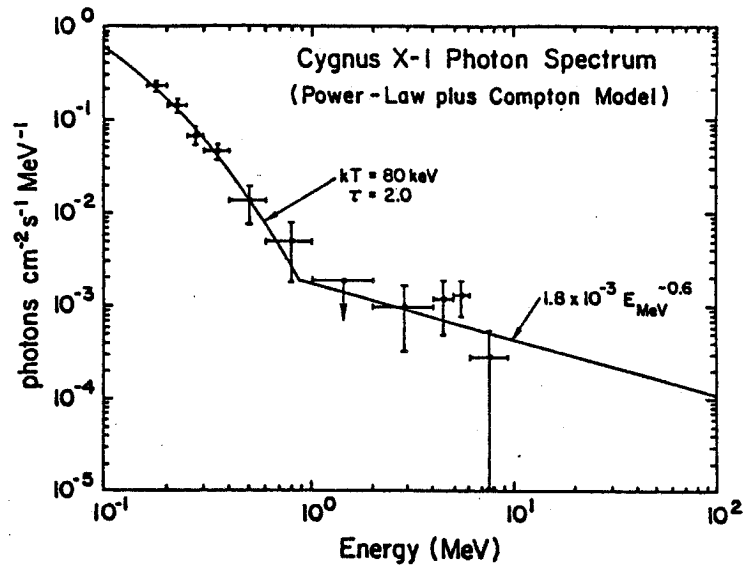


Figure 4.

Table 1

Crab Region 1σ Upper Limits

Energy (keV)	A0535+26*	Diffuse**
160-200	2.22×10^{-2}	3.15×10^{-1}
200-250	1.60×10^{-2}	1.91×10^{-1}
250-300	1.12×10^{-2}	1.34×10^{-1}
300-400	6.50×10^{-3}	7.76×10^{-2}
400-800	2.80×10^{-3}	3.34×10^{-2}
800-2000	1.49×10^{-3}	1.78×10^{-2}
2000-9300	2.49×10^{-4}	2.97×10^{-3}

(* $\text{cm}^{-2}\text{s}^{-1}\text{MeV}^{-1}$)(** $\text{cm}^{-2}\text{s}^{-1}\text{rad}^{-1}\text{MeV}^{-1}$)

Table 2.

Cygnus X-3 1σ Upper Limits

Energy (keV)	Cygnus X-3*
160-200	2.60×10^{-2}
200-250	3.12×10^{-2}
250-300	1.57×10^{-2}
300-400	1.61×10^{-2}
400-600	1.07×10^{-2}
600-1000	4.05×10^{-3}
1000-2000	2.28×10^{-3}
2000-3000	1.72×10^{-3}
3000-6000	5.14×10^{-4}
6000-9300	3.19×10^{-4}

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