FIRST FLIGHT OF A NEW BALLOON-BORNE GAMMA-RAY IMAGING TELESCOPE

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Abstract

The first flight of a new balloon-borne gamma-ray imaging payload (GRIP) occurred on Oct. 15 and 16, 1986 from Palestine, Texas. Observations included the quasar 3C273, the galactic center, and the Crab and Cygnus regions. We discuss the instrument performance and present images of the Crab and Cygnus regions with 0.6 degree resolution over a 20 degree field of view.

1. Instrument Description. The GRIP instrument is a balloon-borne imaging γ-ray telescope for galactic and extra-galactic astronomy observations. The telescope employs a rotating lead coded-aperture and a large-area shielded NaI(Tl) scintillation camera to achieve good flux sensitivity over the energy range from 30 keV to 5 MeV and an imaging capability of 1070 0.6 degree pixels over a 20 degree field of view.

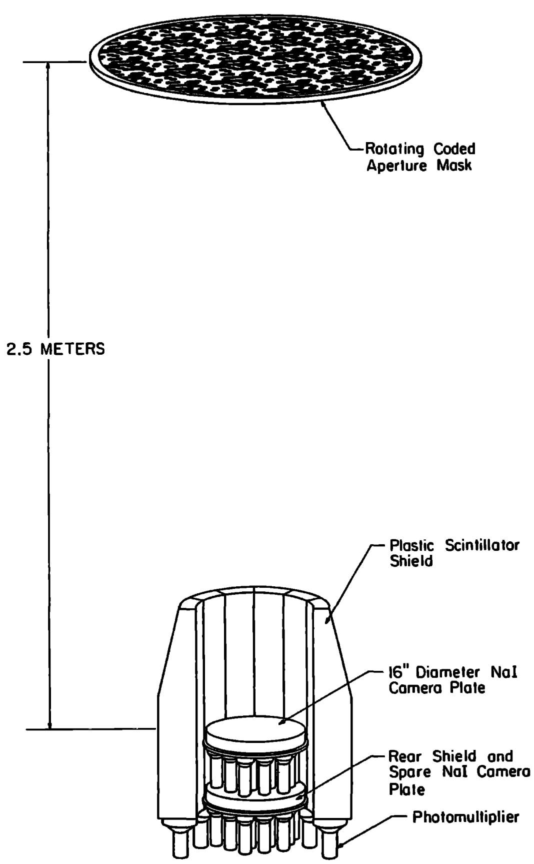

Fig. 1. GRIP telescope

A schematic view of the GRIP detector system is shown in Figure 1. The primary detector is a position-sensitive NaI(Tl) scintillator viewed by 19 photomultiplier tubes (PMTs) which are individually pulse-height analyzed. Background in the primary detector is reduced by an active anti-coincidence shield. The side of the shield consists of 12 plastic scintillator modules which form a cylinder ~16 cm thick. Each module is viewed by a single 5" PMT. The lower shield section is identical to the primary camera plate.

The coded aperture is located 2.5 meters from the detector and is composed of 2000 cells of which half are open and half contain a lead hexagon 2 cm thick and 2.5 cm flat to flat. The pattern of open and filled cells forms a hexagonal uniformly redundant array (HURA) that is optimal for coded aperture imaging (see also [1] and [2]).

During an observation the mask is continuously rotated to impose a time modulation of the γ-ray signal at each location on the detector. Due to the antisymmetry of the coded-aperture pattern under 60 degree rotation (open and closed cell interchange for all but the central cell) the γ-ray signal at each detector position is modulated with a

50% duty cycle. This feature allows a complete background subtraction to be performed for each position on the detector, once every 20 seconds. In addition, the continuous rotation permits extension of the field of view to 20 degrees, increasing the number of pixels imaged by about a factor of ten (as described in [1]).

The telescope is mounted on an elevation/azimuth pointing platform which utilizes active magnetometer feedback. Two magnetometers provide aspect information permitting post-flight correction for pointing inaccuracies. The telescope pointing system is under microprocessor control, allowing steering by ground command or the execution of a preprogrammed flight plan.

Gamma-ray event data and engineering data are recorded onboard and can also be telemetered to the ground for real-time and redundant recording. The on-board data recording system was developed for high capacity (25 Gbyte) and bandwidth (1.4 Mbit/s) using commercial VCRs and audio digitizers [3].

A more detailed discussion of the GRIP instrument may be found in [4].

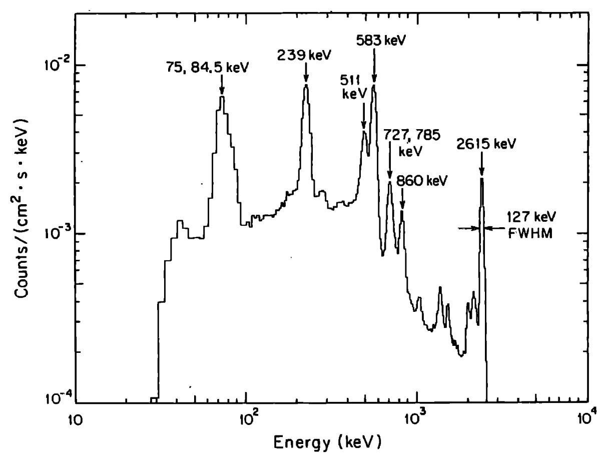

Fig. 2. Calibration spectrum of ^{228}Th

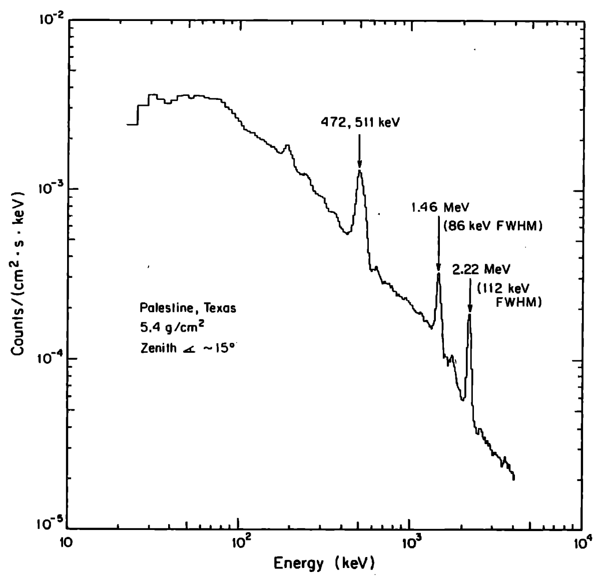

Fig. 3. In-flight background spectrum

2. Instrument Performance

GRIP was launched for its first flight at 14:18:25 UT October 15, 1986 from Palestine, Texas and landed 28 hours later in the southeast corner of Arkansas. The functionality of the instrument was verified in real time via imaging of both an onboard calibration source and the black hole candidate Cygnus X-1. Detailed analysis of the instrument's in-flight performance is now in progress. However, the major subsystems, including the detector and shield, the rotating lead mask, and the pointing system, have already been shown to have performed as expected.

The in-flight background spectrum measured by the NaI detector is shown in Figure 2. The line feature at 2.22 MeV is due to neutron capture on protons in the plastic shield. The line at 1.46 MeV is probably due to ^{40}K in instrument material and has nearly the same intensity as on the ground. The line feature near 0.5 MeV is likely a blend of lines at 472 and 511 keV due to inelastic neutron scattering on Na and positron annihilation (see [5]).

The 5% FWHM energy resolution measured for the in-flight 2.22 MeV background line is consistent with resolution performance obtained on the ground, as

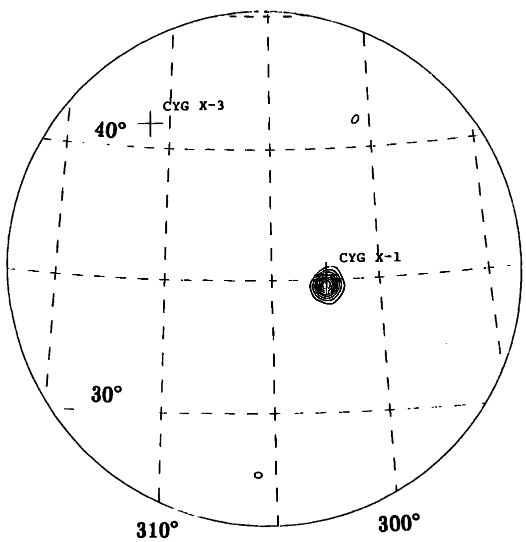

Fig. 4. Image of the Cygnus region.
Contours occur every 2σ, beginning at 3σ

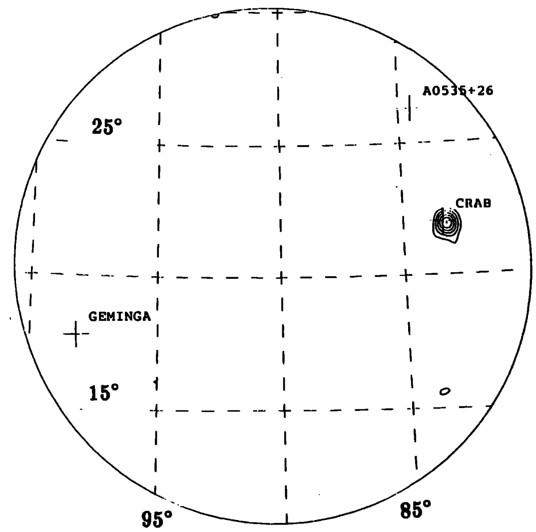

Fig. 5. Image of the Crab region.
Contour levels as in Figure 4

can be seen by comparison to Figure 3, an energy spectrum measured in the laboratory using a ^{228}Th source. The good in-flight energy resolution of the detector, which approaches that of the best single PMT NaI(Tl) detectors, is the result of detailed mapping of the detector response as a function of event location and the successful operation of an array of light emitting diodes for continuous in-flight PMT gain monitoring.

3. Imaging. Much of the observing time for the first flight was devoted to the Crab and Cygnus regions which contain the two most intense gamma-ray sources in our energy range: the Crab Nebula and Cygnus X-1. These objects can be imaged in less than 15-minute exposures and can therefore be examined for variability on these time scales. Such studies are currently in progress as is the determination of the overall spectral characteristics of these sources. The objects also provide important functional checks on the performance of the pointing system over a wide range of azimuth and elevation.

Figures 4 and 5 show preliminary images of the Crab and Cygnus regions based on two-hour exposures over the energy range 50 to 150 keV. Each figure shows a 20-degree diameter field of view with dashed lines indicating right ascension and declination coordinates. The positions of candidate sources are marked by crosses. The Crab Nebula and Cygnus X-1 are clearly identified at the 13 and 19 sigma levels respectively. The finite widths of the image peaks for the Crab Nebula and Cygnus X-1 are due to the instrumental resolution of approximately 0.6 degrees, and the measured source locations are consistent with the current estimated pointing uncertainty.

In addition to the Crab Nebula and Cygnus X-1 there are several features in Figures 4 and 5 which appear above the 3-sigma level. However, these are likely due to statistical fluctuations which are expected to produce on average 6 such features in each image [6]. The candidate sources Cygnus X-3, Geminga, and A0535+26 are not seen in these images. However, specification of flux limits or possible detection of these sources awaits work in progress to verify instrument sensitivity and the processing of the full 6-hour exposure for each source region.

3. Acknowledgements. We thank R. E. Vogt for his numerous contributions to the GRIP project. We also thank the staff of Caltech's Space Radiation Laboratory and Central Engineering Services and the personnel of the National Scientific Balloon Facility for their excellent technical support. This work was supported in part by NASA grant NGR-05-002-160.

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