A Balloon-Borne Imaging Gamma-Ray Telescope

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1. Introduction. This paper describes a balloon-borne coded-aperture γ-ray telescope for galactic and extragalactic astronomy observations. The instrument, called GRIP (Gamma Ray Imaging Payload), is designed for measurements in the energy range from 30 keV to 5 MeV with an angular resolution of 0.6° over a 20° field of view. Distinguishing characteristics of the telescope are a rotating hexagonal coded-aperture mask and a thick NaI scintillation camera. Rotating hexagonal coded-apertures and the development of thick scintillation cameras are discussed in *Cook et al.* [1984 and 1985, referred to as Papers I and II respectively].

2. Instrument Description. The basic elements of GRIP are shown in Figure 1. The telescope consists of a shielded detector system separated by 2.5 m from a lead coded-aperture mask. The primary detector is a position-sensitive scintillator which records the characteristic spatial pattern of photons cast by a γ-ray source through the mask.

The mask is made of lead hexagons 2 cm thick and 2.5 cm across (flat-to-flat), supported by an Al honeycomb sandwich which is transparent at γ-ray energies. The aperture contains 2000

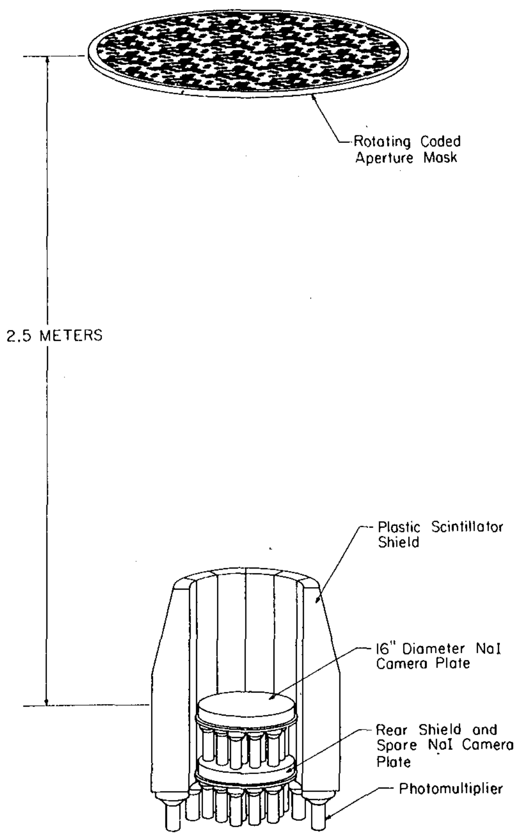

Figure 1.

Table I: **GRIP Balloon Telescope**

Primary Detector	41 cm x 5 cm NaI Anger Camera Position Resolution: < 5 mm rms (0.1 - 5 MeV)
Shield	Back Plate: 5 cm NaI Side: 16cm plastic scintillator
Mask	Hexagonal URA: 2000 cells (2.5 cm) Rotation Rate: 1 rpm Spacing: 2.5 m from NaI detector Size: 1.2 m diameter x 2 cm (Pb)
Energy Range	0.03 - 5 MeV
Energy Resolution	8.3 keV FWHM @ 50 keV 70 keV FWHM @ 1 MeV
Imaging	Resolution: 0.6° (1070 pixels in 20° FOV) Angular Localization: 3 arc min (10σ source)

hexagonal cells of which half are open and half contain a lead hexagon. The cell pattern (see Figure 2) forms a hexagonal uniformly redundant array (HURA) that is optimal for coded-aperture imaging. HURA's are discussed in more detail in Paper I and in paper OG 9.2-1 in these proceedings.

Continuous mask rotation imposes an additional level of coding on the γ-ray signal. Due to the antisymmetry of the coded-aperture pattern under 60 degree rotation (open and closed cells interchange for all but the central cell) the γ-ray signal at each position on the detector is time-modulated with a 50% duty cycle. This feature allows a complete background subtraction to be performed for each detector position once every 20 seconds assuming a 1 rpm rotation rate. In addition, the continuous rotation permits extension of the field of view to 20 degrees, greatly increasing the number of pixels imaged [Paper I].

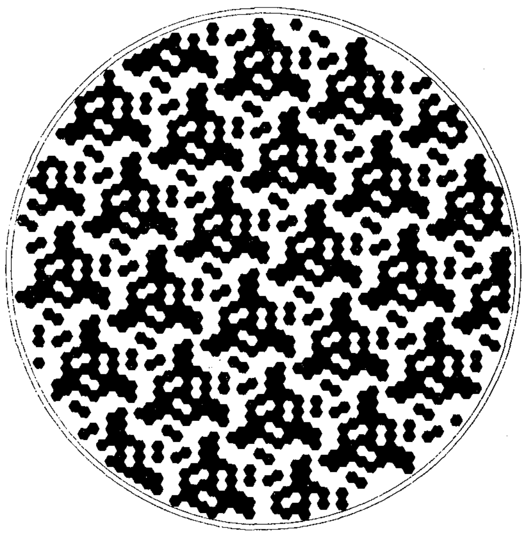

Figure 2.
GRIP coded-aperture mask pattern.

The primary detector is a NaI(Tl) camera plate 41 cm in diameter and 5 cm thick manufactured by the Harshaw Chemical Co. The NaI is viewed by nineteen 3 inch Hamamatsu R1307 photomultiplier tubes (PMT's) which are individually pulse height analyzed. The PMT gains are calibrated continuously using pulsed LED's for short term relative gain calibration and an ^{241}Am tagged γ-ray source for long term absolute gain calibration. The ^{241}Am source is situated 1 m above the coded-aperture mask and can be imaged continuously during flight, allowing a thorough checkout of the mask-detector imaging system.

Background suppression is provided by an anti-coincidence shield. On the side are 12 plastic scintillator modules which form a cylinder ~16 cm thick. Each module is viewed by a single 5 inch Hamamatsu R1416 PMT. The lower shield section is a NaI camera plate identical to the primary sensor. Further background suppression is provided by the primary scintillation camera itself. The PMT pulse heights contain information on the depth of the interaction in the crystal. Thus the lower half of the detector can be used as an effective "integral shield" for the reduction of background at low energies [Paper II].

The telescope is mounted on an elevation pointing platform suspended from an azimuthal torquing system. Azimuthal stabilization and orientation are achieved using active magnetometer feedback to the azimuthal torque motor. Elevation orientation is under command control. Two Schonstedt MND-5C-25 magnetometers provide 2-axis aspect information accurate to 1.5 arc minutes. This aspect information is recorded in the telemetry stream and allows correction of the event positions for pointing inaccuracies such as displacement and rotation of the telescope field of view.

For the initial flight of GRIP, we will record all nineteen 12 bit PMT pulse heights for each event. Event rates of up to 5×10^3/s are possible and consequently a data recording system with a 1 Mbit/s data rate is required. We have developed a 1.4 Mb/s recording system with 25 Gbyte capacity using commercial VCR's and audio digitizers. This development is described in paper OG 9.3-11 in these proceedings.

The characteristics of the instrument are summarized in Table I.

3. Instrument Performance.

Position and Energy Resolution: The GRIP scintillation camera has been designed to have ~1 cm FWHM or better position resolution over an energy range from 100 keV to 5 MeV. Figures 3a and 3b show histograms of γ-ray event positions computed by a maximum likelihood method for beams of photons of 122 keV (^{57}Co) and 662 keV (^{137}Cs) incident on the center of the detector [Paper II]. At the lower photon energy, the 10.5 mm FWHM of the distribution is dominated by photon statistics. At the higher photon energy, both Compton scattering and photon statistics contribute to the 7.0 mm width of the distribution. The effect of Compton scattering is most noticeable in the extended non-Gaussian tails of the distribution.

Although the standard deviation of the distribution of computed event positions increases with energy, the FWHM of the distribution continues to narrow due to an increase in the yield of optical photons per γ-ray event [Paper II]. As a consequence, the point-source angular resolution of the GRIP telescope improves with energy. The primary effect of Compton scattering is a reduction in sensitivity due to a removal of events from the core to the tail of the position distribution.

The energy resolution of the GRIP scintillation camera is comparable to that of single PMT NaI detectors. We have measured a resolution of 7% FWHM at 662 keV.

Imaging: Figures 4a and 4b are laboratory images of 122 keV and 662 keV γ-ray sources taken with the fully configured GRIP telescope. The sources were suspended 10 m from the coded-aperture mask and the imaging algorithms were adjusted to account for the finite distance to the source. The images demonstrate the ability of the telescope to locate and resolve point sources at γ-ray energies.

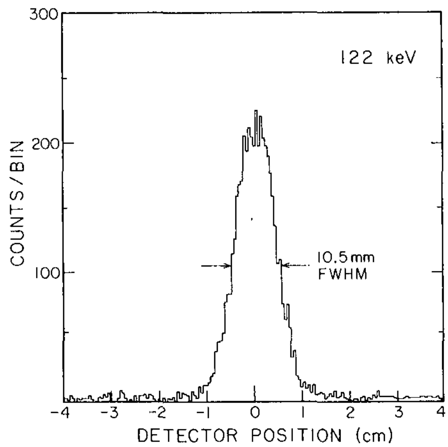

Figure 3a. Histogram of computed event positions showing position resolution at 122 keV.

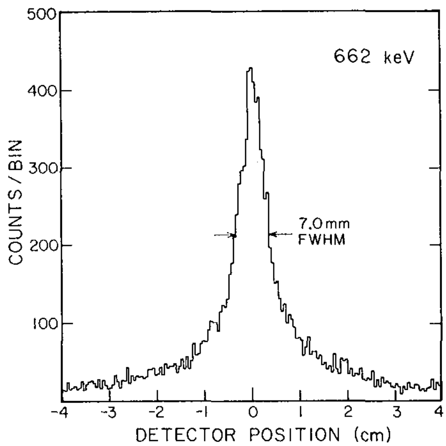

Figure 3b. Histogram showing position resolution at 662 keV.

Effective Area and Sensitivity: The geometrical imaging area of the GRIP scintillation camera is approximately 615 cm^2. This area is determined by the maximum radius (~14 cm) for which good position resolution can be maintained. Additional factors determining the imaging effective area are the point-spread position determination function shown in Figure 3, the full energy detection efficiency, and the mask contrast [Paper I]. Figure 5 shows a plot of imaging effective area versus energy for the GRIP telescope.

The instrument sensitivity depends on the observed background which depends on such factors as flight location, zenith pointing angle, shielding, and instrument mass. We estimate our sensitivity to be approximately 1×10^{-5} ph/cm^2 s kev at 100 keV and 1×10^{-6} ph/cm^2 s kev at 1 MeV for a 3σ 8 hour observation from equatorial latitudes.

4. Flight Plans. The GRIP telescope is scheduled for an initial flight from Palestine, Texas in Fall 1985. Observing targets include the Cygnus region, NGC4151, and the Crab region. Future flights are anticipated from both the northern and southern hemispheres.

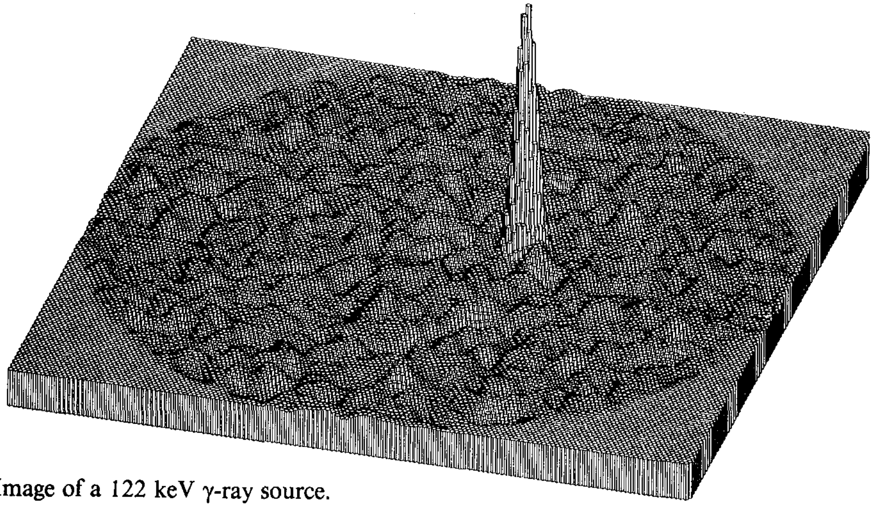

Figure 4a. Image of a 122 keV γ-ray source.

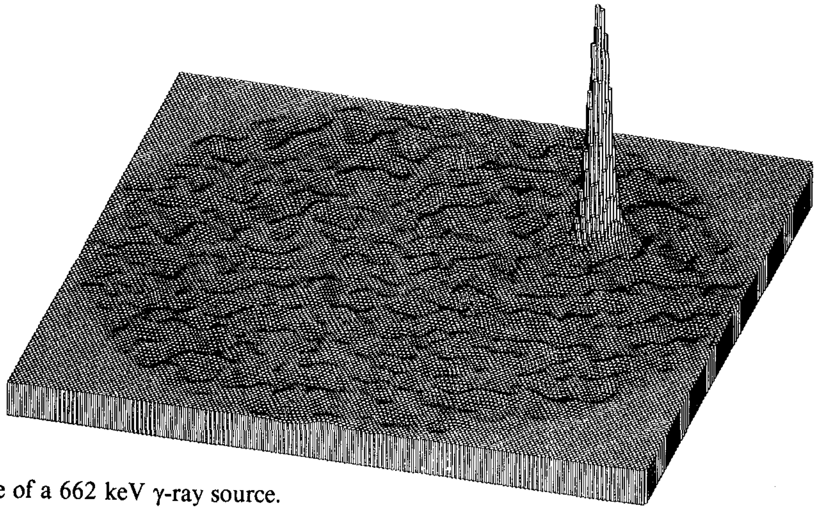

Figure 4b. Image of a 662 keV γ-ray source.

5. Acknowledgments. We thank R. E. Vogt for contributions to this project. This work is supported in part by NASA grant NGR 05-002-160.

6. References

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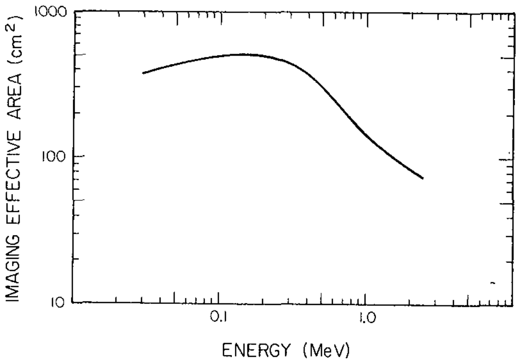

Figure 5. Effective area of the GRIP telescope taking into account position resolution, full-energy detection efficiency, and mask contrast.