THE GAMMA-RAY IMAGING SPECTROMETER (GRIS): A NEW BALLOON-BORNE EXPERIMENT FOR GAMMA-RAY LINE ASTRONOMY

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1. INTRODUCTION High resolution gamma-ray spectroscopy is a relatively new field that holds great promise for further understanding of high energy astrophysical processes. Preliminary results such as the annihilation radiation from the galactic center (Leventhal et al. 1978; Riegler et al. 1981), the ^{26}Al line from the galactic plane (Mahoney et al. 1984) and cyclotron lines from neutron stars (see e.g. Trumper et al. 1978) may well be just the initial discoveries of a rich and as yet undeveloped field. When the high resolution gamma-ray spectrometer (GRSE) was removed from the GRO payload NASA decided to initiate a balloon program to permit continued development and improvement of instrumentation in this field, as well as continued scientific observations. The Gamma-Ray Imaging Spectrometer (GRIS) is one of the experiments selected as part of this program. The instrument contains a number of new and innovative features that are expected to produce a significant improvement in source location accuracy and sensitivity over previous balloon and satellite experiments.

2. EXPERIMENT DESCRIPTION The basic instrument consists of an array of seven coaxial n-type germanium detectors surrounded by a thick active NaI shield/collimator. Located above this assembly is an active NaI coded-aperture mask for imaging and precise source location. The instrument performance is summarized in Table 1, and the central (pointed) section shown in Figure 1. The seven germanium detectors are each enclosed in individual cryostats. This design (rather than a single large multi-detector cryostat) was chosen for two principal reasons: 1) minimization of internally produced background (to be discussed in more detail later) and 2) ease of replacement of individual detectors, as well as upgrades and modifications.

A new concept has been introduced in the design of the germanium detectors wherein the cathode (outer surface layer) is divided into segments. The active germanium volume is therefore effectively divided into a stack of pancake-shaped detectors each ~1 cm thick. This takes advantage of the fact that over most of the relevant energy range the majority of photons undergo more than one interaction before they deposit all of their energy in the germanium crystal. Furthermore, the great majority of the background events over this same energy range are single point interactions. The resultant background suppression and improvement in sensitivity will be discussed later in more quantitative terms.

TABLE 1.

SUMMARY OF EXPERIMENT CHARACTERISTICS

Energy Range	0.02 to 10 MeV
Detector Size	6.5 cm dia. x 6.5 cm length nominal (Up to 7.5 cm detectors can be accomodated if available.)
Total Detector Area	232 cm^2 (309 cm^2 for 7.5 cm detectors)
3 Sigma Narrow Line Sensitivity	4.6×10^{-5} cm^{-2}-sec^{-1} at 60 keV 1.4×10^{-4} cm^{-2}-sec^{-1} at 511 keV 4.8×10^{-5} cm^{-2}-sec^{-1} at 2 MeV
Fields-of-view	20° FWHM coarse 3° x 3° FWHM fine 9° x 15° imaging
Imaging Pt. Spread Function (FWHM)	4°
Source Location Accuracy	± 0.2° for f = 10^{-3} cm^2-sec^{-1} at 511 keV
Pointing Accuracy and Stability	± 0.1°
Experiment Power	233 W
Experiment Weight	1500 kg
Telemetry Rate	56 K bits/sec

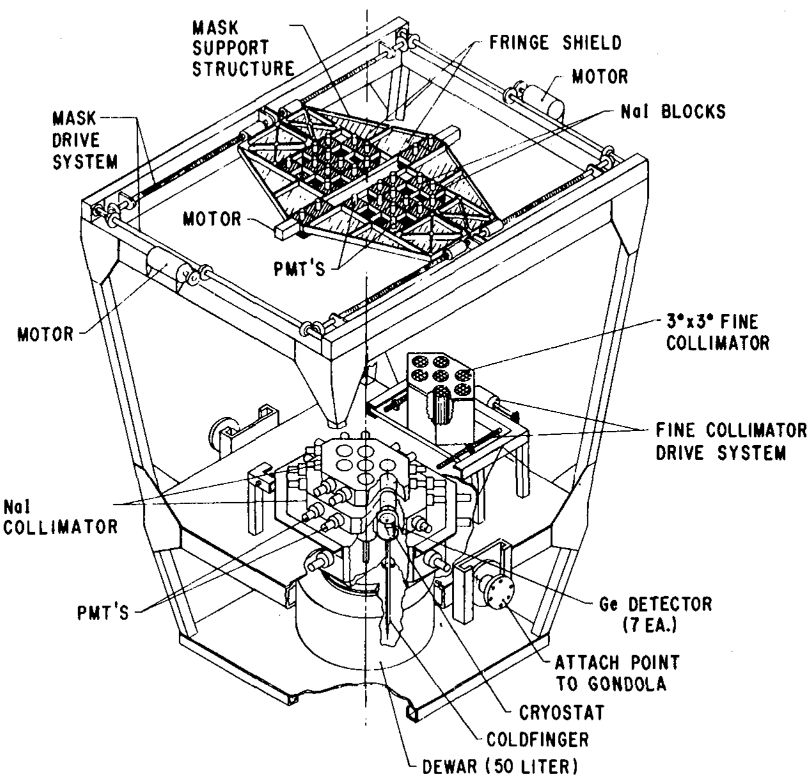


Fig. 1. GRIS pointed section.

The germanium detector array is cooled conventionally by a LN_2 dewar located beneath the detectors. NaI polyscin was chosen for the shield because of a) its relatively low cost, b) its high light output which allows a low threshold to be set and c) its fast response time which results in a lower overall shield dead time.

An active, uniformly-redundant mask system is used to generate sky maps

Fig. 1. GRIS pointed section.

over a 9^ox15^o field-of view. A detailed descripion if the GRIS imaging system is presented elsewhere in these proceedings (Gehrels et al. 1985). The mask is constructed from blocks of NaI scintillator since a passive mask would result in an unacceptably high 511-keV background. We have chosen a mask/antimask configuration for this experiment since it provides a direct unambiguous determination of the instrument background. We have discovered a unique method whereby the mask can be converted into its own antimask by a simple motion of components. This reduces the total amount of scintillators required by approximately a factor of two. The system is designed such that the mask can be completely removed from the 20^o FOV defined by the NaI collimator. In this configuration the instrument will operate in the usual on-source/off-source mode. This mode will be used in observations where the ultimate instrument sensitivity is required as well as for observing the diffuse galactic plane emission.

A passive fine collimator has been included for observing single isolated hard X-ray sources. Its primary purpose is to reduce the diffuse x-ray contribution to the overall background. It can be moved in and out of the field-of-view during the flight to allow maximum flexibility of the observing program. When it is in place the mask is moved out of the FOV.

A conventional azimuth-over-elevation pointing system with a momentum wheel for azimuth control will be used. Coarse pointing control will use the earth's magnetic field as a reference. A CID camera will be used to image star fields and the sun to obtain an independent and more accurate measure of the absolute pointing direction. The system is expected to have an overall accuracy and stability of $\sim \pm 0.1^o$.

3. INSTRUMENT BACKGROUND AND SENSITIVITY Extensive modelling of the GRIS instrumental background has been performed (Gehrels 1985). The primary sources of this background are:

Continuum

1) Diffuse X-ray and atmospheric background photons entering through the experiment aperture.
2) Elastic collisions of secondary neutrons with Ge nuclei.
3) Beta-decay from cosmic-ray induced radioactivity in the Ge detectors.
4) Leakage of high energy atmospheric background photons through the shield.

Lines

1) De-excitation of nuclei in the Ge detectors that have been excited by primary cosmic rays and secondary neutrons.
2) $Beta^+$-decay of excited nuclei in the passive material surrounding the Ge detectors.
3) Pair-production due to high-energy atmospheric background photons interacting in the passive material surrounding the Ge detectors.

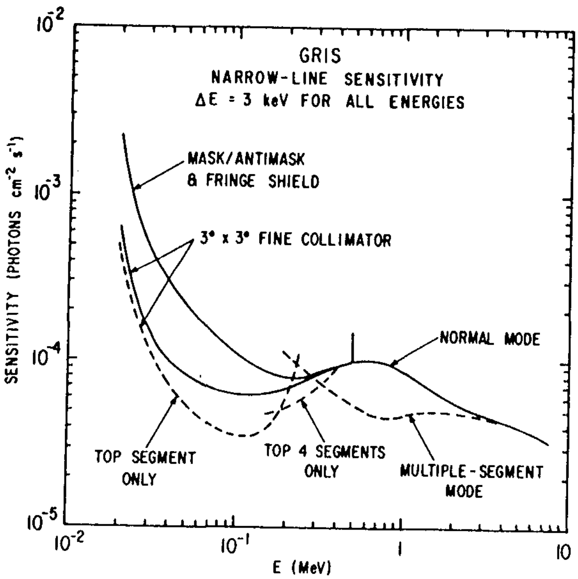
The effect of atmospheric gamma rays has been modelled using a Monte

Carlo program. A complete analysis of the effect of all possible cosmic-ray interactions has been carried out. This has involved examining ~ 2000 different interaction channels. These calculations have led to a number of key results that have had a profound effect on the design of the GRIS experiment. These are summarized as follows:

1) Nearly all of the important beta-decays go into the ground state. This means that there is no accompanying gamma-ray and that the energy deposition in the Ge is localized. Rejection of single-point interactions will therefore produce a significant supression of the continuum background.

2) Passive material inside the shield and in the FOV is a significant contributor to the background. This has led to the choice of an active mask and to a minimal-mass cryostat design.

3) The shield thickness and threshold are critical. This has lead to the choice of NaI for the shield.



The results of these calculations have been compared with previous balloon results and found to be in excellent agreement. The resultant sensitivities are plotted in Fig 2. and represent typically a factor of ~5 improvement over the best previous balloon and satellite measurements.

Fig. 2. GRIS narrow line sensitivity. Cases for different segment requirements are shown.

4. REFERENCES

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