ADVANCED TECHNIQUES FOR HIGH RESOLUTION SPECTROSCOPIC OBSERVATIONS OF COSMIC GAMMA-RAY SOURCES

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ABSTRACT

We describe an advanced gamma-ray spectrometer that is currently in development. It will obtain a sensitivity of < 10^{-4}ph/cm^2-sec in a 6 hour balloon observation and uses innovative techniques for background reduction and source imaging.

1. Introduction. Over the past decade gamma-ray spectrometers have achieved sensitivities of 10^{-4} to 10^{-3}ph/cm^2-sec to steady sources. This has lead to the discovery of gamma-ray line emission and narrow band continuum structure in the spectra of a wide variety of objects and phenomena [1], e.g. the galactic center, X-ray pulsators, the Crab pulsar, gamma-ray bursts and transients, and solar flares, the interstellar medium [2] and SS433 [3]. In spite of the impressive observational progress, it is generally true that line emission has been detected from only the brightest sources. The discovery of fainter sources and detailed study of the brighter ones requires factors of 10 to 100 sensitivity gain [4]. This is only practical with much lower background instruments than are available today. The goal of the collaborative program described here is to develop an instrument that has much lower background per unit area and is an order of magnitude more sensitive per unit observing time than present instruments. This will be used for observations of isolated sources and complex source fields from balloons at a sensitivity of < 10^{-4}ph/cm^2-sec, and its techniques will be applicable to future instruments carried in space, where < 10^{-5}ph/cm^2-sec could be achieved.

Instrumentation. The instrument, shown in Figure 1, contains an aray of twelve 5.5 x 5.5 cm, coaxial, n-type Ge detectors. These have an energy resolution of 1.4 (<0.6) keV at 511 (<100) keV, a total area of ~ 300 cm^2 and operate from 10 keV to 10 MeV. They are contained in a single cryostat that has very high thermal efficiency, allowing 80 hours of operation with a 10 liter LN_2 Dewar. This is surrounded by anticoincidence shield made of 5 cm thick BGO at the sides and rear and 10 cm thick CsI at the front. Apertures in the latter define a 19° FWHM field of view. The instrument has 3 operating modes, or configurations, which result from the use of additional collimation components. (a) The "Source Mode" uses a 3° FWHM passive collimator which is optimized for observations of discrete sources at known positions. (b) The "Image Mode" uses an optimum coded modulator to observe complex source regions by imaging a 12° FWHM field with 2.5° angular resolution (c) In the "Diffuse Mode" the 19° FWHM aperture is left clear in order to maximize the sensitivity to diffuse sources. The instrument mass is 450 kg.

The detectors use dual electrical segments and pulse shape discrimination to distinguished between Compton scattered gamma-rays, which are multiple site interactions, and β-decays which are essentially single site [5]. The latter are the dominant background component from a few hundred keV to > 1 MeV in heavily shielded Ge instruments [6,7,8] and represent a fundamental obstacle to sensitivity improvements. Their elimination is a major goal of this program. Gamma-rays $\leqslant$ 200 keV are mostly detected in the 1.5 cm thick front segment. Higher energy gamma-rays are mostly detected as a coincidence between the two segments or a multiple site event in the rear, 4.0 cm thick, segment. The latter is possible because the detector's finite charge drift velocity results in a sharp (broad) charge pulse for single (multiple) site events which is sensed by a pulse shape discriminator. This rejects > 95 percent of the single site events while accepting >80 percent of the multiple site events.

Imaging is achieved through the use of the optimum coded modulator. This produces temporal aperture modulation that is mathematically equivalent to the better known spatial aperture modulations [9]. It consists of 63 opaque and transparent moving elements which are located ~ 200 cm above the detectors and modulate the flux from gamma-ray sources. The resulting moving shadowgram produces temporally modulated counting rates in the detectors, from which a 2-dimensional, sidelobe-free gamma-ray image is deconvolved. The modulator elements, made of BGO with PIN photodiodes, operate in anticoincidence with the detectors.

The anticoincidence shield is primarily made of BGO, which offers greater attenuation per unit shield mass than CsI or NaI and also results in a more compact shield due to its high density, 2 times that of NaI. However, the low light output of BGO necessitates good PMT light collection in order to achieve a low anticoincidence threshold, < 100 keV. Therefore the shield will use ~ 50 separate BGO elements, based on a nominal 5 x 7 x 21 cm size, each with its own PMT.

3. Background and Sensitivity. The background is shown in Figure 2 and the sensitivity for a 6 hour balloon observation is shown in Figure 3. At 1 MeV the background is 0.14 and the detector volume is 11.5 times that of the

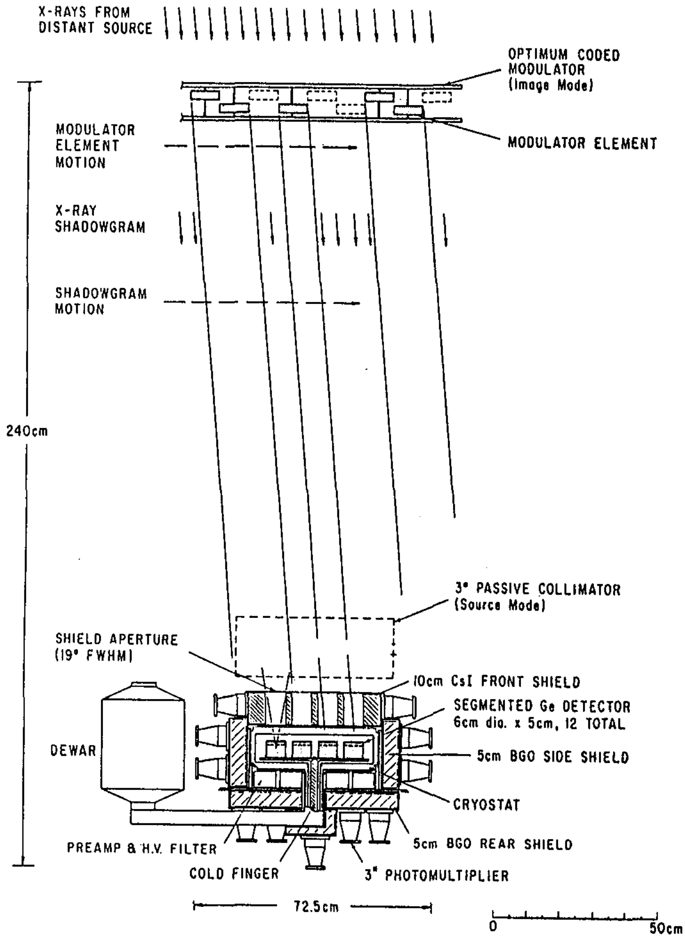

Figure 1. The high reduction gamma-ray spectrometer contains an array of 12 coaxial Ge detectors surrounded by a BGO and CsI anticoincidence shield. A cross section is shown of the optimum coded modulator, which is located 200 cm above the detector and used for imaging observations.

most sensitive contemporary instrument [10,11] resulting in a sensitivity improvement per unit observing time that is a factor of 9 (= 11.5/0.14). The detectors' superior energy resolution results in an additional sensitivity gain of a factor of ~ 1.5 below ~ 500 keV.

4. Program Status and Plans. The detector, shield and modulator concepts have been proven in extensive laboratory tests. In the fall of 1985 a test balloon flight of a single, heavily shielded detector will be performed. The 8 cm thick CsI shield will reduce the gamma-ray leakage to a point where rejection of detector radioactivity can be clearly seen. It is planned to conduct the first scientific observations with the complete instrument in the fall of 1987.

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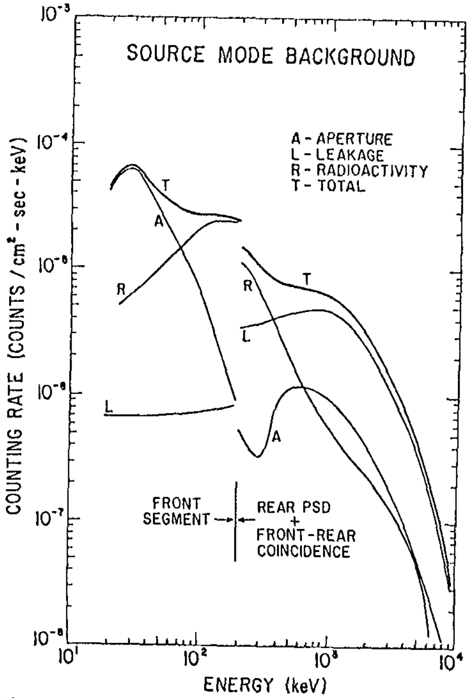

Figure 2. The Source Mode background components are shown for the different gamma-ray acceptance modes of the detectors. The 3° collimator results in a small aperture flux which is ~ 20 times greater below 300 keV in the Image Mode. A 98 percent rejection of detector radioactivity at 1 MeV is assumed. Such a reduction would allow a 10 times further reduction in the total background of future instruments through the use of a thicker anticoincidence shield.

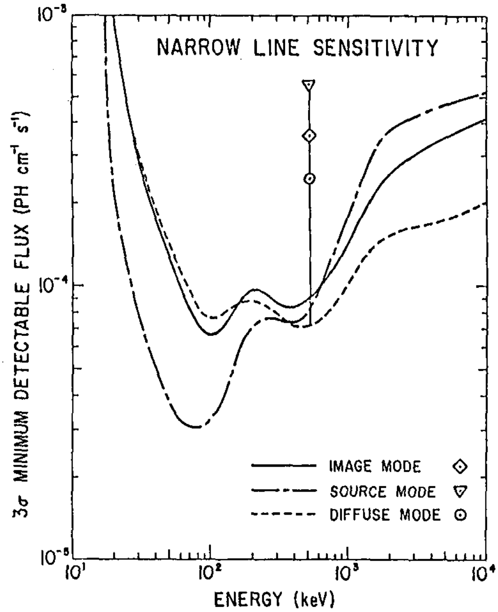

Figure 3. The sensitivity to narrow lines is shown for a 6 hour balloon observation. The increase below ~ 50 keV is primarily due to decreasing atmospheric transmission. Differences among the observing modes are due to different backgrounds and source modulation efficiencies. Carried in space with a 10 cm BGO shield, this instrument could achieve an Image Mode sensitivity of 10^{-5}ph/cm^2-sec over most of its energy range in a 7-day observation.

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