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HIGH-SPATIAL RESOLUTION AND HIGH-SPECTRAL-RESOLUTION DETECTOR FOR USE IN THE MEASUREMENT OF SOLAR FLARE HARD X-RAYS

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ABSTRACT

In recent years several new technologies have been developed that allow hard X-ray detectors to be made with significantly improved spatial and spectral resolution. These include the development of a new high-density scintillator glass that can be drawn into very fine fibers down to 5 microns in diameter and new semiconductor detectors with keV energy resolution that can be operated at, or significantly closer to, room temperature. It is the purpose of the proposed effort to investigate these new technologies with the objective of developing advanced hard X-ray instruments suitable for use on spacecraft or balloons during the next period of high solar flare activity from 1989 to 1994.

Specifically, in the area of high spatial resolution, we propose to evaluate a new hard X-ray detector with 65-micron spatial resolution for operation in the energy range from 30 keV to 400 keV. The basic detector is a thick large-area scintillator faceplate, composed of a matrix of high-density scintillating glass fibers, attached to a proximity type image intensifier tube with a resistive-anode digital readout system. Since the scintillation glass has excellent optical qualities, provides 15% of NaI(Tl) light output, and has a density of 3.31 g/cm^3 (comparable to NaI), such a detector would operate like a NaI or CsI scintillation spectrometer, but with high spatial resolution. Such a detector, combined with a coded-aperture mask, would be ideal for use as a modest-sized hard X-ray imaging instrument up to X-ray energies as high as several hundred keV. As an integral part of this study we also propose to critically evaluate several techniques for X-ray image coding which could be used with this detector.

In the area of high spectral resolution, we propose to evaluate two different types of detectors for use as X-ray spectrometers for solar flare observations. (1) Planar silicon detectors operating at room temperature that have 1-2 keV FWHM energy resolution and can be used from ~5 keV to ~30 keV. These semiconductor detectors not only offer high spectral resolution, but can also be fabricated for use as high-spatial-resolution detectors. This can be achieved by using either electro-etching or charge-sharing techniques. (2) High-purity germanium detectors (HPGe) can now be made to operate with keV energy resolution at much warmer than liquid-nitrogen temperatures (~90 K). Such detectors would require significantly lower-capacity coolers than those required for normal HPGe detectors and could be used to significantly higher X-ray energies than the silicon detectors.

Instruments utilizing these high-spatial-resolution detectors for hard X-ray imaging measurements from 30 to 400 keV and high-spectral-resolution detectors for measurements over a similar energy range would be ideally suited for making crucial solar flare observations during the upcoming maximum in the solar cycle.

INTRODUCTION

Observations made with instruments aboard the Solar Maximum Mission, Hinotori, ISEE-3, PVO, and Venera spacecrafts, as well as observations carried out with balloon-borne and ground-based instrumentation during the last solar maximum have greatly advanced our knowledge and understanding of solar flare phenomena. This is particularly true for solar flare X-ray emissions, where key observations have been made in three areas: 1) the rapid temporal structure observed in hard X-ray flare emission alone and simultaneous with other flare emissions, 2) the first-ever imaging of flares in hard X-rays, and 3) the first and only high-spectral-resolution observations of flare hard X-ray emissions. For example, despite limitations on the instrumental spatial and time resolution, the HXIS instrument on SMM and SXT on Hinotori have shown the existence of spatially separated hard X-ray footpoints in the impulsive phase of some flares, as well as more spatially extended sources in other flares. High-spectral-resolution observations do exist, but for only one flare observed with a balloon-borne spectrometer (Lin, et al. 1981).

While these results have demonstrated how important hard X-ray imaging measurements and high-spectral-resolution measurements are to understanding the complex solar flare processes, they also clearly show the need for hard X-ray measurements with improved spatial resolution and with high spectral resolution, obtained simultaneously and with high time resolution. The need for such measurements is clearly expressed in the The Solar Maximum Mission Flare Workshop Proceedings (Chapter 5, p. 5-18) and is strongly supported by the Report of the MAX '91 Science Study Committee (Dennis, et al. 1988).

We propose to continue a research program initiated in FY'88, whose goals have been to investigate two types of detectors which take advantage of recent advances in technology. The first is a high-spatial-resolution detector which utilizes a faceplate fabricated from newly-developed glass scintillator fibers coupled to an image intensifier tube with a resistive-anode readout system. The high-spectral-resolution effort involves two separate devices, one an ion-implanted planar silicon detector operated at room temperature, and the second, an HPGe detector tailored for operation at temperatures significantly higher than the normal liquid-nitrogen range. These detectors will be studied with a view toward developing hard X-ray imaging and spectrometer instruments which are compatible with small-payload concepts, as opposed to developing larger facility-class instruments. For example we propose to develop a simple, light-weight, low-power spectrometer suitable for Scout-launched payloads or piggy-back flights, opportunities which may be available during the next solar maximum (~1990-1993). A small spectrometer can still produce significant scientific results if it is optimized to operate in the range from 5-200 keV where the photoelectric cross-section is large and there are many observable flares. We feel that such detectors offer great promise in providing the required instrumentation for measurements during the next solar maximum.

Also for the imager, we plan to continue our investigation into various techniques for aperture coding which can best take advantage of the detector's capability for detecting hard X-rays with very high spatial resolution. This effort will ultimately lead to the development of a hard X-ray imaging instrument which will utilize a high-spatial-resolution detector coupled to the appropriate aperture coding device and electronic readout system.

A. High-Spatial-Resolution Detectors

Hard X-rays cannot be imaged by either reflection or refraction techniques. Total absorbtion - shadow casting - is the only modulation imaging technique available. Various ideas have been proposed for imaging hard X-rays and gamma-rays (Mertz and Young 1961; Oda 1965; Dicke 1968; Brandt, et. al. 1968; Makashima 1982; Fenimore and Cannon 1978; Hudson 1978; McConnell, et. al. 1981). Of these techniques, there are basically two methods for achieving high angular resolution. Variations on the pinhole technique require detectors with very high spatial resolution and/or long distances between the mask and the detector plane, as the angular resolution is given by d/D, where d is the detector resolution and D is the distance between the mask and detector. Instead of making direct images, or their convolution through multiple holes, the requirement of high spatial resolution in the detector plane can be relaxed by using a Fourier-transform technique. However this approach requires extreme precision in the fabrication and alignment of the mask elements. Currently, the Fourier-transform technique is receiving more attention due to the relatively poor spatial resolution, 2-5 mm, of the best crystal scintillator detectors. A detector with greatly superior position resolution would allow the development of competitive instruments which use direct pinhole imaging techniques.

A recently developed high-density (3.3 gm/cm^3), optical-quality scintillating glass which can be drawn into thin fibers (diameters down to 5 microns) offers the opportunity of making a position-sensitive scintillating face-plate. This material has a scintillating efficiency equivalent to 15% of NaI. The superior spatial resolution is achieved by the inherent property of the fibers to pipe the scintillating light output and confine it to a single fiber. We will evaluate this material for its spectral light output characteristics, as well as its hard X-ray detection

However, our primary effort will be the evaluation of a 25-mm dia., five-stage image intensifier tube which has a digital resistive-anode readout system. This tube has already been ordered with FY '88 GSFC Director's Discretionary Funds. We anticipate delivery of the tube soon and will begin evaluation of the tube under the present proposal. This tube is expected to have a spatial resolution of 65 microns. An evaluation of the photocathode noise and the contribution to noise from the channeltron will be carried out.

The ultimate goal is to investigate this faceplate/tube combination as an image sensor in a coded-aperture imaging system for hard X-ray measurements. To this end we intend to investigate various methods of aperture coding for use with this detector system. In particular, we are extremely interested in evaluating both the Fresnel zone plate coded-imaging technique and the "Fresnel Sandwich" coder (Mertz 1965). These techniques have not enjoyed popularity because of the relatively poor spatial resolution of existing detectors. However, the high spatial resolution of the proposed detector allows us to take much better advantage of these image-coding techniques.

B. High-Spectral-Resolution Detectors

The purpose of this investigation is to explore the operation of planar germanium and silicon detectors at temperatures well above the normal liquid nitrogen range and within a charged-particle environment for use as instruments designed to measure solar flare X-ray spectra. High-purity germanium detectors have been in routine laboratory use for at least 15 years for X-ray and gamma-ray spectroscopy. They offer superior energy resolution of ~300-700 eV FWHM, may be cycled from room temperature to liquid-nitrogen temperatures repeatedly with no degradation, can accurately measure spectra without distortion at count rates exceeding 20,000 events/sec, and enjoy excellent linearity and gain stability.

Recently developed room-temperature, ion-implanted silicon detectors are commercially available for 3igh-resolution spectroscopy from 2-30 keV. Such room-temperature ion-implanted silicon detectors developed by Enertec, Inc. have achieved 1-keV energy resolution. This is made possible by reducing the leakage current to the nanoampere range by proper surface passivation techniques, a process which reduces the internal background noise to a very low level. The use of low-noise FET preamplifiers aids in the achievement of keV spectral resolution. Silicon detectors do offer excellent spectral resolution, but with a Z of 14, their photoelectric stopping power limits their usefulness to X-ray energies below 40 keV. We propose to evaluate several of these units, one of which has already been ordered with current FY'88 funds.

Other semiconductor detectors may be operated at room temperature but suffer from severe problems. CdTe detectors have poor energy resolution because of incomplete charge collection. HgI_2 detectors are small, unstable, and have poor charge transport characteristics. CdTe and HgI_2 may someday be ready for space applications, but at the present time silicon and germanium detectors are the only ones which offer the necessary combination of resolution, stopping power, and reliability for the proposed application.

BASIC REQUIREMENTS FOR X-RAY IMAGING IN ASTROPHYSICS

NON-SOLAR	SOLAR
O WIDE F.O.V.	O ~ 1° F.O.V.
O ARCMIN RES.	O ARCSEC RES.
O HI SENSITIVITY VERY LOW NOISE BACKGROUND	O SOLAR FLARE EVENTS ARE INTENSE; SMALL AREA O.K.
O MOD. TIME RES. γ-RAY BURSTS X-RAY BURSTS COSMIC BKGND	O HI TIME RES. (~5msec) SOFT (2 - 20 keV) & HARD (20 - 200 keV) EVENTS

X-RAY IMAGING

O COLLIMATION - SCANNING

O CODED-APERTURE IMAGING

RECENT DEVELOPMENTS:
  ASTROPHYSICAL
  MEDICAL

CODED APERTURE IMAGING

FILLED APERTURES
TRANSMISSION > 50%

- ZONE PLATE
- UNIFORMLY REDUNDANT ARRAY
- STOCHASTIC
- BIGRID & MULTIGRID

DILUTE APERTURES
OPAQUENESS > 50%

- ANNULUS
- ROTATING SLITS
- NON REDUNDANT HOLES

THICKNESSES REQUIRED FOR 90% ATTENUATION FOR TWO ENERGIES AND VARIOUS MATERIALS:

	Cu	Al	Pb (cm)	NaI'	W
50 keV	0.11	2.6	0.04	.06	--
100 keV	1.26	6.3	0.11	1.09	0.1

X-RAY IMAGING DETECTORS

O LARGE AREA MULTI-ANODE P.C.

O ELECTRON OPTICS: X-RAY IMAGE INTENSIFIERS

O PROXIMITY TYPE: X-RAY IMAGE INTENSIFIERS
  WITH MULTIPLE DIODE TYPE OF AMPLIFICATION
  WITH MULTIPLE MICROCHANNELTRON AMPLIFICATION

HIGH DENSITY SCINTILLATING GLASS

O OHARA OPTICAL SCG-1 CERIUM-DOPED
($SiO_2 + LiO_2 + Al_2O_3 + MgO + Ce_2O_3$)

O NE902a (12% NaI)

O "SES" CONSULTANTS - SC56, SC61
BaO ADDED TO INCREASE DENSITY
AS WELL AS FIBER DRAWING CAPABILITY

SPECIFICATIONS

DENSITY 3.31 gm/cm^3 (NaI = 3.65 gm/cm^3)

REFRACTIVE INDEX n_D (5893Å) = 1.591
n_A (4047Å) = 1.607

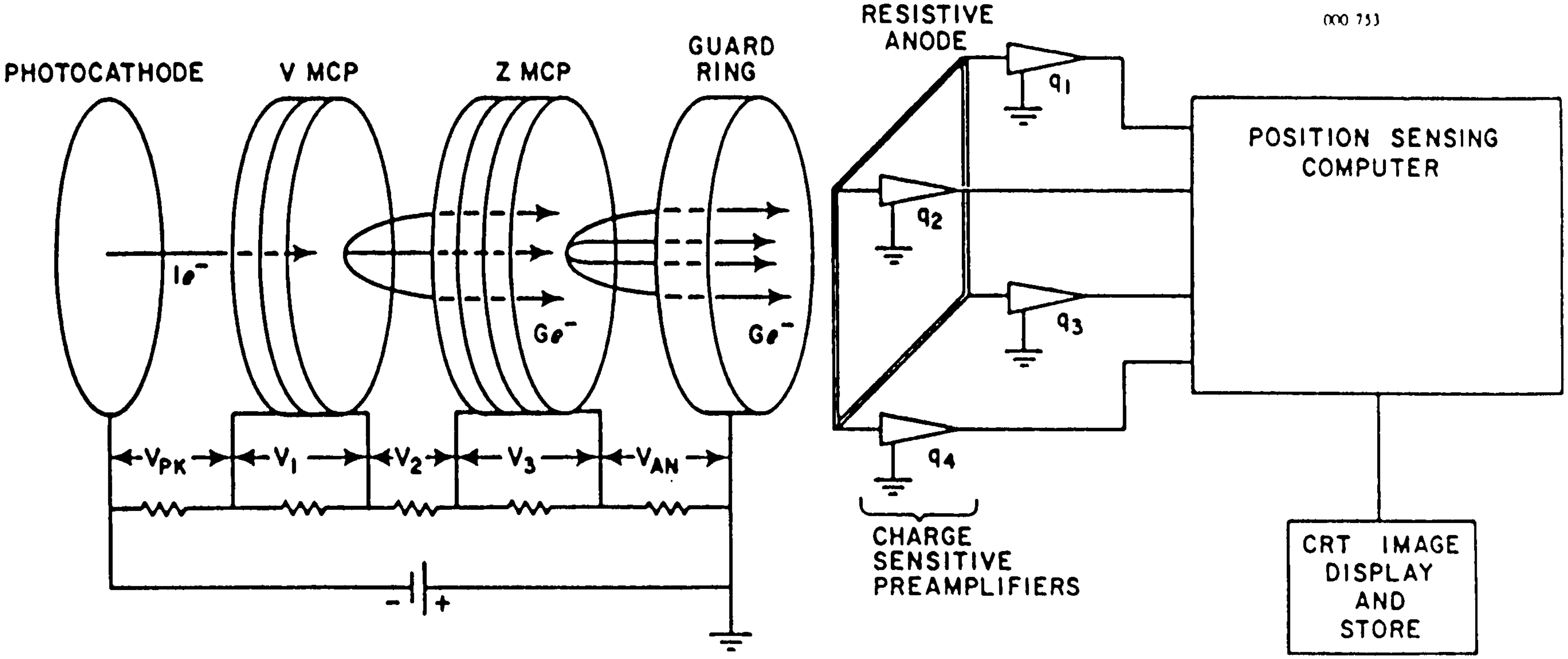
λ OF EMISSION: BROADBAND CENTERED @ 4000Å

DECAY TIME <u>56 nsecs</u>

LIGHT OUTPUT ≃ 15% OF NaI

RADIATION LENGTH 4.8 cm

CLEAR TRANSPARENT GLASS, STABLE UP TO 500° C, NON-HYGROSCOPIC



THEORY OF OPERATION