N82 26069 D14

A WIDE-FIELD SOFT X-RAY CAMERA

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ABSTRACT

We describe a Wide-Field Soft X-ray Camera (WFSXC) sensitive in the 50 - 250 eV band. which is presently under development by MIT and Leicester University. The camera features Wolter-Schwarzschild optics with an 8 degree field of view and 300 cm^2 collecting area. The focal plane instrument is a microchannel plate detector. Broad-band energy discrimination is provided by thin-film filters mounted immediately in front of the focal plane. The WFSXC is capable of detecting sources with intensities > 5 per cent of HZ 43 during typical sounding rocket exposures, and it would approach the same sensitivity range as EUVE during a typical exposure from the Shuttle.

The X-ray Astronomy sounding rocket group at MIT, along with collaborators from Leicester University, have developed a Wide Field Soft X-ray Camera (WFSXC). The instrument features Wolter-Schwarzschild optics (Wolter 1952a,b) with an 8 degree diameter field of view and a microchannel plate detector at the focal plane. The WFSXC was designed to carry out an all-sky survey in the ultrasoft X-ray band (50 - 250 eV; 50 - 250 A), with moderate sensitivity and arc-minute angular resolution.

The primary attractions of using WFSXC as part of an explorer mission or Shuttle payload are its wide field and its operation in an energy band that is complementary to the traditional soft X-ray band (e.g.,the 0.1-4 keV band of Einstein). Although this camera by itself would not warrant an explorer mission, especially in light of the pending EUV Explorer, WFSXC would be an ideal complement on an explorer mission to a more conventional soft X-ray telescope or other soft X-ray spectrometer. Perhaps the most appropriate application of the WFSXC would be as a Shuttle payload. Since it is a survey instrument, it could simply be mounted in the Shuttle bay without any independent pointing mechanism, observing in whatever direction the Shuttle points. Alternatively, its short focal length makes it easily adaptable into an Experiment of Opportunity (EOP) package.

A schematic of the WFSXC appears in Fig. 1. A photo of the payload (prior to final wiring for a sounding rocket experiment) is shown in Fig. 2. Briefly, the experiment consists of three nested Wolter-Schwarzschild type I mirrors. with a microchannel plate detector in the focal plane. Broad-band energy discrimination is provided by thin-film filters mounted immediately above the focal plane.

The mirrors have an 8 degree field of view and a geometrical area of ~300 cm^2. In order to obtain a reasonable angular resolution over such a wide field, it was necessary to machine the mirrors in a Wolter-Schwarzschild type I configuration, rather than the more commonly used Wolter type I paraboloid-hyperboloid. The Wolter-Schwarzschild optics are similar to those of the Wolter type I (Wolter 1952a), except that the surfaces exactly fulfill the Abbe sine condition (Wolter 1952b). The optimum focal surface is therefore free of those aberrations which grow linearly with off-axis angle (i.e., coma). Hence the Wolter-Schwarzschild is the superior design for wide-field grazing-incidence optics (Chase and VanSpeybroeck 1973).

The design of such a wide-field mirror also necessitated a small focal ratio and the associated large grazing angles. The mirrors therefore have little response above ~250 eV. This is indicated in Fig. 3a, which shows the effective area of the optics as a function of off-axis angle for various wavelengths. Approximately two-thirds of the effective area is preserved out to 4 degrees off axis. The mirrors essentially comprise an f:1 optical system, with a 35 cm focal length and a 38 cm entrance aperture.

The resolution of the mirrors (rms blur circle radius) as a function of off-axis angle is illustrated in Fig. 3b. The dotted curve shows the focal plane characteristics for a flat detector located at the on-axis focus. Since a major aberration is curvature of field, it is possible to significantly improve the off-axis point response by curving the front microchannel plate to match the optimum focal surface. The optimum focal characteristics of the mirrors are represented by the solid line in Fig. 3b. The Leicester University group is developing such a curved-plate microchannel plate detector for future use with the WFSXC. At the present time, a flat microchannel plate detector has been repositioned 1.25 mm in front of the on-axis focal position to provide the best average imaging properties over the inner 5 degree diameter of the focal plane, as represented by the dashed line in Fig. 3b.

The mirrors were machined out of 18 cm aluminum plate stock. Since each of the two reflecting surfaces is so short, it was possible to machine both surfaces from a single piece of aluminum. The mirrors were machined on an ordinary numerically-controlled lathe and plated with 250 microns of electroless nickel. The final surfaces were then cut on the single-point diamond-turning lathe at the Y-12 plant at Oak Ridge, Tennessee. The reflecting surfaces were polished to a low-scatter finish and electroplated with 1000 A of gold to enhance their reflectivity below 250 eV (Malina and Cash 1978).

In order to attain even a modest (~1 arc minute) angular resolution (the scale of an image on the focal plane is 10 arc minutes / mm), as well as detect X-rays with energies less than ~100 eV, it was necessary to use a microchannel plate detector as the focal plane instrument. The detector consists of two microchannel plates in the chevron configuration with a resistive anode readout (Lampton and Paresce 1974). The detector was designed and constructed by the Leicester University group using plates supplied by Mullard, Ltd. and a resistive anode fabricated by EMI, Ltd.. Since the reflected X-rays are incident on the microchannel plate at large angles (~30 degrees) and microchannel plates are relatively inefficient at these angles, a top plate with a 0 degree bias was chosen, thus preventing asymmetries in the camera efficiency across the focal plane. The microchannel plate efficiency was enhanced in the soft X-ray region by coating the top plate with magnesium fluoride (Lapson and Timothy 1976). The resistive sheet readout provides positional information accurate to ~0.1 mm (1 arc minute).

Broad-band filters are placed in front of the focal plane to provide crude spectral information as well as to filter out unwanted geocoronal background radiation (304 A and 584 A). The transmissions of three such filters as a function of wavelength are shown in Fig. 4a. We have chosen the parylene N and the Beryllium/parylene N filters for our first sounding rocket flight. For the sounding rocket experiment we have simply mounted the two filters side by side, each covering half the focal plane. (A filter wheel would be used on a Shuttle or explorer mission.) The camera will perform its observations scanning at a constant rate in the direction that allows a source passing across the focal plane to be observed through both filters. In addition to the two transmitting filters, an opaque filter covers a small portion of the detector surface so that the counting rate from non-imaged events may be monitored during flight. Fig. 4b shows the on-axis effective area of the entire camera (filter, telescope and detector) for the various filters as a function of wavelength.

The sensitivity of WFSXC as a function of time is shown in Fig. 5. In sounding rocket exposures (~10 sec) we can detect sources down to ~1/20 the intensity of HZ 43, the brightest known ultrasoft X-ray / EUV source (Lampton et al. 1975). In a typical exposure available during a Shuttle flight (100-1000 sec), the experiment will be 10-100 times more sensitive, placing it in the same sensitivity range as EUVE. Of course, the primary advantage of this instrument is its wide field of view, which makes it particularly suitable for survey application. The entire celestial sphere can be imaged in ~1000 exposures. An example of such an application is on the German satellite ROSAT. The WFSXC complements the energy band of the main ROSAT telescope, and is ideally suited for the survey mission ROSAT is to undertake. In fact, a scaled-up version of WFSXC has been proposed by a consortium of British groups as an ancillary experiment on ROSAT, and has been tentatively incorporated into the satellite design.

The rocket-borne version of the WFSXC was launched from White Sands Missile Range on October 16, 1981. Its flight plan consisted of a series of scans across ~100 degrees of sky in which several potential ultrasoft X-ray / EUV sources are located. The data from the flight are presently being processed, and the instrument is being refurbished for a spring, 1982 launch.

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Figure 1: Schematic of the Wide-Field Soft X-ray Camera payload. Key components include: (1) aspect camera, (2) nested telescopes, (3) detector vacuum housing, (4) ion pump, (5) electronics boards.

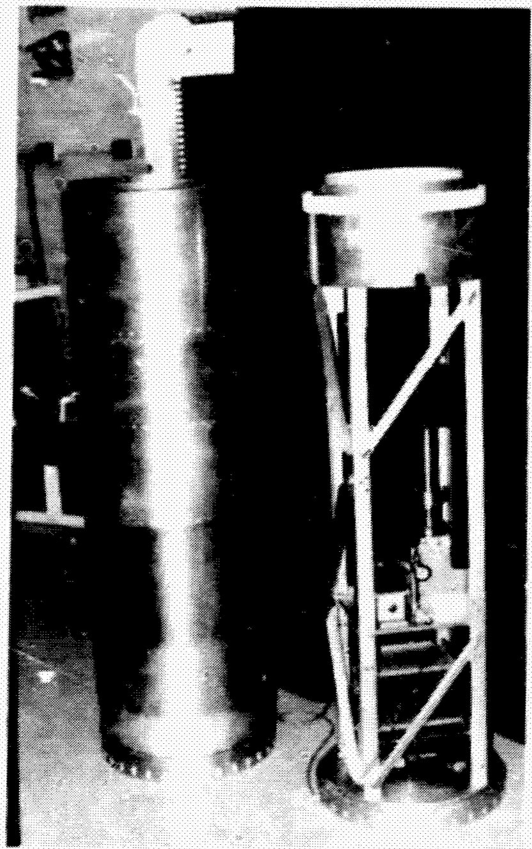
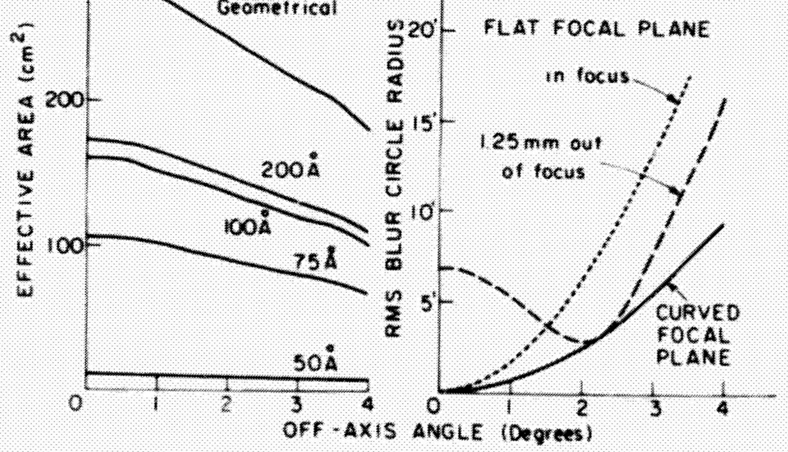


Figure 2: The rocket-borne version of the WFSXC, prior to final wiring.

Figure 3: Imaging properties of the WFSXC mirrors. (a) Effective area at various wavelengths vs. off-axis angle. (b) RMS blur circle radius vs. off-axis angle for various focal plane configurations.



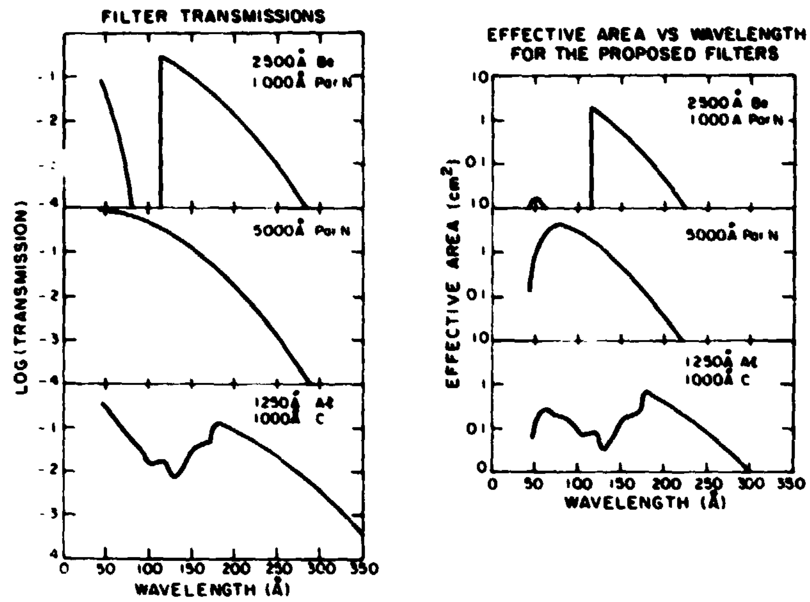


Figure 4: (a) Transmission of the thin-film filters vs wavelength. (b) Effective area of the Wide-Field Soft X-ray Camera vs. wavelength for each of the three filters. These areas include the reflectivities of the X-ray mirrors, transmission of the filters, and efficiency of the microchannel plate detector.

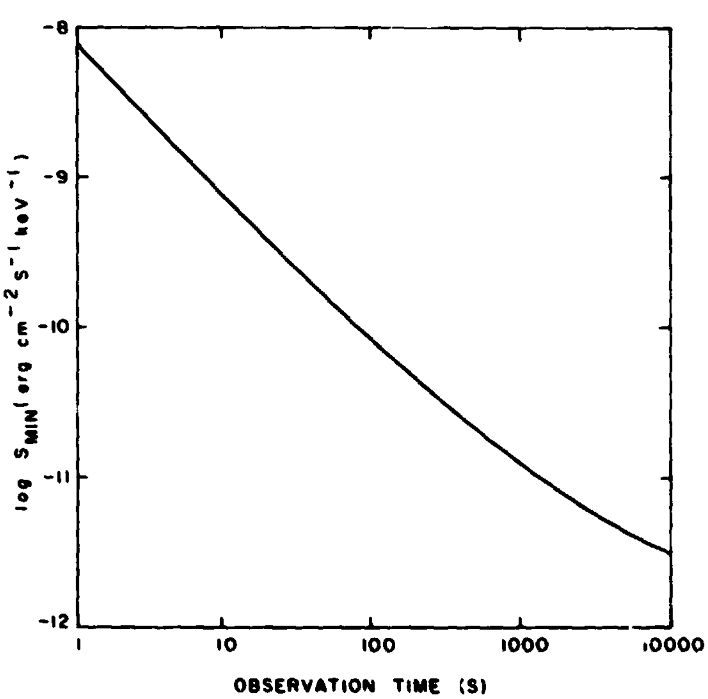


Figure 5: Sensitivity of the WFSXC vs. observation time. Sensitivity represents the minimum source flux observable with 5 sigma significance over imaged background for the Parylene N filter. Imaged background rate is approximately 300 photons s^{-1} sr^{-1}.