X-RAY IMAGING ABOVE 3 keV

by

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I. INTRODUCTION

My original motivation for the designs presented here was to produce energy dependent x-ray maps of clusters of galaxies. Of course, these designs can also be used to study supernova remnants, galactic nuclei, etc.

II. PENCIL BEAM DESIGN

The first design is that for a stacked, etched grid collimator, shown in Figure 1. This could, in principle, be put on the XTE. This would allow the XTE satellite to be used for diffuse object study as well as for point sources in confused regions of the galaxy. Admittedly, AXAF will study diffuse emission. The AXAF's large focal plane scale is not optimal for 10' to 1° extents, however. Furthermore, the stacked, etched grid design can be used out to 15 or 20 keV quite easily, and AXAF only has a token effective area above ~7 keV.

The particular design and experiment parameters that we present below are based on a Space Lab proposal done in collaboration with G. Fritz and R. Cruddace. It demonstrates the power of this relatively simple experiment. The collimator design has more than one solution; the one presented here was done by the Bendix Corporation. Note, the only drawback to usage of this design on the XTE is that the pointing requirements are higher than those of the XTE saltellite. Also, note that the 8 x 10^{-3} UFU sensitivity is quite good, and is achievable because of the small field of view.

Experiment Summary Table 1

Objective To study clusters of galaxies, galactic nuclei and other extended and point x-ray sources with high sensitivity and large dynamic energy range.

Technique Passive collimators and gas filled proportional counters.

Field of View 4' x 4' and 12' x 12'.

Collimators 9 units of stacked electroformed invar gold coated mesh.

Detectors Low background wire wall proportional counters.

Energy Range .25 - 15 keV.

Effective Area 3000 cm^2 at 2-10 keV, 1000 cm^2 at 0.1-0.25 keV and 10-15 keV.

Sensitivity (5σ) Point source 8×10^{-3} UFU in 10^5 seconds, 2-6 keV.

Required Pointing Stability and accuracy 1' of arc, measurement to better 20" of arc.

Accomodation 1 meter square by 0.6 meter in height.

Mass 215 kg power 100 watts.

Table 2: Collimator Properties

Field of View	4 x 4 arc min and 12 x 12 arc min
Transmission (Over active area of proportional counter)	50 per cent
Effective Area (each)	320 cm^2
Size (each collimator)	230 mm x 280 mm x 360 mm high
Weight	13.1 Kg
Thermal Heat Leak (each)	7W @ °C (10 watts @ 30° C)
Total Weight (9 collimators, optical bench, thermal cover)	135 Kg
Total Heat Leak (9 collimators and thermal cover)	81W

III. MIRROR ARRAY DESIGN

The second design we present overlaps with the capabilities of AXAF, but the design is optimized to work at 7 keV. Below, we show below that at 7 keV, the present design is quite good for sources that are to be studied on scales >1'

The basic design was used for a Space Lab proposal which I submitted in collaboration with the University of Birmingham group (A. P. Willmore, P.I.). A single mirror module consists of 4 nested Wolter Type I mirrors (Figure 2). Then 80 of these modules would be combined as shown in Figure 3. The 80 separate images would be formed, and combined later by software. The design and sensitivities are summarized below.

Experiment Summary: Table 3

*80 mirror units, each comprising 4 nested sections, focal length 200 cm, maximum mirror ~12 cm diameter, ~40 cm long (Figure 2)

*Grazing angle 25' allowing operation to at least 8 keV

*Resolution 2'; Field of view ~20' diameter

*Large effective area from one position sensitive proportional counter for detecting the images from 20 mirror units. Background consequently minimized by large guard region surrounding each image region and manufacturing problems reduced.

*Cost minimized by:

(1) Aiming for moderate resolution, as above

(2) 'Mass' producing mirrors by electro forming replicas from a superpolished master

Table 4: Sensitivity in 4×10^4 seconds (5σ)

Energy	Point Source	20' Diameter Source
2-7 keV	2×10^{-3} UFU	2×10^{-2} UFU
7-9 keV	6×10^{-3} UFU	6×10^{-2} UFU
at 6.7 keV, iron line	5×10^{-6} photons/cm^2 sec	5×10^{-5} photons/cm^2 sec

Table 5

Source Detected	Time Required
10^{35} ergs/sec at the Galactic Nucleus..................	200 seconds
10^{36} ergs/sec in M31 Nucleus⁺..........................	4×10^5 seconds
NGC4151-like object at Z = .13........................	4×10^4 seconds
Iron line from Coma-like Cluster at Z = .3............	4×10^4 seconds
Cluster 1/3 as bright as Coma with 10' isothermal sphere 80 resolution elements > 5σ........	4×10^4 seconds
Cluster 1/30 as bright as Coma--simple detection if 10' radius.............................	4×10^3 seconds

⁺2' resolution allows a region of .2kpc radius to be isolated.

We calculated the effective area of the entire system, and this is shown in Figure 4. Note, this area is only ~30% of the geometrical area, because of estimated losses due to scattering, shadowing, and proportional counter response. This area of ~300 cm^2 compares quite well with the AXAF area at 7 keV of ~200 cm^2. The AXAF quoted area does not take into account losses due to scattering or the proportional counter. We estimate that the true effective area could be as low as 100 cm^2, and hence the design we present here has 1.5 to 3 times the area of AXAF at 7 keV. The focal plane scale of AXAF is ~5 times that of our design, and therefore, for diffuse sources, with scales >1', the signal to noise ratio will be similar for AXAF and the design presented here.

IV. MIRROR REPLICATION

Is it possible to make many mirrors cheaply? We have been re-evaluating and old technique--electro-forming. We found that optical flats that have a "low scatter" or "super polished" finish can be quite easily reproduced. Total integrated scattering (Bennett, 1978) tests were performed on both the mandrel (prior to use) and the 14th electro-formed nickel pieces. For both pieces, the r.m.s. surface roughness was 15 ± 2 Å (Bennett, private communication). The 7 keV x-ray scattering results we performed are being analyzed. The present preliminary analysis showed that the reflected x-ray beams from the flats had < 1.4' half power radii, and the total reflectivity of the flats was > 60 %. Electro-forming optical flats is actually more difficult than electro-forming cylindrical pieces. Thus, we are optimistic about this technique, and we are proceeding ahead with plans to reproduce super-polished cylindrical pieces.

V. CONCLUDING REMARKS

In conclusion, designs of modest projects that are not covered by XTE and AXAF are difficult to find. The designs presented here would make available more observing time for projects that would not require the high spatial resolution capabilities of AXAF. Given the funding situation, and the high interest in ~7 keV astronomy, modest instruments with capabilities that overlap XTE and AXAF should be given consideration.

REFERENCES

Bennett, H. E. 1978, Optical Engineering, 17, 480.

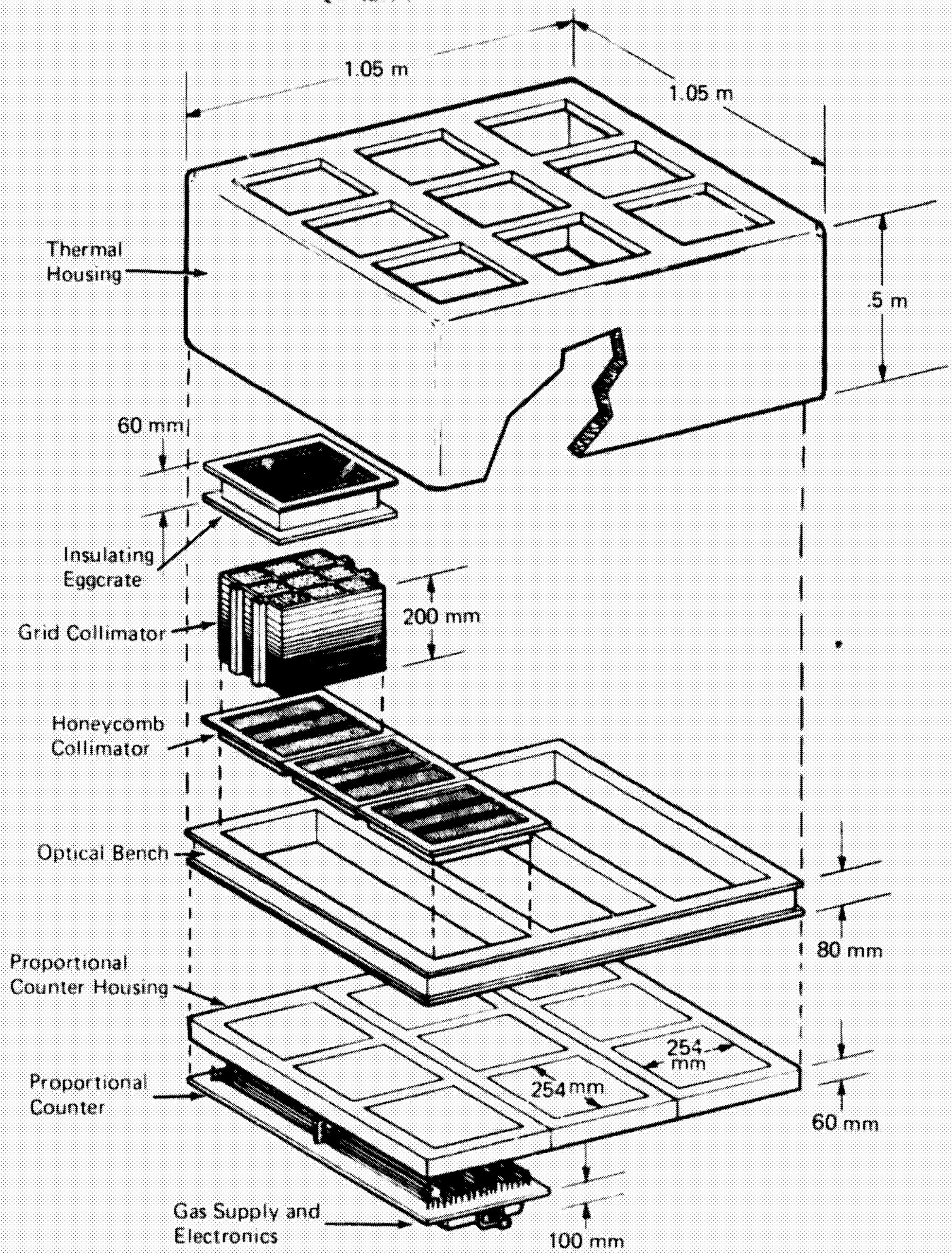

Figure 1 X-Ray Collimator (Exploded View)

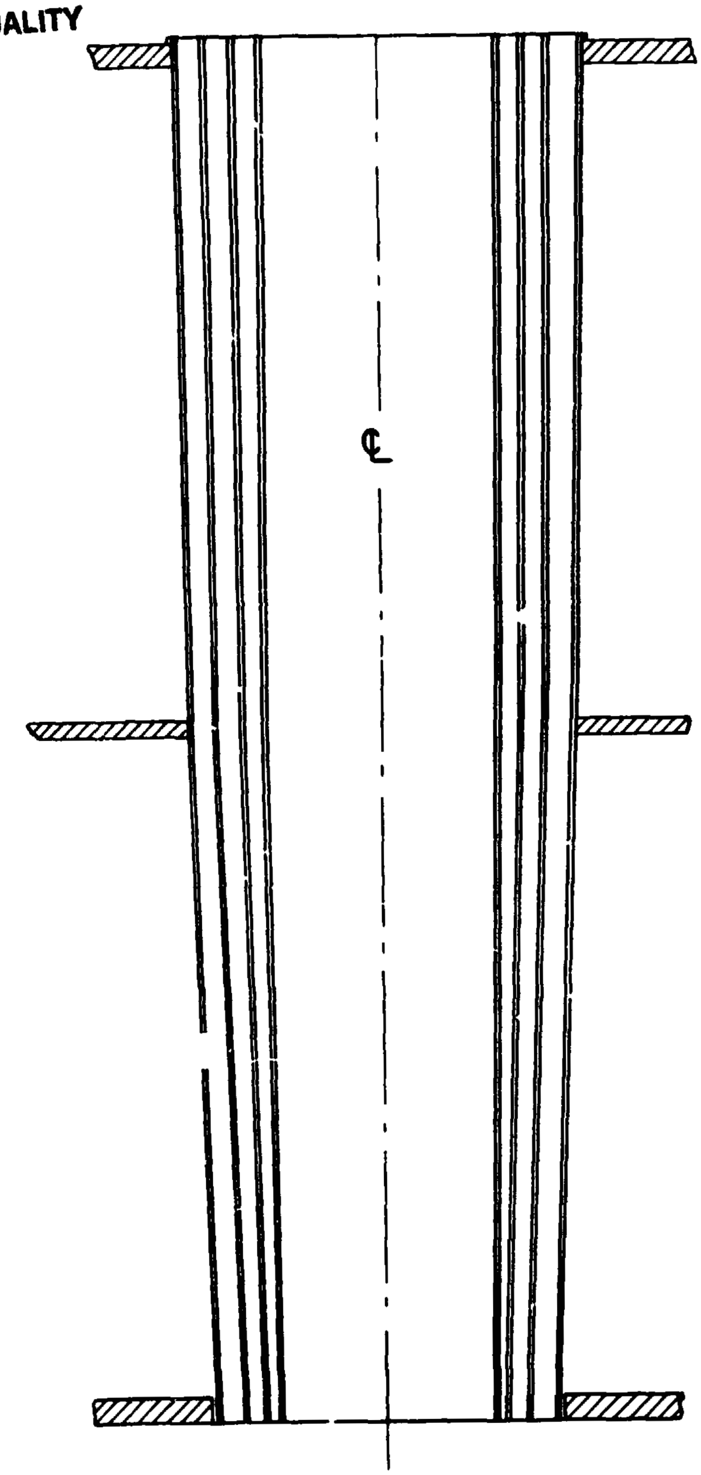

Figure 2 Four nested Wolter Type I mirrors. One of 80 modules

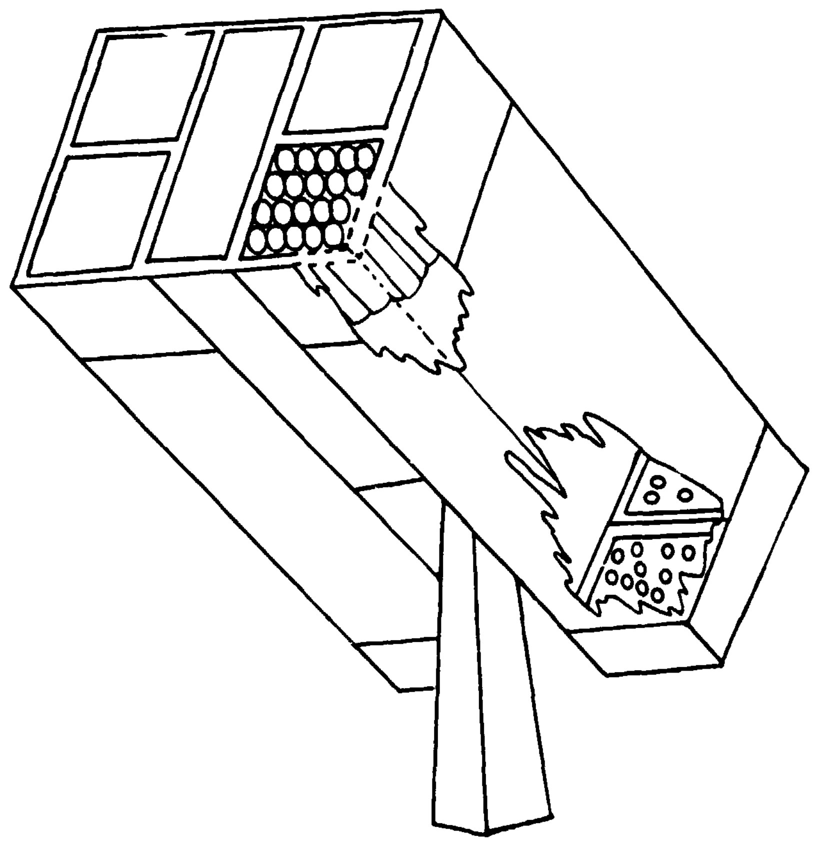

Figure 3 Four units, each comprised of 20 nests of 4 mirrors and approximately .64x.64x2.5m are mounted 2 on each side of the Birmingham SL2 pointing system. The startracker, gyros, etc., are situated in the central space.

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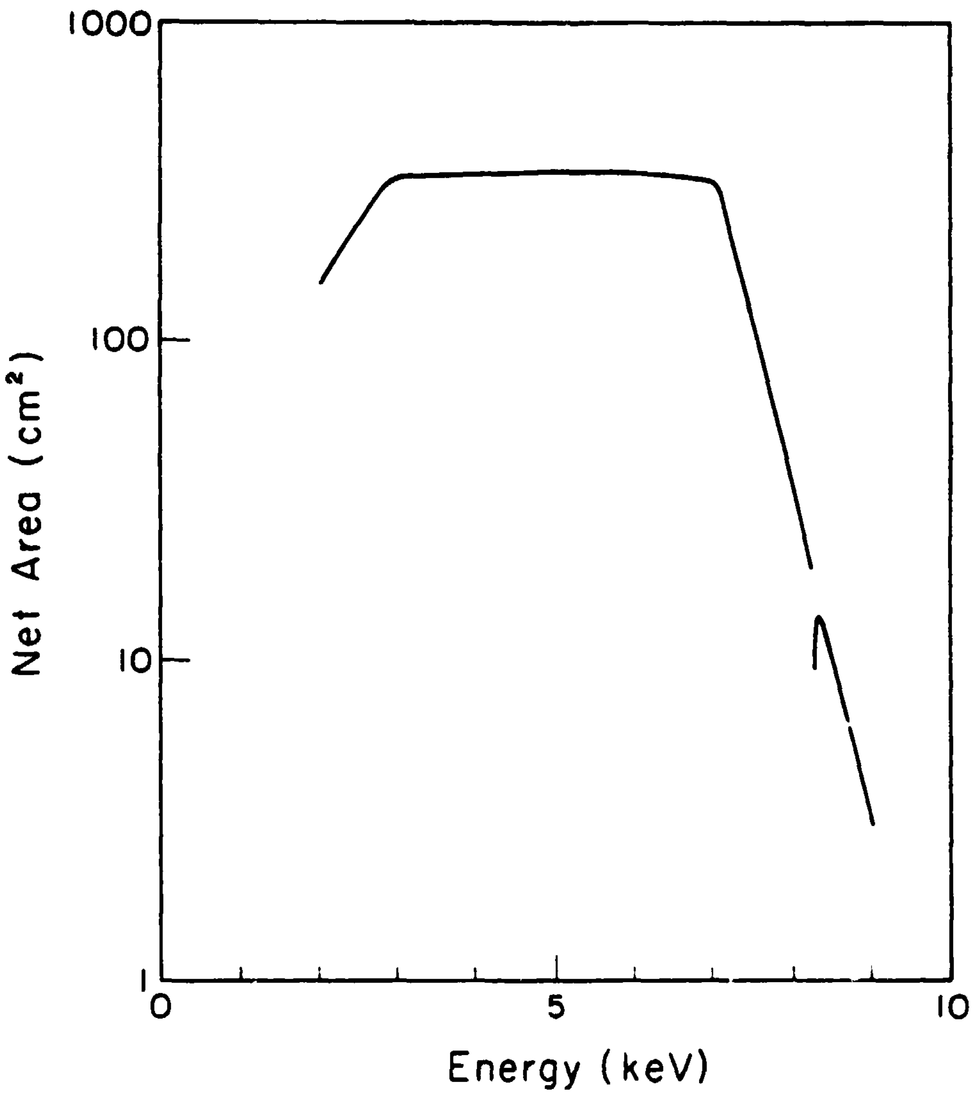

Figure 4 The effective area versus energy for the full 80 mirror/proportional counter system