4.2. Concentrator Optical System[1]

4.2.1. Introduction

Each Mirror Unit is composed of thirty nested coaxial and confocal mirrors having thickness from 0.2 to 0.4 mm. The mirrors have a double cone geometry to approximate the Wolter I configuration, with diameters ranging from 162 to 68 mm, focal length of 1850 mm and total length of 300 mm. Each MU has a weight of about 13 Kg.
Due to the large number of mirrors needed for the qualification and for the flight models of the MU and considering the requirements for angular resolution and thickness of the mirror walls, a replica technique by nickel electroforming from mandrels was considered the most appropriate for making the optics: a 1000 Å thick gold layer is evaporated on a superpolished mandrel to provide the X-ray reflecting surface and to separate the electroless nickel of the mandrel from the nickel of the mirror, deposited in an electroforming bath. The separation of the replicated mirror from the master is accomplished by cooling the aluminium mandrel. The following table lists the nominal values of the optical project of the Mirror Units.

Number of nested coaxial double-cone mirrors	30
Mirrors overall length	300 mm
First (input) cone length	150 mm
Second (output) cone length	150 mm
Mirror Unit focal length	1850 mm
Total geometrical collecting area	123.964 cm^2
Total weight of mirrors	8.702 Kg

Mirror Unit characteristics for SAX MECS and LECS instruments.

Two front end stainless steel spiders with eight arms are supported by a tube on which the flange for the interface to the satellite is mounted. The support and the alignment of the nested mirrors are provided by precise grooves machined on the spiders' arms.The diameters of the grooves are within 5 μm of the nominal requested values; the out of roundness error of a single groove and the mutual concentricity errors of the grooves are better than 5 μm.
A silicon compound is used to fix the mirrors and to damp the mechanical vibrations between mirrors and spiders during qualification tests and launch phase.

4.2.2. Performance

The EQM Mirror Unit (spare Flight Model) was tested at the PANTER X-ray facility of Max Planck Institut fuer Extraterrestische Physik, Munich in August 92, the FM1 and FM2

[1]Contribution by G. Conti, B. Sacco, L. Chiappetti

in August 93 end the FM3 and FM4 in January 94.
The measurements were made at 0.3 keV (C-Kα), 0.9 keV (Cu-Lα), 1.5 keV (Al-Lα), 3 keV (Ag-Lα), 4.5 keV (Ti-Kα), 6.4 keV (Fe-Kα), and 8 keV (Cu-Kα).

4.2.2.1. Effective Area measurements

The geometric collecting area of the MUs is 123.9 cm^2. The finite distance of the source at the PANTER facility (130 m away from the MU) causes a loss of area because of the divergence of the X-ray beam, that amounts to 15.7 cm^2. Spider obstruction also diminishes the useful area by the 10.1% and so the utilised geometrical area for the PANTER tests is 97.3 cm^2.
The measured on axis effective areas are are the following:

	0.3 KeV cm^2	**0.9 KeV cm^2**	**1.5 KeV cm^2**	**3 KeV cm^2**	**4.5 KeV cm^2**	**6.4 KeV cm^2**	**8 KeV cm^2**
EQM	84.2	81.4	80.9	54.1	57.6	56.9	37.6
FM1	83.0	80.8	81.7	55.4	59.7	56.9	38.3
FM2	82.4	79.2	80.1	54.8	57.7	55.4	36.7
FM3	82.2	79.8	80.6	55.2	58.1	57.9	38.8
FM4	83.2	79.2	80.9	54.7	57.2	57.7	38.9
theory	*84.4*	*82.2*	*82.0*	*47.4*	*58.0*	*53.7*	*37.6*

Measured and theoretical on axis effective areas of SAX EQM and FM Mirror Units.

The experimental data have not been corrected to bring the source to infinity and the ray tracing simulations from which the theoretical data are calculated reproduce the configuration utilised at the PANTER facility. The gold reflectivity curves versus grazing incidence angle and versus energy, used for the simulations, were derived from Zombek .

4.2.2.2. Encircled Energy measurements

The imaging characteristics of a MU are defined by the Encircled Energy Function (EEF) that is the fraction of total energy at the focal plane contained in a circle of radius r, versus r. The EEF is derived from the Point Spread Function (PSF), the intensity function of a point source imaged by the MU.
The following table lists the values of the 50%, 80% and 90% energy radius derived from the measured PSF. As for Effective Area, the measured data have not been corrected to bring the source to infinity. The radius are expressed in ***arcsec.*** With the source at 136 meters, the plate scale is 110.06 arcsec/mm and the focal length is 1874 mm.

	0.3 KeV			0.9 KeV			1.5 KeV		
	r 50 % ± .2	**r 80 %** ± 1.0	**r 90 %** ± 3.5	**r 50 %** ± .3	**r 80 %** ± 1.3	**r 90 %** ± 4.0	**r 50 %** ± .3	**r 80 %** ± 1.5	**r 90 %** ± 5.0
EQM	27.5	61.3	98.5	28.3	63.7	103.7	29.5	67.7	114.1
FM1	27.0	61.3	98.5	-	-	-	28.7	65.8	107.6
FM2	27.2	61.3	98.0	-	-	-	28.8	63.7	101.7
FM3	30.5	71.3	116.9	31.8	72.8	119.1	32.1	75.1	124.1
FM4	32.1	73.5	120.5	31.8	74.0	122.2	33.6	78.9	133.9

	3 KeV			4.5 KeV			6.4 KeV		
	r 50 % ± .3	**r 80 %** ± 2.0	**r 90 %** ± 7.0	**r 50 %** ± .4	**r 80 %** ± 2.3	**r 90 %** ± 8.5	**r 50 %** ± .5	**r 80 %** ± 2.5	**r 90 %** ± 9.0
EQM	32.1	76.9	138.7	35.2	90.0	172.5	39.3	106.2	205.0
FM1	32.0	79.6	147.7	34.9	92.2	180.8	40.1	111.5	217.6
FM2	31.7	74.4	129.9	34.2	83.8	153.8	38.4	101.2	198.4
FM3	34.5	84.0	151.4	37.8	103.8	223.5	40.4	111.4	214.7
FM4	35.2	87.2	157.9	38.6	98.9	191.2	41.7	112.0	217.9

	8 KeV		
	r 50 % ± .5	**r 80 %** ± 3.0	**r 90 %** ± 9.5
EQM	40.0	110.6	210.7
FM1	42.7	122.1	226.8
FM2	40.6	109.7	212.7
FM3	41.2	113.8	213.4
FM4	40.8	110.8	207.8

Measured 50 % , 80% and 90% Energy Radius of SAX EQM and FM Mirror Units.

Figure captions

Fig 4.2.1 Effective area of one mirror unit on axis

Fig. 4.2.2 Effective area of one mirror unit for different energies as a function of the off-axis angle

Fig. 4.2.3a-d Encircled energy at different energies and off axis angles as a function of the circle radius

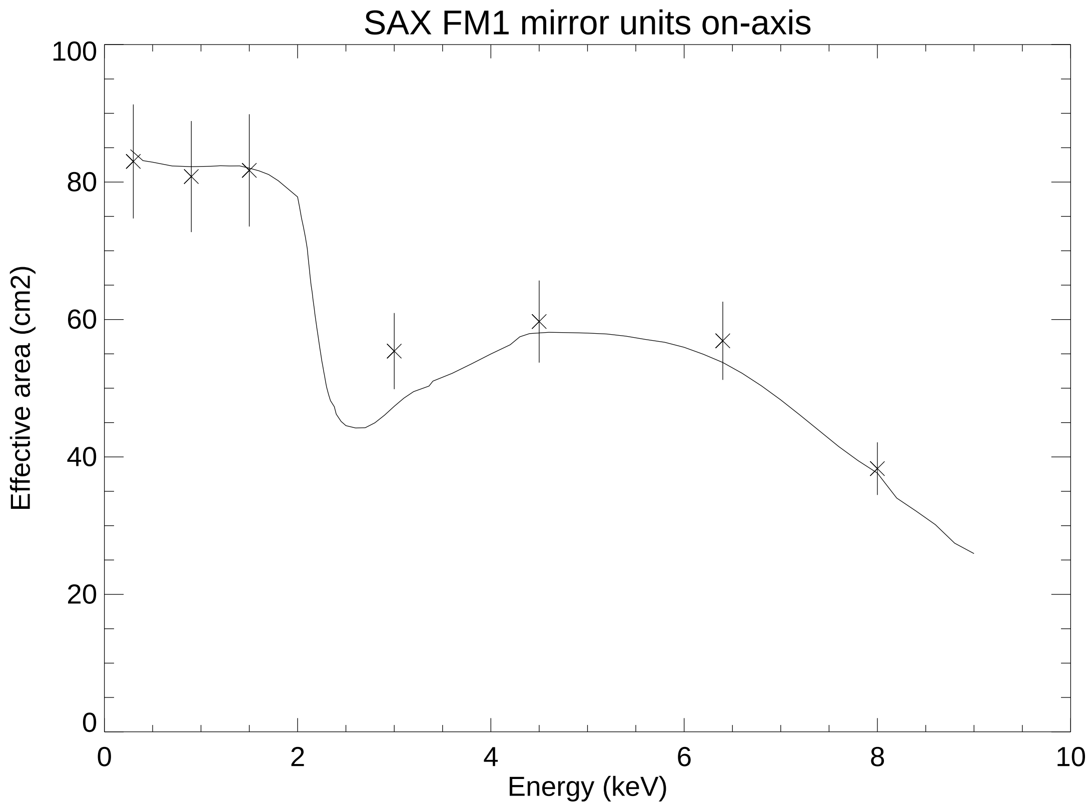
SAX FM1 mirror units on-axis
Effective area (cm2)
Energy (keV)
0
20
40
60
80
100
0
2
4
6
8
10

Fig. 4.2.1

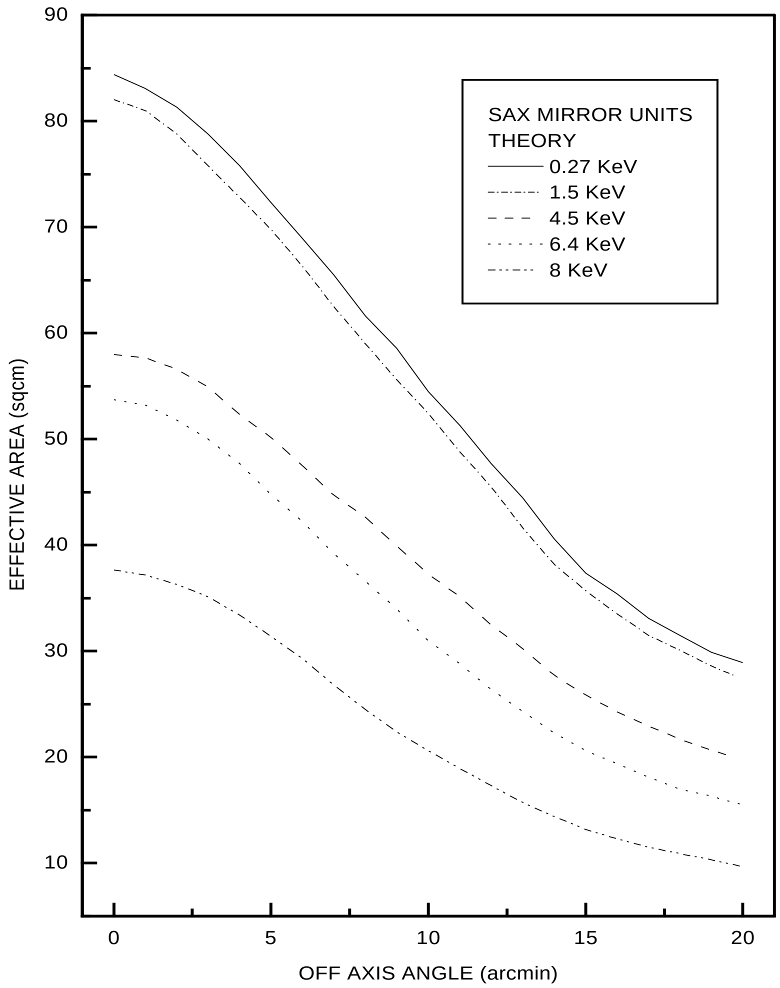
SAX MIRROR UNITS
THEORY
0.27 KeV
1.5 KeV
4.5 KeV
6.4 KeV
8 KeV
EFFECTIVE AREA (sqcm)
OFF AXIS ANGLE (arcmin)
90
80
70
60
50
40
30
20
10
0
5
10
15
20

Fig.4.2.2

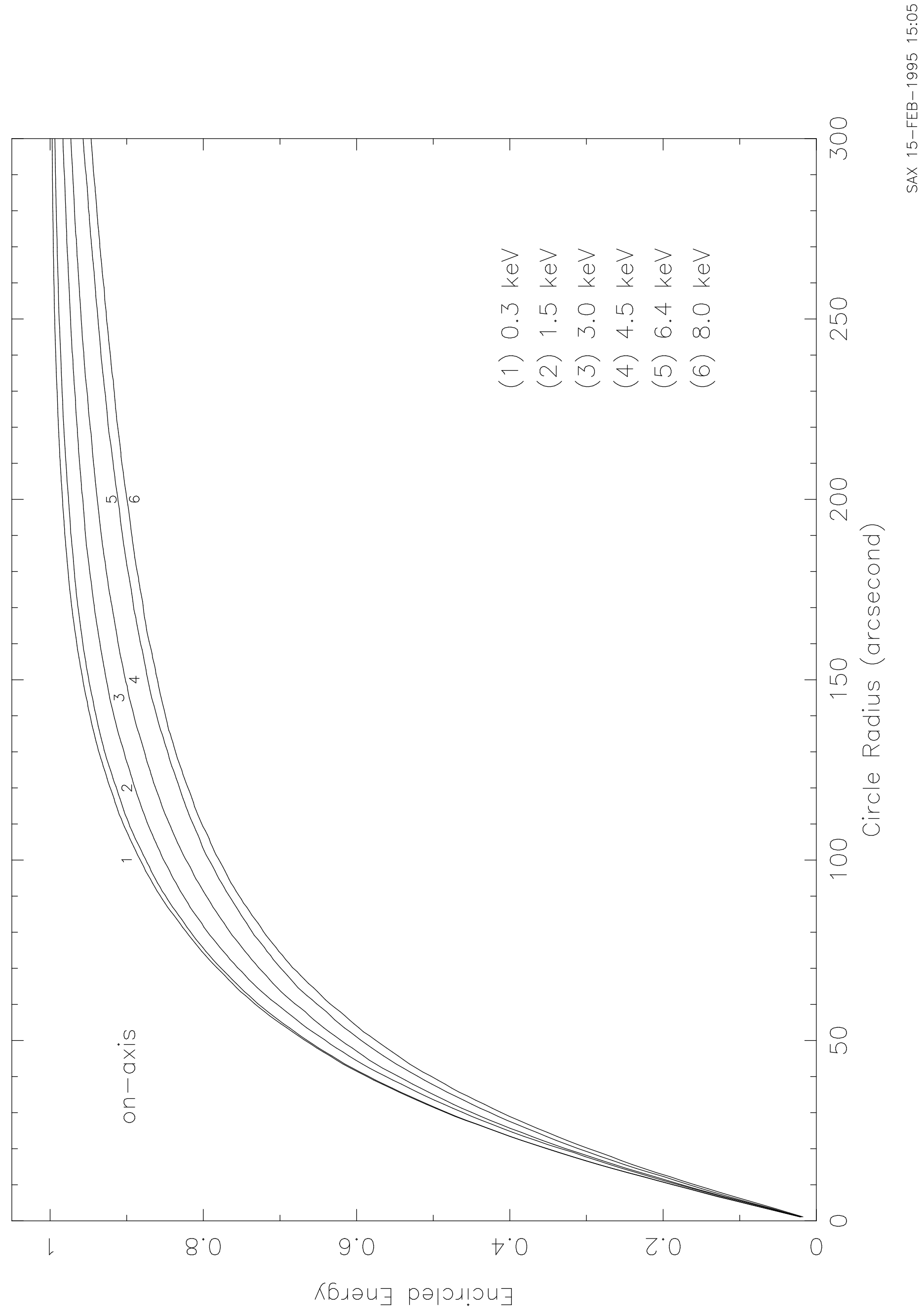
on-axis
(1) 0.3 keV
(2) 1.5 keV
(3) 3.0 keV
(4) 4.5 keV
(5) 6.4 keV
(6) 8.0 keV
Encircled Energy
Circle Radius (arcsecond)
SAX 15-FEB-1995 15:05

Fig. 4.2.3a

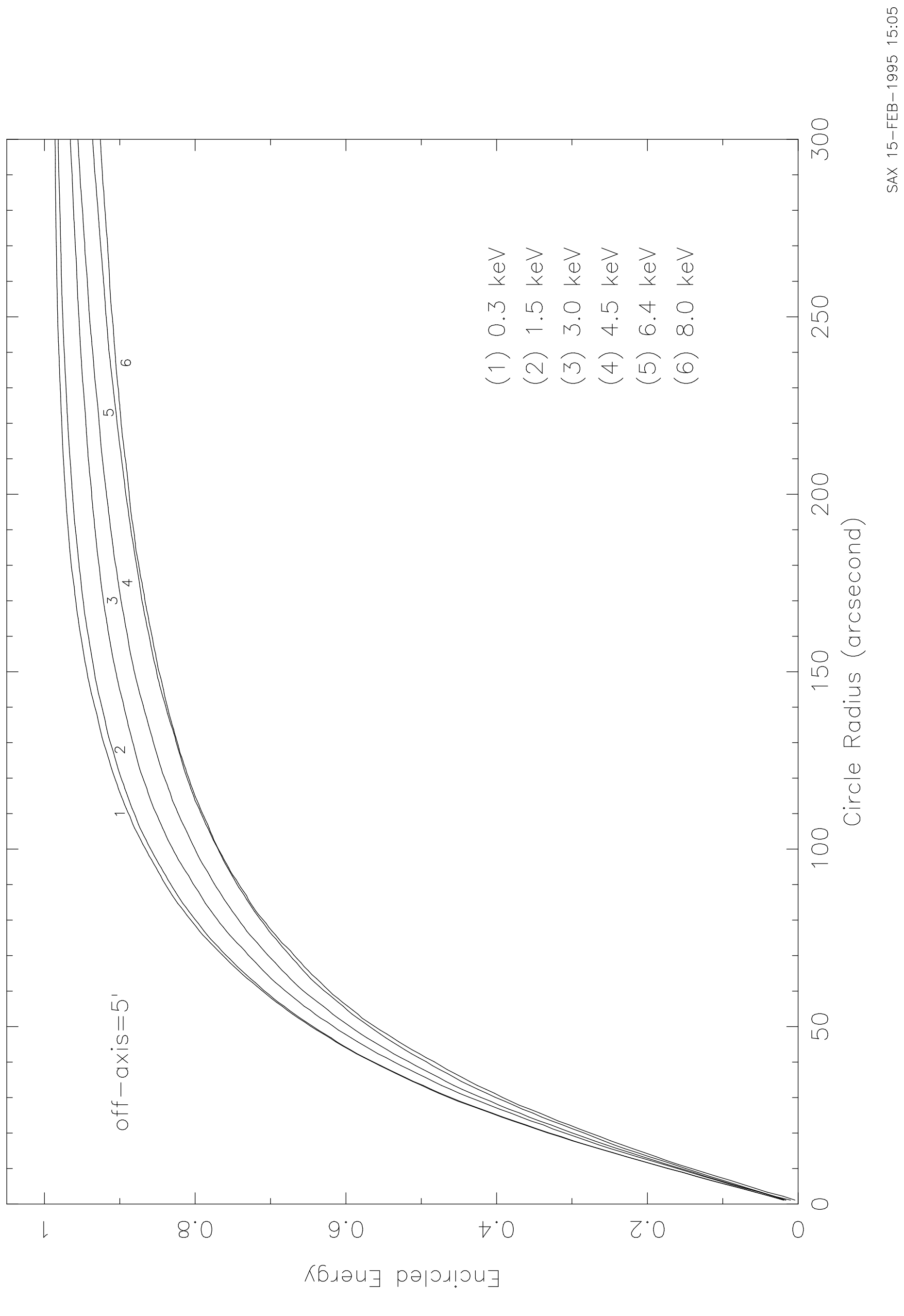
off−axis=5'
(1) 0.3 keV
(2) 1.5 keV
(3) 3.0 keV
(4) 4.5 keV
(5) 6.4 keV
(6) 8.0 keV
Circle Radius (arcsecond)
Encircled Energy
SAX 15−FEB−1995 15:05

Fig. 4.2.3b

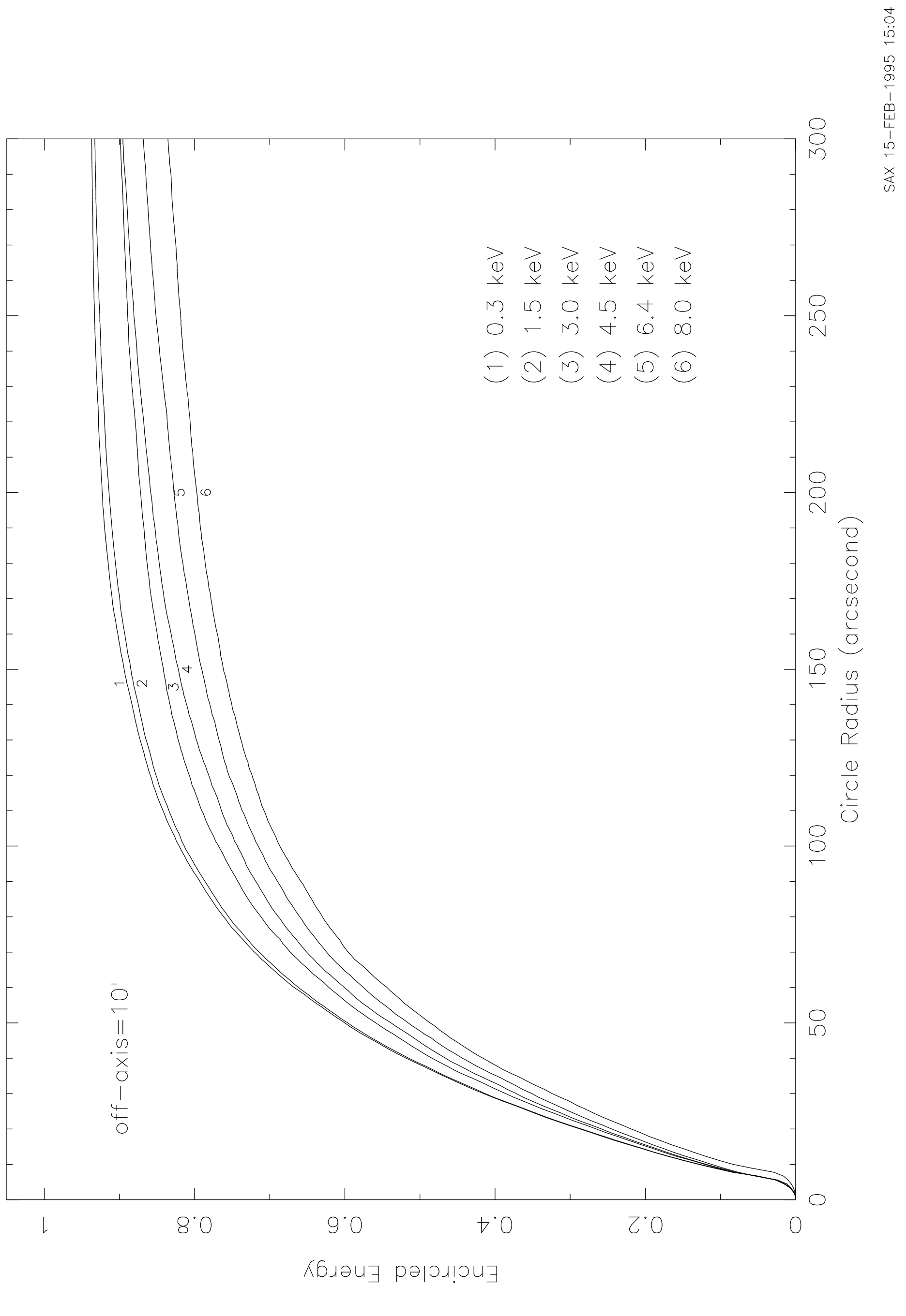
off−axis=10'
(1) 0.3 keV
(2) 1.5 keV
(3) 3.0 keV
(4) 4.5 keV
(5) 6.4 keV
(6) 8.0 keV
1
2
3
4
5
6
0
50
100
150
200
250
300
Circle Radius (arcsecond)
0
0.2
0.4
0.6
0.8
1
Encircled Energy
SAX 15−FEB−1995 15:04

Fig. 4.2.3c

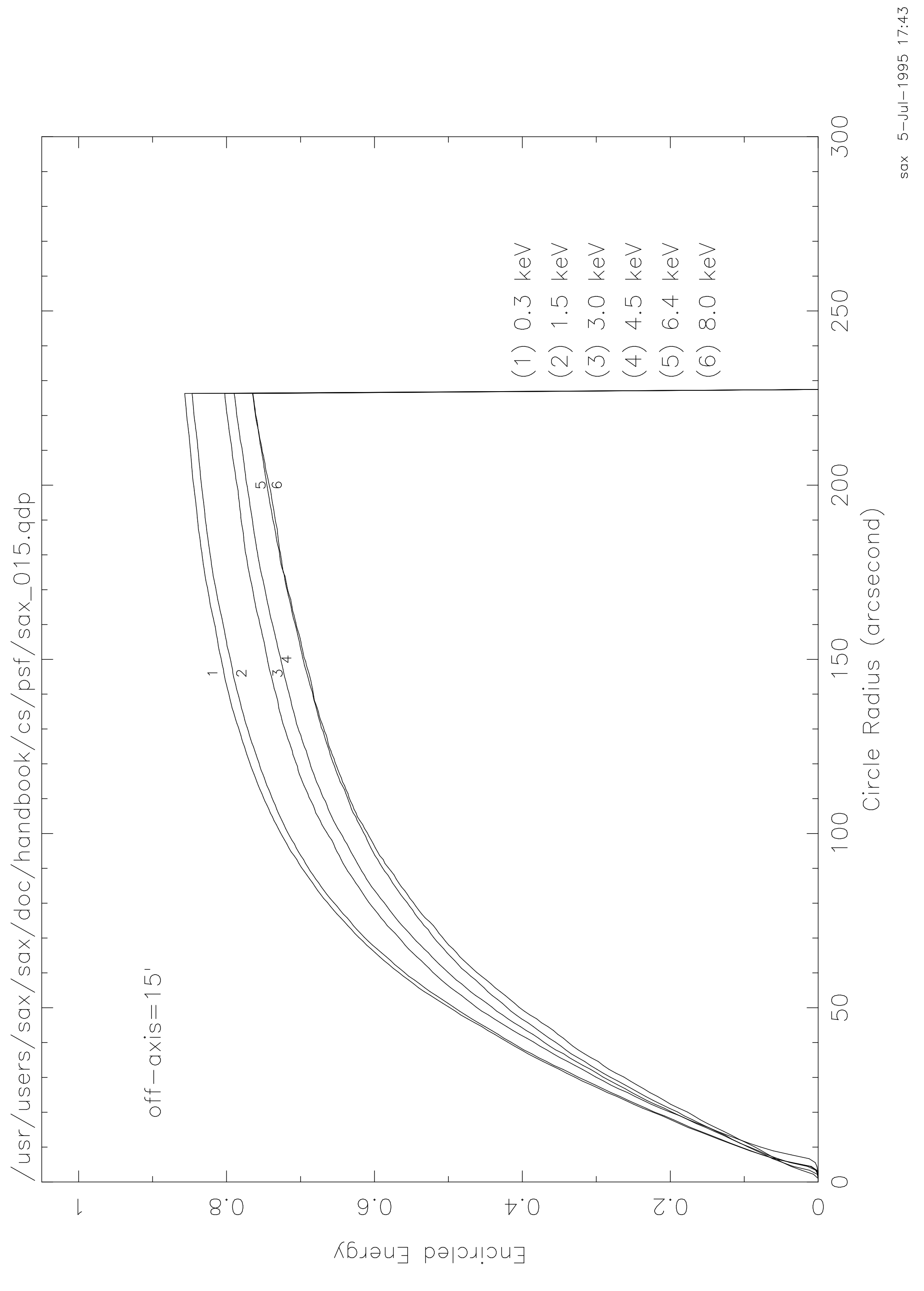
/usr/users/sax/sax/doc/handbook/cs/psf/sax_015.qdp
off−axis=15'
(1) 0.3 keV
(2) 1.5 keV
(3) 3.0 keV
(4) 4.5 keV
(5) 6.4 keV
(6) 8.0 keV
Encircled Energy
Circle Radius (arcsecond)
0
0.2
0.4
0.6
0.8
1
0
50
100
150
200
250
300
sax 5−Jul−1995 17:43

Fig. 4.2.3d