The foundamental parameters of X-ray telescopes

INAF OAS BOLOGNA

What happens

.. a X-ray source…

…mirrors, concentrators or collimators

… board …ellites..

…ctors …icrocal., etc.)

INPUTS
Source photons+
~~Mirrors response+~~
~~Detector response+~~
~~All kinds of Background s~~

OUTPUTS
Images
Light Curves
Spectra

Take into account telescope response… and remaining bgds

Remove "some" backgrounds and malfunctioning

INPUTS
Source photons+
Mirrors response+
Detector response+
All kinds of Background s

things to do

..since the birth of X-ray Astronomy in 1962, improvements were carried out in terms of sensitivity, angular resolution, energy resolution and energy bandpass

The once-golden age of X-ray Astronomy

….where we were in 1999…. and we still are there…

XMM-*Newton*

Chandra

Final note……

Sensitivity: $S/N = S/(S+B)^{0.5}$ → $\propto t^{0.5}$

$S^{0.5}$=Poisson Noise source counts

B_{sky}=Const x Sky region

$B_{dark\ current}$= Const x det. reg.

$B^2_{rea\text{-}out\,(electronic)}$= Const x det. Reg.

How to increase the sensitivity….

Increasing the collecting/effective Area

$S = F \times A_{eff}$

S/N increases……

(….but sometime also the bgd increases)

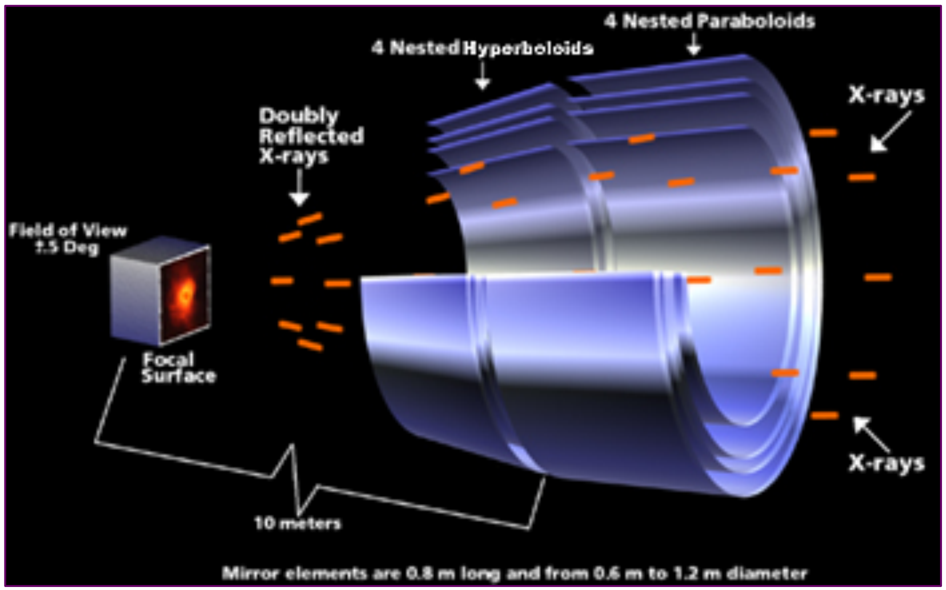
the ESA (XMM-Newton) way

Reducing the B.

S/N increases

the NASA (Chandra) way…

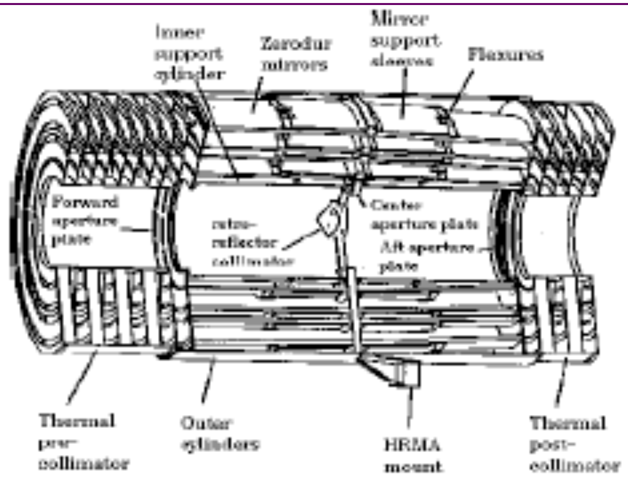
Chandra = angular resolution



Only four, robust shells
High-quality of shell production
to allow <arcsec on-axis angular
resolution (the best so far in X-rays)

$$\vartheta_{crit} \propto \frac{\sqrt{\rho}}{E}$$

High Resolution Mirror Assembly (HRMA)



Ottica Wolter Type-I

Mirror diameters: 1.23, 0.99, 0.87 0.65 m

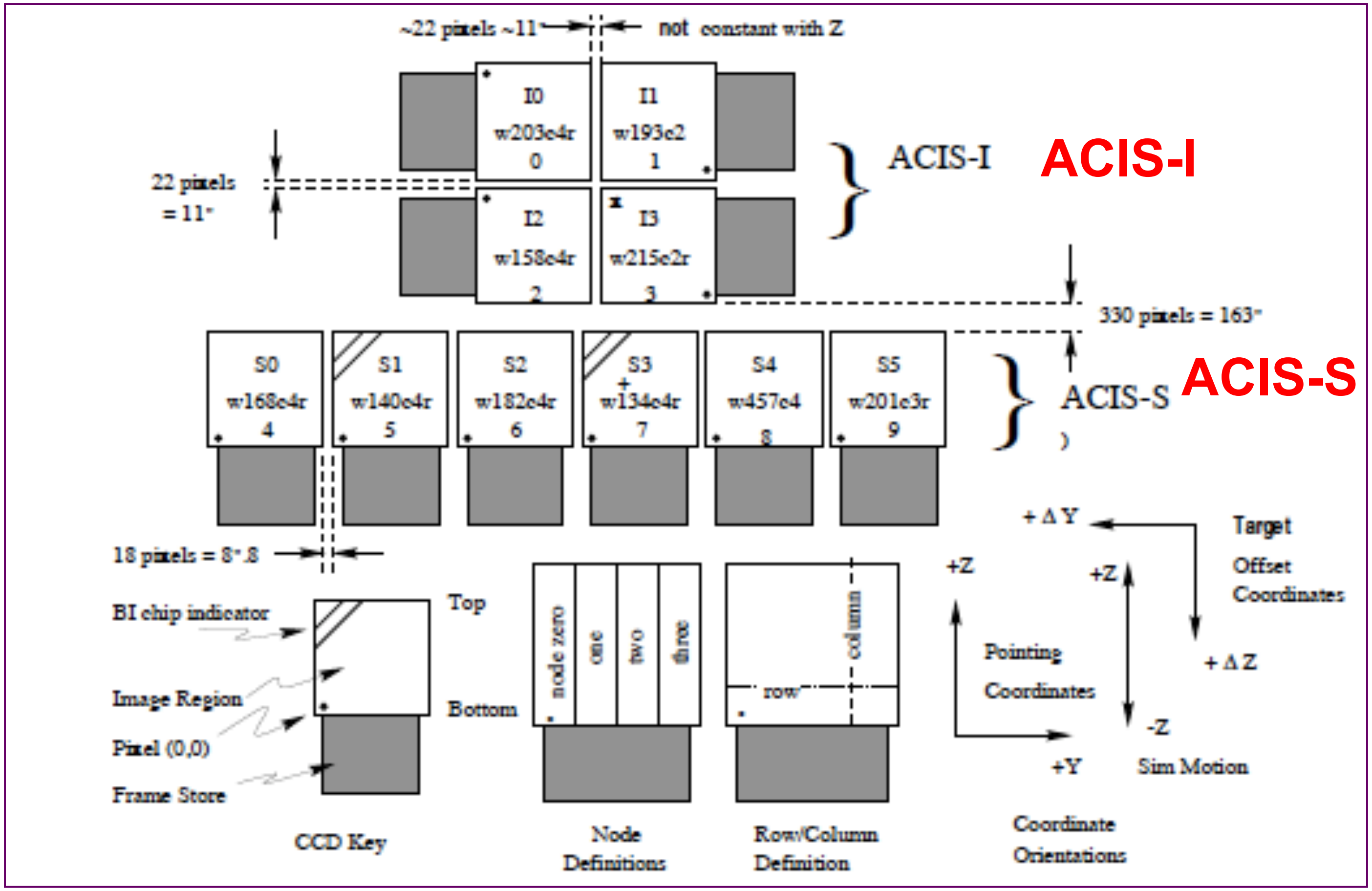
Mirror lengths: 84 cm

HRMA mass: 1500 kg

Focal length: 10 m

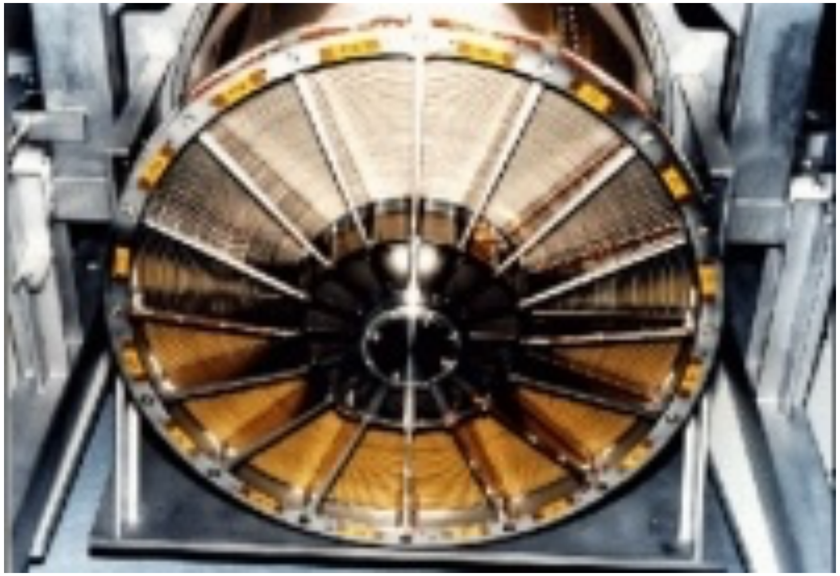
PSF FWHM: 0.5”

Chandra focal-plane detectors: CCDs

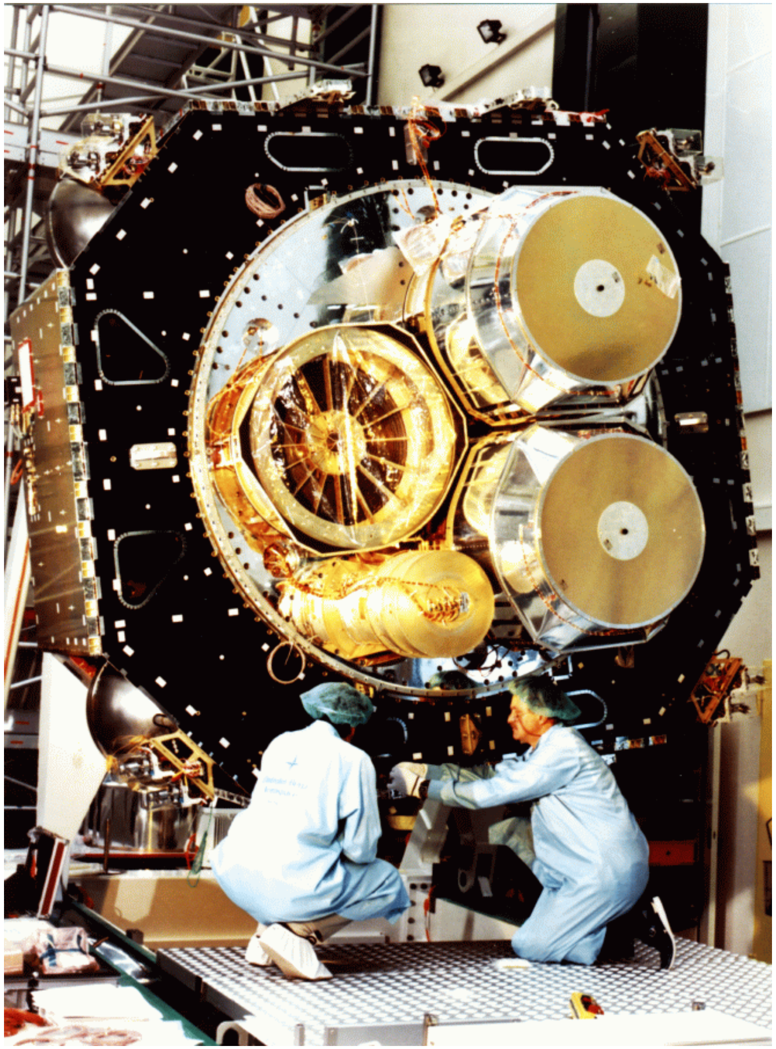


XMM-*Newton* = large effective area

3 modules, 58 shells



$$\vartheta_{crit} \propto \frac{\sqrt{\rho}}{E}$$



XMM-Newton: all instruments at work simultaneously

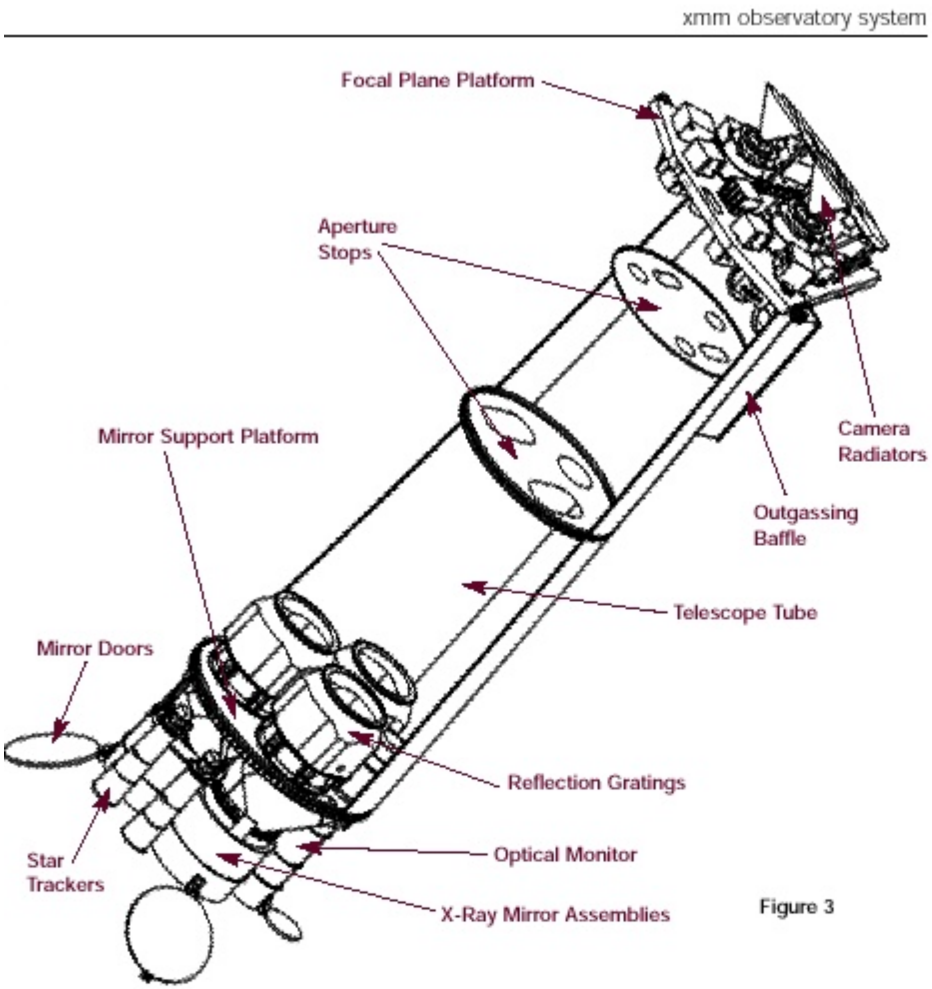
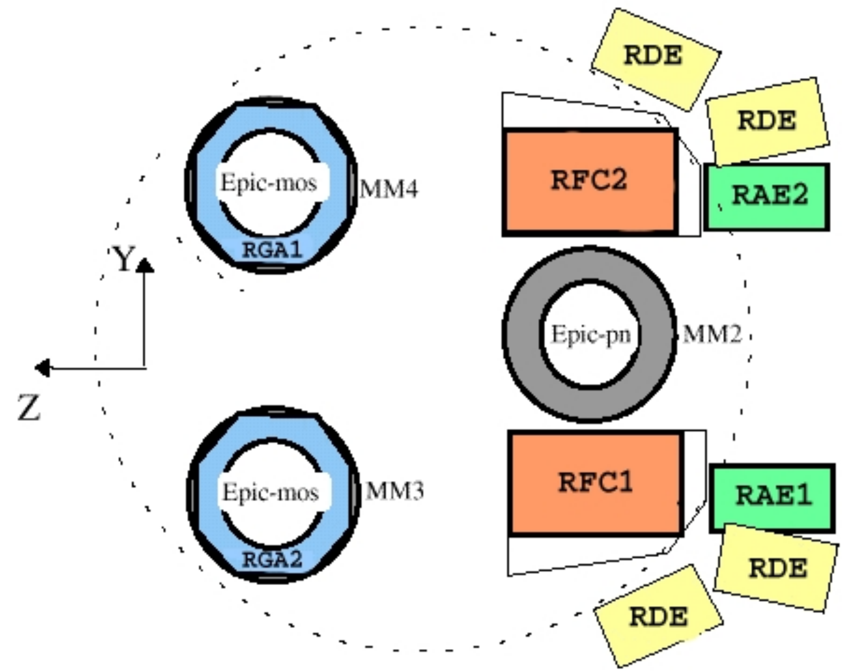
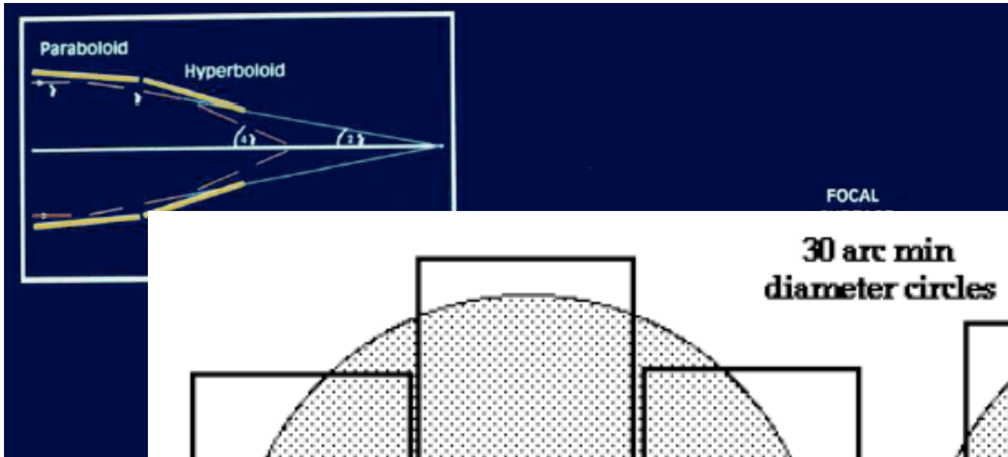
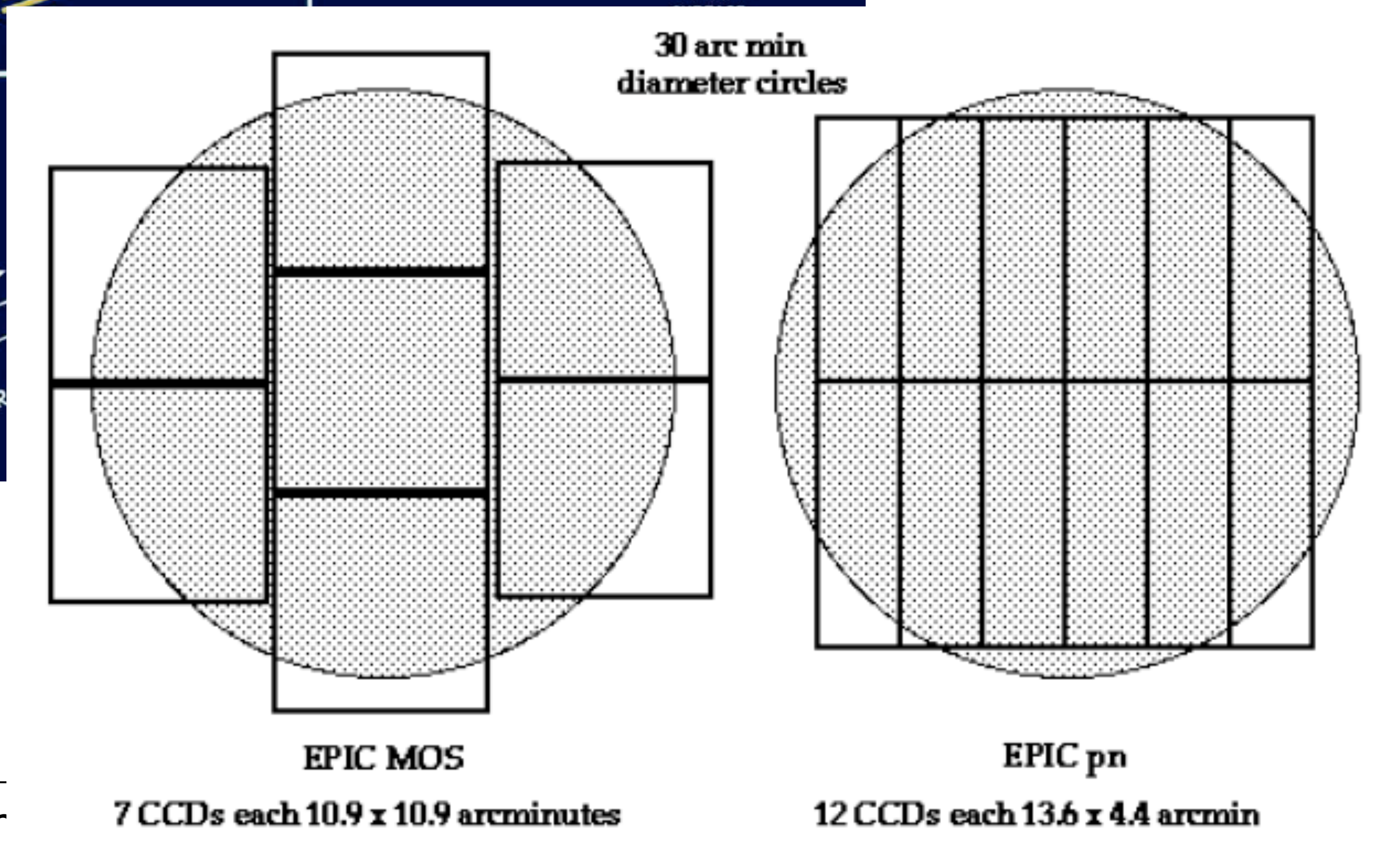


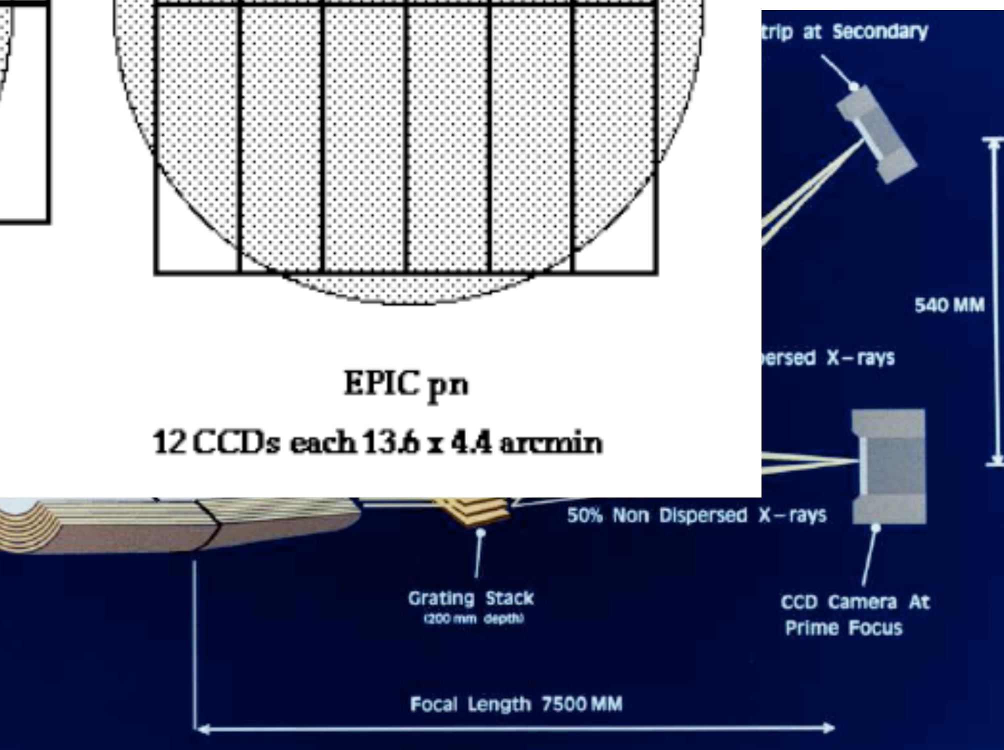
Figure 3





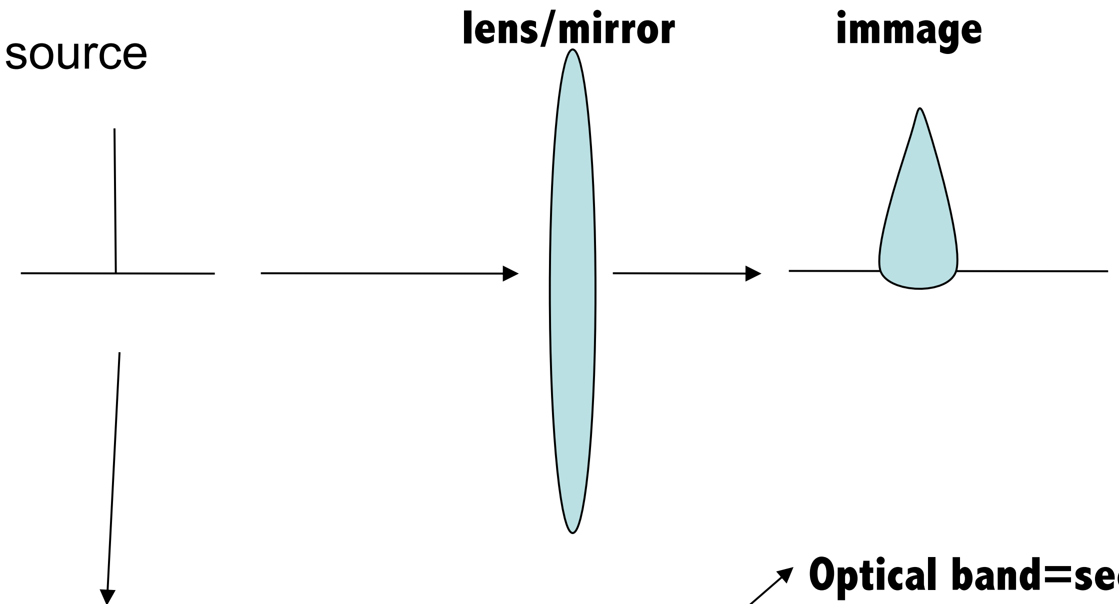
Wolter I solution

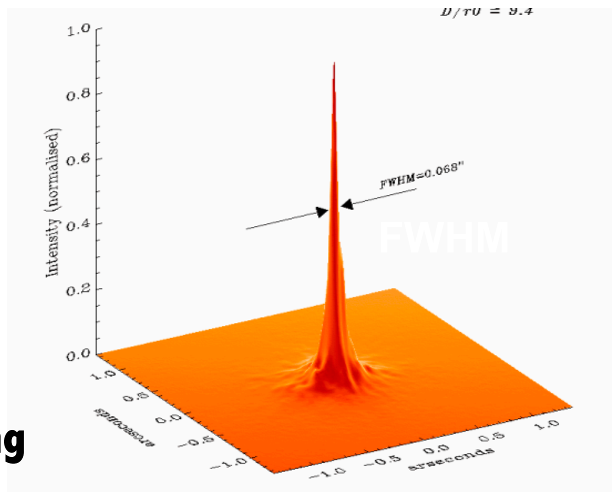




Full ir
pn CCD, ≈50% to the
MOS1-2, the rest to the
grating spectrometers
(RGS)

First fundamental element od the telescope: Mirrors and PSF





Optical band=seeing

Intrinsic limit (θ=1.22 λ/D)
+ operations…

X-rays= mirrors properties
+ mirror array assembly

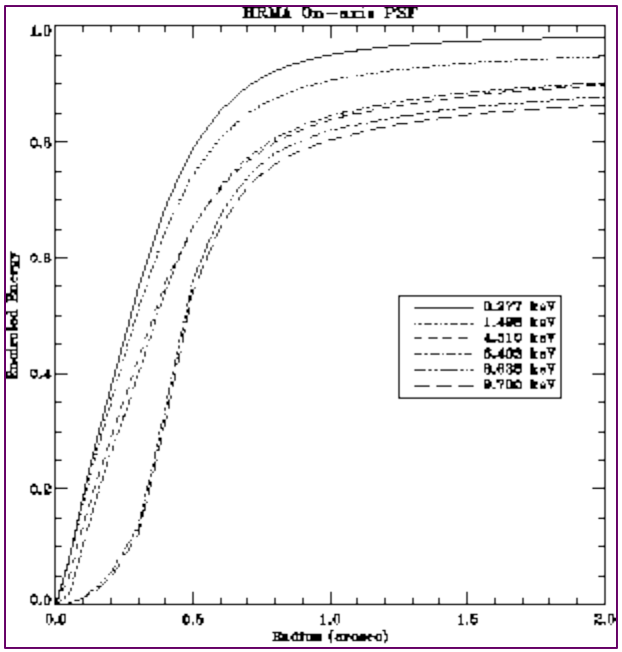
<u>Point Spread Function (PSF)</u> – describes the response of an imaging system to a point source or point object.

HEW (PSF), FWHM (PSF) = angular resolution

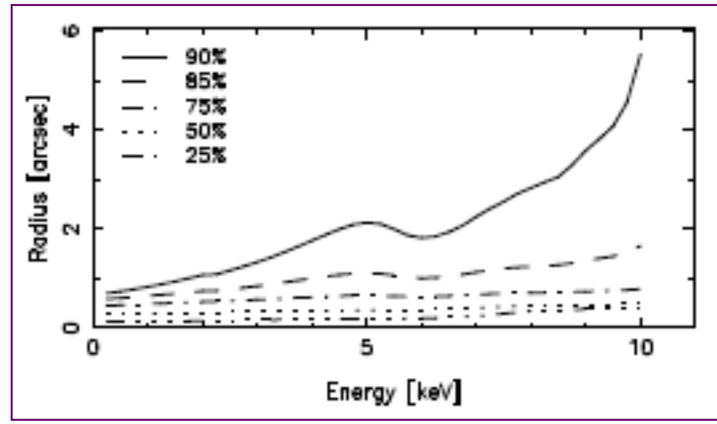
PSF = function of (x,y) or (r, ϑ).

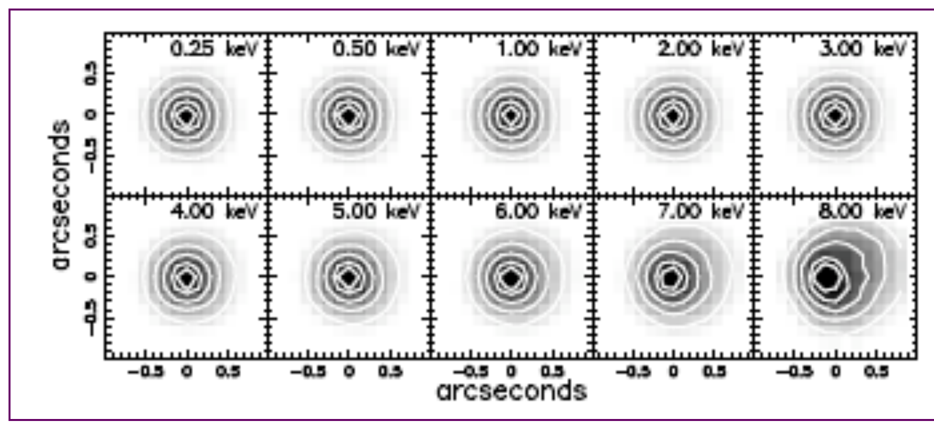
High Resolution Mirror Assembly (HRMA): On-axis PSF

Radius encompassing NN% of the counts
as a function of the energy



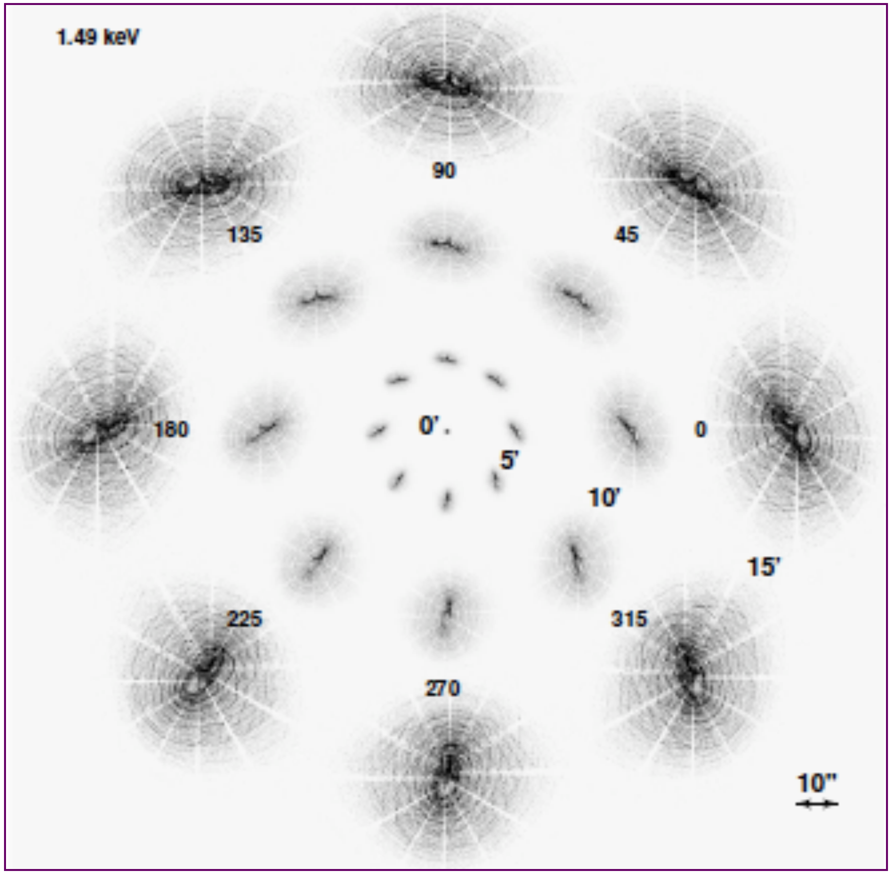
Encircled energy vs. radius
at different energies

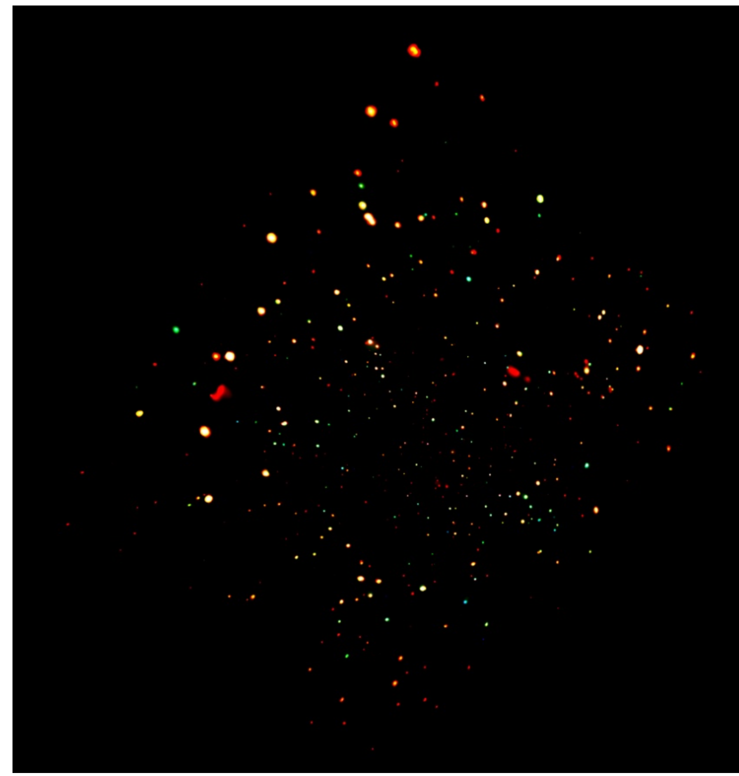




On-axis PSF size and shape

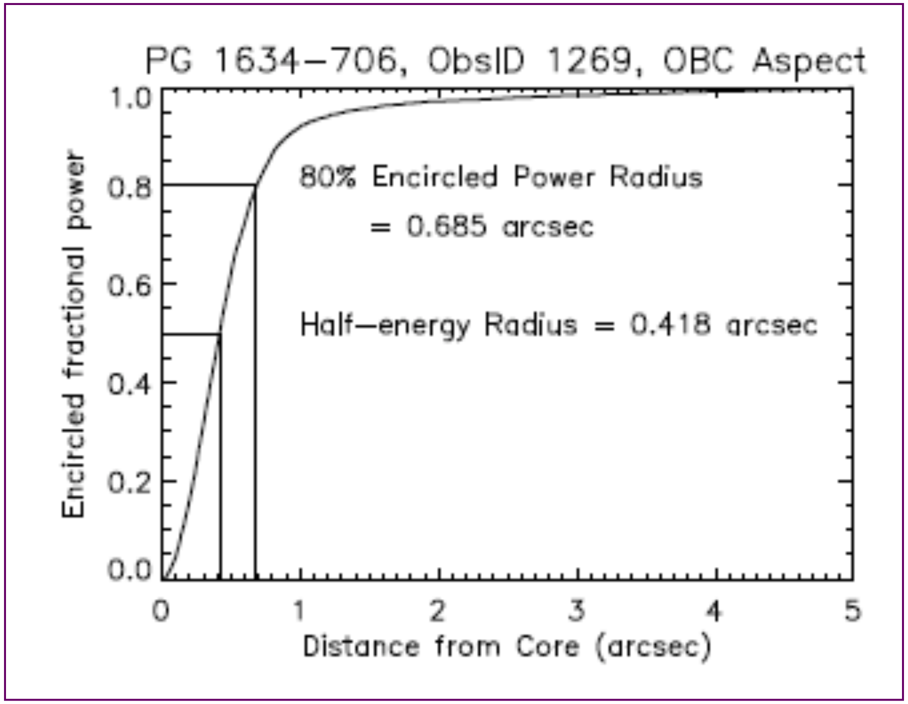
High Resolution Mirror Assembly (HRMA): Off-axis PSF



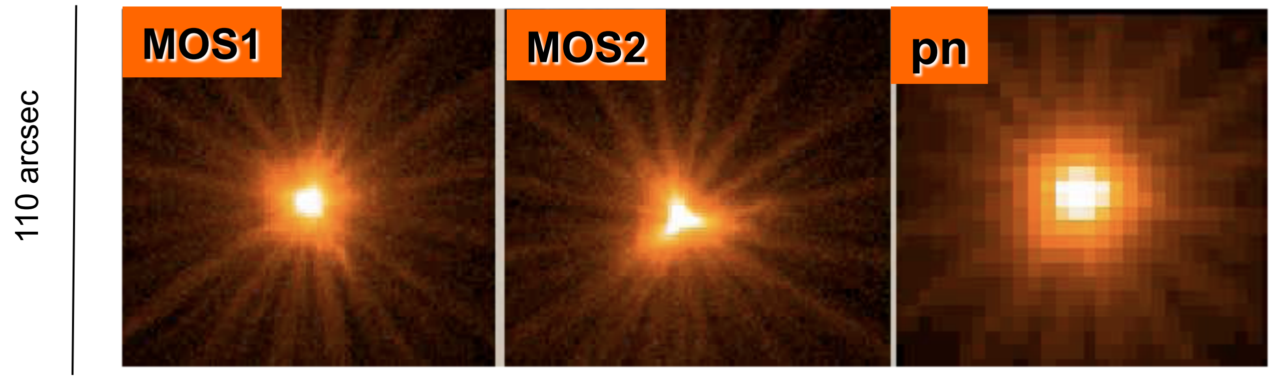


CDF-N 2Ms exposure

Resulting image on the focal plane of ACIS



XMM-*Newton:* the EPIC on-axis PSF

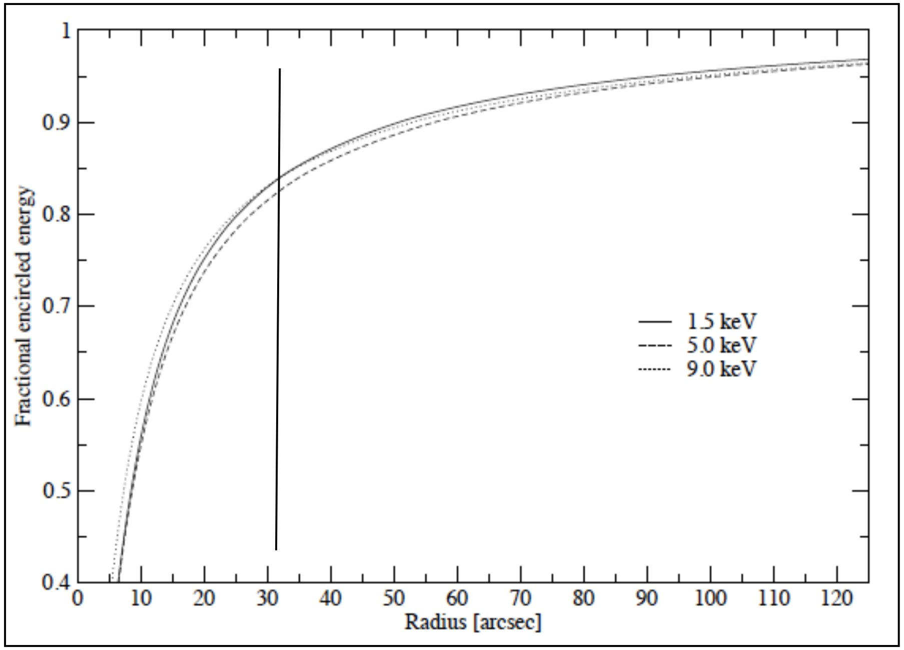


spider-like pattern due to the support of the Wolter I mirrors

Mirror module	2	3	4
Instr. chain[a]	pn	MOS-1+RGS-1	MOS-2+RGS-2
	orbit/ground	orbit/ground	orbit/ground
FWHM [″]	$< 12.5^b/6.6$	4.3/6.0	4.4/4.5
HEW [″]	15.2/15.1	13.8/13.6	13.0/12.8

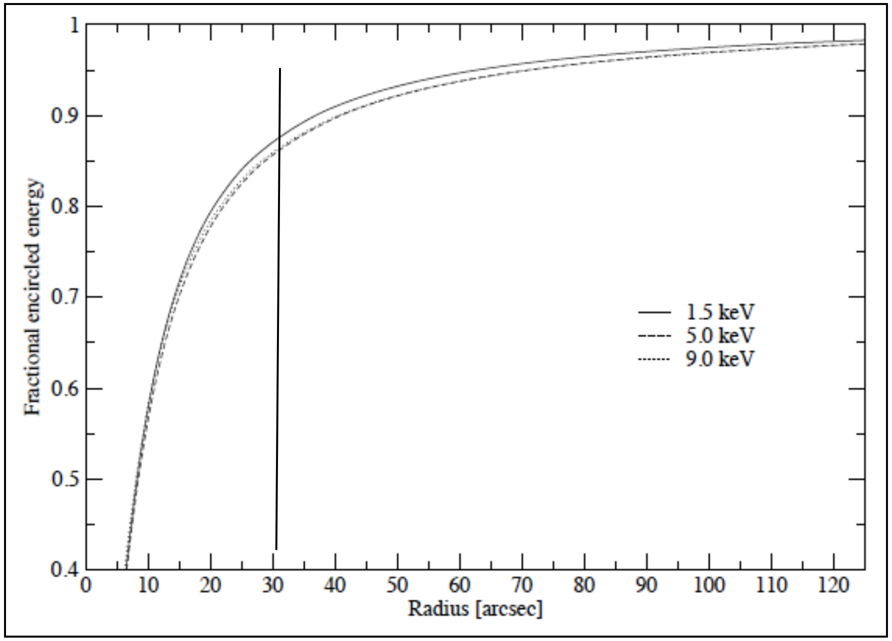
PSF FWHM higher than in *Chandra* but much larger effective area
Background (and confusion limit) can be an issue

XMM-*Newton:* the EPIC on-axis PSF

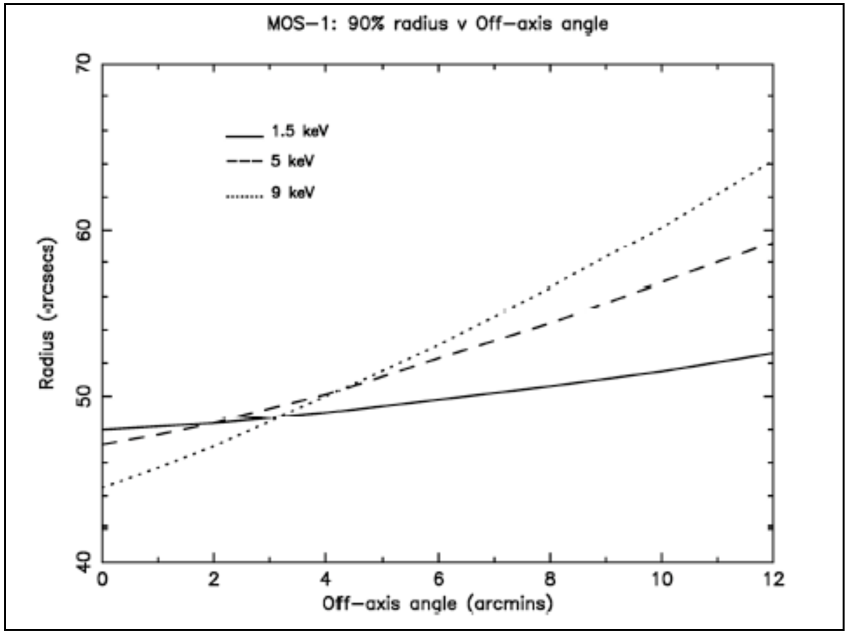


Encircled energy vs. radius
at different energies for the MOS1-2

Encircled energy vs. radius
at different energies for the pn

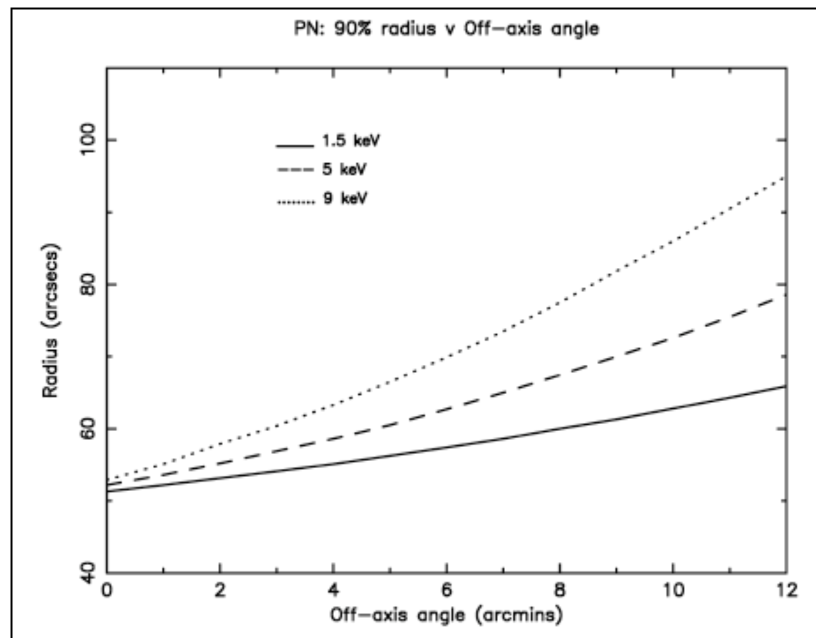


XMM-*Newton:* the EPIC off-axis PSF



90% radius (radius encompassing 90% of the incoming photons) vs. off-axis angle for the MOS1-2 at different energies

90% radius vs. off-axis angle for the pn at different energies



Second fundamental element of the telescope: mirrors and detector
Effective Area

$$A_{effective}(E,q,x,y) = A_{geometric} x R(E) x V(E,x,y) x QE(E,x,y)$$

Detector

Specchio

Effective area

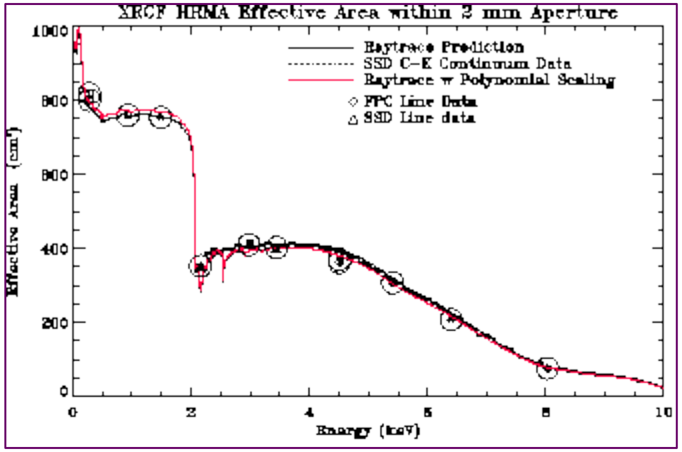
Geometric Area

Reflectivity

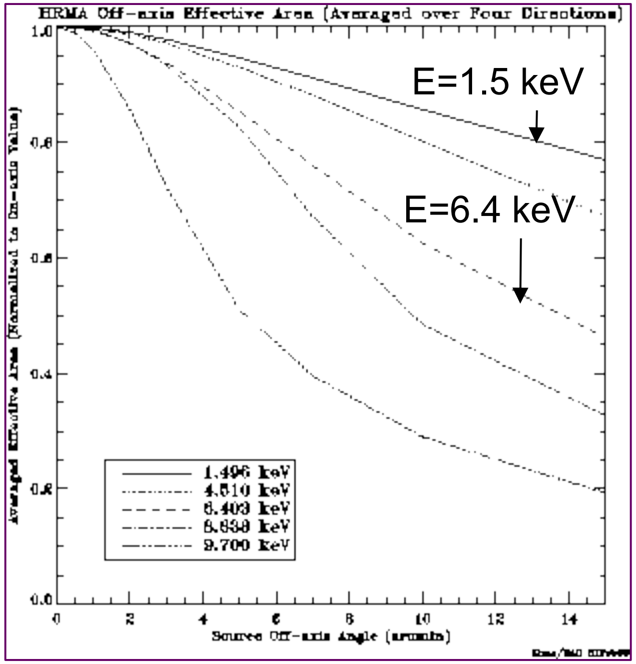
Vignetting

Quantum Efficiency

Chandra: High Resolution Mirror Assembly (HRMA): Effective Area



Effective area vs. Energy

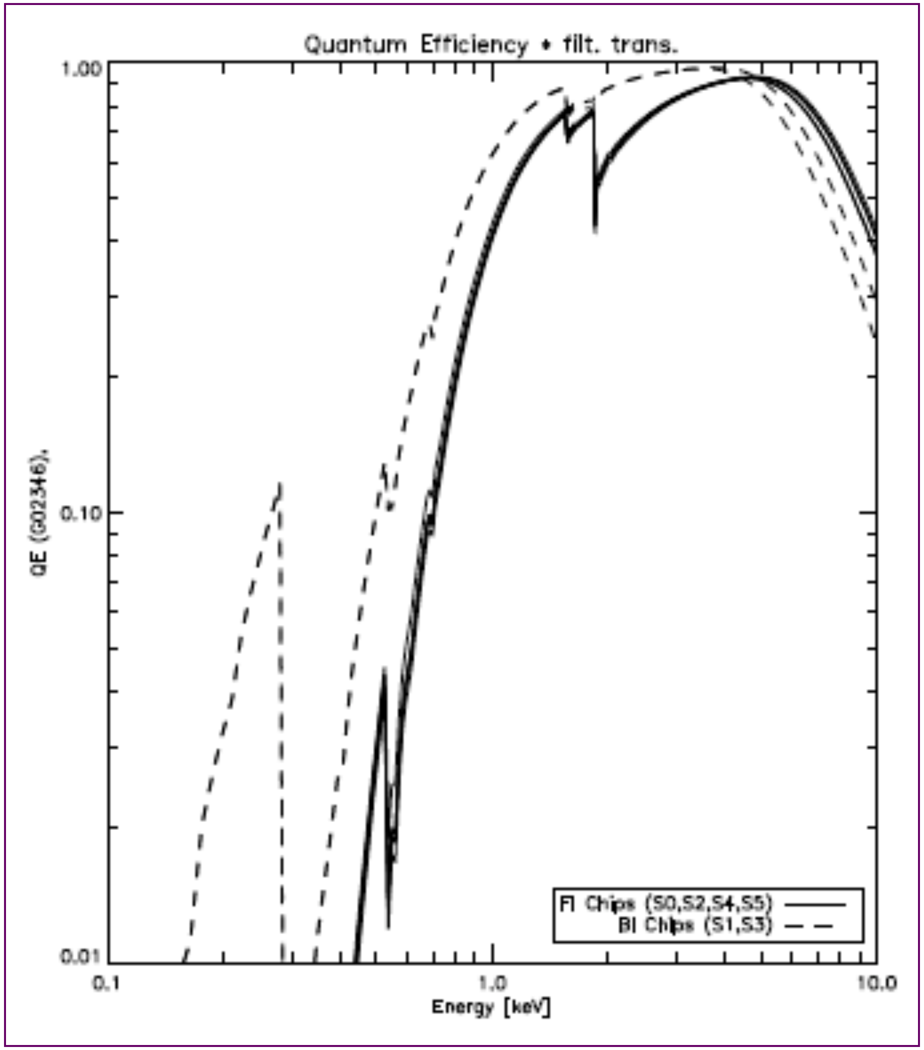


Effective area vs. off-axis angle at different energies

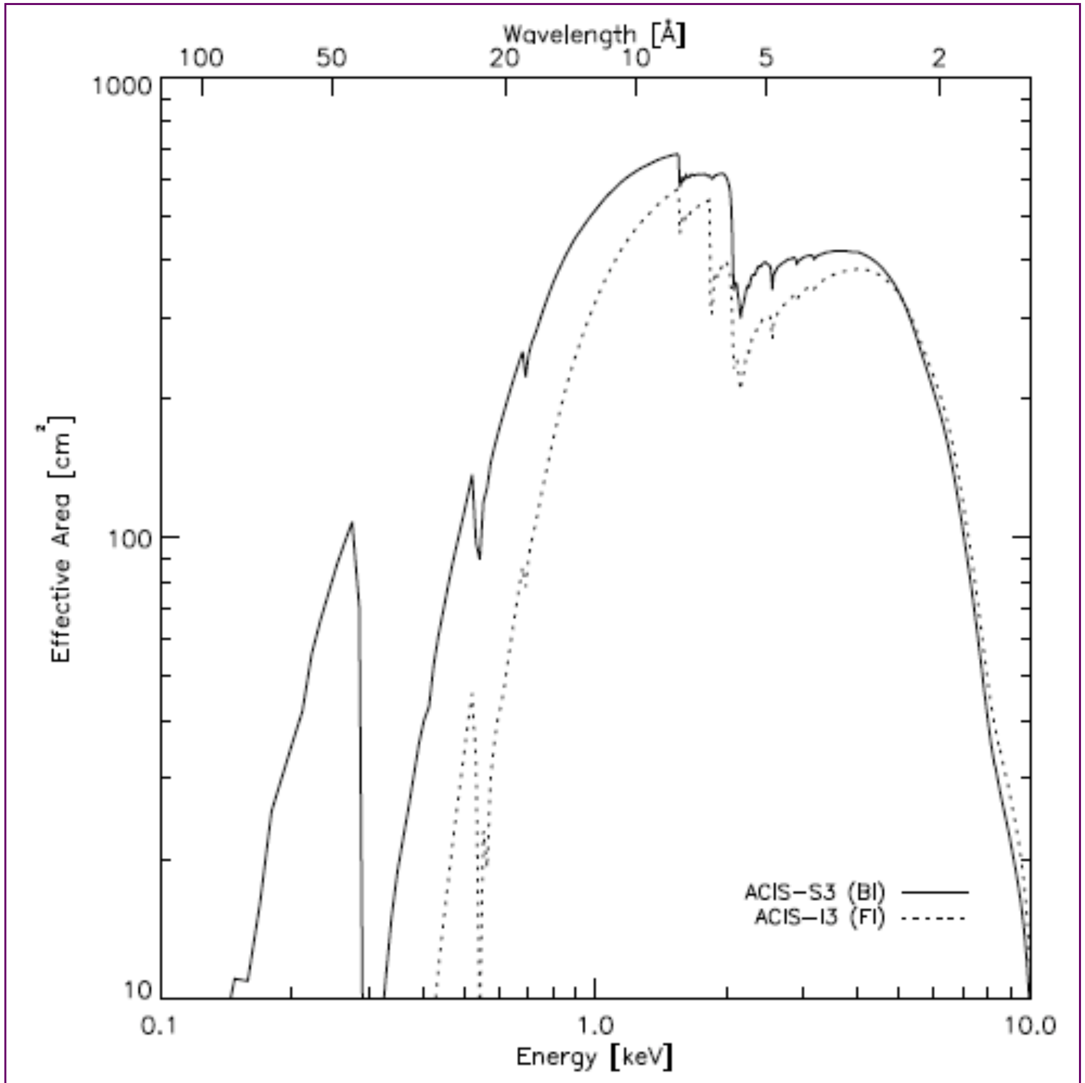
Effect of vignetting

$$\vartheta_{crit} \propto \frac{\sqrt{\rho}}{E}$$

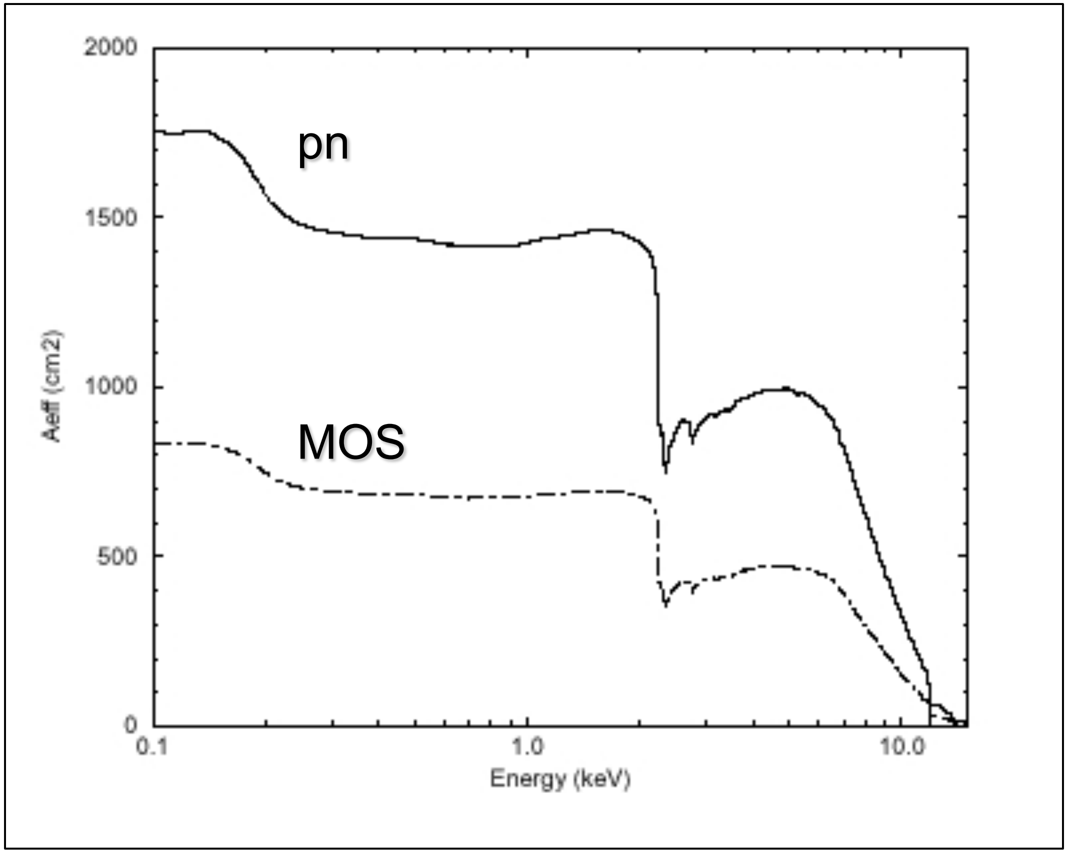
Chandra: quantum efficiency



Chandra: effective area

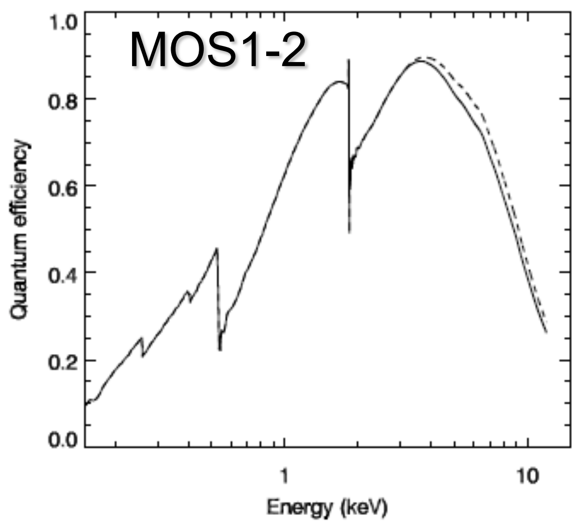


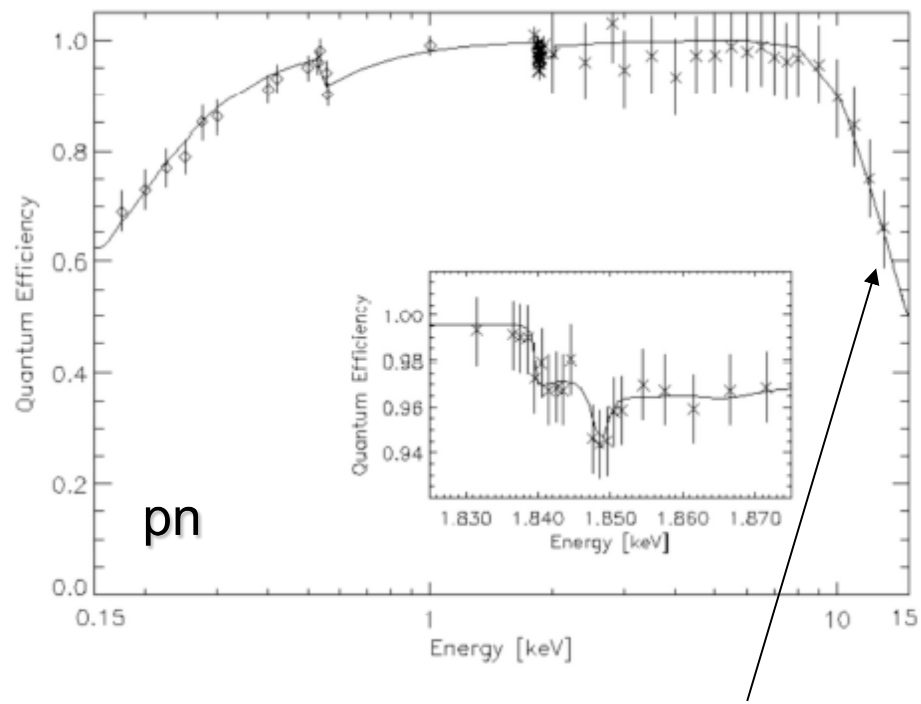
XMM-*Newton:* mirror effective (geometric) area



$$\vartheta_{crit} \propto \frac{\sqrt{\rho}}{E}$$

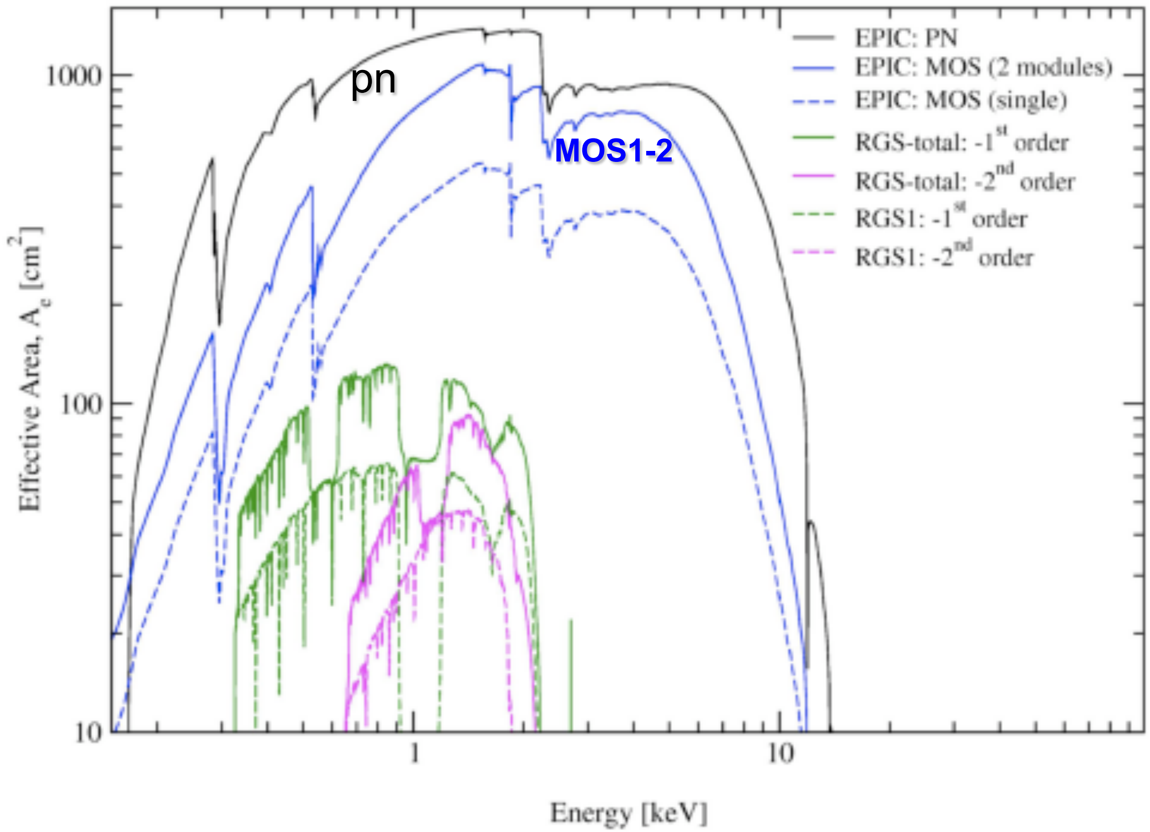
XMM-*Newton:* quantum efficiency



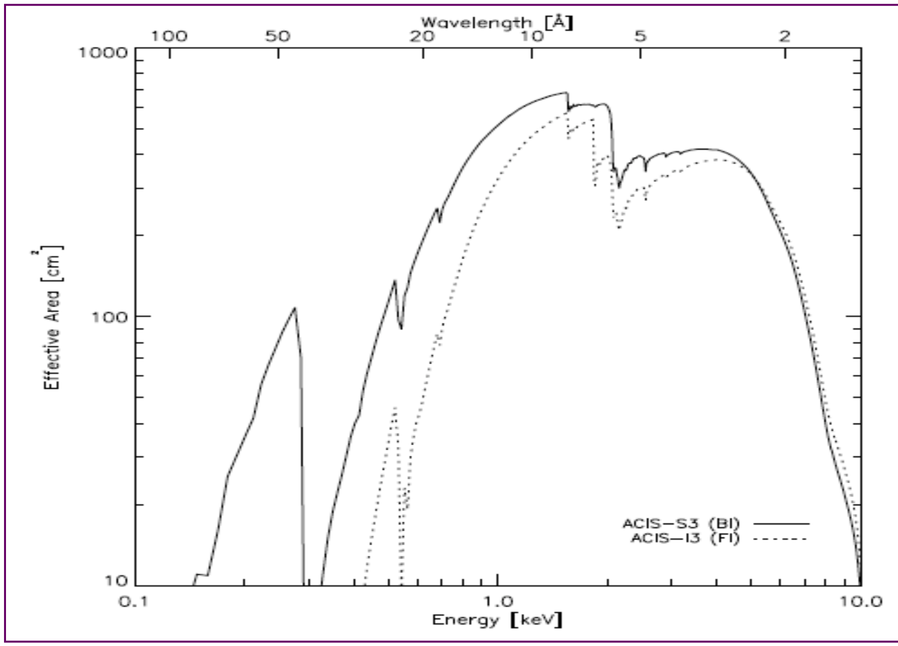


Strong decrease in the QE above 10 keV, where also the effective area due to the mirrors has a significant decrease

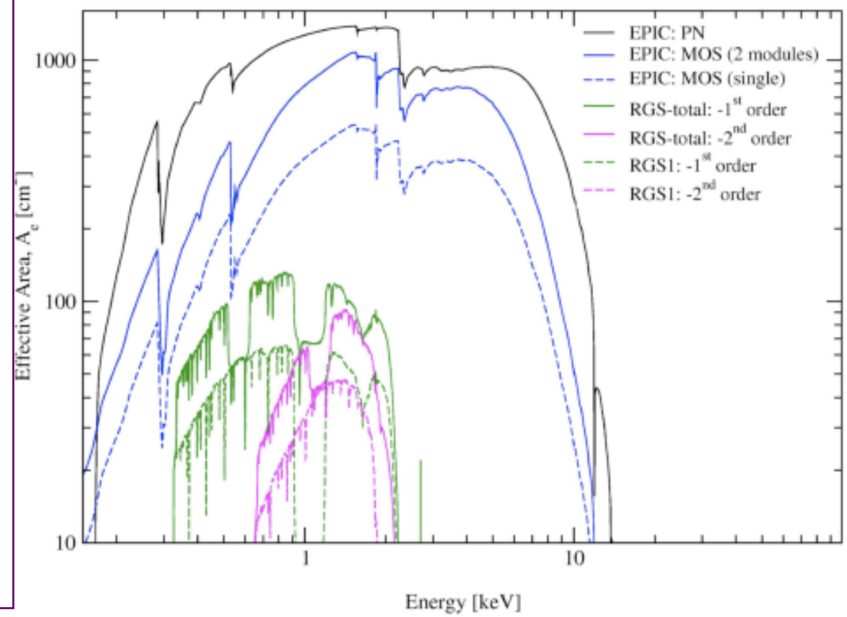
XMM-*Newton:* effective area



Chandra



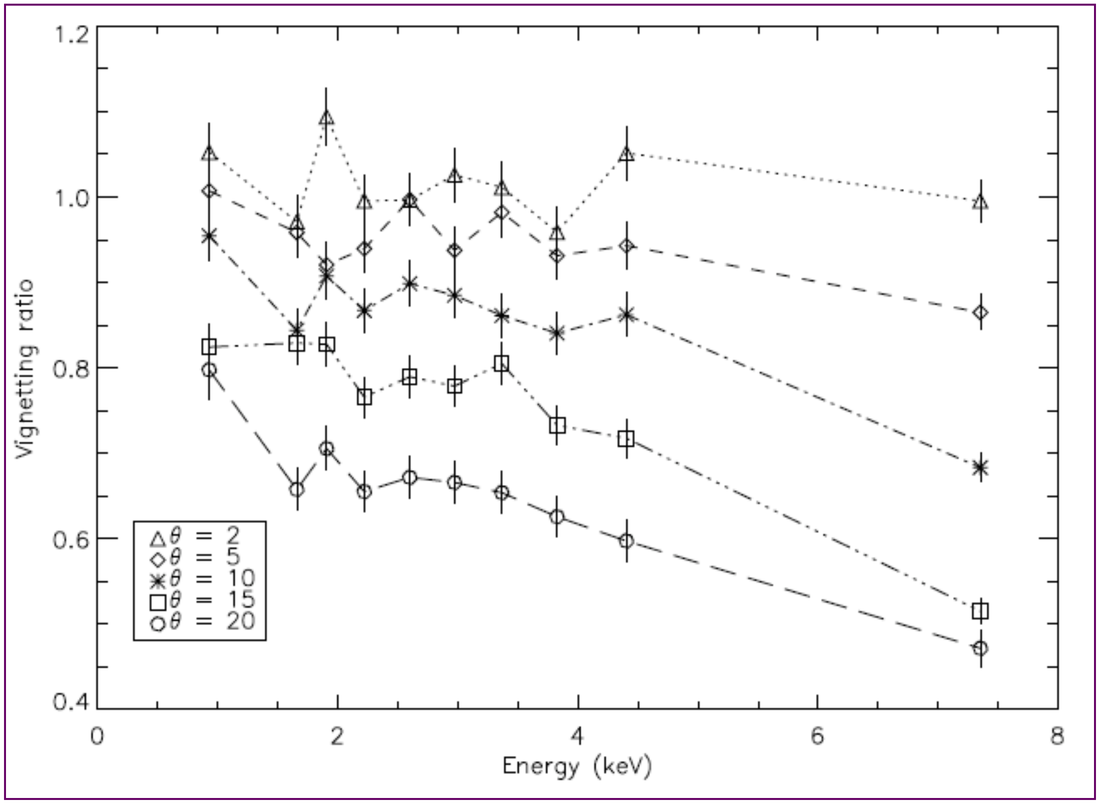
XMM-Newton



$$\vartheta_{crit} \propto \frac{\sqrt{\rho}}{E}$$

Chandra: vignetting

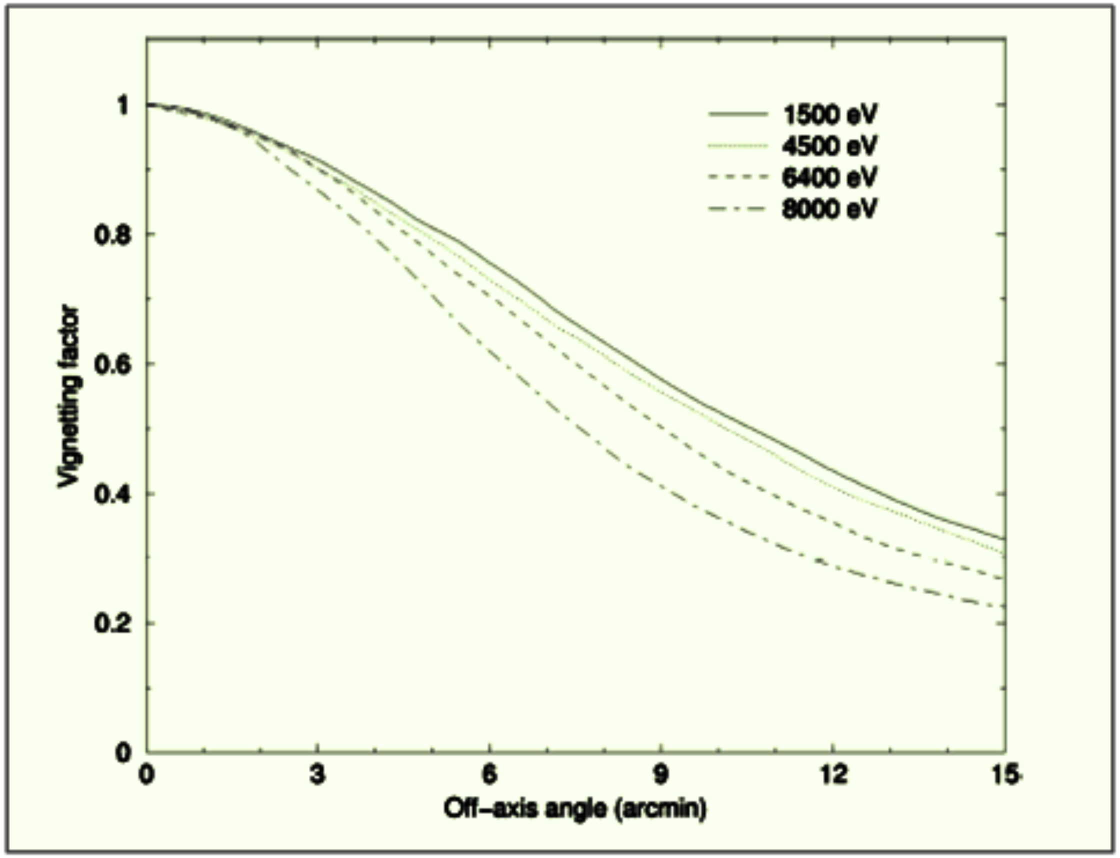
Ratio of the off-axis vs. on-axis counts at different off-axis angles



Hard X-ray photons are more difficult to focus

➔ **Vignetting**

XMM-*Newton:* vignetting



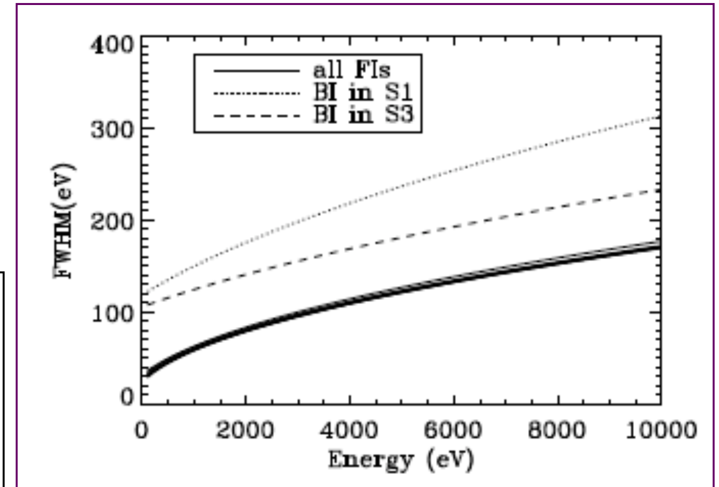
Strong vignetting (as expected) for high-energy photons,
partly compensated by the large effective area (e.g., wrt. *Chandra*)

You willl account for all this information creating a file named arf (ancillary response file)

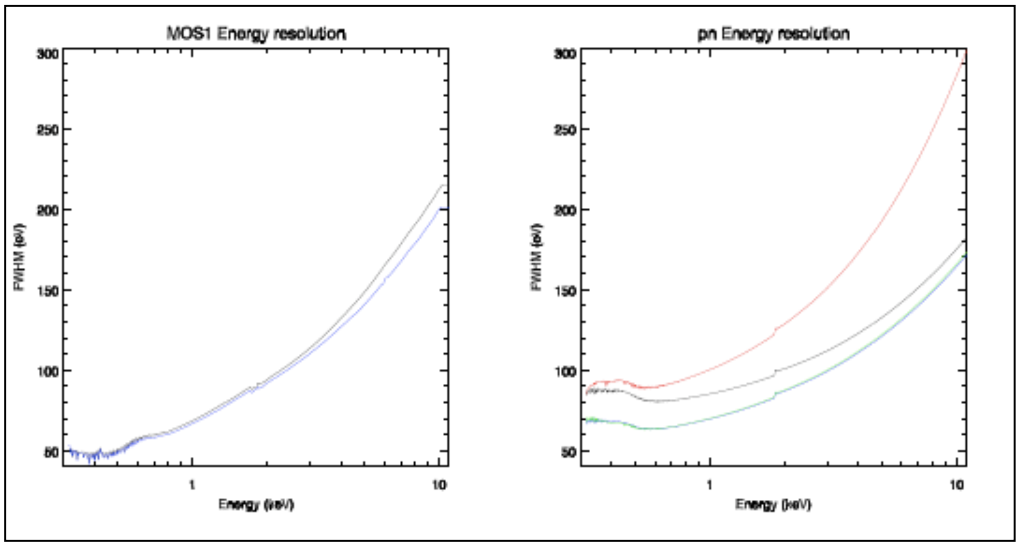
Last but not least….

Energy resolution

Chandra: energy resolution



XMM-*Newton:* energy resolution



Typical CCD resolution
100-150 eV

$\Delta E(\mathrm{FWHM})/E \propto E^{-1/2}$ (E in keV)

You willl account for all this information creating a file named rmf (redistribution matrix file)