X-ray optics after 50 years: a roadmap to the future

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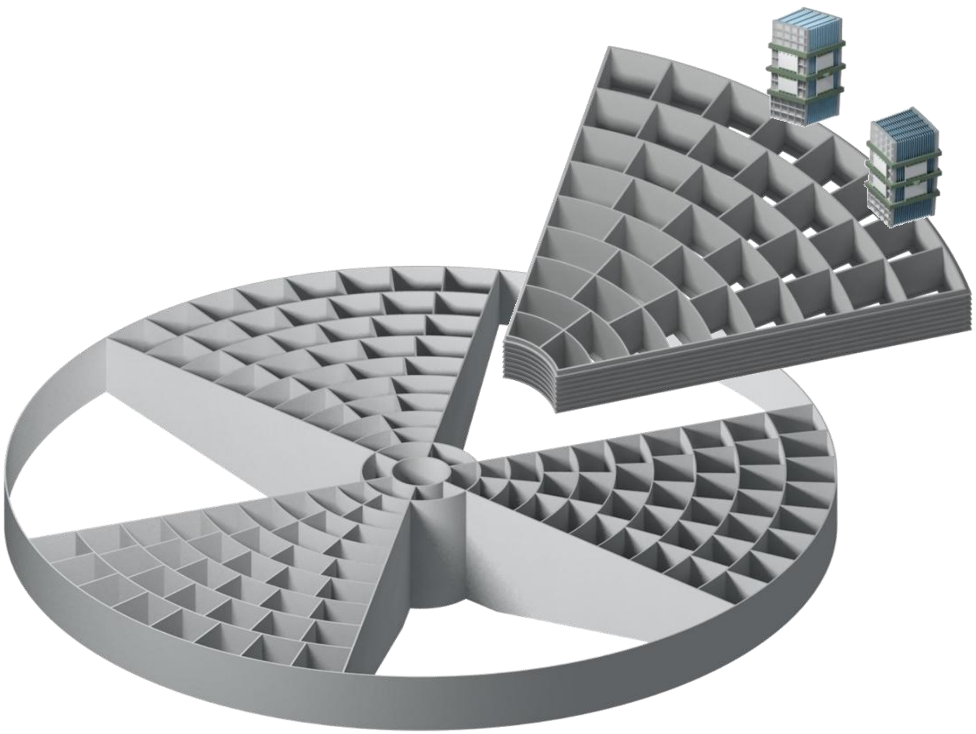

The Avengers - MARVEL

http://www.washingtonpost.com/blogs/comic-riffs/post/the-avengers-trailer-5-things-you-may-have-missed/2011/10/12/gIQAmCgPfL_blog.html


AVENGERS VS X-MEN
MARVEL
A VS X
ROUND 1
BENDIS
ROMITA JR.
HANNA
MARTIN
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The X-ray optics of the past (..but also current...) decades

Mission	Energy Band (keV)	Foc. Length (m)	Coll. Area (cm^2)	Diam . Max (cm)	FOV (arcmin)	HEW (arcsec	Techn.
XMM	0.2 - 12	7.5	1450 x 3	70	30	15 - 25	Ni repl.
Chandra	0.2 - 8	10	400	120	16	0.5	Direct Polishing
Swift	0.2 - 8	3.5	150	30	16	18	Ni repl.
Suzaku	0.2 - 12	4.7	450	40	17	120	Al foils

PS: now also NUSTAR, see later

Manufacturing techniques utilized so far

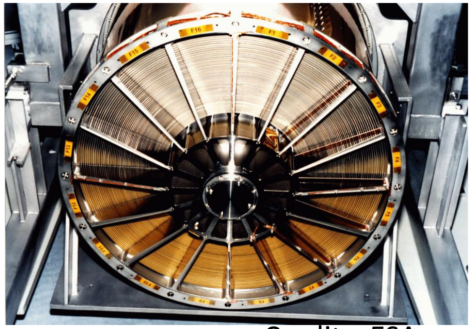
Credits: NASA

1. Classical precision optical polishing and grinding

Projects: *Einstein, Rosat, Chandra*

Advantages: *superb angular resolution*

Drawbacks: *high mirror walls ➔ ➔ small number of nested mirror shells, high mass, high cost process*



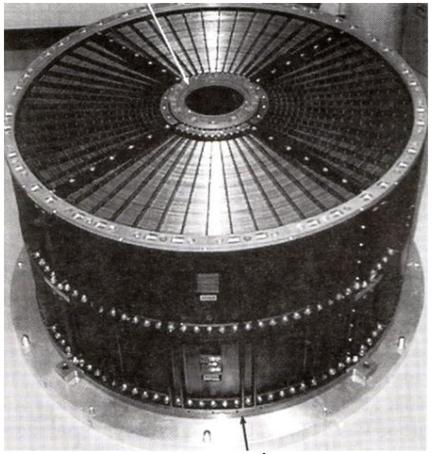
Credits: ESA

2. Replication

Projects: *EXOSAT, SAX, JET-X/Swift, XMM, ABRIXAS, e-Rosita, ART-X*

Advantages: *good angular resolution, high mirror "nesting" the same mandrels for many modules*

Drawbacks: *relatively high cost process; high mass/geom. area ratio (if Ni is used).*



Credits: ISAS

3. "Thin foil mirrors"

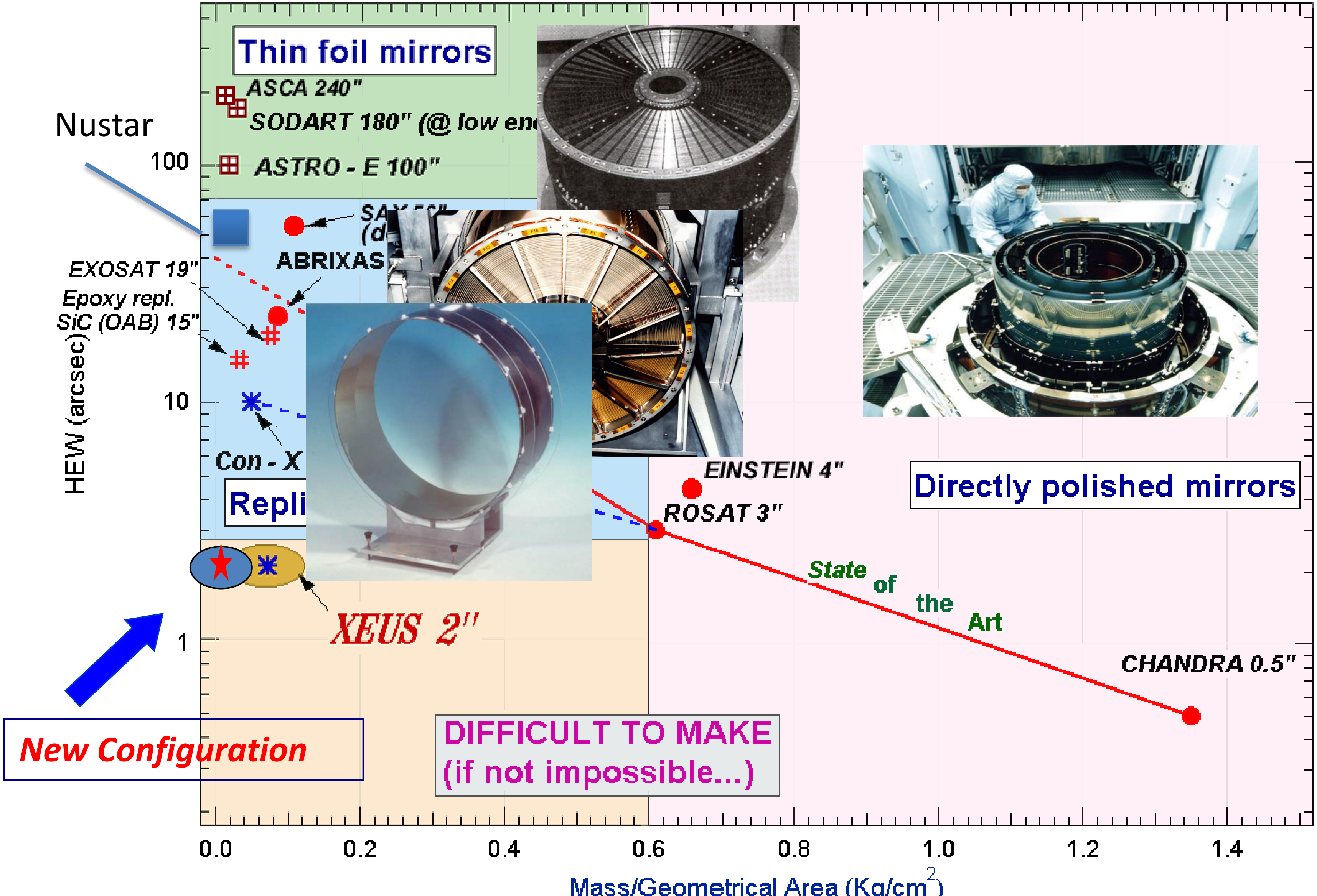
Projects: BBXRT, *ASCA, SODART, Suzaku,,ASTRO-H*

Advantages: *high mirror "nesting" possibility, low mass/geom. area ratio (the foils are made of Al), cheap process*

Drawbacks: *until now low imaging resolutions (1-3 arcmin)*

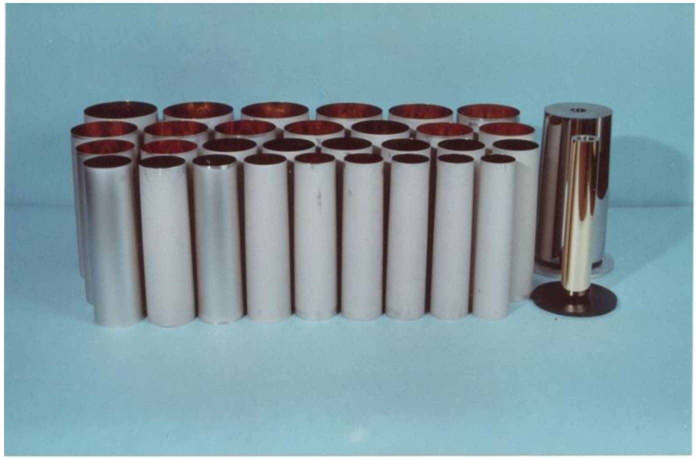
NB: Promising variation based on glass foils ➔ ***NUSTAR***

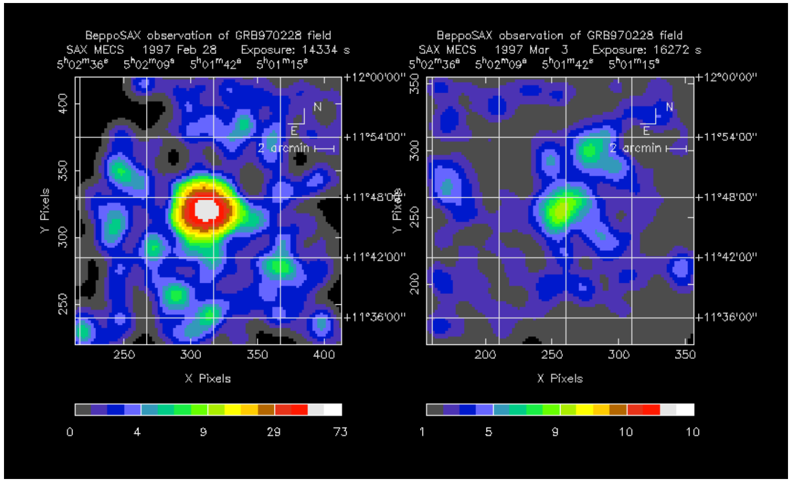
Present Astronomical optics technologies:
HEW Vs Mass/geometrical area



Beppo-SAX soft X-ray (0.1 - 10 keV) concentrators

- *Wolter I double-cone approx. - Au coating*
- *4 modules – 30 shells/mod.*
- *F.L. = 180 cm Max diam = 16.1 cm*
- *A_{eff} @ 1 keV = 85 cm^2 /module*
- *HEW= 60 arcsec (corresponding to the two-cones geom. aberration!)*





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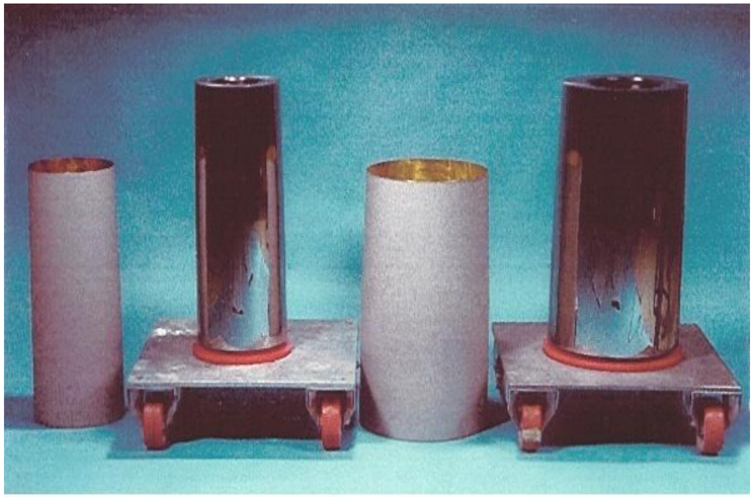
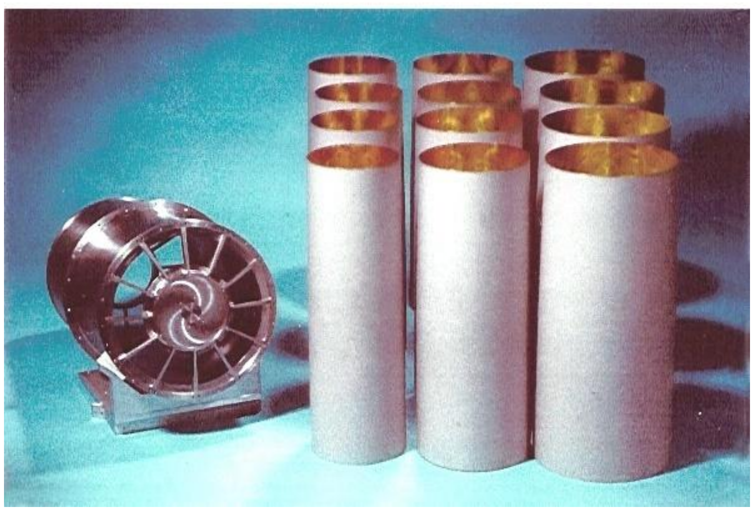
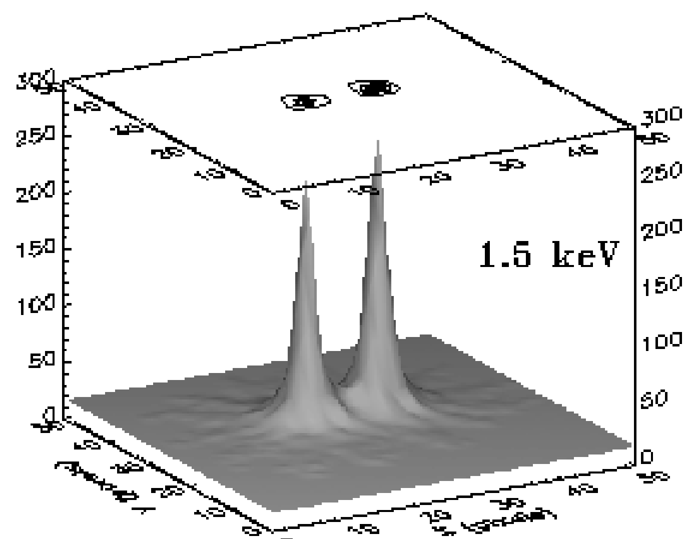
Swift-XRT(2004) optics





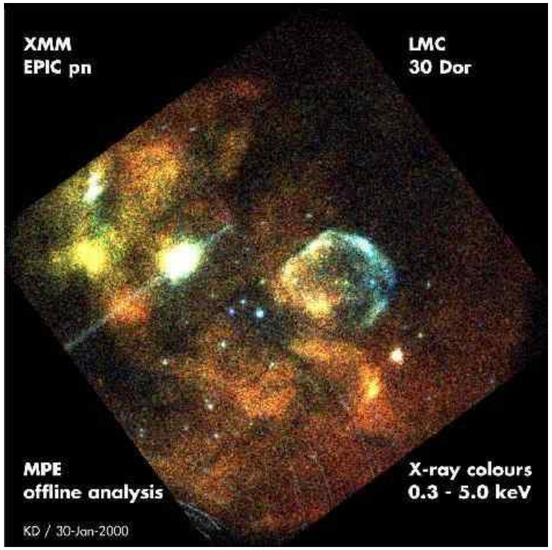
- *Wolter I profile – Au coating*
- *12 shells/mod.*
- *F.L. = 350 cm - Max diam = 30 cm*
- *A_{eff} @ 1 keV= 150 cm^2 /module*
- *HEW= 15 arcsec*
- *3 spares available (from JET-X)*



Source separation: 20”

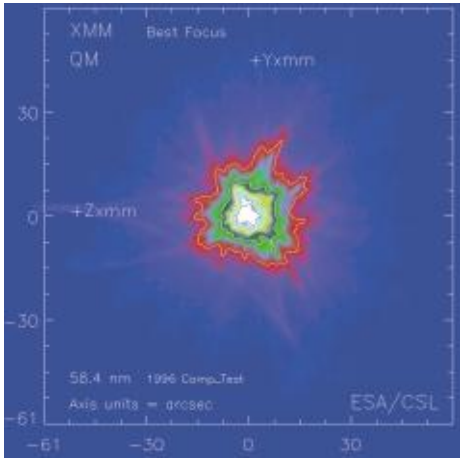
XMM-Newton (operational since dec. 1999)

- *Wolter I profile – Au coating*
- *3 mod. - 58 shells/mod.*
- *F.L. = 750 cm - Max diam = 70 cm*
- A_{eff} *@ 1 keV= 1500 cm*^{2} */module*
- *HEW= 15 arcsec*

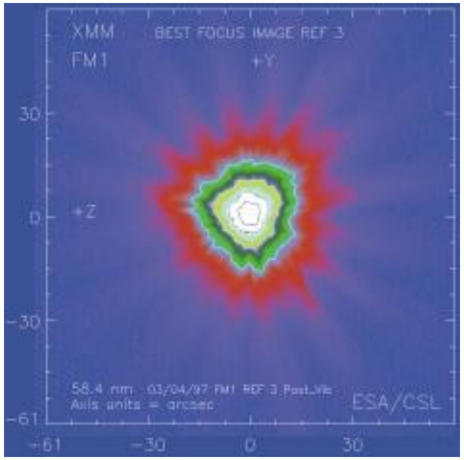


Credits: ESA

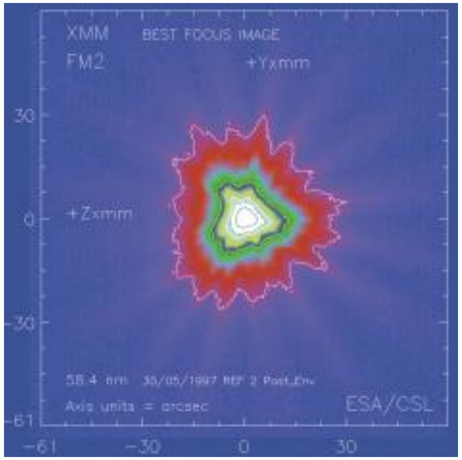
XMM Point Spread Function of the QM and FM Mirror Modules (log scale of intensity)



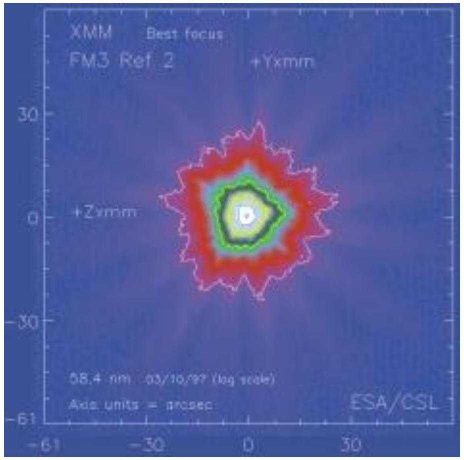
MM QM



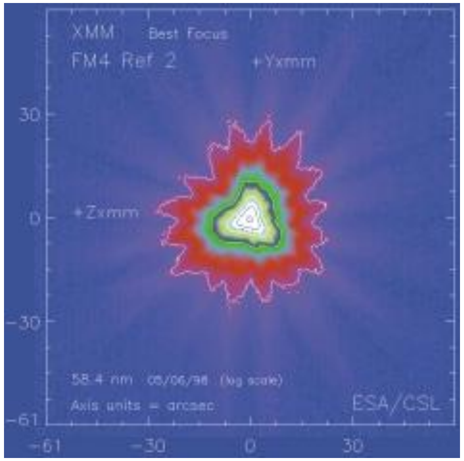
MM FM1



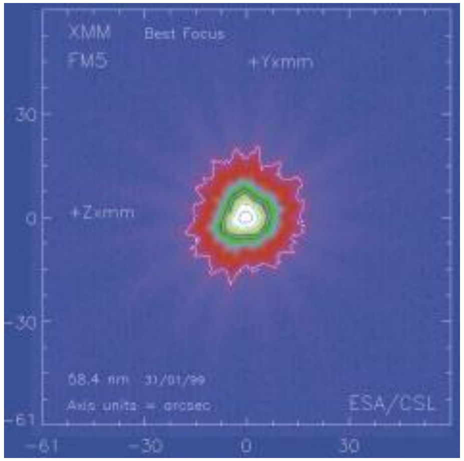
MM FM2



MM FM3



MM FM4



MM FM5

XMM Flight Modules Angular Resolutions

Table 3. X-ray image quality of the five Flight Models of the Mirror Module at best focus, in arcsec
(HEW data corrected by quadratic subtraction of the intrinsic resolution of the PSPC at the corresponding energy)

	FM1			FM2			FM3			FM4			FM5		
	PSPC		CCD	PSPC		CCD	PSPC		CCD	PSPC		CCD	PSPC		CCD
Energy (keV)	W90	HEW	FWHM	W90	HEW	FWHM	W90	HEW	FWHM	W90	HEW	FWHM	W90	HEW	FWHM
1.5	57	15.2	8.4	57	15.1	6.6	49	13.6	6	58	12.8	4.5	55	11.1	4.3
4.5	117	15.4	8.3	139	15.8	7.3	-----	-----	-----	135	13	4.5	-----	-----	-----
6.4	169	15.2	8.2	147	15.3	6.6	-----	-----	-----	158	12.5	4.4	-----	-----	-----
8.0	161	14.4	7.7	182	14.8	6.6	153	12.5	5.1	130	12.2	4.2	211	10.9	4.7
9.9	-----	14.3	7.3	-----	-----	-----	-----	-----	-----		12.3	4.4	-----	-----	-----

Frontiers for the X-ray telescopes of the new decade(s) based on optical systems

- enhanced imaging on wide field of views
  - e-Rosita
  - WFXT

- Hard X-ray high angular resolution optics
  - NUSTAR ➔ GOAL ACHIEVED
  - ~~NHXM/SIMBOL-X~~ ➔ decsoped

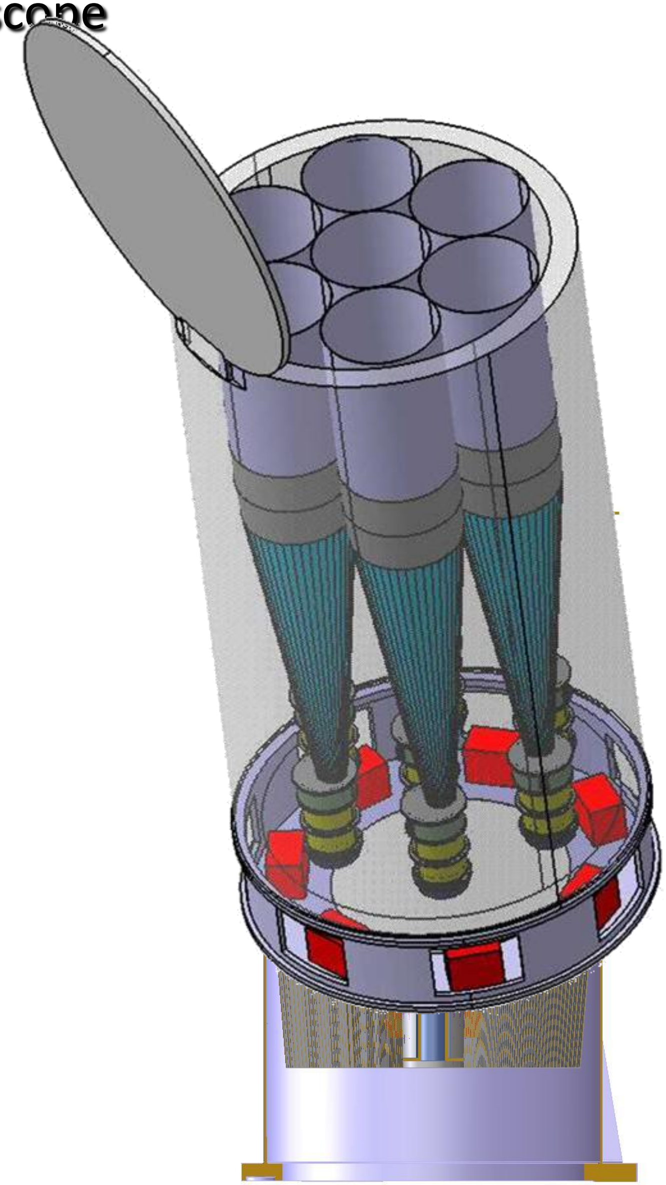
- IXO/ATHENA/N-CAL: Very high effective area with a good angular resolution for imaging spectroscopy

- SMART-X/European Imaging Telescope: Chandra-like imaging capabilitities but with a an effective area enhancement of a factor 10

E-Rosita Mirror Design

Basic Data of the eROSITA Telescope

Mirror Type	Wolter 1
Number of mirror modules	7
Orientation of mirror modules	parallel
Degree of nesting	54
Focal length	1600 mm
Largest mirror diameter	365 mm
Smallest mirror diameter	76 mm
Micro-roughness	<0.5 nm
Energy range	~0.2 – 10 keV
Coating	Gold (> 50 nm)
Field-of-view	61’ ∅



e-Rosita Point Spread Function (PSF)