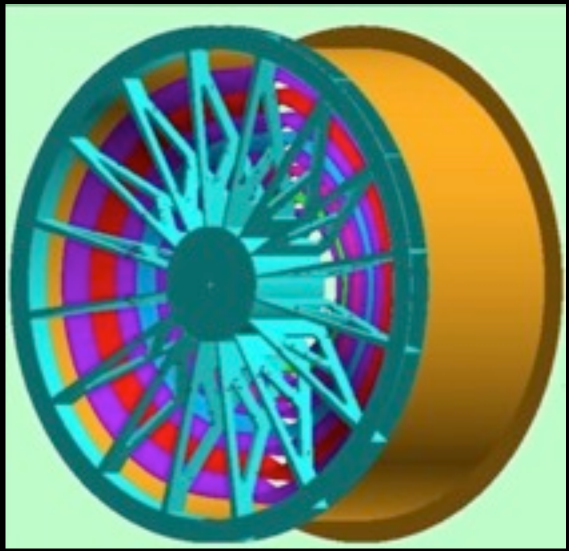
High angular resolution optics for the next generation of Wide Field X-ray Telescopes (WFXT): beyond eROSITA

G. Pareschi, O. Citterio , S. Campana, M. M. Civitani, P. Conconi, G. Tagliaferri



Acknowledgmnents:
S. Murray, R. Giacconi, P. Rosati, A. Ptak ....and the WFXT collaboration

OSSERVATORIO ASTRONOMICO DI BRERA

agenzia spaziale italiana

X-ray optics with polynomial profile

- Mirrors are usually built in the Wolter I (paraboloid-hyperboloid) configuration that provides, in principle, perfect on-axis images.

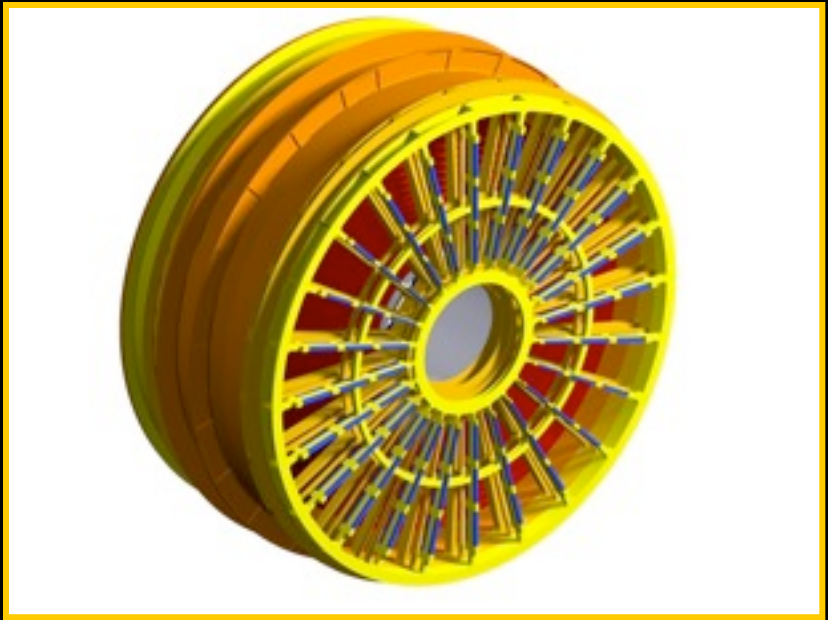
- Wolter I design exhibits no spherical aberration on-axis **but suffers from field curvature, coma and astigmatism**
 ➔ **the angular resolution degrades rapidly with increasing off-axis angles**

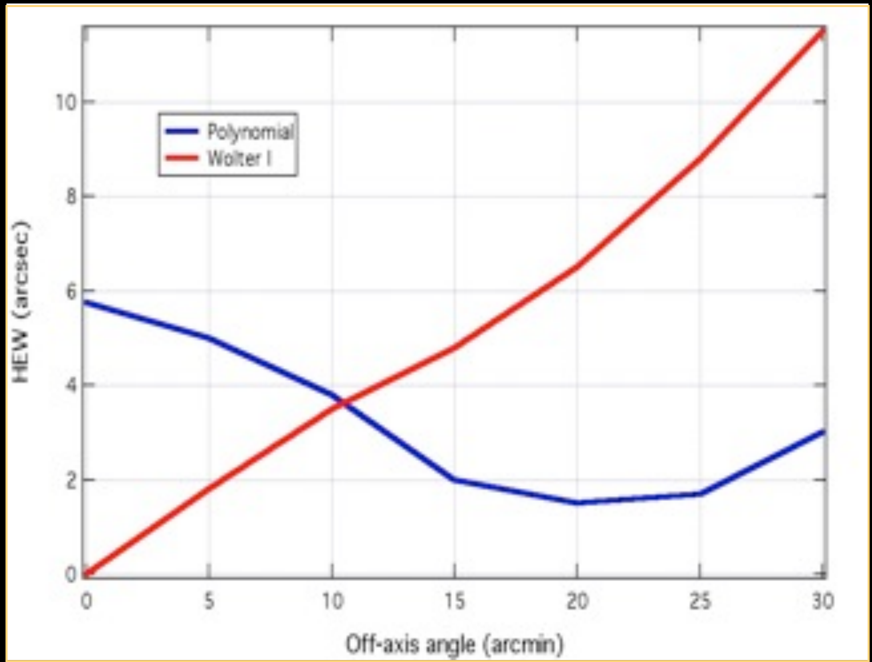
- More general mirror designs than Wolter's exist, in which the primary and secondary mirror profiles are expanded as a **power series**;

- These **polynomial solutions**, together with the use of **short mirror shells (wrt the focal length)**, are well suited for optimization purposes, which may be used to increase the angular resolution at large off-axis positions, degrading the on-axis performances (Burrows, Burg and Giacconi 1992)

Thin glass shell oriented to Wide Field X-Ray Telescope

(P.I. S. Murray; Sen. Scient. R. Giacconi)





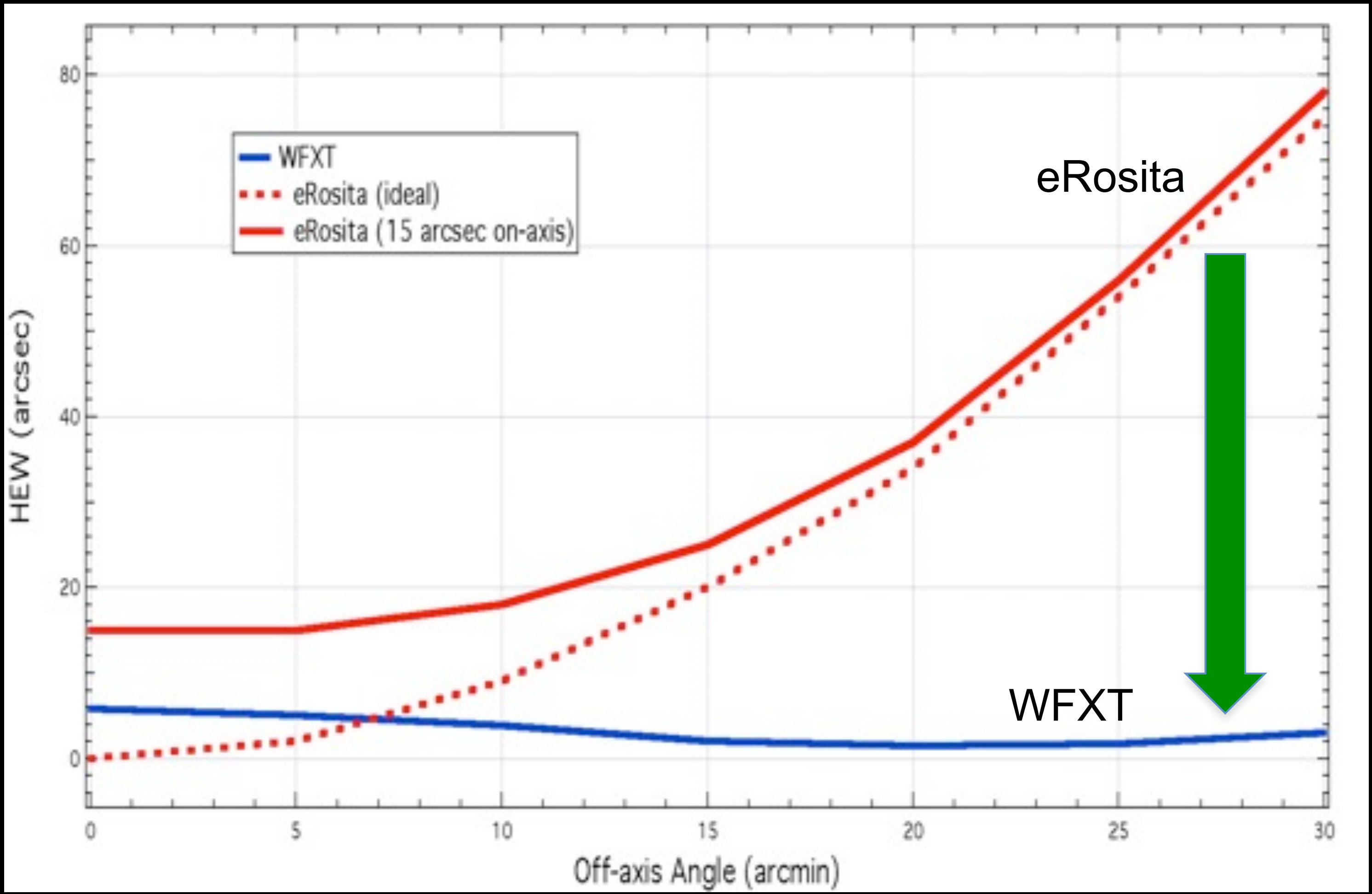
N.B.: same mirror height/FL aspect ratio =0.07

WFXT being proposed to NASA in the context of the RFI call (Sept 2011)- P.I. S. Murray

WFXT Telescope Configuration

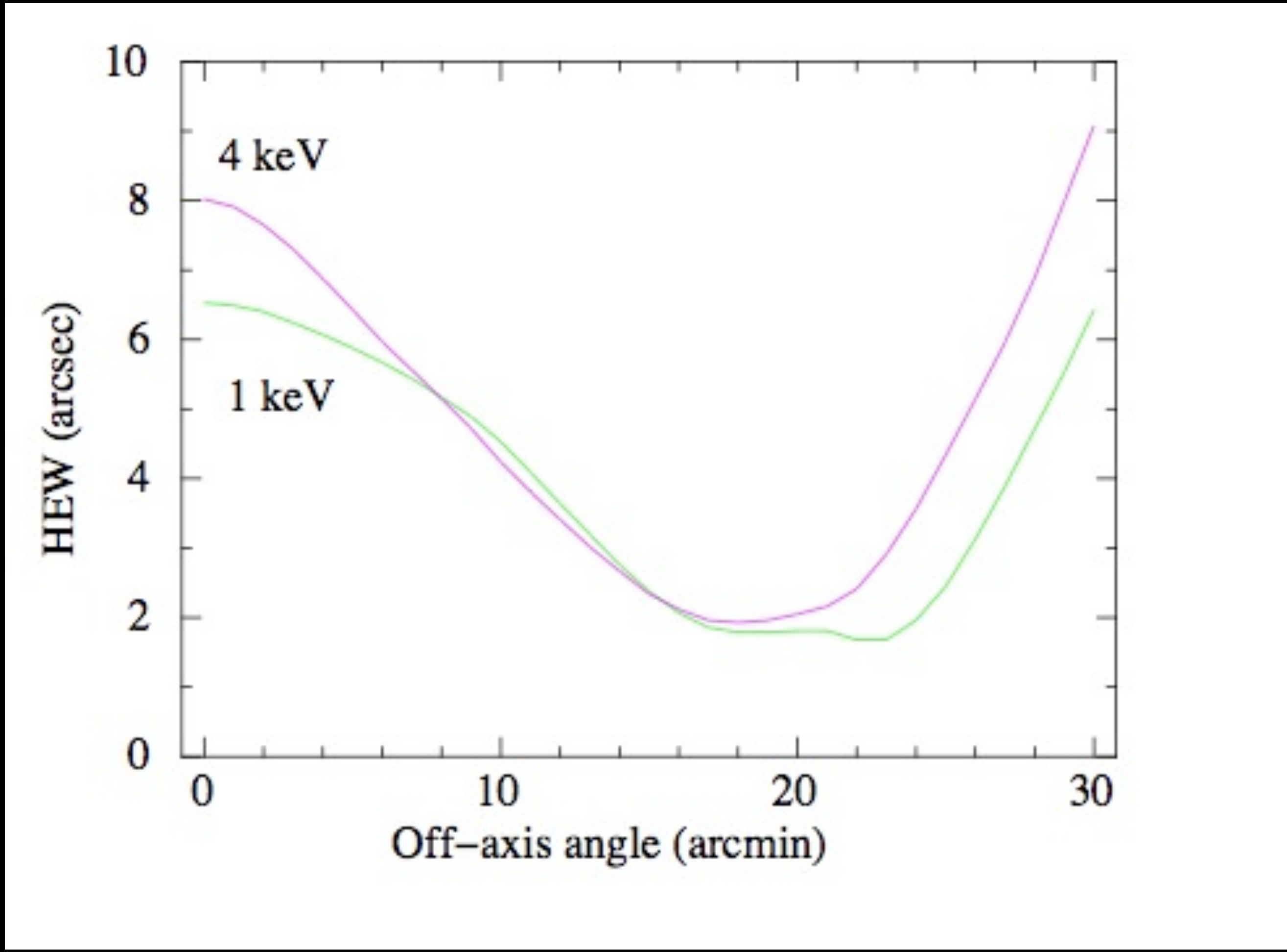
Parameter	Design
Number of Modules	3
Material	Fused Silica
Configuration	Polynomial Profile
Focal Length	5.5 m
MAX & min top diameters	0.36 & 1.1 m
MAX and min mirror Length (2 reflections)	408 & 220 mm
Coating	Pt + C overcoating
Wall Thickness	3 – 1.7 mm
Number of mirror shells / module	55
Total Weight	900 kg (3 modules including structure)

HEW across the FOV: WFXT vs. eRosita



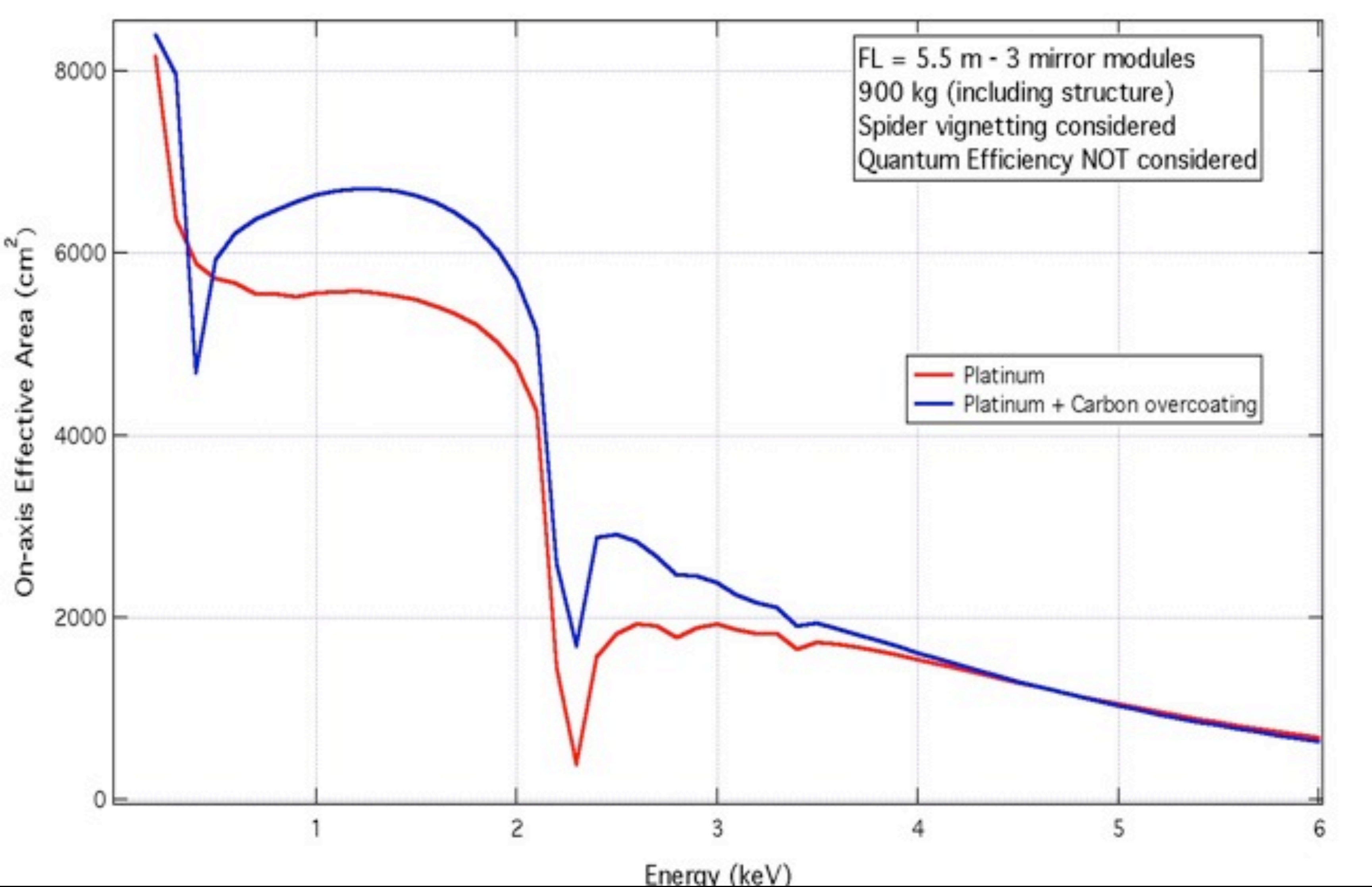
N.B.: Aspect ratio WFXT = 0.07 – Aspect ratio eRosita = 0.16

HEW for the mirror module (theoretical design)

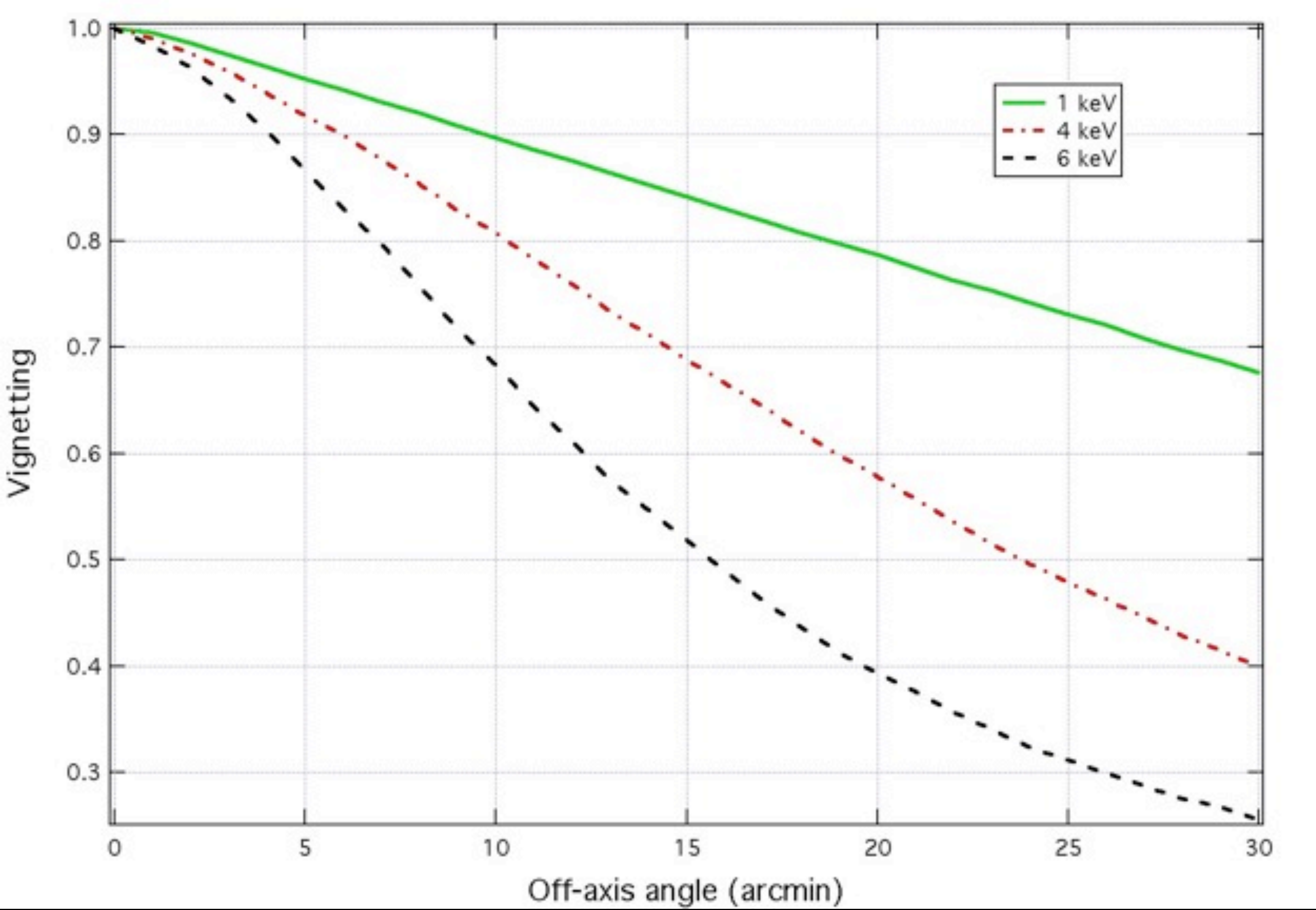


N.B.: Manufacturing and integration errors not yet included

On-axis effective area



WFXT Vignetting



Survey capabilities

GRASP = on-axis A_{eff} x 0.75 * FOV

MERIT FACTOR FOR SURVEY= GRASP / HEW^2

	ROSAT	CHANDRA	XMM	eROSITA	ATHENA	WFXT*
GRASP @1 keV (cm^2 deg^2)	300	50	240	750	2300 (just imager)	4400
HEW @2/3 FOV (arcsec)	30	3	20	30	10	5
MERIT FACTOR (cm^2 deg^2 / $arcsec^2$)	0.3	5.5	0.6	0.83	23	176

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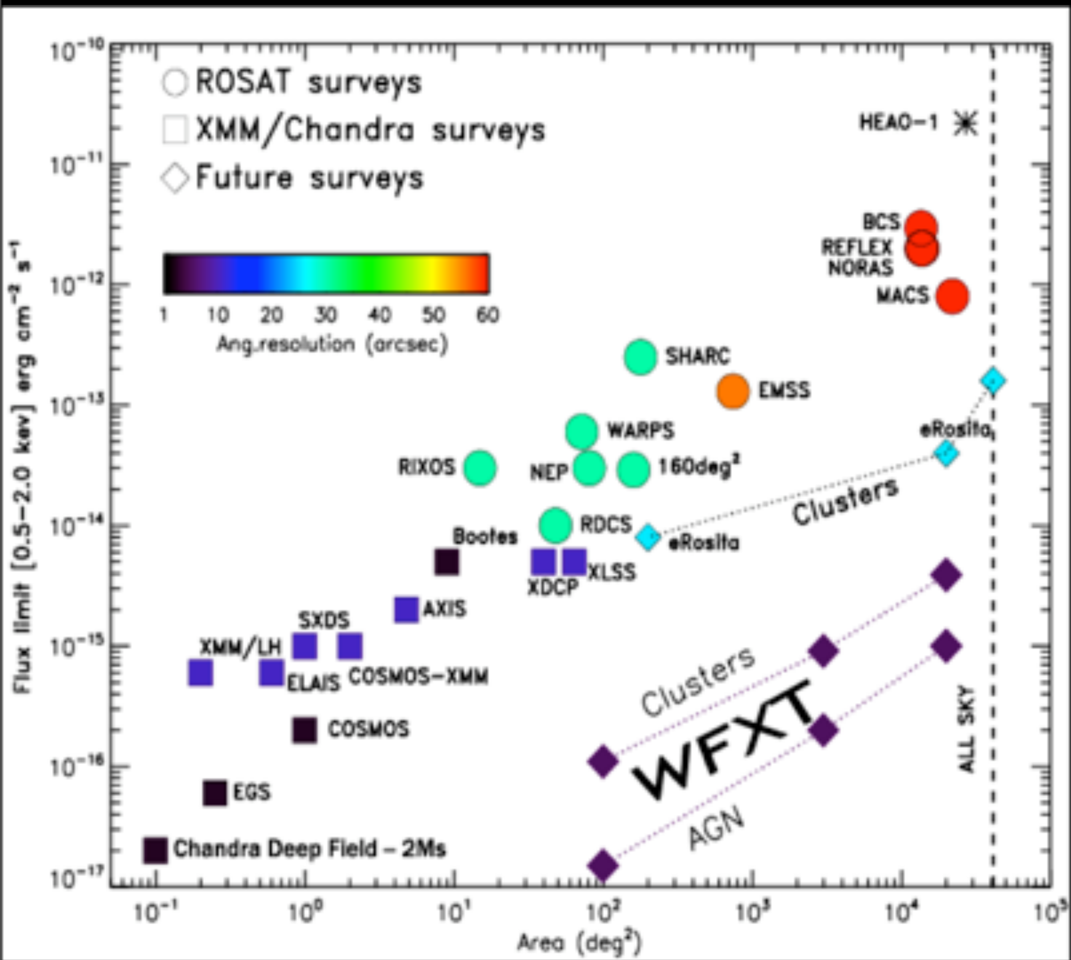
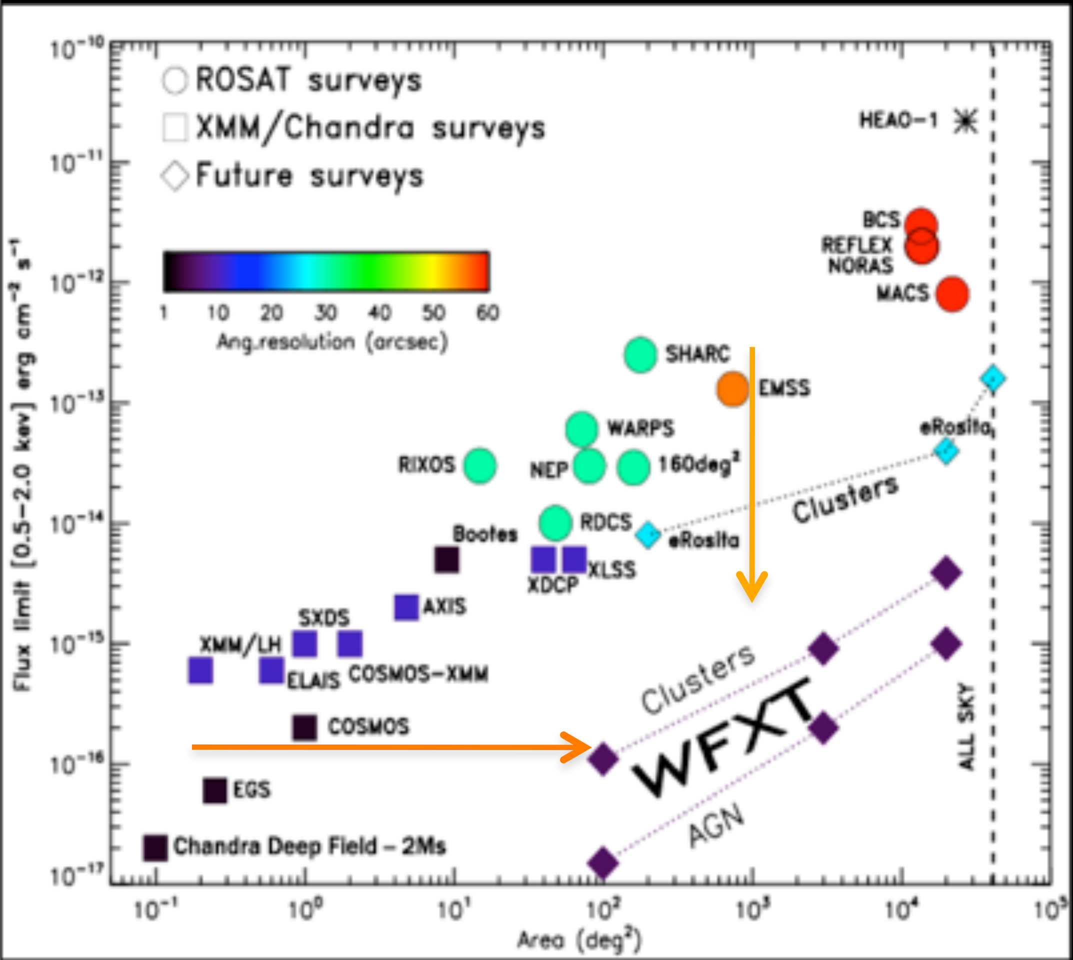
Sensitivity



- WFXT sensitivity provides orders of magnitude increase over other missions
- The good angular resolution easily identifies extended sources and avoids confusion

CREDITS: P. Rosati

Sensitivity



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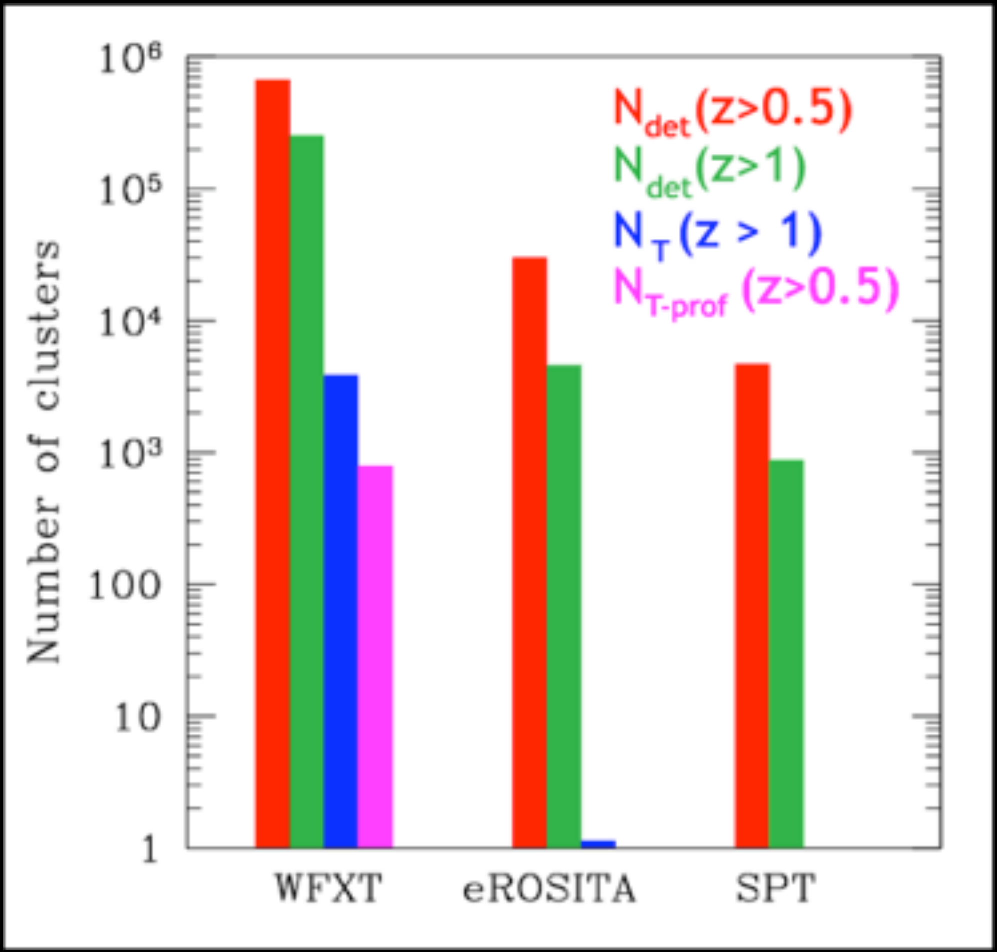
CREDITS: P. Rosati

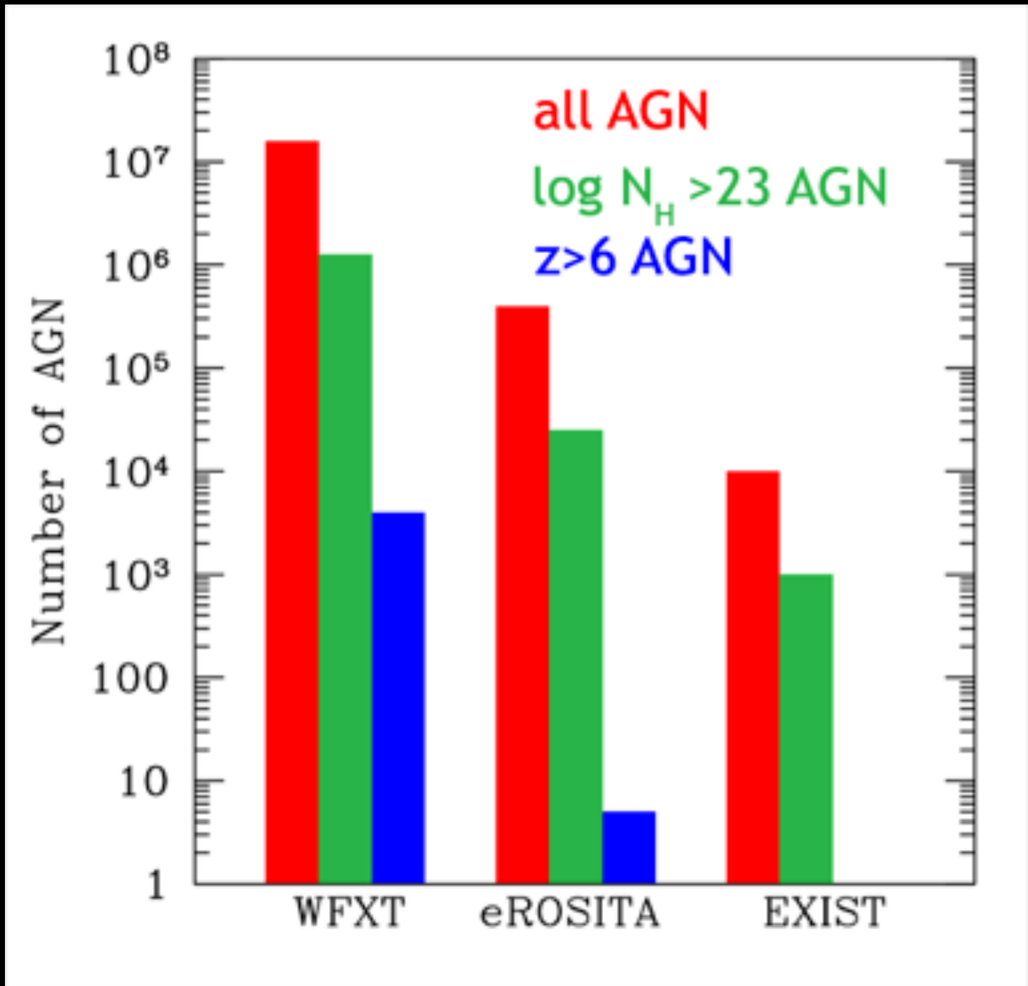
Cluster Science



- Temperatures critical to cluster cosmology
- Profiles permit cluster physics
- Large samples allow study of systematics
- WFXT can reach into early groups

CREDITS: P. Rosati

Science Highlights: AGN and Galaxies

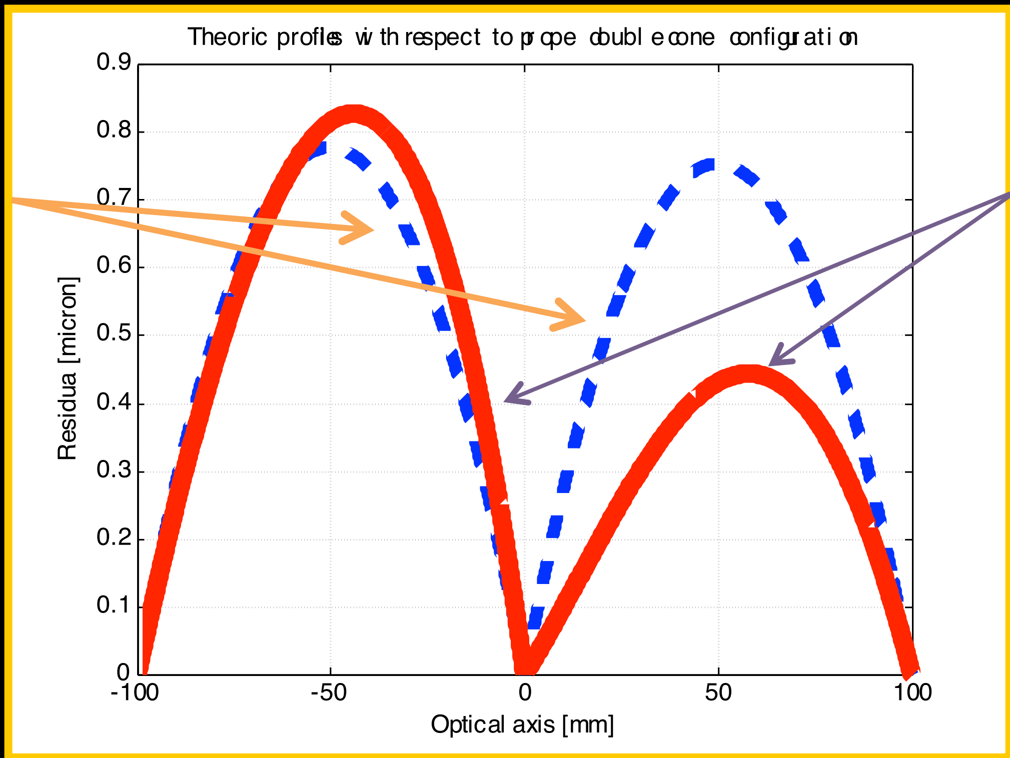


- WFXT will be an “X-ray GALEX”, detecting $>10^7$ AGN, $>10^5$ galaxies
  - Luminosity function
  - Minimal bias
  - Environment and evolution
- Variability in AGN, galaxies (XRB and tidal captures)
- Deep survey will reach

CREDITS: Roberto Gilli

Polynomial profiles

Mirrors are usually built in the WOLTER-I which provides, in principle, perfect on-axis images
But rapid degradation with increasing off-axis angles



Optimization with POLYNOMIAL profiles increase the angular resolution at large off-axis positions but degrading the on-axis performances

See Burrows, Burgh and Giacconi (1992), Conconi et al. (2010)

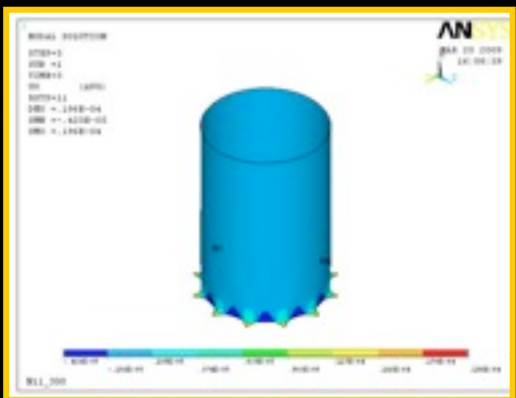
Small aspect ratio optics

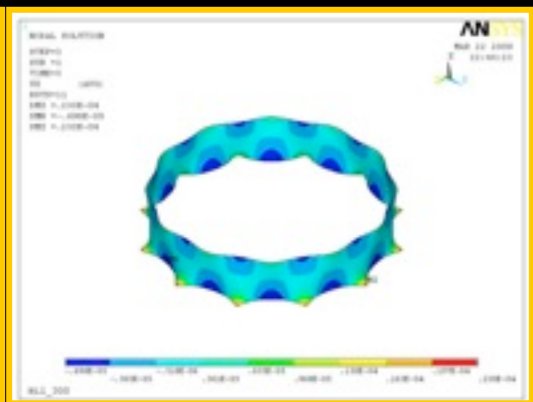
➔Increased difficulty in reaching very good angular resolution

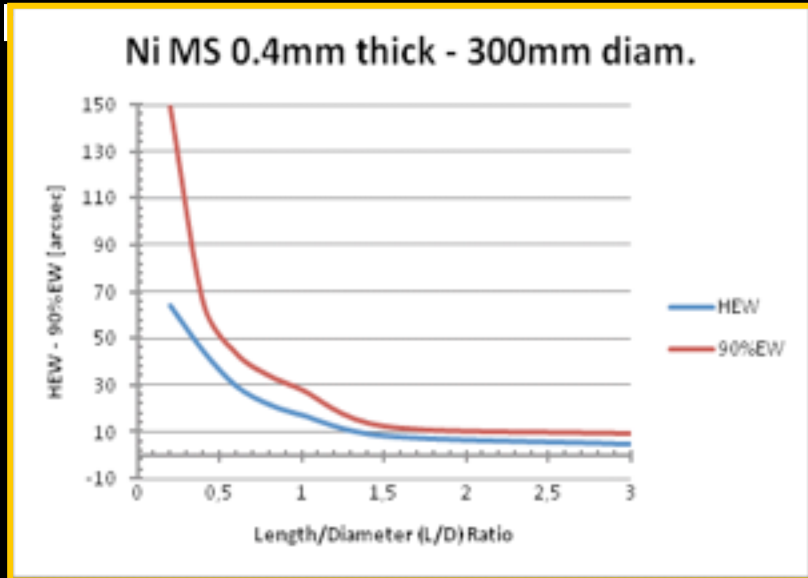
- mechanical behavior closer to a “belt-like” configuration rather than a “tube-like”

- border effect errors with a much higher weight in determining the PSF

- angular resolution more strongly affected by the slope errors caused by out-of-phase azimut



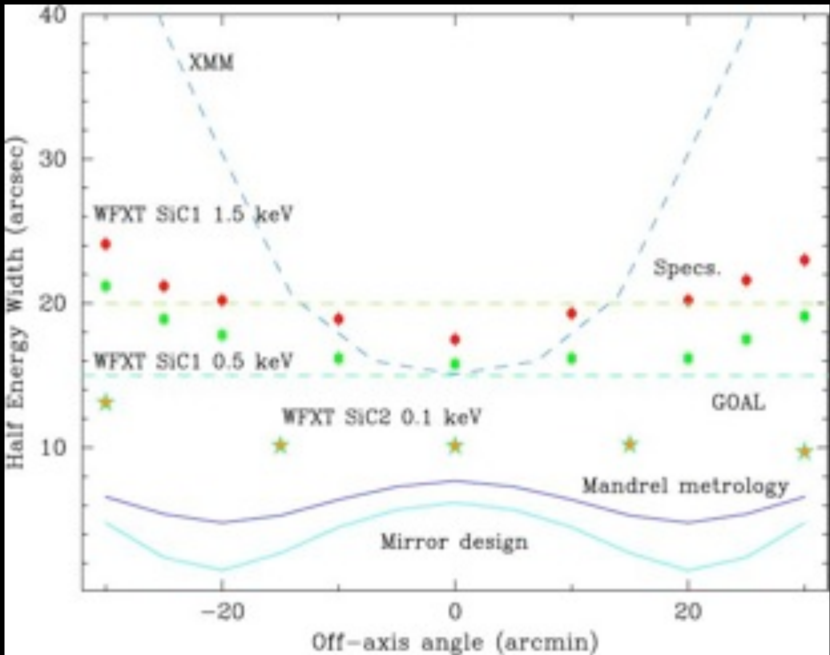




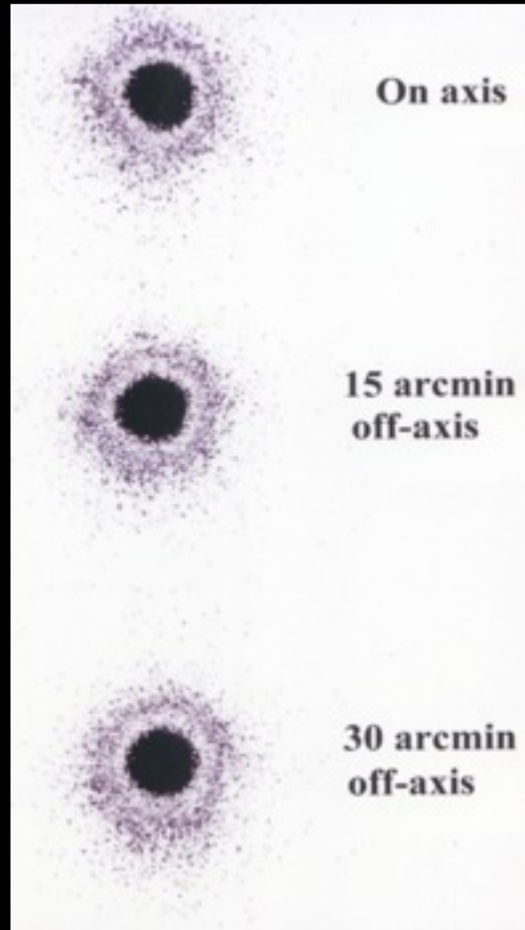
Edge load: outward tangential moments (10Nmm each) applied at front section in 12 point 30° spaced.

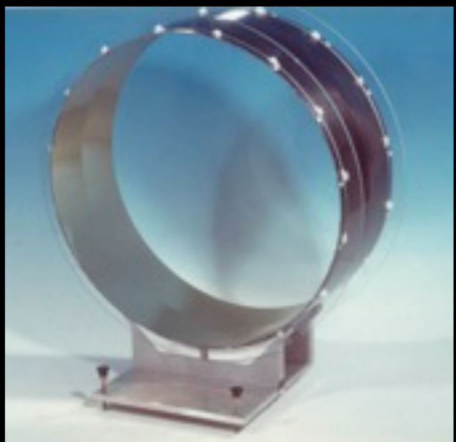
WFXT prototypes in SiC by epoxy replication

Polynomial mirrors developed in Italy (1998-2001)



Tests @ Panter-MPE & Marshall XRF





Tuesday Jan 20, 2009

WFXT (epoxy replication on SiC) – Ø = 60 cm

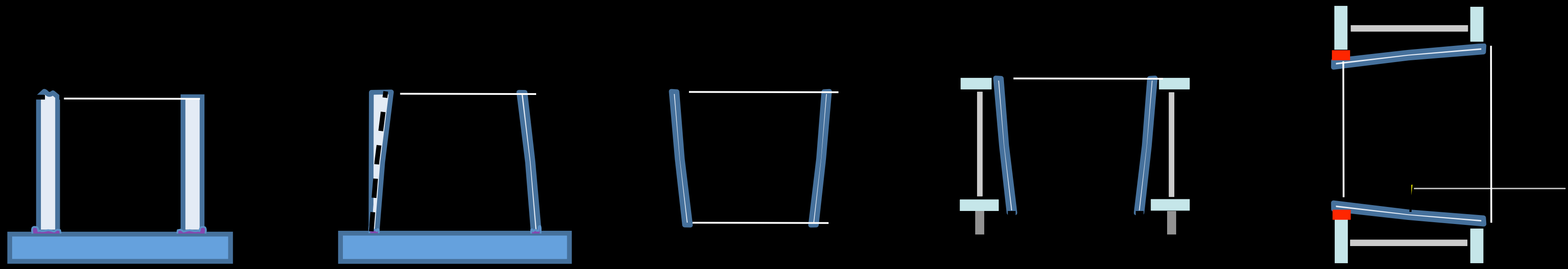
Height = 20 cm

F. L. = 300 cm

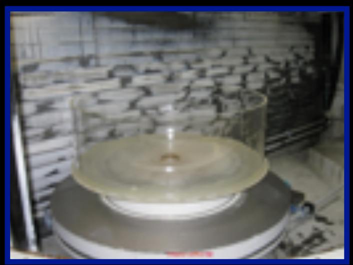
HEW = 10 arcsec @ 0.1 keV

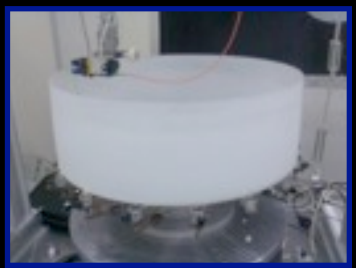
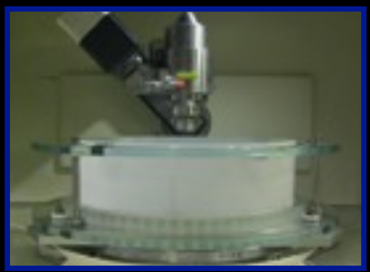
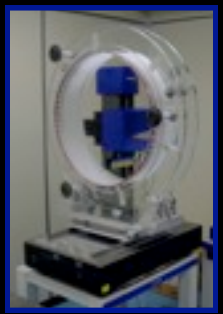
Ref:. O. Citterio, et al., ”, *SPIE Proc*., 3766, 198 (1999)
Ghigo et al., *SPIE Proc*., 3766, 209 (1999)

Quartz Direct Polishing Approach

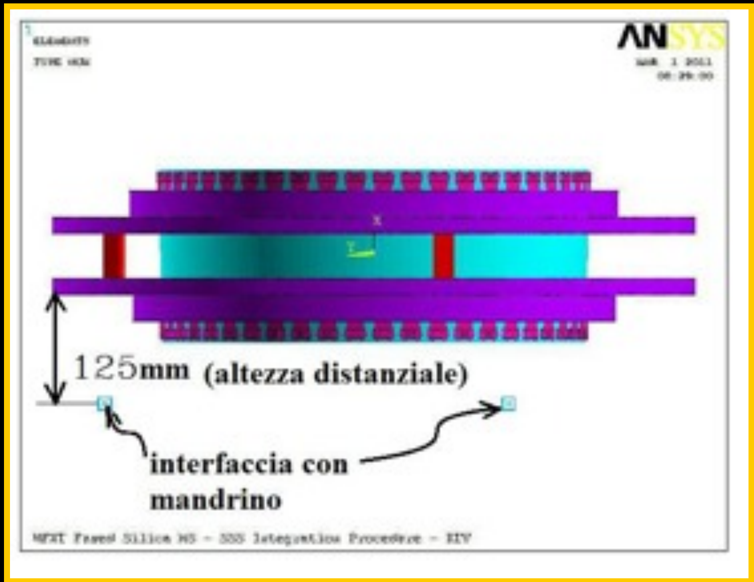


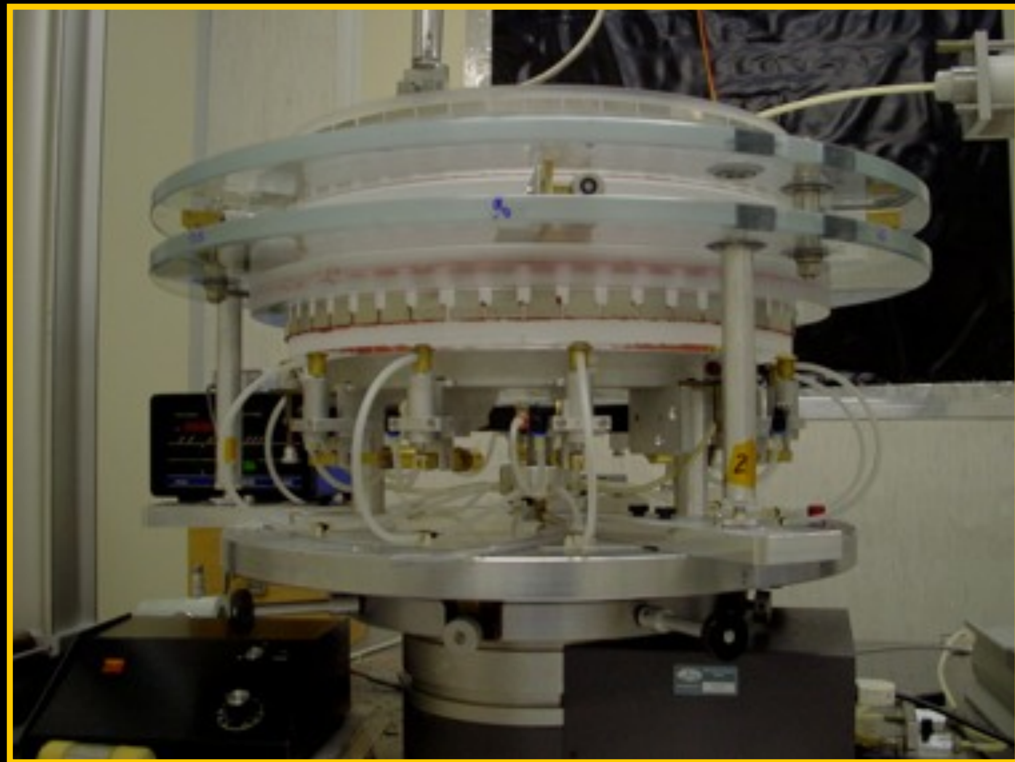
Raw material is a Quartz tube available on the market	Grinding of the quartz tube	Delivery of the carrier	Integration on a suitable interface structure by means of an astatic support	Polishing and last manufacturing steps until final integration in the mirror structure



Temporary stiffening



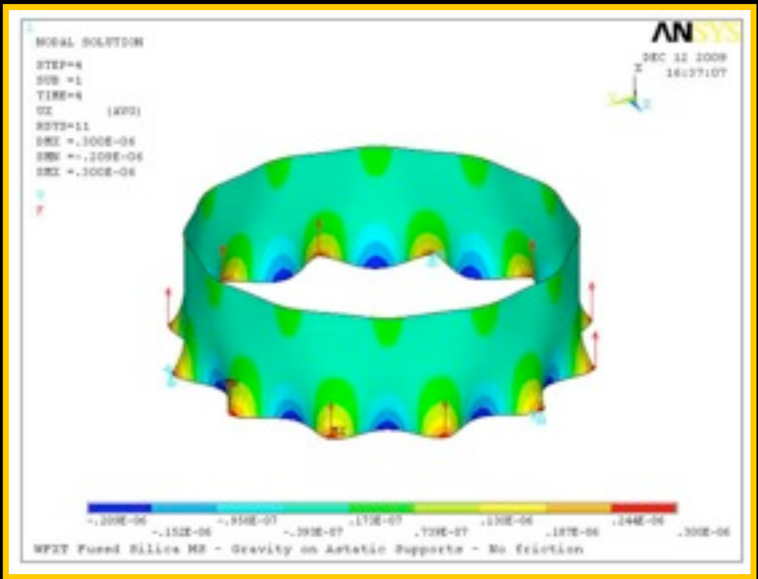


-Temperature effects
-Gravity effects
-Integration errors

Shell Support System (SSS)

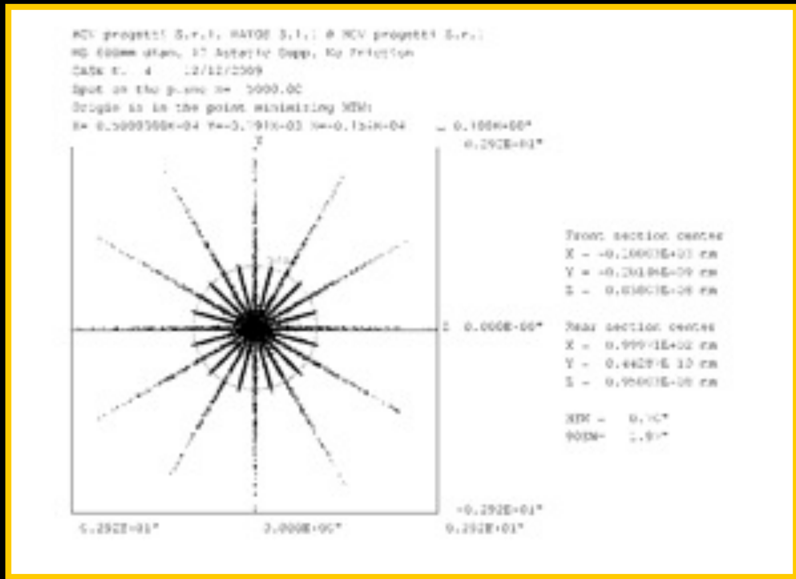
Integration effects

12 points astatic support – friction free



PtoV = 0.51 μm

Corresponding spot diagram at the nominal focus

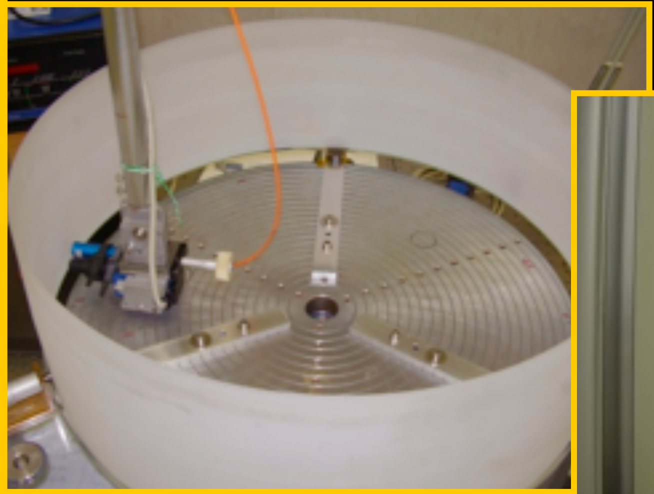


HEW = 0.70 arcsec
90% EE = 1.97 arcsec

Production Flow (1/2)

@Heraeus

A quartz shell manufactured by Heraeus under grinding operations



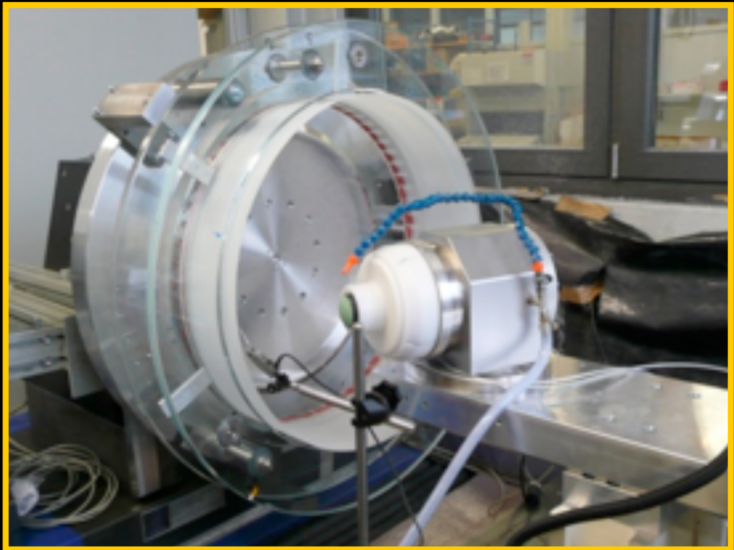
The shell is characterized in terms of out of roundness errors on an astatic support jig

The shell is integrated in the Shell Support Structure.

@OAB

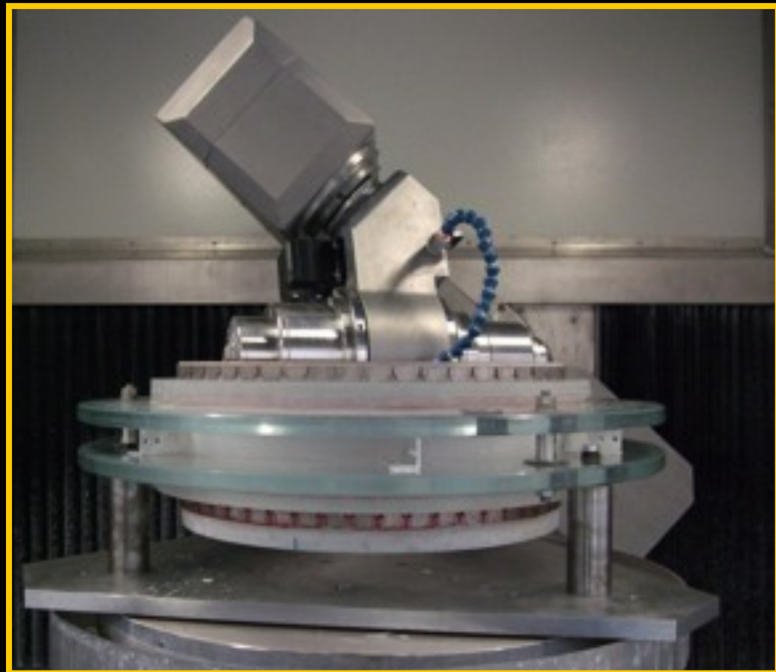
Production Flow (2/2)

@LT-Ultra



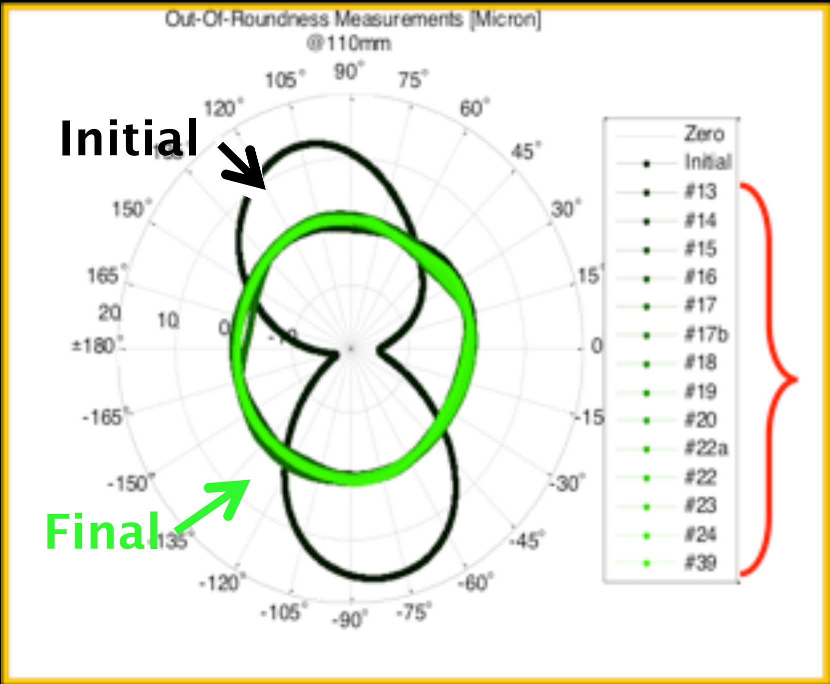
A shell mounted on the Lt-Ultra precision lathe ready for the fine grinding process to correct Out-Of-Roundness

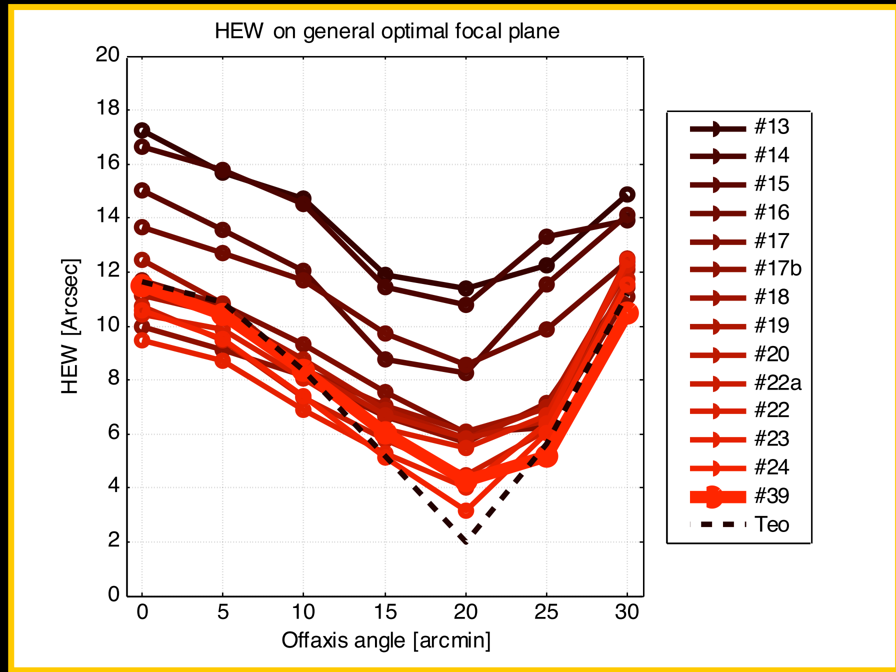
@Zeeko



A shell in its support structure mounted on the Zeeko polishing machine for surface damage removal and longitudinal profile correction

Out of Roundness (OOR) correction with fine grinding process

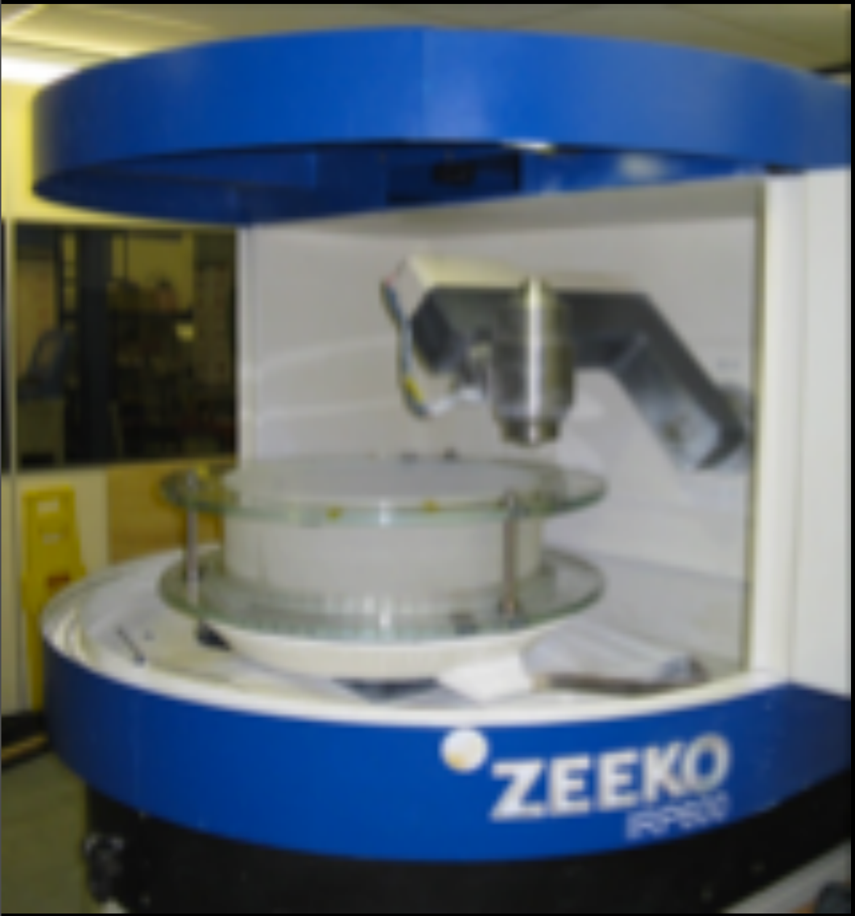




OOR PtV:
35μm → 1.5μm

Ray tracing simulations show that with present values of OOR and assuming correct profiles longitudinal, the theoretical optical quality of the shell is almost reached (in the graph it is considered a flat focal plane).

Operations with Zeeko IRP 600



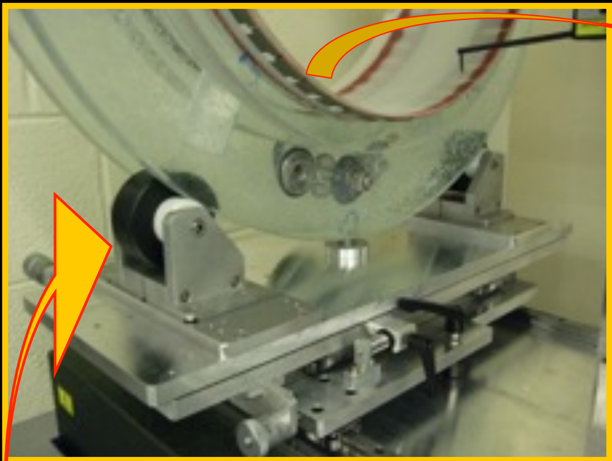
- surface damage (due to the fine grinding) removal
- " Bonnet " polishing for the "moderation" of longitudinal and azimuthal profiles ➔ needed for getting the polynomial shape
- " Pendulum " polishing for the removal of mid and high frequency slope error

eRosita mandrel under “Bonnet” polishing with a Zeeko machine

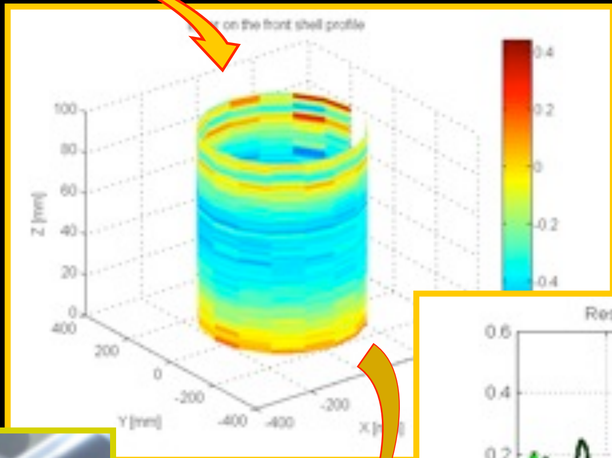
Wolter I profile mandrel
150 + 150 mm long.

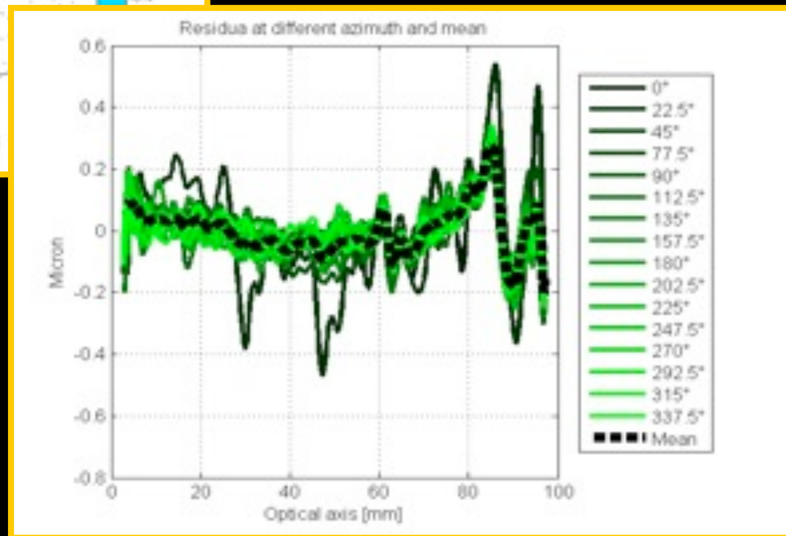
Azimuthal longitudinal profiles correction

16 longitudinal profiles
(FormTalysurf measurements)



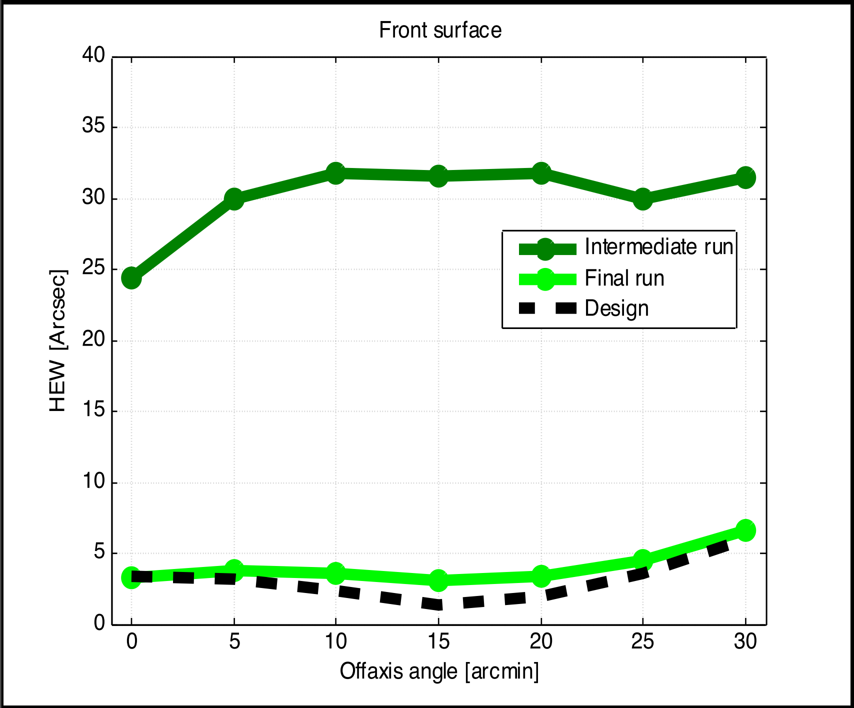
Moderation function
calculation





Polishing HEW performances

Front reflecting surface



Rear reflecting surface

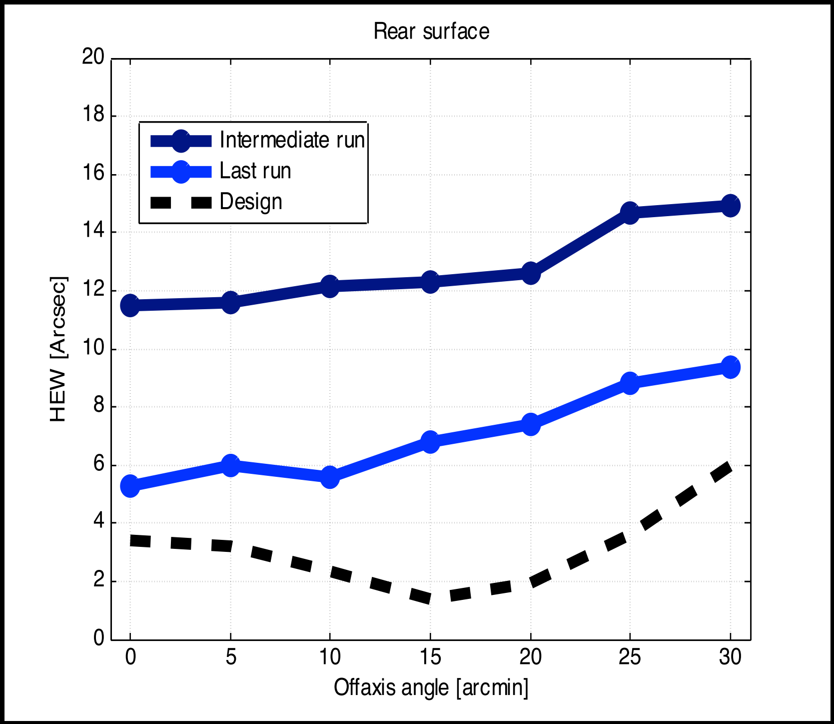
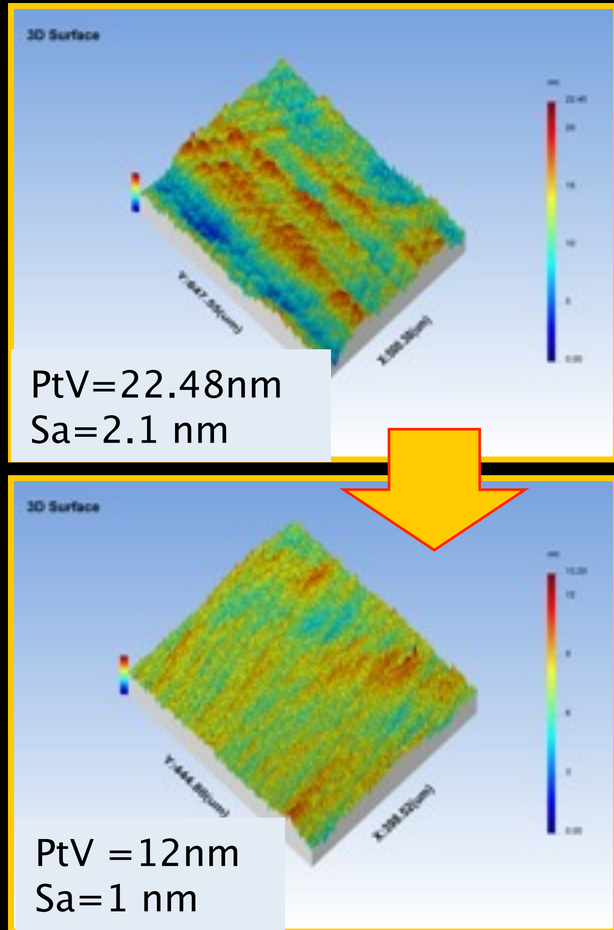


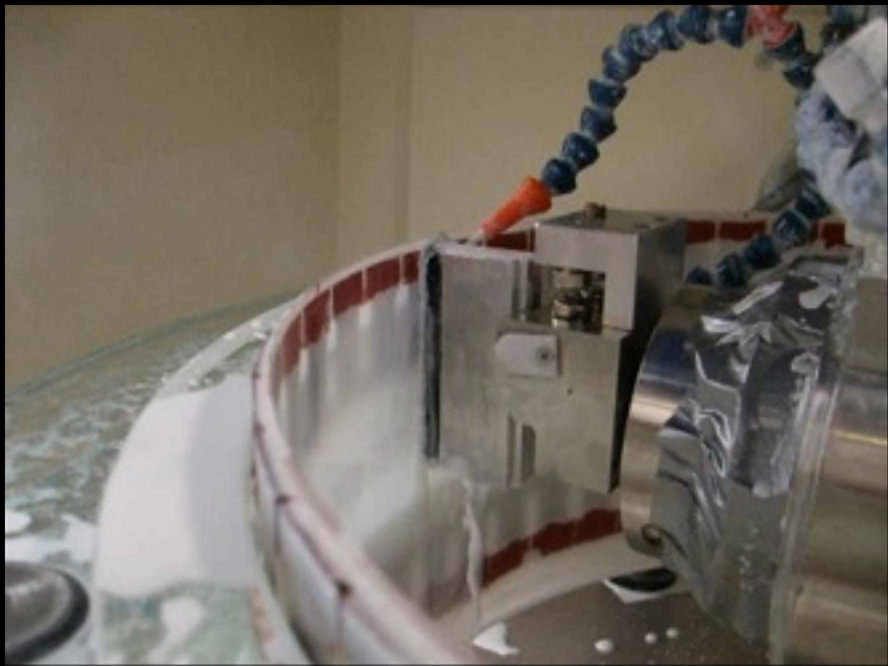
Figure Errors are already within specification!

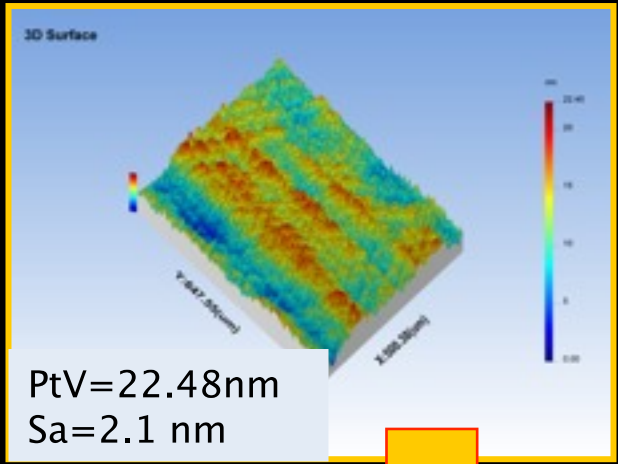
Super-polishing with 'Pendulum'

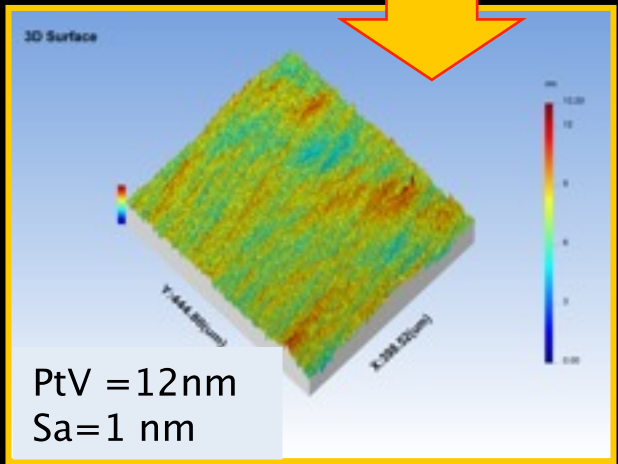


Dedicated to:
- Micro-roughness requirement achievement (0.5nm)
- Mid frequencies removing

Super-polishing with 'Pendulum'







Dedicated to:
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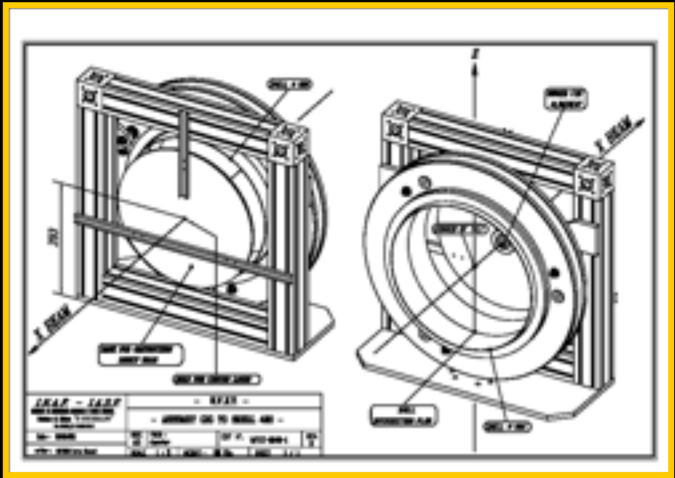
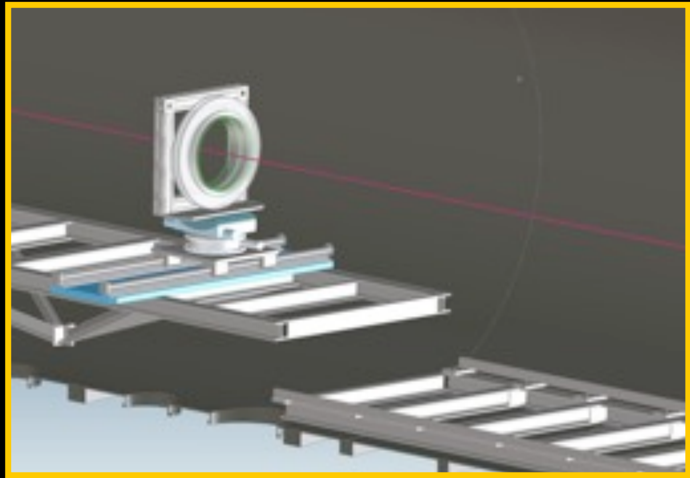
Jig for test @Panter





The jig for the SSS to be mounted in Panter facility.

Next activities

- Completion of the prototype shell with full metrology and final verification with X-Ray test @Panter facility

Fall 2011

- Coating of the shell (with X-Ray test @Panter) – Integration into a mechanical structure (with X-Ray test @Panter)

March 2012

- Development of an engineering model with 3 mirror shells to prove the achievement of optical quality with 3 different shells and the viability of the proposed integration scheme.

December 2012

WFXT Key Features

Planned Surveys

	Wide	Medium	Deep	(Milky Way)
Area (deg^2)	~15,000	~3,000	~100	~1000
$F_{lim,ext}$ (cgs)	$4x10^{-15}$	$1x10^{-15}$	$1x10^{-16}$	$5x10^{-16}$
$F_{lim,pt}$ (cgs)	$1x10^{-15}$	$2x10^{-16}$	$1.5x10^{-17}$	$1x10^{-16}$
Exposure Time (sec)	~3–4x10^3	~2x10^4	~3x10^5	~5x10^4
Duration	~2 yr	~2 yr	~1 yr	~1 yr

Survey locations TBD

Conclusions

-Temporary stiffening of the shell by two rigid glass rings coupled to the shell by flexure blades is proving to be effective for handling and optical processing of thin glass shell

- A diamond wheel mounted on a precise diamond turning late operating in positional mode has been able to bring the out-of-roundness of the shell within the specifications (OOR<1.5μm)

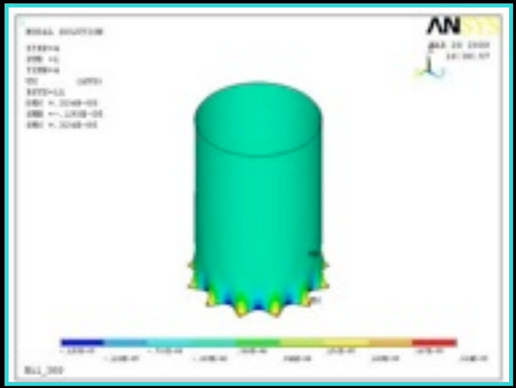
-A Zeeko polishing machine operating with a bonnet tool in dwell time mode has provided removal of surface damage left by grinding and azimuthal and longitudinal low frequency error correction down to the required specification

-We have in progress the optimization of a new polishing tool (pendulum) to be use to correct mid-frequency errors and achieve the requested roughness of 0.6nm

-After polishing completion of the parabolic side, X-Ray testing at Panter are planned for fall 2011.

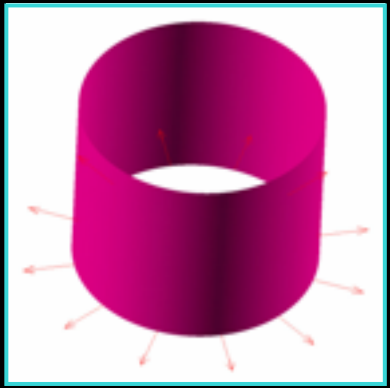
Challenge of thin shells with small aspect ratio

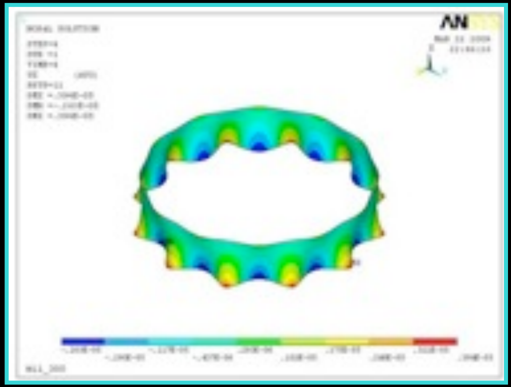
Small aspect ratio ➔ difficulty in reaching good angular resolution because they are **more sensitive to perturbing effects related to edges loads**:



- mechanical behavior closer to a “belt-like” configuration rather than a “tube-like”
- border effect errors with a much higher weight in determining the PSF
- angular resolution more strongly affected by the slope errors caused by out-of-phase azimuthal errors

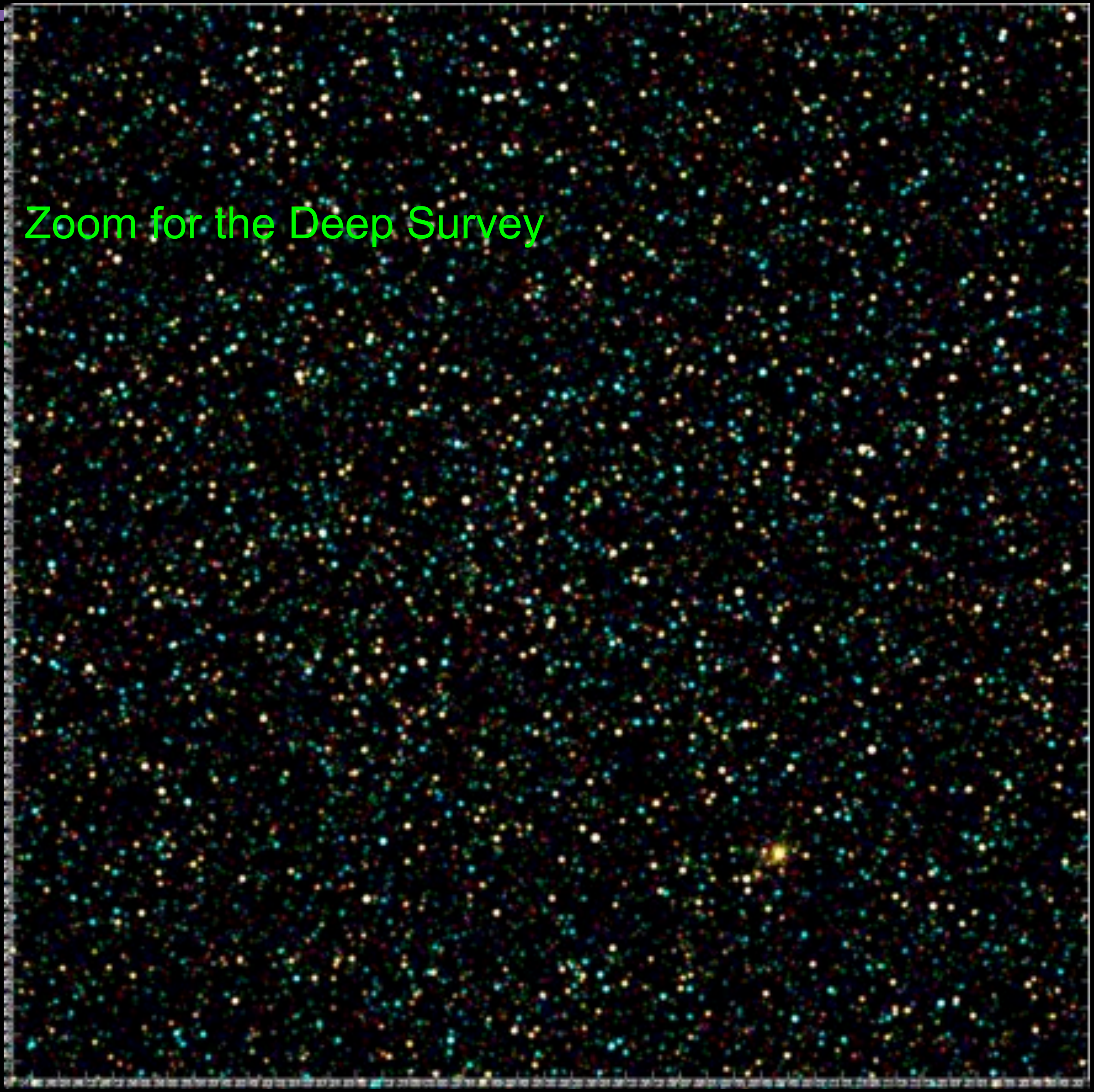
12 r F 0.1N in 12 front section points 30°





very short MSs show degradation 6-16 times larger with respect to long MS

How would it be observed by WFXT?



Detected with:

~ 70 counts in the shallow survey.

~ 500 counts in the medium survey.

~ 17,000 counts in the deep survey.
~100 @ z>2 as massive as this within $2x10^4$ sq.deg.

Well suited targets for deep repointings!

(credit J. Santos & A. Bignamini)

How would it be observed by WFXT?

Zoom for the Deep Survey

Detected with:

~ 70 counts in the shallow survey.

~ 500 counts in the medium survey.

~ 17,000 counts in the deep survey.
~100 @ z>2 as massive as this within $2x10^4$ sq.deg.

Well suited targets for deep repointings!

(credit J. Santos & A. Bignamini)

SINGLE MODULE NORMALIZED TO THE THICKNESS OF THE PROTOTYPE UNDER DEVELOPMENT

Thickness variatiation law Th(M.S.(dmax))= 2.0*sqrt(dmax/500.)
Lo F# variation between 5 e 15
Minimum length (total parab +hyp.) 220mm

"	) *	!	+ & , - . /01 /	+ 2 , - . /01 /	+ 3 , - . /01 /		4 5
		2 60	2160&317	3130 2	&80 1	1 0&8	11
	8	18 0	830&162	2 0 &&	&6 021	60&3	&63
2	6	11 0	&8110&&23	23 0&6&	& 013	80&3	&27
2	6	780	&2 3066&	1620&22	& 60 7	30&26	&&6
1	6	3 0	&&270 3 6	1 0& 6	& 60 &	20&13	66

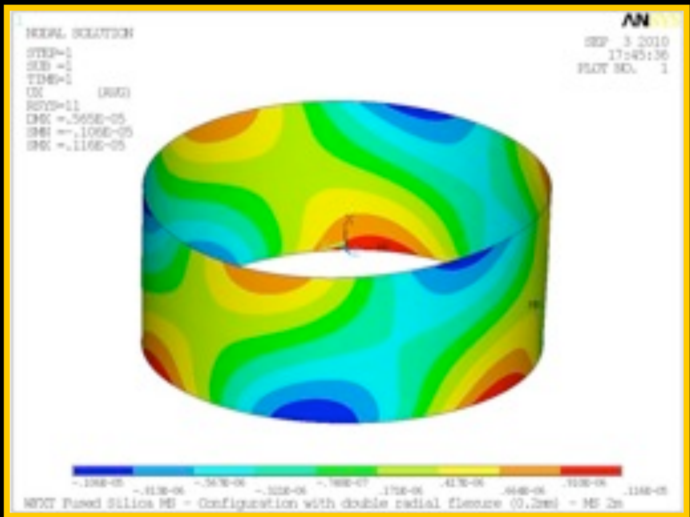
NB thickness of 2 mm for diameter of 500 mm

NB: we have to add 30 % more to the weight in order to account for the structure mass

Gravity effects

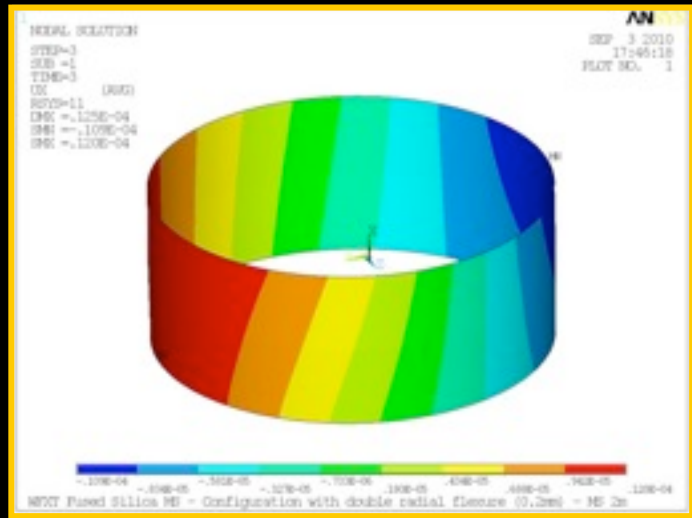
Isocontours of radial displacement compontent of the MS attached to the temporary stiffening structure

Axial gravity



PtoV = 2.2 μm
HEW = 0.14 arcsec
90% EE = 0.75 arcsec

Lateral gravity

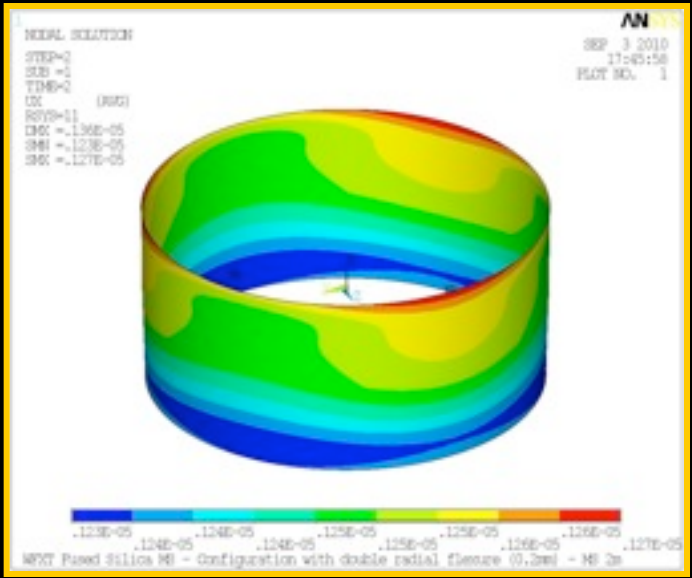


PtoV = 22.9 μm (rigid body mov.)
HEW = 0.15 arcsec
90% EE = 0.55 arcsec

Temperature effects

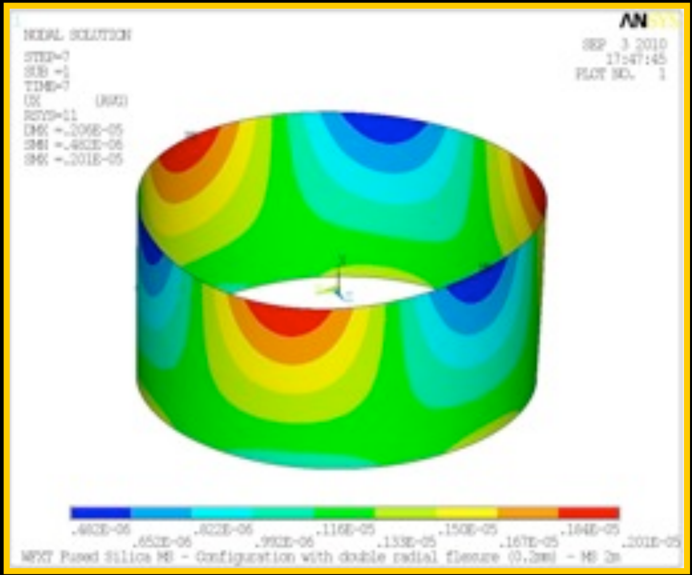
Isocontours of radial displacement compontent of the MS attached to the temporary stiffening structure

ΔT = +10°C
just on MS (machining heating)



PtoV = 0.04 μm(*)
HEW = 0.14 arcsec
90% EE = 0.47 arxsec
(*) uniform expansion

ΔT = +1°C
on whole assembly



PtoV = 1.53 μm
HEW = 0.16 arcsec
90% EE = 0.52 arcsec