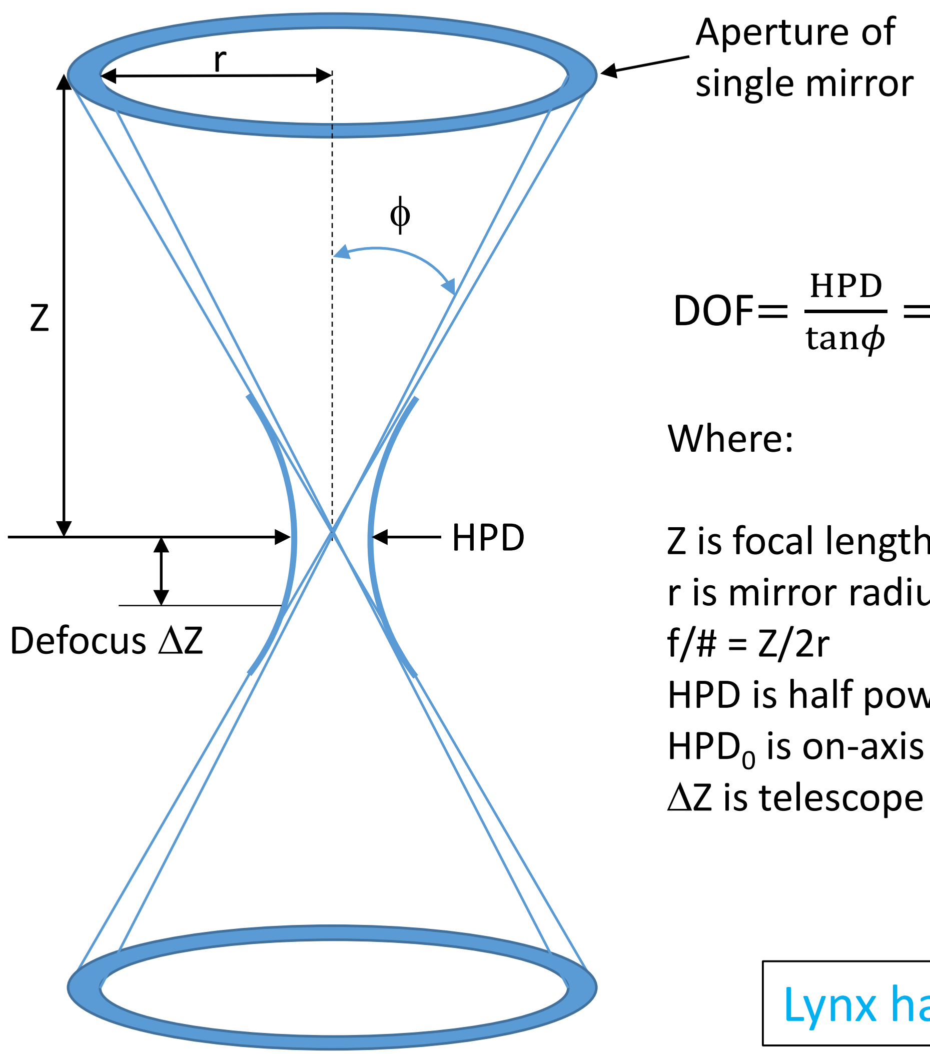
Lynx Telescope Mirror Physics

Part 2: Depth of Focus and Field of View (DOF and FOV)

Lynx Optics Working Group

August 30, 2017

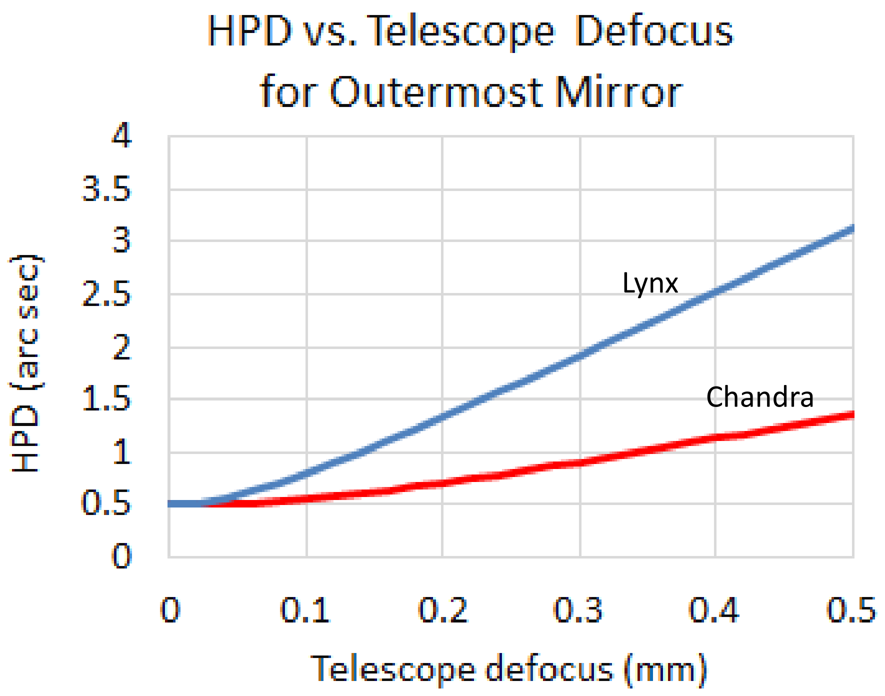
Telescope Mirror Depth of Focus (DOF)



$$\text{DOF}=\frac{\text{HPD}}{\tan\phi}=2*\text{HPD}*\text{f/\#}$$

Where:

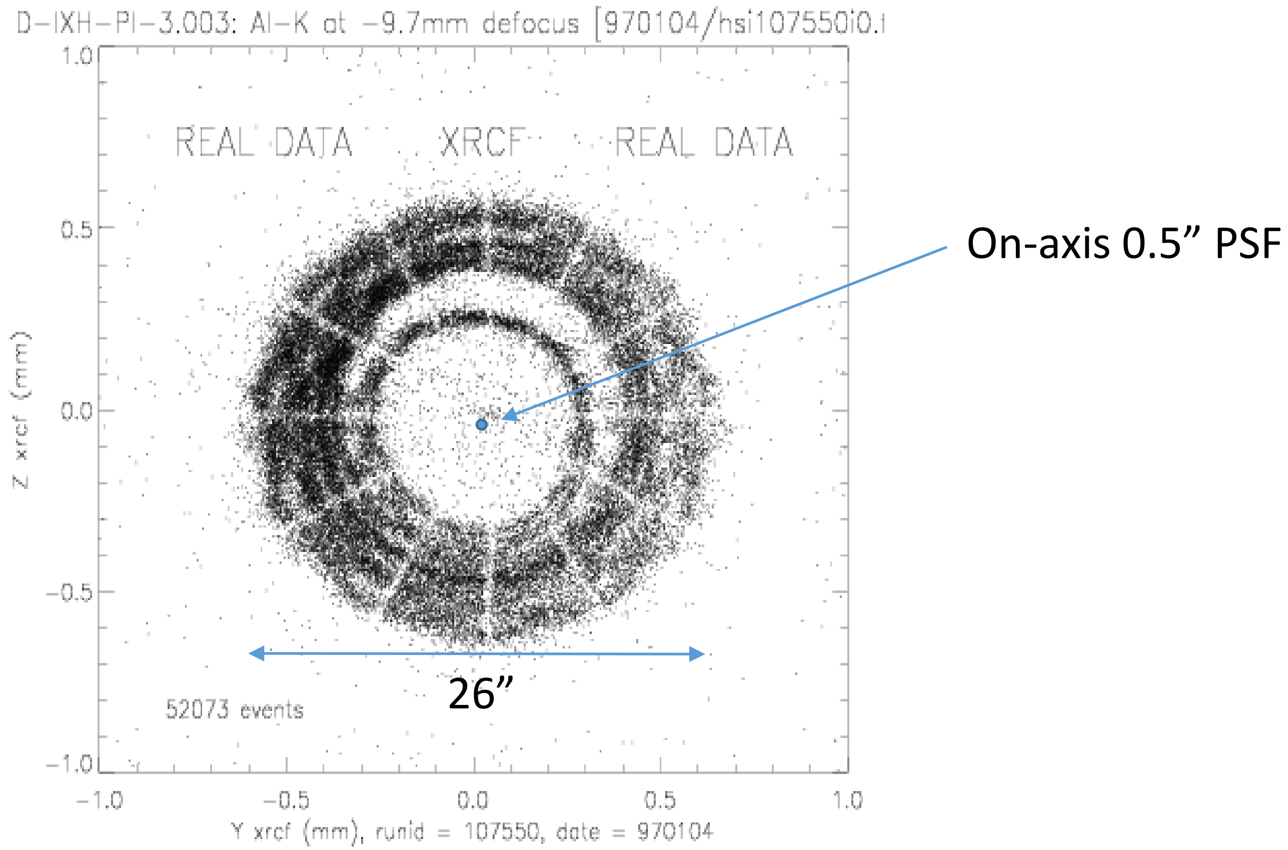
Z is focal length
r is mirror radius
f/# = Z/2r
HPD is half power diameter
HPD_0 is on-axis HPD
ΔZ is telescope defocus



$$HPD(\Delta Z)=\sqrt{HPD_0{}^2+\left(\frac{\Delta Z}{f/\#}\right)^2}$$

Lynx has 2.4X tighter focus budget than Chandra

Measured Chandra Telescope PSF De-Focused by 9.7 mm



http://space.mit.edu/CXC/MARX/indetail/hardwaremodel.html

Parametric Studies of Chandra vs. Lynx

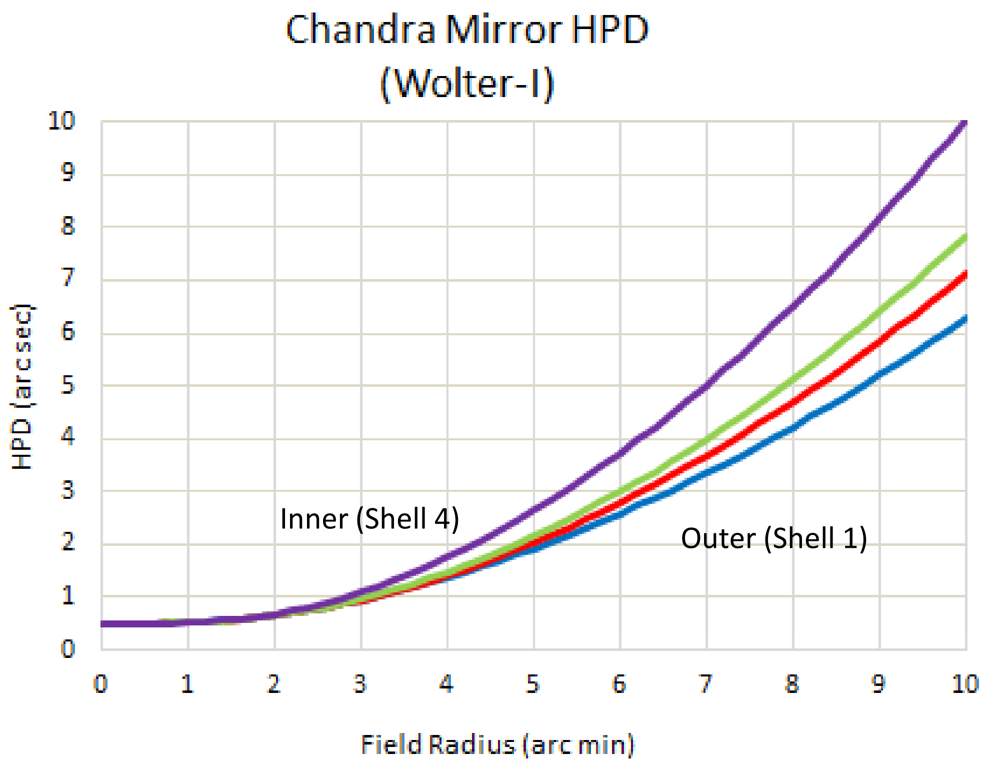
Mission	Chandra	Lynx
Focal Length, F (m)	10	10
Min diameter, D_{min} (m)	0.65	1
Max diameter, D_{max} (m)	1.23	3
Length, L (m)	0.84	0.2

Warning!

Simulations do not take into account vignetting.

Ray trace follow-up required!

Chandra Field of View (FOV)



Chandra mirrors

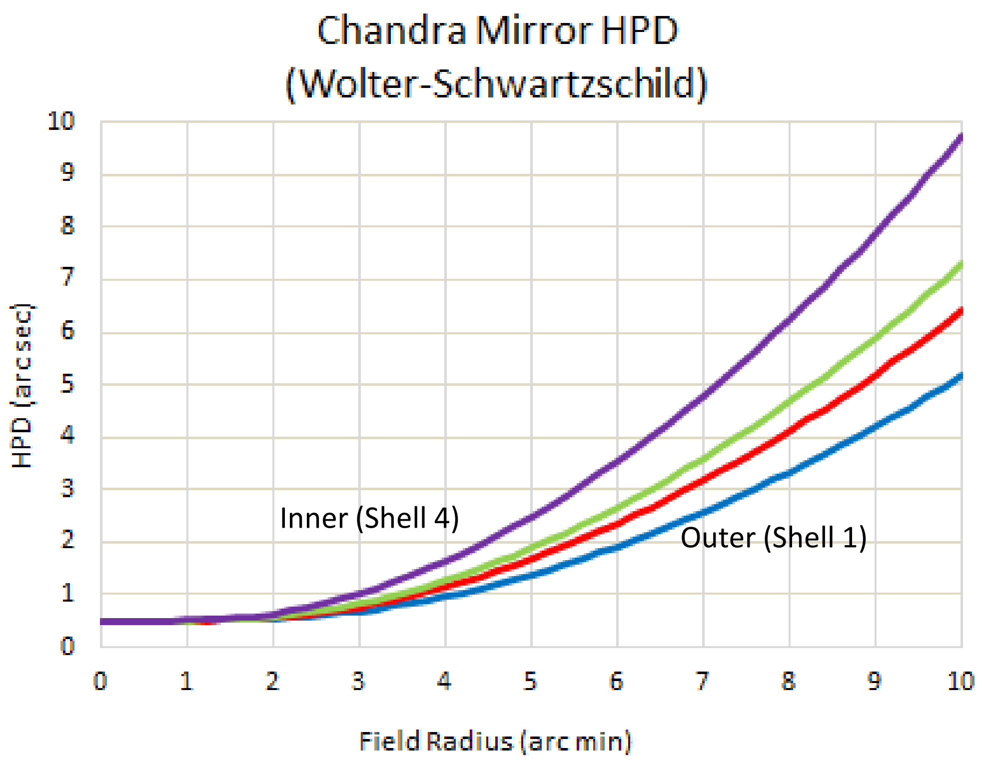
L = mirror length
Z = focal length
λ = wavelength
α = graze angle
θ = field radius
HPD_0 = on-axis HPD

Half power diameter (HPD)

$$HPD = 2\sqrt{\left(0.27\frac{\tan^2\theta}{\tan\alpha}\frac{L}{Z} + \tan\theta\tan^2\alpha\right)^2 + \left(\frac{\lambda}{2L\tan\alpha}\right)^2 + HPD_0^2}$$

Geometry — Diffraction — Engineering

Chandra Field of View (FOV)



Chandra mirrors

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Geometry Diffraction Engineering

L = mirror length
Z = focal length
λ = wavelength
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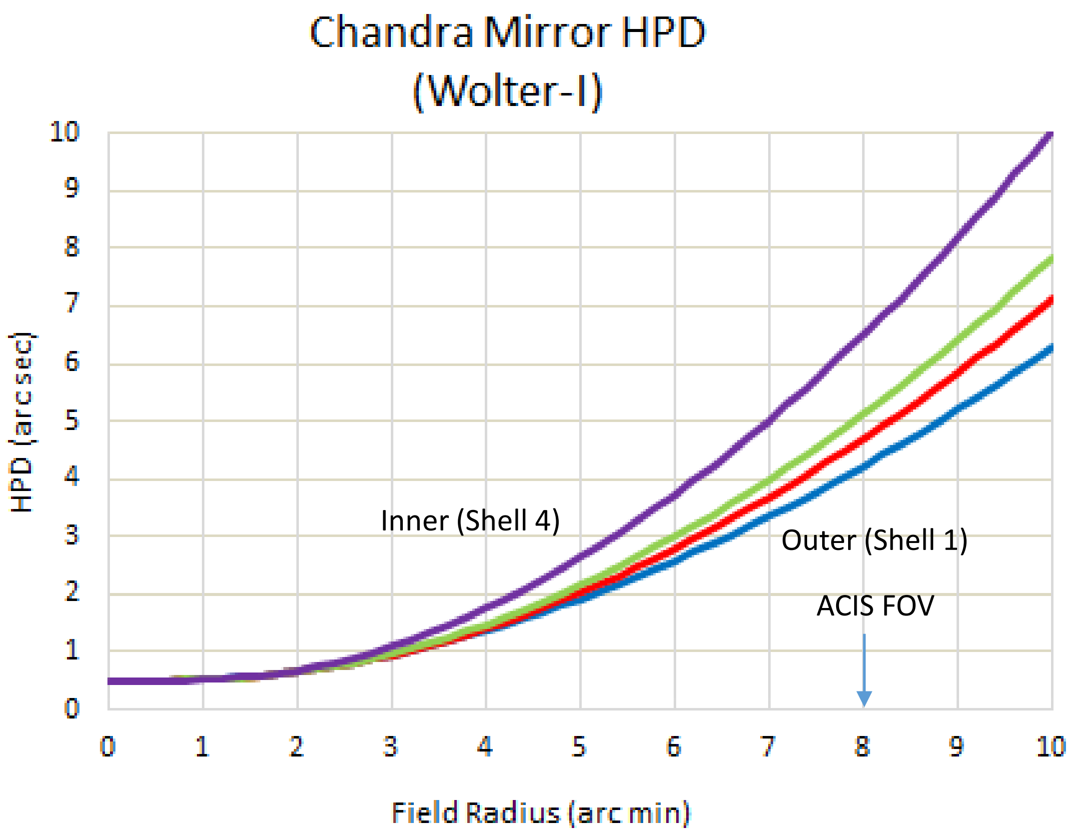
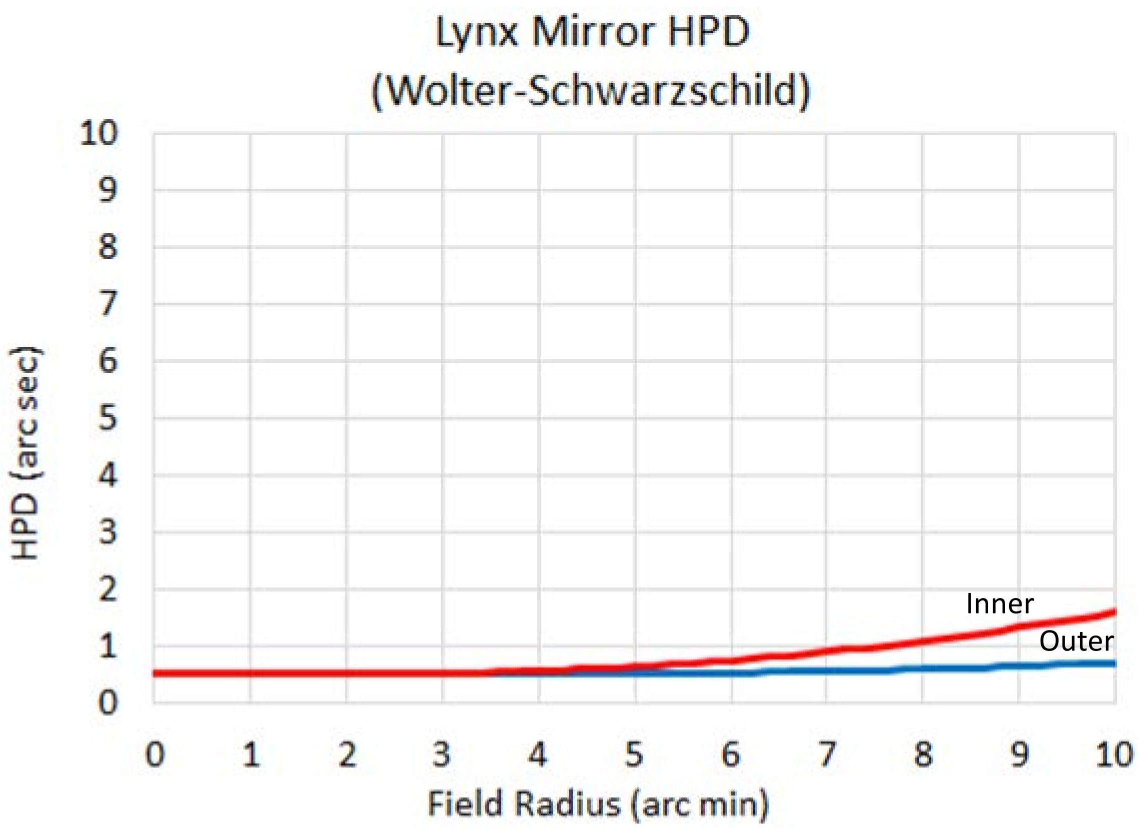
HPD_0 = on-axis HPD

Both geometry and diffraction degrade HPD of inner mirrors

Chandra vs. Lynx FOV





Lynx has >3X wider FOV compared to Chandra (10X smaller L/tanα)

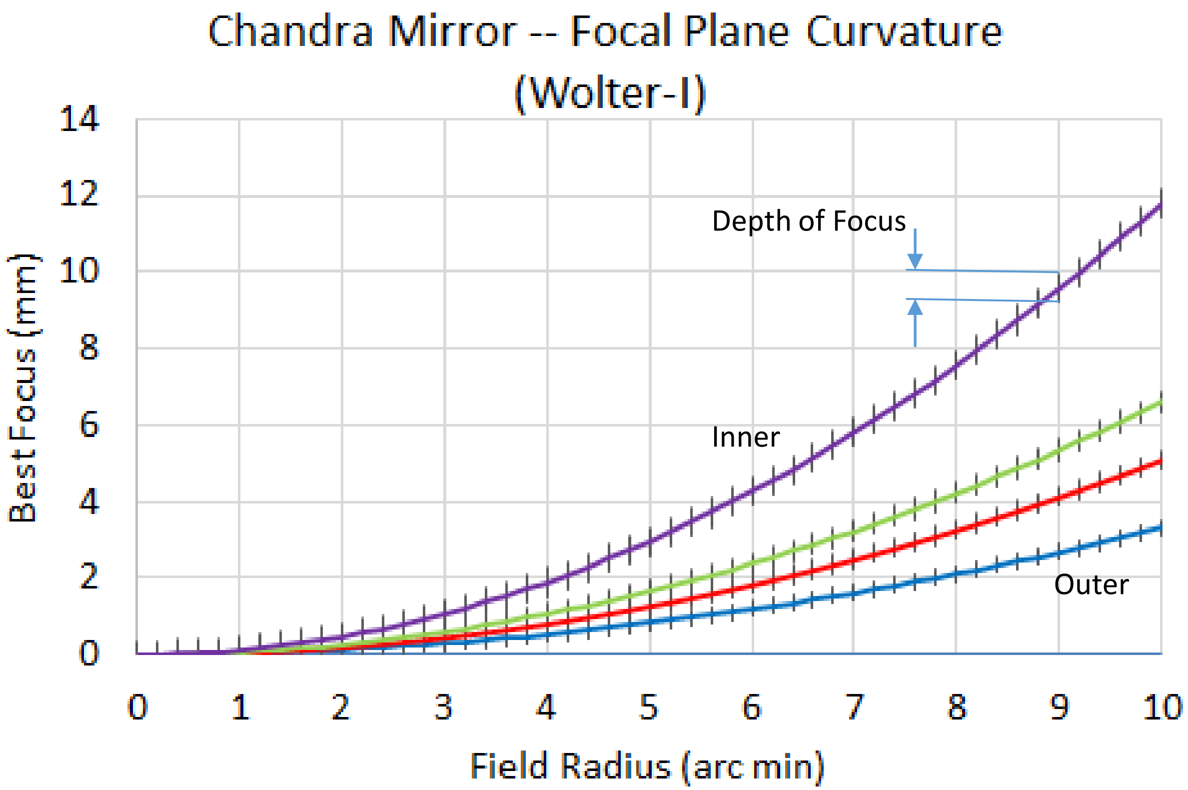
$$HPD_g = 0.27 \frac{\tan^2\theta}{\tan\alpha} \frac{L}{Z}$$

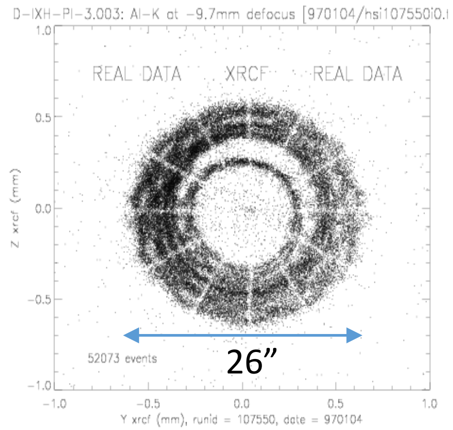
But wait, there’s more …

Lynx focal plane is much flatter than Chandra’s!

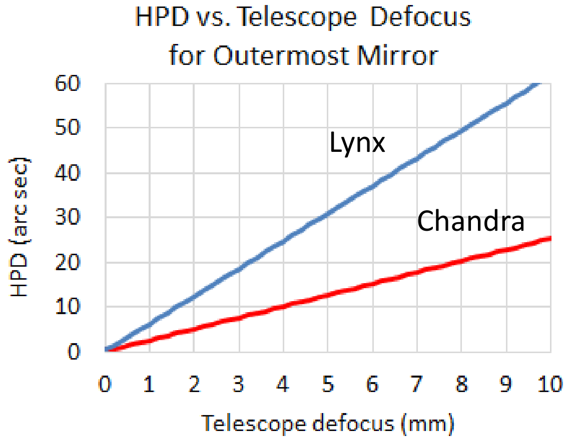
Chandra Focal "Plane"

X-ray telescopes do not have a flat focal surface!





Chandra PSF 9.7 mm defocus



Each shell has a unique best focal surface

Field sag

$$\delta = 1.1\, L \left(\frac{\tan\theta}{\tan\alpha}\right)^2$$

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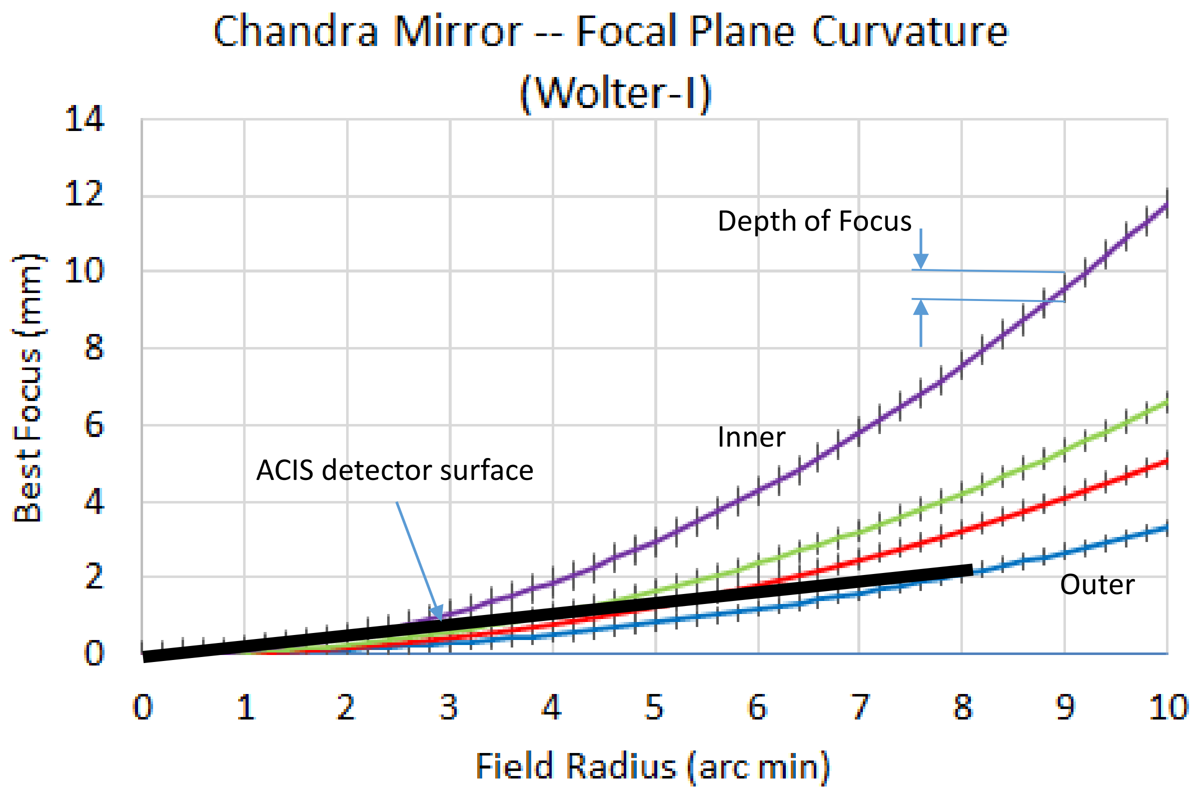

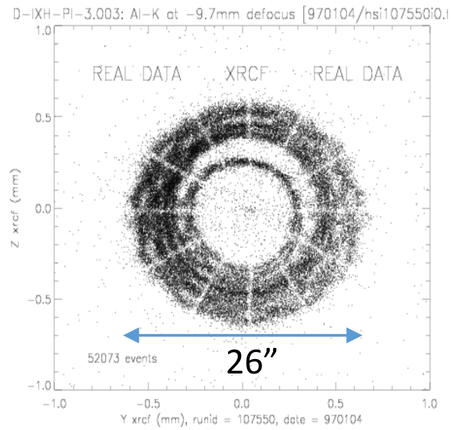

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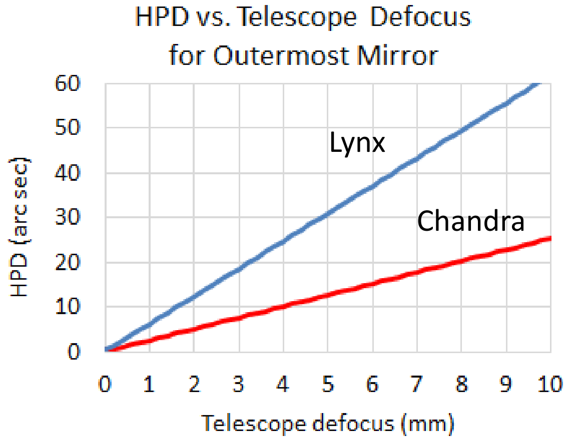

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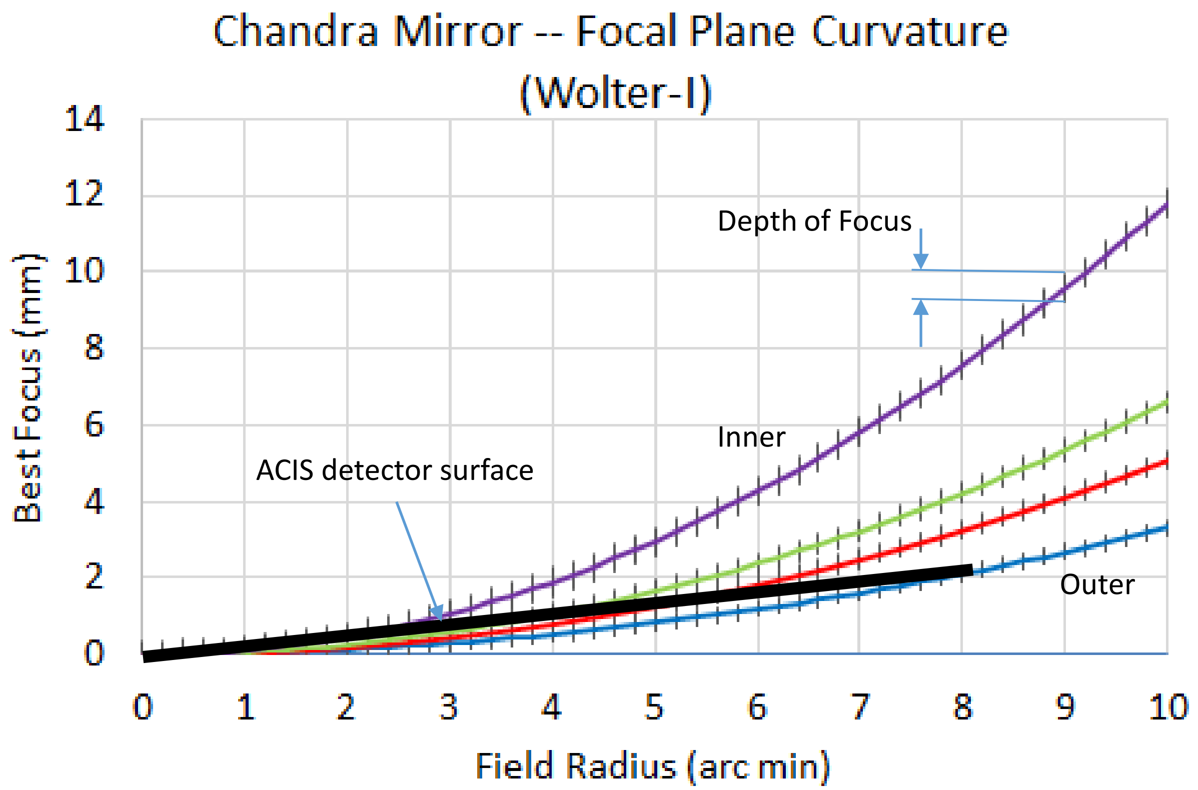
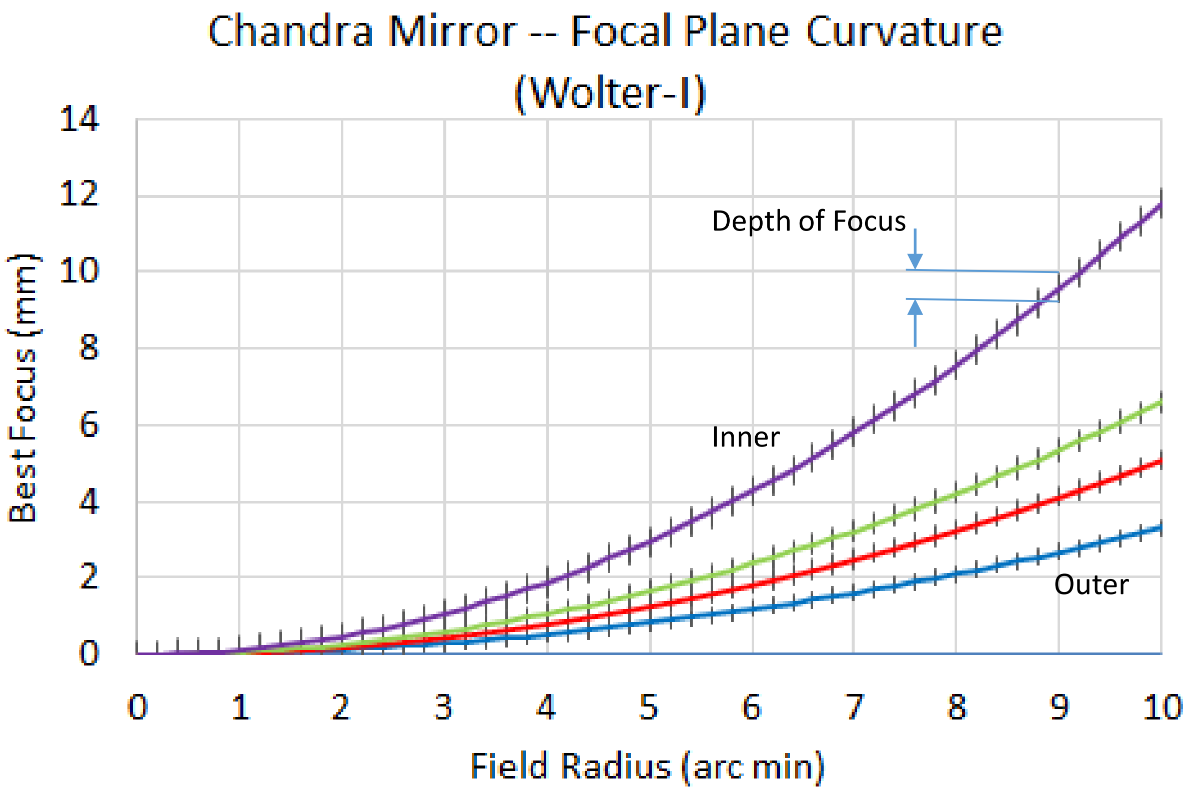


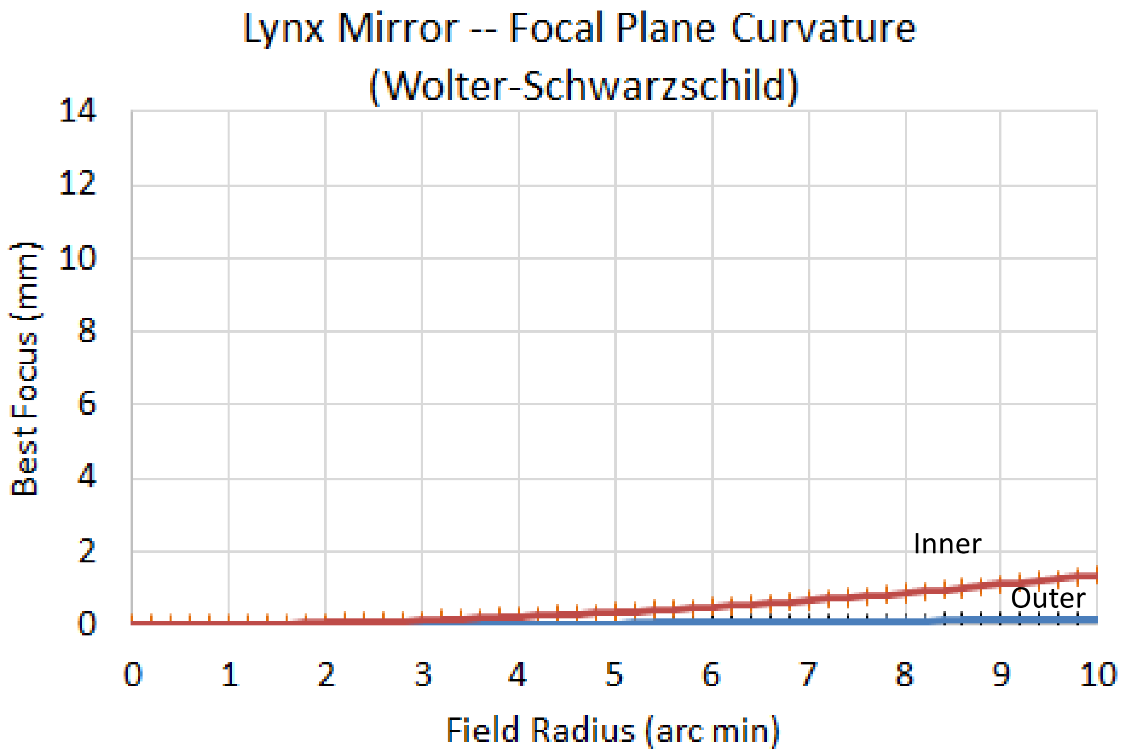
Hard x-rays (inner mirrors) have poor PSF compared to soft x-rays (outer mirrors) for two reasons:

1. PSF is smaller for inner mirrors due to smaller α
2. Detector plane is optimized to outer mirrors!

$$HPD_g = 0.27 \frac{\tan^2\theta}{\tan\alpha} \frac{L}{Z}$$

Chandra vs. Lynx Focal Surfaces





Field sag

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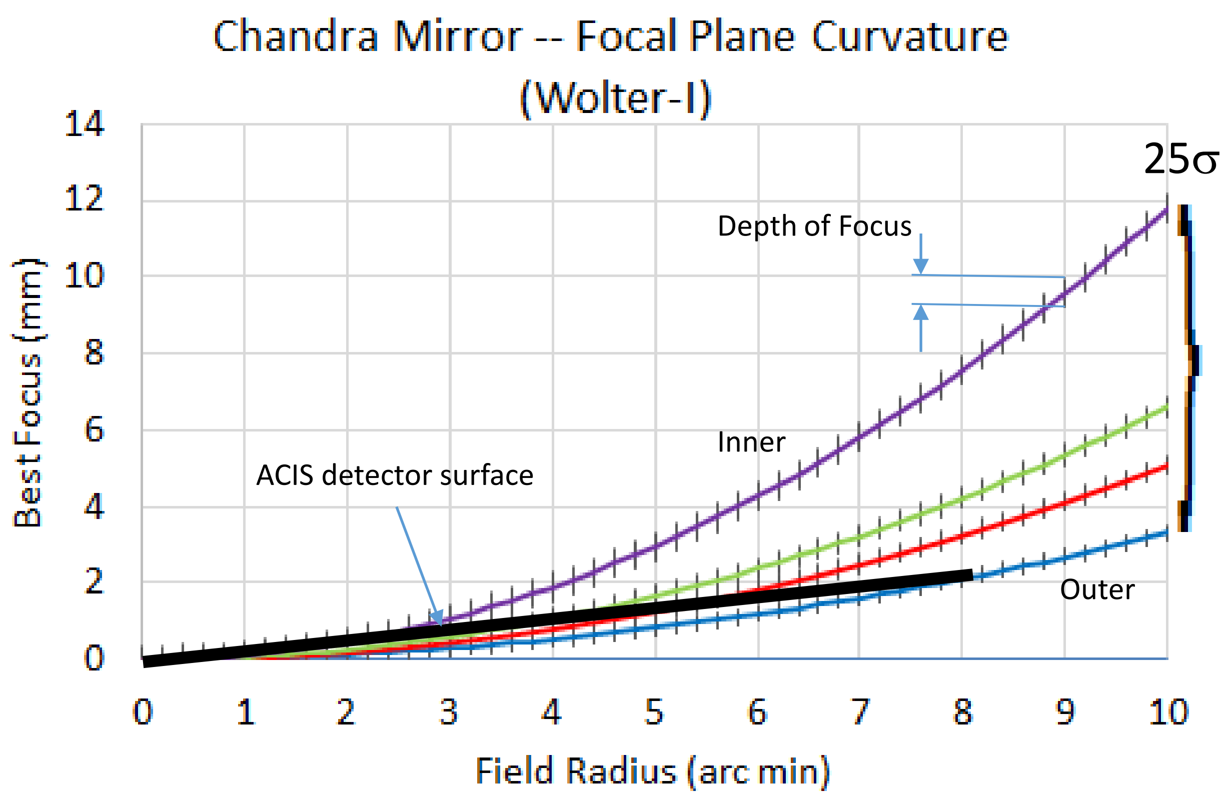
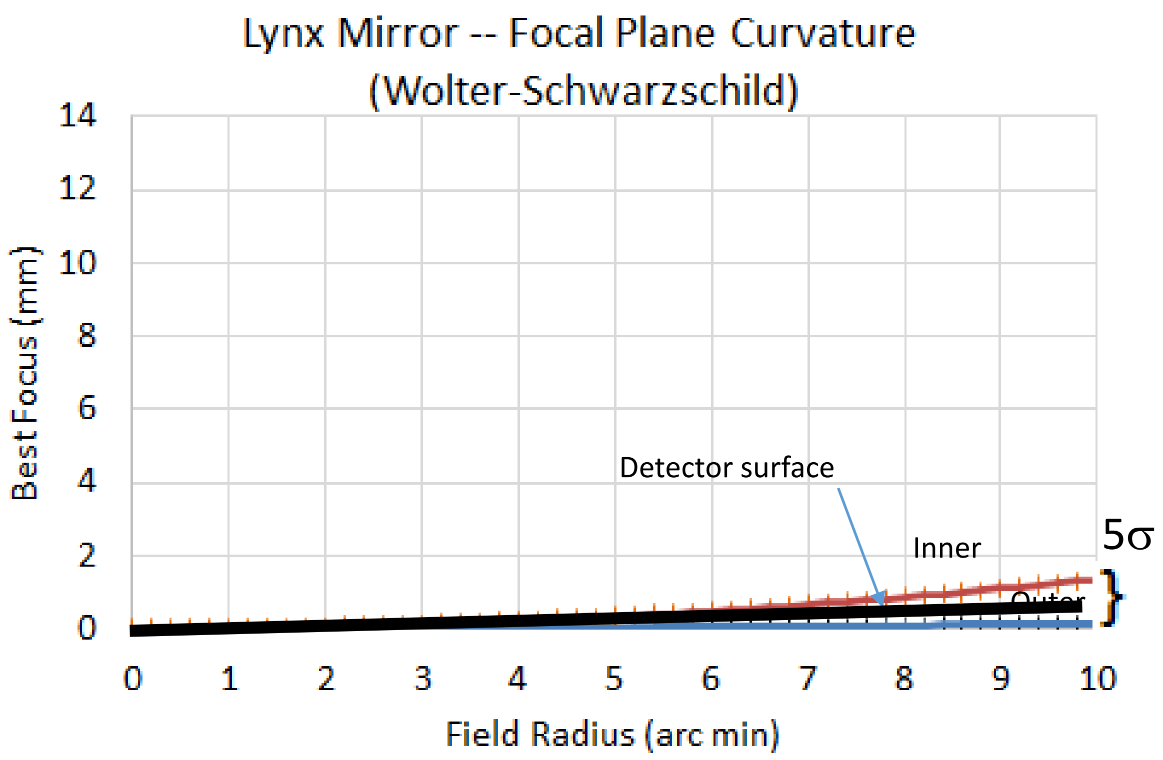
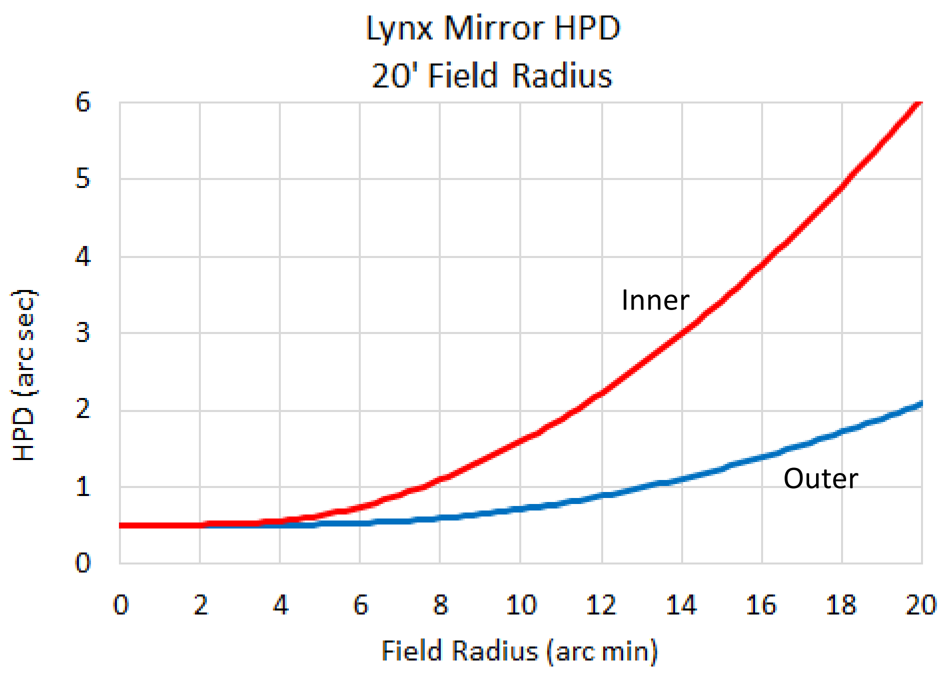
Chandra vs. Lynx Focal Surfaces

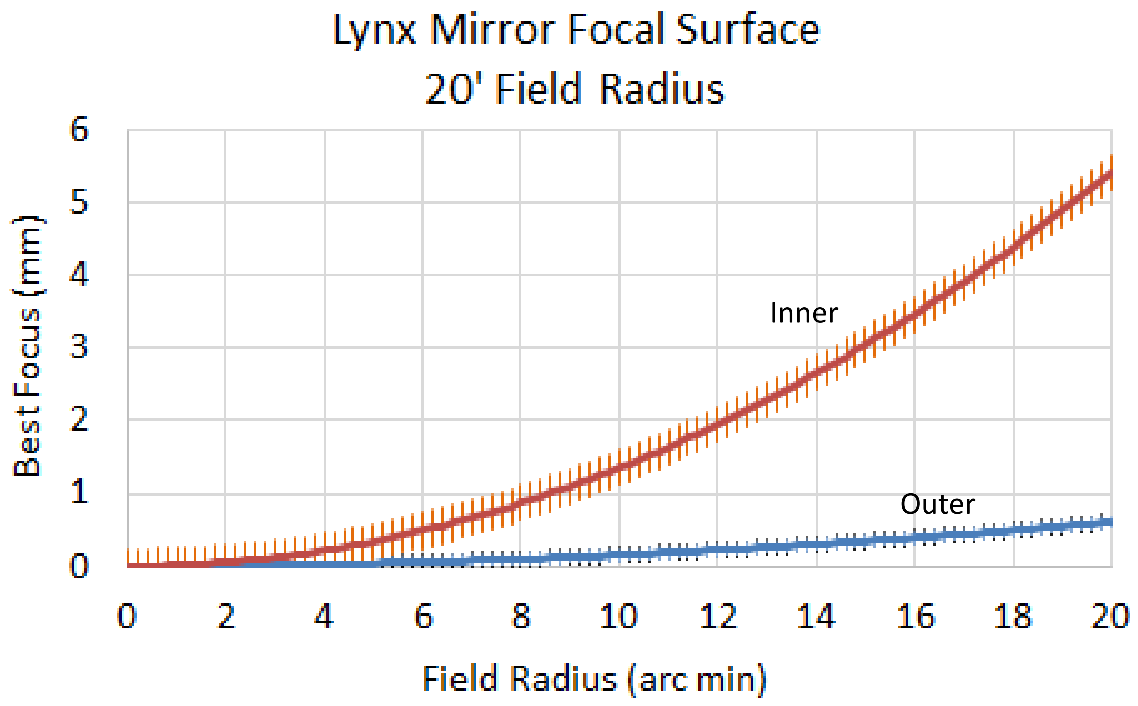




Lynx has ~40X flatter focal surface compared to Chandra!

Lynx with 40’ Field of View





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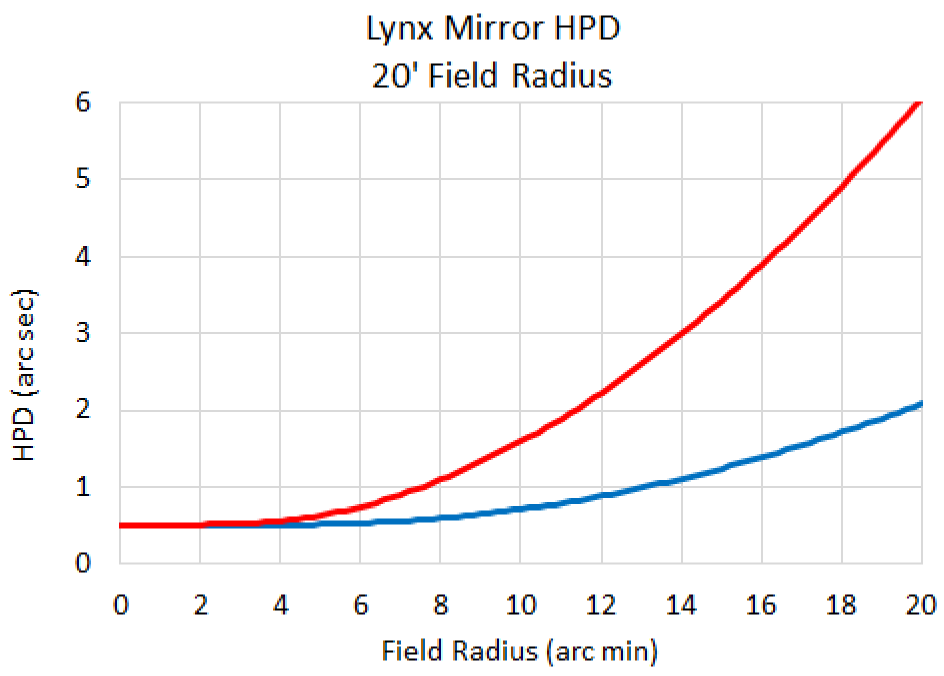
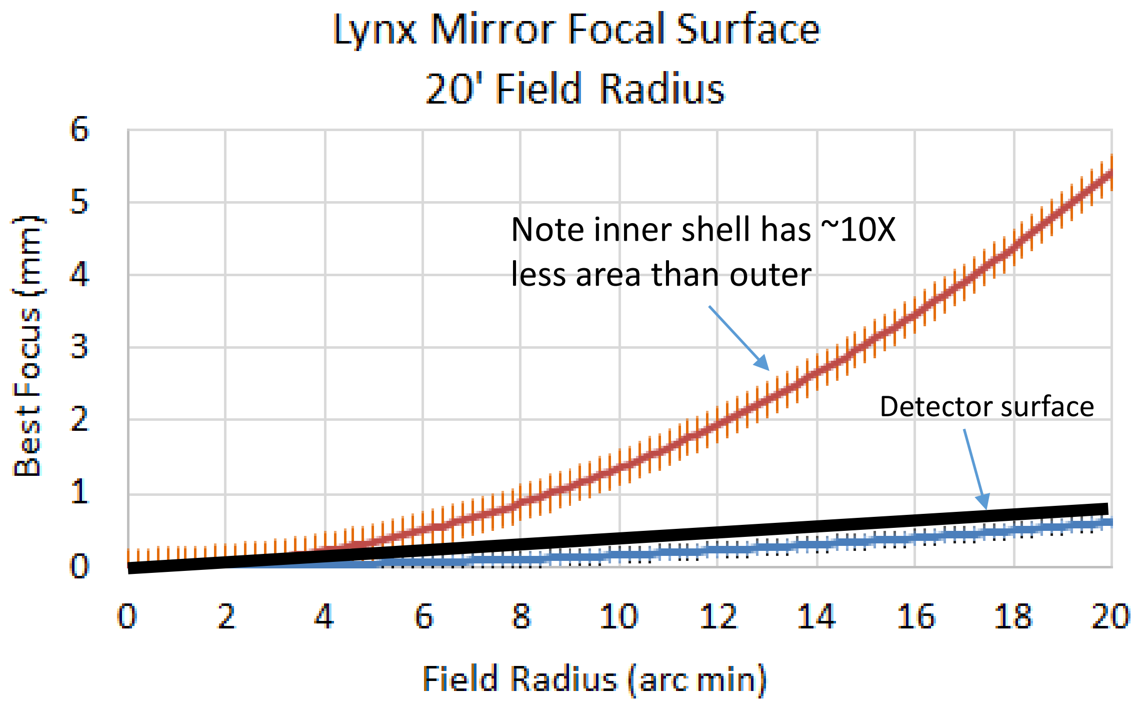
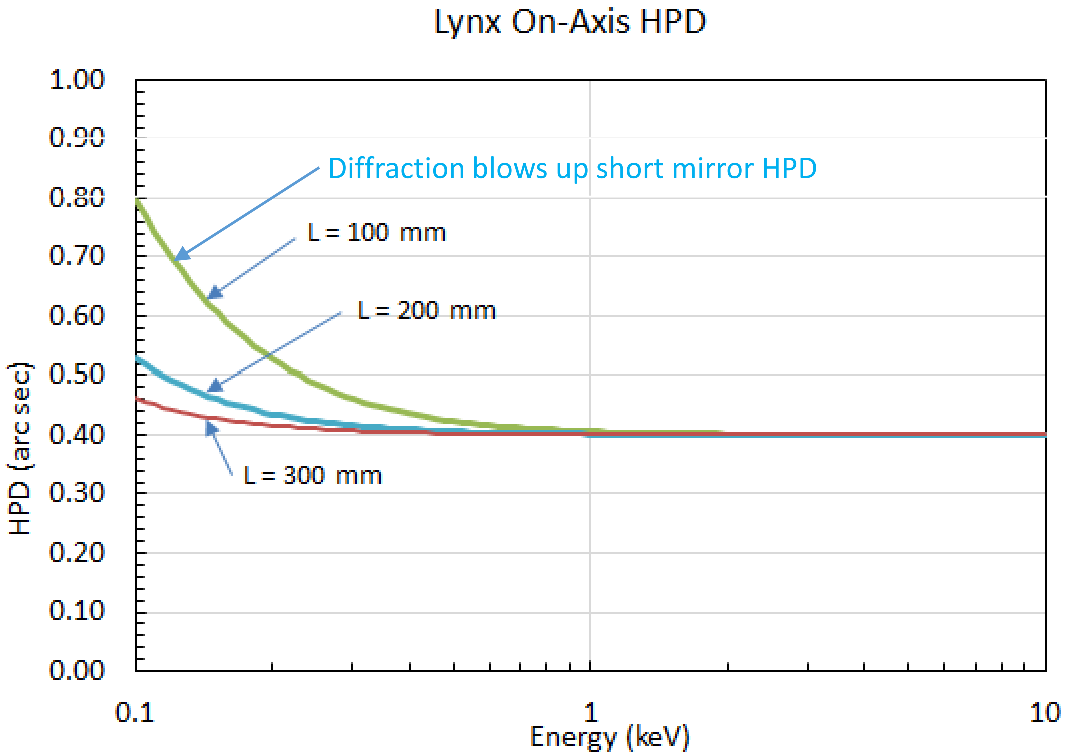
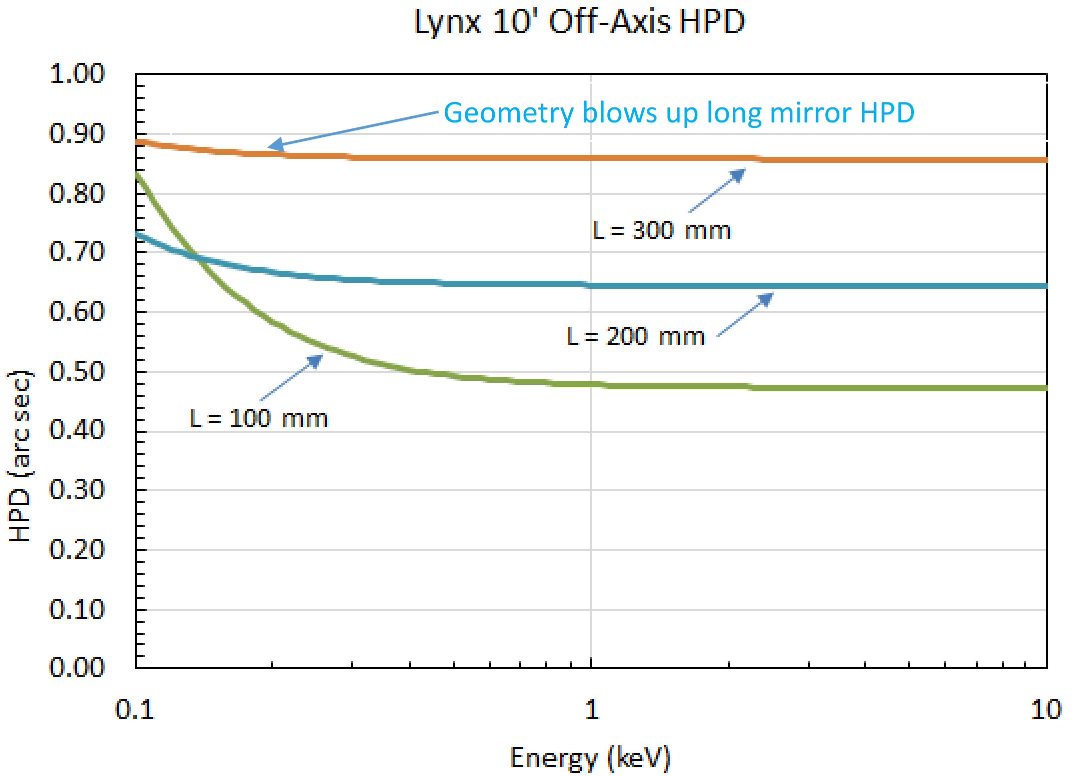




A 40’ FOV Lynx “looks like” a 16’ FOV Chandra

FOV Tradeoff to Optimize Mirror Length





200 mm-long mirror is sweet spot for Lynx!
(Optimal trade-off of
diffraction and geometry terms)

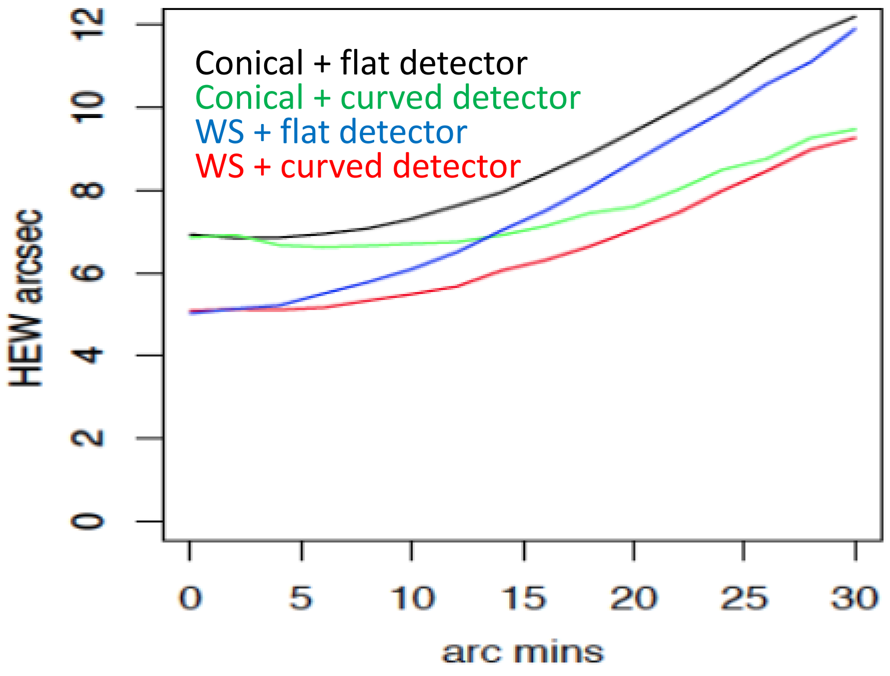
Half power diameter (HPD)

$$HPD = 2\sqrt{\left(0.27\frac{\tan^2\theta}{\tan\alpha}\frac{L}{Z}\right)^2 + \left(\frac{\lambda}{2L\tan\alpha}\right)^2 + HPD_0^2}$$

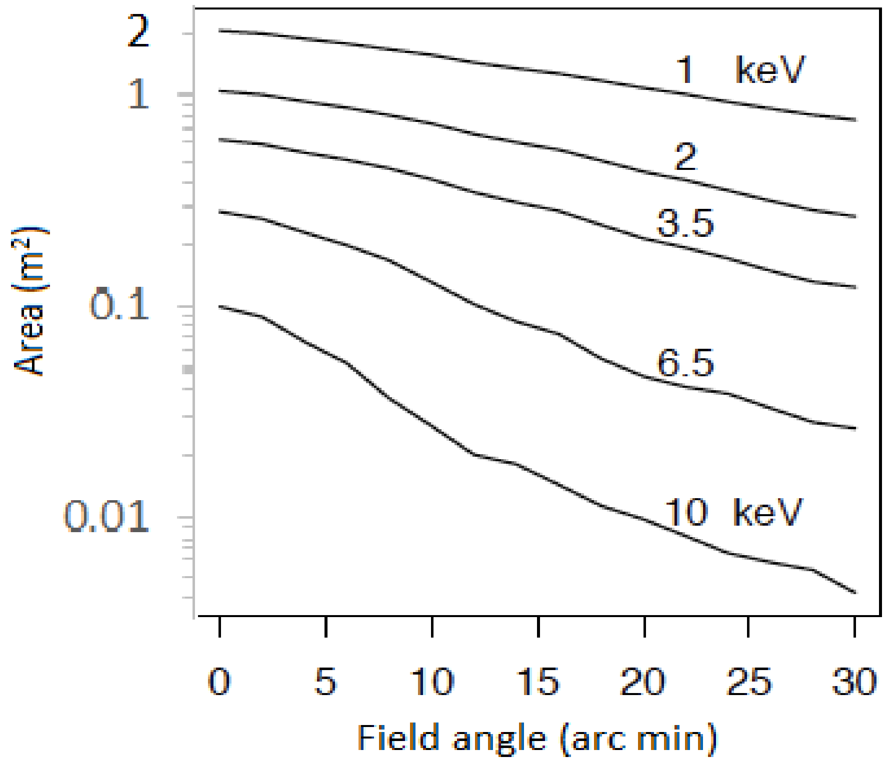
Geometry | Diffraction | Engineering

Nominal Athena FOV and Vignetting

Athena HPD vs. field angle



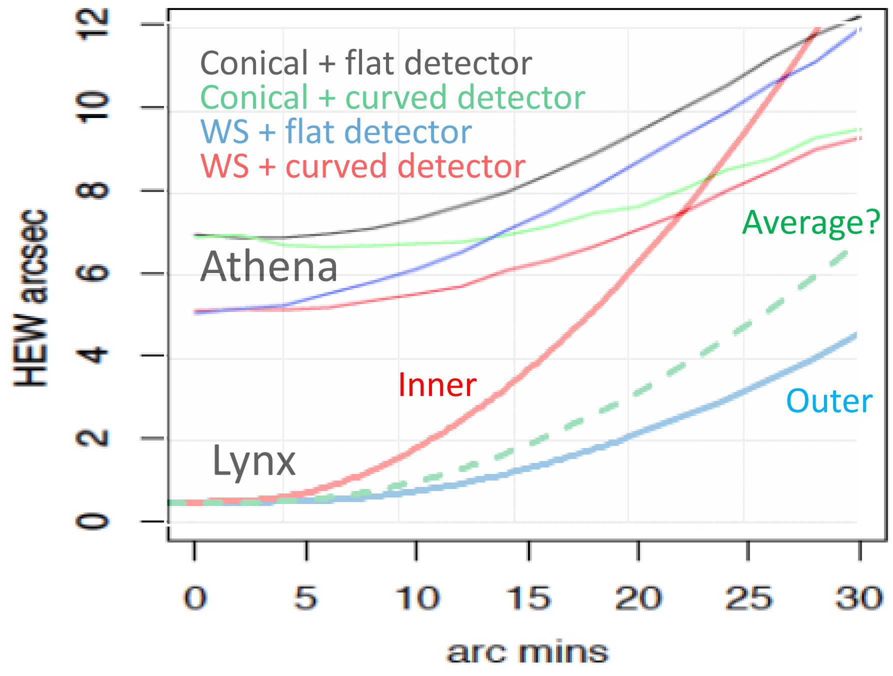
Athena vingetting



The Hot and Energetic Universe: The Optical Design of the Athena+ Mirror, Willingale et al., 2013.

Lynx vs. Athena FOV

Athena & Lynx HPD vs. field angle



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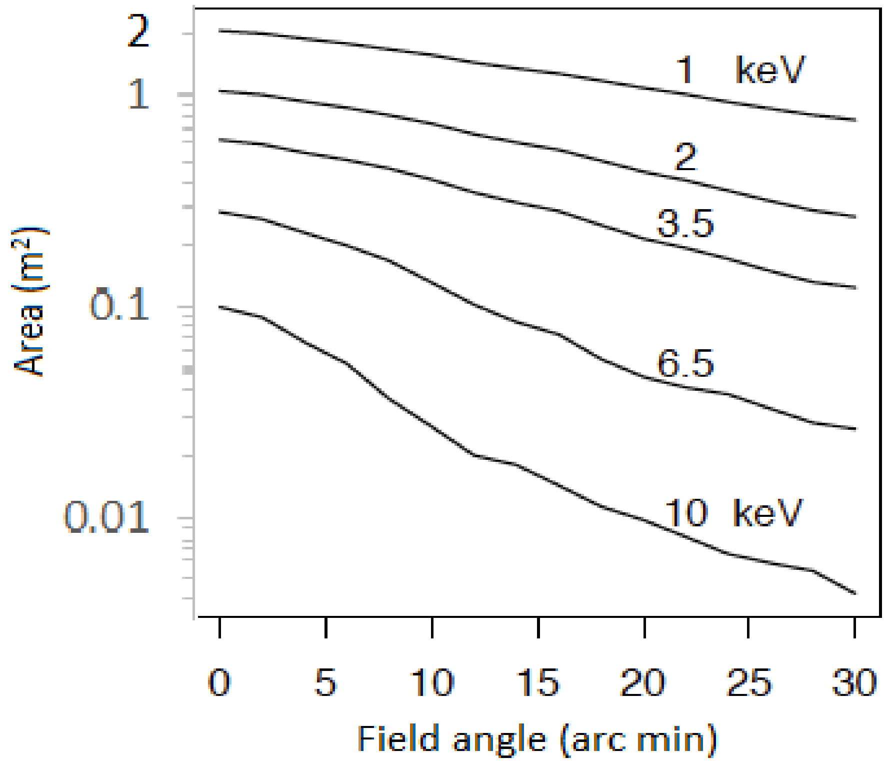

Lynx can challenge Athena in FOV comparison!

Athena @ 1 keV vignettes by 2.5X at 30’

The Hot and Energetic Universe: The Optical Design of the Athena+ Mirror, Willingale et al., 2013.

Every proposal tells a story, don't it?

Here is our story:

- ➢ Sustained NASA investment has enabled technical advances leading to a $(10X)^4$ more powerful X-ray Surveyor concept …
- ➢ … in turn enabling exciting, breakthrough science

Why $(10X)^4$?

- 10X larger area
- 10X improved spectral resolution
- 10X better detectors
- 10x larger FOV merit function (i.e., number of resolvable point sources in FOV)

Large FOV strong selling point for Lynx!

Summary

- Lynx optics performance is huge leap from Chandra:
  - Larger diameter and shorter mirrors have large positive impact on FOV
  - Lynx has a much flatter best-focus surface
  - Geometry and diffraction can be balanced to optimize FOV
- Lynx can challenge Athena in FOV comparison
- Parametric studies need to be backed up with ray traces
  - Vignetting should be considered if >10’ FOV ray trace study requested by STDT

Questions?