Design of the STAR-X telescope

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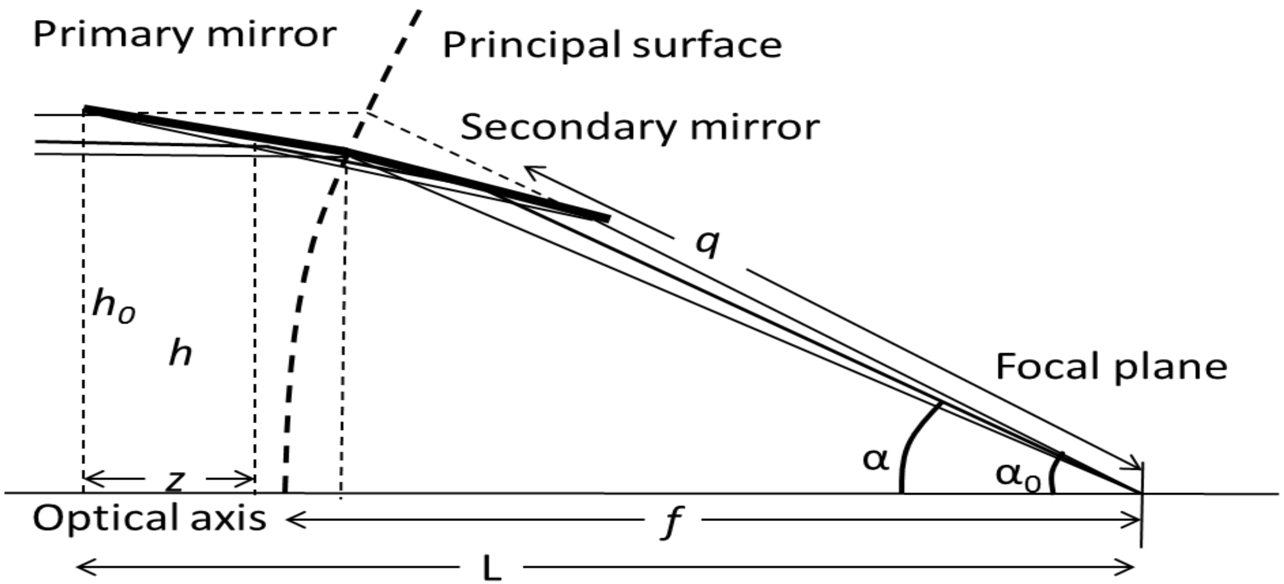
Outline

- Telescope designs considered
  - Wolter-Schwarzschild telescopes
  - Modified-Wolter-Schwarzschild telescopes
- Design principles of nested x-ray telescopes
  - Principal surface
  - Packaging considerations
- Baffle design
  - Telescope internal baffles
  - Front tube-baffles
- Optical performance of single pair design and nested design
  - Half power diameters calculated at 1.0 KeV and 4.0 KeV
  - At Gaussian focal plane
  - At best focal surface
  - 4 detector array in pyramid configuration
- Telescope effective area at 1.0 KeV and 4.0 KeV
- Conclusions

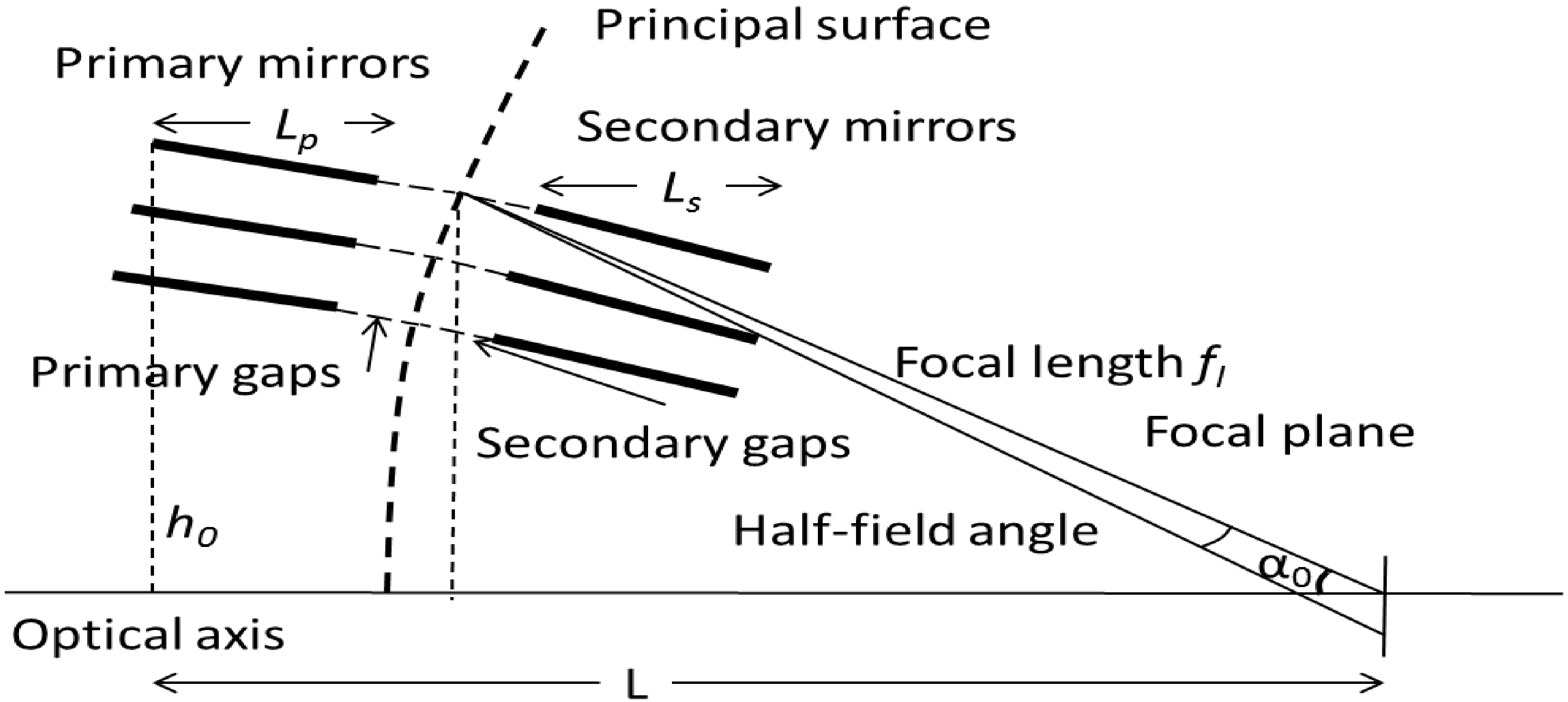
Considered telescope designs

- Wolter-Schwarzschild (WS) telescope
  - Principal surface is spherical and satisfies Abbe's sine condition
  - *h=fsin(α)*
- Modified-Wolter-Schwarzschild (MWS) telescope
  - Adjust axial sag to optimize the on-axis and off-axis image size



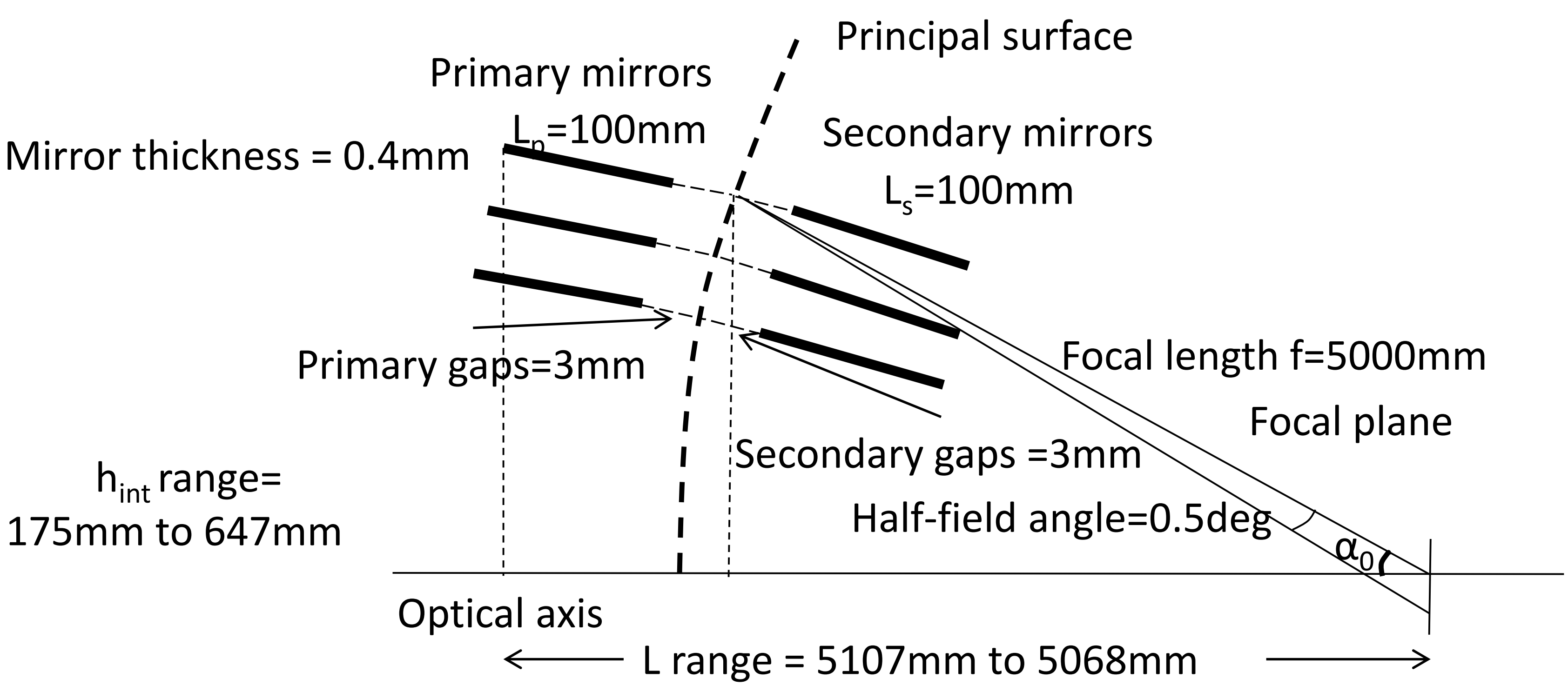
Design of nested telescopes

- Primary-secondary intersections of the telescopes have to be on a spherical surface to optimize the off-axis image size
- Adjacent surfaces cannot obstruct the field-of-view
- Physical lengths of the telescopes are the same
- Axial lengths and gaps between the mirrors are the same
- Finite mirror shell thickness assumed



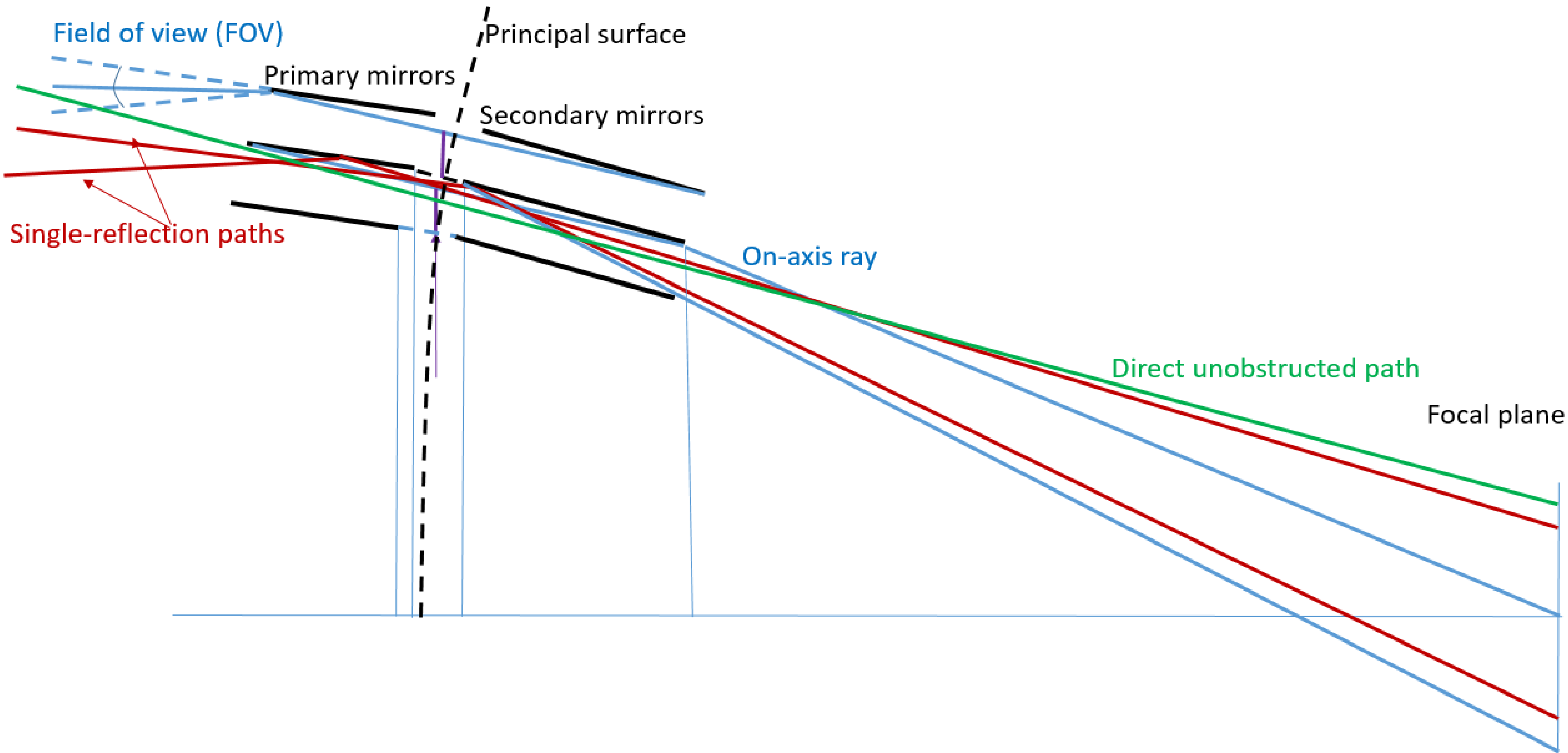
Wide field of view nested telescope design

- Wolter-Schwarzschild, and Modified-Wolter-Schwarzschild telescopes have the same basic dimensions
- Minimum radial height is determined by field of view requirement
- 148 mirror pairs fit between minimum and maximum radii



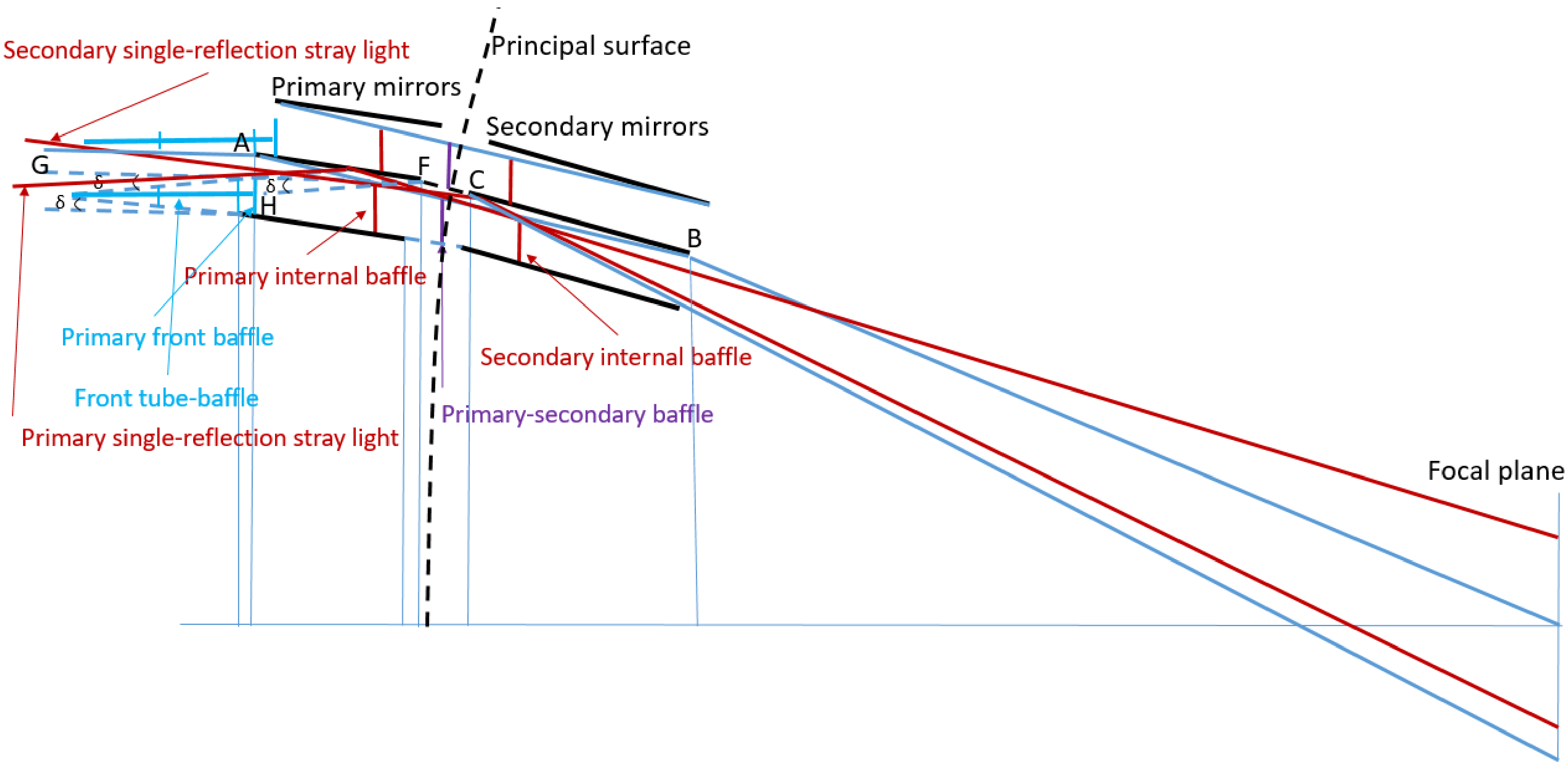
Baffle design principles

- Baffles are placed to restrict the FOV of the detector to secondary mirrors only and FOV of the secondary mirror to primary mirrors only



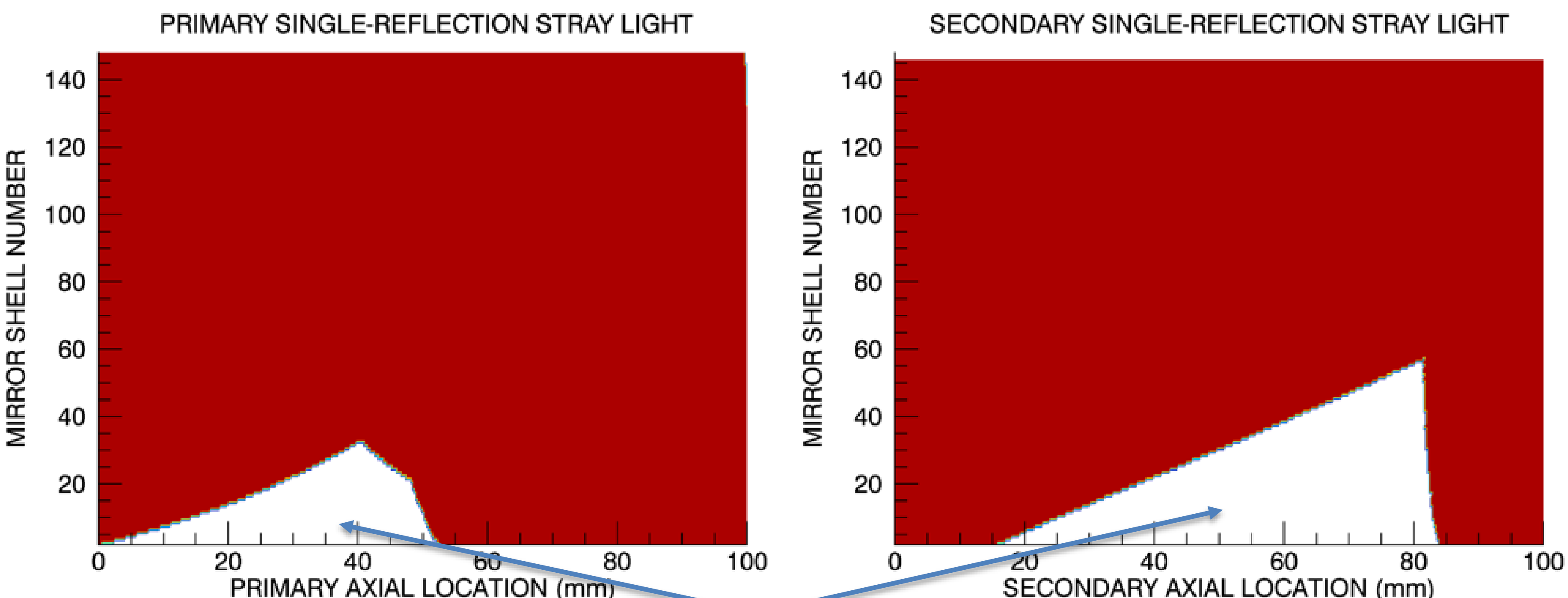
STAR-X baffle design

- Front tube-baffles
- Internal baffles of the primary mirrors and secondary mirrors
- Primary-secondary baffles at the intersections of the mirrors



Stray light of tightly packed design

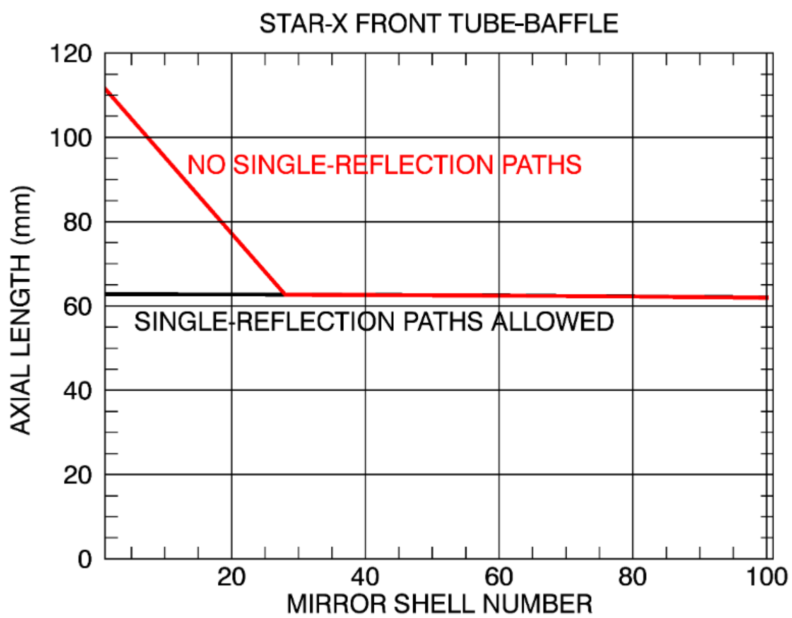
- 148 nested telescopes
- Inner 29 primary mirrors and 77 secondary mirrors cannot be completely baffled



Exposed axial areas on the mirror surfaces

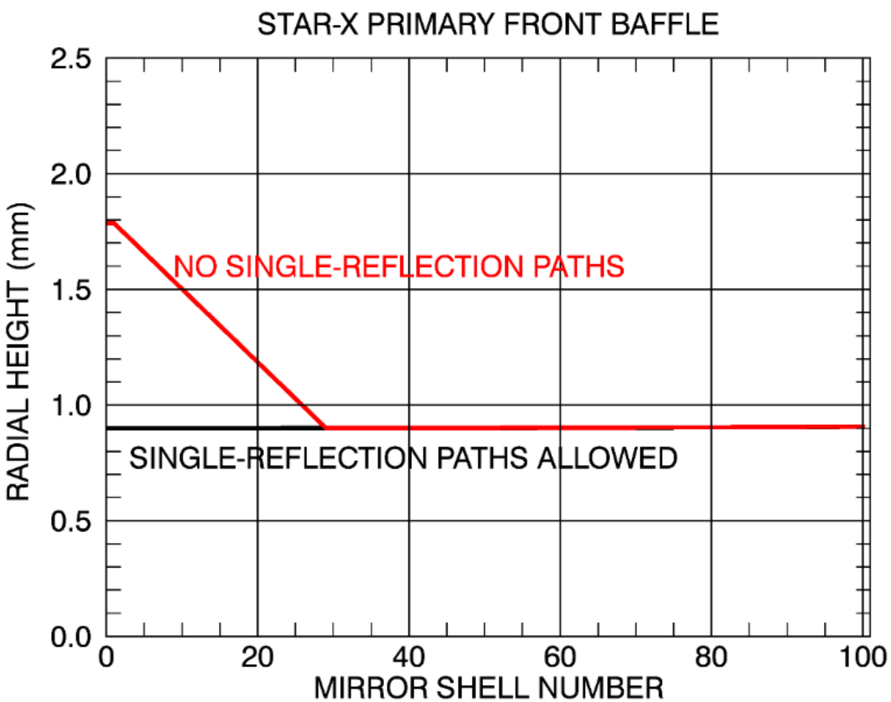
STAR-X front tube-baffle

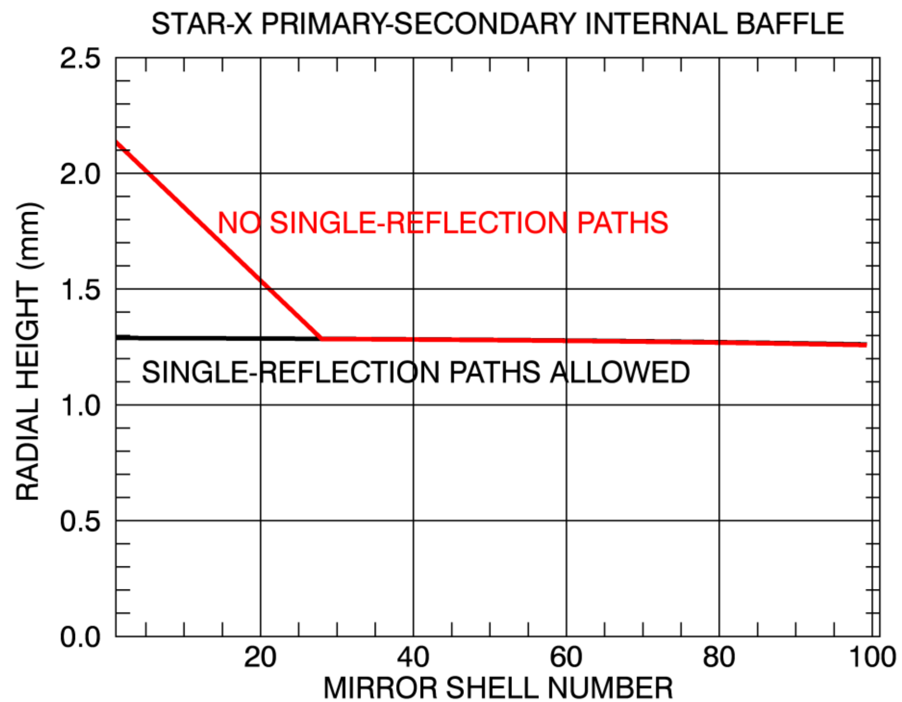
- Limit axial length of the tube-baffles to 111.0 mm
  - 47 innermost telescope out of 148 telescopes need to be removed
  - Radial heights of the mirrors are limited to 284.0 mm – 650.0 mm
  - Inner 29 telescopes out of residual 101 telescopes have single reflection stray light problems
- Increased radial heights of the cavity of inner 29 telescopes to eliminate single-reflection stray light paths



Baffles in front of primary and secondary mirrors

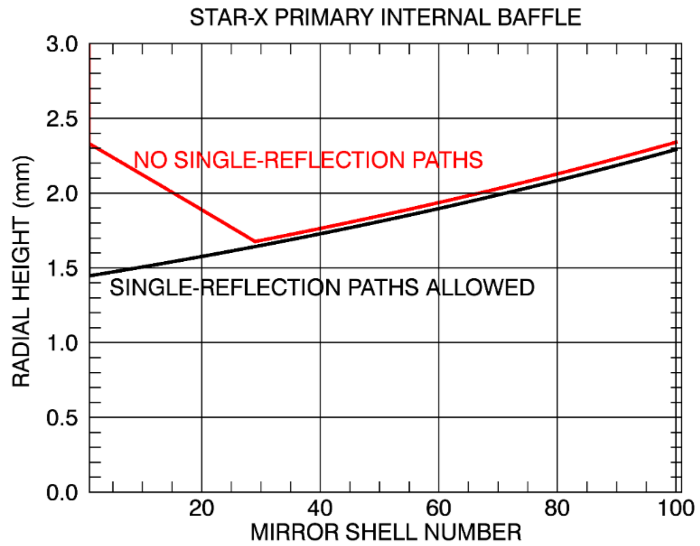
- Increased cavity size of 29 innermost telescope allows taller baffles and eliminate single-reflection stray light
- Front baffles of the primary mirrors are mounted on front tube-baffles
- Primary-secondary baffles are placed on the principal surface of the telescopes

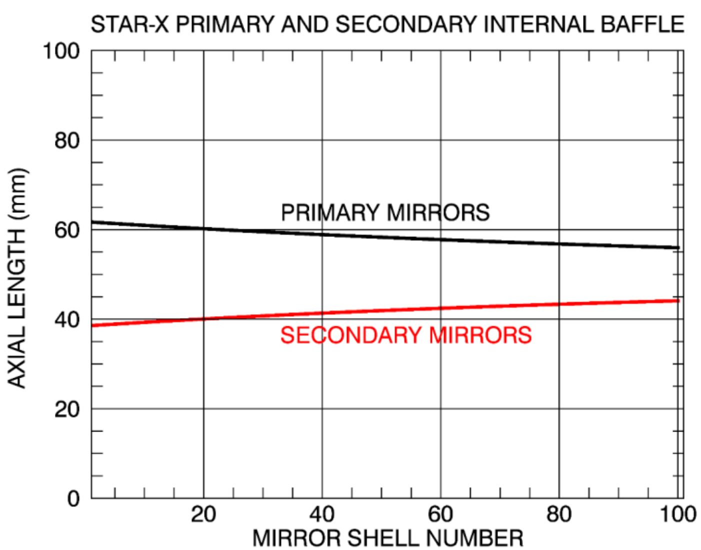


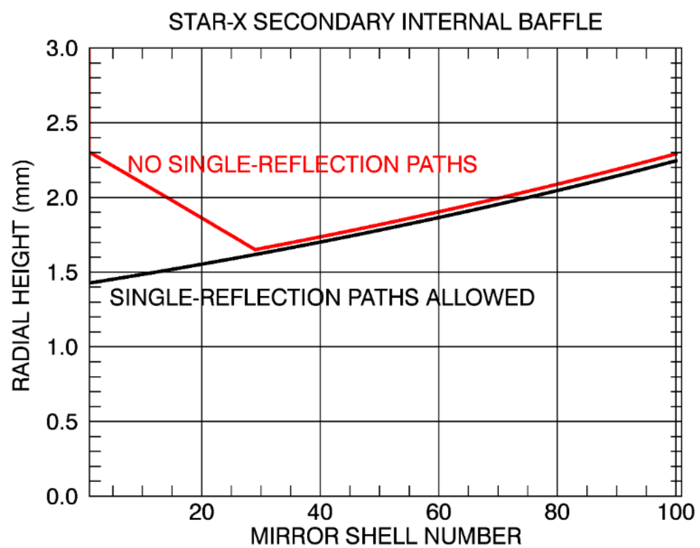


Internal baffles of primary and secondary mirrors

- Increased cavity size between inner 29 telescopes increases radial height of the baffles
- Baffles are mounted on the backside of the mirrors



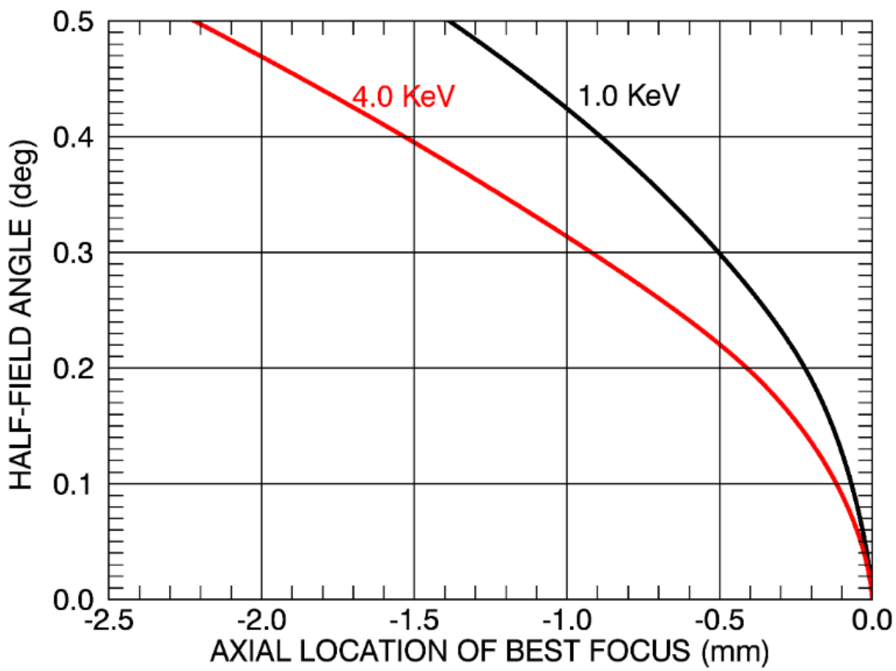




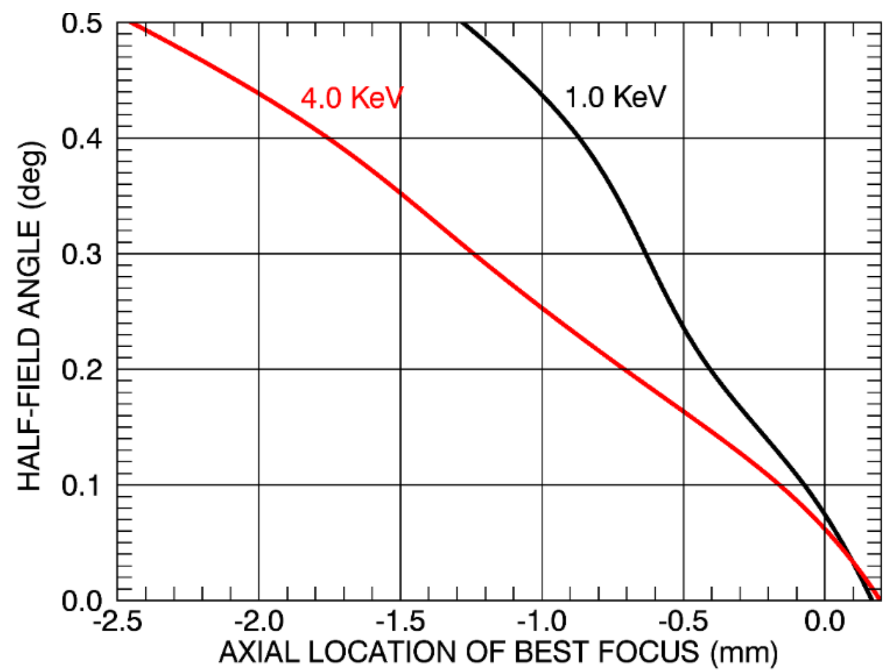
Best focal surface of WS and MWS telescopes

- Best focal surface of WS telescope is parabolic
  - Field curvature is dominating aberration
- Best focal surface of MWS telescope is slightly worse
  - Added axial sag terms on the primary mirrors changes the shape of the best focal surface inside 0.15 degree field of view
- At higher energies best focal surfaces are steeper

Wolter-Schwarzschild telescope



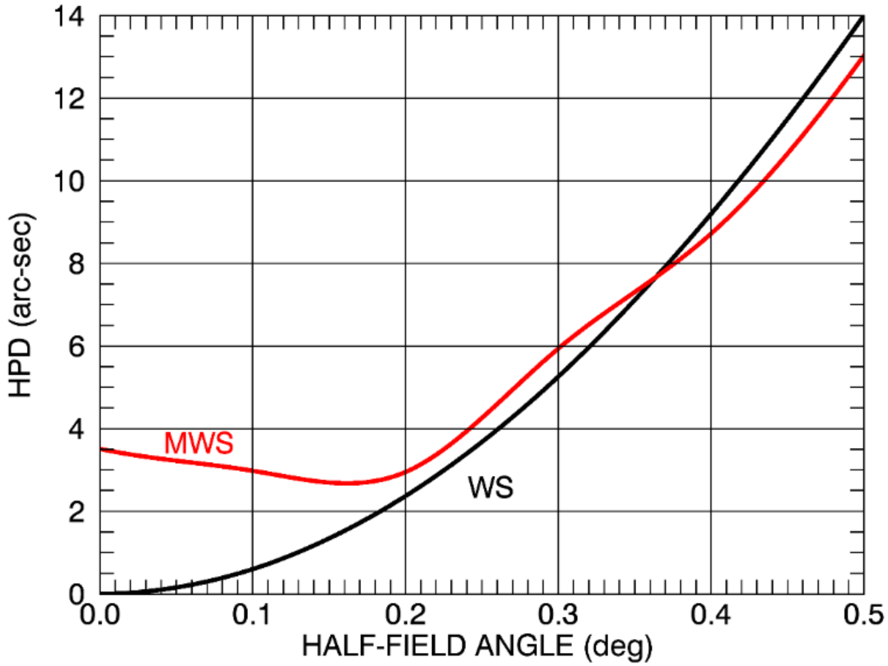
Modified-Wolter-Schwarzschild telescope



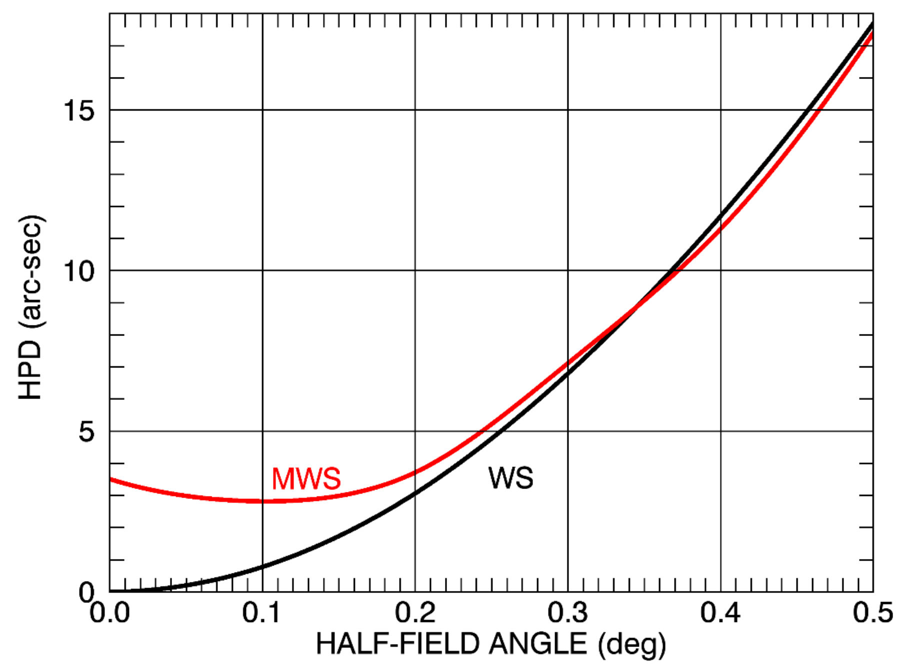
HPDs at Gaussian focal plane

- Increase of HPD is parabolic. Field curvature is dominating aberration
- Added axial sag of MWS telescope improves the optical performance very little at 1.0 KeV and 4.0 KeV

Optical performance at 1.0 KeV



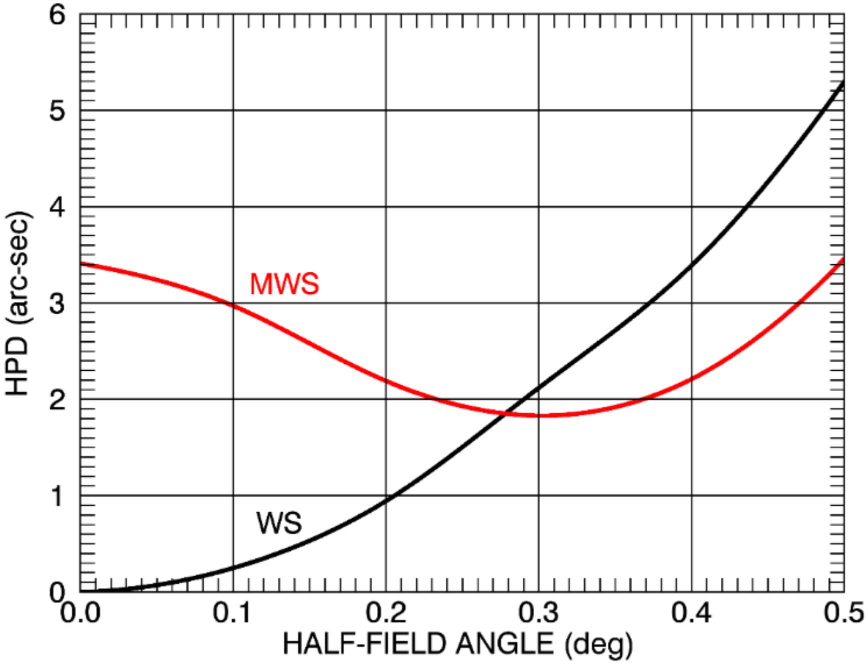
Optical performance at 4.0 KeV



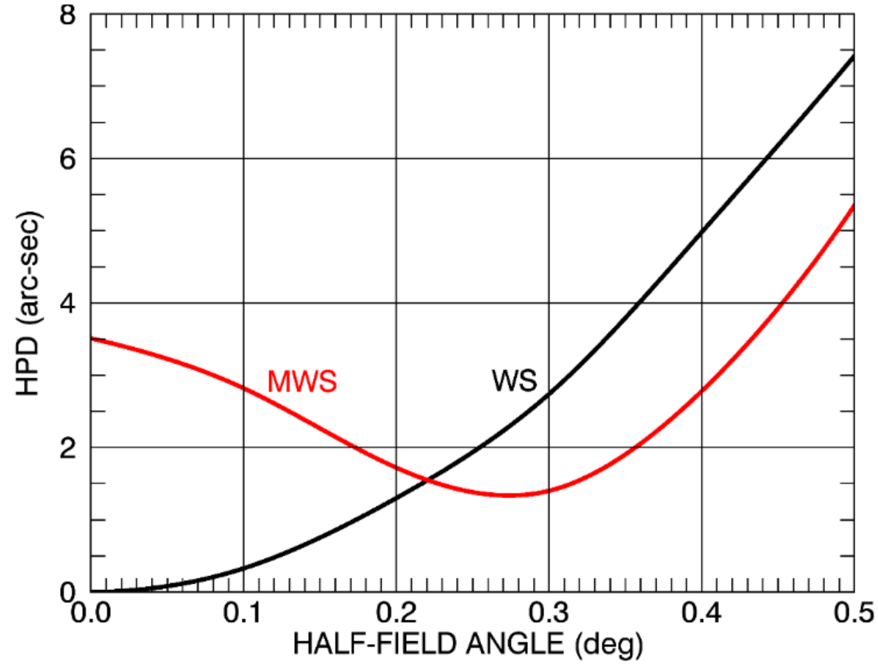
HPDs at best focal surface

- Added axial sag (0.21 μm PV) of the primary mirrors of Modified-Wolter-Schwarzschild telescope distribute HPDs more uniformly across the field of view at 1.0 KeV and 4.0 KeV
- Minimum HPD is below 2.0 arc-sec

Optical performance at 1.0 KeV



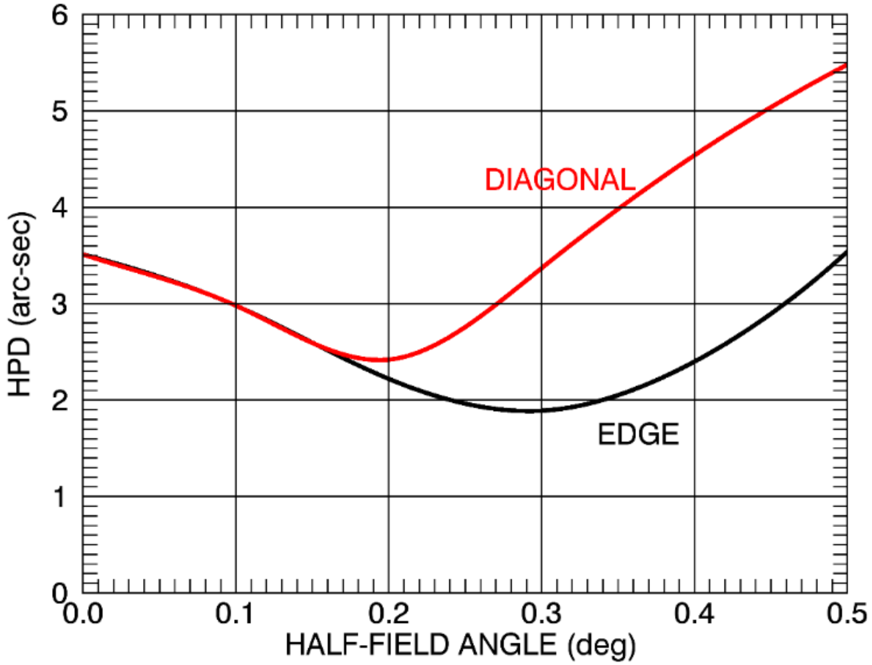
Optical performance at 4.0 KeV



Optical performance of 4 focal plane detectors

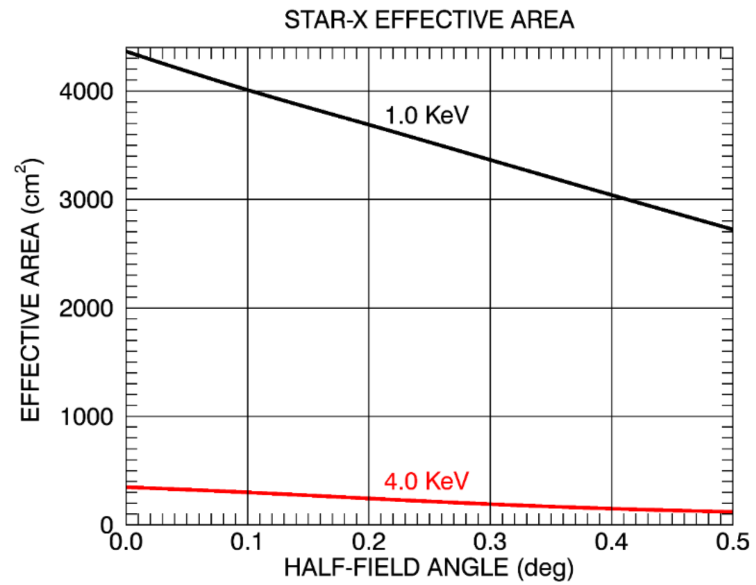
- Inverted pyramid configuration of 4 detectors
  - Tip of the pyramid at the common focus of the telescopes
  - Edge of the field-of-view in the corners of the detectors
- HPD depends strongly along radial locations in 0.2-deg to 0.5-deg range
- 8 detectors needed to keep HPD below 5.0 arc-sec

Optical performance at 1.0 KeV



Effective area

- Assumed Iridium coating on the optical surfaces
- No structural obscurations are assumed
  - Structural components reduce effective area typically ~25-30%
- At 1.0 KeV
  - On-axis effective area is ~4400 cm^2
  - Vignetting nearly halves the effective area at the edge of the field of view
- At 4.0 KeV
  - On-axis effective area is ~350 cm^2
  - Vignetting reduces the effective area to ~120 cm^2
  - Inner shells contribute more to the effective area leading to larger reduction in the effective area



Conclusions

- Utilization of spherical principal surface optimizes the off-axis optical performance on nested telescopes
- Nested mirrors of the design cannot be completely baffled for stray light without sacrificing a small fraction of on-axis effective area and a larger fraction of off-axis effective area
- Modified-Wolter-Schwarzschild designs provide uniform optical performance across the field of view
- At the best focal surface image aberrations can be controlled to ~3.4 arc-sec level at 1.0 KeV. At 4.0 KeV, the inner shells of the design significantly degrade the optical performance
- Effective area of well-baffled nested telescope is over 4000 cm^2 at 1.0 KeV for short focal length telescope designs