X-ray Surveyor Optical Design Studies

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Summary of RFI Responses I

- **Received two responses:**
  - MSFC full shell design
    - 300mm long elements, made as a 600mm long single primary+secondary element
    - 1mm thick
  - SAO segmented modular mirror design
    - 200mm long segments (primary and secondary each)
    - 0.4mm thick
  - Both provided:
    - 3.5m OD, with 5, 10, and 15m focal length designs
    - Effective area on-axis as a function of energy
    - Vignetting as a function of field position
    - Estimated PSF as a function of field position
    - Maximally packed shells, consistent with design inputs
  - Small minor differences in the modeling:
    - Ir coating density (90% assumed by MSFC, 95% assumed by SAO)
    - Structure obscuration differences (90 to 85% MSFC, 90 to 80% SAO)
    - Scattering losses (0.5nm rms for MSFC, 0.4nm rms for SAO)
    - SAO included additional 2 per cent loss for each of alignment and particle contam.
    - Different optical constants for calculating reflectance (*Chandra* and LBL)

Summary of RFI Responses II

- **With all these differences, both sets of designs give very similar results:**
  - EA at 1 and 6 keV (10m FL results shown here and below as examples)
    - Full shell: 2.92 and 0.15 m^2, respectively
    - Segmented: 2.84 and 0.21 m^2, respectively
  - Vignetting at 10 arcmin:
    - Full shell: 8.2 per cent
    - Segmented: 8.4 per cent
  - PSF's as a function of field angle similar
    - Full shell: 0.87 arcsec rms diam. @ 5 arcmin
    - Segmented: 0.74 arcsec rms diam. @ 5 arcmin

- **No significant difference between full shell and segmented mirror design for the performance parameters of effective area, vignetting, or PSF**

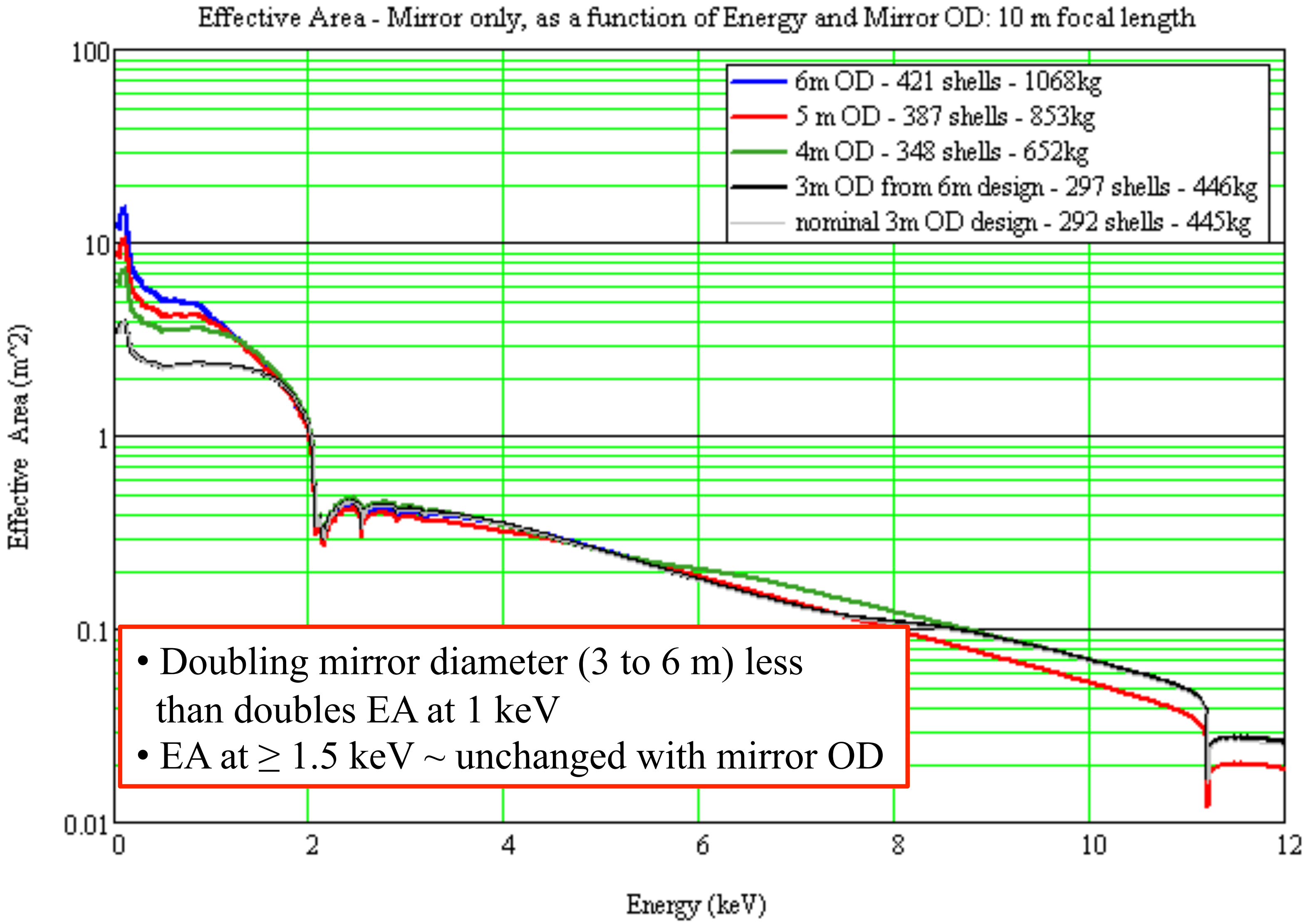
- **Any small performance differences between segmented and full shell designs is not significant with respect to choosing telescope envelope parameters (outer diameter and focal length).**

Performance sensitivities to design parameters

- **The various design parameters will impact different performance, and system and fabrication parameters. Table below shows with a check mark (✓) which performance and/or system parameters (in columns) are impacted by the design parameters (to the right).**

Design Parameter	Performance, System, or Fabrication Parameter							
	On-axis PSF	Off-axis PSF	EA	Plate Scale	FOV/ Vign.	Mass	Ass'y	Align.
Focal length	√	√	√	√	√	√		√
Mirror OD			√			√		
Shell length		√			√			√
Shell thick			√			√	√	

Impact of Mirror Diameter on Effective Area



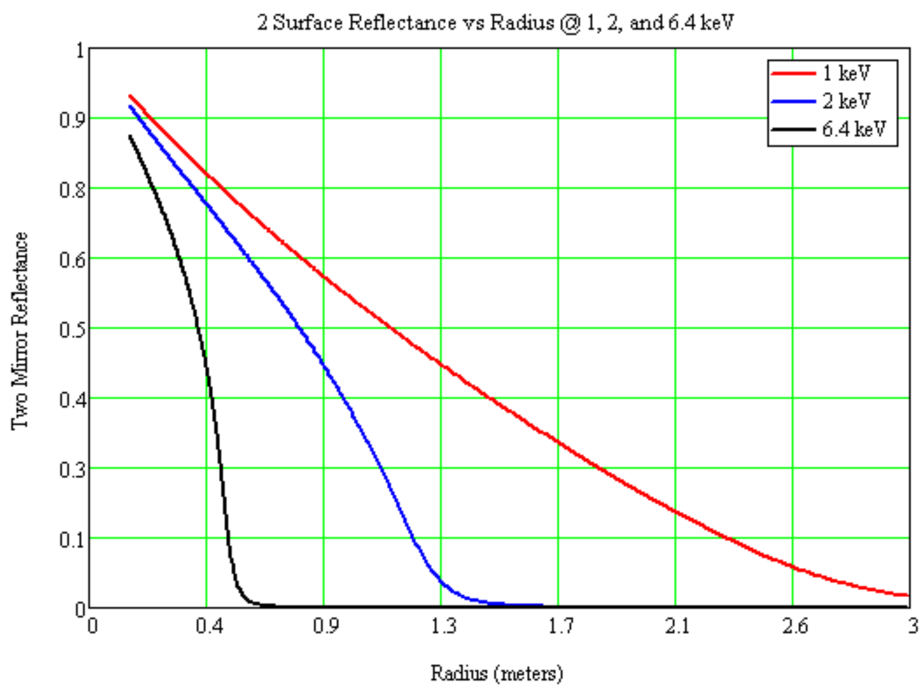
- Doubling mirror diameter (3 to 6 m) less than doubles EA at 1 keV
- EA at ≥ 1.5 keV ~ unchanged with mirror OD

Why little to no improvement in EA with larger diameter?

- **Graze angle *α* increases linearly with increased mirror diameter *2r* for a constant focal length *FL***

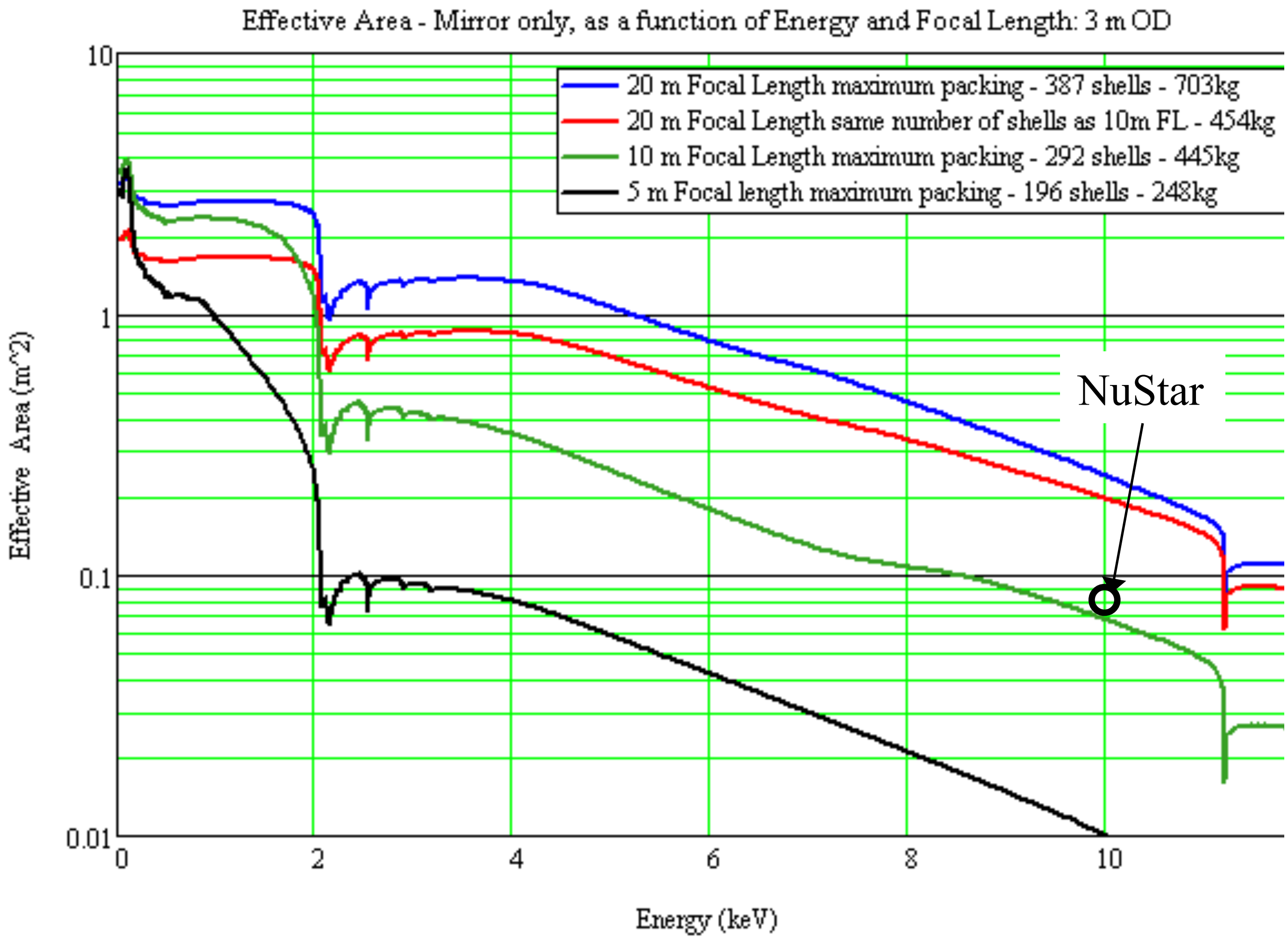
$$\alpha \approx \frac{1}{4} \times \frac{r}{FL}$$

- **Mirror reflectance decreases with increasing graze angle**



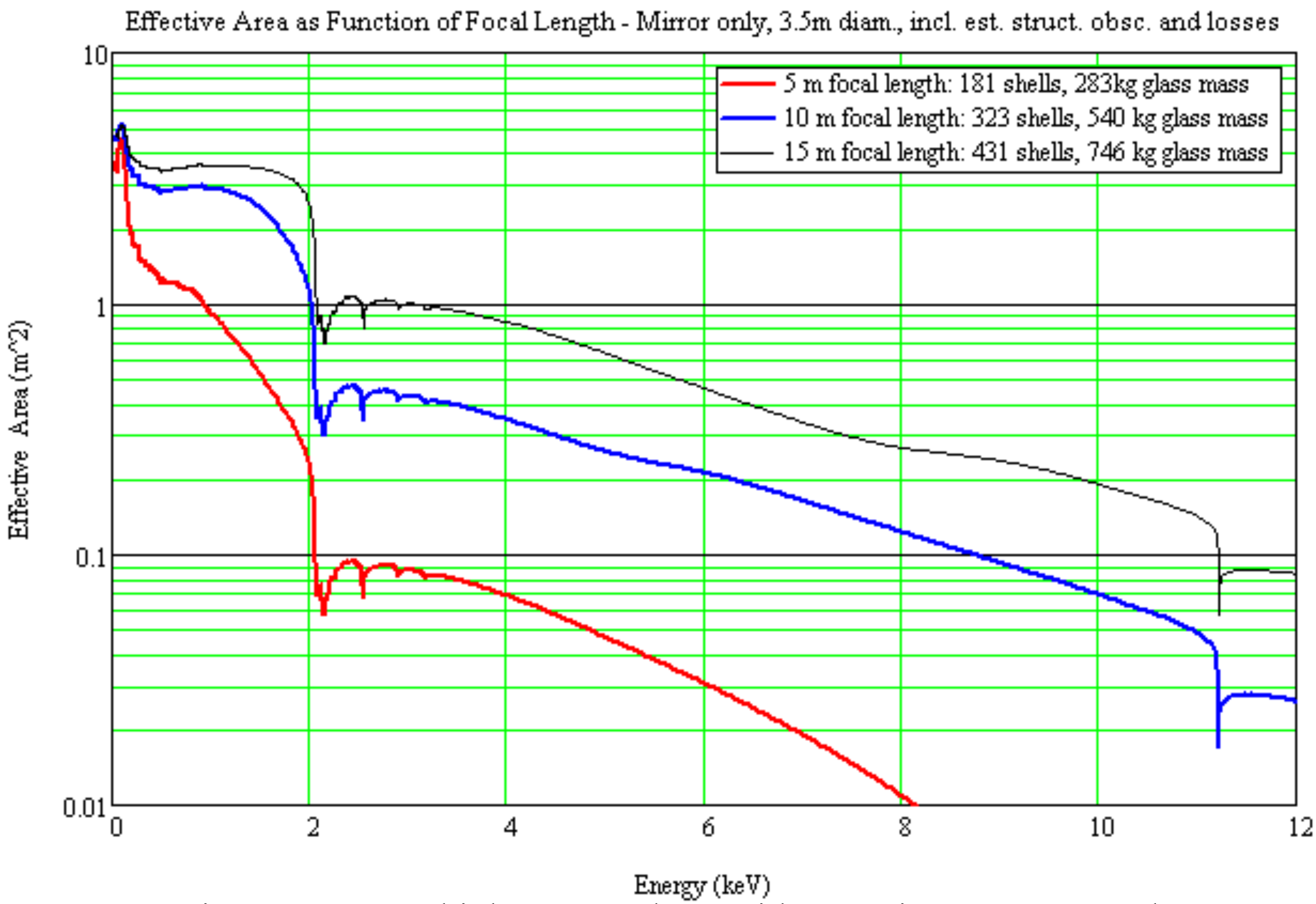
Assume iridium coating thick enough so substrate is irrelevant

Impact of Focal Length on Effective Area



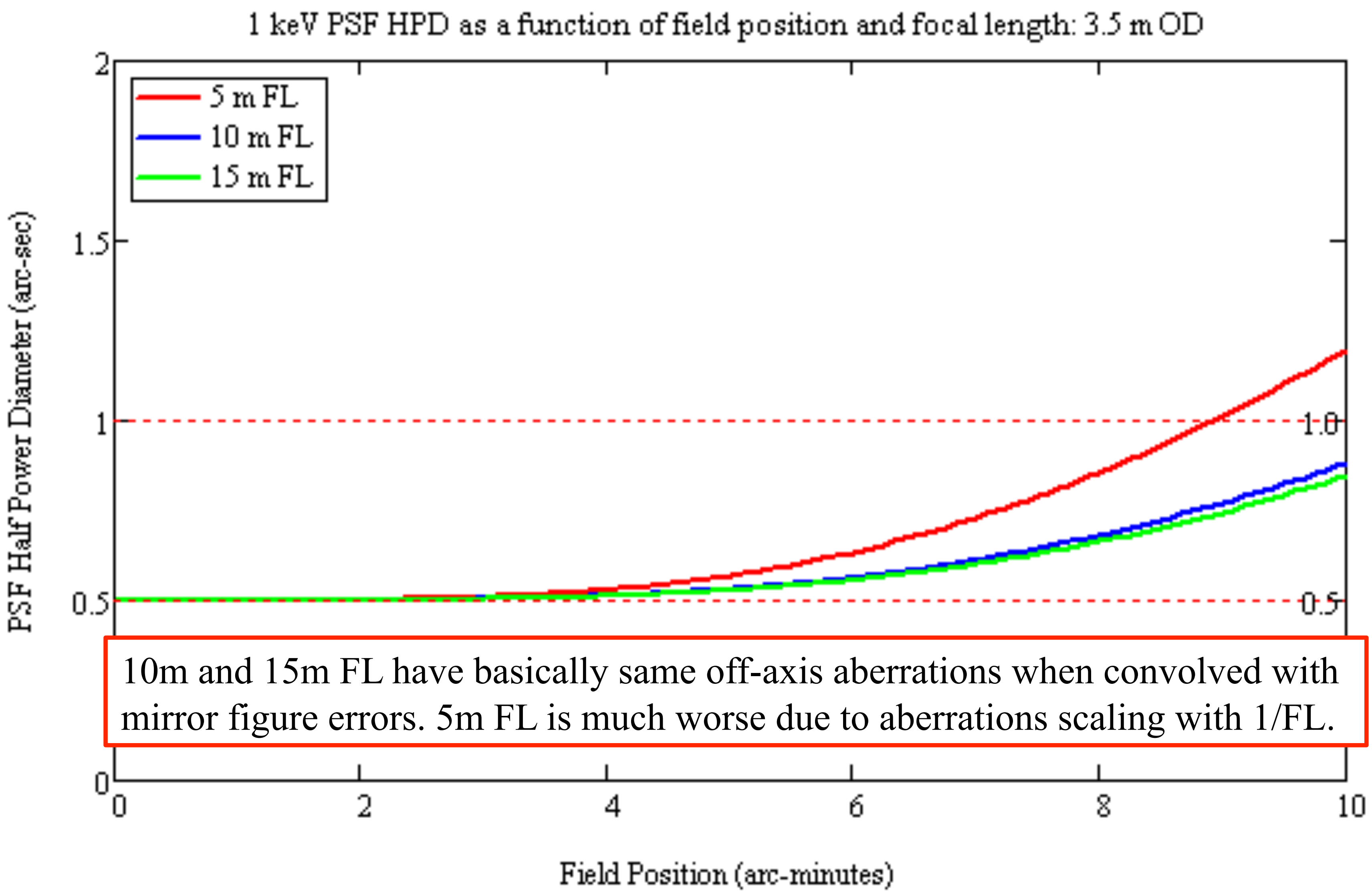
- 5m FL not so good.
- 20m FL with limited number of shells: ~3x increase in high E area, but less area at 1 keV
  - smaller graze so less projected aperture at low energy
  - smaller graze so higher reflectance at high energy
- 20m FL max. packing: comparable at low E, good at high E, but very heavy (candidate IXO design but too heavy.

15 m focal length?



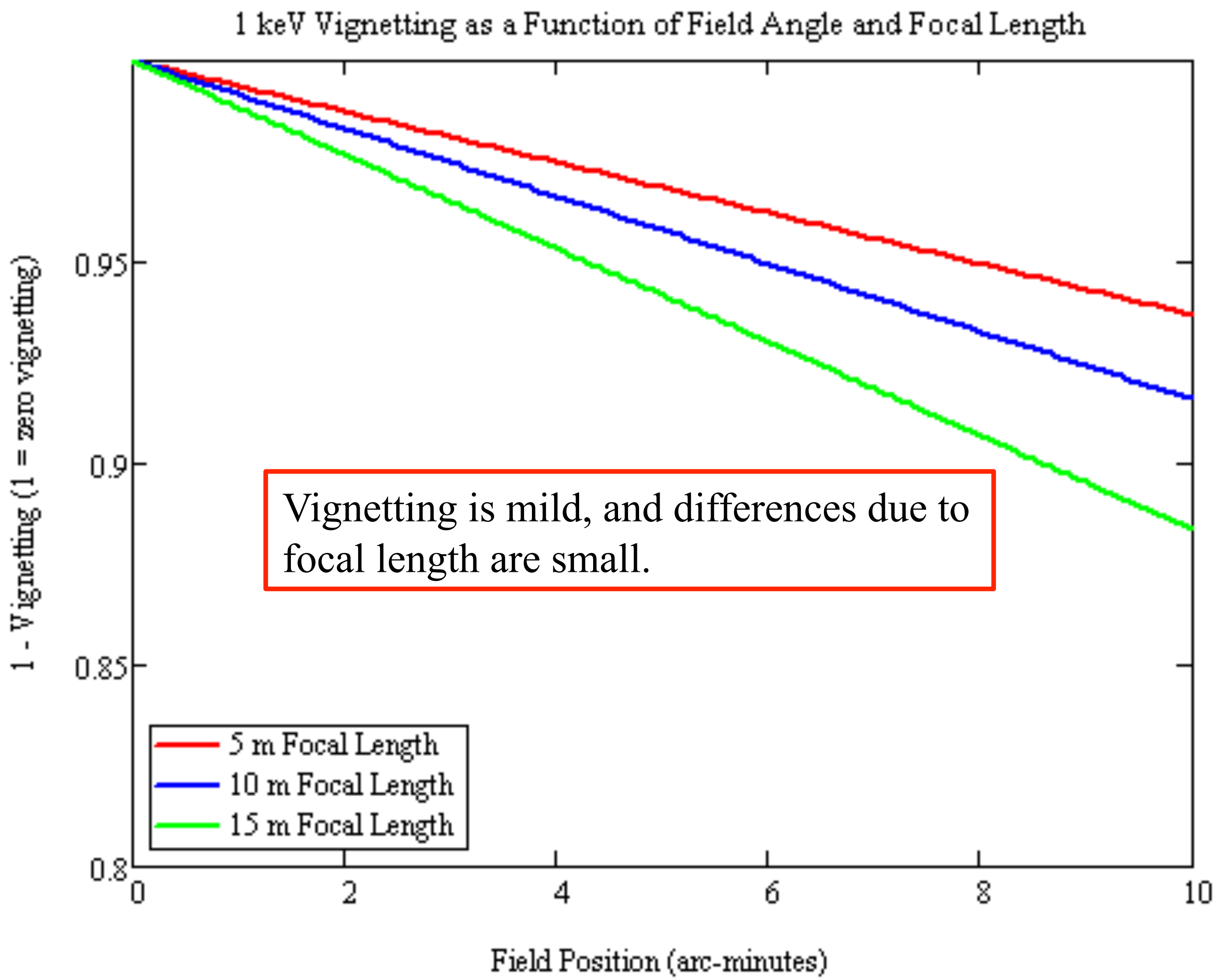
- 15 m gives ~ 2x more high E area, along with some improvement at low E

Off-axis PSF and Focal Length



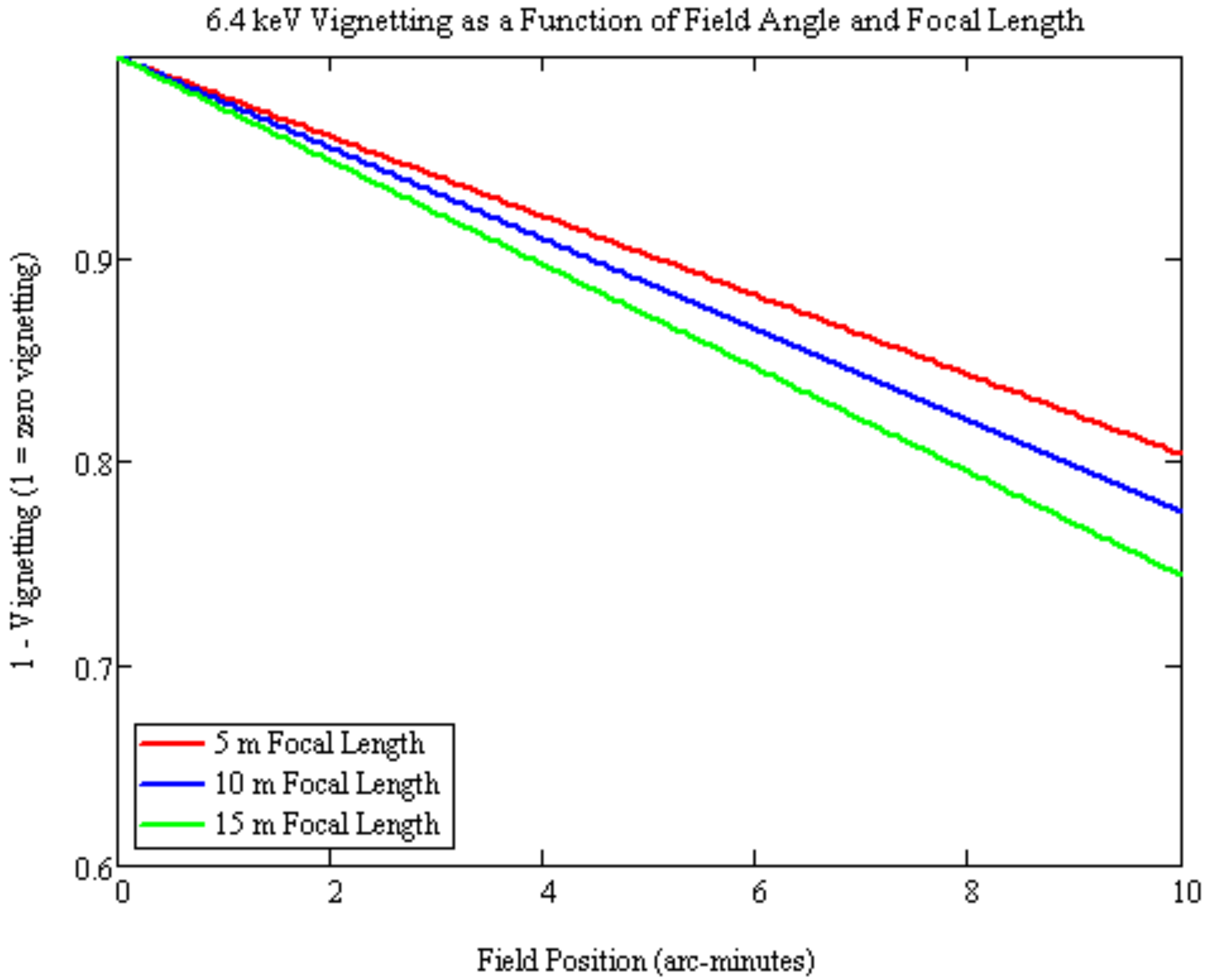
10m and 15m FL have basically same off-axis aberrations when convolved with mirror figure errors. 5m FL is much worse due to aberrations scaling with 1/FL.

Vignetting as a function of Focal Length: 1 keV



Vignetting is mild, and differences due to focal length are small.

Vignetting as a function of Focal Length – 6.4 keV



Recommendations

- **Alexey's proposal for further action (for what it's worth, I agree):**
- **No further consideration of 5 m focal length**
- **Optics Working Group to examine implications of longer focal length**
  - Requirements on mirror surface quality
  - Size of shell-to-shell spacing
  - Off-axis performance
  - Consider:
    - 3m diameter 10, 15, and 20 m focal lengths
    - 6m diameter 20m focal length
- **MSFC Advanced Concepts Office to determine maximum focal length that fits into an Atlas V 551 or Falcon 9 Heavy fairing**
- **ARFs for the 4 design cases above will be provided shortly for science modeling**