X-ray Surveyor Optical Design Studies

Paul B. Reid
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 m², respectively
    • Segmented: 2.84 and 0.21 m², 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).

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Performance, System, or Fabrication Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focal length</td>
<td>✓</td>
</tr>
<tr>
<td>Mirror OD</td>
<td></td>
</tr>
<tr>
<td>Shell length</td>
<td>✓</td>
</tr>
<tr>
<td>Shell thick</td>
<td></td>
</tr>
</tbody>
</table>
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 $\alpha$ 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

![Graph showing vignetting as a function of field angle and focal length for 6.4 keV radiation.]
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