Example telescope simulations with the AstroX telescope toolbox for McXtrace


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ABSTRACT

We present a number of example studies of telescope optics using the latest version of the AstroX add-on toolbox for McXtrace. Among which are first, a benchmark study of effective area and vignetting for the Chandra X-ray Observatory. Second, a convenient way of building a telescope model (in this case NuSTAR) with many similar optical elements scripted using a python module. This lends itself well to be included in online notebooks and/or for teaching. Third, we show a new AstroX module for lobster eye optics, and fourth, a study of the proposed solar axion telescope BabyIAXO.

ASTROX LIBRARY

Components

- Shell (ph/bh/ct)
- Ring (ph/bh/ct)
- Pore (ph/bh/ct)
- Mirror Module (ph/bh/ct)
- Detector (ev, Q eff)

Example Instruments

- Wolter I Shell
- Wolter I Ring
- NuSTAR
- Wolter I Pore
- Wolter I Mirror Module
- BabyIAXO (experimental)

CHANDRA

Left: Effective area for the Chandra optic as modeled by AstroX (blue) and extracted from the plots Chandra Proposers’ Guide (POG). For AstroX the coatings of the mirrors were modeled using IM. Bottom: Normalized effective area as a function of off-axis angle, i.e. vignetting function for a set of X-ray energies, matching those reported in the POG.

In both cases, we measure the curves using monitors before and after the optic and compute the effective area as:

\[ A_{e} = A_{i} \frac{I_{e}}{I_{i}} \]

where:

- \( A_{e} \): Illuminated area before the optic
- \( I_{e} \): Incident parameter, e.g. Energy
- \( A_{i} \): Measuring intensity
- \( I_{i} \): Recorded intensity

NuSTAR Simulations

We can (easily), through a new python package, script the creation of AstroX/McXtrace simulations. As you would normally do in python scripts, we can create loops etc. to ease building very large and repetitive geometries, and easily inject them into AstroX/McXtrace.

This way integrates well with jupyter notebooks for teaching

MCP/Lobster eye optic

A lobster eye module, or micro-channel plate (MCP) is now included in AstroX. Below we show a 3D rendering of the structure showing the square channels with reflecting parabolic/hyperbolic mirrors. Above are heatmaps of radiation immediately after the optic, for 2 keV, 12 keV, and a representative solar spectrum. Using the fact that AstroX can flag photons according to events in their paths. Left: Effective area for the two optical module parts and in combination. This clearly shows in which region the parts are most significant.

NuSTAR Simulations

With the upcoming next generation code-generator (nicknamed cogen 3) of McXtrace we have succeeded in cutting code-size significantly – in particular for geometries that have many components of the same type. As is often the case for Wolter optics.

<table>
<thead>
<tr>
<th>Telescope</th>
<th>McXtrace 1.5 / lines of code</th>
<th>McXtrace cogen 3 / lines of code</th>
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<tbody>
<tr>
<td>NuSTAR</td>
<td>308 k</td>
<td>19 k</td>
</tr>
<tr>
<td>Chandra XO</td>
<td>24 k</td>
<td>10 k</td>
</tr>
<tr>
<td>MCP</td>
<td>18 k</td>
<td>15 k</td>
</tr>
<tr>
<td>BabyIAXO</td>
<td>237 k</td>
<td>51 k</td>
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</tbody>
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REFERENCES

1. Wolter, A. d. Physik (1952)