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Example telescope simulations with the AstroX telescope toolbox for McXtrace.

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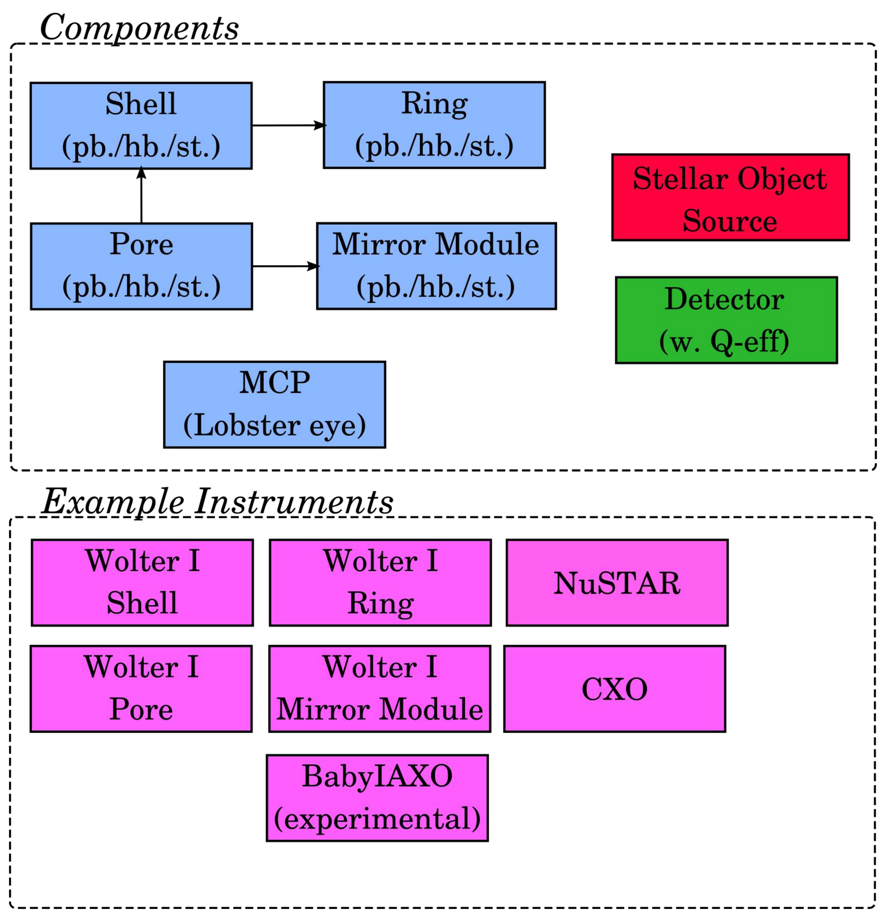
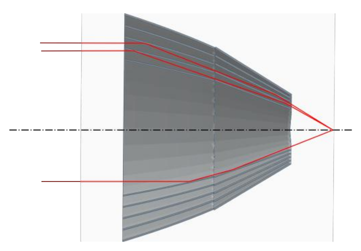
ABSTRACT

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.

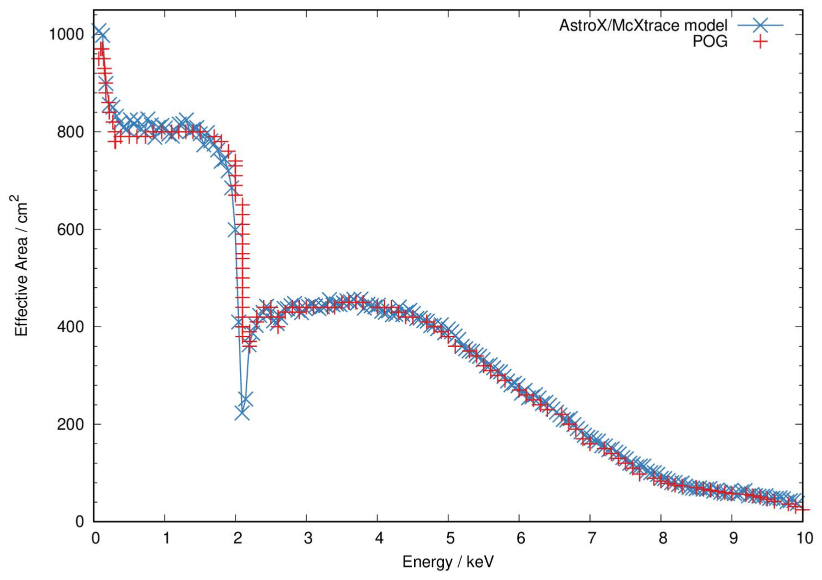
ASTROX LIBRARY

Component Contents of the AstroX toobox aswe move towards release 1.0. The most basic module that could make up a Wolter telescope is the **Pore** from which the other elements may be derived. The MCP is the basic block of a lobster eye optic.





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 modelled using IMD.

Bottom: Normalized effective area as a function of off-axis angle, i.e. vignetting function for a set of X-ray energies, mathcing 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:

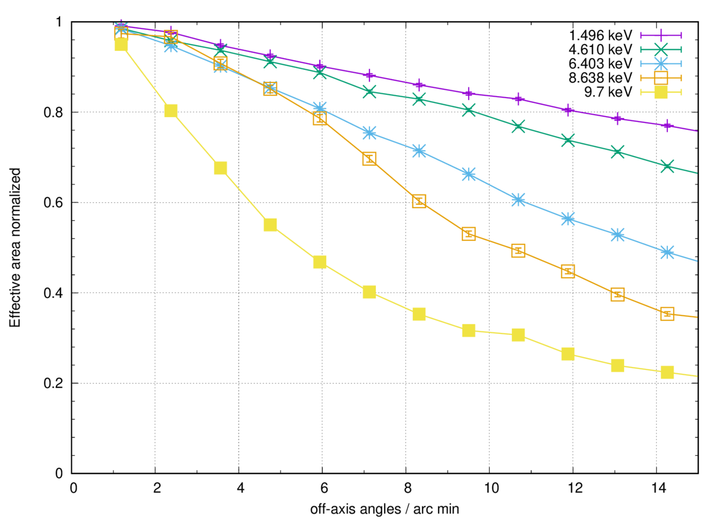
$$A_{eff} = A_0 \frac{I(\xi)}{I_0(\xi)}$$

A_0 Illuminated area before the optic

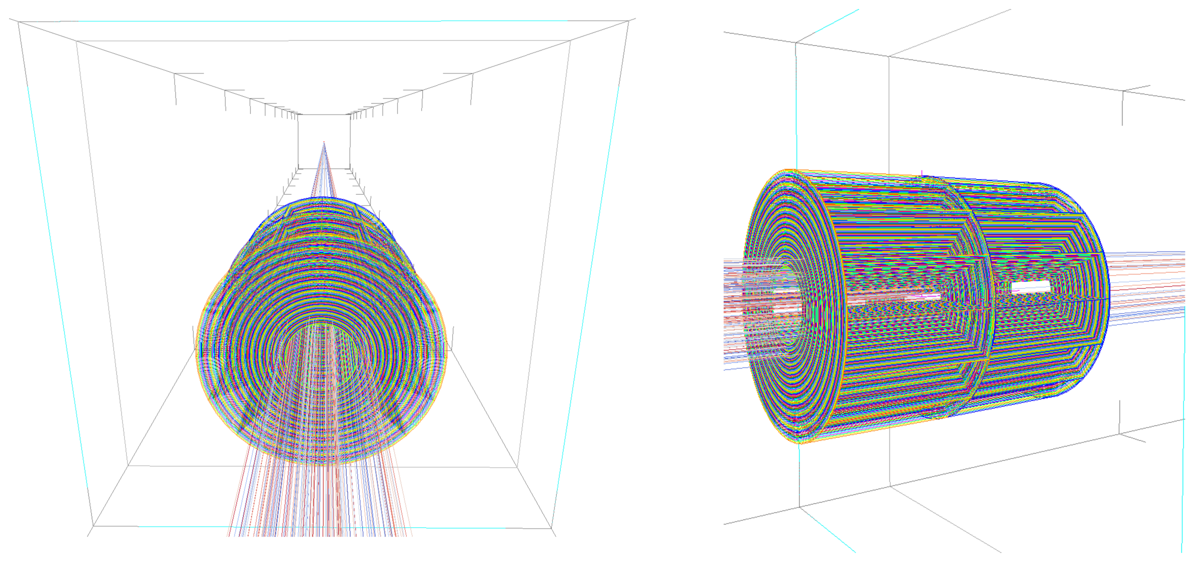
ξ Independent parameter, e.g. Energy

I_0 Impinging intensity

I Recorded intensity

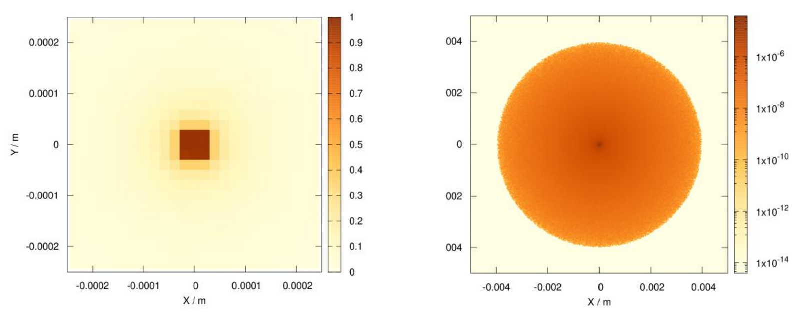


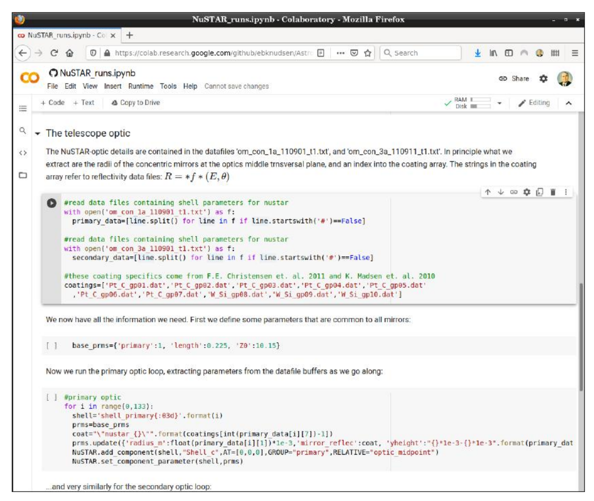
NuSTAR Simulations



```
base_prms={'primary':1, 'length':0.225, 'Z0':10.15}
#primary optic
for i in range(0,133):
  shell='shell_primary{:03d}'.format(i)
  prms=base_prms
  coat="\"nustar_{}\"".format(coatings[int(primary_data[i][7])-1])
  prms.update({'radius_m':float(primary_data[i][1])*1e-3,'mirror_reflec':
              coat, 'yheight':"{}*1e-3-{}*1e-3".format(primary_data[i][9],
              primary_data[i][8])})
  NuSTAR.add_component(shell,"Shell_c",AT=[0,0,0],GROUP="primary",
                       RELATIVE="optic_midpoint")
  NuSTAR.set_component_parameter(shell,prms)
#secondary optic
base_prms['primary']=0
for i in range(0,133):
  shell='shell_secondary{:03d}'.format(i)
  prms=base_prms
  coat="\"nustar_{}\"".format(coatings[int(secondary_data[i][7])-1])
  prms.update({'radius_m':float(secondary_data[i][0])*1e-3,'mirror_reflec':
              coat, 'yheight':"{}*1e-3-{}*1e-3".format(secondary_data[i][9],
              secondary_data[i][8])})
  NuSTAR.add_component(shell,"Shell_c",AT=[0,0,0],GROUP="secondary",
                       RELATIVE="optic_midpoint")
  NuSTAR.set_component_parameter(shell,prms)
```

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.





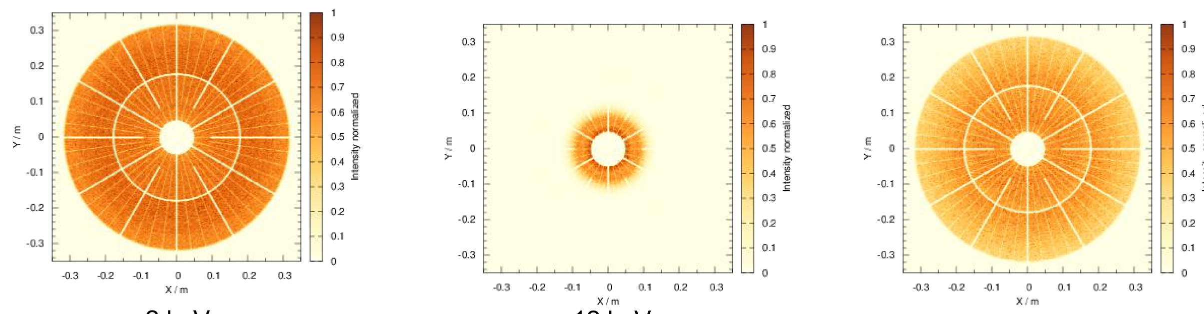
This way integrates well with jupyter notebooks for teaching

Code generator

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.

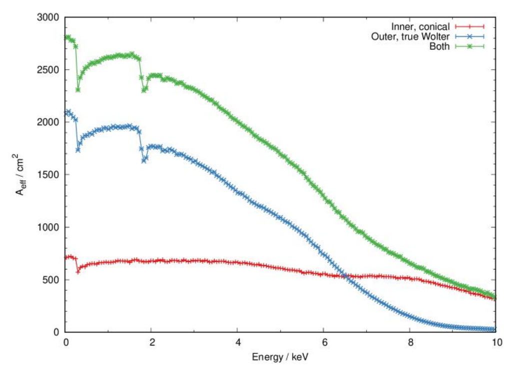
Telescope	*McXtrace 1.5 / lines of code*	*McXtrace cogen 3.0 / lines of code*
NuSTAR	198 k	39 k
Chandra XO	24 k	19 k
MCP	18 k	15 k
BabyIAXO	257 k	51 k

BabyIAXO



2 keV 12 keV Solar axion spectrum

BabyIAXO is a scaled down version of the proposed observatory IAXO. In this study the optical module is a Wolyter type scope consisting of a combination of an inner, NuSTAR-like conical module, and an outer true Wolter-I part with parabolic/hyperbolic mirrors. Above are heatmaps of radiation immediately after the optic, for 2 keV, 12 keV, and a representative solar spectrum.

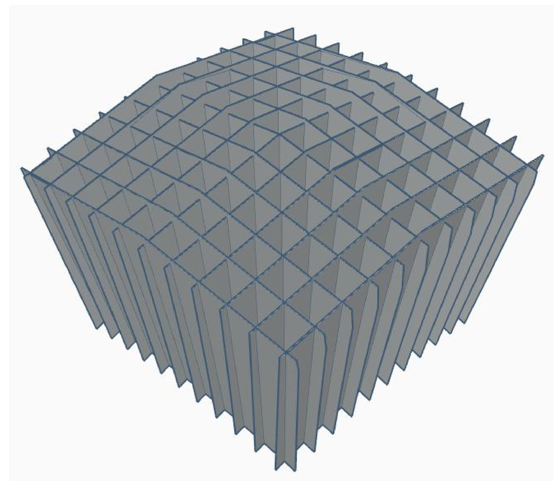


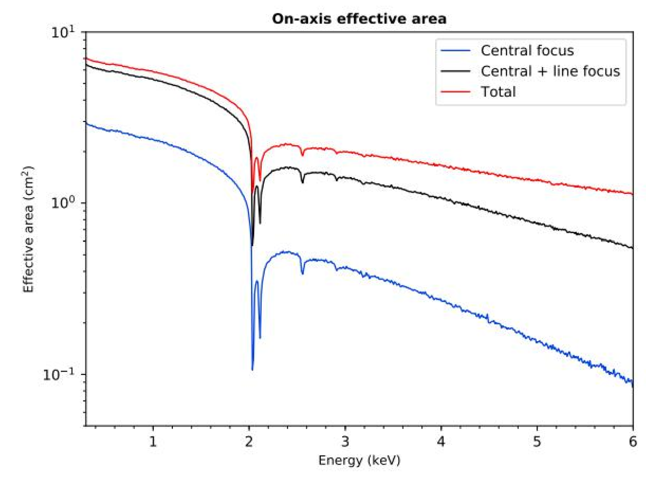
Using the fact that AstroX can flag photons according to events in their paths.

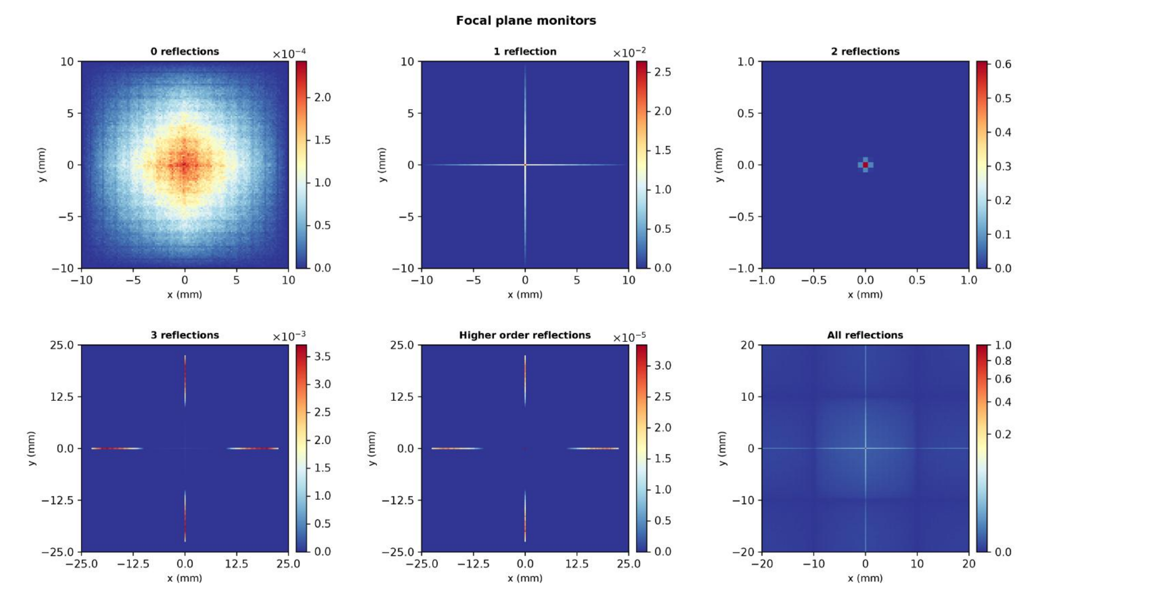
Left: Effective area for the two optical module parts and in combination. This clearly shows in in which region the parts are most significant.

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 surfaces (top left), the computed effective area for such an optic separated into focused and incomplete/over-focused signals (top right), and heatmaps of signals transmitted to the focal plane by the optic (bottom). The bottom plots clearly indicates whre the spurious signals may be found (and thus gives a handle on shielding them).







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