Photon Distribution on the HTRS aboard IXO

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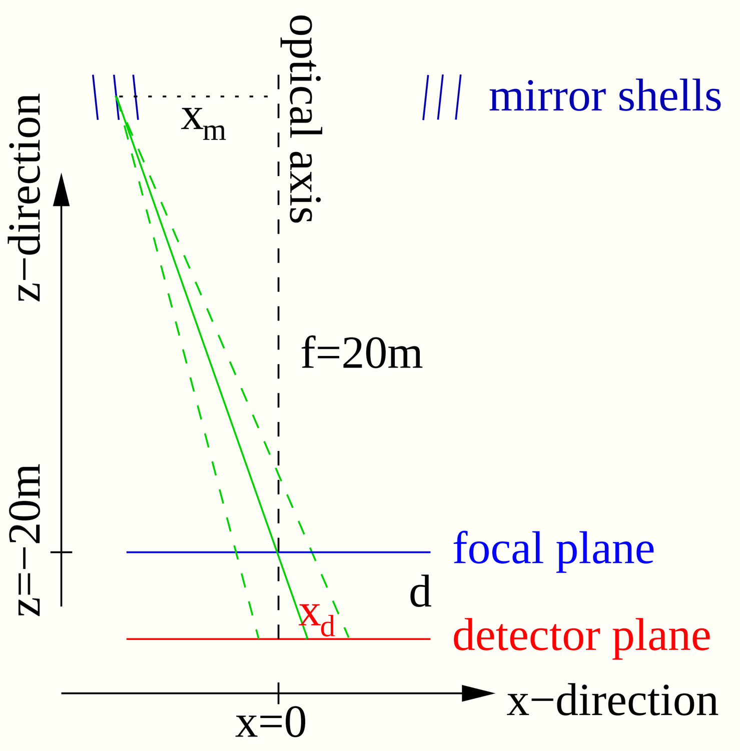
Abstract

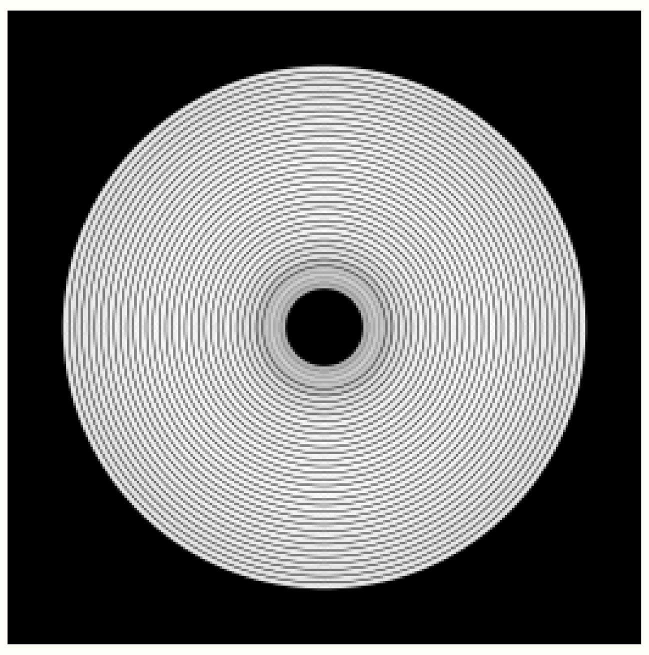
We have studied the photon distribution on the HTRS aboard IXO using a Monte-Carlo simulation that models the path of individual photons in the telescope with some simplifying assumptions. Due to the particular out-of-focus position of the HTRS the photons from an observed X-ray source are not focussed to a sharp spot but are distributed over the entire pixel array in order to improve the bright source performance. The simulation is based on the Silicon Pore Optics (SPO) design proposed for IXO and the corresponding radial effective area distribution of the mirrors.

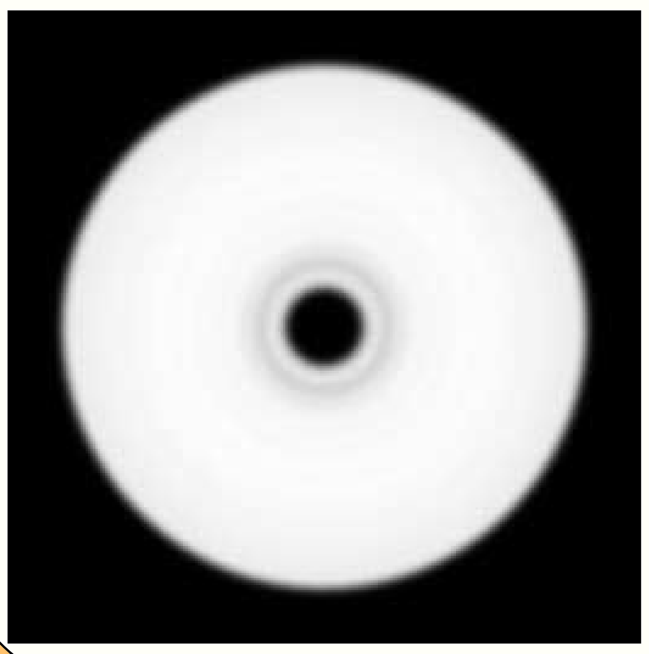
The data from the simulations have been used to optimize the design of the HTRS with respect to pixel sizes and the out-of-focus distance. With our analysis we show that the HTRS fullfills the imposed requirements with respect to alignment and pointing stability and we have studied the impact of jitter effects on the instrument calibration.

Geometrical Setup

In order to determine the photon distribution on the HTRS we have used a sample of photons. The figure on the right-hand side presents the simplified geometrical setup implemented in the simulation (according to an idea of Tim Oosterbroek). After the reflection by the mirrors each photon is moving on a straight line from its position on the mirror shell $(x_\mathrm{m}, y_\mathrm{m})$ through the focal spot. The HTRS is an non-imaging instrument located at a particular distance $d = 12.6\,\mathrm{cm}$ behind the focal plane. Therefore the photons do not hit the detector in the focal spot, but the intersection of their path with the detector plane at $(x_\mathrm{d}, y_\mathrm{d})$ is slightly off-axis depending on the respective mirror shell the photon is coming from.







For this simplified geometry the impact position for a particular photon is:

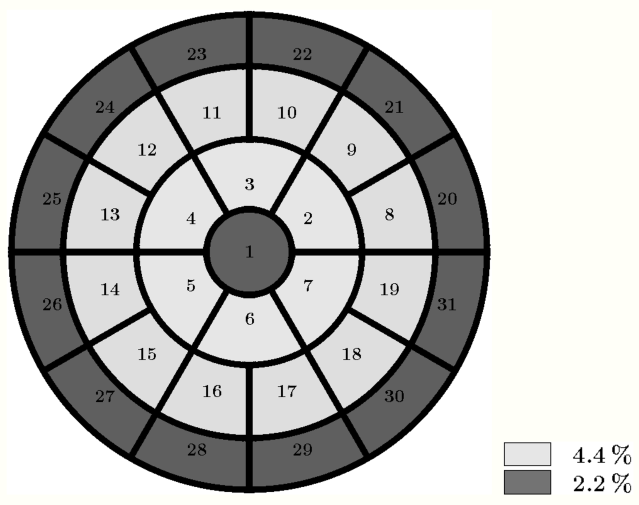
$$\begin{pmatrix} x_\mathrm{d} \\ y_\mathrm{d} \end{pmatrix} = \frac{d}{f} \cdot \begin{pmatrix} x_\mathrm{m} \\ y_\mathrm{m} \end{pmatrix} \qquad (1)$$

According to Eq. (1) the impact position of a photon on the detector is directly related to its reflection position in the mirror system. In the simulation the incident photons are distributed among the mirror shells according to their relative effective area. Switching off blurring effects in the simulation, the image of the photons on the detector resembles the effective area distribution, as shown in the figure on the upper left-hand side (for 1 keV photons).

However, in reality the shape and alignment of the mirror shells is not perfect and we have to consider some blurring. In the simulation these effects are implemented by smearing the photon impact positions with a 2-dimensional Gaussian distribution with a Half Energy Width (HEW) of 5 arcsec. With this additional blurring the shell structure of the photon spot in the upper figure vanishes as displayed in the lower figure.

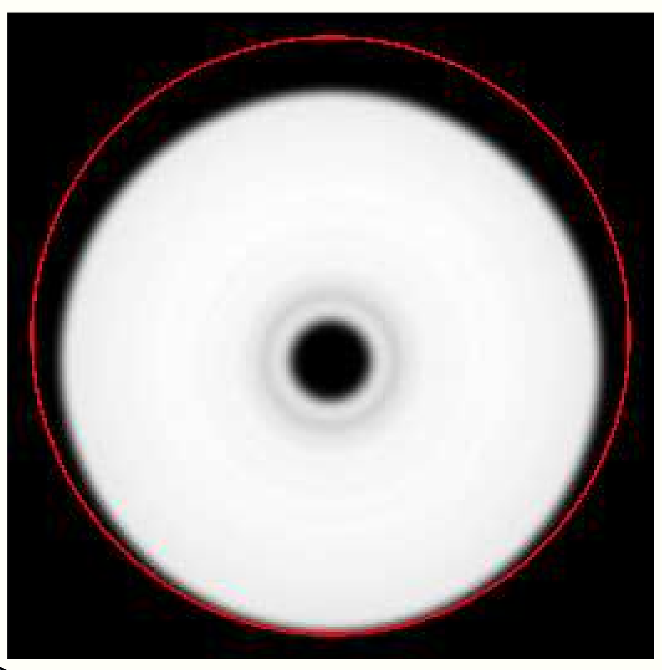
Note: The simulations have been performed with $6 \cdot 10^8$ photons per m^2 effective area. We have used a mirror model taking into account the energy-dependent radial distribution of the effective area, which results in the presented shell structure. In reality azimuthal effects due to the modular assembly of the SPO mirrors have to be considered.

Photon Distribution



Based on the Monte-Carlo simulations we have calculated the photon distribution among the individual pixels for 1 keV photons (most typical sources have a maximum around 1 keV in their spectrum). The brightness scale reflects the fraction of photons. The radii of the rings in the presented geometry are $r_1 = 2.16\,\mathrm{mm}$, $r_2 = 5.70\,\mathrm{mm}$, $r_3 = 9.39\,\mathrm{mm}$, and $r_4 = 12.0\,\mathrm{mm}$ and have been adapted to the simulated photon distribution. On top of pixel edges there is a mask with a spoke width of $200\,\mu\mathrm{m}$ in order to avoid split events. The numbers in the figure are used to identify the pixels.

Misalignment

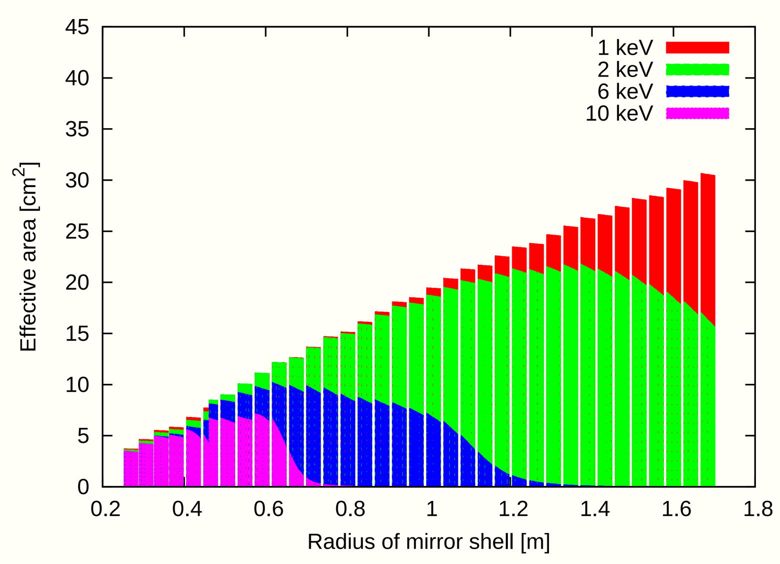


We have studied the impact of misalignment effects on the photon distribution on the HTRS by shifting and tilting the detector with respect to its nominal position. According to the HTRS / Platform Interface Requirement Document (HTRS-SP-21-009-CESR) the alignment requirements are:

- horizontal position $\pm 1\,\mathrm{mm}$
- vertical position $\pm 1\,\mathrm{mm}$
- tilt $\pm 2°$

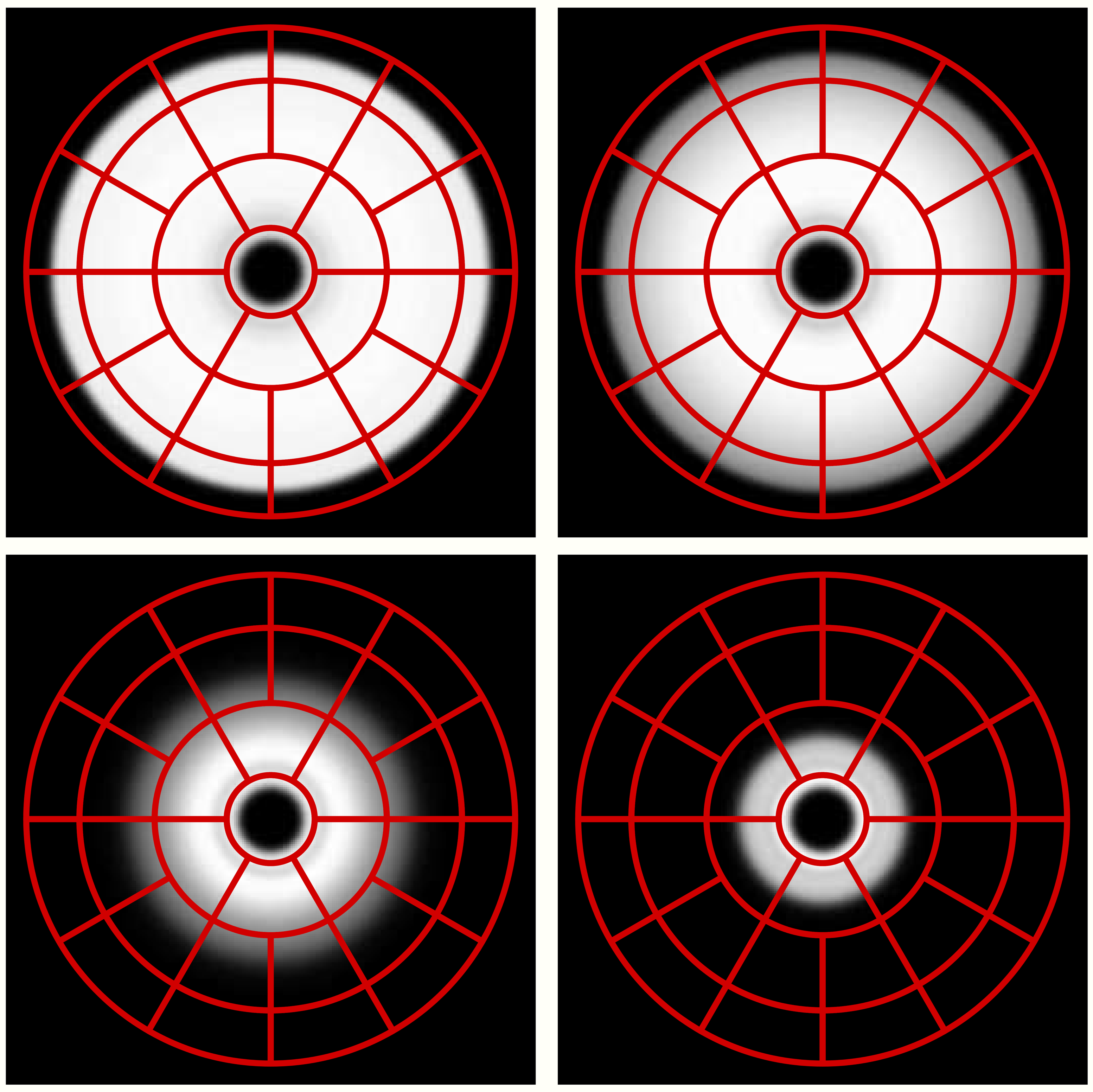
The left-hand figure displays the photon distribution for 1 keV photons in the worst case scenario (according to the requirements). Despite of the misalignment the spot is still located within the detector boundaries with a diameter of 24 mm (marked by the red circle).

Effective Area



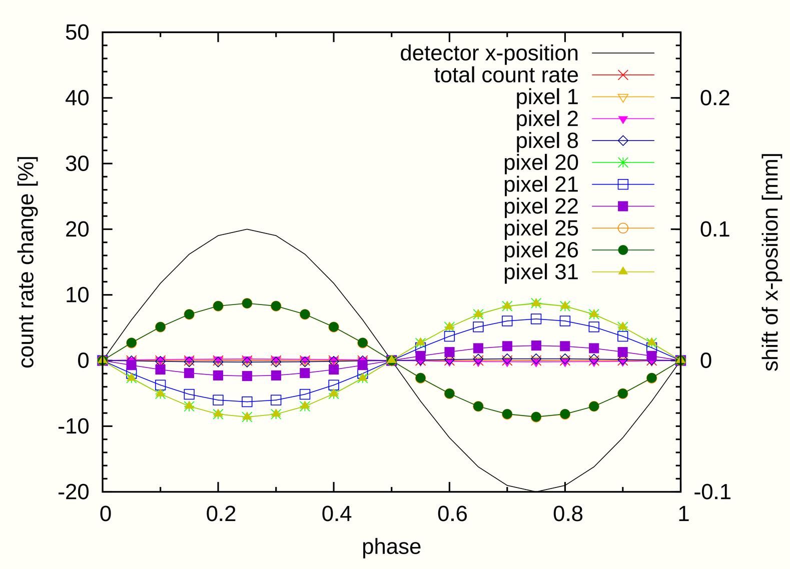
The relative effective area distribution among the individual modules of the SPO mirrors is a crucial part of the simulation. We assume a simplified model for the energy-dependent radial profile neglecting any azimuthal dependence. For the particular assembly of the SPO modules this profile exhibits a shell-like structure, as displayed in the figure on the left hand side for the photon energies 1, 2, 6, and 10 keV.

Energy Dependence



Simulated photon distribution on the HTRS for monochromatic photon samples of 1, 2, 6, and 10 keV (from top left to bottom right). For low energies around 1 keV the photons are quite homogeneously distributed over the detector surface, whereas for higher energies the photons are strongly concentrated to the inner parts of the detector, because the effective area contribution of the outer mirror shells is negligible in this regime. Even the biggest photon spot for 1 keV does not completely fill the detector circle, providing some margin in case of misalignment.

Jitter



The HTRS might be affected by vibrations caused by other instruments on the Movable Instrument Platform (MIP) of IXO. The graph on the left-hand side displays the impact of vibrations with an amplitude of $100\,\mu\mathrm{m}$ in the horizontal plane and a frequency of 100 Hz on the simulated HTRS count rate (for 1 keV photons). In the outer pixel ring the count rate variation might be significant due to the motion of the outer edge of the photon spot. However, the impact on the total count rate is negligible.

Note: Due to the particular modular structure of the SPO mirrors in reality vibrations might have a stronger impact than in this simplified approach.

References & Acknowledgments

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Lechner P. et al., 2010, Proc. of SPIE 7742, 0W-1–0W-10
HTRS-SP-21-009-CESR

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