Transmission of STIX sub-collimators in energy range 4 – 150 keV by using Geant4 simulations.

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ABSTRACT

The Spectrometer/Telescope for Imaging X-rays (STIX) will be launched on board Solar Orbiter in October 2018. The instrument will measure X-ray radiation from the Sun. STIX imaging module consists of 30 sub-collimators. The sub-collimator is a pair of tungsten grids and CdTe detector. The pair of grids produce a Moiré pattern on the detector which is divided into 12 active pixels. The system allows to reconstruct X-ray distribution of solar sources. The reconstructed image quality strongly depends on the parametrization of grids transmission. It is simple for low energy because grids are perfectly opaque for energies of 10 keV. However, STIX will measure photons up to 150 keV, and we have to take into account that transmission of grids depends on photons energy. This can be estimated analytically, but the result is not exact. We decided to use other method which will allow to test analytical solutions. One of available tools is the Geant4 in which we can easily define geometry and materials of grids, and simulate how X-ray photons are transmitted through or/and interact with the instrument, and how these effects depends on photon energy. We will present the results of simulations performed for energy 4 – 150 keV including various geometry and energy distribution of solar sources, and various defects in grids structure. We will compare our simulation to analytical results. It will lead us to better understand of STIX performance for various photons energies and what we must take into account when interpreting real measurements.

STIX sub-collimator

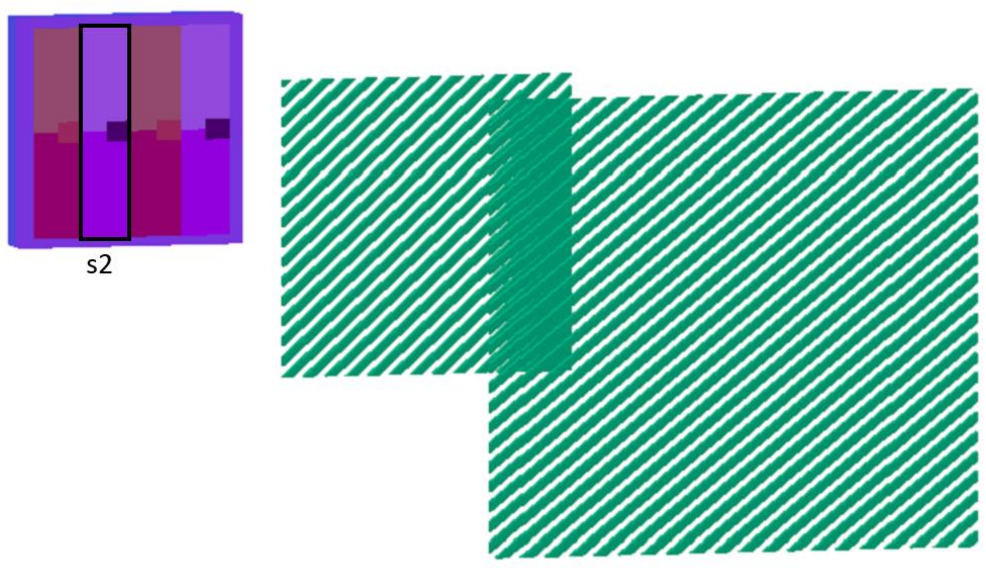

Figure 1. Pair of grids and detector with geometry of sectors and pixels. For example, sector 2 (s2) is marked with black box.

The imager concept is based on sub-collimators which modulate and measure incoming X-ray photons. The sub-collimator is a pair of grids with a pixelated detector placed behind. STIX is equipped with 30 pairs of grids with various pitches and orientations.
Each pair of grids produce Moiré pattern which phase is depending on the inclination of incoming radiation. Each detector is divided into four sectors consisting of three pixels. Such geometry allows for exact measurements of Moiré pattern phase, and amplitude. Obtained values will be used for reconstruction of X-rays spatial distribution (image). The final image quality strongly depends on the calculated transmission of the grids pair. This work presents preliminary results of transmission calculation with a use of two methods.

Geant4 simulations

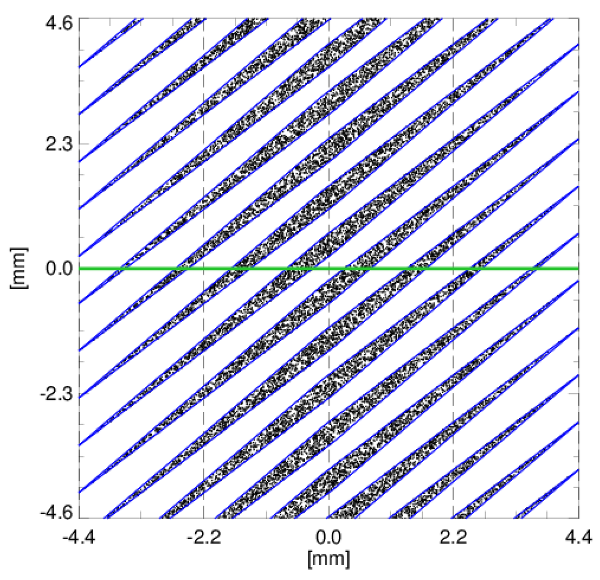

Figure 2. The Moiré pattern on the STIX detector: black dots – result from Geant4 simulations for energy 4 keV, blue lines – theoretical borders of Moiré pattern, green line – cross section of the detector, along which the energy dependency was studied.

Geant4 is a toolkit that allows to simulate a particle flying through matter with all accompanying physical processes. The package takes into account material parameters and geometry of the instrument. Result of simulation is information about particles we study, e.g. energy, position. In this simulation we were interested in reading positions of photons reaching the detector front side. Figure 2 present result of simulation of transmission through pair of grids for 100 000 photons of energy 4 keV. Only 25% of them reached the detector. In higher energies, when grids became more transparent for X-rays, the borders of measured Moiré pattern became more blurred.

Analytical model

The theoretical determination of the Moiré pattern shape is possible when we know precisely parameters of the grids pair. On that basis, we parametrized each slit and slat border with linear functions. Having such set of lines for front and rear grids it is easy to calculate when incoming photon is able to reach the detector or when it is stopped by slats. The transmission is given by:

$$\boldsymbol{T(x)} = \mathbf{exp}\left(-\left(\frac{\boldsymbol{\mu}}{\boldsymbol{\rho}}\right) \times \boldsymbol{\rho} \times \boldsymbol{d(x)}\right)$$

where $\left(\frac{\mu}{\rho}\right)$ is the mass attenuation coefficient from [1], ρ is density of tungsten and d(x) is thickness of tungsten layer (0 when photon go through no grid, 0.4 mm when photon go through one grid, and 0.8 mm when photon go through both of grids). Results of these calculations for four energy ranges are presented in figures 3 a-d, and compared to Geant4 simulations. Both methods give very similar results.

Results

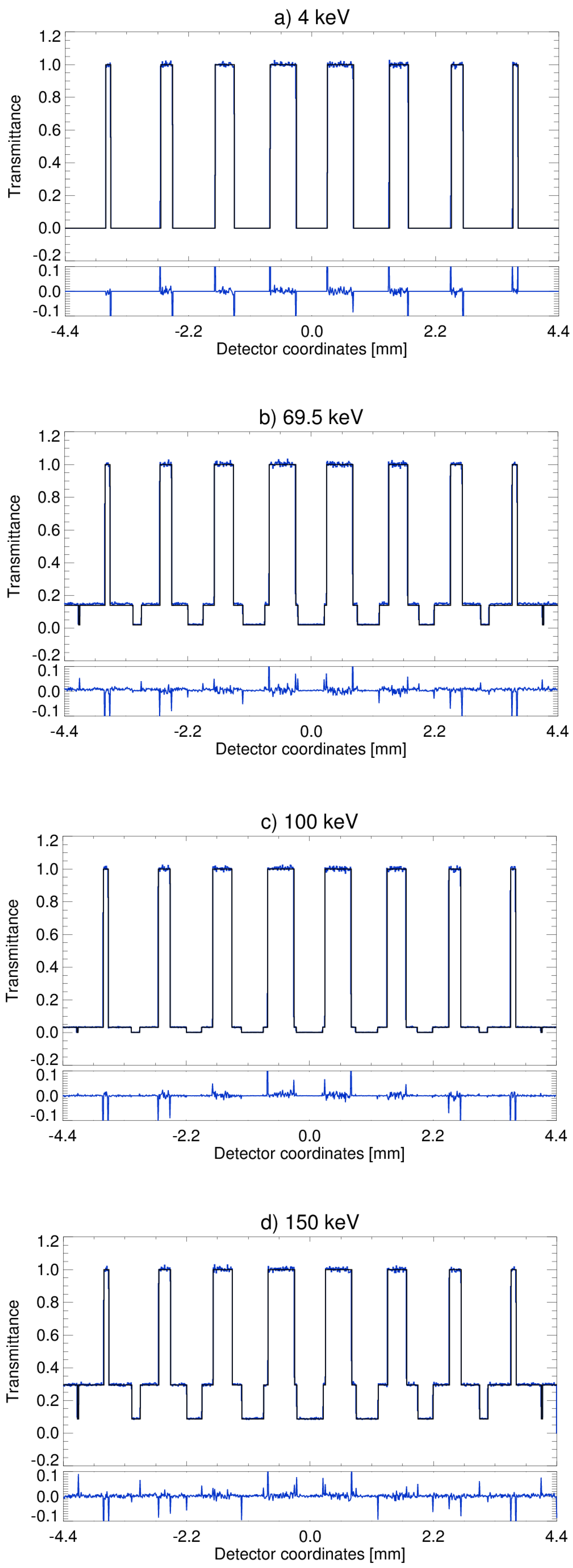

Figure 3 a-d. Transmittance along detector cross section (see Figure 2) for various energies. Blue line – Geant4 simulations, black line – analytical calculations. Under each graph a difference between both methods is shown.

Energy dependent transmittance

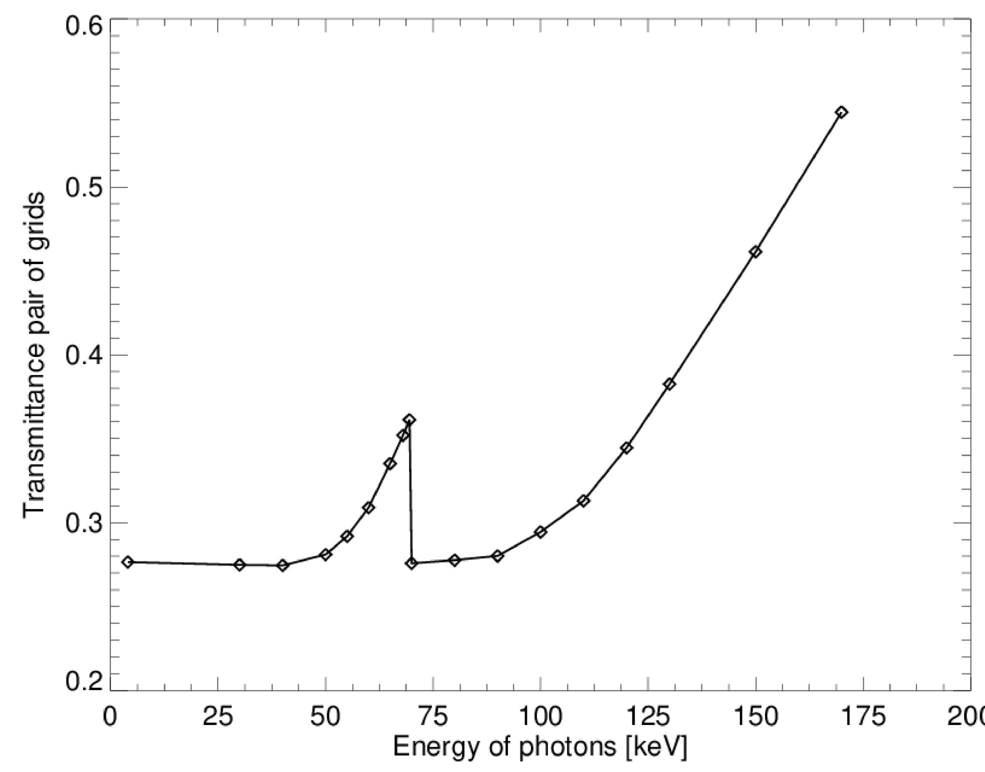

Figure 4. Energy dependence of transmittance for pair of grids – Geant4 simulation.

We can see that for energy below 40 keV grids are opaque. Next, transmittance is increasing until 69.5 keV where absorption edge of tungsten is present. As a consequence we observe abrupt decrease of transmittance to base level. For higher energies transmittance grows monotonically which results in worsening modulation pattern quality.

Moiré pattern from Geant4

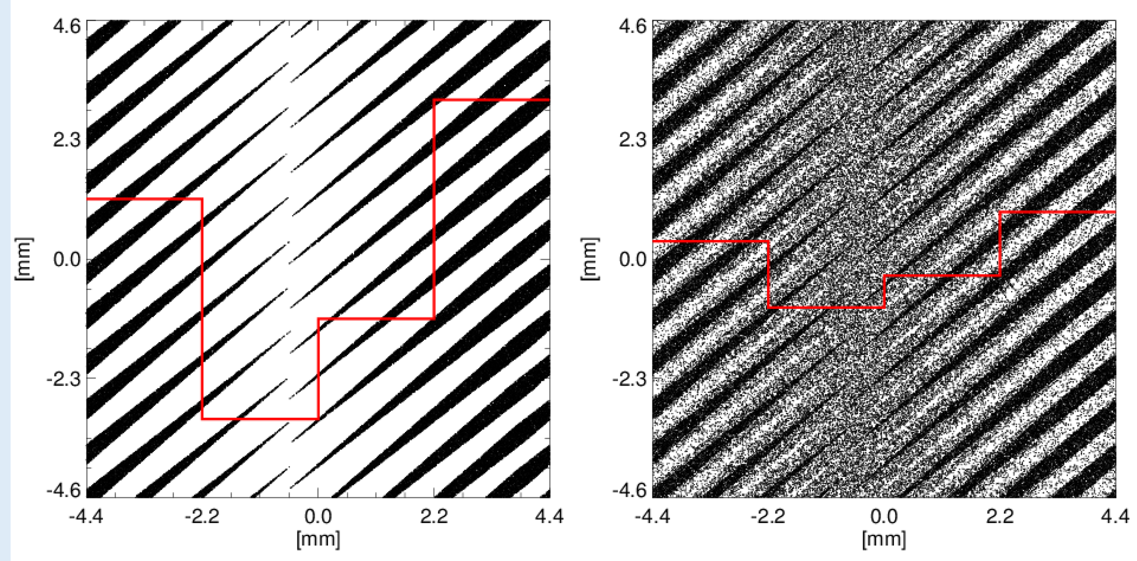

Figure 5. Results of Geant4 simulations for energy 4 keV (left) and 150 keV (right). Red lines correspond to levels of total signal measured in detector sectors.

Figure 5 presents result of Geant4 simulation for two energies: 4 keV, and 150 keV for the same inclination of incoming photons. It is clearly seen that for 4 keV Moiré pattern can be measured very precisely, but for 150 keV the information is blurred because slats are partially transparent for such energetic photons. Therefore we get additional uncertainty in measured modulation which may affect reconstructed image.

Conclusions

1. Geant4 is a suitable tool for simulation of Moiré pattern from pair of grids. Especially, this tool is very useful for precise analysis of energy dependent transmission.

2. Decreasing, with photon energy, opacity of grids may lead to additional uncertainties during image reconstruction process. However, on the basis of simulations conducted, we conclude that the basic parameters of Moiré pattern are still readable even for 150 keV which does not prevent research.

Referencess

[1] https://www.nist.gov/pml/x-ray-mass-attenuation-coefficients

[2] S. Giordano, N. Pinamonti, M. Piana, A. M. Massone, THE PROCESS OF DATA FORMATION FOR THE *SPECTROMETER/TELESCOPE FOR IMAGING X-RAYS (STIX)* IN *SOLAR ORBITER*

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