STIX imaging simulation in IDL

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1. Introduction

This document explains and describes the **simple** STIX imaging simulation tool that can be found in Github (link here). It provides support material to understand what the procedures are doing as well as references.

Definitions:

- Collimator: two grids and a detector
- Pitch: width of a slit and a void together (twice the width of a slit)

In the current state of the software, we can simulate the STIX imaging process for a single source with a chosen incident angle, with no detector response implemented and no energy dependence.

2. Quick launch: wrap-up procedure

The wrap-up procedure **`stix_sim_pipeline`** allows the user to calculate the visibilities and plot the resulting image for a point source observed with STIX. The angle of incidence is defined by its incidence angles projected on axis “x” and “y” (which correspond to a position on the solar disk).

The wrap up will:

- Restore the STIX grid parameters;
- Calculate the moiré pattern and the count number in each pixel, obtained in each collimator for the given incidence angle and given photon flux, using the grid parameters;
- Calculate the corresponding visibilities;
- Create a dirty map;
- Apply a CLEAN algorithm to the dirty map.

Examples to call this wrap-up:

```
stix_sim_pipeline
stix_sim_pipeline, calculate_moire=1, angles_sec=[0., 5.]
```

3. Calculation of the grid specifications for STIX

a. *Link between a STIX collimator and a visibility*

Each STIX collimator (a collimator is composed of two grids and one detector) enable the measure of a complex visibility in the Fourier frequency plane, i.e. a data point in the (u,v) plane. The values of (u,v) is directly linked to the orientation and resolution of the collimator: the resolution itself is proportional to the pitch of the grid and inversely proportional to the separation between the two grids. For a given (u,v) point corresponds a given pitch and a given orientation of the collimator (the distance between the two grids being fixed).

In the STIX design, a small difference in pitch and orientation between the front grid and the rear grid of a given collimator produces a moiré pattern on the detector. The orientation of the moiré pattern and its period depend on the pitch and orientation of both grids. There is therefore only a given set of pitches and orientation to produce a pattern aligned with the detector, and with a period equal to the detector width, for one given collimator.

One must take away from this that the overall pitch and orientation of a collimator determine the (u,v) position of the visibility measured, whereas the individual pitches and orientations of the front and rear grids must be adjusted in order to produce exactly one period of the moiré pattern on the detector.

b. Procedure to calculate the grid parameters

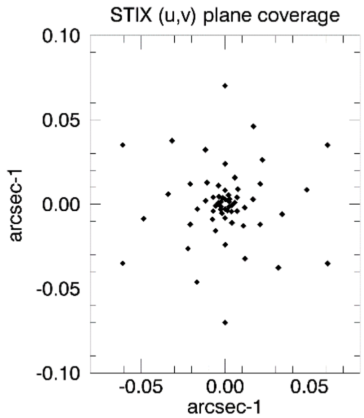

Figure 1: STIX (u,v) plane coverage (Fourier space)

In the STIX experiment, the (u,v) coverage consist of 60 points with 10 different amplitudes (corresponding to 10 spatial resolutions) dispatched as a spiral (see figure 1). The orientation and pitches of the collimators are therefore fixed by this requirement.

To produce the moiré pattern on the detectors, the front and rear grid must have a certain pitch and orientation. Those parameters are documented by G. Hurford, but it is an interesting exercise to make sure that one can calculate again these parameters. The IDL procedure that does this calculation is called **`stix_sim_calculate_grid_param.pro`**, and calls the function **`calcul_stix_grid_param.pro`**. It produces three IDL sav files that contain the following IDL variables:

- `stix_grid_parameters.sav` contains the variables `grid_param` and `grid_names`. `grid_param` is a 30*4 array containing for each collimator the front grid pitch, the rear grid pitch (in mm), the front grid orientation, the rear grid orientation (in degrees), respectively.
- `stix_visibility_uv.sav` contains the variables `u` and `v`, which are the (u,v) coordinates of the 30 visibilities in arcsec-1.
- `stix_collimator_phases.sav` which contains the variable `coll_phases`, the phase orientation of each collimator.

The explanation of the calculation in this procedure is not explained in this document. You can refer to my thesis (section 6.4.5) for more information (in French).

4. Simulate the moiré pattern for a collimator, for a single point source

The function **`stix_sim_single_grid`** returns the 8 pixel intensity values for a given collimator, a given photon flux and a given incidence angle. To do so, it will calculate the transmission pattern (moiré pattern) using the subfunction **`stix_sim_transmission_patterns`** which calculates the transmission pattern through the defined set of grids. Then we calculate the moiré pattern as seen on the detector. The photon flux follows a uniform distribution on the detector and we select only the photons that actually reach the detector using the transmission pattern. The position of those selected counts is used to calculate the intensity of flux in each pixel. The detector response is not implemented.

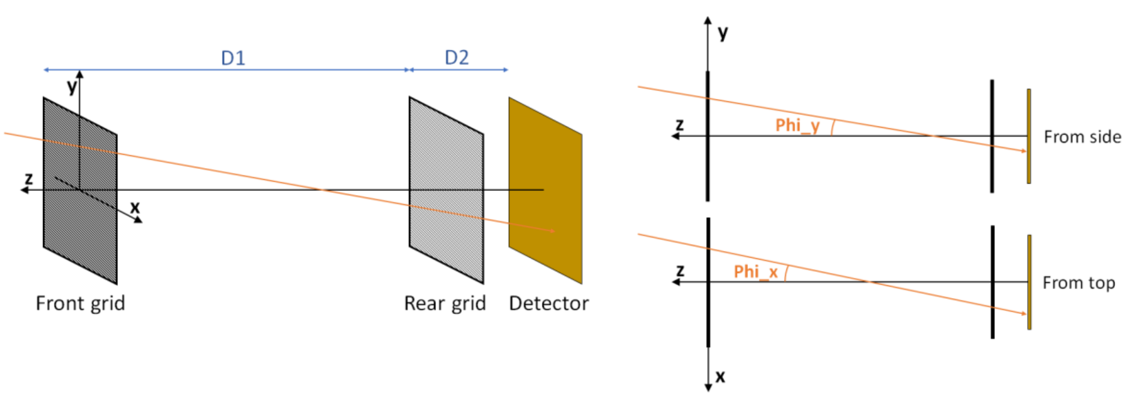

Figure 2: geometry and variables description for the calculation of the transmission of photons in one collimator

The geometry of the instrument and grids are shown in figures 2 and 3, as well as some variables found in the code:

- p is half the grid pitch,
- Ω is the grid orientation,
- (xfront, yfront) are the cartesian coordinate of the photon,
- (a,α) are the polar coordinates of the same photon.
- h is the distance of the photon to the bottom of the slit that passes through the center of the detector.

A photon will pass the grid if h mod p > 1.

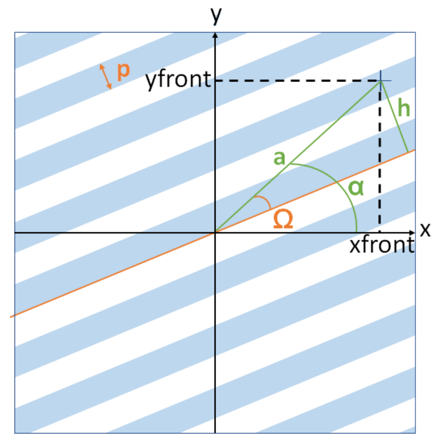

Figure 3: geometry of the grid adopted in the code

This procedure can be applied on the 30 STIX collimator for a given pair of incidence angles [phi_x, phi_y]. The two following figures (figures 4 and 5) show the resulting moiré patterns for incidence angles [0,0] and [0,50] arcsec, with a photon flux of 10000 photons.

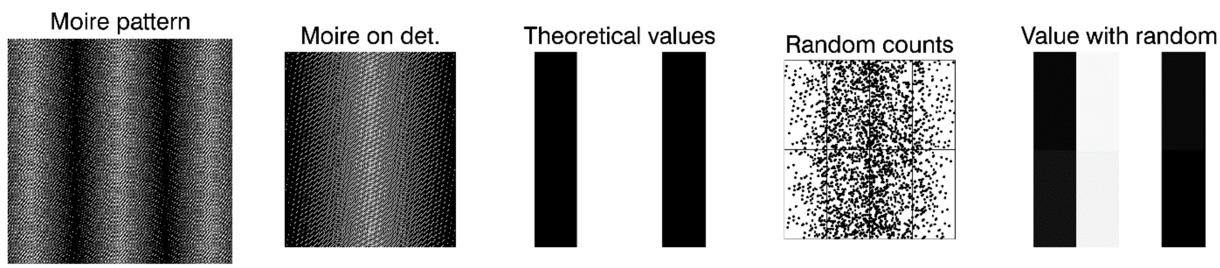

Figure 4: For collimator "22" in the code, for an on-axis point source, from left to right: transmission pattern of the size of the front grid, sample of the transmission pattern on the detector (moiré fringe), pixel value (theoretical), transmitted fraction of 10000 randomly distributed photons on the detectors, pixel values calculated from the transmitted photons.

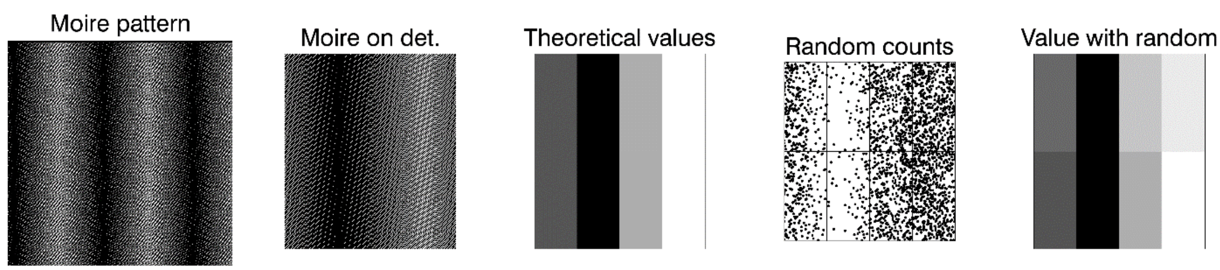

Figure 5: For collimator "22" in the code, for a point source with incidence angles [0,50] arcseconds, from left to right: transmission pattern of the size of the front grid, sample of the transmission pattern on the detector (moiré fringe), pixel value (theoretical), transmitted fraction of 10000 randomly distributed photons on the detectors, pixel values calculated from the transmitted photons.

5. Calculate the visibilities

Using the values in each pixel produced in section 3, we can calculate the corresponding visibilities. Use the function `stix_sim_calculate_visibilities.pro`. There is currently an uncertainty on the way the visibilities should be calculated, regarding the phase of the collimator. More explanation about this problem is in the code header. This problem needs further investigation and I will solve this uncertainty for the next version of the software.

6. Create a dirty image

One can create a dirty image using the calculated set of visibilities by calling the function **stix_sim_dirty_map_from_vs.pro**

The images created with a different number of visibilities are plotted for information. For instance, the images with different set of visibilities for an on-axis point sources are shown in figure 6.

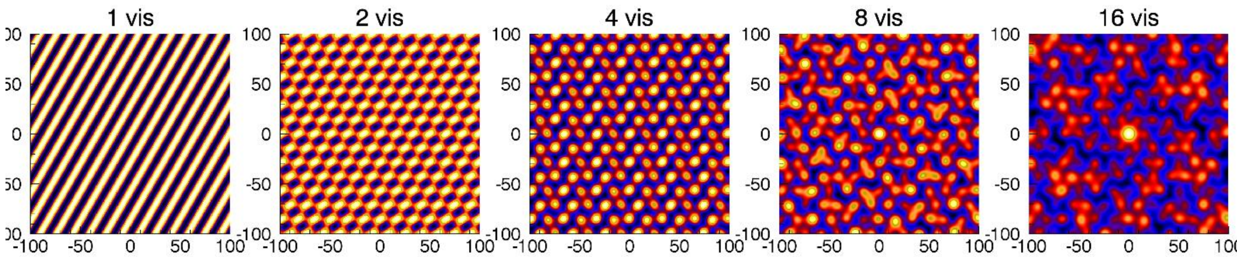

Figure 6: images obtained with different sets of visibilities for an on-axis point source.

7. Clean the dirty image

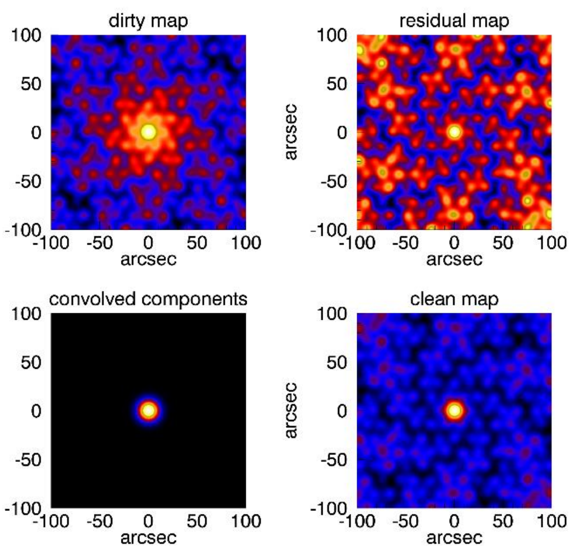

Figure 7: results of the CLEAN process for an on-axis point source

A basic clean process can be applied to a dirty image. This can be done by calling the function **stix_sim_clean_map_from_vs.pro** with a set of visibilities. This function will create a dirty map and clean it with a certain number of iterations by calling the sub function: **stix_sim_clean_iterations**.

The residual map will be plotted and updated with each iteration.

The CLEAN map is then created by convolving the final residual map with the CLEAN component map assuming a beam size, depending on how the weights are assumed.

A plot will then show the initial dirty map, the final residual map, the map of the convolved components and the clean map. An example of this plot for an on-axis point source is shown in figure 7.

8. Useful material

Papers:

- The process of data formation for the Spectrometer/Telescope for Imaging X-rays (STIX) in Solar Orbiter http://adsabs.harvard.edu/abs/2014arXiv1412.6825G
- The spectrometer telescope for imaging x-rays on board the Solar Orbiter mission http://adsabs.harvard.edu/abs/2012SPIE.8443E..3LB

Webpages:

- CLEAN weighting https://www.cfa.harvard.edu/sma/miriad/manuals/SMAuguide/smauserhtml/node107.html
- Visibilities in the RHESSI software https://hesperia.gsfc.nasa.gov/ssw/hessi/doc/image/hsi_visibility_howto.html#Normalize

9. Remaining questions

The dirty and CLEAN maps produced for a source at [0,50] arcsec show two sources, as if a ghost source was present in the reconstruction. This is shown in figure 8. I have to find out if this is expected and how avoid such artifact in the image reconstruction.

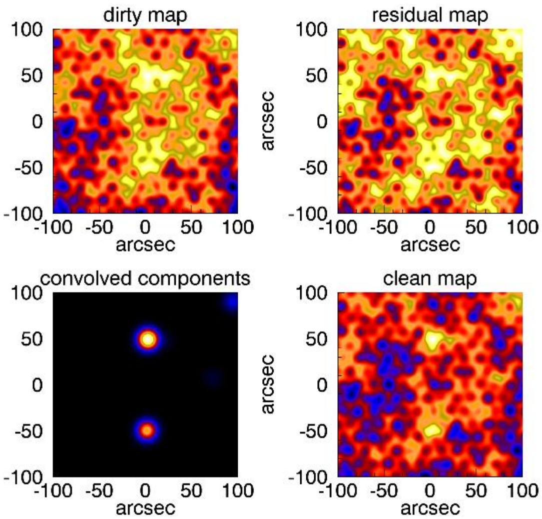

Figure 8: dirty and CLEAN images for a point source located at [0,50] arcsec