SOFTWARE AND HARDWARE SIMULATIONS OF THE OPTICAL CHANNEL AND THE DETECTORS FOR STIX INSTRUMENT ON-BOARD SOLAR ORBITER

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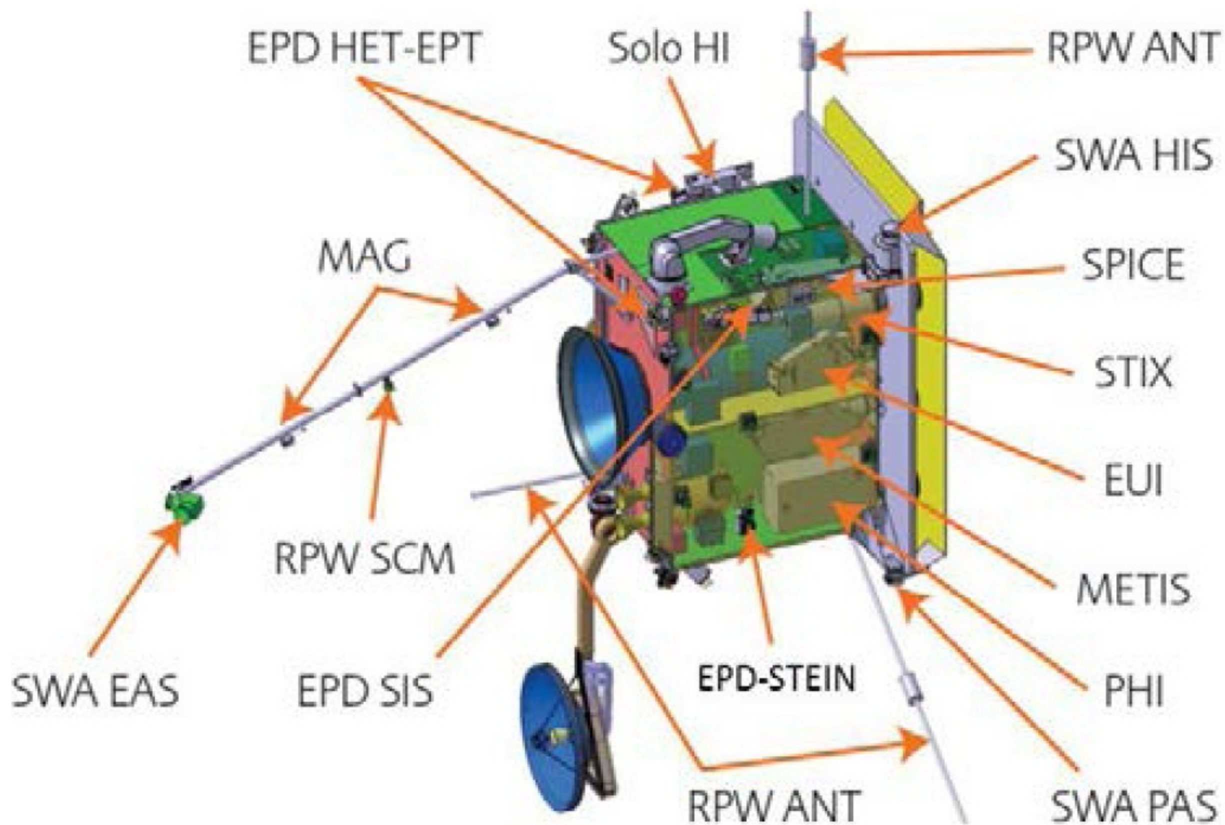
Solar Orbiter Instruments

10 instruments:

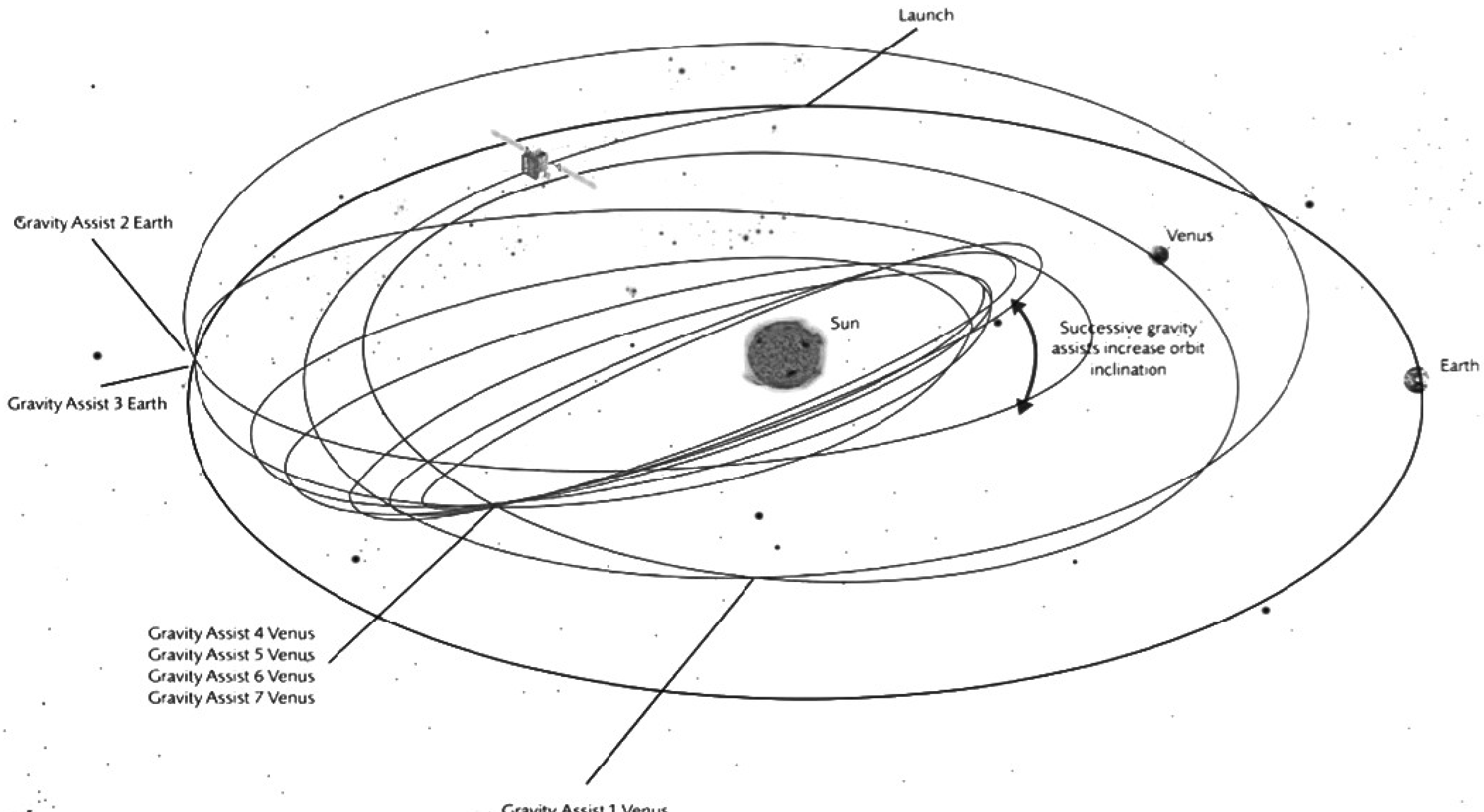
- **EUI**: Extreme Ultraviolet Imager
- **METIS**: Multi Element Telescope for Imaging and Spectroscopy
- **PHI**: Polarimetric and Helioseismic Imager
- **SoloHI**: Heliospheric Imager
- **SPICE**: Spectral Imaging of the Coronal Environment
- **STIX**: Spectrometer/Telescope for Imaging X-rays
- **EPD**: Energetic Particle Detector
- **MAG**: Magnetometer
- **RPW**: Radio and Plasma Waves Experiment
- **SWA**: Solar Wind Analyser



Fahmy et al. (2013)

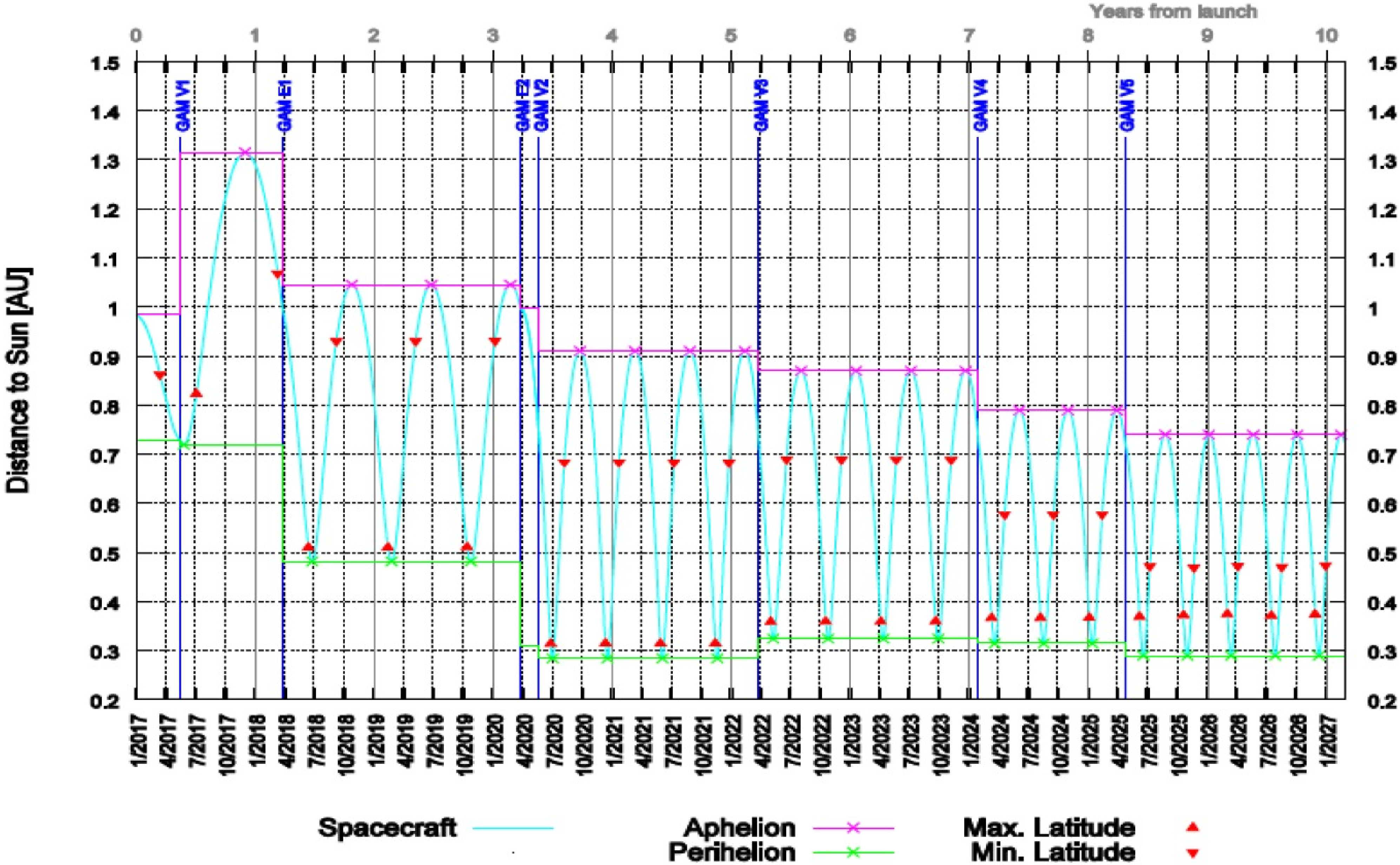
Launch date: 2017-2018
Duration: 3 years cruise + 4 years mission (+ 3 year extension)

The orbit



Launch
Gravity Assist 2 Earth
Venus
Sun
Successive gravity assists increase orbit inclination
Earth
Gravity Assist 3 Earth
Gravity Assist 4 Venus
Gravity Assist 5 Venus
Gravity Assist 6 Venus
Gravity Assist 7 Venus
Gravity Assist 1 Venus

Mission profile



Fahmy et al. (2013)

STIX science goals and observations

detection X-rays from 4 to 150 keV

STIX will determine the intensity, spectrum, timing, and location of solar hard X-ray sources.

Hard X-ray Spectrum and Image from RHESSI

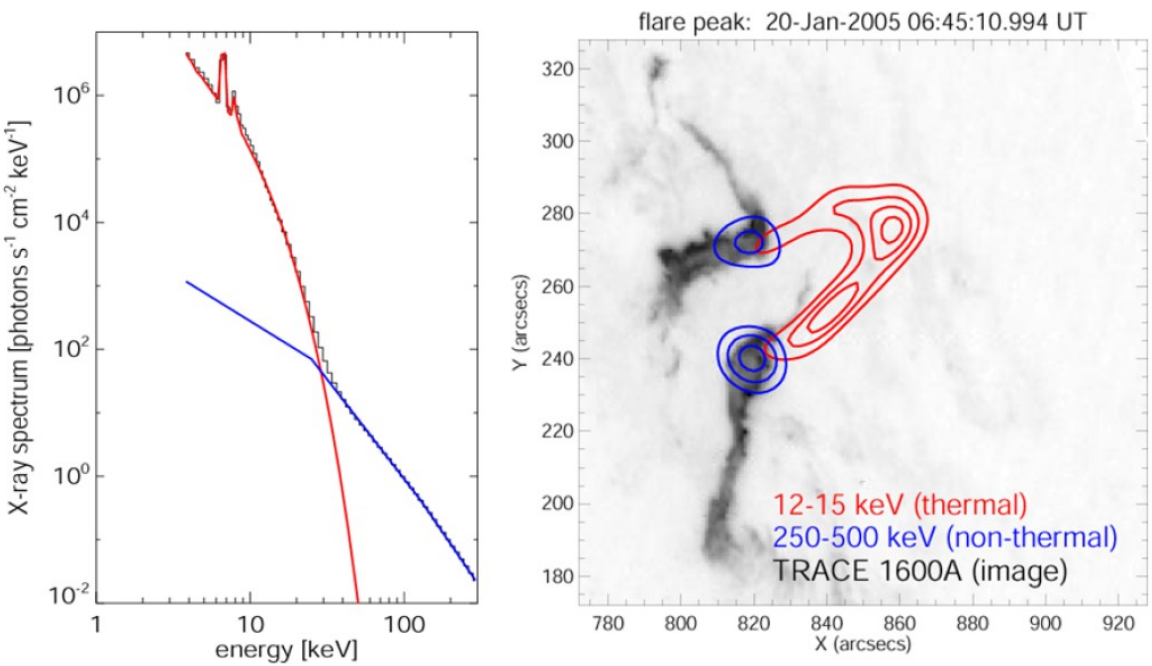
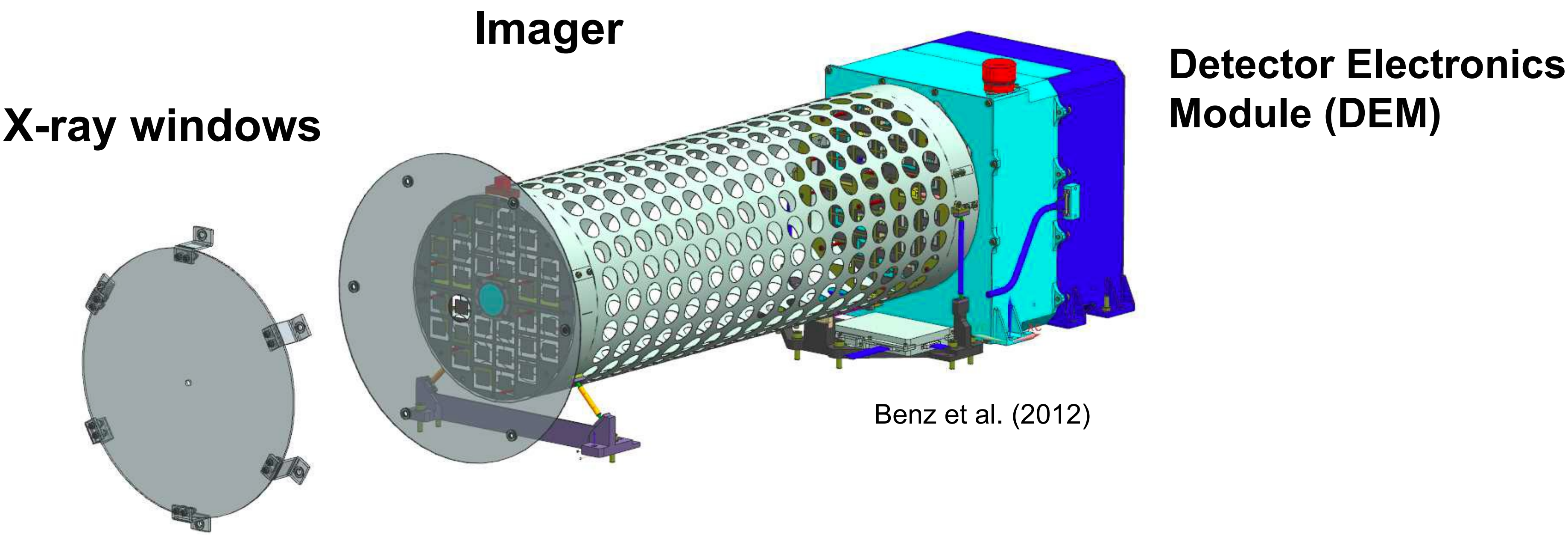


Figure 1.Typical hard X-ray observations of a solar flare (observations are taken by RHESSI). *Left:* Solar flare spectrum (black histogram) with a thermal (red) and non-thermal (blue) fit to the data. *Right:* Imaging observations of the same event. The non-thermal emission is seen from the chromospheric footpoints (blue) of the thermal flare loop (red).

Benz et al. (2012)

The STIX instrument

The STIX instrument consists of three mechanically separate parts



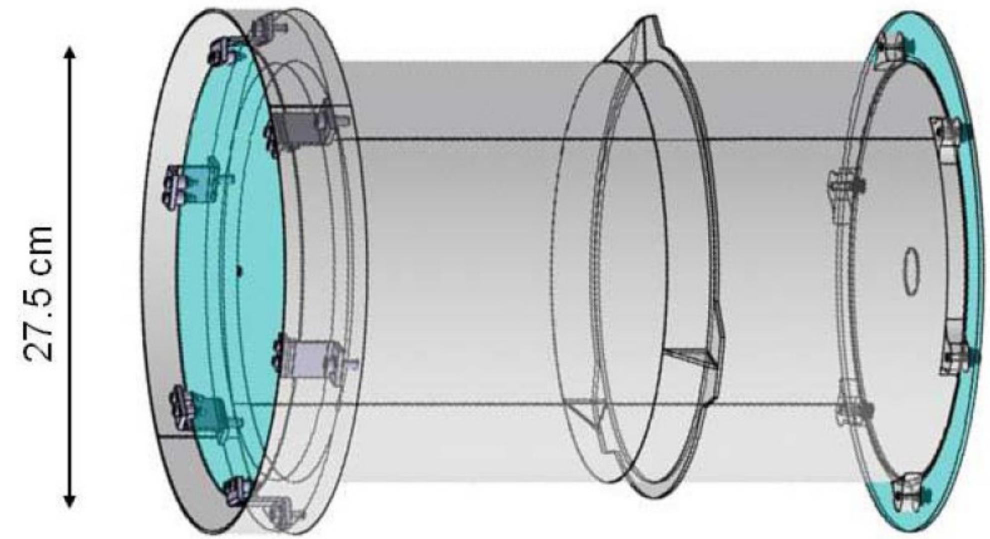
Benz et al. (2012)

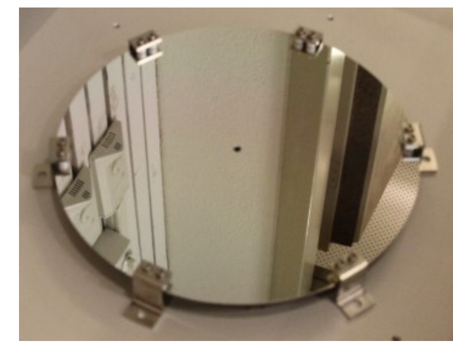
Energy Range	4 – 150 keV
Energy Resolution (FWHM)	1-15 keV (energy dependent)
Effective area	6 cm^2
Finest angular resolution	7 arcsec
Field of view	2°
Image placement accuracy	~4 arcsec
Time resolution (statistics limited)	$\geq$ 0.1 s

X-ray windows

Placed in the heat shield of the spacecraft

A thermal baffle that rejects all radiation below 4 keV



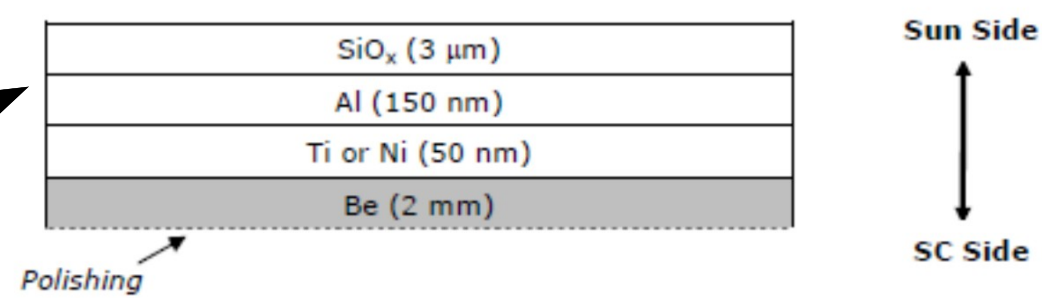


∅ 275 mm

Benz et al. (2012)

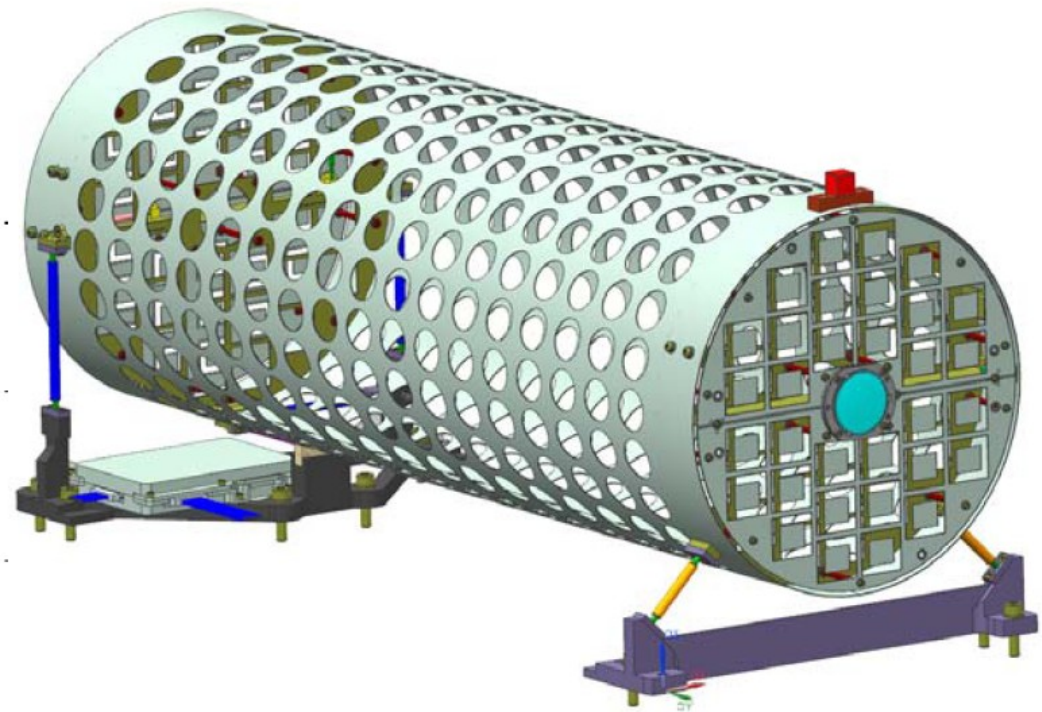
Solar flux at 0.28 AU: 17 kW/m^2

protective thermal coating



Fahmy et al. (2013)

The imager



- 32 collimators made of pairs of grids
- Aspect system for absolute pointing with accuracy ±4 arcseconds

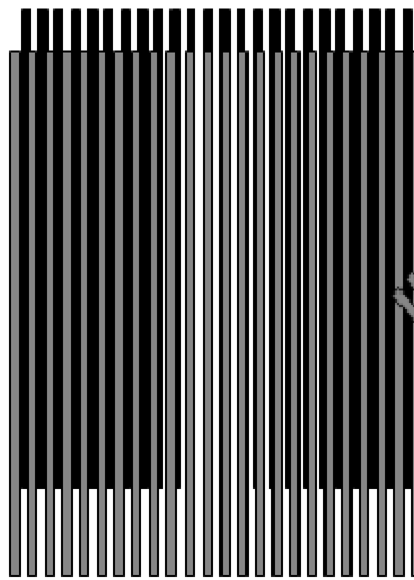
Structural and thermal model of the imager (2013)

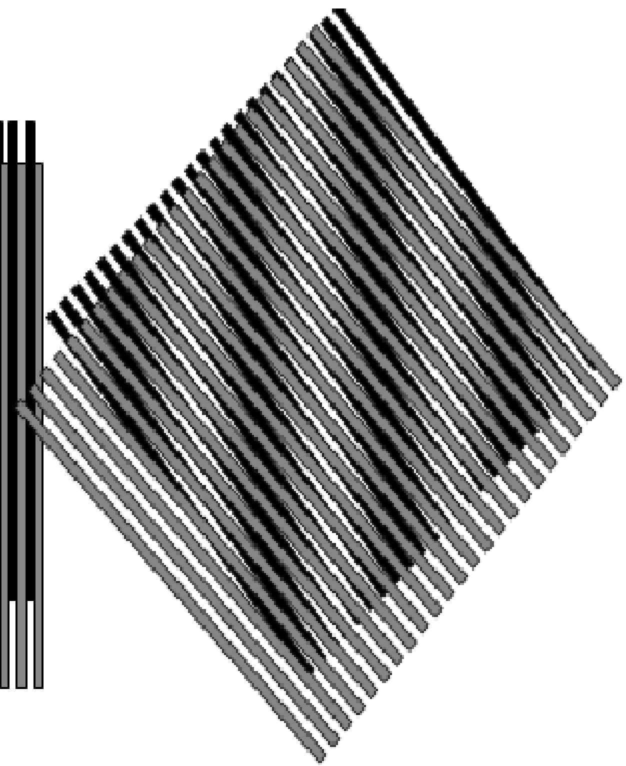
Imaging: grids and Moire patterns

Moire patterns

Slightly tilted pair of grids

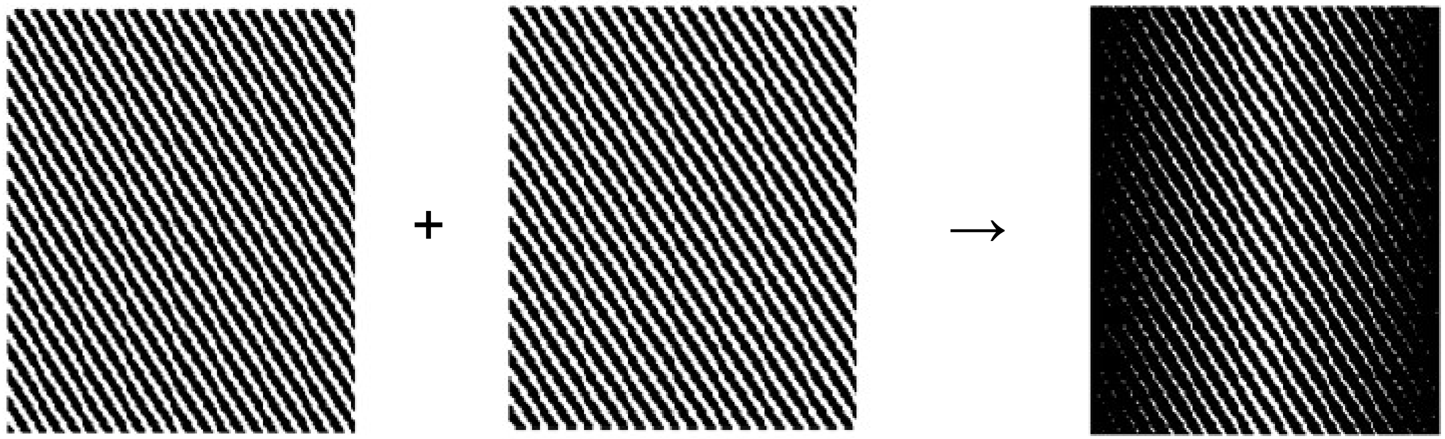
Slight differences in pitch of grids

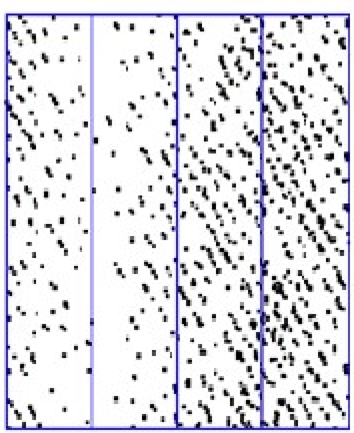




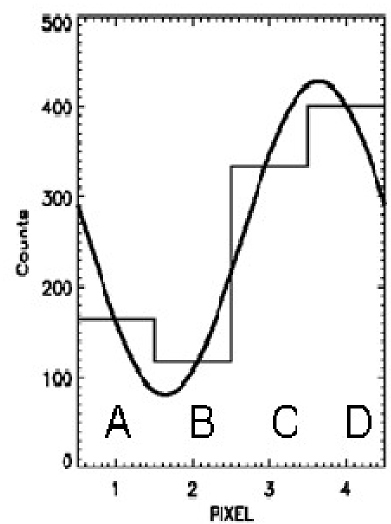
Phase of Morie pattern is very sensitive to incident direction of X-ray in plane perpendicular to slits

Pixel pattern → visibilities





Simulated incident X-rays from an arbitrary direction



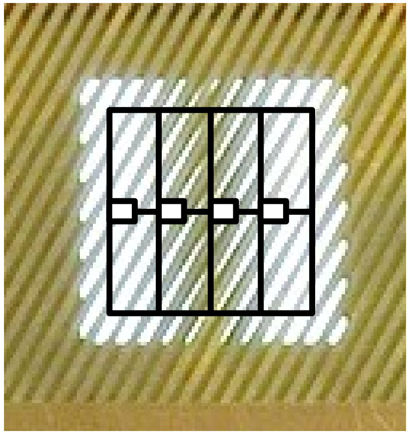
The amplitude and phase of a sinusoid fitted to the histogram directly measures the visibility

*Real (V) = C - A
*Imag (V) = D – B
**Flux = A+B+C+D
**Check: A + C = B + D

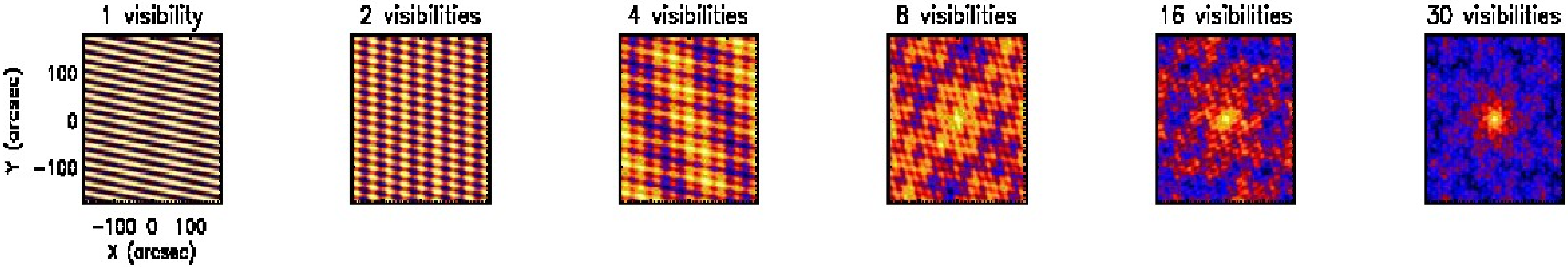
* Independent of background
**Independent of source morphology

Benz et al. (2012)

Converting Visibilities to Images



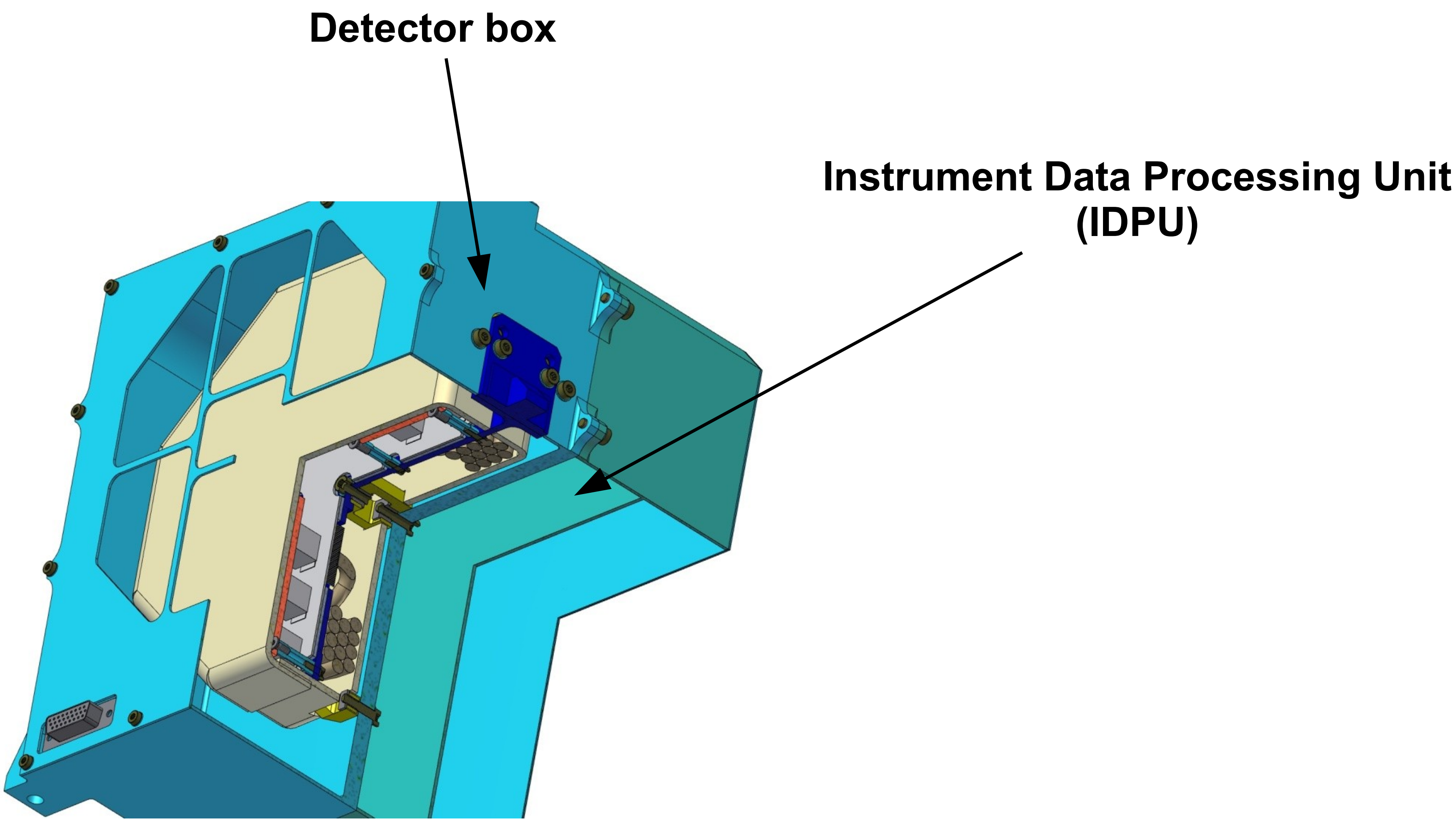
- The process of converting a set of measured visibilities to an image is identical to that used for many years in radio interferometry.
- The simplest algorithm for doing this is "back projection" whereby a measured visibility is expressed as a probability map on the sky of possible origins of the source.
- For a single visibility, this takes of the form of parallel stripes with a sinusoidal profile, whose period and orientation corresponds to the period and orientation of the x-ray grids.
- By combining the visibilities with different angular resolution and orientation, the ambiguities associated with any single visibility are removed



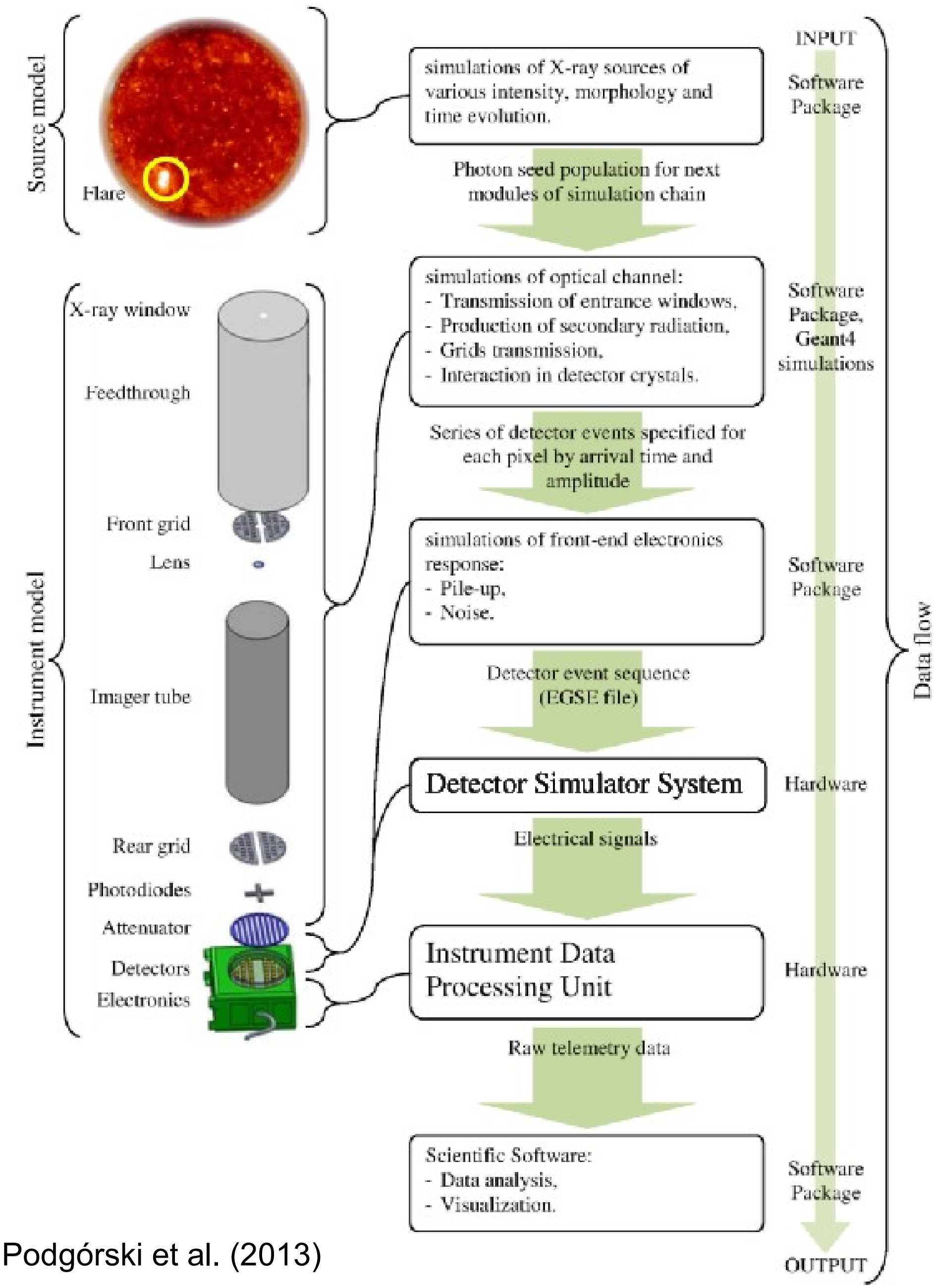
Hurford et al. (2012)

Detector Electronics Module (DEM)

The DEM consist of two sub-units



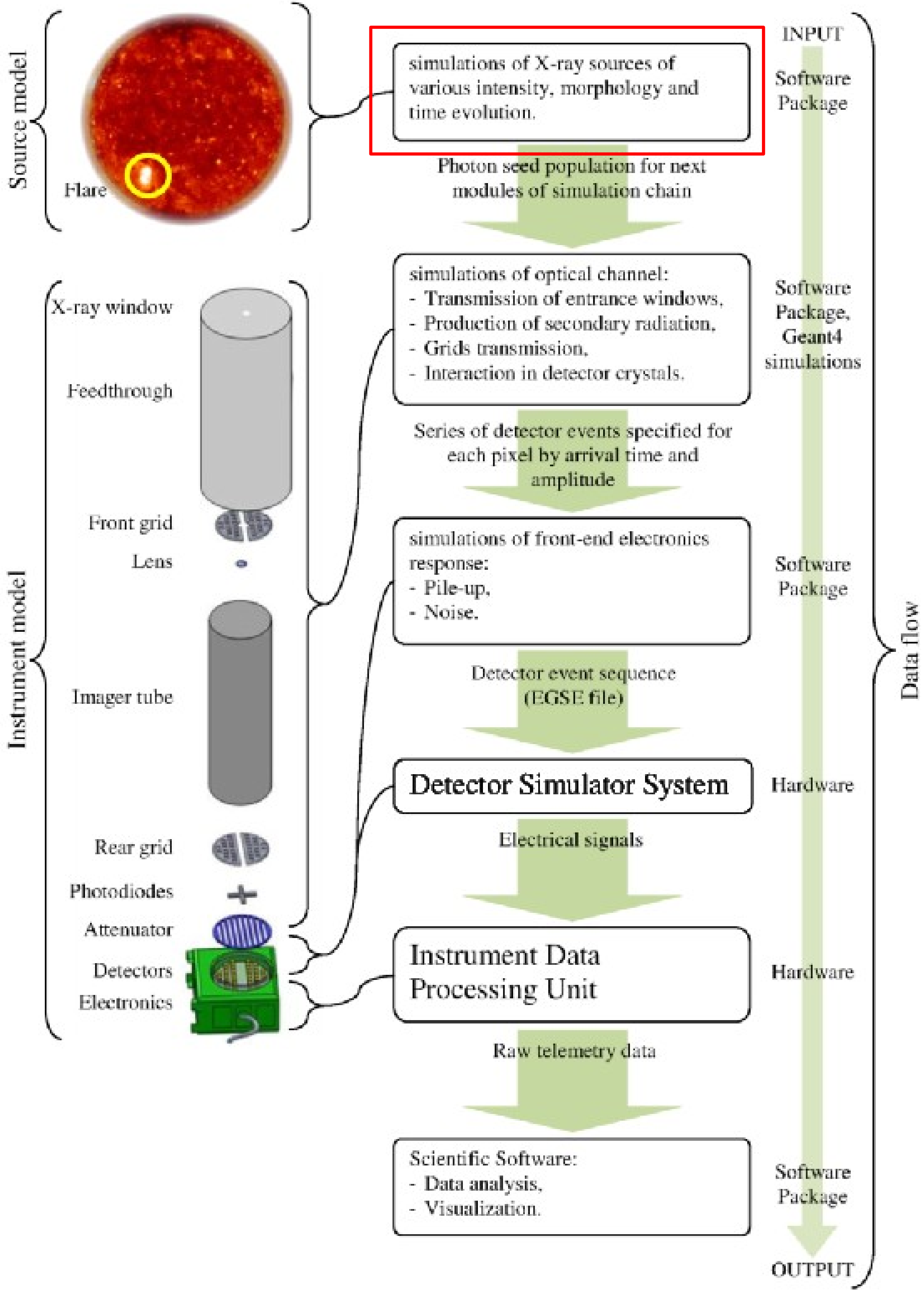
Complex instrument simulation



Podgórski et al. (2013)

It can be divided into several important steps:

- simulations of solar X-ray emission sources,
- simulations of optical channel,
- simulations of photon interaction in detector crystals,
- simulations of front-end electronics response,
- injecting the data to IDPU using hardware detector simulator,
- data handling with real IDPU,
- comparison of output data with input photon population.

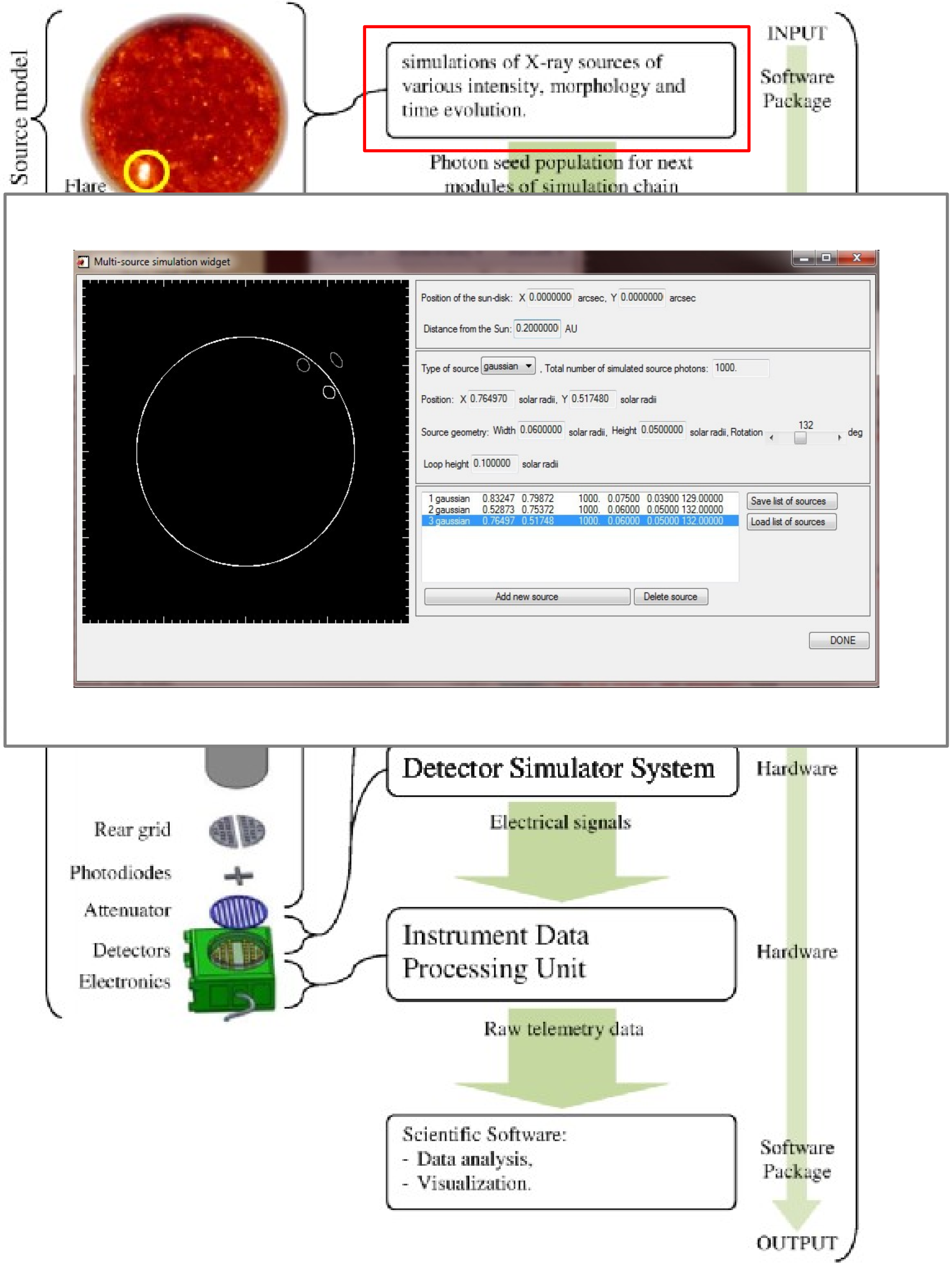


Simulations of solar X-ray emission sources

Three steps:

- Define the number and shape of sources.
- Include the spectral information for every source (and/or every patch). For this purpose RHESSI spectra obtained for real solar flares will be used.
- Assign time to each photon. Having spectral fits to RHESSI data for an entire flare we have a set of parameters which characterize the spectra for consecutive time intervals.

The generated population is a series of photons as seen in front of the instrument entrance window.



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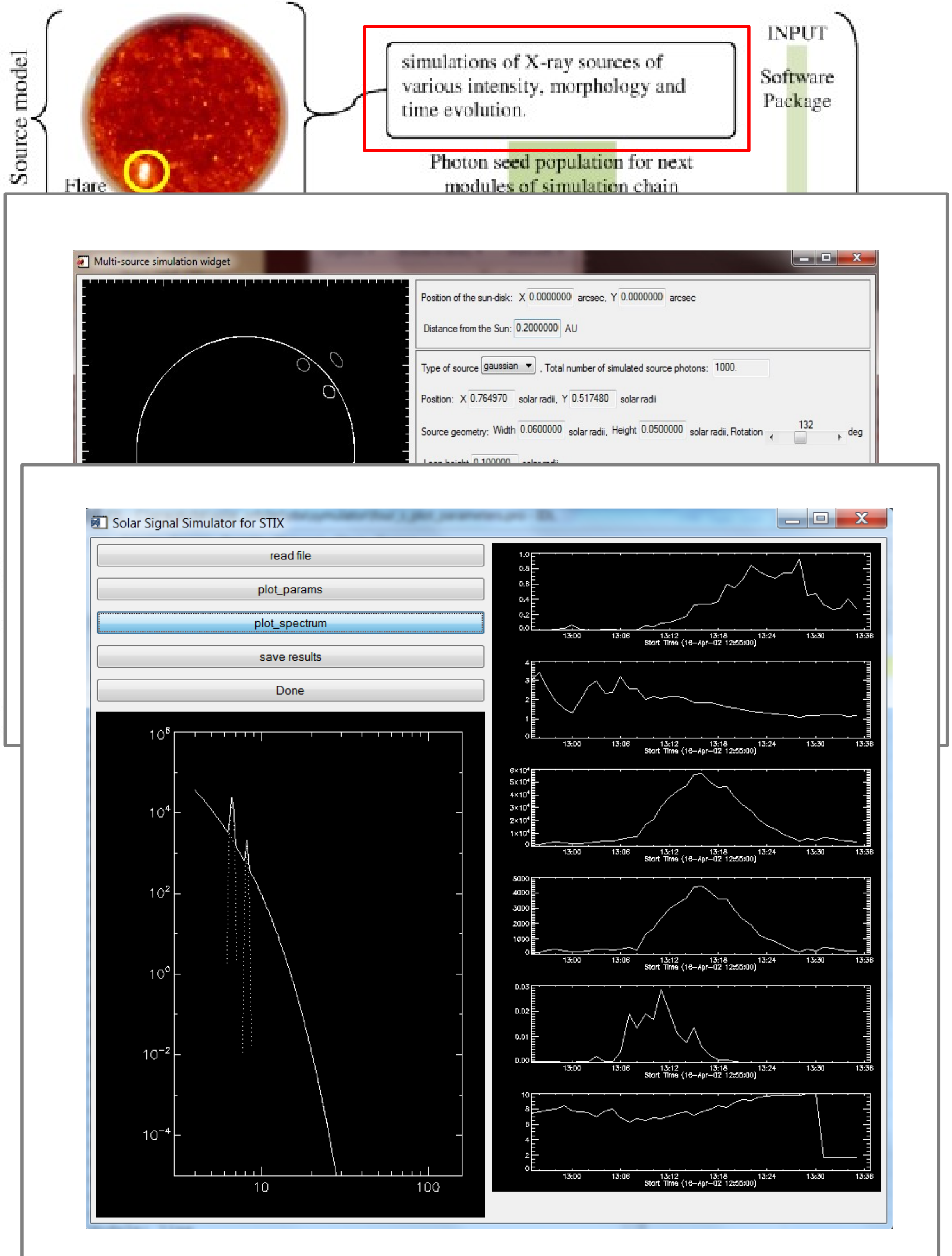

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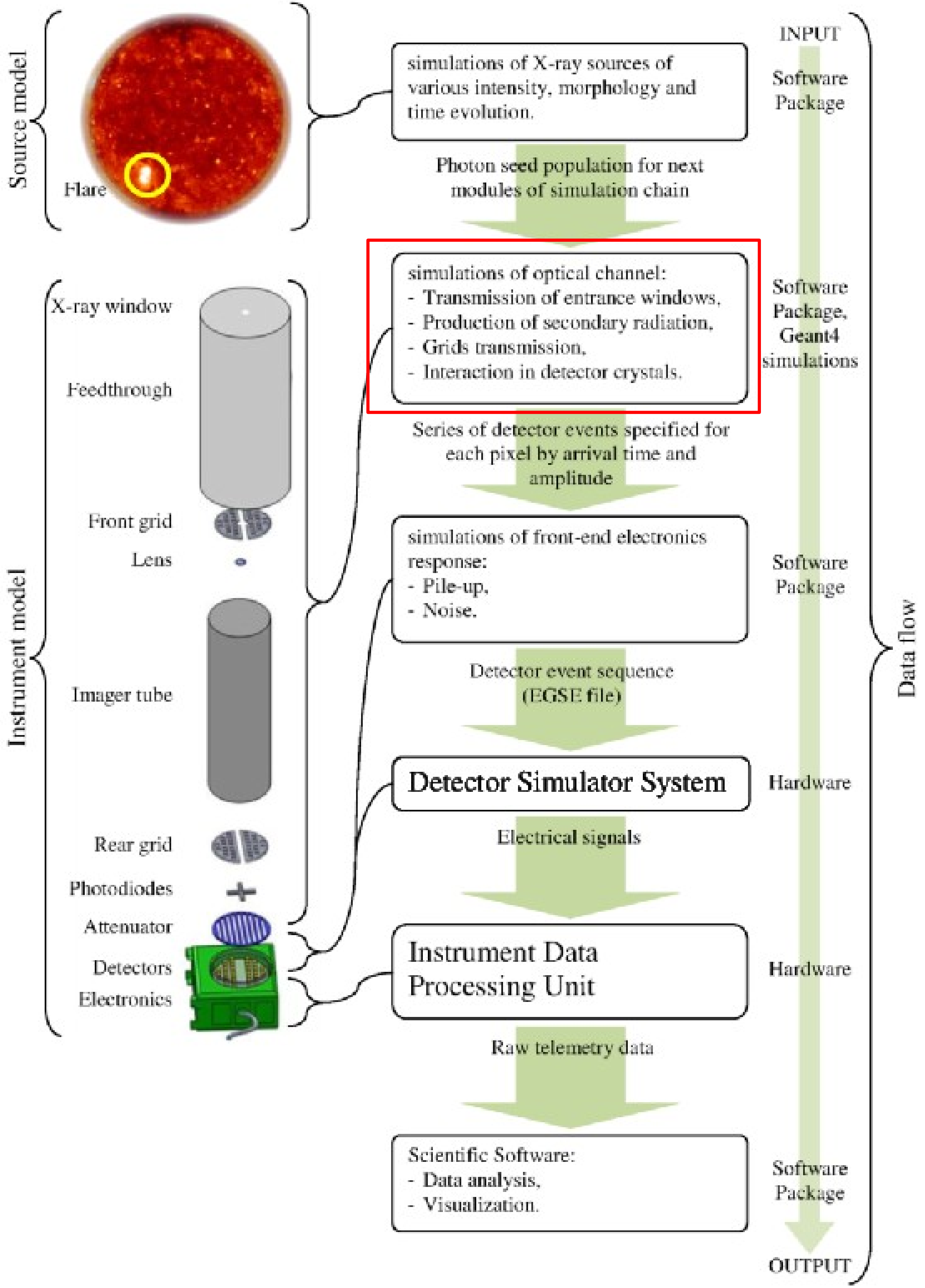
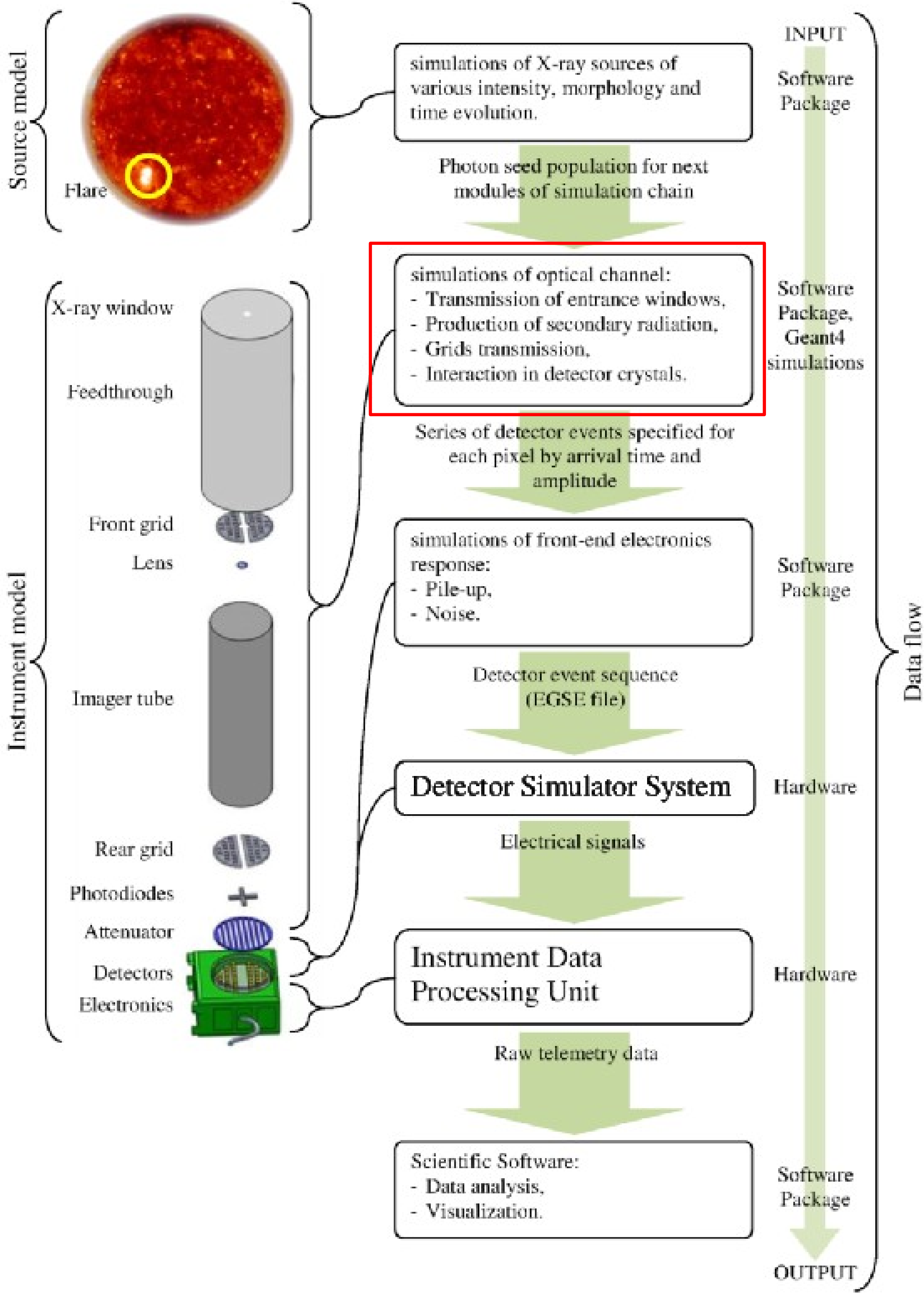


Simulations of an optical channel

- Simulation of the thermal baffle (that rejects all radiation below 4 keV).
- Simulation of an optical tube with grids As a geometry of the instrument is well known algorithm can simply use ray-tracing and calculate if the photon will pass through grids and reach one of the detectors at a given position.

Alternatively, we will use the GEANT4 toolkit to perform calculations of photon path in more complicated way which will take into account, for example, scattering of photons in the optical tube..



Simulations of photon interaction in detector crystals

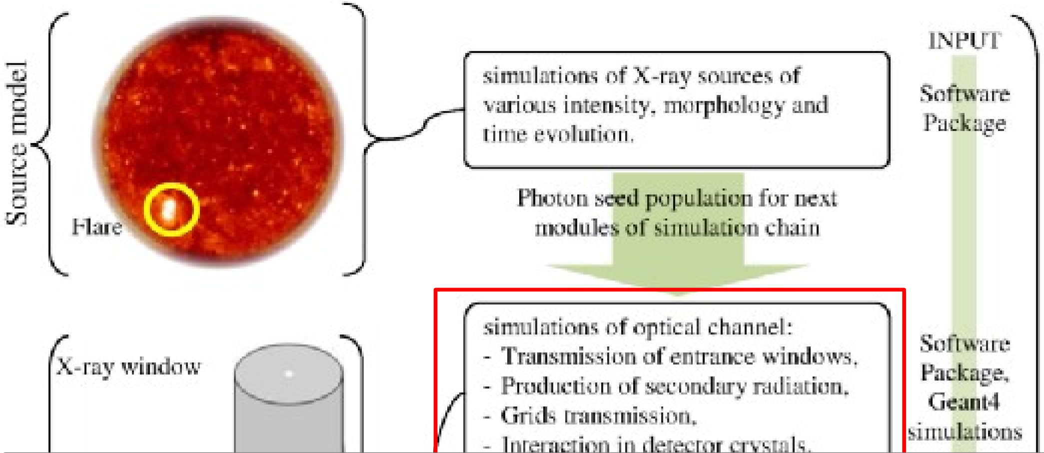
The efficiency of the CdTe detectors is calculated on the basis of a model where photo-electric response dominate, and the detector is assumed to be infinite planar.

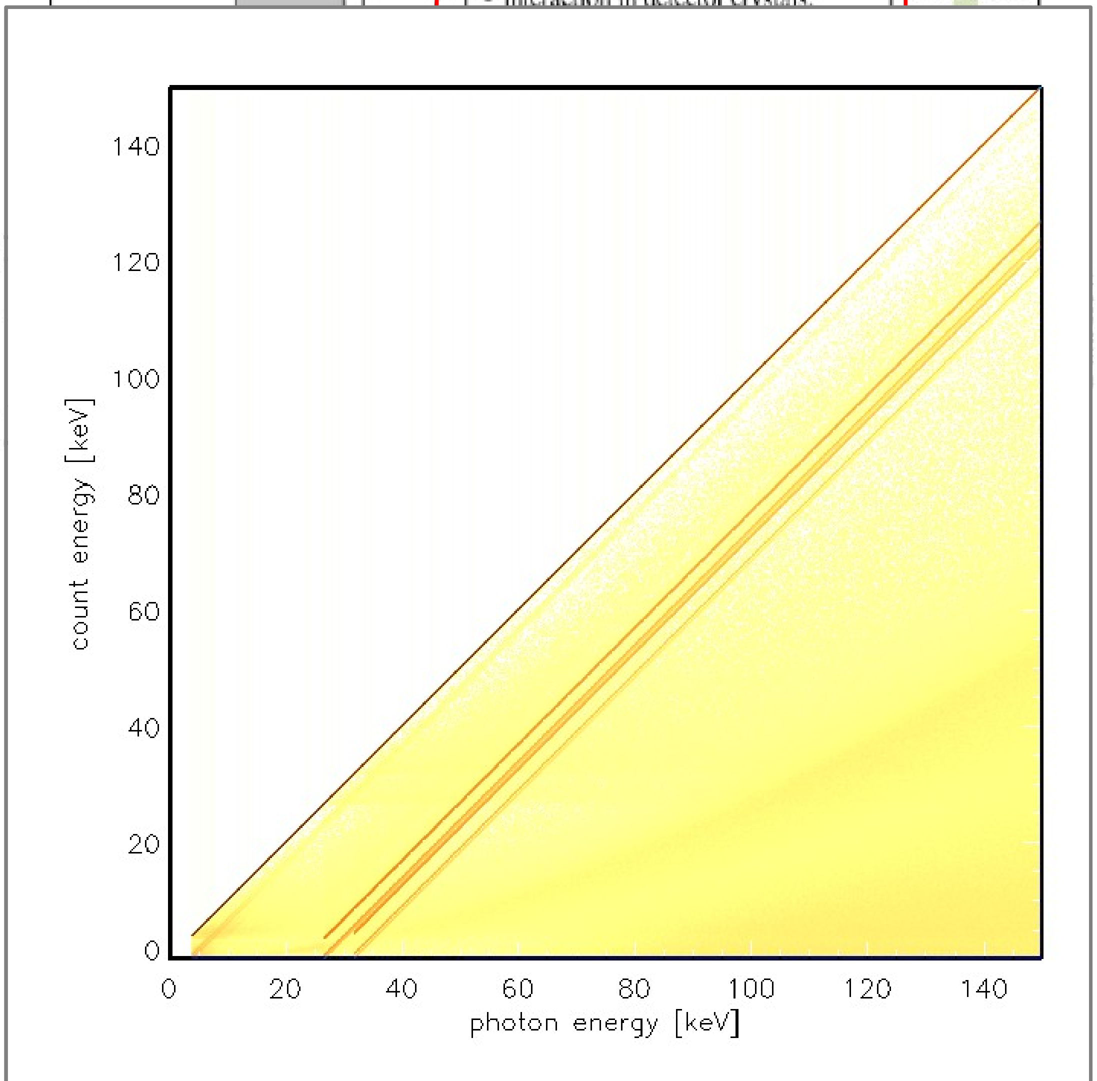
This method will allow including:

- effects connected with single Compton scattering (scattered photon will escape)
- escaping by fluorescent photons

But this method will not include edge effects:

- GEANT4 simulations of the interaction of HXR photons in detectors crystals will be performed





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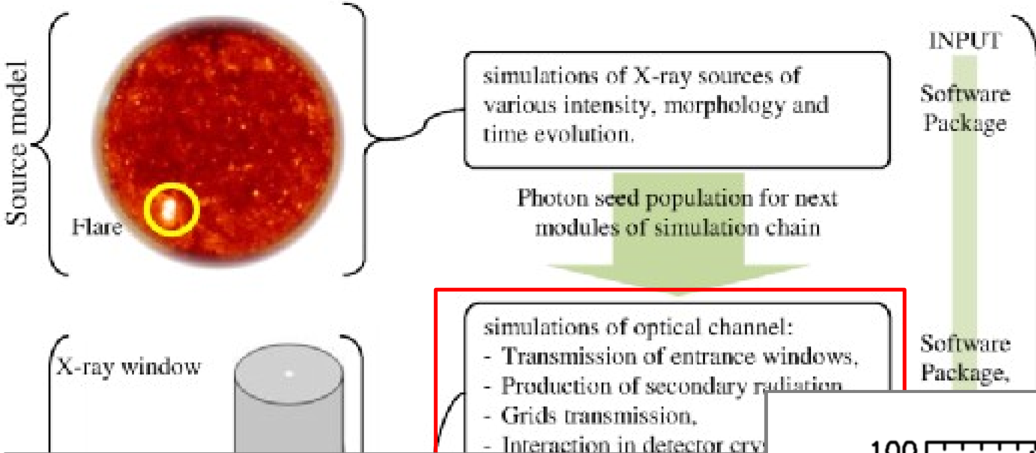
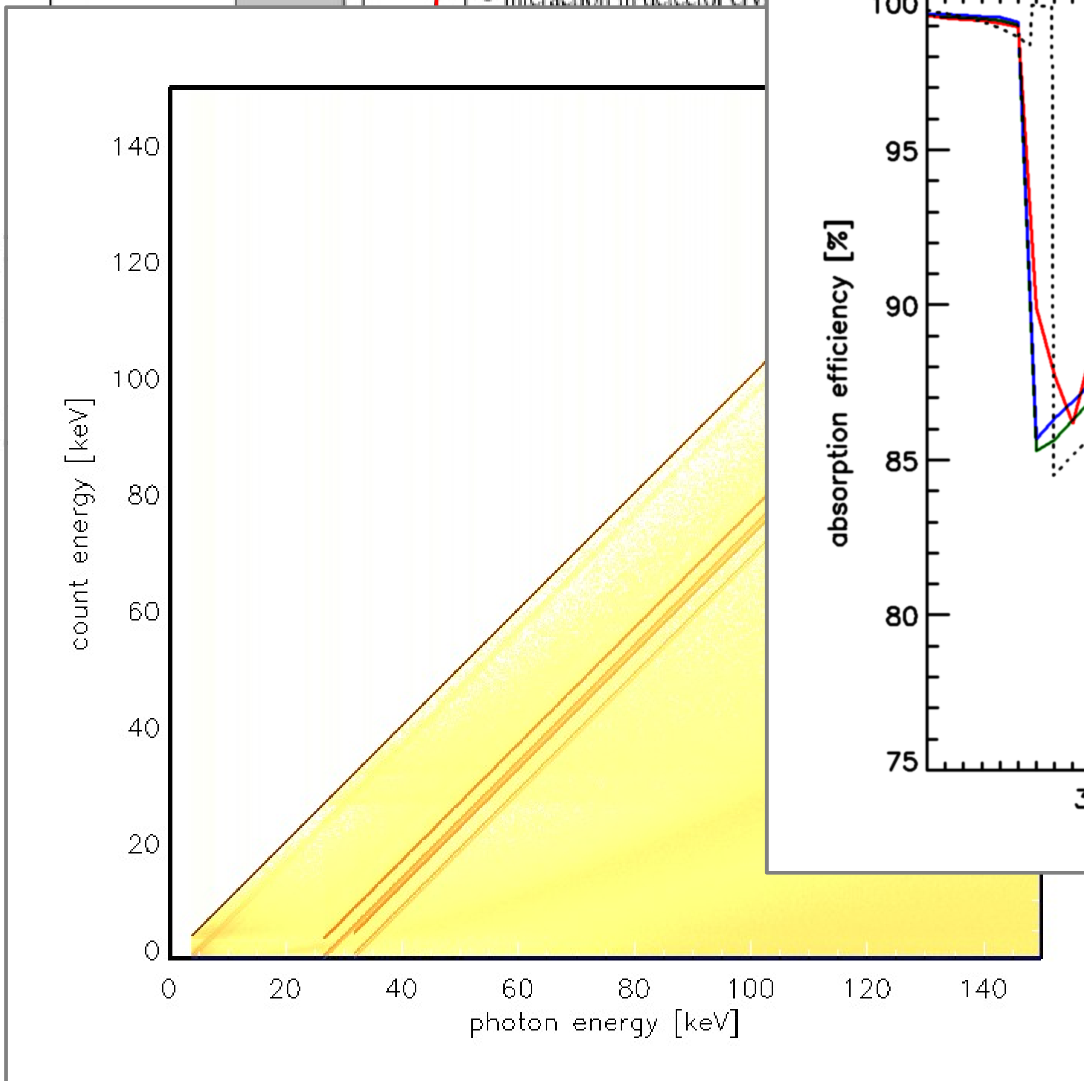
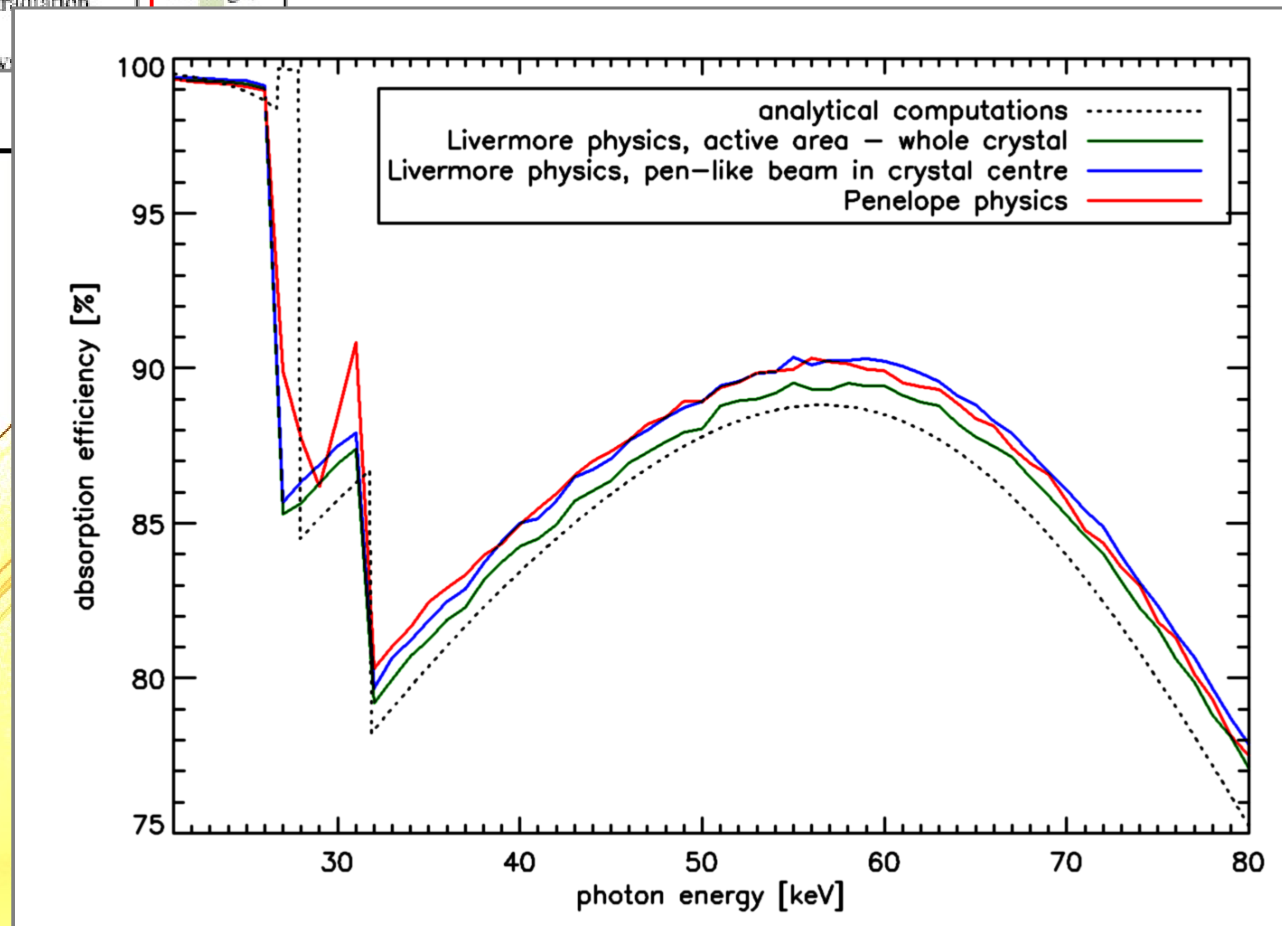
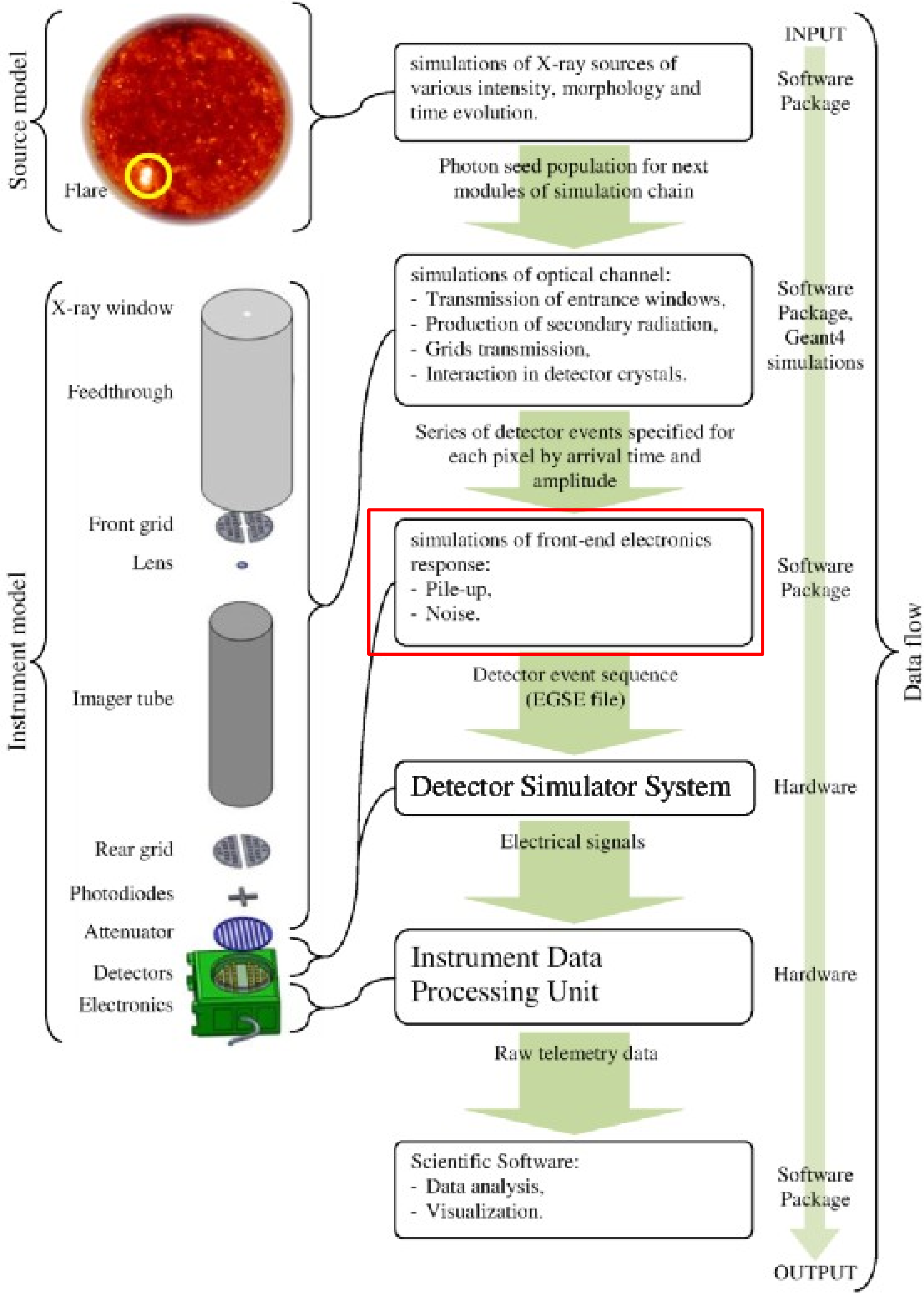


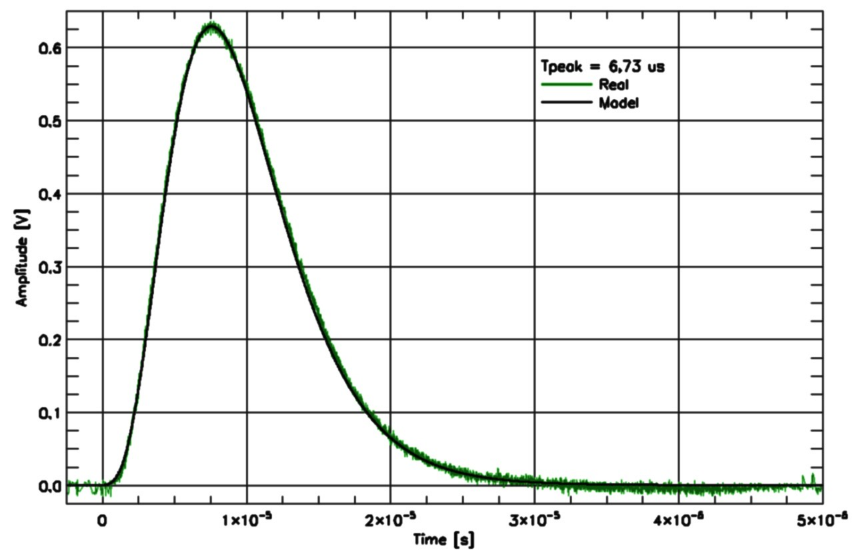




Simulations of front-end electronics response



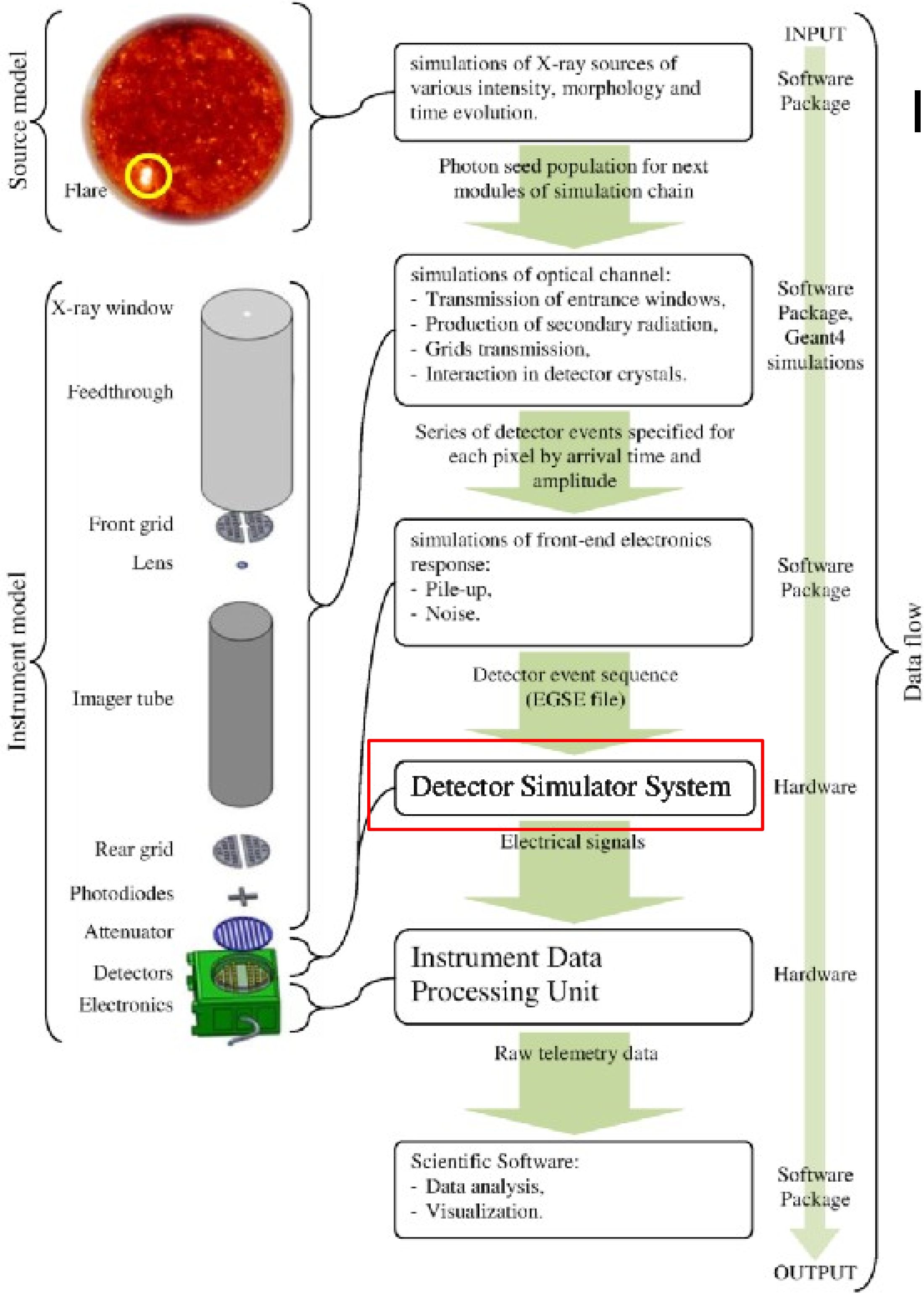
The simulated photons absorbed in detector crystals produce a signals that are processed by detector front-end electronics to shape pulses.



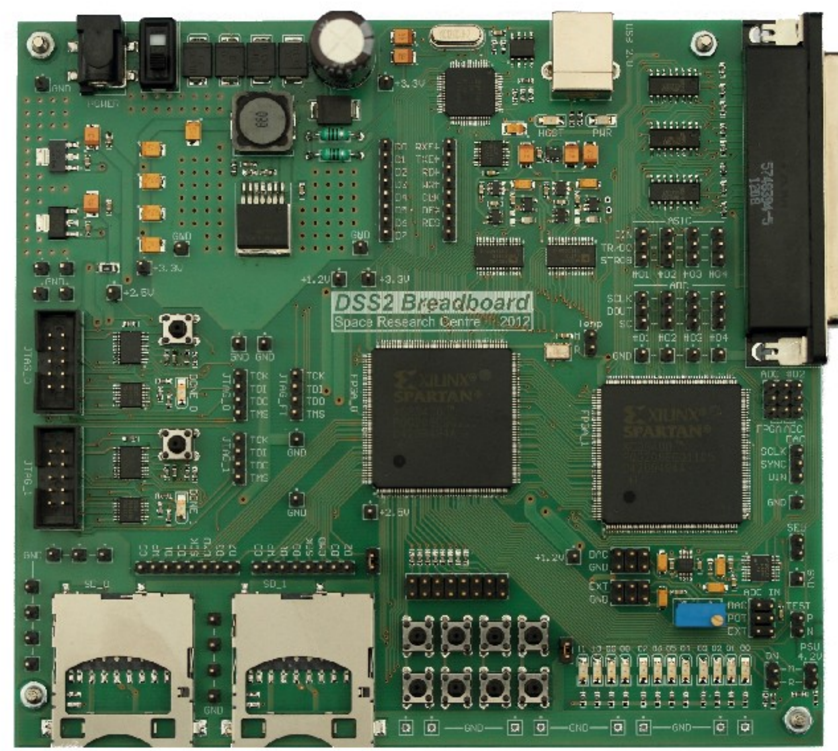
Two effects that need to be taken into account:

- a pulse pile-up
- electronics noise

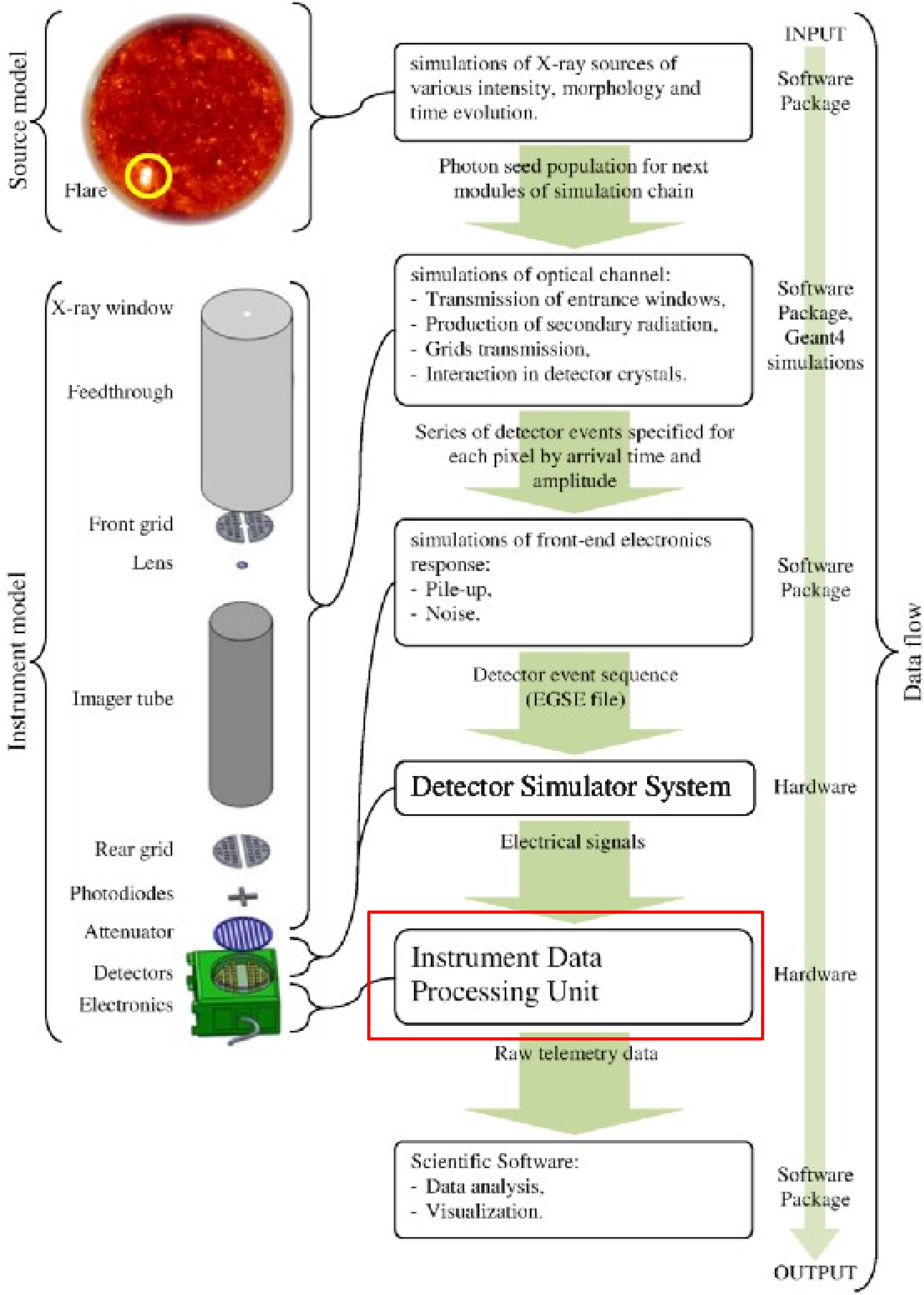
Injecting the data to IDPU using hardware detector simulator



The detector simulator is a hardware device which allows injecting to IDPU an arbitrary detector event sequence taken as the output of STIX detector module.



The Detector Simulator System



Data handling with real IDPU

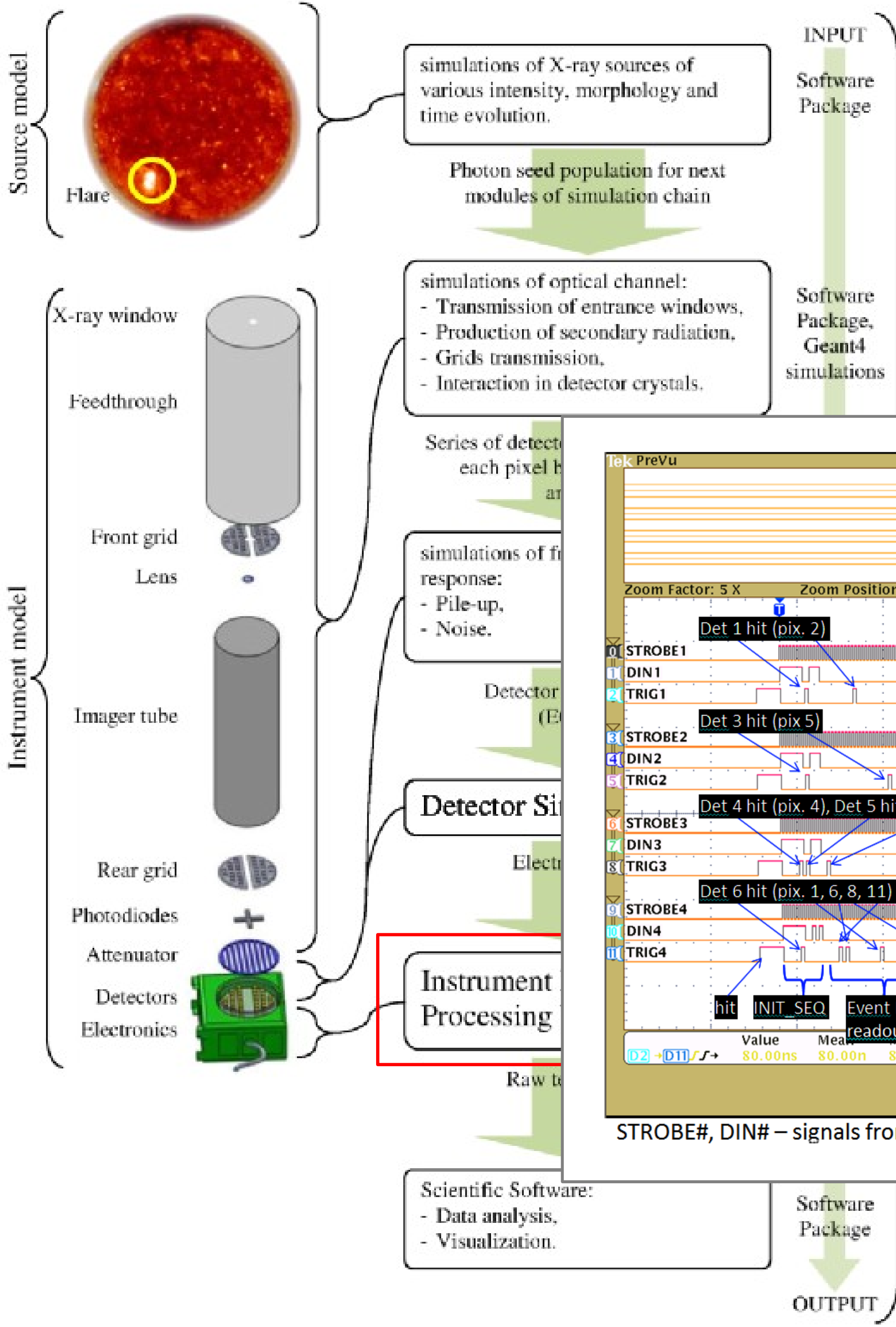
The IDPU controls the detectors and collects data from them. These data are processed by on-board data handling algorithms.

The on-board algorithms perform **data selection and compression** based on the solar flare detection and adaptive algorithms, supplemented by specific requests from the ground.

Other data processing functions include:

- quick-look of a data accumulations;
- live-time measurements;
- background monitoring;
- on-board coarse flare location;
- acquisition of aspect system data;
- the quiet-time long-term accumulation of background counts to monitor the detector energy calibration

Data handling with real IDPU



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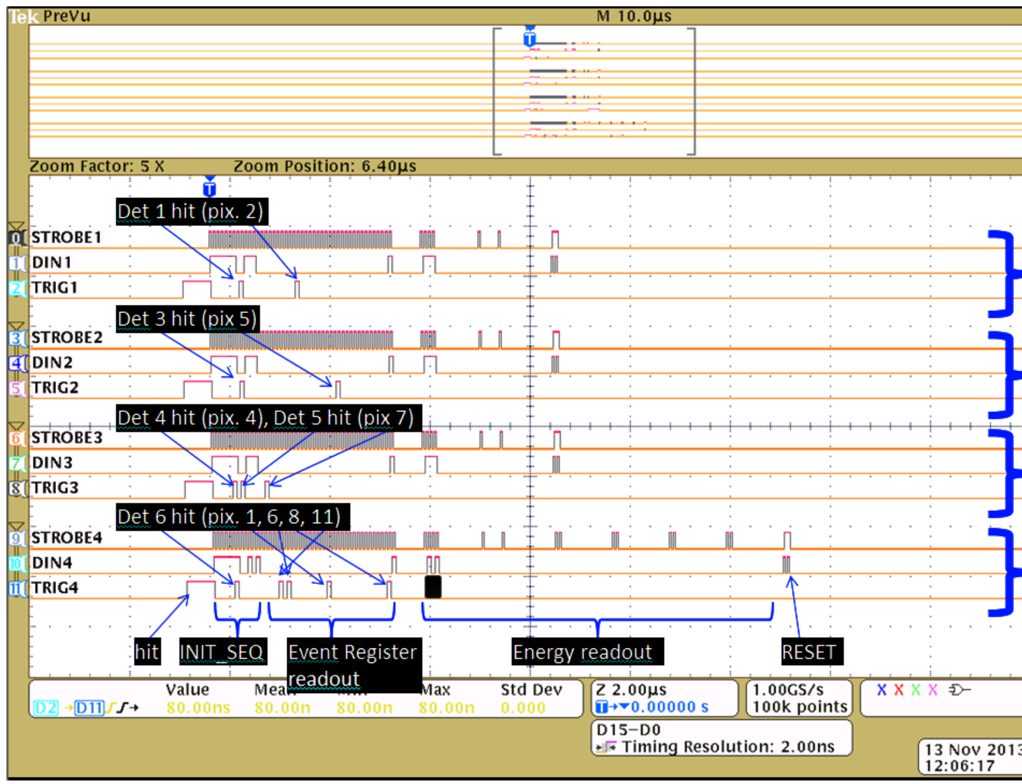
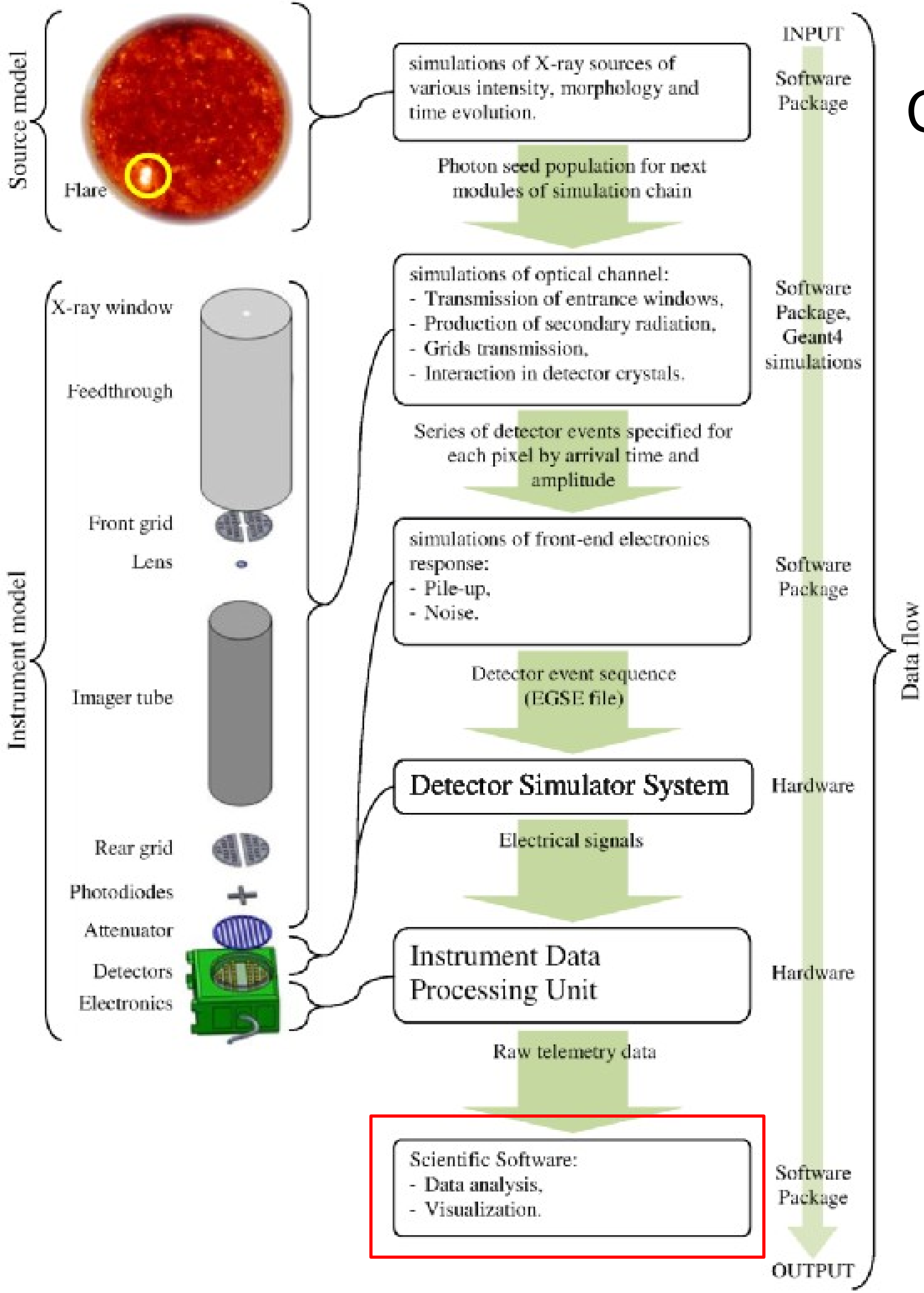


STROBE#, DIN# – signals from IDPU; TRIG# – signals from detectors.



Comparison of output data with input photon population

The scientific and housekeeping data are monitored using dedicated EGSE software or they are converted to FITS files that can be used as an input for science analysis software.

The analysis of output data using the EGSE software allows verifying whether the data have been correctly processed by the IDPU.

Using the science software the spectra, light curves and reconstructed images may be compared directly with the simulated sources.

Summary

- The instrument will provide the observations of solar flares in HXR range that allows understanding the electron acceleration mechanism in the solar corona and their transport through the interplanetary space.

- To support the instrument development a complex instrument simulations are being prepared.

- The simulation will cover entire data flow
  - beginning from solar photon population at origin
  - passing through the instrument model
  - resulting in data seen at the instrument output.
  -

- The novelty simulation approach combines a software simulation of sources based on:
  - RHESSI data,
  - a simulation of STIX imager and sensors (in some cases using GEANT4 toolkit)
  - finally injecting the simulated data to STIX IDPU using dedicated hardware detector simulator.

- In this way, obtained output data can be compared with known input sources characteristics in order to carry out the analysis of instrument response.