Search for GRBs with MXT telescope onboard of SVOM satellite

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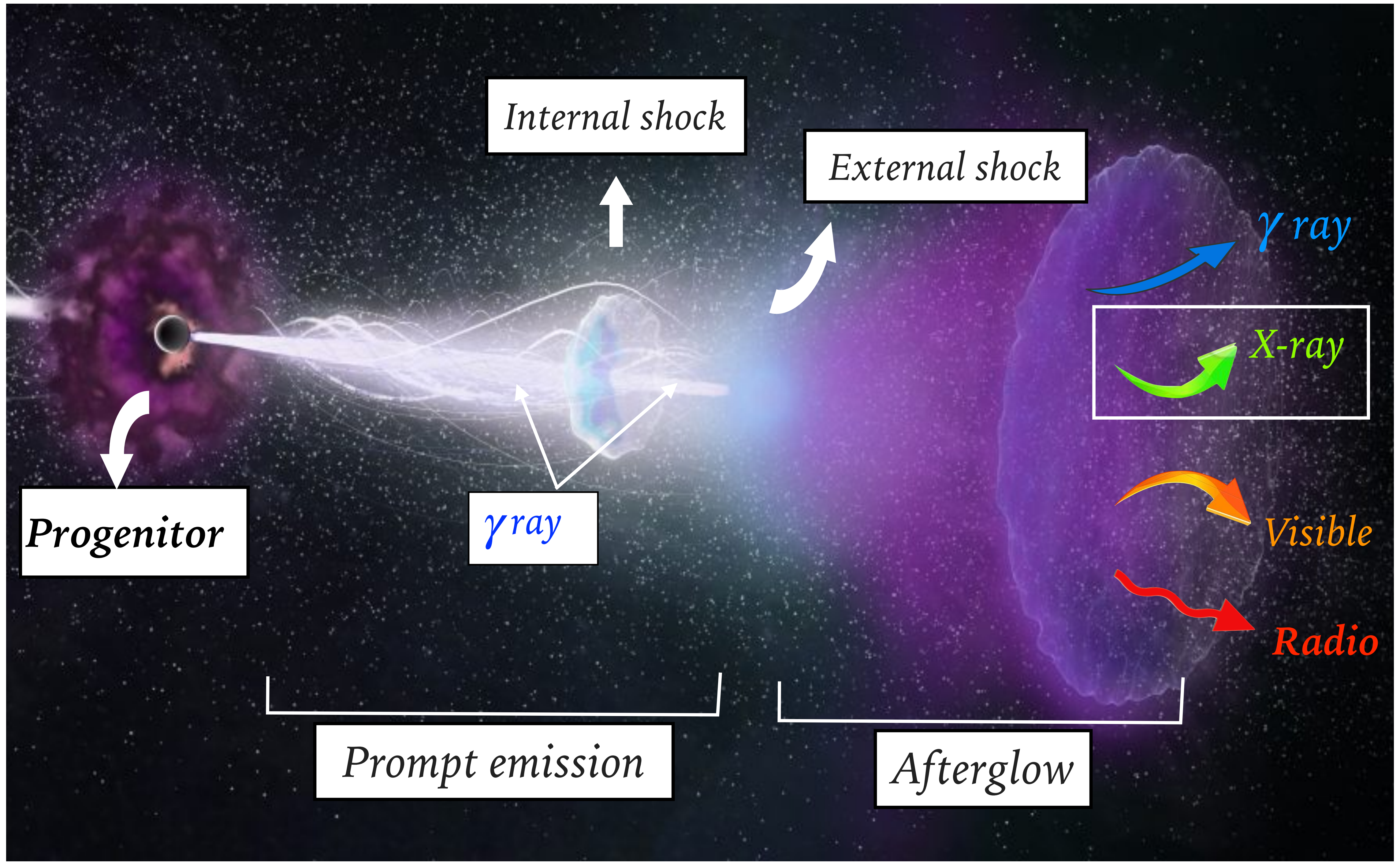
(I) Physics of Gamma Ray Bursts (GRBS):

- Progenitors & formation.
- Physics interests.

Physics of Gamma Ray Bursts (GRBs)

- *What are GRBs?*
  - *Most energetic electromagnetic phenomena in the universe.*
- *GRBs progenitor candidates*
  - *Core collapse* → *long burst*
  - *Coalescence of 2 compact objects.* → *short burst*
- *Physics interests*
  - *Cosmological probes.*
  - *Study the nature of the progenitors.*

- *GRBs formation:*

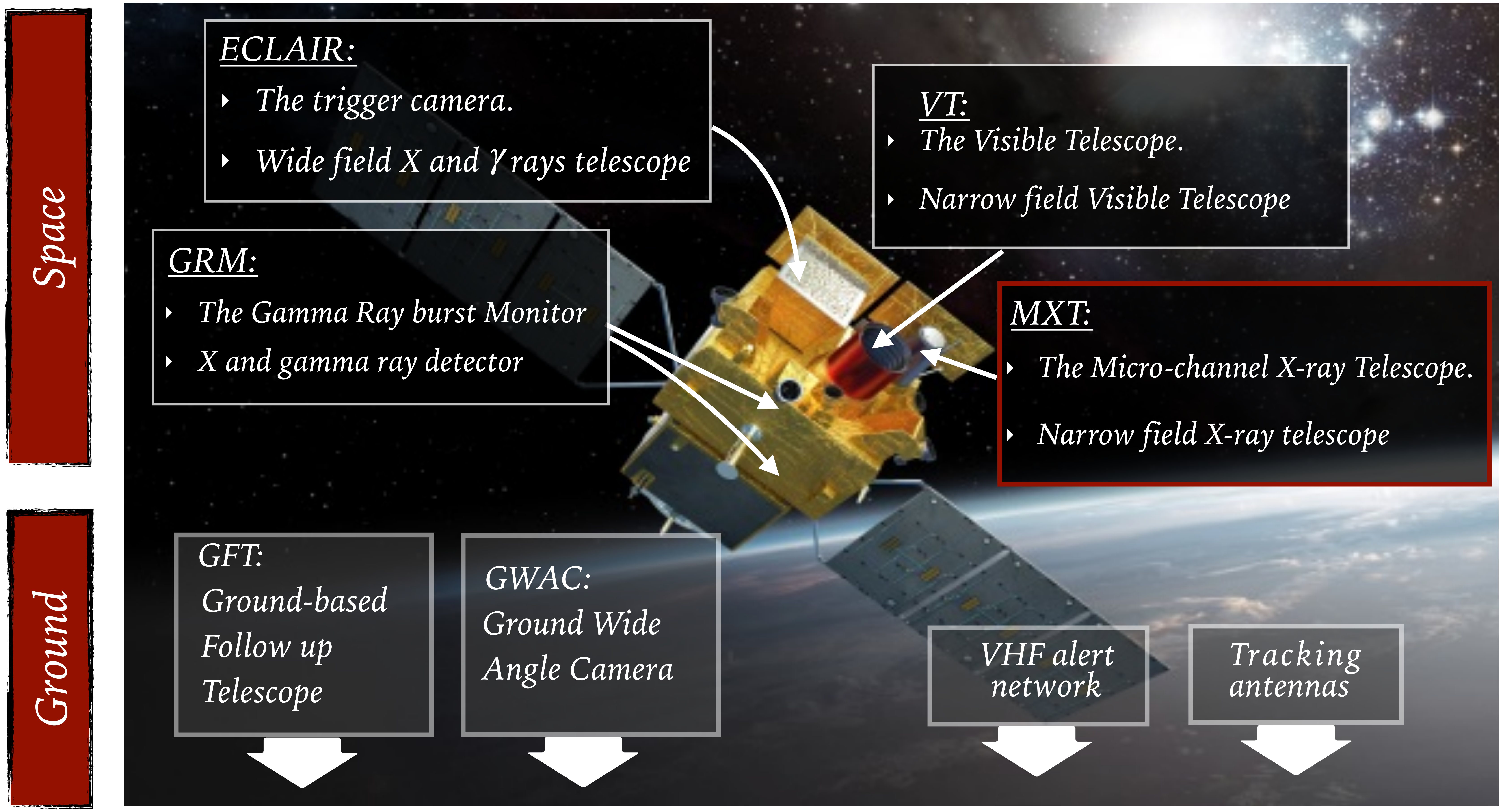


fireball model

(II) SVOM satellite overview.

SVOM satellite

- **S**pace **V**ariable **O**bjects **M**onitor.
- A French-Chinese mission (with contribution from Germany & UK), dedicated to GRBs.
- To be launched end 2021, duration 3 + 2 years.



(III) Detection of GRBs with MXT

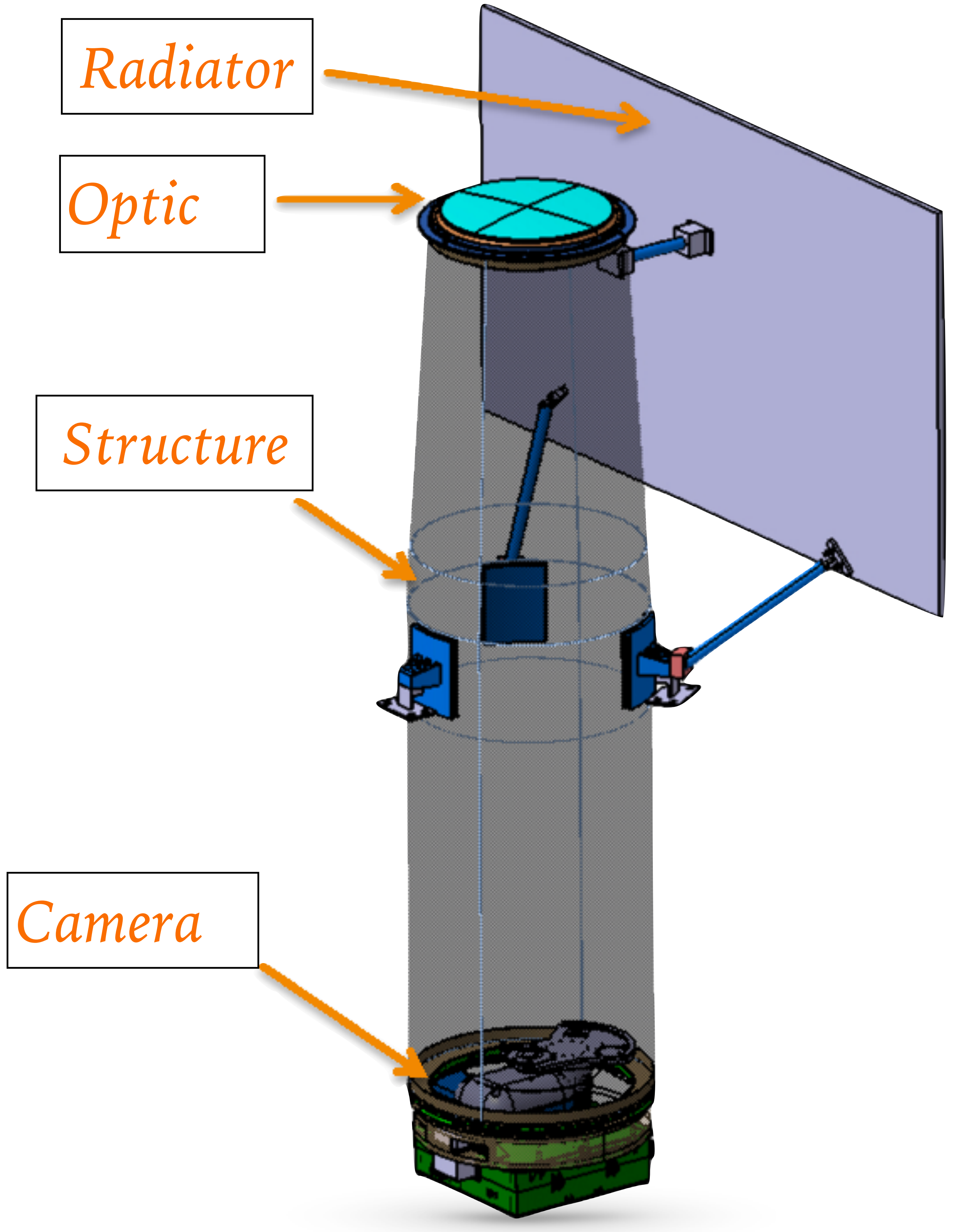
The Micro-channel X-ray Telescope (MXT)

Main characteristics:

- Soft X-ray instrument
- Triggered by ECLAIR telescope.
- Light and compact: ~35 kg & ~1.2 m.
- Focal length: 1m & FoV: 1.1° x 1.1°.

Main functions:

- Observe GRBs in X-rays (0.2-10 keV).
- Localize GRB afterglows (~1 arcmin).

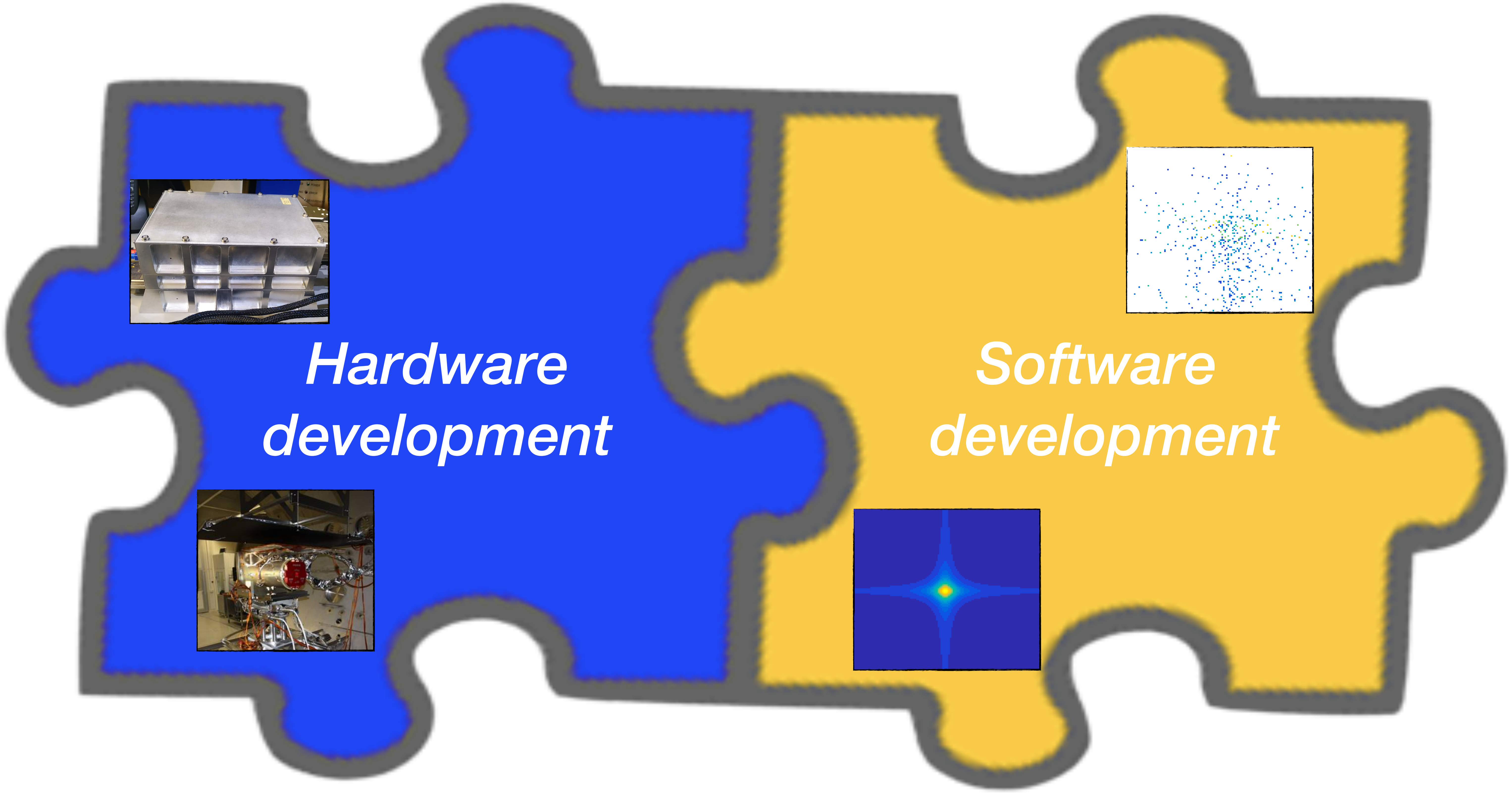


MXT subsystem

MXT performance

The telescope performance rely on :

- *Development at CNES, CEA, UoL, MPE.*
- *Test at PANTER facility In MPE-Germany*



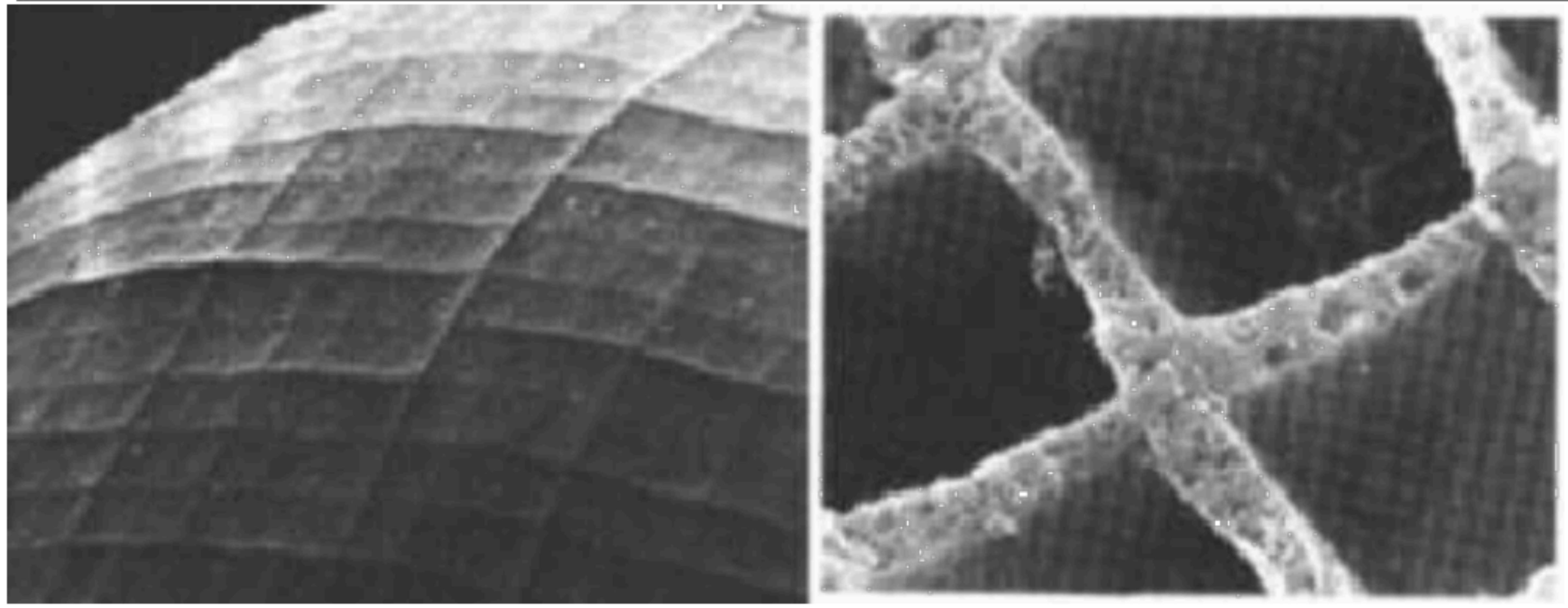
Development and test at IJCLab & CNES.

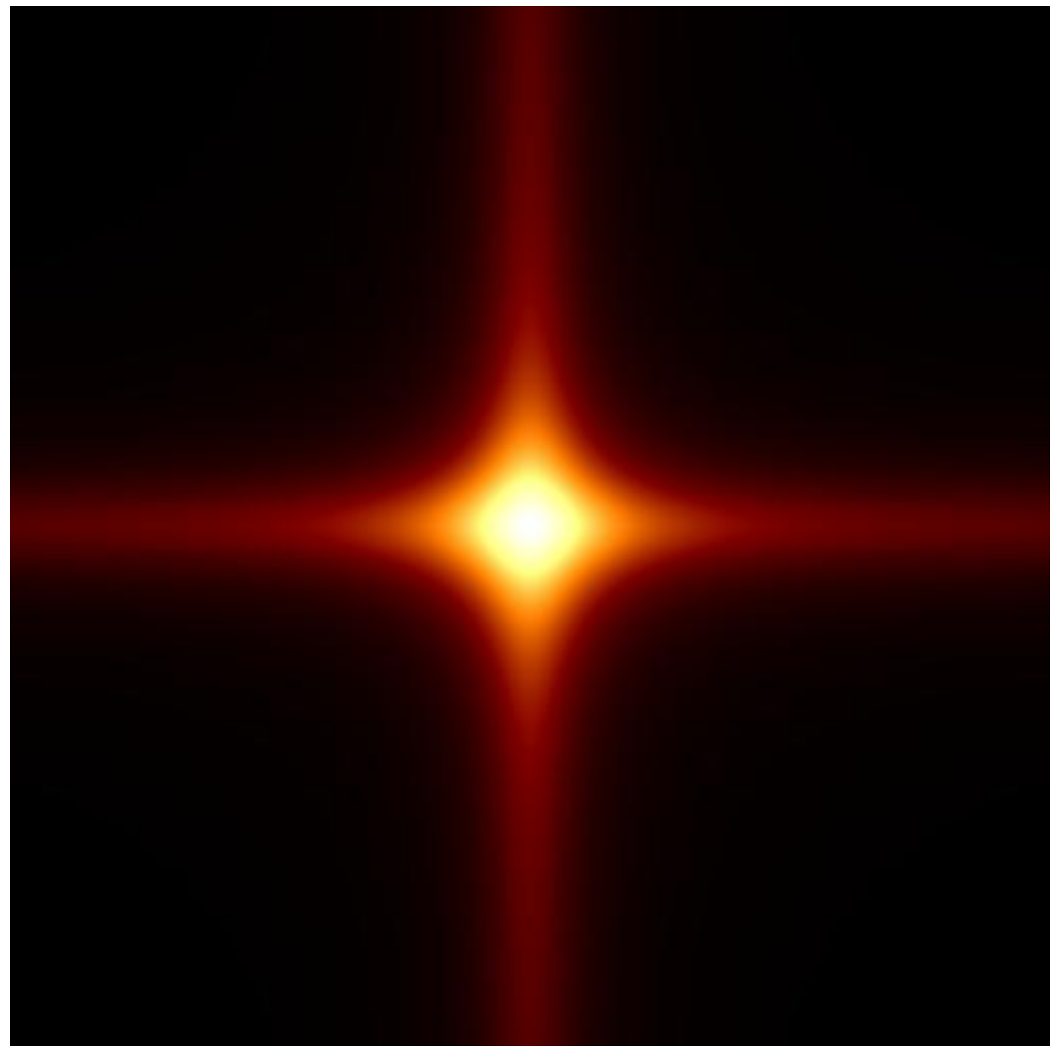
(IV) MXT hardware status:

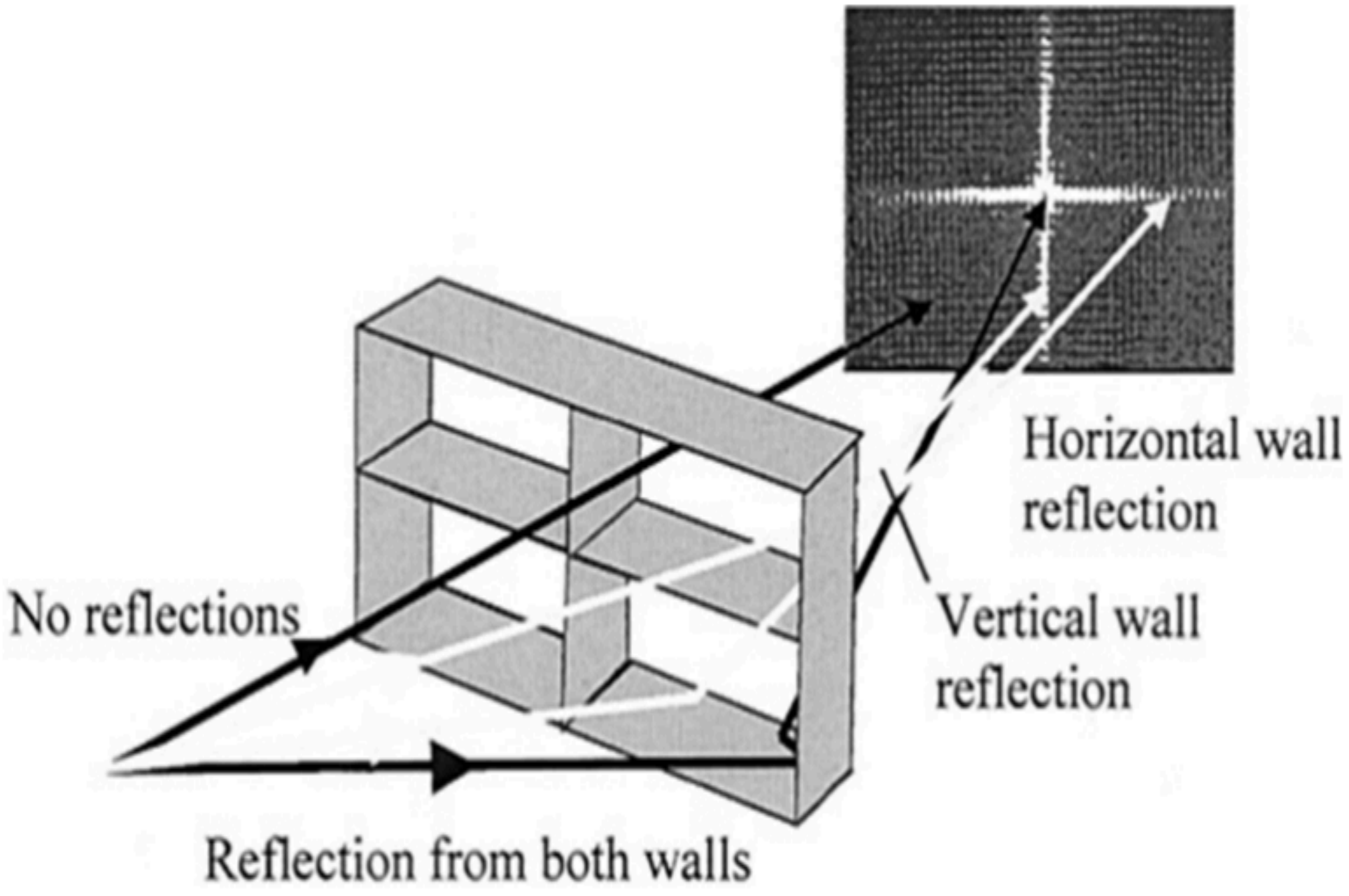
- Development & test of MXT subsystem.

MXT subsystem - optics

- *X-rays have a relatively low intensity → grazing incidence mirrors is used to collect enough photons.*
- *The MXT optics is based on a "**Lobster Eye**" geometry.*
- *Under the responsibility of UoL team.*
- *The Point Spread Function PSF: Central spot with 2 cross arms*

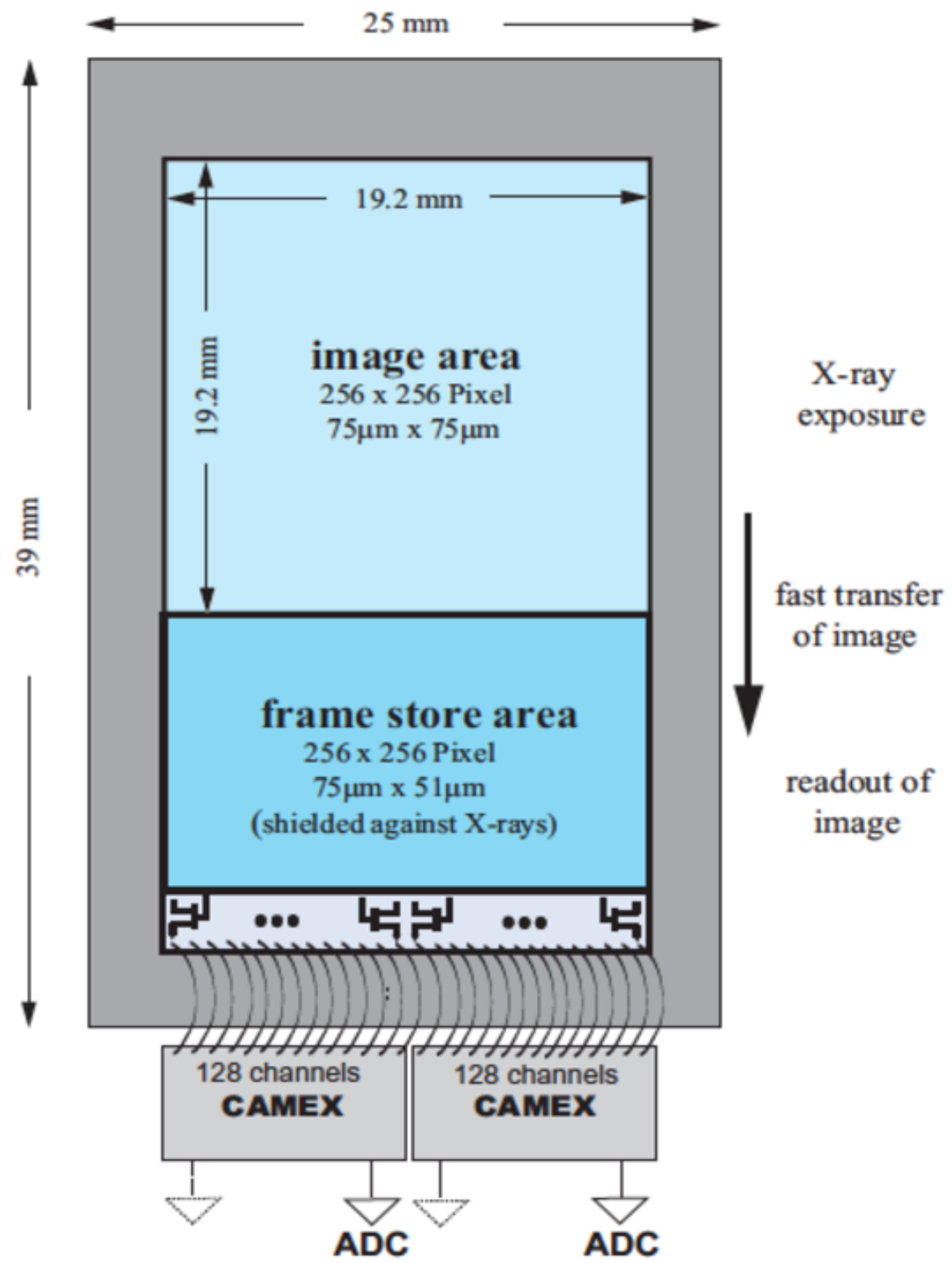






MXT subsystem - camera

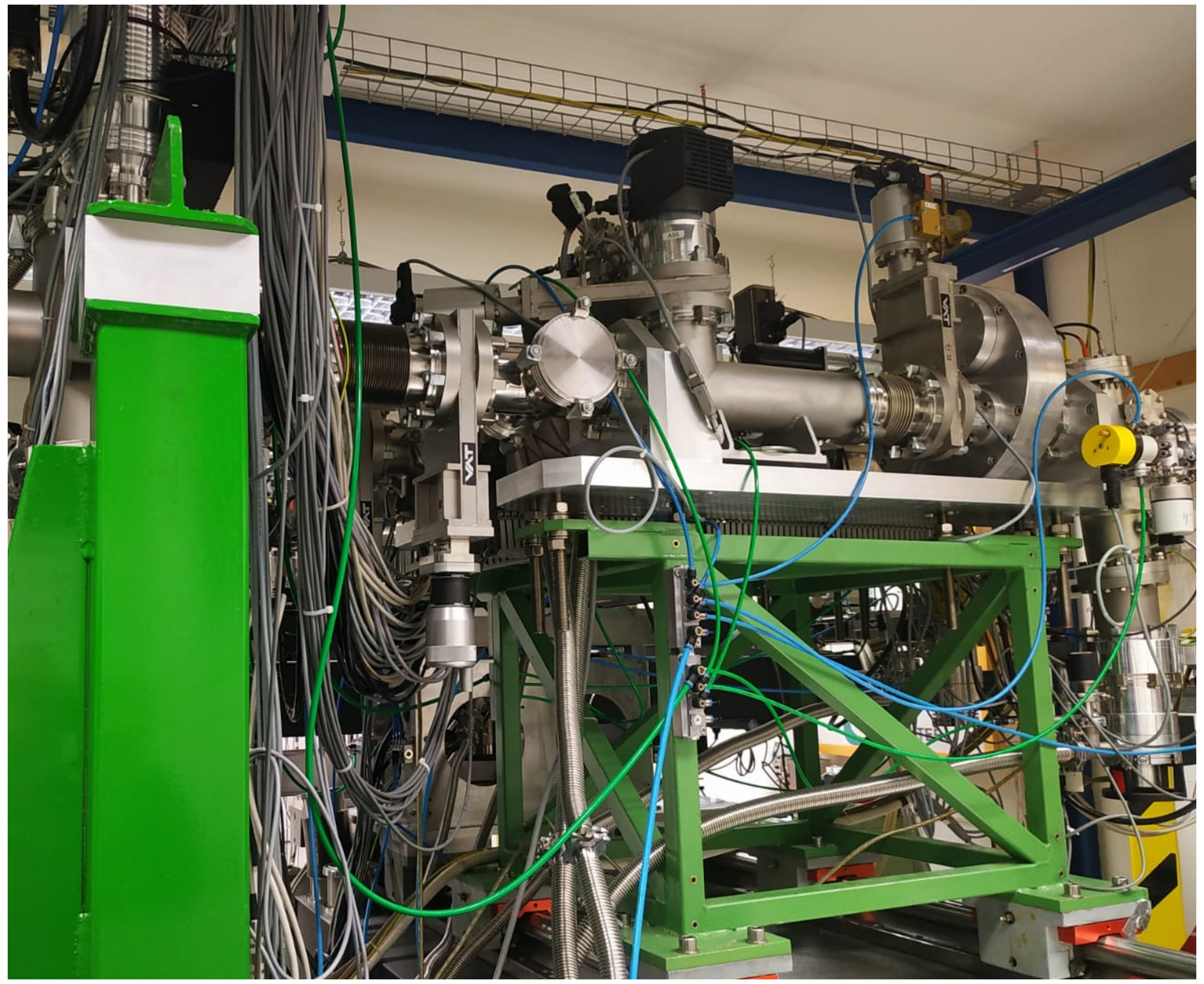
- *Under responsibility of CEA team.*
- *Si based pn CCD.*
- *256 x 256 75 µm side pixels.*
- *Associated with FEE (Front-End Electronics) based on two CAMEX.*
- *Excellent low-energy response.*

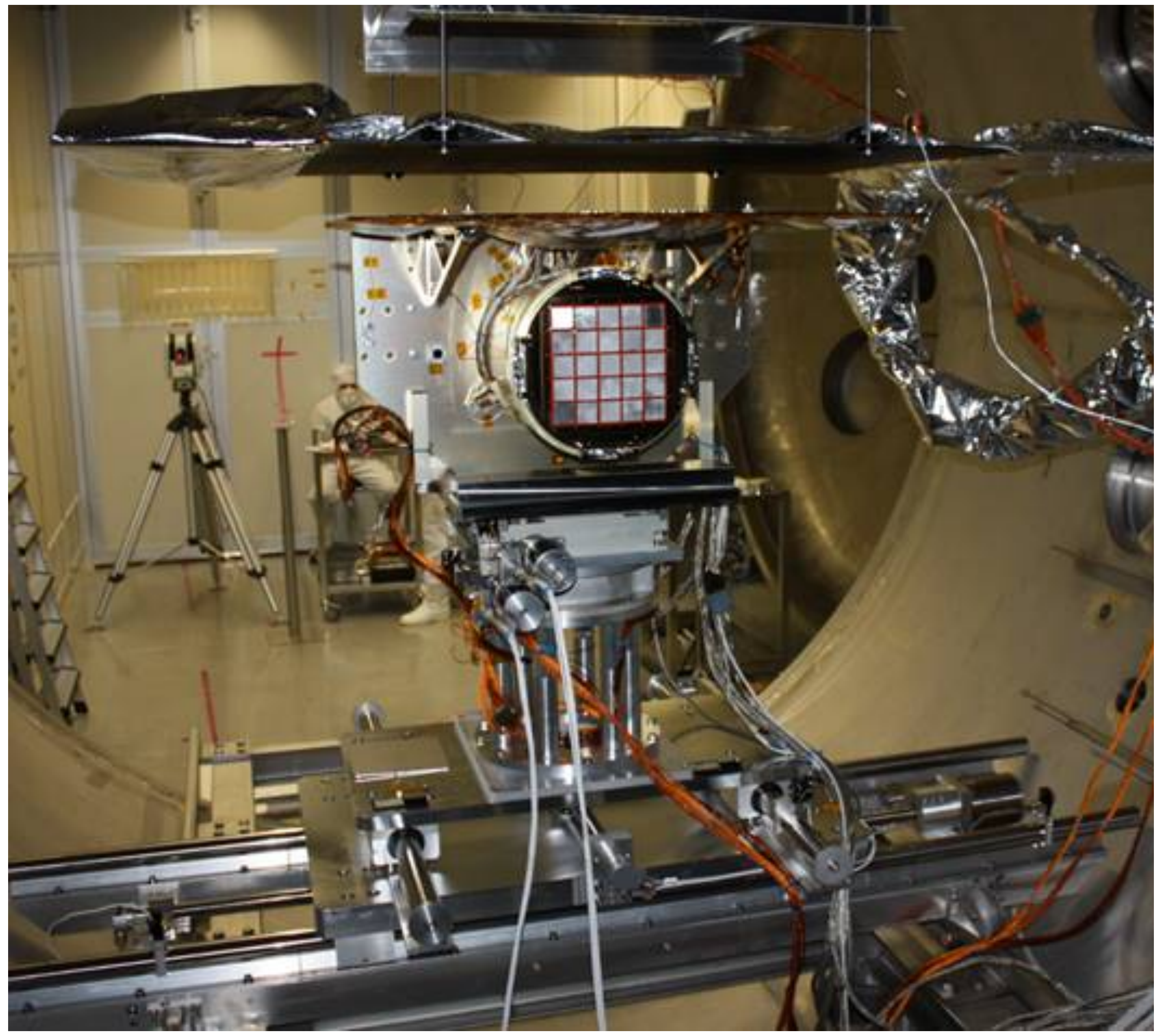


MXT subsystem test

Test environment:

- PANTER X-ray facility at Munich.
- 22/01/2020 - 22/02/2020
- 130m long vacuum tube (Ø1 m), with the X-ray source at one end and the test chamber at other end.





MXT subsystem test

Test MXT detector:

- ➤ Test detector performance with different temperatures (-45°, -65°, -75°).
- ➤ Characterize detector performance with different sources:

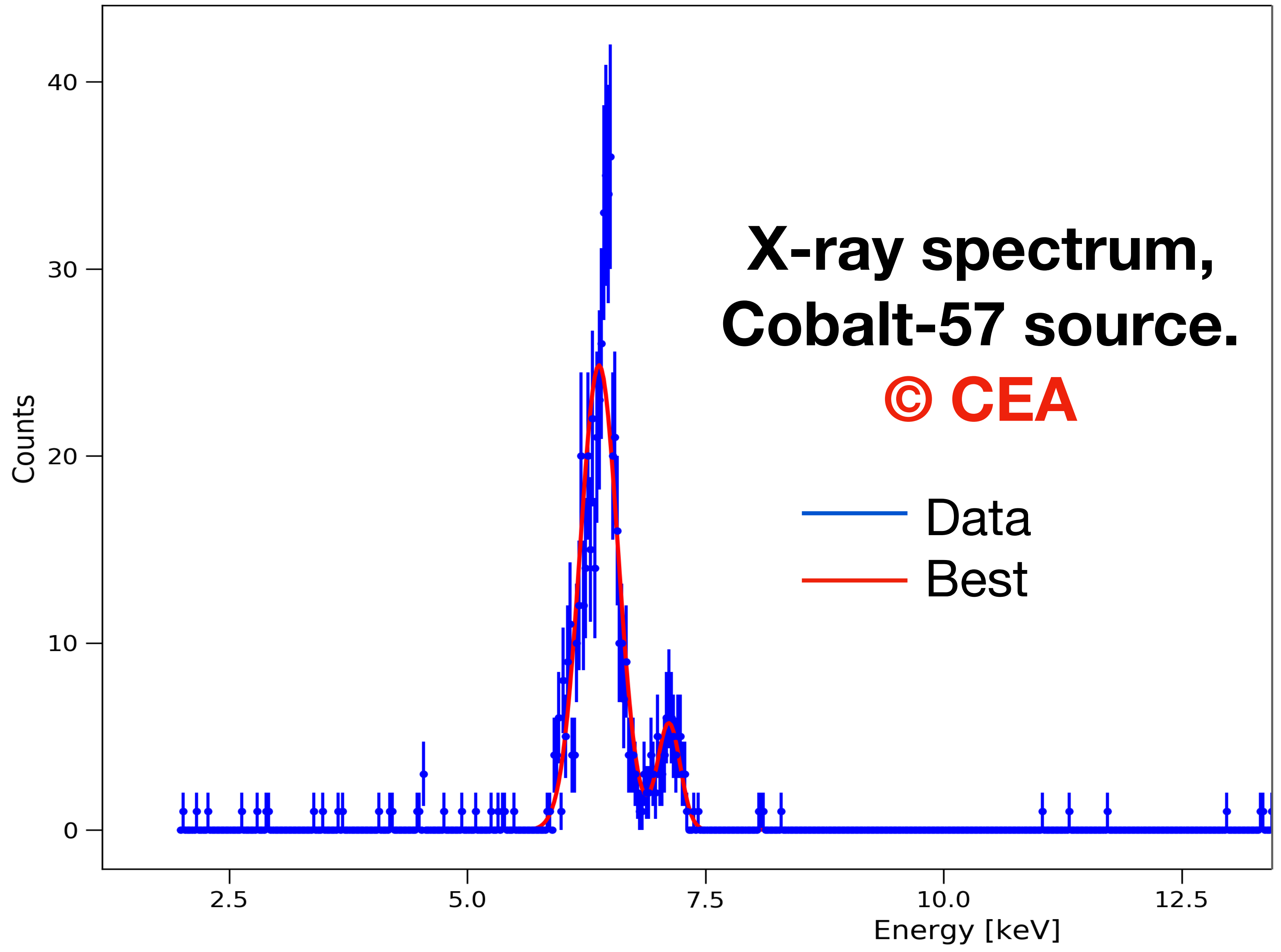
  Ge (9.90 keV), Cu -L (0.93 keV), C -K (0.28 keV), O -K (0.53 keV).

Test MXT optics:

- ➤ Test optics performance with different temperatures (15°, 20° ,25° ,30°).
- ➤ Test different positions of telescope relative to X-ray source.

Status:

Successful tests at PANTER (camera, optics, characterization …).



(IV) MXT software status:

- MXT Camera frames simulation.
- Development and test of onboard scientific software (SCSW).

SatAndLight - simulation tool

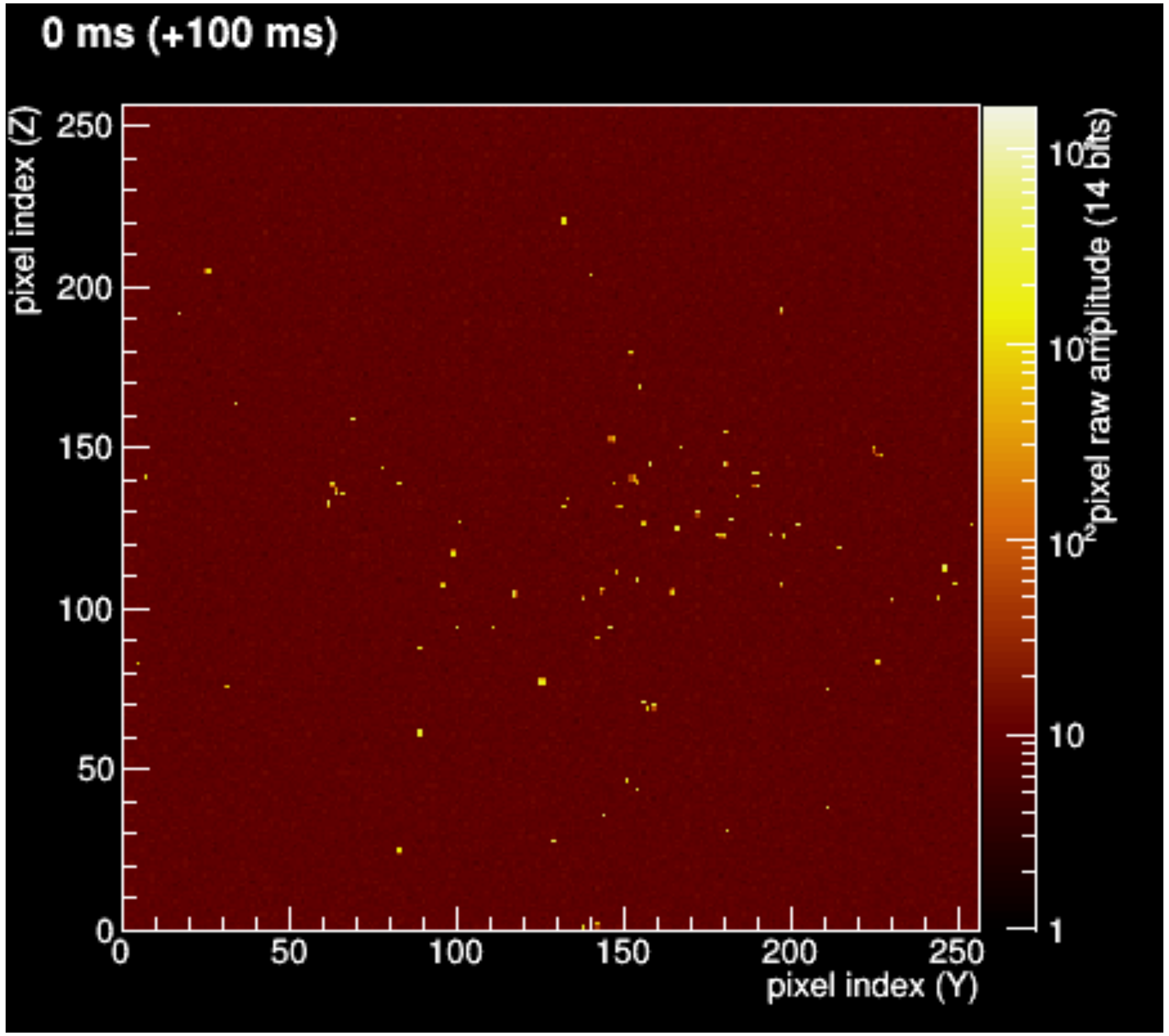
Simulate the input frame for SCSW:

1.Simulated MXT dark sequence main features:

- *1 frame / 200 ms.*
- *Noise (offset and sigma).*

2.Simulated MXT observation sequence main features:

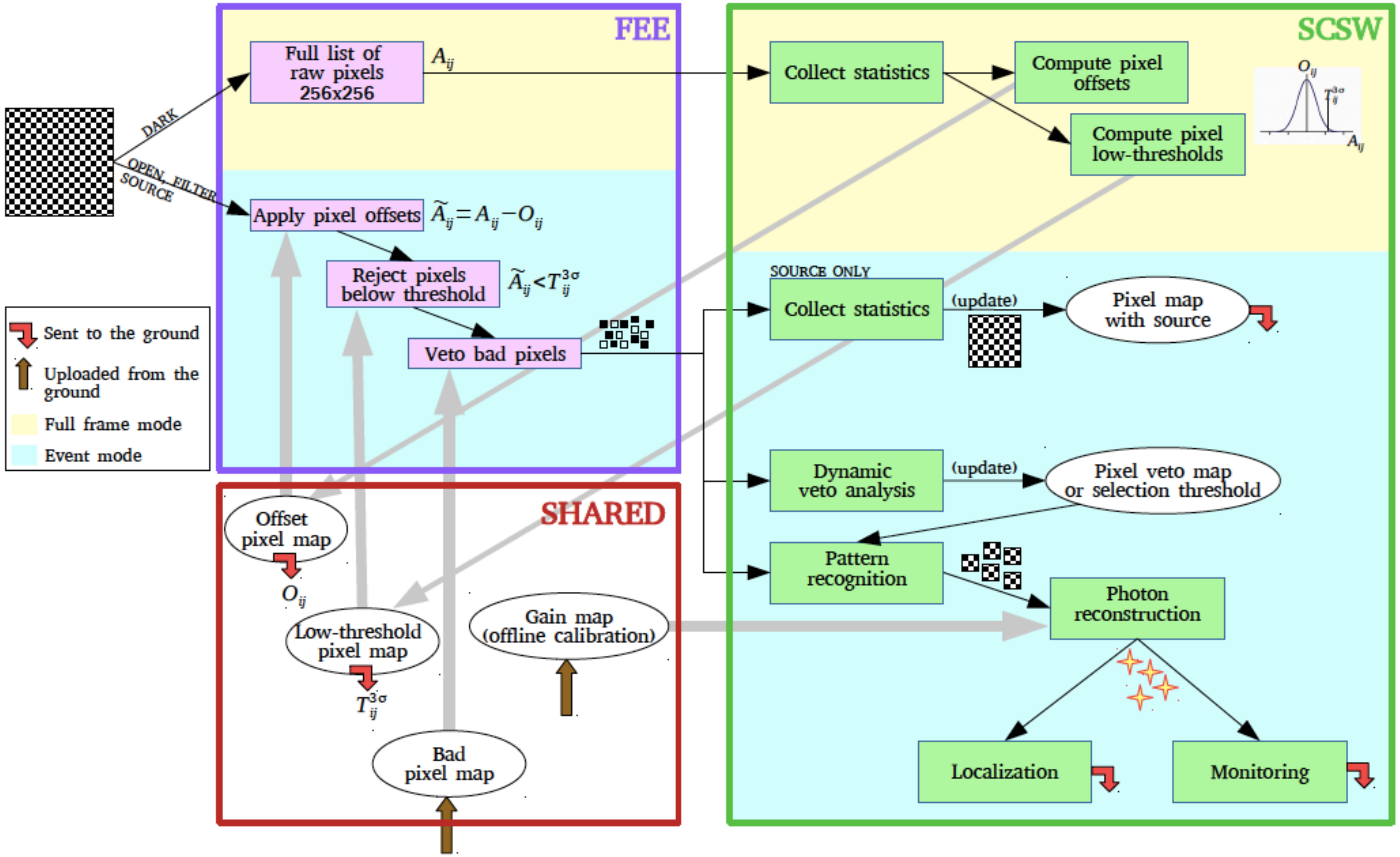
- *1 frame / 100 ms.*
- *Source position, light curve and energy spectrum can be tuned.*
- *The photons position is shifted according to PSF.*
- *Photons energy added on top of noise.*



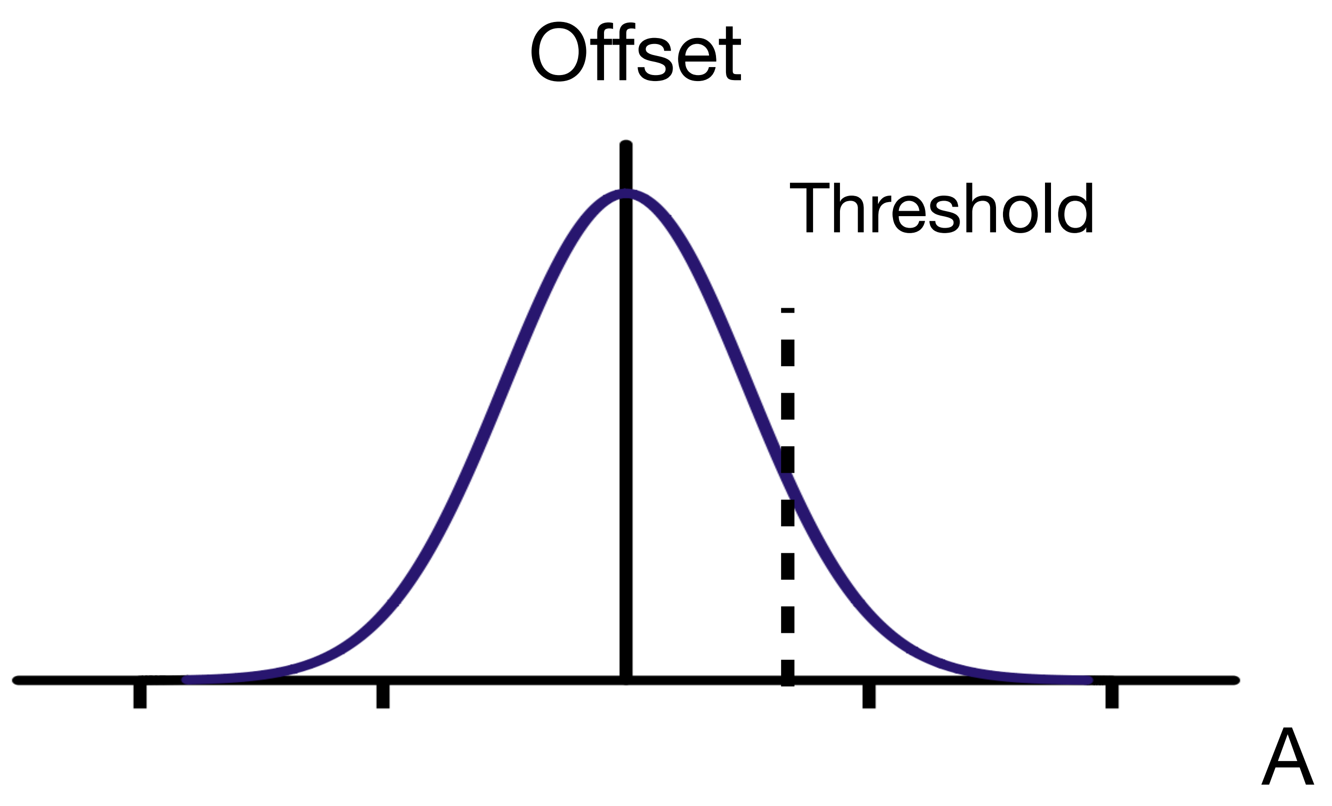
MXT onboard scientific software

Main algorithms:

- *Camera noise characterization.*
- *Source localization.*
- *Prepare and format science telemetry packets.*
- *Extract quick look products.*



Camera noise characterization algorithm - development



Objectives:

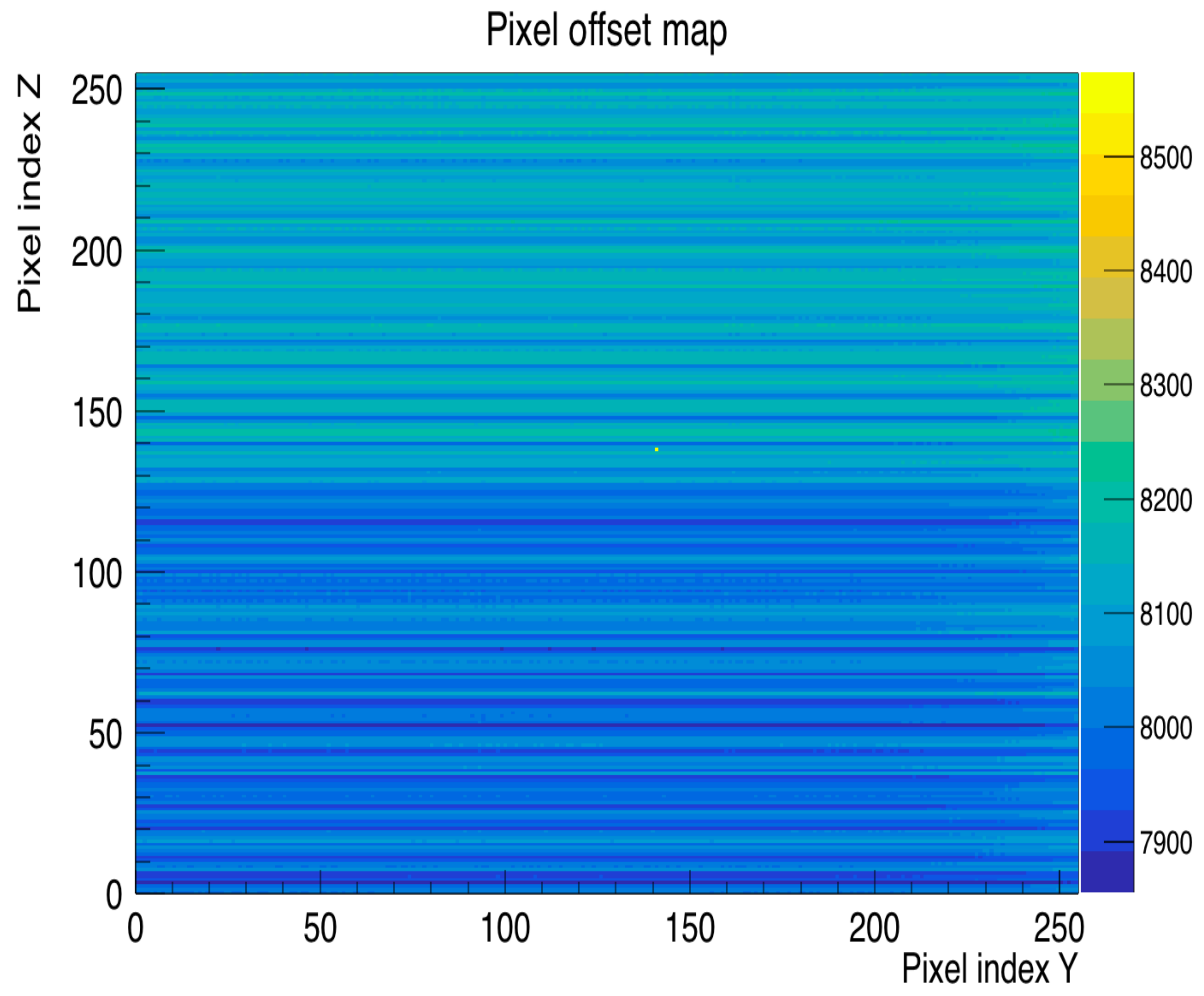
Compute the pixels noise offset & threshold maps.

Method:

- ➤ Mean (biased by cosmic ray) & Median (Need a big memory) ✗ →

  use the "Mean" method but set a threshold to reject outliers.

- ➤ Offset (threshold) map is filled with noise mean (4σ) after outlier rejection.



Status:

implemented inside the partition (SCSW) and tested with real camera frames.

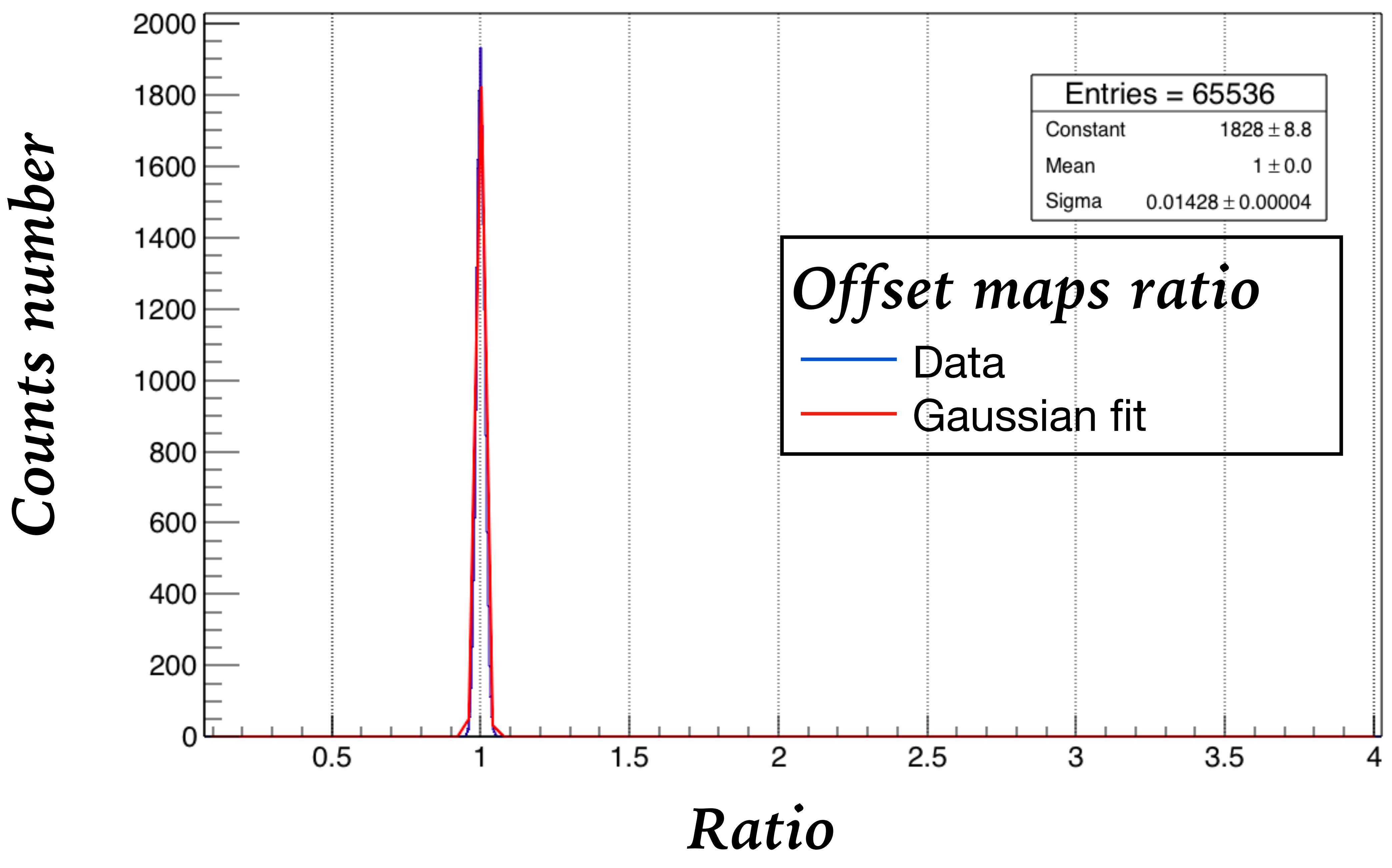
Camera noise characterization algorithm - test

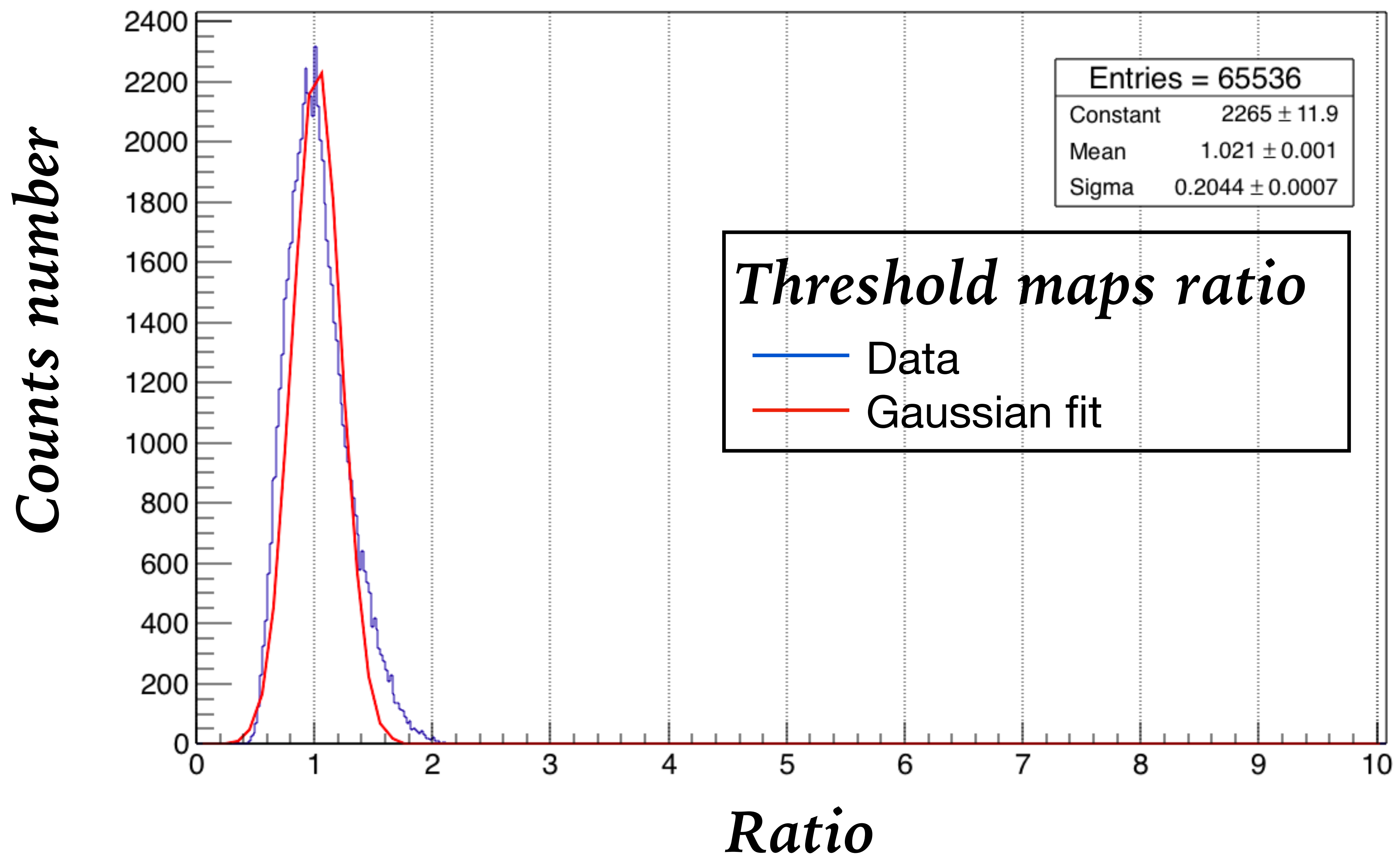
Objective: *test outlier rejection*

Input: *2 simulated sequences with same noise distribution, and N frames. One with outlier & one without*

Output: *~ same offset & threshold maps from both sequence →*

ratio of offset & threshold distributions ~ 1 → robust method in case of outlier.





Source localization algorithm - development

1. Photon reconstruction and clustering:

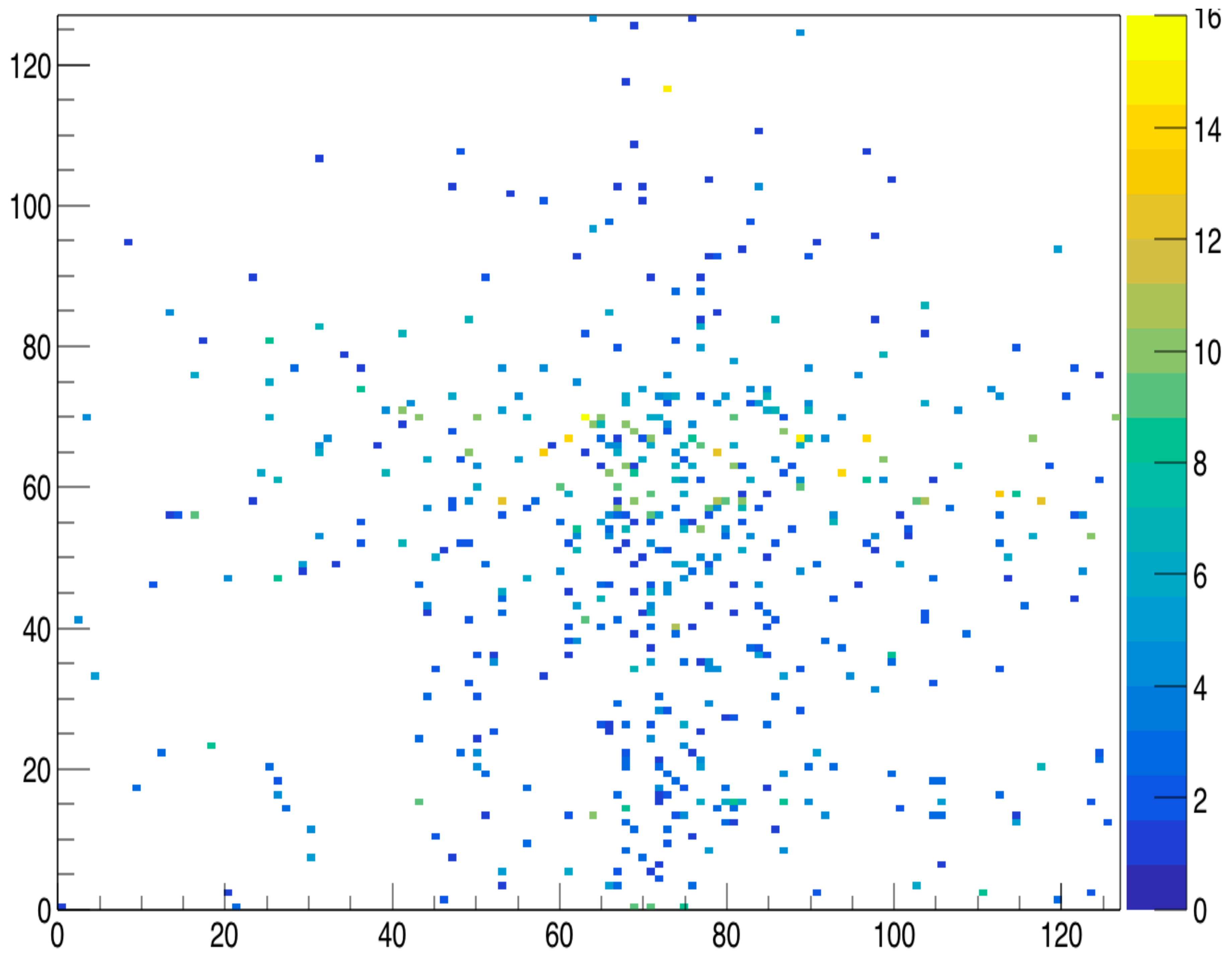
Input:

Simulated frame sequence with ~ realistic source simulation

Method:

- *Cluster contiguous pixels.*
- *Identify photon from cosmic rays.*
- *Photon position is given by barycentre.*
- *Fill the photon cumulative map:*

Photon cumulative map



Status:

Implemented inside the partition.

Source localization algorithm - development

2. Correlation between photon map & PSF:

Input:

Photon cumulative map, and PSF transformed to Fourier space.

Method:

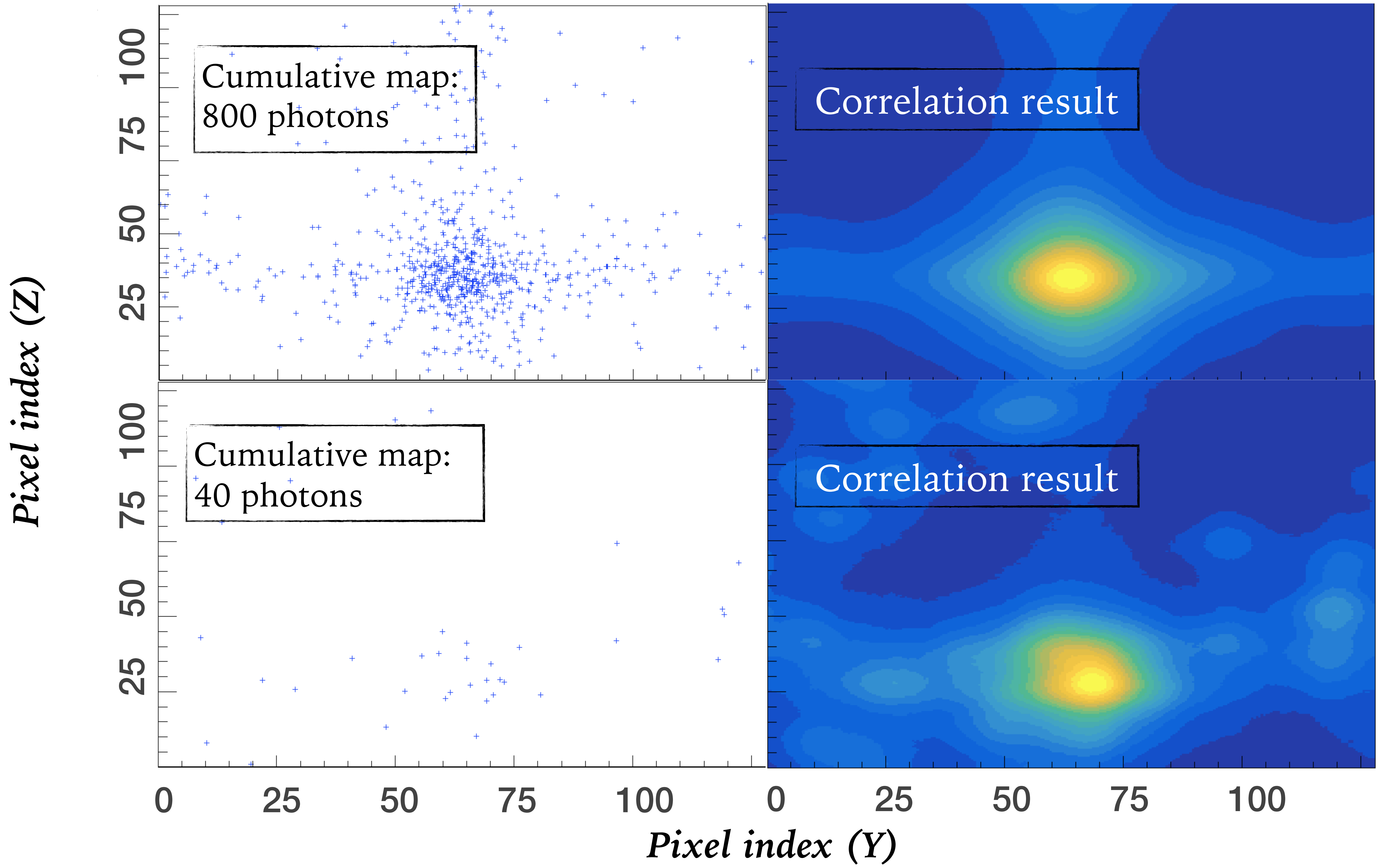
- Correlation(PixY, PixZ) = IFT[FT{Photon_map(PixY, PixZ)}* x FT{PSF (PixY, PixZ)}].
- A light FT library must be used.
- A desecrate Fourier transform (DFT) is implemented inside the partition.

Status:

DFT algorithm: Implemented inside the partition.

Correlation: Implementation inside the partition is ongoing (implemented in prototype)

Correlation prototype results



For prototype:

FFTW library is used to transform photon map & PSF

Source localization algorithm - development

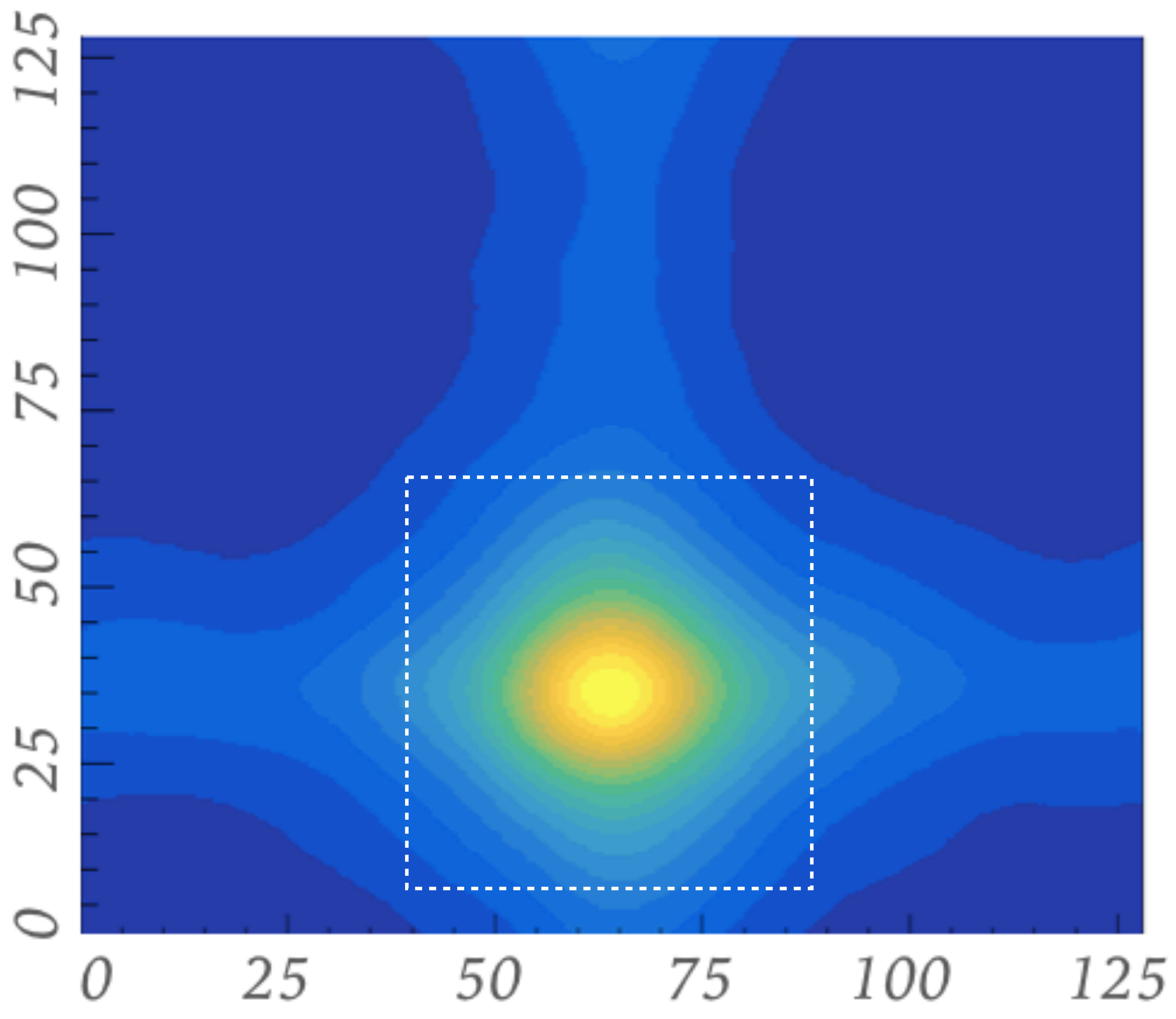
3. 2-D barycentre:

Input:

The correlation map

Method:

- Search for the max.
- Compute barycentre within N pixels window.
- Source peak position is given by barycentre.



Status:

Not implemented inside the partition yet (implemented in prototype).

Summary

MXT Hardware:

- *Qualification model was fully tested at PANTER in Feb. 2020*
- *Flight model test will be in June 2020.*

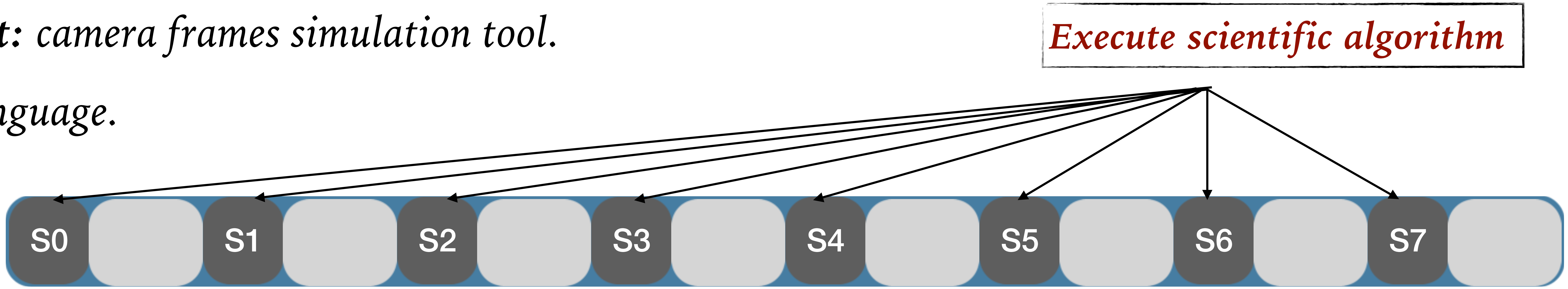
MXT software:

- *Noise characterisation, clustering, X-band, VHF band algorithm are implemented inside the partition.*
- *Localization algorithm implementation is ongoing.*
- *The data from PANTER test will be used to test and validate the SCSW.*

Backup slides

MXT software development environment

- ***Hardware:*** *virtual machine with CentOS Linux.*
- ***TSLEON:*** *a microprocessor core used to emulate the on-board MDPU.*
- ***XtratuM:*** *a hypervisor used to manage real-time processes.*
- ***Sandbox partition:*** *to write/read ports for SCSW.*
- ***SatAndLight:*** *camera frames simulation tool.*
- ***C :*** *coding language.*



The hypervisor implements a cyclic temporal windows in a major frame (MAF).

1 MAF last for 1 sec: the scientific tasks are distributed over 8 slots of 50 ms each, triggered every 125 ms.

SatAndLight - simulate camera frames

- *Simulate realistic sequences of camera frames for both camera modes:*
  - ***FULL_FRAME mode:*** *camera shutter is closed -> simulate a dark sequence (noise only).*
  - ***EVENT mode:*** *camera shutter is open -> simulate a bright sequence (with GRB source).*
- *The sequence is converted to binary format and used to feed the partition:*

EVENT

T_DET_N	Event #1	Event #2	…	Event #N	ASIC SEU	FEE Status	Nb Hit	Frame Time
2B	4B	4B		4B	2B	1B	2B	2B

FULL_FRAME

T_DET_N	Pixel (128,255)	Pixel (0,255)	Pixel (129,255)	Pixel (1,255)	Pixel (130,255)	Pixel (2,255)	…	Pixel (254,0)	Pixel (126,0)	Pixel (255,0)	Pixel (127,0)	ASIC SEU	FEE Status	Nb Hit	Frame Time
2B	4B	4B	4B	4B	4B	4B		4B	4B	4B	4B	2B	1B	2B	2B

Start address — Message size →

Algorithms test

Onboard software test:

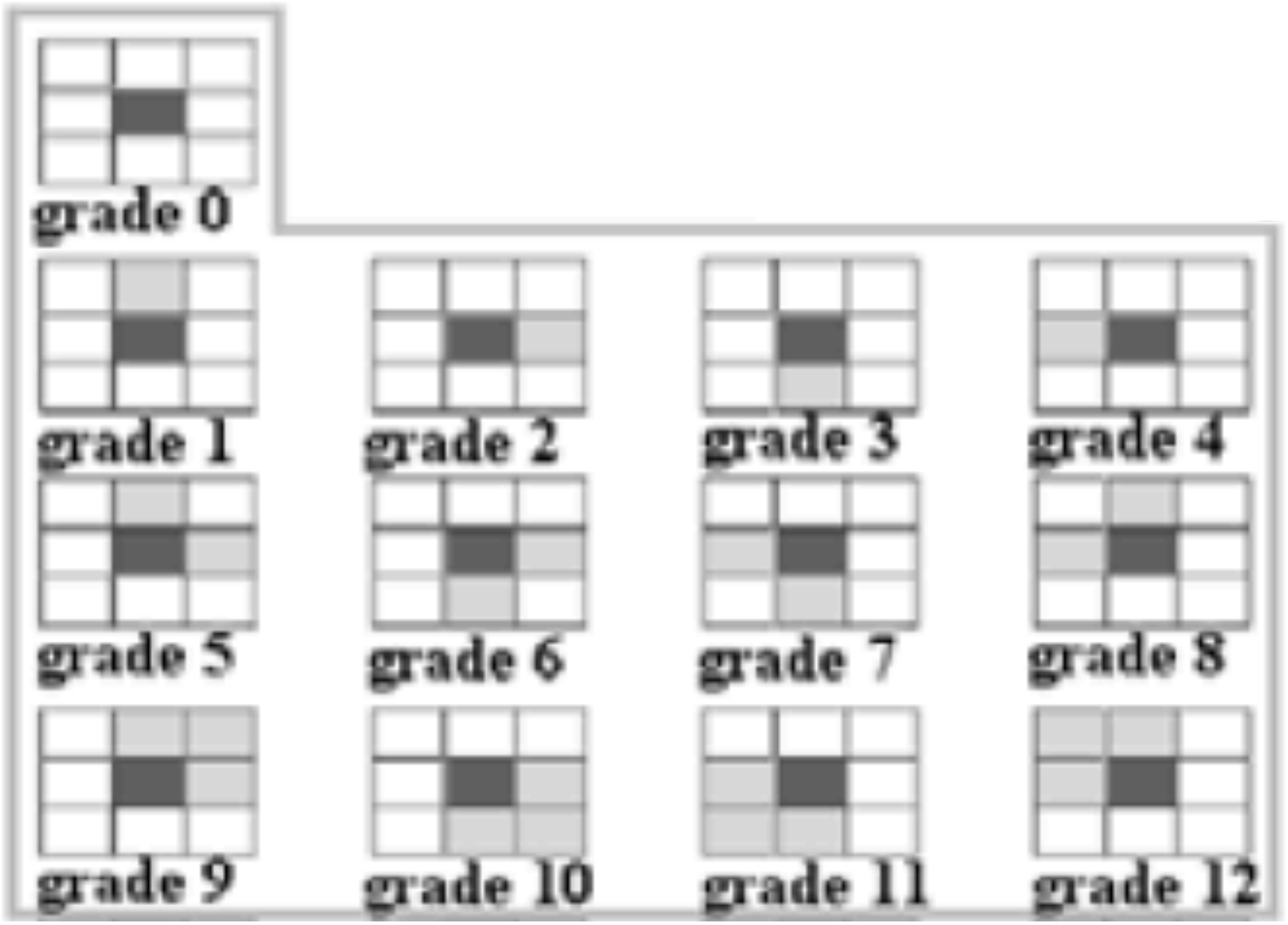
Functional test:

Test if the result satisfy the requirements

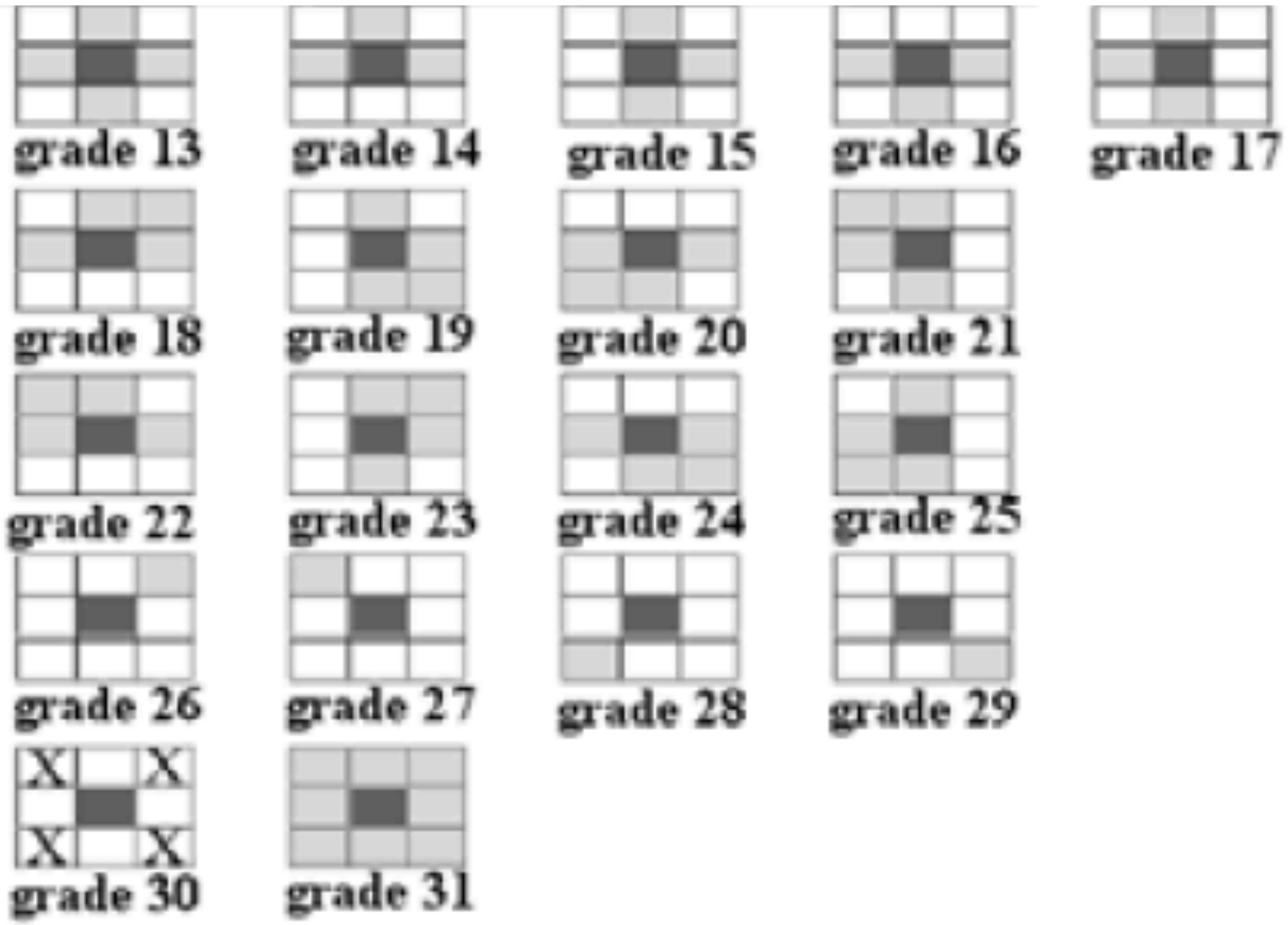
Performance test:

- *Test the time needed to run a specific algorithm*
- *If the algorithm does not fit in specified time slots → optimize*

Swift grade system

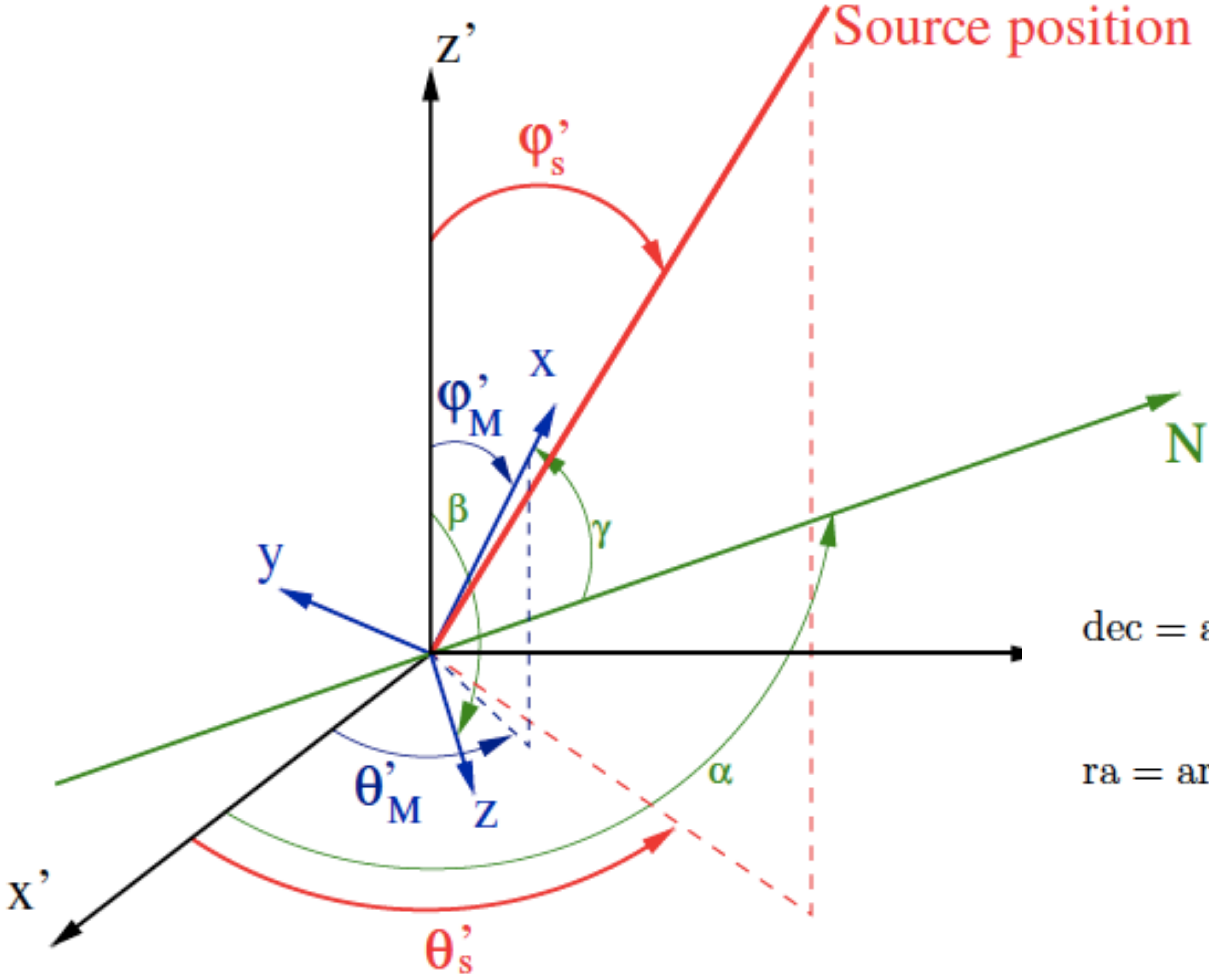


Photon patterns



Cosmic ray

Source localization (ra & dec)



Earth reference frame

MXT reference frame

α, β, γ *Euler angles*

Source position given by :

$$dec = \frac{\Pi}{2} - \phi_s'$$

$$ra = \theta_s'$$

$$\mathrm{dec} = \arcsin\left(\frac{s_\beta s_\gamma F - s_\beta c_\gamma (L_y/2 - y_P) + c_\beta (L_z/2 - z_P)}{\sqrt{F^2 + (y_P - L_y/2)^2 + (z_P - L_z/2)^2}}\right)$$

$$\mathrm{ra} = \arccos\left(\frac{(c_\alpha c_\gamma - s_\alpha c_\beta s_\gamma)F + (c_\alpha s_\gamma + s_\alpha c_\beta c_\gamma)(L_y/2 - y_P) + s_\alpha s_\beta (L_z/2 - z_P)}{\cos(\mathrm{dec})\sqrt{F^2 + (y_P - L_y/2)^2 + (z_P - L_z/2)^2}}\right).$$

Ly, Lz, F : Geometry of the camera.
yp, zp : source peak position in the camera.