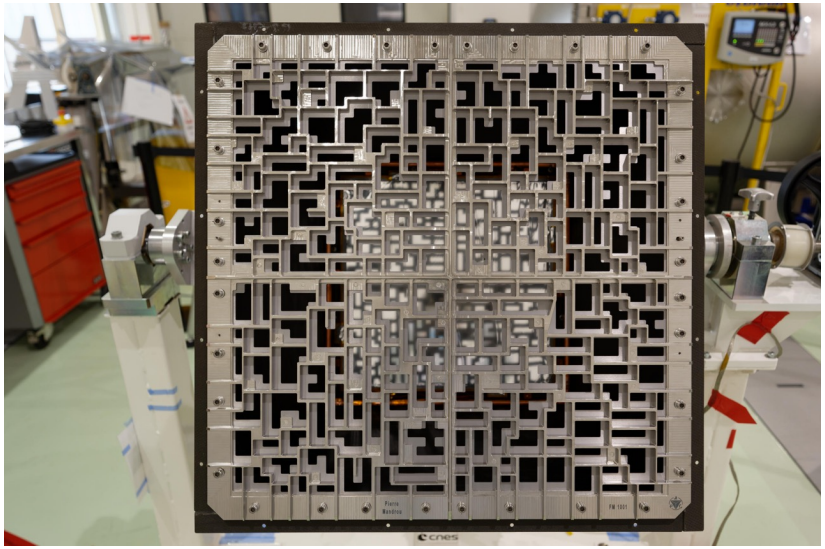
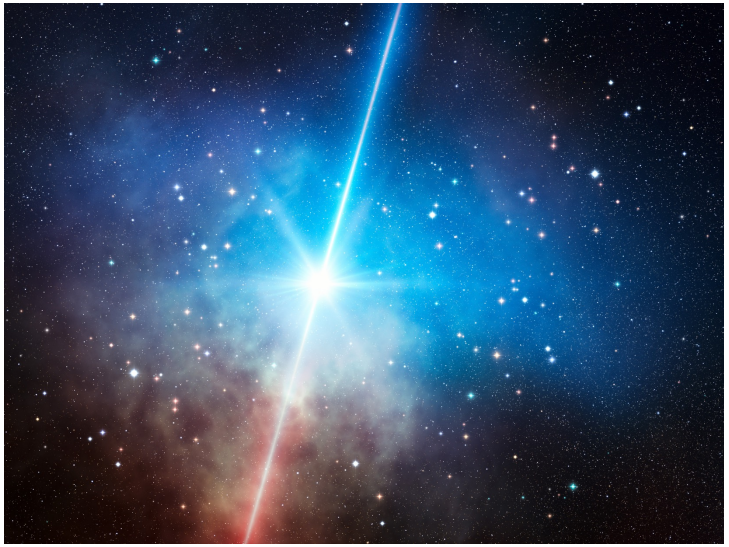
ECLAIRs for dummies,

and the others...



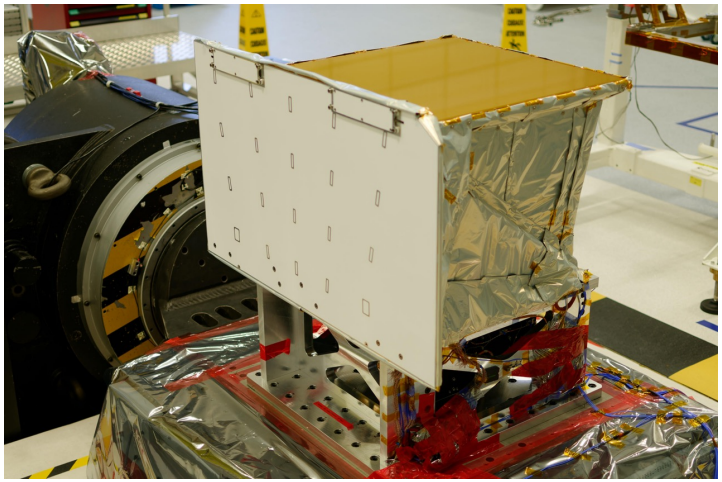


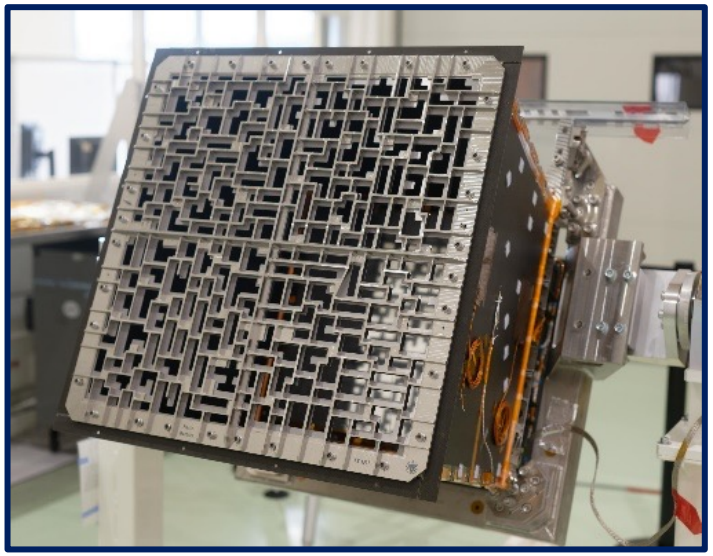
What is ECLAIRs?

- **ECLAIRs is a space-borne coded-mask imager for hard X-ray photons.**
- **ECLAIRs detects and records photons in a square 89° x 89° field of view, in the 4 – 150 keV energy range.**
- **ECLAIRs measures three properties of detected photons:**
  - → Time with 20 μs accuracy.
  - → Position on the 80x80 pixel detection plane.
  - → Energy, with sub-keV resolution.

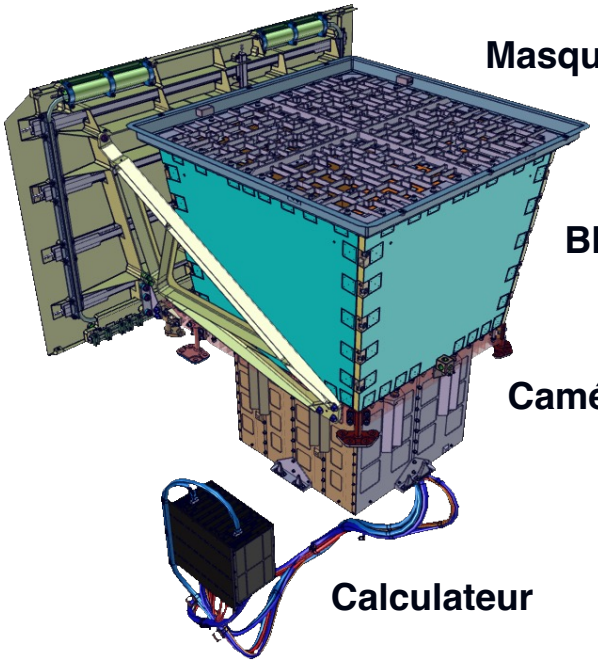
  Ground trigger!
- **Within the SVOM mission, ECLAIRs fulfills two main goals:**
  - ↳ **Monitoring the hard X-ray sky.**
  - ↳ **Looking for new transients.**
- **Some numbers: ~95 kg ; ~80 W ; ~15 Gb/day**

Images of the instrument





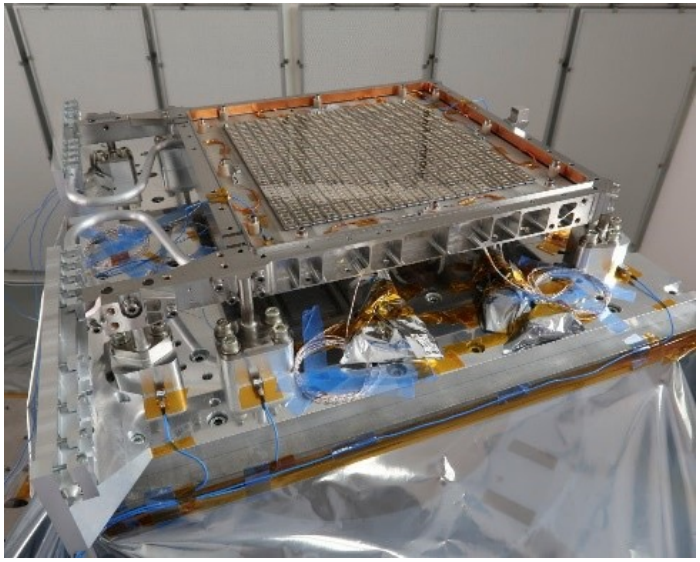
Masque codé



Blindage

Caméra

Calculateur

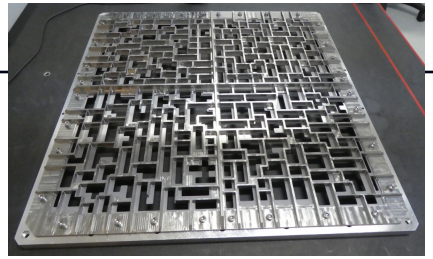


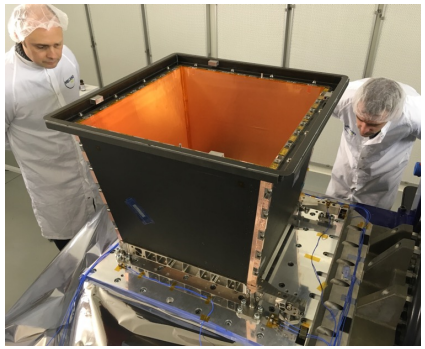
Crédit: ECLAIRs

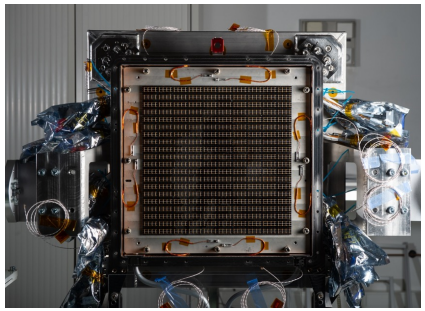
ECLAIRs subsystems

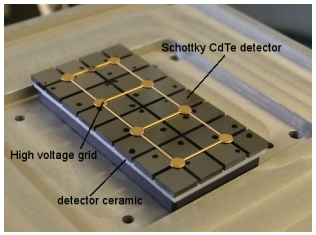
- **Coded Mask (APC):**
  - A foil of tantalum between 2 foils of titanium.
  - 4 quadrants of 23x23 elements.
  - Optimized for sensitivity & localization accuracy.
- **Structure, shielding & thermal control (CNES):**
  - The structure makes a « dark room » opaque to light and to X-rays.
  - Two light-shields transparent to X-rays cover the mask and the detection plane.
  - A radiator cools the detection plane to a stable temperature of –20° C.
- **Detection plane (IRAP):**
  - 200 modules. Each of them is a matrix of 4x8 detectors read by a low noise ASIC (6400 detectors).
  - The modules are interfaced to a complex electronics that detects the photons and measures their time, position & energy.
- **UGTS (CEA): UGTS plays a crucial role, ensuring:**
  - Instrument configuration
  - GRB detection & localization
  - Alerts the satellite

4 keV!









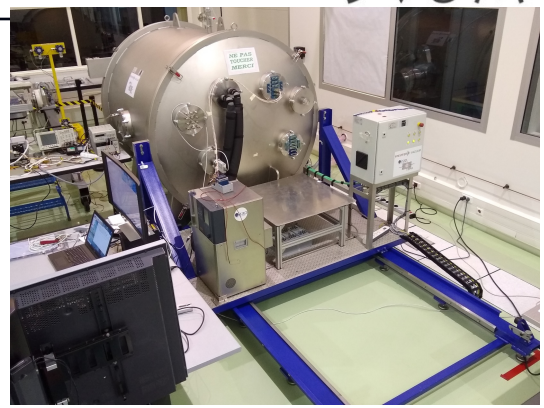
Instrument challenges

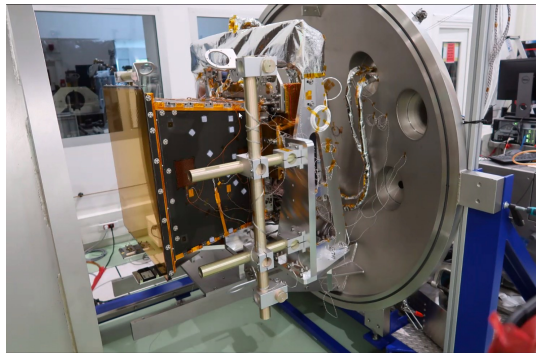
- The 4 keV energy threshold poses several challenges to the instrument:
  - Mask
  - Opacity to visible light
  - Leakage current of the detectors and ASIC readout noise
  - Management of transient hard X-ray sources by the on-board computer
- Mass/volume allocation is very limited: ECLAIRs is 2.5 times lighter than Swift/BAT
- Get reliable GRB triggers with highly variable background: Earth transits, SAA, noisy pixels…

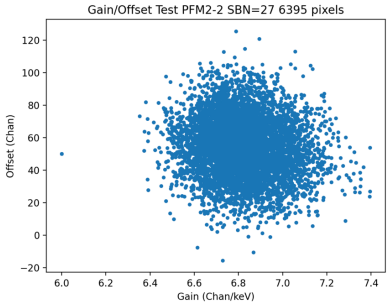
Instrument characterization

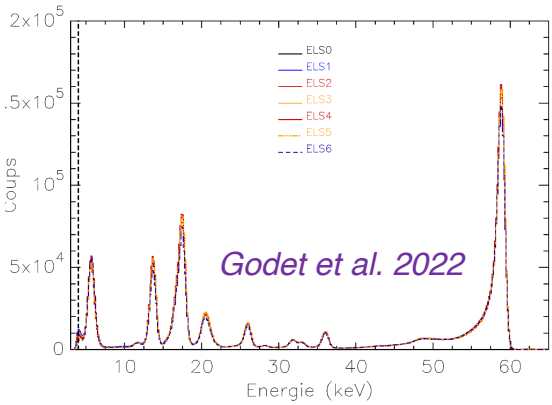
- **A ~1 yr campaign of instrument characterization was carried out in 2021, leading to very good results.**
  - **Detection plane:**
    - Response of individual pixels: effective area A(E,θ), energy threshold, resolution, linearity.
    - Response of the entire plane: uniformity, cross-talk, dead time, temporal stability.

    Measured with radioactive source in a large vacuum chamber.
  - **On-board computer:**
    - Estimation of the sensitivity to GRBs and transients
    - Injection of realistic simulated data, including background, GRBs & SAA
  - **Instrument:**
    - Light opacity
    - RX opacity (low energies)
    - DPIX ⇔ UGTS communication
    - Imaging reconstruction

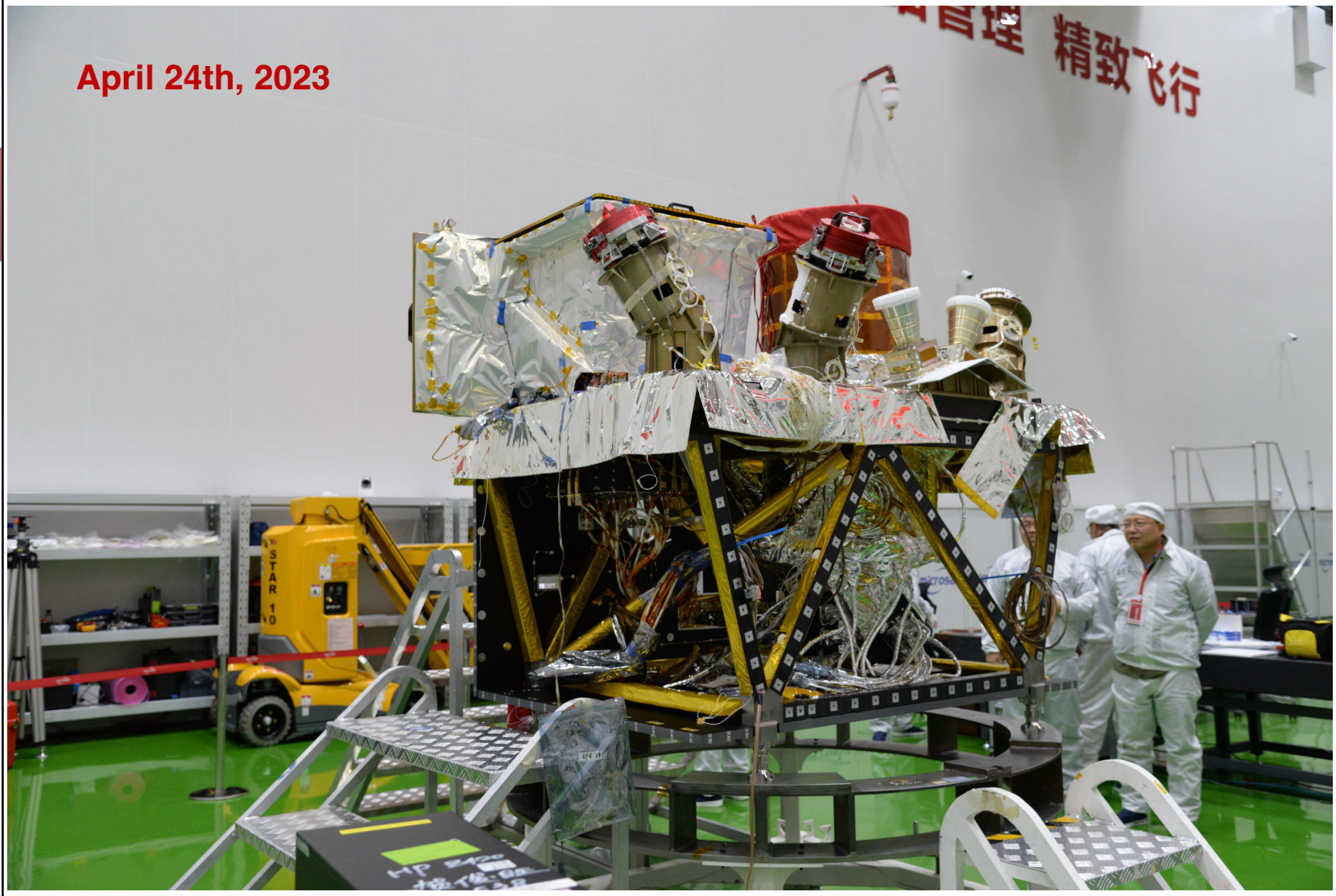








ECLAIRs (& MXT) are now on *SVOM*



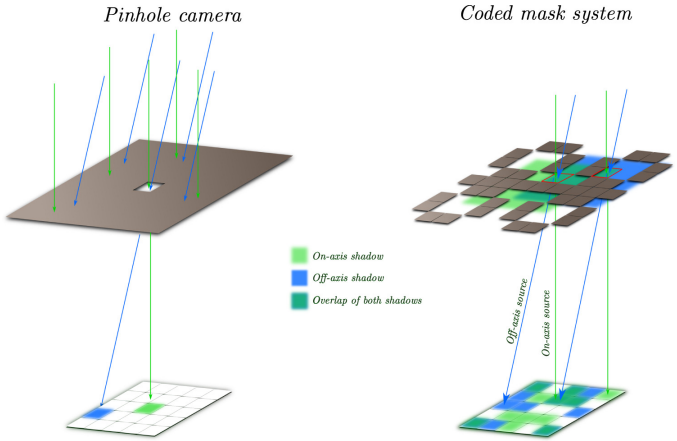
Detecting GRBs with ECLAIRs

- Once or twice a week a GRB arrives in the field of view of ECLAIRs.
  - Don't miss it!
- Most GRBs occur billions of light-years away from the Earth.
  - Their signal is weak despite the power of the initial explosion.
- ECLAIRs detects about 250 millions X-rays per day. A typical GRB adds a few hundred or a few thousand X-rays.
- However, X-rays from GRBs are grouped in time and direction.
  - This is the key of their detection with ECLAIRs.
- ECLAIRs has 2 trigger algorithms:
  - A count trigger, searching count-rates excesses in time intervals from 10 ms to 20 s.
  - An image trigger, looking for unknown sources in sky images (20 s – 20 min).
  - Count triggers must be validated with an image.
  - Triggers are vetted against a list of known transient sources.

Coded-mask imaging

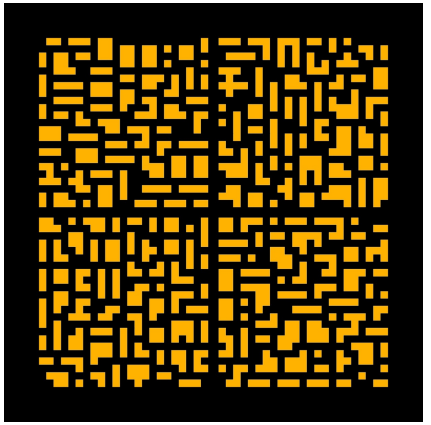
- ECLAIRs builds images of the sky thanks to a coded mask: sources in the sky project the image of the mask onto the detectors.
- As for the sundial, the dark and illuminated pixels allow to reconstruct the position of the source in the sky. This is fundamentally a statistical process!
- Practically, the sky image is constructed as a square of 199 x 199 sky pixels. The signal in a sky pixel is the subtraction (with some normalization) between the counts measured on the detectors that see this sky pixel (because the mask is transparent on the line of sight between the detector and the sky) and the pixels that do not see it, which measure only background
- This simple and elegant principle is however complicated by several factors:
  - A variable, non-homogeous background
  - The non-uniform response of the detectors
  - The presence of several sources in the sky.

Principle of coded-mask imaging

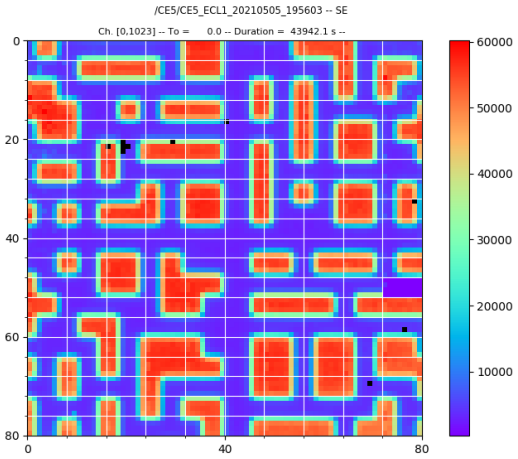


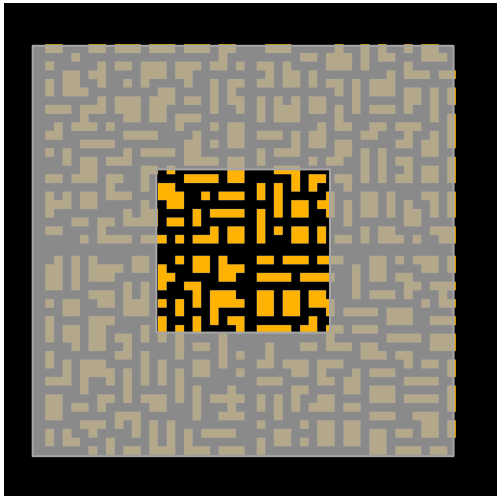
Sun dial

ECLAIRs coded mask



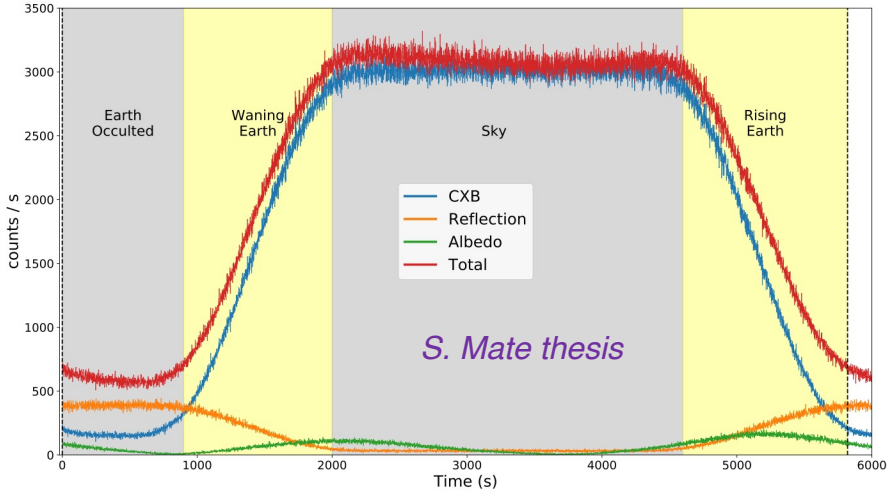
Some examples



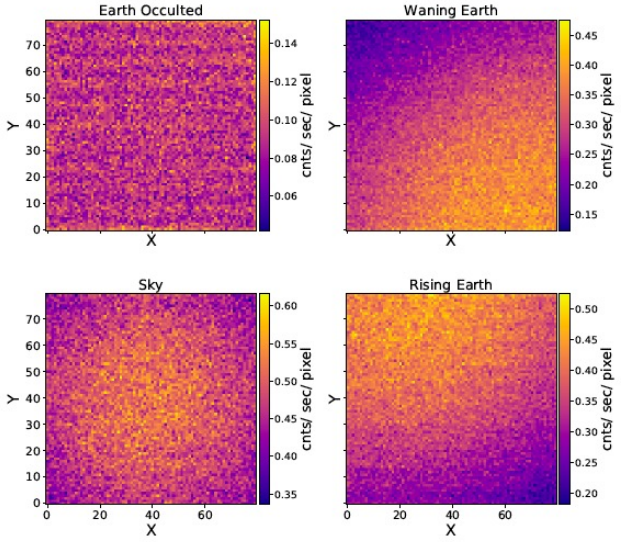


Calibrations

1 orbit ~96 minutes



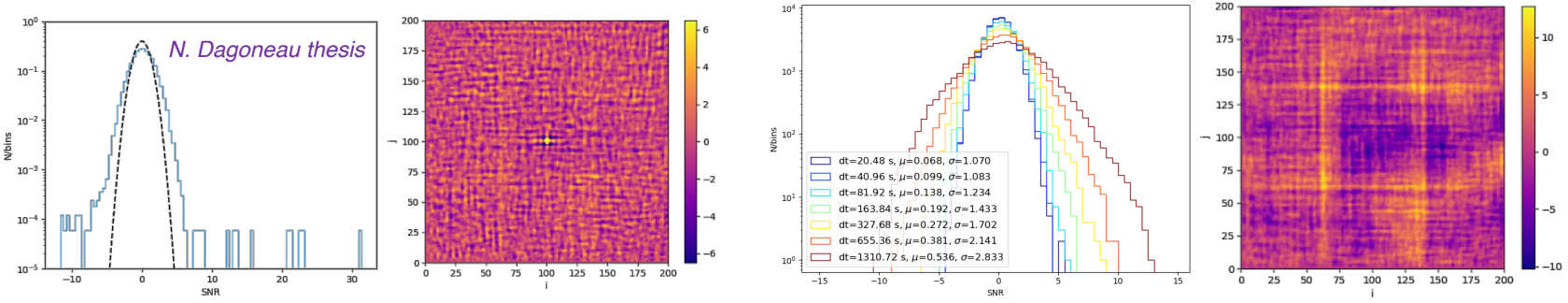
Simulations



Understanding ECLAIRs localizations - 1

- **ECLAIRs localizations are the result of a statistical process...**
  - **2 types of trigger:**
    - **Count-Rate: for timescales shorter than 20 s**
      - Search an excess in the light-curve, if found...
      - Construct the corresponding sky image
      - Search an excess in the image, excluding Earth-masked sky and knwon X-ray sources
      - If SNR (image) sufficient, send alert
    - **Image: for timescales longer than 20 s**
      - Remove the background and construct the sky image
      - Search an excess in the image, excluding Earth-masked sky and knwon X-ray sources
      - If SNR (image) sufficient, send alert

Reconstructed sky image and its SNR distribution for a 20 s exposure (left) and a 20 minute exposure (right) – from N. Dagoneau thesis.



Understanding ECLAIRs localizations - 2

- A trigger is always associated with a position
- There are no « approximately correct » localizations. An incorrect localization can be anywhere in the field of view.
- Some features of ECLAIRs trigger
  - CRT: A minimum number of counts is required to get a position: 100 – 150, even with zero background.
  - IMT: Modeling and subtracting the background before deconvolution is crucial for image trigger.
  - The localization accuracy increases with the image SNR. However, most ECLAIRs triggers will have a SNR close to the threshold (SNR ≈ 8), because ECLAIRs triggers as soon as the signal exceeds the threshold.
- GFTs will be crucial for the validation of ECLAIRs triggers before the activation of the slew.

Performance overview

Energy range	4 – 150 keV
Detecting area	≈1000 cm^2
Detectors	6400 CdTe detectors (200 modules)
Effective area in 10-70 keV	≥340 cm^2
Effective area @ 6 keV	≥200 cm^2
Field of view	2.06 sr total
Sensitivity to 1 sec long GRB	2.5 10^{-8} erg cm^{-2} s^{-1} in [5−50] keV
Source Localization Error	11.5 arcminutes for sources with SNR=8
Energy resolution at 60 keV	< 1.6 keV
Time resolution	20 microsecond
Dead time	<5% for 10^5 cts/s
Data rate	≤18 Gb/day

50 – 70 GRBs /yr

Some references

Two refrence papers:

O. Godet et al. (2014): *The x-/gamma-ray camera ECLAIRs for the gamma-ray burst mission SVOM,* 2014SPIE.9144E..24G

S. Schanne et al. (2014): *A Scientific Trigger Unit for Space-Based Real-Time Gamma Ray Burst Detection, I - Scientific Software Model and Simulations,* 2014arXiv1411.7810S

Many theses in French: G. Nasser, A. Bajat, N. Dagoneau **... and in English:** S. Mate, B. Arcier

1 2022SPIE12181E..5OG 2022/09
On-ground calibration highlights for the SVOM/ECLAIRs camera
Godet, O.; Atteia, J. -L.; Amoros, C. *and 40 more*

2 2022A&A...665A..40D 2022/09
The SVOM/ECLAIRs image trigger with wavelet-based background correction optimised with a one-year simulation of observations
Dagoneau, N.; Schanne, S.

3 2021A&A...645A..18D 2021/01 cited: 6
Onboard catalogue of known X-ray sources for SVOM/ECLAIRs
Dagoneau, N.; Schanne, S.; Rodriguez, J. *and 2 more*

4 2020Ap&SS.365..185A 2020/12 cited: 2
Detection of short high-energy transients in the local universe with SVOM/ECLAIRs
Arcier, B.; Atteia, J. L.; Godet, O. *and 7 more*

5 2020ExA....50...91D 2020/07 cited: 6
Ultra-Long Gamma-Ray Bursts detection with SVOM/ECLAIRs
Dagoneau, Nicolas; Schanne, Stéphane; Atteia, Jean-Luc *and 2 more*

6 2019ExA....48..171M 2019/11 cited: 6
Simulations of the SVOM/ECLAIRs dynamic background: a fast, accurate and general approach for wide-field hard X-ray instruments
Mate, Sujay; Bouchet, Laurent; Atteia, Jean-Luc *and 7 more*

7 2018APh...103..131L 2018/12 cited: 6
Spectral performance of ECLAIRs flight detectors on SVOM mission
Lacombe, K.; Dezalay, J. -P.; Houret, B. *and 12 more*

8 2018ExA....46..337B 2018/11
Characterizing the dead time of the ECLAIRs camera on board the mission SVOM
Bajat, A.; Godet, O.; Atteia, J. -L. *and 13 more*

9 2018SPIE10699E..5KA 2018/07 cited: 1
Status of technological development on ECLAIRs camera onboard the SVOM space mission
Amoros, C.; Houret, B.; Lacombe, K. *and 17 more*

10 2018SPIE10699E..5JB 2018/07
Calibration of the spectral response of the SVOM/ECLAIRs detection plane
Bajat, A.; Godet, O.; Atteia, J. -L.

11 2017ExA....44..113B 2017/10 cited: 8
Scientific prospects for spectroscopy of the gamma-ray burst prompt emission with SVOM
Bernardini, M. G.; Xie, F.; Sizun, P. *and 8 more*

12 2016SPIE.9905E..0JL 2016/07 cited: 1
Development of a 32-detector CdTe matrix for the SVOM ECLAIRs x/gamma camera: tests results of first flight models
Lacombe, K.; Dezalay, J. -P.; Houret, B. *and 19 more*

13 2014arXiv1411.7810S 2014/11 cited: 5
A Scientific Trigger Unit for Space-Based Real-Time Gamma Ray Burst Detection, I - Scientific Software Model and Simulations
Schanne, Stéphane; Le Provost, Hervé; Kestener, Pierre *and 6 more*

14 2014SPIE.9144E..3XN 2014/07 cited: 1
The use of Schottky CdTe detectors for high-energy astronomy: application to the detection plane of the instrument SVOM/ECLAIRs
Nasser, G.; Godet, O.; Atteia, J. -L. *and 16 more*

15 2014SPIE.9144E..24G 2014/07 cited: 19
The x-/gamma-ray camera ECLAIRs for the gamma-ray burst mission SVOM
Godet, O.; Nasser, G.; Atteia, J. -. *and 21 more*

16 2013NIMPA.732..122L 2013/12 cited: 4
Development of a 32-detector CdTe matrix for the SVOM ECLAIRs X/Gamma camera: Preliminary results
Lacombe, K.; Nasser, G.; Amoros, C. *and 19 more*

17 2012ExA....34..705Z 2012/11 cited: 8
Influence of the Earth on the background and the sensitivity of the GRM and ECLAIRs instruments aboard the Chinese-French mission SVOM
Zhao, Donghua; Cordier, Bertrand; Sizun, Patrick *and 5 more*

18 2010SPIE.7732E..25T 2010/07
The scientific and technical drivers of ECLAIRs: the x- and gamma-ray telescope onboard the GRB mission SVOM
Triou, Henri; Sauvageon, Aymeric; Cordier, Bertrand *and 11 more*

19 2010NIMPA.618..199R 2010/06 cited: 6
Extensive testing of Schottky CdTe detectors for the ECLAIRs X-/gamma-ray camera on board the SVOM mission
Remoué, N.; Barret, D.; Godet, O. *and 1 more*

20 2009NIMPA.610..287R 2009/10 cited: 3
Selection of CdTe detectors for the detection plane of the ECLAIRs gamma-ray burst detector
Remoue, N.; Lacombe, K.; Amoros, C. *and 3 more*