Imaging the hard X-ray sky with the ECLAIRs telescope onboard the SVOM mission

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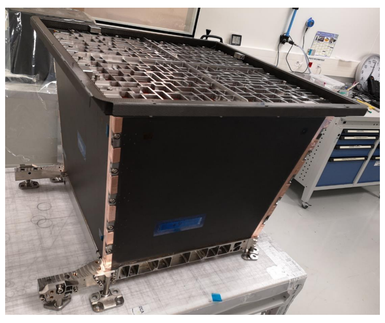
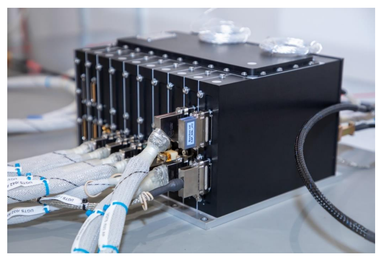
ECLAIRs Coded Mask Telescope

The ECLAIRs telescope is the coded-mask hard X-ray telescope (4-150 keV, 80x80 pixels, 1024 cm²) onboard SVOM.



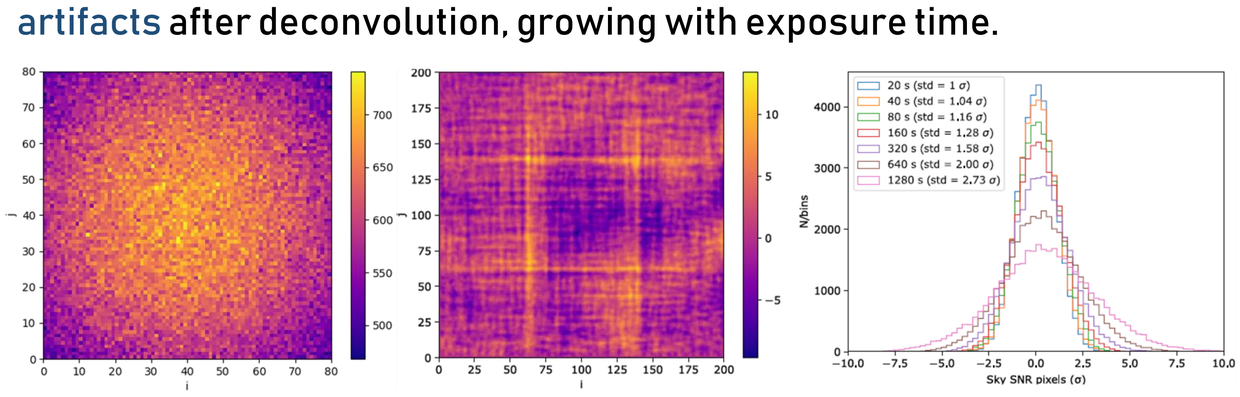


ECLAIRs STM and UGTS EQM

The UGTS (Unit for detector manaGement, Triggering and Scientific processing) carries and runs triggers algorithms (count rate & image) for data processing and GRB detection (see S. Schanne's poster: "SVOM/ECLAIRs GRB Trigger").

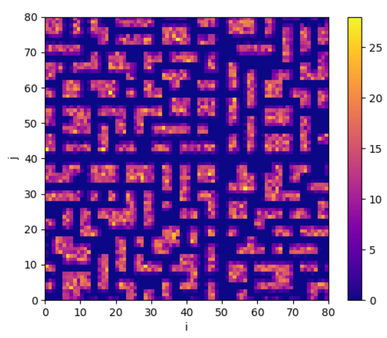
Background inside ECLAIRs: CXB and sources

ECLAIRs is sensitive to various sources of background (*S, Mate, in prep.*). Main is Cosmic X-ray Background (CXB, *Moretti et al., 2009*) producing quadratic shape on the detector (continuously modulated by the Earth, in Fov 66% of time). Uncleaned CXB leads to artifacts after deconvolution, growing with exposure time.

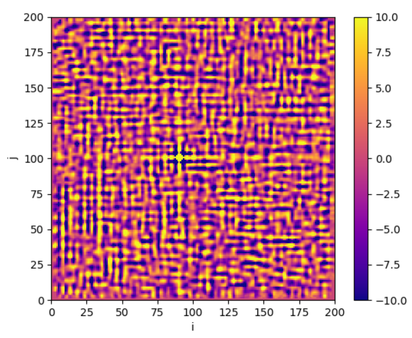


Detector image (1000s), sky SNR image (64 x 20s stacked) and sky pixels SNR distribution.
Internal noise of 0.003 cnt/cm²/s/keV and CXB: 8.74 ph/cm²/s/sr.
Expected SNR distribution for a clean sky is $N(0,1)$.

ECLAIRs is also sensitive to X-ray sources. Brightest ones lead to coding noise (ghosts) in sky images → cannot just mask source peaks in the sky but need to clean them in the shadowgram.



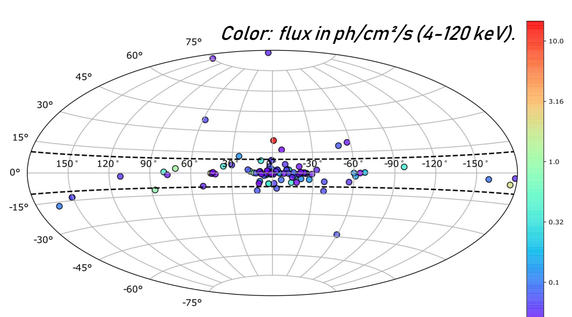
Detector image with a bright source in Fov (100ph/cm² ~ Sco X-1 for 5 s).



Sky SNR image: many points (ghosts) reaches SNR > Threshold (6.5 sigma). SNR at the source position = 170 sigma.

Known source cleaning requires a catalog built from RXTE/ASM, Swift/BAT and MAXI/GSC monitors (~ 100 sources will be seen by ECLAIRs in 20 min, in 4-120 keV, sensitivity in 1 s: 1.4 ph/cm²/s if on axis for Crab-like sources).

Map (galactic coordinates) of the brightest sources (4-120 keV). Bright source contributions will be subtracted from the shadowgram (fit). Faint source positions will be masked in sky images (too faint to produce coding noise, low significance, even in 20 min) .

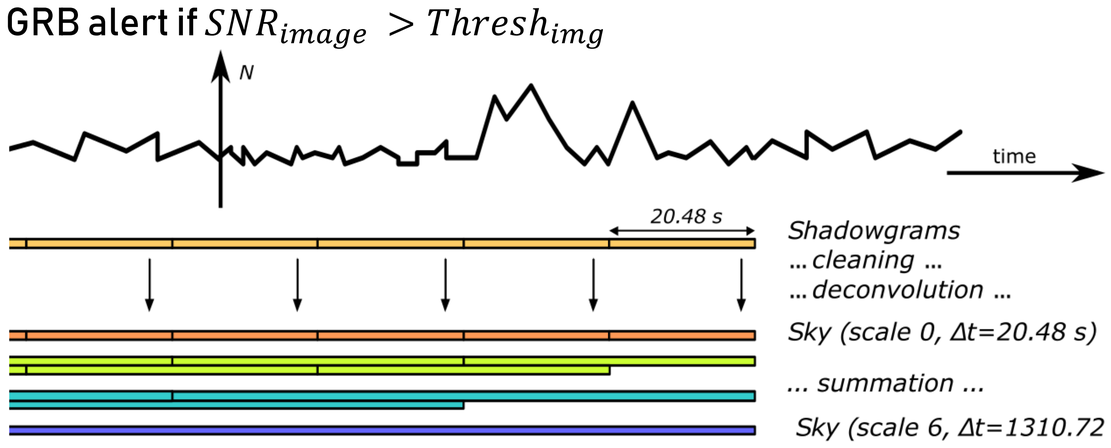


Dashed line: pointing law boundary (avoid galactic plane and Sco X-1). As Fov is wide (2 sr), galactic plane or Sco X-1 may enter Fov after a slew or during general program/target of opportunity observations.

The Image Trigger

Cycle process runs every 20.48s, on 4 energy strips:

1. Shadowgram: image of detector plane from photons in memory from last 20.48 s
2. Cleaning of the shadowgram
3. Deconvolution of the shadowgram → sky image (in counts and variance)
4. Summation of sky images (counts and variance) up to 20min
5. For each scale: $SNR_{image} = \frac{Counts}{\sqrt{Variance}}$
6. For each scale, excesses are searched for in SNR image away from known sources and Earth
7. GRB alert if $SNR_{image} > Thresh_{img}$

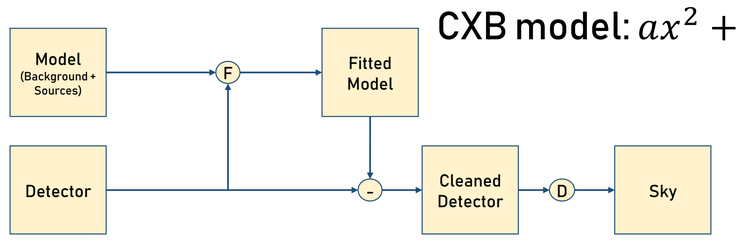


Cleaning methods

CXB and known sources need to be cleaned from shadowgram before deconvolution → 2 methods:

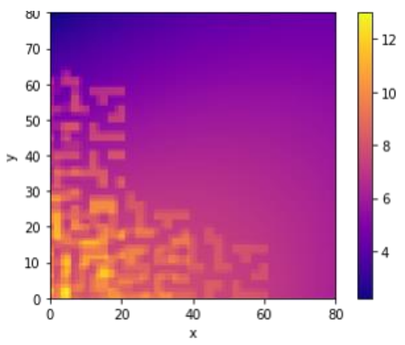
- Fit of the CXB model + sources illumination function in the same time

CXB model: $ax^2 + by^2 + cx + dy + exy + f$

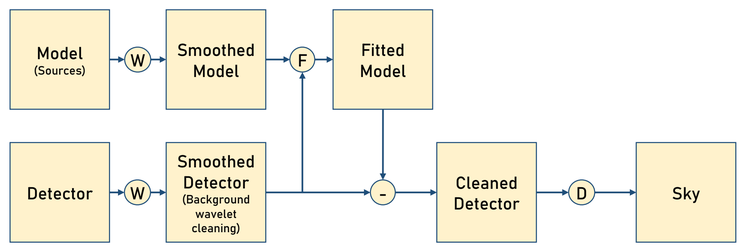


F Fit a model to data
W Wavelet cleaning
D Deconvolution
- Subtraction

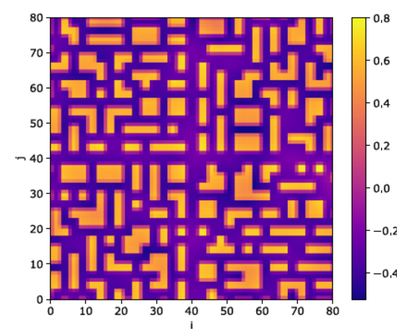
Example of a fitted model (in counts) with an Earth-modulated CXB + 5 sources illumination functions.



- Wavelet cleaning of the CXB then fit of the sources illumination function. Wavelets: "à trou algorithm" (*Starck et al., 2007*) used to remove CXB (large scale) contribution.



Example of a waveleted illumination function used to fit the source contribution after CXB wavelet cleaning.



Wavelets computation: $D_{\mathrm{cnt}}^{\mathrm{cleaned}} = D_{\mathrm{cnt}}^{\mathrm{raw}} - C_s$ where C_s is a shadowgram smoothed with a filter h of length $2l+1$, $(s \geq 1)$.

$$C_s(i,j) = \sum_{m=-l}^{l} \sum_{n=-l}^{l} h(m) \cdot h(n) \cdot C_{s-1}(i + 2^{s-1}m, j + 2^{s-1}n)$$

Both methods give the same cleaning level (reaching $\sigma \sim 1$ in SNR pixels distribution) but wavelets are faster (still need to be benchmarked on board processor) and do not need assumptions on background shape. Both methods will be implemented onboard.

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