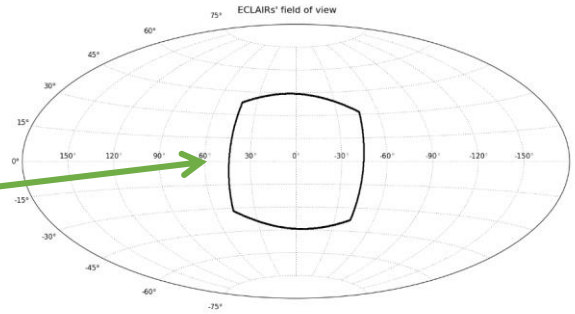
2019 Nanjing GRB Conference

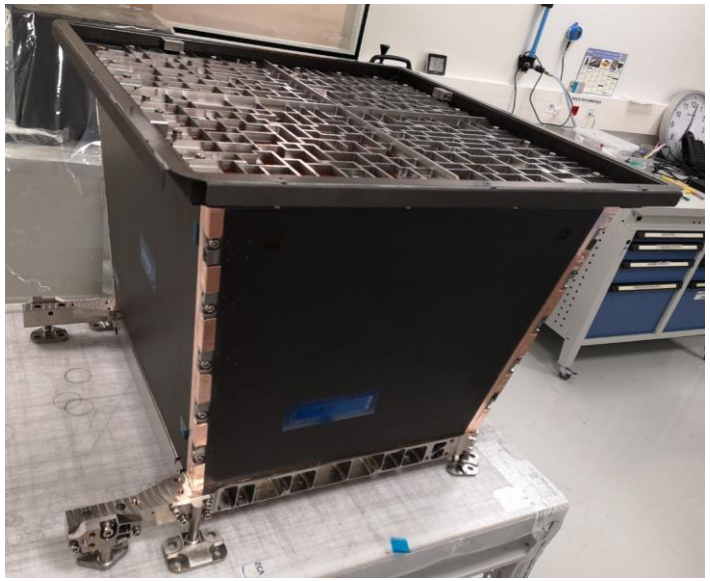
Imaging the hard X-ray sky with the ECLAIRs telescope onboard the SVOM mission

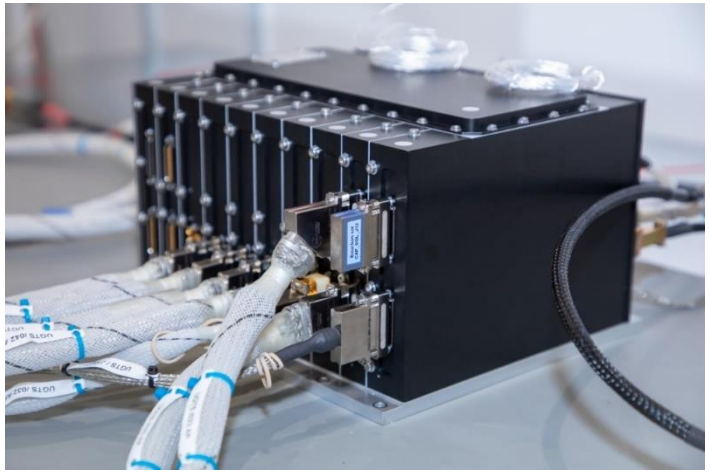
Nicolas Dagoneau (CEA/AIM, France), 2nd year PhD student
nicolas.dagoneau@cea.fr

ECLAIRs: the hard X-ray imager onboard SVOM

- Coded mask telescope
- 4-150 keV
- ~2 sr FOV
- 80x80 pixels, 1024 cm²
- UGTS: Unit for detector manaGement, Triggering and Scientific processing with 2 triggers:
  - count rate trigger (10 ms to 20 s)
  - **image trigger** (20 s to 20 min)



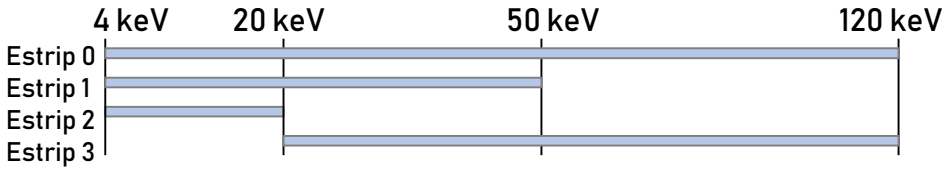




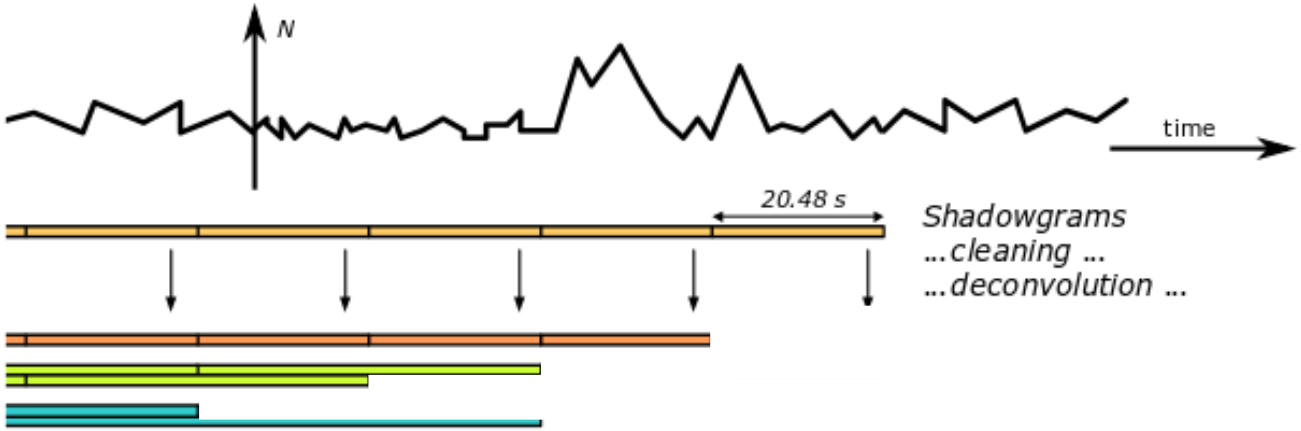
ECLAIRs STM and UGTS EQM

The image trigger

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



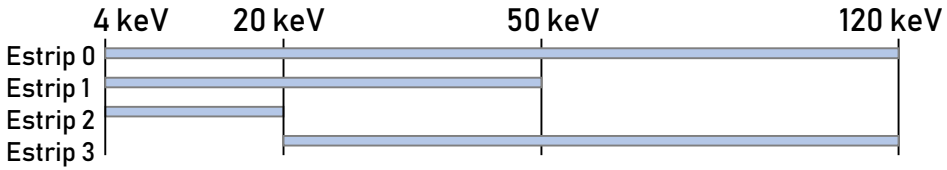
1. Shadowgram: image of detector plane from photons in memory from last 20.48 s



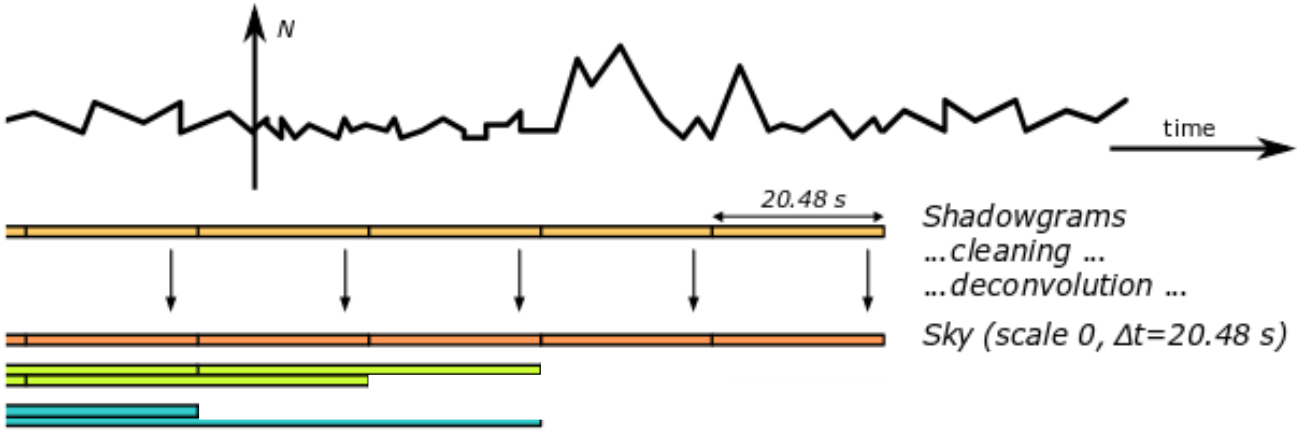
Trigger algorithm:
as currently implemented (S. Schanne, Qianmen presentation) final version TBC

The image trigger

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



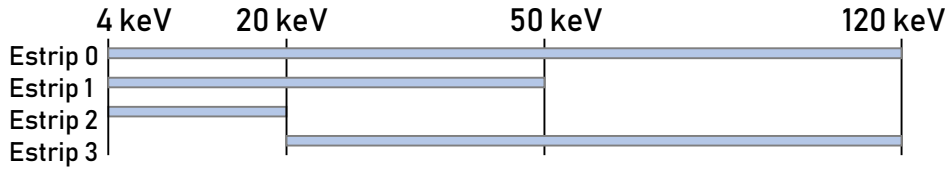
1. Shadowgram: image of detector plane from photons in memory from last 20.48 s
2. Cleaning of the shadowgram (remove background, known X-ray sources)
3. Deconvolution of the shadowgram → sky image (in counts and variance)



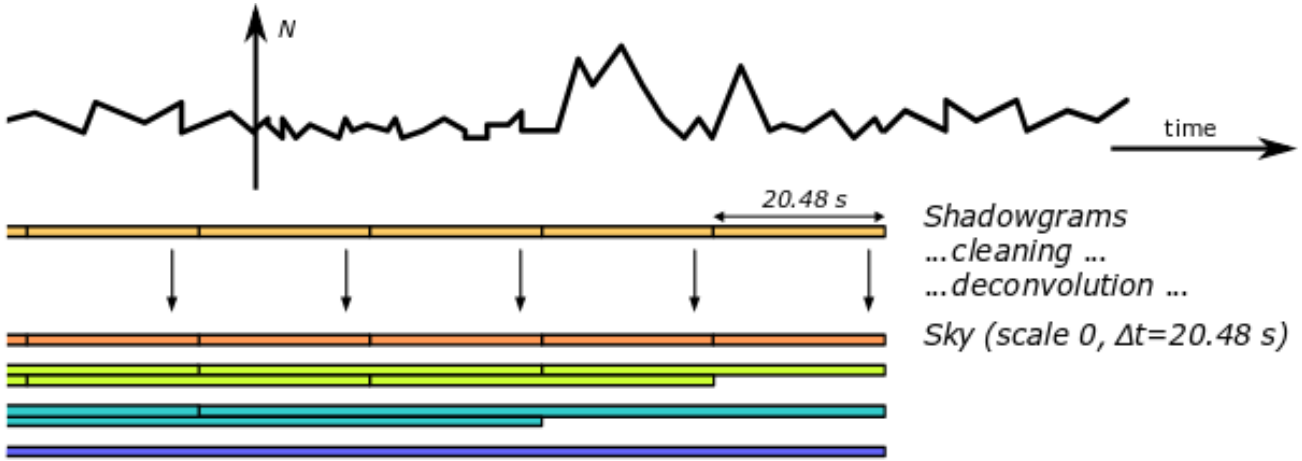
Trigger algorithm:
as currently implemented (S. Schanne, Qianmen presentation) final version TBC

The image trigger

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



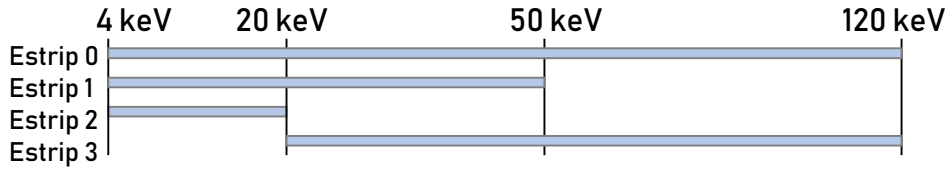
1. Shadowgram: image of detector plane from photons in memory from last 20.48 s
2. Cleaning of the shadowgram (remove background, known X-ray sources)
3. Deconvolution of the shadowgram → sky image (in counts and variance)
4. Summation of sky images (counts and variance) up to 20min



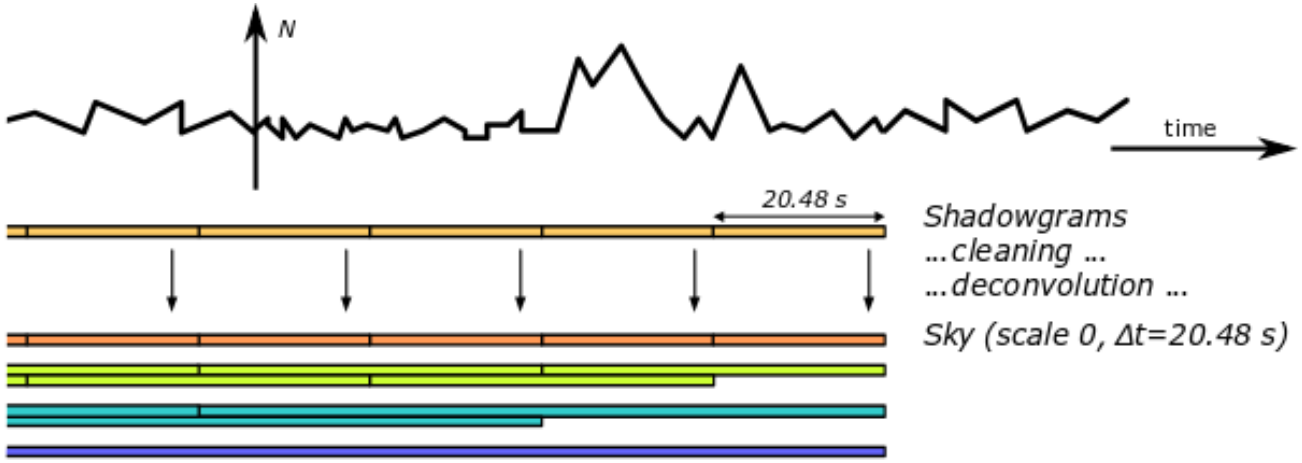
Trigger algorithm:
as currently implemented (S. Schanne, Qianmen presentation) final version TBC

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 (remove background, known X-ray sources)
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 $SNR_{image} > Thresh_{img}$



Trigger algorithm:
as currently implemented (S. Schanne, Qianmen presentation) final version TBC

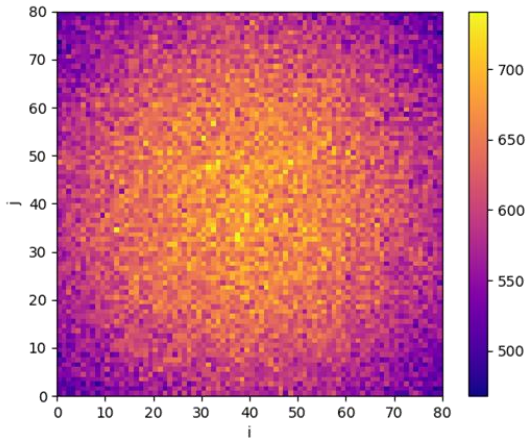
Background: 2 components and 2 effects

Cosmic X-ray Background (Moretti et al. 2009)

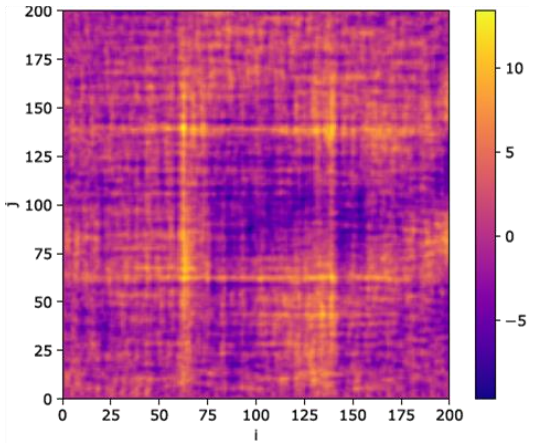
X-ray sources

Background: 2 components and 2 effects

Cosmic X-ray Background (Moretti et al. 2009)



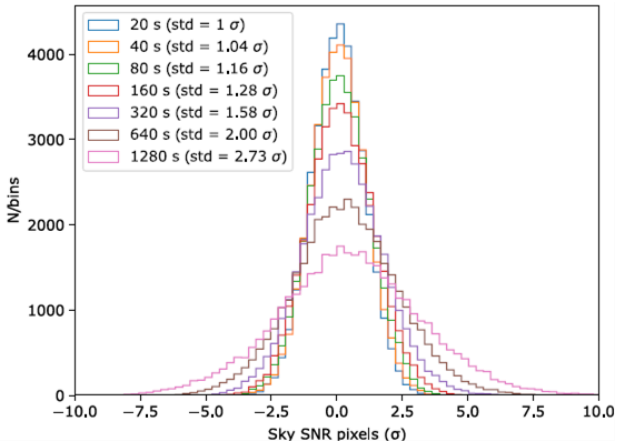
Detector image (1000s)



Sky SNR image (64 x 20s stacked)

CXB: 8.74 ph/cm²/s/sr + internal noise: 0.003 cnt/cm²/s/keV

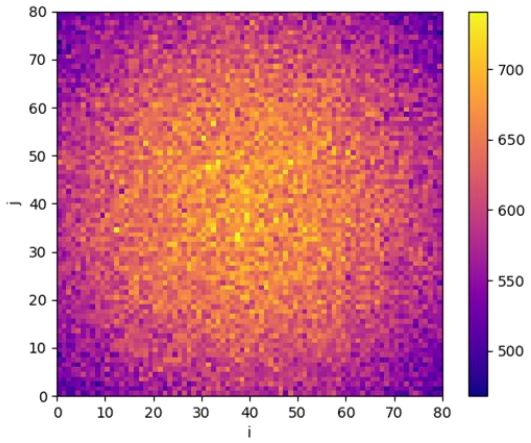
Sky SNR pixels distribution. Expected SNR distribution for a clean sky is $N(0,1)$.



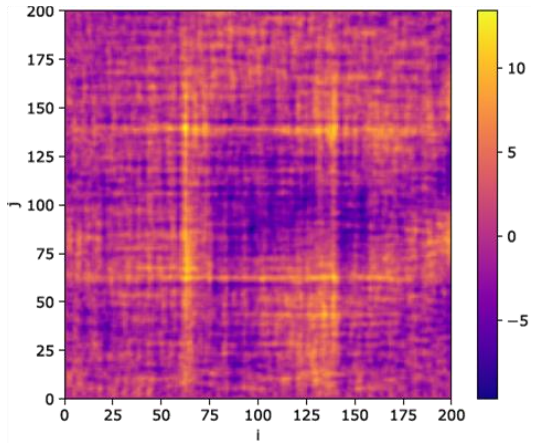
X-ray sources

Background: 2 components and 2 effects

Cosmic X-ray Background (Moretti et al. 2009)



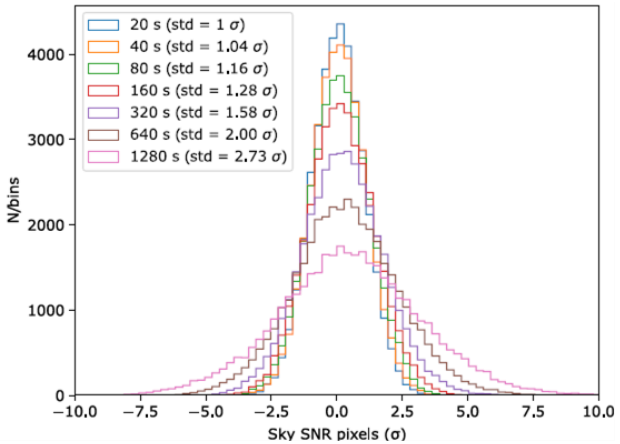
Detector image (1000s)



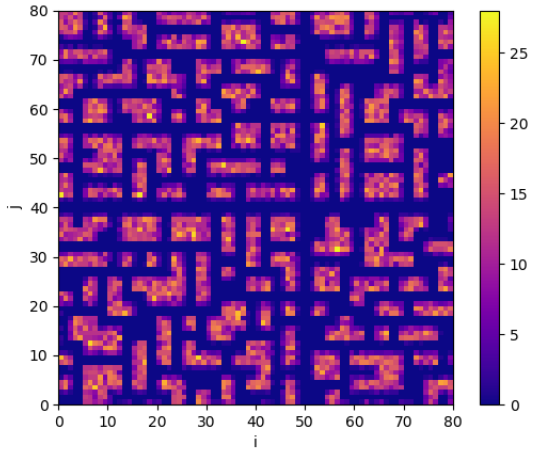
Sky SNR image (64 x 20s stacked)

CXB: 8.74 ph/cm²/s/sr + internal noise: 0.003 cnt/cm²/s/keV

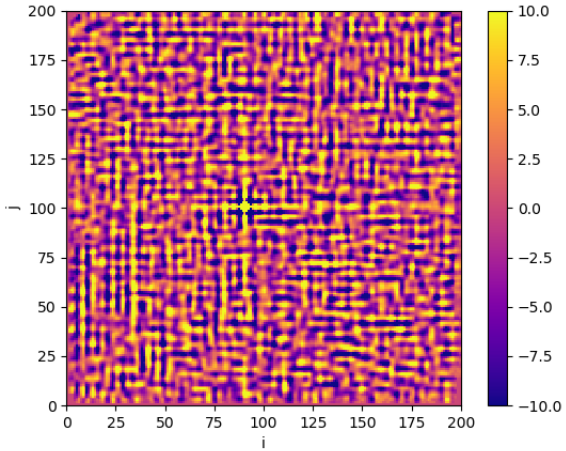
Sky SNR pixels distribution. Expected SNR distribution for a clean sky is $N(0,1)$.



X-ray sources



Detector image (100 ph/cm²)

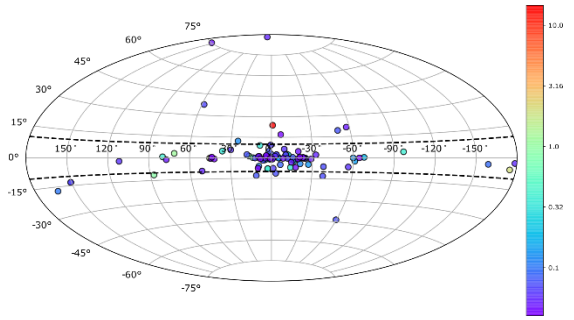


Sky SNR image

Bright sources lead to coding noise (ghosts) in sky images → cannot just mask source peaks in the sky

~ 100 sources will be seen by ECLAIRs in 20 min, in 4-120 keV

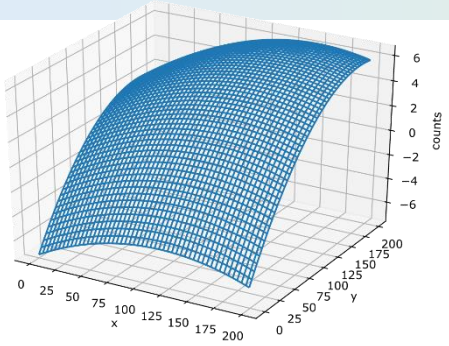
Catalog of source being built…

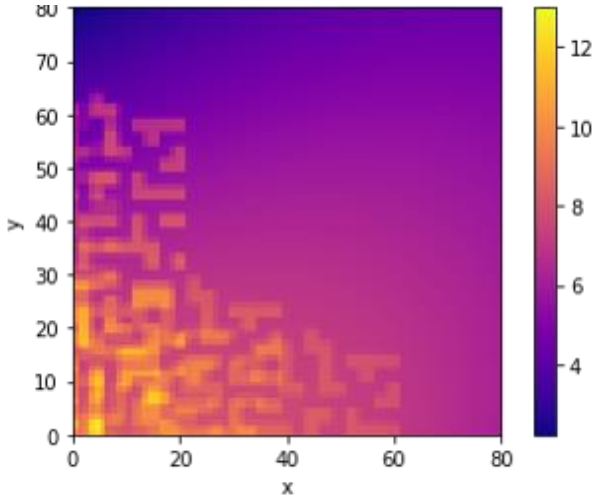


Cleaning background

2 methods :

Earth in Fov (66% of time) changes the CXB counts shape in the detector.





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

- Fit CXB model + source contributions simultaneously
  - CXB model: $ax^2 + by^2 + cx + dy + exy + f$
  - Source contributions: known from source positions in Fov
- Remove CXB with wavelets then fit source contributions
  - Wavelets: “à trou algorithms” (Stark et al. 2007) remove large scales in detector images (Krivonos et al. 2010 used wavelets on Integral/IBIS sky images)
  - Source contributions are fitted after background subtraction

Cleaning background

Methods : performance

Images of 20 s with a GRB in the totally coded Fov (random fluence in 5-10 ph/cm², canonical Band spectrum, $\alpha = -1, \beta = -2$), no Earth, no source, only CXB, no energy redistribution.

Stdev of sky SNR pixel (=1 for a clean sky)

SNR of the GRB

GRB SNR normalized by the stdev of the sky SNR distribution

Execution time increases if additional sources fitted

A: no cleaning B: fit C: wavelets on the detector D: wavelets in the sky

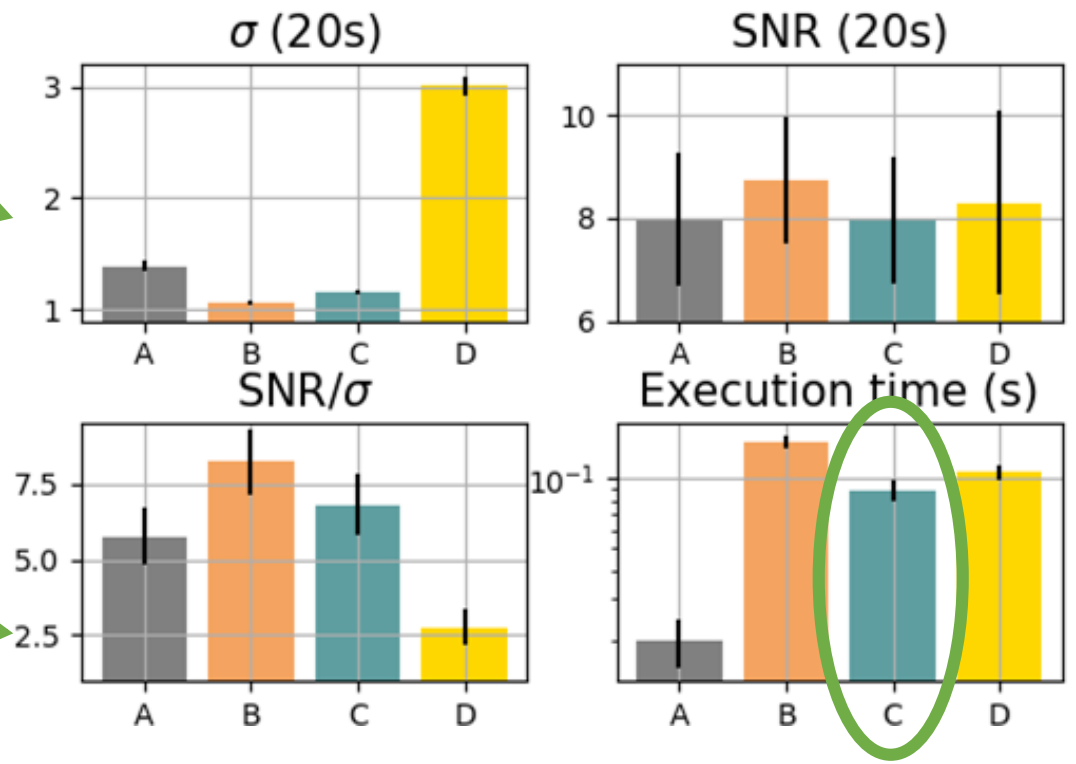
Cleaning background

Methods : performance

Images of 20 s with a GRB in the totally coded Fov (random fluence in 5-10 ph/cm², canonical Band spectrum, $\alpha = -1, \beta = -2$), no Earth, **sources** (Cyg X-1, X-2, X-3, Her X-1), only CXB, no energy redistribution.

Stdev of sky SNR pixel (=1 for a clean sky)

GRB SNR normalized by the stdev of the sky SNR distribution



SNR of the GRB

Execution time increases if additional sources fitted

A: no cleaning B: fit C: wavelets on the detector D: wavelets in the sky

Cleaning background

Both fit and wavelets on the detector give good cleaning, but:

- Wavelets are faster
- Wavelets do not need assumptions on CXB shape (and will also help to clean albedo and reflection)

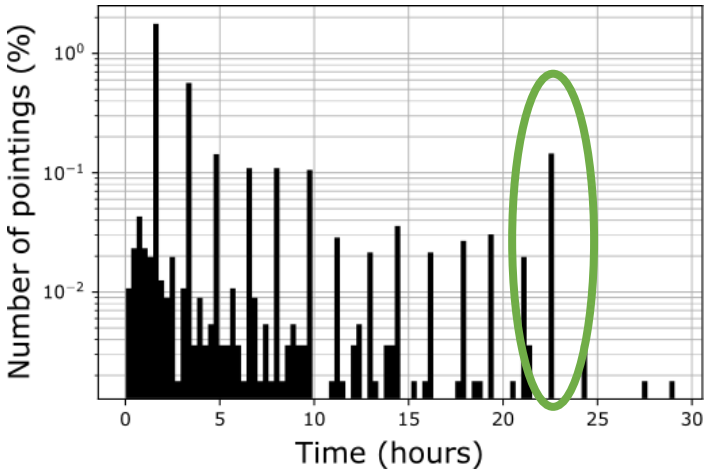
For ECLAIRs, wavelets in sky (like on Integral/IBIS, Krivonos et al. 2010) are not relevant: CXB is not flat and need to be removed before sources.

Both methods will be implemented onboard.

If we fit source illuminations on uncleaned CXB shape, the flux of the CXB is added to flux of the sources ➔ fitted source flux bigger that real flux ➔ holes in the sky.

ECLAIRs: opening a discovery space for Ultra-long GRBs

ECLAIRs allows long pointing durations (up to 1 day) which may help to monitor transient events on long timescales.



Classical long GRB are detected on smallest scales of the image trigger, no detection from 160 s up to 20 min for Goldstein sample at z = z0 (arXiv:1810.12052).

Simulation of Swift GRBs through ECLAIRs image trigger prototype. Most GRB are detected in 20s image.

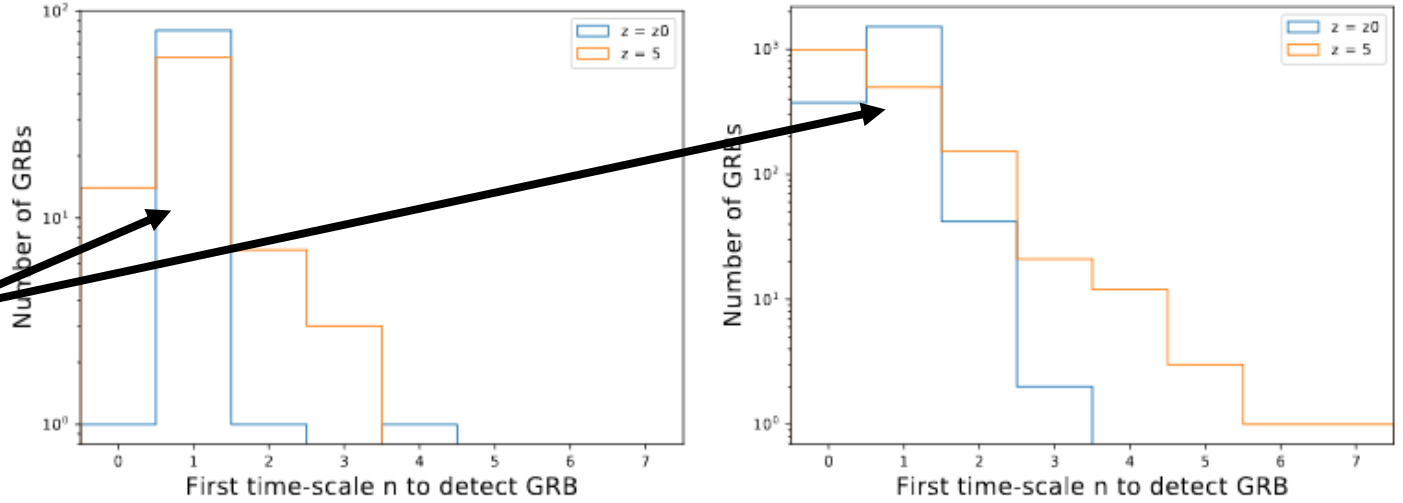


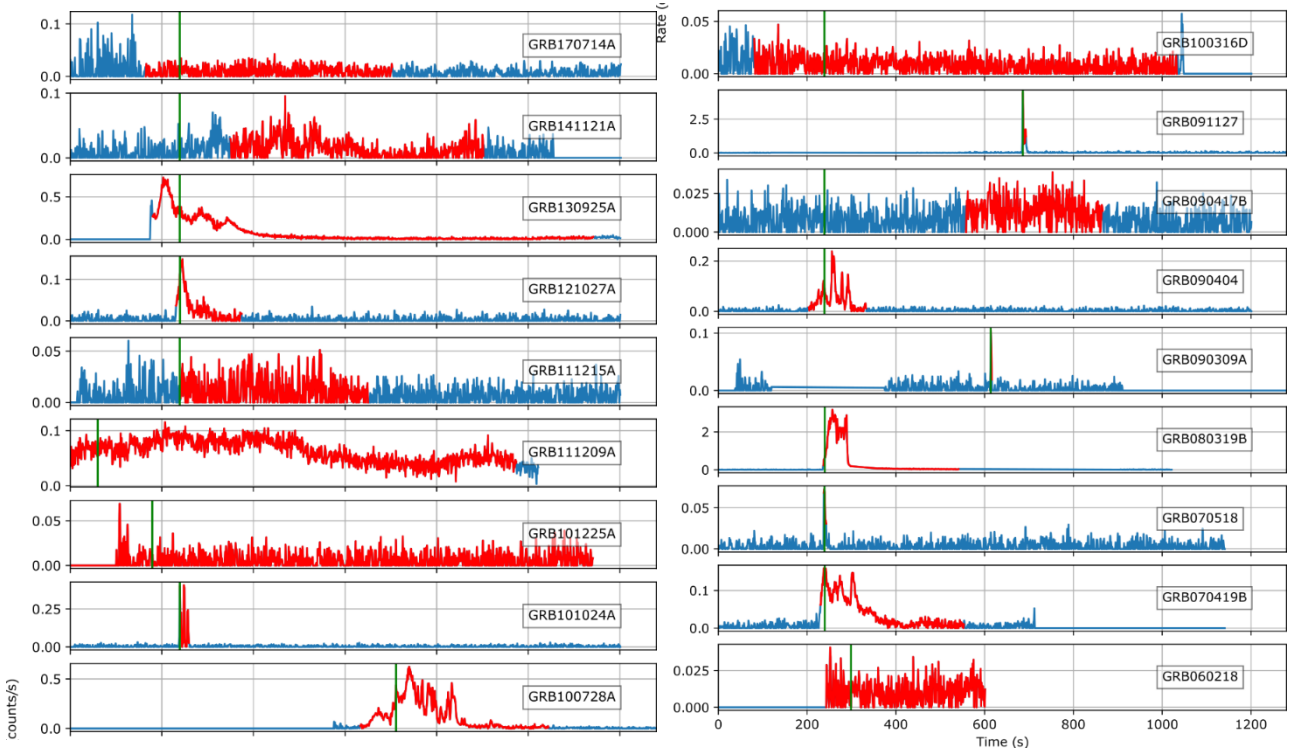
Fig. 6. Histogram of first time-scale n of the image-trigger which detects a GRB from each of the two different databases: **Left:** from Heussaff (2015). **Right:** from Goldstein et al. (2013).

ECLAIRs: opening a discovery space for Ultra-long GRBs

UL GRBs (BAT lightcurve and spectra) are processed through ECLAIRs image trigger (prototype) to study their detectability.

Sample of 10 UL GRBs with long lasting emission in BAT lightcurve (UL GRB may also define long lasting X-ray emission). To be compare with classically long GRBs.

Swift list of Ul-GRBs (130427A and 160623A mentioned by Donggeun Tak not included)



Blue: full lightcurve
Red: lightcurve when spectrum is given

Summary

- ECLAIRs will image the X-ray sky in 4-150 keV
- Background cleaning could be achieved with fit or wavelets (wavelets are faster)
- Source cleaning (achieved by fit) requires an onboard catalog
- ECLAIRs may open a discovery space for ultra-long transients detection and monitoring