SVOM / ECLAIRs / Trigger
Overview

S. Schanne
260325, APC, BA-T training

SVOM mission overview

Space-based Variable Objects Monitor

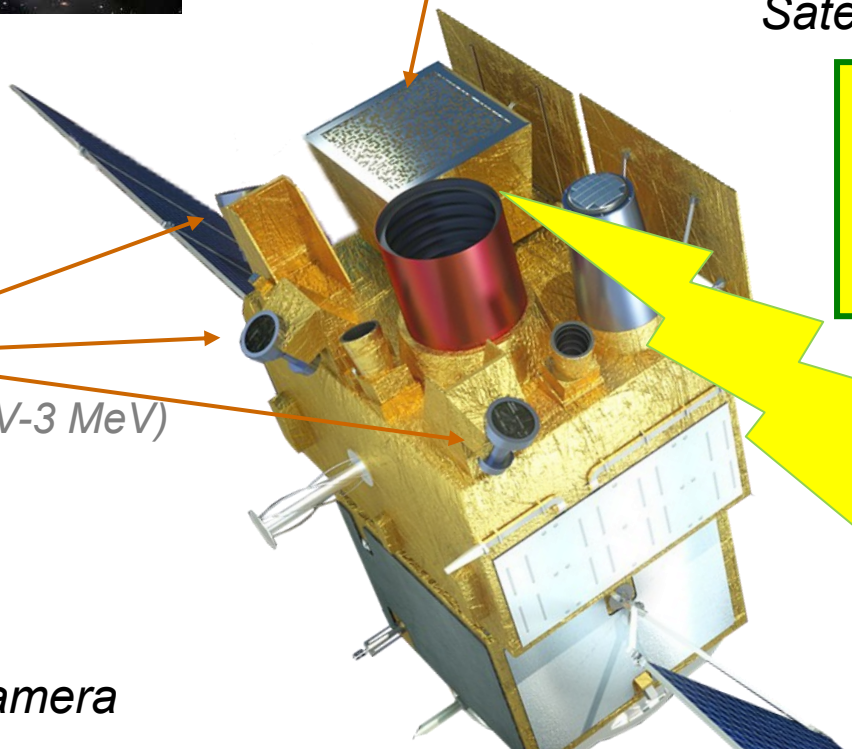
Prompt, Large FoV

ECLAIRs *french*

X/γ telecope (4-120 keV), FoV(2 sr)
Localisation of GRB (<12 arcmin)
Onboard trigger Alert to ground
Satellite repointing

SVOM GRB Trigger

GRM *chinese*
Spectrometer γ (30 keV-3 MeV)



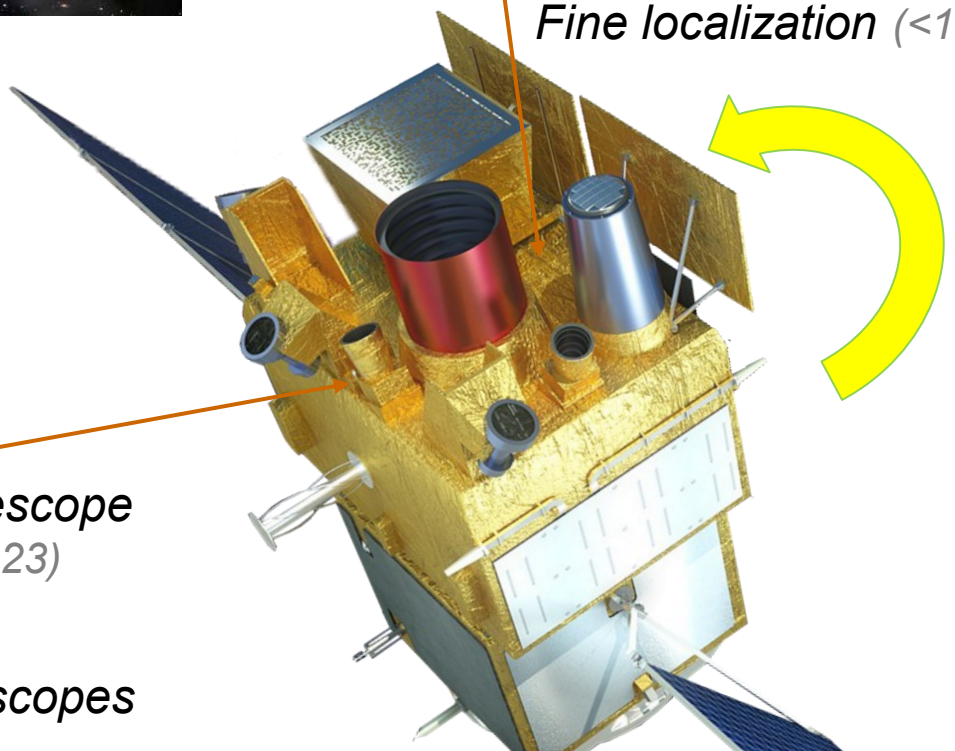
GWAC *chinese*
Ground wide angle camera

SVOM mission overview

Space-based Variable Objects Monitor

Delayed, Narrow FoV

MXT *french (+german & british)*
X-ray telescope
Fine localization *(<1 arcmin)*



VT *chinese*
Visible Telescope
(magnitude~23)

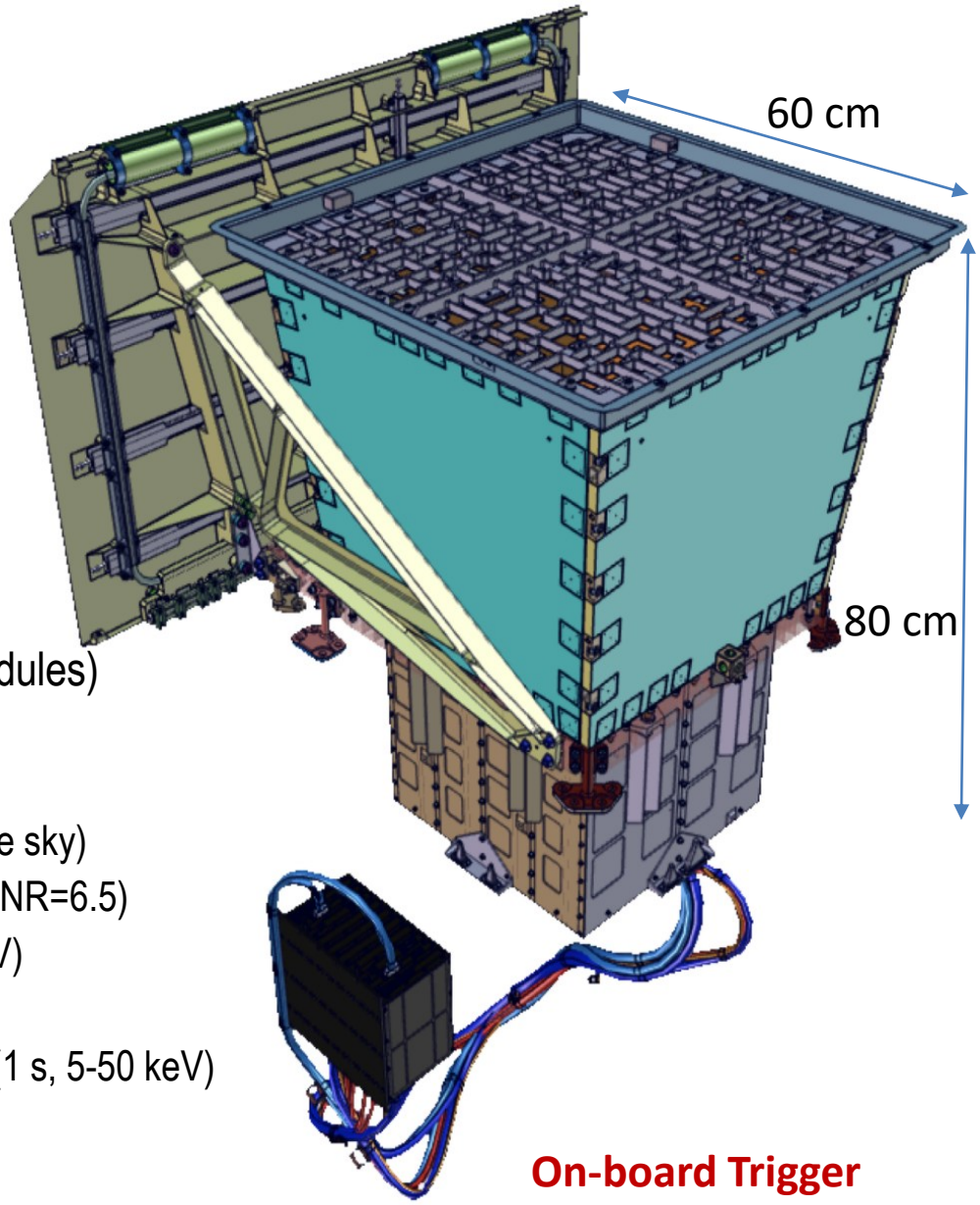
GFT *french + chinese*
Ground folow-up telescopes

ECLAIRs instrument

Soft gamma-ray spectroscopic imager

ECLAIRs instrument

Coded mask-imager with large field of view, and spectroscopy in the soft gamma-ray band



Energy range	4 – 150 keV
Energy resolution	1.6 keV (at 60 keV)
Detectors	6400 CdTe (200 modules)
Detecting area	1000 cm^2
Mask open fraction	40%
Field of view	2 sr (total, 1/3 of visible sky)
Localization accuracy	11.8 arcmin (at limit SNR=6.5)
Effective area	≥ 340 cm^2 (10-50 keV)
	≥ 200 cm^2 (at 6 keV)
Sensitivity	2.5 10^{-8} erg cm^{-2} s^{-1} (1 s, 5-50 keV)
Time resolution	20 μs
Dead time	< 5% (for 10^5 count/s)
Data rate	< 18 Gb/day (X-band)

On-board Trigger
expect ~ 50-70 GRB/yr

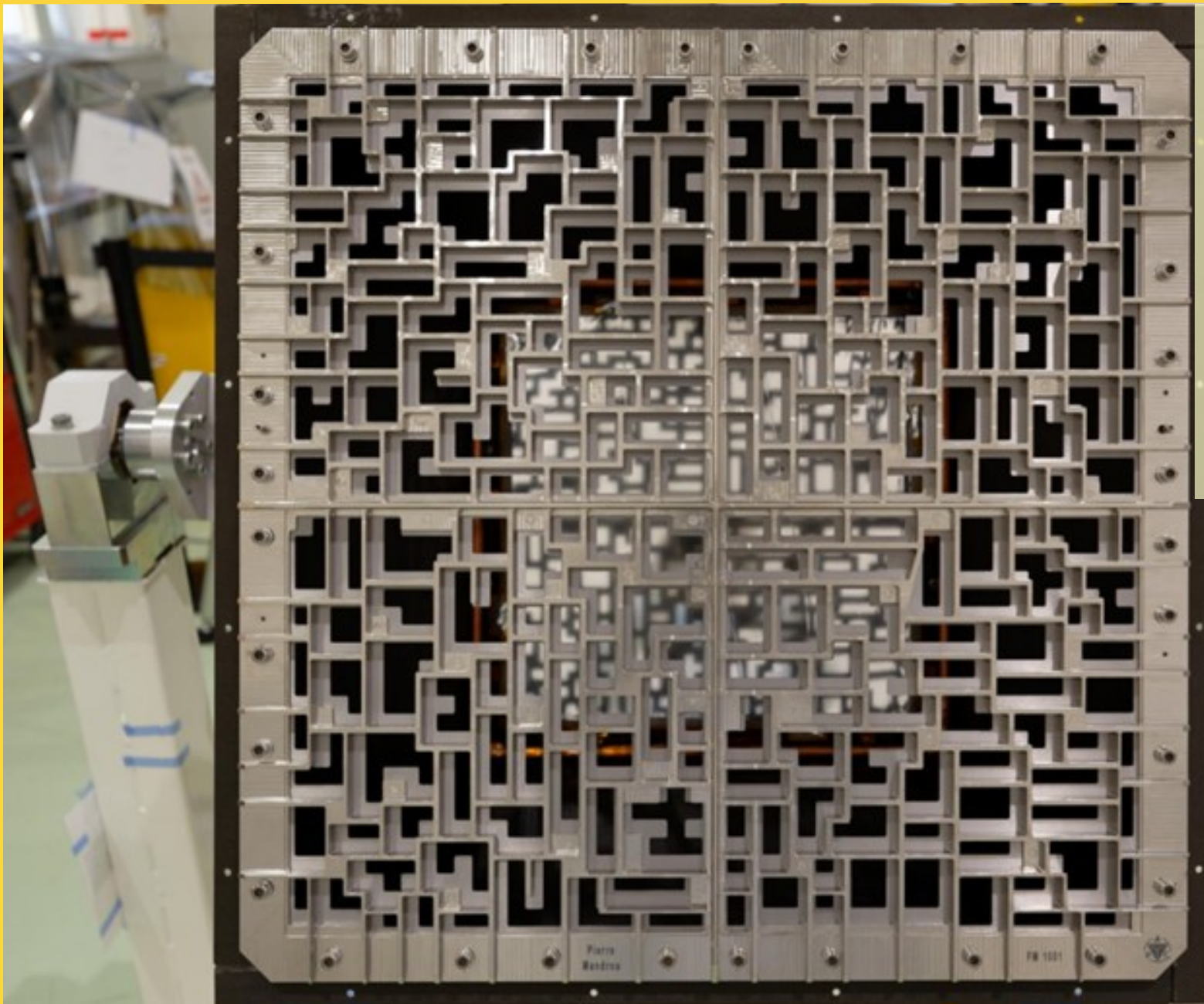
ECLAIRs flight model

CNES

ECLAIRs at CNES Toulouse, July 2022

ECLAIRs coded mask

APC



Mask
self-supporting
40% open

Ta 0.6 mm
sandwhiched
between
Ti structure

56x56 cm
46x46 pixels
+ central cross

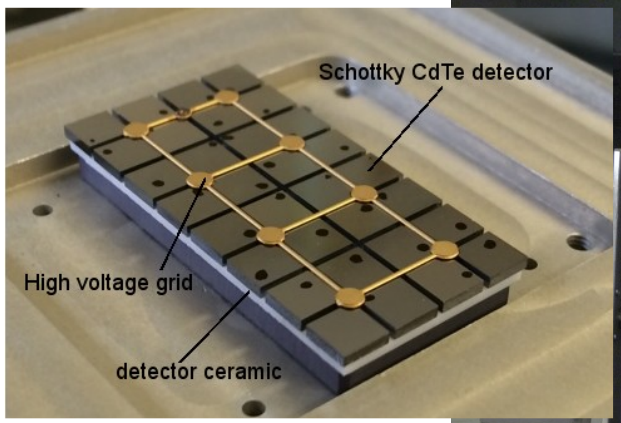
ECLAIRs detector unit

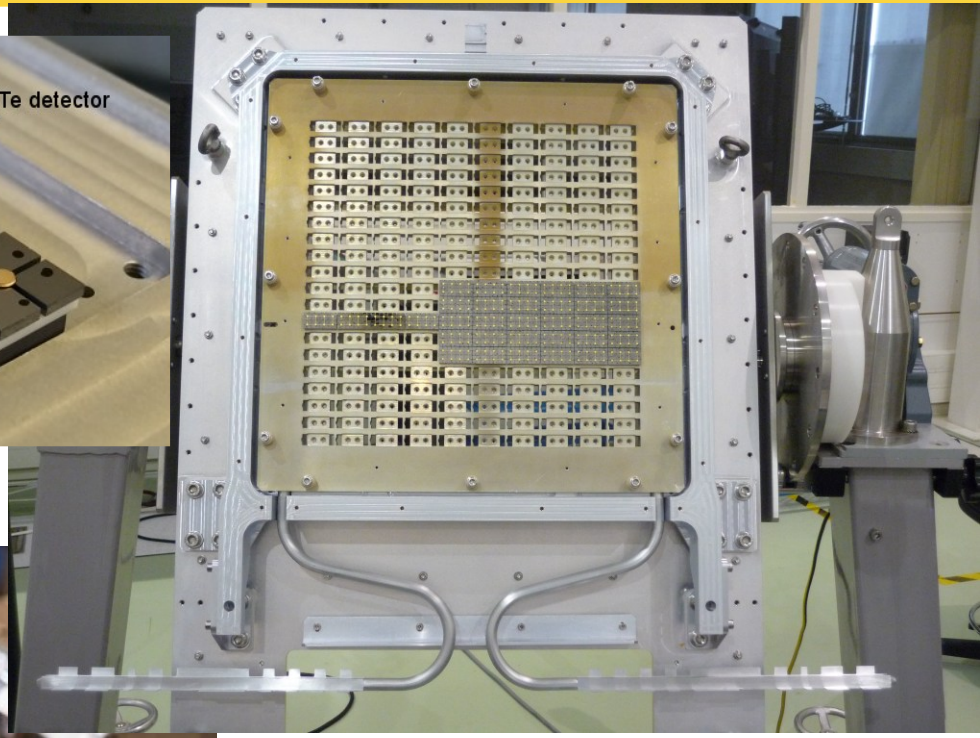
IRAP

XRDPIX module
(4x8 CdTe pixels)

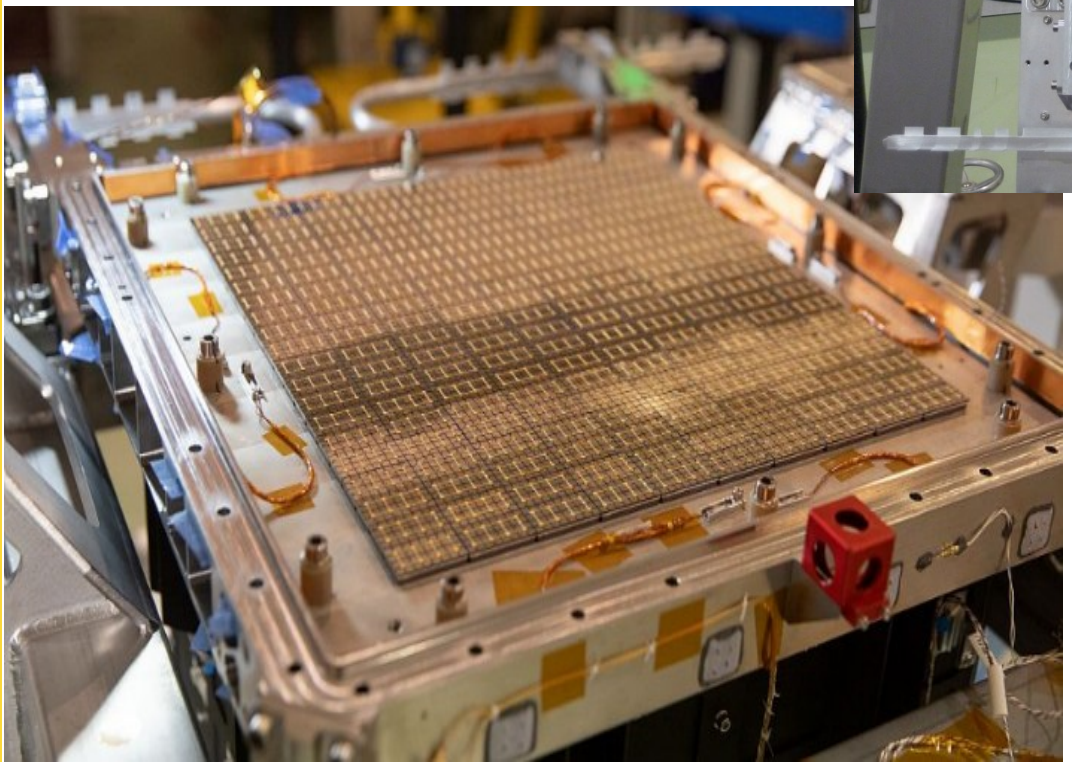
200 modules

arranged in
8 sectors

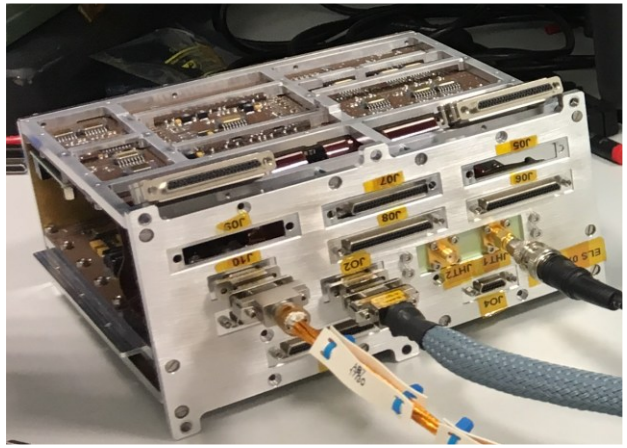




Detection plane FM



8 sector-readout electronics (ELS)



ECLAIRs trigger & control unit (UGTS)

CNES, CEA

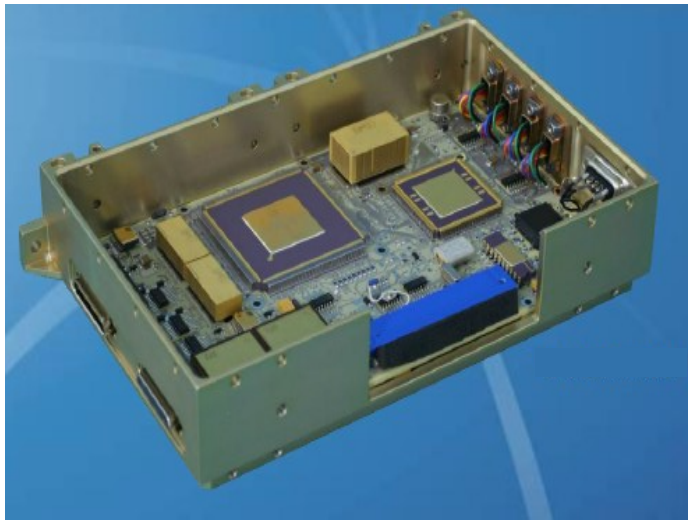
Functions

- Control of instrument (cmd/ctrl, HK, FDIR, thermal ctrl, noisy pixels) + Power supply
- Data acquisition: all detected counts
  → RawData packets → mass-memory
- **GRB Trigger** Scientific Processing (detection and localization of new source, based on *coded mask image deconvolution*)
  → Alert messages to ground (via VHF)
  → Slew requests to satellite

Hardware : rad tolerant, ITAR-free, cold-redundant

- I/O board (×2) + Power supply (×2+4)
- CPU board (with FPGA and CPU) (×2)
  FPGA : data acquisition and pre-processing
  CPU: dual-core, 80 MHz, 2×50 Mflops
  OS : time partitioning hypervisor

Image Reconstruction on UGTS CPU: ~ 1 s

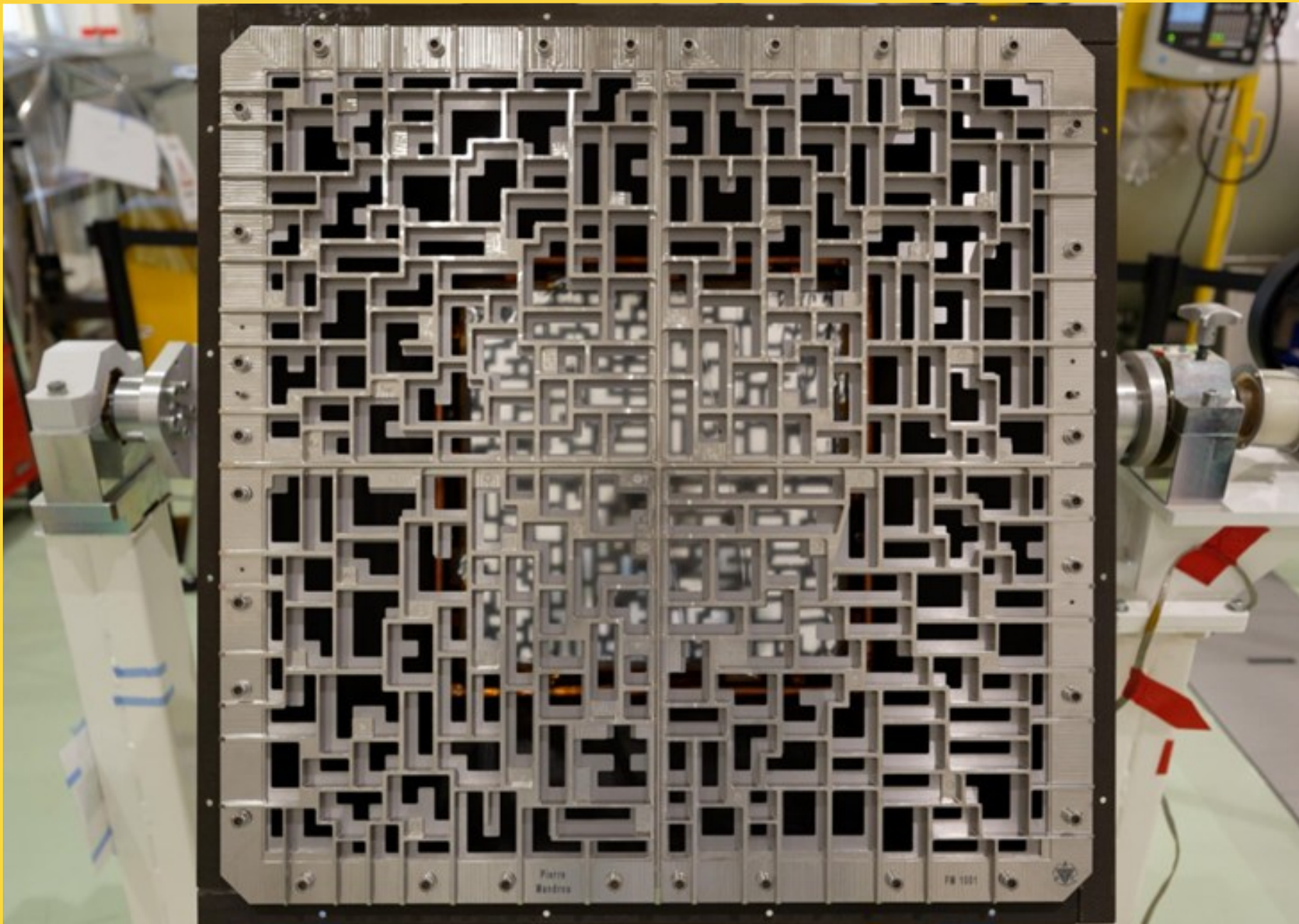


On-Board Software + Firmware : CEA

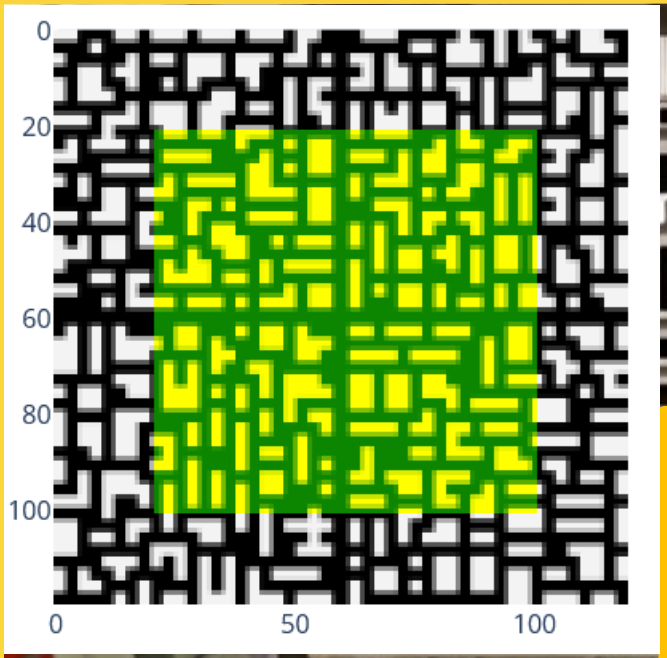
ECLAIRs coded mask imaging illustration

Sky image reconstruction by
Detector image deconvolution

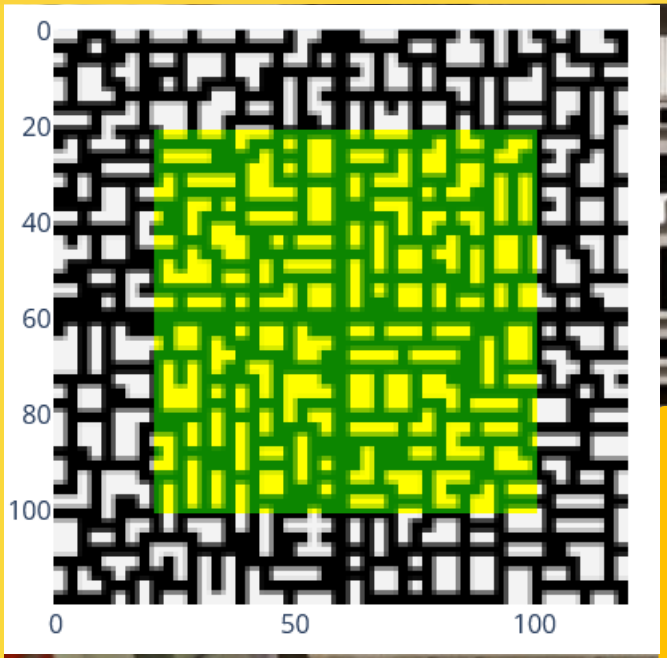
ECLAIRs imaging: on-axis source

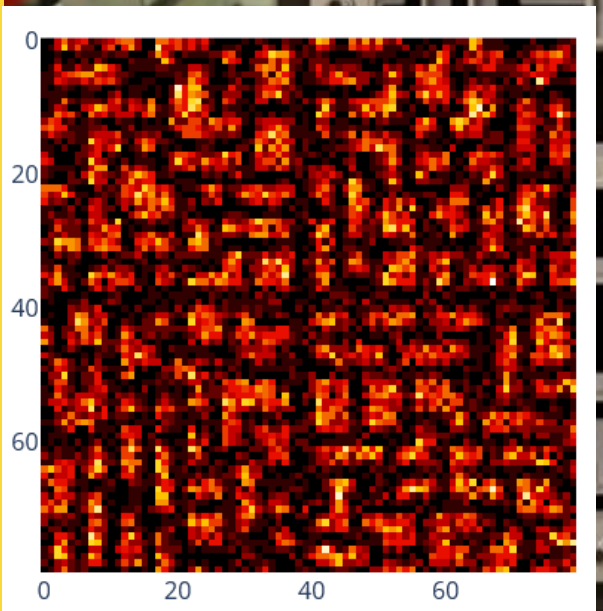


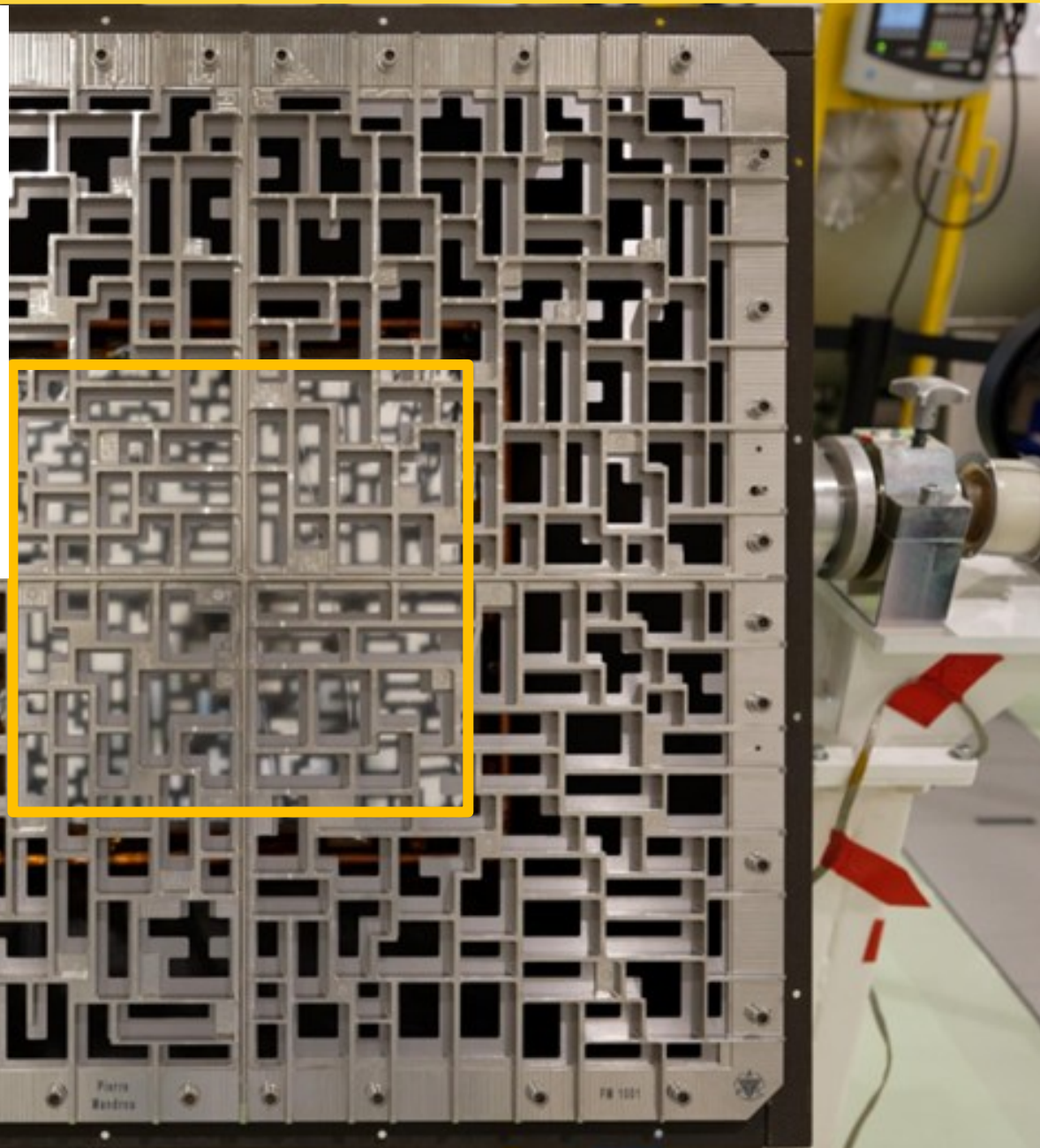
ECLAIRs imaging: on-axis source



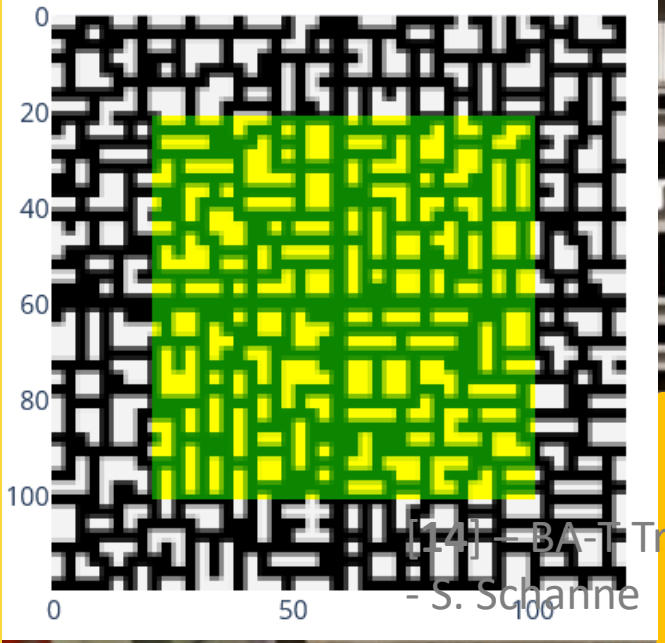
ECLAIRs imaging: on-axis source

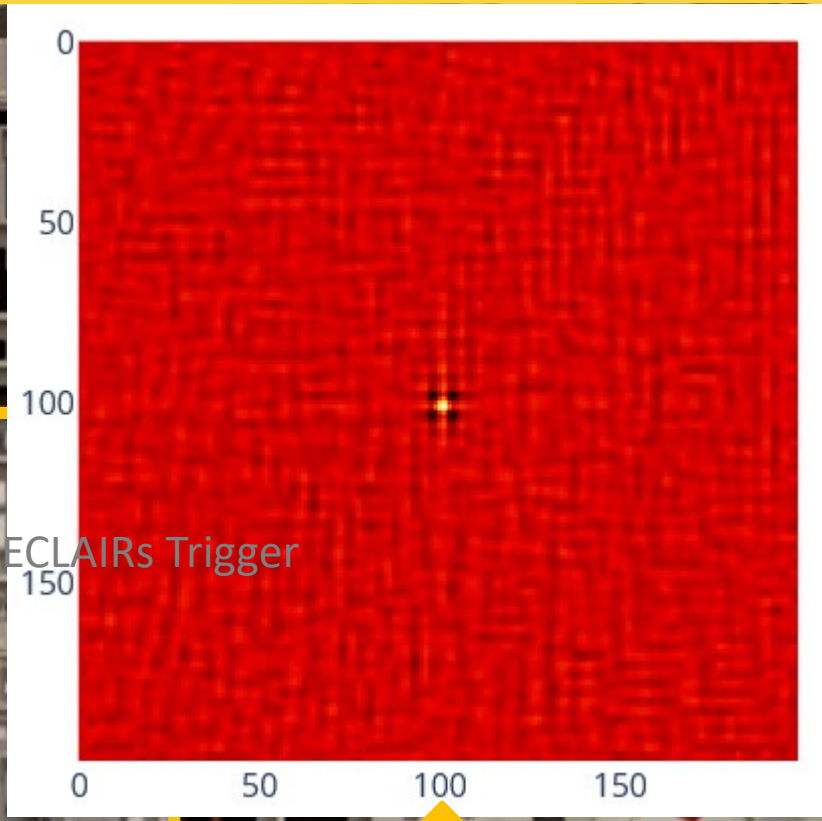


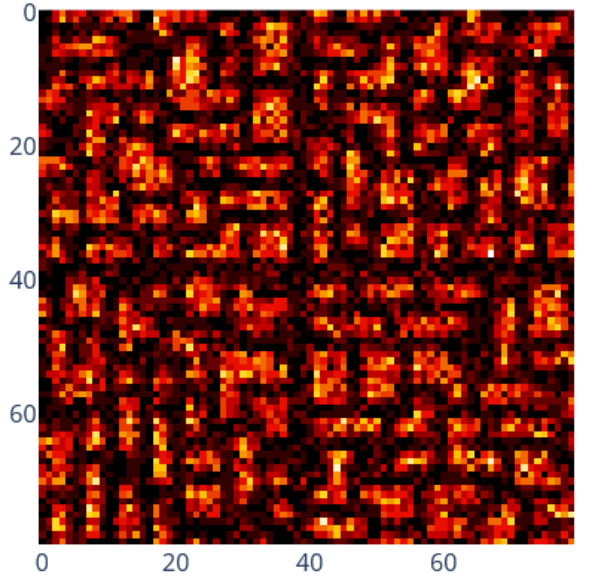




ECLAIRs imaging: on-axis source





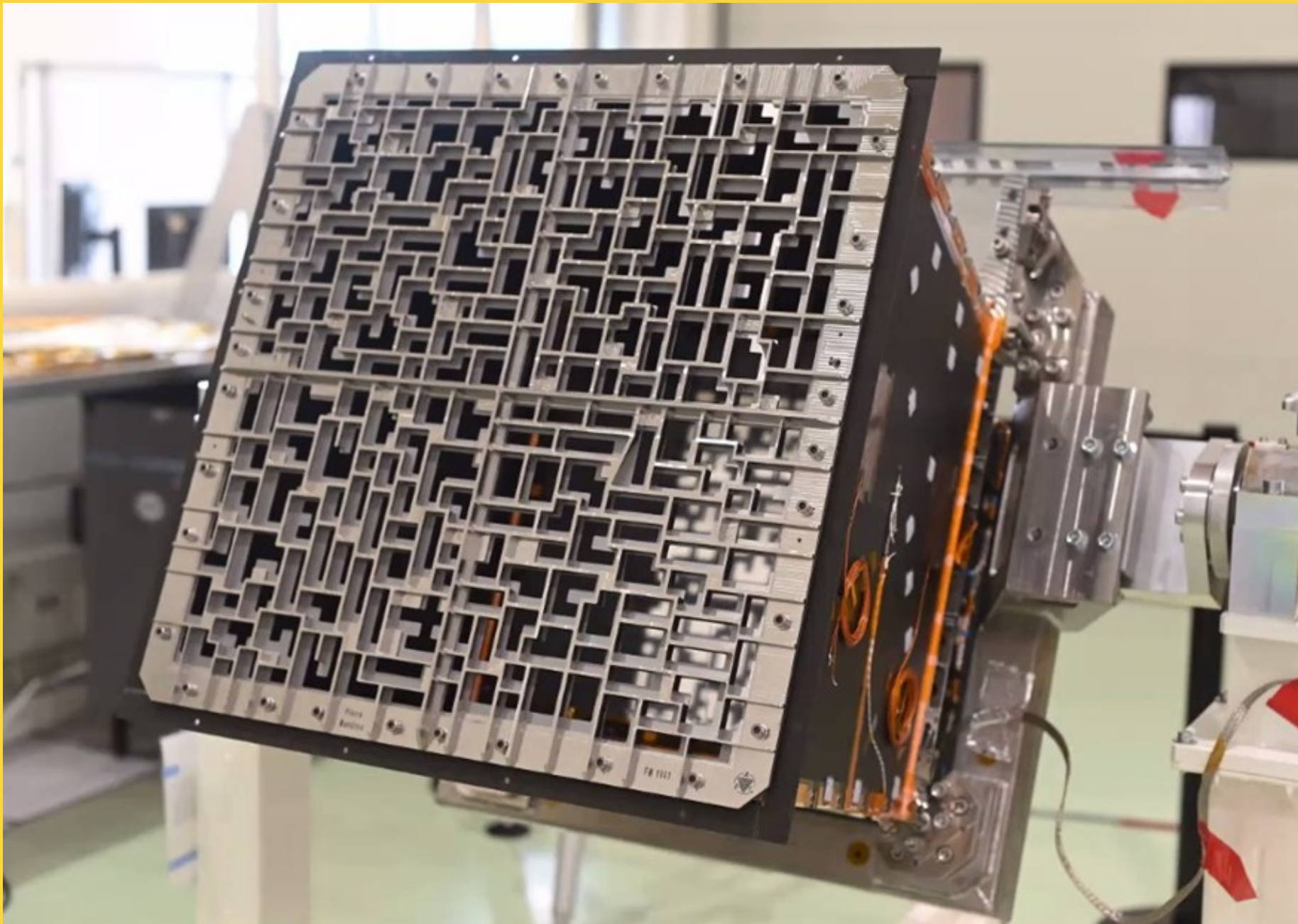


Deconvolution

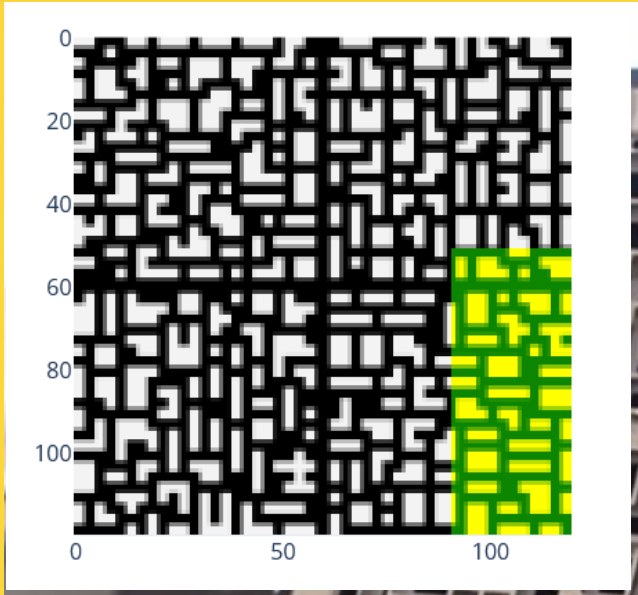
$$S_{ij} = \frac{\sum_{kl} G^{+}_{i+k,j+l} W_{kl} D_{kl}}{\sum_{kl} G^{+}_{i+k,j+l} W_{kl}} - \frac{\sum_{kl} G^{-}_{i+k,j+l} W_{kl} D_{kl}}{\sum_{kl} G^{-}_{i+k,j+l} W_{kl}}$$

[14] – BA-T Training - 260325 - ECLAIRs Trigger - S. Schanne

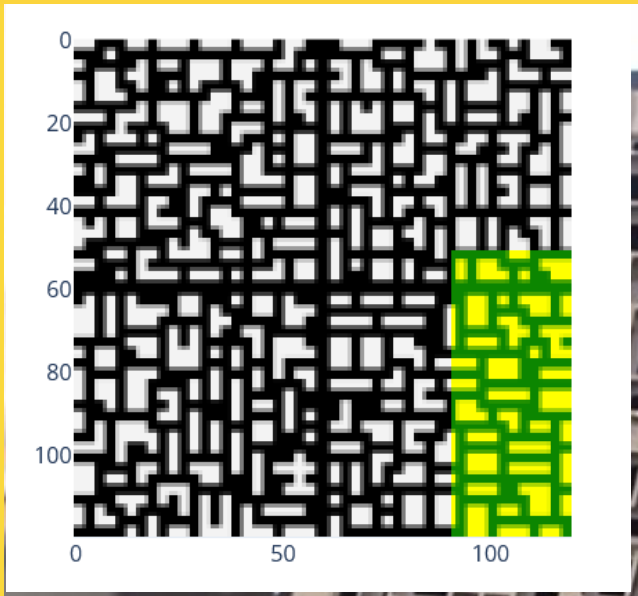
ECLAIRs imaging: off-axis source

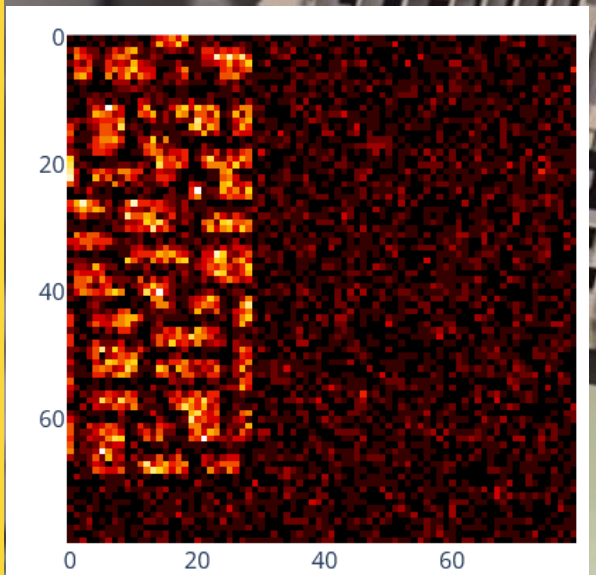


ECLAIRs imaging: off-axis source

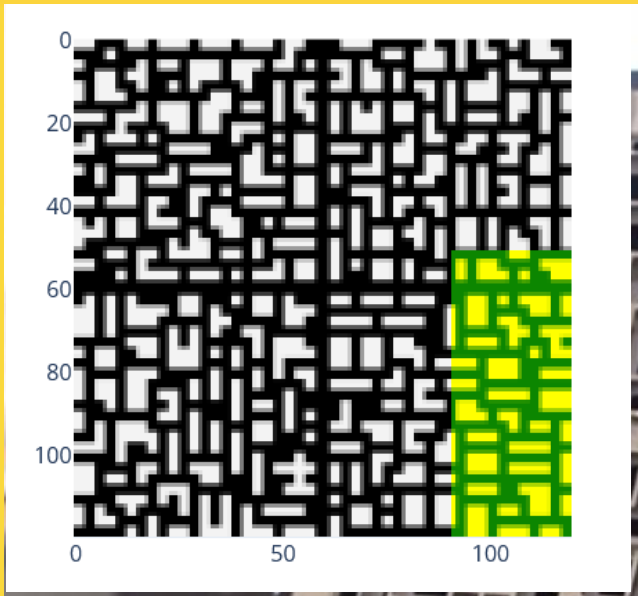


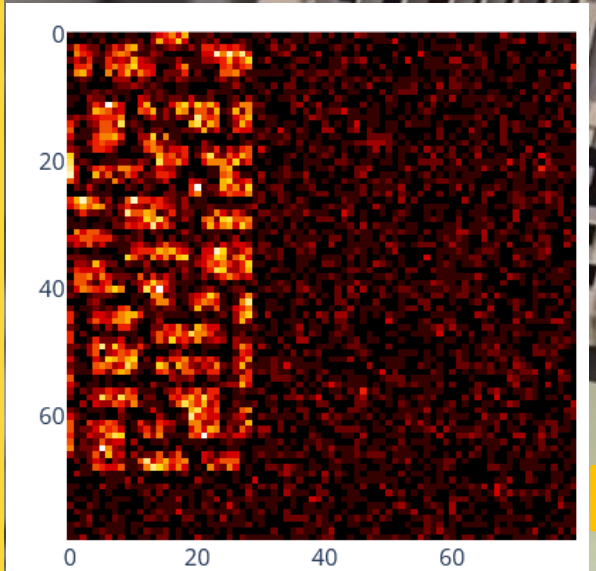
ECLAIRs imaging: off-axis source

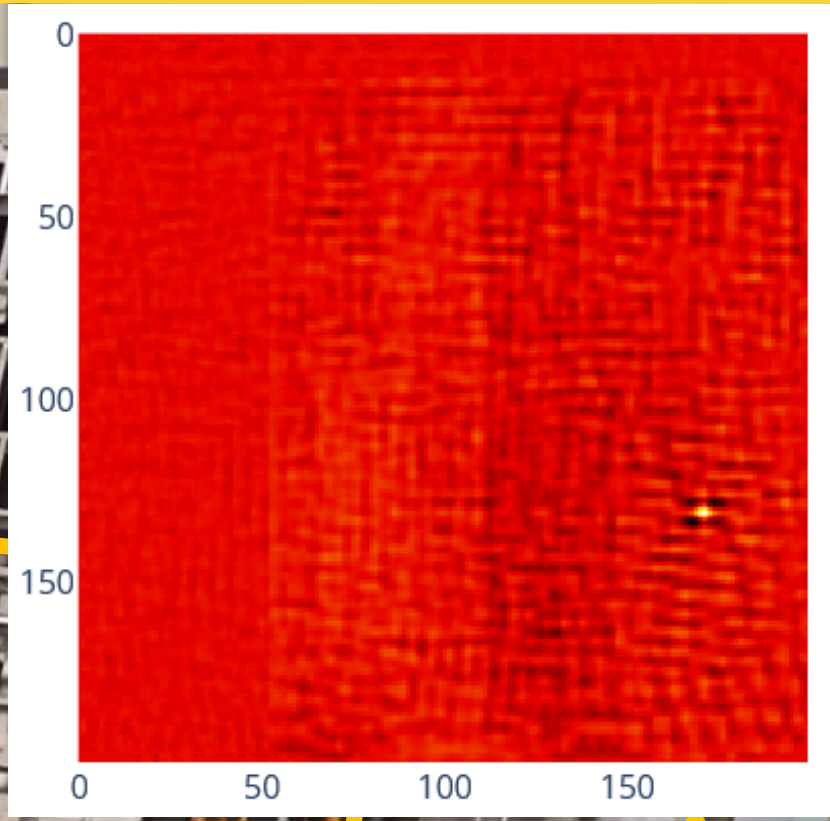




ECLAIRs imaging: off-axis source



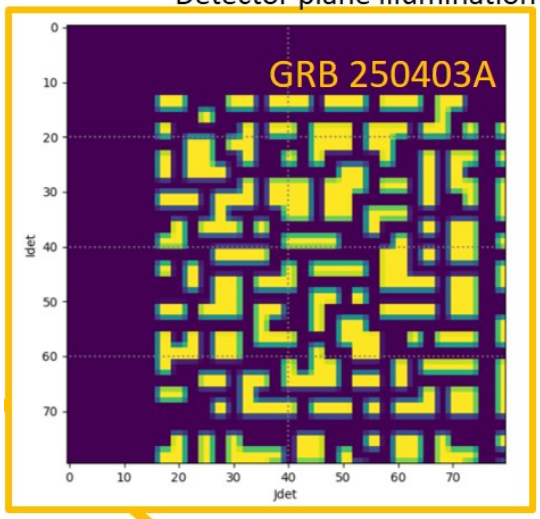


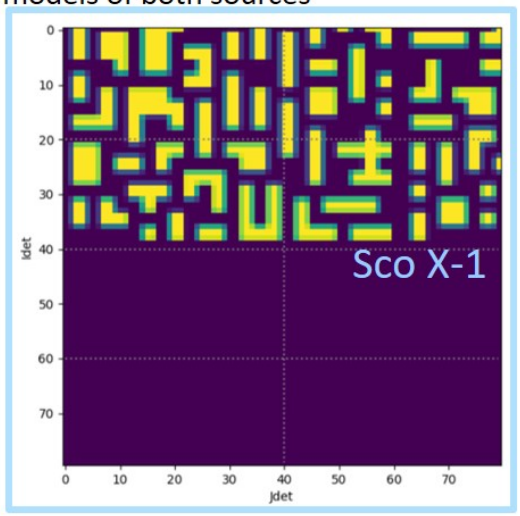


Deconvolution

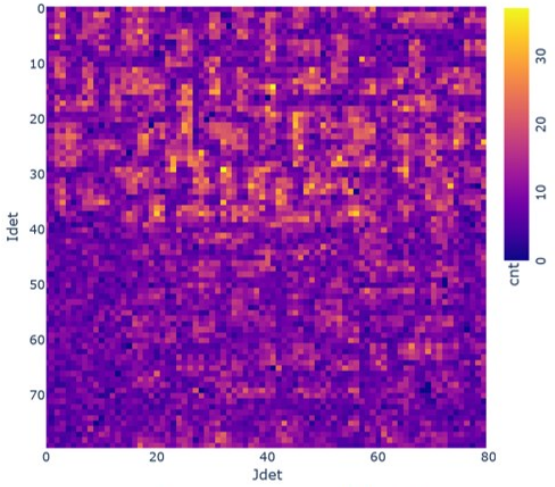
Proof in flight: Sco X-1 and GRB 250403A !

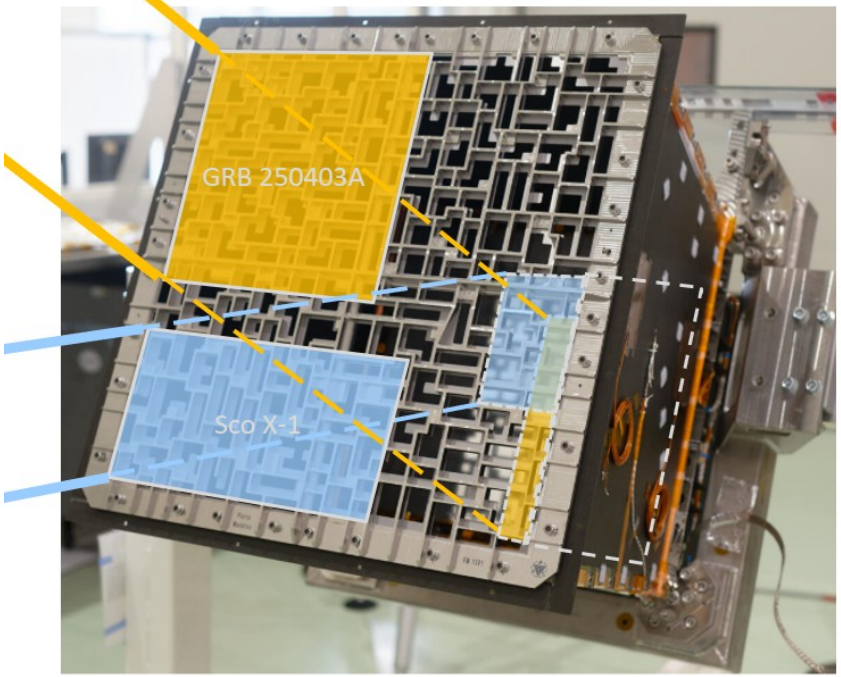
Detector plane illumination models of both sources



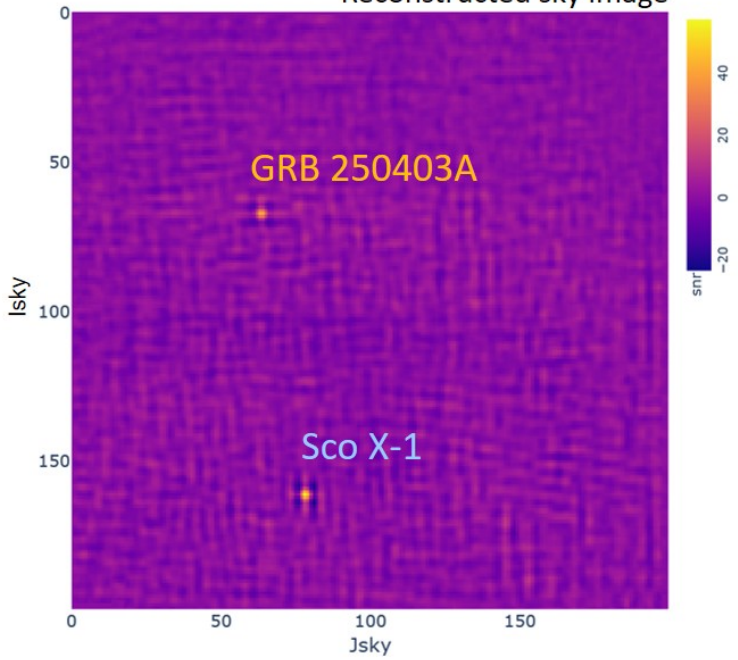


Detector plane image (recorded data)





Reconstructed sky image

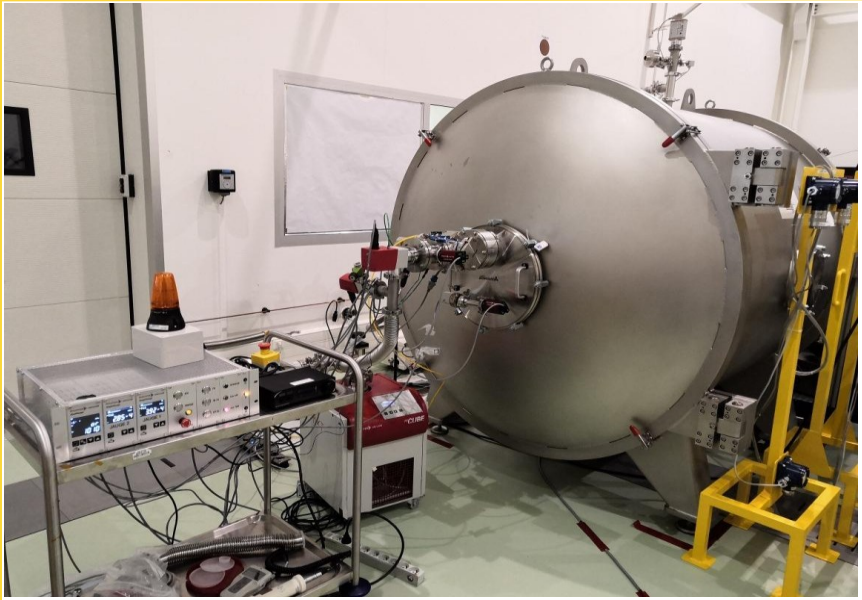


z=1.85, light travel time: 10.1 Gyr (comoving distance: 16.4 Gly) / Sco X-1: 9000 ly

ECLAIRs trigger algorithms

constraints

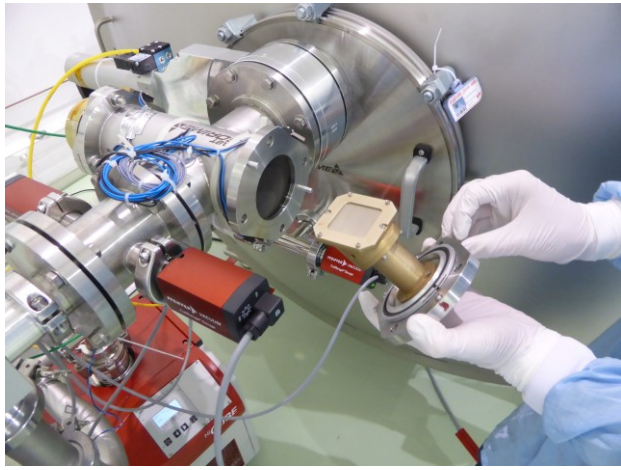
UGTS trigger: **detector instrumental effects**



CNES Toulouse ECLAIRs (March 2021)
ECLAIRs FM without mask

Thermal Vac.

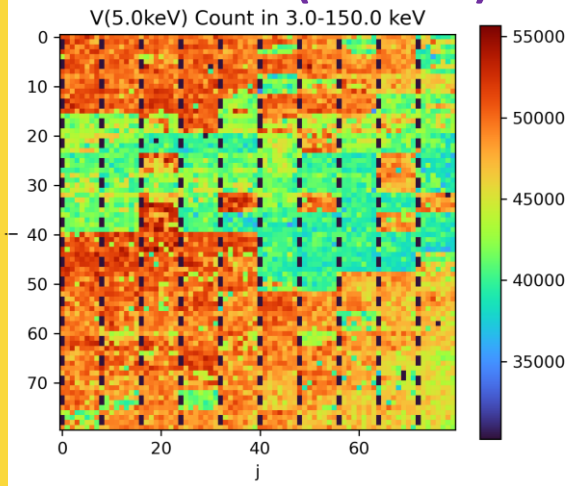
X-ray generator
Targets
Fluoresc. lines



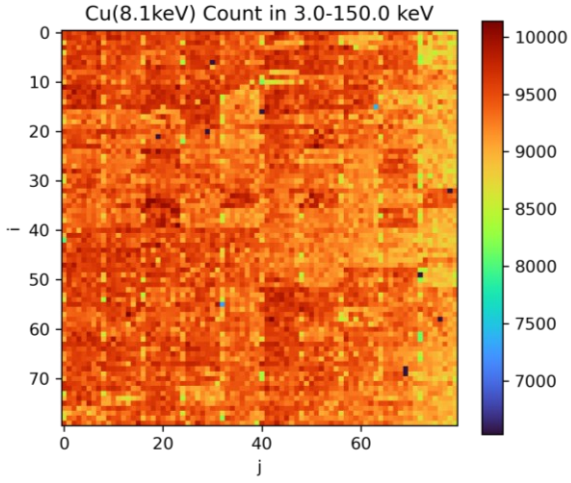
***Wenjin Xie* (CEA, thesis 2021-2024)**

W. Xie et al A&A arXiv 2401.13619 (2024)

Vanadium (5.0 keV)



Copper (8.1 keV)



Detection plane inhomogeneity at low Energy (4 to 8 keV)

Config UGG_TRIG table

➔ Estrip def for flight:
- Estrip 0,1,2 > 8 keV
- Estrip 3: 5-8 keV

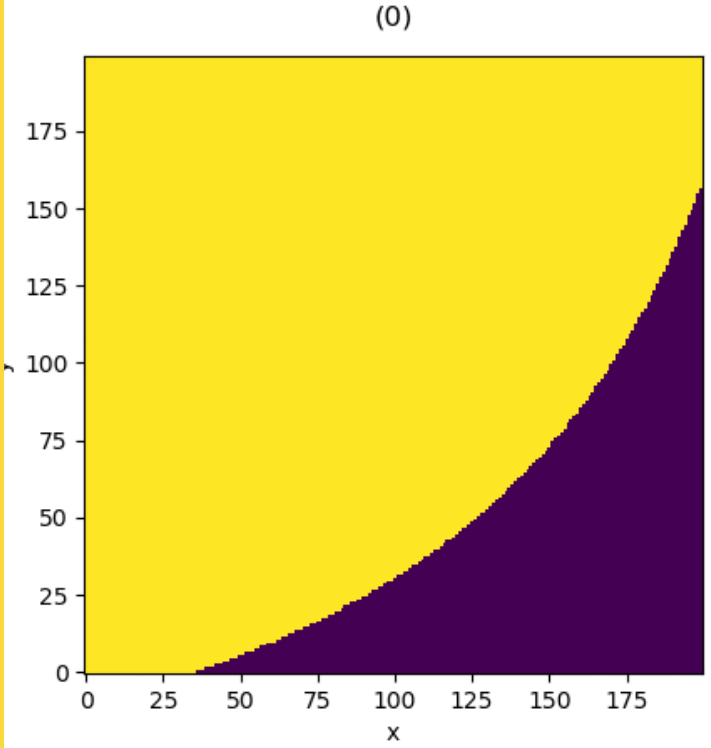
➔ Efficiencies and weights for UGTS deconvolution

➔ Noisy pixel management

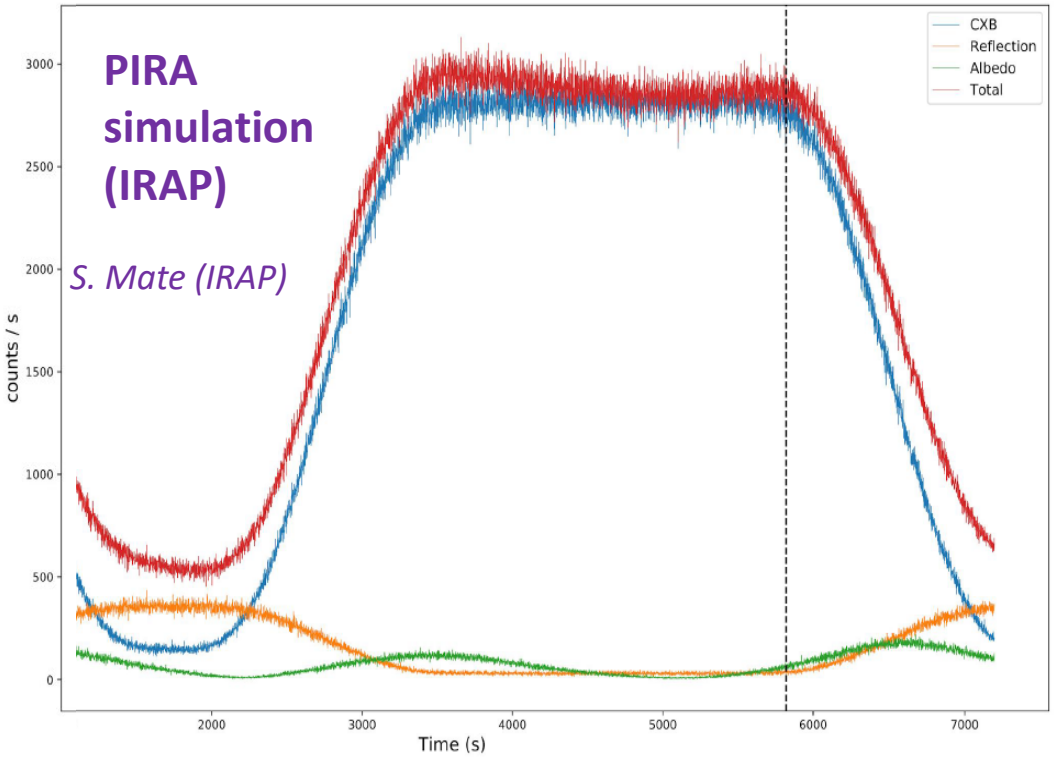
UGTS trigger: **variable background**

Background expected :
- CXB (cosmic X-ray background)
- Reflection (of CXB on athmosphere)
- Albedo (of cosmic rays in athmosphere)

Earth Transit in FoV ➔ modulation of bkg
Temporal and Spatial (on detector plane)
➔ *modelled in trigger algorithms*



Earth transit trough FoV
(1 frame = 20 s, 270 frames/orbit)



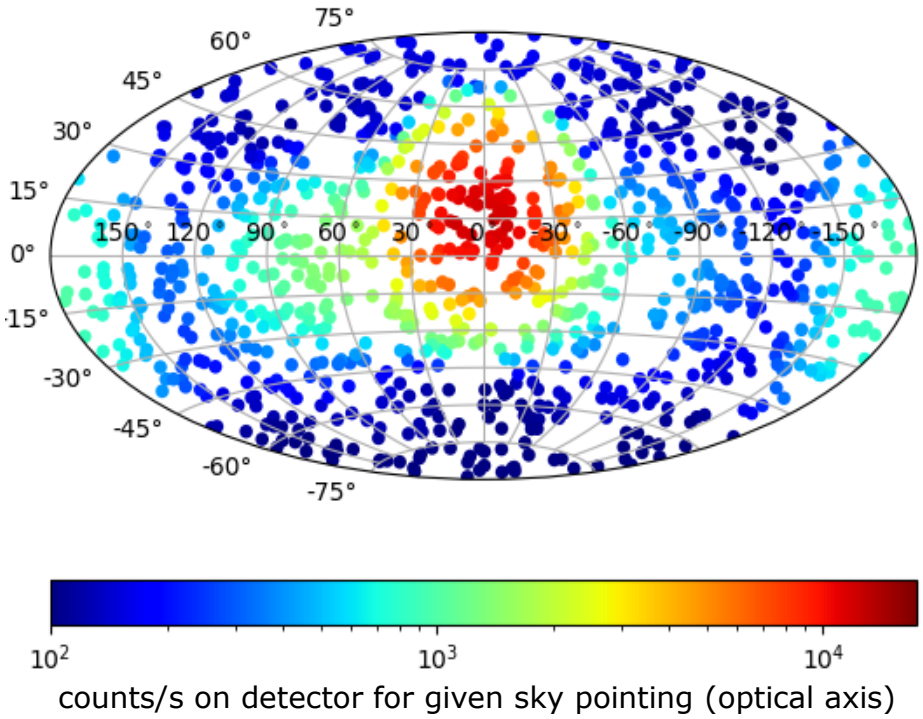
Note : Albedo rate changes significantly with orbit to orbit. From peak varying between average of 100 counts/sec to 200 counts/sec.

UGTS trigger: **known sources catalog**

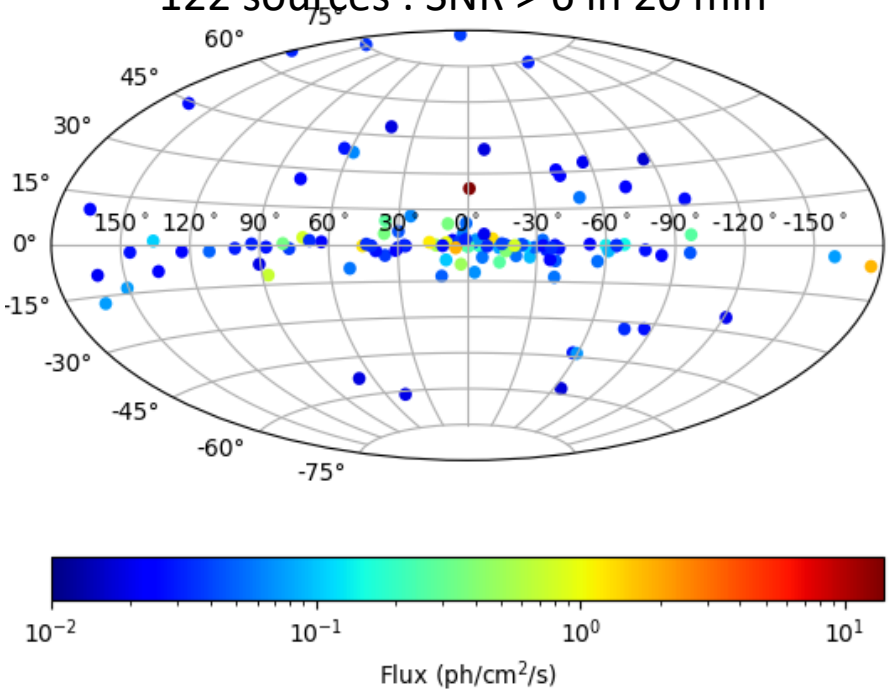
***Nicolas Dagoneau* (CEA, thesis 2017-2020)**

N. Dagoneau, S. Schanne et al A&A 645A (2021)

using 425 sources from MAXI (2-20 keV) + Swift/BAT (15-195 keV)
spectra modelled (broken-powelaw), flux over ECLAIRs 4-120 keV band



122 sources : SNR > 6 in 20 min



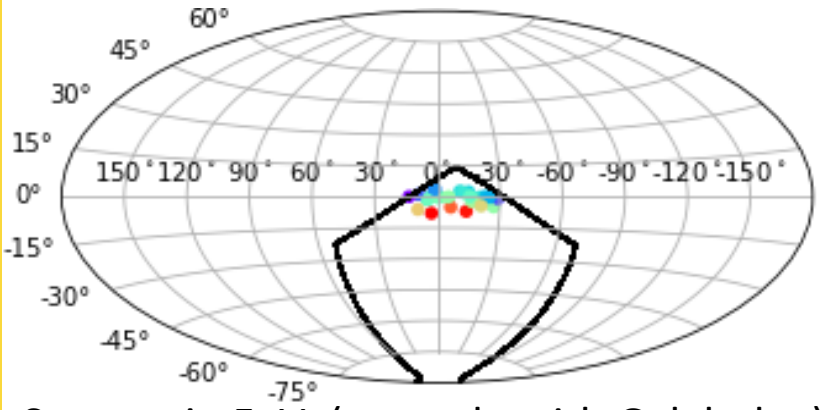
- Most of sources excluded by B1 pointing law (|b|>10° & Sco X-1 avoidance)
- But we may be outside B1 law during >¼ of the time (GRB follow-up & ToO)

➔ ***Onboard source Catalog included for trigger algorithms***

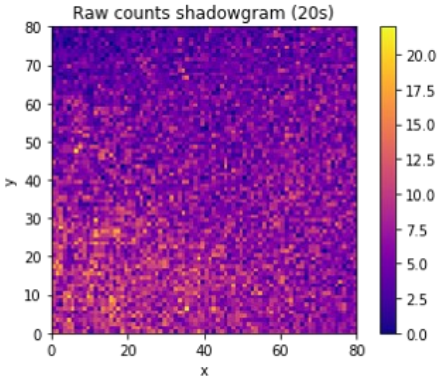
UGTS trigger > 20s: **fit bkg & strong sources**

N. Dagoneau & S. Schanne A&A 665A (2022)

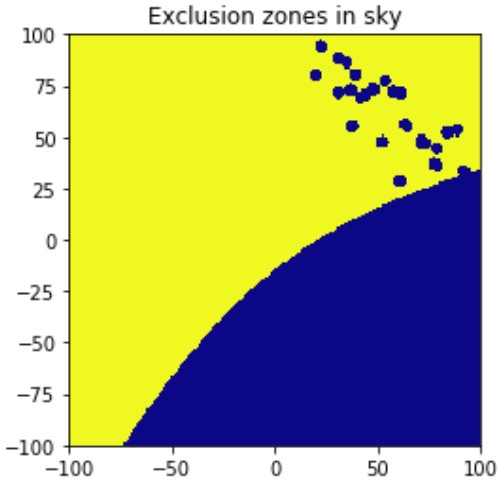
***Nicolas Dagoneau** (CEA, thesis 2017-2020)*



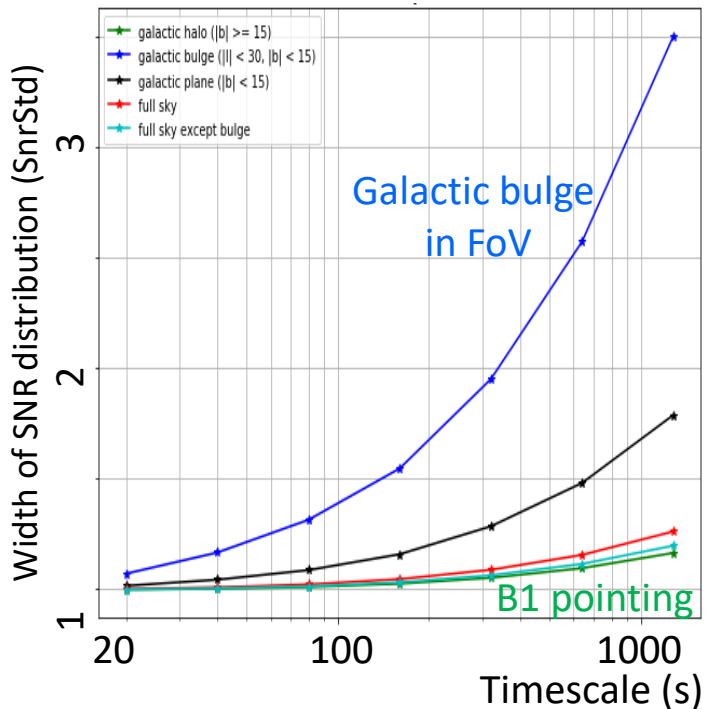
Sources in FoV (example with Gal. bulge)

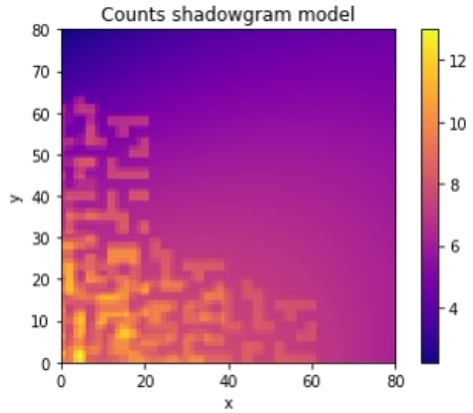


Raw shadowgram
(20 s, sources +
Earth modulated CXB)

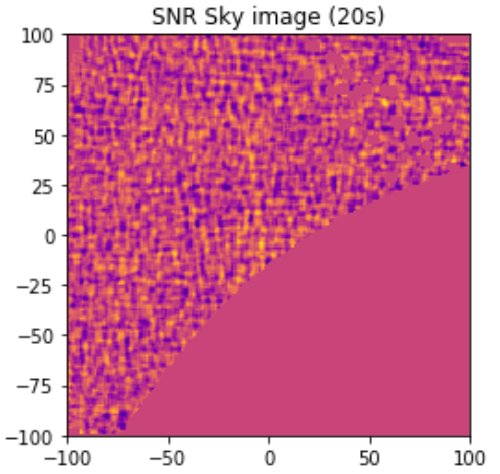


Sky exclusion region





Model fit to shadowgram:
CXB 6 par + 1 par/source
(max 5 sources fitted)



Sky SNR image
(20 s, Earth exclusion)

UGTS trigger: **driven by GRB diversity**

GRBs appear randomly on the sky

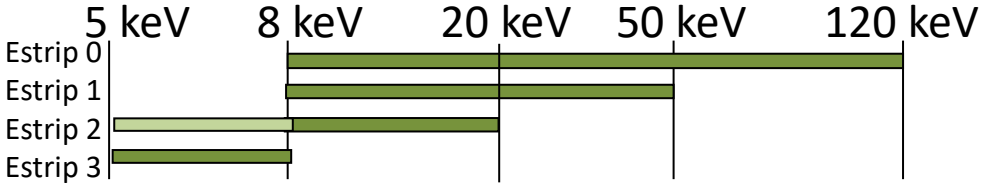
➔ search in full FoV (2 sr, taking into account position of Earth and known sources)

Faint GRBs are the most numerous ones

➔ AlertThresh, SlewThresh as low as possible (with acceptable false alarm rate)

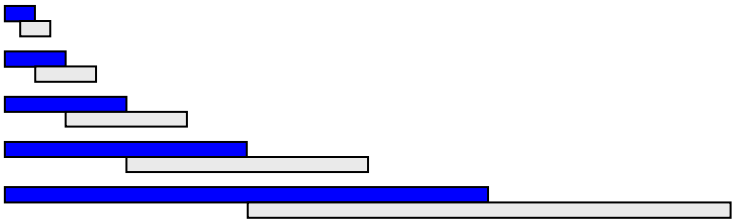
GRB spectral diversity (normal, XRF, high-z)

➔ 4 Energy strips



GRB durations and variability

➔ All Time-scales from 10 ms to 22 min
(17 powers of 2)



But sky-image computation takes ~1 second on UGTS hardware!

➔ **Two trigger algorithms running in parallel (each on 1 CPU core):**

- "**Image Trigger**" on long time-scales (> 20s), 1 step:
  build sky images every 20 s, stack up to 20 min, search for new source
- "**Count-Rate Trigger**" or short time-scales (< 20 s), 2 steps:
  first select time window with count-rate increase,
  then build sky image and search for new source

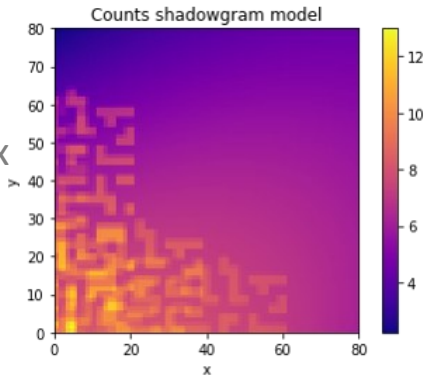
ECLAIRs trigger algorithms:
IMT and CRT

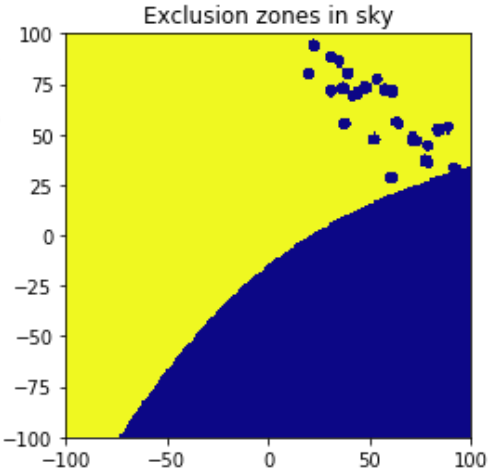
UGTS: **Image Trigger (IMT) algorithm**

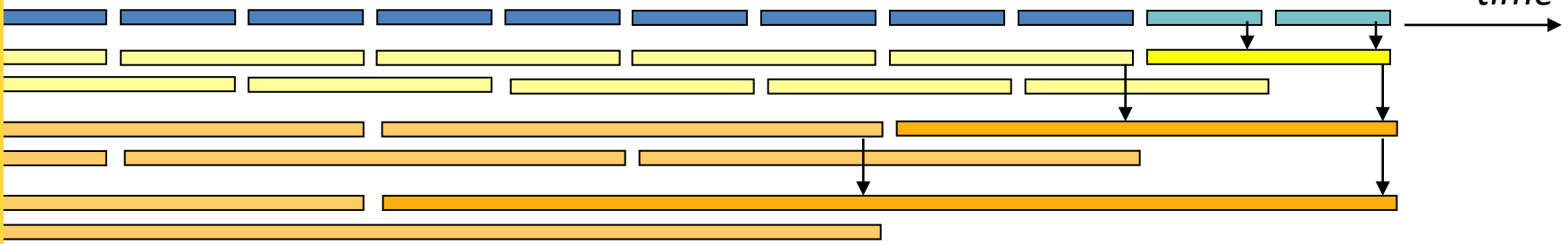
Cyclic process every 20.48 s, in 4 Estrips

- build detector image and clean noisy pix
- fit & subtract background shape
  (Earth modulated CXB + bright sources)
- deconvolution (using mask pattern)

⇒ **Sky Images of 20 s duration** (remove part behind Earth)





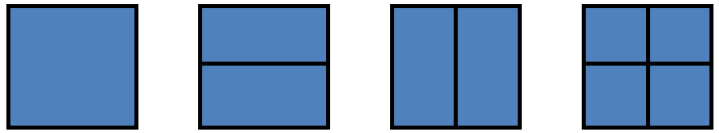


- **Summation of sky images (using sky image history)**
  → Sky-images up to 20 min duration (7 time scales: 20 s to about 20 min)

- **Search in each sky image: pixel *SNRmax*** (for which *SNRmax/stdev > thresh*)
- if not in known source catalogue, fit peak to get precise position.
  if *SNRmax* > *AlertThresh* ➔ **GRB-Alert to VHF**
  if *SNRmax* > *SlewThresh* ➔ **GRB-Alert to VHF with satellite slew request**
- if at known source position: if *SNRmax* > *CatThresh* ➔ **CAT-source Alert with slew req.**

UGTS: **Count-Rate Trigger (CRT) algorithm**

Cyclic process every 2.56 s



First step: *detect excesses in count-rate*

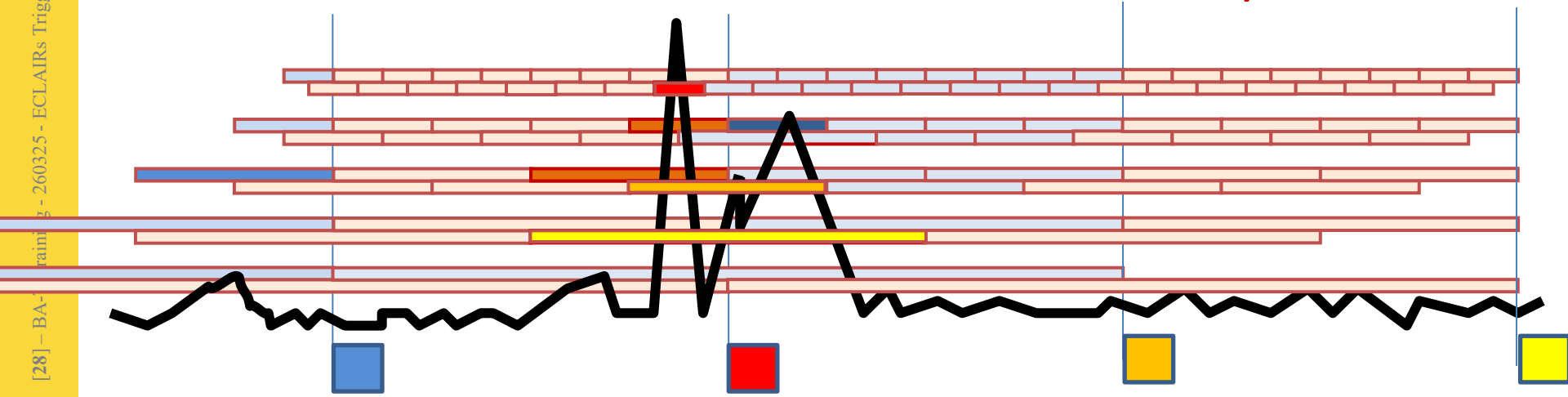
- background estimate (from temporal bkg-model)
- build counts in all Time-Windows from 10 ms to 20 s (in 4 Estrips, and in 9 detector zones)
- compute count excess significance: *SNRcnt > CntThresh* ➔ stored into **buffer**

Second step: *imaging of best excess detected up to now*

- search best excess present in buffer (not too old, not yet processed)
- build detector image of best excess (over its TimeWindow and in its Estrip) and clean noisy pix
- deconvolution➔ **sky Image**
- **search in each sky image: pixel *SNRmax*** (for which *SNRmax/stdev > thresh*)
- if not on Earth and not in known source catalogue, fit peak to get precise position.

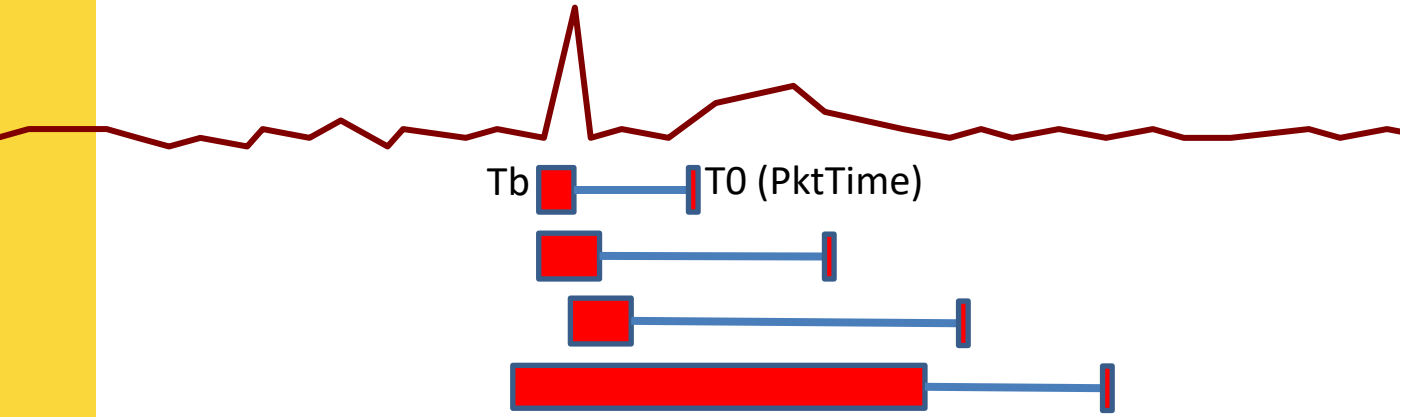
  if *SNRmax > AlertThresh* ➔ **GRB-Alert to VHF**

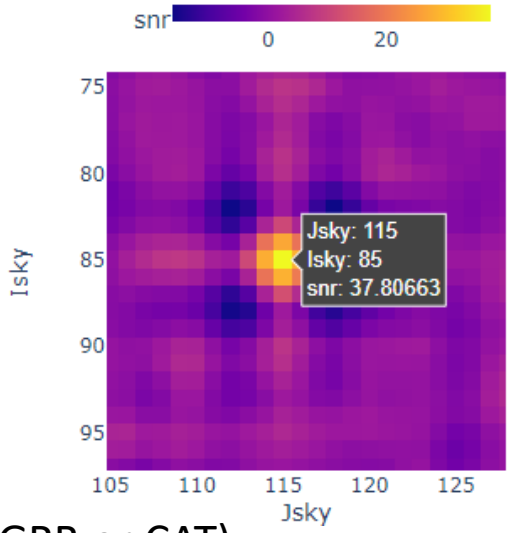
  if *SNRmax > SlewThresh* ➔ **GRB-Alert to VHF with satellite slew request**



ECLAIRs trigger output

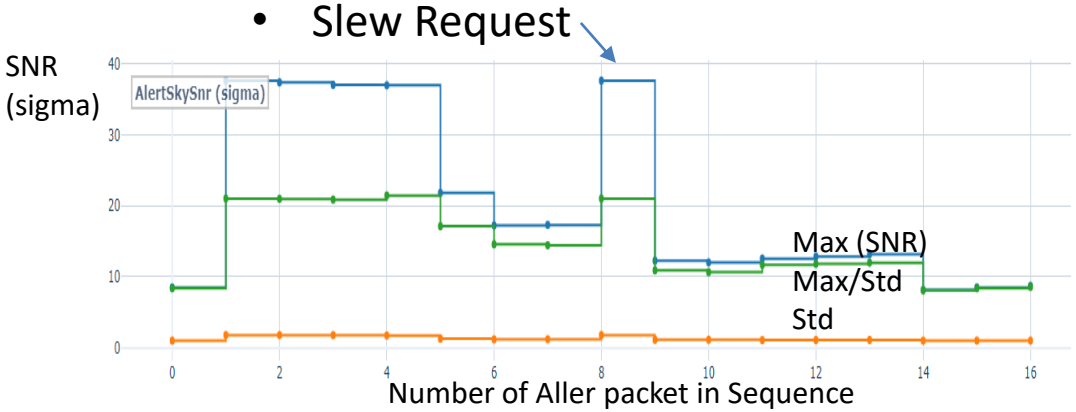
UGTS: **Alert output to VHF & Beidou**

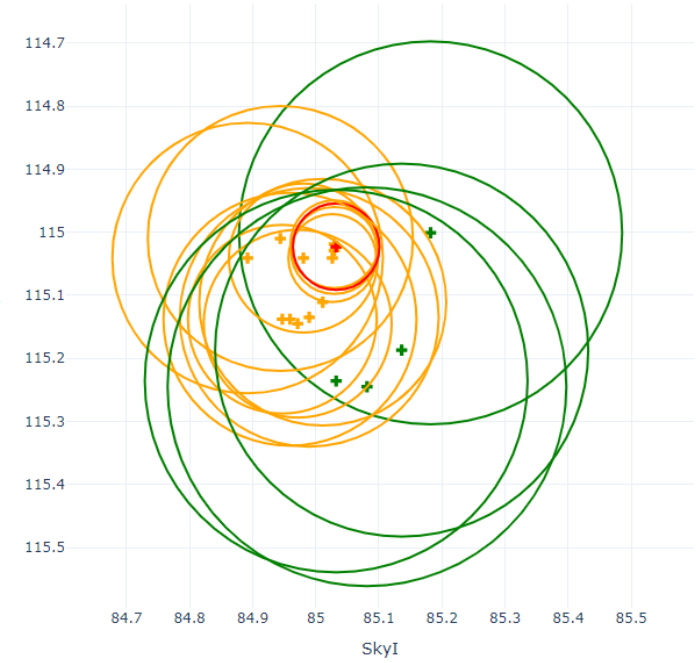




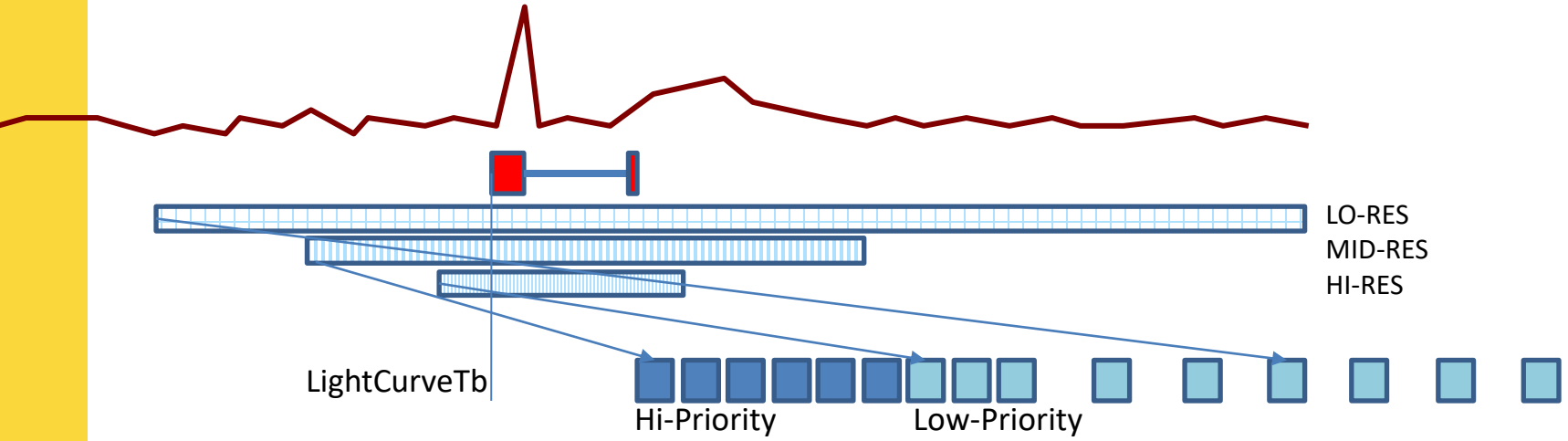
Sequence of Alert packets (dozen of packets):

- ObsNumber (Alert Sequence Number) + ObsType (GRB or CAT)
- Trigger Time-Window (Tb, Exposure)
- SNRmax in image (and Energy range)
- Detection quality (image stdev…)
- Position (local coordinates in FoV)
- Satellite attitude and satellite position
- Slew Request

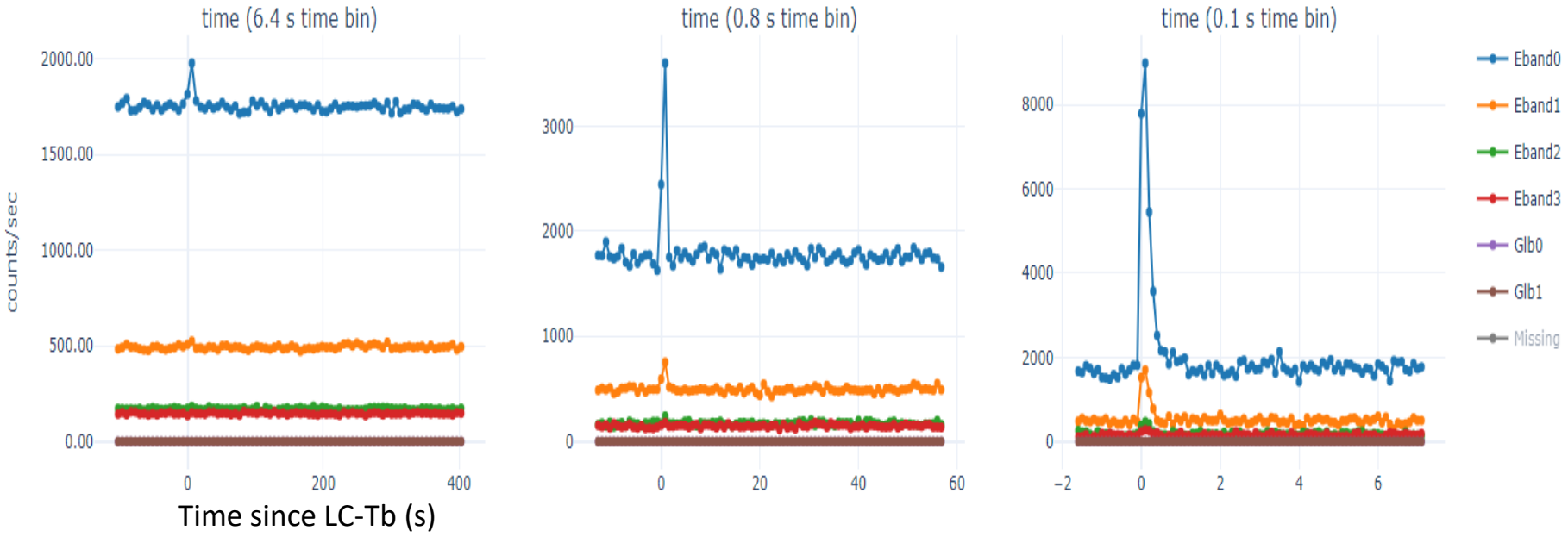




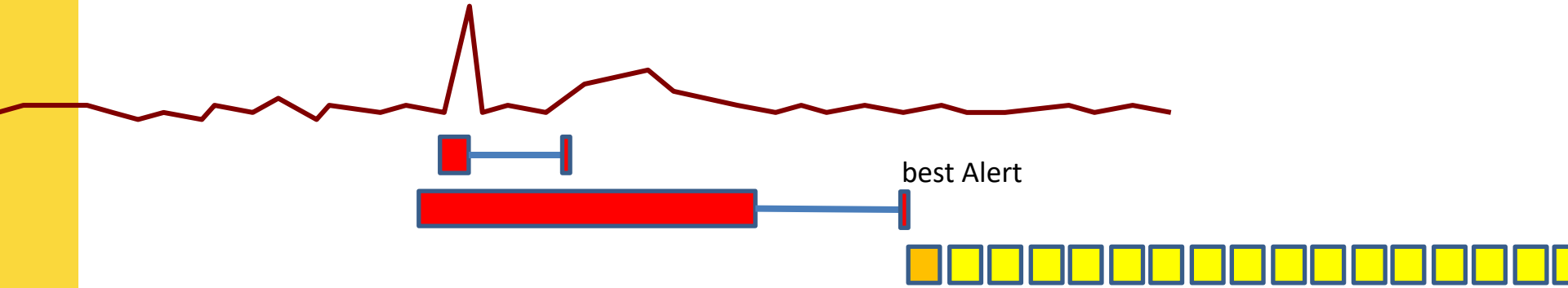
UGTS: **LightCurve output to VHF**



Light-Curve around Trigger Time Window (64 packets)

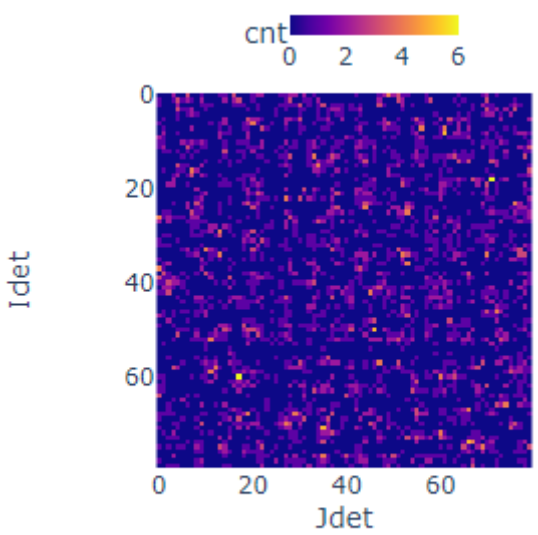


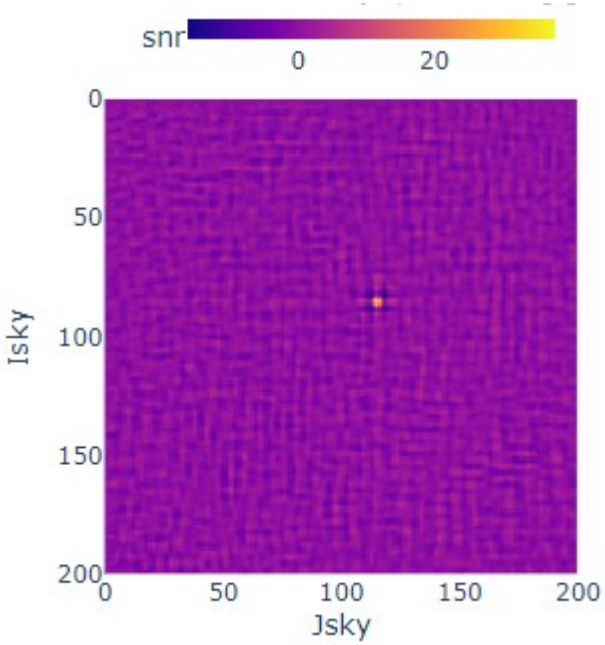
UGTS: **End of AlertSequence output to VHF**



Alert Descriptor packets (AD1: best Alert, AD2-3: CRT, AD4-5: IMT)
Details about best Alert found (+ info if Slew accepted or time-out)

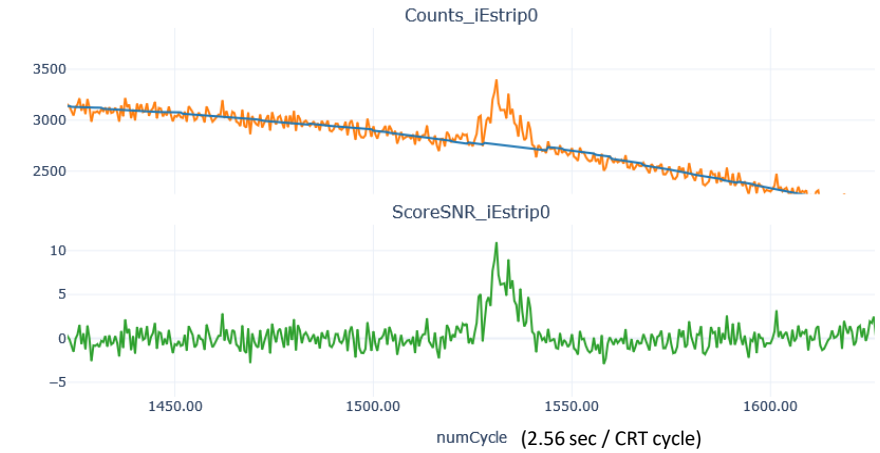
Shadowgram or Subimage around best Alert in sequence (49-64 packets)



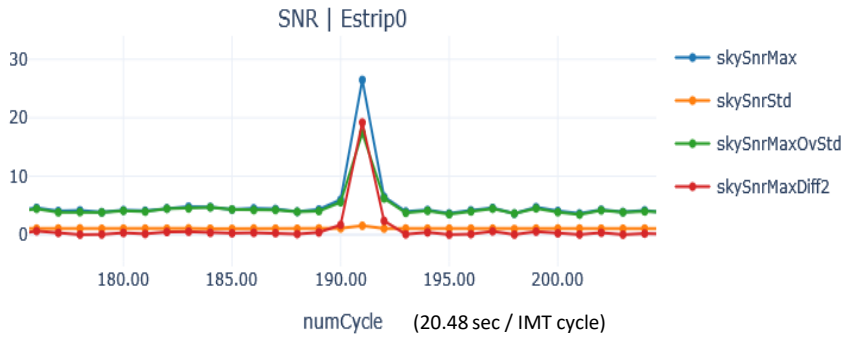


UGTS-output: **X-band UssMessages + DuplicVhf**

CRT excesses (in SNR counts, before imaging)

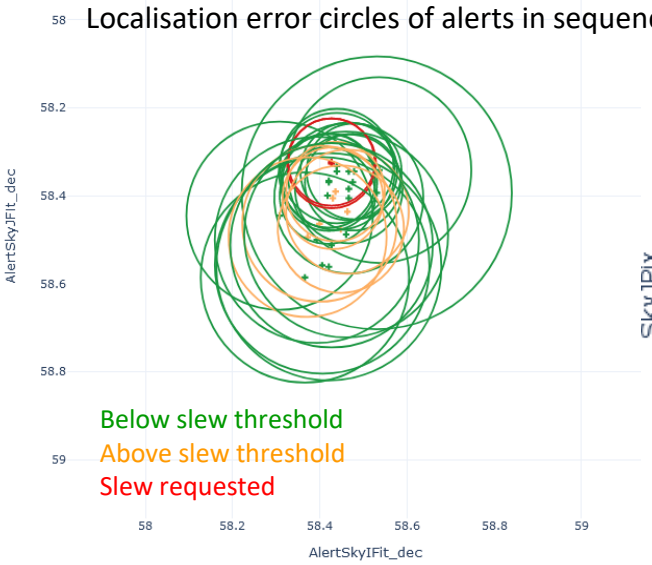


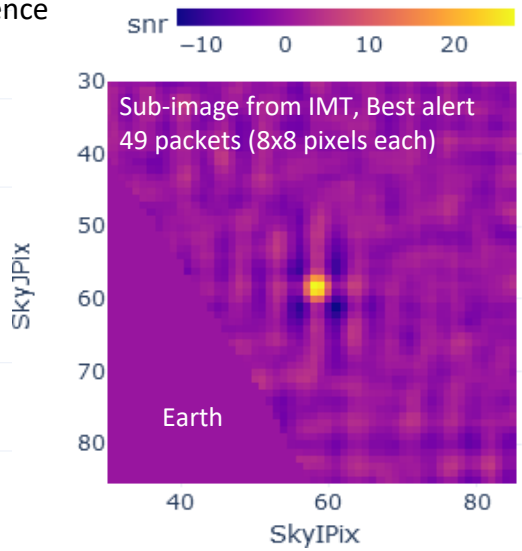
IMT excess in SNR sky image



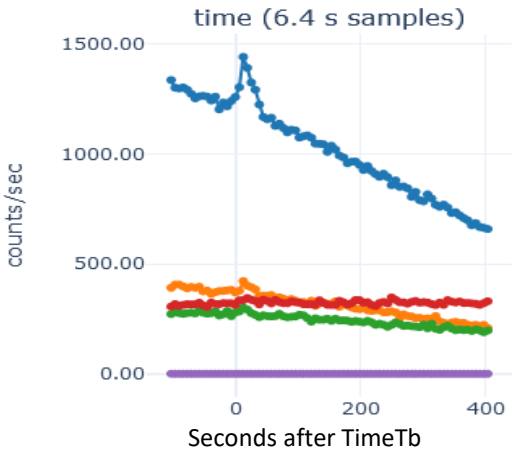
VHF alert sequence (output products built)

Localisation error circles of alerts in sequence





Lightcurves (3 resolutions):
- High/Mid/Low (0.1/0.8/6.4 s binning)
- Each: 4 Ebands + Saturating + Multiples



Flight software V7.0.3 (CEA delivered to CNES 2023 / 2 / 14)

ECLAIRs trigger flight statistics

UGTS trigger prototype: **Estimate Num GRBs**

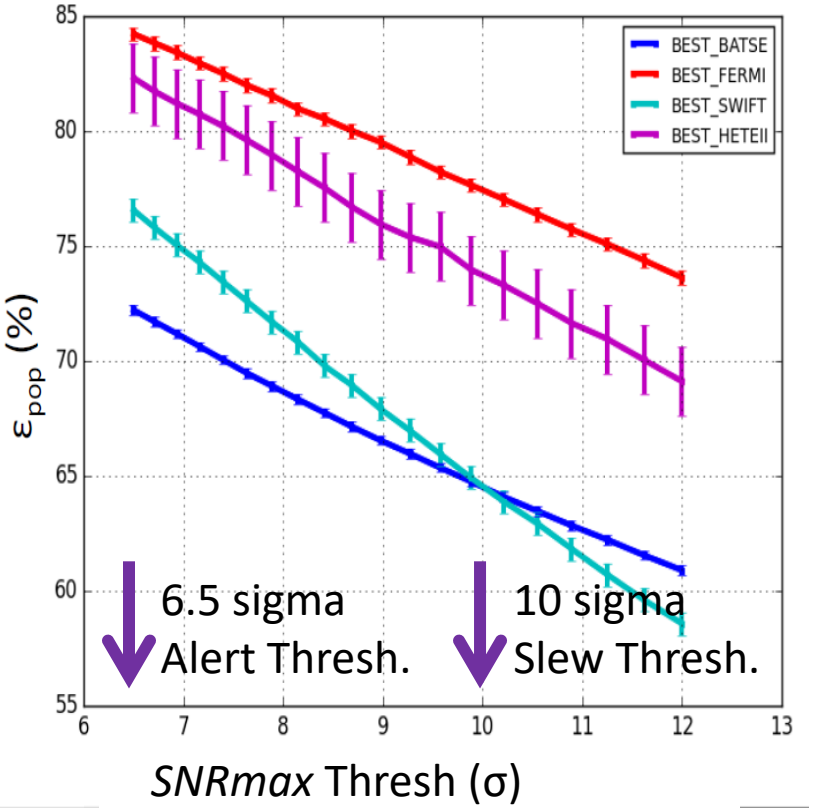
Sarah Antier (CEA, thesis 2013-2016)

B. Cordier, J. Wei, et al (astroph) White paper SVOM

- **Database** of ~2000 GRBs detected by **Batse**, **Fermi/GBM, Swift/BAT**, and **Hete-II**
  → GRBs with light curves, extrapolated to ECLAIRs band (4-120 keV)
- Background: 100 periods of 1500 s of CXB with Earth, chosen in 1 yr B1 law

For each GRB, chose Bkg period and 70 positions in FoV outside Earth in 1yr B1 law ➔ though CxgSim (counts) ➔ through both Triggers (SSM)

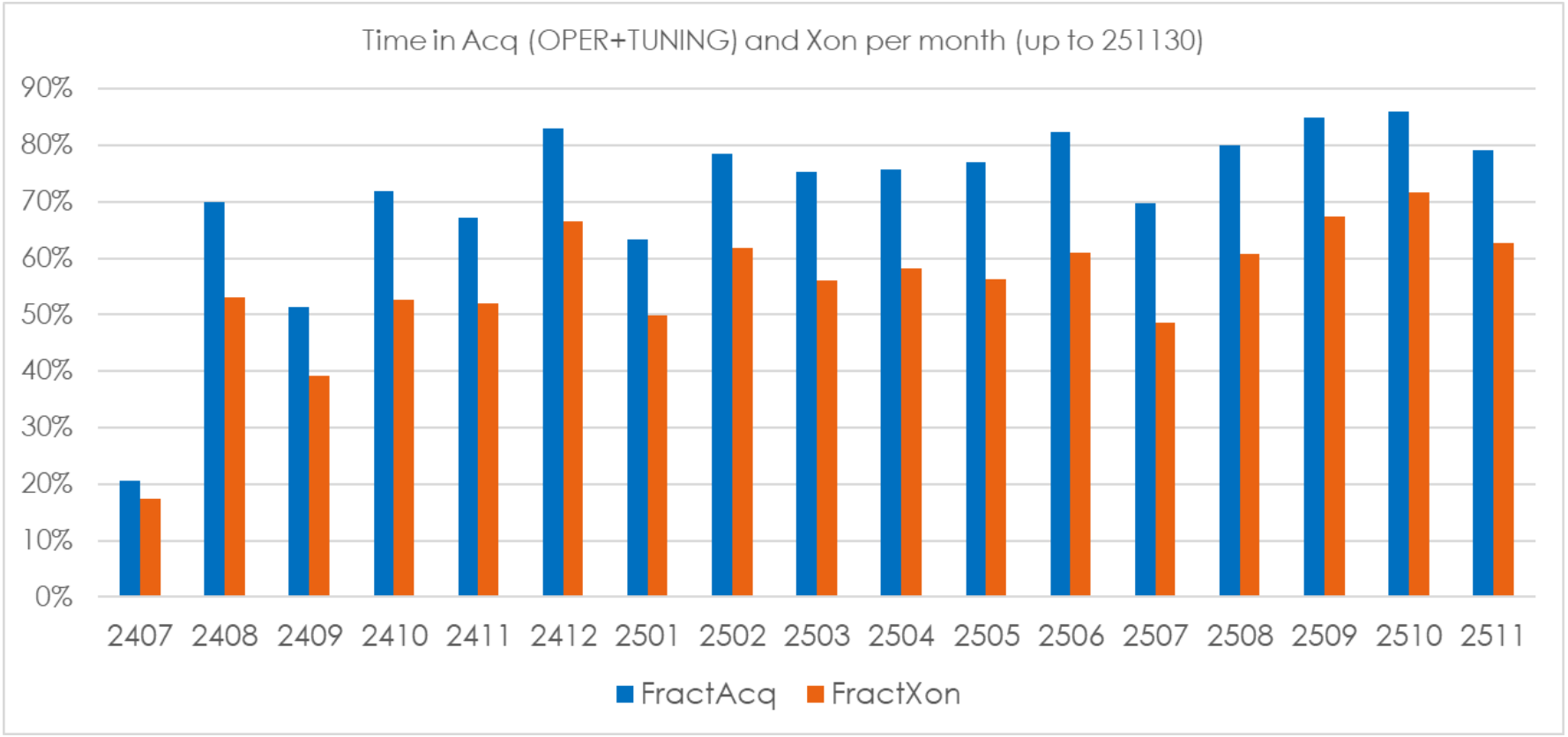
using det. efficiency, BATSE GRB/yr norm, FoV-10pix= 1.8sr, 65% EarthFree, 85% TimeOutSAA



	Expected ECLAIRs GRB rates (GRB/yr)	
	> AlertThr (6.5 σ)	> SlewThr (10 σ)
BATSE S+L GRBs	46 – 57 ±8	40 – 49 ±8
bonus low E (XRR GBM, XRF Hete)	4 – 10 ±1	4 – 9 ±1
bonus ImageTrig (low fluence LGRBs Swift)	4 – 5 ±1	4 - 5 ±1
Total	54 – 72 ±10	47 – 63 ±7

UGTS flight results: **Time in OPER and Xon**

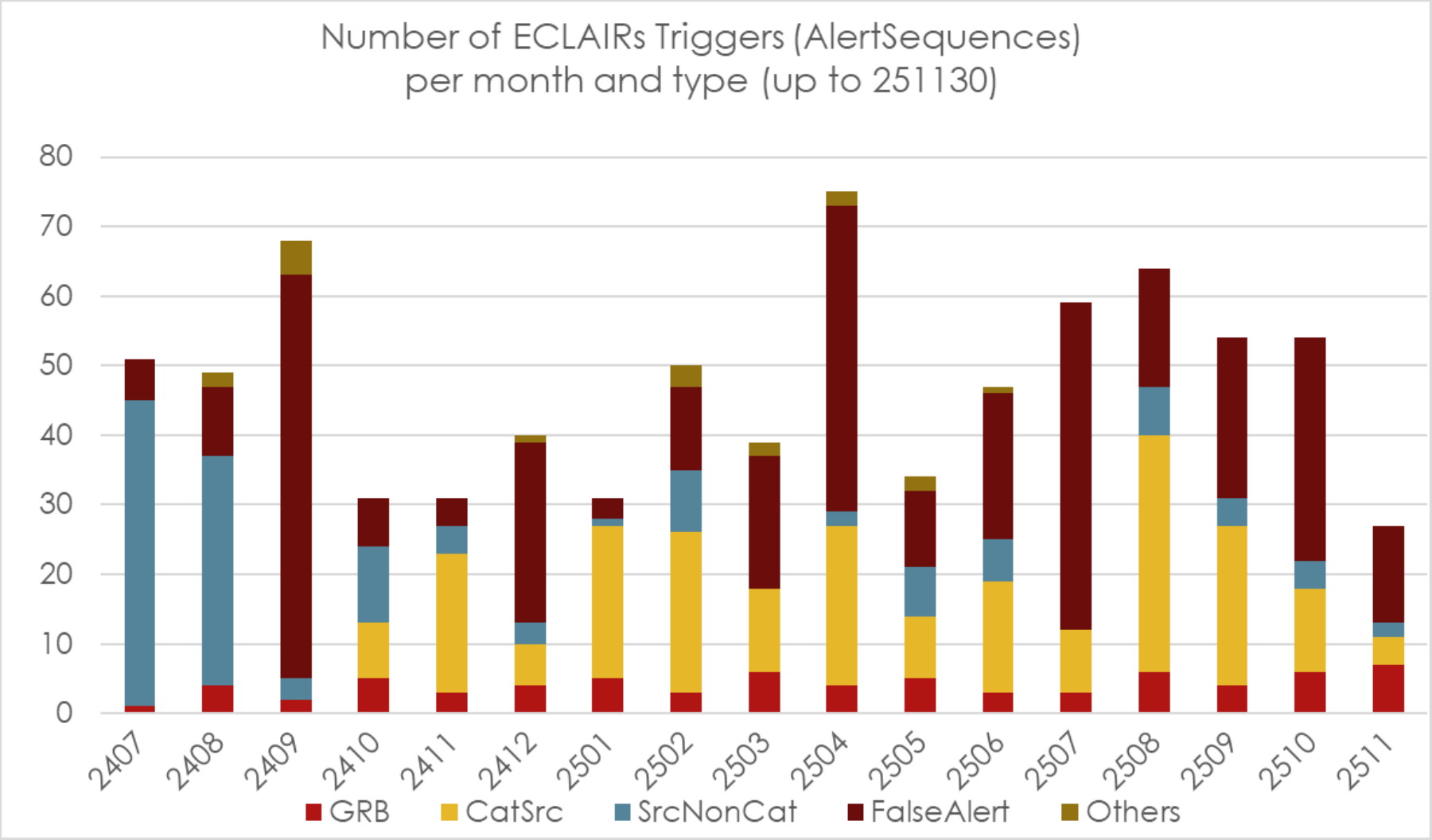
- since 240701 up to 251131



While Time in OPER is typically 85% in good months (time outside SAA-core)
The actual XON time (due to high background zones in SAA-ext with ph acquisition OFF)

UGTS flight results: **Num Triggers**

- since 240701 up to 251131
- by type of trigger



UGTS trigger flight results: **Num GRBs**

- since 240701 up to 251131

	Alert Sequences per month						Time		Estimates GRBs		
Month	Total	GRB	CatSrc	SrcNonCat	FalseAlert	Others	FractOp	FractXon	Xon100	Xon85	Xon60
2407	51	1	0	44	6	0	20.5%	17.5%	5.7	4.9	3.4
2408	49	4	0	33	10	2	70.0%	53.0%	7.6	6.4	4.5
2409	68	2	0	3	58	5	51.3%	39.1%	5.1	4.3	3.1
2410	31	5	8	11	7	0	71.8%	53.0%	9.4	8.0	5.7
2411	31	3	20	4	4	0	67.2%	52.0%	5.8	4.9	3.5
2412	40	4	6	3	26	1	82.9%	66.5%	6.0	5.1	3.6
2501	31	5	22	1	3	0	63.3%	49.8%	10.0	8.5	6.0
2502	50	3	23	9	12	3	78.5%	61.8%	4.9	4.1	2.9
2503	39	6	12	0	19	2	75.4%	56.0%	10.7	9.1	6.4
2504	75	4	23	2	44	2	75.8%	58.1%	6.9	5.9	4.1
2505	34	5	9	7	11	2	76.9%	56.3%	8.9	7.5	5.3
2506	47	3	16	6	21	1	82.4%	61.0%	4.9	4.2	3.0
2507	59	3	9	0	47	0	69.7%	48.7%	6.2	5.2	3.7
2508	64	6	34	7	17	0	80.0%	60.8%	9.9	8.4	5.9
2509	54	4	23	4	23	0	84.9%	67.4%	5.9	5.0	3.6
2510	54	6	12	4	32	0	86.0%	71.7%	8.4	7.1	5.0
2511	27	7	4	2	14	0	79.1%	62.6%	11.2	9.5	6.7
17	months										
Total	804	71	221	140	354	18	71.5%	55.0%	127.40	108.29	76.44
	100.00%	8.83%	27.49%	17.41%	44.03%	2.24%					
Mean/month	47.29	4.18	13.00	8.24	20.82	1.06			7.49	6.37	4.50
Mean/year	567.53	50.12	156.00	98.82	249.88	12.71			89.93	76.44	53.96