The ECLAIRs GRB trigger camera onboard the SVOM mission

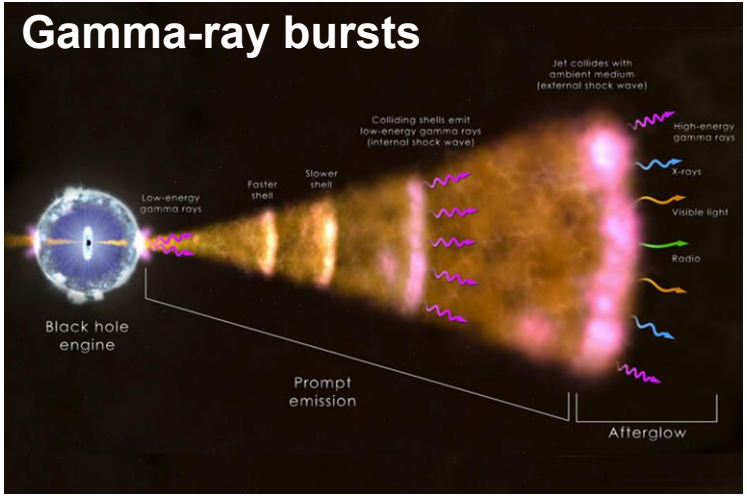
Laurent Bouchet
on behalf of the SVOM/ECLAIRs team

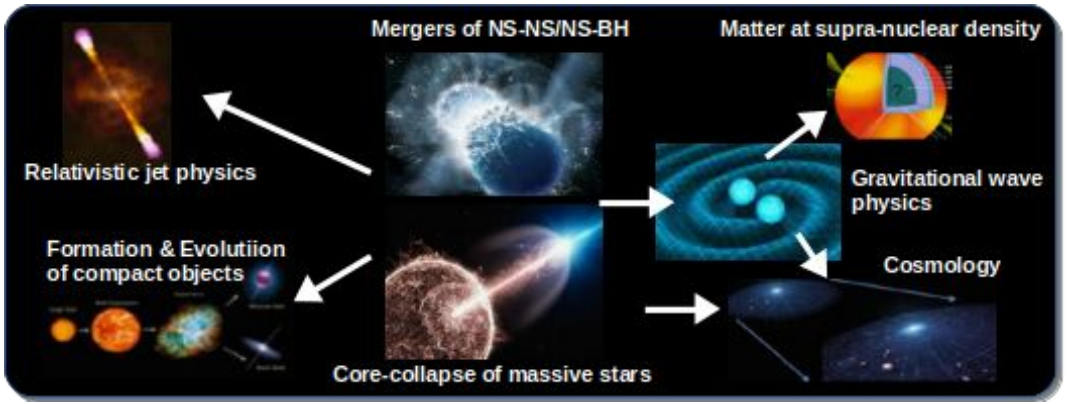
17th IACHEC meeting — 2025-05-12

Outline

- SVOM mission overview
- The ECLAIRs camera
- Science operations
- Performances

Sciences objectives





- **Detection of all classes of gamma-ray bursts (GRBs), with a particular focus on high-redshift GRBs and low-luminosity GRBs in the local Universe.**
- **Study the formation and evolution of compact object (BH, NS) population with z**
- **Relativistic jet physics**
- **Cosmology (galaxy formation/evolution, star formation history, reionization phase, history of metal enrichment)**
- **Multi-messenger astrophysics (GW, neutrinos)**

SVOM: Space-based multi-band astronomical Variable Objects Monitor

Launched : June 2024
Duration: 3 + 2 years

VT
"The visible telescope"
Ritchey Chretien Ø = 400 mm
FoV : 26' x 26'
Localization accuracy < 1 arcsec

GRM
"The Gamma-Ray burst Monitor"
X-rays and Gamma-rays detectors
Spectral range 15 keV - 5 MeV
Localization accuracy < 5°

ECLAIRs
"The trigger camera"
Wide-field X and Gamma rays telescope
FoV : 89° x 89°
Spectral range 4 -150 keV
Localization accuracy < 13 arcmin

MXT
"The Micro-pore X-ray Telescope"
FoV: 58'×58'
Spectral range 0.2 - 10 keV
Localization accuracy < 2 arcmin

GFT-1
« Ground-based Follow-up Telescope »
Φ>1000mm

GWAC
« Ground Wide-Angle Cameras »
Φ=180mm

GFT-2
« Ground-based Follow-up Telescope »
Φ>1000mm

VHF Alert Network
... and more !

Tracking antennas

Response to a trigger: SVOM strategy

Space segment

ECLAIRs & GRM observe the high-energy sky to seek for transients

ECLAIRs detects a GRB at t_0 ⇒ Compute source position

General Coordinates Network

t_0 + < ~5 min

Satellite repoints towards ECLAIRs position ⇒ Observations with MXT & VT

Ground segment

t_0 + 1 min

GWAC (visible) Wide field of view

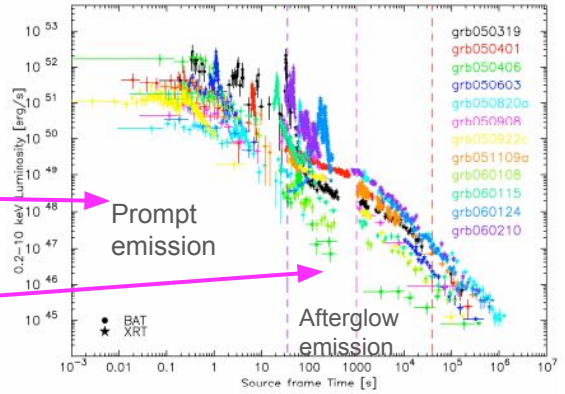
Colibri (nIR, visible) in Mexico
C-GFT (visible) in China
Narrow-field instruments

Robotic telescopes

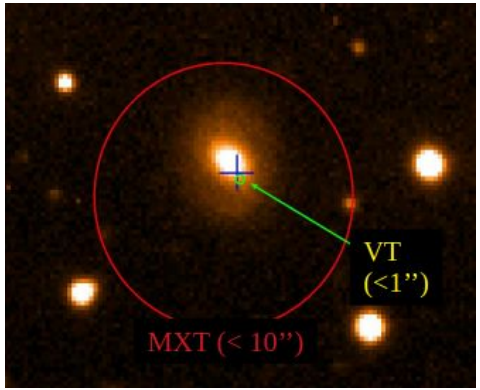
More accurate positions

More accurate positions

Multi-messenger follow-up facilities

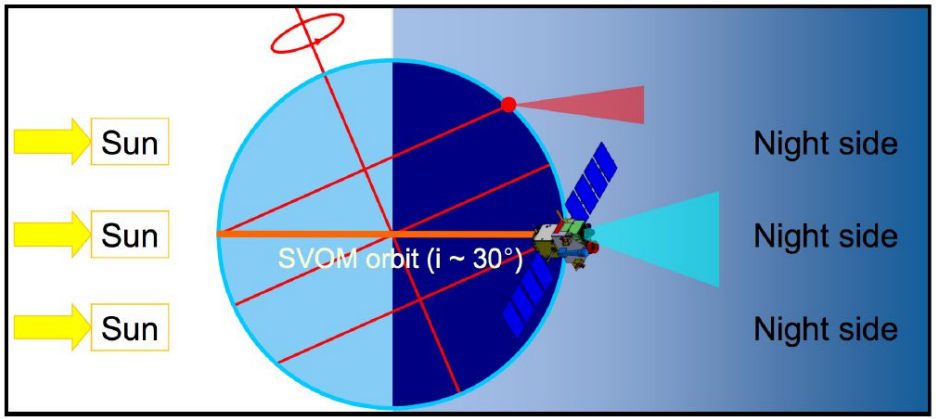


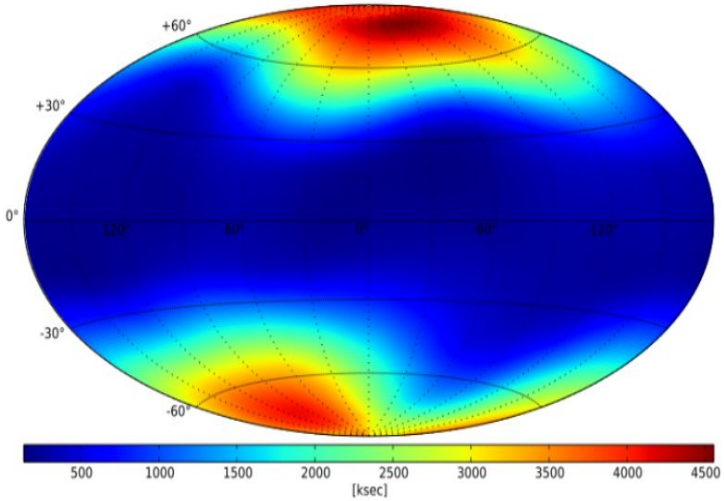
After the slew:
ECLAIRs localization < 12 arcmin (90% c.l.)



- Repointing in < 5 min for GRB follow-up
- Alerts transmitted through a network of ~ 50 on-ground VHF receivers
- ECLAIRs + post-slew X-ray and Visible information is also sent through the VHF link

Pointing strategy





- Low Earth Orbit (625 km, 96 min), 30° inclination
- **Nearly anti-solar pointing to facilitate follow-up observations from ground**

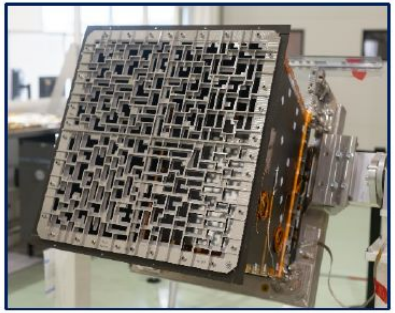
  → Earth in the FoV: 65% duty cycle for ECLAIRs (50% for MXT and VT)

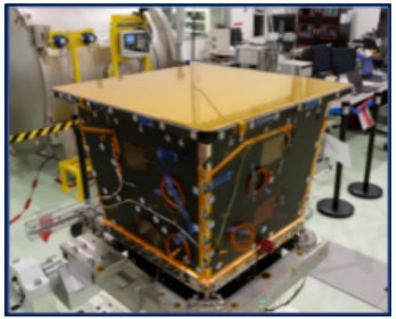
  → Redshift measurement for ~2/3 of detected GRBs
- **ECLAIRs FoV: avoidance of Galactic plane and Sco-X1 (B1-Law)**

- ECLAIRs annual exposure time
  - ~4000 ks on the Galactic poles
  - ~500 ks on the Galactic plane

The  camera

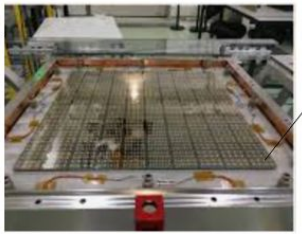
ECLAIRs in a nutshell

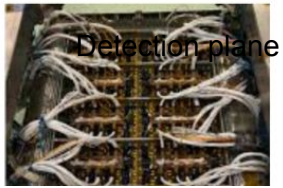




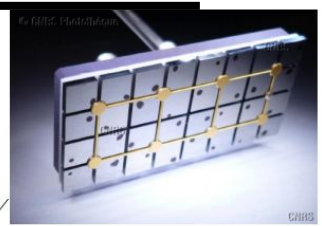
Data processing unit

8 x Readout electronics

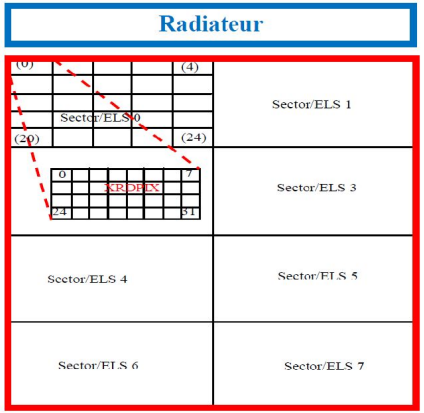




Interface cardboards under the detection plane



Elementary detection module



- 80x80 4x4 mm² and 1 mm-thick Schottky-type Pt/CdTe/In detectors from Acrorad Ltd (Japan)
  - operated at –300 V & nominal temperature range of [–25°C ; –18°C]
- Mask-to-plane distance = 46 cm & Mask dimension = 54 x 54 cm² & Ti-Ta (0.6 mm)-Ti sandwich
  - 40 % mask open fraction & quasi-random pattern
- Total FOV = 89 x 89 deg² (~2 sr) & Fully coded FOV ~ 22 x 22 deg² (~0.15 sr)

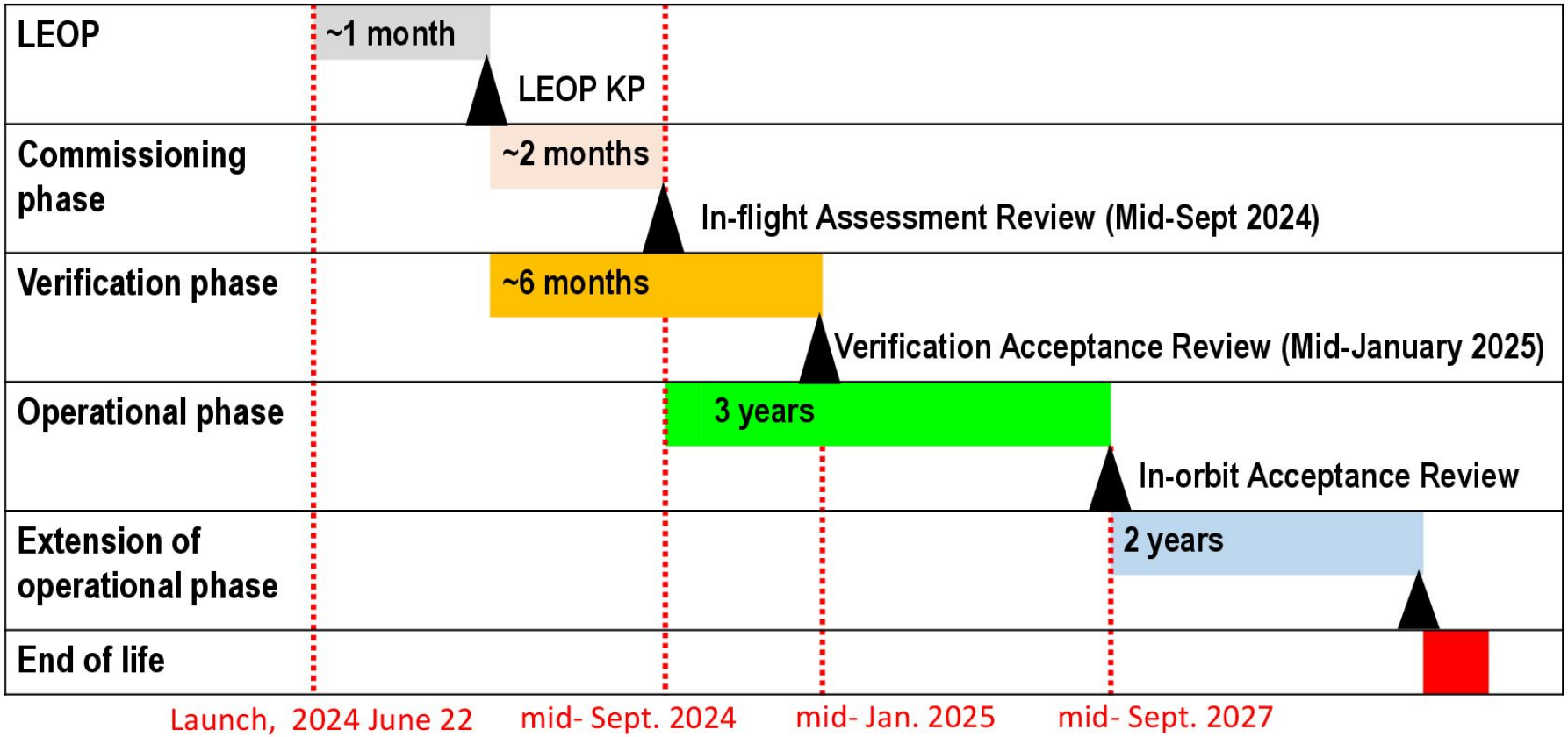
ECLAIRs in a nutshell

Parameter	Requirement
Energy range	4 – 150 keV
Detecting area	~950 cm^2
Detectors	6400 CdTe detectors
Total effective area in 10-70 keV	≥ 340 cm^2
Photopeak effective area @ 6 keV	≥ 200 cm^2
Field of view	2.05 sr total
Sensitivity to 1 second long GRB	2.5 10^{-8} erg cm^{-2} s^{-1} in [5–50] keV
Source Localization Error	11.5' for sources with SNR=8
Energy resolution at 60 keV	< 1.6 keV
Time resolution	20 µs
Dead time	< 10% for 10^5 c/s
Single/multiple interaction tagging	
Data acquisition	mode Photon mode
Data rate	≤ 18 Gb/day
Energy calibration accuracy	≤0.3 keV below 80 keV

Performance measured on ground,validated in-flight!

- **4 keV energy threshold to increase sensitivity to X-Ray Flashes (soft GRBs) & high-z GRBs**
- **Photon counting mode**
  - All photons transmitted to the ground
  - Readout electronics able to flag particles showers, fluorescence and Compton events as multiple events
- **Automatic software to disable noisy pixels**
- **On-board autonomous detection [count-rate + image triggers] & localisation**
  - Time scales from 10 ms to 20 min
  - 4 energy bands, 9 detector zones
  - **Expected rate ~ 45-50 GRBs /year**

SVOM Status

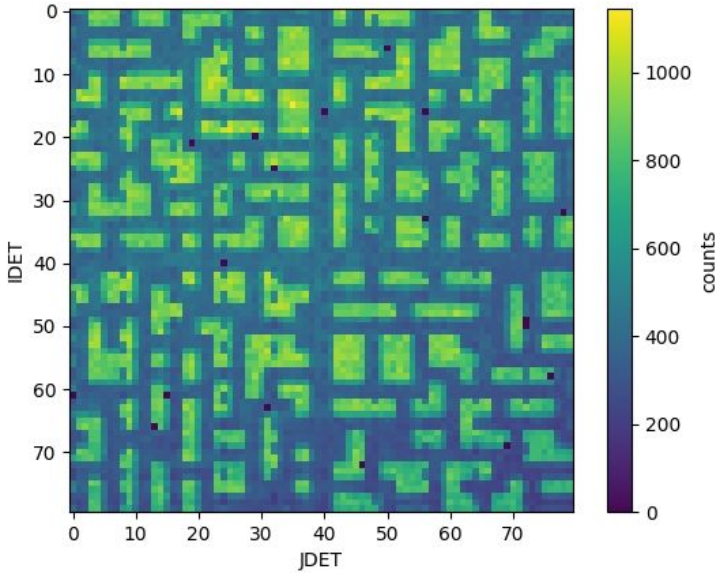

LEOP
~1 month
LEOP KP
Commissioning phase
~2 months
In-flight Assessment Review (Mid-Sept 2024)
Verification phase
~6 months
Verification Acceptance Review (Mid-January 2025)
Operational phase
3 years
In-orbit Acceptance Review
Extension of operational phase
2 years
End of life
Launch, 2024 June 22
mid- Sept. 2024
mid- Jan. 2025
mid- Sept. 2027

Science operations

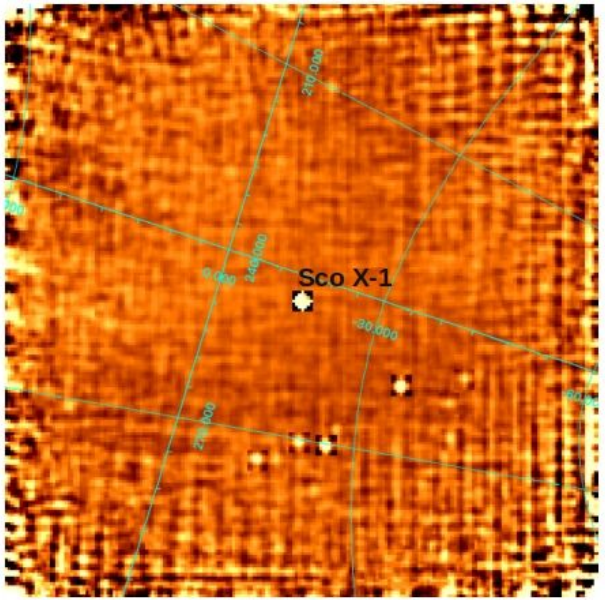
- ECL first light
- Noisy pixels
- Data rate / Xoff
- South Atlantic Anomaly (SAA)
- Trigger

First light

- **On-axis observation of Sco X-1 on July 5th 2024 (duration : 16 mn)**



Shadowgram



Sky reconstructed image

⇒ Good integrity of the camera after the launch, in particular the mask and MLI layers (no optical loading when Earth within FoV)

South Atlantic Anomaly

The SAA is a zone of high particle flux above the South Atlantic.

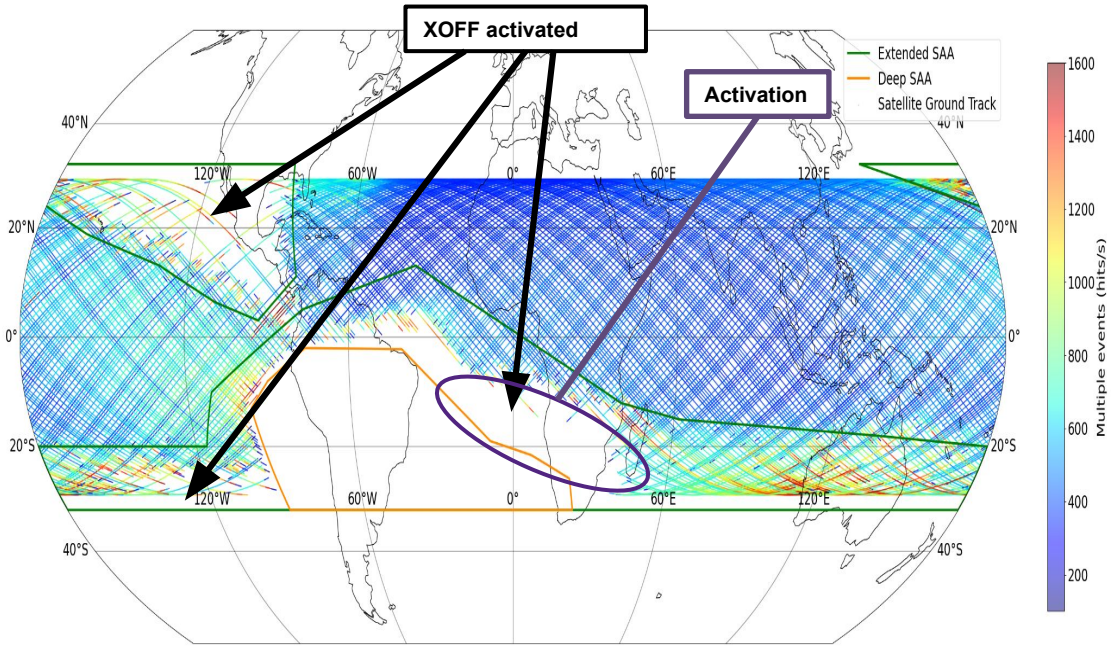
Inside the core SAA, detectors are depolarized.

Outside the core SAA, regions of high particle background that induce high count rates (in particular when the Sun is active)

In these regions called “extended SAA” the operation is slightly modified, with no management of noisy pixels.

SAA management via time-tagged TCs works fine.

SVOM proton particle monitor (GPM) can be used to determine the core contour of the SAA.



Applied core & extended SAA contours since 2024-12-03. Count tracks shown as coloured lines.

Trigger

Count-Rate Trigger and Image Trigger software activated early after launch and works very well.

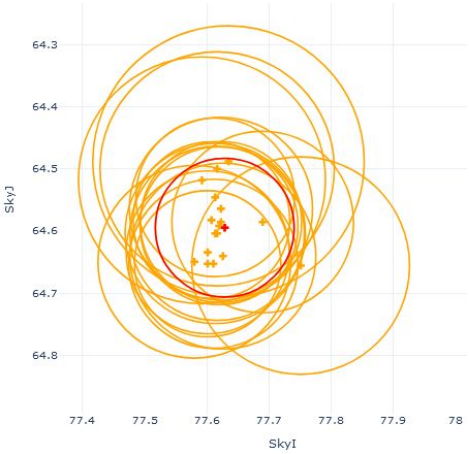
VHF Alert Sequence messages and Slew Request messages to the spacecraft

Each Alert is an independent observation (Time Window, Detection SNR, localization).

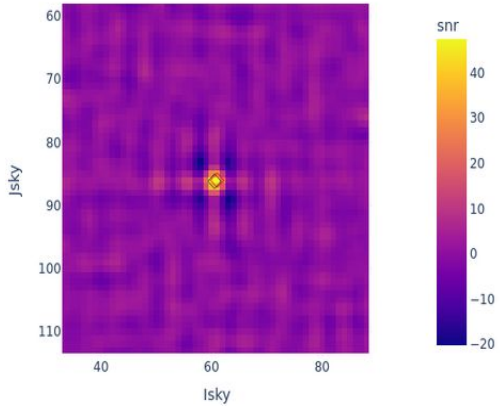
Several Alerts permit to check the consistency and to obtain a better localization.

The VHF sub-images (or shadowgrams) help to quickly validate ECL triggers.

Step-by-step fine-tuning of the trigger settings to decrease the false trigger rates and to robustify the performances of the trigger software.



VHF ECLAIRs subimage



Performances

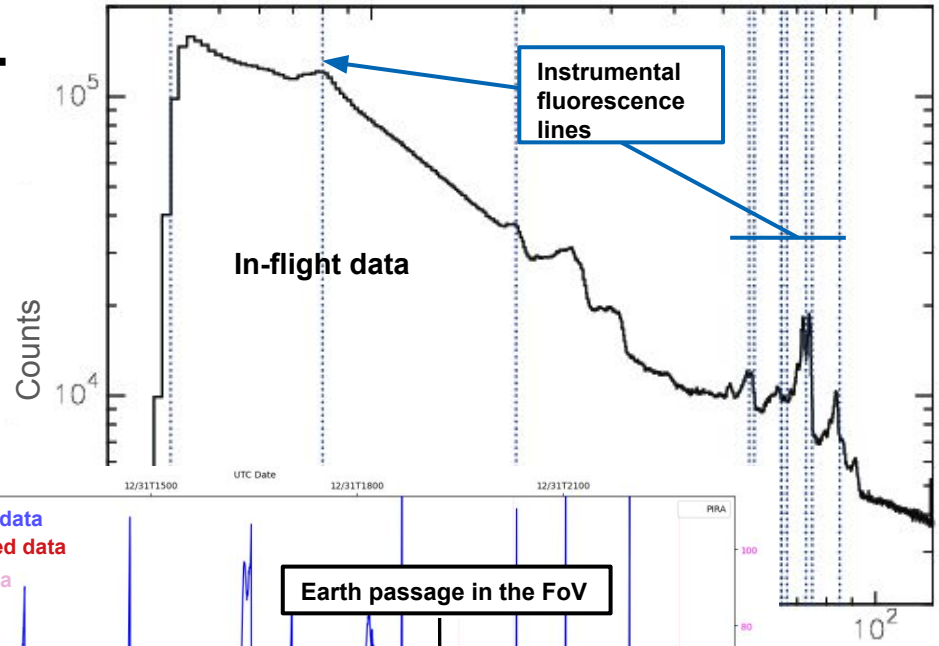
- Background
- Energy threshold, energy scale and camera uniformity
- Spectral
- Science summary

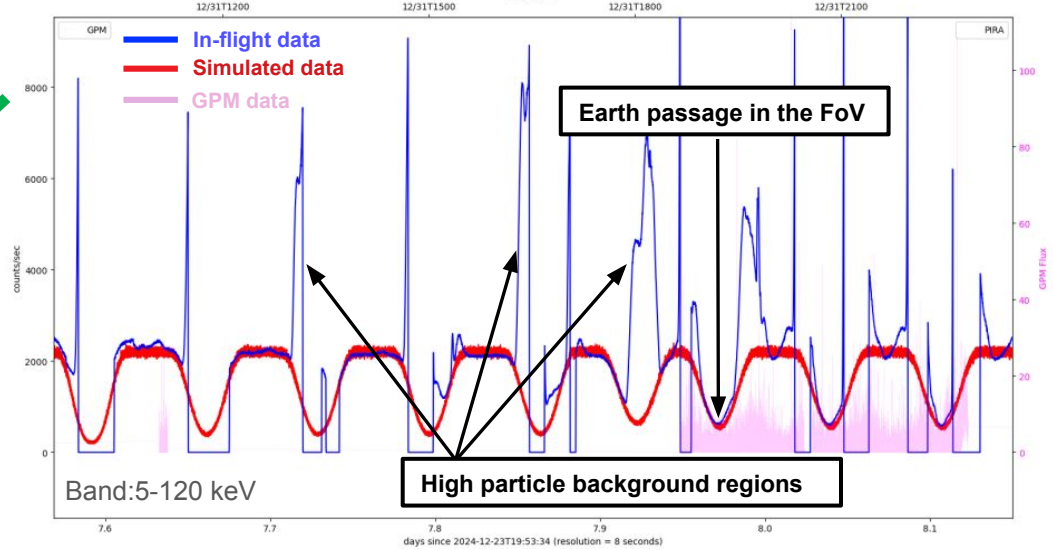
Background

The background level is continuously monitored at the ECL Instrument Center.

Due to the high solar activity, the count rates are strongly affected by particles trapped in the magnetosphere.

During calm portions of the orbit, the background is close to predictions of Monte Carlo simulations.

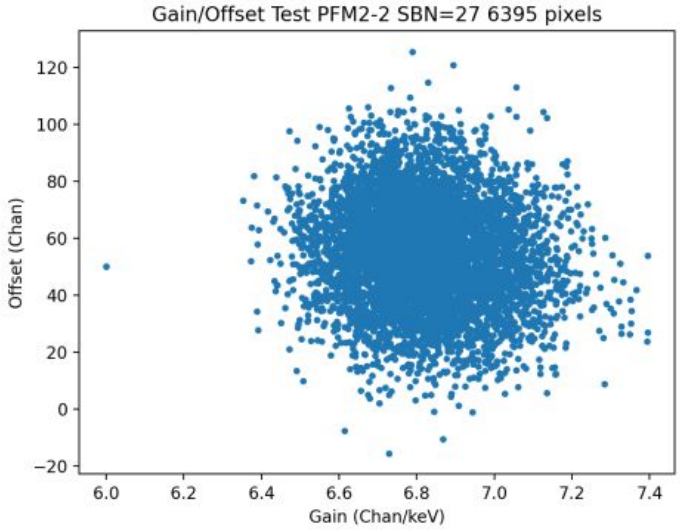




NB: The activation process that increases the background at the exit of the SAA core.

L. Bouchet et al. paper in preparation

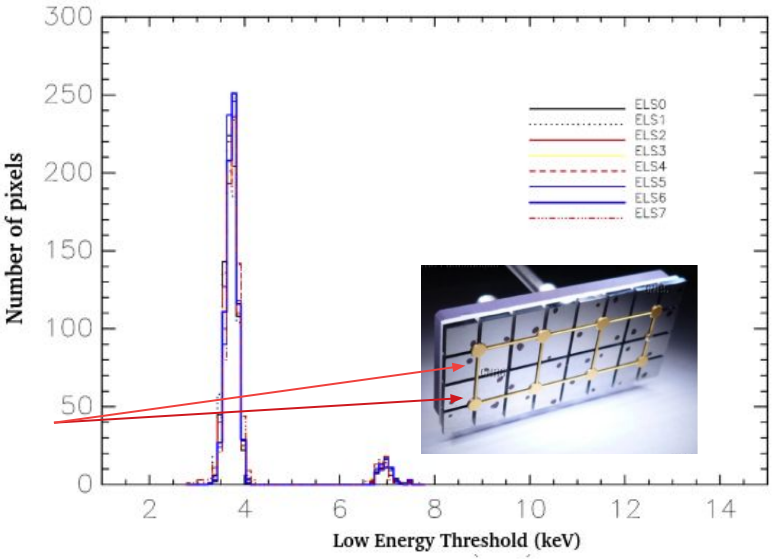
Before launch: Energy scale and low-energy threshold (SBN)



Calibration of the Channel -Energy relation to reconstruct the energy scale

=> Very good homogeneity of the gain/offset coefficients

detectors no 8 & 16



Calibration of the SBN – Ethr(keV) relationship with SBN, a number setting the low-E threshold

⇒ Building of the SBN table so that Ethr = 3.8 keV except for pixels 8 & 16 with Ethr = 7 keV to mitigate cross-talk effects (6 % of the 6400 pixels)

⇒ Very good homogeneity of the SBN values

⇒ Very precise setting of the low-energy threshold!

⇒ Only 7 dead pixels (SBN=63) over 6400 detectors

Energy Threshold, energy scale and camera uniformity

The 4 keV threshold is reached for ≈ 91% of pixels.

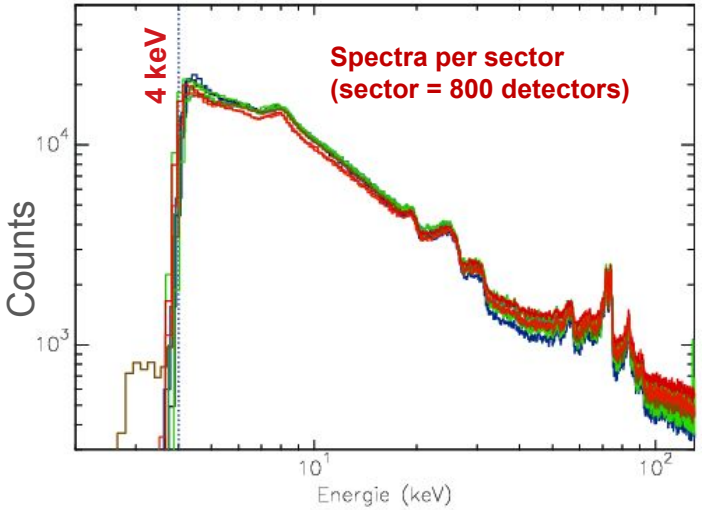
- After 9 months in space, on-ground calibration settings still valid for most pixels

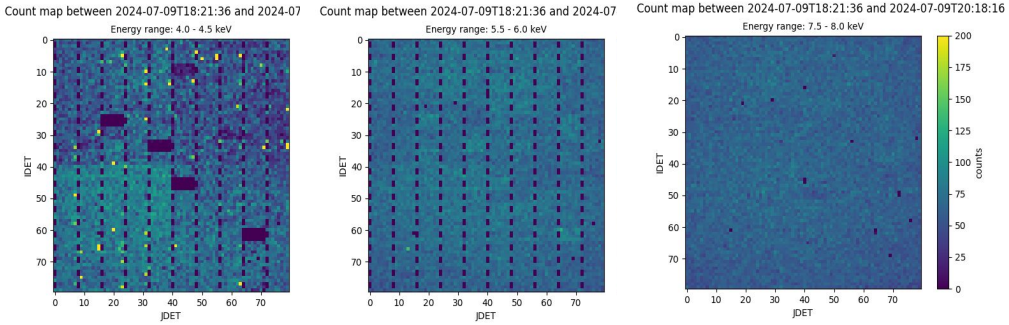
Above 7.5 keV the detection plane is very uniform (bottom right figure)

Below 7.5 keV, there are 2 types of non-uniformity, already observed on the ground:

- The energy threshold of 2 detectors per module was raised to ≈ 7 keV to avoid cross-talk (middle figure).
- Five modules show a change in their energy scale, for an unknown reason when compared to ground measures (left figure).
  - They have been inhibited for the in-flight trigger.
  - No significant loss of sensitivity

➜ **Update of the gain/offset coeff. of these modules (on-going)**





4 – 4.5 keV **5.5 – 6 keV** **7.5 – 8 keV**

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Spectral (cross) calibration

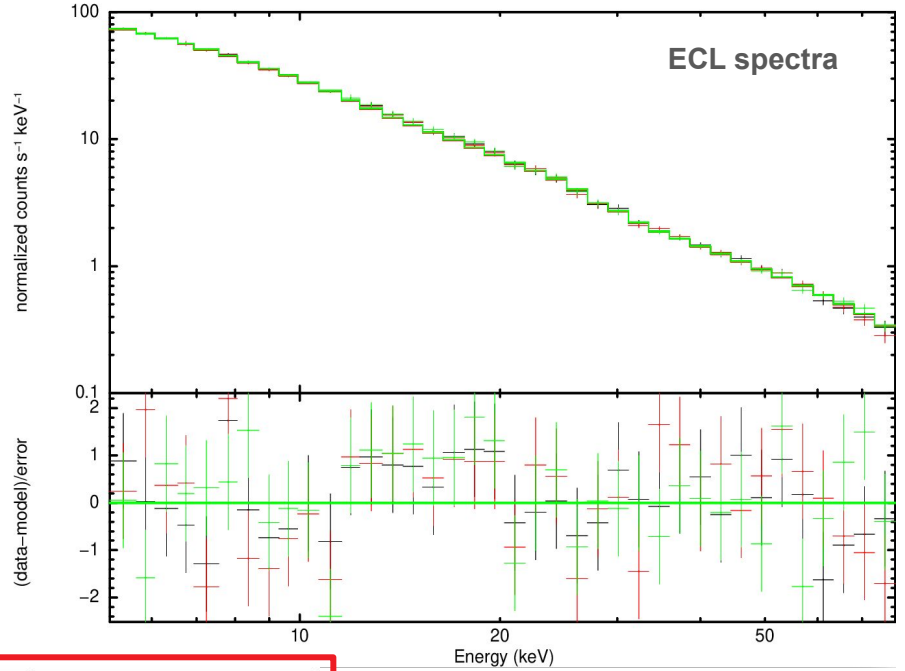
Observing campaigns ECL (inc. with MXT, GRM):

- The Crab with Swift/BAT and INTEGRAL
- Cyg X-1 with Swift/BAT in two occasions + EP
- Sco X-1 for localization

Preliminary results on the Crab spectrum are rather good

➜ Spectral files are performing well

➜ ECLAIRs scientific pipeline works overall nicely

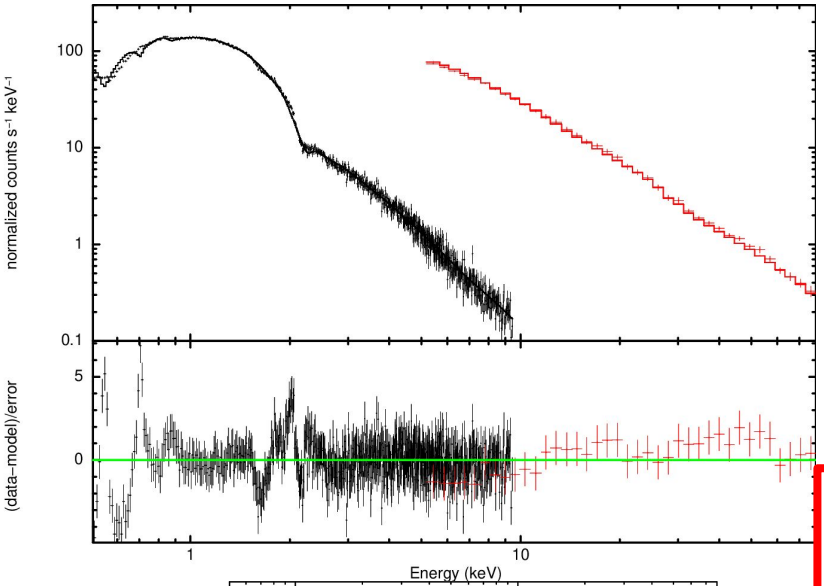


Spectra	Gamma	K (ph/cm²/s/keV)	Flux [4 – 120 keV] (10^{-8} erg/cm²/s)	Flux [4 – 10 keV] (10^{-8} erg/cm²/s)
NEO1	2.147 ± 0.011	12.9 ± 0.3	4.52 +0.04/-0.05	1.45 ± 0.01
NEO2	2.147 ± 0.010	12.8 ± 0.3	4.48 ± 0.05	1.43 ± 0.01
NEO3	2.145 ± 0.008	12.9 ± 0.3	4.53 ± 0.03	1.45 ± 0.01

Model: N(E) = K E^-Gamma
5% systematic between 12 and 20 keV
Chi²/dof = 102.5/108

Errors quoted at 90% c.l.

CROSS-CALIBRATION WITH SVOM/MXT

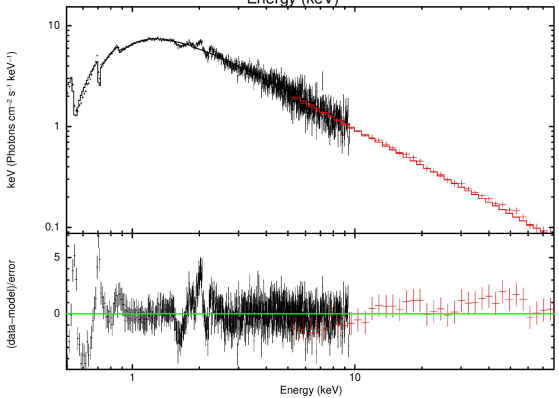


	MXT (0.5 – 10 keV)	ECL (5 – 80 keV)	Diff.
Model	*Tbvarabs*PL	PL	
Gamma	2.212 ± 0.012	2.152 ± 0.017	2.7%
K	15.8 ± 0.2 ph/cm²/s/keV	13.2 ± 0.6 ph/cm²/s/keV	16.5%
Chi² / dof		1093.7 / 749 dof	
Flux [4 – 10 keV]	(1.56 ± 0.02) 10^{-8} erg/cm²/s	(1.45 ± 0.03) 10^{-8} erg/cm²/s	7%

* Model: Tbvarabs*PL with abundance parameters fixed to MXT best-fit values

Model = Const*Tbvarabs*PL with parameters fixed to MXT best-fit

MXT	MXT	ECL
Relative normalization	Fixed to 1	0.9729 +0.0127/-0.0129
Chi² / dof		1125.8 / 750



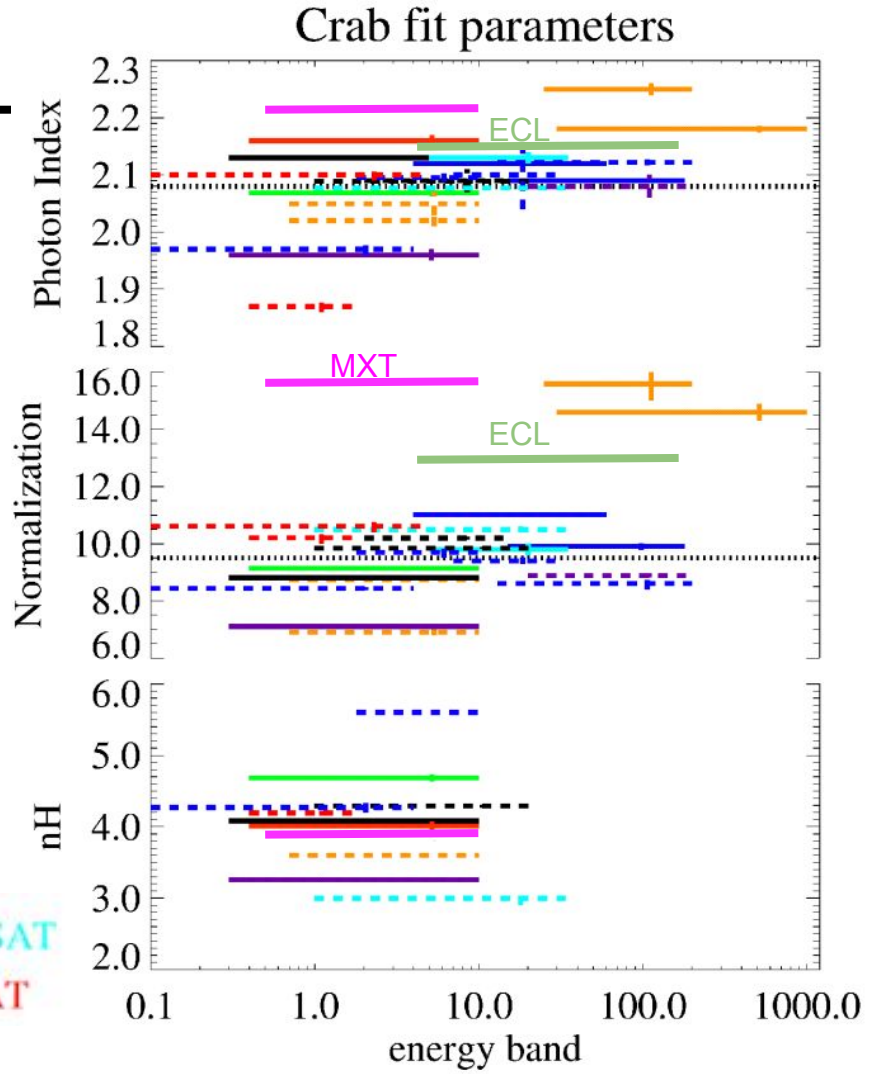
[MRR-CAL5]

MXT and ECLAIRs cross-calibration:
(1) The flux inter-calibration between MXT and ECLAIRs in the 4-10 keV energy band shall be accurate at a level better than 10 (TBC) % at the end of the Performance and Verification phase.
(2) The spectral slope of sources described by a single power law model shall be in agreement among the two instruments to better than 10 (TBC) % over the same energy range at the end of the Performance and Verification phase.

Spectral (cross) calibration

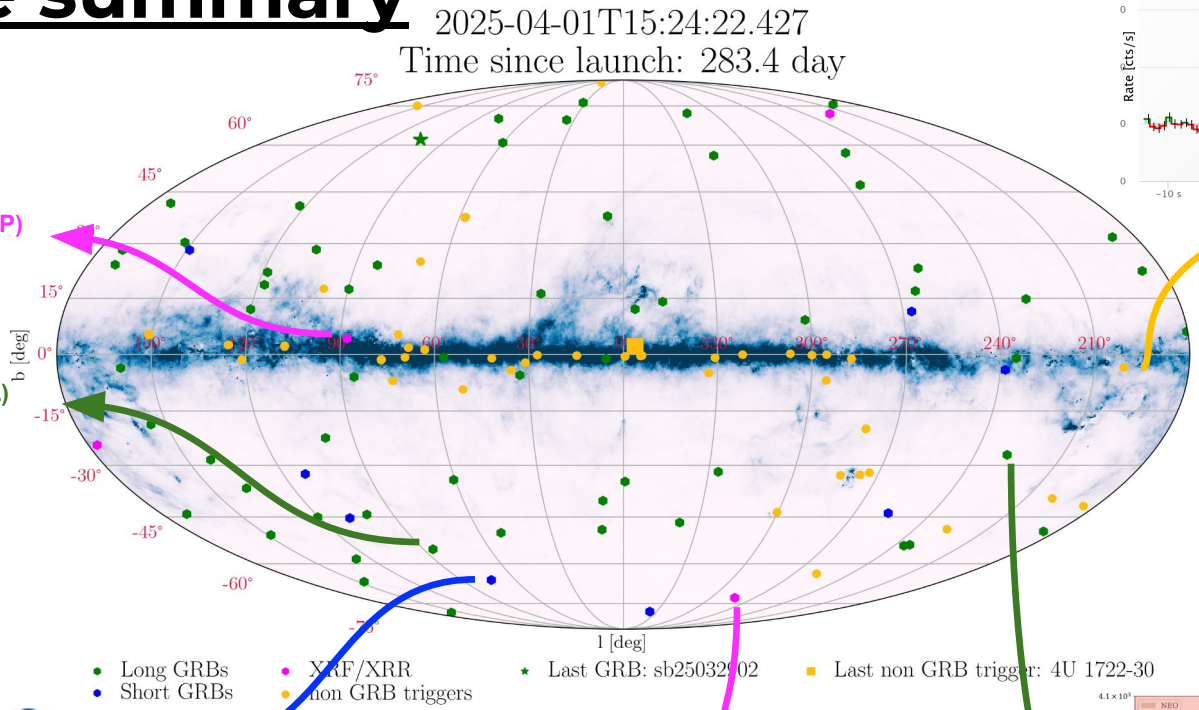
- Comparison with previous measurements
- ECL photon index more or less OK
- ECL norm. slightly higher
- MXT photon index and norm. larger than expected

Kirsch+14



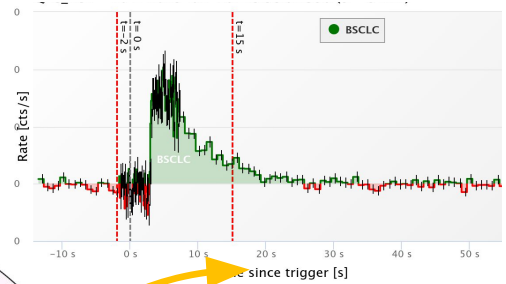
XMM-pn XMM-M2 Integral Swift XRT Chandra RXTE EXOSAT
--- ASCA --- BeppoSAX -- Ginga --- MIR --- Einstein --- ROSAT

Science summary



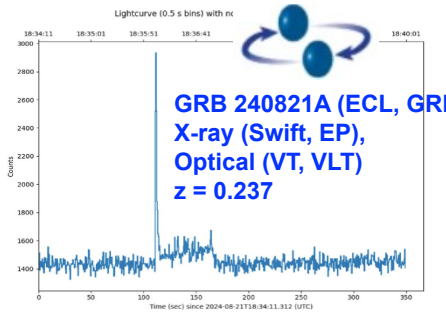
XRF 240819A (ECL)
X-ray afterglow (Swift, EP)
Optical upper limits

Long GRB 240713A (ECL)
X-ray (Swift, EP)



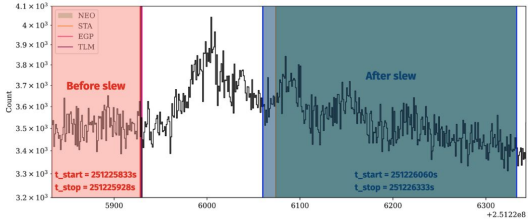
LMXB 4U 0614+091 (ECL+GRM)
Thermonuclear X-ray burst

On 2025/04/01
ECLAIRs has detected and located **35 GRBs** :
- Afterglow emission : 32
- Distance : 15



GRB 240821A (ECL, GRM)
X-ray (Swift, EP),
Optical (VT, VLT)
z = 0.237

XRF 241001A (ECL)
X-ray afterglow (Swift, EP)
+ Optical afterflow and JWST supernova
z = 0.573



Ultra-long GRB 241217A (ECL+GRM)
X-ray (MXT, EP) and optical (VT)

Summary: ECLAIRs instrument

- **ECLAIRs is fully operational and works very well!**
  - The low energy threshold at 4 keV is achieved for ≈ 91% of the pixels (7 keV for the remaining 9%)
- **We understand how to operate the instrument, even with the current high solar activity:**
  - SAA management – Data management – On-board source catalog – Trigger activation...
- **The allocations are respected:** Data rate – Number of GRB triggers
- **The performances are excellent and are fully compliant with the requirements:**
  - Background level – Spectral resolution & response – Timing – Localization biases – Trigger performance
  - The current configuration is effective to mitigate triggers due to particles, X-ray sources and camera non-uniformities.
    - Still second 2nd-order corrections/improvements to do, but nothing impacting the scientific studies

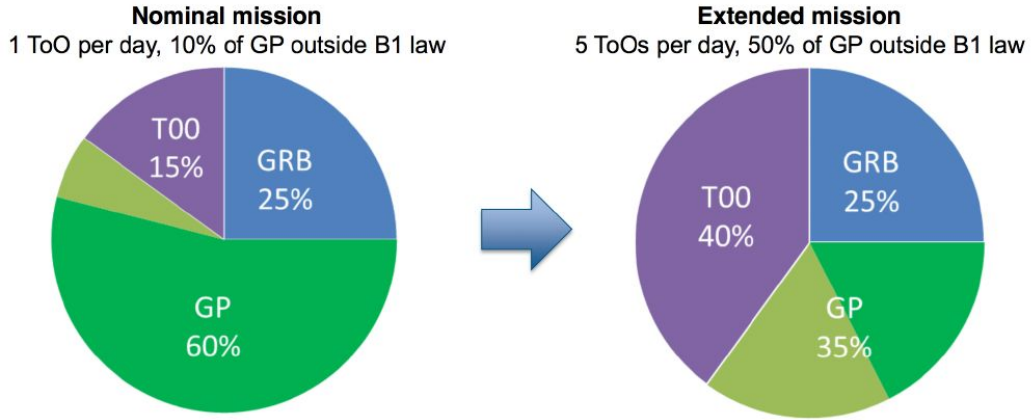
➜ **Significant scientific results have been obtained during the commissioning and Validation phases!**

➜ **Thanks to its 4 keV threshold, ECLAIRs has started to unveil new populations of X-ray transients in synergy with EP!**

➜ **On 2025/05/07: 40 GRBs detected onboard by ECL**
➜ **additional detections with a ground trigger (offline-trigger) :**
4 GRBs , 1 SGR, 32 Type 1 bursts (LMXB) and many bursts from the Slow Burster

SVOM scientific programs

- **Core Program (CP):** GRB science (25% of time, with the highest priority)
- **General Program (GP)** or SVOM as an open observatory: observations will be awarded by a TAC for astrophysical targets - starting in 2026 (a SVOM co-I needs to co-sign your proposal)
  - 10% of the time can be spent on low Galactic latitude sources during nominal mission
  - Up to 50% during mission extended phase
- **Targets of Opportunity (ToO) Program:** alerts sent from the ground to the satellite
  - Initially 1 ToO per day focused on TDA and multi-messengers
  - GRB revisit
  - Devoted time will increase during mission extended phase



THANK YOU !