SVOM/ECLAIRs Gamma-Ray Burst Trigger: In-Flight Commissioning

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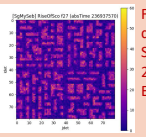
Abstract

The French-Chinese SVOM satellite (Space Variable Objects Monitor) was launched on June 22, 2024, from the Xichang launch site in China. The mission's objectives focus on detecting and studying astrophysical transient events, with a primary emphasis on Gamma-Ray Bursts (GRBs). The GRB Trigger of the ECLAIRs instrument onboard SVOM has already detected several notable bursts and initiated autonomous satellite slews to enable follow-up observations by the MXT and VT instruments onboard. Additionally, it transmits real-time burst alerts via the SVOM VHF network, enabling follow-up campaigns by the broader scientific community.

We provide a status update on the ECLAIRs GRB Trigger following the recent completion of the in-flight commissioning phase. It emphasizes the complementarity between the Count-Rate Trigger and the Image Trigger algorithms, running both in parallel, and details some of the configuration adjustments made in response to real in-flight data. Coupled with the very good performances of the ECLAIRs detector plane and onboard processing unit, the Trigger has enabled SVOM to detect and localize accurately several notable GRBs, including X-ray rich GRBs and GRBs with redshift determinations, as reported in GCN circulars already from the early stages of commissioning.

Milestones in ECLAIRs Commissioning and Trigger tuning

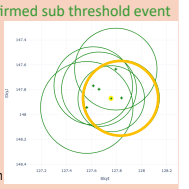
Launch and Early Orbit Phase
2024-06-22: SVOM launch from Xichang (Sichuan, China on 15:00 local time)
2024-07-01: power-on of ECLAIRs and camera
2024-07-02: first acquisitions, camera hot conditions, without Triggers
2024-07-05: first acquisitions, camera cold (nominal) conditions, Sco X-1 first light
2024-07-11: first activation of onboard Trigger
2024-07-13: first GRB seen by CRT and IMT (Alerts copy in Xband, send to VHF off)
2024-07-13: activate trigger output to VHF, Alerts for SNR > 6.5, SlewRequest off
2024-07-18: activate trigger in extended SAA (highly-variable bkg well supported)
Commissioning Phase
2024-07-31: optimize Mask-Detector distance using Sco X-1, update trigger config
2024-08-02: running ECLAIRs continuously in OPER mode
2024-08-05: first major onboard Catalog update (several performed since)
2024-08-21: first short GRB (+extended low energy tail) detected, redshift (z=0.238)
2024-08-31: optimize CRT background fit, update trigger config
2024-08-30: test Alerts on Request to point Cyg X-1 (check alignment)
2024-08-30: trigger on Cyg X-1 (removed from onboard Cat) rising above Earth limb
Performance Validation Phase
2024-09-14: 1 XRDPIX producing False Alerts, removed from trigger deconv config
2024-10-01: first XRF detected by IMT at 5-8 keV, redshift (z=0.57), JSWST follow-up
2024-10-08: activate SlewRequest for Alerts with SNR > 8
2024-10-18: strongest GRB detected up to now (SNR > 120), with Slew
2024-12-03: reduce trigger observing time before SlewRequest
2024-12-03: onboard software patch to prevent IOServer FDIR to Standby mode
2024-12-16: lower SlewThreshold to SNR > 7
Early Routine Phase
2025-02-05: long GRB 240205A detection, slew, perfect follow-up, redshift (z=3.55)
2025-02-24: aurorae X-rays produce False Alerts, update trigger Earth config
2025-03-14: detection of most distant GRB 250314A in last 12 years (z=7.3 by VLT)



First light: detector image Sco X-1 + bkg, 20 s exposure, E=5-120 keV

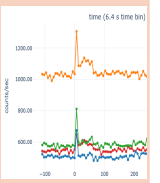
GRB 240713A – 6 Alerts (3 CRT, 3 IMT)
Fermi confirmed sub threshold event

Best Alert:
IMT, Δt=40s,
E=8-120 keV,
SNR:
-Max=9.7σ
-Std=1.04σ
-Dif2=5.7σ
R.A=352.59°
Dec=1.88°
R_{90}=8.7arcmin



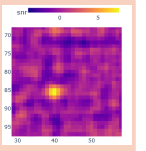
GRB 240821A, short burst with low energy tail

Ebands:
5-8 keV
8-20
20-50
50-120

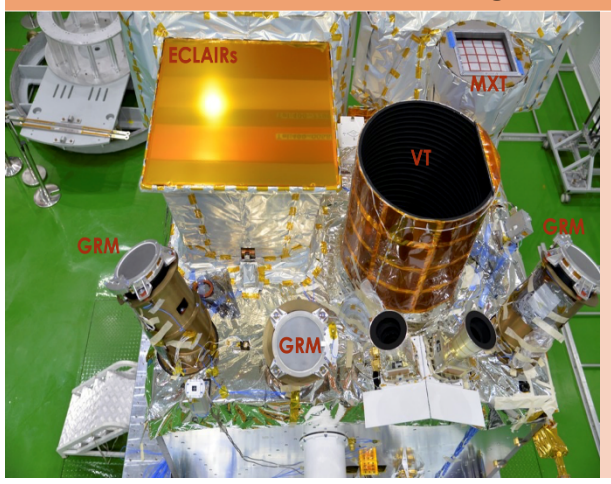


XRF 241001A Sky sub-image from VHF shg

Best Alert:
CRT, Δt=5.12 s
E=5-8 keV
SNR Max=7.5σ



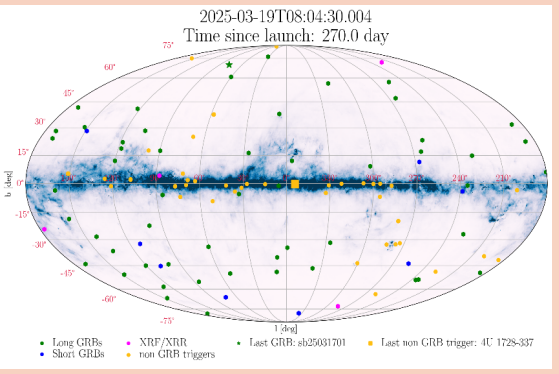
SVOM satellite onboard and ground instruments



4 on-board instruments:
- ECLAIRs: soft γ-ray coded-mask imager GRB trigger (4-120 keV)
- GRM: γ-ray spectrometer (NaI, 15-5000 keV)
- MXT: X-ray Telescope (0.2-10 keV)
- VT: Visible Telescope (Blue & Red, 400-950 nm, Mv=23.5)

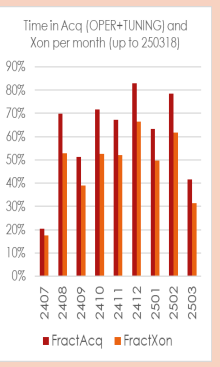
on-ground instruments:
- GWAC: ground wide-angle camera (500-800 nm, Mv=16, 5000 deg2).
- GFT: ground follow-up telescopes (400-1800 nm)

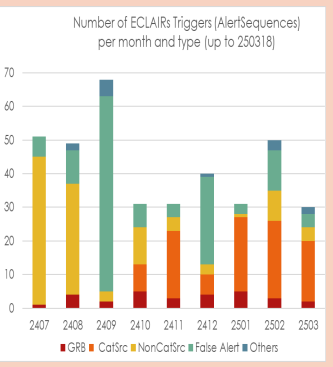
Trigger statistics since launch (including Commissioning)



SVOM sources
- 98 GRBs validated
  86 GRM, 31 ECLAIRs, 18 ECLAIRs+GRM
- 18 GRBs with measured redshift
- 108 outbursts of known Sources

ECLAIRs triggers
- 380 Alert Sequences sent over VHF
- 174 False Alerts (73 from one XRDPIX)
- 163 Astrophys. Triggers (known Src)
- 55 Astrophys. Triggers (onboard Cat Src)
- 31 GRBs validated
- 10 GRBs with measured redshift





The variability in numbers of Triggers and Trigger types during Commissioning Phase is due to parameter setting adjustment and Tuning or Standby periods, confirming an expected detection rate of > 55 GRBs per year in stable Operational conditions.

Several GRB detections have been obtained thanks to the low energy threshold of ECLAIRs. The GRB trigger performs well on the large time-windows range (for CRT: 10ms to 20 s, for IMT: 20 s to 22 min). It detected several new types of sources (XRFs) in the 5-8 keV lowest energy strip.

ECLAIRs hard X-ray Imager with Trigger & Processing unit

ECLAIRs is a coded-mask imager with its on-board processing electronics UGTS dedicated to promptly detect and localize GRBs of the SVOM mission.

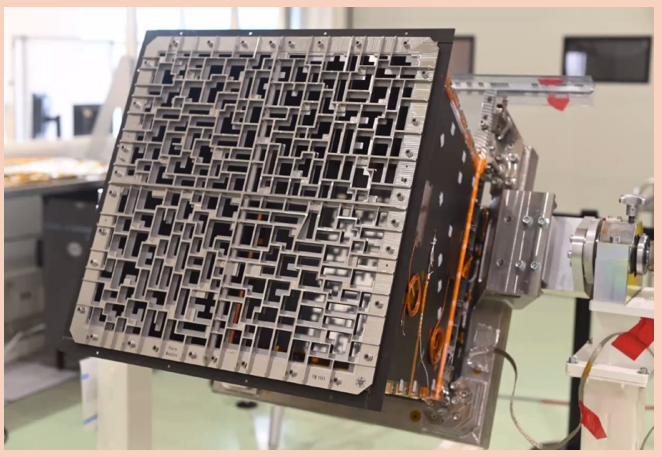
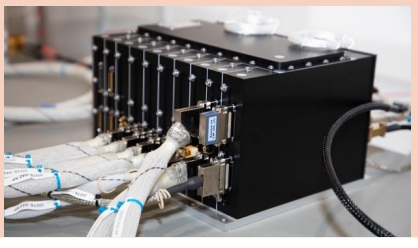


Photo of the ECLAIRs flight-model with its coded mask mounted, and not yet covered by MLI.

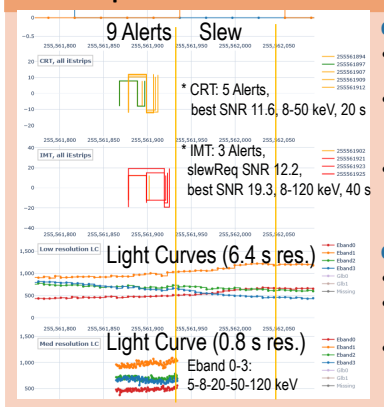
ECLAIRs main properties
- Allocations: Mass 87 kg, Power 84 W
- Detector: 80×80 CdTe pixels (4×4×1 mm³),
- active area: 1024 cm²,
- photon timing: 10 ms
- energy: 4–150 keV (imaging<120 keV)
- Coded Mask: Ta (0.6 mm, 54×54 cm², 40% open)
- Field of view : 2 sr 89°×89°
- Localization: <8 arcmin in most cases.

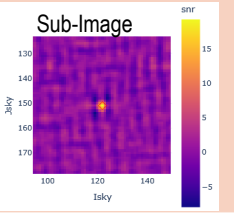
Photo of the flight model of the onboard ECLAIRs management and scientific processing unit (UGTS, unité de gestion et de traitements scientifiques)



UGTS = ECLAIRs onboard management and scientific processing unit
- Camera command/control, HK and FDIR
- Power distribution, thermal control
- Data acquisition (all photons to ground)
- Real-time scientific data processing
  2 trigger algorithms CRT & IMT both performing coded mask-deconvolutions (1 s on UGTS CPU)
- Alert sequences to VHF (Alerts, Light curves, Sub-images/Shadowgram) + Status/Trigger info
- Spacecraft slew requests

Example of GRB 250205A – excellent trigger & follow-up

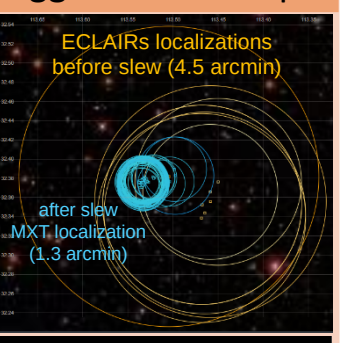


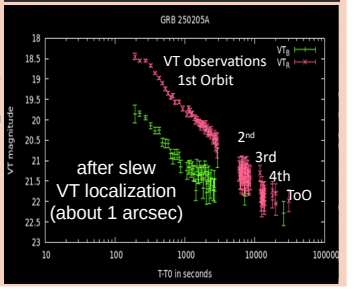


Onboard trigger
- ECLAIRs first detection
  T0 = 2025-02-05T21:24:54 UTC
- ECLAIRs slew request
  21:25:21, on IMT trigger SNR 12.2, starting at Tb = 21:24:38, Δt=20.48s
- ECLAIRs best Alert
  21:25:25, on IMT trigger SNR 19.3, starting at Tb = 21:24:38, Δt=40.96s

Onboard follow-up
- SVOM slew 21:25:28-21:27:10
- MXT detects afterglow
  21:34:31 (T0 + 9.5 min)
- VT detects afterglow
  21:32:08 (T0 + 7 min)
  and follows afterglow up to 8.5 h (during 4 orbits + ToO observations)

Ground follow-up detection
- OHP 2m: T0 + 42mn
- GTC 10.4m: T0 + 1h40
  => spectroscopy of afterglow absorption lines + Damped Ly α redshift z = 3.55, Eiso ~ 10^{52} erg
  Light travel time: 11.6 Gyr
- COLIBRI (F-GFT): T0 + 6h25





- The development of the complex ECLAIRs flight software was a challenge, that our group is happy to announce to be successful. The software has been intensely testes on ground on simulated data prior to launch.
- 3 weeks after launch we turned on the trigger. One day later got the first detected GRB 240713A (confirmed by Fermi). The trigger has proven to go smoothly through the highly variable background (more variable than simulated before launch).
- The False Alert rate is remarkably low (thanks to the coded mask imaging and a very good performance of the detection plane). Further tuning is still ongoing, to dig out low significance busts, which might lead to new discoveries.