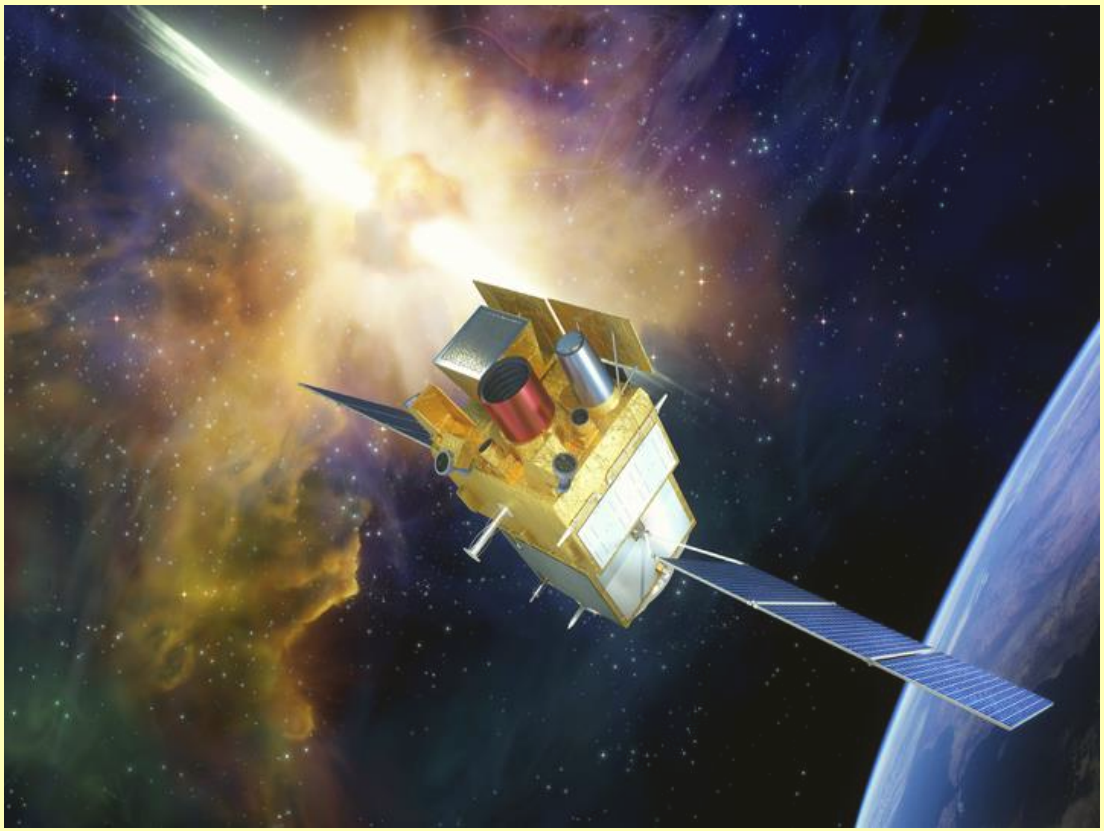
The Gamma-Ray Burst mission

SVOM

"Monitoring the high-energy sky with small satellites" workshop

2022 / Sep. / 6-8

Observatory and Planetarium
Kraví hora 2, 616 00 Brno,
Czech Republic



on behalf of the SVOM collaboration

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CEA Saclay / IRFU

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Institut de recherche sur les lois fondamentales de l'Univers

SVOM mission objectives

Space-based Variable Objects monitor

- Space mission dedicated to the detection and study of Gamma Ray Bursts for astrophysics and related cosmology

- Build a sample of **well characterized GRBs** (~200 in 3yrs) with spectral and temporal coverage of the prompt and afterglow phases, permitting their redshift (distance) determination

- Featuring the Neihl Gehrels Swift observatory and with feedback from Fermi

- **Prompt emission observation:**
  - from Visible to MeV, timing and spectrum
  - trigger on all types of GRBs, including X-ray rich, short & long duration, and high-z
  - fast and reliable (<12 arcmin) positions, with alerts to ground community (<30 s)
- **Afterglow follow-up observation:**
  - from Visible (near-IR) to X-rays, accurate (~arcsec) GRB positions
  - permit redshift measurement for large fraction of triggered GRBs (~1/2)

- Transient events mission within the community (GW, LSST, CTA, SKA, Neutrinos…)
  - send Alerts (GCN, VO-events)
  - accept and perform TOO observations

SVOM consortium and satellite

Cooperation between China and France
at space agency level (CAS+CNSA and CNES) + research labs

- **China (PI J. Wei)**
  - SECM Shanghai
  - Beijing Normal University
  - Central China University Wuhan
  - Guangxi University Nanning
  - IHEP Beijing
  - KIAA Peking University
  - Nanjing University
  - NAOC Beijing
  - National Astronomical Observatories
  - Purple Mountain Observatory Nanjing
  - Shanghai Astronomical Observatory
  - Tsinghua University Beijing
- **Mexico** UNAM Mexico
- **France (PI B. Cordier)**
  - CNES Toulouse
  - APC Paris
  - CEA Saclay
  - CPPM Marseille
  - GEPI Meudon
  - IAP Paris
  - IRAP Toulouse
  - LAL Orsay
  - LAM Marseille
  - LUPM Montpellier
  - OAS Strasbourg
- **UK** University of Leicester
- **Germany**
  - MPE Garching
  - IAAT Tübingen

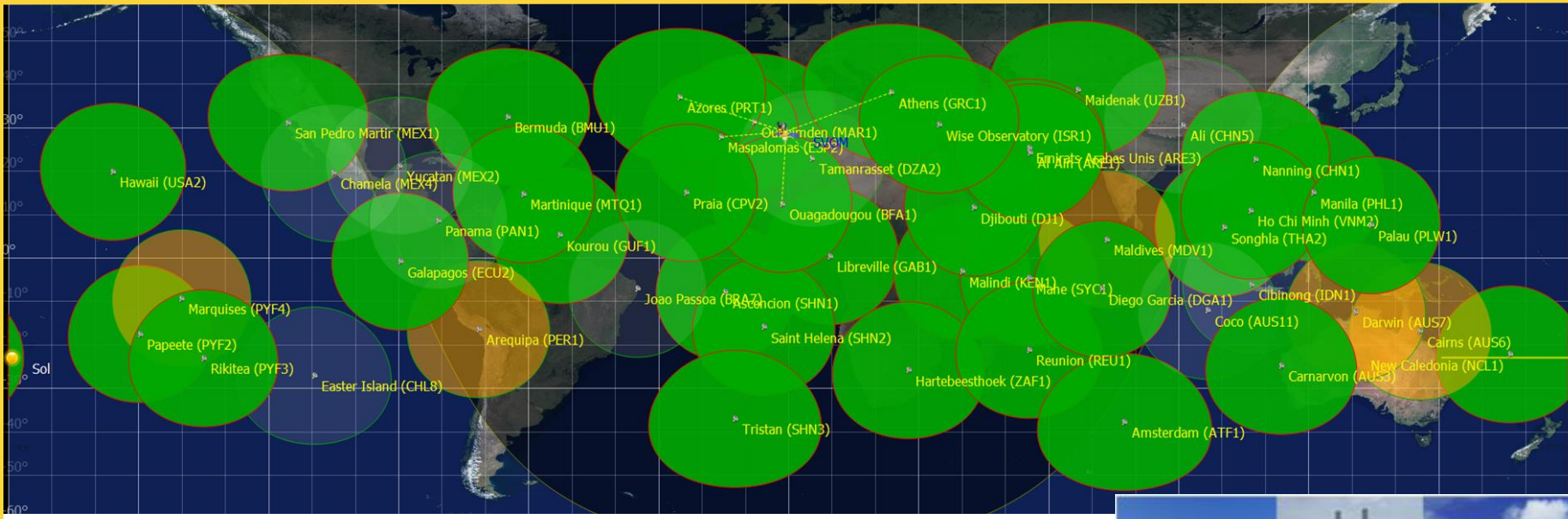
Satellite:
- by CAS (SECM-Microsat)
- 950 kg, 450 kg payload
- 2 Cn + 2 Fr instruments

Launch:
- Foreseen end 2023
- Launcher: LM2C
- Site: Xichang, China
- Orbit: LEO, 620 km, 30°

Operations:
- 3 yr (+ 2 yr extension)

SVOM satellite and instruments

SVOM VHF network



VHF sender on satellite + about 50 VHF receiver stations on Earth

- 36 VHF receiver stations installed (CNES) and operational today →
- Quadrifilar helix antennas (137-138 MHz, LHCP & RHCP) to internet
- Check of the network with VHF data form meteorology-satellites

- Transmission of low-bandwidth data (~ 300 bit/s, 1 pkt/2s):
  Alerts, Light-Curves, SubImages, Recurrent msgs (from ECLAIRs, GRM) and post-slew information from MXT and VT + msg repetitions
- Goal: 65% received within 30 s at the French Science Center

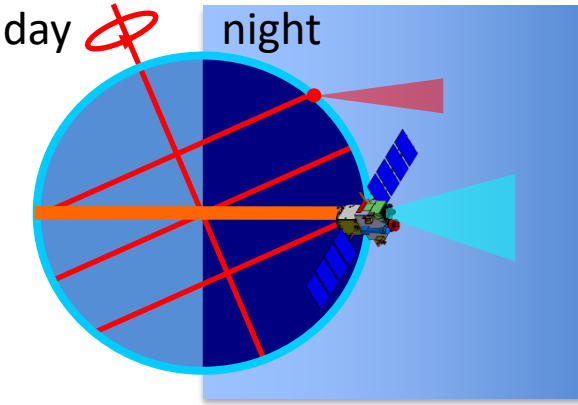
- Network foreseen for **SVOM** and **Einstein-Probe** (+ eXTP, TBC)
  + possibly other satellites if interested

- SVOM also has a Beidou transmitter for redundancy (only Alerts sent)

SVOM pointing strategy

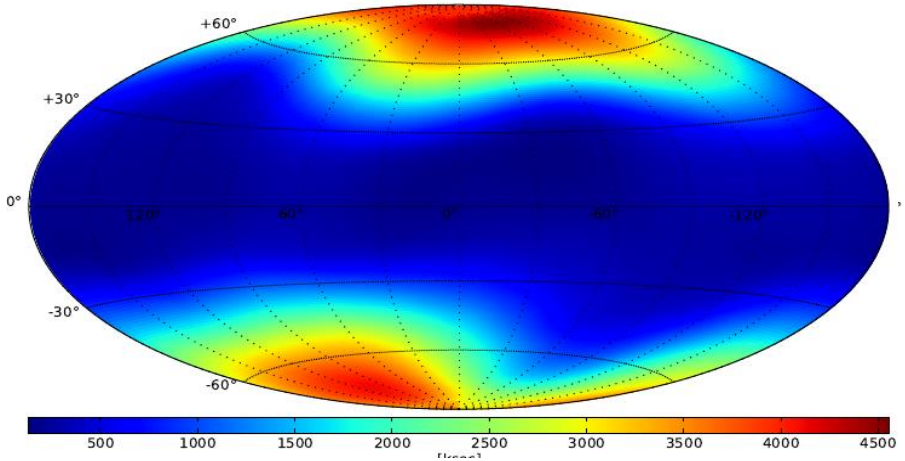
Optimized ground follow-up of GRB candidates:

- nearly anti-solar pointing (within 45°), radiators towards cold
- triggers towards night sky, observable from Hawaii, Chile, Canary
- expect large fraction of GRBs with ground redshift: 50 – 70%
- long stable pointings: detection of long transients (e.g. UL-GRBs)
- drawback: Earth in FoV (ECLAIRs 65% free), variable background

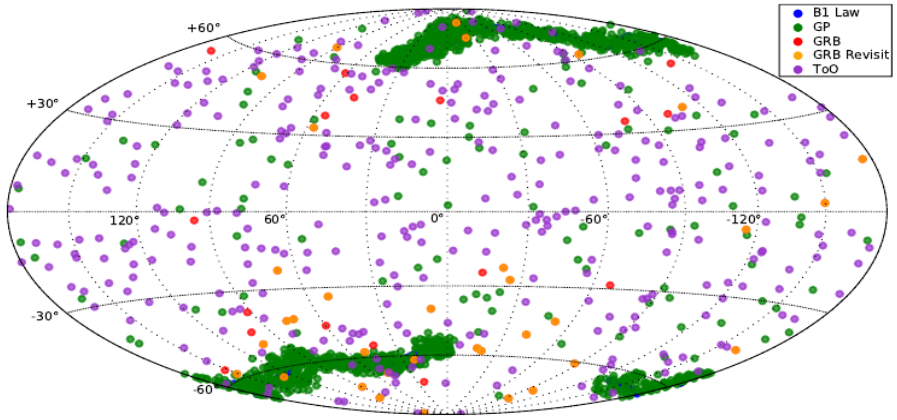


Galactic plane and intense source Sco X-1 avoided in the ECLAIRs FoV (most of the time during the nominal mission)

- Exposure mostly towards galactic poles (so called “B1-pointing law”)
- Expect ~65 GRBs/year by ECLAIRs + allow 1 ToO per day



ECLAIRs sky exposure (ks, 1 yr nominal)



MXT and VT pointings (1 yr, nominal)

SVOM observing program

Core Program (CP): a complete GRB sample

- Prompt, Afterglow and Redshifts
- GRB studies (S-GRB/mergers, L-GRBs/SN…)
- “Burst Advocates” manage GCN/VO-events.
- Scientific products public as soon as available.

General program (GP)

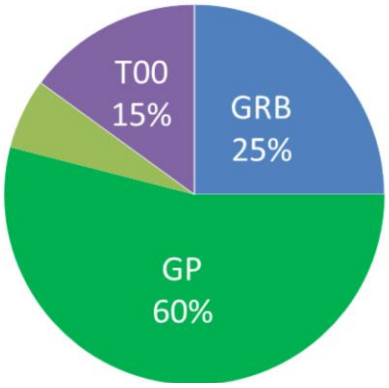
- Observation proposals selected by a Time Alloc. Committee (a SVOM Co-I needs to be part of your proposal) for targets of interest mostly compliant with pointing law.

Target of Opportunity (ToO) program

- ToO-NOM (nominal): transient follow-ups sent from ground (GRB revisits, flaring sources, other new transients – 1 orbit)
- ToO-EX (exceptional): for exceptional astrophysical events which need rapid repointing (many orbits)
- ToO-MM (multi-messenger alert): counterpart search in large error box, tiling with MXT (e.g. GW events)

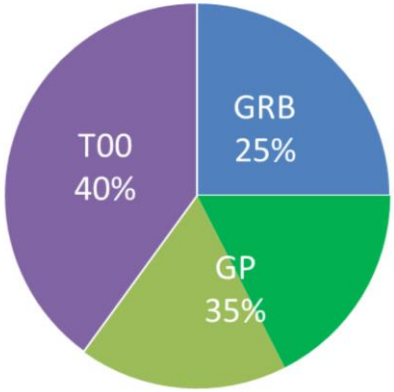
Nominal mission (3 years)

1 ToO per day, 10% of GP outside B1 law



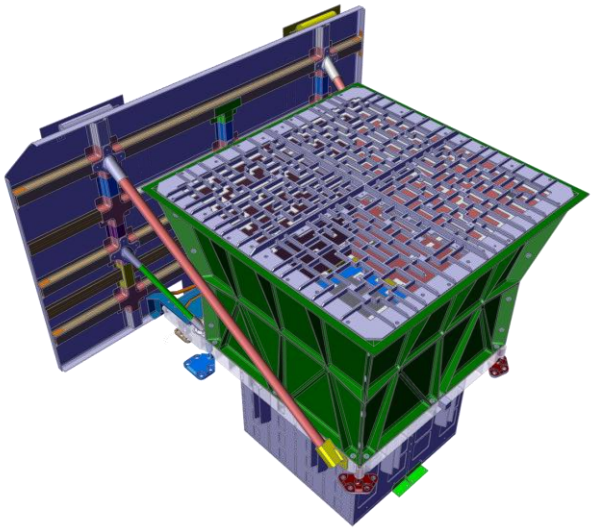
Extended mission (+2 years)

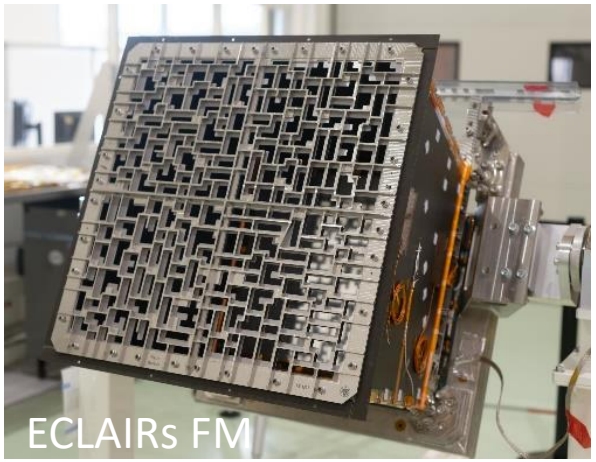
5 ToOs per day, 50% of GP outside B1 law

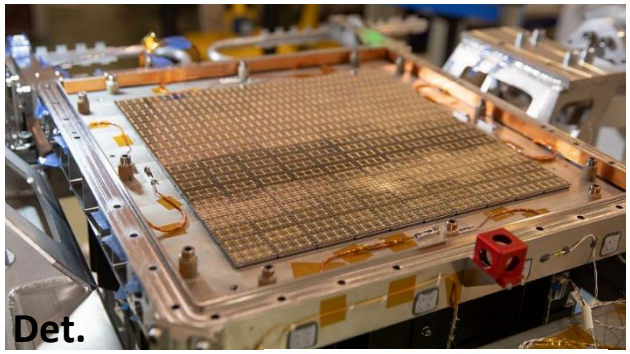


- Repointing possible via Beidou uplink of short messages (few min) or S-band (few hours)
- Initially 1 ToO/day, will increase during extended mission.

ECLAIRs imager & trigger instrument



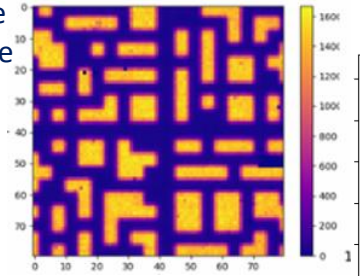


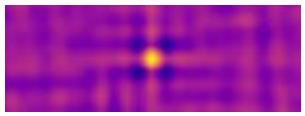


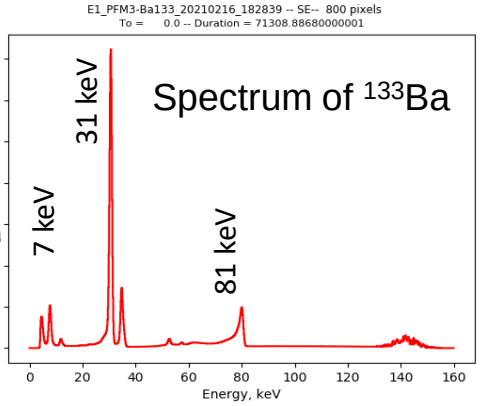
ECLAIRs (CNES, IRAP, CEA, APC)

- Allocation ~ 90kg, 90W
- Detection plane (IRAP): **1000 cm²**
- **6400 CdTe pixels** (4x4x1 mm³)
- **Energy range: 4 - 150 keV**
- **Mask** (APC)**: Ta** 0.6 mm thick, 40% open
- **FoV**: **2 sr** (89°x89°, total)
- **UGTS** software (CEA): cmd/ctrl, DAQ, GRB trigger
- Localisation: **<12 arcmin** at detection limit, 90% CL
- Expected rate: **~65 GRBs/yr**
- All detected photons sent to ground (X-band,>12 h)

First image of rad. source



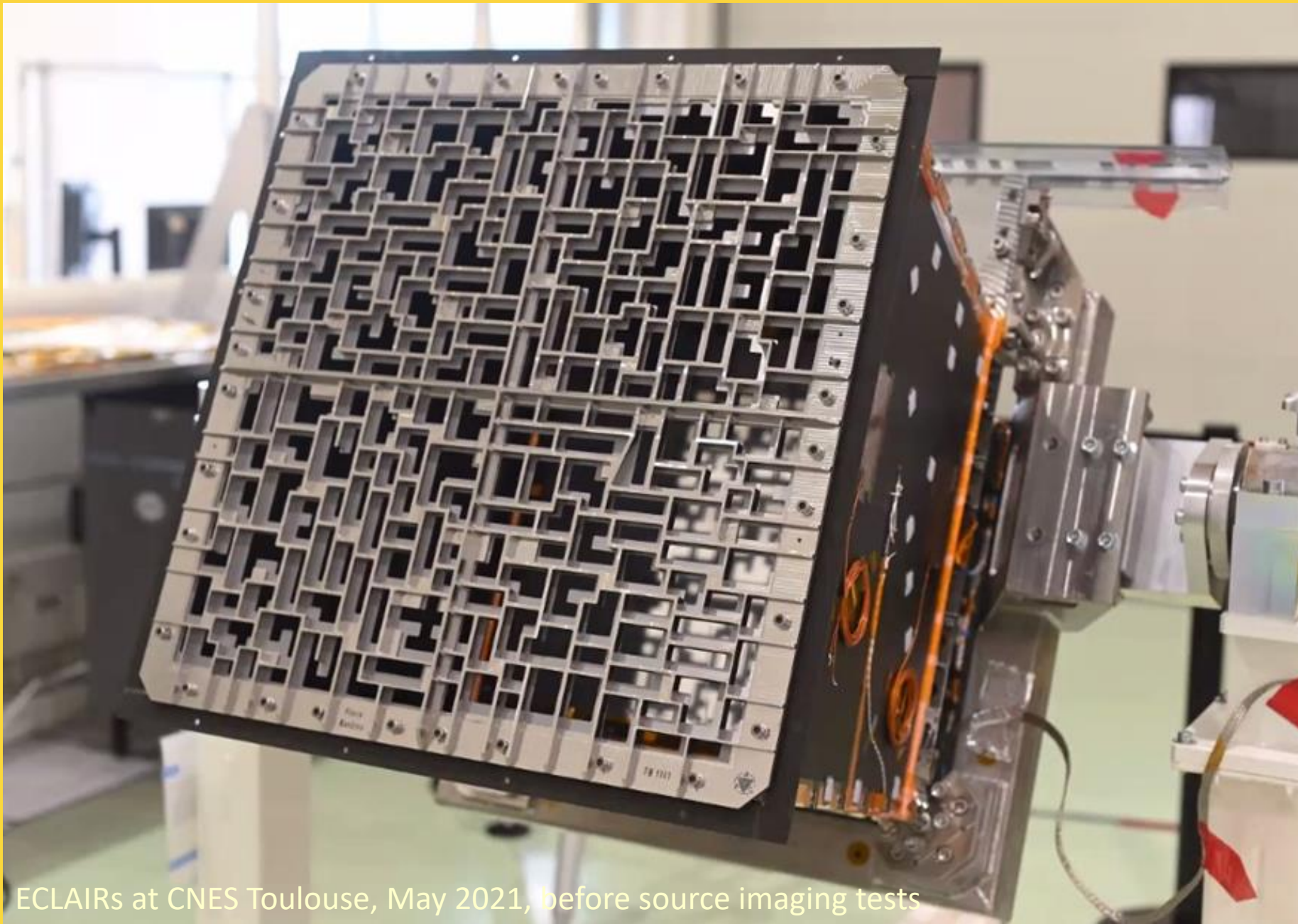




Well suited to detect and localise GRBs with low E_{PEAK}

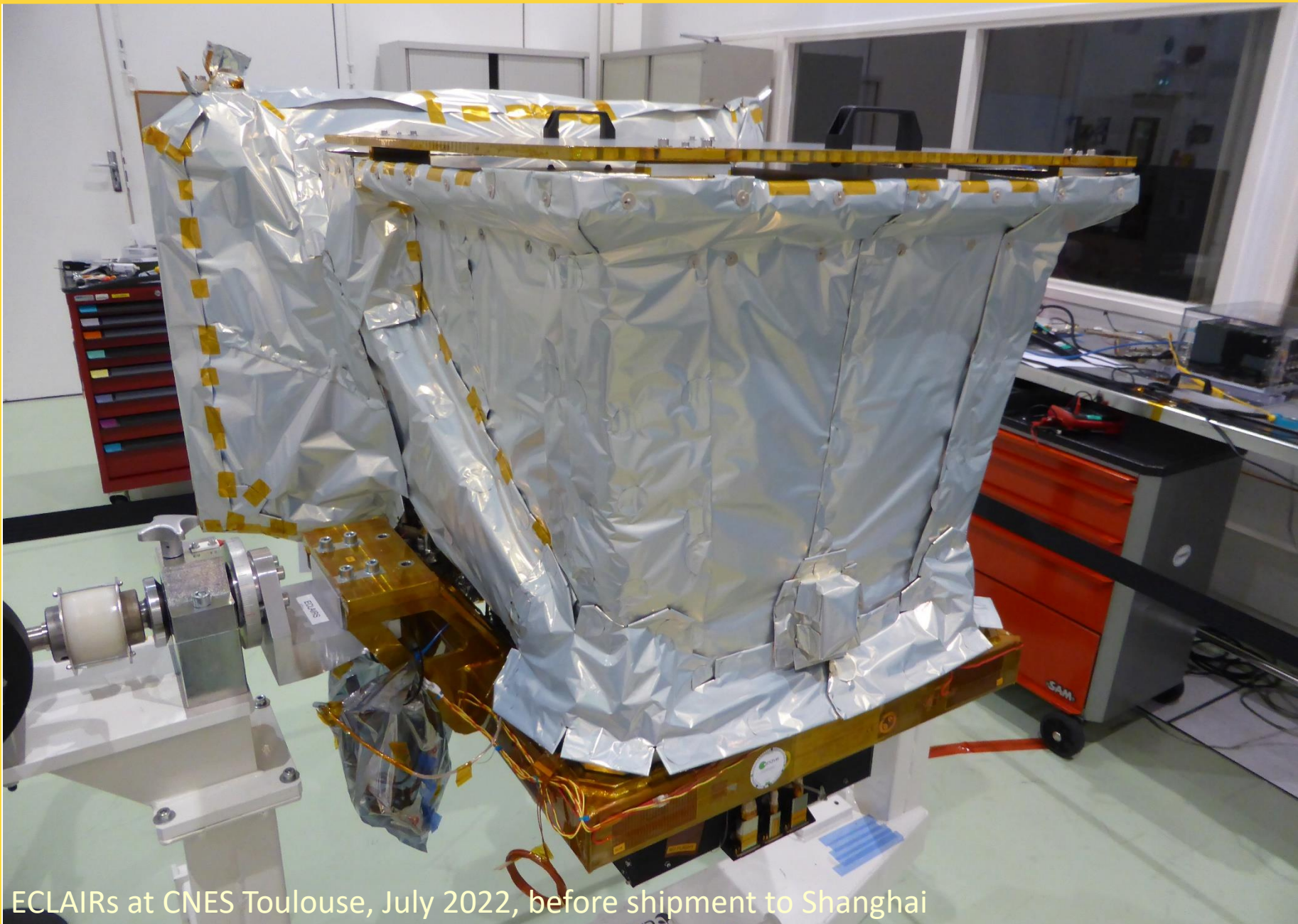
FM completed and tested

ECLAIRs imager & trigger instrument



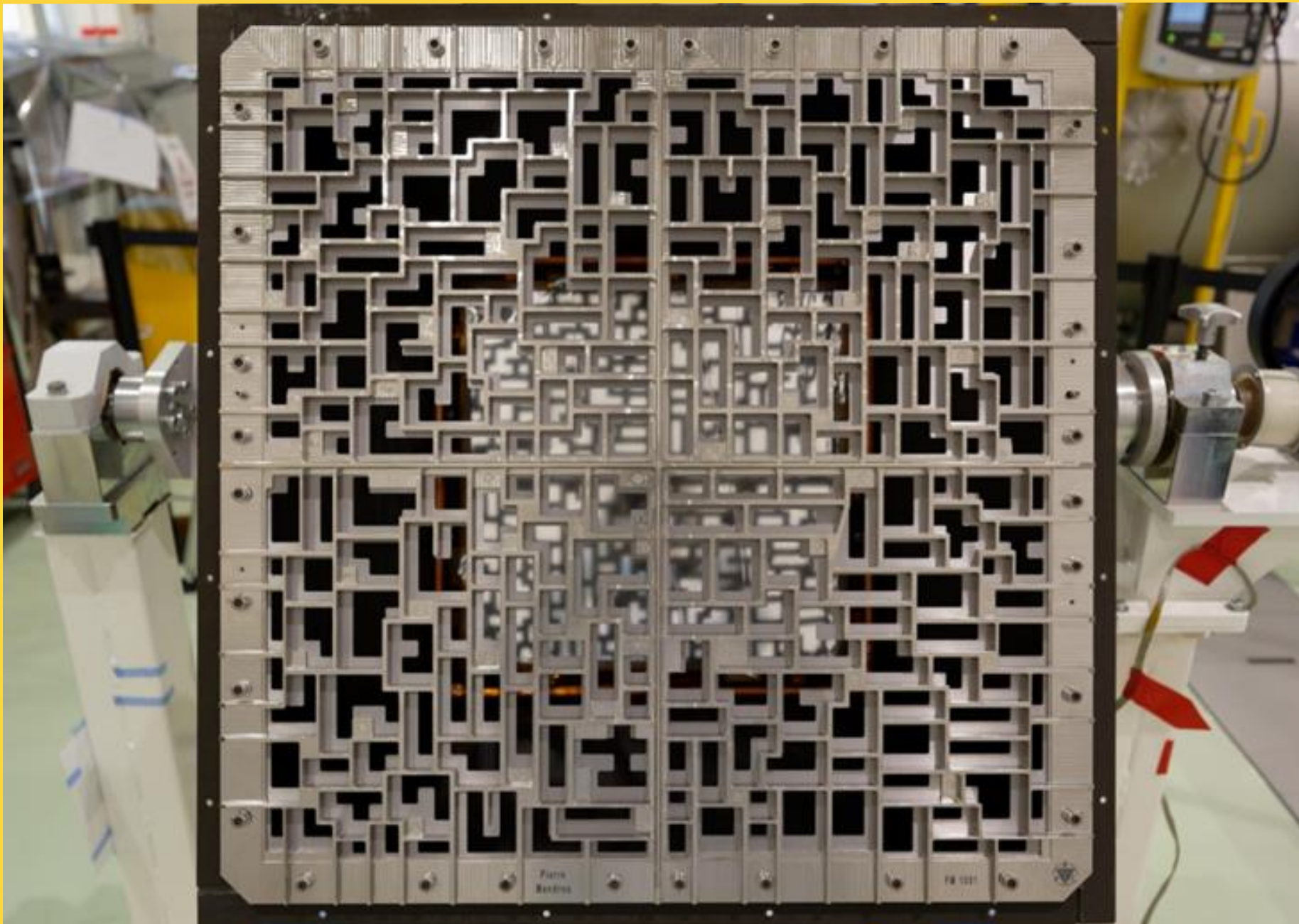
ECLAIRs at CNES Toulouse, May 2021, before source imaging tests

ECLAIRs imager & trigger instrument

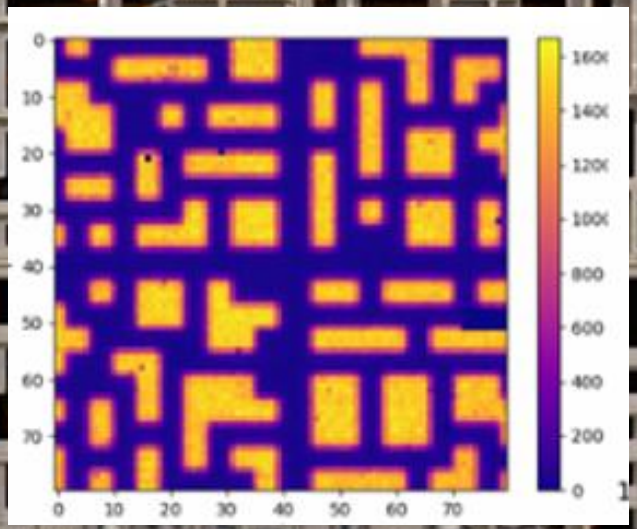


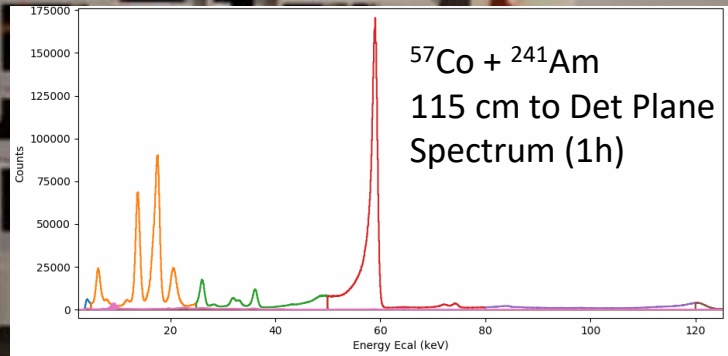
ECLAIRs at CNES Toulouse, July 2022, before shipment to Shanghai

ECLAIRs imager & trigger instrument

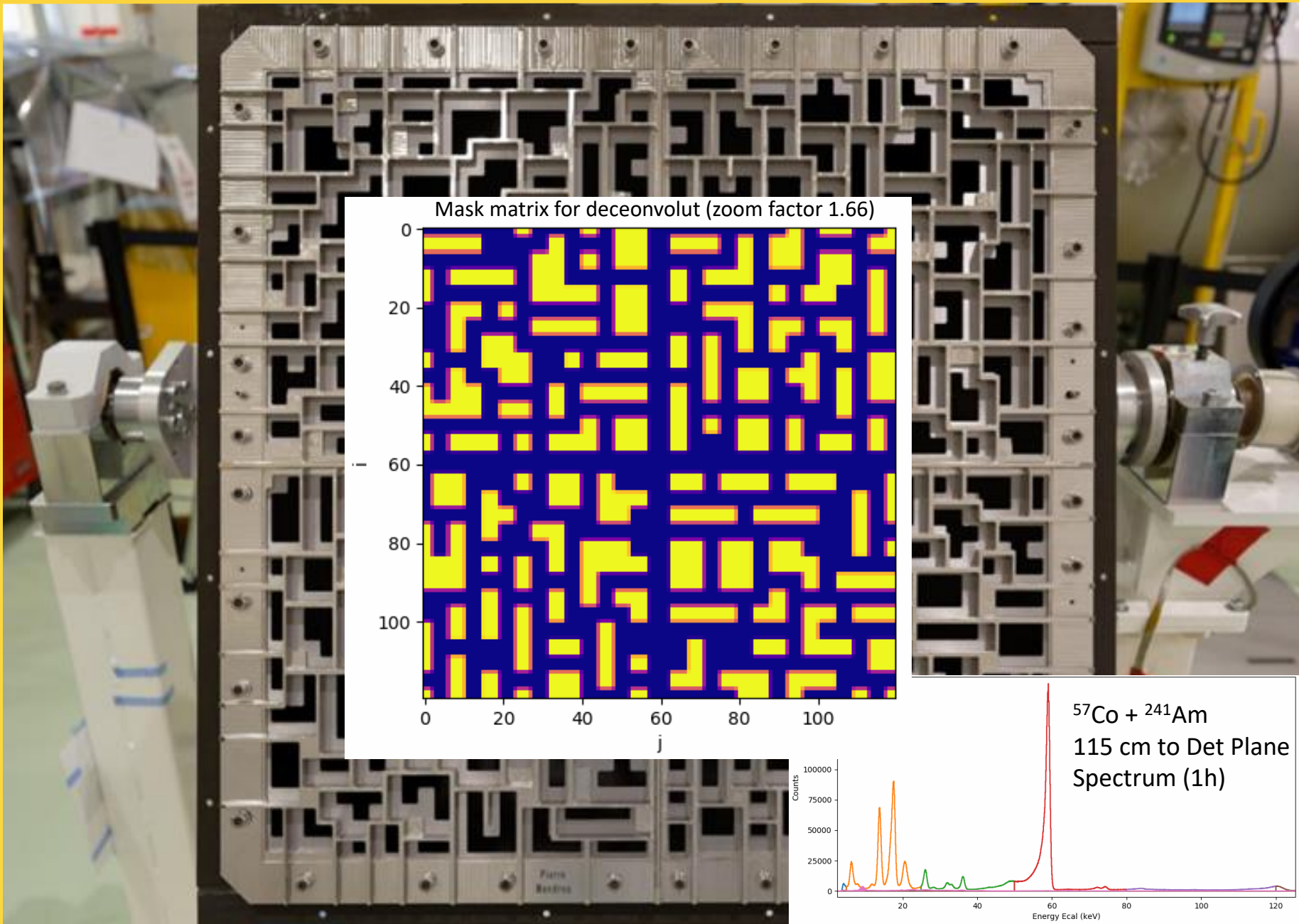


ECLAIRs imager & trigger instrument

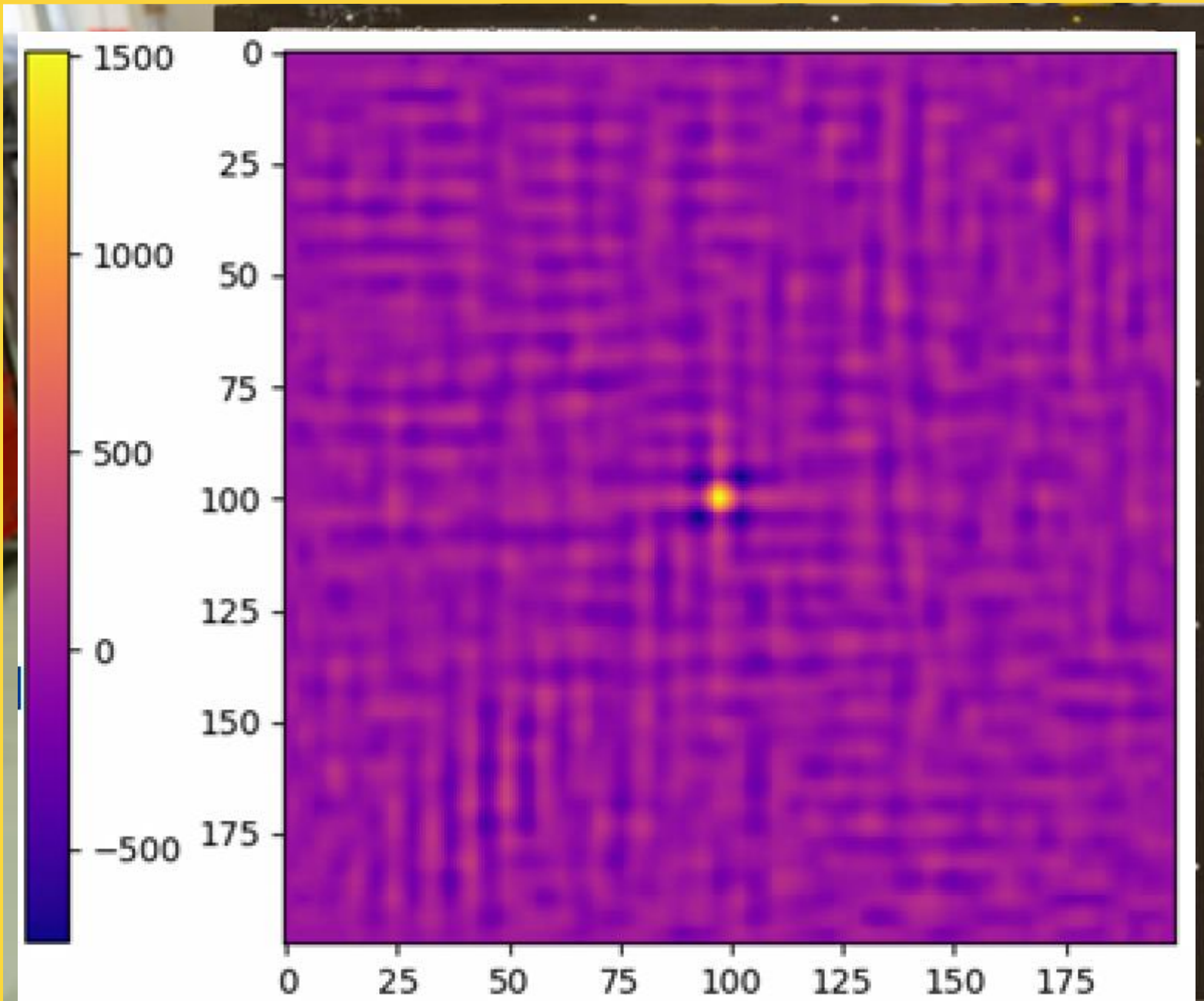




ECLAIRs imager & trigger instrument



ECLAIRs imager & trigger instrument



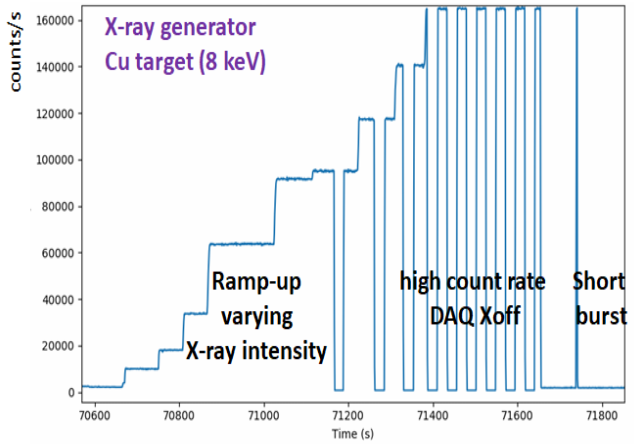
ECLAIRs calibration

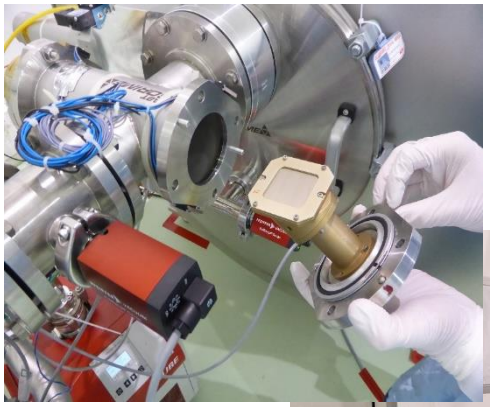
Intensive tests in TVAC at CNES Toulouse (March-May 2021) and Airbus (October 2021)

- Detector plane qualification (spectral properties, homogeneity, temp. response)
- Imaging tests at different energies with coded mask mounted (source at finite distance)
- Data acquisition test at high data rate (simulation of variable sources and high count-rates expected during SAA passages in low Earth orbit).
- Scientific software tests (image trigger, alerts…)

- radioactive sources, e.g. Co57 (6.4, 14.4 and 122 keV)
- X-ray generator + target, e.g. Ti, Mn, Cu, Ag, (4.5/5.9/8/22 keV).
- Variation of the X-ray generator intensity to simulate “bursts”

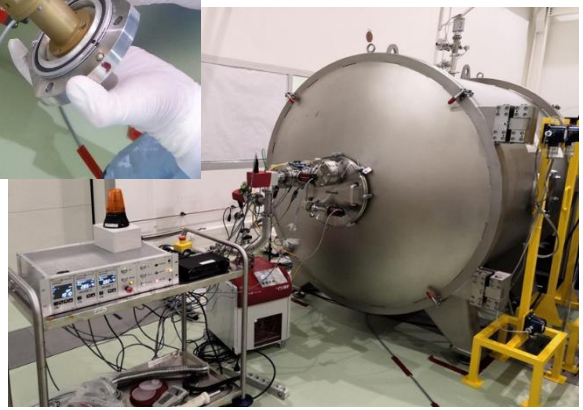
- First “burst” detected by the image trigger (flight software V5)

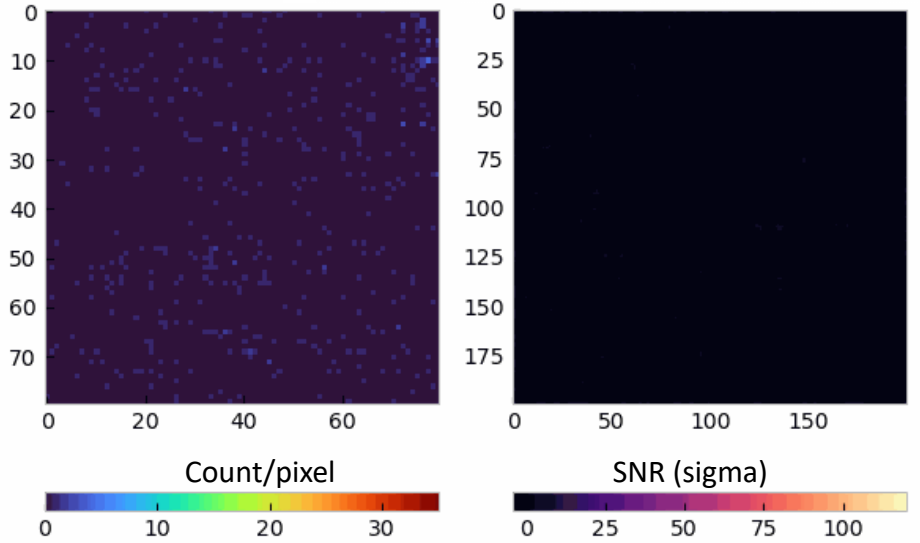




Cu target

ECLAIRs in vac. ch.



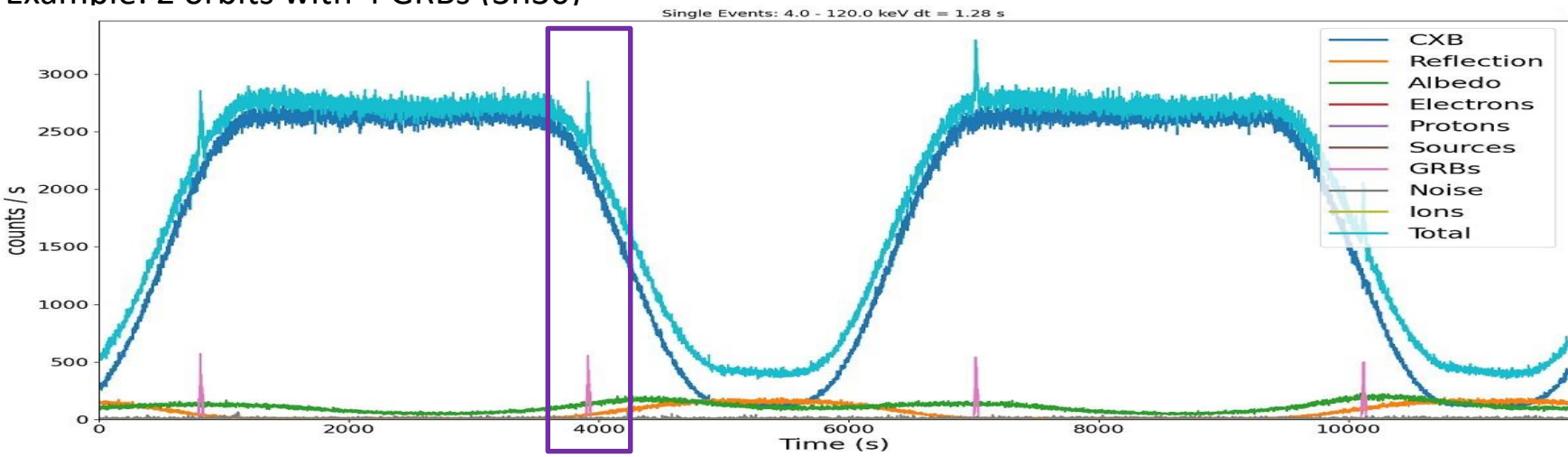


20 images of 20 s | Display: 0.5 s / image

ECLAIRs trigger dev. and test (CEA)

- Simulated satellite pointings, Earth passages, satellite slews and SAA passages
- Simulated photon data: GRBs from previous missions through ECLAIRs response + CBX bkg + instrumental bkg from TVAC tests
- Data injected into UGTS hardware model,
- Running trigger software, telemetry (CCSDS)

- Example: 2 orbits with 4 GRBs (3h30)



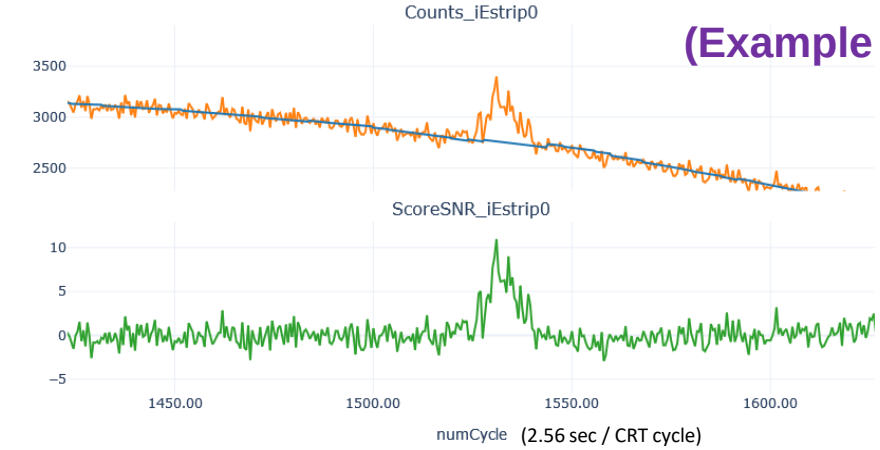
- UGTS triggers (2 algorithms running in parallel, coded in C++, running in hypervisor on Leon3 CPU):

Count-rate trigger (CRT) :
search count excesses (10 ms - 20 s)
in 4 Energy strips and 8 detector zones,
imaging of best excess (each 2.5 s).

Image trigger (IMT) :
systematic imaging (20 s)
in 4 Energy strips,
sum images up to 20 min (each 20 s)

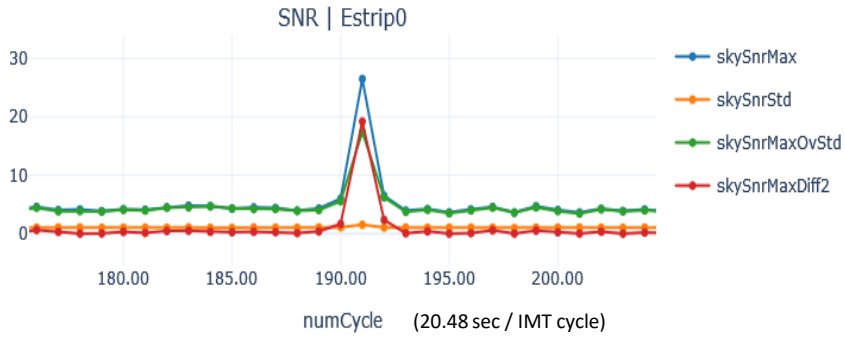
ECLAIRs trigger and alert sequence

CRT excesses (in SNR counts, before imaging)



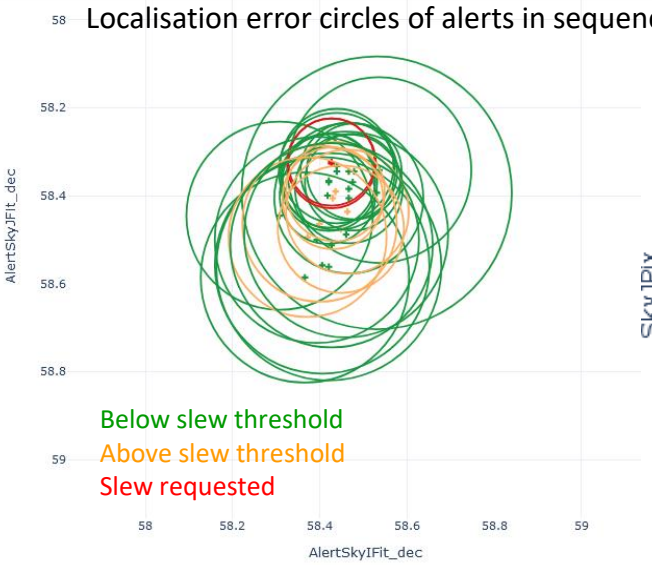
IMT excess in SNR sky image

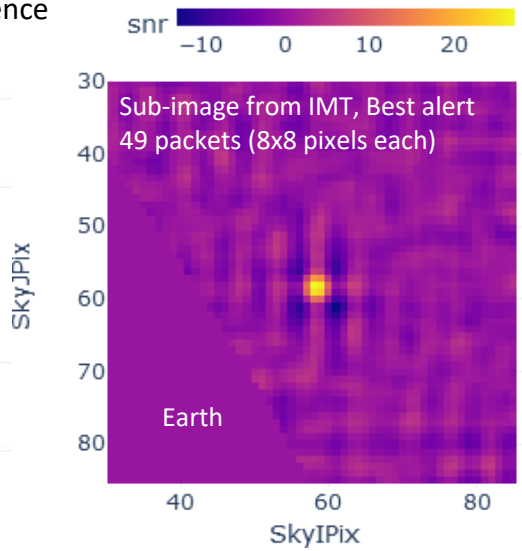
(Example of 2nd GRB)



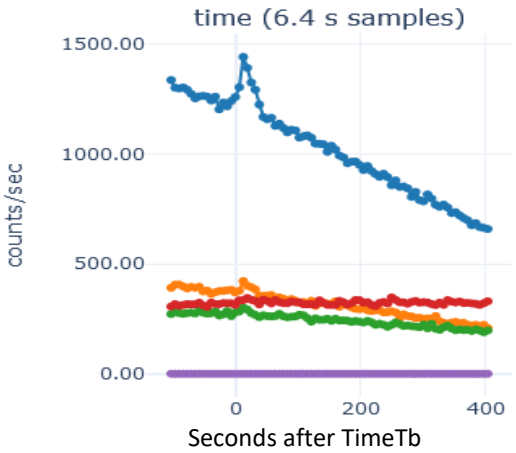
VHF alert sequence (output products built)

Localisation error circles of alerts in sequence



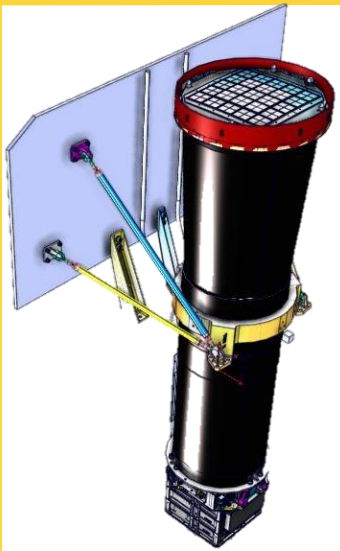


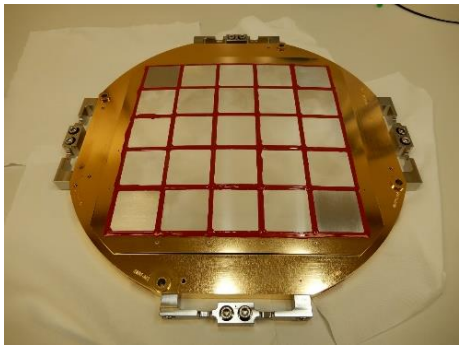
Lightcurves (3 resolutions):
- High/Mid/Low (0.1/0.8/6.4 s binning)
- Each: 4 Ebands + Saturating + Multiples

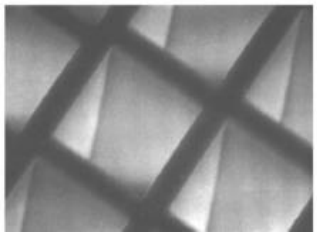


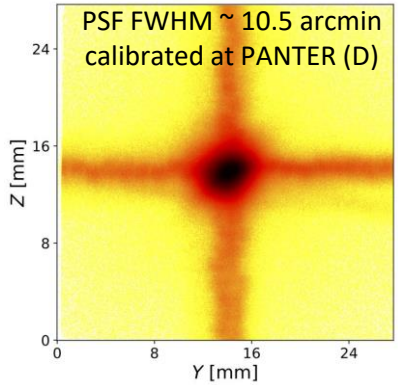
Flight software V7 (CEA delivered to CNES 2022/8/7), baseline for in-flight commissioning

MXT instrument





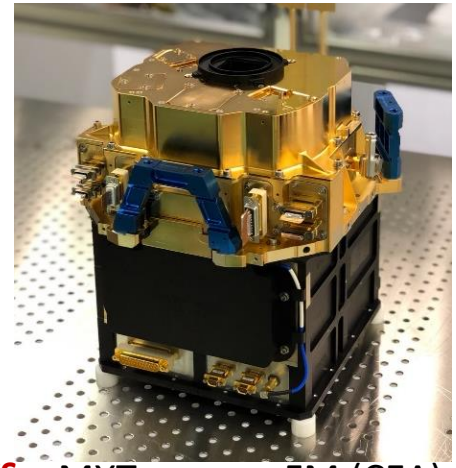




MXT Micro-chan. X-ray (CNES, CEA, IJCL, UL, MPE)

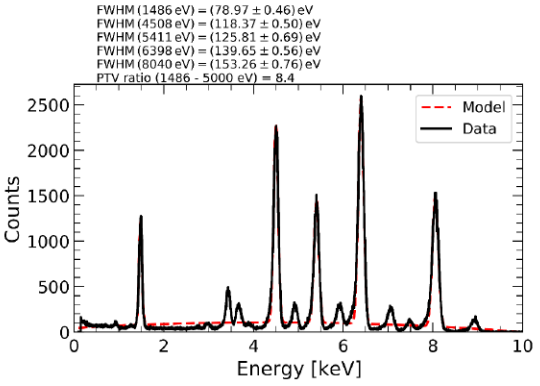
- **Micro-pores optics** (Photonis)
  square 40 µm pores (UL design)
- pnCCD (MPE) based camera (CEA)→
- **FoV: 57x57 arcmin²**
- Focal length: 1.15 m
- **Energy range: 0.2 - 10 keV**
- Energy resolution: ~80 eV @ 1.5 keV
- Aeff = 30 cm² @ 1.5 keV (central spot)
- **Localization accuracy** < 30 arcsec
  within 5 min from trigger for ½ GRB
  (100 arcsec for 5σ source, 90% C.L.)

Innovative focusing «Lobster-Eye» optics well suited for X-ray afterglow observations

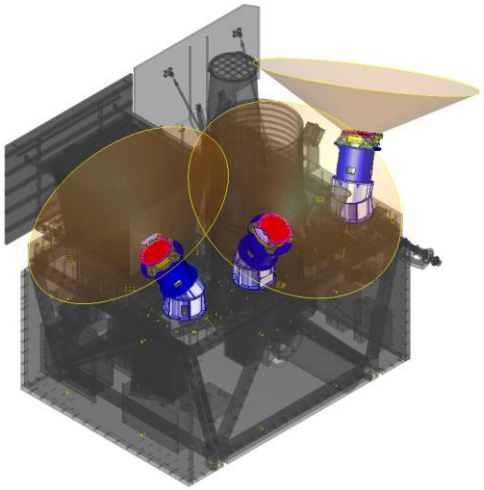


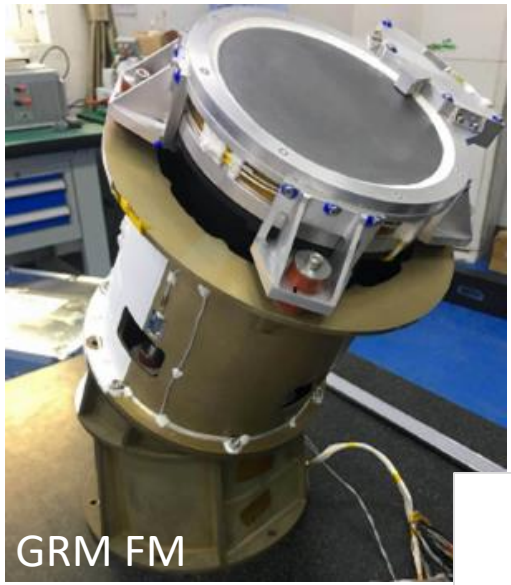
MXT camera FM (CEA)

Energy calibration with multi-line spectrum:
79 eV @ 1,5 keV (single events),
88 eV @ 1,5 keV (all events)



GRM instrument

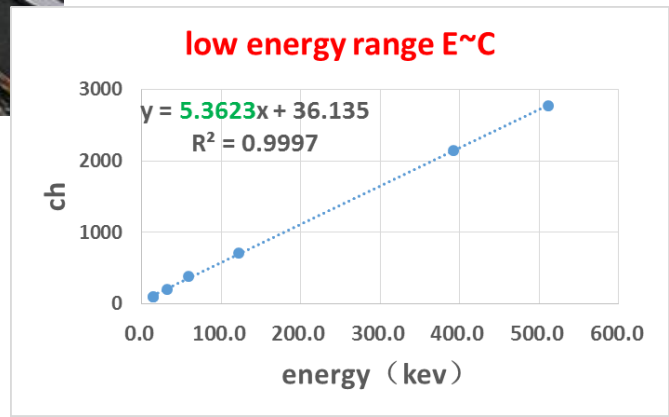


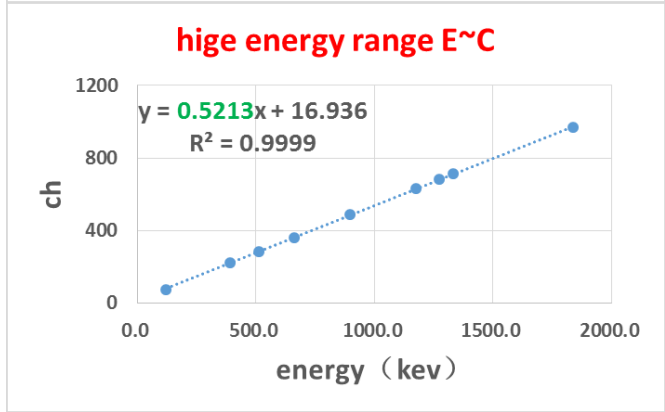


GRM Gamma-Ray Monitor (IHEP)

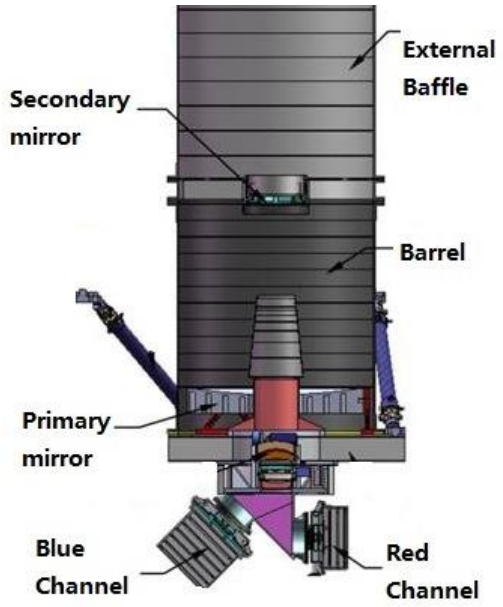
- **3 Gamma-Ray Detectors** (GRDs)
- **NaI(Tl)** (16 cm Ø, 1.5 cm thick)
- Plastic scintillator (6 mm) to monitor particle flux and reject particle events
- **FoV: 2 sr per GRD, 5.6 sr in total**
- **Energy range: 15-5000 keV**
- **Aeff = 190 cm²** (at peak, for each GRD)
- Crude localization accuracy (30° inclination each)
- Expected rate: **~ 90 GRBs/yr**

Suited to detect short & long GRBs
and measure E_{PEAK} for most ECLAIRs GRBs





VT instrument

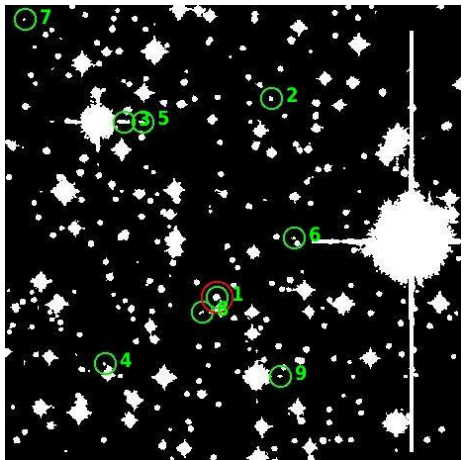


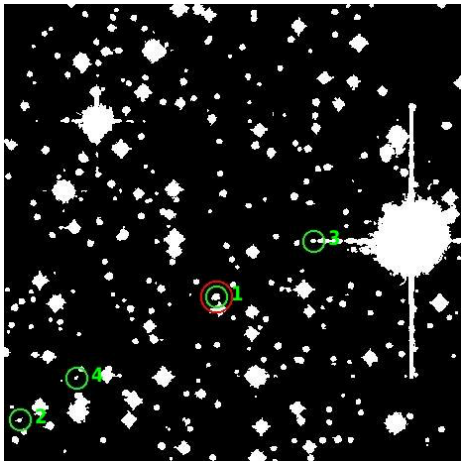
VT test at Xinglong obs.

VT Visible Telescope (XIOMP, NAOC)

- Ritchey-Chretien telescope, **40 cm Ø**, f=9 (focal length 3.6 m)
- **FoV: 26x26 arcmin²**, covering ECLAIRs error box
- **2 channels: blue (400-650 nm) and red (650-1000 nm)**, with 2k x 2k CCD detector each
- **Sensitivity M_V=23 in 300 s**
- Will detect ~80% of ECLAIRs GRBs
- **Localization accuracy < 1 arcsec**

Red and blue channels
Able to detect redshift GRBs up to z~6.5
Identification of high-z GRBs as "dark GRBs"





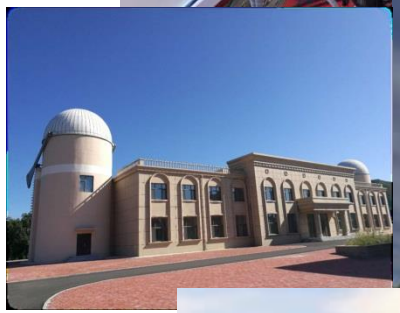
SVOM ground based instruments

Ground-based Wide Angle Camera GWAC (NAOC)

- Explore the prompt optical emission (500-800 nm), 2 sites:
  - **In China (Muztagh Ata)**: 40 cameras of 180 mm diameter
    - **total FOV ~6000 deg²** ; limiting magnitude 16 (10s)
  - **In Chile (CTIO)**: 50 cameras of 250 mm diameter
    - **total FOV ~5000 deg²** ; limiting magnitude 17 (10s)
- Self triggering, or search counterparts of ECLAIRs localisations (incl. low signific.), 16% of ECLAIRs triggers visible by GWAC
- Already operational (in China), participating in LIGO/VIRGO-O3 run

Ground Follow-up Telescopes (GFTs)

- Robotic 1-m class telescopes (fast repointing, <30 s)
- **C-GFT** (Xinglong observatory, China):
  - 1.2 m, FoV: 21x21 arcmin², 400-950 nm
- **F-GFT** (a.k.a. Colibri, San Pedro Martir, Mexico):
  - 1.3 m, FoV = 26x26 arcmin², multi-band photometry (400-1700 nm, 3 simultaneous bands)
- Accurate GRB localization → observations with large telescopes



Agreement to use the LCOGT network (12x1m+2x2m tel.)

75% of ECLAIRs-detected GRBs immediately visible by a GFT
Large telescopes follow-up favored by pointing law
→ redshift expected in 65% of cases

Conclusions

Status : French Instruments (ECLAIRs an MXT)

- Construction completed, very good performances measured
- Thermal vaccum tests and calibrations successfully performed (ECLAIRs in Toulouse, MXT at PANTER in Garching)
- ECLAIRs flight software is ready, tested and delivered, (and can still be updated on ground and in flight if needed)
- Both instruments will be shipped to China very soon

Happy to be at the point where we are (big effort of many people)

Road to go:

- Assembly of VT and GRM onto SVOM Platform in Shanghai (SECM)
- Addition of ECLAIRs and MXT after arrival (expected end of 2022)
- In 2023: endToEnd +TVAC tests of assembled SVOM on ground
- Launcher integration and launch campaign end 2023
- SVOM commissioning phase to take place in 2024

SVOM Qualification Model
(Flight Model to be integrated)

SVOM will be an important observatory for the study of GRBs (+ AGNs, TDEs, GW transients and Black-Holes and their astrophysical impact).

SVOM offers a unique combination of space and ground facilities, expected to become an important player for High-Energy, Time-Domain and Multi-Messenger Astrophysics,
in combination with a new generation of powerful observatories (GW, Vera Rubin Obs, Pan-STARRS, ZTF, SKA precursors & FRB detectors, Large neutrino observatories, CTA …)

Thank you !