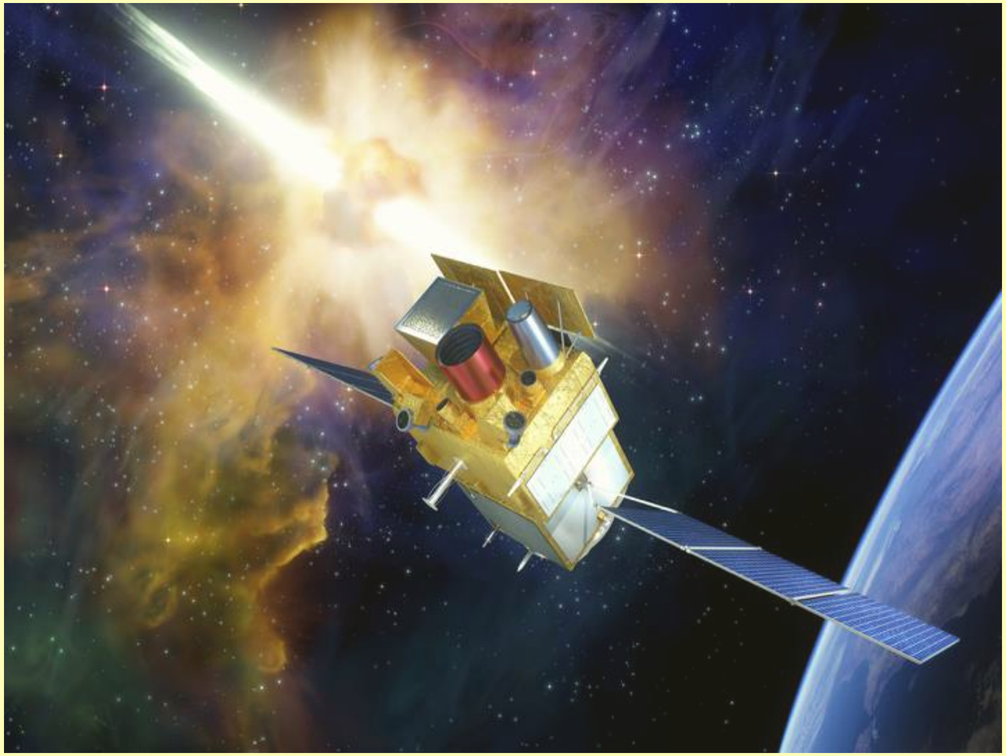
The Gamma-Ray Burst mission

SVOM

and
its GRB trigger



Cargèse School
"The Transient Universe"
2023 June 6

IESC Cargèse, Corsica

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Outline of the lecture

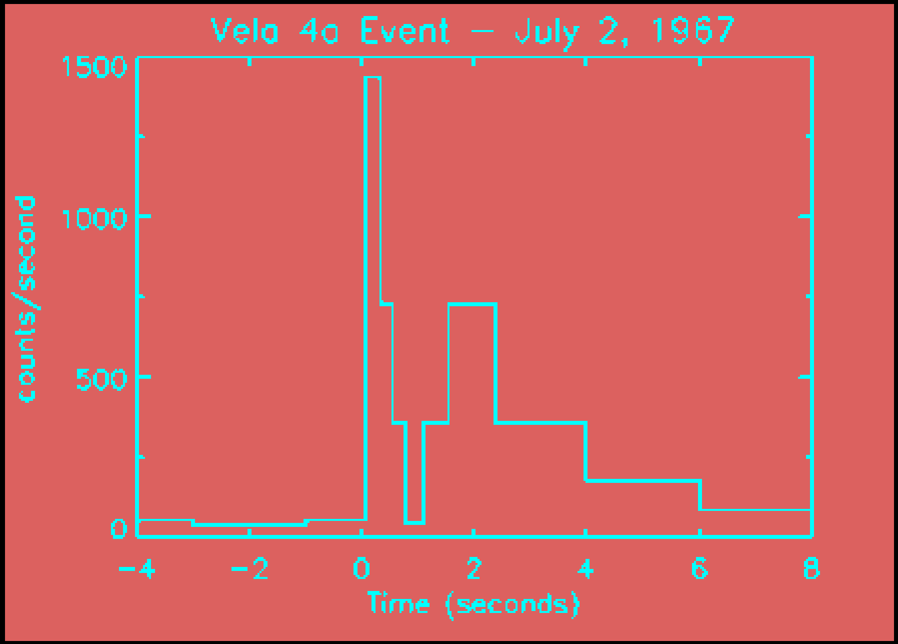
- Introduction
- Current GRB missions
- SVOM : a next GRB mission
- instruments of SVOM
- onboard GRB trigger of SVOM
- status of the SVOM mission
- outlook

GRB discovery : back to 1967

Vela satellite (USA)
gamma-ray detectors in space

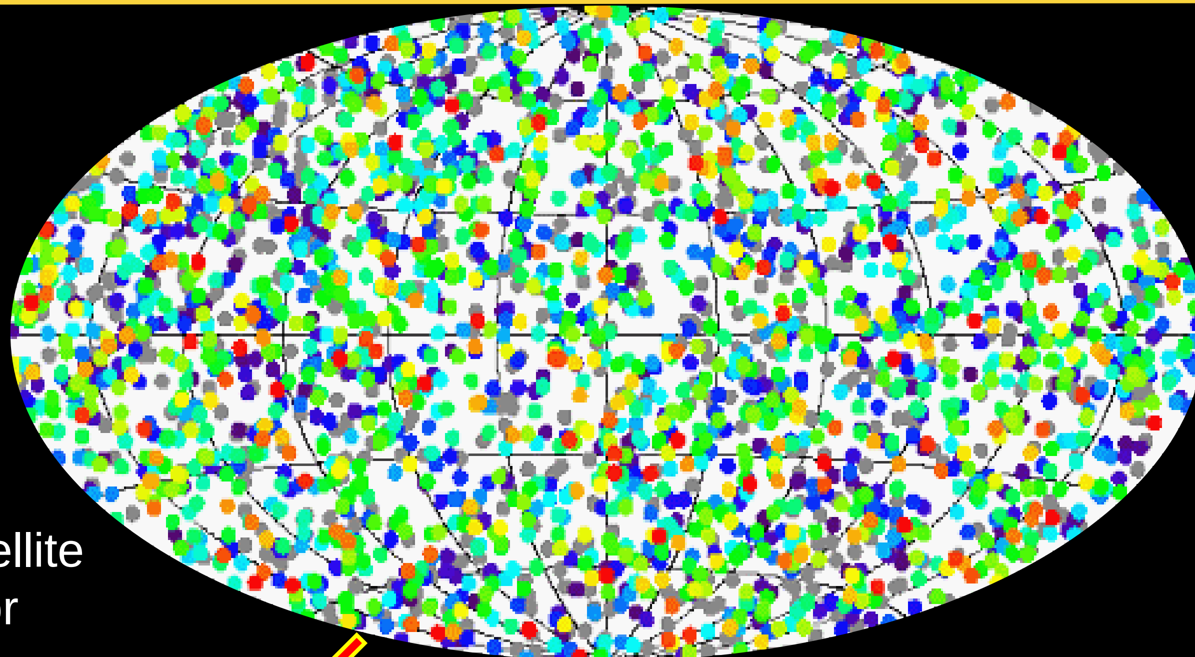
atmospheric nuclear test ban
treaty surveillance

Klebesadel, 1973



What is this ??

GRBs still an enigma during the 1990's

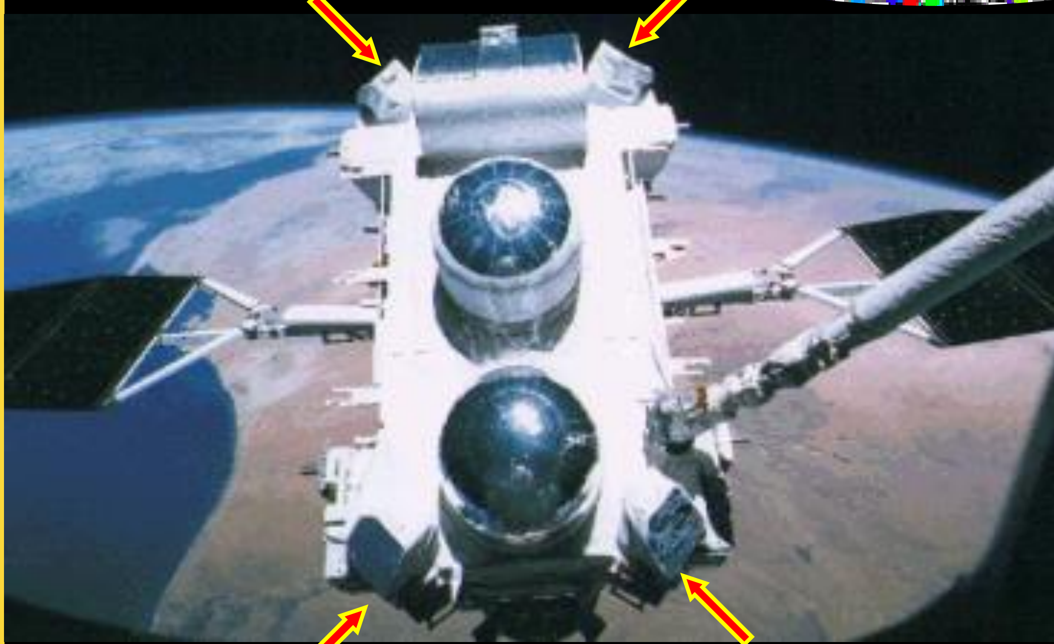


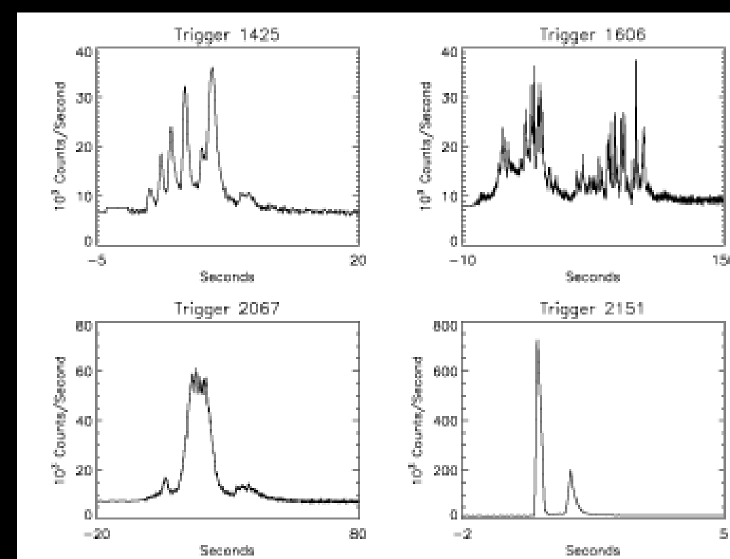
2407
GRBs
(~10 yrs)

Isotropic
on the sky

Duration
Short < 2 s
Long > 2 s

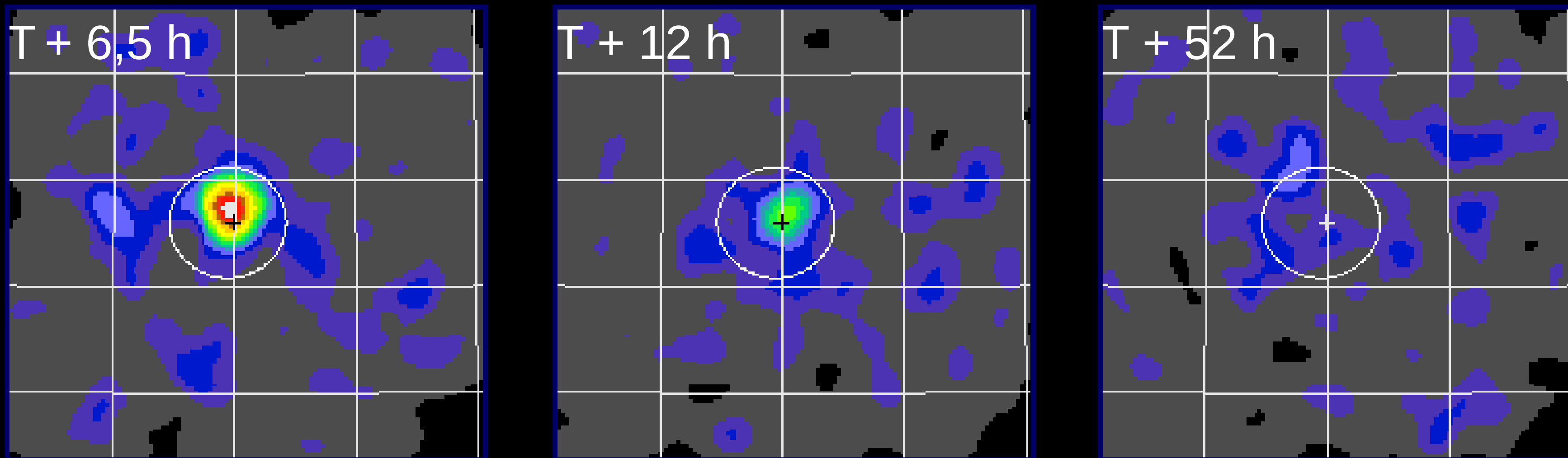
COMPTEL satellite
BATSE detector



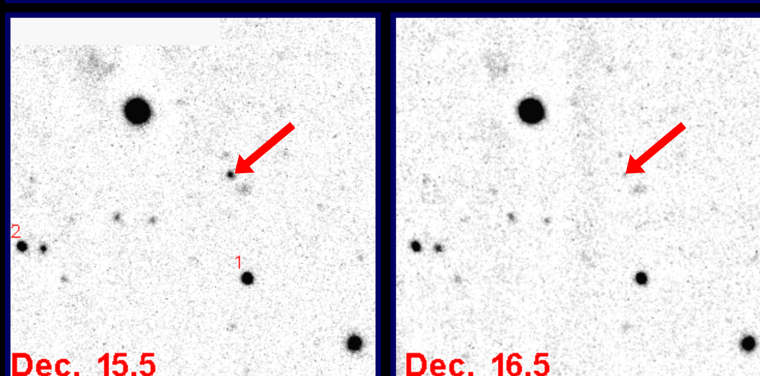


The cosmic revolution of 1997 : BeppoSAX

BeppoSAX discovery of X-ray afterglow emission of GRB 971214

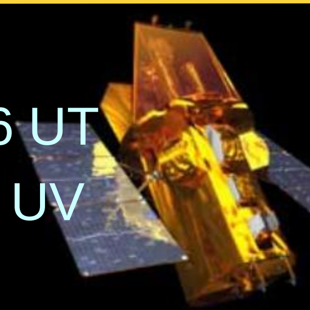


Afterglow in Visible (HST)

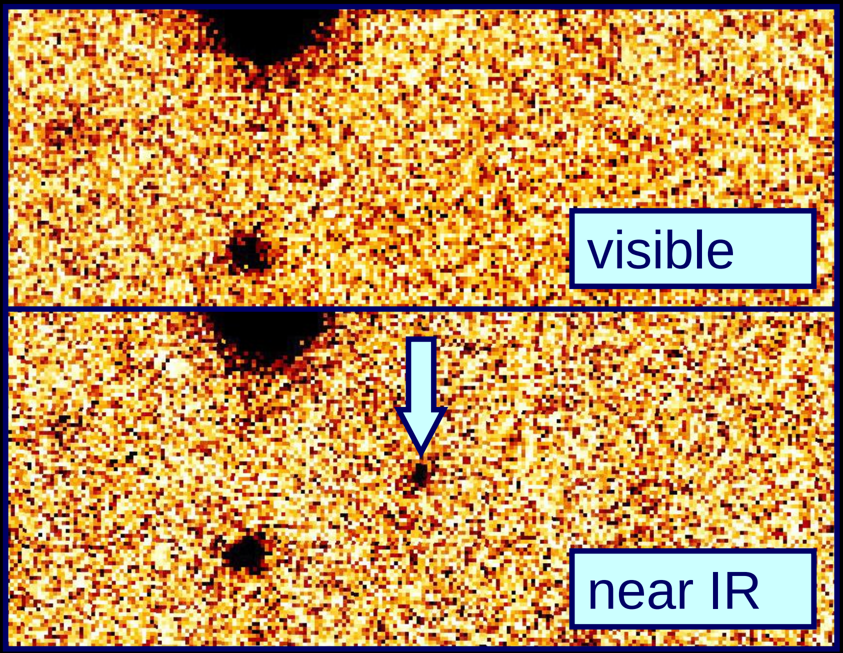


- Detection of host galaxy
- Measure of the redshift
- Cosmological distance
- Extreme energy output
  10^{51} erg radiated in gamma-rays

One of the first very distant GRBs : Swift



- GRB 080913: discovered by Swift on 13 Sept 2008 at 06:46 UT
- T + 2 min : Swift observes the GRB afterglow in X-rays and UV
- T + 3 min : GROND ground follow-up of the field in near IR
- T + 2 h : VLT near IR spectrum, high redshift z = 6,7



z = 6,7 → Event occurred in early Universe, at age 0.835 Gyrs (now aged 13.8 Gyrs)

Gamma-Ray Burst science questions

GRB phenomenon
- Diversity and unity of GRBs, central engine

GRB physics
- Acceleration and nature of the relativistic jet
- Radiation processes, gamma-ray emission
- The early afterglow and the reverse shock

GRB progenitors
- Long GRB-supernova connection
- Short GRB-merger connection

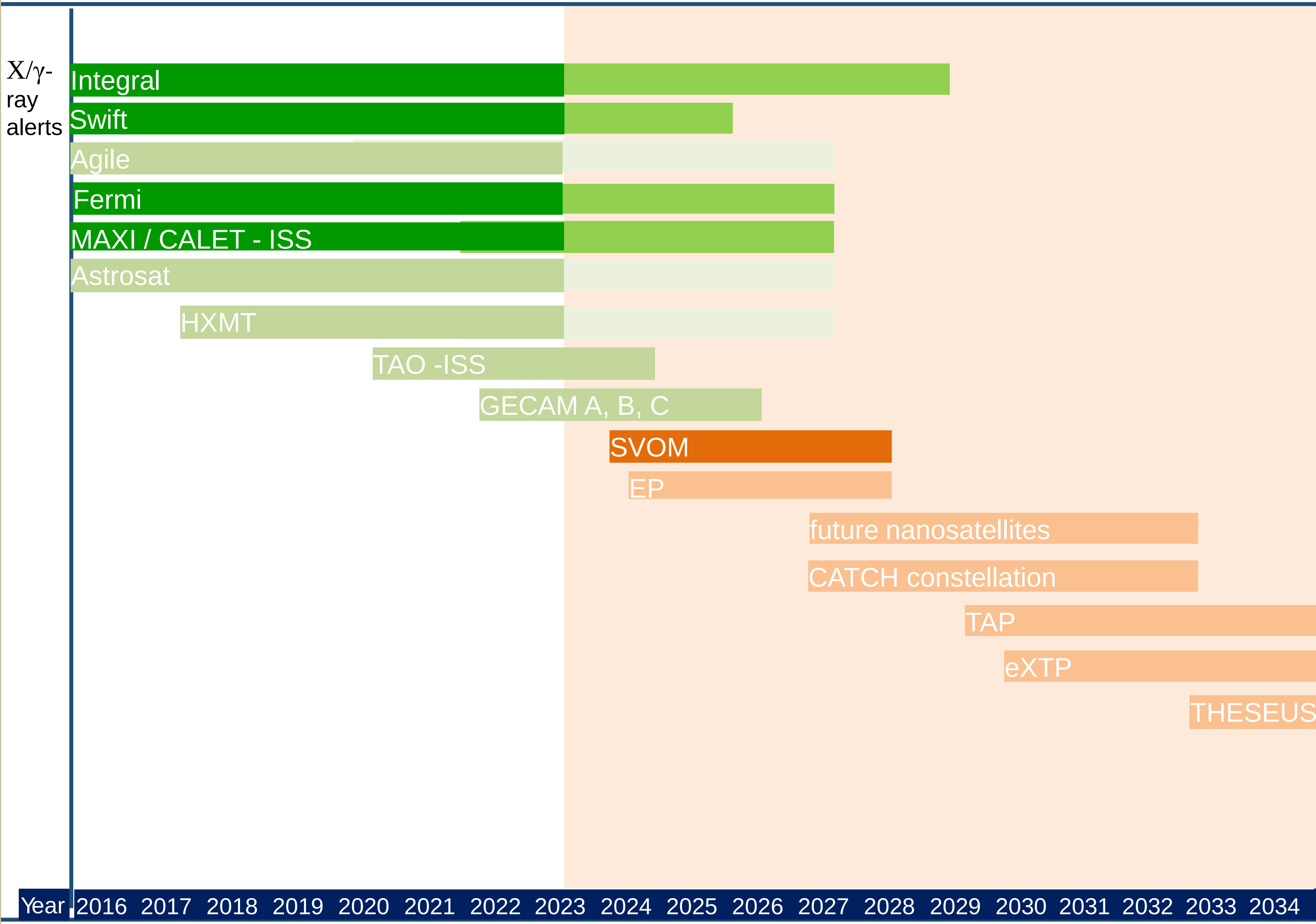
Cosmology
- Cosmological lighthouses (absorption systems)
- Host galaxies
- Star formation tracer
- Re-ionization of the universe
- Cosmological parameters

Fundamental physics
- Short GRBs and gravitational waves
- Origin of high-energy cosmic rays
- Lorentz invariance test

→ **Need of a complete sample of GRBs, with spectral and temporal coverage and a distance measurement**

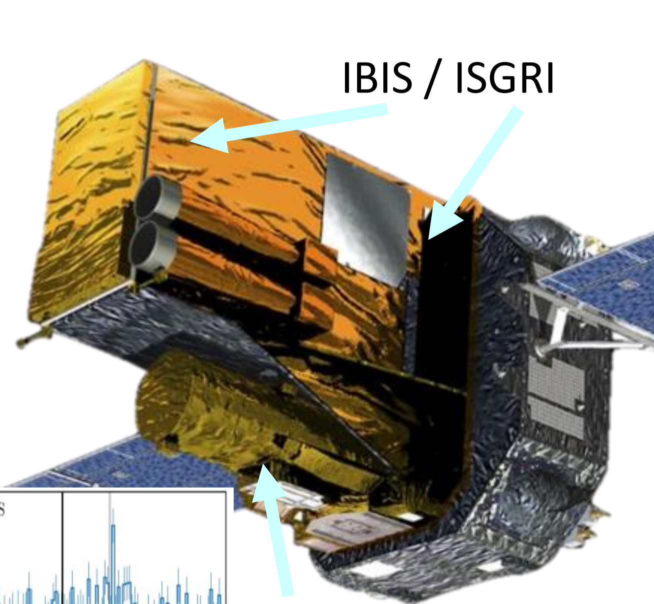
Main GRB missions today

Main missions with GRB alerts: present and future



Integral: International Gamma-Ray Astrophysics Laboratory

Launched : 16 October 2002



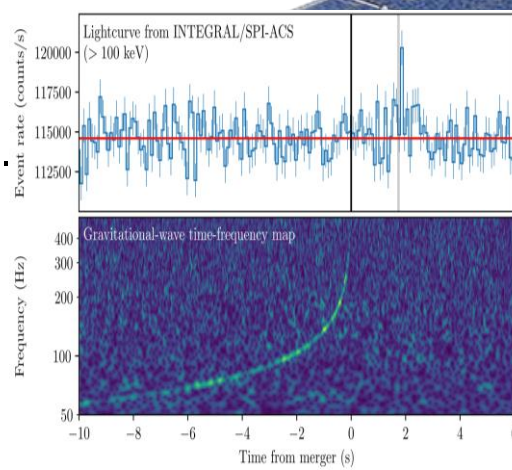
Instruments
IBIS / ISGRI (CdTe) and PICSIT (CsI) + coded mask
SPI (Ge) + SPI/ACS (BGO) + coded mask
Jem-X, OMC

INTEGRAL Burst Alert System (IBAS):
automatic software for near real time detection of GRBs by on ground analysis of the INTEGRAL data received at INTEGRAL Science Data Center (ISDC).

Developed by IASF Milano, MPE Garching & ISDC.

Data from IBIS / ISGRI and SPI / ACS.

- GRB rate ~ 1 / month (IBIS / ISGRI)
  ~ 0.5 / day (SPI / ACS)
- Delay ~20 – 30 s



IBAS trigger types:
- POINTDIR for robotic telescopes
- SPIACS detected by the SPI ACS (no position)
- WAKEUP first alert with position information
- REFINED subsequent messages with better info
- OFFLINE results of interactive analysis
- WEAK low significance triggers

Integral approved for 2 more years

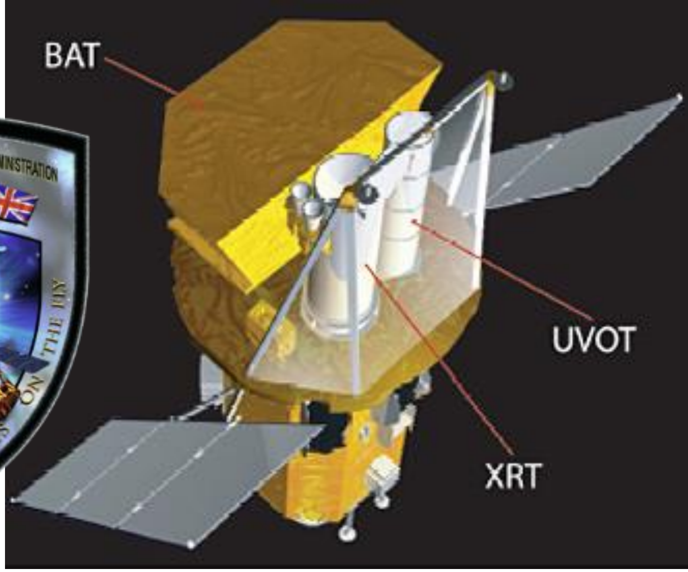
Reentry in Feb 2029

ISGRI:
E = 15 keV ~ 1 MeV
FoV = 29°x29°
Loc = 2 – 3 arcmin

SPI/ACS:
E > 100 keV
FoV ~ 4 pi
Loc: none

Swift: Neil Gehrels Swift Observatory

Launched : 20 November 2004



Multi-wavelength observatory (gamma, X, UV).
Rapid identification and multiwavelength follow-up of gamma-ray bursts (GRBs) and their afterglows.

- ~90 GRBs discovered per year
- <90 s slew: reaction time for onboard follow-up
- 0.5-5 arcsec positions for almost every GRB
- Results publicly distributed within seconds

Rate ~ 90 GRB/yr
Slew in ~1 min
Loc < 5 arcsec

*** Burst Alert Telescope (BAT)**
Coded mask telescope (CdZnTe)
GSFC + LANL (flight software)
Oboard trigger: Count-rate + Image trigger (thresh> 25 keV)

*** X-ray Telescope (XRT)**
After slew: images, spectra & light curves: flaring and long-term decay of afterglow.
XRT built using existing JET-X hardware (MOS CCD)
Penstate, Brera & Uni Leicester

*** UV/Optical Telescope (UVOT)**
Copy of the XMM-Newton Optical Monitor (OM).
Penstate and MSSL.
Images, spectra (via grism) and light curves after slews.

Onbaord fuel (orbit maneuvers) until ~ 2026

BAT: Eff area: 5200 cm^2
E = 15 ~ 150 keV
FoV ~ 2 sr
Loc = 2 – 3 arcmin
Rate > 90 GRB / yr

XRT: Eff area: 120 cm^2 at 1.5 keV
E = 0.3 ~ 10 keV
FoV ~ 23 x 23 arcmin
Loc ~ 5 arcsec
Rate ~ 90 GRB / yr

UVOT: Loc ~ 0.5 arcsec
6 colors: 180-600 nm
→ for brightest UV/optical afterglows, redshift via Lyman-alpha cut-off.

Fermi: Fermi Gamma-ray Space Telescope

Launched : 11 June 2008

Gamma-Ray Large Area Space Telescope (GLAST)
Instruments:

LAT (Large Area Detector)
- 20 MeV – 300 GeV
- Pair conversion telescope (e^+ e^-)
- 18 Si layers (tracker → direction)
- 8 CsI layers (calormieter → energy)

➔ High energy sources (AGN, Pulsars…)

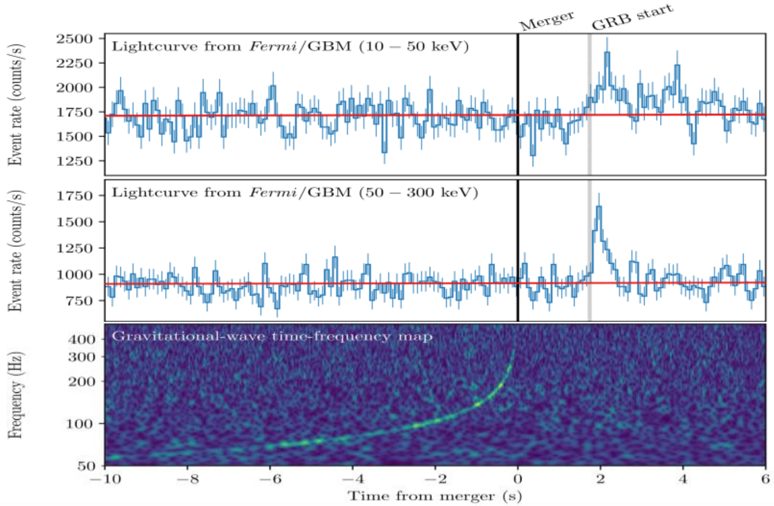
Rate < 1 GRB / month

GBM (GLAST Burst Monitor)
scintiallators: photon energy and time
- 12 NaI (8 keV – 1 MeV, 126 cm^2 each, FoV~2pi)
- 2 BGO (150 keV – 30 MeV)

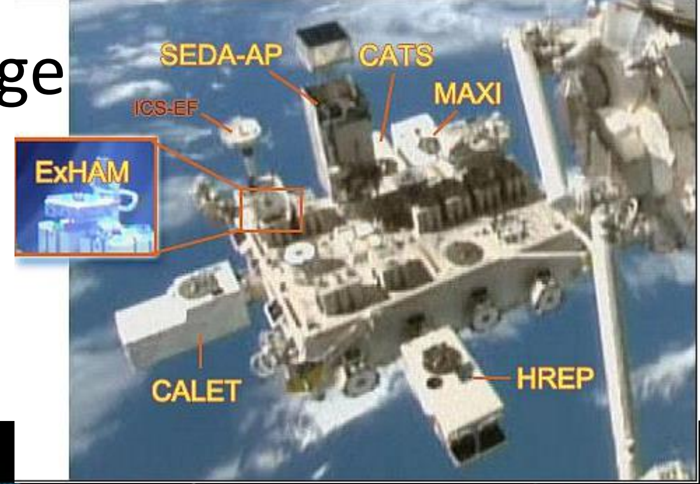
➔ Transient events, variable sources

Rate ~ 240 GRB / yr
Loc > 3 ~ 15° (det ratios)

<u>GBM On-board trigger</u> (count-rate increase),
- different time scales, threshold > ~50 keV
- Alerts via TDRSS to GCN (~30 s delay)
- some Spacecraft slew for LAT.

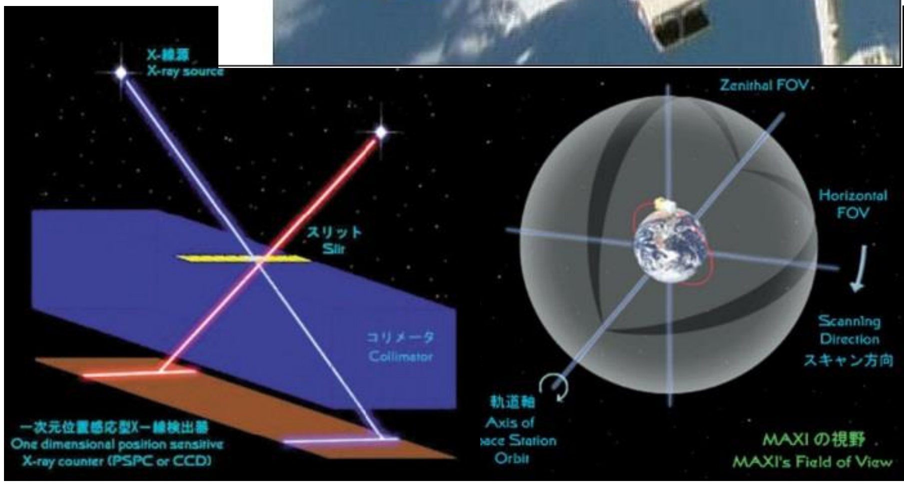


Maxi : Monitor of All-sky X-ray Image



Launched : August 2009, installed on ISS/JEM

All-sky X-ray scanner: sensitive X-ray slit cameras

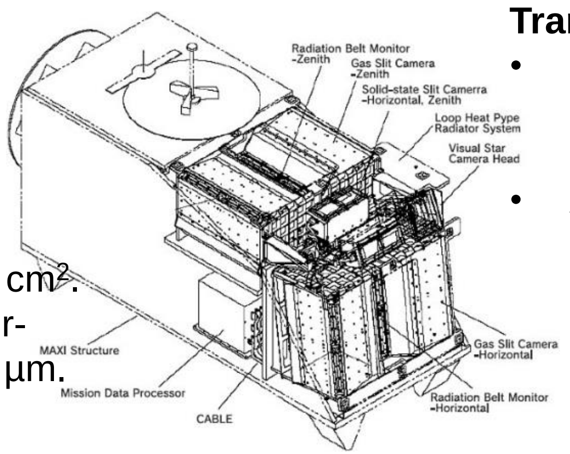


MAXI monitors the X-ray variability once every 96 minutes for more than 1,000 X-ray sources covering entire sky on time scales from a day to a few months.

Overview

- Slit camera ~2% of sky at once.
- E = 0.5 ~ 30 keV
- 1D X-ray detector : determine 1 direction of source
- Motion of ISS: other position when source in FoV.
- ISS orbit every 96 min = 1 full sky scan.

Gas Slit Camera (GSC)
<u>12 gas proportional counters</u>, total 500 cm^2, 2-30 keV, 1D position: 10µm anodes.
Solid-state Slit Camera (SSC)
<u>2 cameras</u>. 16 CCD chips per camera, total 200 cm^2. CCD: X-ray 0.5 to 10 keV, made in Japan, peltier-cooled, 1024x1024 pixels per CCD, pixel:24x24 µm.

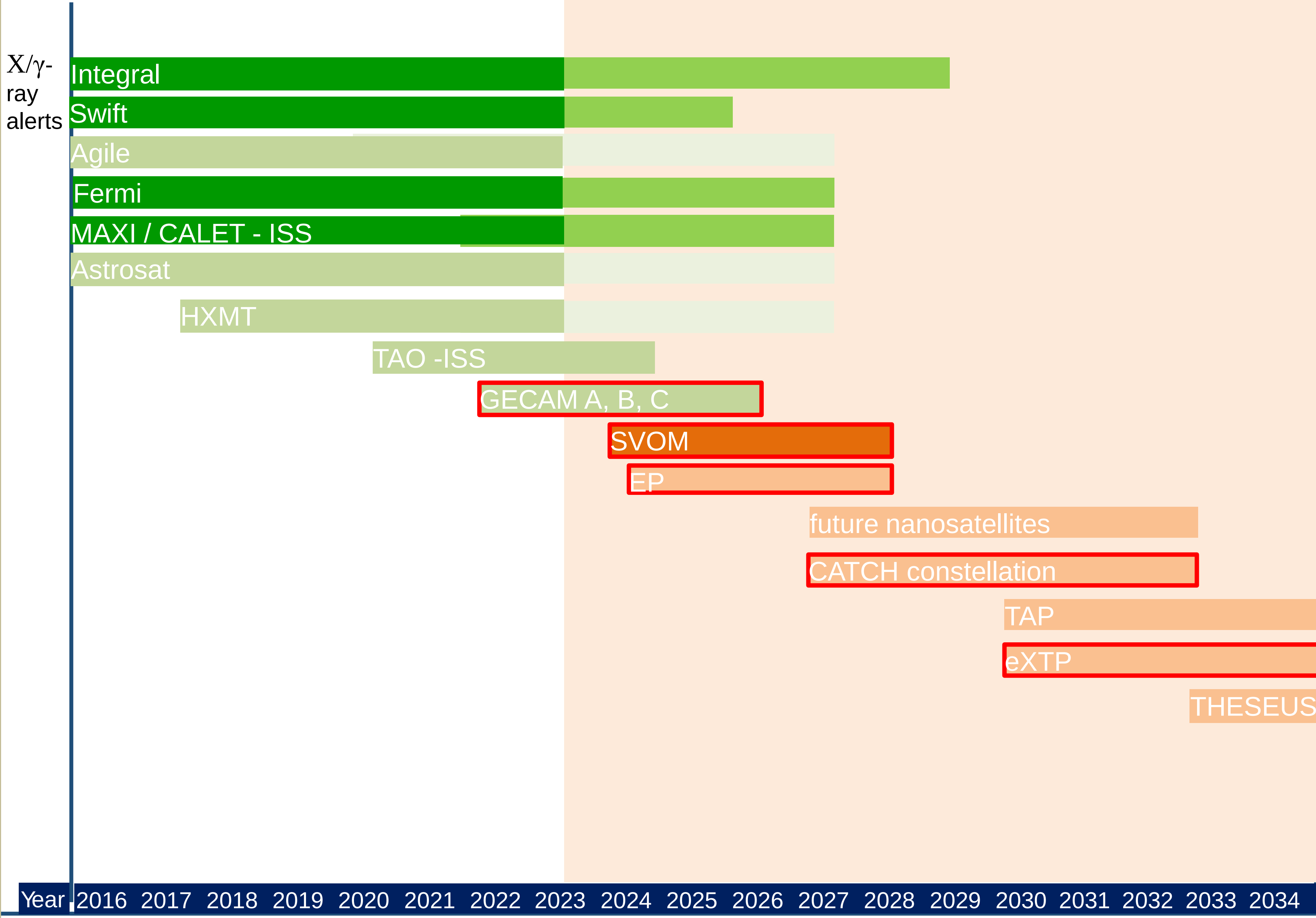


Transient X-ray sources

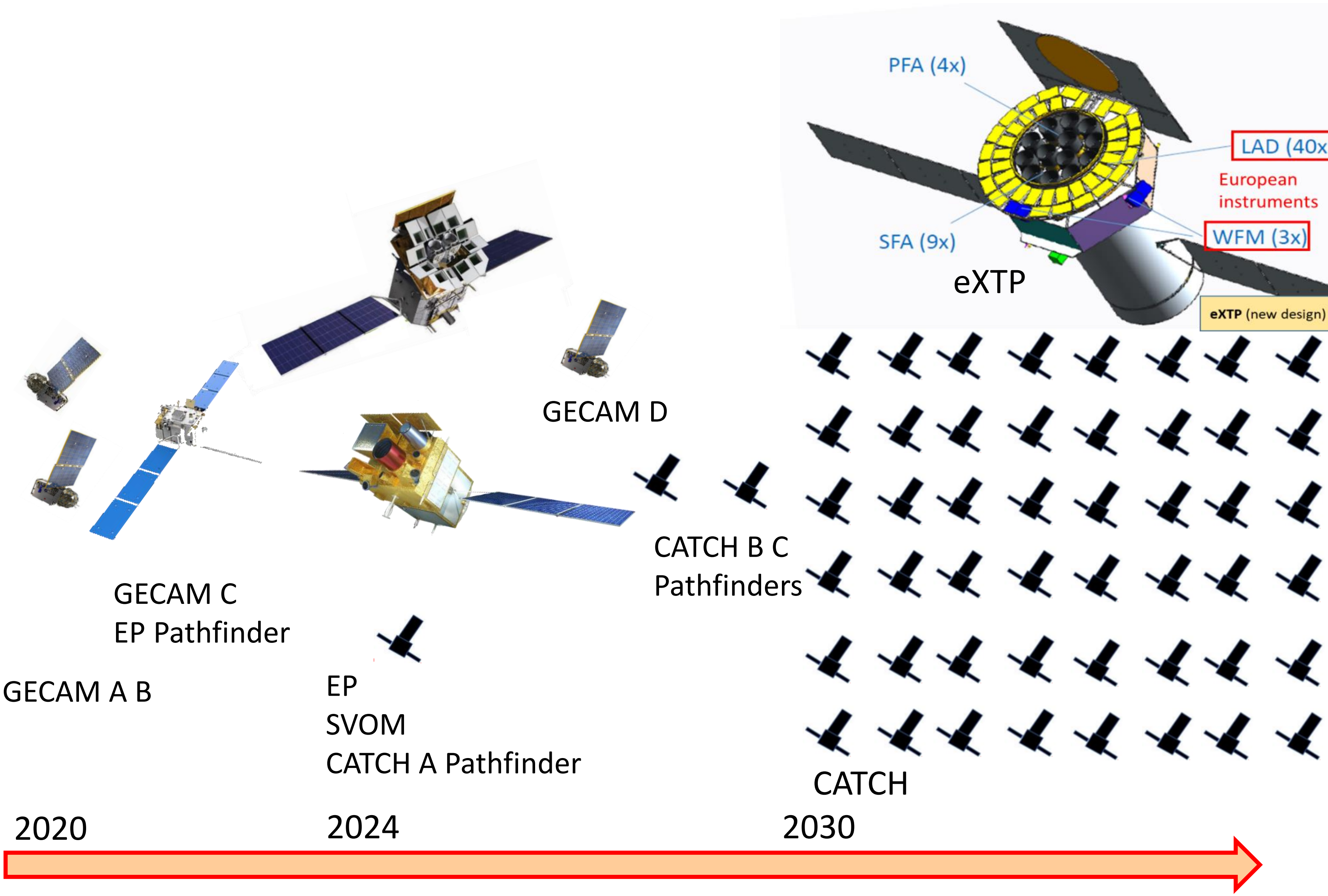
- Ground detection (30 s delay when real-time ISS link available, ~16 h/day)
- Alerts on GCN (Position and detection confidence in the notices, Spectrum in circulars)

Loc ~< 10 arcmin

Main missions with GRB alerts: present and future



A large fleet of X-ray missions planned by China



Projects planned and developped by the Chinese Accademy of Sciences (CAS)

SVOM mission

(Space based Variable Objects Monitor)

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 (IAMC/SECM)
- 950 kg, 450 kg payload
- 2 Cn + 2 Fr instruments

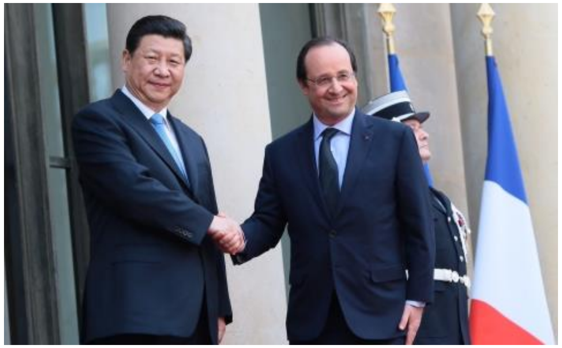
Launch:
- Foreseen beg 2024
- Launcher: LM-2C
- Site: Xichang, China
- Orbit: LEO, 620 km, 30°

Operations:
- 3 yr (+ 2 yr extension)

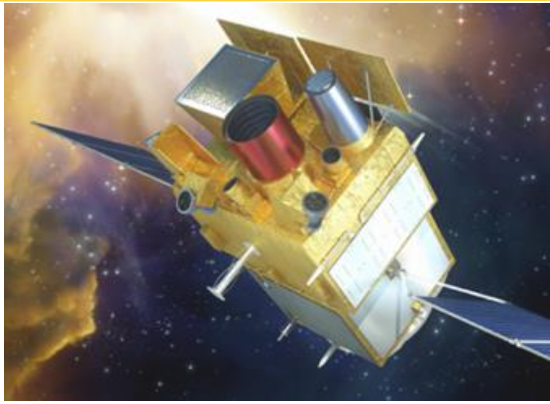
SVOM past milestones

- 2006/03, Toulouse — Phase 0 kick-off
- 2007/03, Xi'an — Phase A kick-off
- 2008/10, Beijing — PRR

- 2013/10, Shanghai — Delta PRR (new configuration)
- 2014/04 presidents Xi Jinping and François Hollande:
  Common statement: « *Poursuivre la coopération franco-chinoise sur les projets CFOSat et SVOM* »
- 2014/09, Shanghai — Phase B kick-off
- 2016/07, Yantai — PDR
- 2017/01, Sanya — Phase C kick-off
- 2020/07, Videoconf — CDR
- 2020/07, Videoconf — Phase D kick-off



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

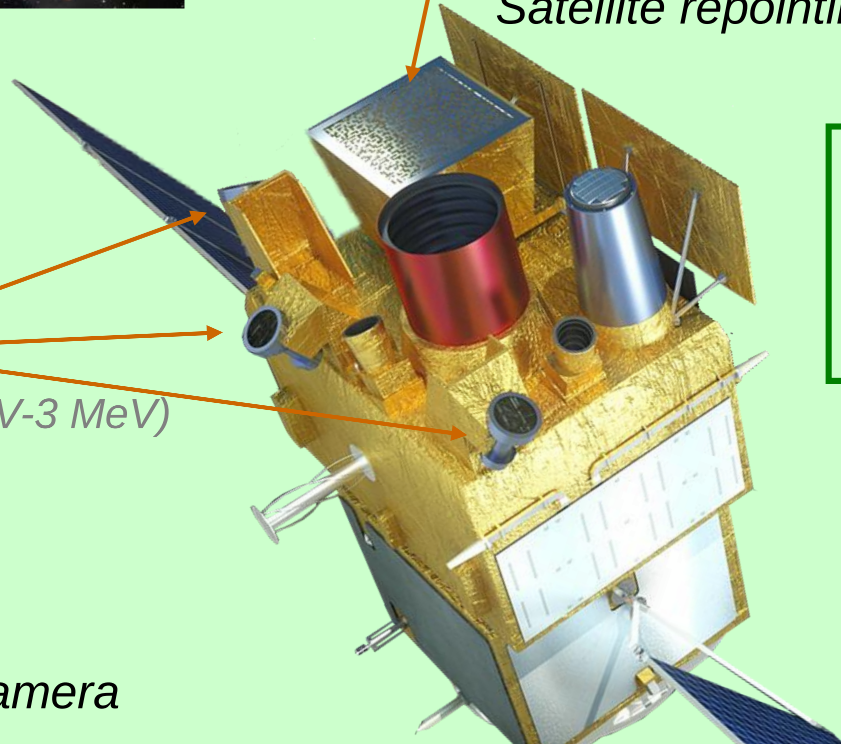
SVOM mission overview

Space-based Variable Objects Monitor

Prompt, Large FoV

ECLAIRs *french*

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



SVOM GRB Trigger

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

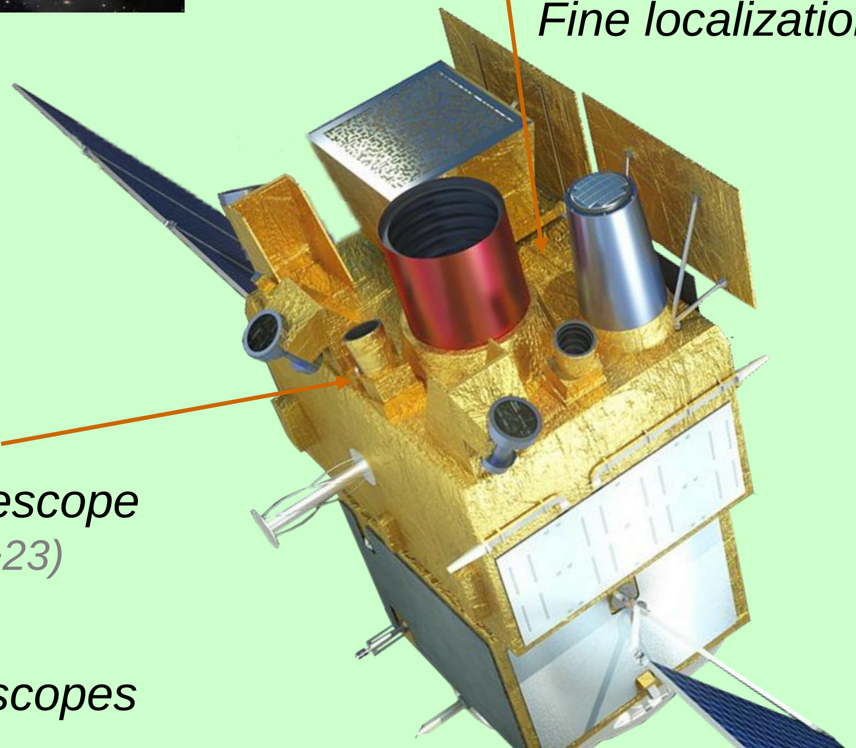
GWAC *chinese*
Ground wide angle camera

SVOM mission overview

Space-based Variable Objects Monitor

Delayed, Narrow FoV

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

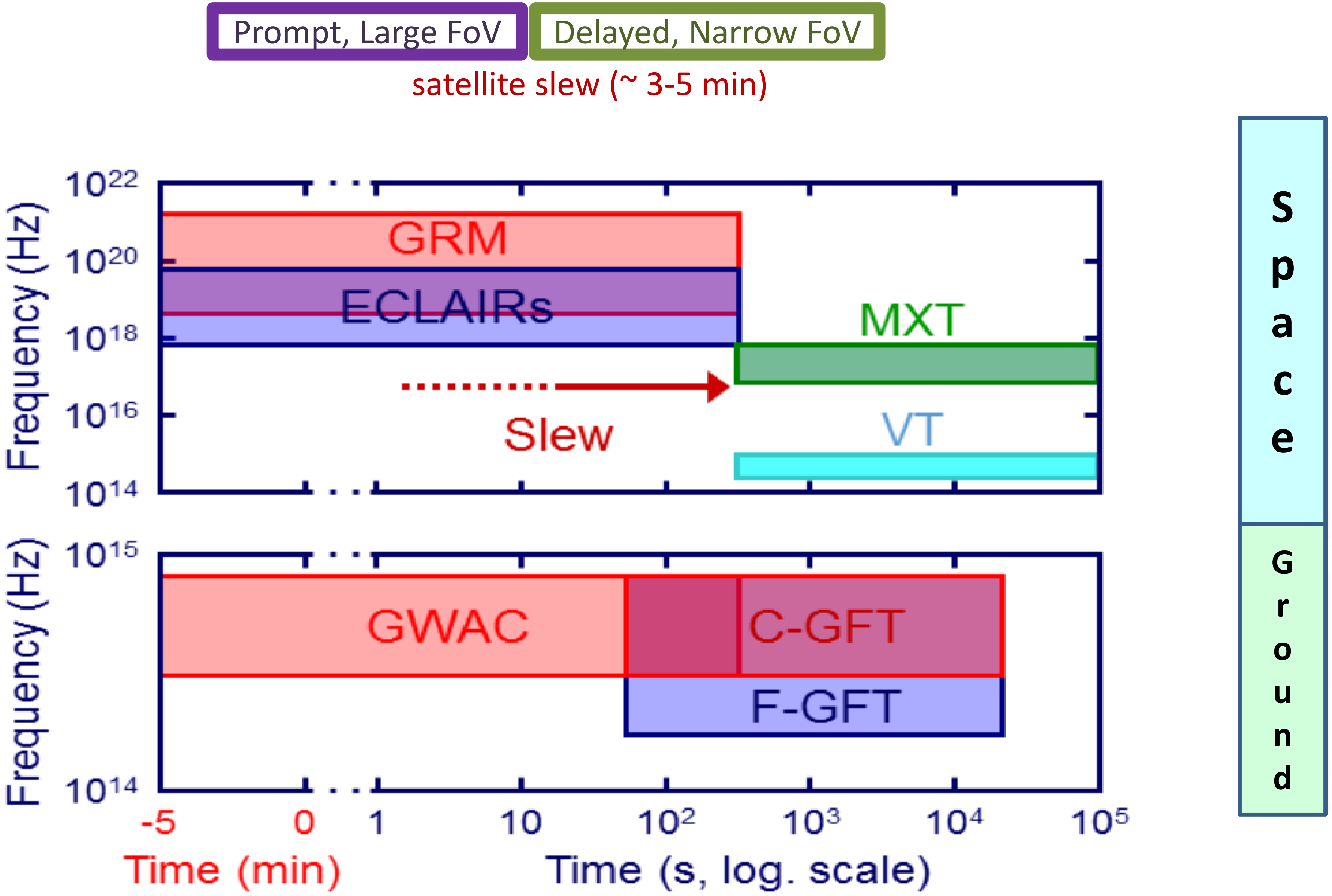


VT *chinese*
Visible Télescope
(magnitude~23)

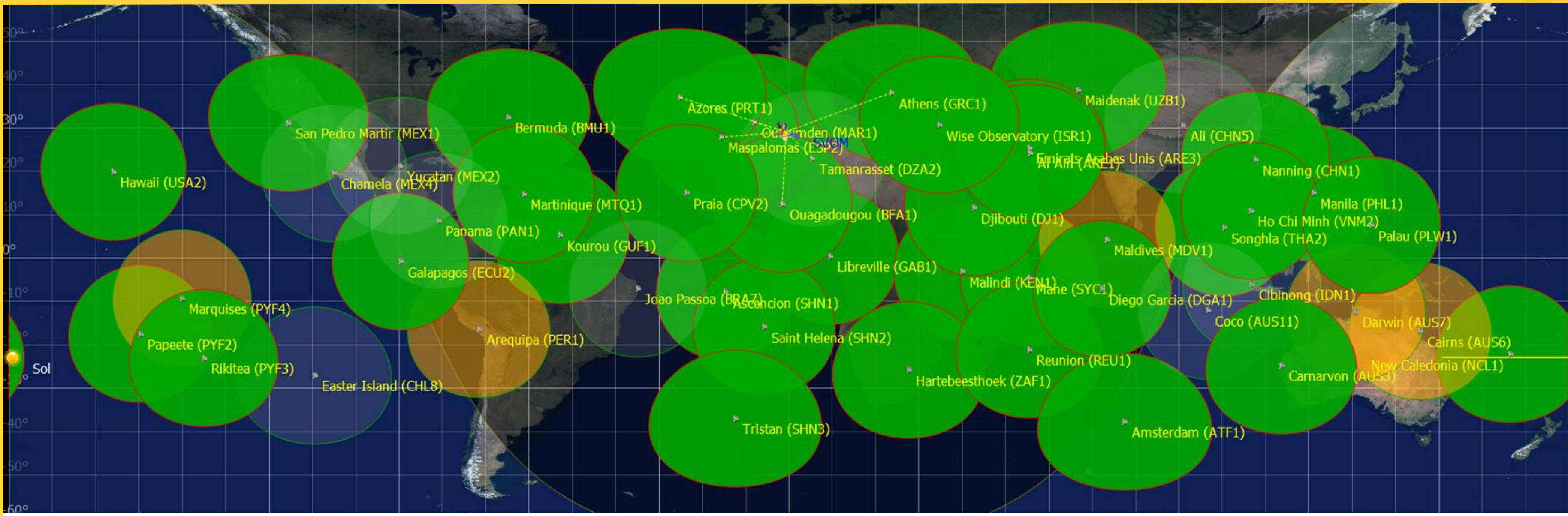
GFT *french + chinese*
Ground folow-up telescopes

SVOM satellite and instruments

SVOM temporal and spectral coverage



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

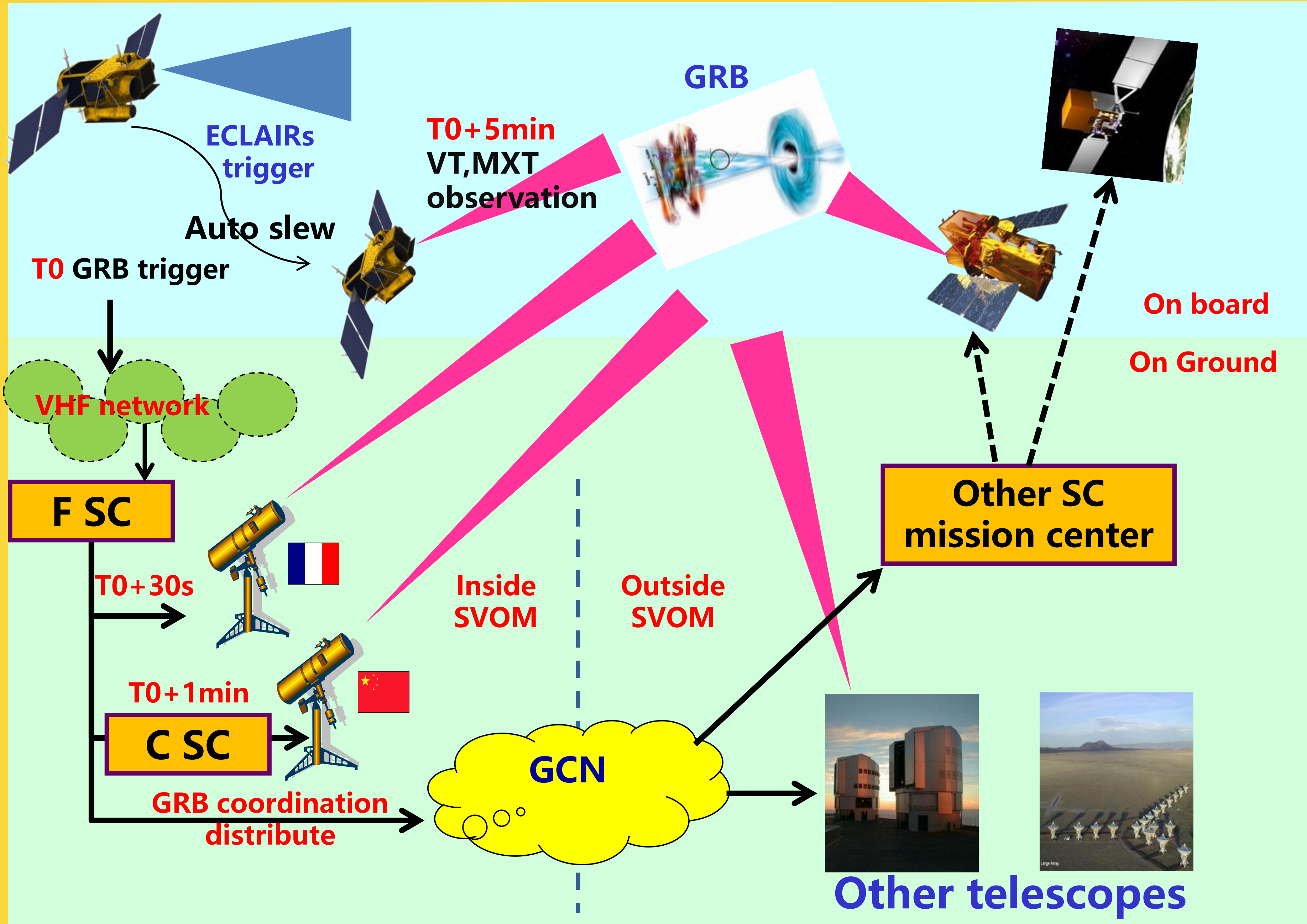
- Transmission of low-bandwidth data (~ 300 bit/s, 1 pkt/2s):
  Alerts, Light-Curves, SubImages, Recurrent msgs (from ECLAIRs, GRM) and post-slew information from MXT and VT + msg repetitions
- Goal: 65% received within 30 s at the French Science Center

- 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 VHF network

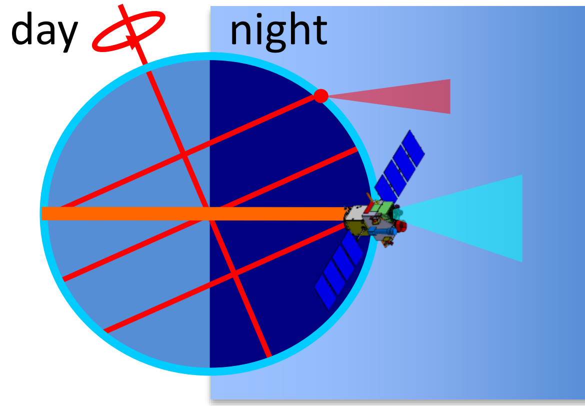
GRB observation scenario



SVOM pointing strategy

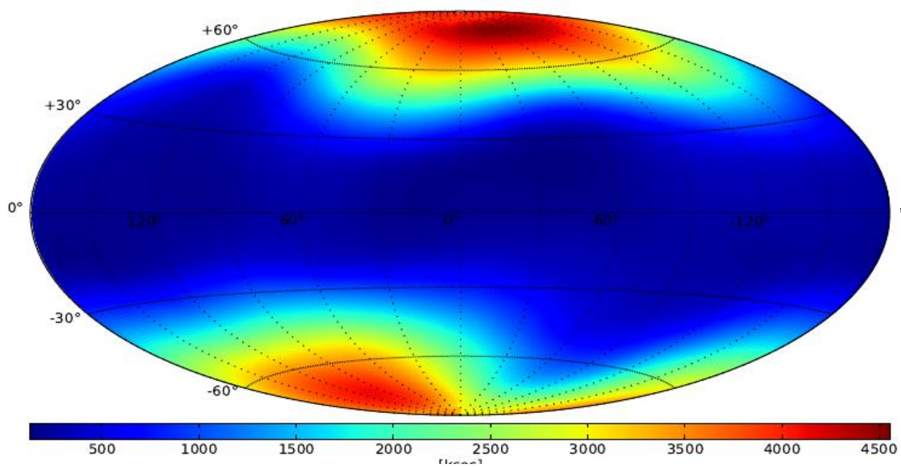
Optimized ground follow-up of GRB candidates:

- 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

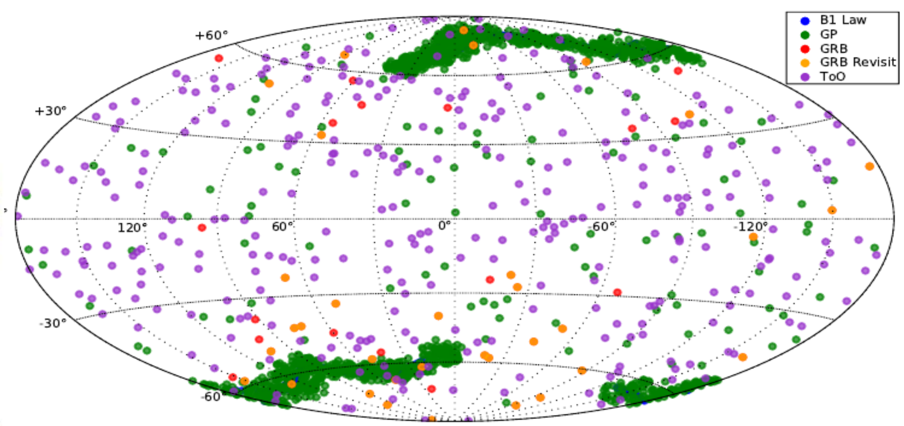


Galactic plane and intense source Sco X-1 avoided in the ECLAIRs FoV (most of the time during the nominal mission)

- 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)

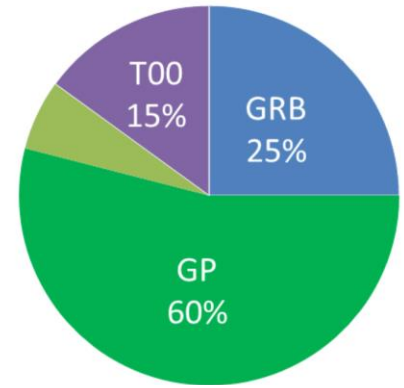
- Observation proposals selected by a Time Alloc. Committee (a SVOM Co-I needs to be part of your proposal) for targets of interest mostly compliant with pointing law.

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)

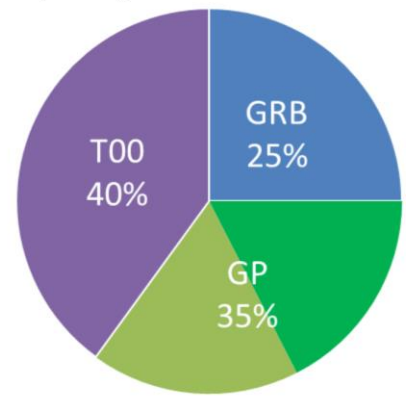
Nominal mission (3 years)

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.

Data policy:

- CP and ToO data products: immediately public (positions, spectral, lightcurves…)
- GP data products: contact a SVOM Co-I to participate to data analysis of photon data

SVOM instruments

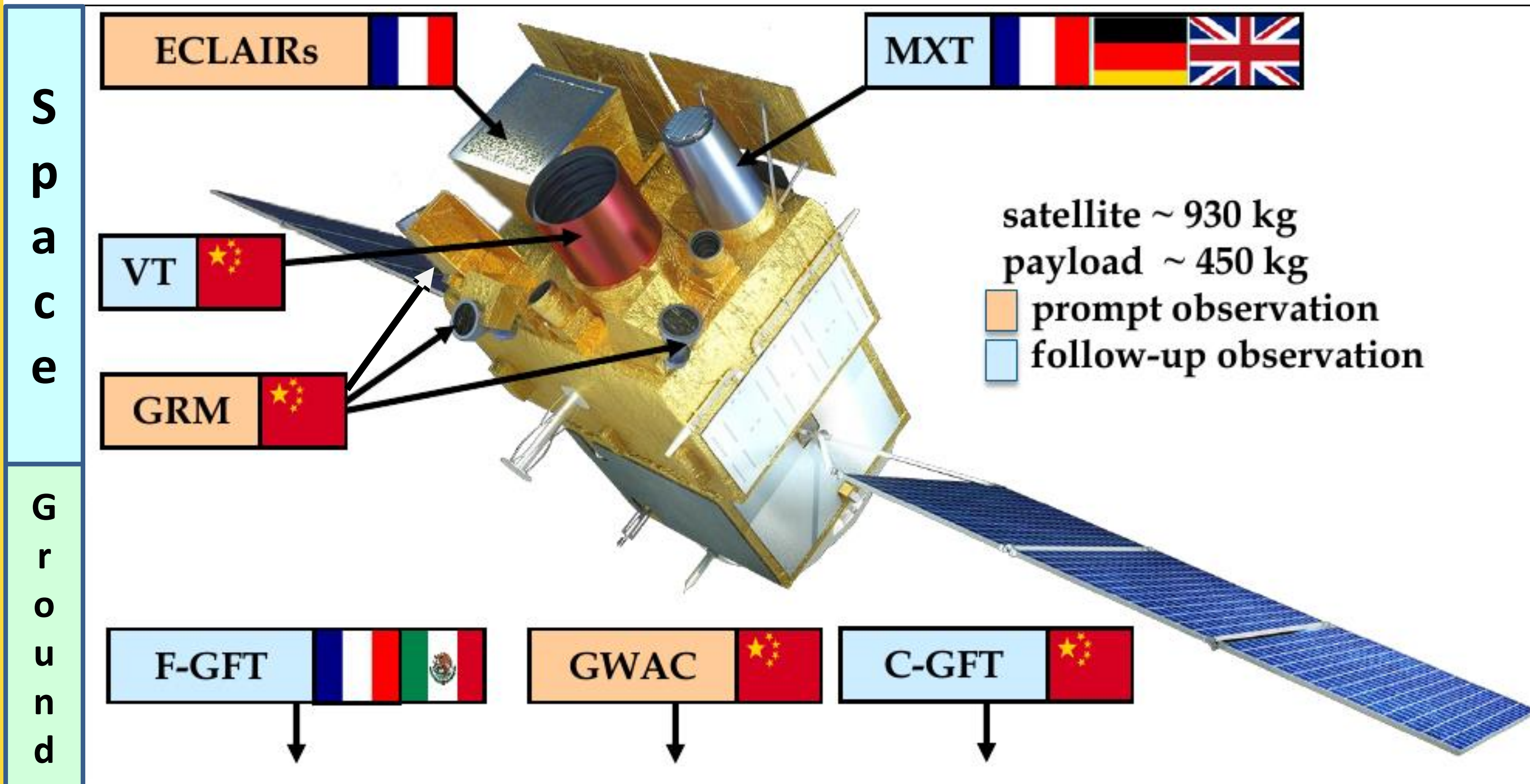
SVOM instruments

4 space instruments:

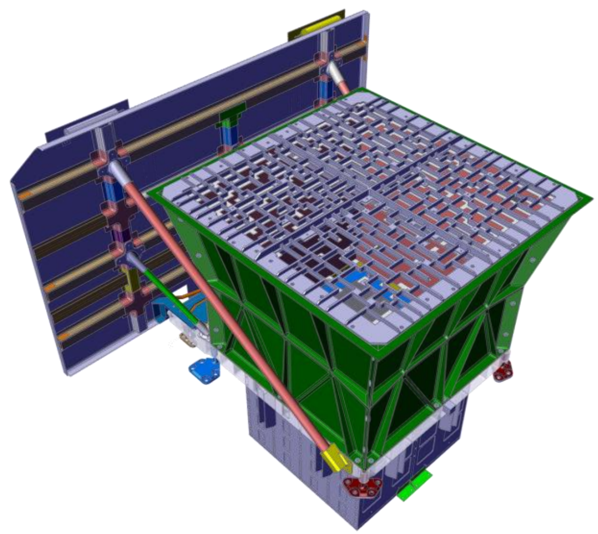
- ECLAIRs gamma-ray imager & trigger
- GRM gamma-ray monitor
- MXT X-ray focusing telescope
- VT visible band telescope

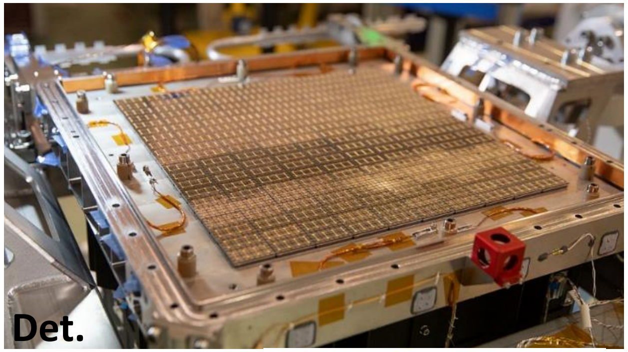
3 ground telescopes

- GWAC ground wide angle camera
- F-GFT & C-GFT: ground follow-up telescopes



ECLAIRs imager & trigger instrument

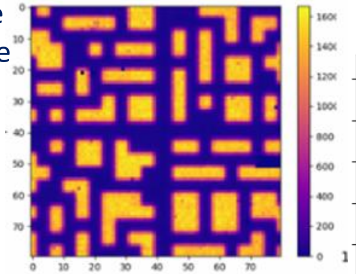


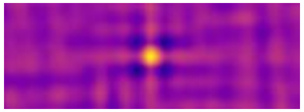


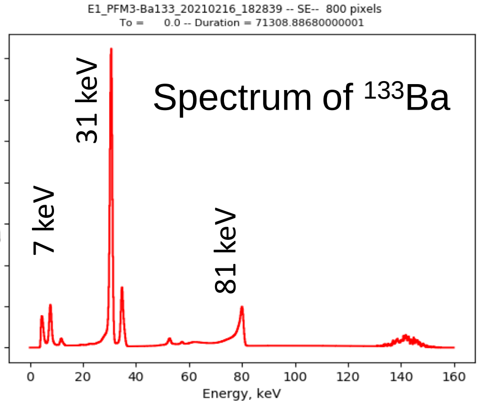
ECLAIRs (CNES, IRAP, CEA, APC)

- Allocation ~ 90kg, 90W
- Detection plane (IRAP): **1000 cm²**
- **6400 CdTe pixels** (4x4x1 mm^3)
- **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



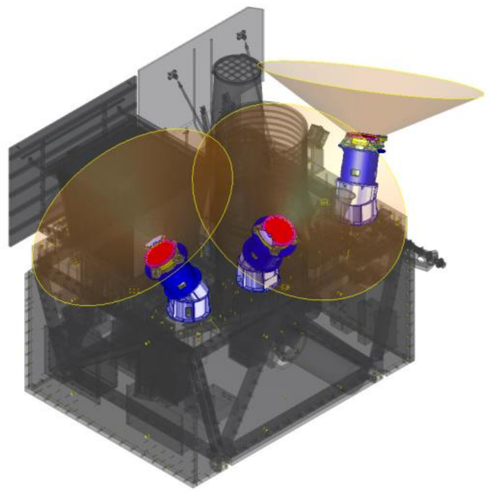


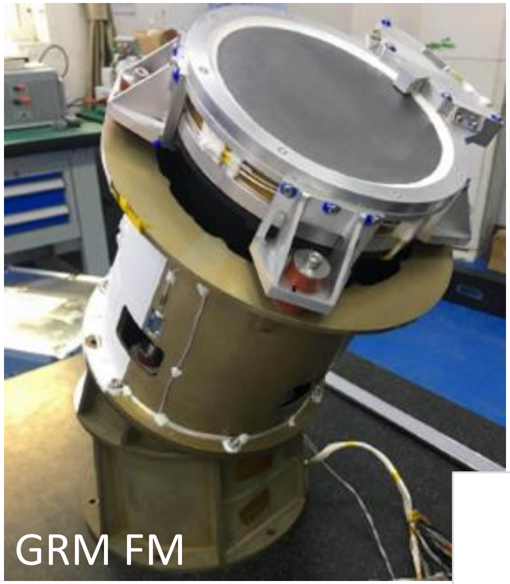


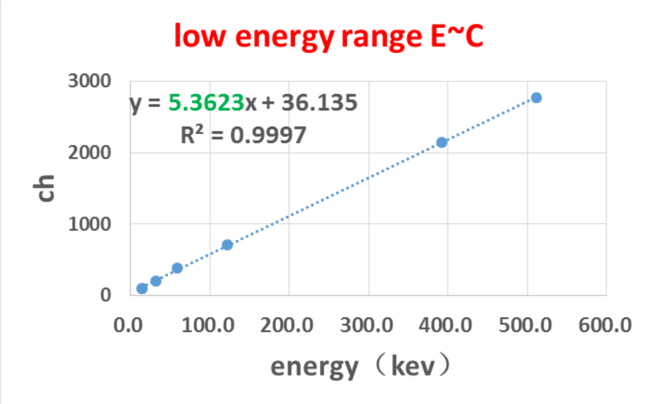
Well suited to detect and localise GRBs with low E$_{PEAK}$

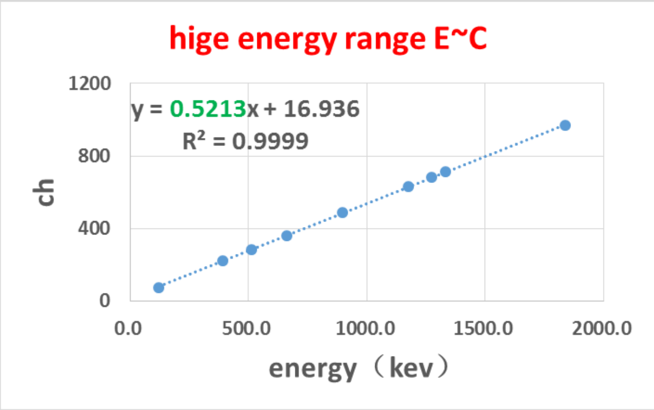
<u>FM completed and tested</u>

GRM instrument







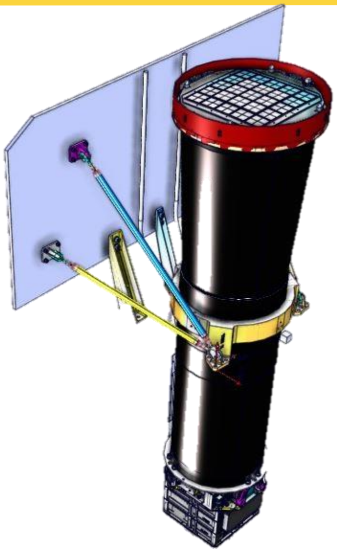


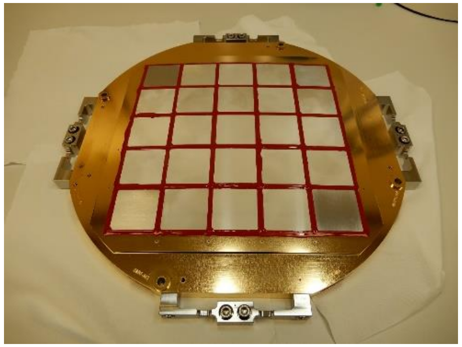
GRM Gamma-Ray Monitor (IHEP)

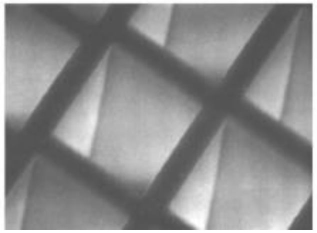
- **3 Gamma-Ray Detectors** (GRDs)
- **NaI(Tl)** (16 cm Ø, 1.5 cm thick)
- Plastic scintillator (6 mm) to monitor particle flux and reject particle events
- **FoV: 2 sr per GRD, 5.6 sr in total**
- **Energy range: 15-5000 keV**
- **Aeff = 190 cm²** (at peak, for each GRD)
- Crude localization accuracy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

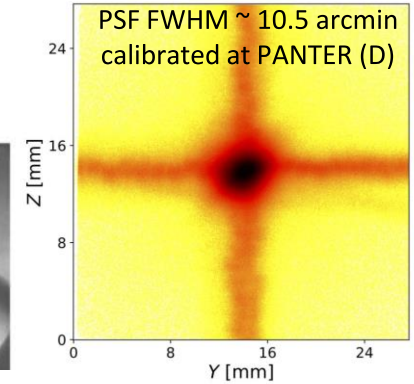
Suited to detect short & long GRBs
and measure E_{PEAK} for most ECLAIRs GRBs

MXT instrument



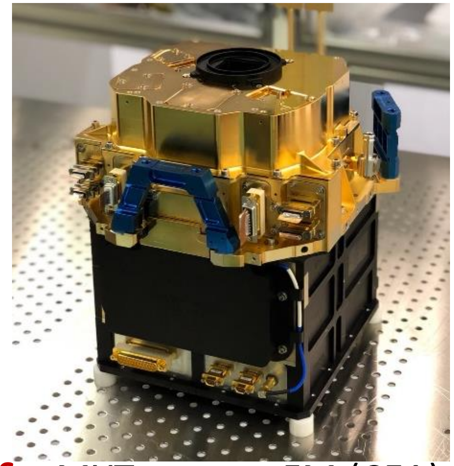






MXT Micro-chan. X-ray (CNES, CEA, IJCL, UL, MPE)

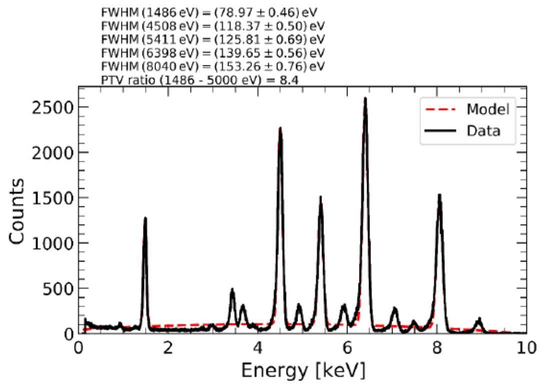
- **Micro-pores optics** (Photonis)
  square 40 µm pores (UL design)
- pnCCD (MPE) based camera (CEA)→
- **FoV: 57x57 arcmin²**
- Focal length: 1.15 m
- **Energy range: 0.2 - 10 keV**
- Energy resolution: ~80 eV @ 1.5 keV
- Aeff = 30 cm² @ 1.5 keV (central spot)
- **Localization accuracy** < 30 arcsec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



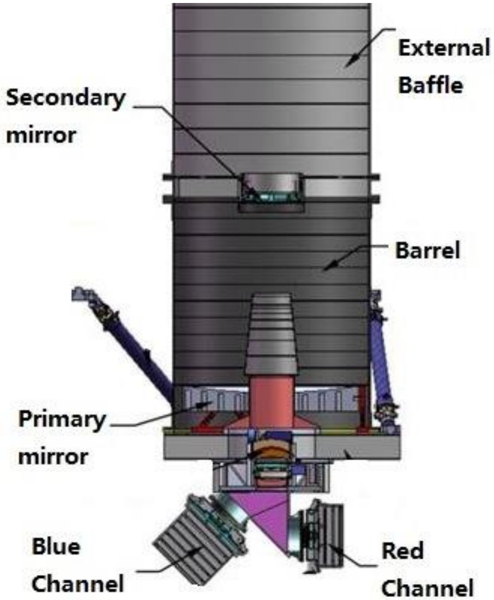
MXT camera FM (CEA)

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

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



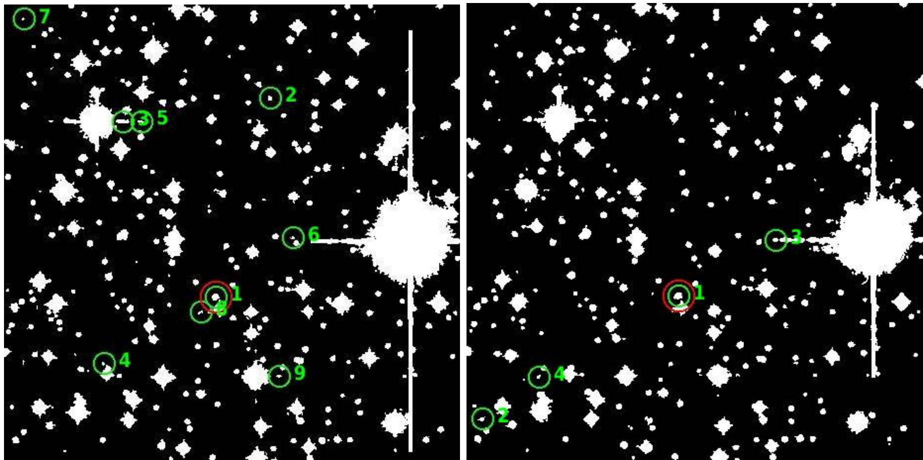
VT instrument



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"

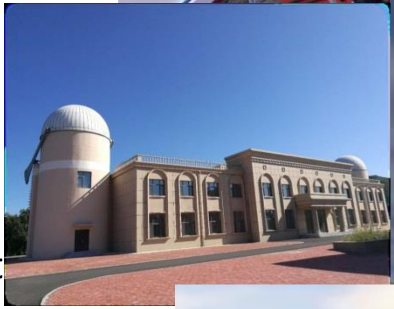
SVOM ground based instruments

Ground-based Wide Angle Camera GWAC (NAOC)

- Explore the prompt optical emission (500-800 nm), 2 sites:
  - **In China (Xinglong obs)**: 40 cameras of 180 mm diameter
    - **total FOV ~6000 deg²** ; limiting magnitude 16 (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 + O4 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 photomet (400-1700 nm, 3 simultaneous bands)
- Accurate GRB localization → observations with large telescopes



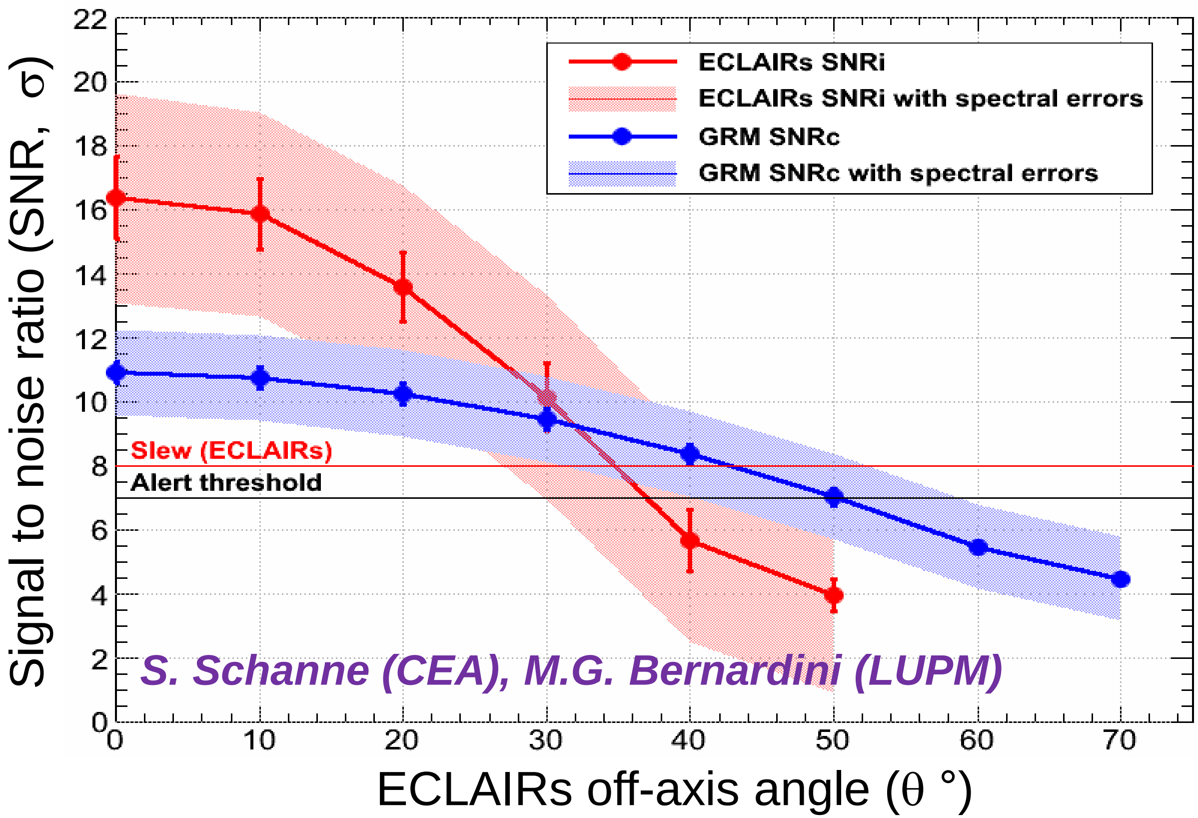
Agreement to use the LCOGT network (12x1m+2x2m tel.)

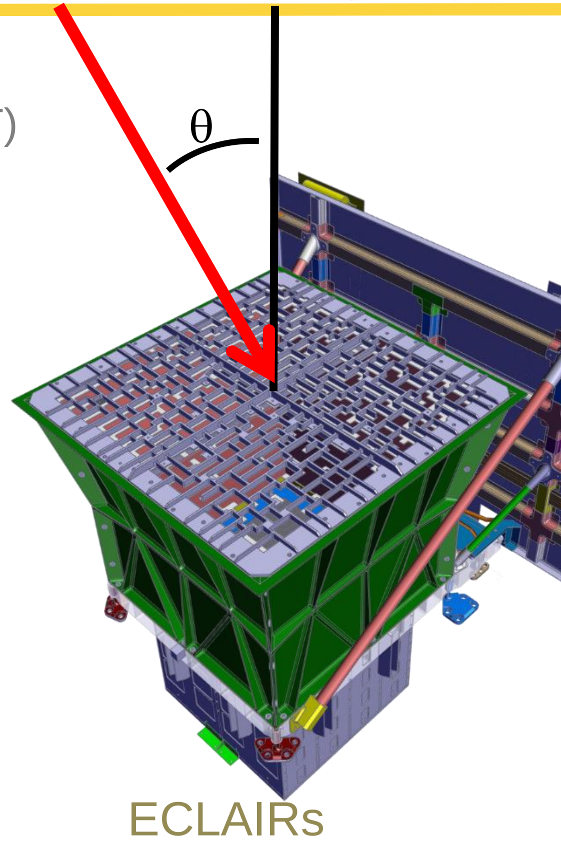
75% of ECLAIRs-detected GRBs immediately visible by a GFT
Large telescopes follow-up favored by pointing law
→ redshift expected in 65% of cases

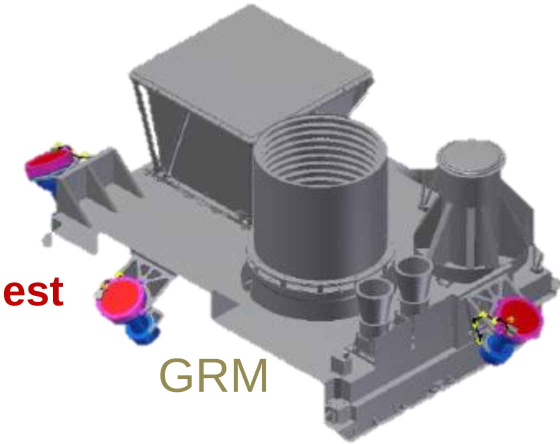
GRB 170817A in ECLAIRs & GRM

Simulation of event (counts+background)

Parameters of Fermi-GBM (public GCN 2017/8/17 10:00 GMT)







➔ **Up to 11°: detection, localization < 6 arcmin (90%)**
detectable up to 1.5 × distance (60 Mpc)

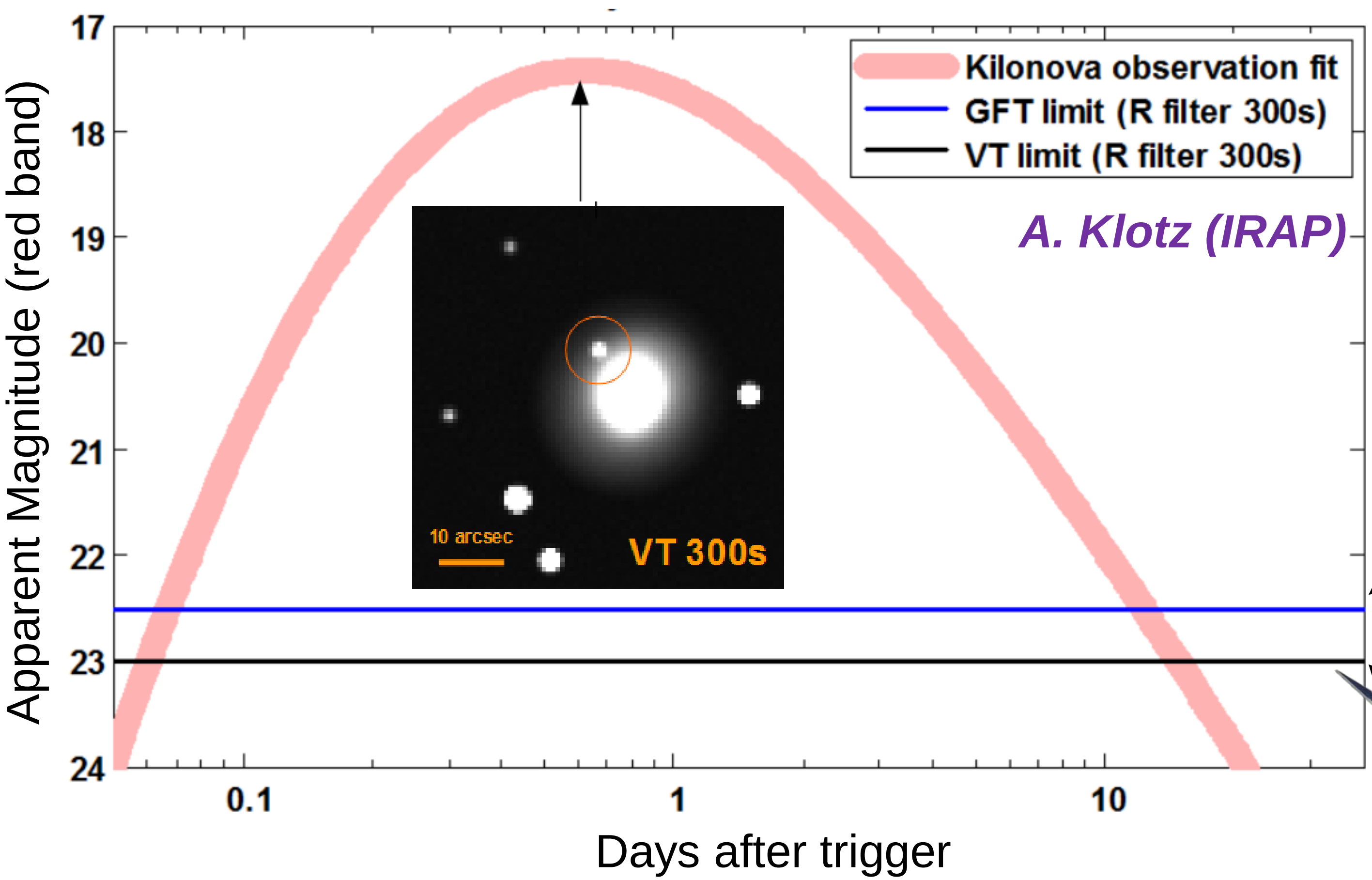
➔ **Up to 35°: ECLAIRs alert to ground (good loc.) + slew request**

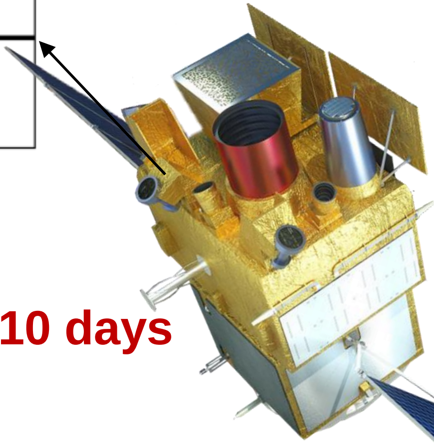
➔ **Up to 50°: GRM alert to ground (crude loc.)**

GRB 170817A in VT & GFT

Simulation of the event (counts+background)

Parameters of the kilonova in NGC 4993





➔ **VT and GFT can observe the kilonova from beginning to 10 days**

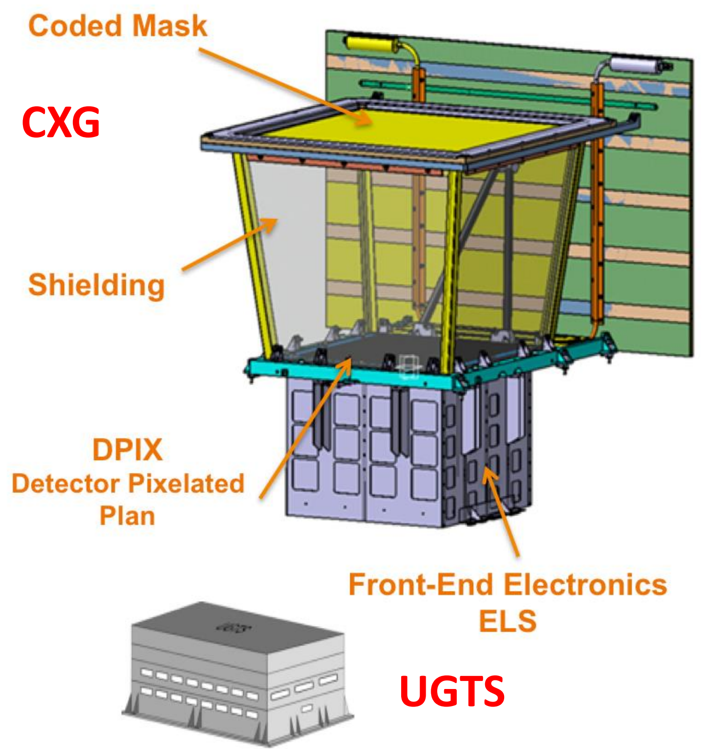
➔ **In case of no ECLAIRs detection: SVOM ToO within 1 day**

ECLAIRs camera

ECLAIRs : design & performance

- **ECLAIRs design:**
  - coded-mask imager made of a detection plane with 6400 CdTe detectors
  - located behind a coded mask of Tantalum
  - 80 cm high, surface of 60×60 cm (without its radiator), weight ~80 kg.
- **ECLAIRs performances include:**
  - energy range extending down to 4 keV (for soft and highly redshifted GRBs)
  - capability to detect and localize GRBs autonomously over timescales from 10 ms to 20 min with count-rate and image triggers
  - transmission of all the photons to the ground, allowing detailed offline analysis of the transient hard X-ray sky.

Energy range	4 – 150 keV
Detecting area	~1000 cm^2
Detectors	6400 CdTe (200 modules)
Mask open fraction	40%
Effective area in 10-70 keV	≥340 cm^2
Effective area @ 6 keV	≥200 cm^2
Field of view	2.06 sr total
Sensitivity (1 s, 5-50 keV)	2.5 10^{-8} erg cm^{-2} s^{-1}
Localization accuracy	11.5 arcmin (at SNR=8)
Energy resolution at 60 keV	< 1.6 keV
Time resolution	20 μs
Dead time	<5% for 10^5 cts/s
Data rate	≤18 Gb/day

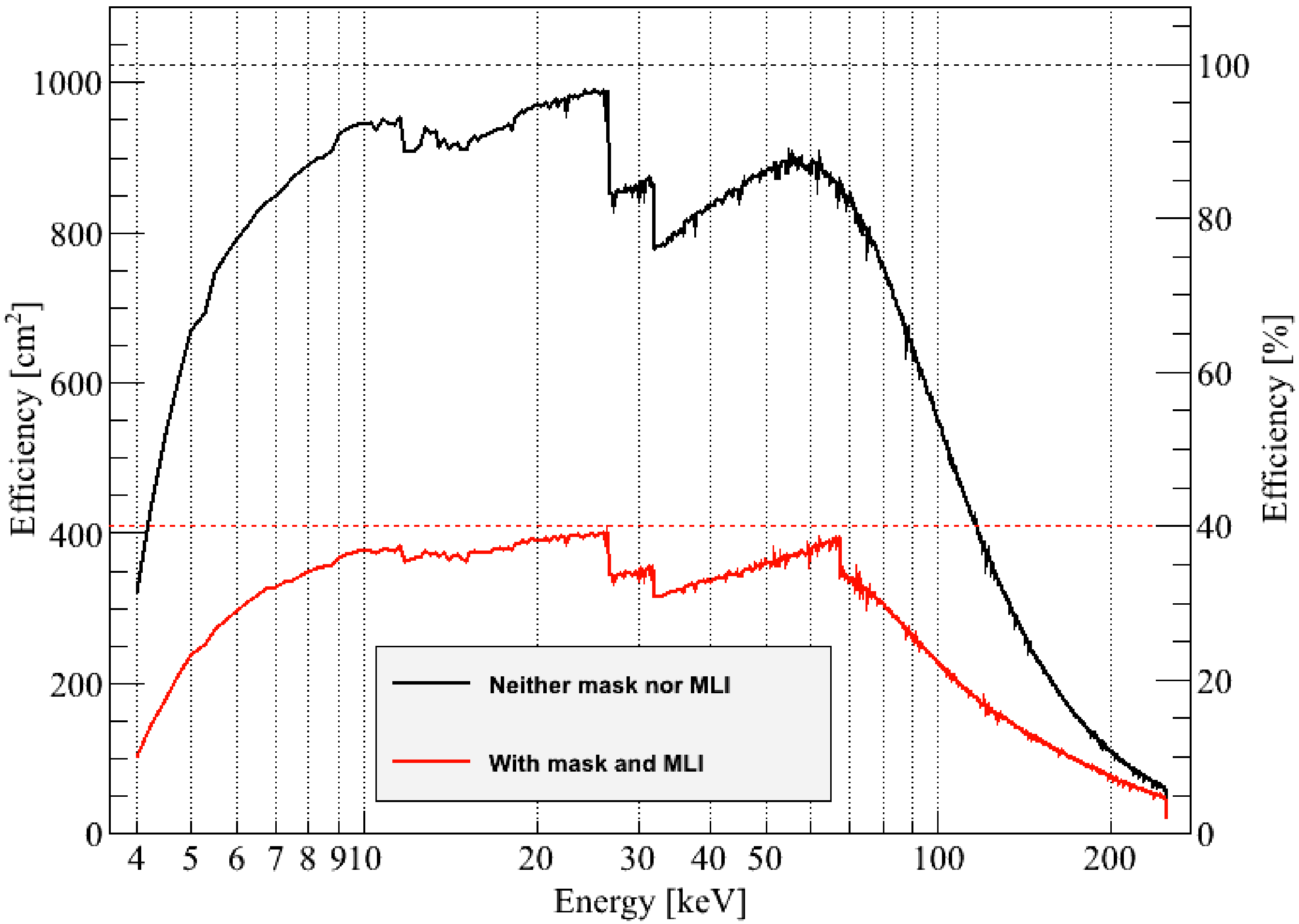


ECLAIRs : effective area (simulation)

- **Response of the instrument**

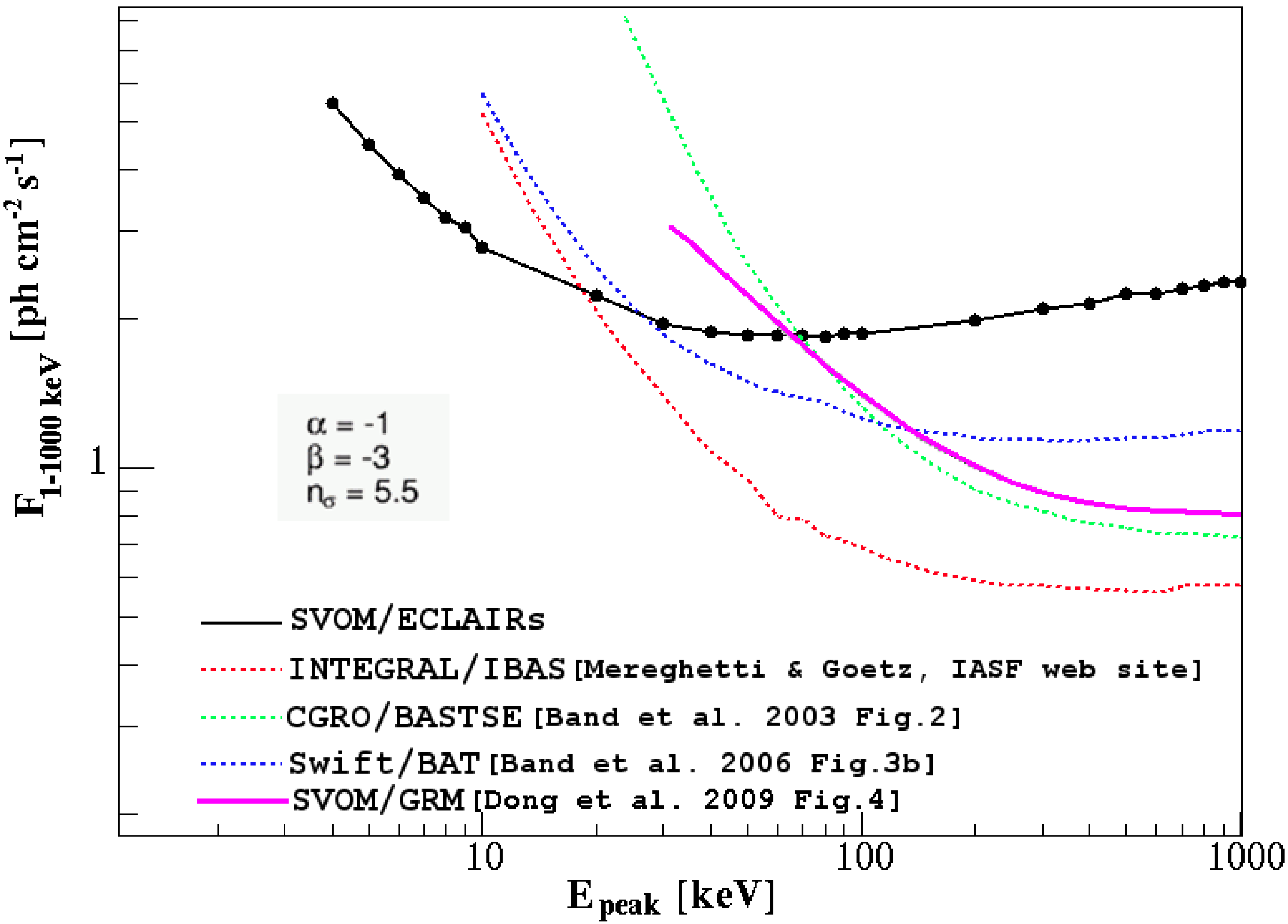
simulated with Monte Carlo Geant-4 P. Sizun (CEA)

→ effective area of the instrument



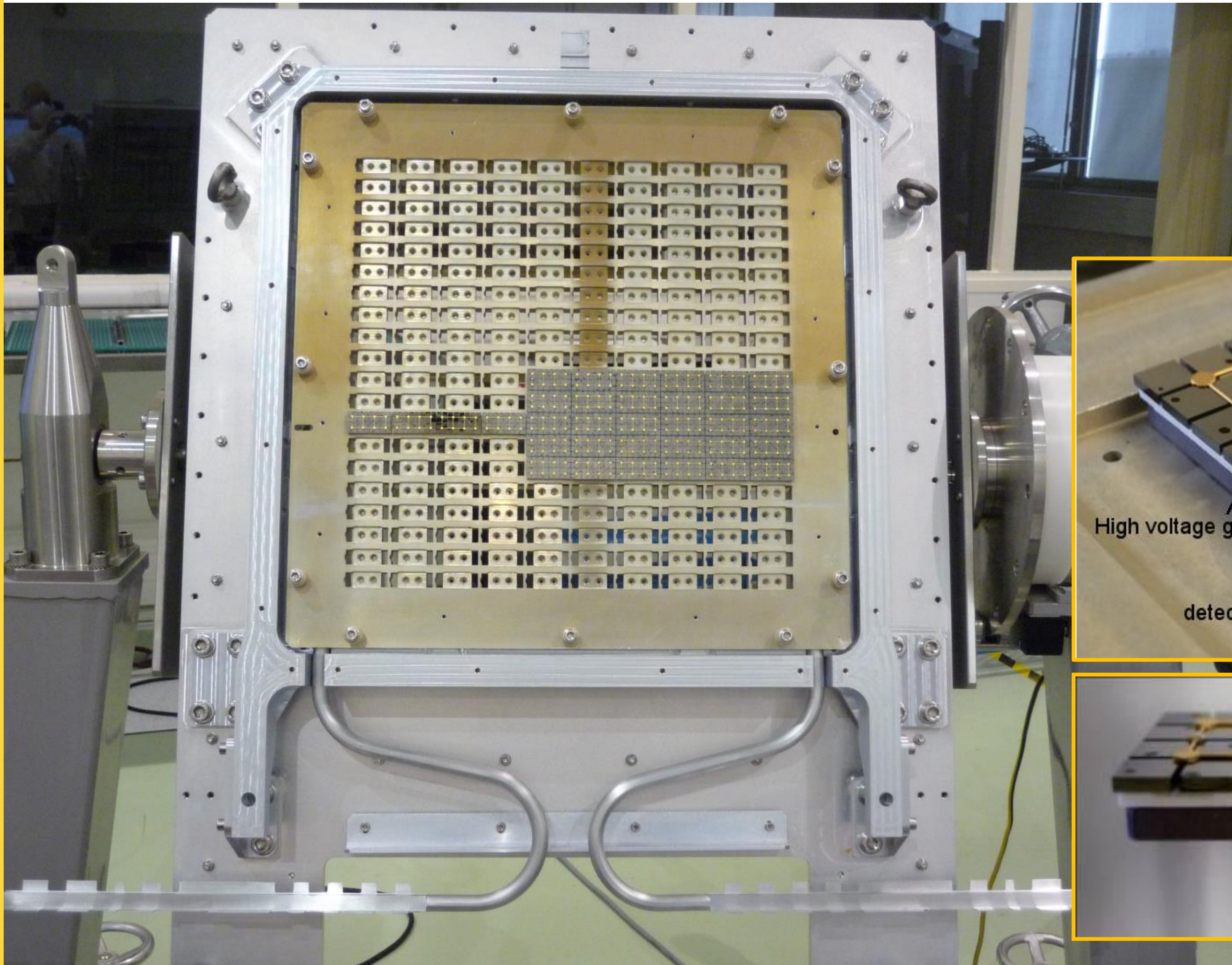
ECLAIRs : detection limit (peak flux)

Limit in the 1 s Peak flux (in 1-1000 keV range) vs Epeak

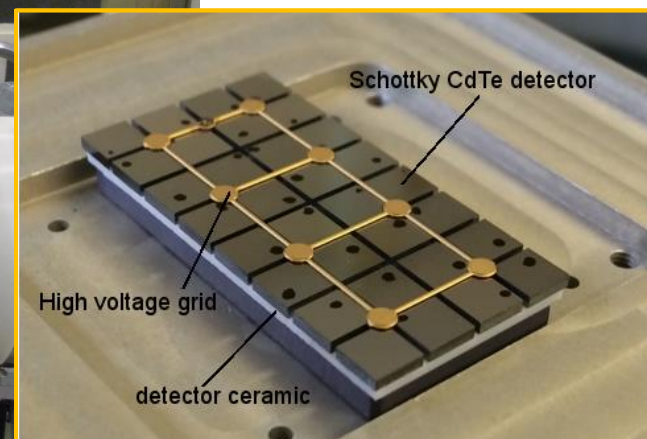


ECLAIRs: detection plane prototype

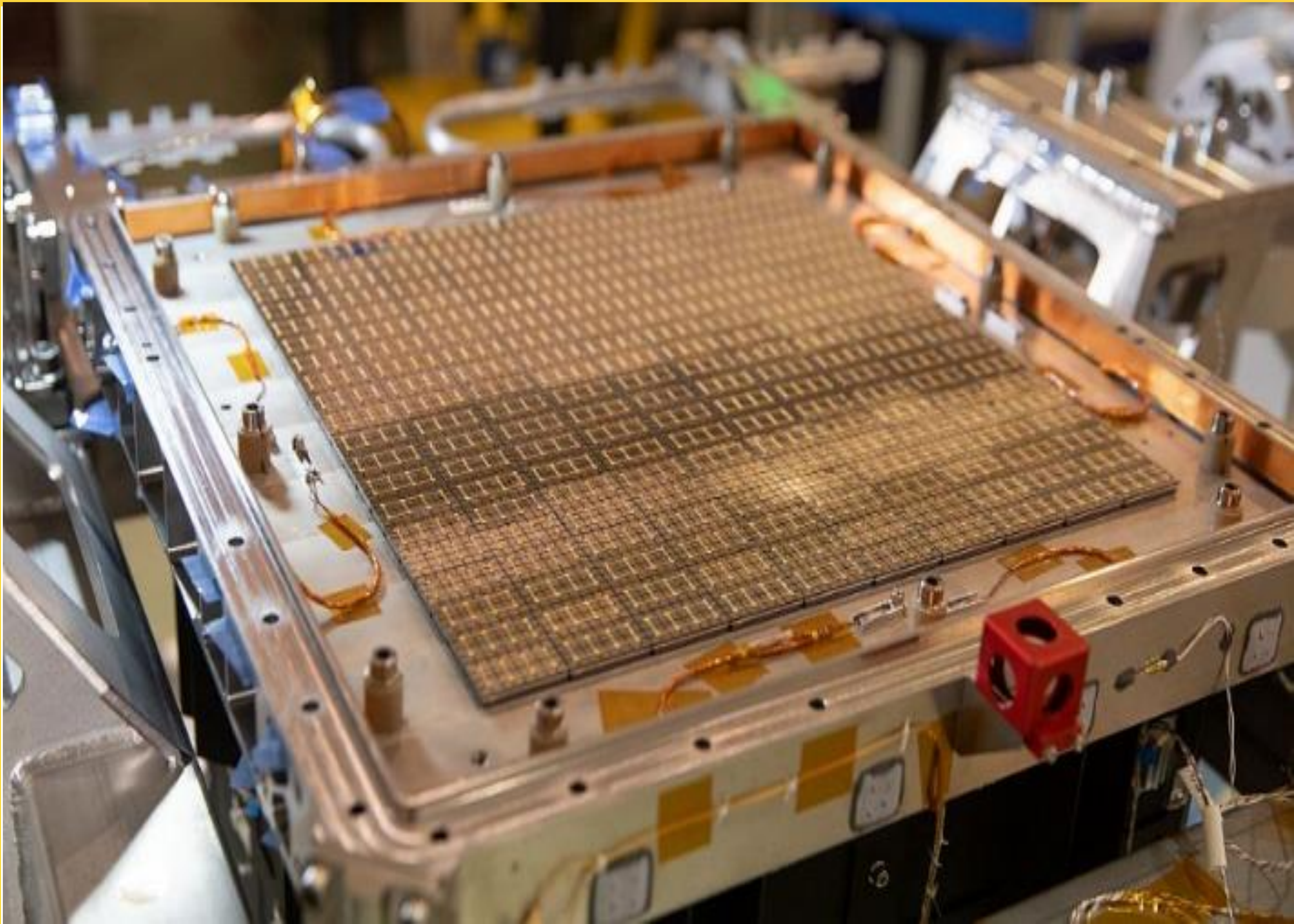
– 6400 active detectors of CdTe (shown: 960 out of 6400)
– arranged in 200 modules of 32 pixels each (shown: 30 modules)



One detector module (of 32 pixels, read-out by 1 IDeF-X ASIC)



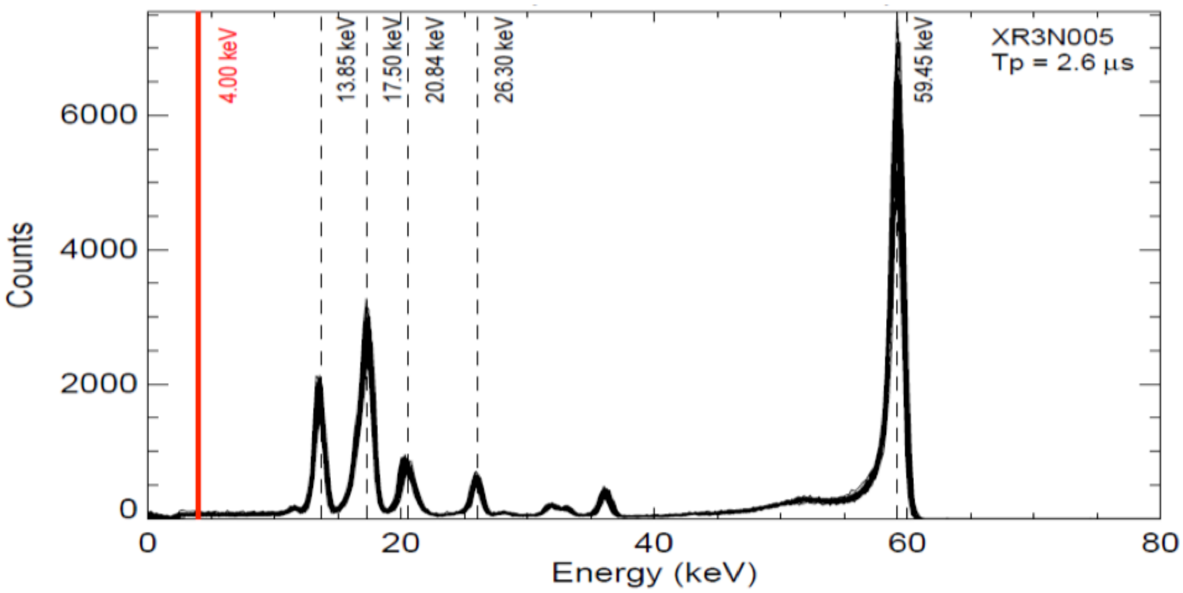
ECLAIRs: detection plane FM

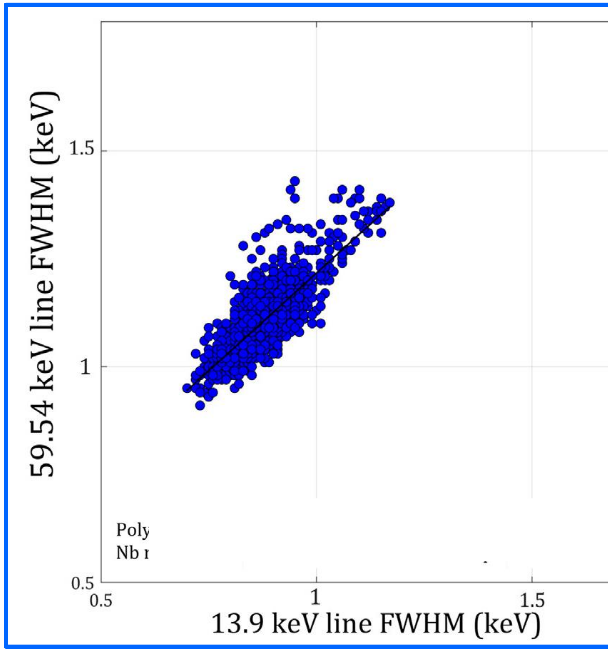


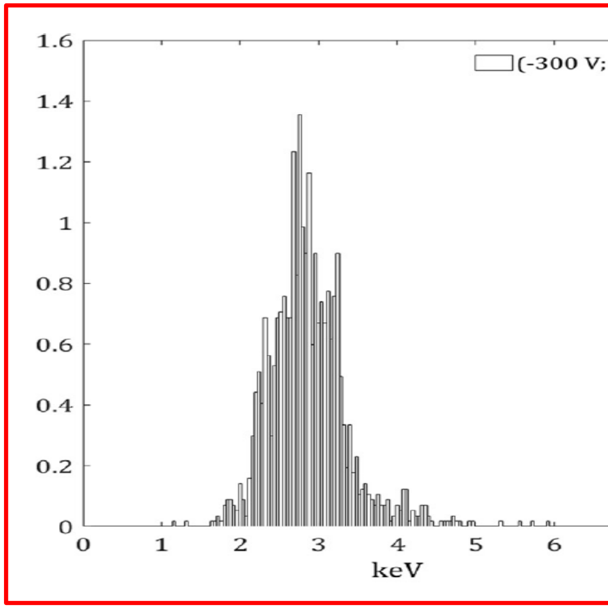
ECLAIRs: detection plane performances

- **performances of several DPIX modules** measured with ^{241}Am source (K. Lacombe+2018)

- superimposition of calibrated spectra of the 32 pixels of one module → **homogeneous energy response**





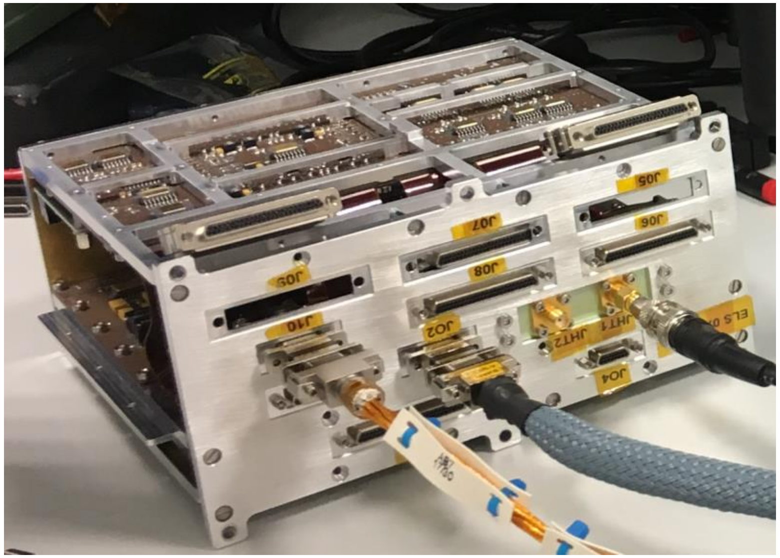


- **spectral resolution** < 1.5 keV (99% of pixels) for both ^{241}Am lines (14 and 60 keV)

- **energy threshold** < 4 keV (95% of pixels)

ECLAIRs ELS : construction & performances

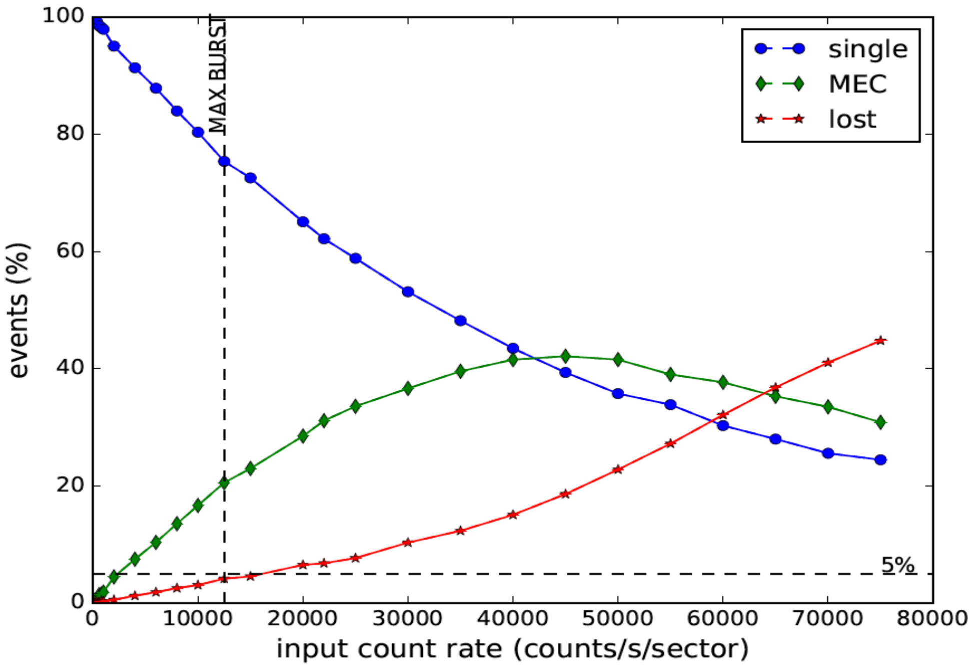
- **ECLAIRs front-end electronics (Proto ELS at IRAP)**
  - read out 1 sector (800 detectors)
  - detection plane is made of 8 sectors



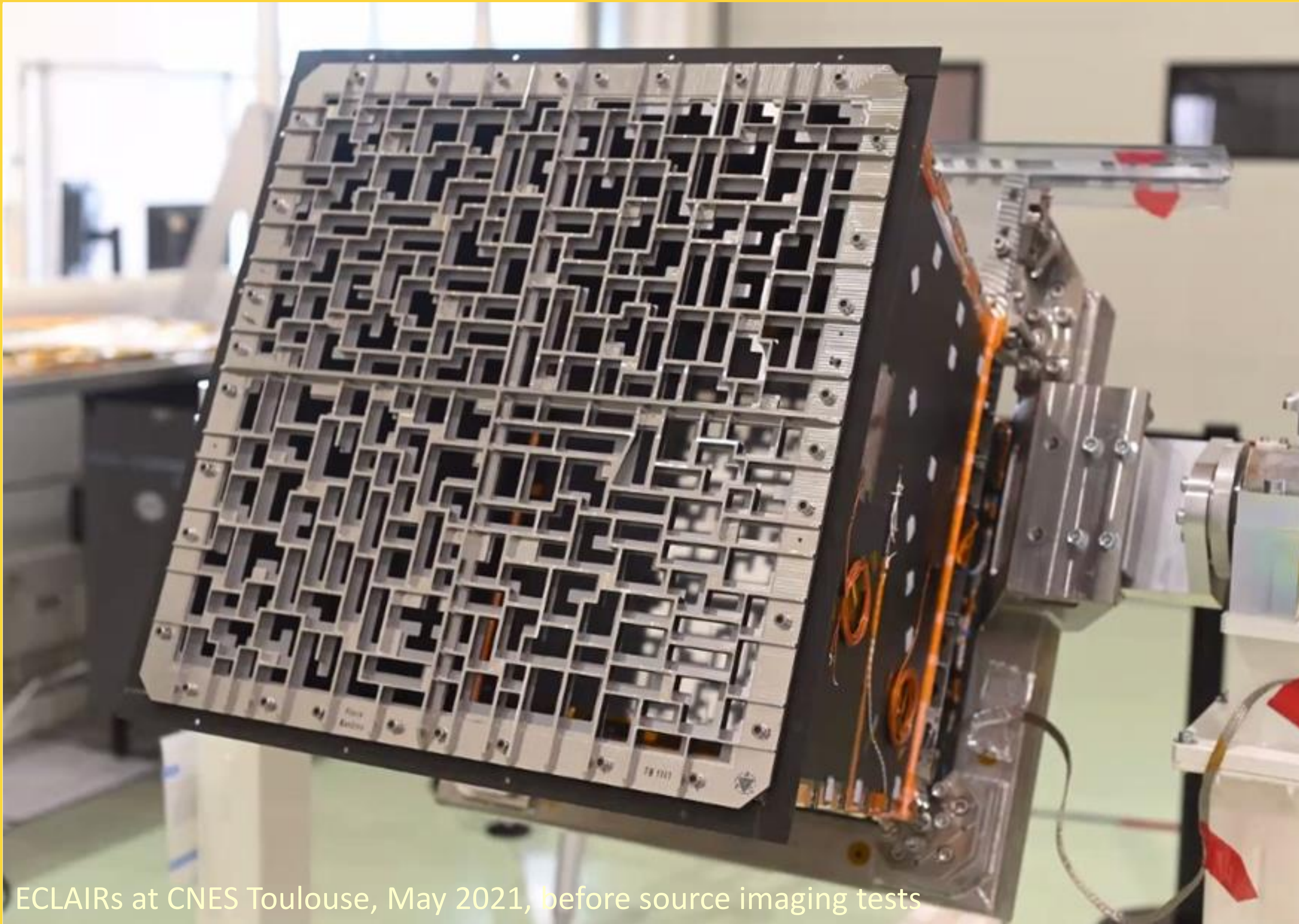
Proto ELS (IRAP)

deadtime < 5% (A. Bajat, PhD 2018)
for count rates < 10^5 counts/s
on detection plane
(corresponding flux:
250 counts/s/cm^2)

event types (SE, ME, others)
as function of input count rate
(counts/s on 1/8th of detector

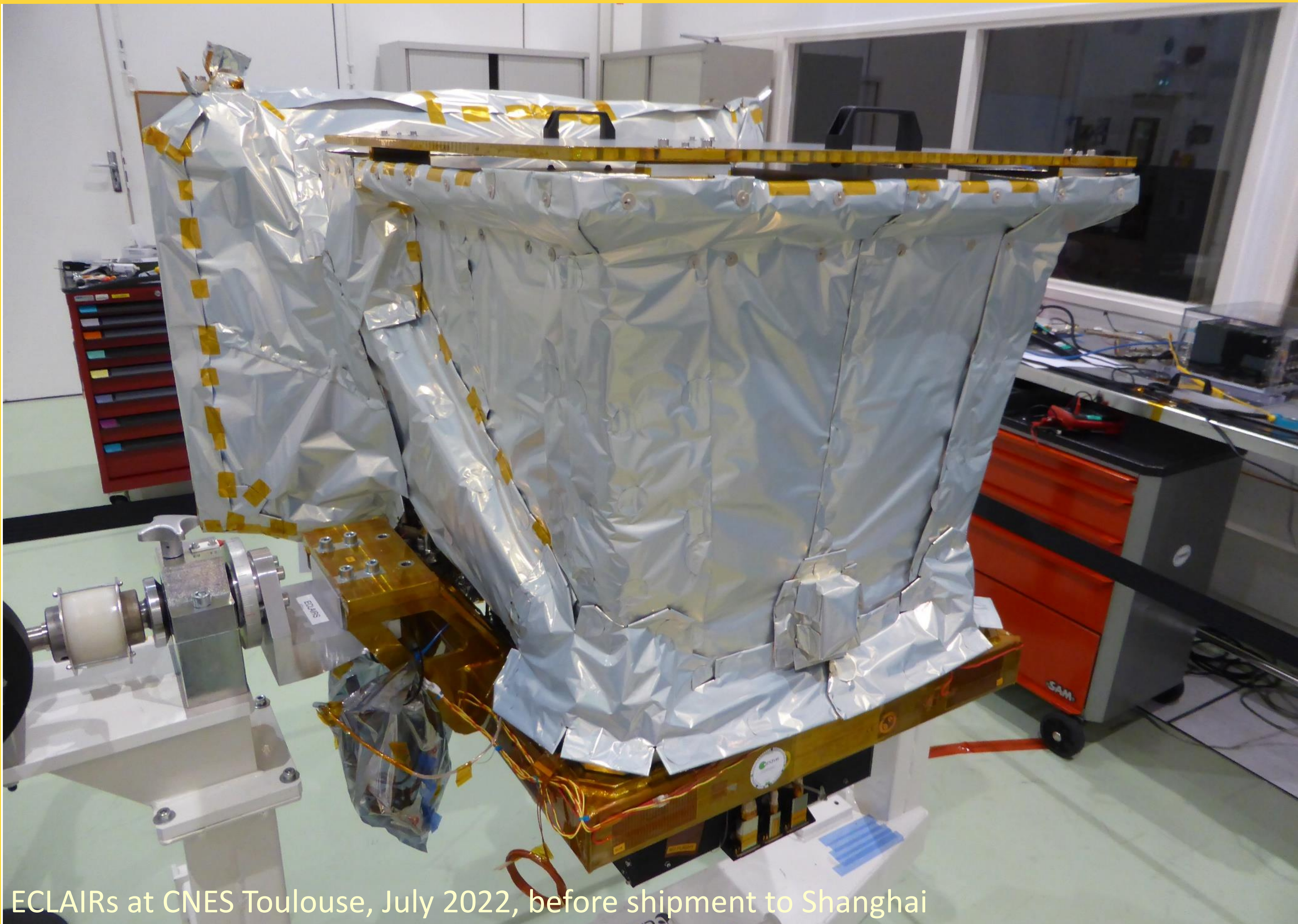


ECLAIRs: coded mask imager (FM)



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

ECLAIRs: coded mask imager (FM)



ECLAIRs trigger

ECLAIRs trigger & control unit (UGTS)

CNES, CEA

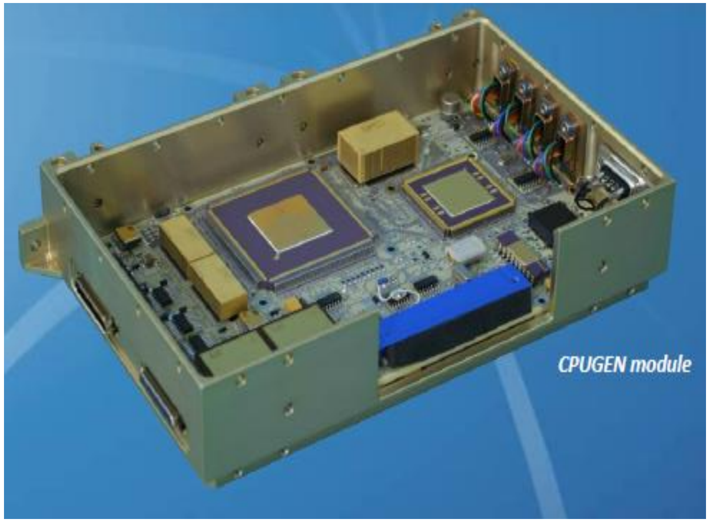
Functions

- Control of instrument (cmd/ctrl, HK, FDIR, thermal ctrl, noisy pixels) + Power supply
- Data acquisition: all detected counts
  → RawData packets → mass-memory
- Scientific Processing - the **Trigger** (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

- I/O board (x2) + Power supply (x2+4)
- CPU board (with FPGA and CPU) (x2)
  FPGA : data acquisition and pre-processing
  CPU: dual-core, 80 MHz, 2×50 Mflops
  OS : hypervisor for time partitioning

Image Reconstruction on UGTS CPU: ~ 2 s



Purpose of the UGTS Science Trigger

- **analyze in real-time** photon data from ECLAIRs DPIX (and GRM triggers)
- **detect and localize in near real-time outbursts of transient sources**
  - unknown sources (GRB candidates)
  - and outbursts of known X/gamma-ray sources (onboard catalog)
- **send corresponding alerts** to the SVOM space mission PDPU

Remarks:

- *Localization accuracy of sources on the sky*
  - *~12 arcmin for weak sources (SNR ~ 6.5)*
  - *>3 arcmin for strong sources*
- *Delay between start of outburst and localization on the sky is generally <10 s, but cannot be specified, depends on physical evolution of source.*
- *Delay between localization of the source and the emission of alerts is <2 s.*

Output of the UGTS Science Trigger

- **alert messages** with detection and localization of a transient source
- **sent to the spacecraft and the ground** to inform them as soon as possible.

For highly significant detections the UGTS requests a spacecraft slew onto the source position, to place it into the FoV MXT and VT for follow-up observations.
The slew is performed by the S/C typically within 5 min after request.

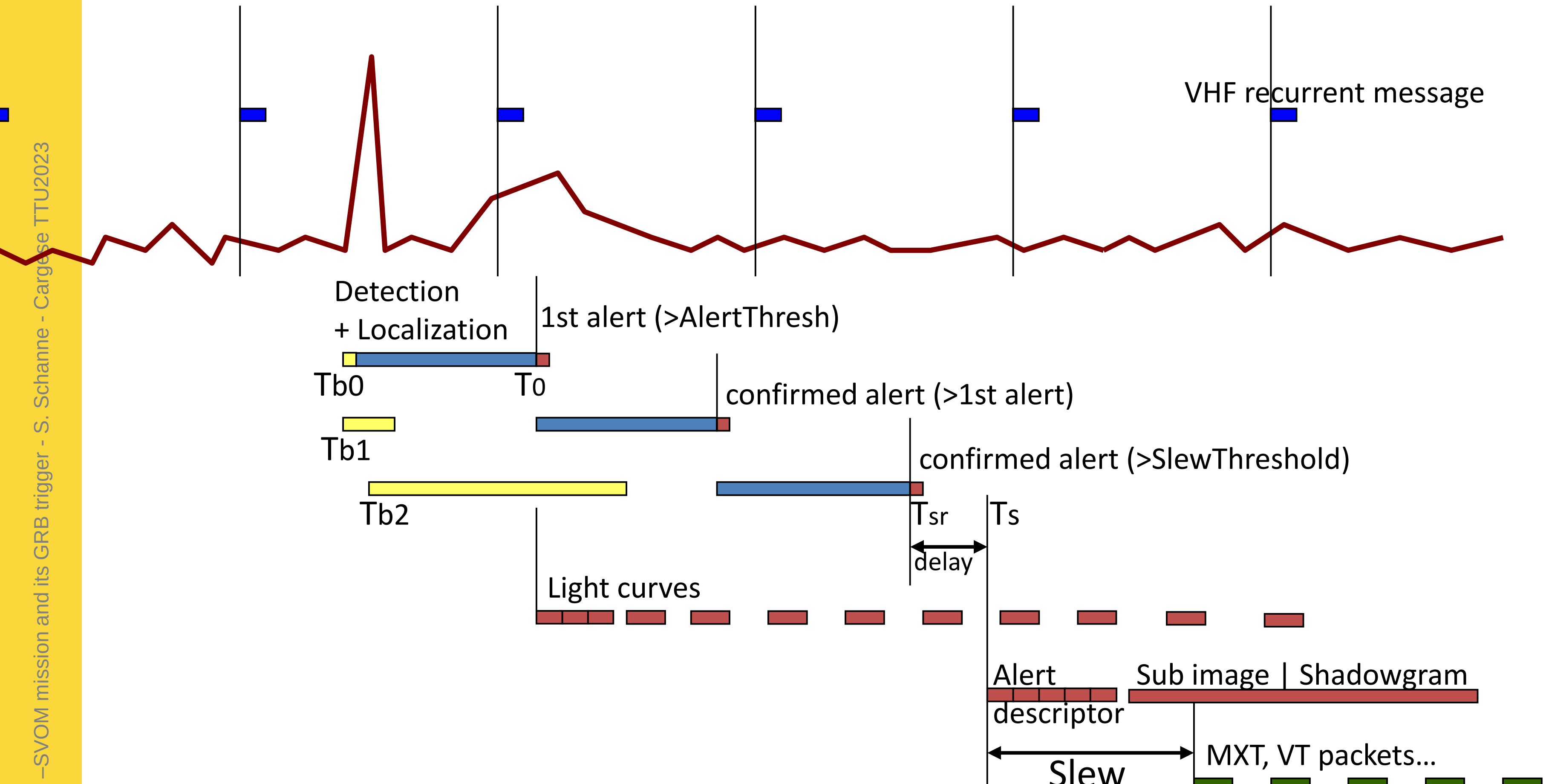
For significant detections the UGTS sends an alert message sequence over the VHF network to the SVOM science center on ground.
The first alert messages are available on ground within max 30 s after emission.

The UGTS also stores in its scientific housekeeping data (ScHK) the results of its onboard data analysis, as well as a copy of the VHF messages, and orbital data, together with the Raw Data. Those are sent to the SVOM mass memory and downloaded over the X-band.
The X-band data are received on ground typically not earlier than 6-12 h after their insertion to mass memory.
Because of this fact, the Science Trigger must be on-board the UGTS (ground triggers have a too long delay).

Alert Sequence Output by UGTS

- if *SNRimg* > **AlertThresh** → Alert msg sequence → **GFT**
- if *SNRimg* > **SlewThresh** → request satellite Slew → **MXT & VT**
- Sub threshold excesses → included in VHF recurrent msg → **GWAC**

+ Light curves, sub image or shadowgram + alert descriptor → Burst Advocate



Source localization by UGTS

A transient source detected is **localized** on the sky using the ECLAIRs data.

To do this, the detector plane image (called a **shadowgram)** is transformed into a **sky image** using the coded mask pattern via the “deconvolution algo”:

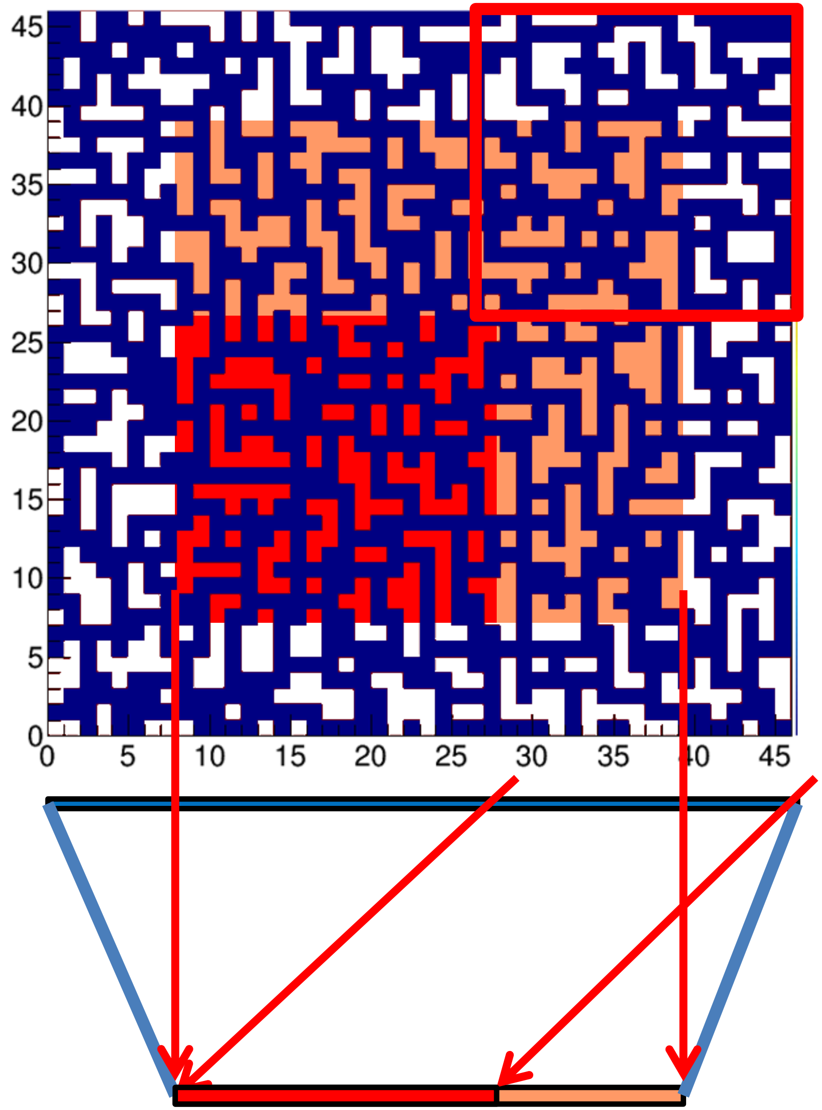
- produces sky counts (SkyCnt) and sky variance (SkyVar)
- significance : *Sky SNR = SkyCnt/sqrt(SkyVar)*
- position of source : fit a shape (point spread function, gaussian) to the source peak in the SkyCnt.

Shadowgram : 80 × 80 pixels (6400 detector pixels)
Reconstructed sky : 200 × 200 pixels.
Sky pixel angular size : 25 acmin (at the edge of FoV) and 33 arcmin (at center).
Source position can be determined to about 12 arcmin (at detection limit).

Image reconstruction by deconvolution is time consuming!
about 2 s on the UGTS hardware, using the FFT

Imaging with ECLAIRs (example)

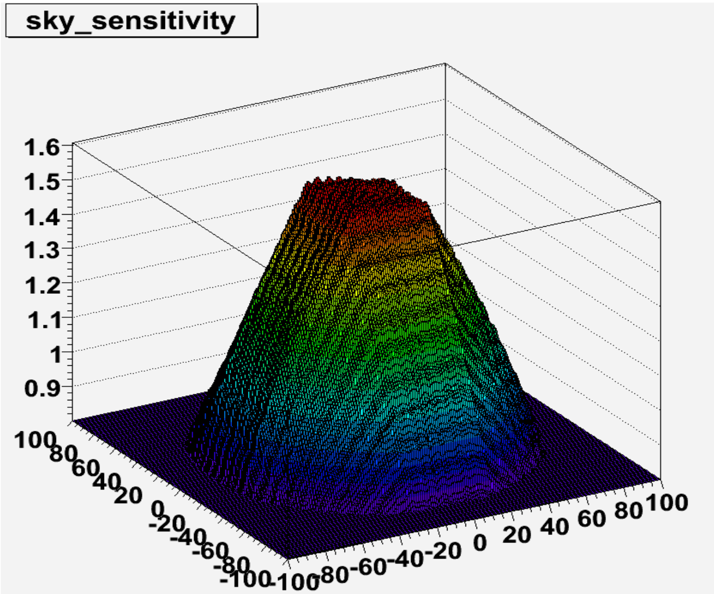
Example: prototype mask « ACS »



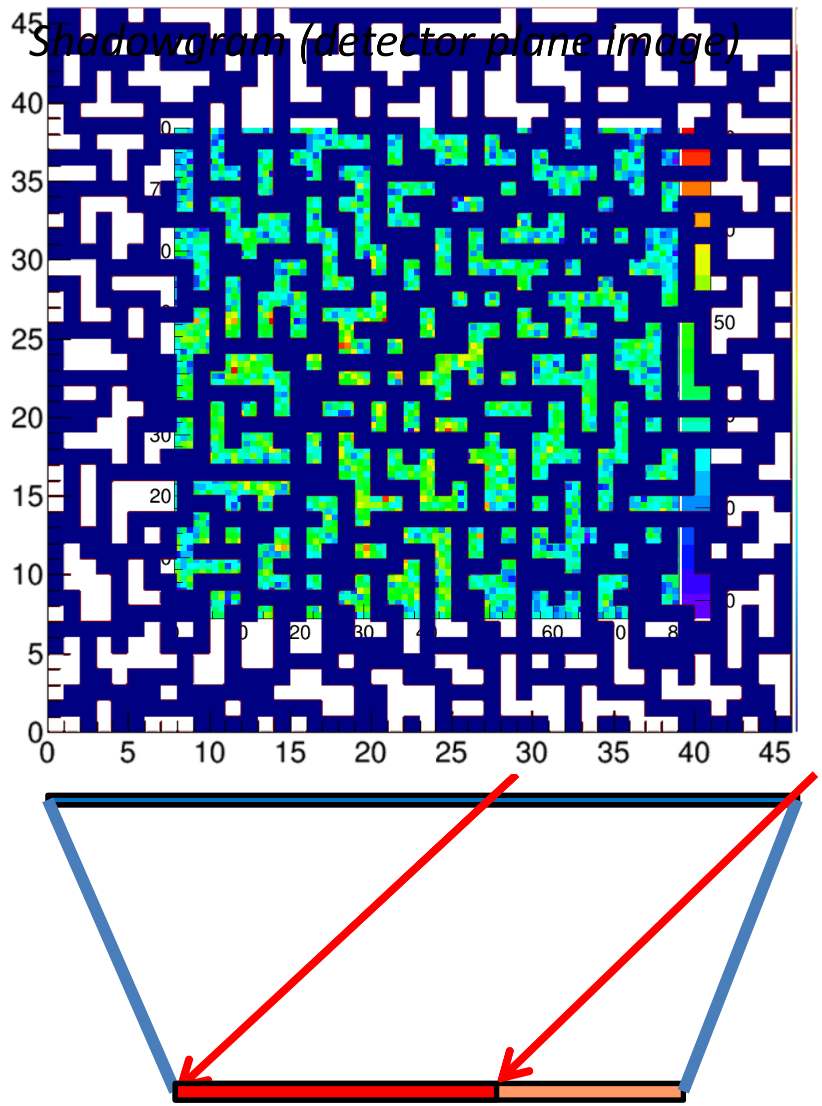
Source position at sky pixel (50,50) (35° off axis)

Principle of imaging:

Projection of a portion of the mask onto the detector permits to reconstruct the source sky position



Imaging with ECLAIRs (example)



Source position at
sky pixel (50,50)
(35° off axis)

Exposure: 100 s

Energy: 4-120 keV

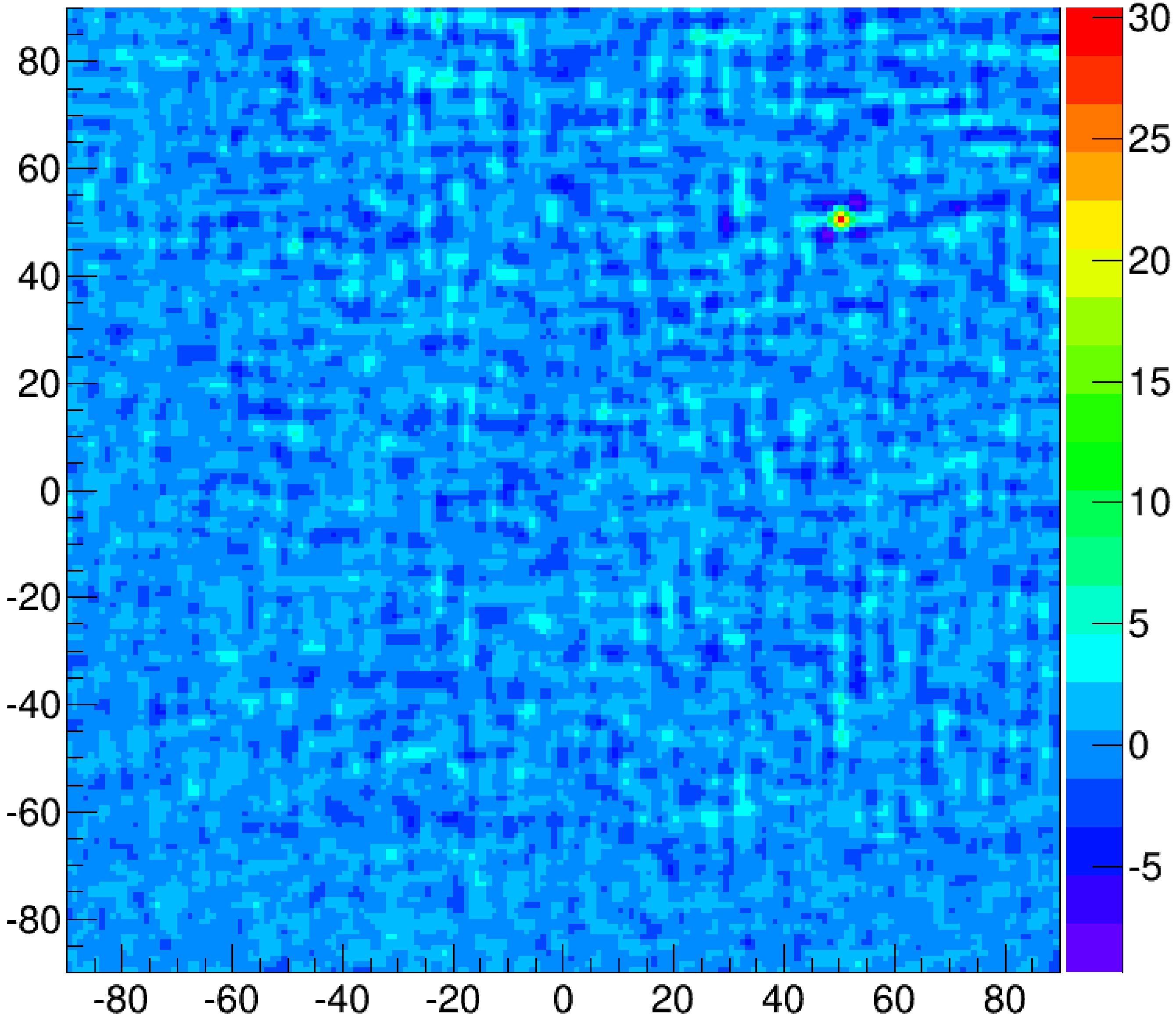
Source fluence
100 ph/cm^2 (~ 0.5 Crab)

Source counts:
~ 10 000 on det

CXB counts:
~ 250 000 on det

Source reconstructed
at sky pixel 50,50
with 30 sigma in image

Imaging with ECLAIRs (example)



Source position at sky pixel (50,50) (35° off axis)

Exposure: 100 s

Energy: 4-120 keV

Source fluence 100 ph/cm^2 (~ 0.5 Crab)

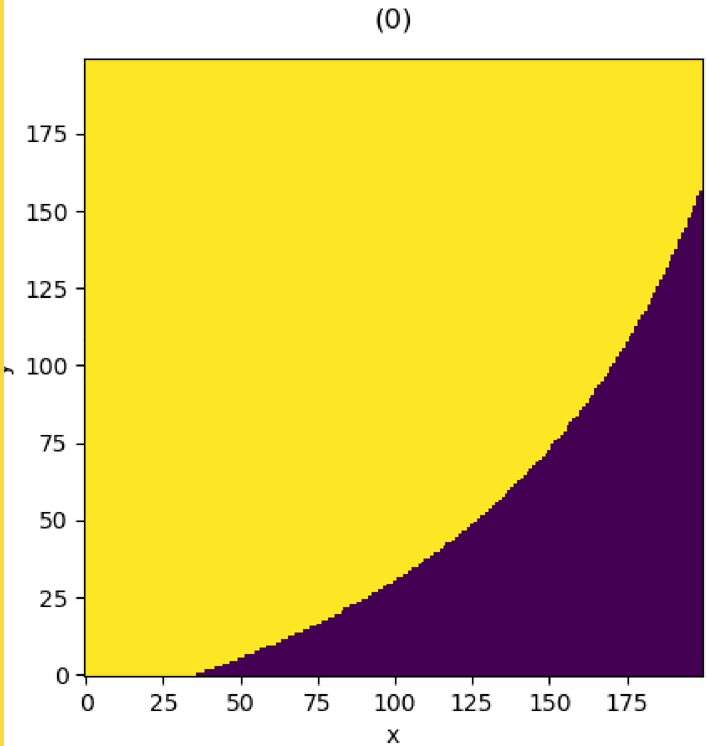
Source counts: ~ 10 000 on det

CXB counts: ~ 250 000 on det

Source reconstructed at sky pixel 50,50 with 30 sigma in image

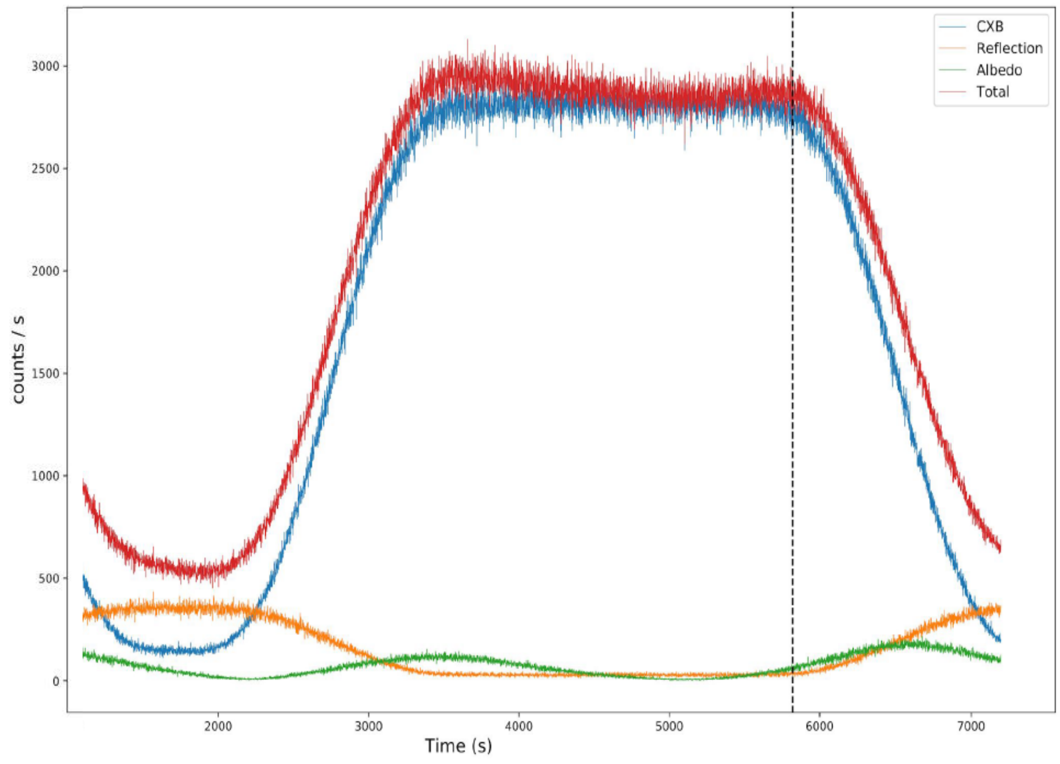
Variable background due to Earth transit

Modulation of Background du to Earth Transit in FoV
- CXB (cosmic X-ray background)
- Reflection (of CXB on athmosphere)
- Albedo (of cosmic rays in athmosphere)



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

N. Dagoneau (CEA)



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

S. Mate (IRAP)

Earth transits

The UGTS Science Trigger **does not search** sources in the part of the sky image **where the Earth is** present.

This prevents from triggering on sources appearing over Earth horizon.

No triggers are generated for TGFs (Terrestrial Gamma-ray Flashes),
ECLAIRs has not a good sensitivity on TGFs,
their detection on ground using the Raw Data on-ground is sufficient.

Because of the pointing strategy of SVOM,
the Earth is present in the field of view about 2/3 of the time.
It covers a large part of the field of view in about 1/3 of the time.

The presence of the Earth in the field of view is determined by the UGTS using the position and attitude information received from the S/C.

Unknown transients searches

Unknown transient sources are considered GRB candidates.

GRB candidates:

- In reconstructed sky images (in the FoV part free of Earth) pixels located away from known sources (typically >1°) generate an alert if their SNRi is above the **AlertThresh** (~ 7 sigma), to trigger follow-up observation by ground telescopes GFT and GWAC.

- Additionally a slew request is generated if the SNRi is above the **SlewThresh** (~ 10 sigma ≥AlertThresh), to trigger follow-up observations with MXT and VT.

Thresholds have to be tuned (in flight) to have acceptable false alert rates (about 1 every 10 orbits) and false slew rates (about 1 every 10 days).

Known transients searches

Known transient sources are outbursts of sources of the source catalog.

Known source outburst:

- Pixels at a position of a source in the known source catalog
  generate an alert with slew request,
  if the detected SNRi exceeds the threshold in the catalog for this source.

To prevent retriggering on a GRB candidate, the position of the last GRB candidate is temporarily inserted in the known source catalog.

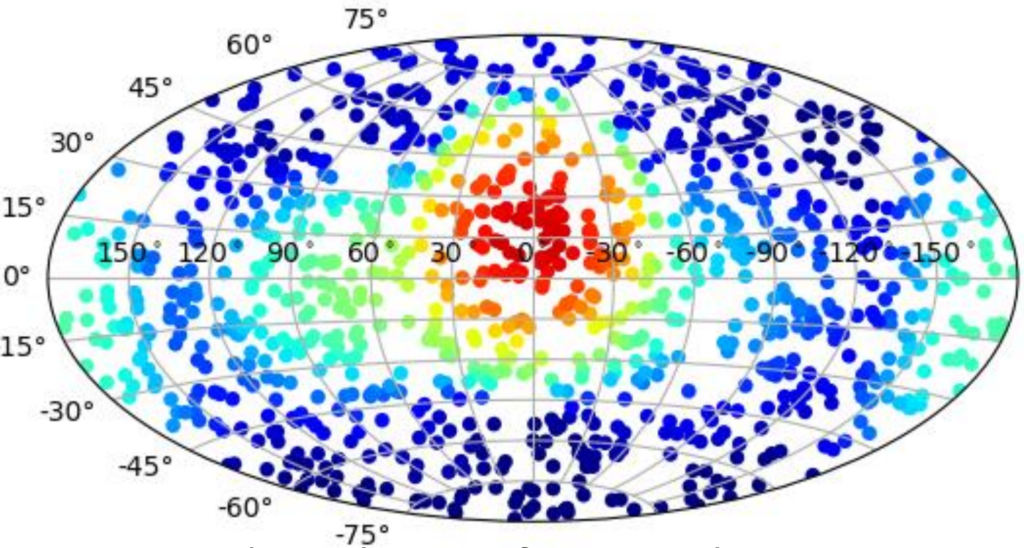
To prevent frequent retriggering on known sources, once a source triggered, its threshold in the known source catalog is automatically increased. It can then be put back later to a lower value by tele-command from ground.

The known source catalog is stored in global sky coordinates (J2000) and is configurable. A translation into local coordinates in the FoV is performed after each satellite slew.

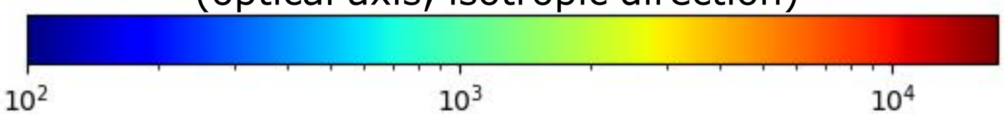
Known sources catalog

***Nicolas Dagoneau* (CEA, thesis 2017-2020)** *N. Dagoneau, S. Schanne et al A&A 645A (2021)*

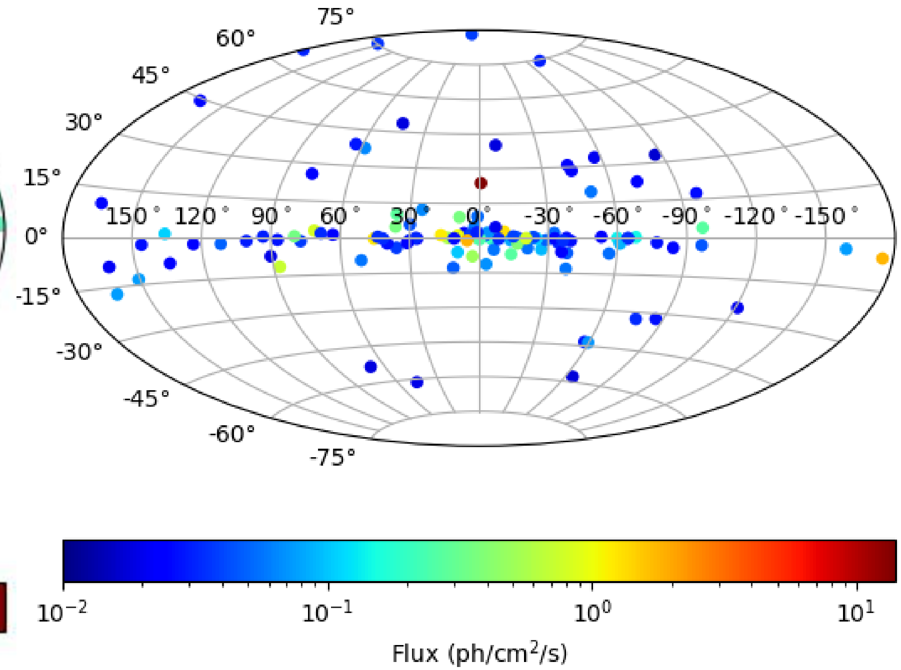
425 sources from MAXI (2-20 keV) + Swift/BAT (15-195 keV)
spectra modelled (broken-powelaw), flux over ECLAIRs 4-120 keV band



counts/s on detector for given sky pointing
(optical axis, isotropic direction)



122 sources : SNR > 6 in 20 min



- Most of sources excluded by B1 pointing law (ouside FoV : |b|<10° & Sco X-1),
- Not always in B1 pointing: GRB follow-up, ToO, GP > 1/3 of time

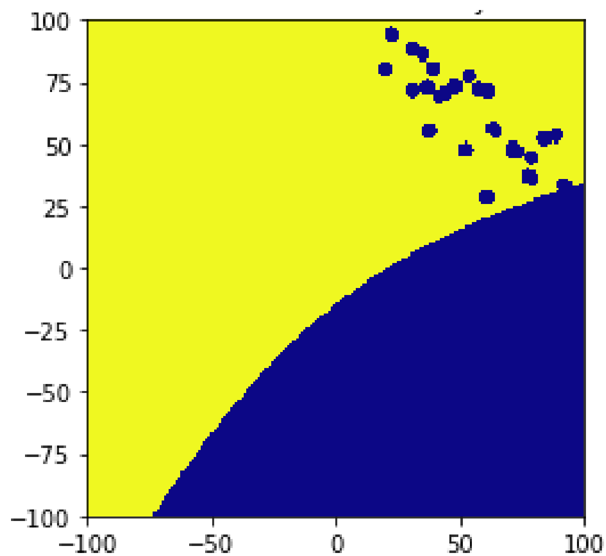
➔ Need to include management of sources in the trigger algorithms
(shadowgram differences in Count Trigger, Source modeling in ImageTrigger)

GRB diversity drives Trigger design

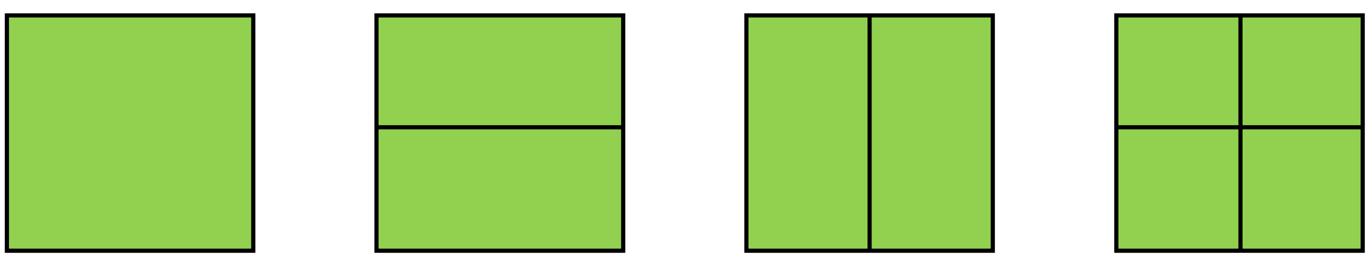
GRBs appear randomly on the sky.

➔ The trigger has to search for GRBs in the whole field of view of ECLAIRs.

Sky image total field-of-view (2 sr),
except zones with Earth and known sources



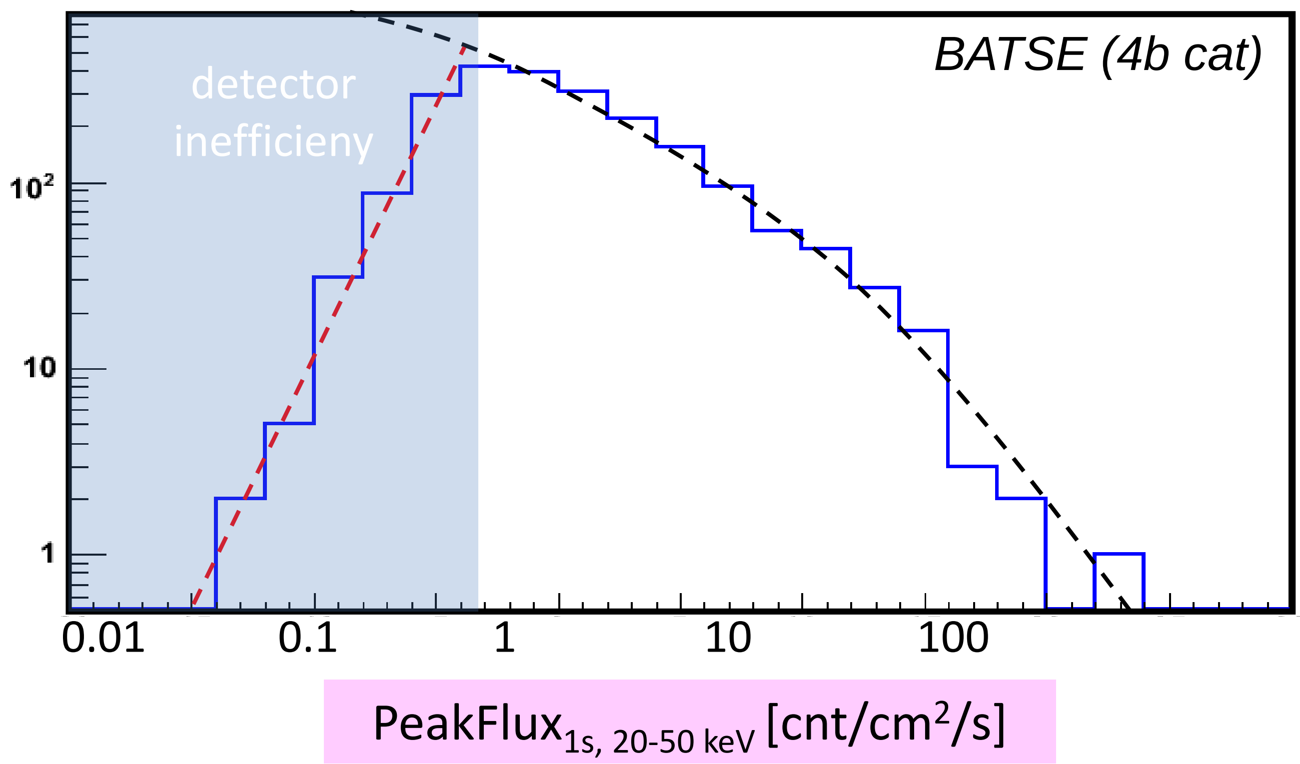
Count-rates in 9 detector plane zones (for partially coded sources)



GRB diversity drives Trigger design

Gamma-ray fluxes and fluences of GRBs are also very diverse.
BATSE catalog (2000 GRBs and in the 20-50 keV energy band),
peak fluxes : 0.03 to 300 ph/cm^2/s, and fluences : 10^{-10} to 10^{-4} erg/cm^2
The faintest GRBs are the most numerous ones.

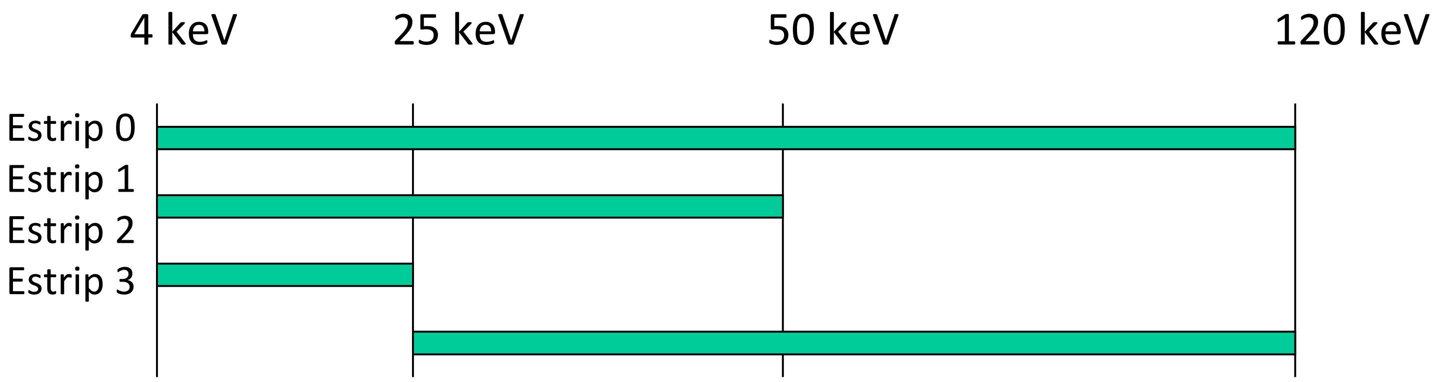
➔ The trigger has to have an **AlertThresh** and **SlewThresh** as low as possible,
in the limit of the acceptable false alarm rates,
the weak bursts may be the most interesting ones!



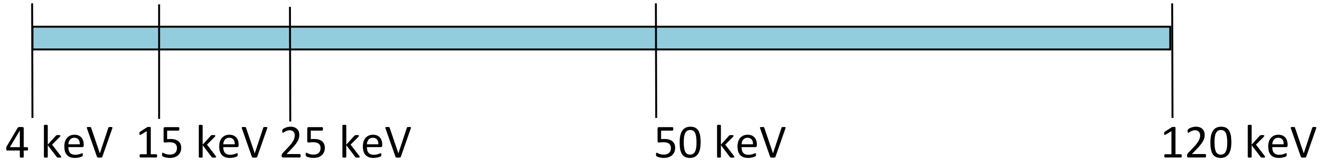
GRB diversity drives Trigger design

GRBs exhibit a large spectral variety. ~ powerlaw, broken (Epeak)
Some GRBs (X-ray flashes) are very soft and emit mostly below 20 keV,
high read-shifted GRBs have a softer spectrum,
SGRBs a harder spectrum, some have low energy tails.
→ The trigger has to analyze in different energy bands.

4 Energy strips (overlapping)

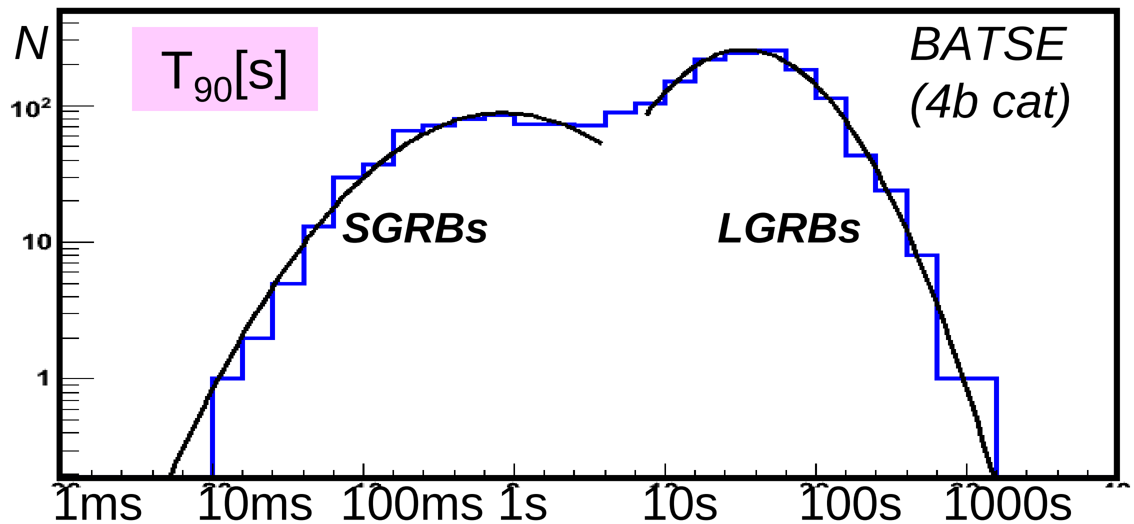


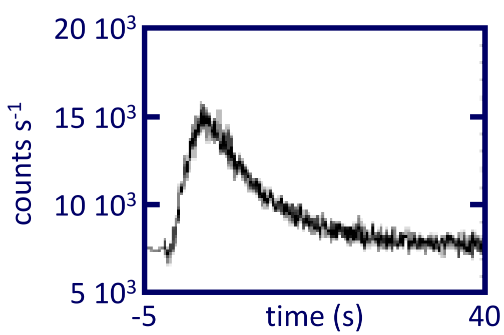
The Energy strips are built from the 4 Energy bands (adjacent, defined in ELS)

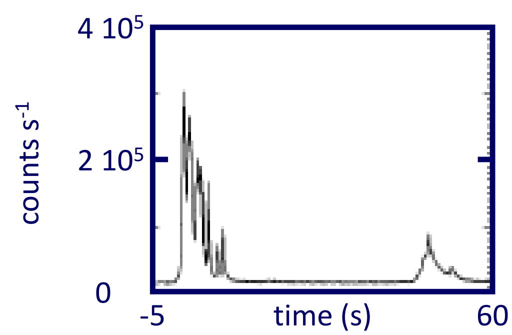


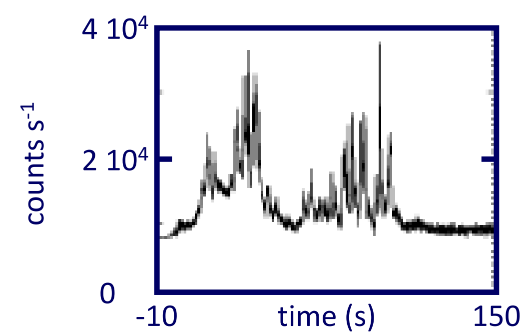
GRB diversity drives Trigger design

GRBs durations are very diverse, as well as their intrinsic variability.
Some only a few 10 ms, others > 15 min.
SGRB: T90mean ~ 850 ms, LGRB: T90mean ~ 33 s.
→ The trigger has to analyze a range of time scales, from 10 ms to 20 min.







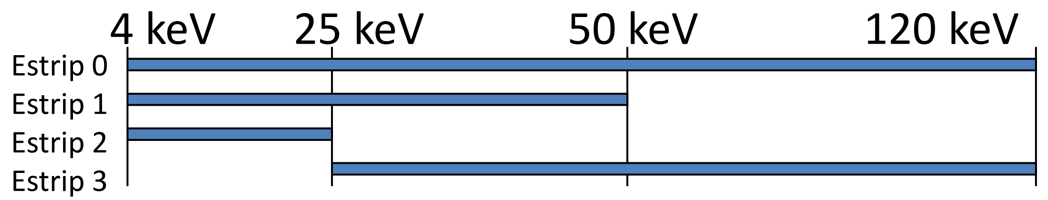


GRB diversity drives Trigger design

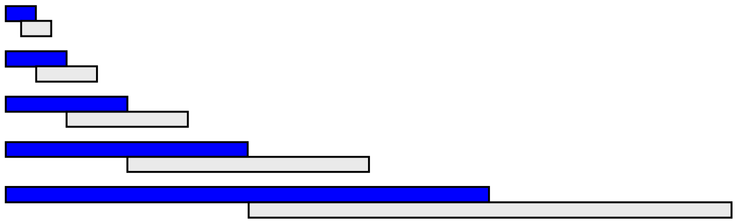
➔ search in full FoV randomly appearance on the sky

➔ low AlertThresh, SlewThresh (FAR!) low-intensity sources most numerous

➔ 4 Energy strips
spectral diversity:
standard GRBs,
high-z GRBs, XRF



➔ Time scales
from 10 ms to 20 min
(17 powers of 2)
durations & variability



But image computation on UGTS hardware takes 2 seconds !

➔ Two separate trigger algorithms:

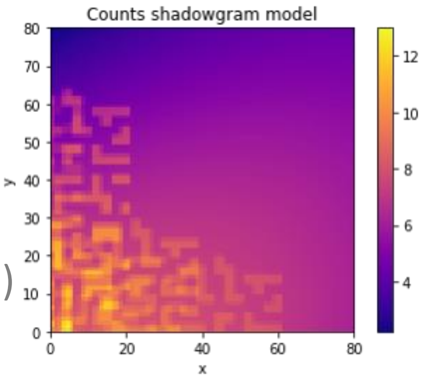
- "**Image Trigger**" for long time-scales > 20s:
  systematic sky imaging
- "**Count-Rate Trigger**" for shorter time-scales < 20 s:
  select first appropriate time scale, then image it!

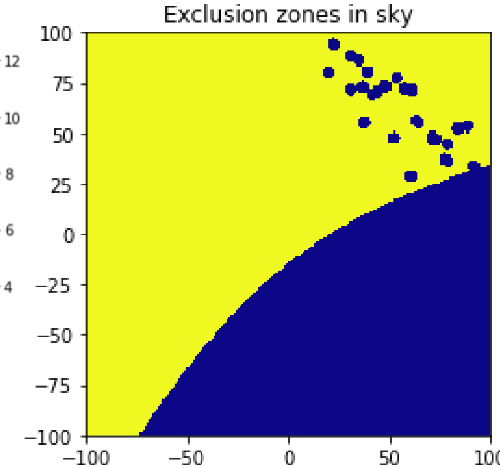
The two Trigger algorithms of UGTS

IMAGE TRIGGER

Cyclically every 20 s, for 4 Estrips:

- build shadowgram, fit & subtract bkg
  (earth modulation & bright sources)
- deconvolve → stack sky images (20 s to 20 min)





COUNT-RATE TRIGGER

- **Cyclically** every 2.5 s, for 4 Estrips, 9 detector zones:
- detect count-rate excess (10 ms to 20 s) over background model → into buffer
- build shadowgram for most significant excess in buffer (not too old)
- deconvolve → sky image (10 ms to 20 s duration)

For any sky image reconstructed (by both algorithms):

- search for maxima in portion not obscured by Earth and away from known sources
- refine localization by peak fit

if *SNRimage* > *AlertThresh* → VHF Alert GRB

if *SNRimage* > *SlewThresh* → VHF Alert GRB with slew request

For image trigger: check at known source positions:

if *SNRimage* > *CatThresh* → VHF Alert known source with slew request
(+ increase *CatThresh* for this source)

GRM info in both Triggers of UGTS

inserted in UGTS triggers :

If GRM detects (in 3 detectors) a spike:

➔ Search for short GRB seen in ECLAIRs image, but not in rate-excess:

- ECLAIRs **Count Trigger** (scales< 20s)

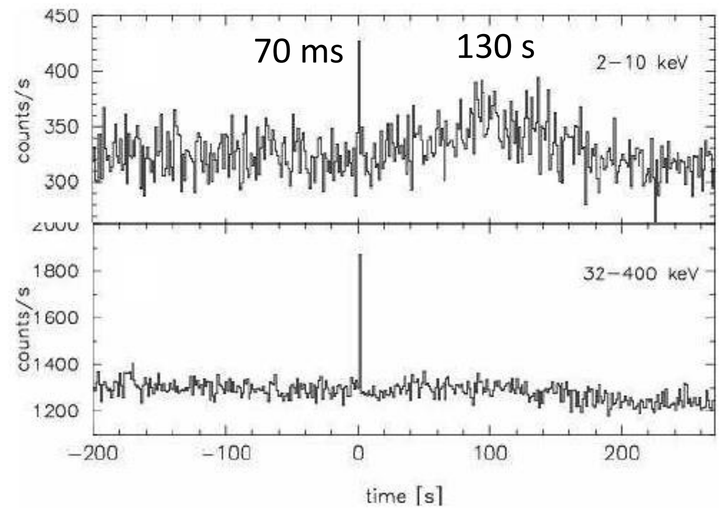
→ *insert GRM detection in excess buffer*
→ *build ECLAIRs image on time window of GRM trigger.*
→ *lower SNRimage Threshold to search for weak source*

➔ Search GRB with extended emission:

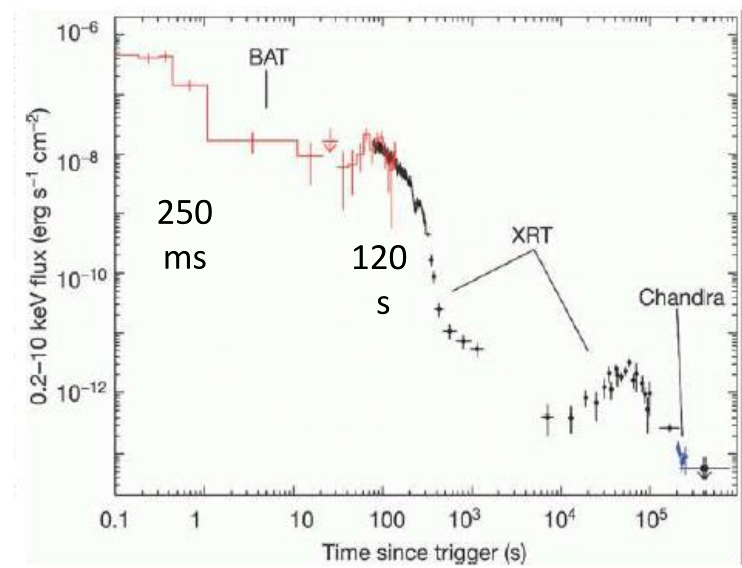
- ECLAIRs **Image Trigger** (scales>20s)

→ *lower SNRimage Threshold during the next ~300 s (predefined) to catch extended emission*

GRB050709 *(HETE-2)*



GRB050724 *(Swift)*

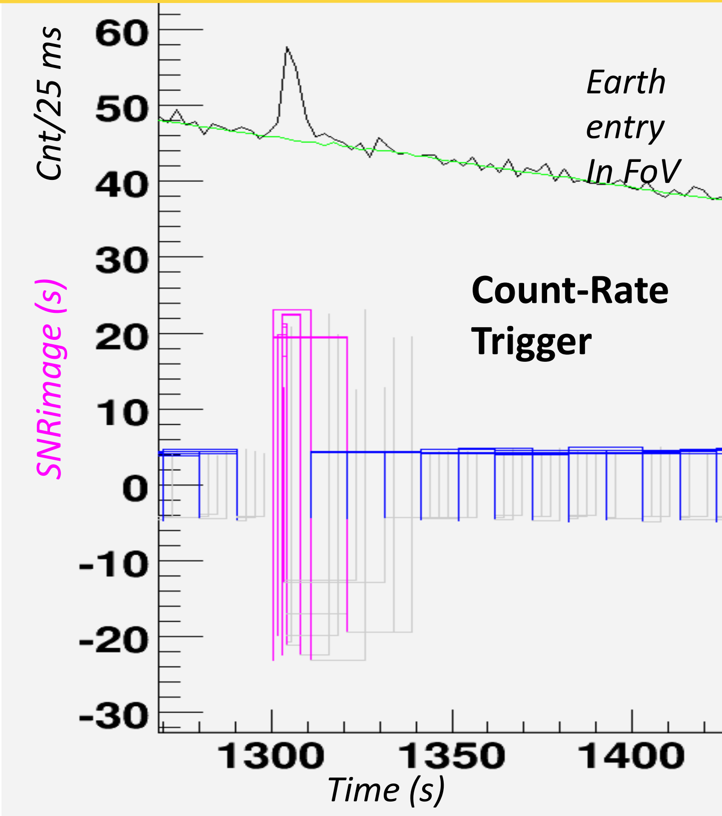


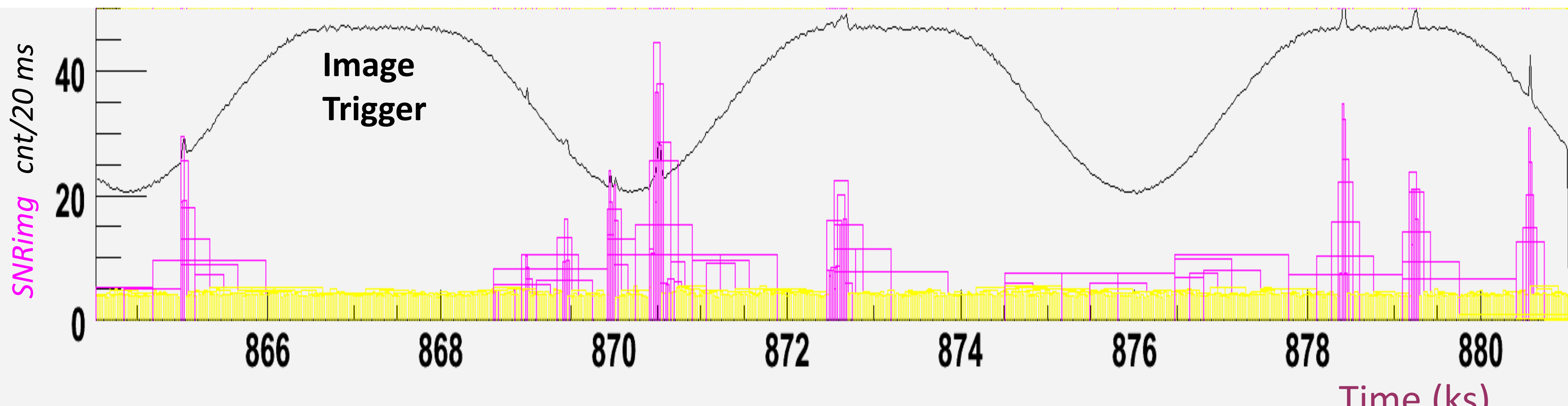
NS-BH merger, possibly GW event

Trigger prototype implemented (w/o sources)

- coded as C++ libraries
- **Scientific Software Model** (SSM) :
  both triggers: standalone programs on Linux
  ➔ simulate thousands of GRBs
  check scientific performance

Sim individual photons CXB + GRBs (time, energy) through CxgSim (detector simulation)
→ time, energy, pixel → input to Triggers



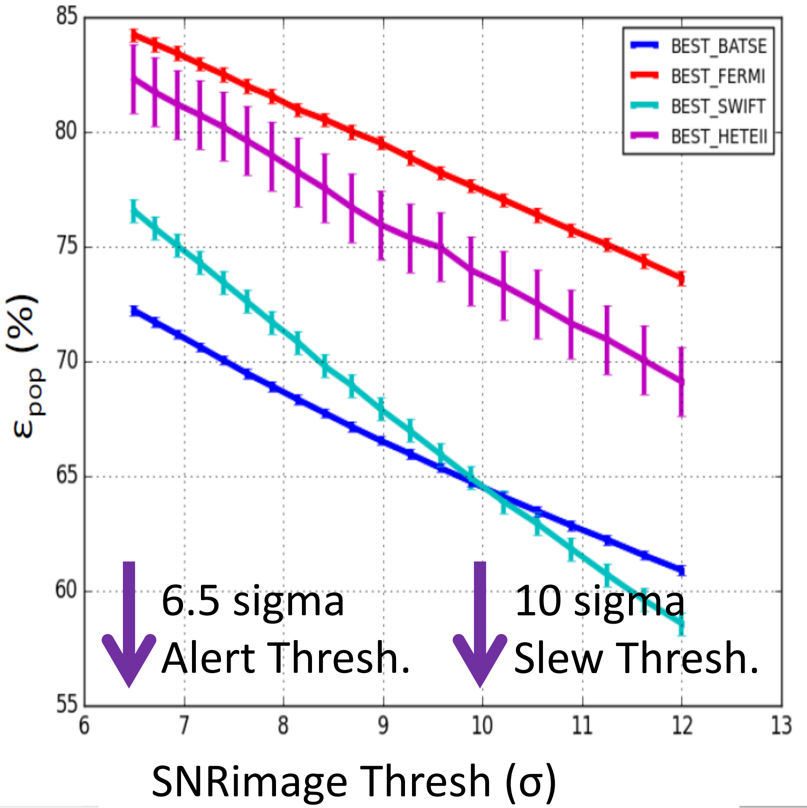


Expected number of GRBs (Trigger prototype)

Sarah Antier ***(CEA, thesis 2013-2016)*** *B. Cordier, J. Wie, et al (astroph) White paper SVOM*

- **Database** of ~2000 GRBs detected by **Batse**, **Swift/BAT**, **GBM** 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)



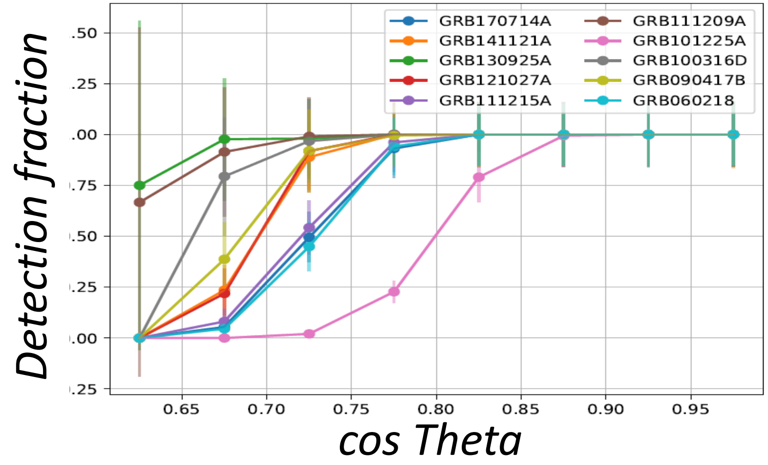
using detection efficiency, BATSE GRB/yr norm, ECL FoV = 1.83 sr, Duty cycle = 54% (Earth, SAA)

	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

Ultra-long-GRB detection (Trigger prototype)

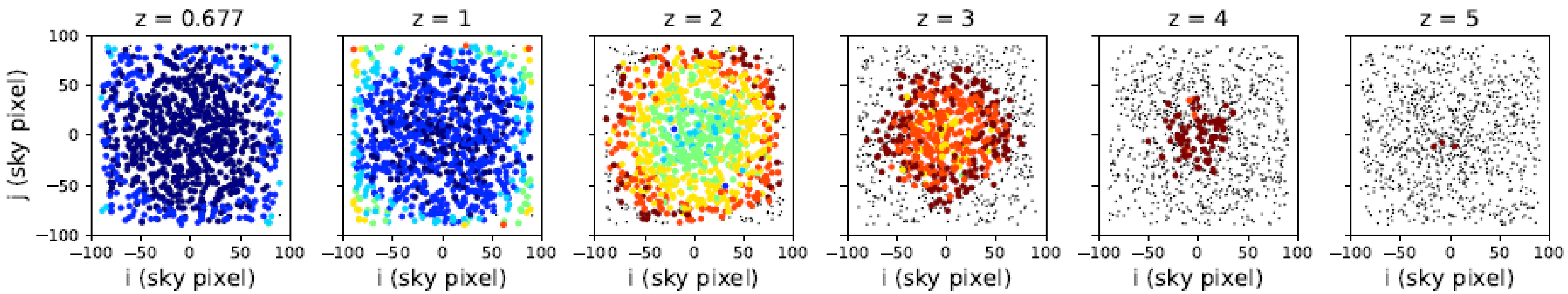
***Nicolas Dagoneau* (CEA, thesis 2017-2020)**

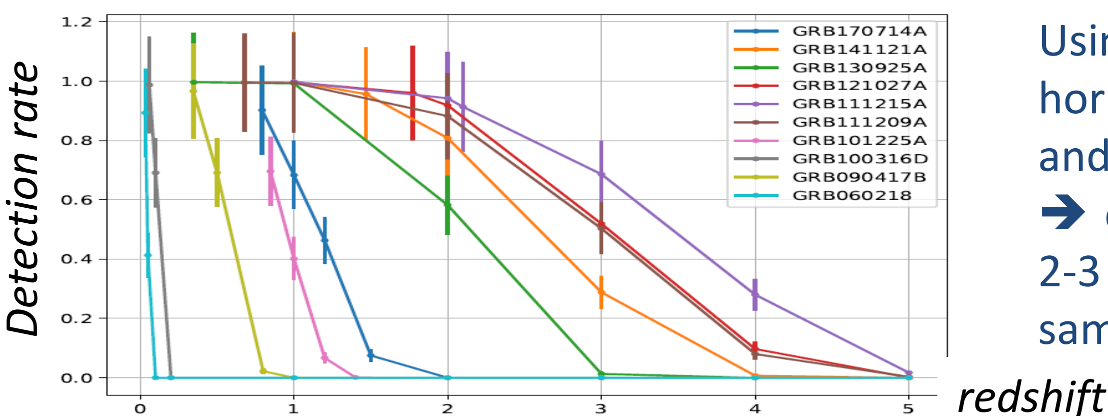
N. Dagoneau, S. Schanne et al Exp Astr. (2021)



Sample of 10 ulGRBs detected by Swift/BAT, simulated in ECLAIRs (Trigger prototype). All ulGRBs detected Image Trigger, even at large off-axis angles (Theta).

Transport of GRBs to higher redshifts: longer time slices needed for detection (especially off axis: 20 s to 20 min).





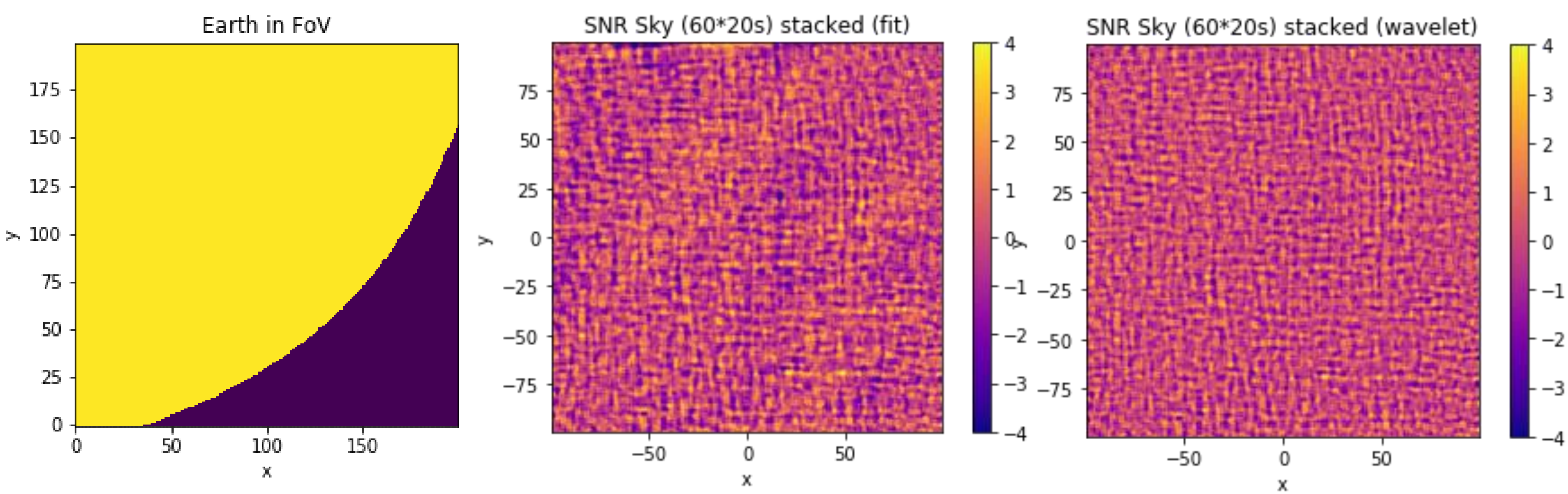
Using the estimated detection horizon in redshift for each burst, and a GRB population model ➔ estimated ECLAIRs ulGRB rate 2-3 higher than Swift (given the same duty cycle).

ECLAIRs UGTS : image trigger optimization

- Construction of detector plane images of 20 s duration, background removal, deconvolution
- Stacking of the 20 s sky images to produce 20 s to 20 min sky images
- Search for new sources (outside known sources and Earth).

- **Background removal: now 2 methods** *N. Dagoneau & S. Schanne A&A 665A (2022)*
  1) Fit of theoretical (quadratic) bkg shape on shadowgram together with illumination function of strong known sources in FoV, and subtract
  2) Wavelet transform of shadowgram, remove large scales (bkg) keep only small scales (containing mask coding), then fit illumination functions of strong known sources, and subtract

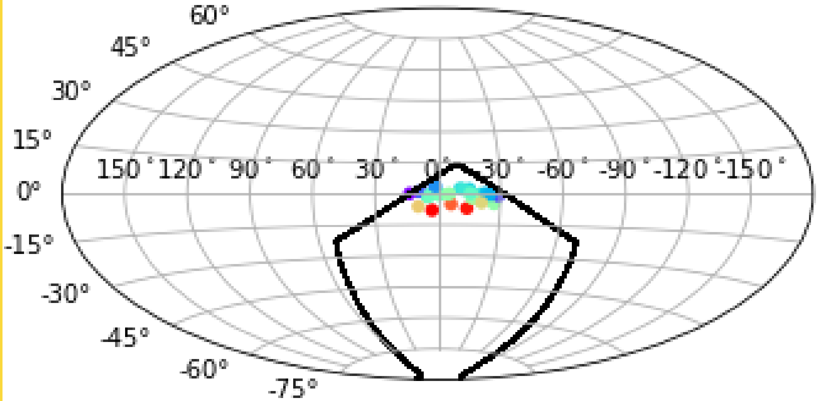
Example without sources in FoV:



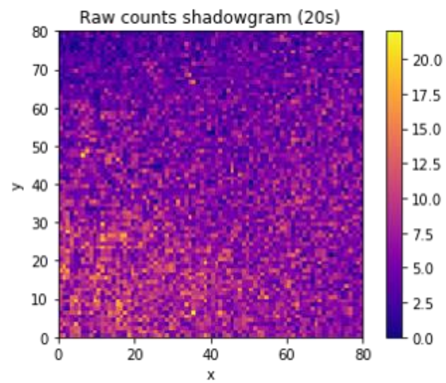
ECLAIRs UGTS : image trigger optimization

- **Onboard source catalog:**

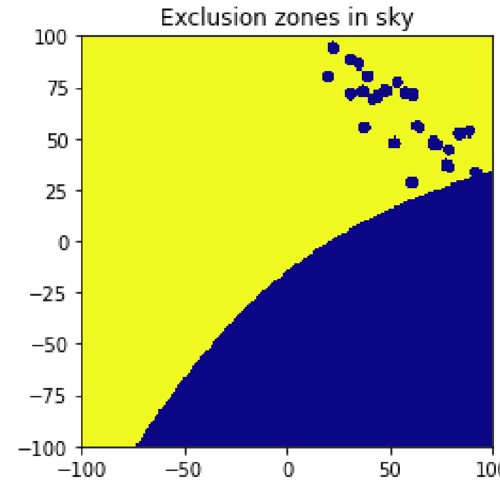
N. Dagoneau & S. Schanne A&A 665A (2022)



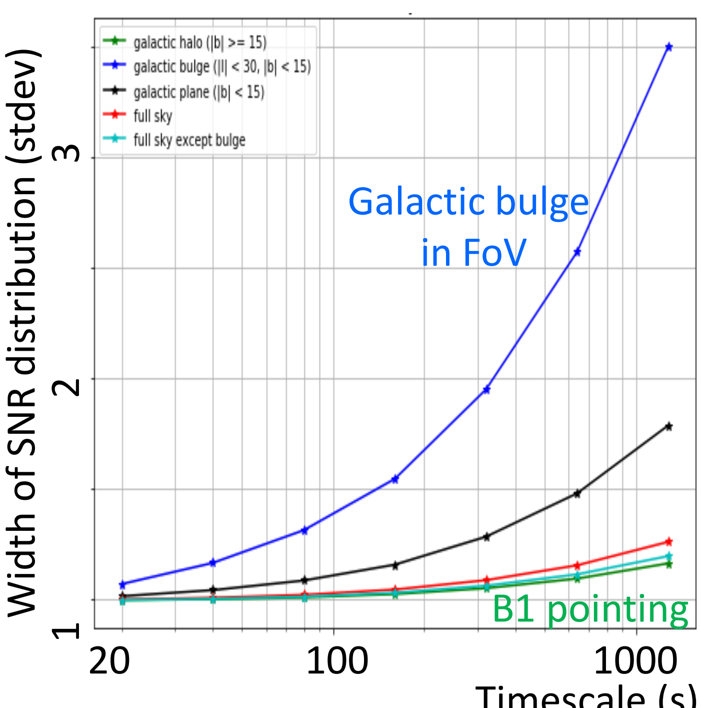
Sources in FoV (bulge pointing)

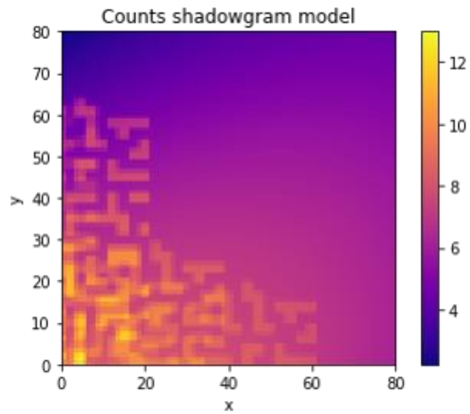


Raw shadowgram (20 s, sources + Earth modulated CXB)

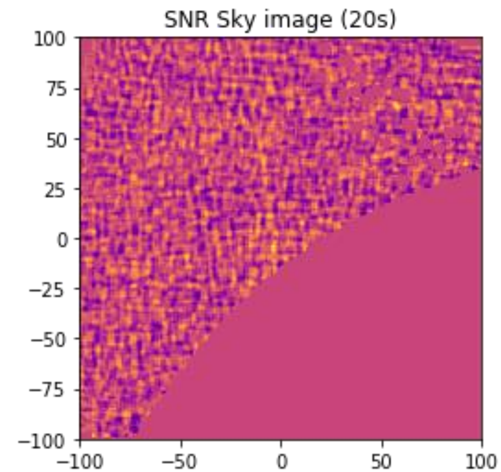


Sky exclusion region





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



Sky SNR image (20 s, exclusion applied)

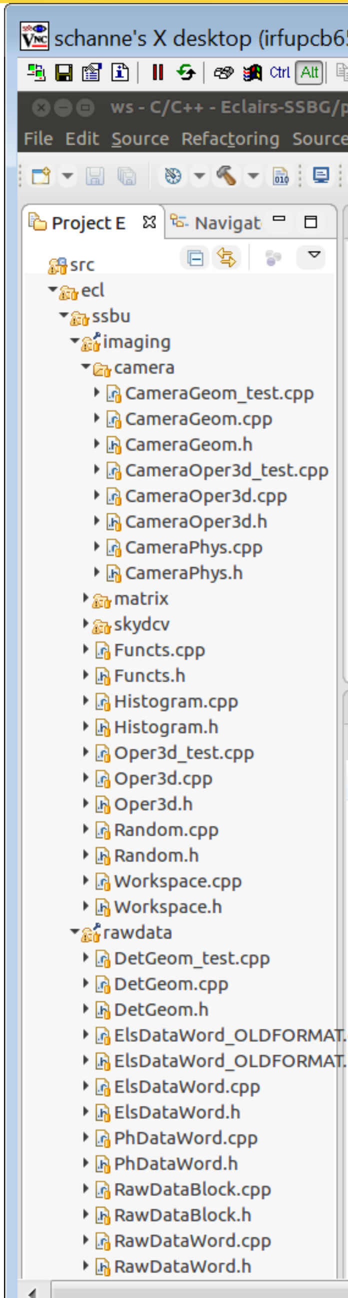
UGTS Scientific Software: **co-development**

- **USS-FM** : flight UGTS Scientific Software
  - running on the Flight processor (Flight-Model or Bread-Board Model)
  - Need to be updatable during flight (as shown by many space missions: Swift and Fermi updated their software several times!)

- **USS-GM** : UGTS Scientific Software Ground-Model
  - running on Linux, same code (+ ground extensions)
  - Needed for the ground validation of the software and parameter tuning
  - at CEA: before flight (simulated data)
  - at CEA/EIC: during commissioning and routine flight phase (raw data)

1) Modification of configuration parameters (or modification of software)
2) Many test cases: Data through USS-GM
   (many test cases can be run quickly on linux)
3) Specific test cases: Data through USS-hardware model (BB2)
3) Verification of algorithm output (VHF and EventMessages)
   comparison to expectations.

UGTS Scientific Software: **FAIR** (but not open)

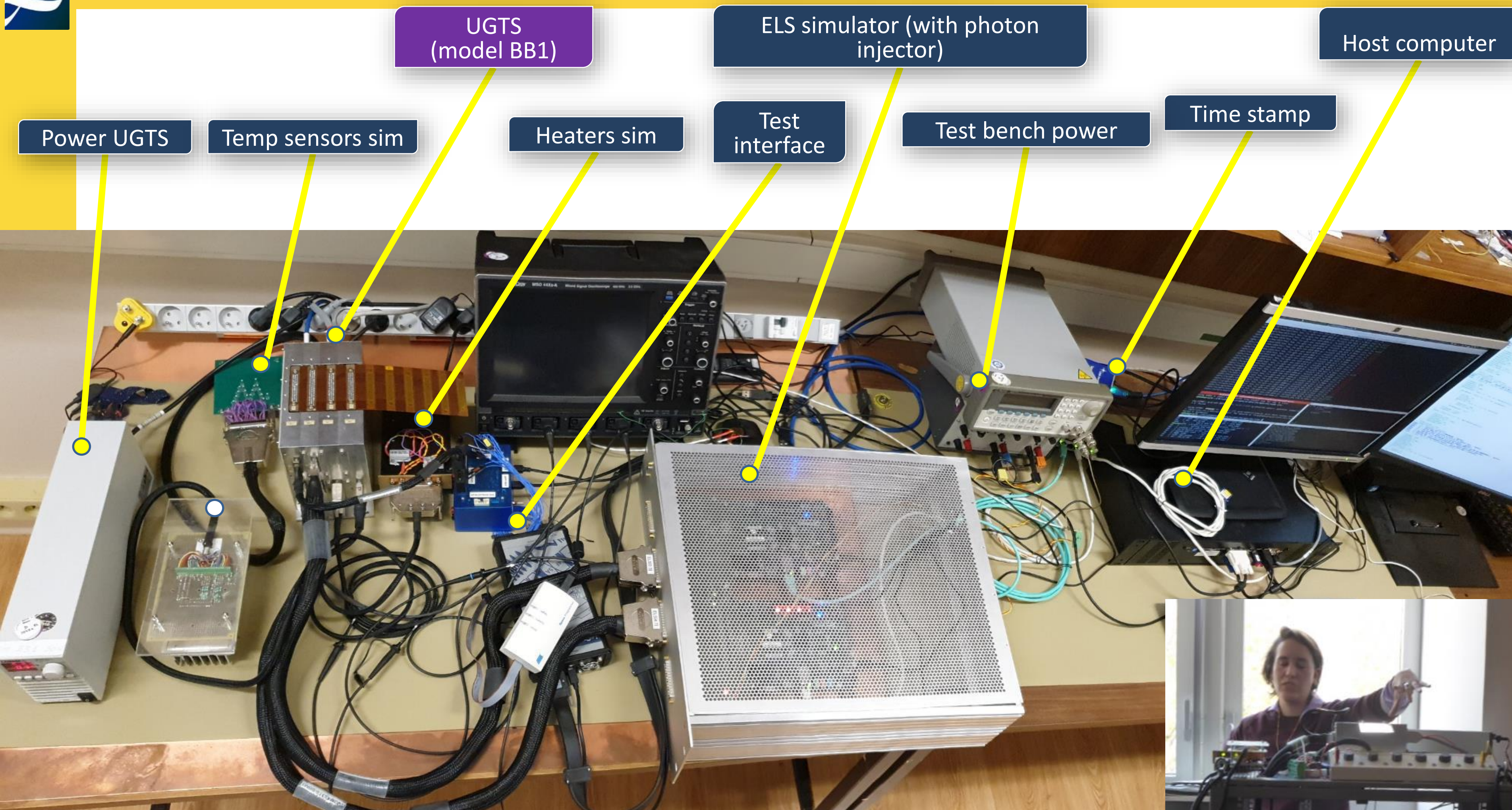


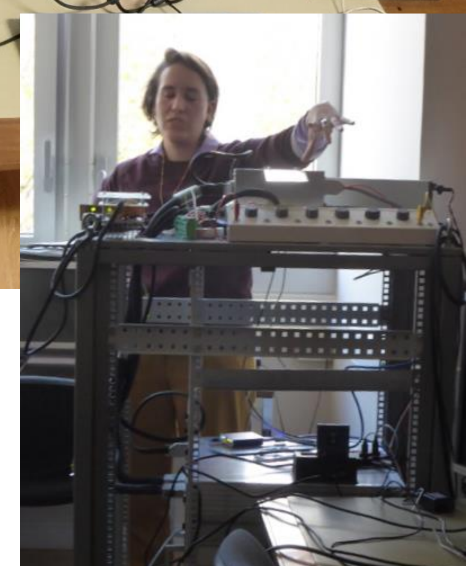
- Code repository on gitlab
- Build system autotools, configure, make
- Eclipse to edit and manage compilation and commits to gitlab

- Custom code developed as C++ libraries
  - compile on Linux (→ dev, test, scientific performance, EIC)
  - compile same library on Onboard processor (→ UGTS)
- Linked libraries

- Specific ground tools in C++ (visualization, file IO, etc)
  - additional libraries and executables
- Interface of C++ libraries with Python (swig, pybind11)
  - additional python scripts
- run python scripts, or jupyter notebooks

UGTS local test unit (LTU)



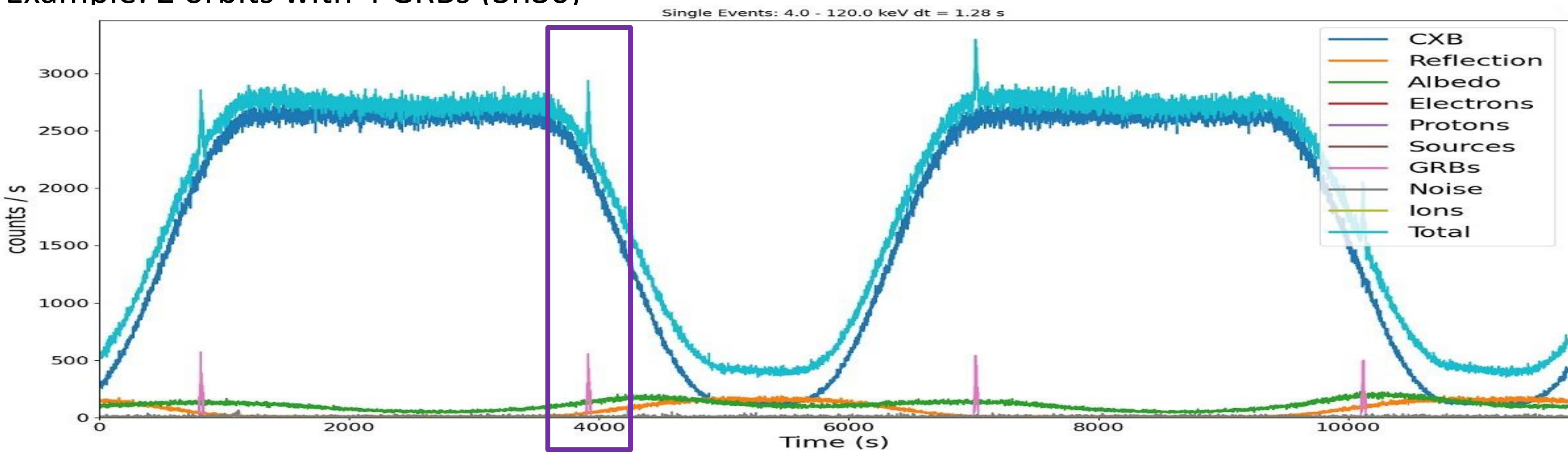


All in a rack now ➔
to be used for date playback in flight

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 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).

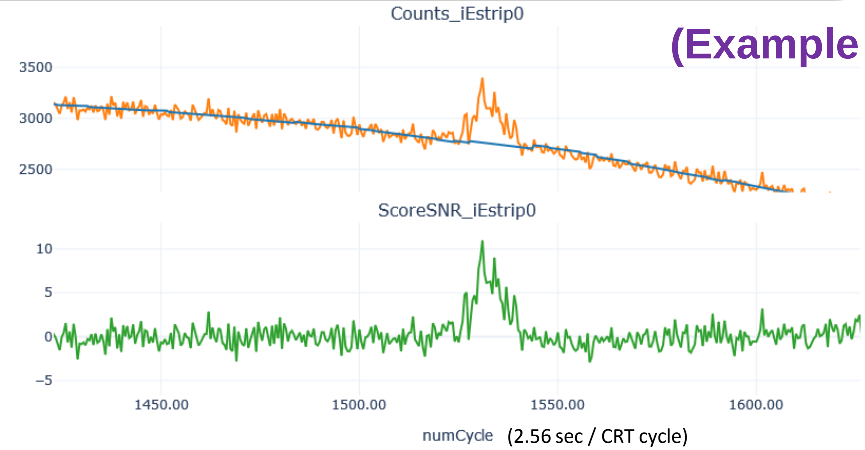
Image trigger (IMT) :
systematic imaging (20 s)
in 4 Energy strips,
sum images up to 20 min (each 20 s)

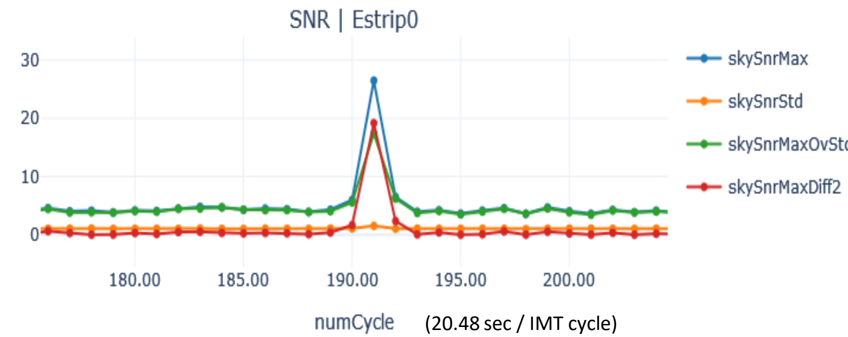
ECLAIRs trigger and alert sequence

CRT excesses (in SNR counts, before imaging)

IMT excess in SNR sky image

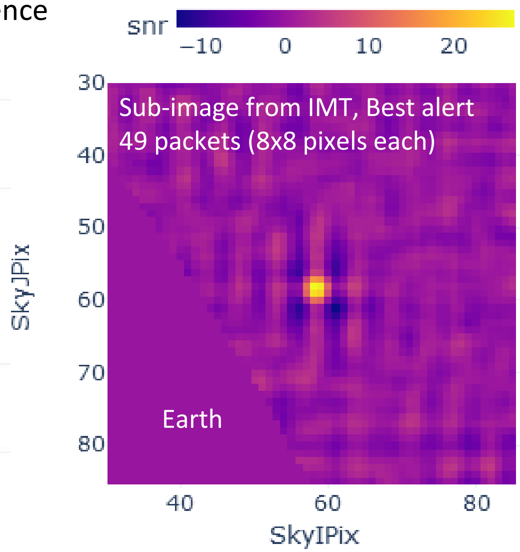
(Example of 2nd GRB)



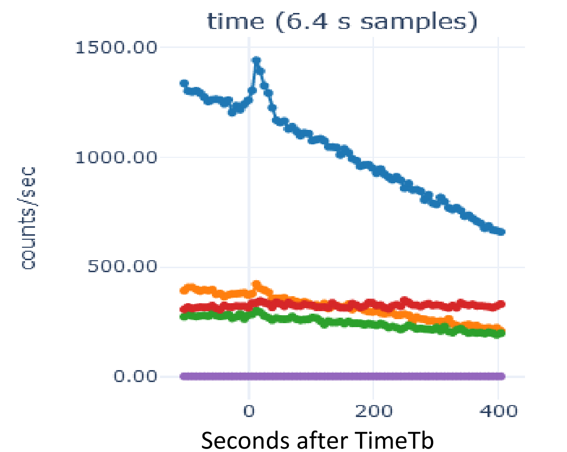


VHF alert sequence (output products built)

Localisation error circles of alerts in sequence



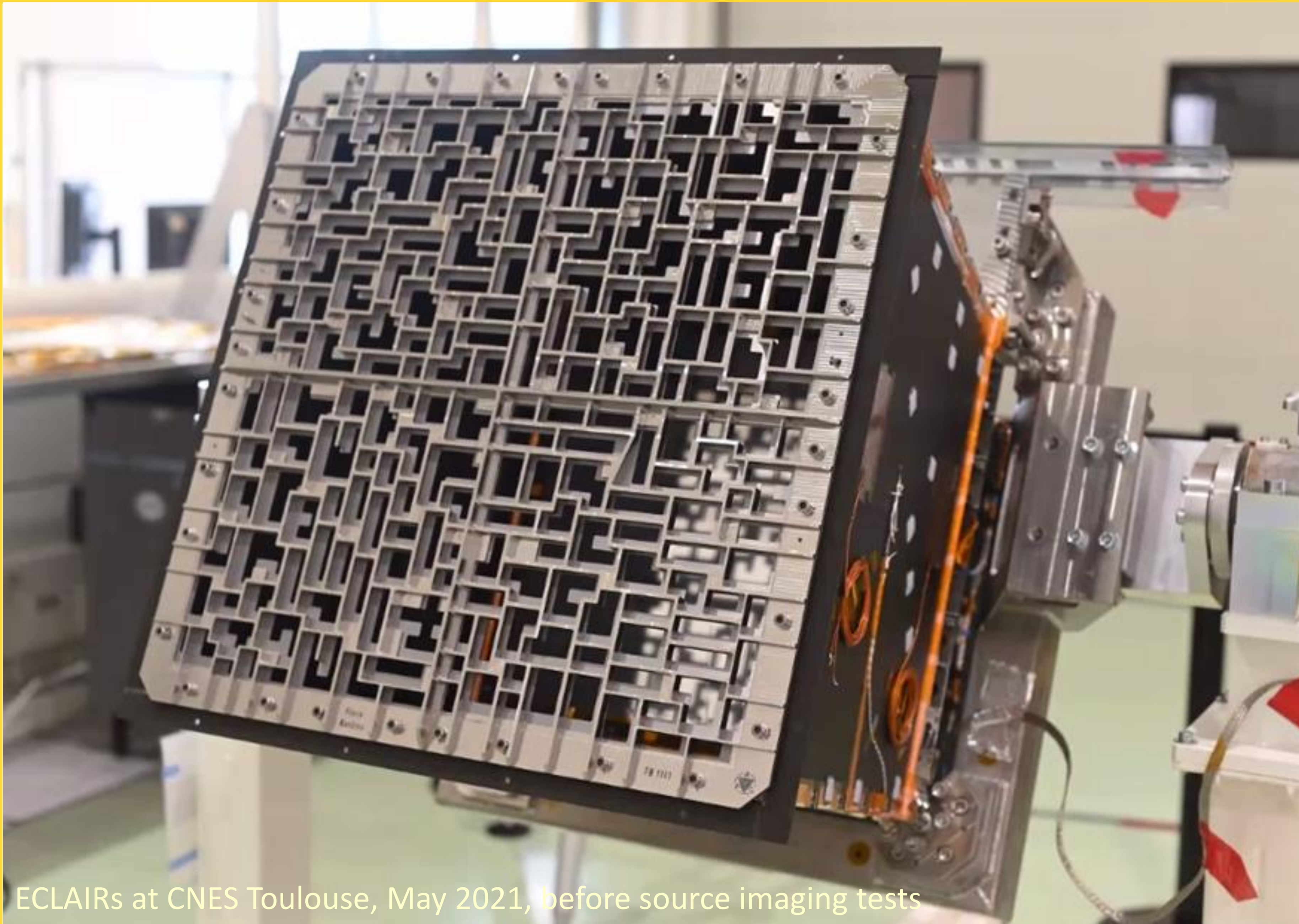
Lightcurves (3 resolutions):
- High/Mid/Low (0.1/0.8/6.4 s binning)
- Each: 4 Ebands + Saturating + Multiples



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

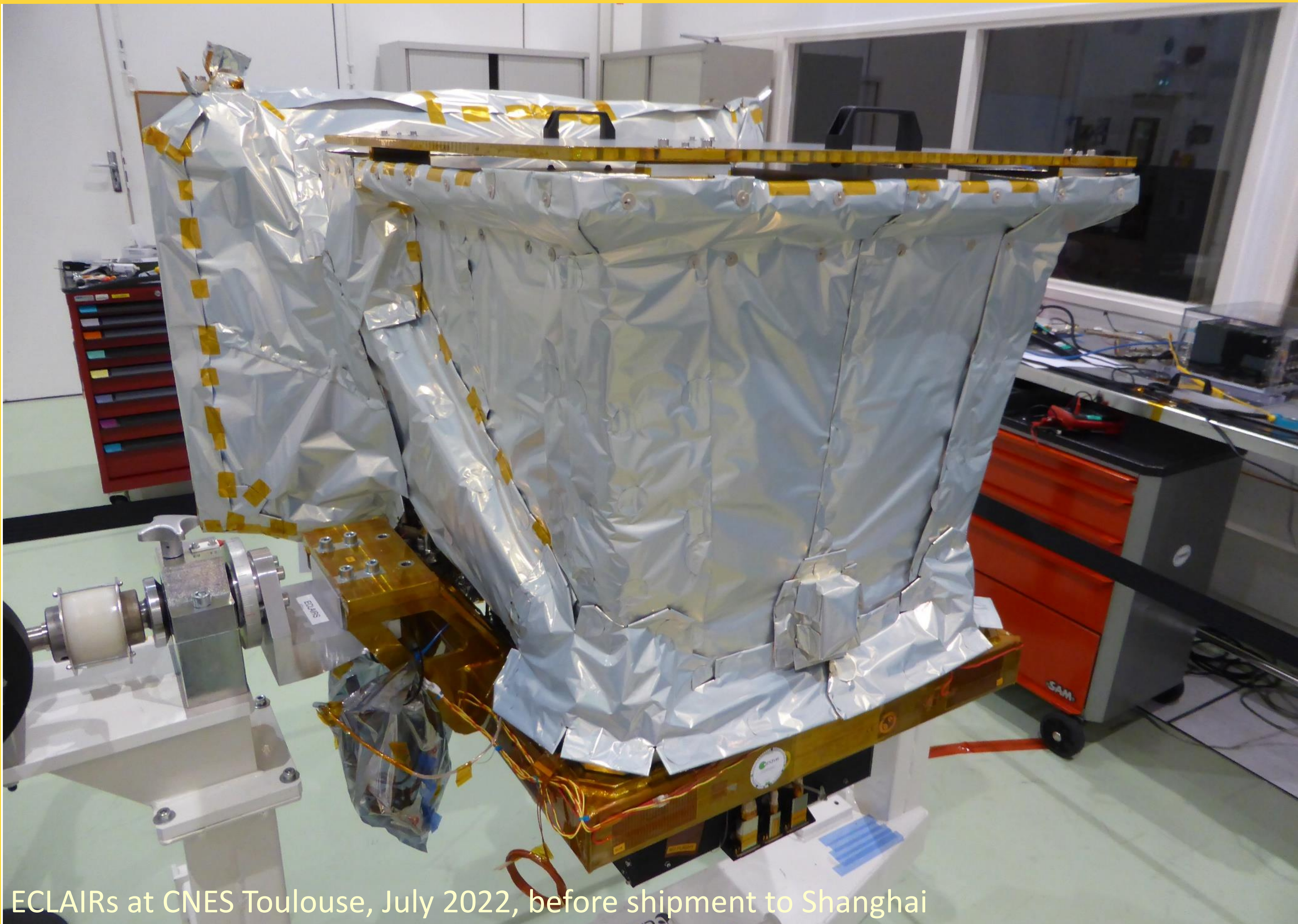
ECLAIRs calibration

ECLAIRs: coded mask imager (FM)



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

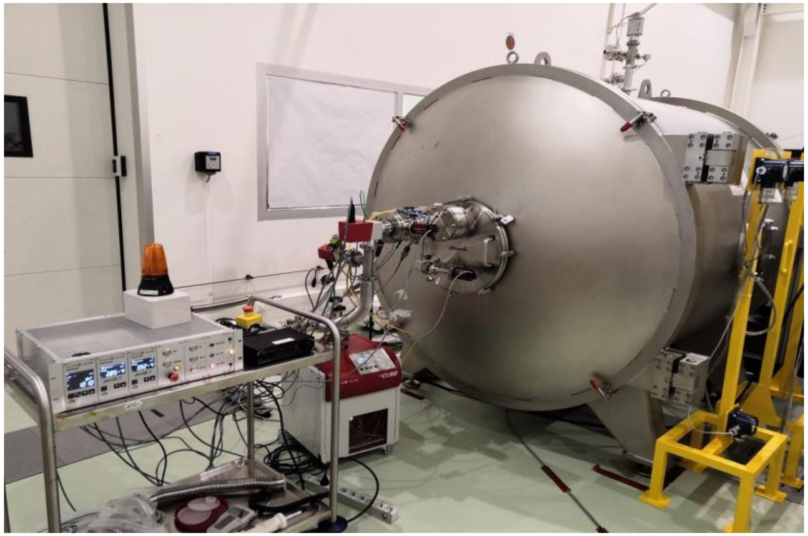
ECLAIRs: coded mask imager (FM)

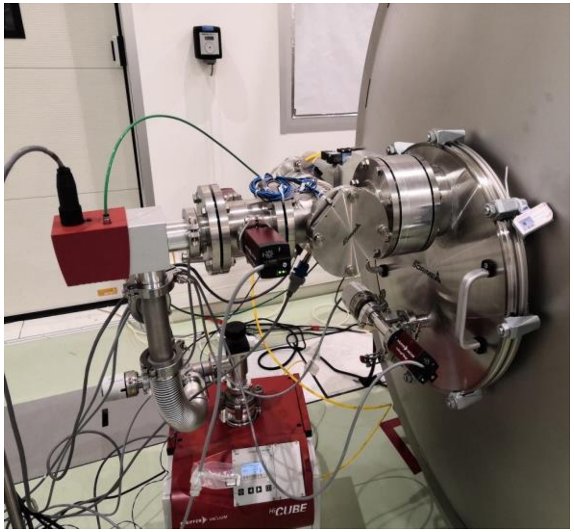


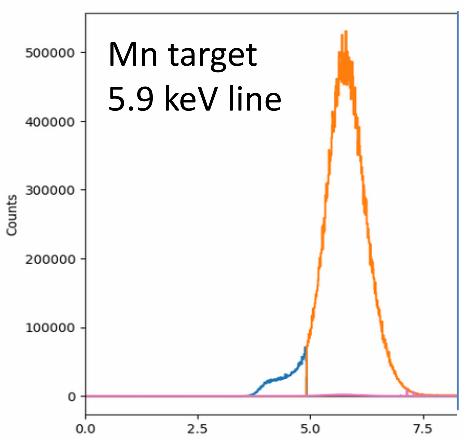
ECLAIRs at CNES Toulouse, July 2022, before shipment to Shanghai

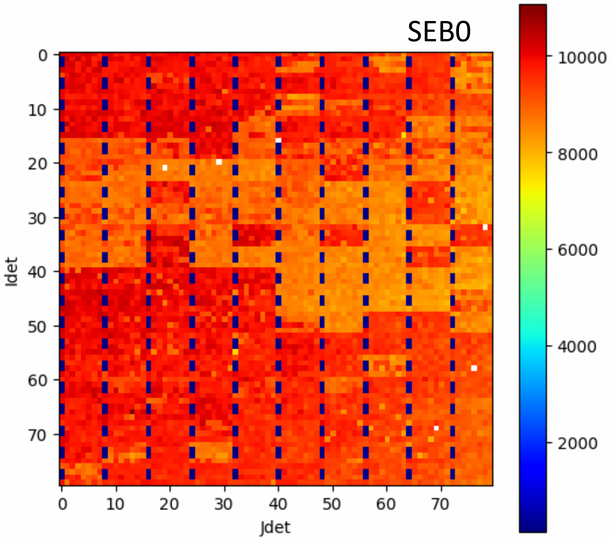
ECLAIRs without mask calibration

March 2021, CNES Toulouse, in clean room, Thermal Vaccum test
Test with X-ray generator, **ECLAIRs without mask**









- Inhomogeneity of detection plane at low Energy
- ***need to configure different efficiencies and weights in the deconvolution process***

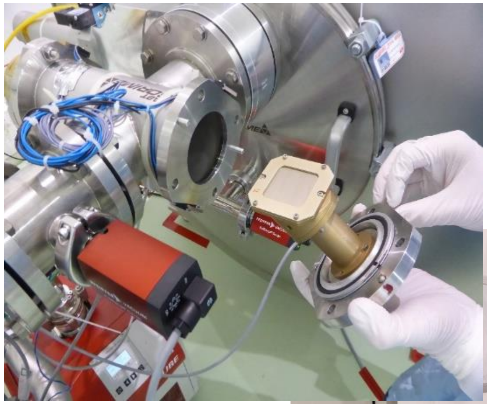
➔ ***Wenjin Xie (Thesis 2021-2024)***

ECLAIRs with mask calibration

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

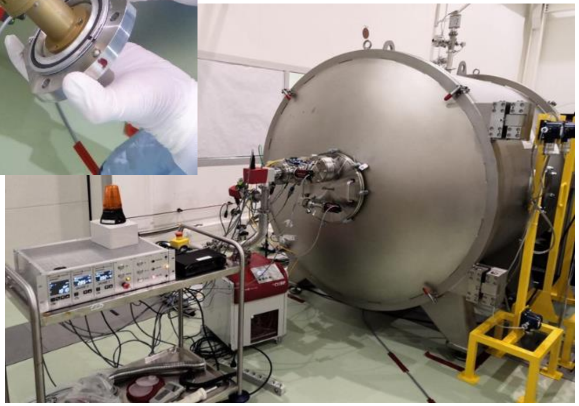
- Detector plane qualification (spectral properties, homogeneity, temp. response)
- Imaging tests at different energies with coded mask mounted (source at finite distance)
- Data acquisition test at high data rate (simulation of variable sources and high count-rates expected during SAA passages in low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

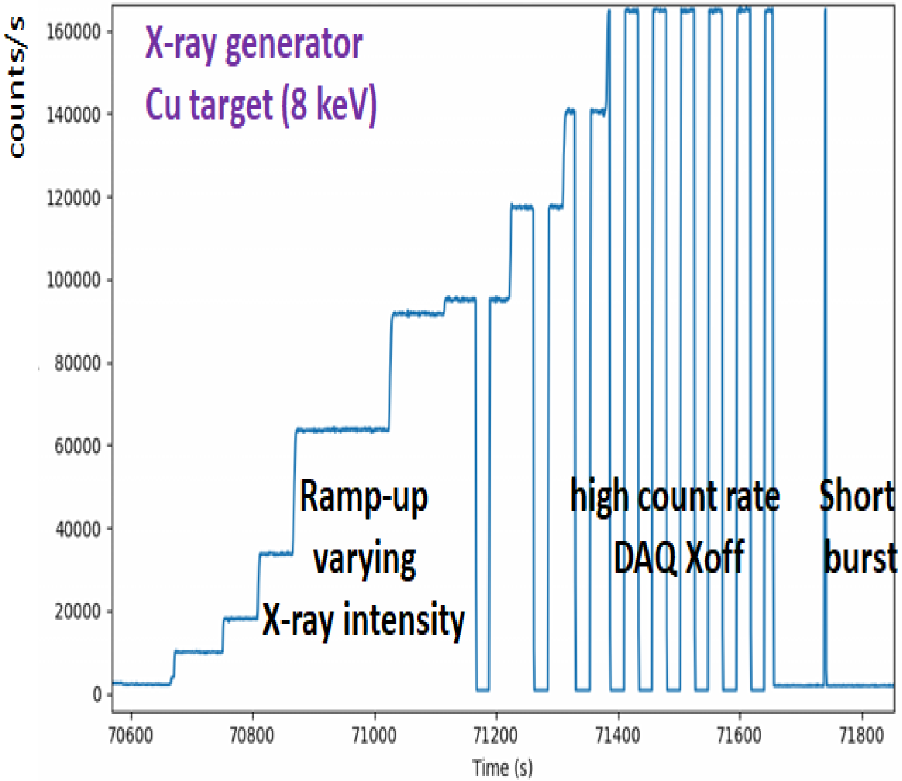
- radioactive sources, e.g. Co57 (6.4, 14.4 and 122 keV)
- X-ray generator + target, e.g. Ti, Mn, Cu, Ag, (4.5/5.9/8/22 keV).
- Variation of the X-ray generator intensity



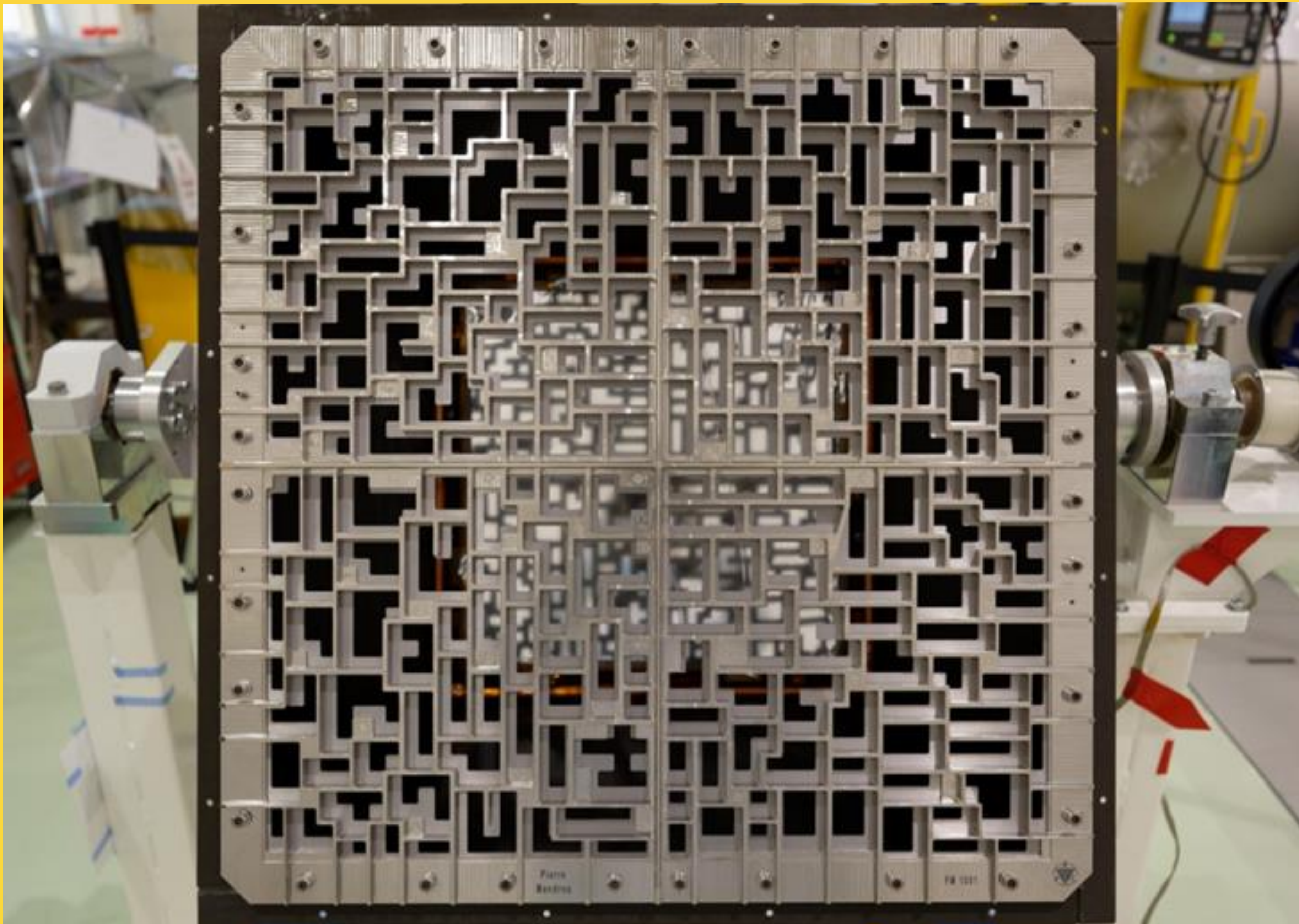
Cu target

ECLAIRs in vac. ch.

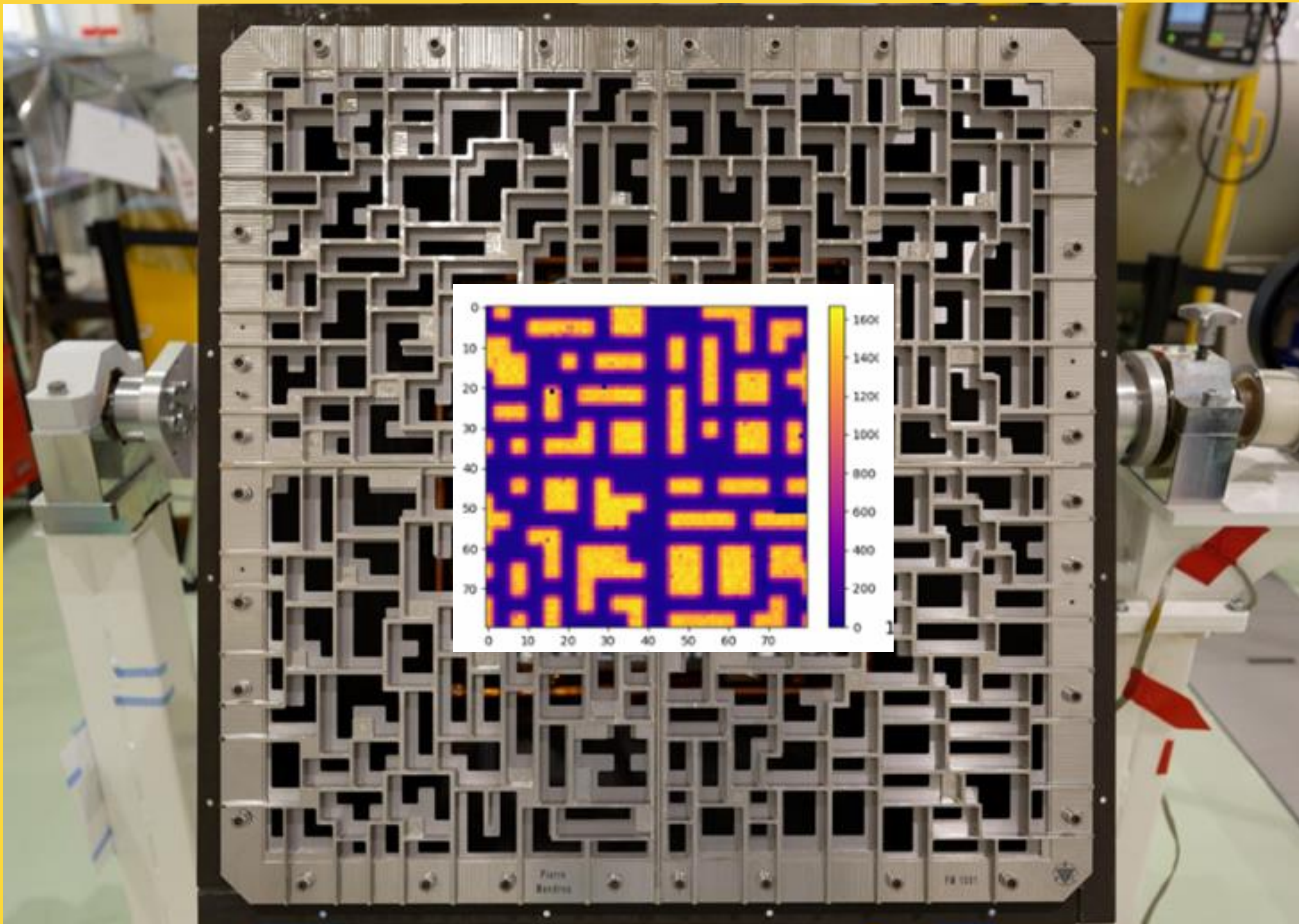




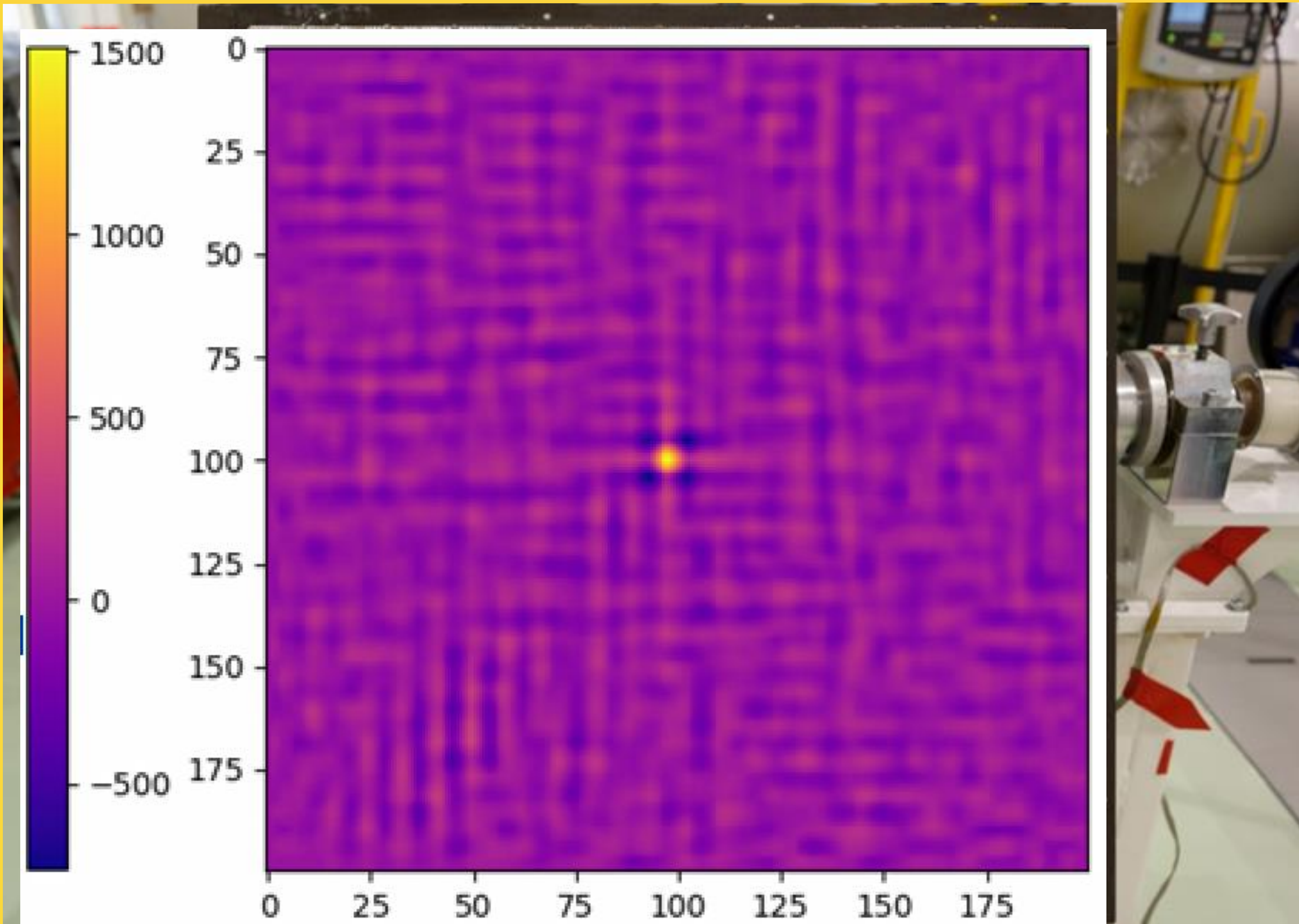
ECLAIRs imager & trigger instrument



ECLAIRs imager & trigger instrument



ECLAIRs imager & trigger instrument



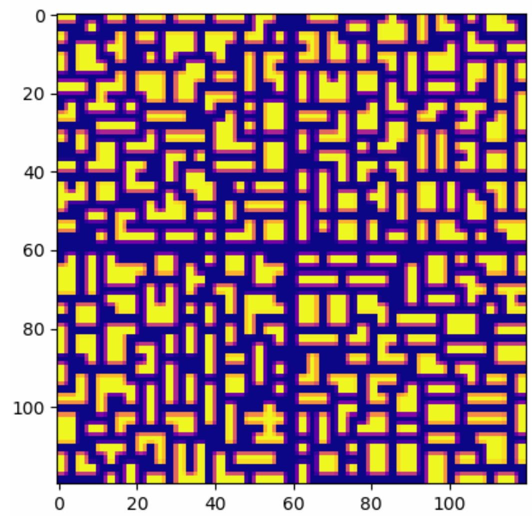
UGTS ASW first imaging test with ECLAIRs

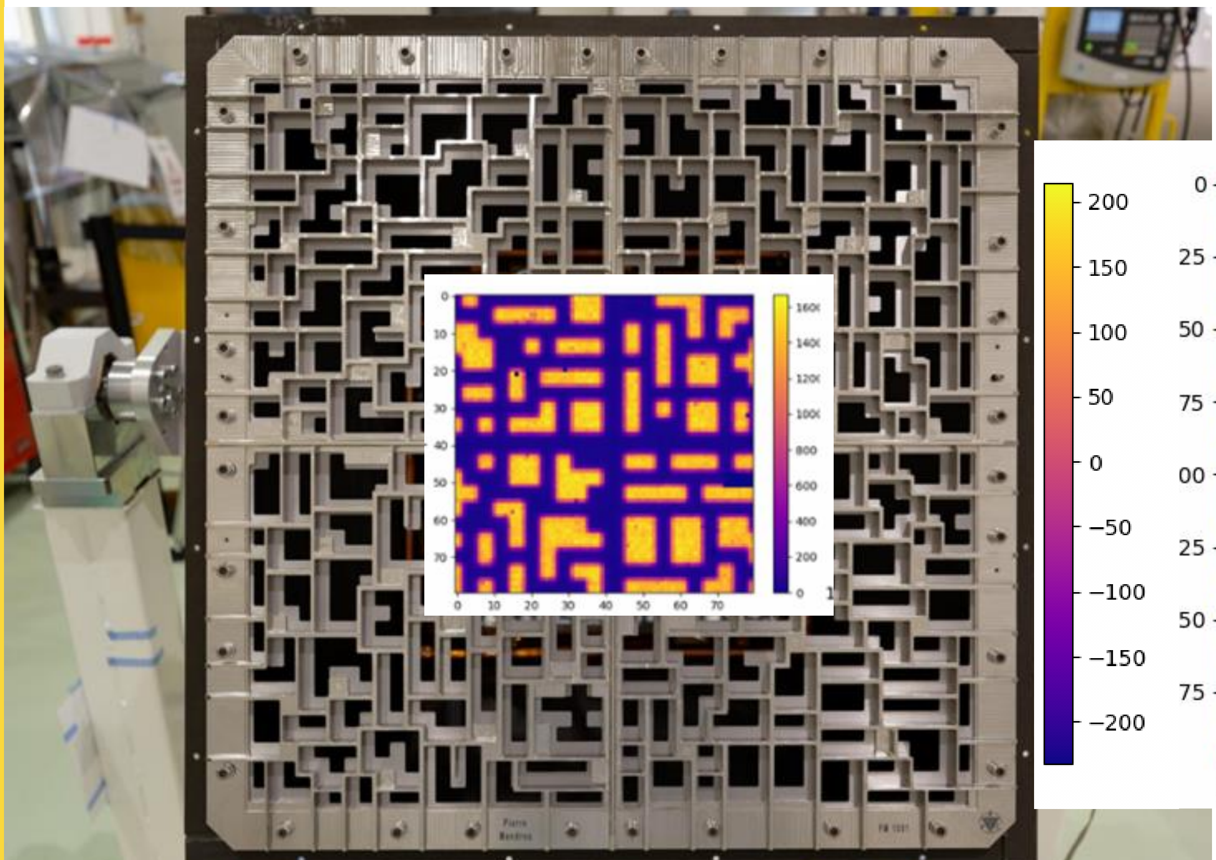
Test at CNES Toulouse (May 2021)

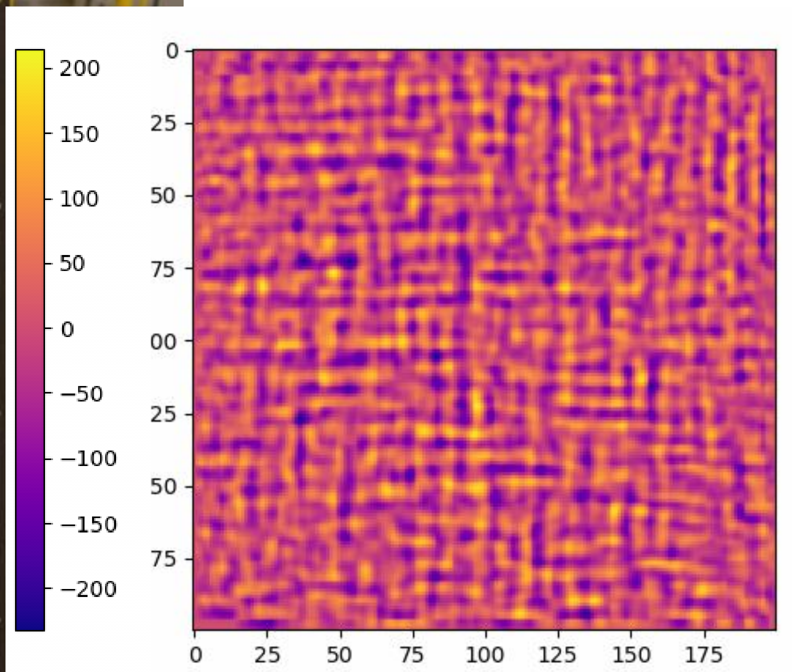
- **ECLAIRs with mask mounted**
- **UGTS with imaging software inside**

^{57}Co + ^{241}Am radioactive source
at 115 cm in front of ECLAIRs det plane

Mask zoom=1







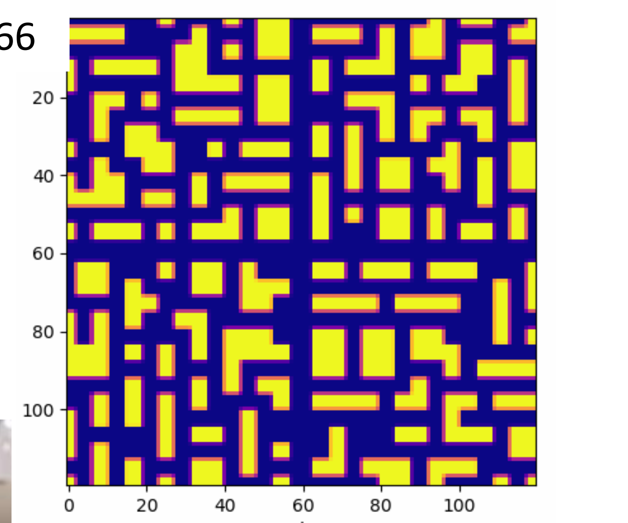
UGTS ASW first imaging test with ECLAIRs

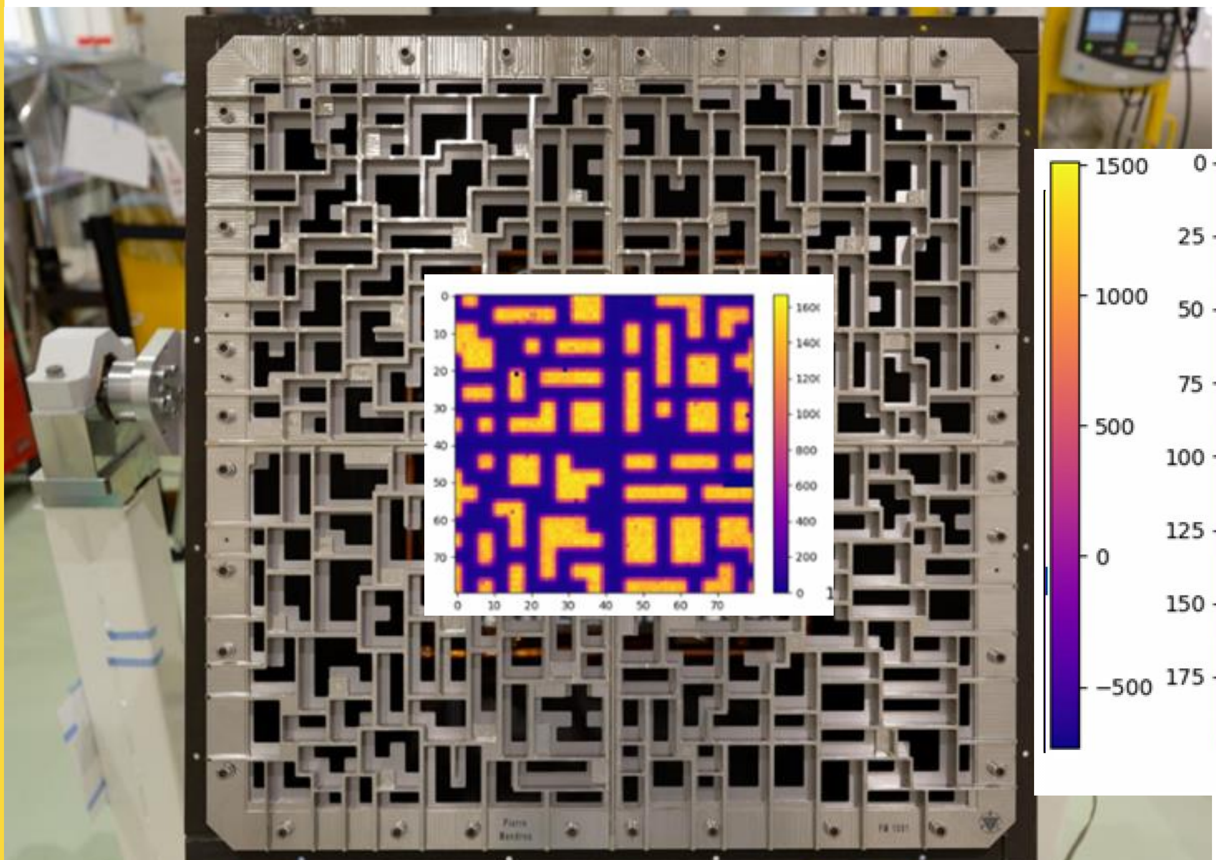
Test at CNES Toulouse (May 2021)

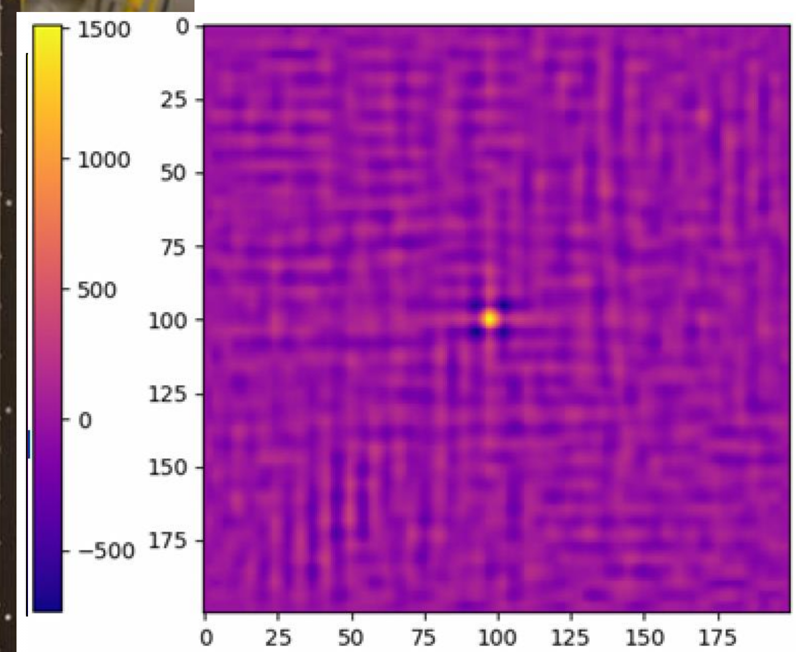
- **ECLAIRs with mask mounted**
- **UGTS with imaging software inside**

^{57}Co + ^{241}Am radioactive source
at 115 cm in front of ECLAIRs det plane

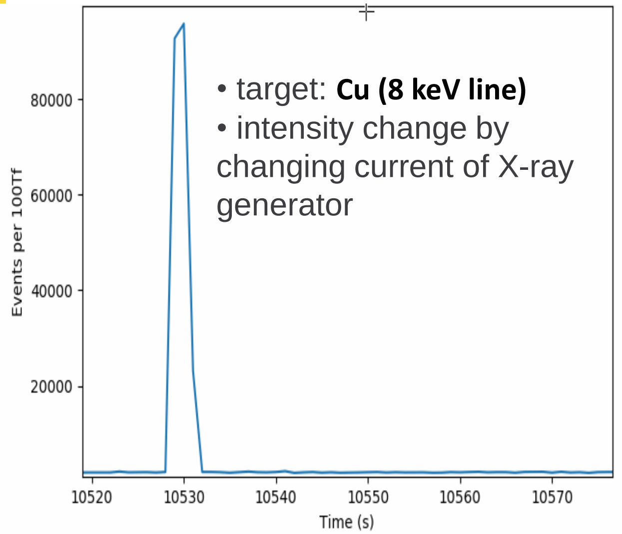
Mask zoom=1.66

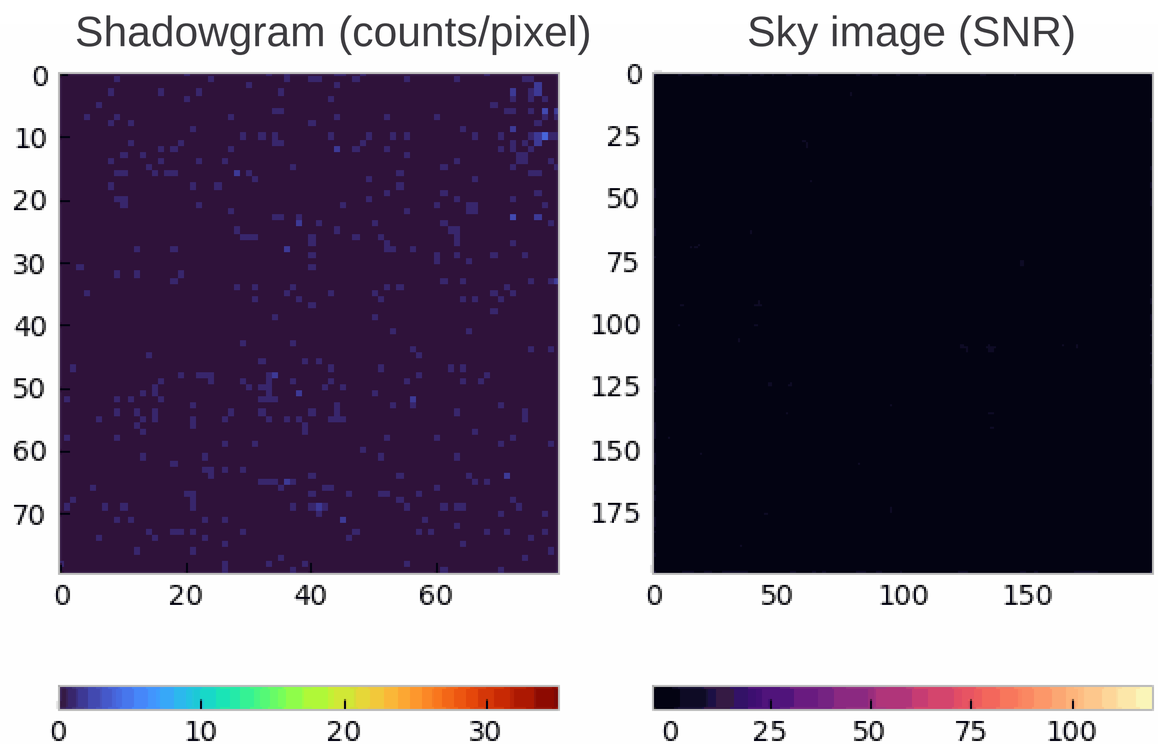


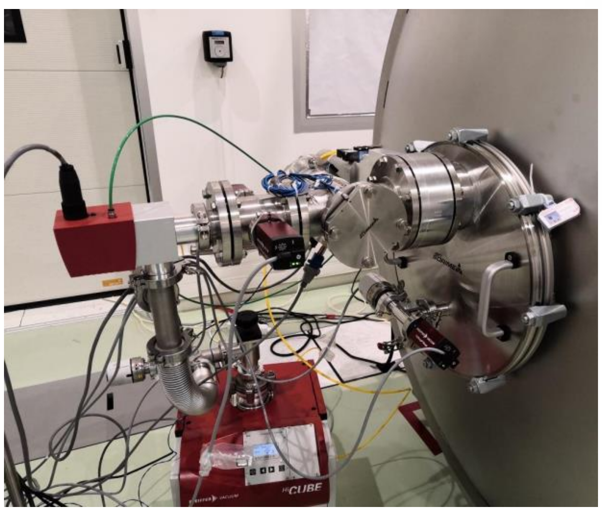




Artificial "GRB" with X-ray generator







X-ray generator "GRB" (duration ~2 s)

- animation with RawData output
- 10 s (20 images of 0.5 s exposure)
- déconvolution with zoom=1.38 (distance of source: 1.71 cm from detector)

UGTS LV 4.0.1 ***mai 2021***

SVOM integration pictures

SVOM integration: **VT instrument**

In 2022, the VT's flight model encountered two issues discovered:

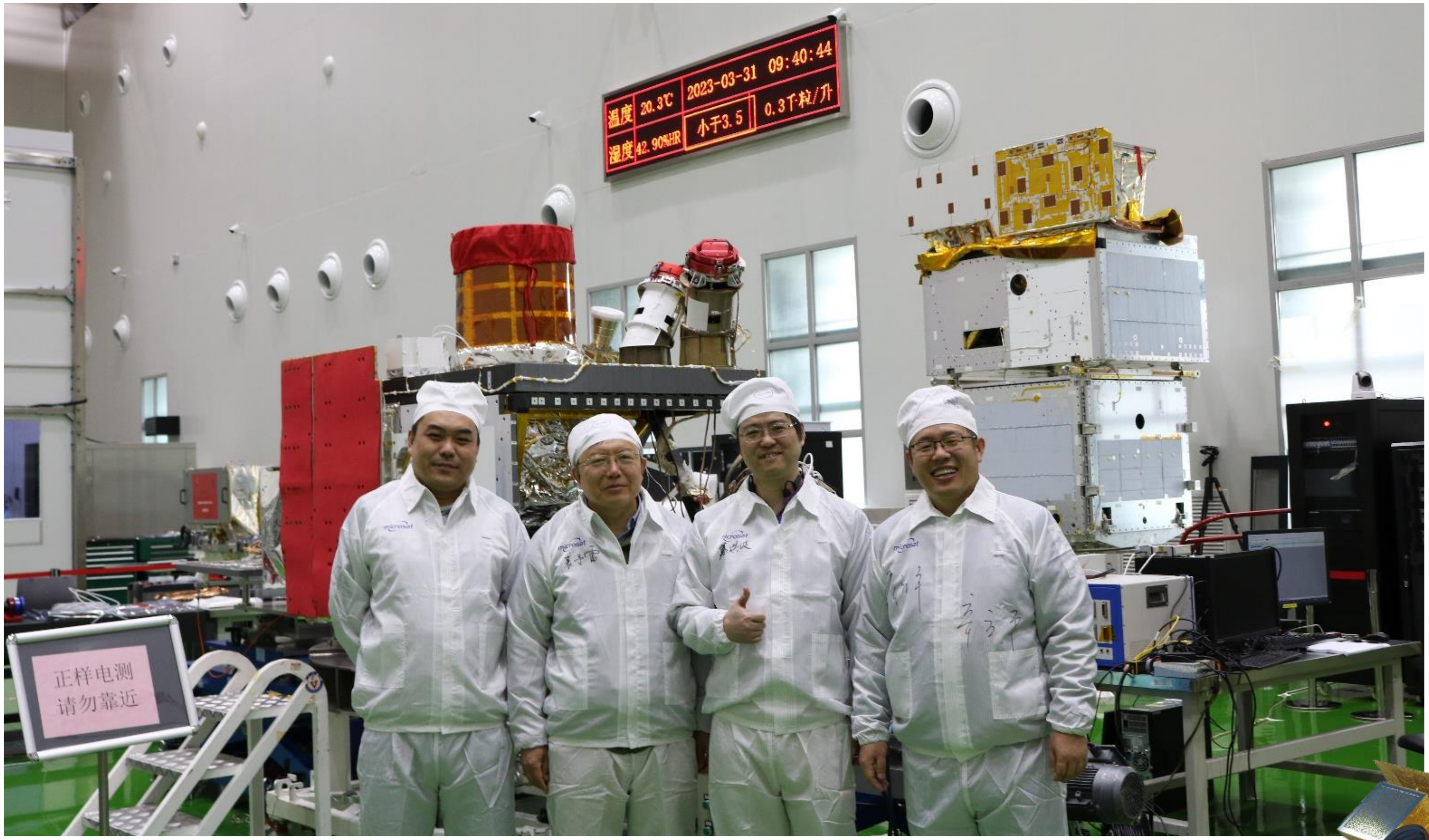
- thermoelastic instability in the secondary mirror, resulting in an enlarged PSF.
  - ➔ Modification of design and additional thermal control (+37 W).
- presence of stray light in the red channel
  - ➔ Addition of a micro-baffle at the entrance of the telescope

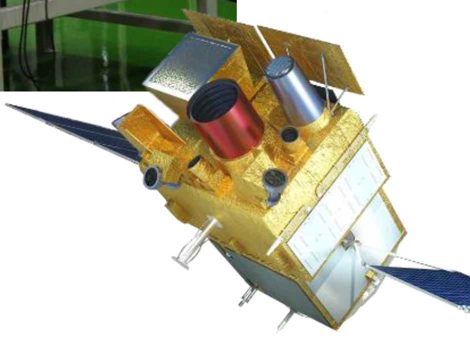
  Solutions has a very low impact on the performance of the VT.

The VT was delivered to Shanghai on February 10, 2023.
VT in integration room at Shanghai SECM/IAMC

SVOM integration: **VT instrument integration**

End March 2023 VT integration on the Payload module at Shanghai IAMC





SVOM integration: **French instruments delivery**

- The delivery of French instruments to China (Shanghai) was a complicated task that had to overcome difficulties related to the pandemic and the war in Ukraine.
- After several episodes, CNES finally managed to ship the ECLAIRs and MXT instruments by plane on March 10. The entire set arrived in Shanghai on March 11.
- A mixed team (CNES + labs) left at the end of March to start the integration activities of the French instruments on the Payload module (PIM).

SVOM integration: **French instruments delivery**

10 March 2023

The French instruments ECLAIRs and MXT as well as the equipment necessary for the integration activities have left CNES for Shanghai.

10-12 March 2023

The French instruments ECLAIRs and MXT are transported by plane from Luxembourg to Shanghai, over Baku/Azerbaijan

SVOM integration: **French instruments delivery**

24 March 2023

The two instruments ECLAIRs and MXT, together with part of the French team, have arrived at the integration site, at the Innovation Academy for Microsatellites of the Chinese Academy of Sciences (IAMC).

SVOM integration: **French instruments integration**

5 April 2023

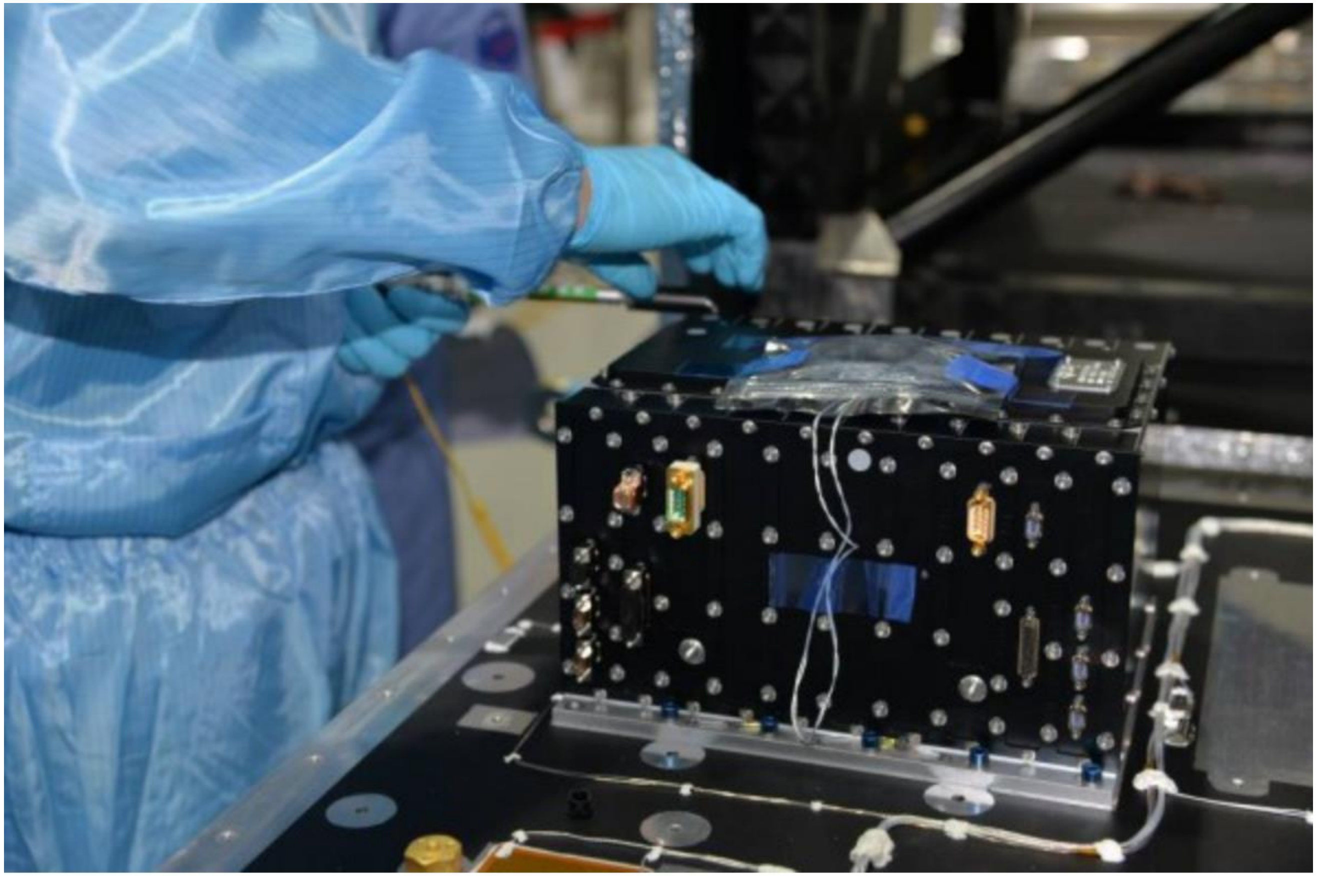
- Week of 27 March: the ECLAIRs and MXT instruments were taken out of the transport boxes and placed on mechanical supports. The electronic boxes of the two computers were tested on their own, then connected to ECLAIRs and MXT: "everything is ok".
- Checks were carried out to verify the mechanical interfaces of the French instruments with the PIM (Payload Interface Module, between the instruments and the satellite). This ensures that ECLAIRs and MXT are aligned on the same optical axis.

SVOM integration: **French instruments integration**

5 April 2023

- Flight software of ECLAIRs/UGTS**: Version 7.0.3**, delivered to CNES on Feb 14, is implanted on the UGTS FM (8 onboard copies in various memory locations, replacement of version 7.0.2

ECLAIRs UGTS box in Shanghai



SVOM integration: **French instruments integration**

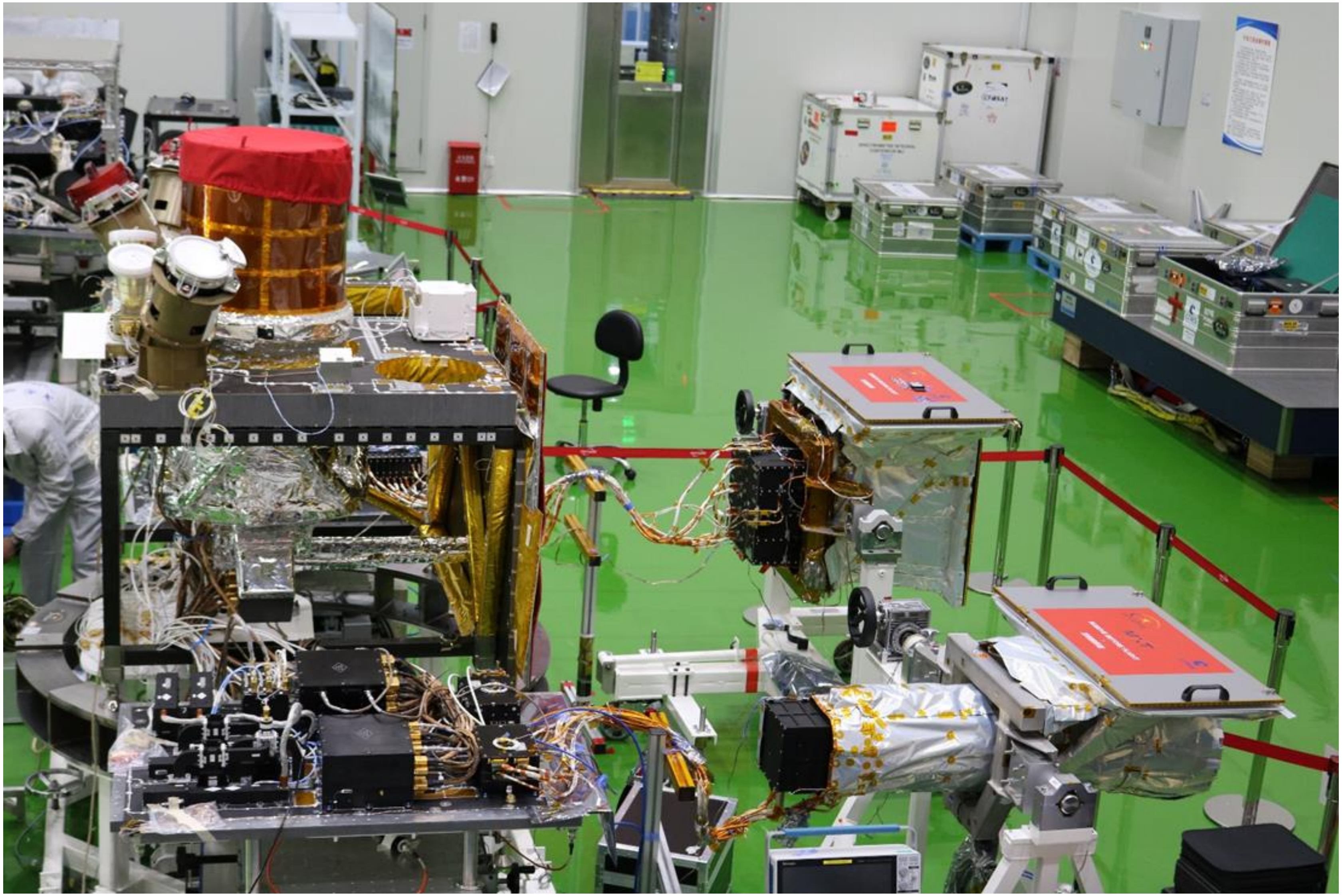
11 April 2023

- The electronic boxes of the two French instrument computers: ECLAIRs (UGTS box) and MXT (MDPU boxes) were attached to the PIM (Payload Interface Module, between the instruments and the satellite) and the connection with the instruments was tested.
- In parallel, on the mechanical side, rehearsals of the instrument integration activities were carried out with the qualification model of the satellite platform and the structural and thermal models of the instruments.

SVOM integration: **French instruments integration**

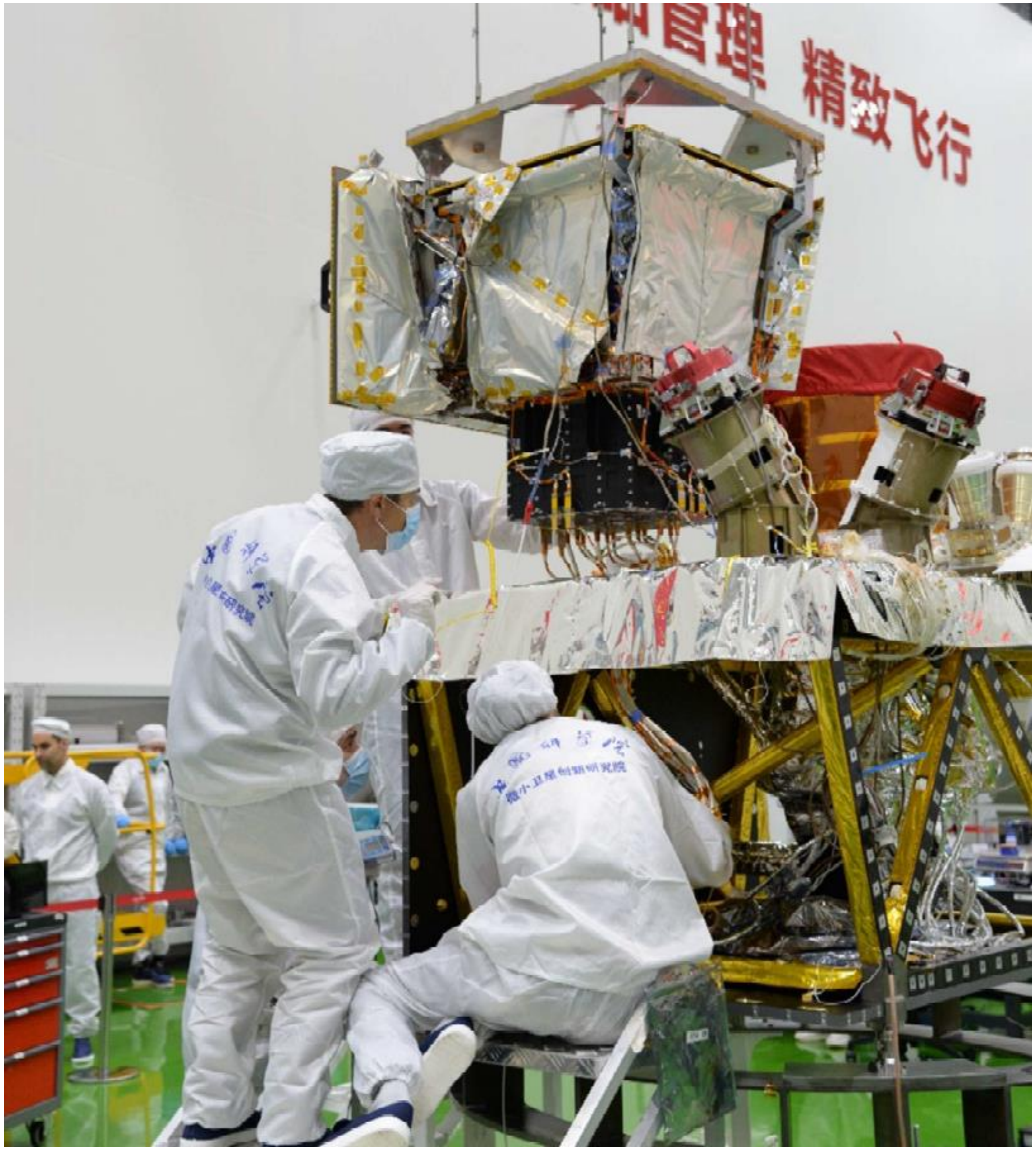
mid April 2023

Preparation of the integration of ECLAIRs and MXT on the PIM



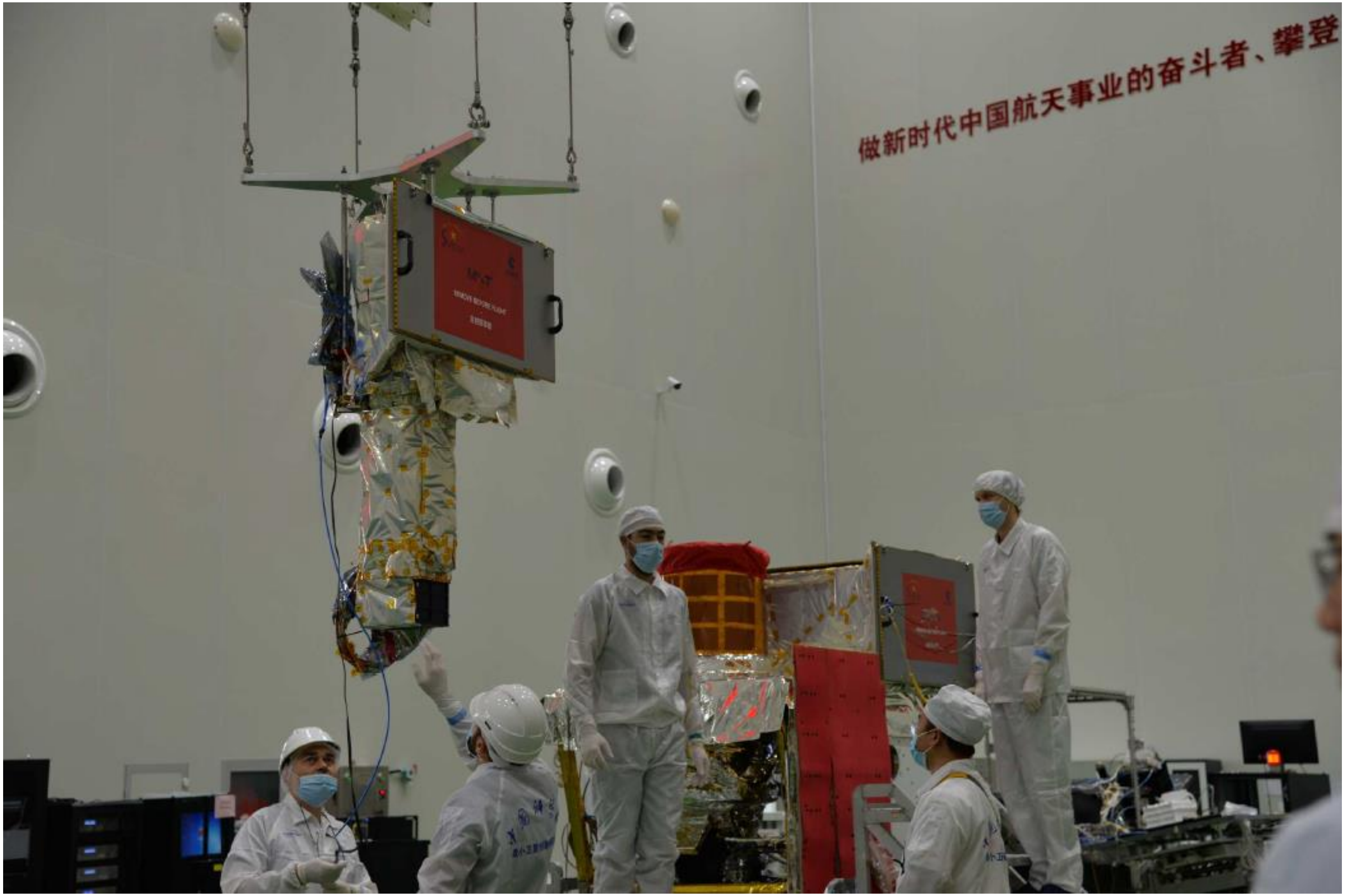
SVOM integration: **ECLAIRs instrument integration**

24 April 2023 integration of ECLAIRs on the PIM



SVOM integration: **MXT instrument integration**

26 April 2023 integration of FM on the PIM



SVOM integration: **All instruments are integrated**

SVOM integration: **All instruments are integrated**

- Satellite integration activities and system tests are continuing normally.
- The satellite is expected to be ready by the end of 2023.

SVOM: **Next milestones**

- Satellite integration and associated tests:

  - In May 2023, system tests are conducted to test the ground segment with a satellite simulator (Nominal Mission Scenario).
  - In June 2023, compatibility tests for onboard-to-ground links, X-band, S-band, and VHF (for SVOM and Einstein Probe) will be conducted.
  - In July 2023, an End-to-End system test will be conducted with the flight model of the satellite, but with the instruments at ambient temperature.
  - From July to September, environmental tests will be conducted (at the end of which there will be three weeks of thermal vacuum testing, including two days of instrument performance testing at operating temperature).

- In early December, the Final Acceptance Review will be held in China.

- One month before the launch, a general rehearsal of the ground segment will be organized by NSSC in Beijing (with all operational centers included).

- The launch of SVOM is expected to take place before end of March 2024.

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)
- Satellite integration ongoing

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

SVOM Qualification Model

Road to go:

- EndToEnd +TVAC tests of assembled SVOM on ground
- Launcher integration and launch campaign before march 2024
- SVOM commissioning phase to take place in 2024

Go SVOM !!

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 …)*