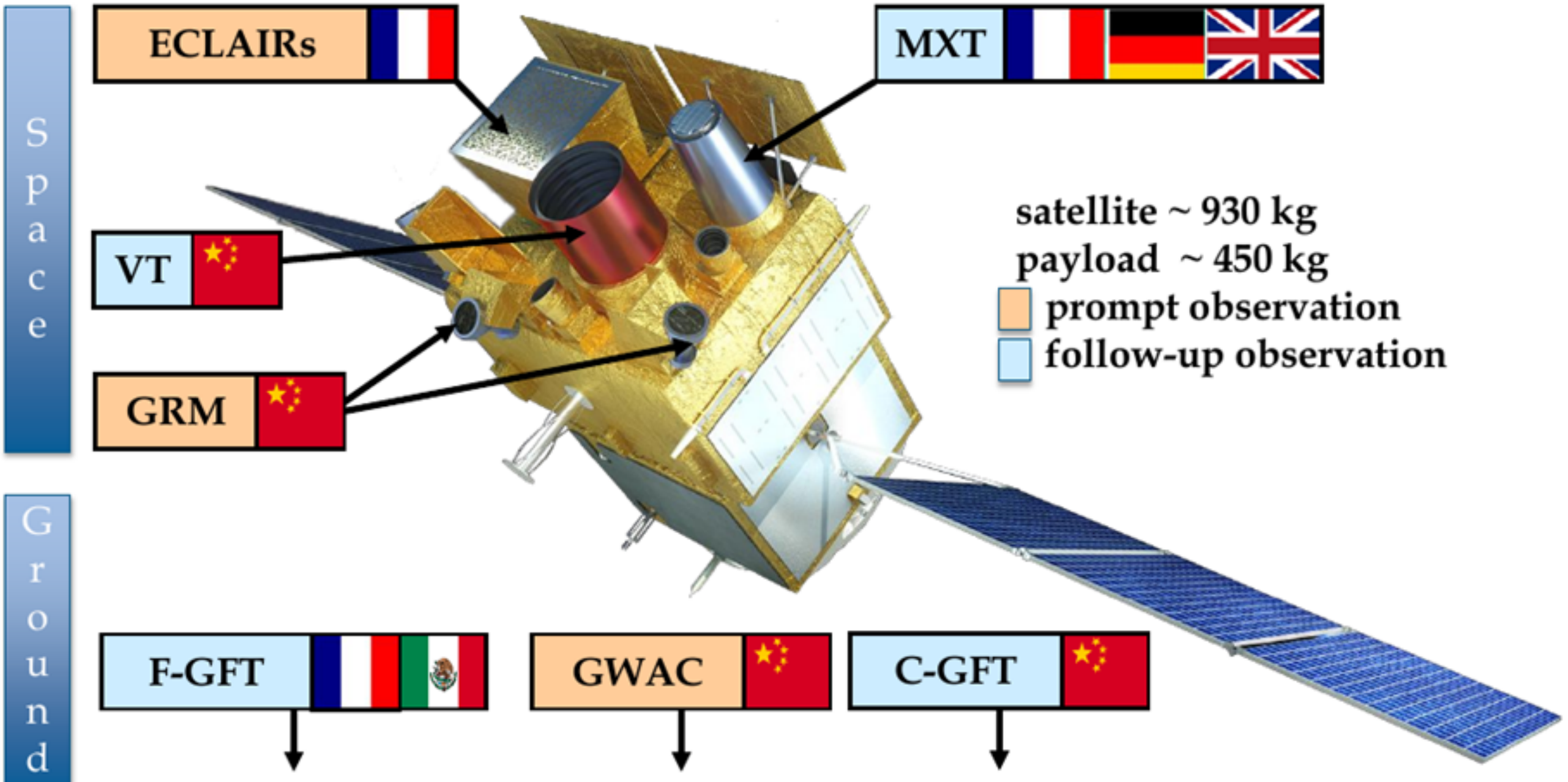
ECLAIRs: THE GRB DETECTOR AND IMAGER FOR THE SVOM MISSION

J.-L. ATTEIA (IRAP, TOULOUSE)
ON BEHALF ON THE SVOM/ECLAIRs COLLABORATION



THE SVOM CONSORTIUM

- **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
- **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

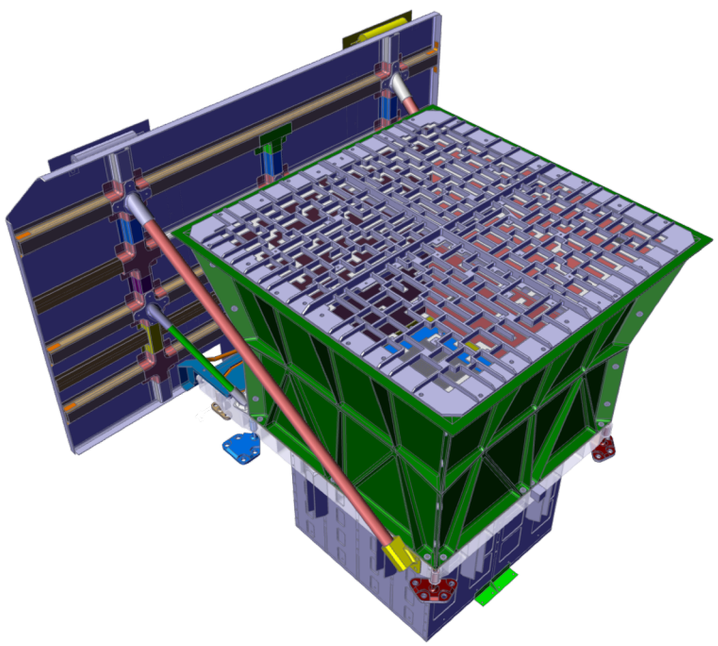
Taking into account the feedback from

Neil Gehrels Swift obs. & Fermi
for space observations

TAROT
for ground observations

- **Mexico** UNAM Mexico
- **UK** University of Leicester
- **Germany**
  - MPE Garching
  - IAAT Tübingen

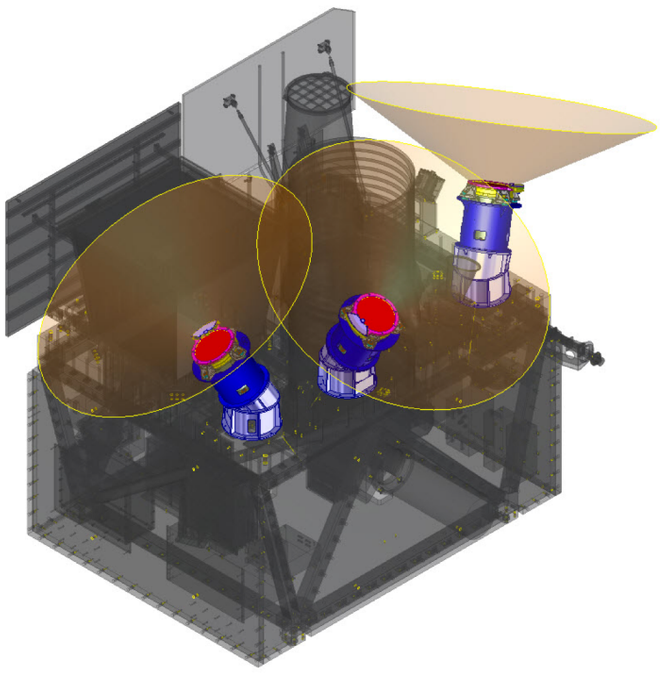
SPACE INSTRUMENTS with LARGE FIELD OF VIEW



ECLAIRs (CNES, IRAP, CEA, APC)

- 40% open fraction
- Detection area: **1000 cm²**
- **6400 CdTe pixels** (4x4x1 mm^3)
- **FoV: 2 sr** (zero sensitivity)
- Energy range: **4** - 150 keV
- **Localization** accuracy **<12 arcmin** for 90% of sources at detection limit
- Onboard trigger and localization: **~65 GRBs/year**

Well adapted for the detection of long GRBs with low E_{PEAK}

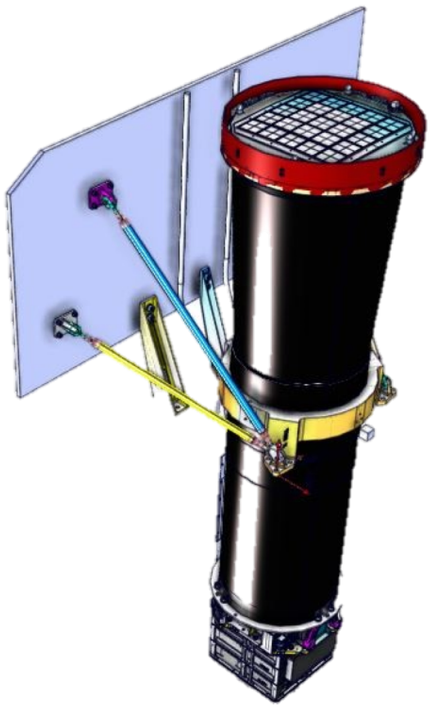


GRM Gamma-Ray Monitor (IHEP)

- **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:2.6 sr per GRD**
- **Energy range: 15-5000 keV**
- Aeff = 190 cm² at peak
- Rough localization accuracy
- Expected rate: **~90 GRBs / year**

Will provide E_{PEAK} measurements for most ECLAIRs GRBs
Will detect GRBs and transients out of the ECLAIRs FOV (with poor localization)

SPACE INSTRUMENTS with NARROW FIELD OF VIEW



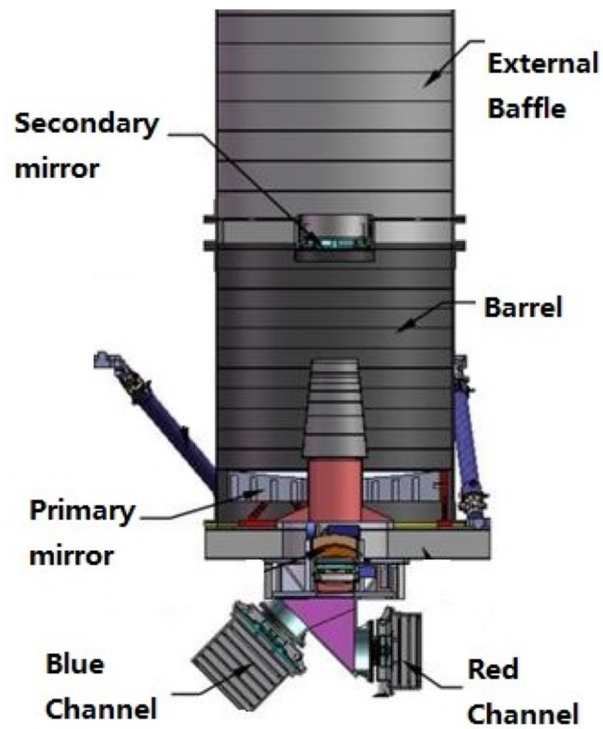
MXT Micro-channel X-ray Telescope (CNES, CEA, UL, MPE)

- **Micro-pores optics** (Photonis) with **square 40 µm pores** in a "Lobster Eye" conf. (UL design)
- pnCCD (MPE) based camera (CEA)
- **FoV: 64x64 arcmin²**
- Focal length: 1 m
- **Energy range: 0.2 - 10 keV**
- Aeff = 27 cm² @ 1 keV (central spot)
- Energy resolution: ~80 eV @ 1.5 keV
- **Localization accuracy <13 arcsec** within 5 min from trigger for 50% of GRBs (statistical error)

Implements innovative focusing X-ray optics based on « Lobster-Eye » design
Will be able to promptly observe the X-ray afterglow

VT Visible Telescope (XIOMP, NAOC)

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



Able to detect high-redshift GRBs up to z~6.5 (sensitivity cutoff around 950 nm)
Can quickly provide redshift indicators due to the presence of two channels

GROUND BASED INSTRUMENTS

Ground-based Wide Angle Camera (GWAC)

- **In China:** 40 cameras of 180 mm diameter at Ali Obs.
  - **total FOV ~6000 deg²** ; limiting magnitude 16 (V, 10s)
- **In Chile**: 50 cameras of 250 mm diameter at CTIO
  - **total FOV ~5000 deg²** ; limiting magnitude 17 (V, 10s)

- Operational since 2017, currently participating to O3.

Chinese Ground Follow-up Telescope (C-GFT)

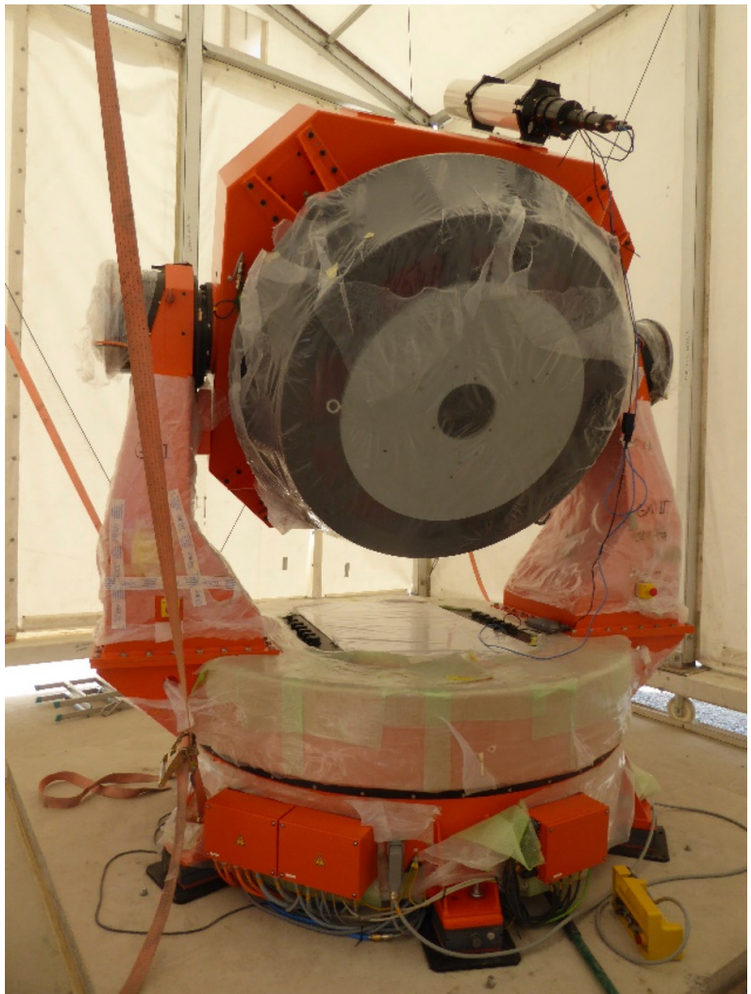
- **Robotic 1.2m telescope**, Weihai Observatory
- FoV = 21x21 arcmin², 400-950 nm

French Ground Follow-up Telescope (F-GFT)

- **Robotic 1.3m telescope**, San Pedro Mártir **(Mexico)**
- FoV = 26x26 arcmin²
- Multi-band photometry (400-1780 nm, 3 simultaneous channels)

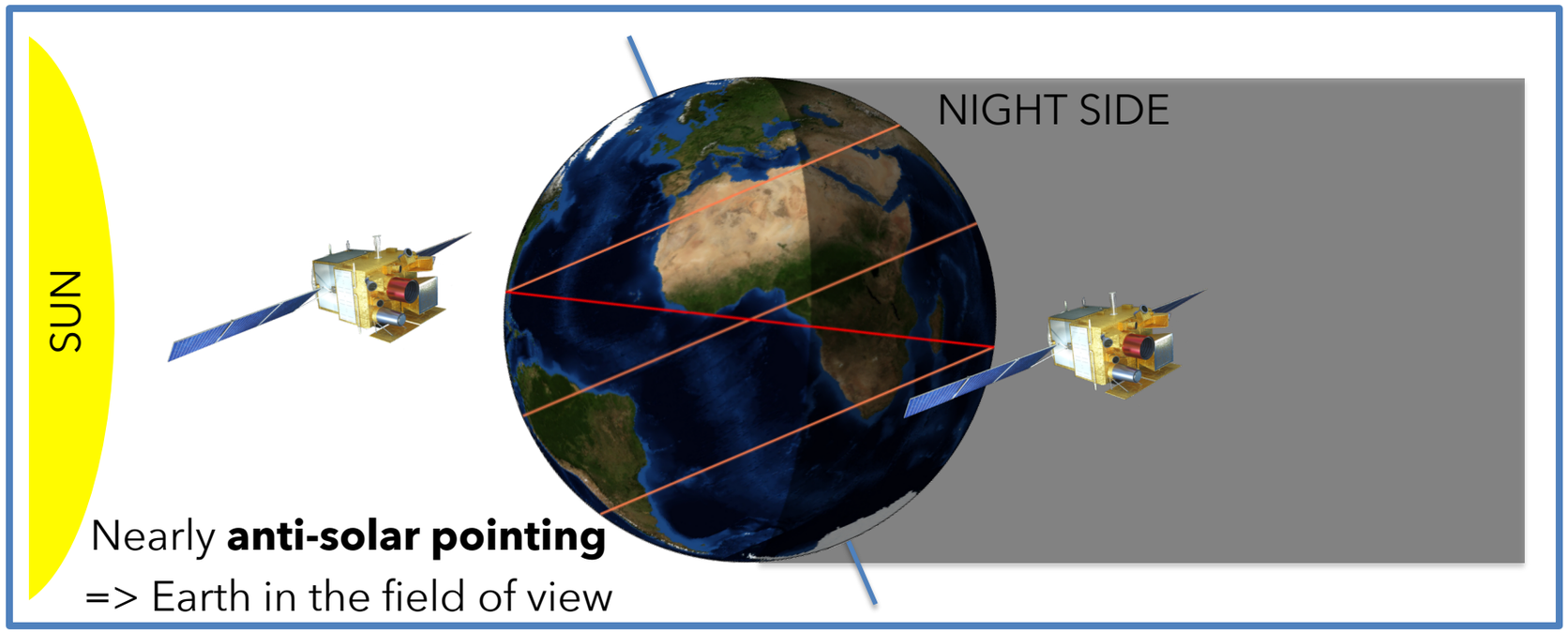
Contribution to the LCOGT network (12x1m+2x2m tel.)

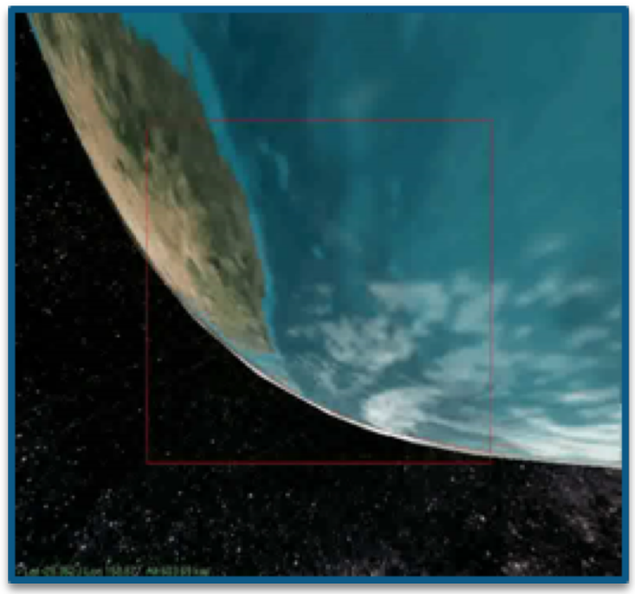
- >75% of ECLAIRs-detected GRBs will be immediately visible by one ground telescope (GFT or LCOGT)



ORBIT AND POINTING STRATEGY

Optimizing the ground follow-up of GRB candidates in order to increase the success of ground-based redshift measurements.



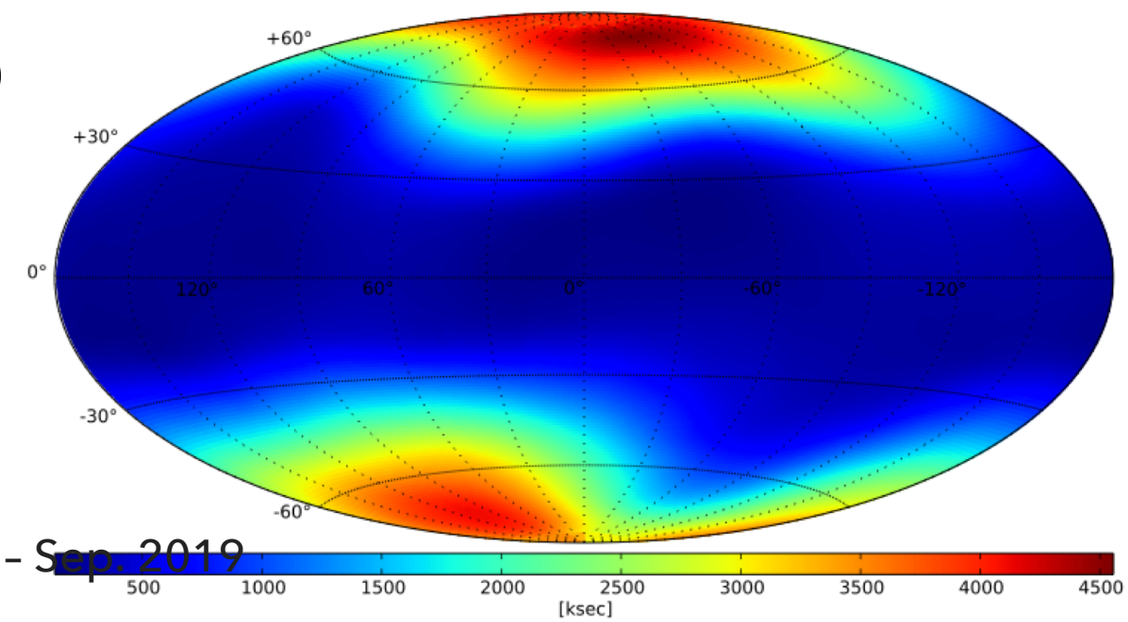


65% of duty cycle for ECLAIRs
about 50% for MXT and VT

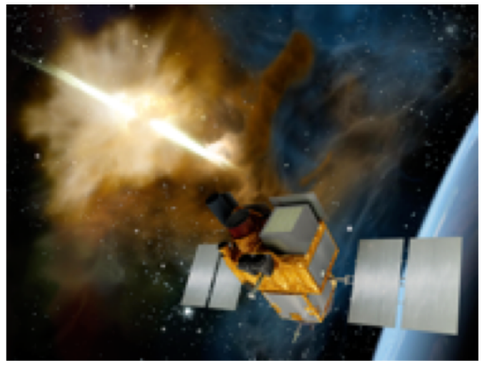
Waiting for GRB detection…

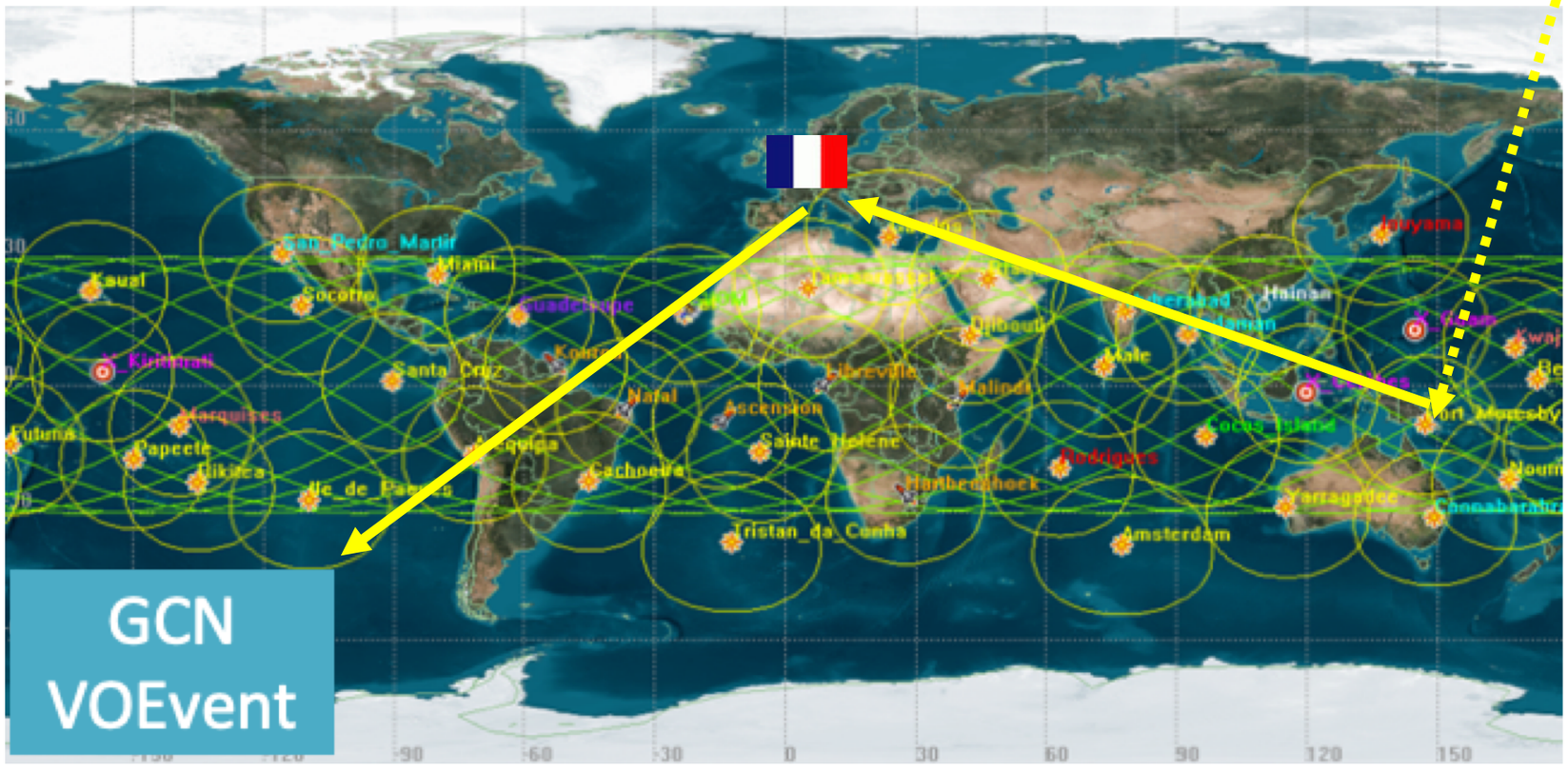
Avoidance of the galactic plane (most of the time)
and intense sources such as **Sco X-1**

ECLAIRs exposure map
(65 GRBs/year, 1 ToO per day)
- 4 Ms in the direction of the galactic poles
- 500 ks on the galactic plane



SVOM ALERT SYSTEM





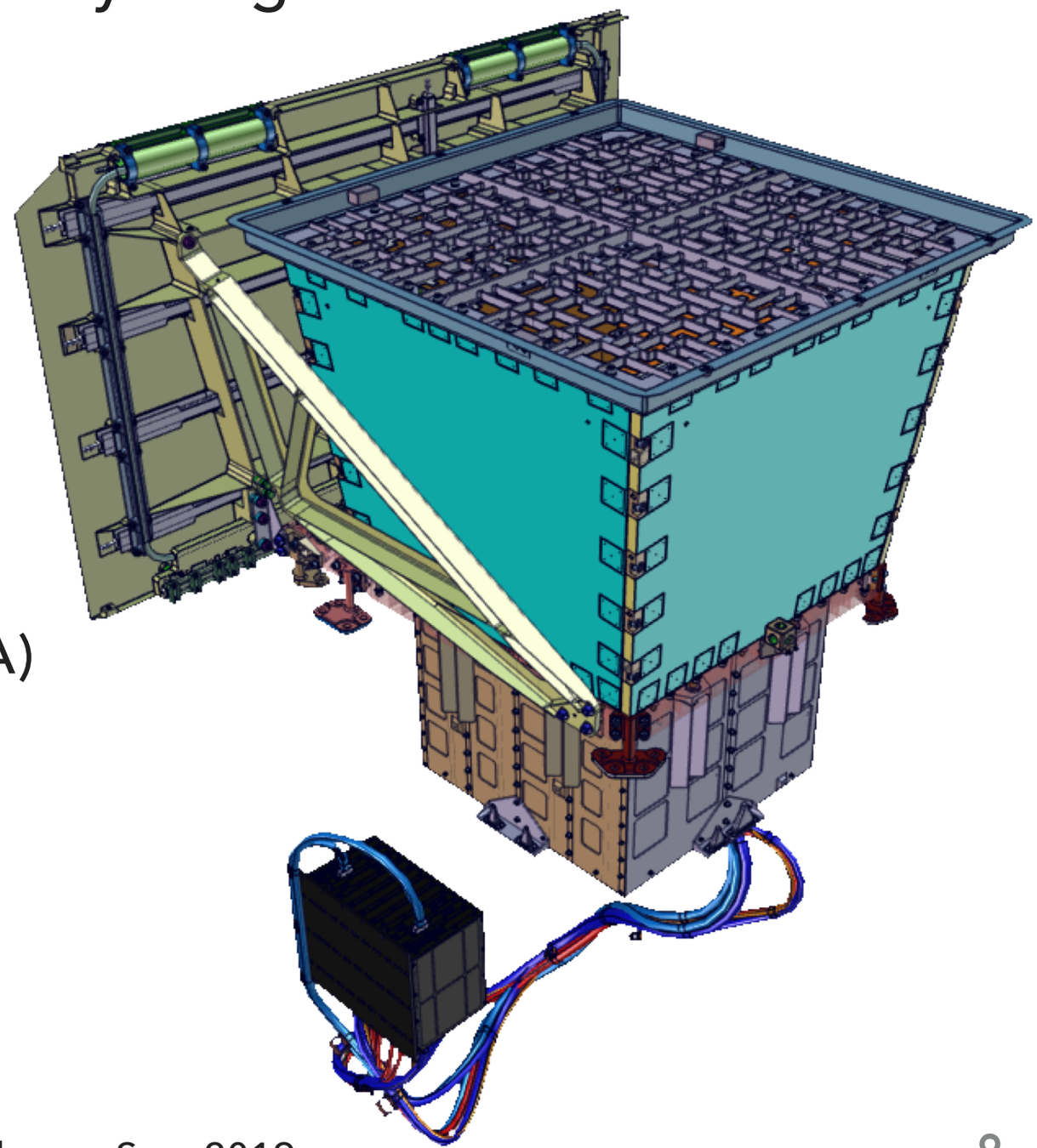
Alerts are transmitted to a network of **>40 VHF receivers on Earth**

Goal: 65% of the alerts received within 30 s at the French Science Center

ECLAIRs + post-slew X-ray and Visible information is also sent through the VHF link

ECLAIRs INSTRUMENT

- ECLAIRs is a coded mask hard X-ray imager made of 4 sub-systems:
  - The detection unit DPIX (IRAP)
  - The mask (APC)
  - The structure & shield (CNES)
  - The on-board calculator UGTS (CEA)



CENTRE NATIONAL D'ÉTUDES SPATIALES

astrophysique & planétologie

EXPECTED PERFORMANCE

Energy range	4 – 150 keV
Detecting area	≈1000 cm^2
Detectors	6400 CdTe detectors (mounted as 200 modules)
Effective area in 10–70 keV	≥340 cm^2
Effective area @ 6 keV	≥200 cm^2
Field of view	2.06 sr total
Sensitivity to 1 sec long GRB	2.5 10^{-8} erg cm^{-2} s^{-1} in [5–50] keV
Intrinsic Source Localization Error	11.5 arcminutes for sources with SNR=8
Energy resolution at 60 keV	< 1.6 keV
Time resolution	10 microsecond
Dead time	<5% for 10^5 cts/s
Data rate	≤18 Gb/day

ECLAIRs ROLE

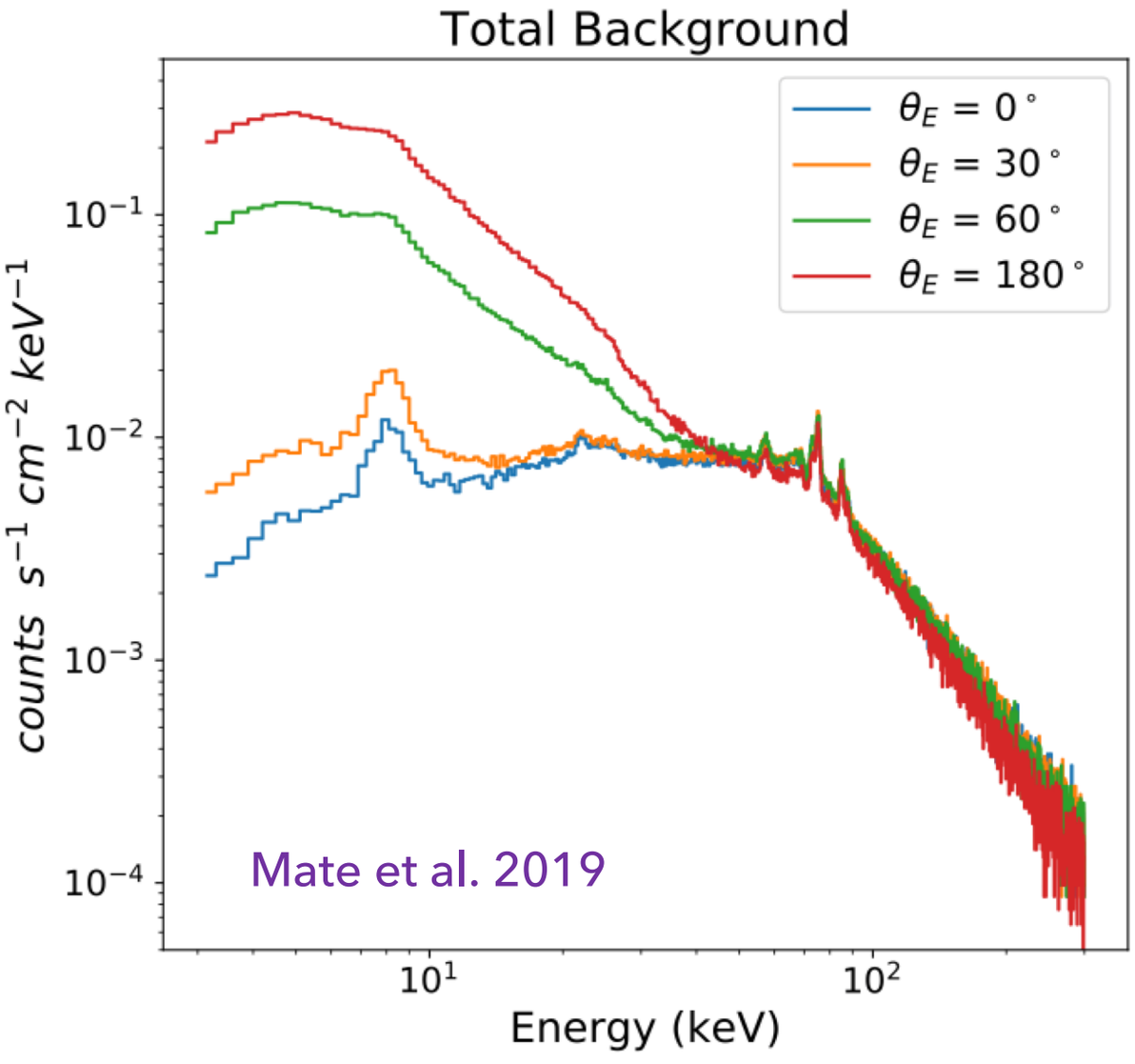
- Being the wide-field imager and trigger of SVOM, ECLAIRs fulfills various tasks:

  - **Monitoring the hard X-ray sky:** ECLAIRs records the time, position, and energy of ***all*** detected photons -- you can make your own trigger on the ground. ☺

  - **On-board trigger and imaging:** ECLAIRs detects, localizes and characterizes HE transients. It generates alerts and slew requests:
    - 2 types of trigger: **count trigger** (10 ms – 20 s) & **image trigger** (20 s – 20 min)
    - Count triggers must be validated with an image showing a significant excess
    - Triggers are vetted against a list of known transient sources

ECLAIRs OPERATIONS AND IN-FLIGHT CALIBRATION

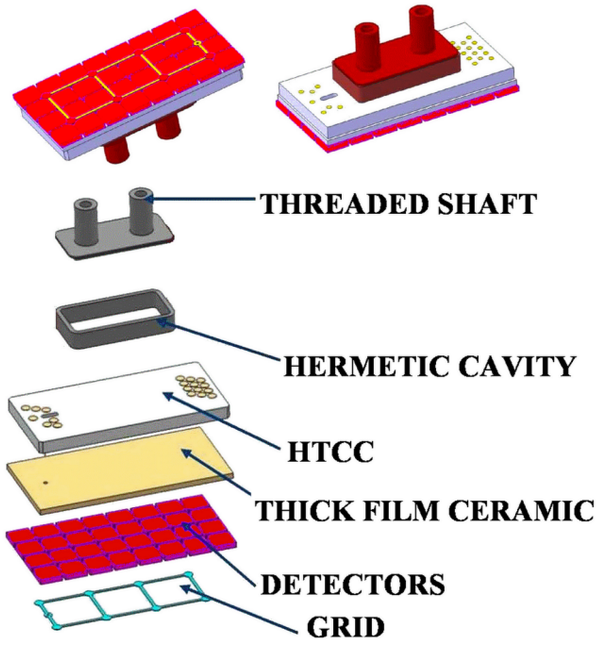
- ECLAIRs is always working, except inside the SAA
- When it is **in operation**, ECLAIRs…
  - Records the properties of all detected photons: time, position, energy, multiplicity
  - Look for count and image triggers
  - Manages its internal status
- **In-flight calibration** relies on internally produced fluorescence lines of Cu (8 keV) and Ta/Pb (≈70 keV) produced in the graded shield and in the mask.



INSTRUMENTAL CHALLENGES

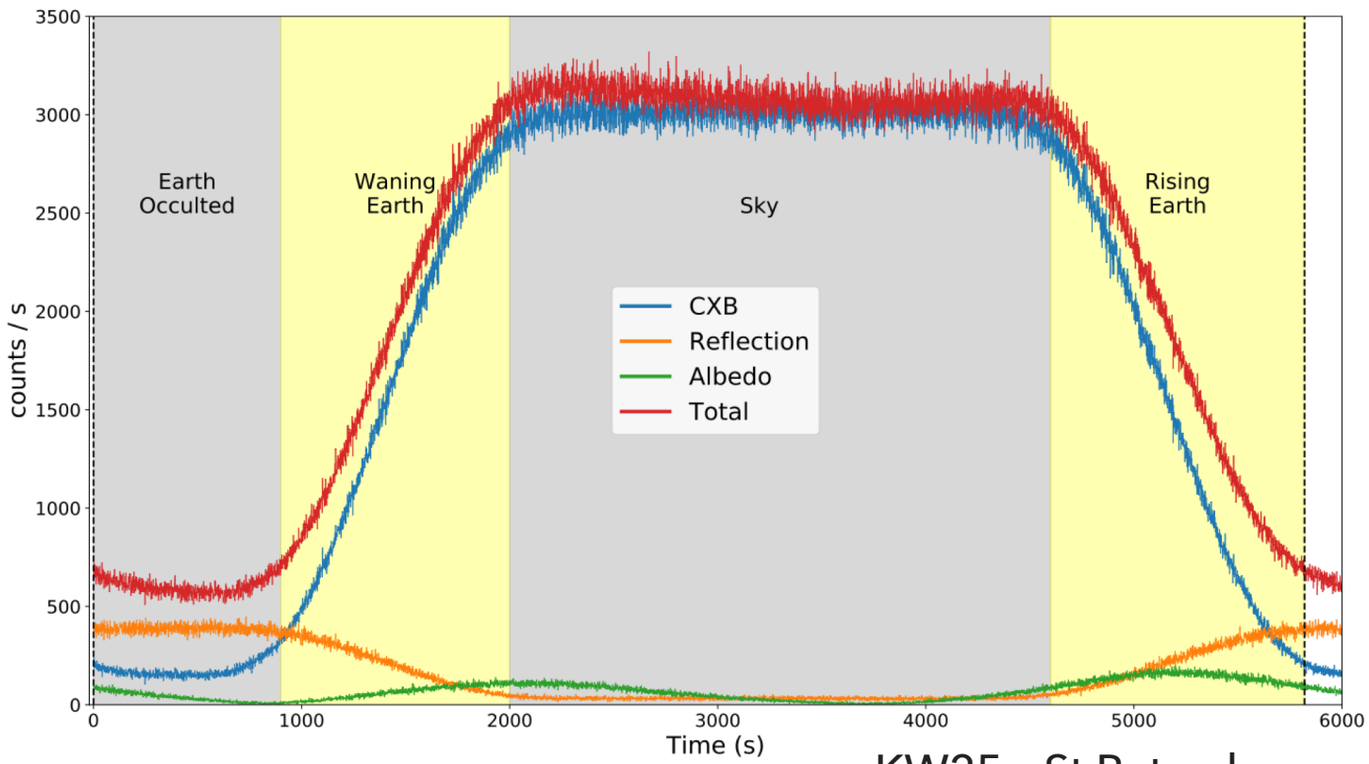
- **The low energy threshold** poses several challenges to the instrument:
  - Mask structure (next slide)
  - Opacity to visible light
  - Leakage current of the detectors and ASIC readout noise →
  - Management of transient hard X-ray sources by the on-board computer

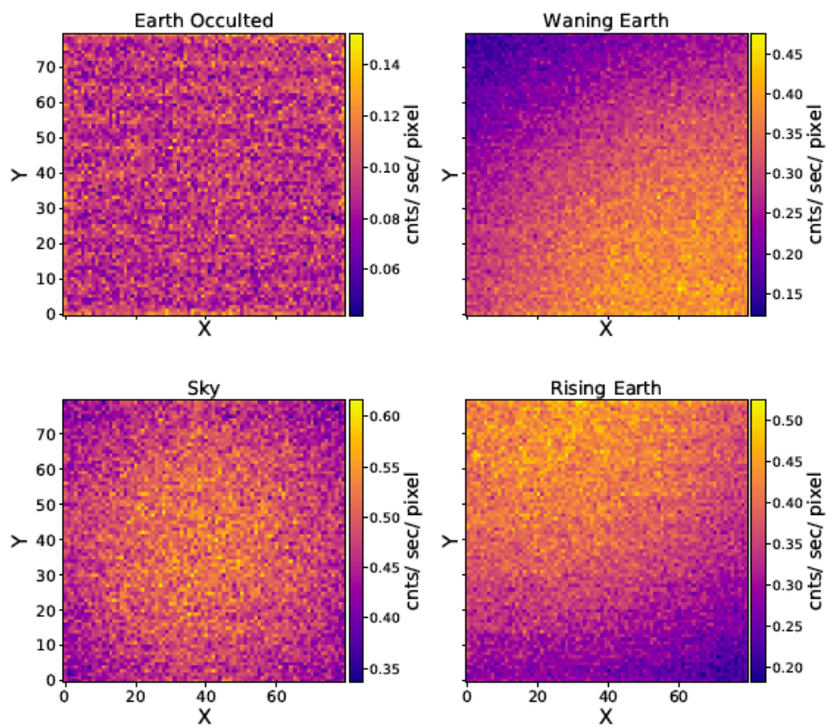
- **Mass/volume allocation** is very limited: ECLAIRs is 2.5 times lighter than *Swift*/BAT



- **Get reliable GRB triggers with highly variable background: Earth transits, SAA, noisy pixels…**

Lacombe et al. 2018





SOME PICTURES

Column 1:

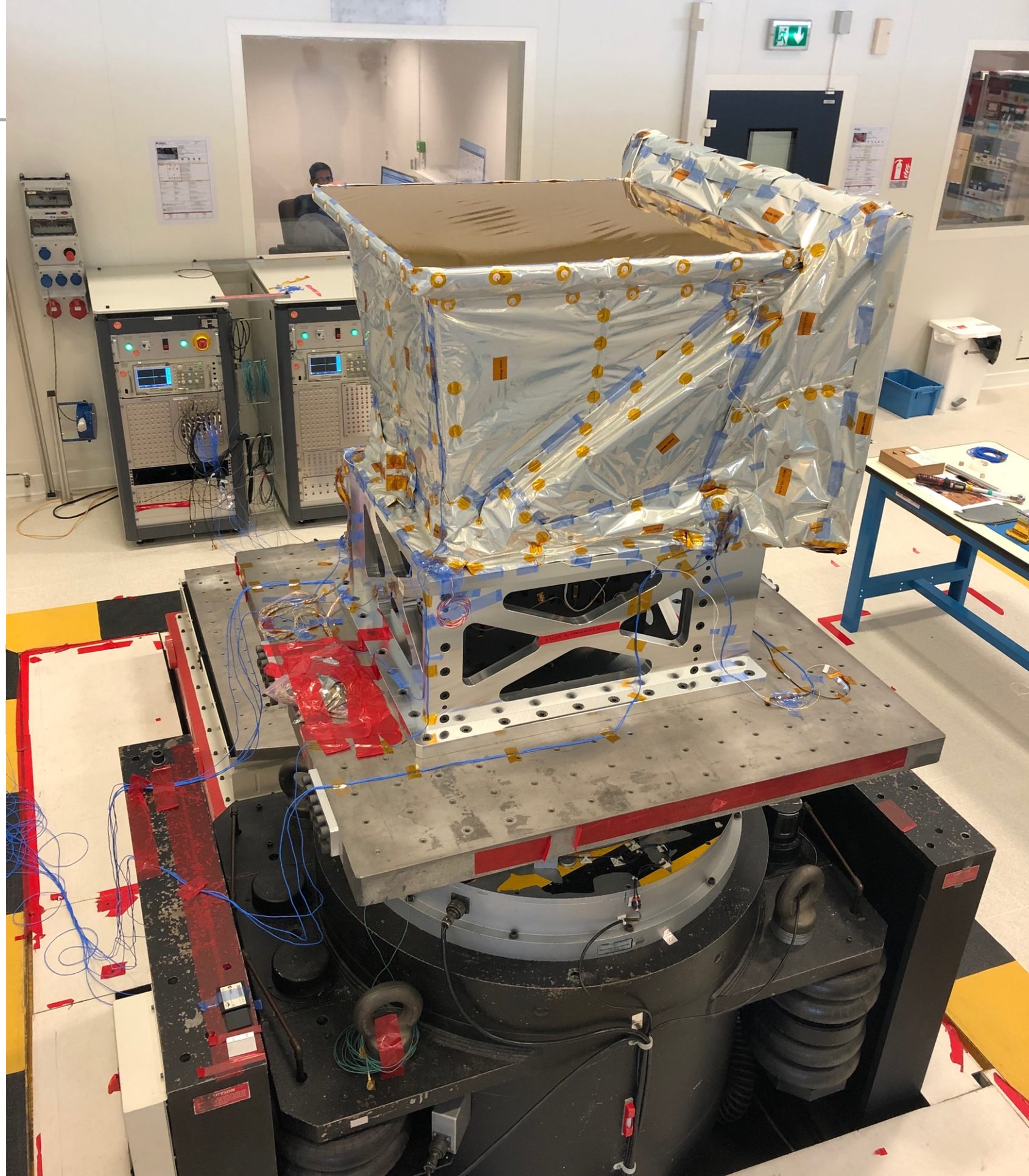
On-board computer

Column 2 (top to bottom):

Detection plane (partly filled)
and detection module (inset)
Detection plane electronics

Column 3 (top to bottom):

Mask
Structure & shield
Structure with the mask



INSTRUMENT CHARACTERIZATION

- Detection plane:
  - Response of individual pixels: effective area A(E,θ), energy threshold, resolution, linearity,
  - Response of the entire plane: uniformity, cross-talk, dead time, temporal stability.

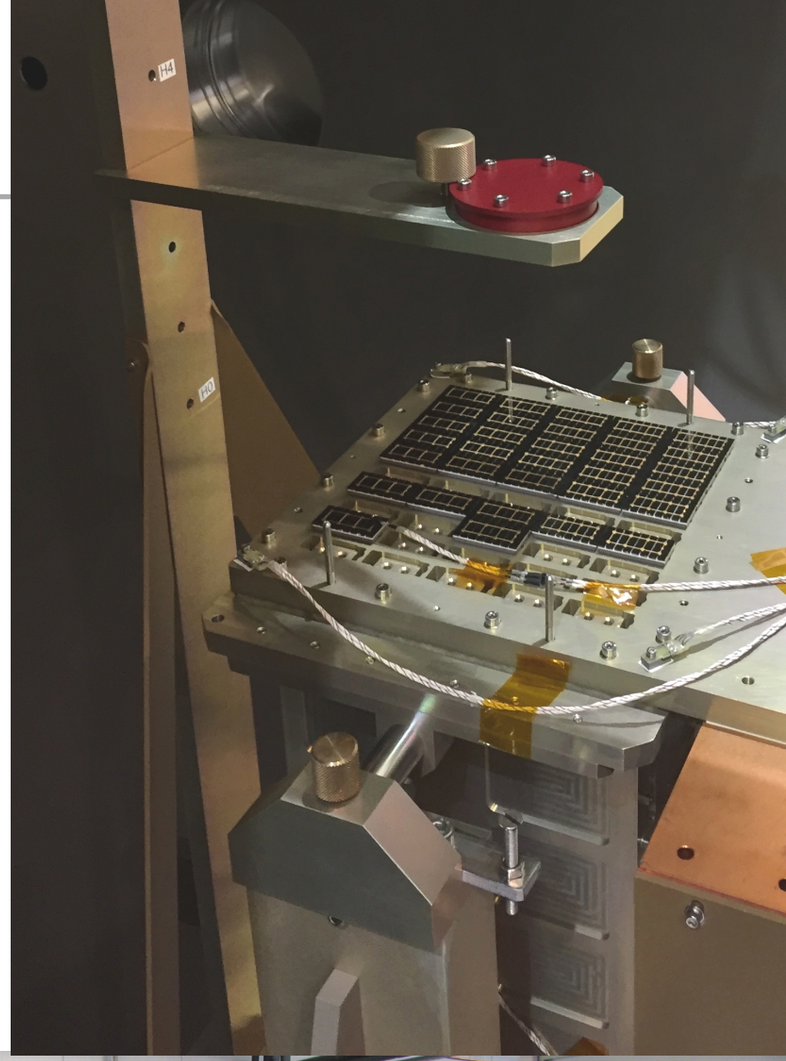
  → **Measured with radioactive sources (next slide)**

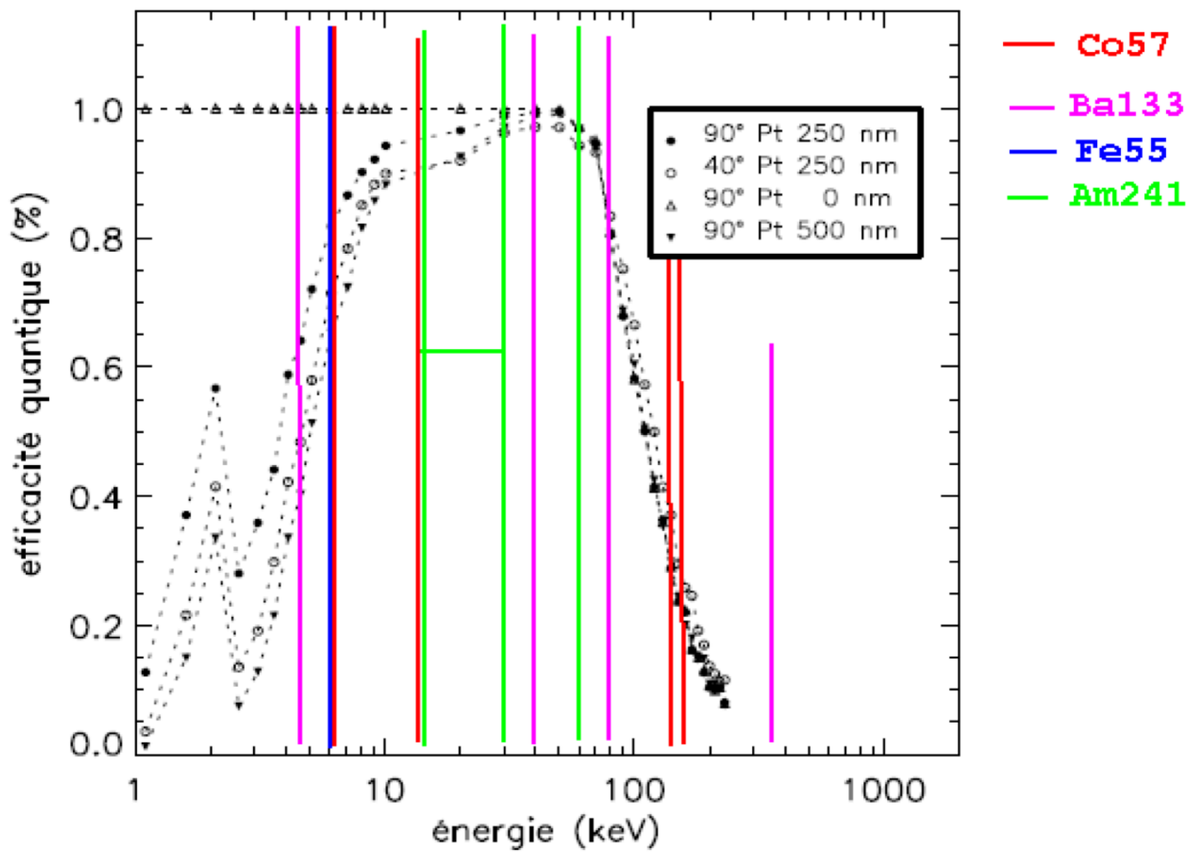
- On-board computer:
  - Estimation of the sensitivity to various GRBs and transients
  - Injection of realistic simulated data, including background, GRBs & SAA

- Instrument:
  - Light opacity
  - RX transparency (down to low energies)
  - DPIX ⇔ UGTS communication
  - Imaging and source reconstruction

PERFORMANCE OF THE PROTOTYPE

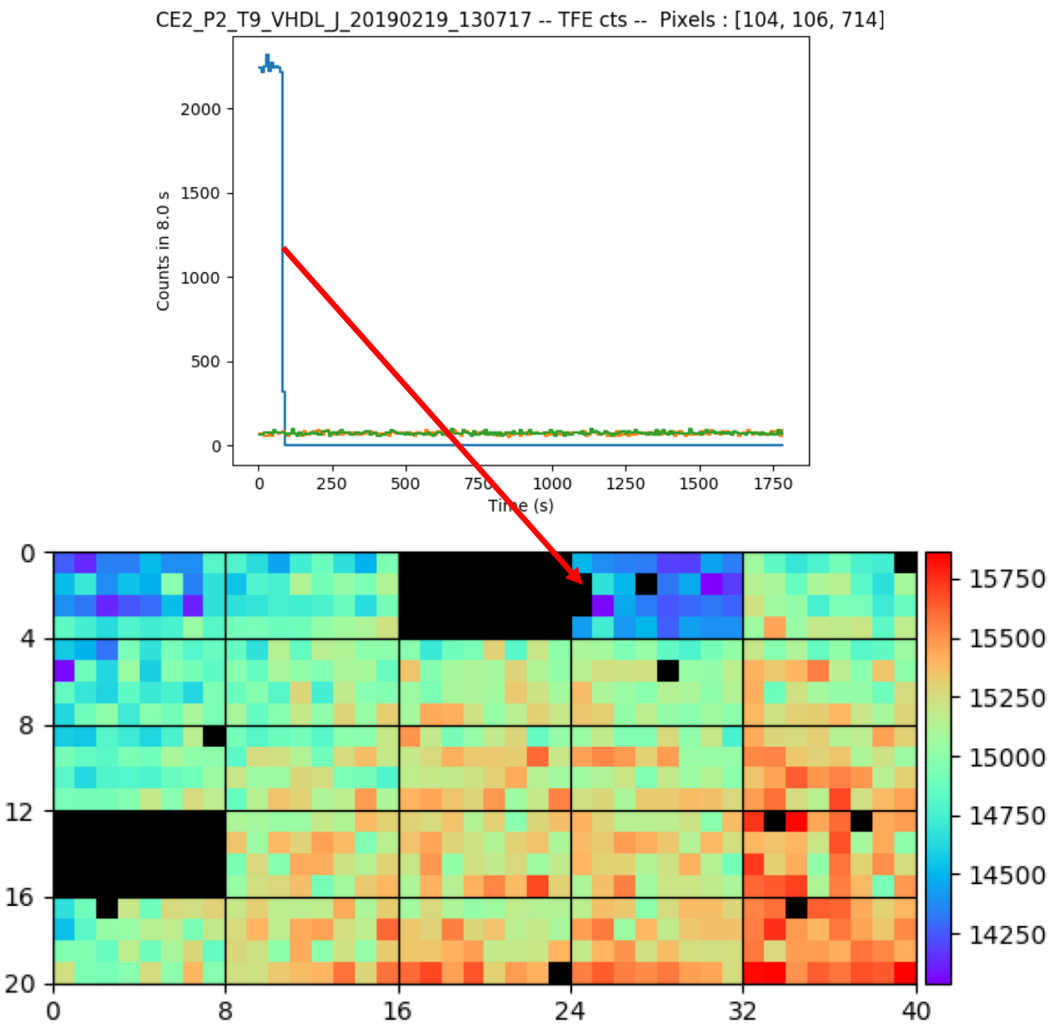
- The prototype detection plane involves ≈1000 detectors (32 modules of 32 detectors).
- Its characterization involves many complex measurements, and detailed simulations.
- Performance is measured with radioactive sources in a large vacuum chamber.

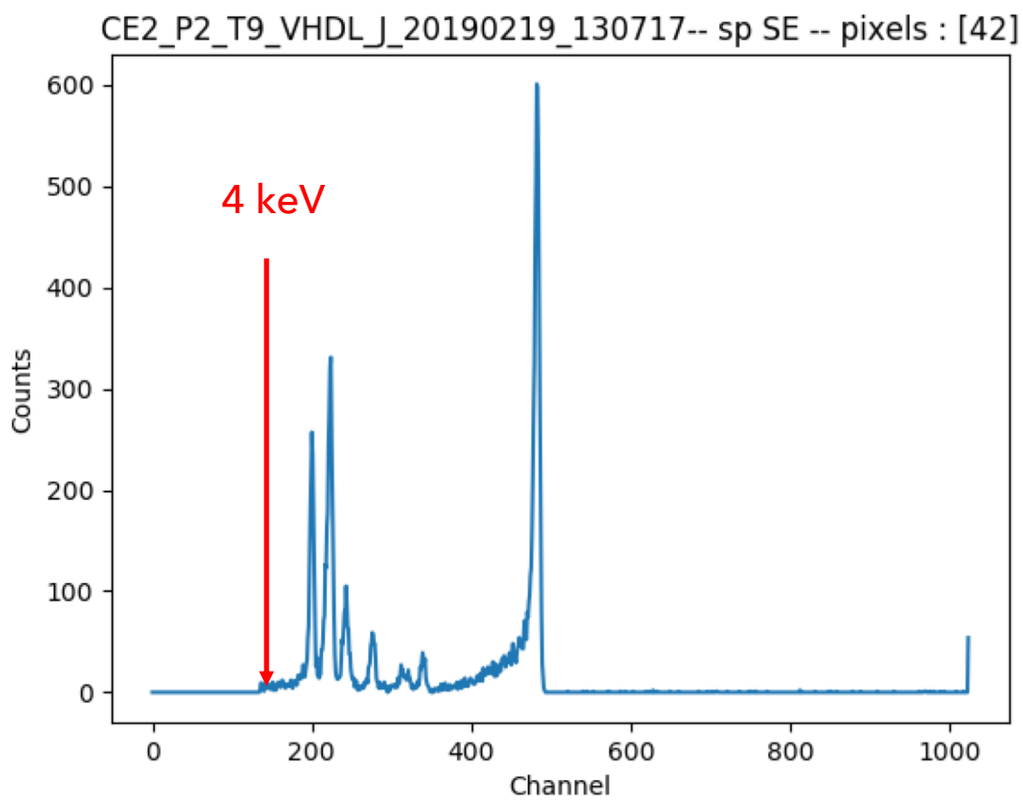




FEW EXAMPLES

- The left plot shows a map of the counts recorded by 725 detectors (2 modules and 11 detectors are switched off)
- The right plot shows a typical spectrum
- The prototype shows excellent performance!





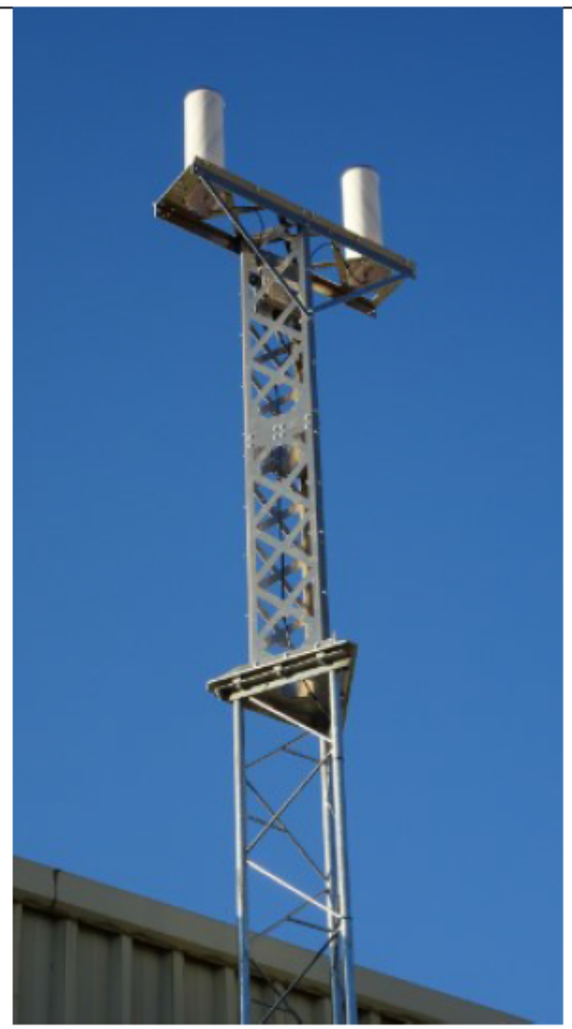
ECLAIRs delivered to China by the end of 2020

SVOM to be launched at the end of 2021

SVOM web pages: http://www.svom.fr/en/

SVOM white paper: http://arXiv:1610.06892

VHF Ground Stations



First Tests of the VHF Ground Station Prototype: Excellent Results!

The first 10 Ground Stations to be deployed in 2019

Core Program : a complete GRB sample

	Swift	Fermi	SVOM
Prompt	Limited	Excellent 8 keV -100 GeV	Very Good 4 keV - 5 MeV
Afterglow	Excellent	/	Excellent
Redshift	~1/3	/	~2/3

Physical mechanisms at work in GRBs

nature of GRB progenitors and central engines

acceleration & composition of the relativistic ejecta

Diversity of GRBs: event continuum following the collapse of a massive star

X-ray rich GRBs/X-ray Flashes and their afterglow

GRB/SN connection

Short GRBs and the merger model

GW emission from the final stages of orbital decay and merger

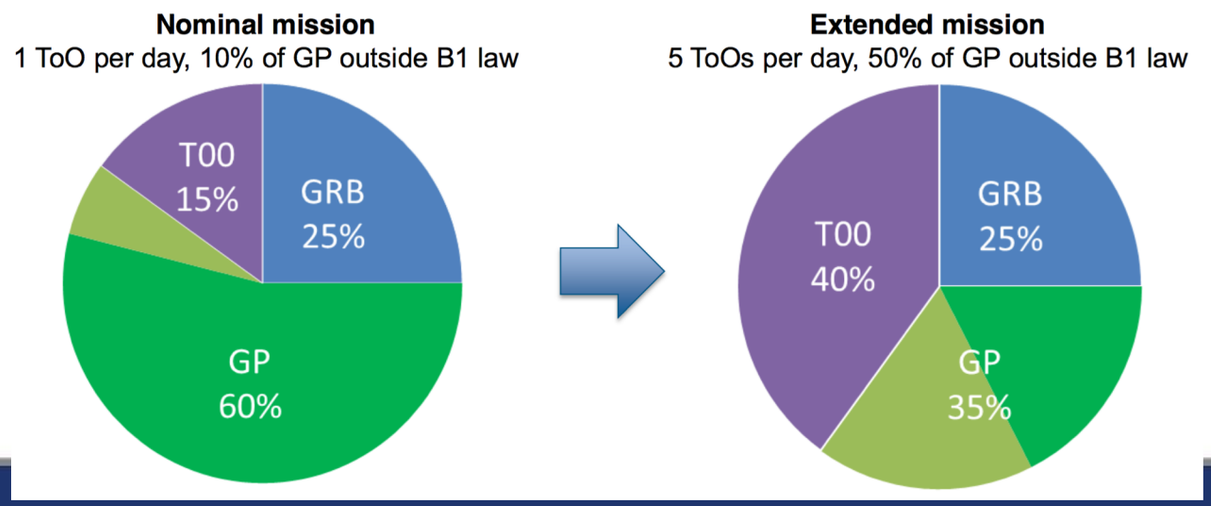
besides GRBs …svom as an open observatory

The general program (GP)

- Observation proposals being awarded by a TAC (a SVOM co-I needs to be part of your proposal) for astrophysical **t**argets of interest mostly compliant with the satellite attitude law
- Only 10% of the time can be spent on low Galactic latitude sources during the nominal mission, up to 50% during the extended mission

Target of Opportunity (ToO) programs

- **ToO-NOM** is the nominal ToO which covers the basic needs for efficient transient follow-up alerts sent from the ground to the satellite (GRB revisit, known source flaring, new transient)
- **ToO-EX** is the exceptional ToO which covers the needs for a fast ToO-NOM in case of an exceptional astrophysical event we want to observe rapidly.
- **ToO-MM** is the ToO-EX dedicated to EM counterpart search in response to a multi-messenger alert. What differs from the ToO-NOM and ToO-EX is the unknown position of the source within a large error box…
- Initially 1 ToO/day focussed on time domain astrophysics including multi-messengers, will increase during the extended mission



ToO	Approval	From accep-tance/ trigger	GRB inter-ruption	Frequency	Duration
ToO-NOM	PI	<48h	Yes	MAX 1/day => 5/day	1 orbit
ToO-EX	PI	<12h	No	MAX 1/month	1-14 orbits