SVOM : Catching high-energy transients on the fly!

Olivier Godet

On behalf the SVOM collaboration

SVOM Consortium

- **China (PI J. Wei)**
  - SECM Shanghai
  - NSSC Beijing
  - NAOC Beijing
  - IHEP Beijing
  - GuangXi University

- **France (PI B. Cordier)**
  - CNES Toulouse
  - APC Paris
  - CEA Saclay
  - CPPM Marseille
  - GEPI Meudon
  - IAP Paris
  - IJCLab Orsay
  - IRAP Toulouse
  - LAM Marseille
  - LUPM Montpellier
  - ObAS Strasbourg

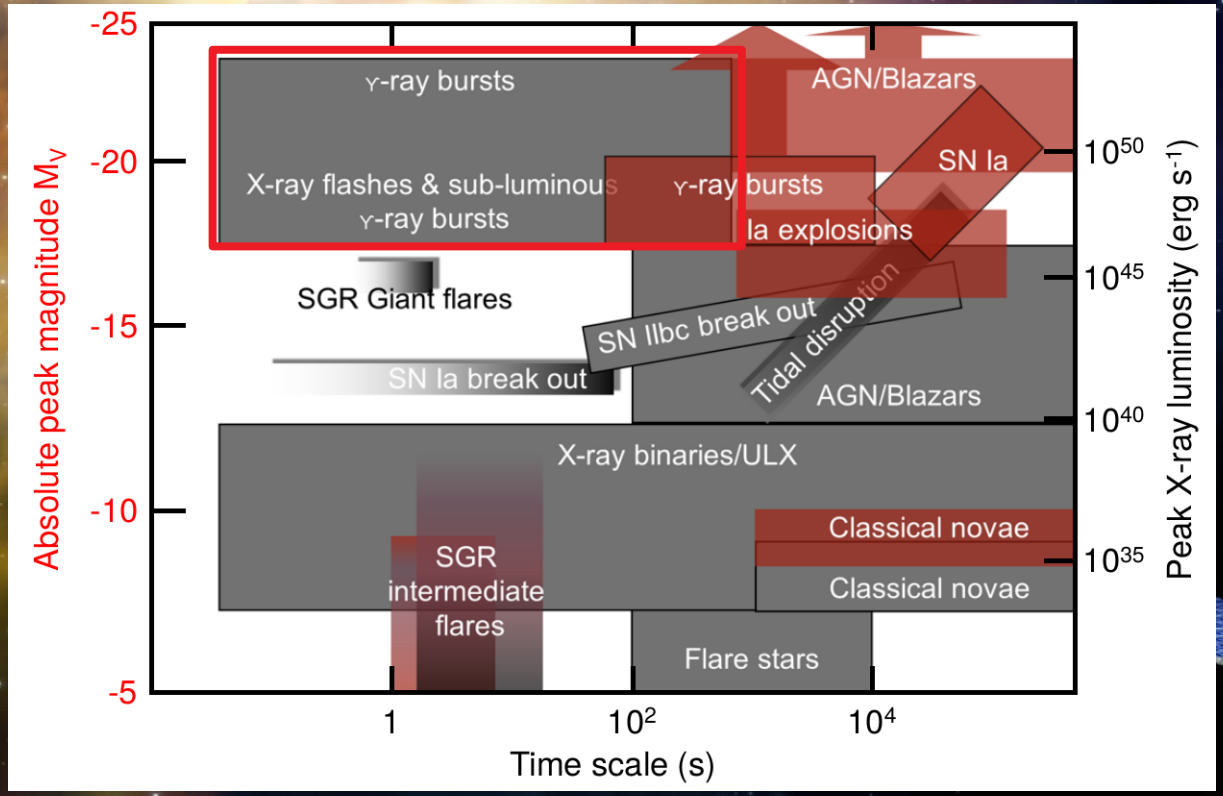
- **Mexico** UNAM (Colibri)

- **UK** University of Leicester (MXT)

- **Germany** MPE Garching & IAAT Tübingen (MXT)

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

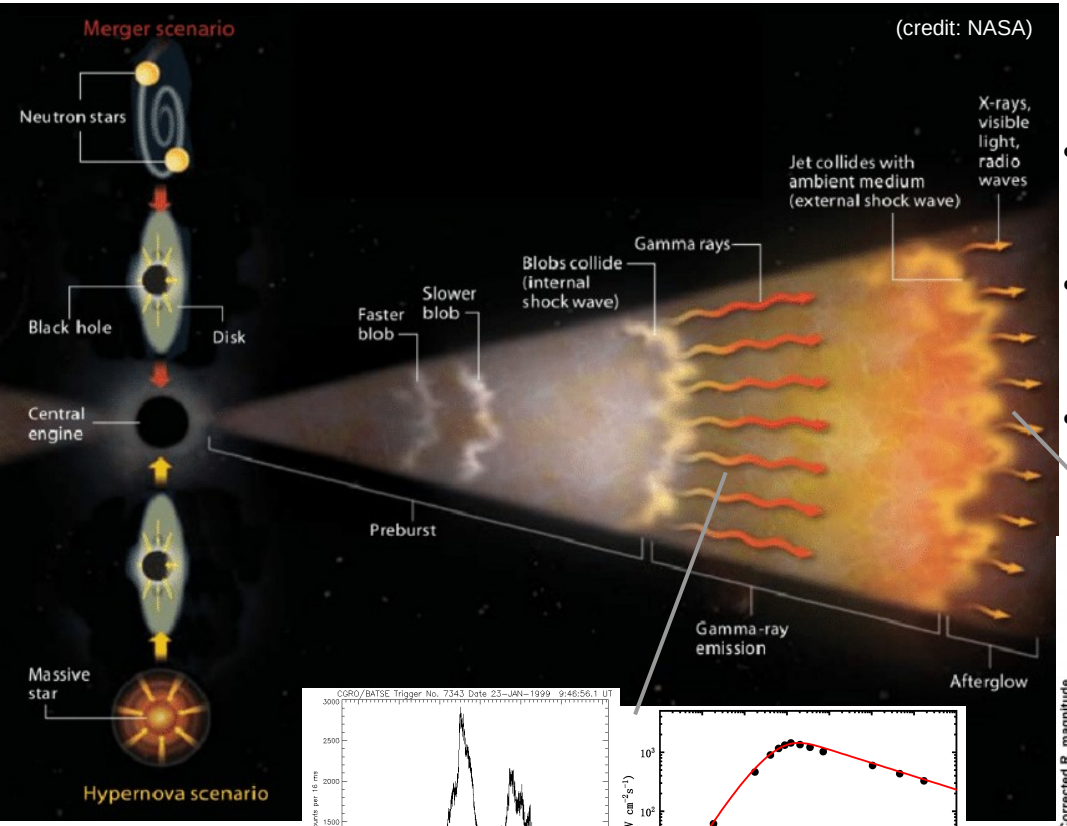
Launch: 24/06/2024
Duration: 3+2 years

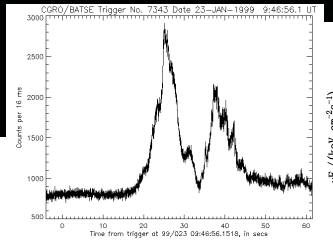


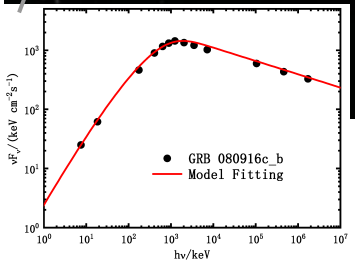
FRBs, FBOTs, TGFs, ...

SVOM white paper: arXiv:1610.06892

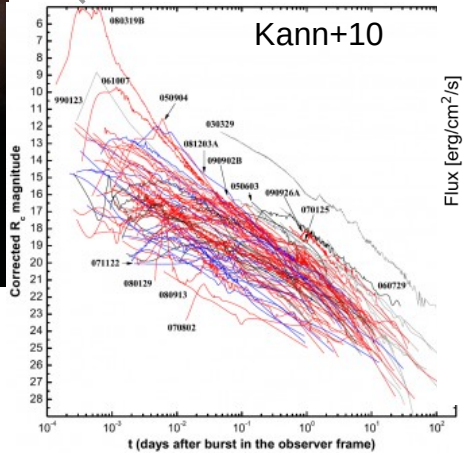
Gamma-Ray Bursts

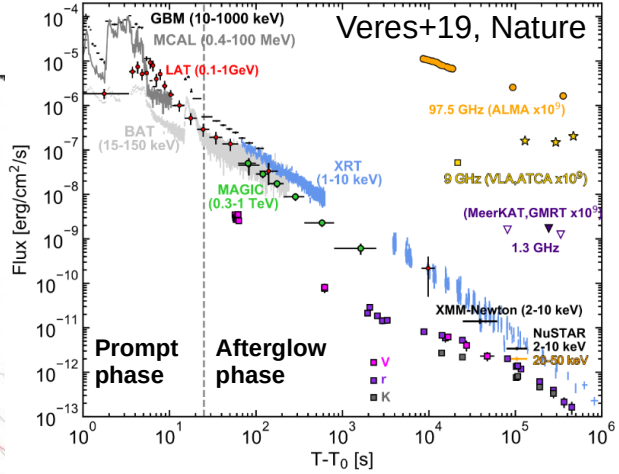




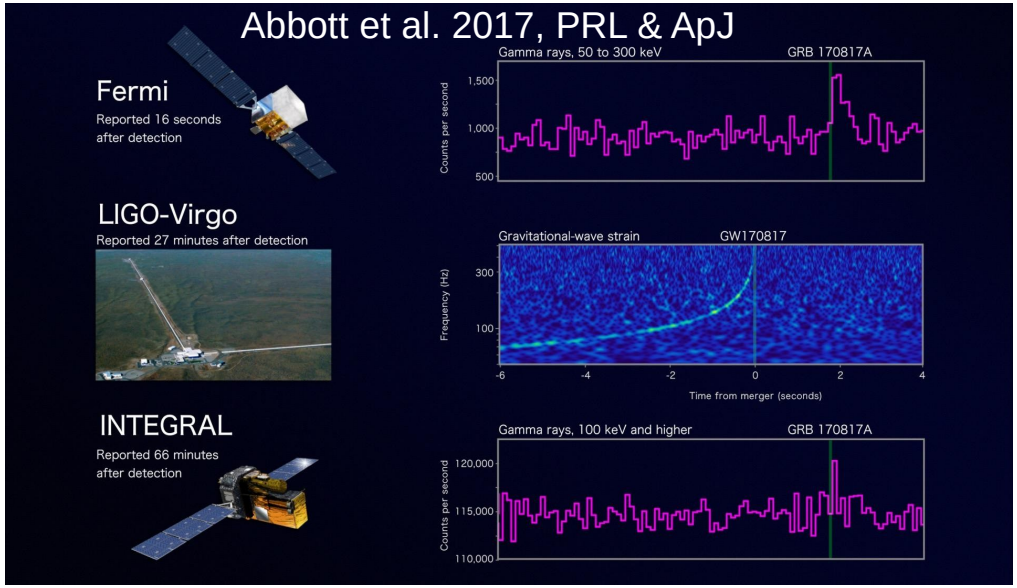


- GRBs signal the violent formation of stellar-mass BHs and the launch of relativistic jets oriented more or less towards the Earth.
- HE prompt emission duration from a few ms to a few 10^2 s
- Cosmological events – distance from 42 Mpc up to z ~ 9.3 (< 1 Gyr after Big-Bang)
- Extremely bright – Energetics ~ 10^{46-55} erg (isotropy)



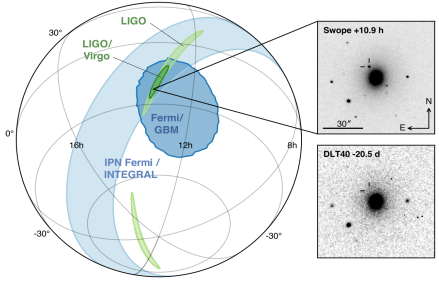


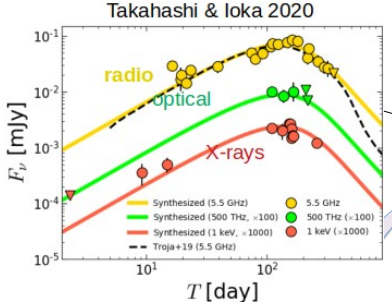
GRB/GW 170817 – Start of the multi-messenger era

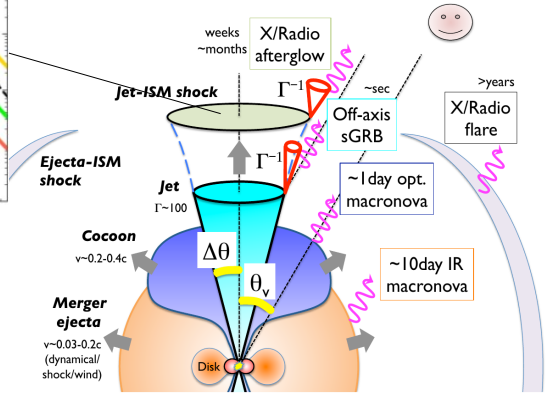


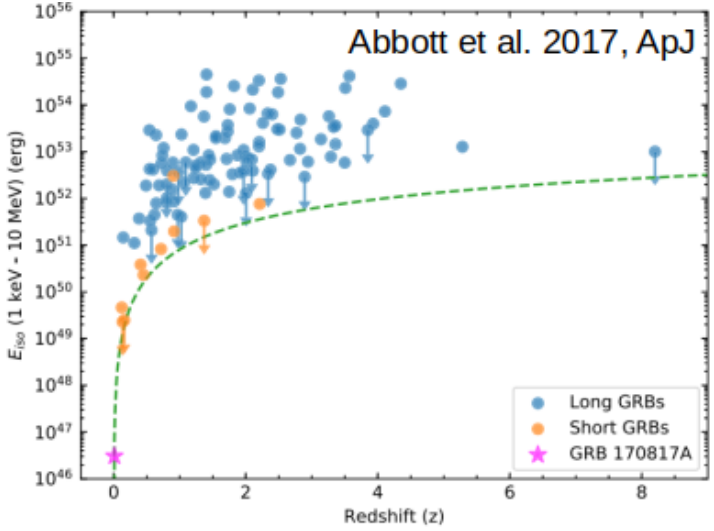
- Coalescence of a binary NS followed ~2 s later by a short off-axis GRB and a few hours later by the rise of a kilonova (r-process nucleosynthesis of heavy elements)

⇒ Contraints on H_0, the speed of gravity, NS EoS, structures of relativistic jets, ISM enrichment in heavy elements ...





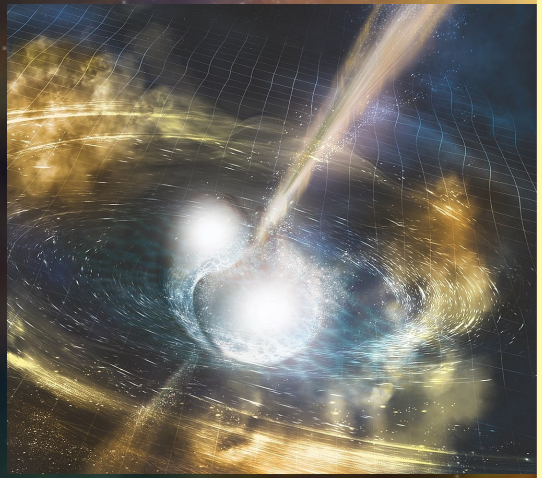




SVOM: Space-based multi-band astronomical Variable Objects Monitor

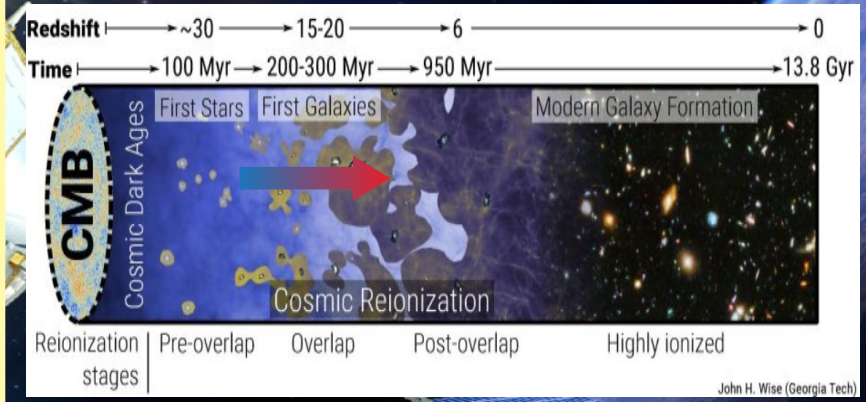
Launch: 24/06/2024
Duration: 3+2 years

Study of the local universe in synergy with GW / neutrino / EM facilities



- Demography of compact objects & tracing SF on cosmic times
- Studying accretion, relativistic jet physics
- Cosmological studies (e.g. re-ionization, formation of the first structures of the Universe, …)
- Multi-messenger studies (e.g. speed of gravity, H_0 measurements)

Study of the early Universe (z > 5) and its contents



SVOM white paper: arXiv:1610.06892

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

Launch: 24/06/2024
Duration: 3+2 years

VT
"The Visible Telescope"
Narrow-field visible telescope
Ritchey Chretien Φ=400mm
Localization accuracy < 1arcsec

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

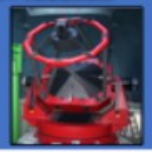
ECLAIRs
« The trigger camera »
Wide-field X and Gamma rays telescope
Spectral range : 4 keV – 150 keV
Localization accuracy < 12arcmin

MXT
"The Micro-pore X-ray Telescope"
Narrow-field X-ray telescope
Spectral range : 0.2 keV – 10 keV
Localization accuracy < 1arcmin

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

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

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

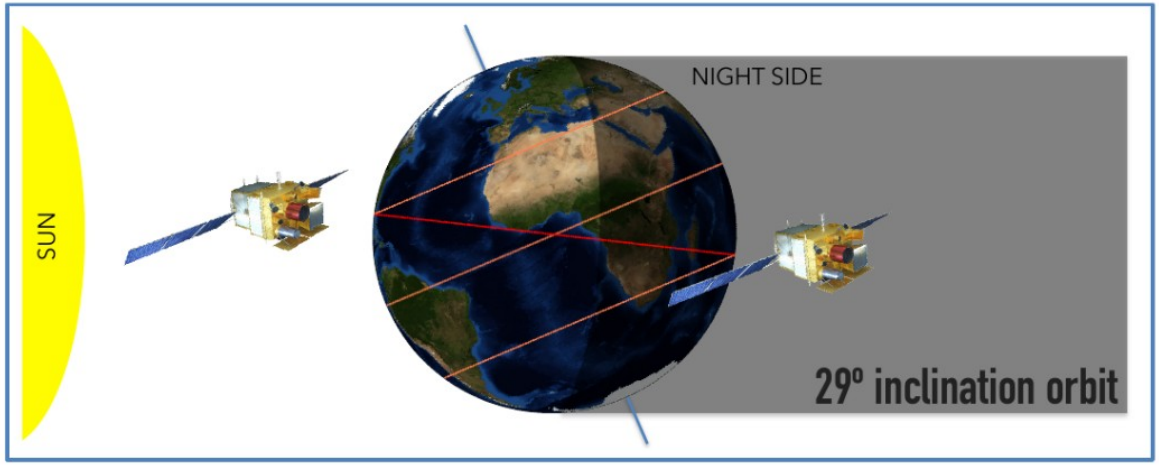


VHF Alert Network

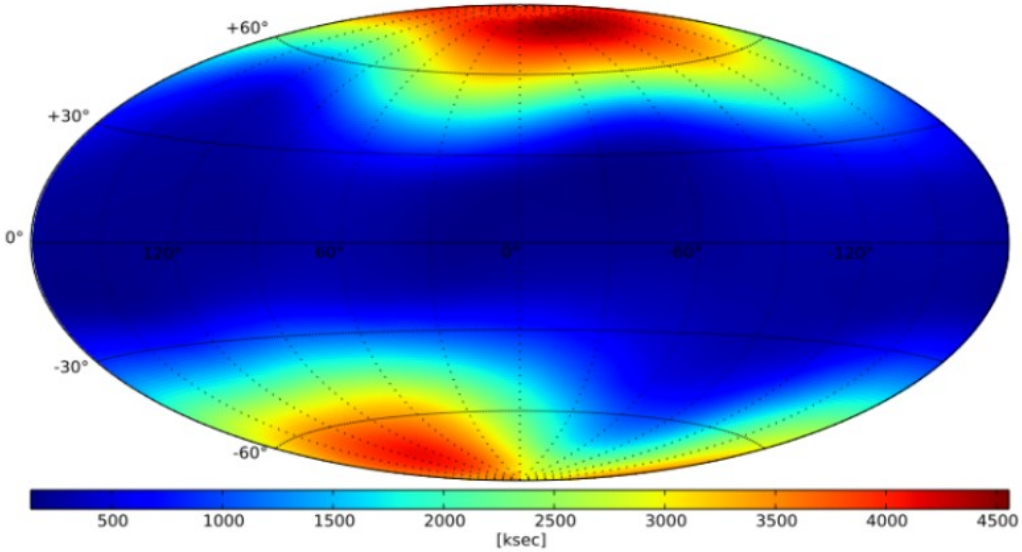
... and more !

Tracking antennas

Pointing Strategy



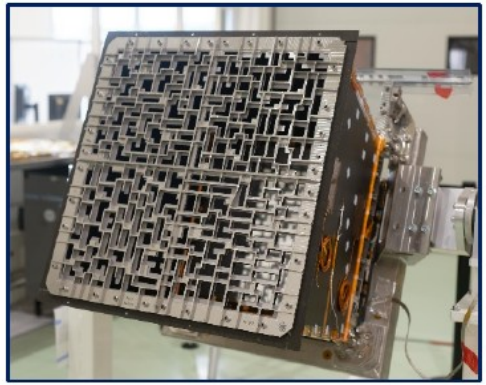
- **Optimized for ground follow-up of detected transient events**
  - Nearly anti-solar pointing (with Earth in instrument FOVs each orbit)
  - 65 % duty cycle for ECLAIRs
  - 50 % duty cycle for MXT & VT

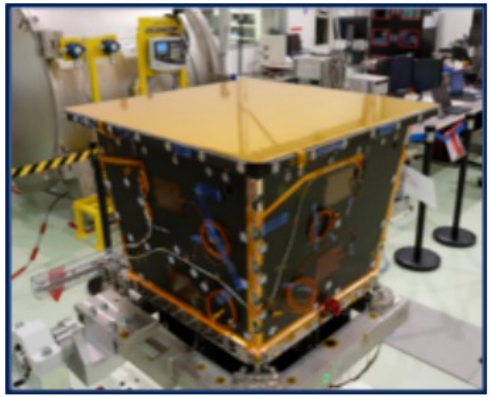


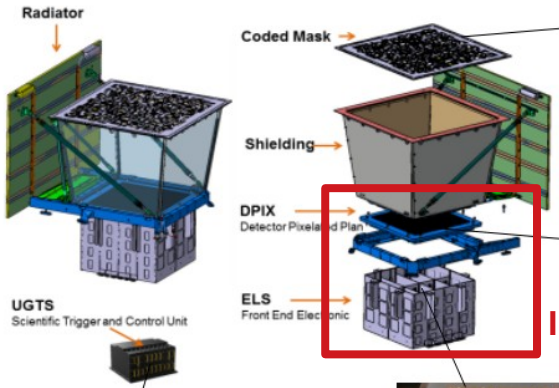
- Avoidance of the Galactic plane + bright sources (e.g. Sco X-1)

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

ECLAIRs in a nutshell: 4–150 keV coded-mask camera



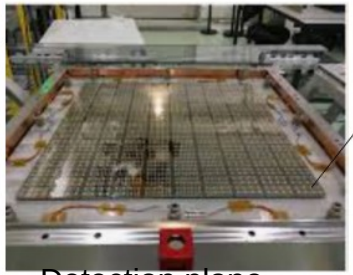




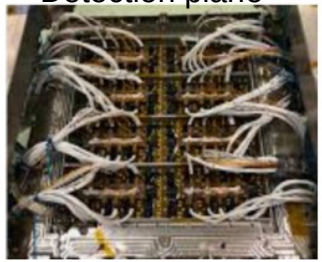
Data processing unit

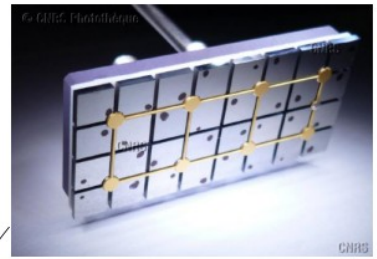
8 x Readout electronics

Coded mask

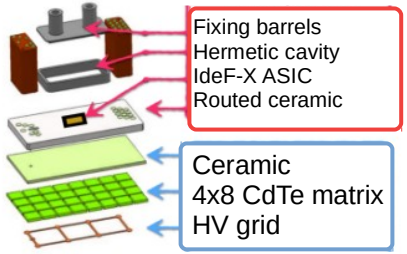


Detection plane



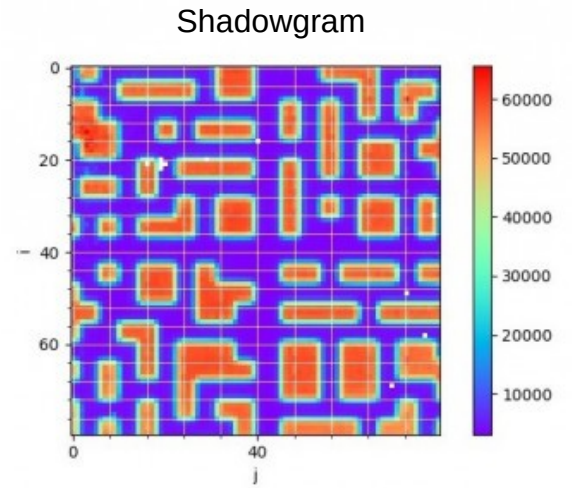


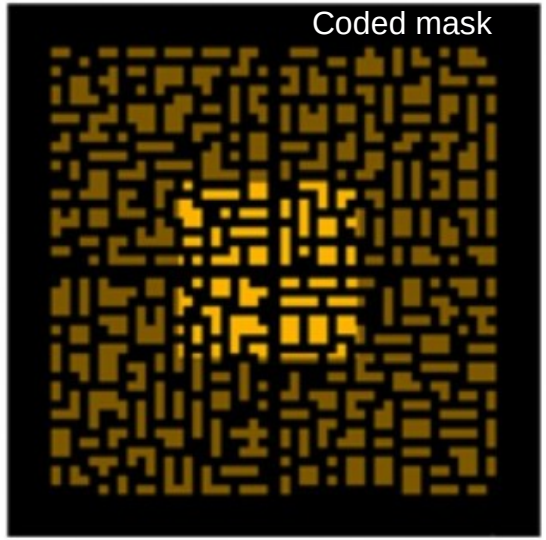
Elementary detection module

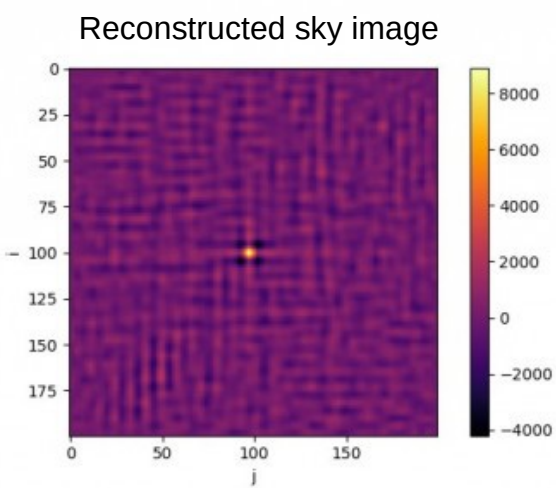


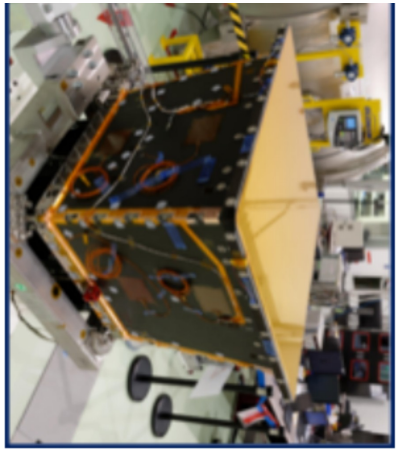
- Total FOV = 89 x 89 deg² (~2 sr)
- 80 x 80 Schottky-type CdTe detectors operated at –300 V & T = –20°C
- Geometrical area ~ 950 cm² – Total effective area ~360 cm² at peak – FWHM < 1.6 keV @ 60 keV
- **On-board autonomous detection + on-board source catalogue & localisation (< 13') – ~65 GRBs/yr**
- **Photon Counting Mode ⇒ All detected photons downloaded to the ground**

ECLAIRs in a nutshell: 4–150 keV coded-mask camera



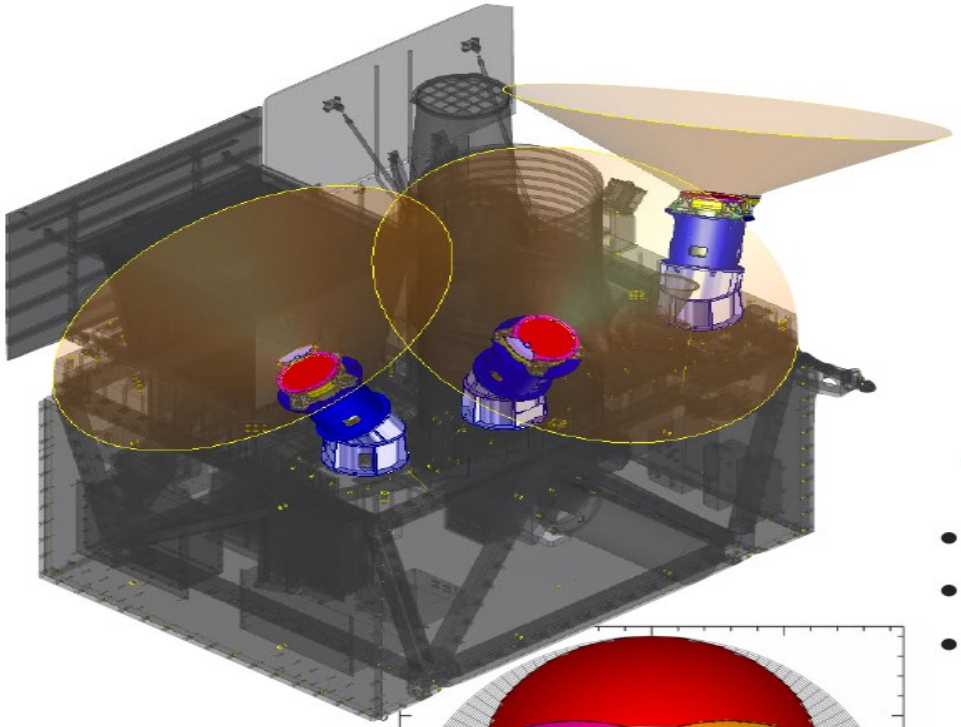


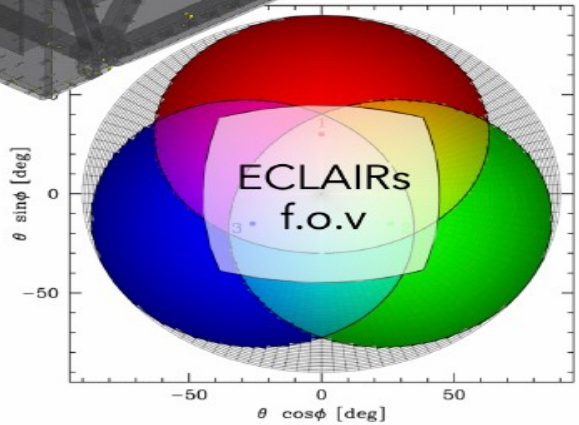




source

GRM — Gamma-Ray Monitor



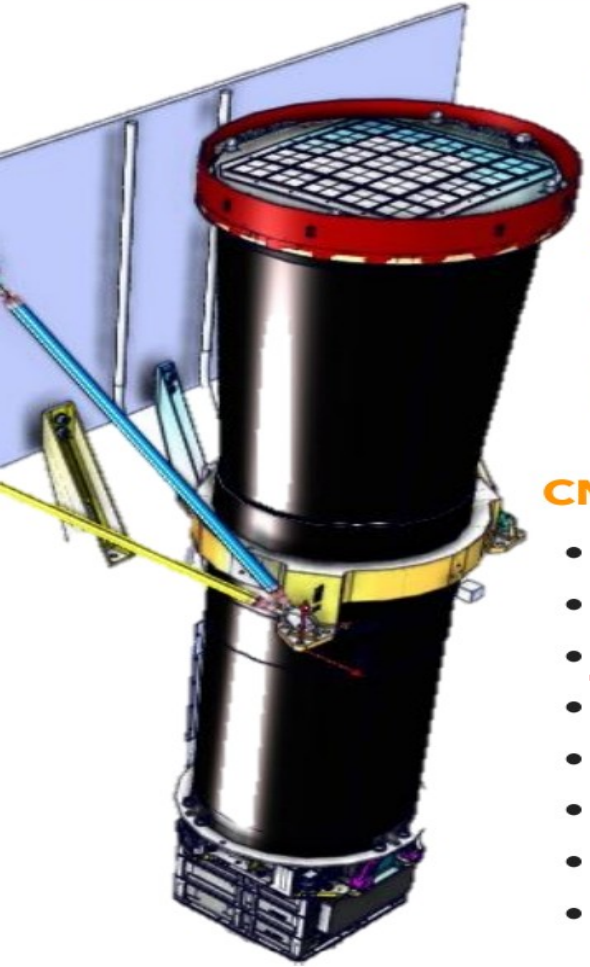


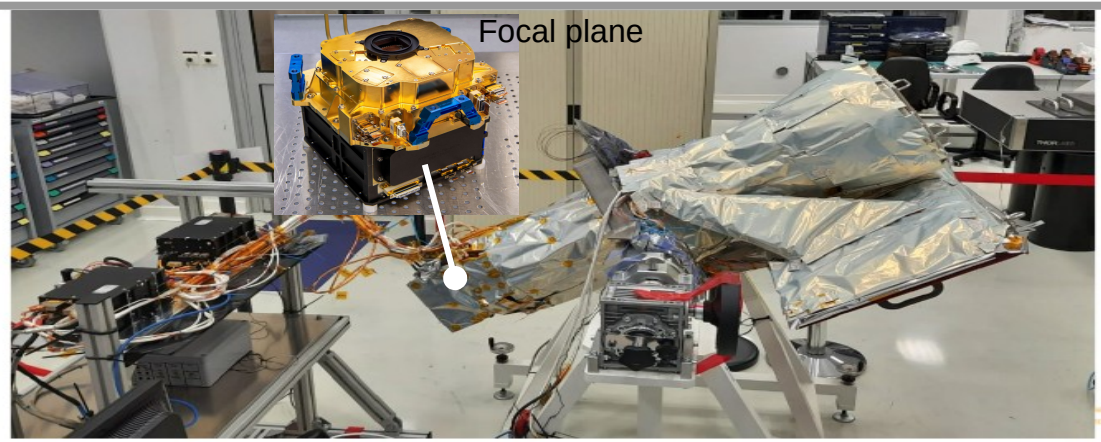
IHEP

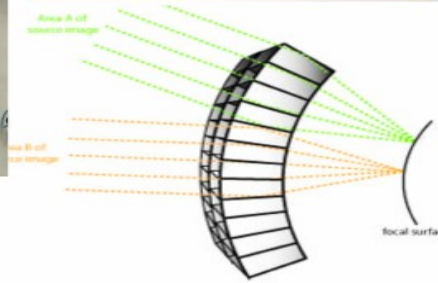
- **3 Gamma-Ray Detectors** (GRDs)
- **NaI(Tl)** (16 cm ∅, 1.5 cm thick)
- Plastic scintillator (6 mm) to monitor particle flux and reject particle events
- **FoV: 2.6 sr per GRD**
- **Energy range: 15 – 5000 keV**
- Aeff = 190 cm² at peak
- Crude localization accuracy (5-10 deg² with 3 GRDs)
- Onboard rate trigger ~ 90 GRBs/year

Will detect transients out of the ECLAIRs FOV

MXT — The Micro-channel X-ray Telescope

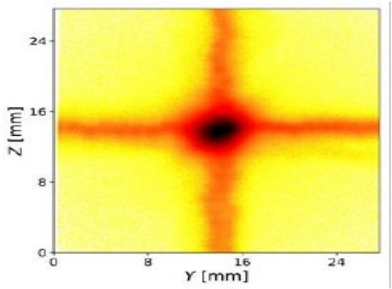






CNES, CEA, UL, MPE

- **Micro-pores optics** with **square 40 µm pores** ("Lobster Eye" optics, U.L.)
- 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



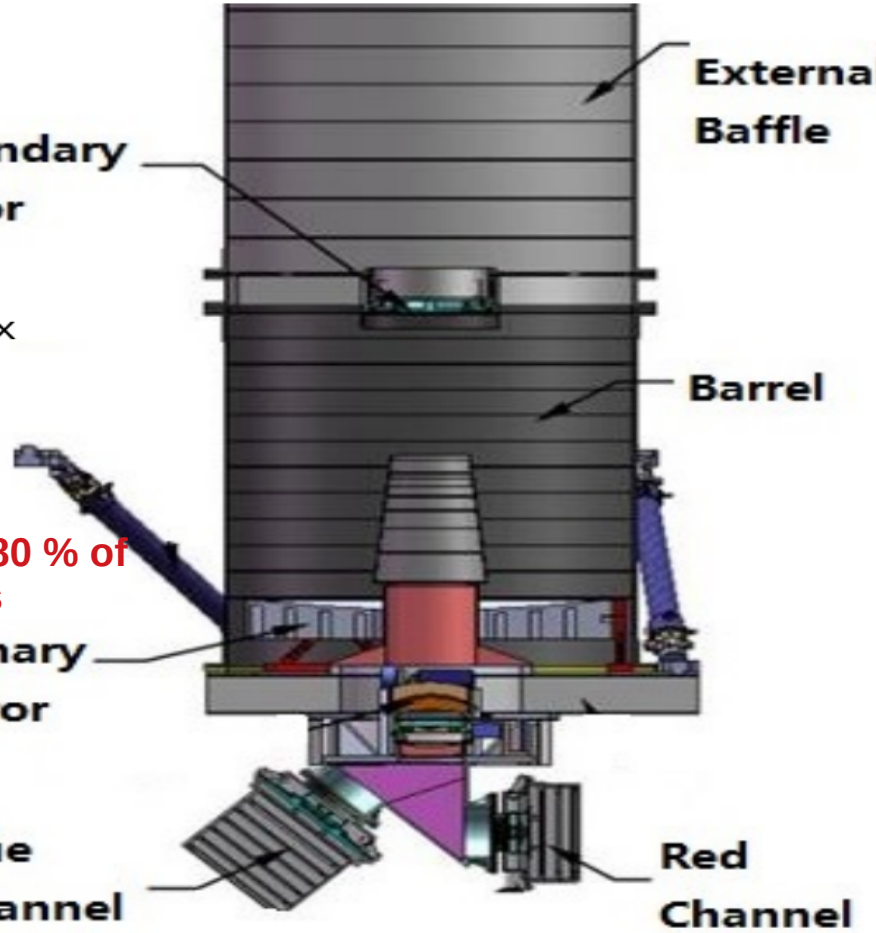
Innovative focusing « Lobster-Eye » X-ray optics

VT — The Visible Telescope

XIOMP, NAOC

- Ritchey-Chretien telescope, 40 cm ∅, f=9
- **FoV: 26x26 arcmin²**, covering ECLAIRs error box
- 2k * 2k CCD detector in **2 channels:**
  - **blue (400–650 nm)**
  - **red (650–1000 nm)**
- **Sensitivity: M_V=22.5 in 300 s** → Detection of ~ 80 % of ECLAIRs GRBs
- **Localization accuracy: <1 arcsec**

Detection of the optical counterparts in two bands



SVOM from the ground

- Ground Follow-up Telescopes permit the fast identification and measure of early optical/NIR afterglows using the ECLAIRs positions, while the spacecraft is slewing to the source.
  - C-GFTs is located at Weihai observatory (Jilin province)
  - F-GFT will be located at San Pedro Martir (Mexico)

Ground Wide Angle Cameras
2 x 20 camera units
Ø = 180 mm // **Total FOV ~ 5000 deg²**
500 – 800 nm
Limitting mag ~ 16-17 (10 s)

C-GFT

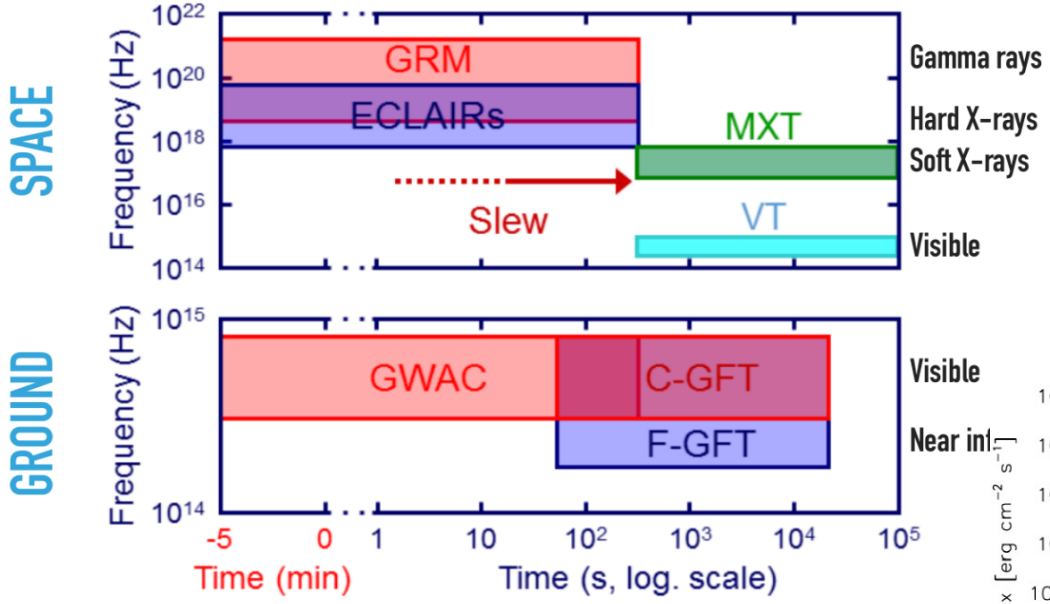
F-GFT(Colibri)
Diameter : 130 cm
FOV : 26 x 26 arcmin
400 – 1700 nm → **NIR capabilities (CAGIRE, IRAP)**
Limiting mag ~ 22 (R, 300 s)

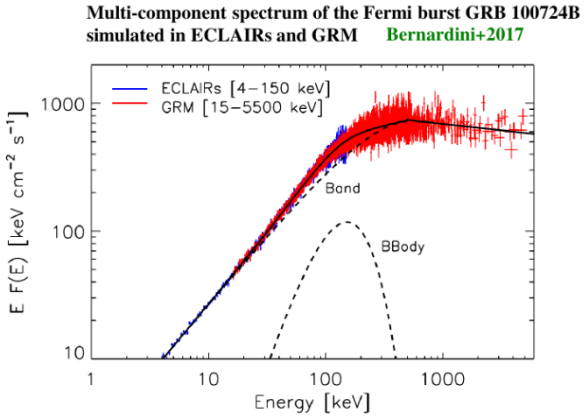
Diameter : 120cm
FOV : 90 x 90 arcmin
400 – 900nm
Limiting mag ~ 20 (R, 300 s)

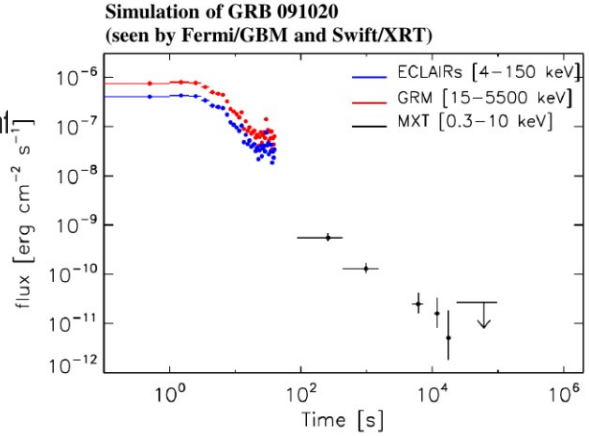
- Agreement to use the LCOGT network through NAOC guaranteed time (2000 h/yr)
- **> 75 % of ECLAIRs GRBs immediately visible by one of the ground telescopes**

Response to a trigger

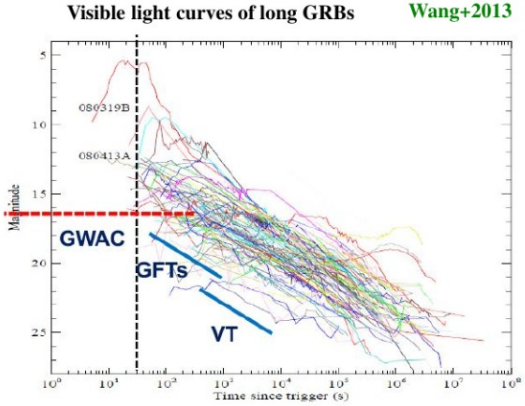
- **Complete coverage of GRB emission over 7 decades in energy from trigger up to the late afterglow phase**







> 90 % AG detection for MXT

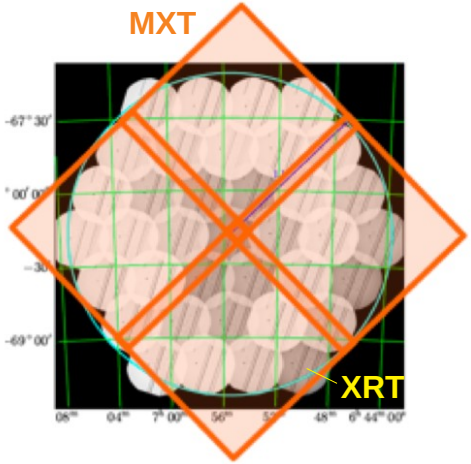


> 80 % AG detection for VT

	Swift	Fermi	SVOM
Prompt	Poor	Excellent 8 keV -100 GeV	**Very Good** **4 keV - 5 MeV**
Afterglow	Excellent	> 100 MeV for LAT GRBs	**Excellent**
Redshift	~1/3	Low fraction	**~2/3**

SVOM Reactions to MM event

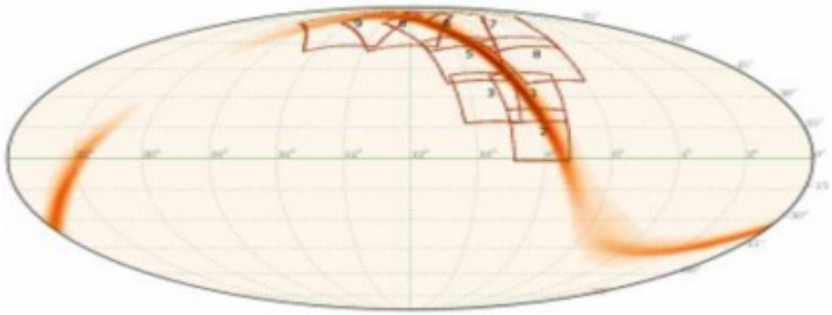
- **Wide FOV HE instruments: ECLAIRs + GRM**
  - Slew if event is above ECLAIRs trigger threshold in less than 5 min
  - Sub-threshold events sent through VHF to SVOM ground segment
  - Otherwise, off-line detection on ground within ~6 – 12 h



- **Narrow FOV instruments: MXT + VT**
  - Require a decision to slew following the alert (ECLAIRs trigger or ToO)
  - Require a tilling strategy if error box > 1 deg²

- **Wide FOV ground-based instrument: GWAC**
  - Rapid automated response

- **Narrow FOV ground-based instruments: GFTs**
  - Rapid response (robotic telescopes)
  - Need an accurate localization

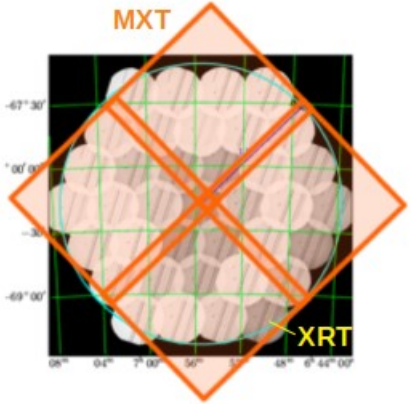


Follow-up of GW170608 with early version of GWAC

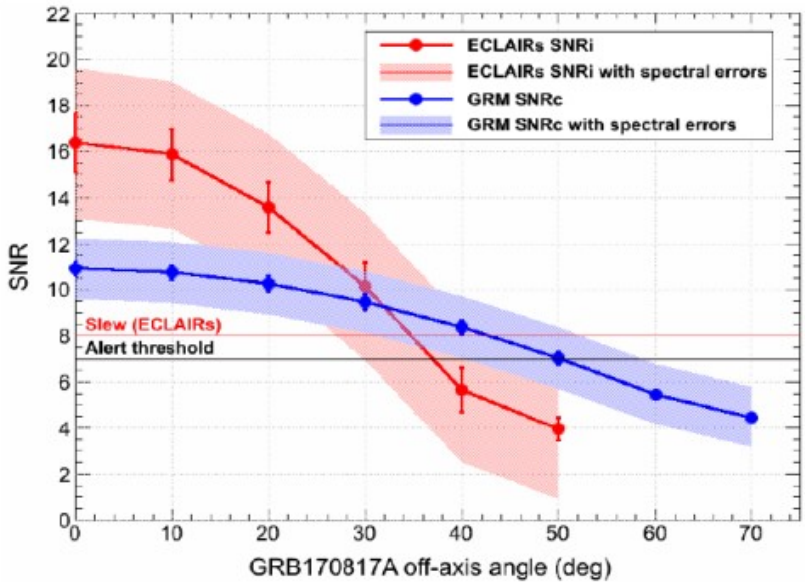
- **SVOM followed GW events from the O4 run (GWAC + C-GFT).**

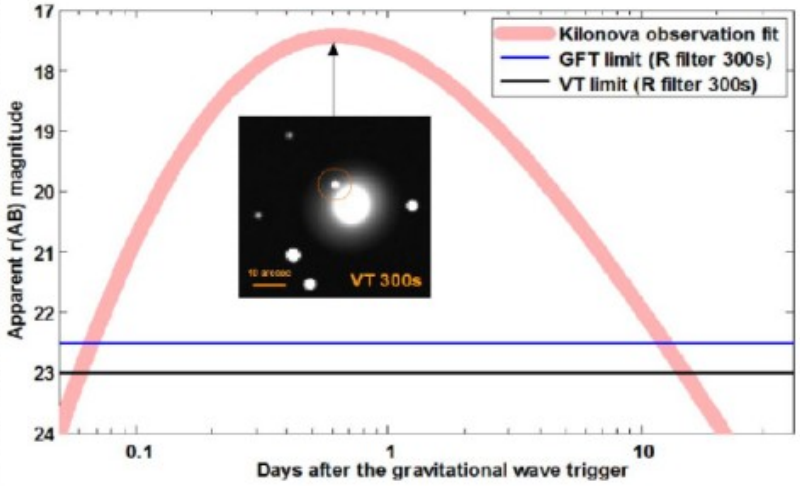
SVOM Reactions to GRB/GW170817-like events

- **If the GRB appeared in ECLAIRs/GRM FoV**
  - ECLAIRs & GRM detection with high probability → slew request sent by ECLAIRs
  - MXT & VT follow-up observations → kilonova easily detectable by VT



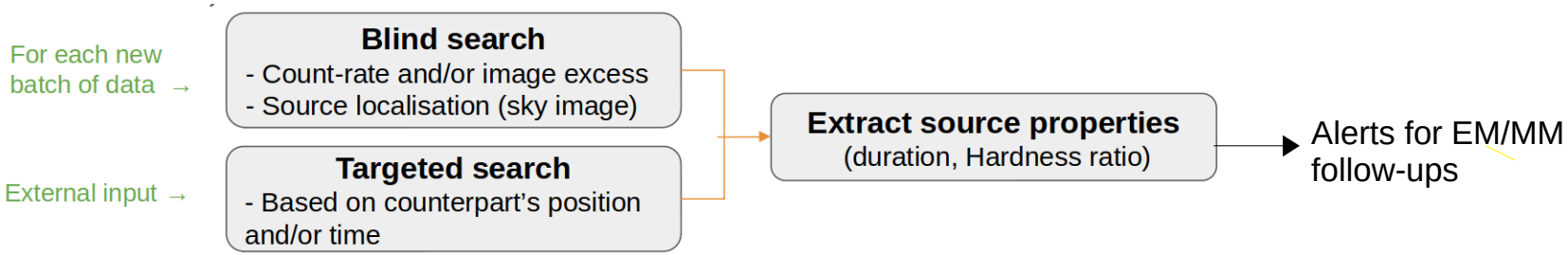
- **If not in ECLAIRs & GRM FoV**
  - LV alerts received at the French science center
    → GWAC tilling of the GW error contour
    → GFT observations triggered, nearby galaxy targeting within the GW error contour
    → Upload ToO-MM to tile the GW error contour with MXT





Boosting transient search/follow-up

- **ECLAIRs offline trigger** designed to complement the onboard triggers with a more thorough search
  - Knowledge of the context (e.g. data before and after the detected transients)
  - More computing resources, less constraints on time and less conservative thresholds
  - Enable targeted searches on archival data from external facilities (VRO/LSST, GCN, LVK, IceCube, etc.)



- **ECLAIRs Quick Look Analysis –** Pipeline to detect serendipous sources from each pass of data (several orbits) & to build science products enabling to track source long-term variability

- MXT pipeline will have similar features as the ECLAIRs QLA for detected serendipously sources from each pass of data.

- On-going internal discussion to see if on the long run possibility to build a live SVOM catalog

- Development of science modules for FINK (e.g. orphan GRB afterglows, kilonovae, TDE)

- Possibility to obtain SVOM prompt reaction to follow up one source in the ECLAIRs catalogue

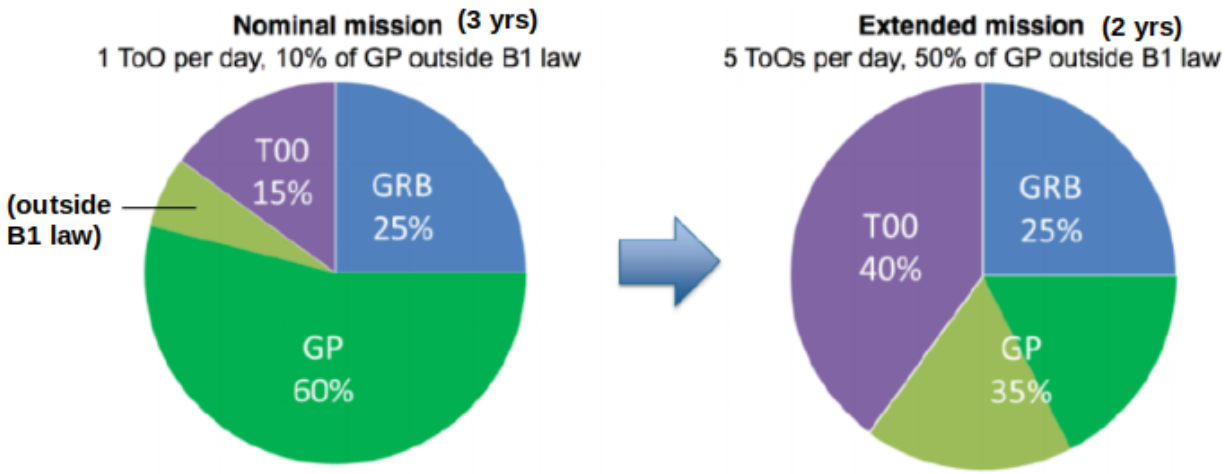
SVOM Scientific Programs

- **Core Program (CP):** GRB science (25 % of time, highest priority)

- **General Program (GP)** – guest observing program: Observations will be awarded by a TAC (a SVOM member needs to co-sign the proposal)
  - 10 % of time on low Galactic latitude sources during the mission nominal phase
  - Up to 50 % during the mission extended phase

- **Targets of Opportunity (ToO) program:** Alerts sent from the ground to the satellite
  - Initially, 1 ToO per day focused on transient and MM follow-ups
  - Devoted time will increase during the mission extended phase

Urgent ToOs uploaded onboard in < 12 h



SVOM Data Policy

Core Program (GRB)

Real-time VHF scientific products (under the supervision of the Burst Advocates) will be **public as soon as they are available** => similar to Swift or Fermi-GBM.

All the **scientific products are public six months** after the data production.

General Program (GP)

Semester Call for proposal (**in association with a SVOM Co-I**), it can include ToO.

All the SVOM data will be distributed to the Responsible Co-I.

One year of proprietary period before all the scientific products become public.

ToO Program (still under discussion)

ToOs triggered by the SVOM CO-Is => we will make **publicly available as soon as possible** any scientific product that is relevant to perform follow-up observations. The number of products to be publicly released will be addressed case by case.

ToOs triggered by non SVOM CO-Is => **all the scientific products will be public** as soon as they are available.

Raw data and data reduction pipelines not released outside the collaboration

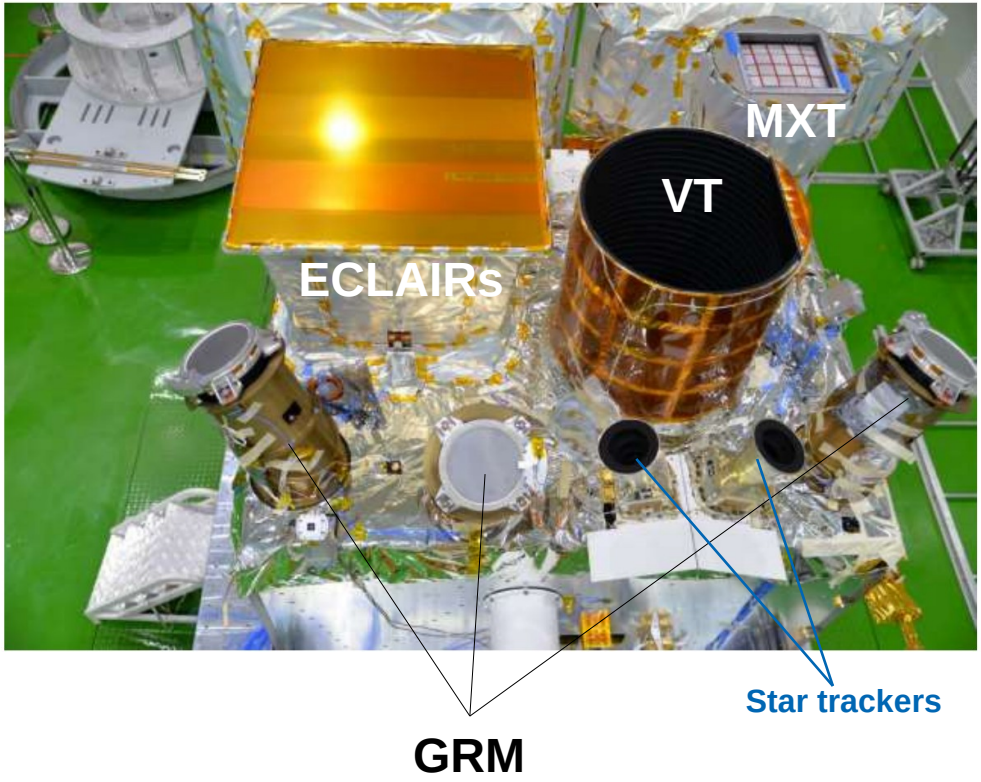
Possibility for external people to contribute to science WGs

Affiliated members if agree to provide any useful pieces of information (data, models) in a regular basis

Proprietary time on request to the SVOM PIs

Take away

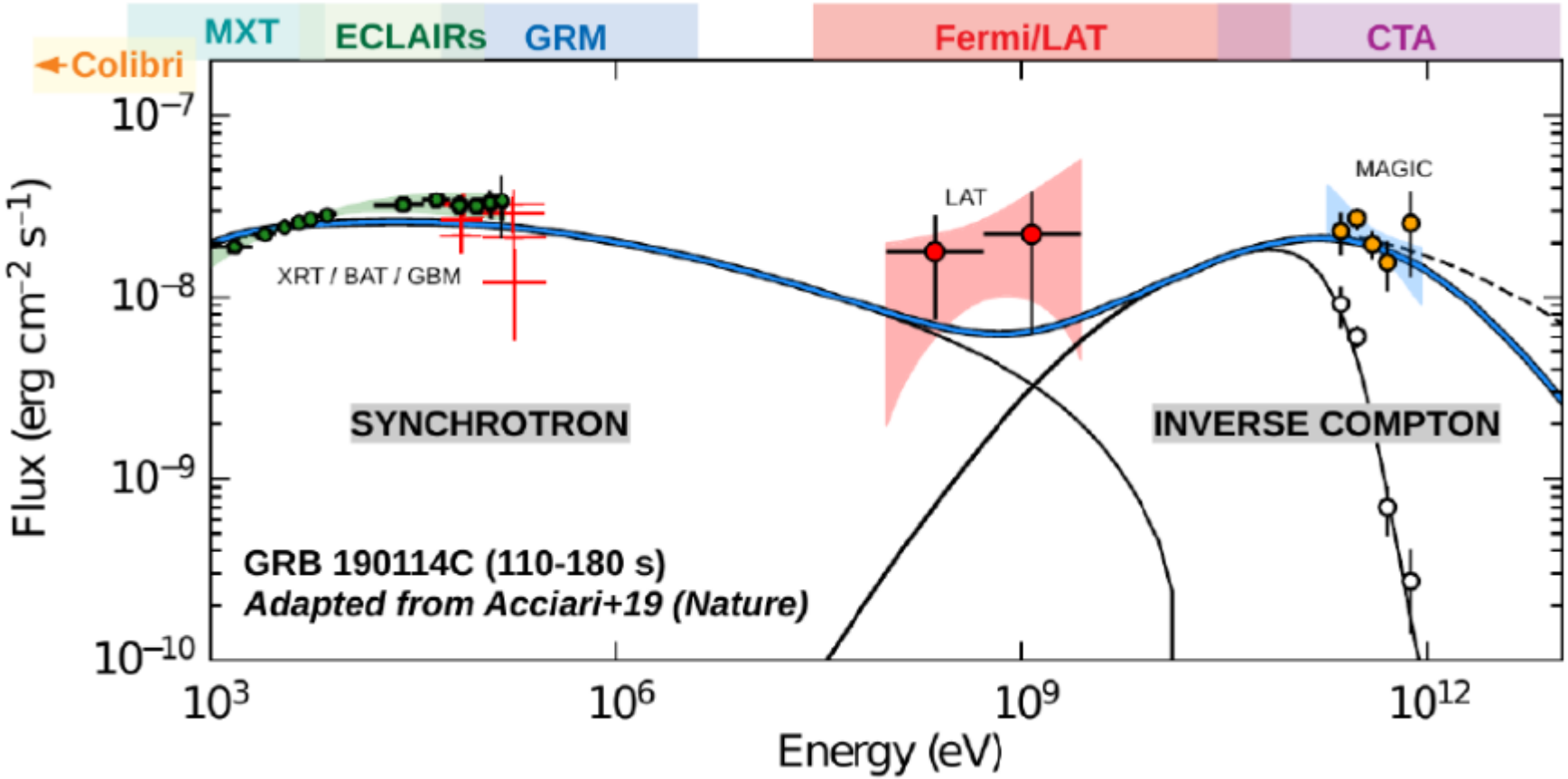
- All instruments integrated on the satellites
- Satellite TVAC and environmental tests performed with success!
- **The Flight Acceptance Review in January 2024 gave the go for the launch at the end of June 2024.**
- Preparing the commissioning phase actively and finishing developments of the ground segment



- SVOM will be a **powerful HE transient machine** working in synergy with MM facilities!
- SVOM will be also **an observatory open to the community** (through Guest Observer and ToO programs).
- If you are interested in using SVOM data for your research or to contribute to the SVOM science activities, please get in touch with us.

BACK-UP SLIDES

Synergy with HE & VHE instruments



ECLAIRs in a nutshell (Godet+14, Godet+22)

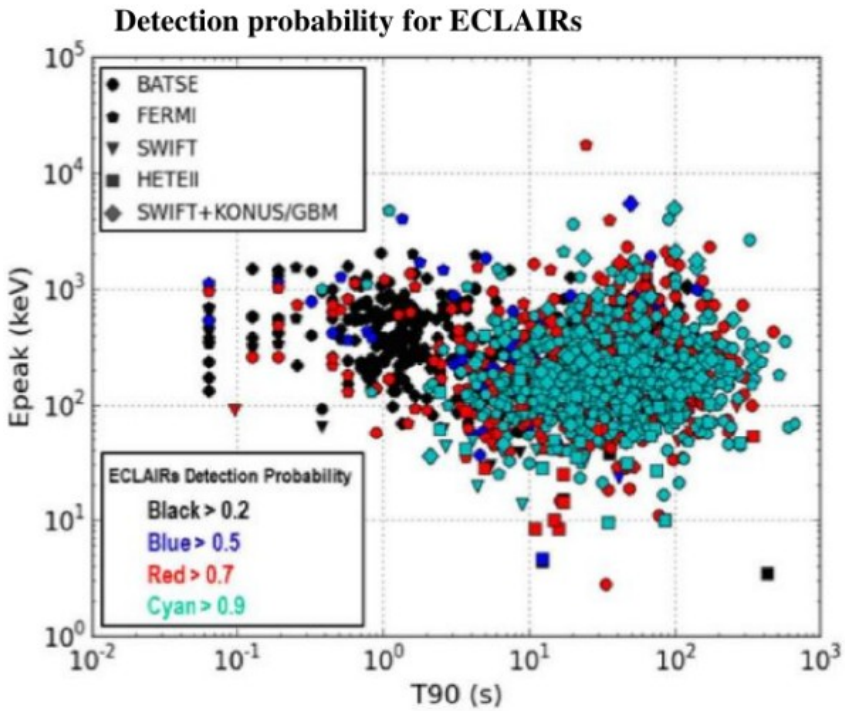
Energy range	4 – 150 keV
Detecting area	~950 cm^2
Detectors	6400 CdTe detectors
Total effective area in 10-70 keV	≥340 cm^2
Photopeak effective area @ 6 keV	≥200 cm^2
Field of view	2.05 sr total
Sensitivity to 1 second long GRB	2.5 10^{-8} erg cm^{-2} s^{-1} in [5–50] keV
Source Localization Error	11.5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

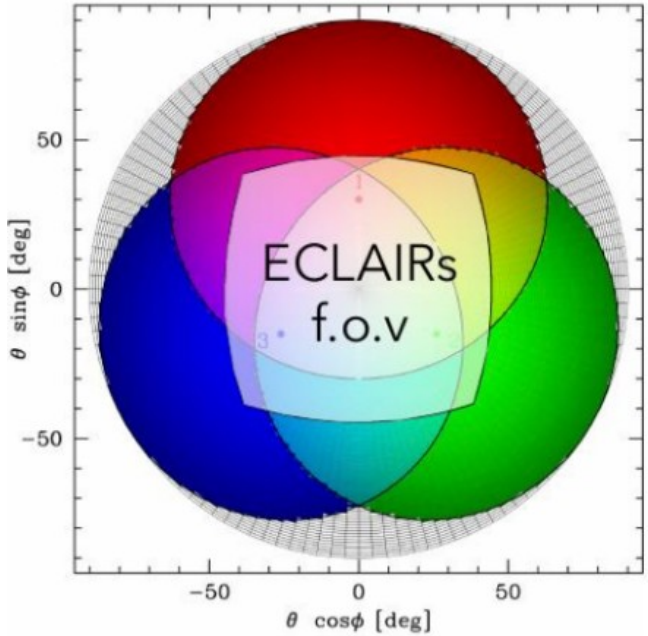
- Detection plane segmented in 8 sectors with an independent electronics each
- Shield made of Pt (0.8 mm) / Cu (0.1 mm)
  - Opacity > 80 % below 150 keV
  - Use for in-flight monitoring of energy scale

- **4 keV energy threshold to increase sensitivity to XRFs & high-z GRBs**
- 3 MLI covers to make sure the camera cavity to prevent optical loading
- **Photon counting mode**
  - All photons transmitted to the ground
  - Readout electronics able to discard particles showers, fluorescence and Compton events as multiple events
- **Automatic software to disable noisy pixels**
- **On-board autonomous detection [count-rate + image triggers] & localisation**
  - Time scales from 10 ms to 20 min
  - 4 energy bands, 9 detector zones
  - **Rate ~ 65 GRBs /year**

GRB Outputs

- **ECLAIRs sensitive to all classes of GRBs**
- **Rate ~ 65 GRBs/yr including a few GRBs with z > 5**





- **GRM FOV wider than ECLAIRs one**
- **Rate ~ 90 GRBs/yr** – poorer localization (5-10 deg with 3 GRD)
- ECLAIRs sensitivity to short GRBs can be improved when combined with GRM.