SVOM: a multi-wavelength observatory to study the transient sky

Bertrand Cordier
CEA-Saclay/Irfu

On behalf of the SVOM consortium

19eme rencontre du Vietnam, ICISE, Quy Nhon, janvier 2023

The 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

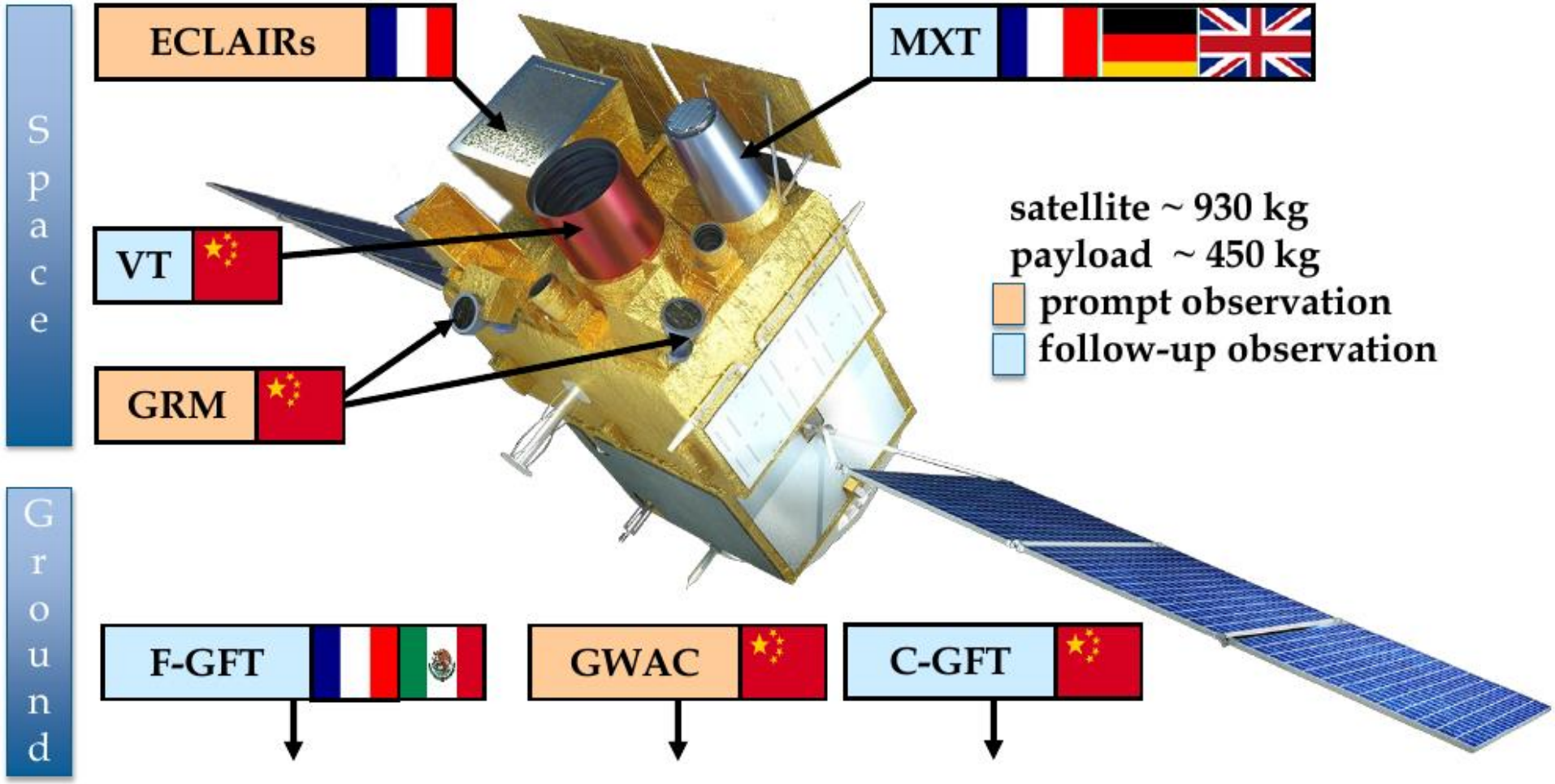
- **Mexico** UNAM (Colibri)

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

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

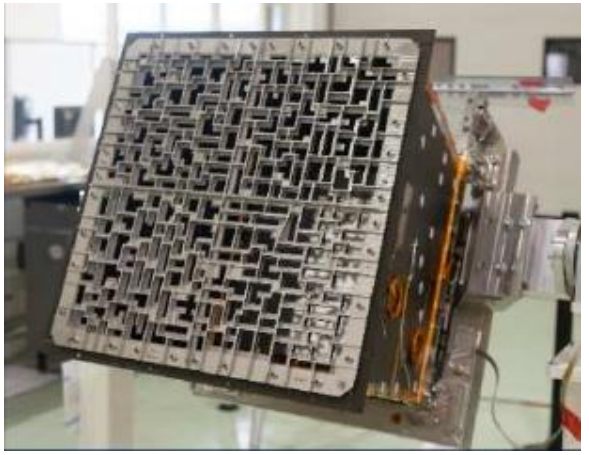
SVOM space and ground segments

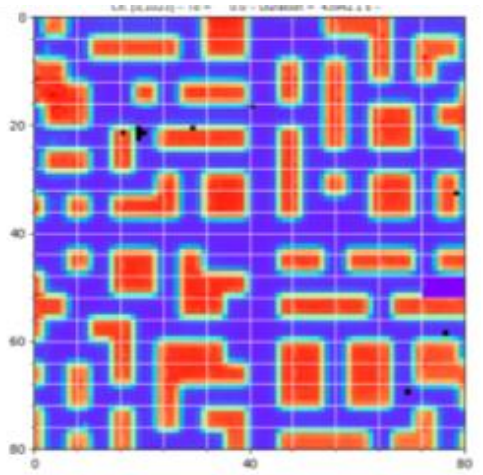
- **"Space-based multi-band astronomical Variable Objects Monitor"**
  - To be launched end-2023, duration 3+2 years (+extension)
- **A space segment with 4 instruments and rapid slewing capabilities**
- **A VHF network to quickly disseminate onboard alerts**
- **A ground segment with 3 telescopes for rapid follow-up observations**

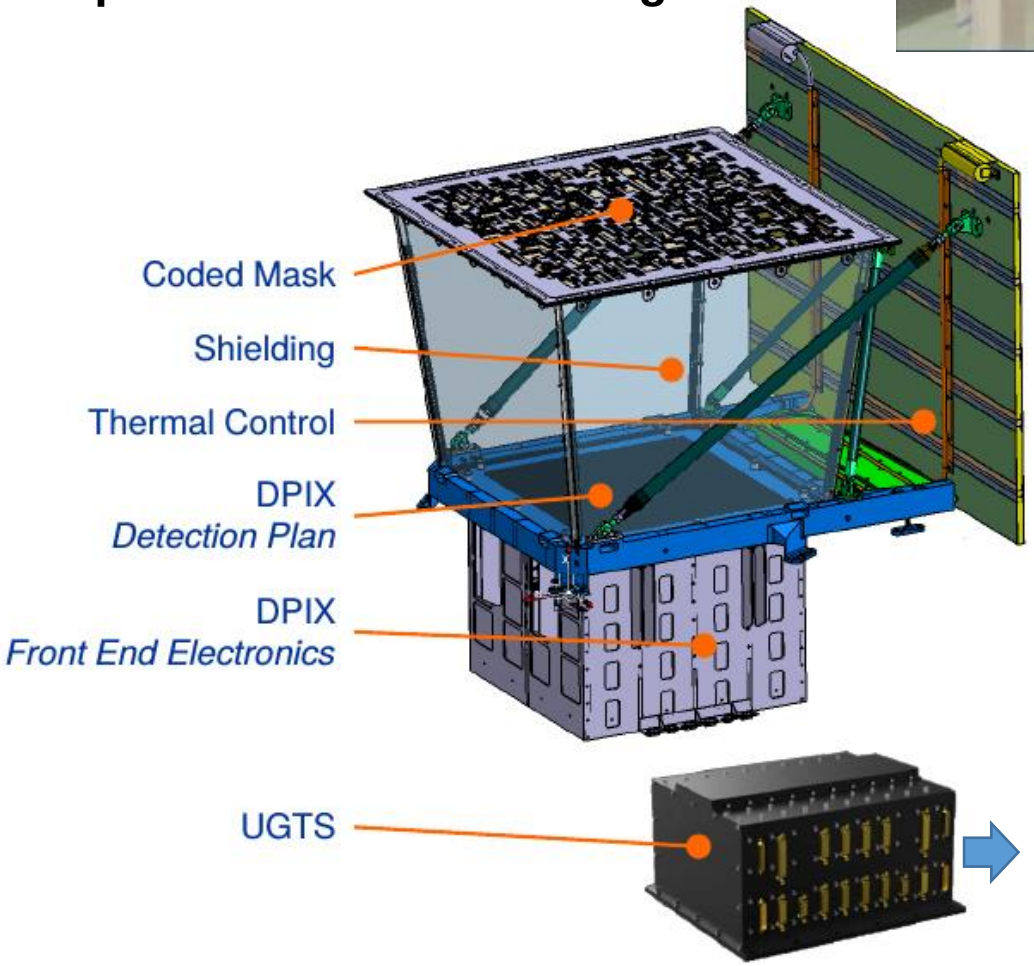


Large FOV : The ECLAIRs gamma-ray imager

- **54x54 cm² coded mask**
  - 40% open fraction
  - 46 cm above detection plane
- **Detecting area 1024 cm²**
  - 6400 CdTe pixels (4x4x1 mm^3)
- **All photons are sent to the ground**





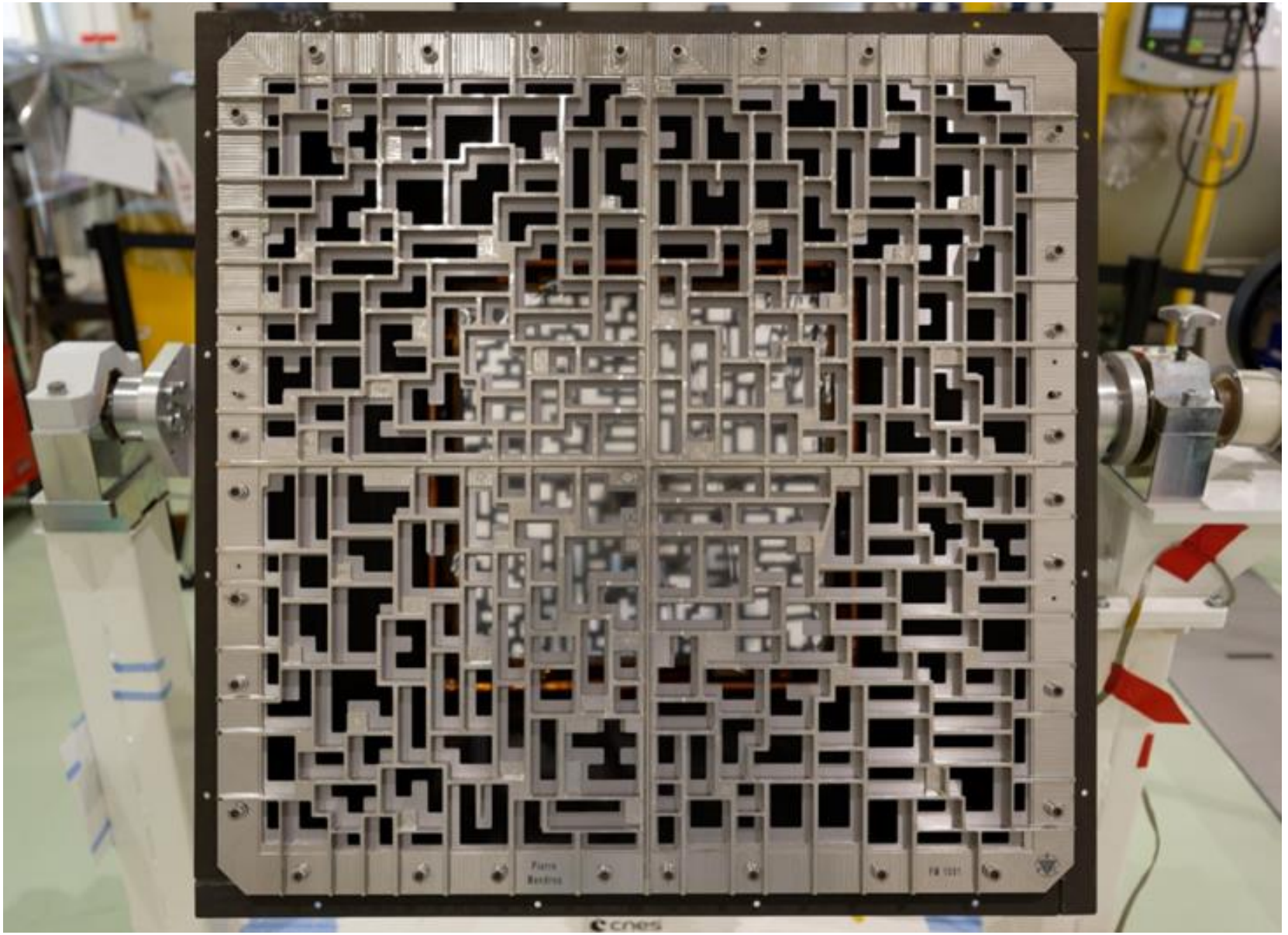


- **Performance**
  - FoV ~ 2 sr total
  - Energy range**: 4**-150 keV
  - Energy resolution <1.6 keV @60 keV
  - A_{eff} = 200 cm² @6 keV
  - Localisation accuracy <12' for 90% of the sources at detection limit

Onboard trigger and localization

- Time scales from 10 ms to 20 min
- 4 energy bands, 9 detector zones
- Rate trigger and image trigger
- **65 GRB /year**

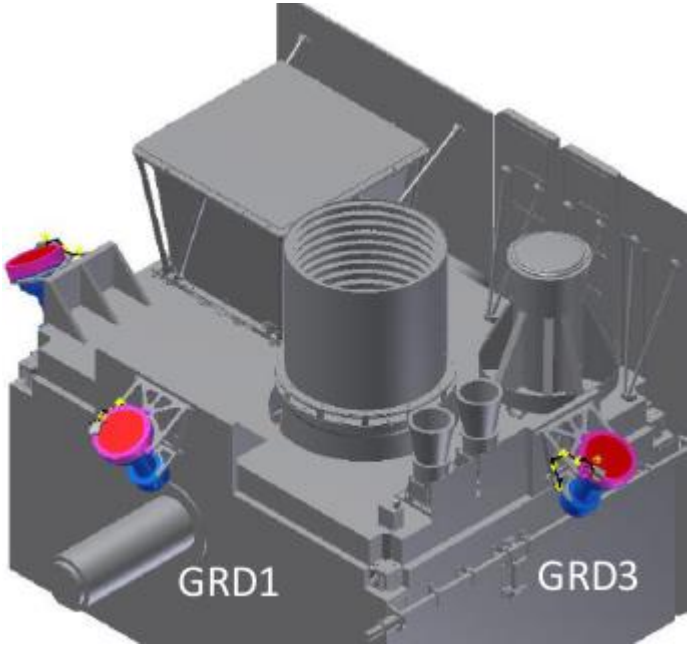
Large FOV : The ECLAIRs gamma-ray imager

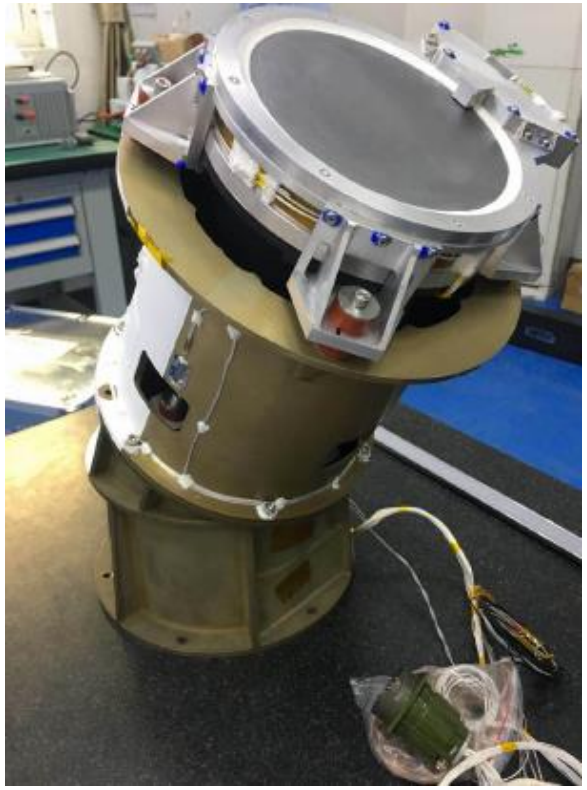


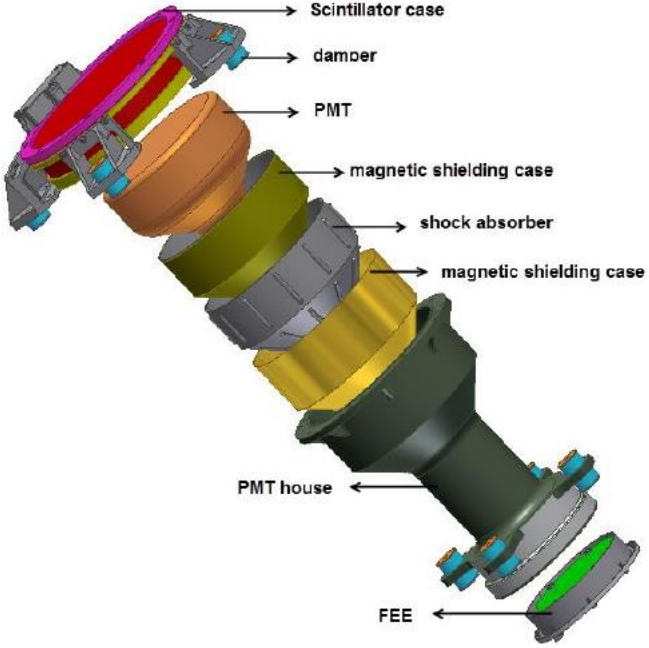
ECLAIRS FM - July 2022

Large FOV : The Gamma-Ray Monitor

- **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
  - 30° inclination w.r.t. ECLAIRs optical axis







- **Performance**
  - FoV ~ 5.6 sr (~2 sr per GRD)
  - Energy range: 15-5000 keV
  - A_{eff} = 190 cm² at peak (each unit)

- **Onboard rate trigger (2 GRDs)**
  - Rough localization accuracy (3GRDs)
  - **90 GRB /year**

Large FOV : Ground-based Wide Angle Camera (GWAC)

- **Two sets of 20 camera units**

- Each camera unit has a diameter of 180mm
- One set already installed at Xinlong observatory
- One set foreseen to be installed at Muztagh Ata observatory

- **Performance**

-500-800 nm; m_{lim}=16-17 (10 s exposure)

-Total FOV of **~5000 deg^2**

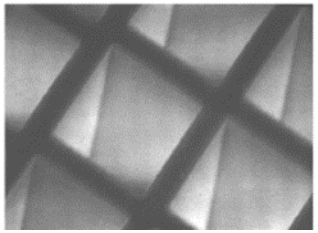
-Self triggering capabilities: will be able to catch autonomously optical transients

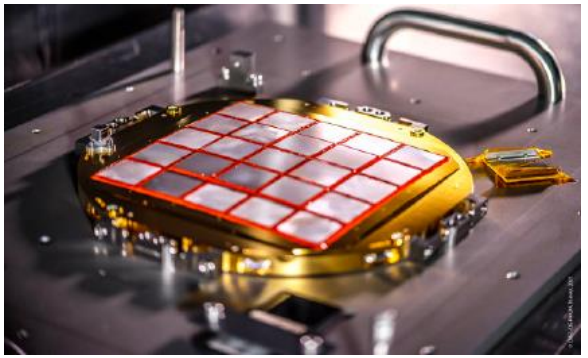
-Explore the prompt optical emission

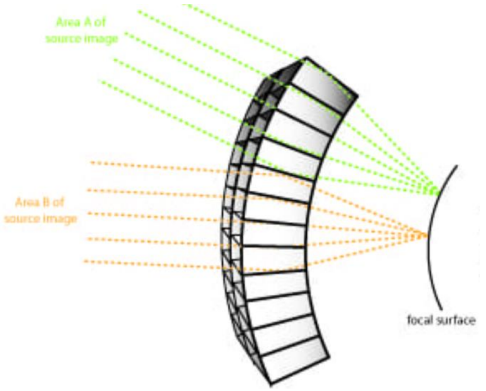
→GWAC can cover 75% of the ECLAIRs FOV when it is observable from both sites

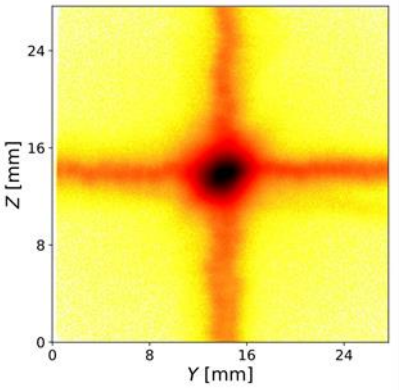
GWAC is in commissioning phase, should be ready to follow-up the LIGO/Virgo 04 run

Narrow FOV : The Micro-channel X-ray Telescope



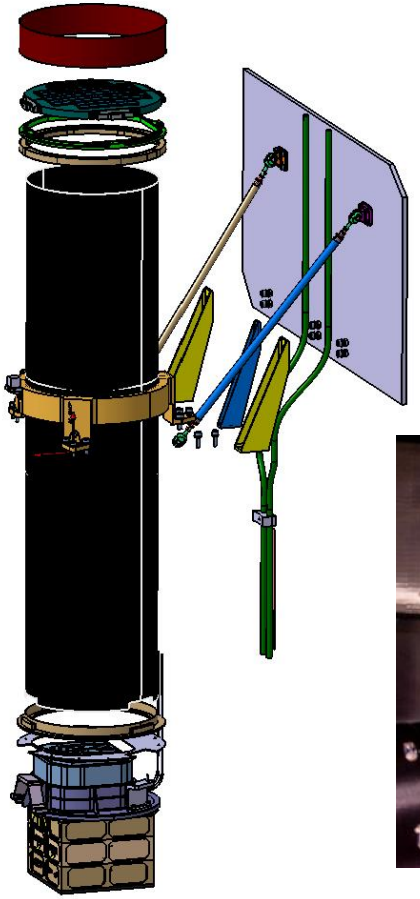






- **Micro-channel plate optics**
  - 20 micron size pores in a “lobster eye” configuration
  - Focal length: 1 m
  - pnCCD camera (256x256 pixels of 75 microns)

- **Performance**
  - FoV = 57x57 arcmin²
  - Energy range: 0.2-10 keV
  - Energy resolution ~80 eV @1.5 keV
  - A_{eff} = 27 cm² @1 keV (central spot)
  - Localization accuracy <30” within 5 min from trigger for 50% of GRBs



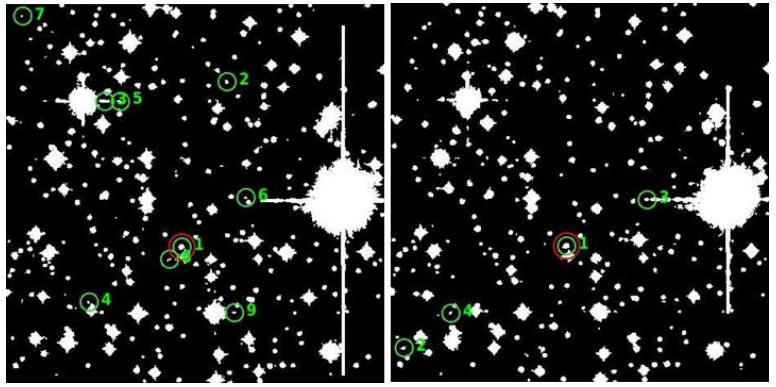
Narrow FOV : The Micro-channel X-ray Telescope

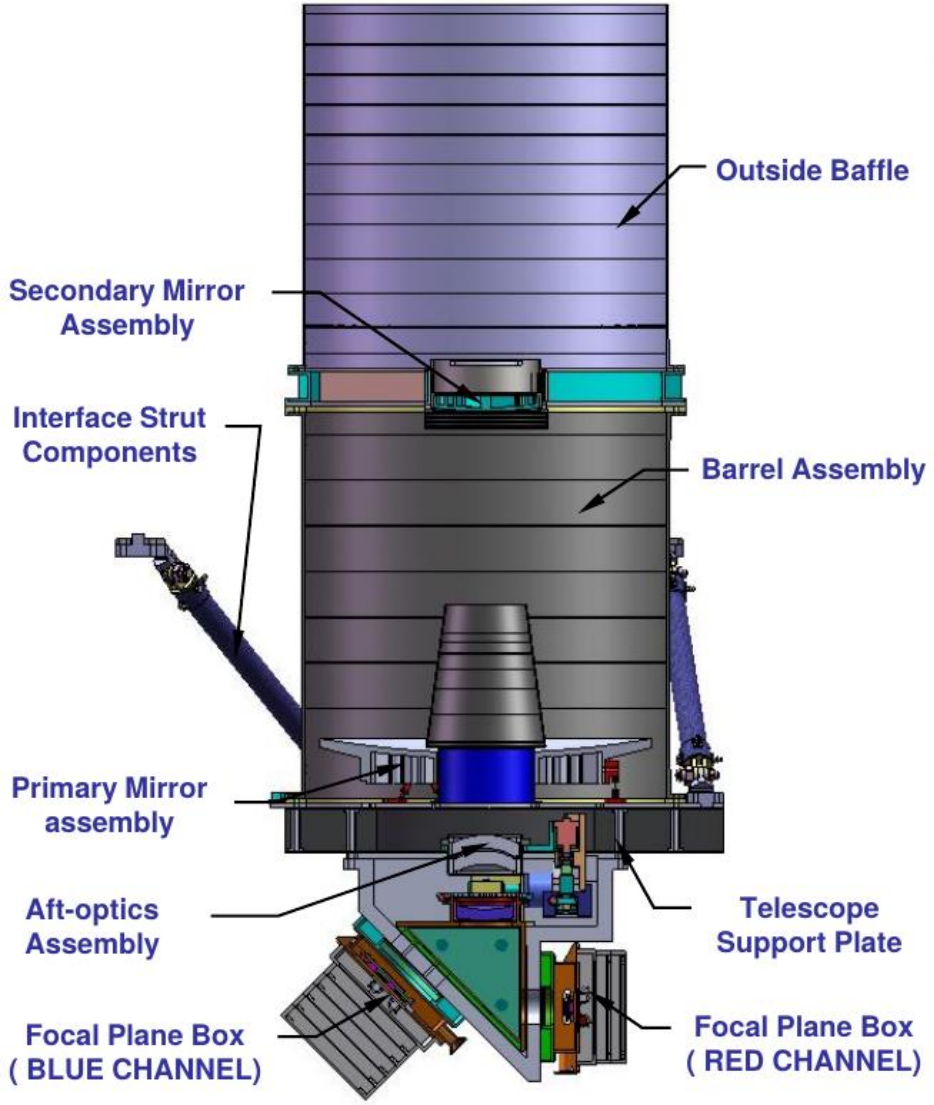
MXT FM - July 2022

Narrow FOV : The Visible Telescope

- **Ritchey-Chretien telescope**
  - 40 cm Ø, f=9
  - Focal length: 3.6 m
  - 2 channels: blue (400-650 nm) and red (650-1000 nm)
  - 2k * 2k CCD detector each

- **Performance**
  - FoV 26x26 arcmin²
  - ⟶ covering ECLAIRs error box in most cases
  - Sensitivity M_V=22.5 in 300 s
  - ⟶ will detect ~80% of ECLAIRs GRBs
  - Localization accuracy <1”





Narow FOV : Ground Follow-up Telescopes (GFTs)

Grounf 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)

Diameter : 130 cm
FOV : 26 x 26 arcmin
400 – 1700 nm

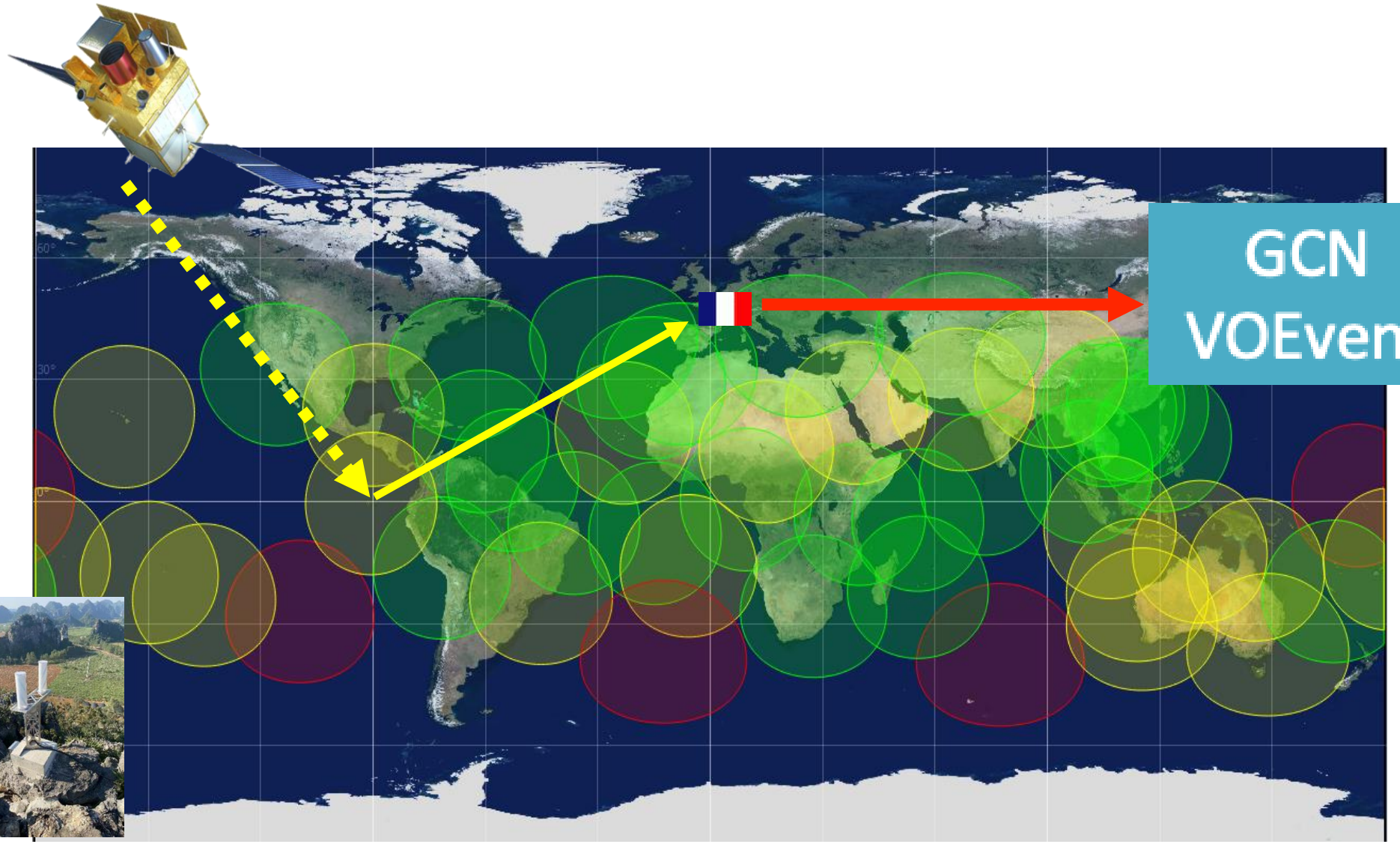
Diameter : 120cm
FOV : 90 x 90 arcmin
400 – 900nm

- **Agreement to use the LCOGT network through NAOC guaranteed time (2000hr/year)**
- **>75% of ECLAIRs GRBs immediately visible by one ground telescope (GFTs+LCOGT)**

Narow FOV : Ground Follow-up Telescopes (GFTs)

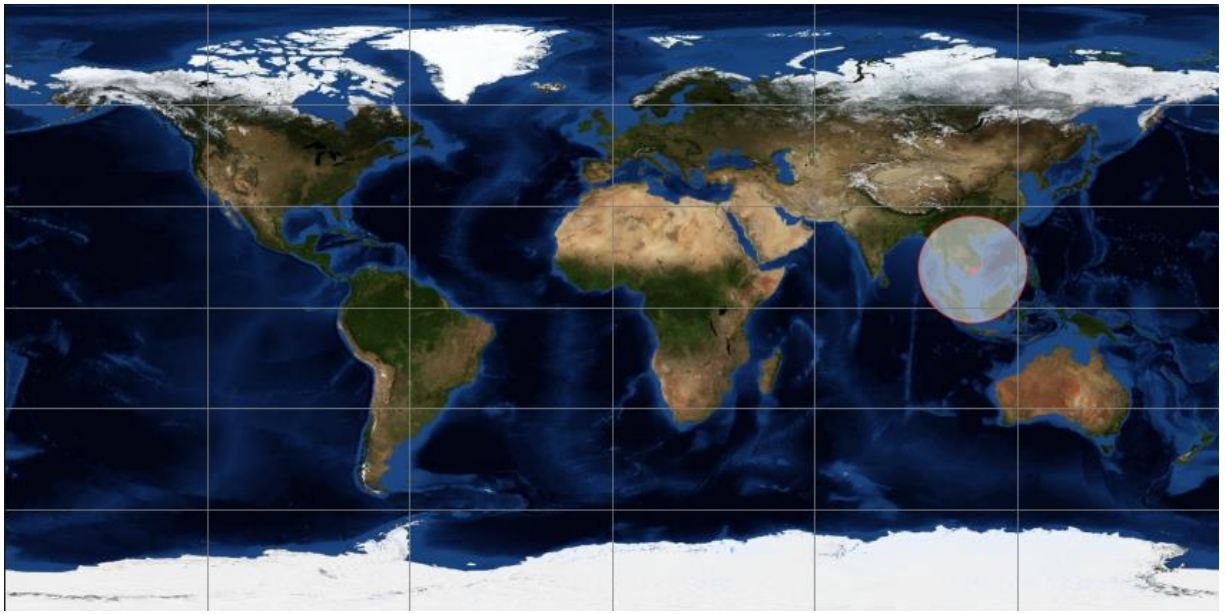
F-GFT november 21

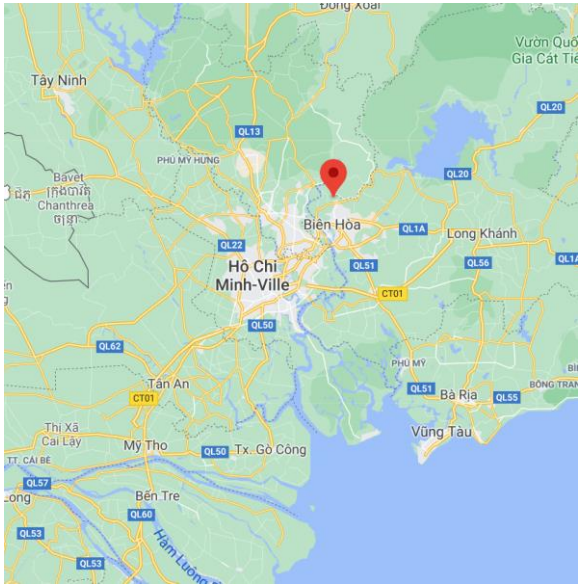
SVOM alert system



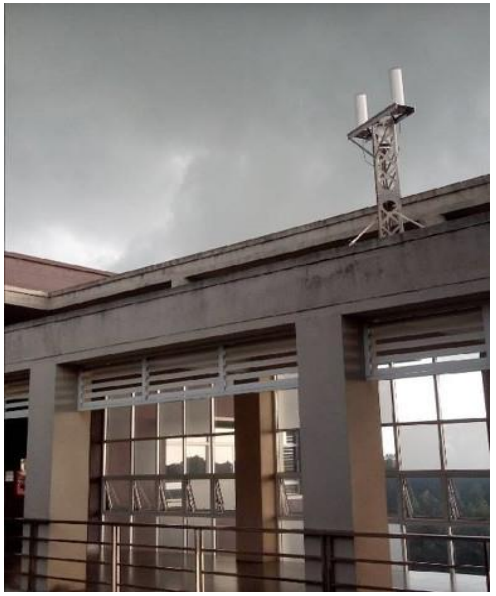
- Alerts are transmitted to a network of ~40 VHF receivers on Earth
- Goal: 65% of the alerts received within 30 s at the French Science Center

SVOM alert system – the HOCHIMIN station



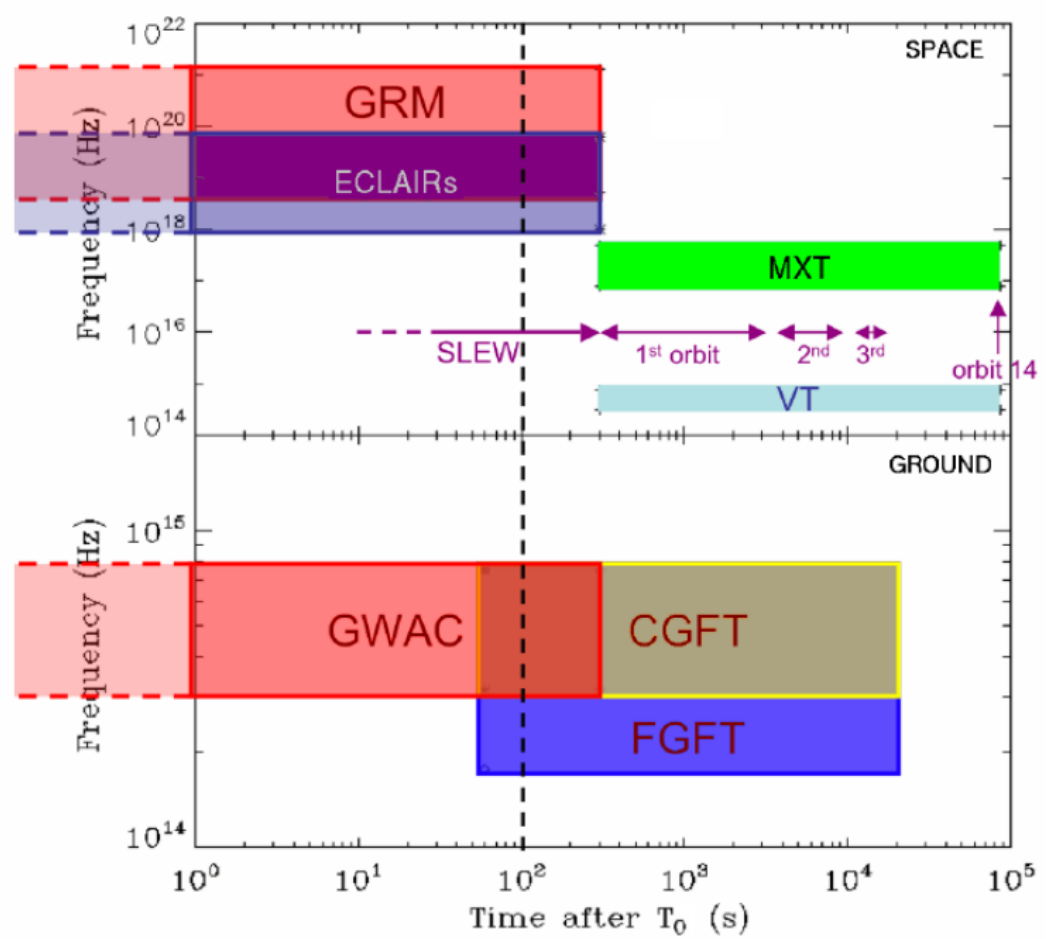


This station has been deployed on the campus of the Vietnamese-German University in Binh Duong, on the periphery of Ho Chi Minh City.



A powerful time domain machine

Spectro-temporal coverage



Synergy between all 7 instruments in space and on ground

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

SVOM orbit and pointing strategy

- **Launch from Xichang by a LM-2C rocket**

-Low Earth Orbit (625 km, 96 min), 30° inclination

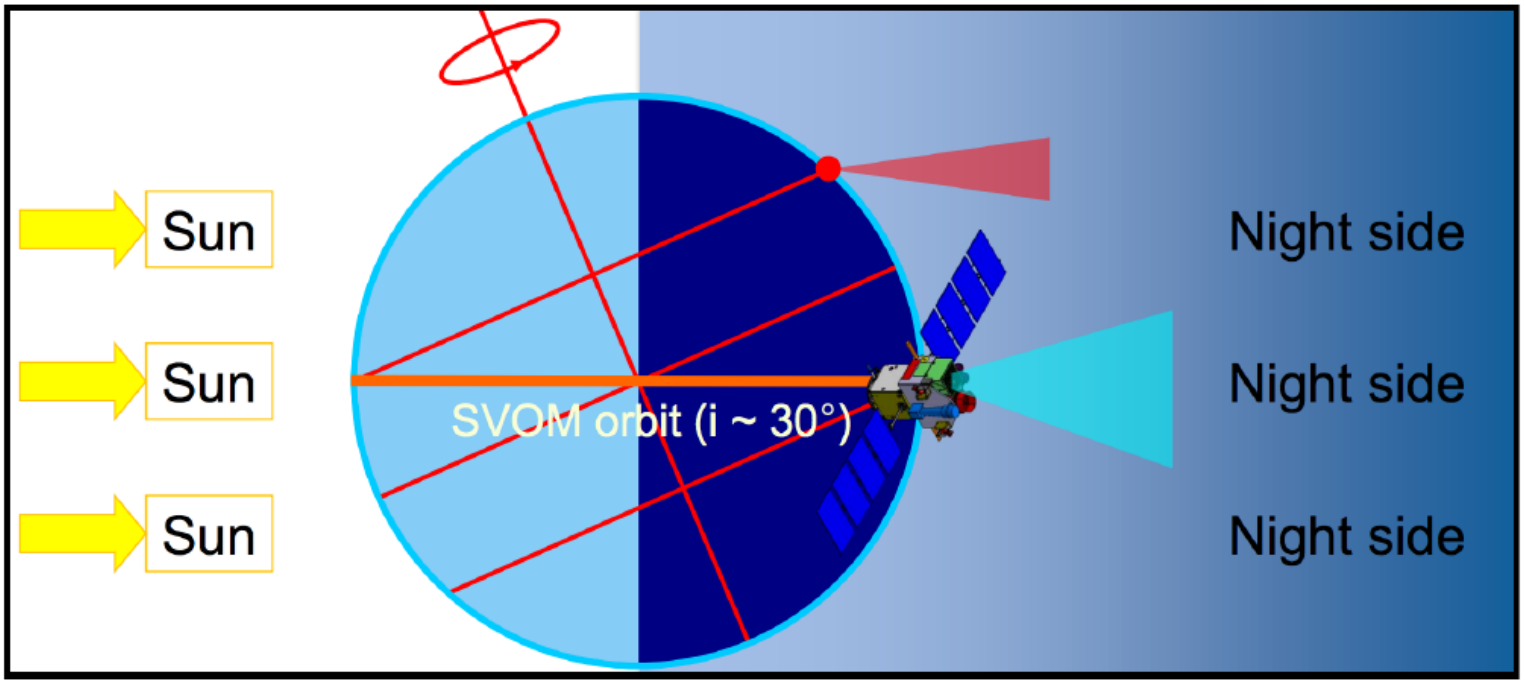
- **Nearly anti-solar pointing to facilitate follow-up observations from ground**

→ Earth in the FoV: 65% duty cycle for ECLAIRs (50% for MXT and VT)

- **ECLAIRs FoV: avoidance of Galactic plane and Sco-X1**

→ Redshift measurement for ~2/3 of detected GRBs

- **Repointing in <5 min, GRB follow-up up to 14 orbits (~1 day)**

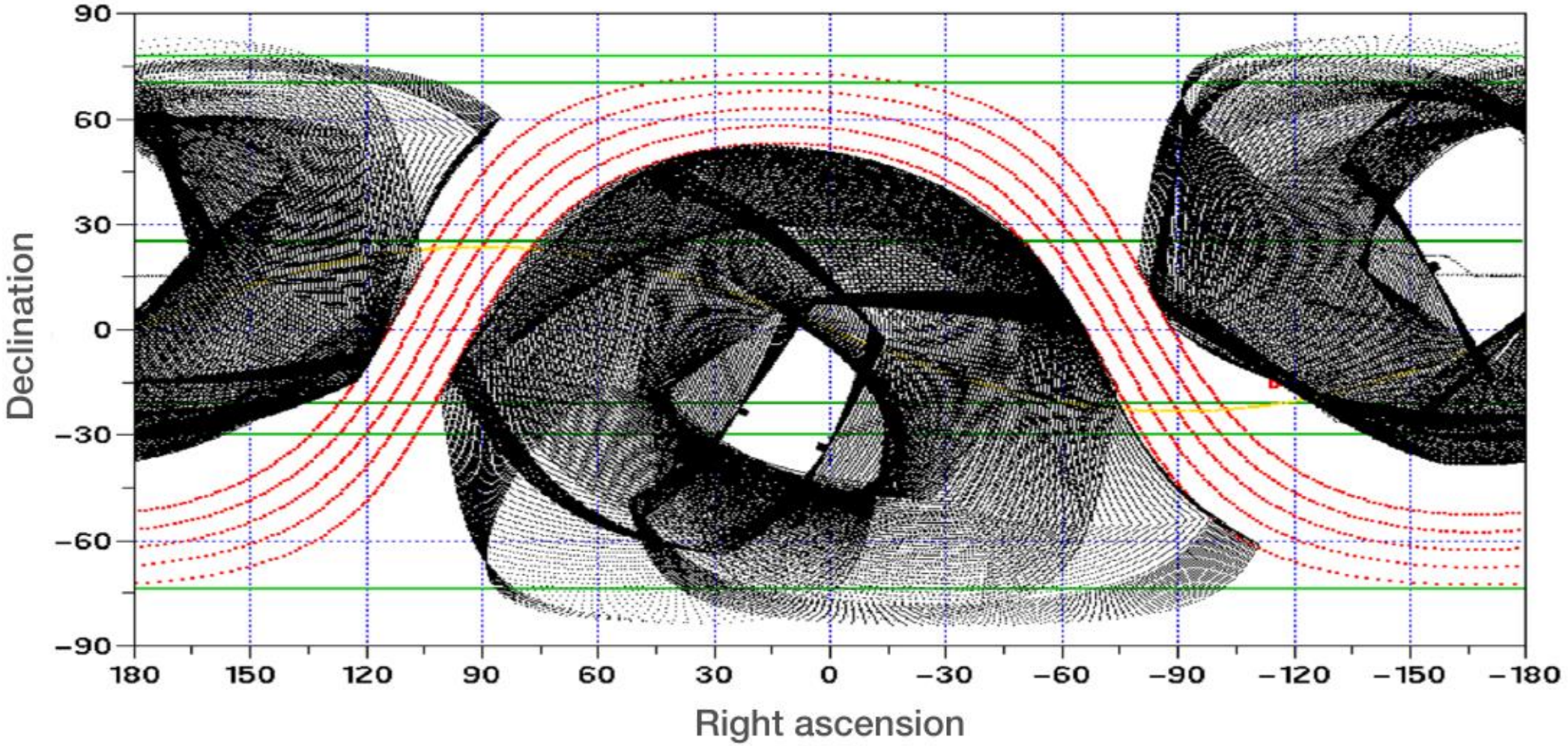


The B1 attitude law

- **ECLAIRs coverage over 1 year**

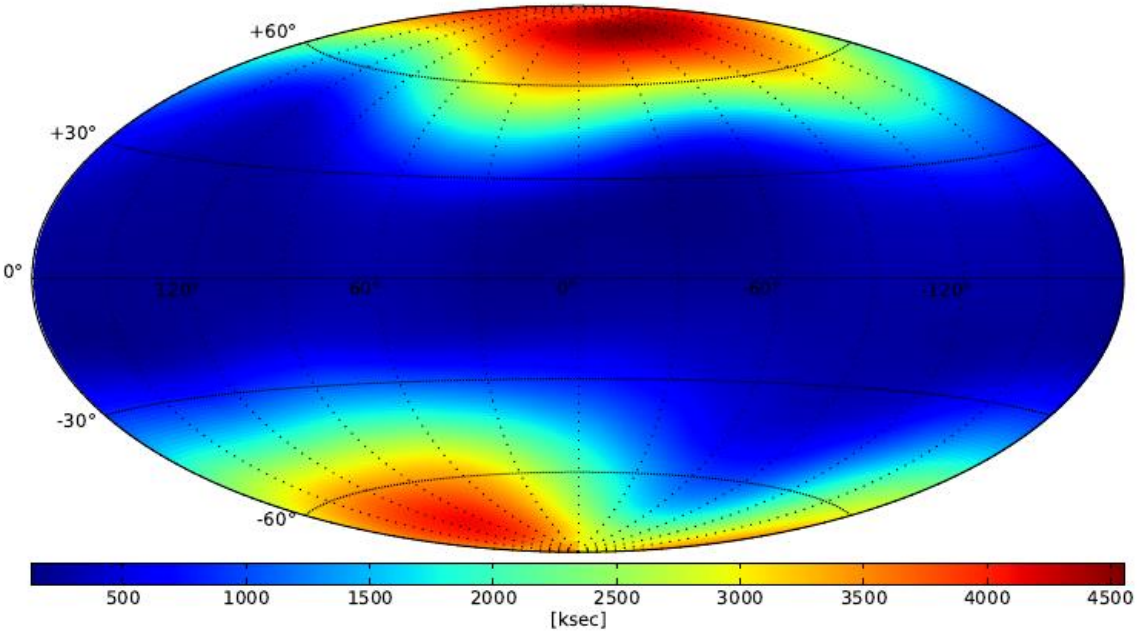
-Avoidance of Galactic plane (red lines, ±5° and ±10°)

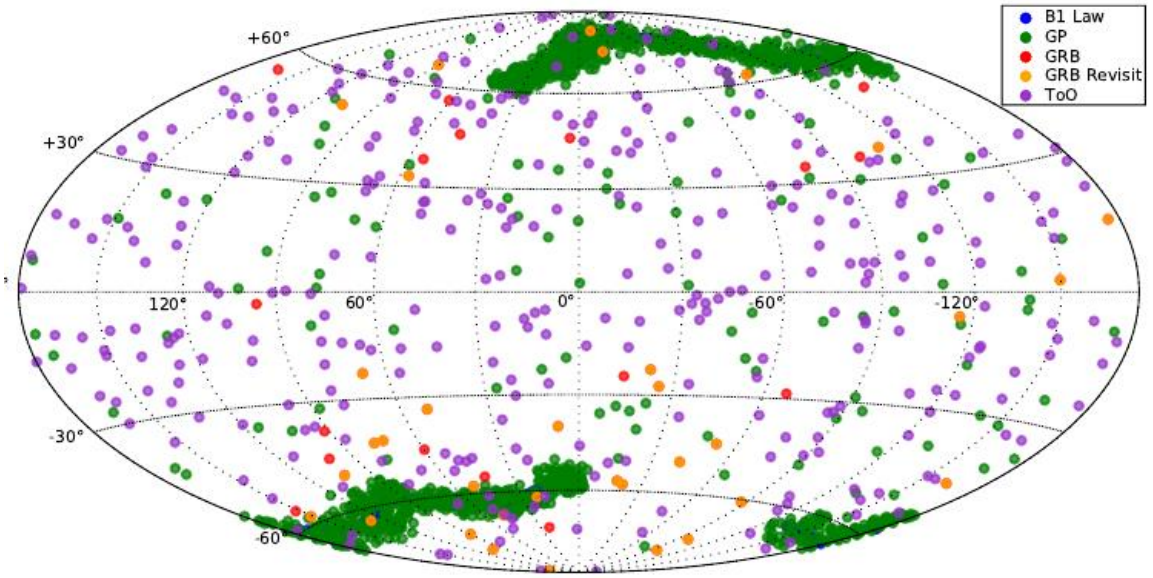
-Green lines: Chile, Hawaii and Canary islands



One year of simulated observation

- **Following the B1 attitude law**
  - Including 65 GRBs & 1 ToO / day
- **ECLAIRs sky exposure**
  - ~4 Ms near the galactic poles
- **MXT and VT pointing direction**





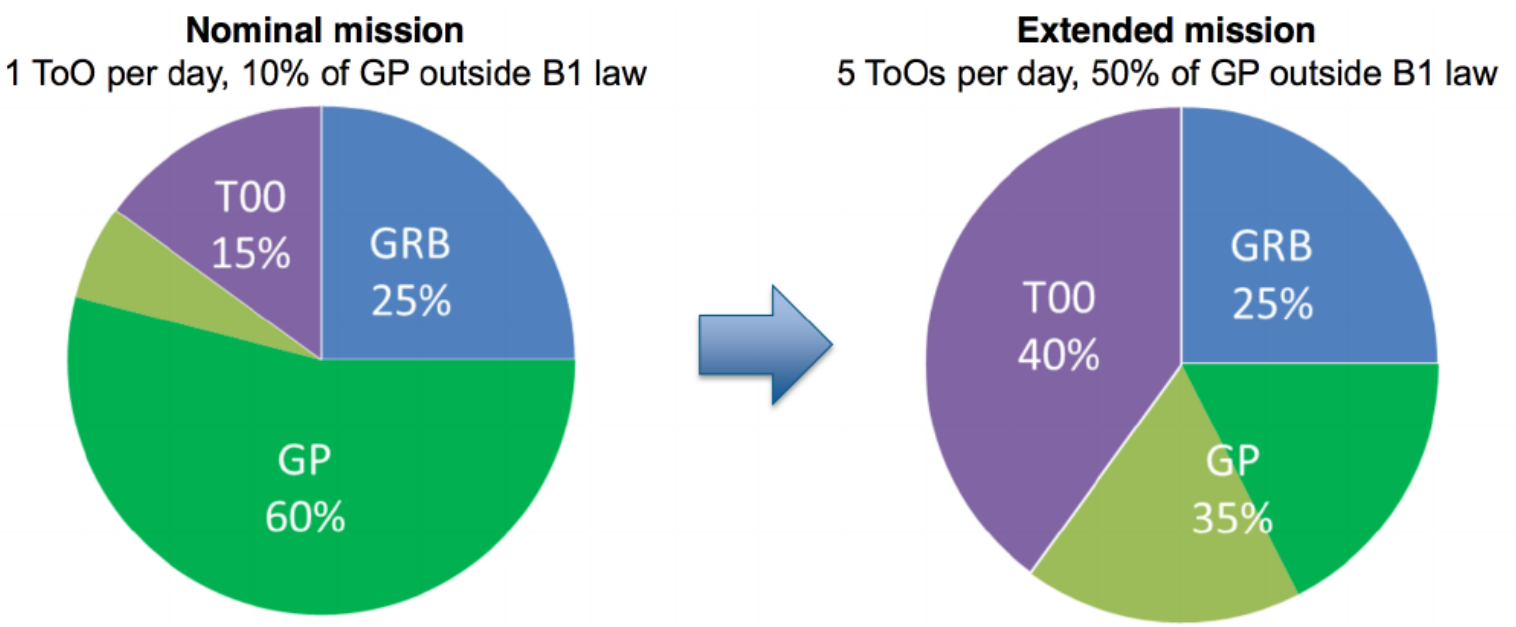
Galactic coordinates

SVOM scientific programs

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

- **General Program (GP)** or SVOM as an open observatory: observations will be awarded by a TAC for astrophysical targets (a SVOM co-I needs to co-sign your proposal)
  - 10% of the time can be spent on low Galactic latitude sources during nominal mission
  - Up to 50% during mission extended phase

- **Targets of Opportunity (ToO) Program:** alerts sent from the ground to the satellite
  - Initially 1 ToO per day focused on TDA and multi-messengers
  - Devoted time will increase during mission extended phase

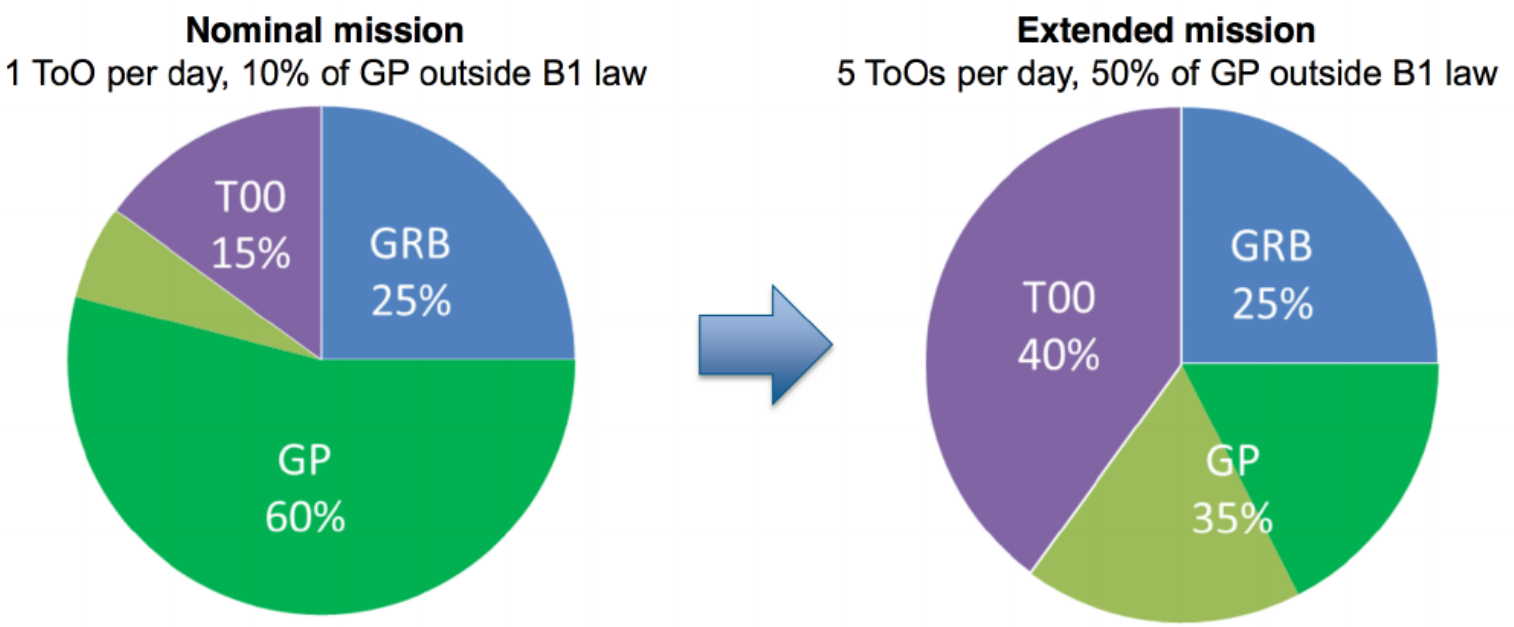


SVOM scientific programs

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

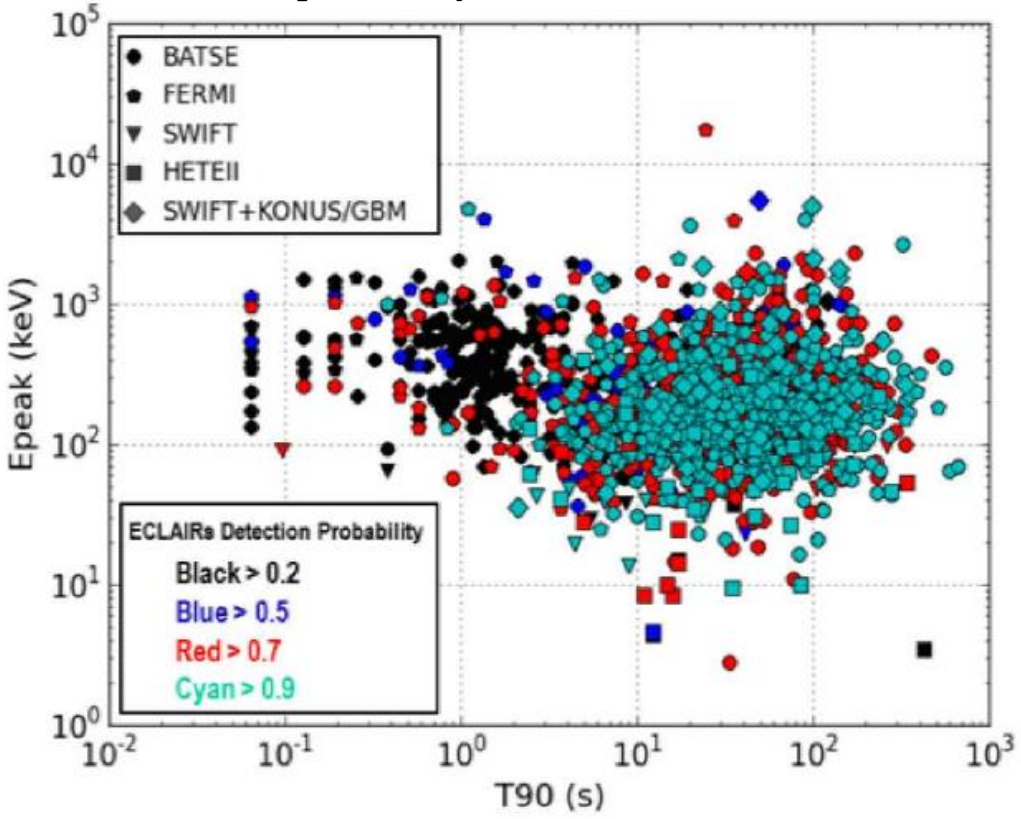
- **General Program (GP)** or SVOM as an open observatory: observations will be awarded by a TAC for astrophysical targets (a SVOM co-I needs to co-sign your proposal)
  - 10% of the time can be spent on low Galactic latitude sources during nominal mission
  - Up to 50% during mission extended phase

- **Targets of Opportunity (ToO) Program:** alerts sent from the ground to the satellite
  - Initially 1 ToO per day focused on TDA and multi-messengers
  - Devoted time will increase during mission extended phase

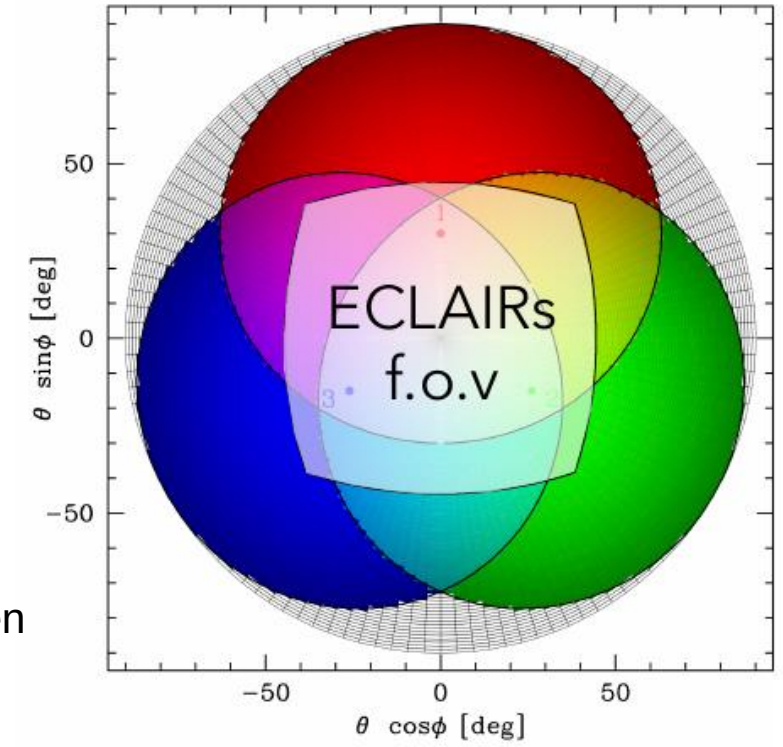


GRB detection

Detection probability for ECLAIRs



- **ECLAIRs is sensitive to all classes of GRBs**
  - Classical long GRBs
  - Soft GRBs (XRR, XRF)
  - Short GRBs (with a moderate efficiency)
  - **~ 65 GRBs / year**
  - **Including 3-4 GRBs / year at z>5**
  - **Loc. <12'**

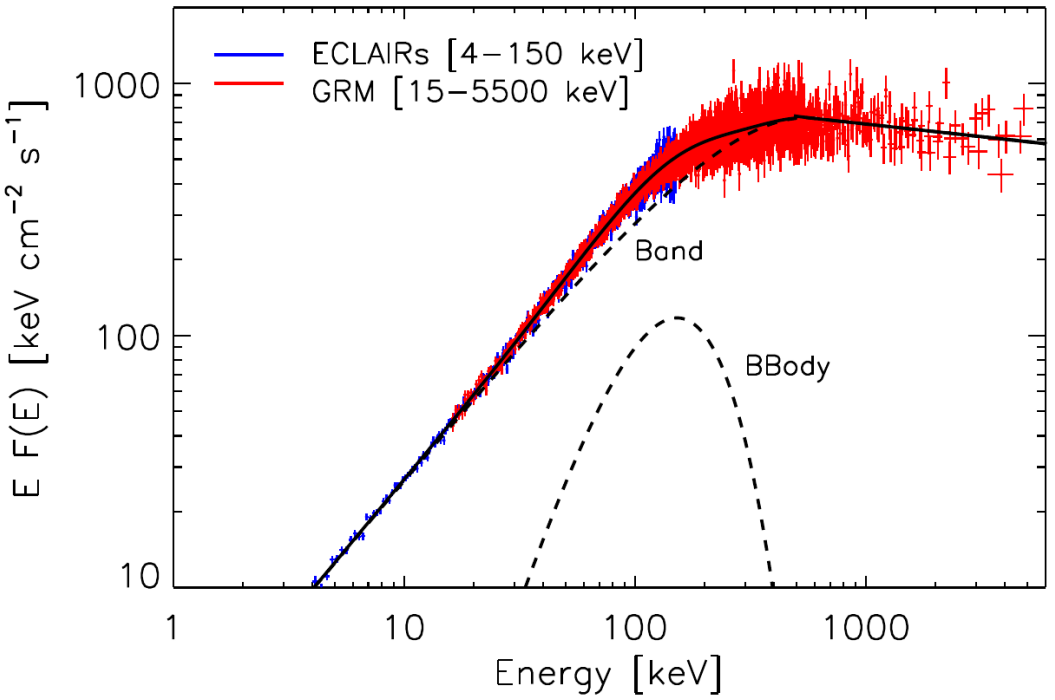


- **GRM has a larger FoV than ECLAIRs**
  - **~90 GRBs / year**
  - **Loc. ~ 5-10 deg (3 GRDs)**
  - ECLAIRs sensitivity to short GRBs can be improved when combined with the GRM

GRB prompt emission

- **ECLAIRs and GRM will measure the prompt emission spectrum over 3 decades in energy**

Multi-component spectrum of the Fermi burst GRB 100724B simulated in ECLAIRs and GRM **Bernardini+2017**

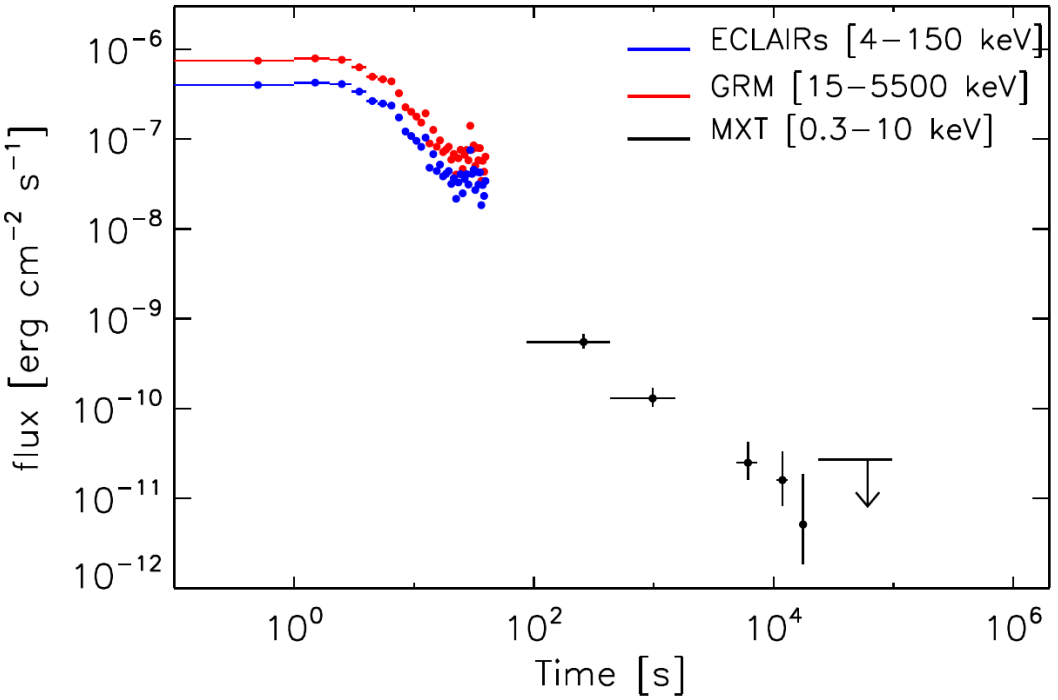


- **GWAC (see next) will constrain the prompt visible emission in ~16% of cases**

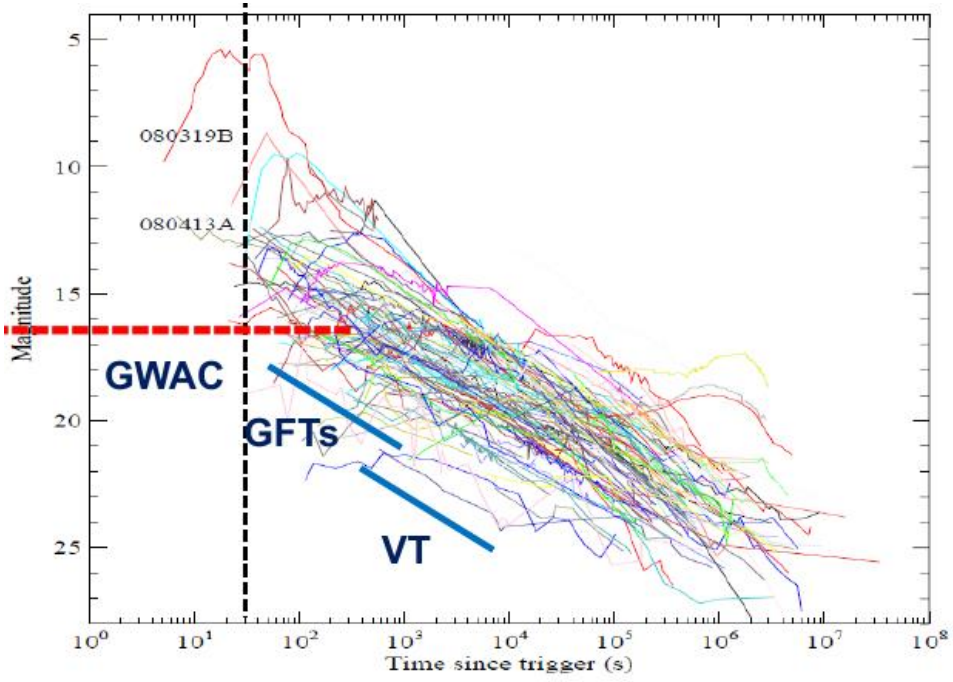
GRB afterglow emission

- **ECLAIRs will cause a slew of the satellite for 50 GRBs / year**
- **MXT will detect and localize the X-ray afterglow in >90% of GRBs after a slew**
- **VT, C-GFT and F-GFT will detect, localize and characterize the NIR / visible afterglows**
- **(lightcurve + photo-z)**

Simulation of GRB 091020
(seen by Fermi/GBM and Swift/XRT)



Visible light curves of long GRBs **Wang+2013**



A GRB sample with a complete description

- **A unique sample of ~35 GRBs / year with**

-Prompt emission over 3 decades (+ optical flux/limit: 16%)

-X-ray and visible / NIR afterglow

-Redshift

	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**

- **Physical mechanisms at work in GRBs**

-Nature of GRB progenitors and central engines

-Acceleration, composition, dissipation & radiation processes of the relativistic ejecta

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

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

-GRB/SN connection

- **Short GRBs and the merger model**

-GW association / Short GRBs with extended soft emission

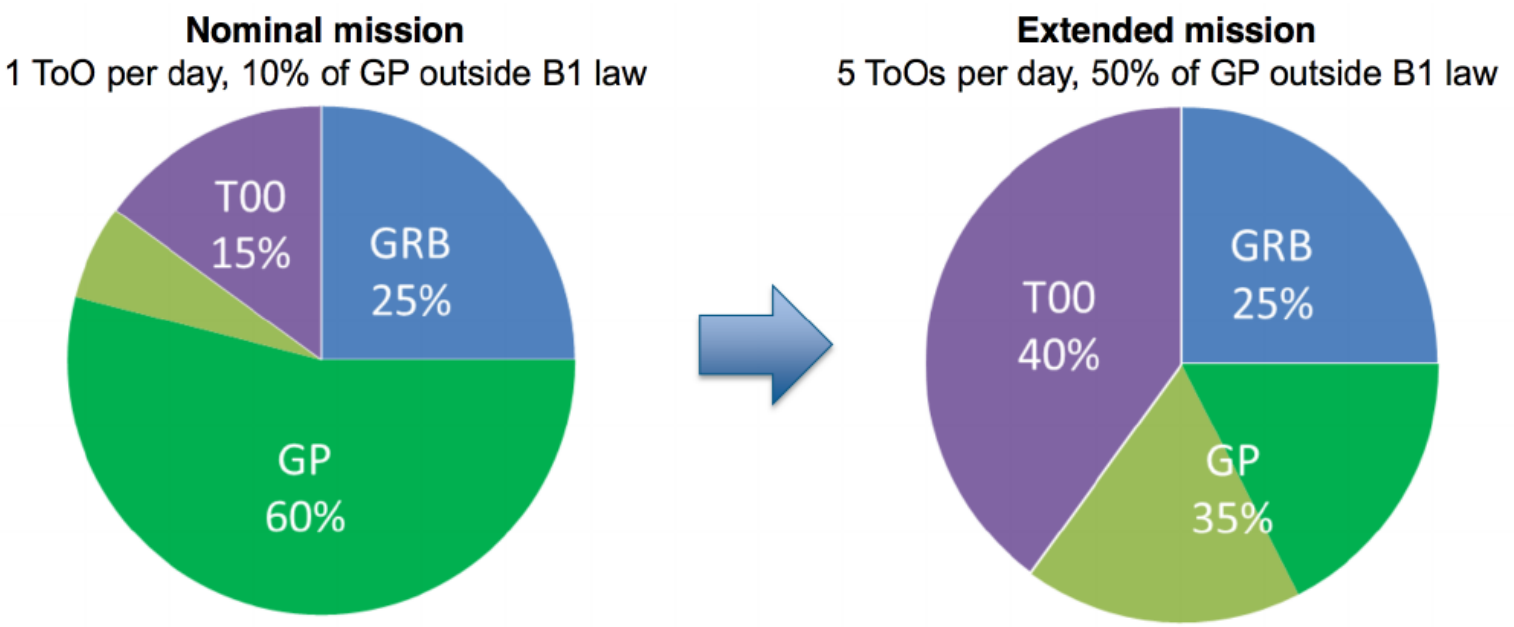
- **GRBs as a tool to study the distant Universe**

SVOM scientific programs

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

- **General Program (GP)** or SVOM as an open observatory: observations will be awarded by a TAC for astrophysical targets (a SVOM co-I needs to co-sign your proposal)
  - 10% of the time can be spent on low Galactic latitude sources during nominal mission
  - Up to 50% during mission extended phase

- **Targets of Opportunity (ToO) Program:** alerts sent from the ground to the satellite
  - Initially 1 ToO per day focused on TDA and multi-messengers
  - Devoted time will increase during mission extended phase



The Target of Opportunity programs

- **ToO-NOM:** Nominal ToO which covers the basic needs for efficient transient follow-up alerts (GRB revisit, known source flaring, new transient)

S-band stations	Standard S-band stations are located in Sanya, Kashi, Qingdao (China). **GP** Work Plan is **uploaded one week in advance**. **ToO-NOM** are uploaded with a typical **48h delay** after decision.

- **ToO-EX:** 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:** ToO-EX dedicated to EM counterpart search in response to a multi-messenger alert

Beidou	**Beidou system will be used to reduce the latency** with respect to S-band stations for **ToO-EX** and **ToO-MM**. Delays still under review. The typical delay between alerts and observations will be **~5 hours at start but will be drastically reduced**

SVOM response to GRB 170817A / AT 2017gfo

- **It the GRB appeared in ECLAIRs or GRM field of view**

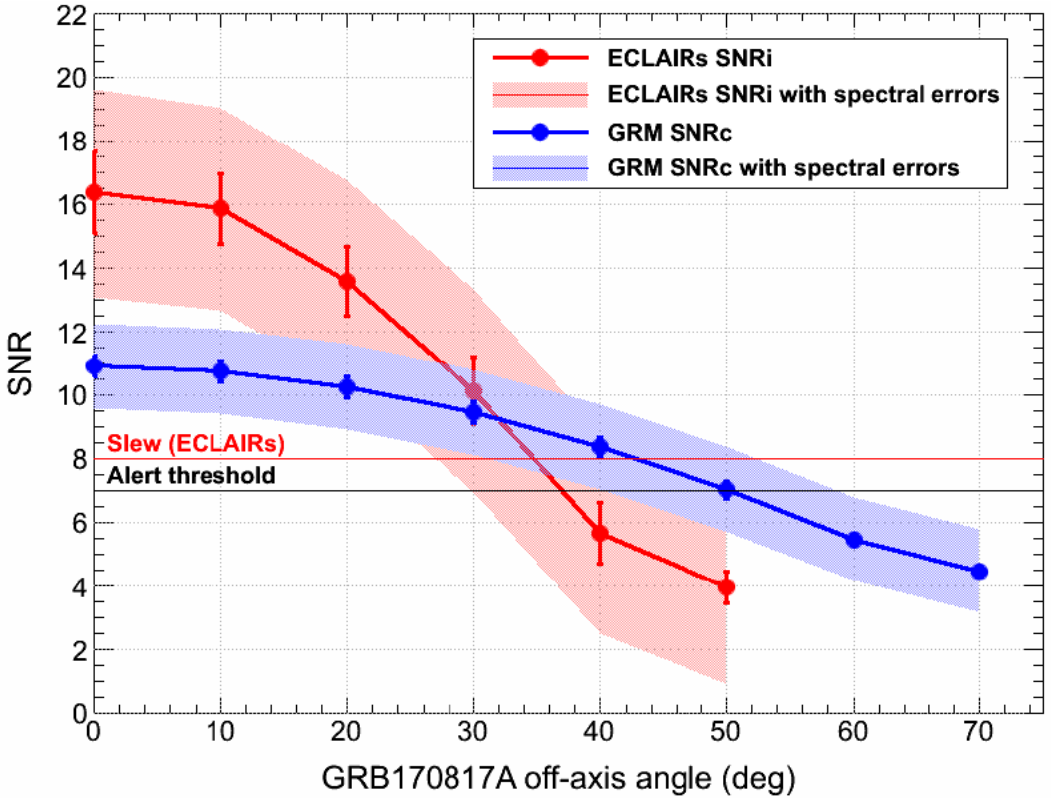
-ECLAIRs & GRM detection with high probability → slew request sent by ECLAIRs

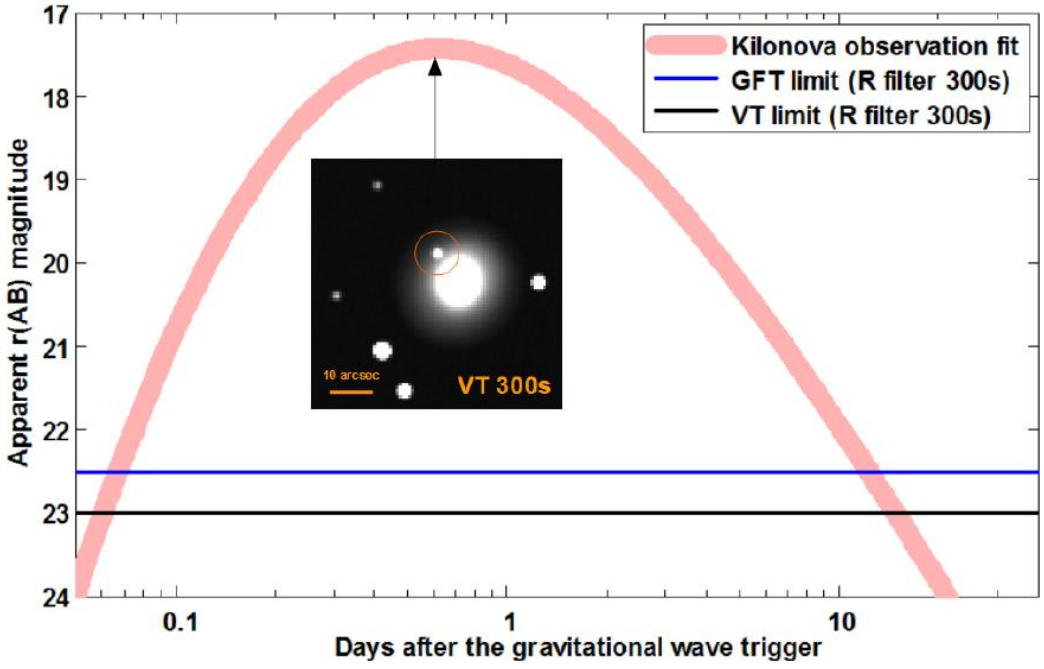
-MXT and VT follow-up observations → kilonova easily detected by the VT

- **If not in ECLAIRs and GRM field of view**

-LIGO-Virgo alert received at the French scientific center → GFT observations triggered, nearby galaxy targeting within the GW error contour (several observation cycles)

-Thanks to its NIR channel, Colibri would certainly have detected the kilonova



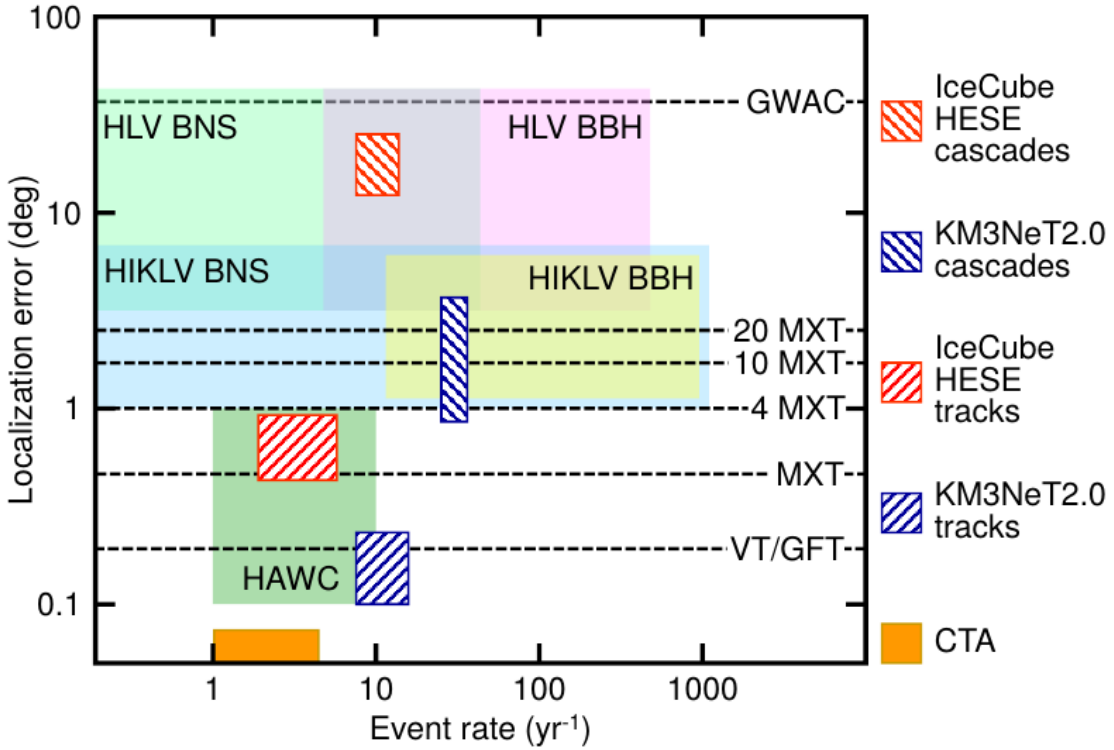


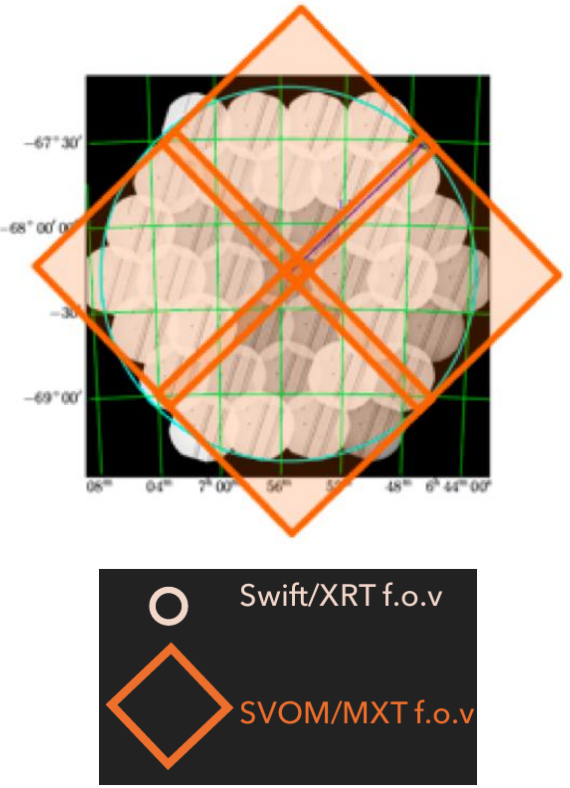
Multi-messenger astronomy with SVOM

- **Search for X-ray / visible counterparts to MM events with MXT and VT**

-Examples: Gravitational Wave sources (large error boxes), kilonova / afterglow (expectations depend on the viewing angle), neutrinos, VHE transients

-Requires a tiling strategy



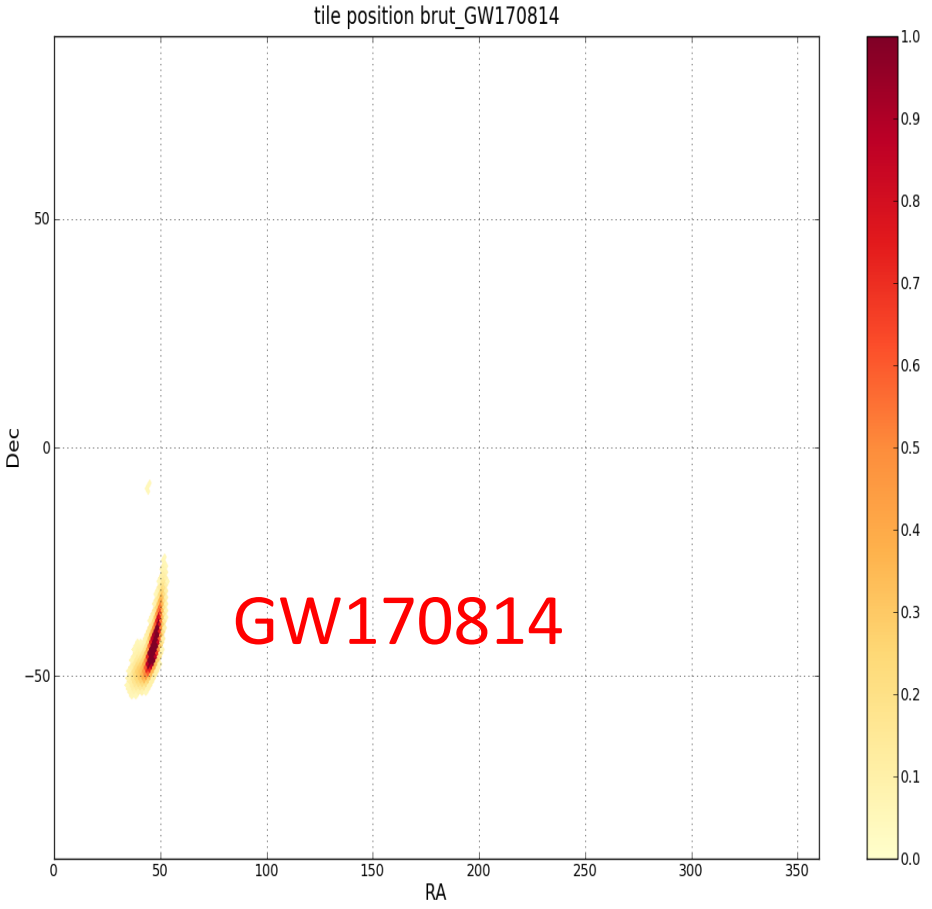


- **Search for NIR / visible counterparts to MM events with the GFTs**

-Search: galaxy targeting within error box

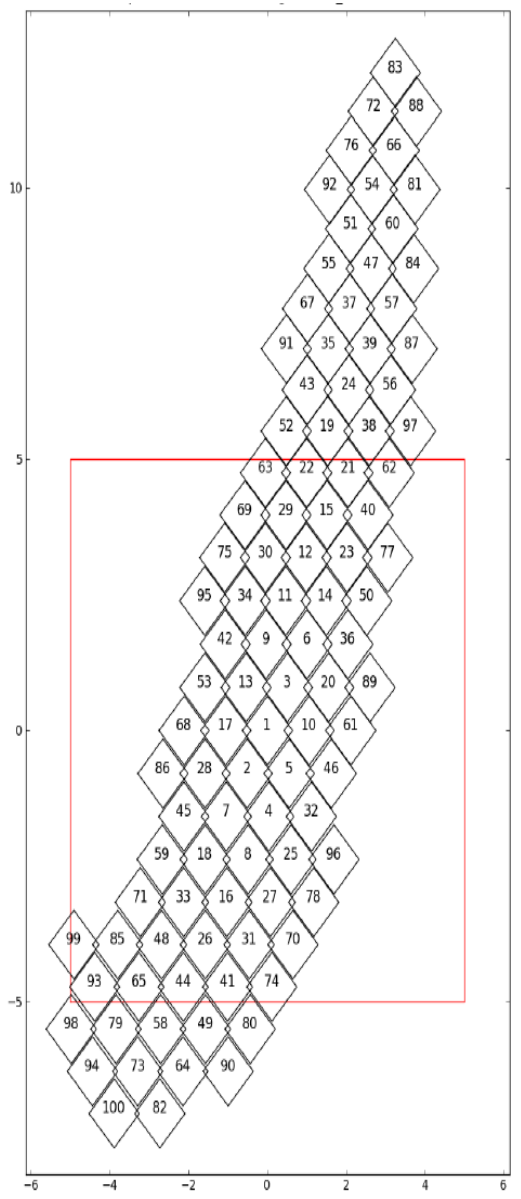
-Photometric follow up to characterize the counterpart (e.g. kilonova from BNS): requires accurate localization (<30')

ToO Multi-Messenger : Tiles sequencing simulations



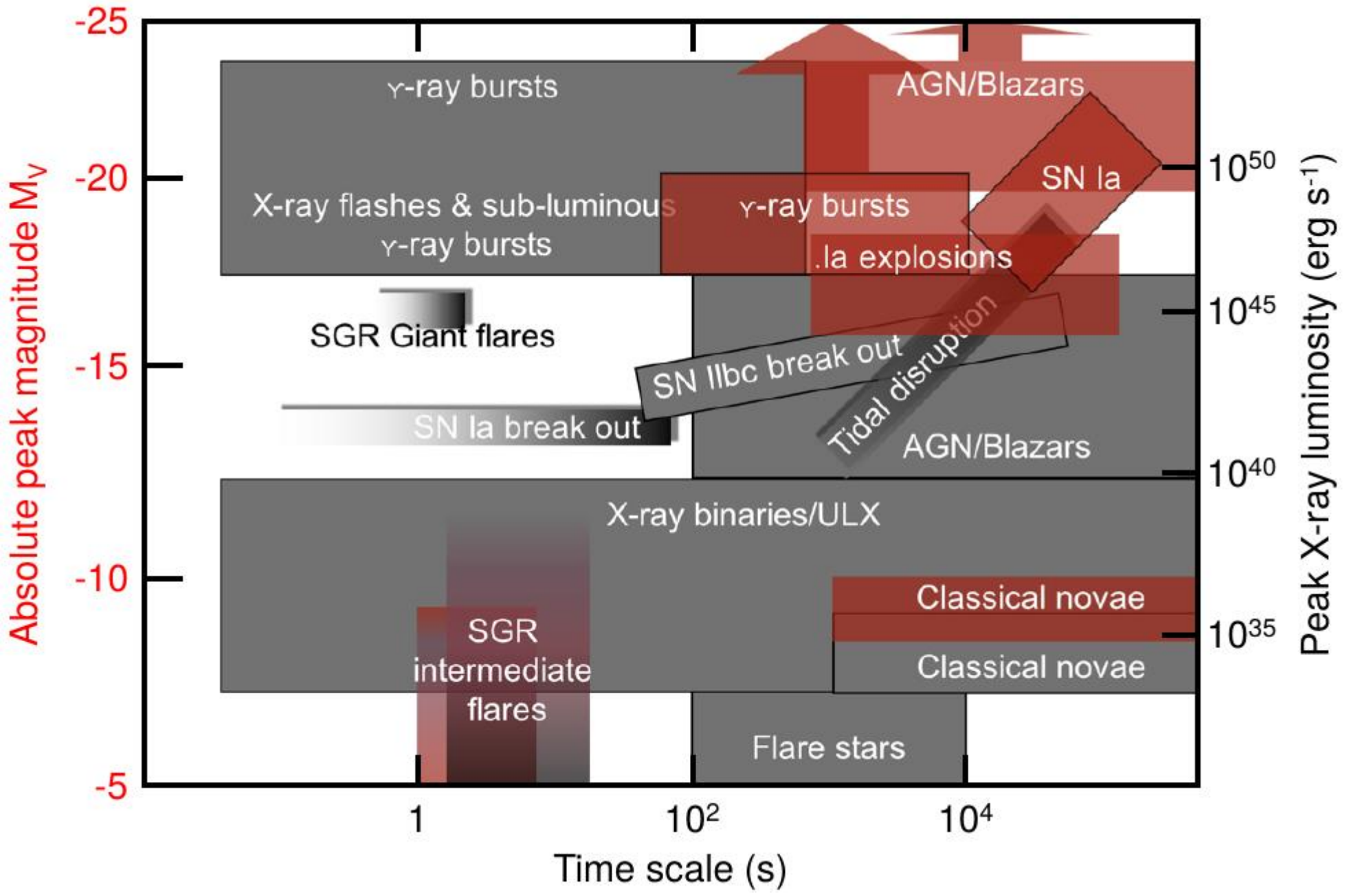
Likelihood

Scenario	170814 GW
Nb. tiles	**230**
RA min (°)	34.4
RA max (°)	53.4
Dec min (°)	-54.3
Dec max (°)	-7.8
LH total (%)	**90.0**
LH 75 (%)	**66.0**



First 100 tiles

Exploring the transient sky with SVOM



Summary

- **SVOM will be a versatile observatory for the monitoring of the transient sky, a provider of alerts, and an important player for multi-wavelength and multi-messenger astrophysics**

- **SVOM is especially designed to study the physics of the GRB phenomenon in all its diversity**

  -Excellent temporal and spectral coverage of the prompt and afterglow emissions

  -Optimized follow-up strategy aiming at redshift determination for a large fraction of GRBs

- **More information**

  -On our web site: www.svom.eu/en

  -In the SVOM White Paper: J. Wei, B. Cordier et al., "The Deep and Transient Universe in the SVOM Era: New Challenges and Opportunities - **Scientific prospects of the SVOM mission**", arXiv:1610.06892

Qualification Model of SVOM satellite