Multi-messenger Astronomy

– Photon detection –

Part 2: High-energy transients

Ecole de Gif - 2024

The connection between MM transients and γ–rays transients

- Multi-messenger *transients* come from violent cosmic phenomena involving compact objects: exploding stars (SNe, long GRBs), coalescence of compact objects (BNS, short GRBs), BH formation and BH activity (AGNs, TDEs)...
- Most often these phenomena also produce γ–rays, see GRB 170817A & GW170817.

→ There is natural synergy between MM instruments and GRB missions. As a consequence, each new GRB mission adds new capabilities to MM astronomy.

- There are also significant practical differences:
  - MM instruments lie on the ground / γ–ray instruments are in space
  - MM instrument are all-sky monitors (or nearly) / γ–ray instruments often have a more limited field-of-view (FoV).
  - The emission pattern of γ–rays and GWs or neutrinos may be very different.

GRB detectors in space

- The γ–ray sky (10's to 100's keV) is very different from the optical sky:
  - There are few transient sources: short γ–ray transients are called gamma-ray bursts (GRBs) and are due to violent cosmic phenomena that may emit GW or neutrinos. We evaluate the number of GRBs to 2-3 per day in the whole sky.
  - The universe is almost transparent at these energies.

- There are various localization methods. One of them uses a ***coded-mask*** placed in front of a pixelated detection plane. If the mask is well designed, each source in the FoV projects a different part of the mask on the detection plane, allowing to reconstruct the sources positions in the sky.

- The *SVOM* mission…

The *SVOM* mission

Your partner in multi-messenger astronomy

The Collaboration

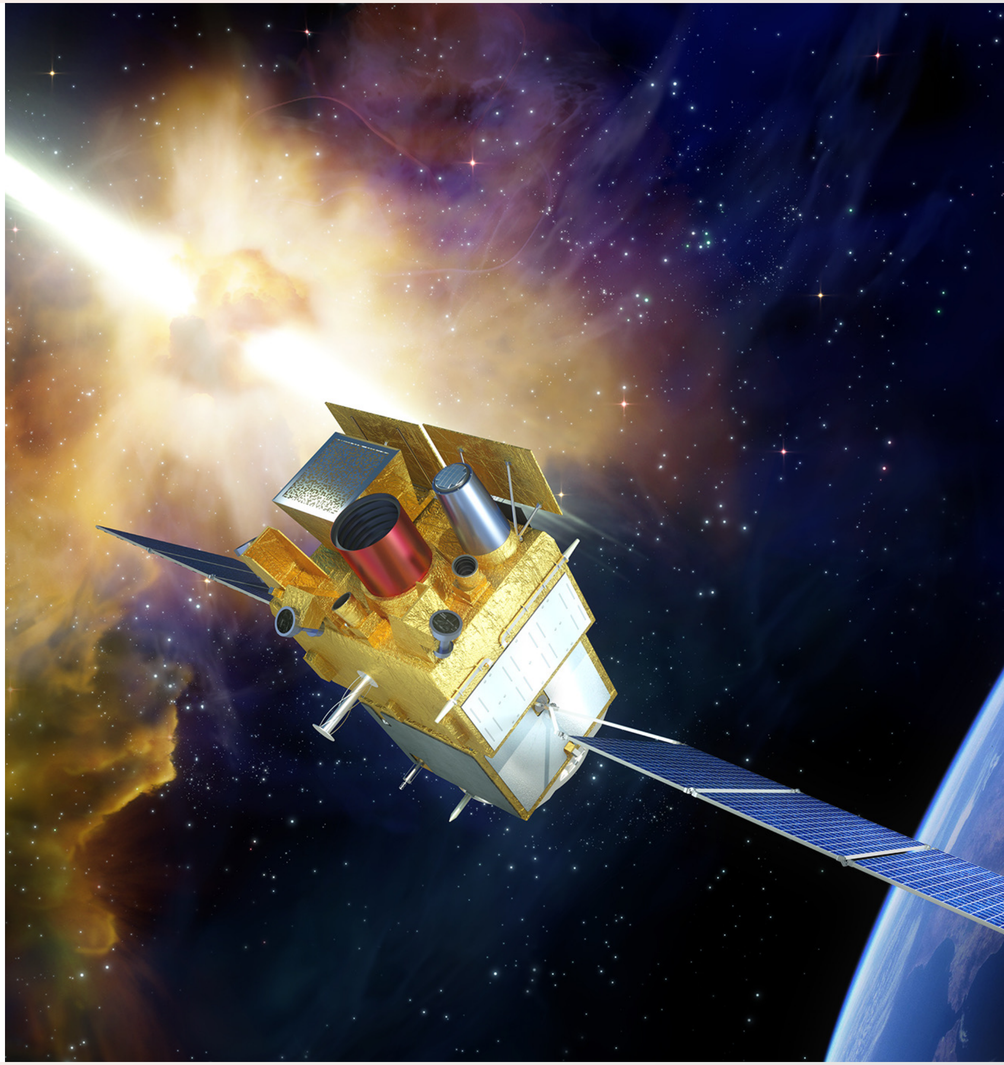
- **China (PI J. Wei)**
  - SECM Shanghai
  - Beijing Normal University
  - Central China University Wuhan
  - Guangxi University Nanning
  - IHEP Beijing
  - KIAA Peking University
  - Nanjing University
  - NAOC Beijing
  - National Astronomical Observatories
  - Purple Mountain Observatory Nanjing
  - Shanghai Astronomical Observatory
  - Tsinghua University Beijing

- **Mexico** UNAM Mexico

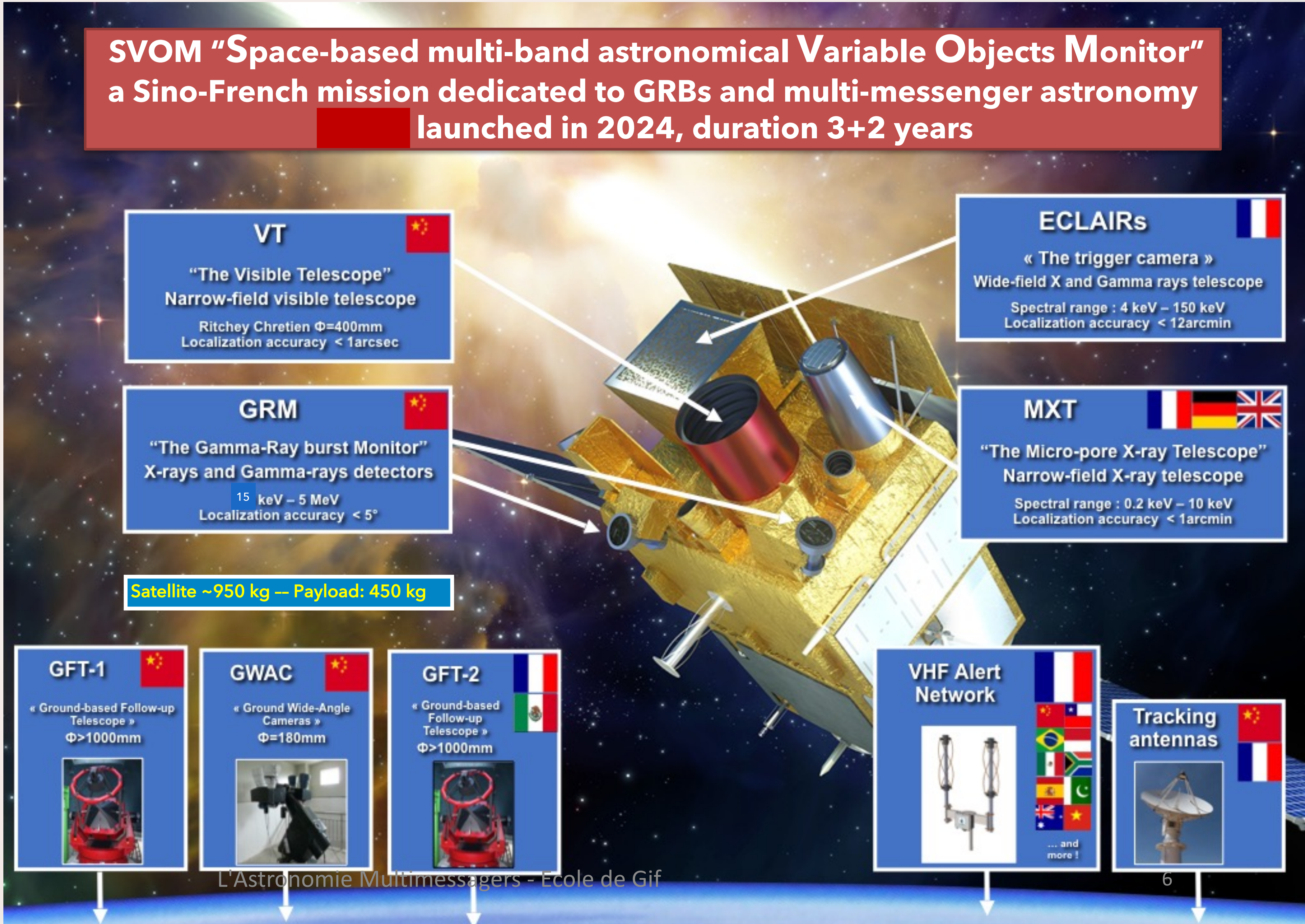
- **France (PI B. Cordier)**
  - CNES Toulouse
  - APC Paris
  - CEA Saclay
  - CPPM Marseille
  - GEPI Meudon
  - IAP Paris
  - IRAP Toulouse
  - LAL Orsay
  - LAM Marseille
  - LUPM Montpellier
  - OAS Strasbourg

- **UK** University of Leicester

- **Germany**
  - MPE Garching
  - IAAT Tübingen

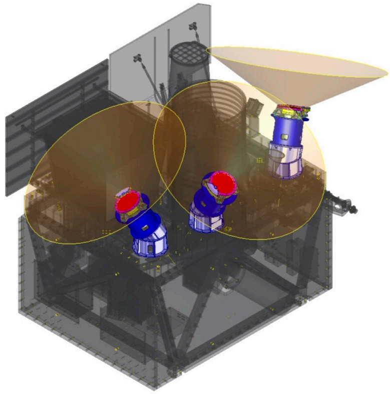


SVOM at a glance



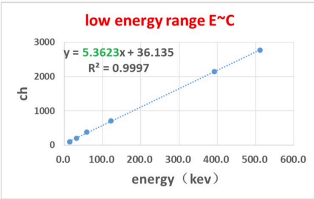
Two Wide-Field Instruments in Space

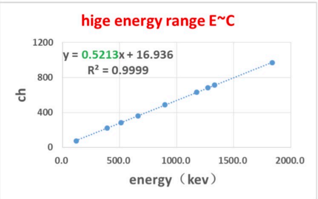
GRM



GRM Gamma-Ray Monitor (IHEP)

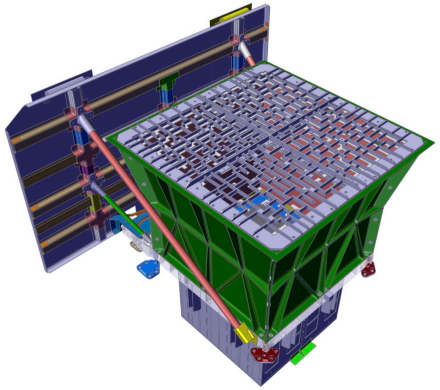
- **3 Gamma-Ray Detectors** (GRDs)
- **NaI(Tl)** (16 cm Ø, 1.5 cm thick)
- Plastic scintillator (6 mm) to monitor particle flux and reject particle events
- **FoV:2.6 sr per GRD**
- **Energy range: 15-5000 keV**
- Aeff = 190 cm² at peak
- Crude localization accuracy
- Expected rate: **~90 GRBs / year**

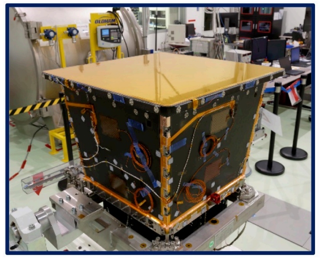


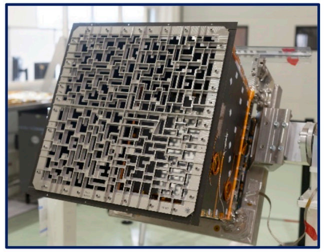


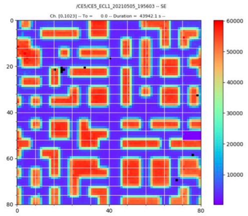
Will measure EPEAK for most ECLAIRs GRBs
Will detect short & long GRBs out of the ECLAIRs FOV

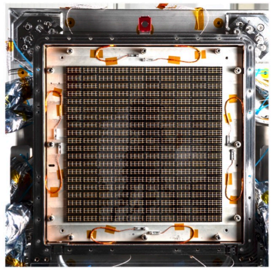
ECLAIRs







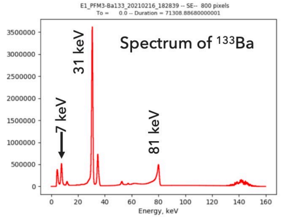




ECLAIRs (CNES, IRAP, CEA, APC)

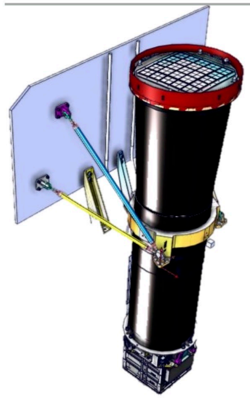
- 40% open fraction
- Detection area: **1000 cm²**
- **6400 CdTe pixels** (4x4x1 mm^3)
- **FoV: 2 sr** (zero sensitivity)
- Energy range: **4** - 150 keV
- **Localization** accuracy **<12 arcmin** for 90% of sources at detection limit
- Onboard trigger and localization: **~65 GRBs/year**

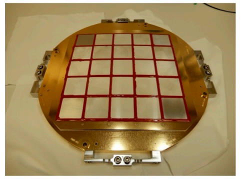
Well suited to detect long GRBs with low EPEAK

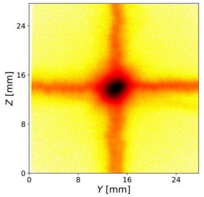


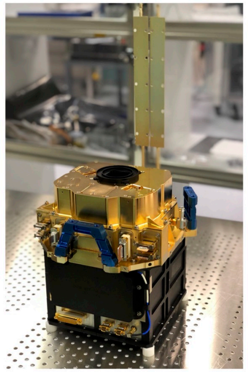
Two Narrow-Field Instruments in Space

MXT

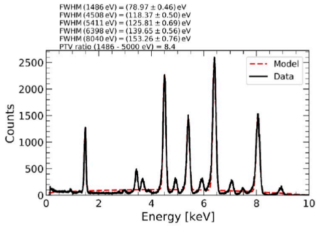








Energy calibration with multi-line spectrum:
79 eV @ 1,5 keV (single events),
88 eV @ 1,5 keV (all events)

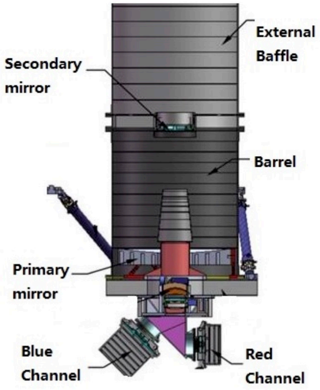


MXT Micro-channel X-ray Tel. (CNES, CEA, UL, MPE)

- **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

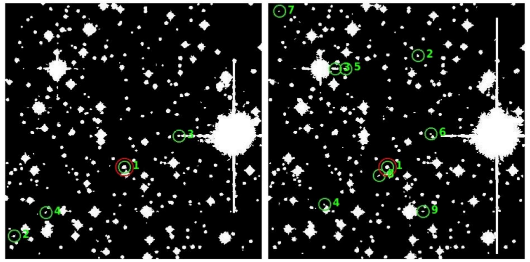
Innovative focusing « Lobster-Eye » X-ray optics
Will observe the X-ray afterglow promptly

VT



VT Visible Telescope (XIOMP, NAOC)

- Ritchey-Chretien telescope, 40 cm Ø, f=9
- **FoV: 26x26 arcmin²**, covering ECLAIRs error box
- **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, with two channels

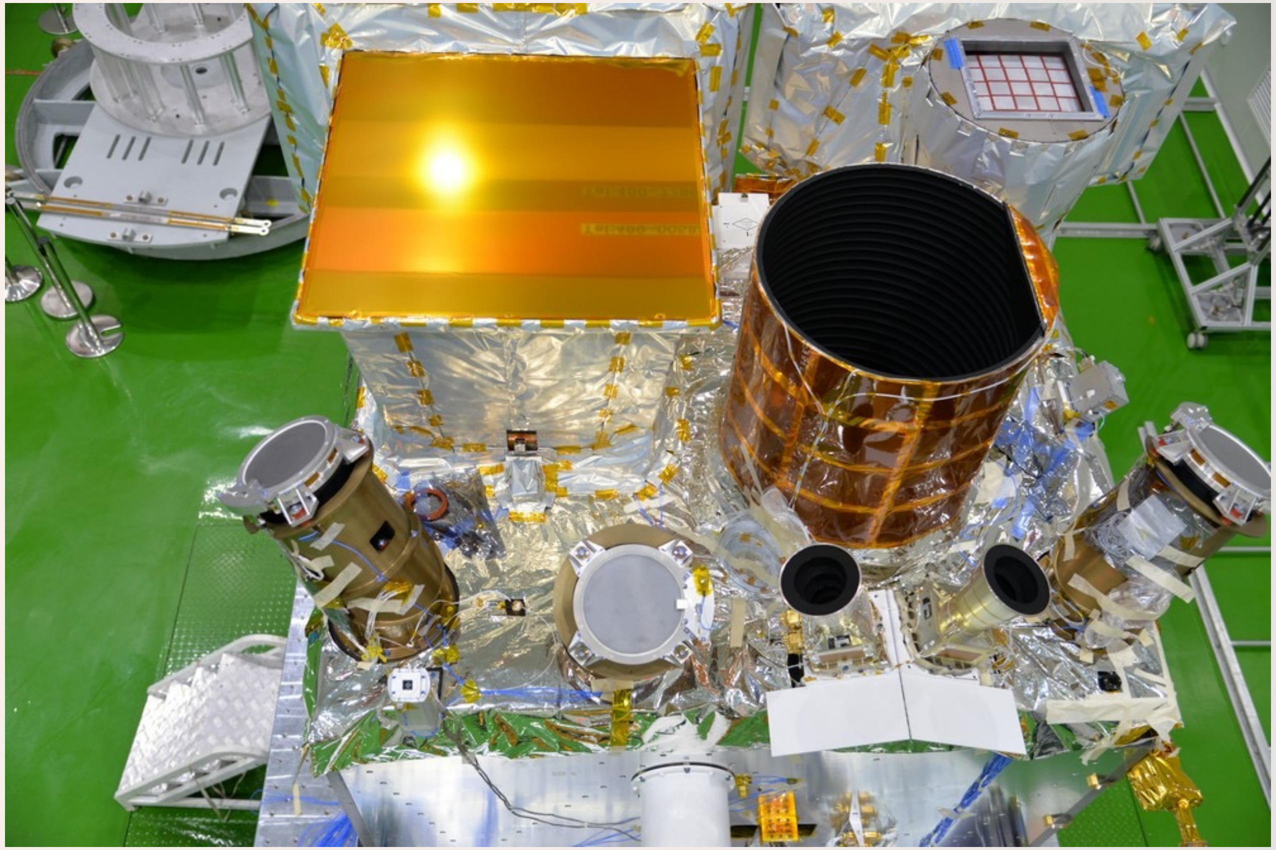
The localization chain

- Localization refinement:

  ECLAIRs (10') => satellite slew

  MXT (15")

  VT (1")



On The Ground…

GFTs

GFTs permit the fast identification and measure of early optical/NIR afterglows (light-curve, SED) 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 OAN in San Pedro Mártir (Mexico)
- Contribution from the LCOGT network (12x1m+2x2m tel.)

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

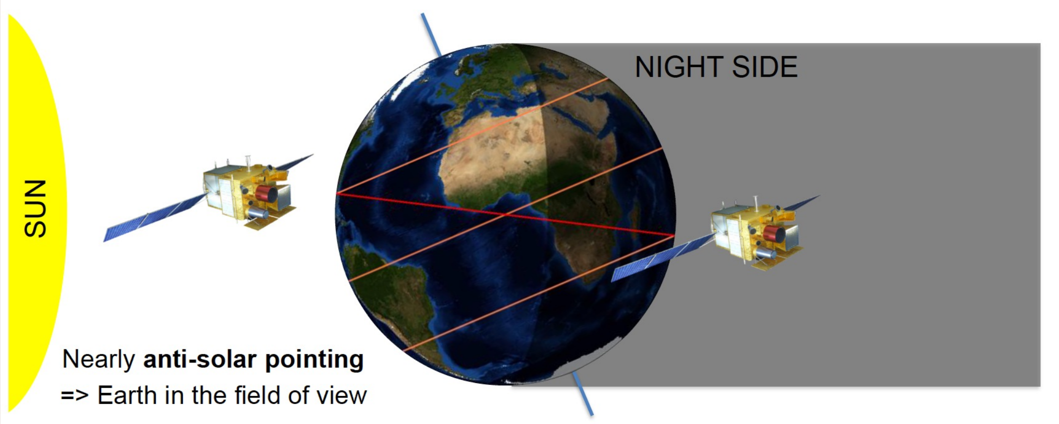
GWAC

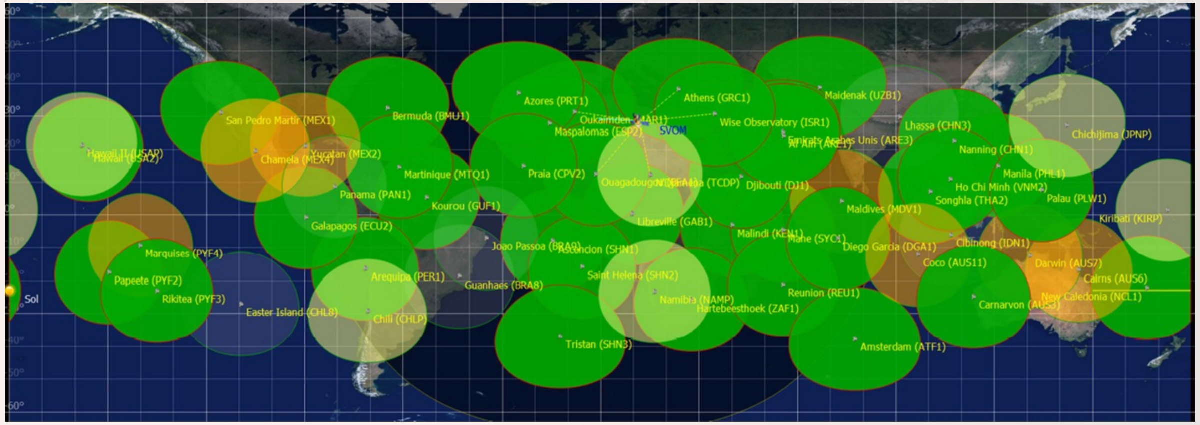
GWAC Ground-based Wide Angle Camera

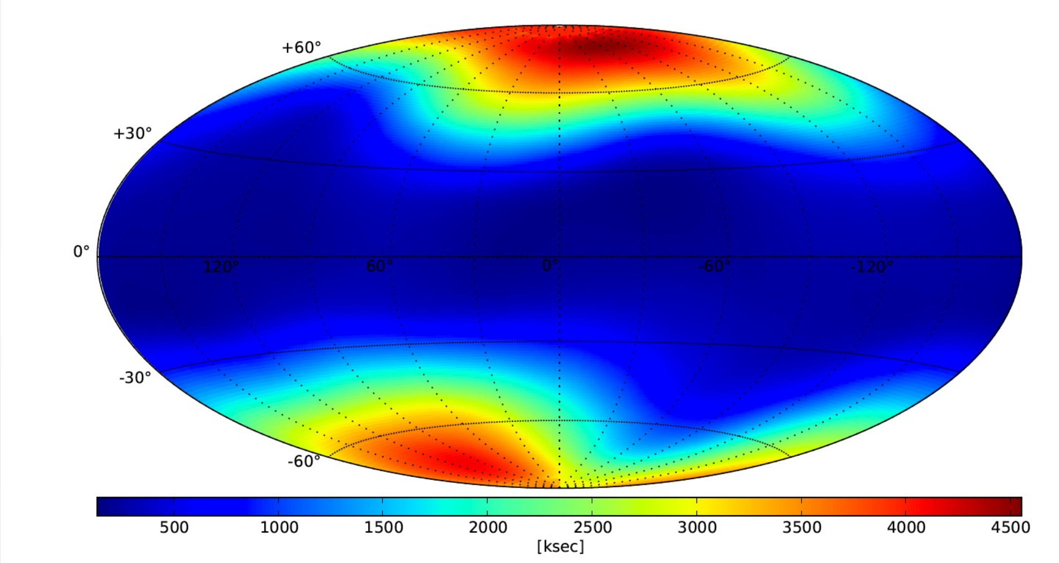
- Installed in Xinglong (5 units) and Muztagh Ata (4 units) observatories
- Each unit encompasses 4 JFoV cameras with an aperture of 180 mm and 1 FFoV camera with an aperture of 35 mm.
- The total FOV and limiting magnitude of JFoV cameras are respectively: **~6000 deg^2**, and **V = 16 (10s)**

- One unit with 4 JFoV covers approximately the fully coded field of view of ECLAIRs
- Will scan the accessible sky each night
- Self triggering capabilities: will be able to catch autonomously optical transients
- The Chinese GWACs are in commissioning phase, already participating to the investigation of LIGO/VIRGO alerts

Pointing Strategy & Alert dissemination

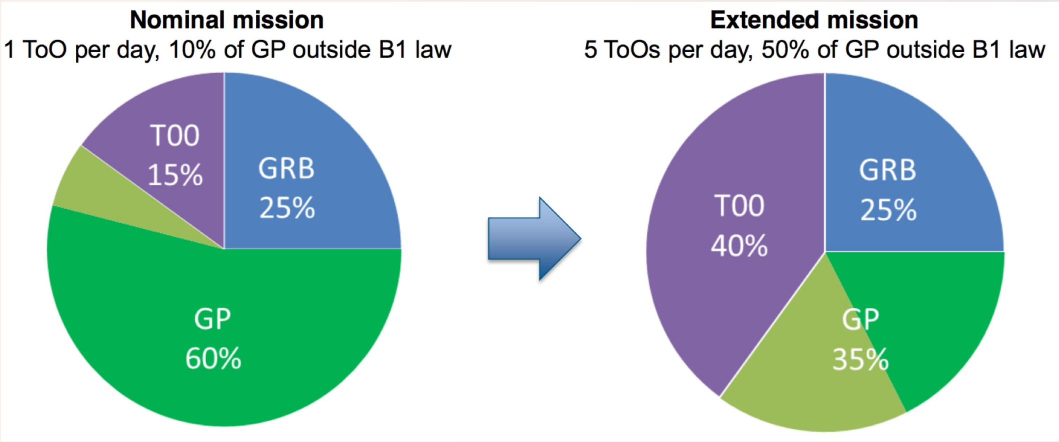






Three Observing Programs

- **Core Program (CP): GRB & HE transients detected by SVOM**
  - The CP includes the follow-up of SVOM detected transients.
- **General Program (GP)**
  - Observation proposals awarded by a TAC (a SVOM co-I needs to be part of your proposal).
  - 10% of the time spent on Galactic sources during the nominal mission, up to 50% during the extended mission.
- **Targets of Opportunity (ToO)**
  - ToO-NOM is the nominal ToO, used for GRB revisit, known source flaring, new transient,etc.
  - ToO-EX is a fast ToO used for exceptional astrophysical events to be observed rapidly.
  - ToO-MM is dedicated to multi-messenger alerts. It includes a **tiling strategy** needed to explore large error boxes
- **Initially 1 ToO/day, will increase during the extended mission.**
- **Many tools have been developed for the quick analysis of SVOM data**



ToO	Approval	From acceptance/ 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

SVOM capabilities for MM astronomy

- The successful launch of *SVOM* on June 22nd 2024, brings additional capabilities for MM astronomy:
  - New instruments for ***transient detection***: GRM – ECLAIRs – GWAC + Sub-threshold triggers. With the GRM, *SVOM* monitors ≥20% of the sky, increasing the overall sky coverage of γ–ray instruments. All detected photons are sent to the ground, allowing searches for off-line triggers and sub-threshold transients
  - *SVOM* offers *n*ew instruments for ***follow-up***: MXT, VT, C-GFT, Colibrí
  - *SVOM* offers new opportunities to perform ***ToO observations.***

- A mission designed to ease the follow-up of detected transients:
  - Transients located in the night hemisphere
  - Strong follow-up capabilities included in the mission
  - Fast NIR follow-up (Colibrí + CAGIRE)

Conclusion…

- *SVOM* is a new facility for the detection and follow-up of high-energy transients and the observation of multi-messenger transient sources.

→ We are happy to work during O4.

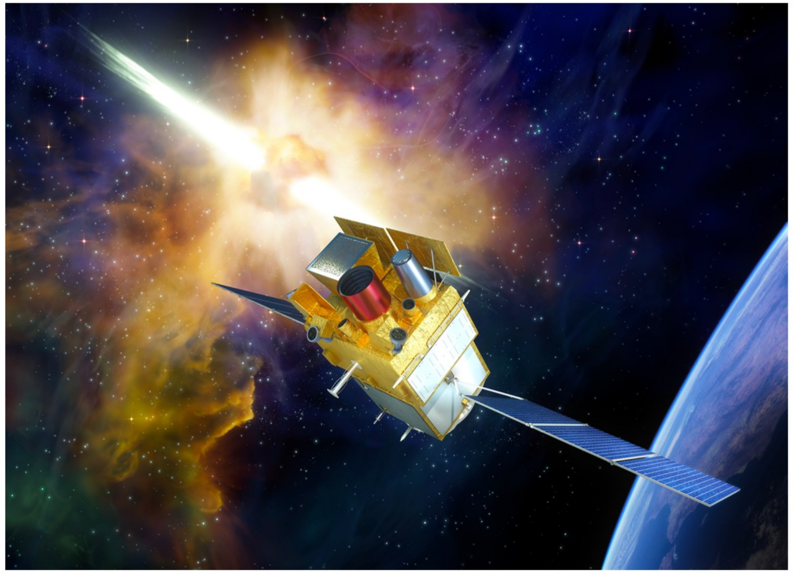
- Additional information:
  - SVOM White Paper: arXiv:1610.06892 (figure)
  - SVOM Website: http://www.svom.fr/en/
  - A series of paper will be published in the first half of 2025.

The Deep and Transient Universe: New Challenges and Opportunities

Scientific prospects of the *SVOM* mission

J. Wei, B. Cordier, et al.
(Version of 05-10-2016, for full list of contributors see overleaf)

arXiv:1610.06892v1 [astro-ph.IM] 21 Oct 2016



Frontispiece : Artist view of the *SVOM* satellite