Time-domain Astronomy with SVOM

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on behalf of the SVOM consortium

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The SVOM consortium

China (PI J.Wei)

- SECM Shanghai
- NSSC Beijing
- NAOC Beijing
- IHEP Beijing
- GuanXi University

France (PI B.Cordier)

- CNES Toulouse
- APC Paris
- CEA Saclay
- CPPM Marseille
- GEPI Meudon
- IAP Paris
- ICJLab Orsay
- IRAP Toulouse
- LAM Marseille
- LUPM Montpellier
- ObAS Strasbourg

Mexico

- UNAM (Colibrì)

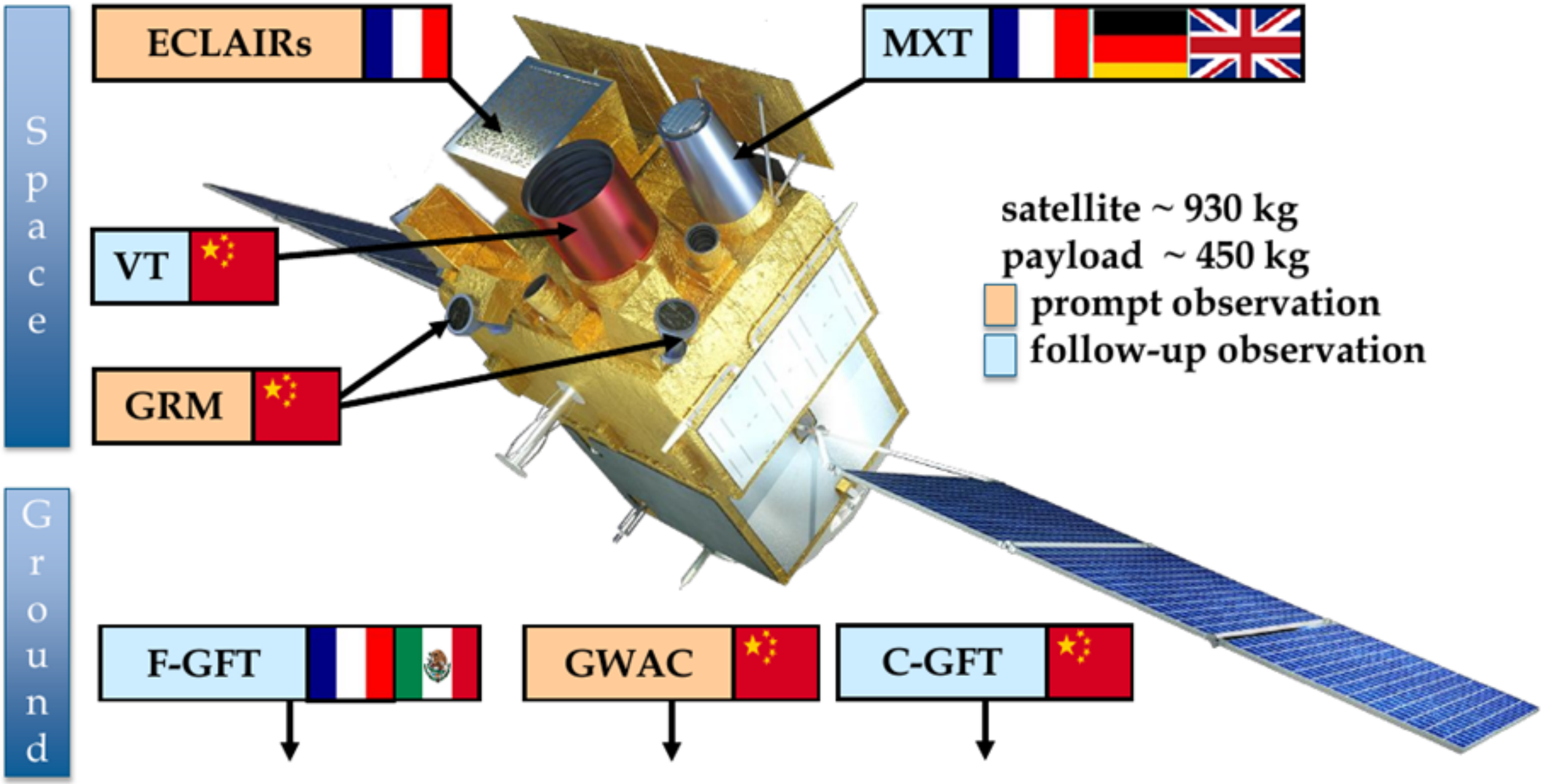
UK

- University of Leicester (MXT)

Germany

- MPE Garching (MXT)
- IAAT Tübingen (MXT)

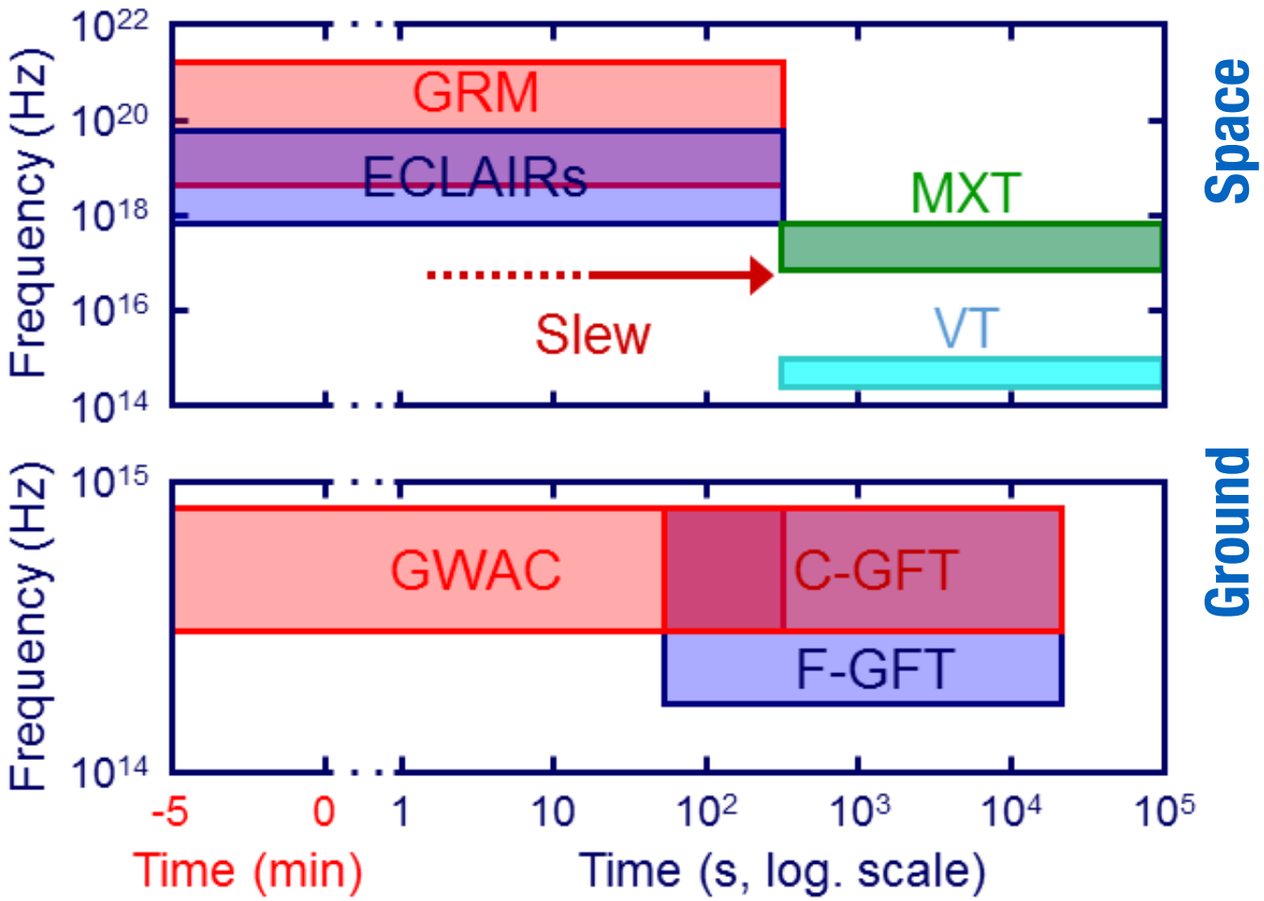
The "Space-based multi-band astronomical Variable Objects Monitor" (SVOM) is a Sino-French mission dedicated to GRBs and transient sources to be launched late-2023, duration 3+2 years



The Core program

Core program: GRBs and transients discovered by SVOM, 25% of time, with the highest priority

- **Trigger and locate GRBs,** alerts distributed in nearly **real-time**
- Slewing capabilities to have accurate location in ~5 min
  - ➡ **Synergy with other space and ground based facilities**
- Broadband characterization of the prompt emission
- Quick discovery and long-term follow-up of the afterglow

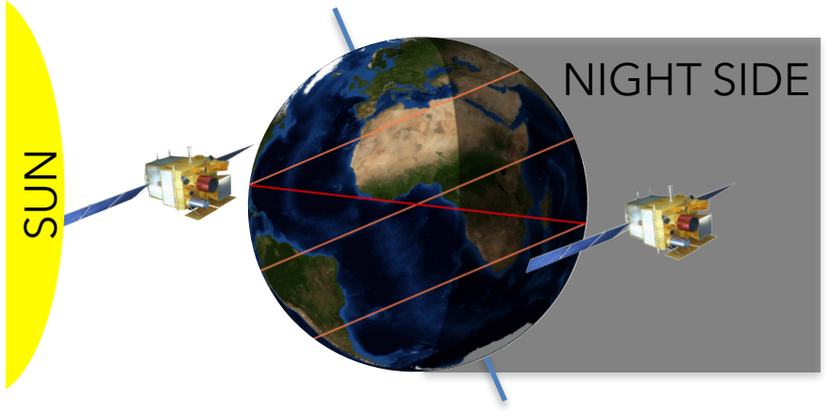


- Synergy among **7 instruments in space and on ground** for a complete monitoring of GRBs and high-energy transients **over 7 decades in energy** and **from the trigger up to the late afterglow**
- Rapid alert dissemination and optimal attitude law for ground-based follow-up to **favor redshift measurement for a large fraction of GRBs**

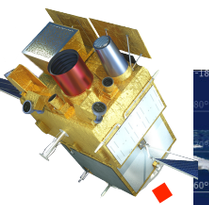
Orbit, pointing strategy and alerts dissemination

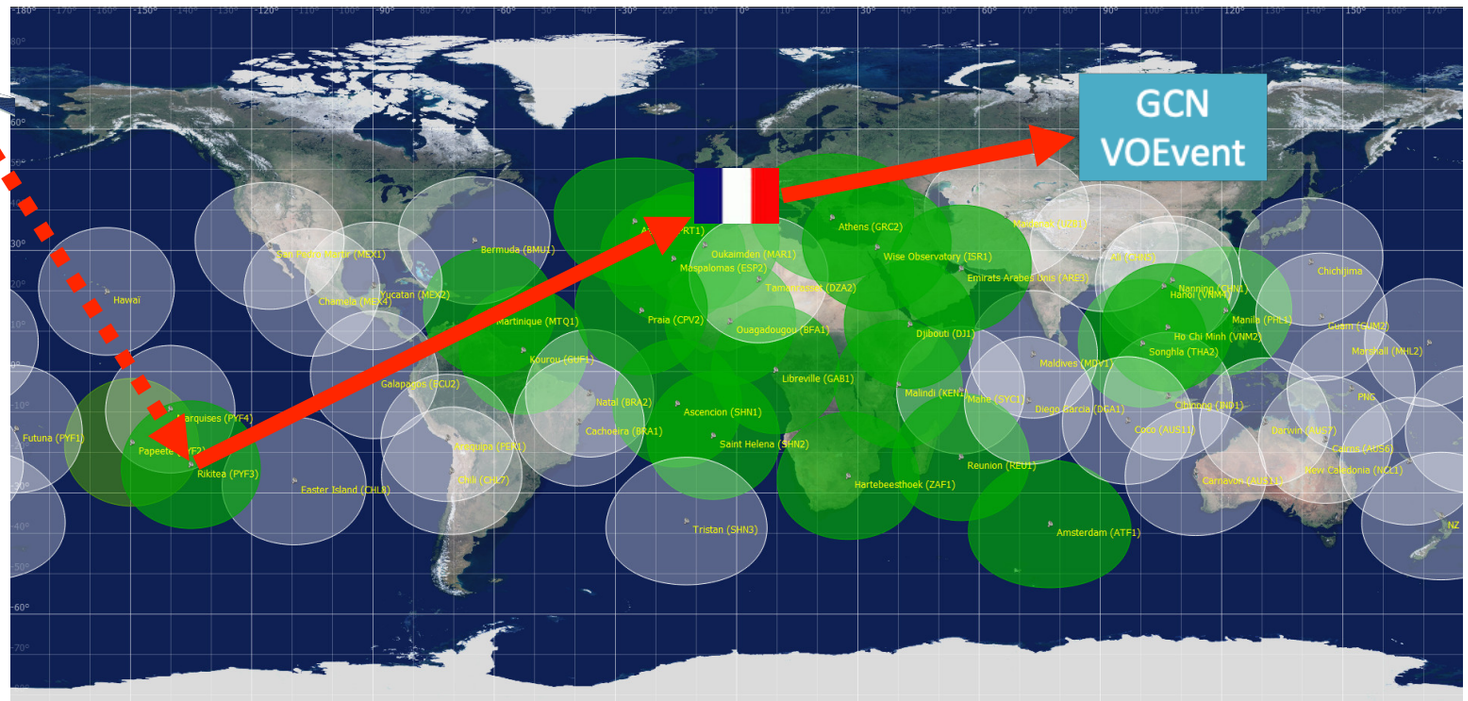
- Low Earth orbit (625 km, 96 min), 30° inclination
- **Nearly anti-solar pointing**
- Avoidance of the galactic plane and bright sources as Sco X-1
- **Alerts transmitted to a network of 40 antennas.** Goal: 65% of alerts within 30s

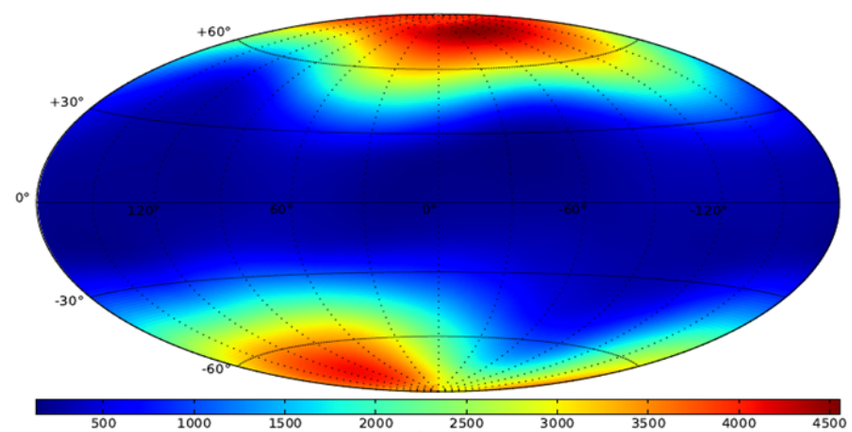
➡Favorable conditions for **early follow-up from other facilities**, especially large ground-based telescopes for **redshift measurement (2/3 of cases)**



➡**Earth in the fov**: 65% duty cycle for ECLAIRs, 50% for MXT and VT



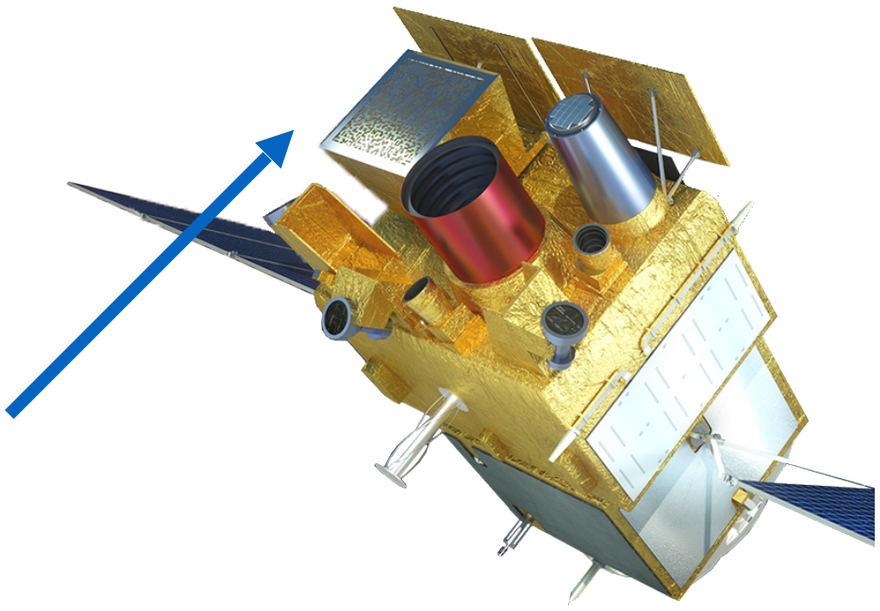




ECLAIRs 1 yr exposure map:
- **4 Ms on the galactic poles**
- **500 ks on the galactic plane**

MXT and VT pointings (1yr scenario, including 65 GRBs and 1 ToO/day)

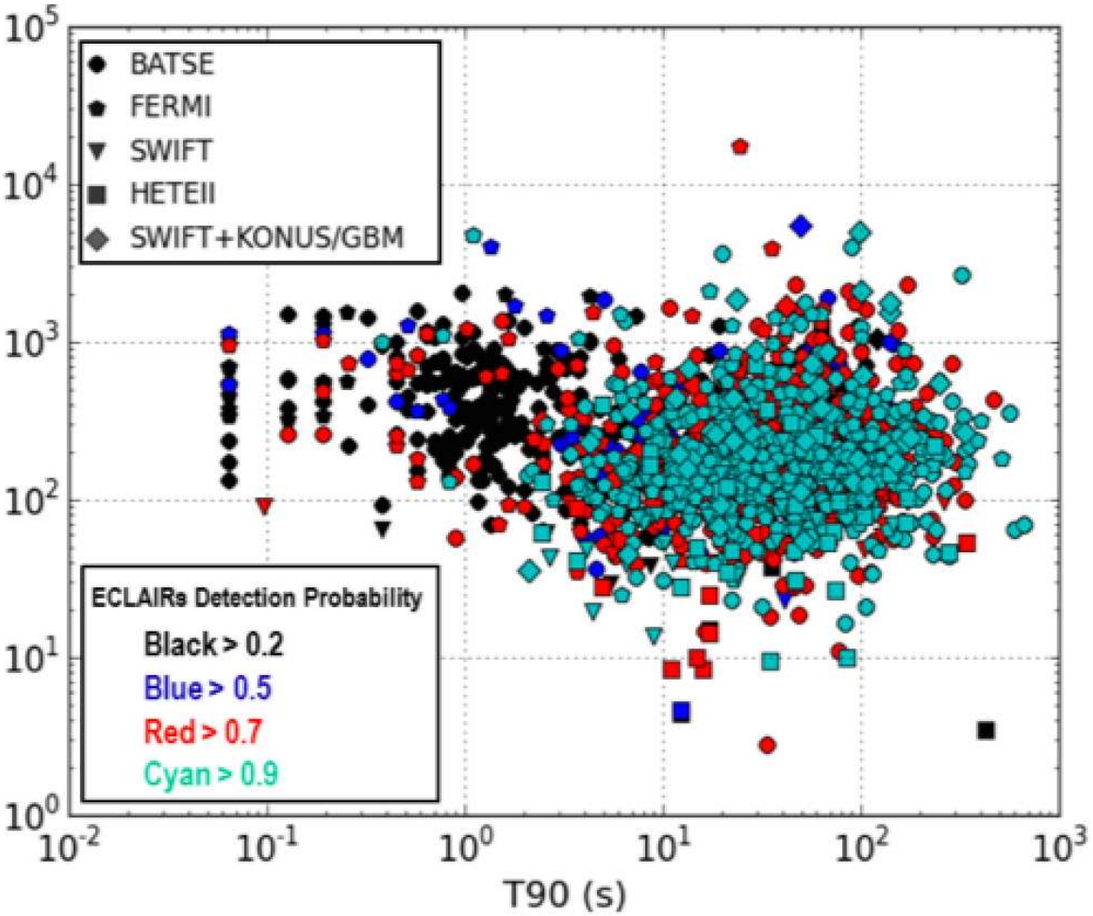
The GRB detection



ECLAIRs

- **4-120 keV**
- Fov ~ 2 sr
- **Loc. < 12'**
- **42-80 GRBs/yr, including 3-4 GRBs/yr at z>5**

Detection probability for ECLAIRs

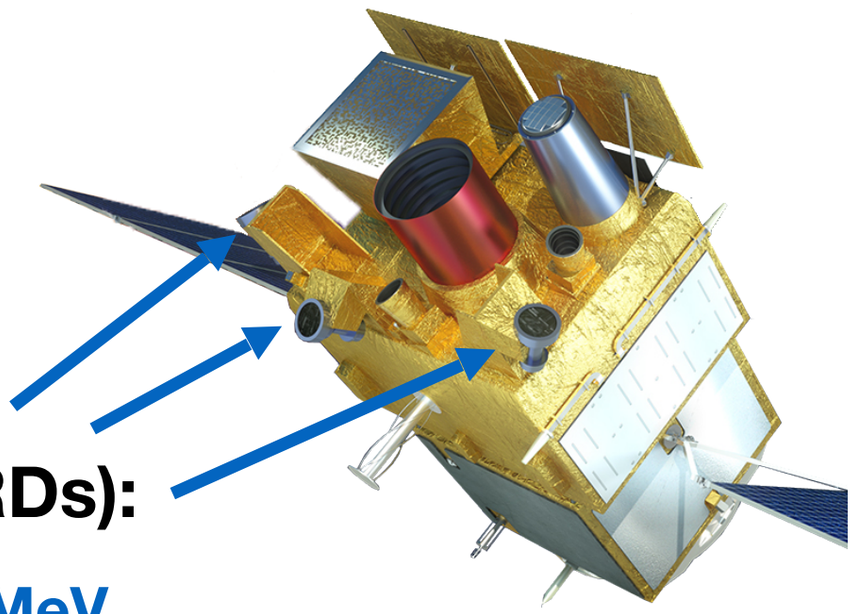


(simulations by S. Antier; Wei, Cordier et al., arXiv:1610.06892)

ECLAIRs is **sensitive to all classes of GRBs**:

- Classical long GRBs
- Soft GRBs (XRR, XRF)
- Short GRBs (but with a moderate efficiency)

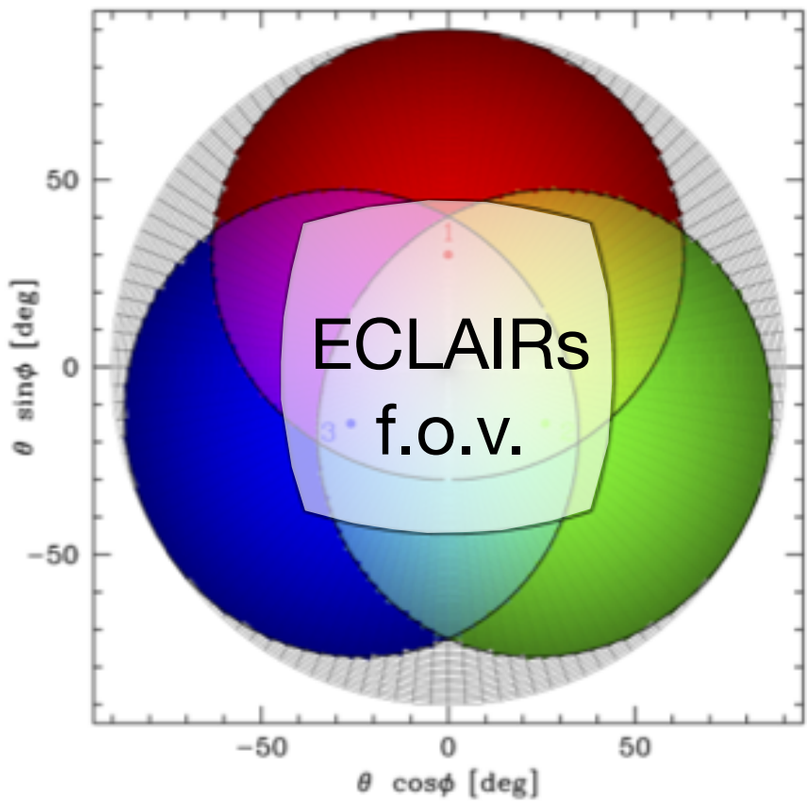
The GRB detection



GRM (3 GRDs):

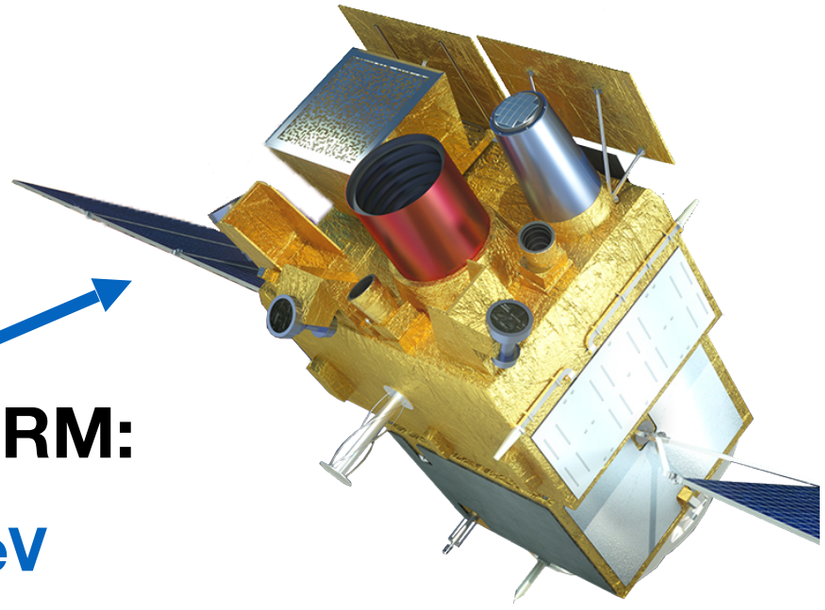
- **15 keV - 5 MeV**
- Fov ~ 5.6 sr
- Loc. ~5-10 deg (3 GRDs)
- ~90 GRBs/yr

GRM field of view



- GRM has a larger field of view than ECLAIRs
- ECLAIRs **sensitivity to short GRBs can be improved** by combining ECLAIRs+GRM

The GRB prompt emission



ECLAIRs+GRM:

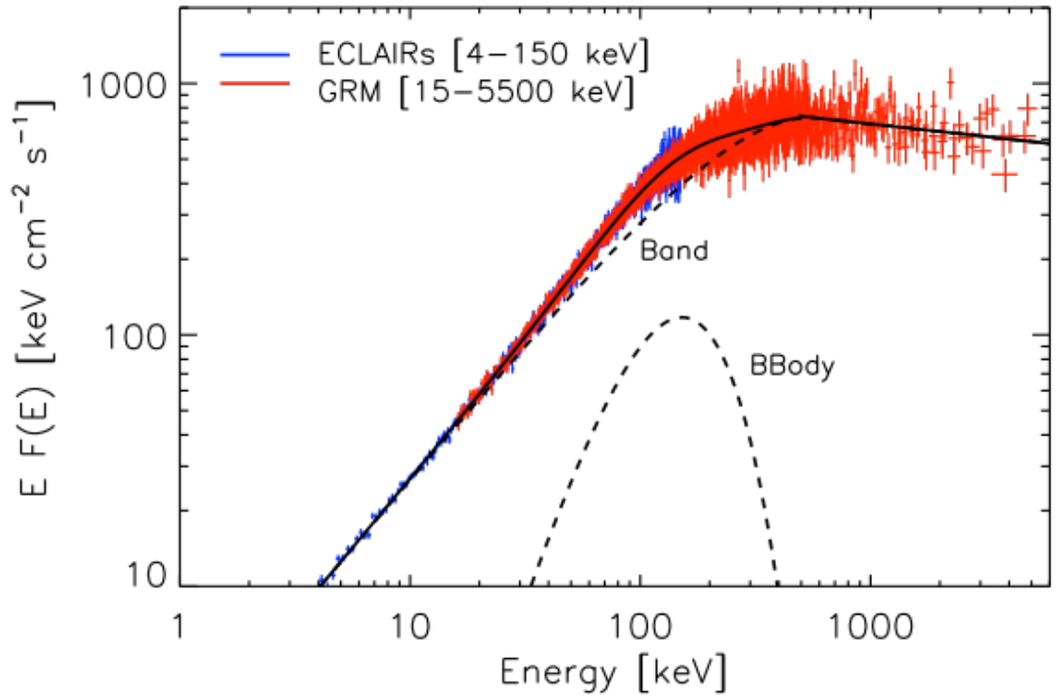
- **4 keV - 5 MeV**

+

GWAC:

- 2x5400 deg^2 (half of ECLAIRs fov)
- 500-800 nm
- m_{lim} ~ 16-17 (10s exposure)

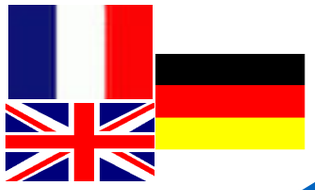
Simulation of the multi-component spectrum of GRB 100724B

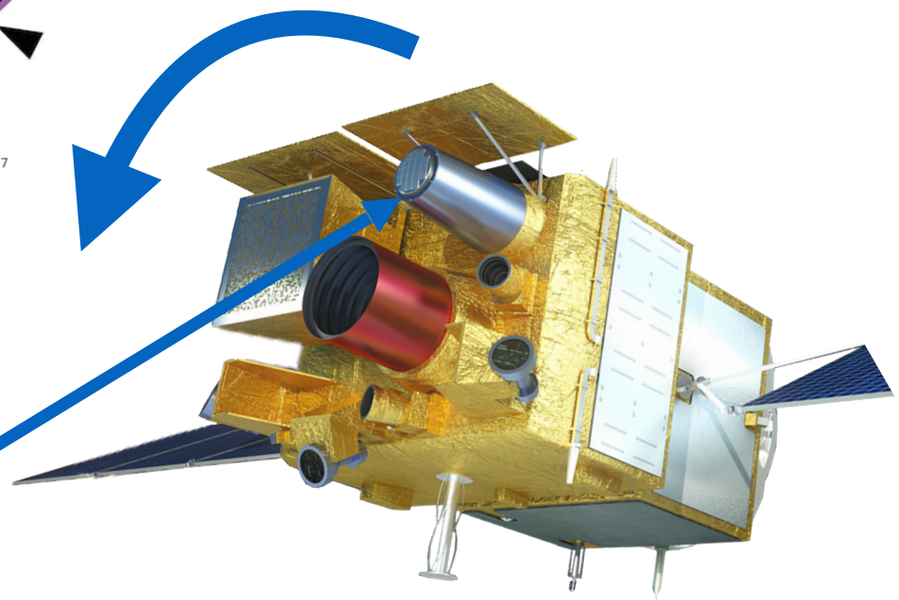


(Bernardini et al., 2017)

- ECLAIRs+GRM measure the **prompt spectrum over 3 decades in energy**
- GWAC will add a constraint on the **associated prompt optical emission** in a good fraction of cases (16%).

The GRB follow-up

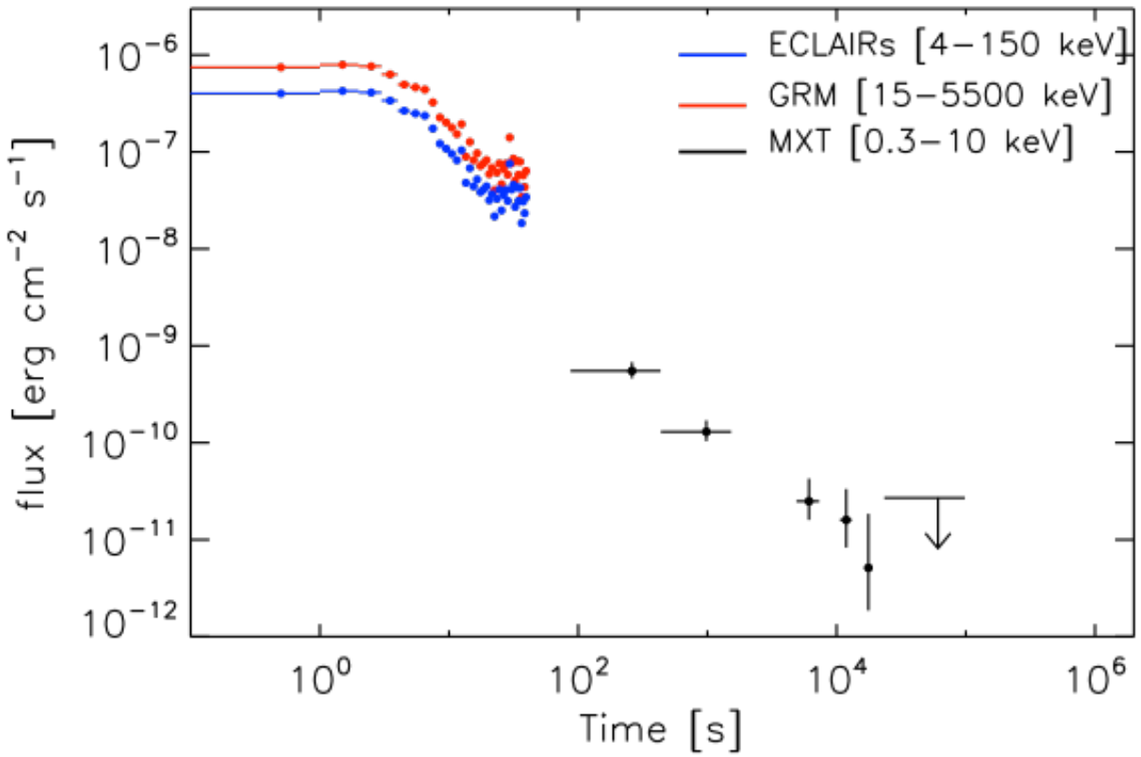




MXT:

- 0.2-10 keV
- 64x64 arcmin^2
- **Loc. <13”** within 5 min after the trigger for 50% of GRBs
- slew request: **~72 GRB/yr**

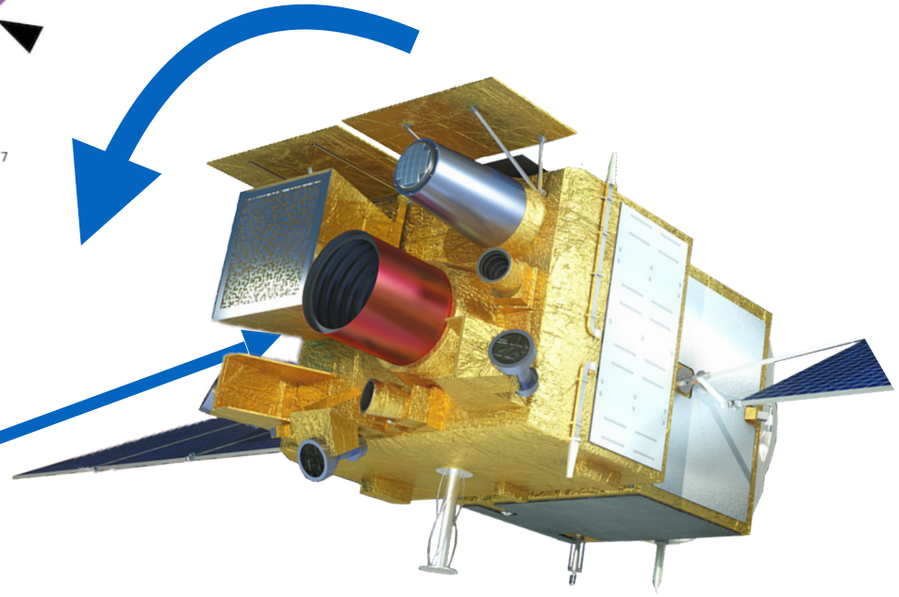
Simulation of GRB 091020



(Wei, Cordier et al., arXiv:1610.06892)

- MXT can **detect and localize the X-ray afterglow** in >90% of GRBs after a slew

The GRB follow-up



VT:

- 400-1000 nm
- Loc. <1”

+

GWAC:

- 2x5400 deg²
- 500-800 nm

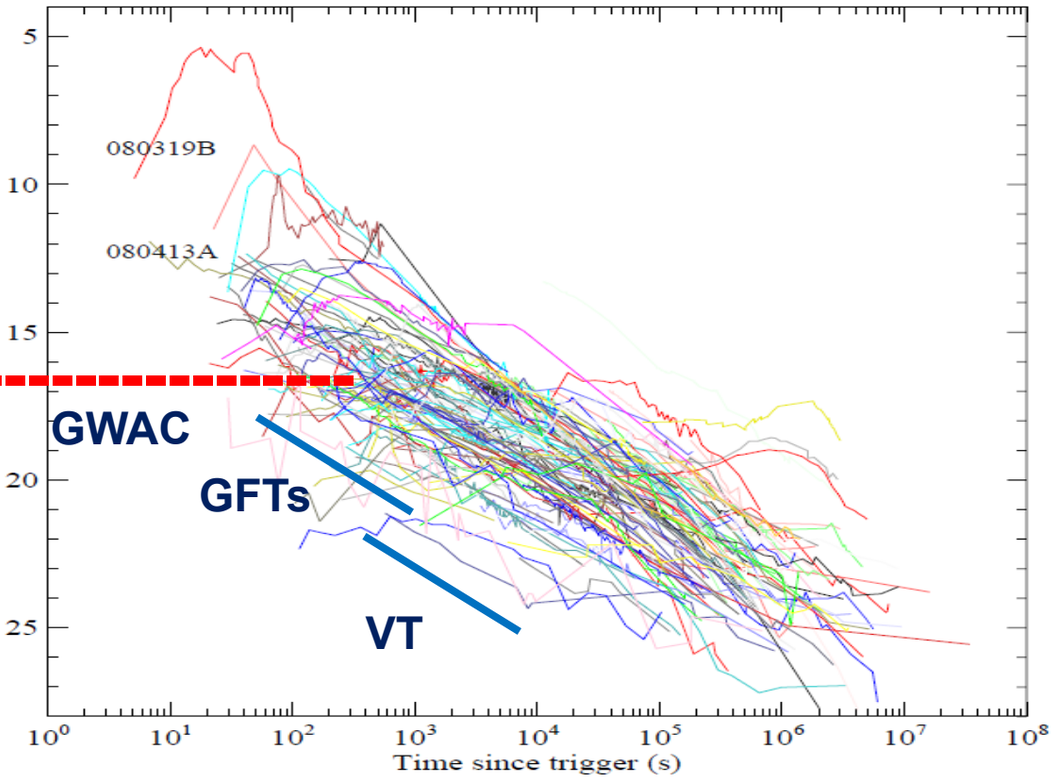
F-GFT (Colibrì):

- 1.3 m
- 400-1700 nm

C-GFT:

- 1.2 m
- 400-950 nm

Optical Light curves of long GRBs



(Wang et al., 2013)

- VT + ground segment will **detect, localize and characterize the visible-NIR afterglow** (light curves + photo-z)

The SVOM GRB sample

A unique sample of **30-40 GRB/yr** with:
- **prompt emission** over 3 decades (+ optical flux/limit: 16%)
- X-ray and V/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**

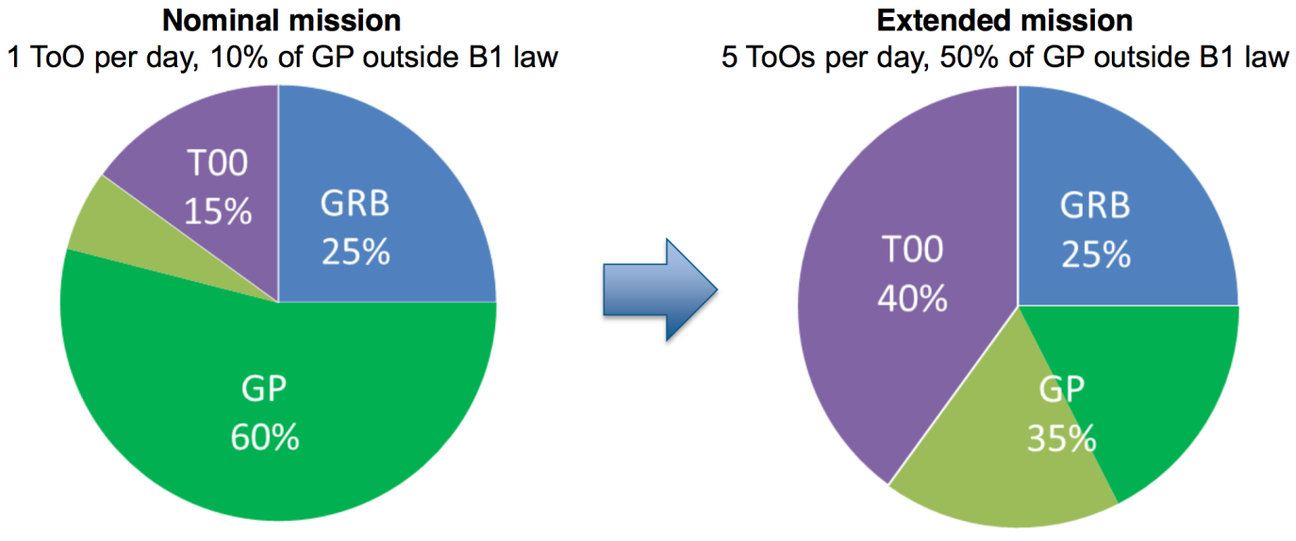
- **Physical mechanisms at work in GRBs**
  - Nature of GRB progenitors and central engines
  - Acceleration & composition of the relativistic ejecta
- **Diversity of GRBs: event continuum following the collapse of a massive star**
  - Low-luminosity GRBs / X-ray rich GRBs / X-ray Flashes and their afterglow
  - GRB/SN connection
- **Short GRBs and the merger model**
  - GW association
- **GRBs as cosmological probes of the early Universe**

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 targets, mostly compliant with the satellite attitude law (form 10% to 50% of time can be spent on low galactic latitude sources). It can include ToOs.

ToO	Latency	Frequency	Duration
ToO-NOM	<48hrs	1-5/day	1 orbit or more
ToO-EX	<12hrs	1/month	7-14 orbits
ToO-MM	<12hrs	1/week	~14 orbits

- **Target of Opportunity (ToO) program:**
  - **ToO-NOM** - nominal ToO which covers the basic needs for efficient transient follow-up alerts (GRB revisit, known source flaring, new transient).
  - **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 (unknown position, tiling of large portion of the sky).



SVOM data policy

- **Core Program:**
  - Real-time VHF scientific products generated under the supervision of the Burst Advocate are public **as soon as they are available** (similar to Fermi or Swift)
  - All the scientific products are public **six month** after the data production

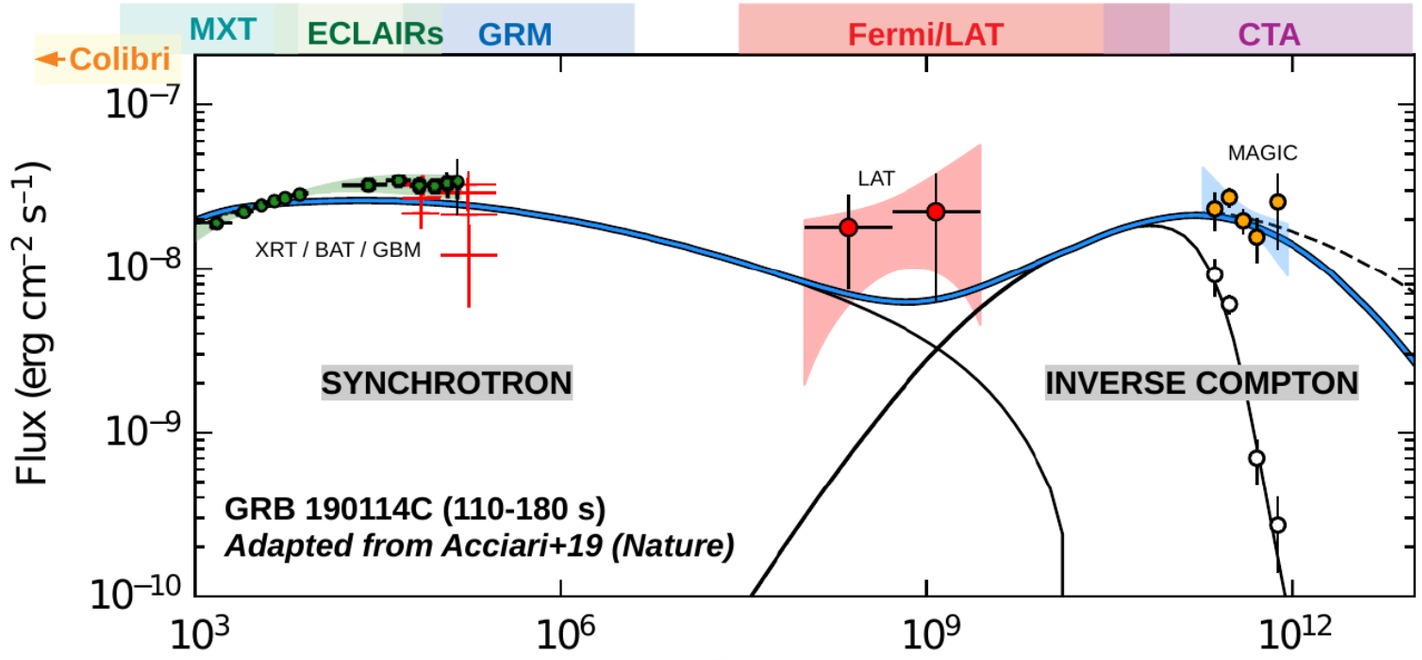
- **General Program:**
  - All the SVOM data will be managed by the Responsible Co-I
  - **One year of proprietary period** before the scientific products become public

- **ToO Program (still under discussion):**
  - **Triggered by SVOM Co-Is**: scientific products relevant to perform follow-up observations will be public as soon as possible**.** Other scientific products to be released will be decided case by case
  - **Triggered by non SVOM Co-Is**: all the scientific products will be public as soon as they are available

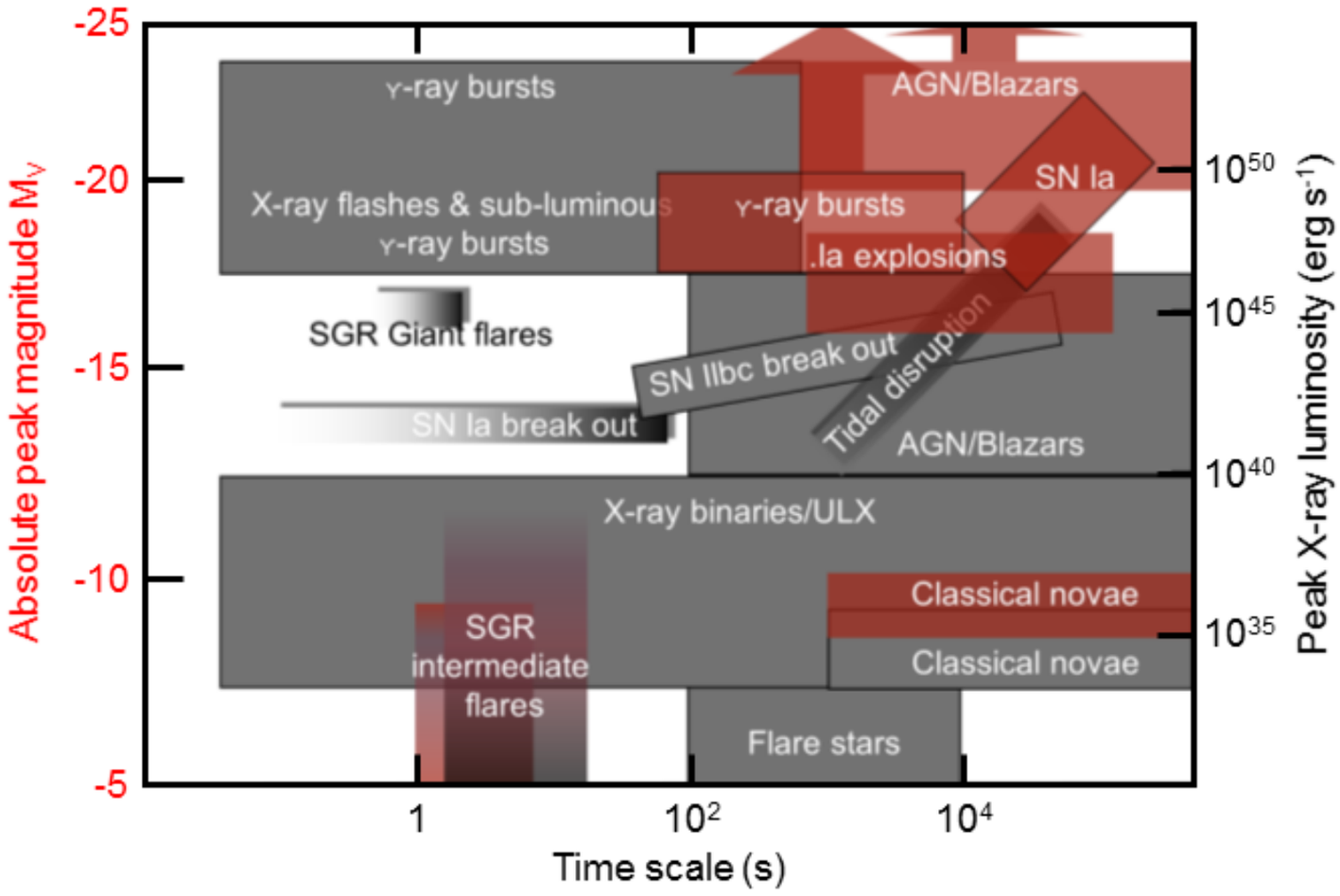
Exploring the Transient sky with SVOM

Core Program (GRBs):

- Multi-wavelength observations of prompt and afterglow emission (in many cases with redshift) that complement the observations at other wavelengths (e.g. HE/VHE with CTA)



(Credits: F. Piron)



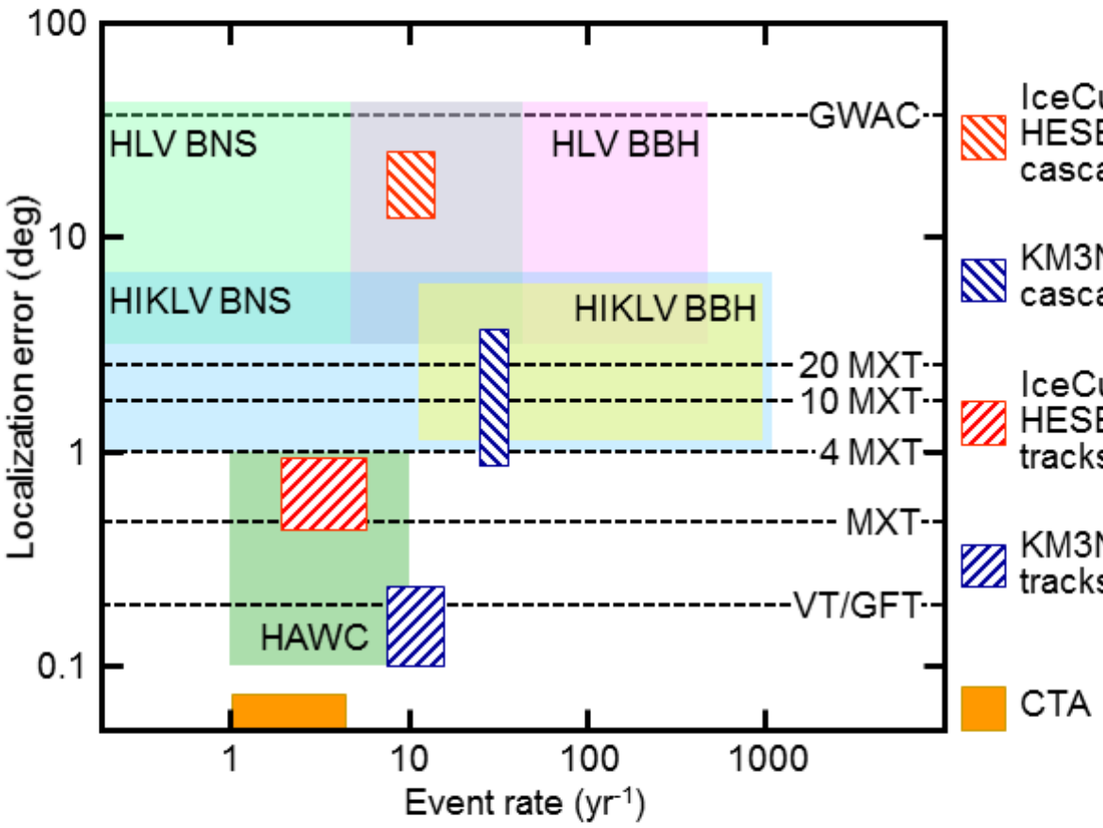
General Program:

- Multi-wavelength observations of transients or flaring sources (AGNs, blazars, SNe, galactic transients, TDEs, ecc..)

ToOs Program:

- Search for X-ray and optical counterparts of external triggers
- Joint searches for counterparts of MM triggers, and validation of candidates at other wavelengths

MM astronomy with SVOM



ECLAIRs/GRM/GWAC

➡ Large fov, independent trigger or search in the fov

MXT/VT

➡ Slew following the alert **ToO-MM**

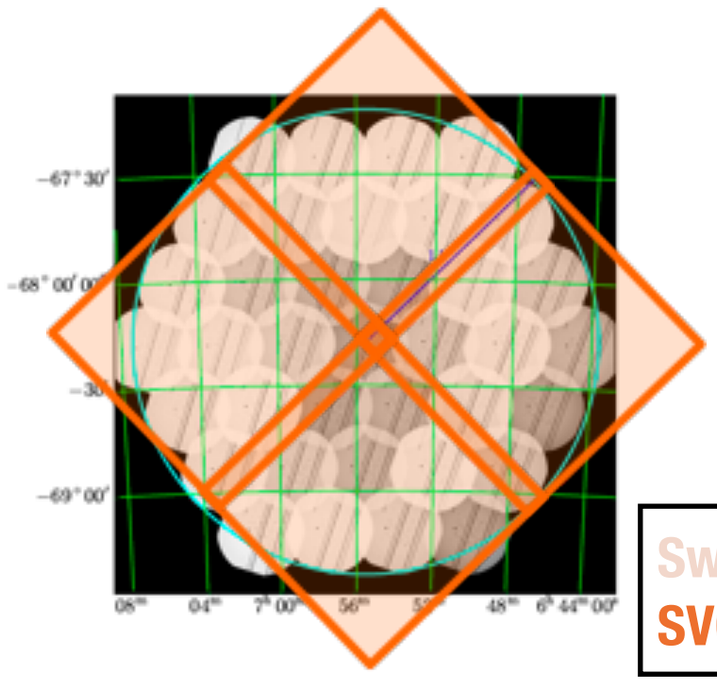
➡ Tiling strategy if the error box is larger than 1 deg²

C-GFT/F-GFT

➡ Rapid response, galaxy targeting search within the skymap

➡ Require accurate localization (<30'), photometric follow-up to characterize the counterpart

MXT vs. XRT tiling



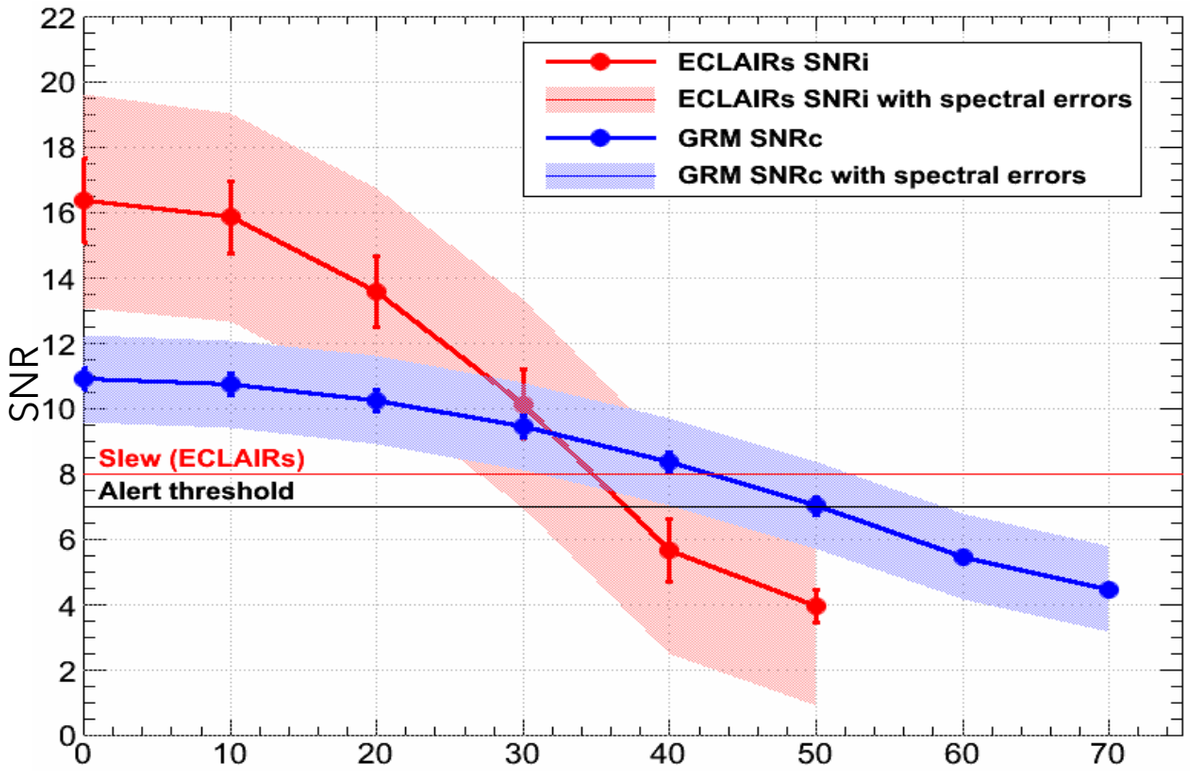
Swift/XRT f.o.v

SVOM/MXT f.o.v

Typical scenario: 5 tiles/orbit – 15 orbits (~ 1 day)

SVOM response to GW 170817

Simulation of the prompt emission of GRB170817A



(Simulations by S.Schanne, MG.Bernardini and F.Piron)

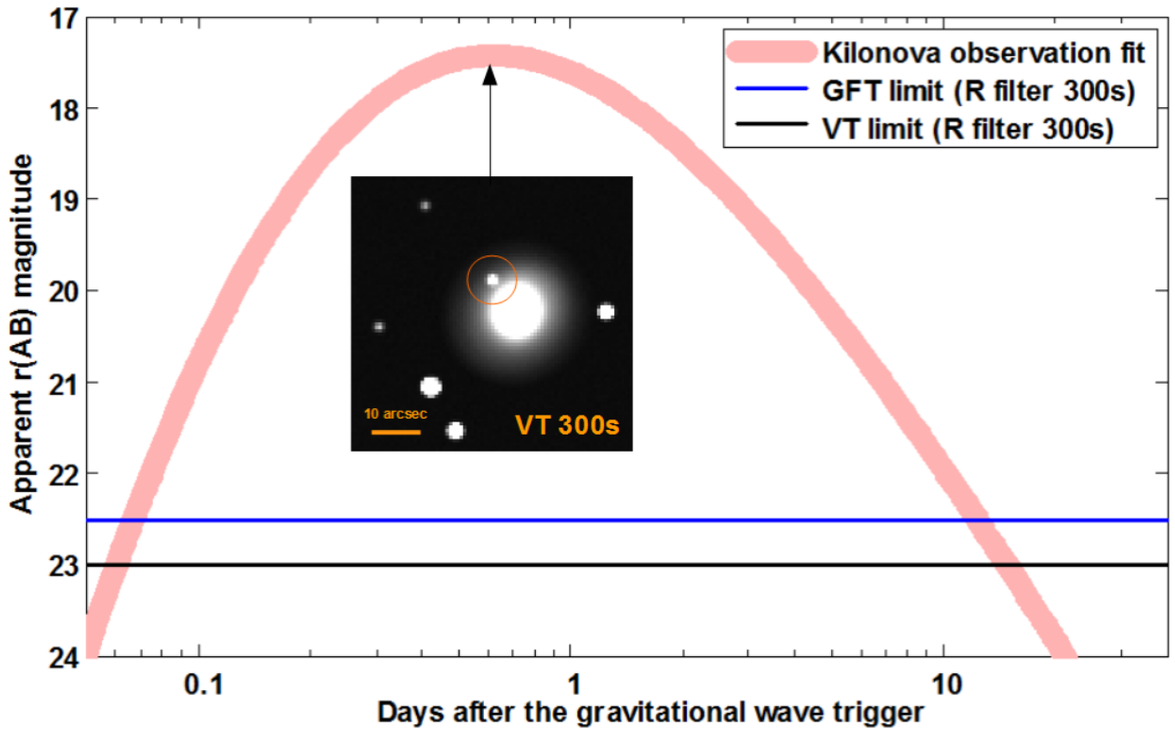
If in the ECLAIRs or GRM fov:

- Up to **35° off axis**: ECLAIRs triggers + alert is sent to the ground + slew is requested
  - ➡MXT and VT follow-up. Kilonova easily detectable by the VT
- Up to **50° off-axis**: GRM triggers + alert is sent to the ground (with rough localization)

If not in the ECLAIRs or GRM fov:

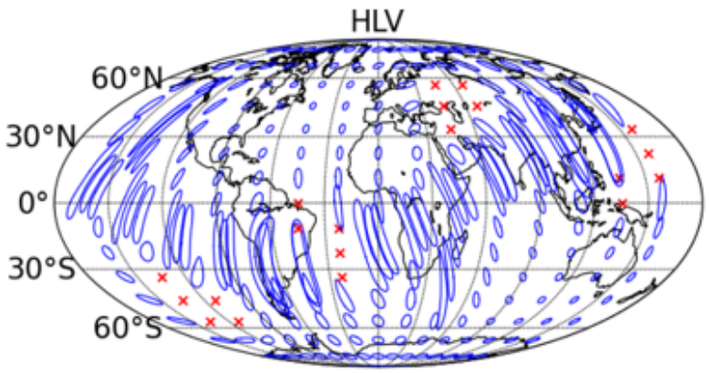
- LVC alert received by the FSC, ToO-MM sent for tiling observations with MXT + GFT observations of nearby galaxies
  - ➡Thanks to its NIR channel, Colibri would have certainly detect the kilonova

Simulation of the kilonova AT2017gfo

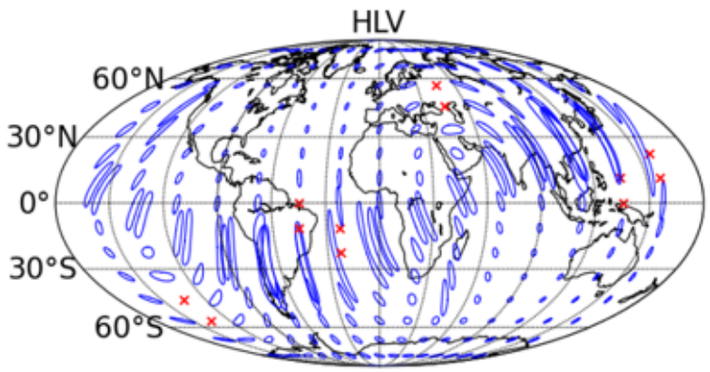


(Simulations by A.Klötz)

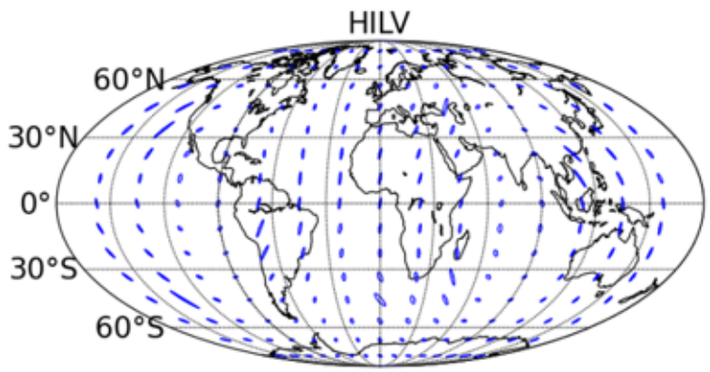
SVOM is already operating!



2017



2019



2023

Error box ≥100 deg^2 ⟶ ≤10 deg^2

GWAC

O2: Mini GWAC (m_{lim}=12)

O3: GWAC (m_{lim}=16, 10s expo)

GRM, ECLAIRs, MXT, VT, GFTs

O1: 1 GW alert followed, 1 GCN issued

O2: 8 GW alerts followed, 9 GCNs issued

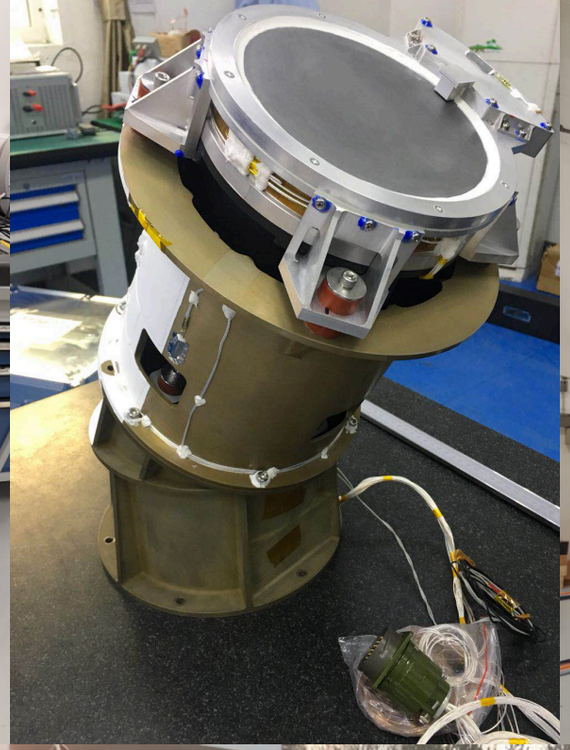
O3: 17 GW alerts followed, 31 GCNs issued

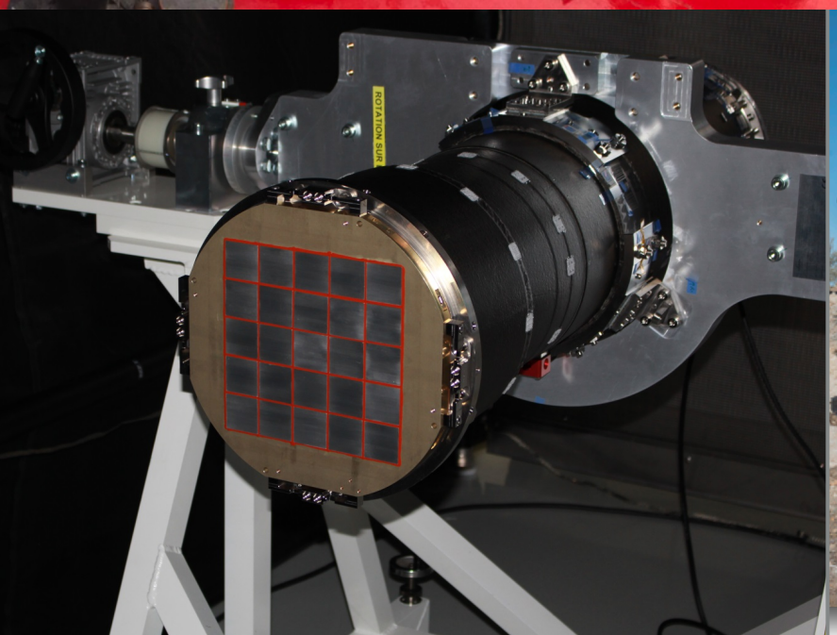
Mini GWAC

GWAC + 30 and 60 cm telescopes

(Credit D.Turpin, see also D.Turpin et al., 2019)

+ monitoring of flaring stars, novae, FRBs and GRBs (Xin+21, Wang+21, Wang+20, Xin+20, …)





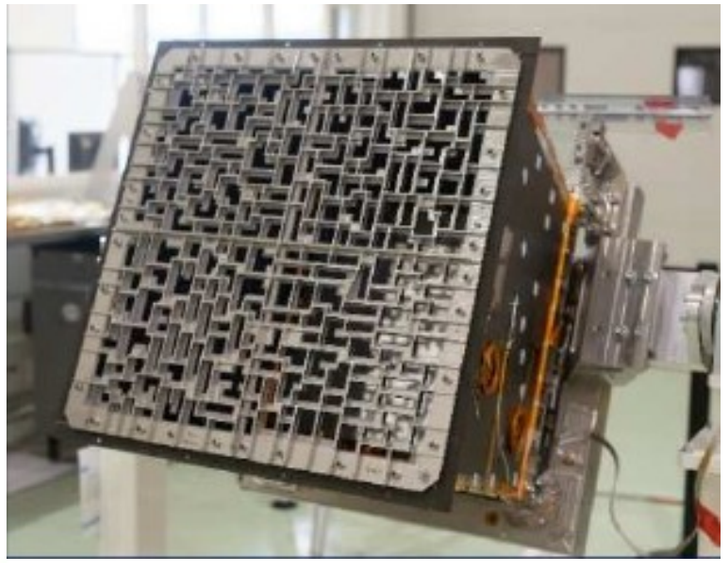
Everything will be ready for late-2023.
Stay tuned!!

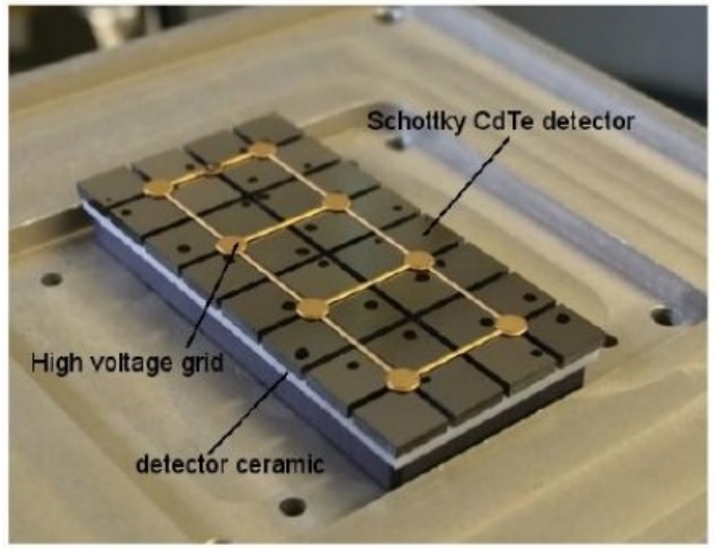
Backup slides

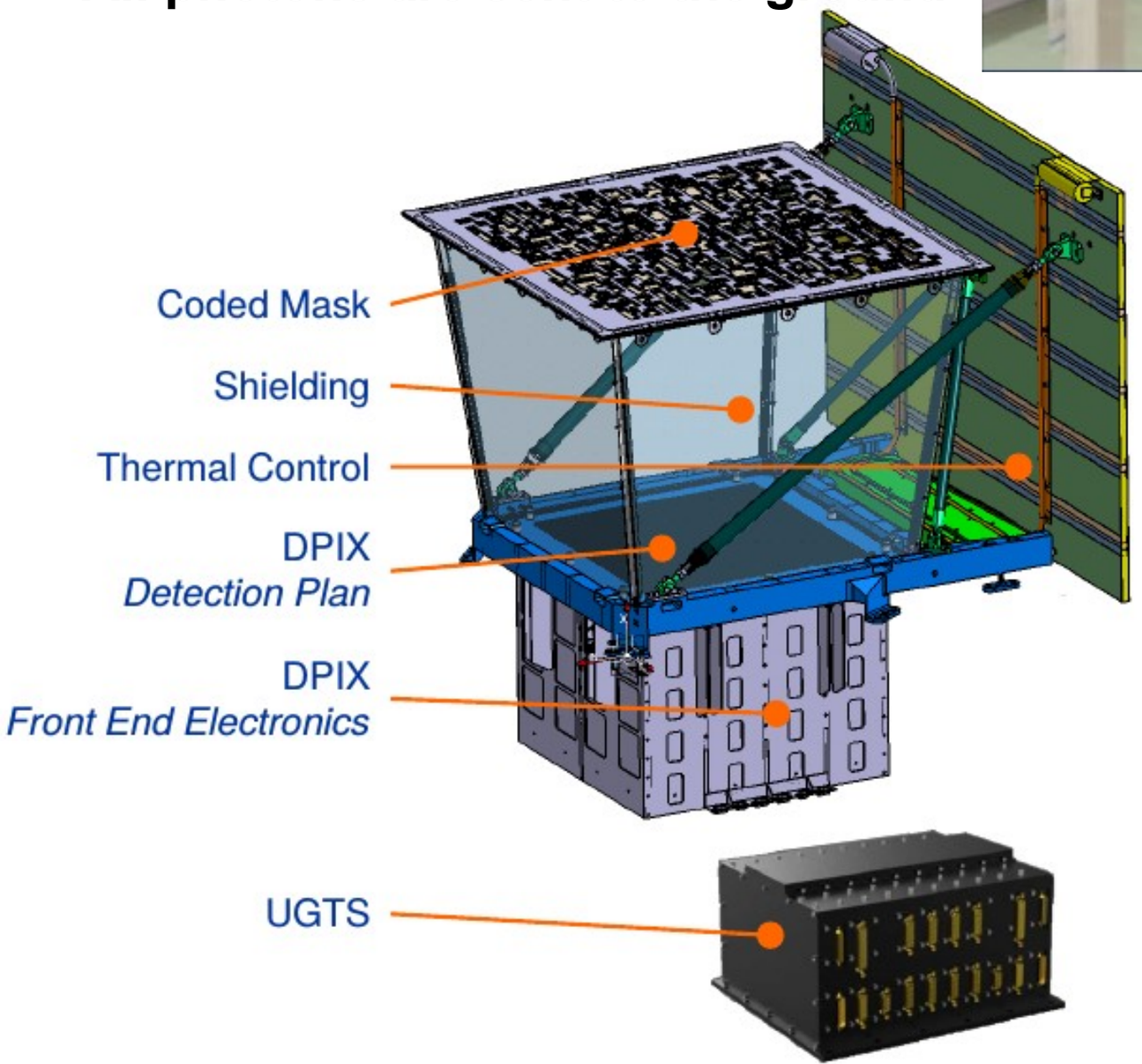
Instruments

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 mm³)
- **All photons are sent to the ground**



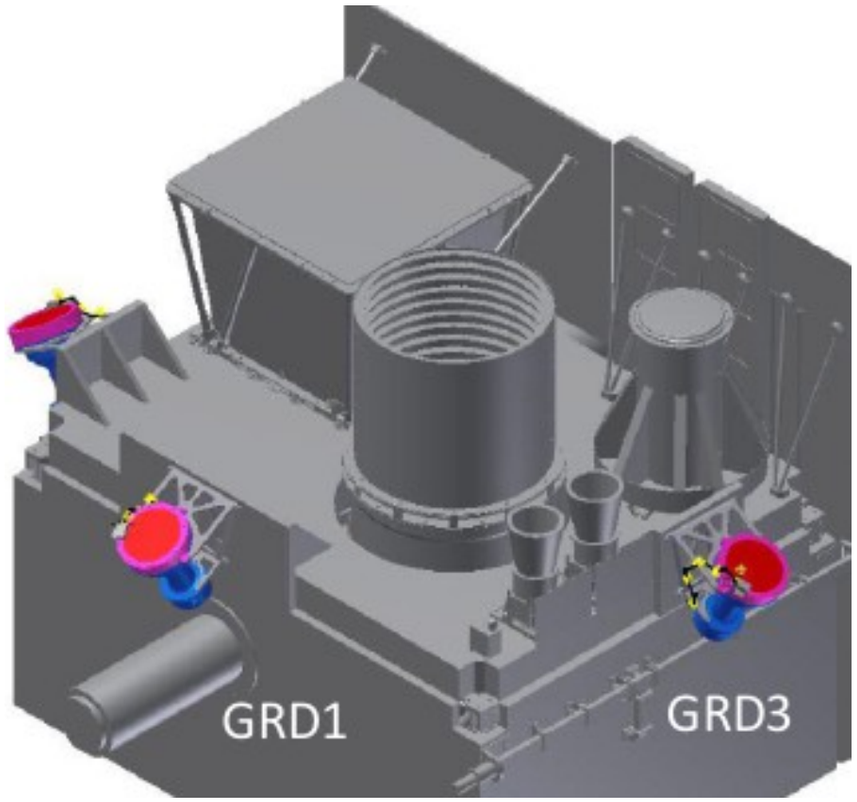


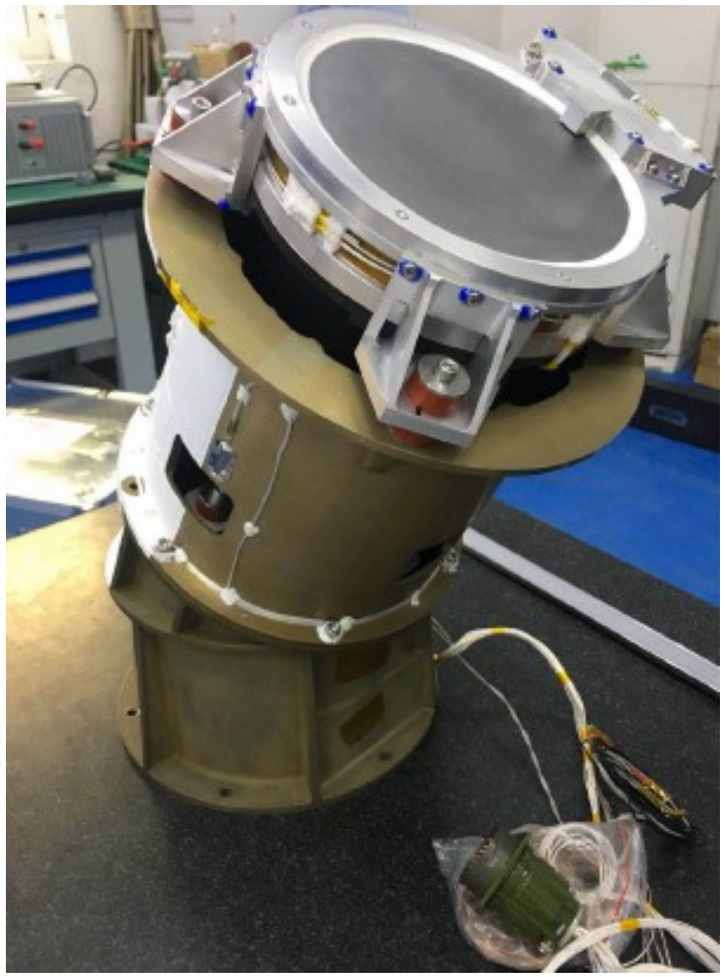


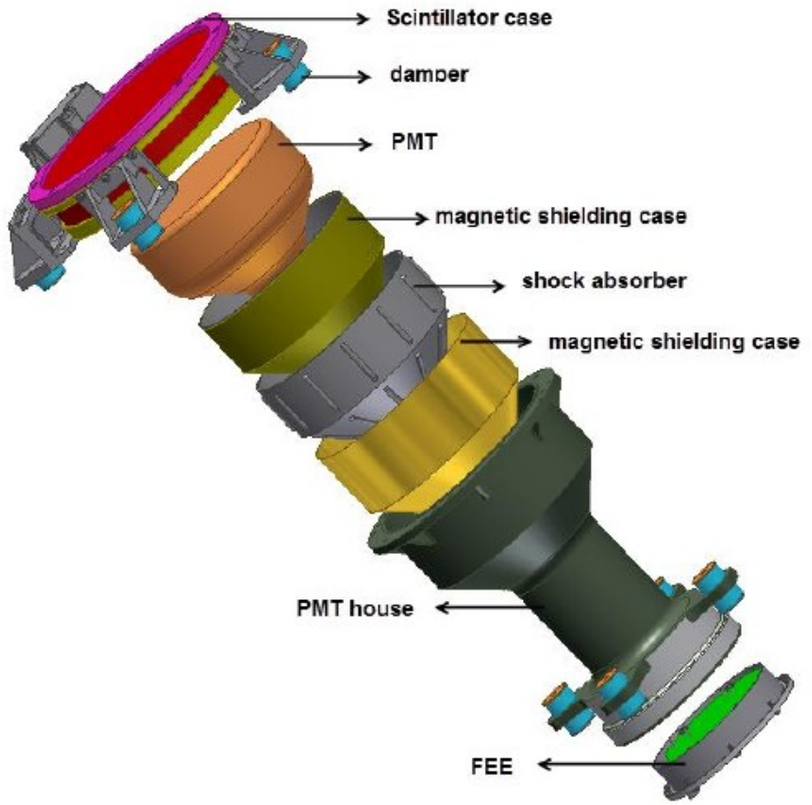
- **Onboard trigger and localization**
  - Strongly varying background modulated by Earth transit through the FoV every orbit
  - Time scales from 10 ms to 20 min
  - 4 energy bands, 9 detector zones
  - Rate trigger and image trigger
- **Performance**
  - FoV ~ 2 sr total
  - Energy range: 4-150 keV
  - Energy resolution <1.6 keV @60 keV
  - A_{eff} = 200 cm² @6 keV
  - Localisation accuracy <12' for 90% of the sources at detection limit

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



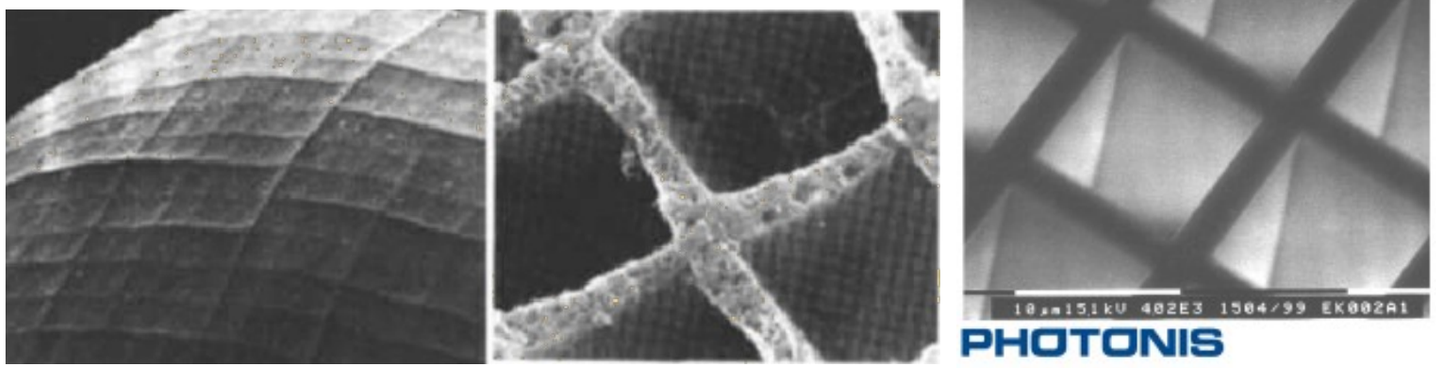


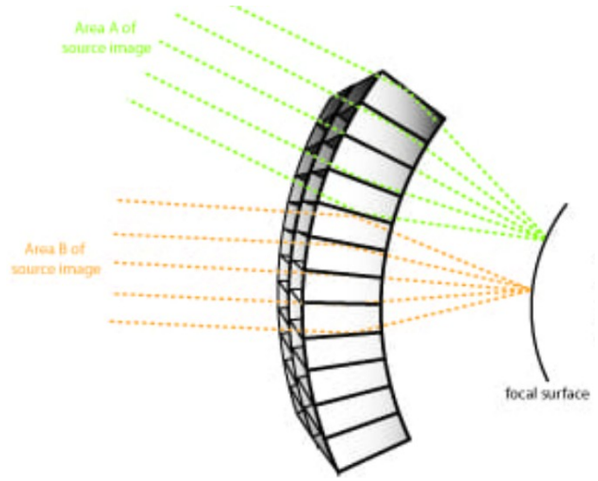


- **Onboard rate trigger (2 GRDs)**
- **Performance**
  - FoV ~ 5.6 sr (~2 sr per GRD)
  - Energy range: 15-5000 keV
  - A_{eff} = 190 cm² at peak (each unit)
  - Rough localization accuracy

The Micro-channel X-ray Telescope

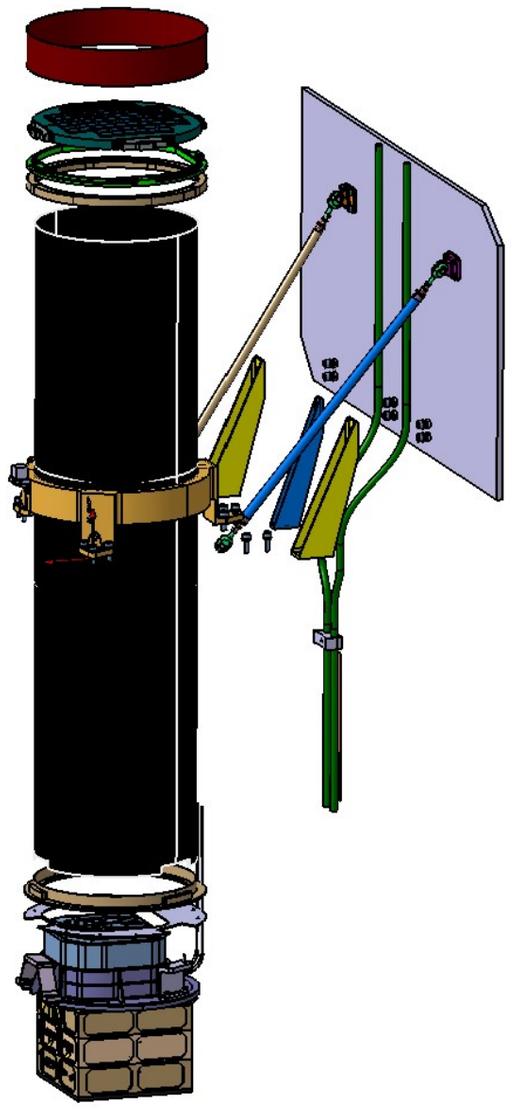
Real vs. manufactured “lobster eyes”

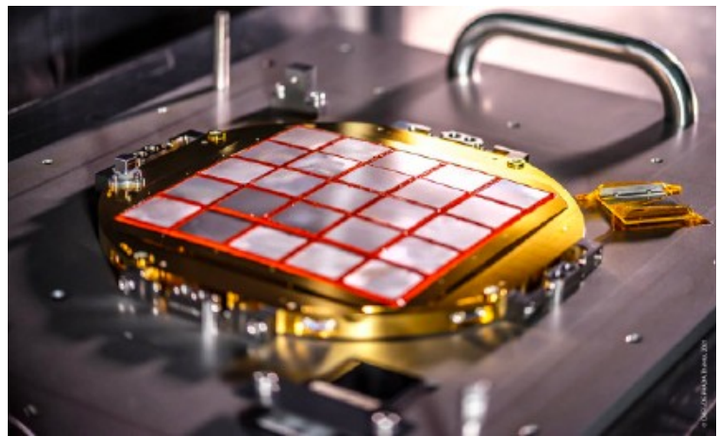




- **Micro-channel plate optics**
  - 20 micron size pores in a “lobster eye” configuration
  - Focal length: 1 m
  - pnCCD camera (256x256 pixels of 75 microns)

- **Performance**
  - FoV = 64x64 arcmin²
  - Energy range: 0.2-10 keV
  - Energy resolution ~60 eV @5.9 keV
  - A_{eff} = 27 cm² @1 keV (central spot)
  - Localization accuracy <13” within 5 min from trigger for 50% of GRBs





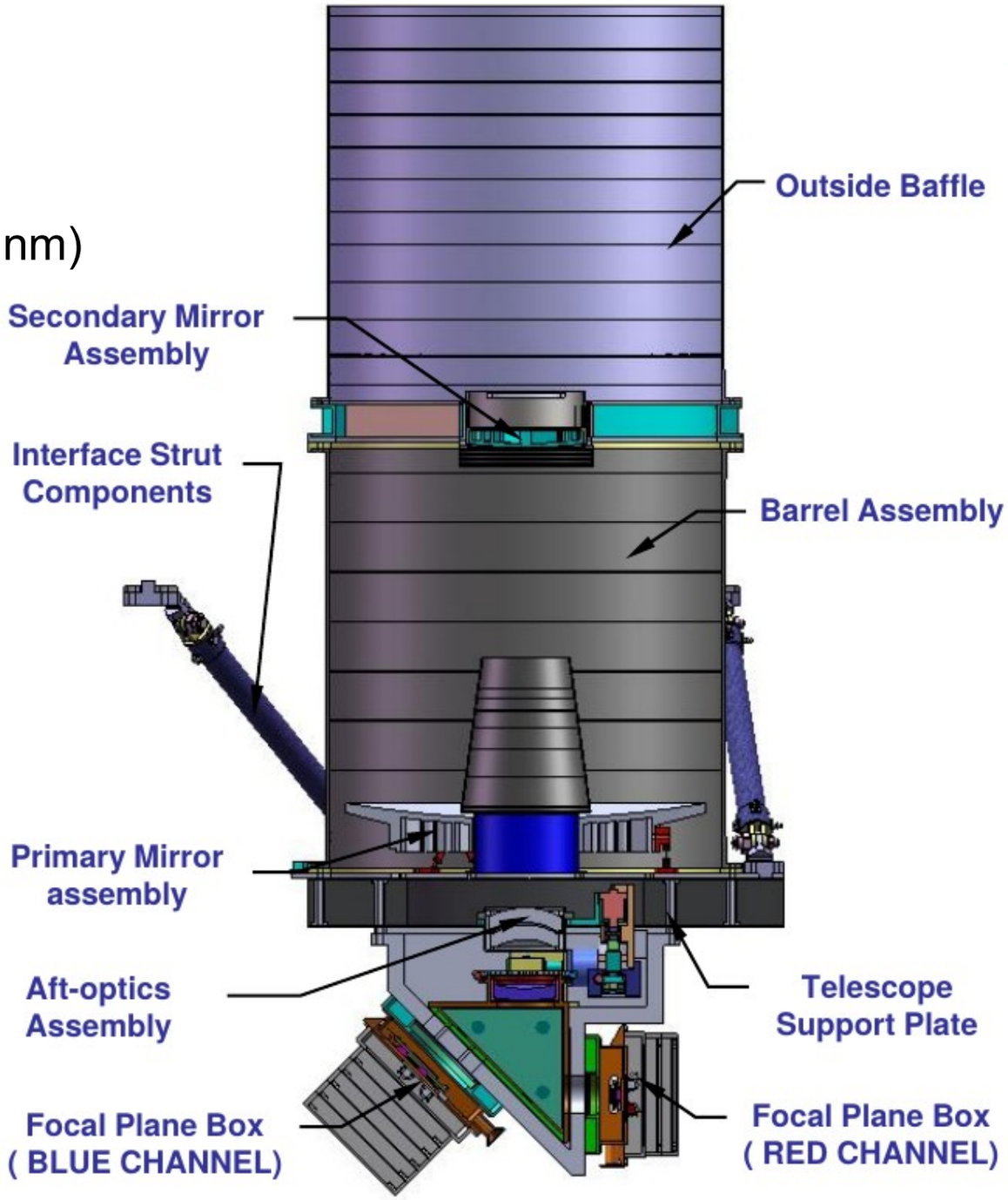
The Visible Telescope

- **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”



Ground segment telescopes

- **Ground-based Wide Angle Camera (GWAC)**
  - 36 camera units covering 5400 deg² (~1/2 ECLAIRs FoV)
  - Installed in Ali (China) and CTIO (Chile)
  - 500-800 nm; m_{lim}=16-17 (10 s exposure)
  - Explore the prompt optical emission
- **Ground Follow-up Telescopes (GFTs)**
  - Robotic 1-m class telescopes (fast repointing, <30 s)
  - San Pedro Martir (Mexico) and Xinglong observatory (China)
  - C-GFT: 1.2 m, FoV = 21x21 arcmin², 400-950 nm
  - F-GFT (a.k.a. Colibri): 1.3 m, FoV = 26x26 arcmin², multi-band photometry (400-1700 nm, 3 simultaneous bands)
  - Accurate GRB localization → observations with large telescopes
- **Agreement to use the LCOGT network**
- **>75% of ECLAIRs GRBs immediately visible by one ground telescope (GFTs+LCOGT)**
- **Early observation by large telescopes favored by pointing strategy → redshift measurement expected in ~2/3 of cases**