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)

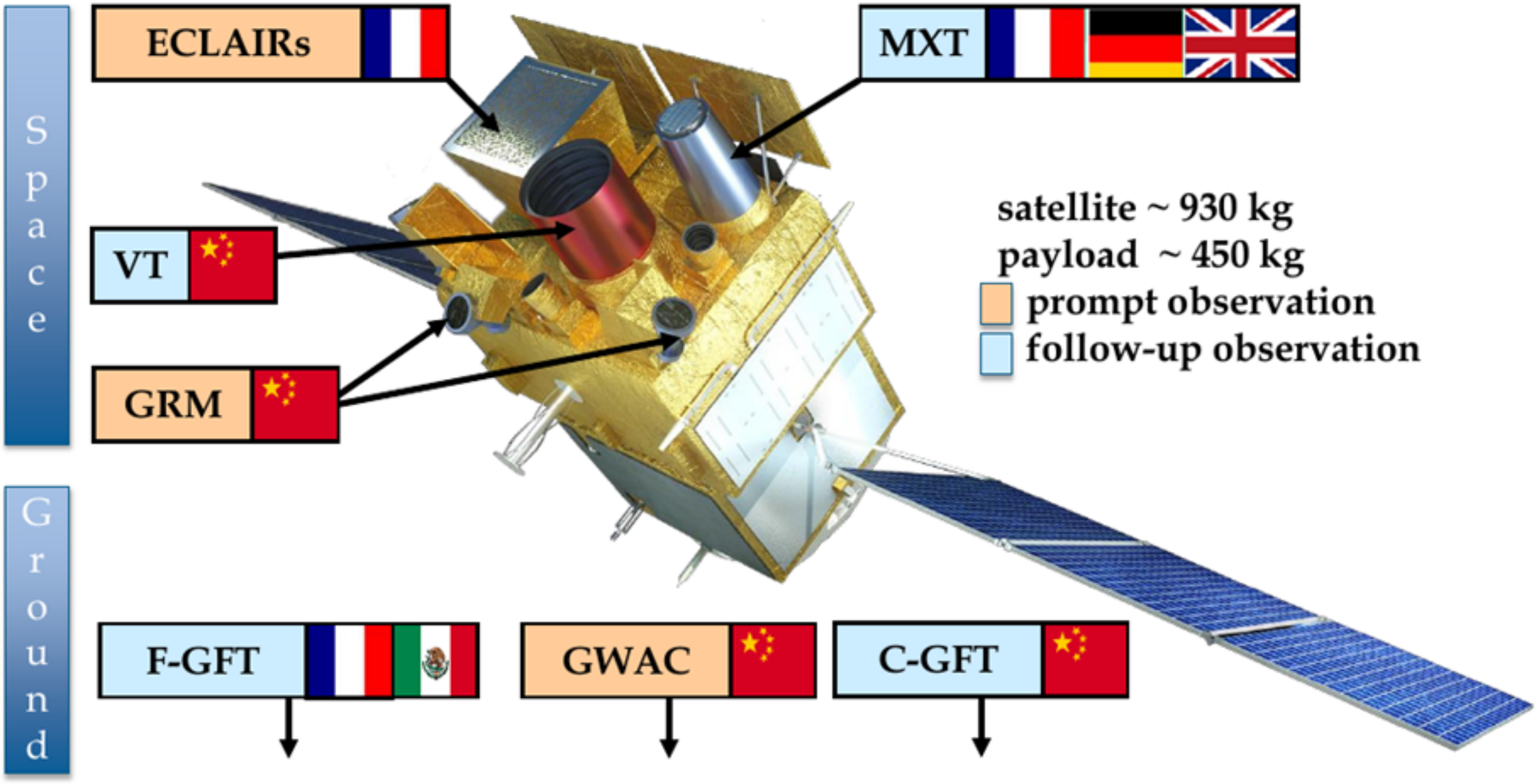
UK

- 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, duration 3+2 years

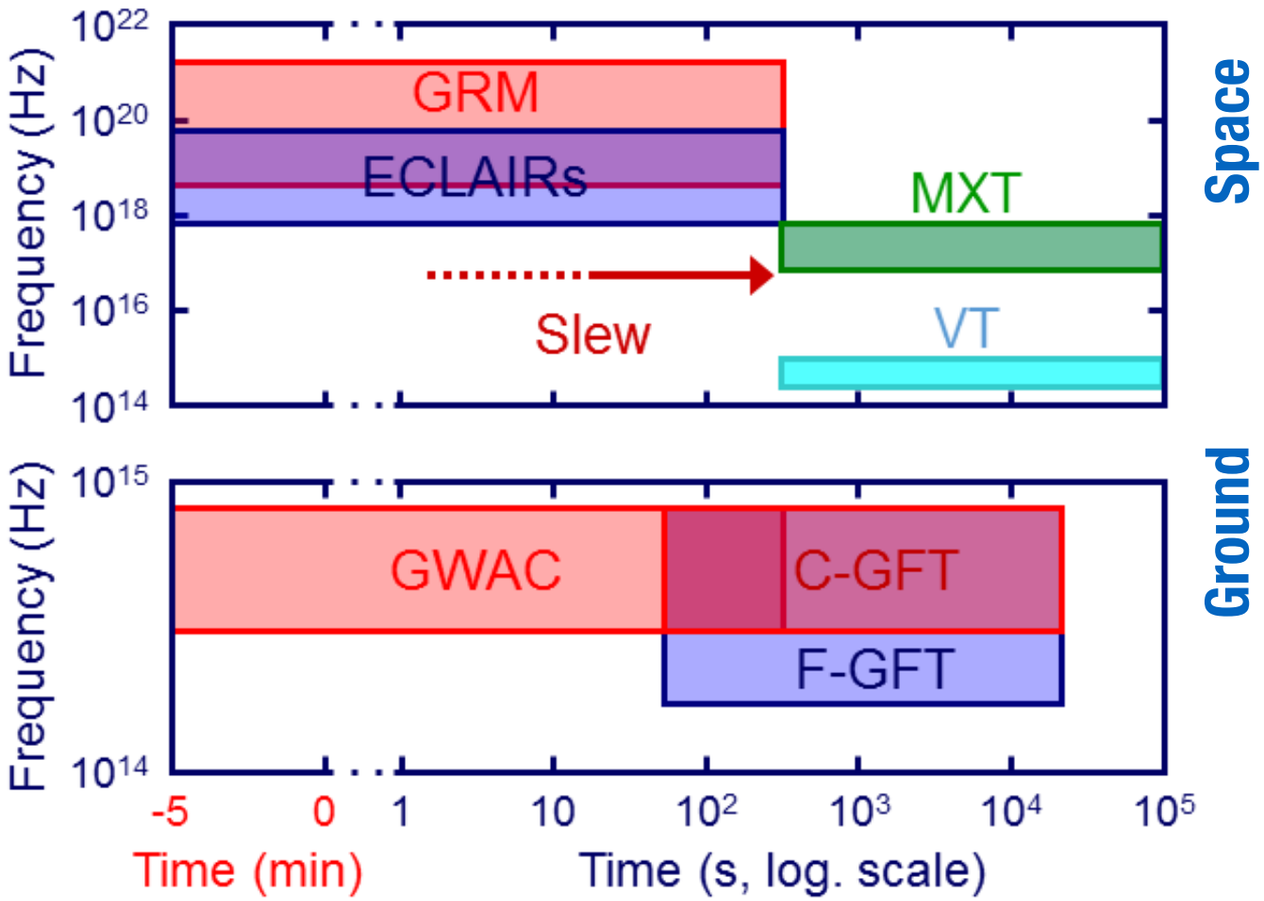


Launch due on June 24, 2024

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

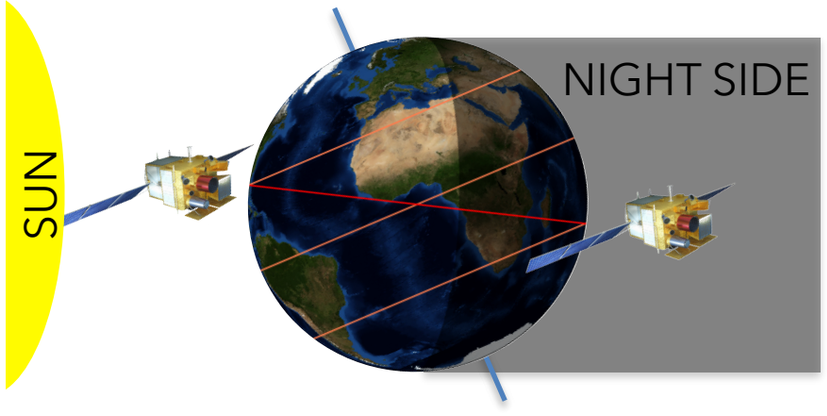


- Synergy among **7 instruments in space and on ground** for a complete monitoring of GRBs and high-energy transients **over 7 decades in energy** and **from the trigger up to the late afterglow**
- Rapid alert dissemination and optimal attitude law for ground-based follow-up to **favor redshift measurement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

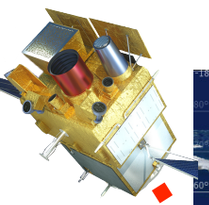
Orbit, pointing strategy and alerts dissemination

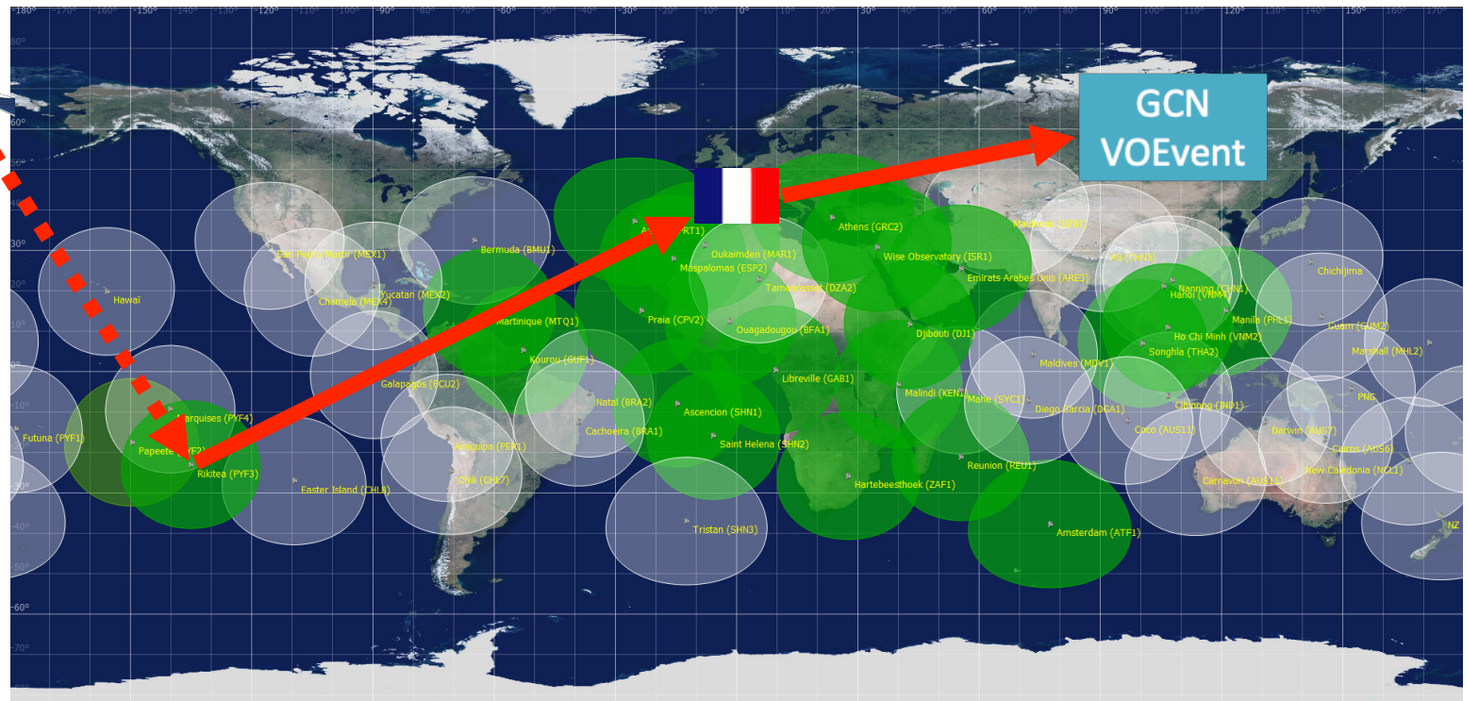
- Low Earth orbit (625 km, 96 min), 30° inclination
- **Nearly anti-solar pointing**
- Avoidance of the galactic plane and bright sources as Sco X-1
- **Alerts transmitted to a network of 40 antennas.** Goal: 65% of alerts within 30s

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



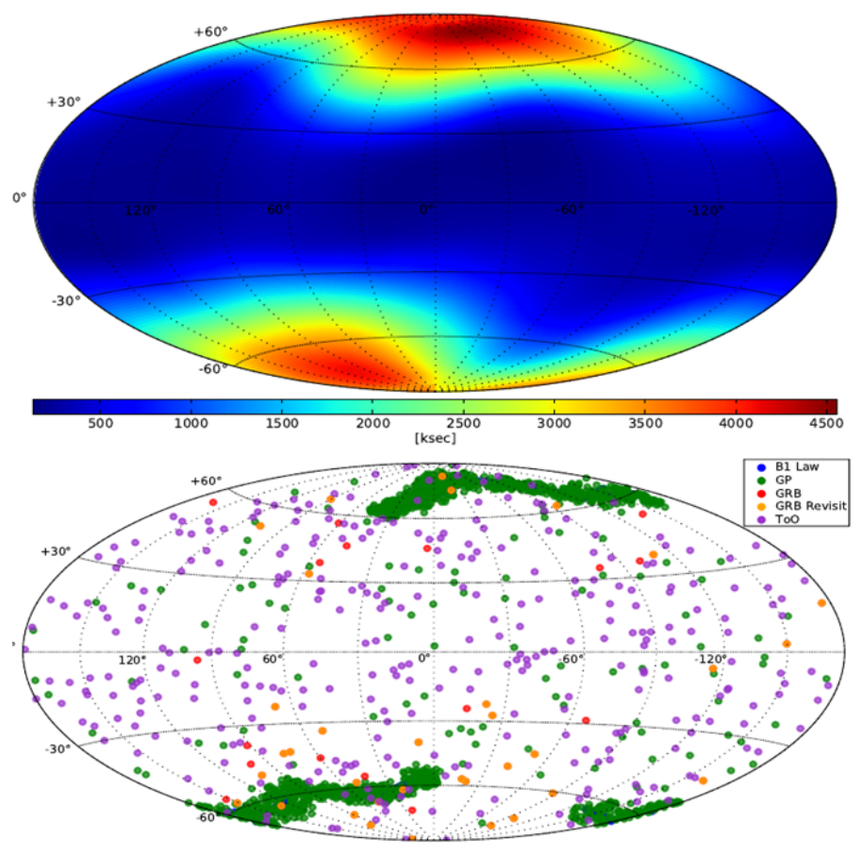
➡**Earth in the fov**: 65% duty cycle for ECLAIRs, 50% for MXT and VT





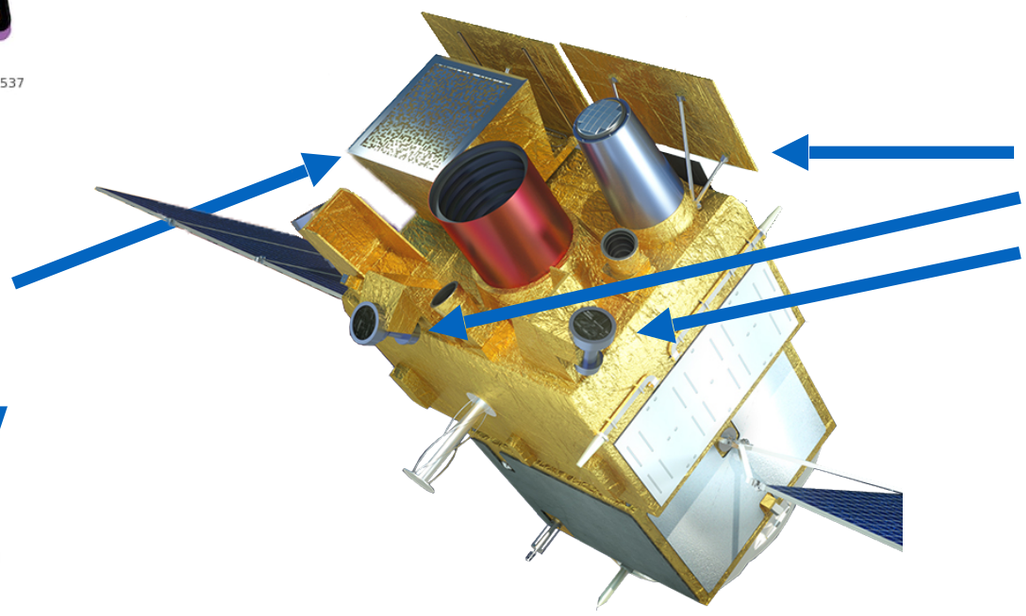
ECLAIRs 1 yr exposure map:

- **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 prompt emission



ECLAIRs:

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

+

GWAC:

- 10 mounts with 4 cameras: ~5000 deg² (half of ECLAIRs fov)
- 500-800 nm
- m_{lim} ~ 16-17 (10s exposure)

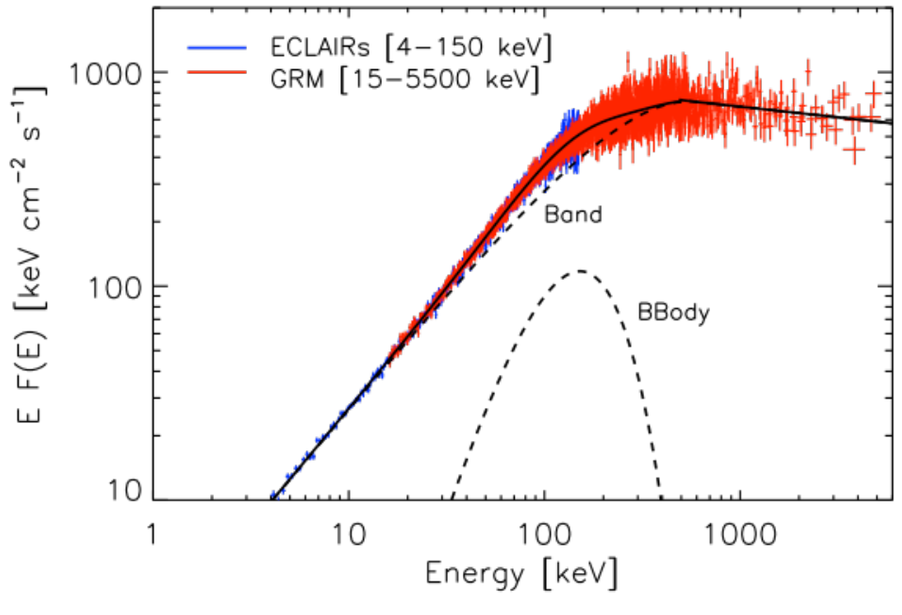
GRM (3 GRDs):

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

- ECLAIRs sensitive to **all classes of long GRBs**
- **Sensitivity to short GRBs improved** by combining ECLAIRs+GRM

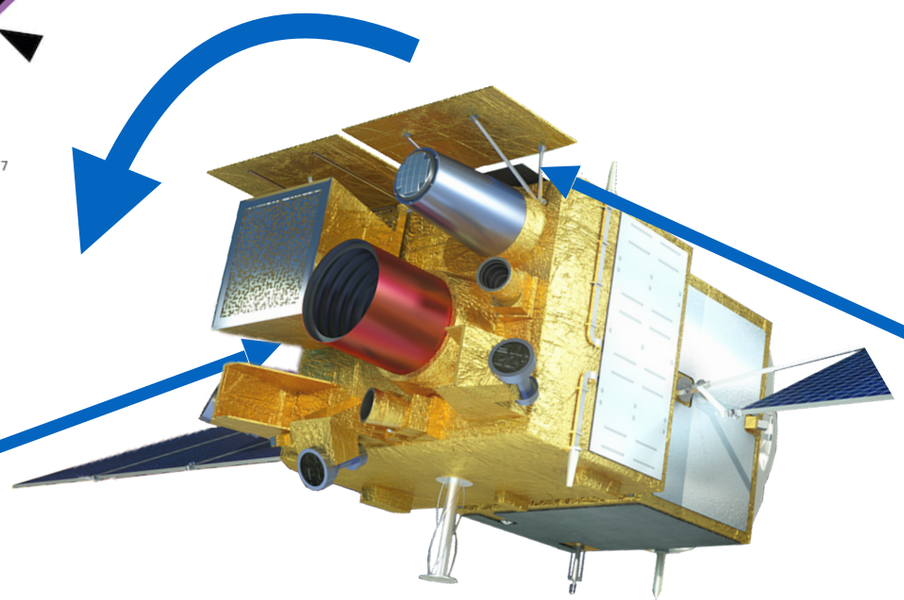
- ECLAIRs+GRM measure the **prompt spectrum over 3 decades in energy**
- GWAC will add a constraint on the **associated prompt optical emission** in a good fraction of cases (16%).

Simulation of the multi-component spectrum of GRB 100724B



(Bernardini et al., 2017)

The GRB follow-up



VT:

- 400-1000 nm
- Loc. <1”

+

GWAC:

- ~5000 deg²
- 500-800 nm

F-GFT (Colibrì):

- 1.3 m
- 400-1700 nm

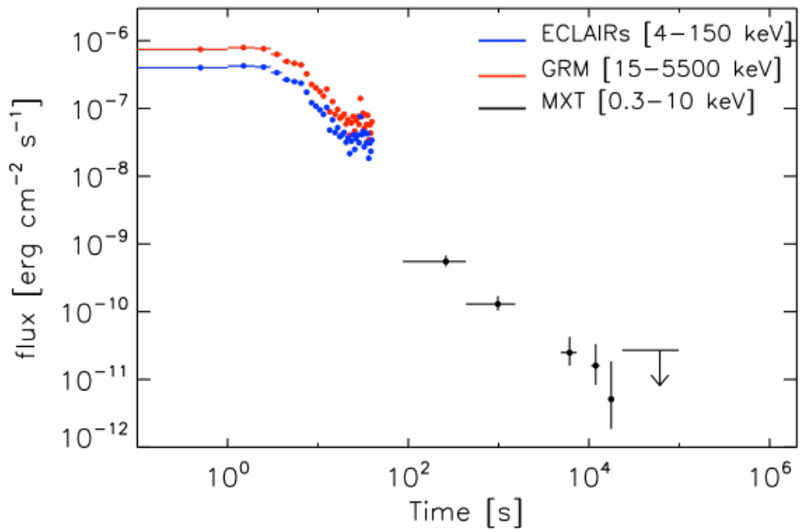
C-GFT:

- 1.2 m
- 400-950 nm

MXT:

- 0.2-10 keV
- 64x64 arcmin²
- **Loc. <13”** within 5 min after the trigger for 50% of GRBs
- slew request: **~72 GRB/yr**

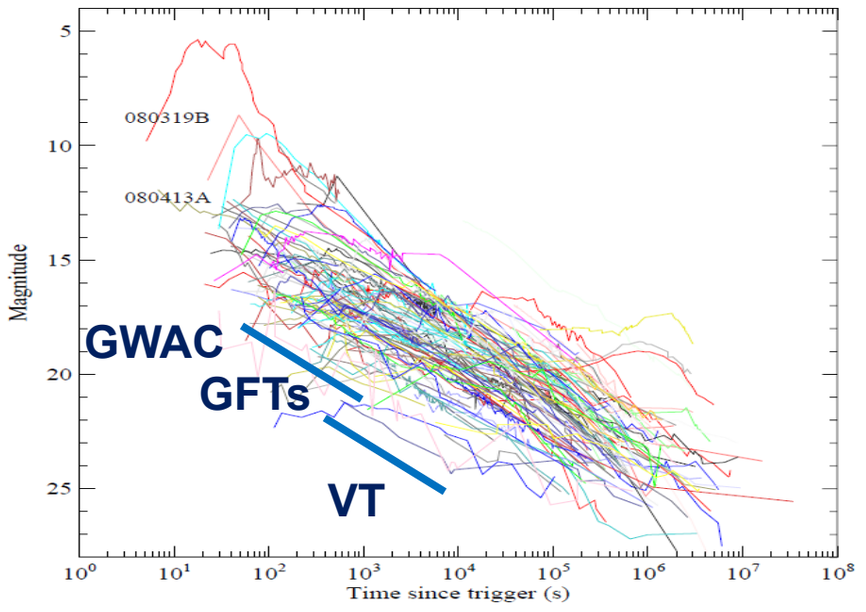
Simulation of GRB 091020



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

- MXT can **detect and localize the X-ray afterglow** in >90% of GRBs after a slew
- VT + ground segment will **detect, localize and characterize the visible-NIR afterglow**

Optical Light curves of long GRBs



(Wang et al., 2013)

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**

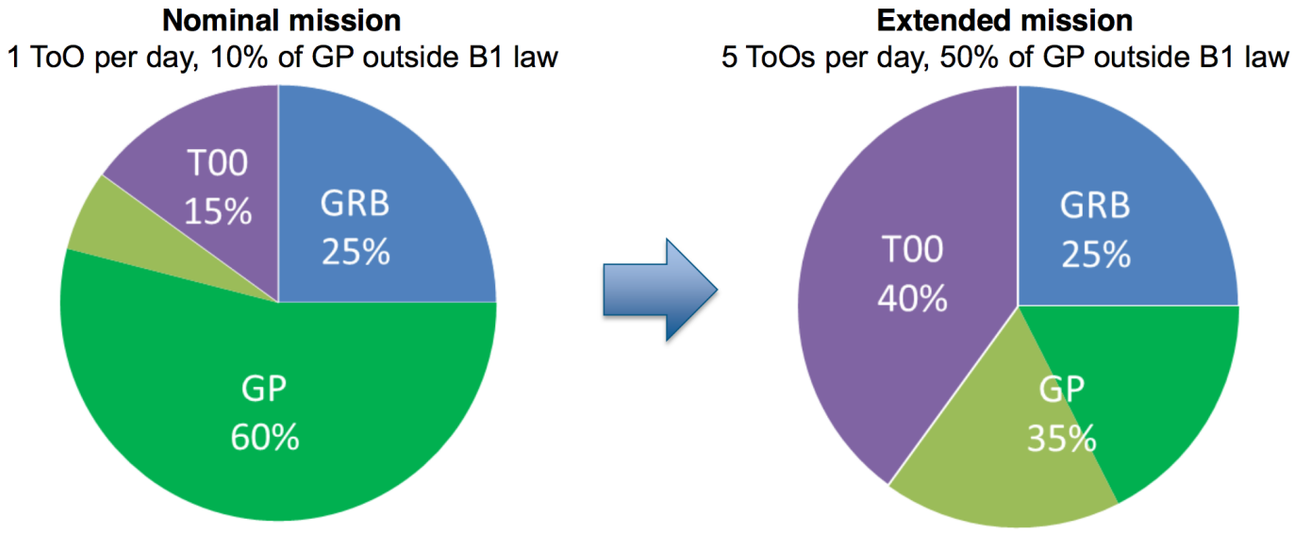
- **Physical mechanisms at work in GRBs**
  - Nature of GRB progenitors and central engines
  - Acceleration & composition of the relativistic ejecta
- **Diversity of GRBs: event continuum following the collapse of a massive star**
  - Low-luminosity GRBs / X-ray rich GRBs / X-ray Flashes and their afterglow
  - 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

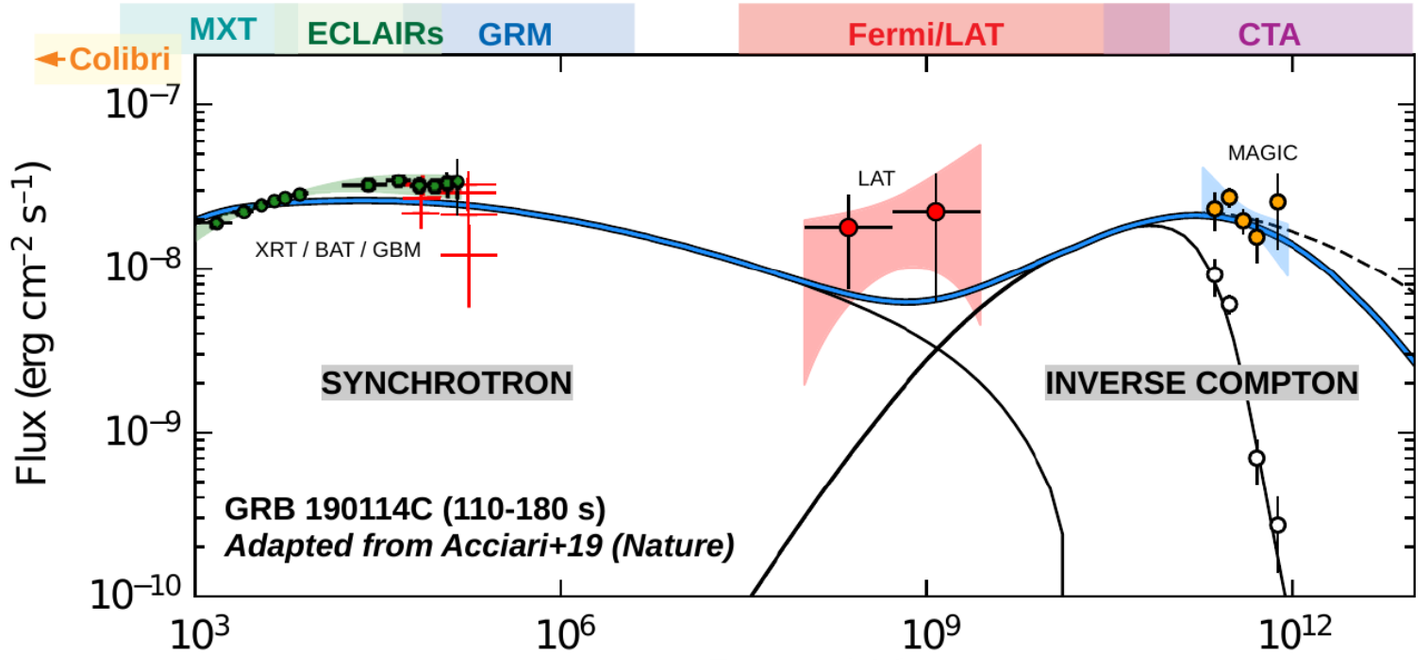
- **General Program:**
  - All the SVOM data will be managed by the Responsible Co-I
  - **One year of proprietary period** before the scientific products become public

- **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

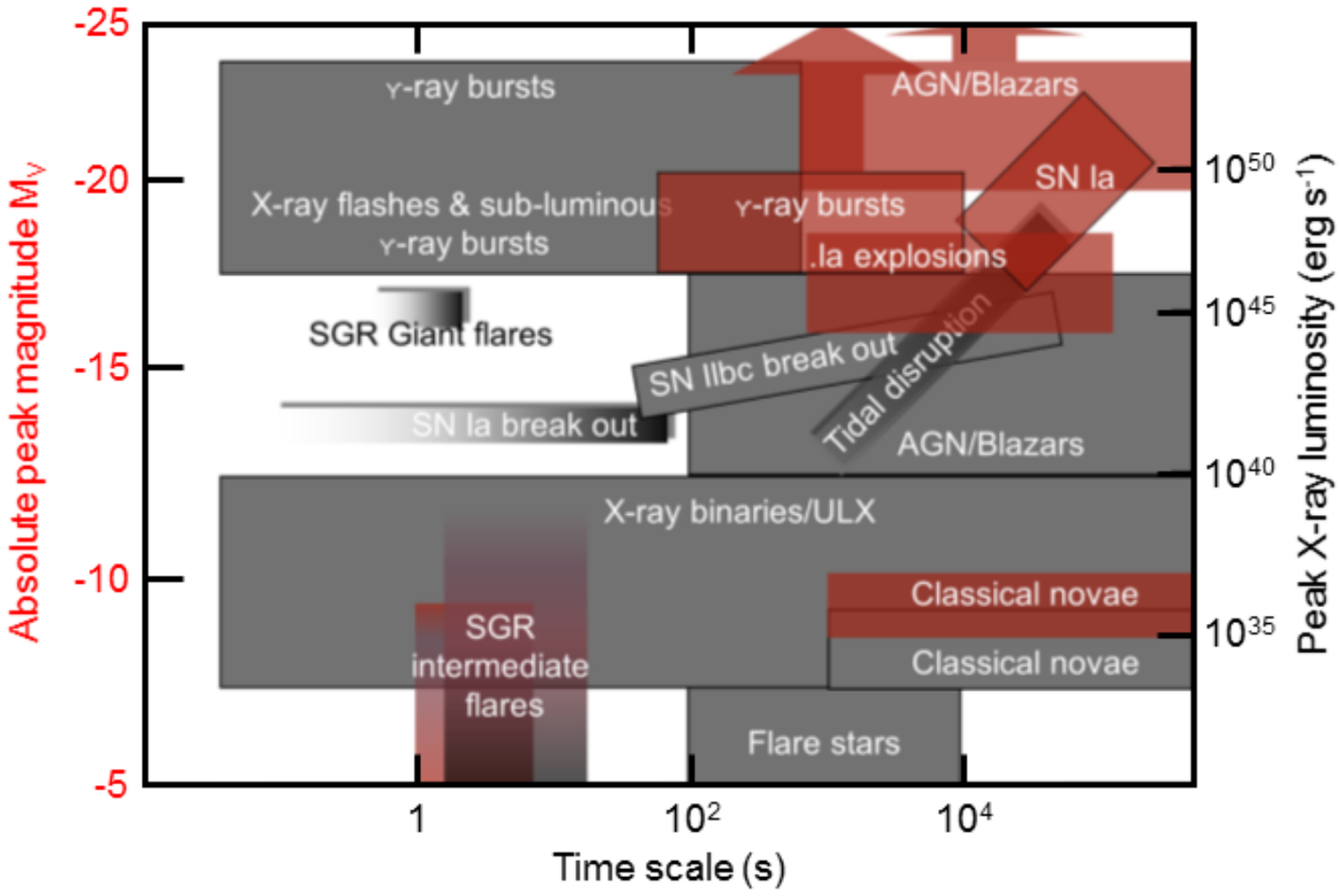
Exploring the Transient sky with SVOM

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)



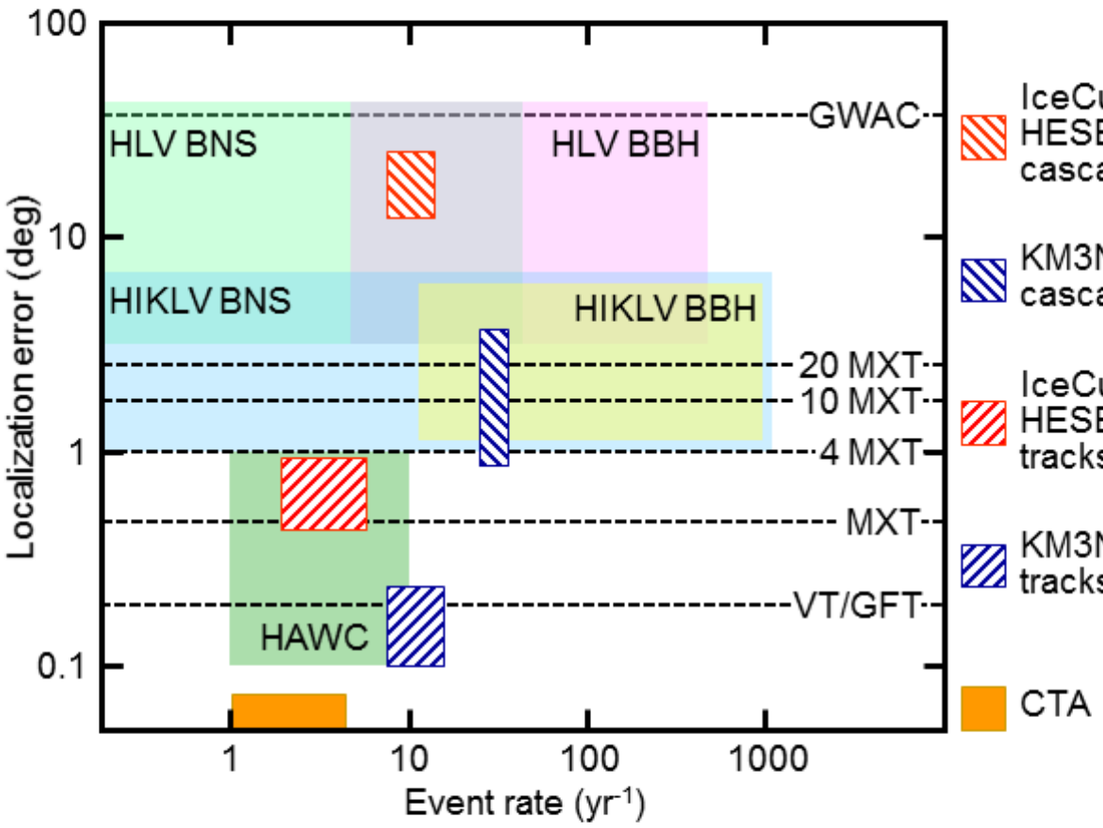
General Program:

- 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**

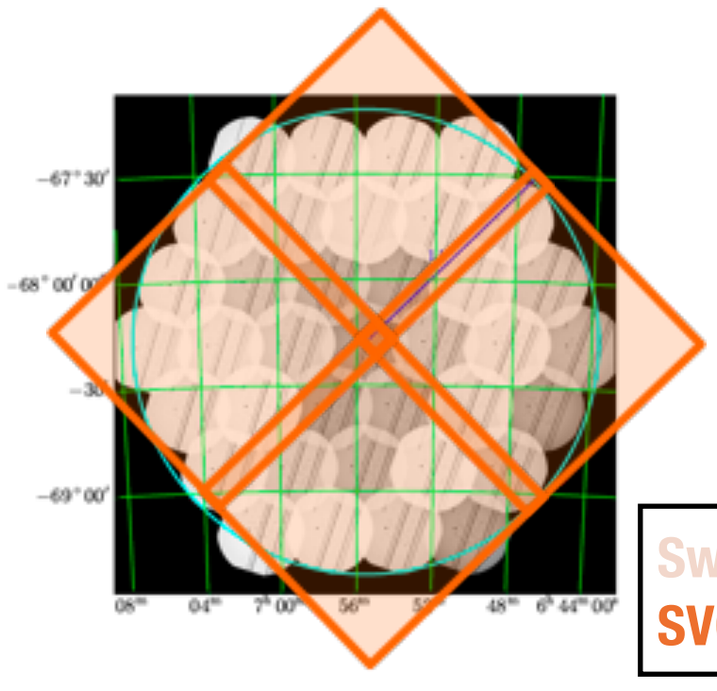
➡ Tiling strategy if the error box is larger than 1 deg²

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



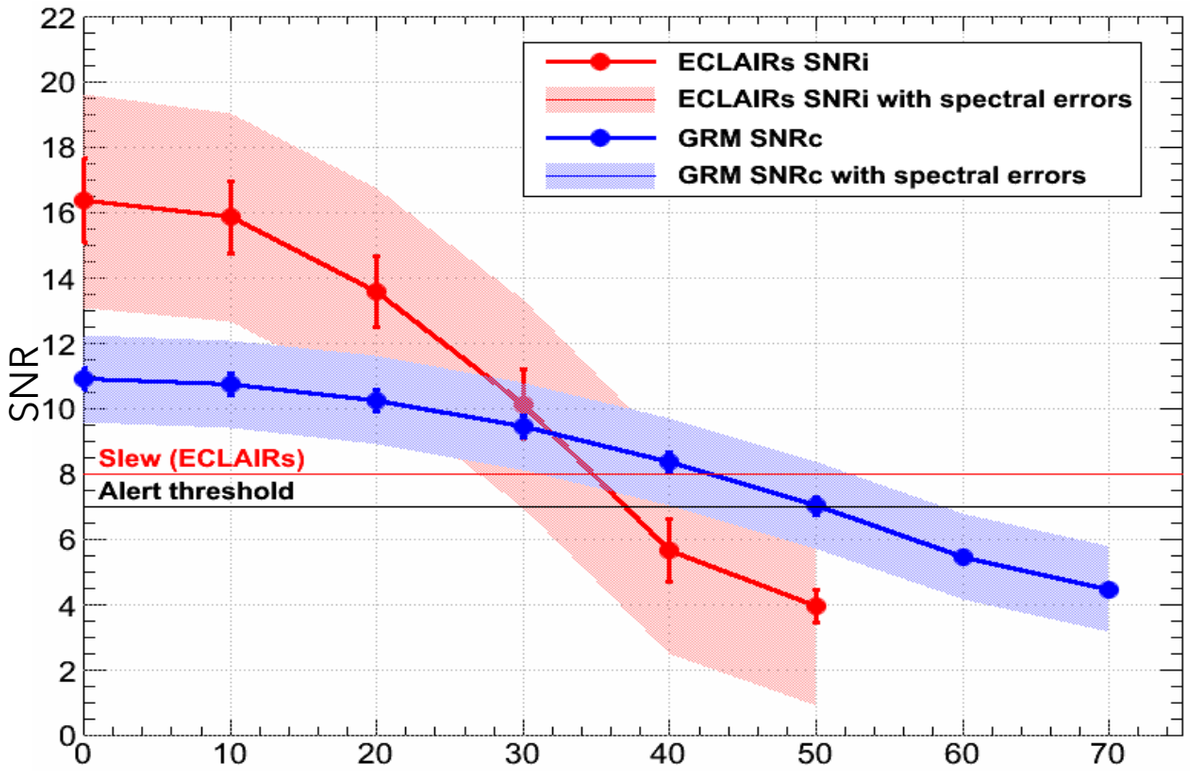
Swift/XRT f.o.v

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)

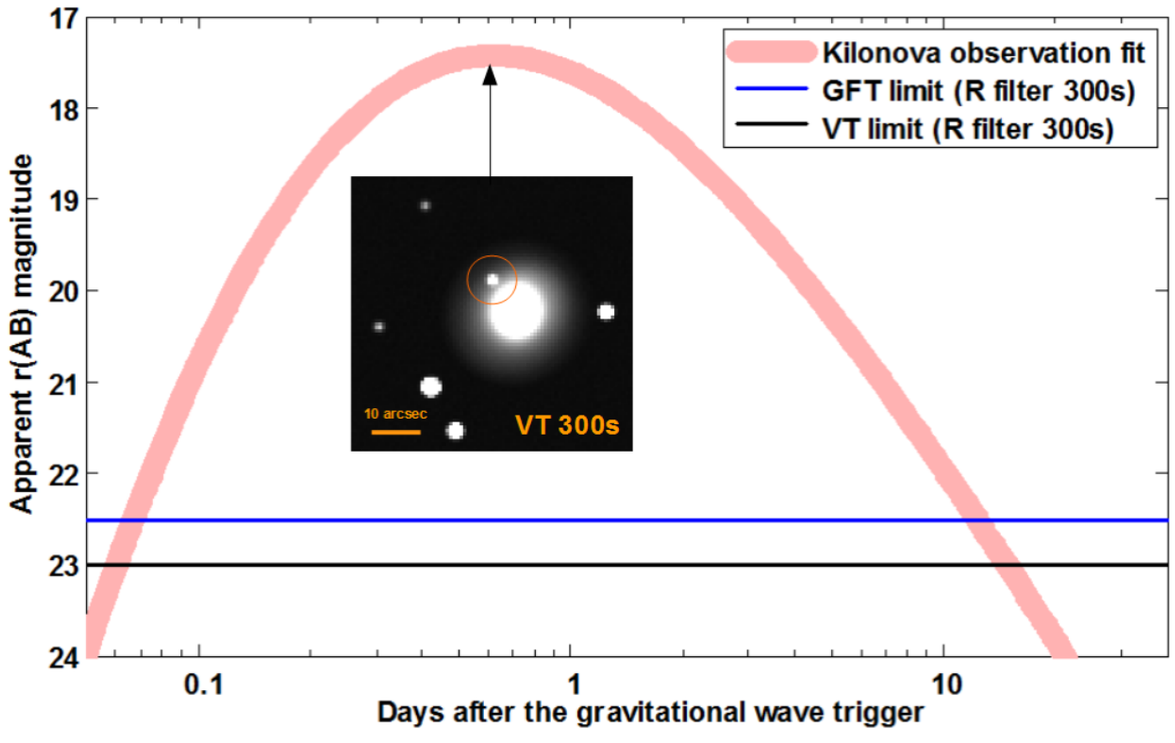
If in the ECLAIRs or GRM fov:

- 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:

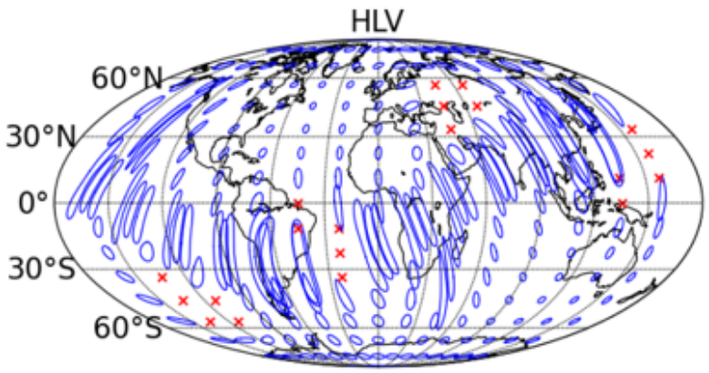
- LVC alert received by the FSC, ToO-MM sent for tiling observations with MXT + GFT observations of nearby galaxies
  - ➡Thanks to its NIR channel, Colibri would have certainly detect the kilonova

Simulation of the kilonova AT2017gfo

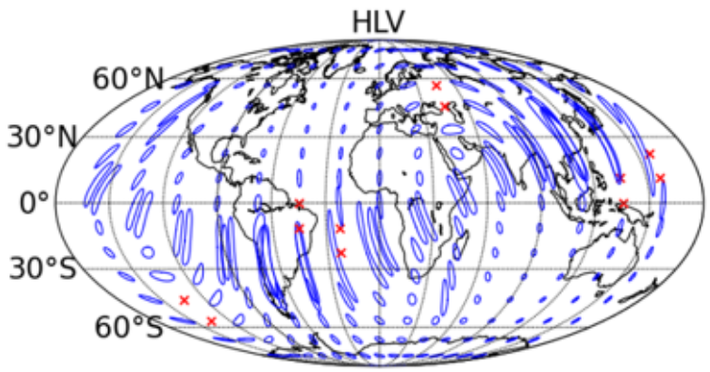


(Simulations by A.Klötz)

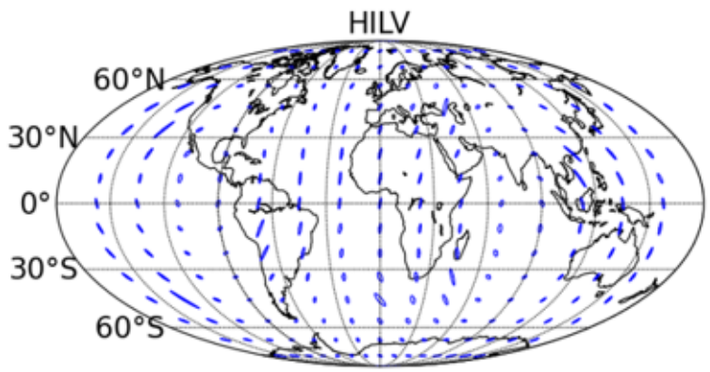
SVOM is already operating!



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

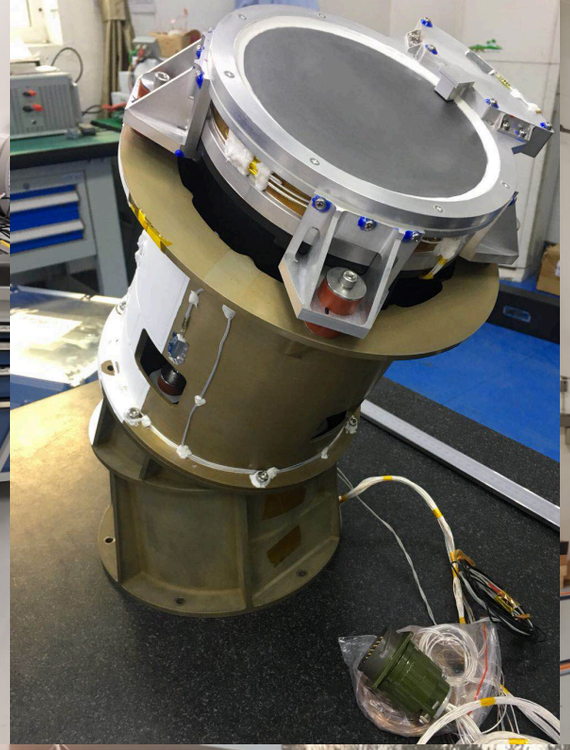
O3: 17 GW alerts followed, 31 GCNs issued

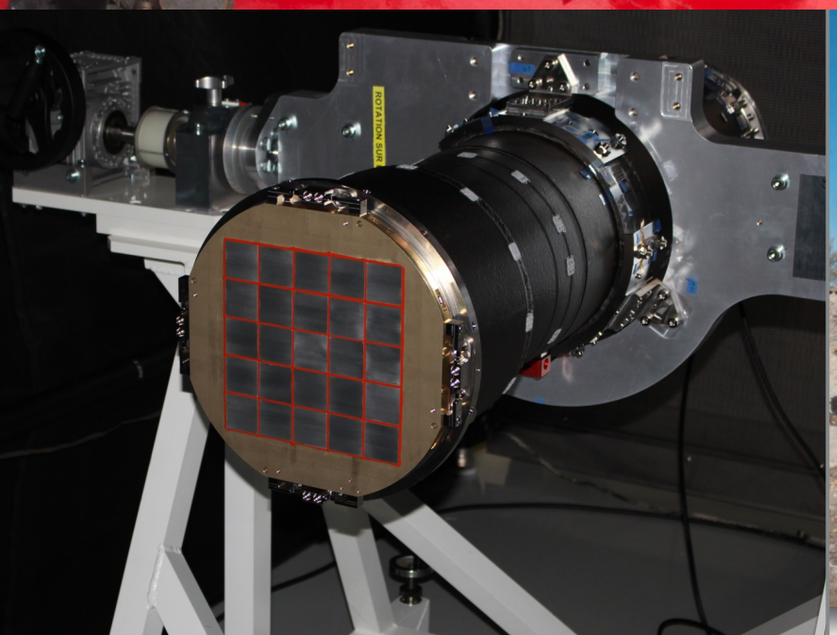
Mini GWAC

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!!