SVOM: a new mission for multi-messenger and time domain astrophysics

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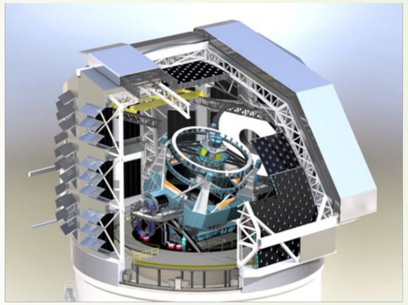
On behalf of the SVOM consortium

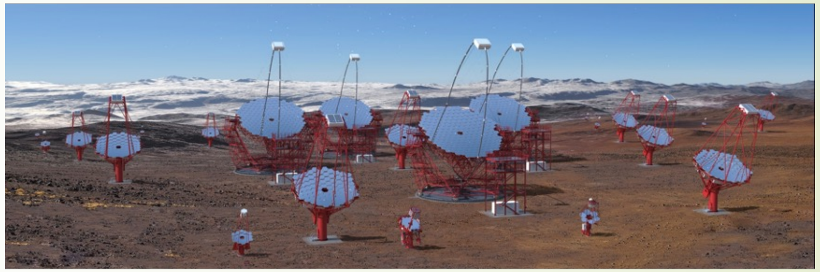
Plan of the presentation

- Time Domain Astrophysics
- The SVOM mission
- The SVOM environment & perspectives
- Conclusions

Time Domain Astrophysics

- Time Domain Astrophysics is the study of time variations of astrophysical objects with the goals of
  - identifying their nature
  - understanding the physical processes at work
- It is one of the hot topics of modern astronomy (LSST/VRO, SKA, LOFAR, CTA, etc.) and one of the major connections to astro-particle physics or multi-messenger astronomy (GW, neutrinos, UHECRs, etc.)



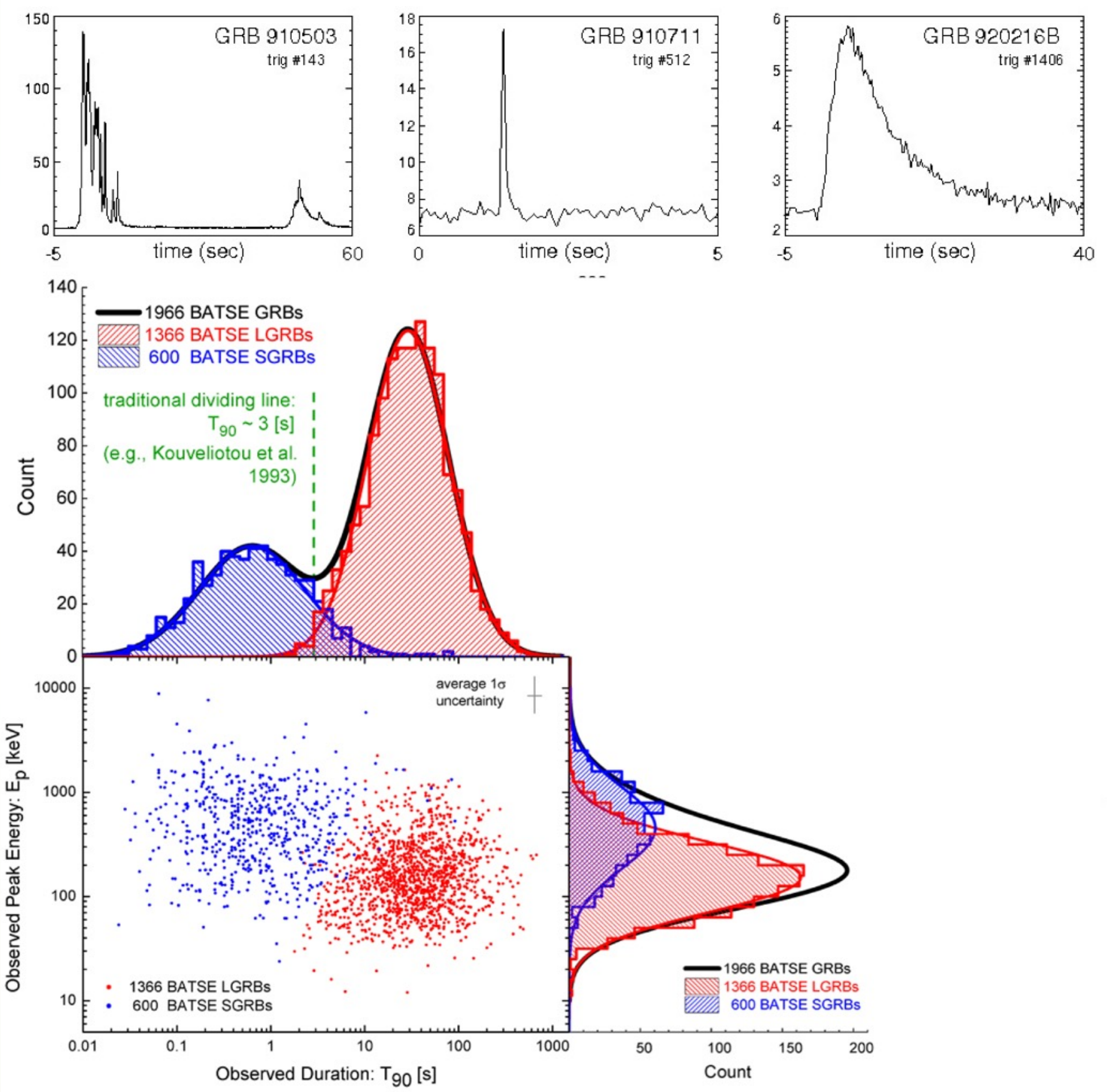



Time Domain Astrophysics

- The study of the time variation of sources is a common practice in astronomy and especially in the X- and gamma-ray domain since the first satellite experiments, but it was made « by hand »
- What we understand today under TDA is the use of modern computational techniques in order to detect characterize transient and variable sources in near real-time and inform on the shortest delays the astronomical community at large in order to organize a follow-up with other instruments
- A "classical example" of TDA is the study of Gamma-Ray Bursts

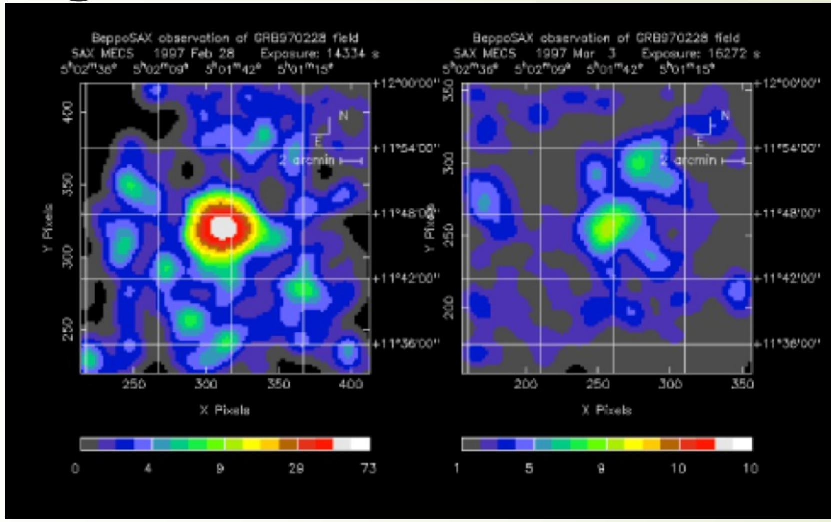
Gamma-Ray Bursts

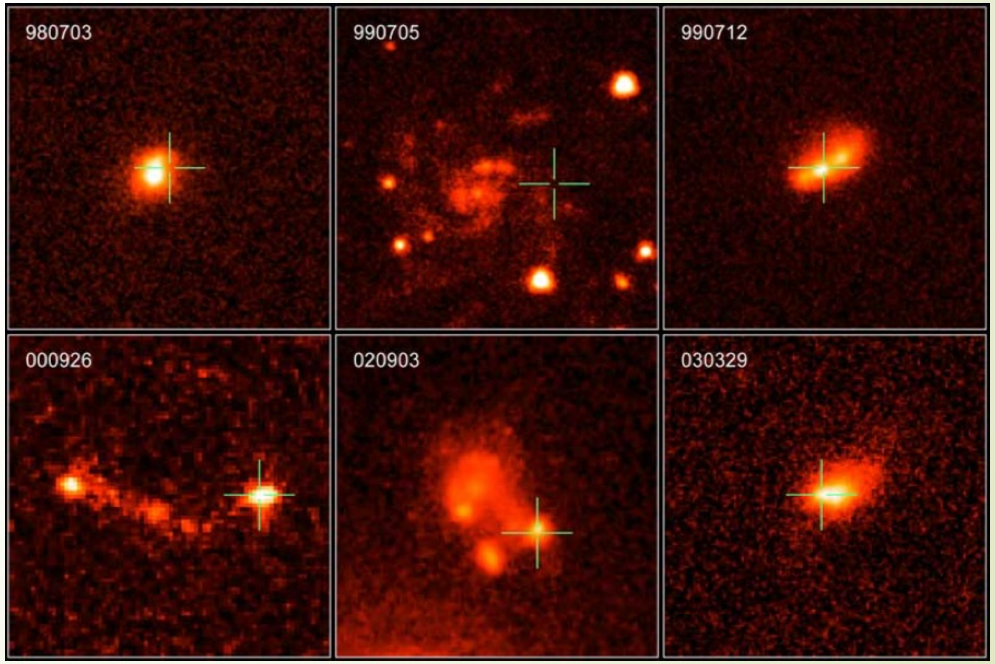
- GRB are short flashes of gamma-ray radiation with a by-modal time distribution
- They appear randomly over the entire sky
- They spectra are mainly-non thermal
- The variability and the spectra imply a relativistic compact object origin



Gamma-Ray Bursts Afterglows

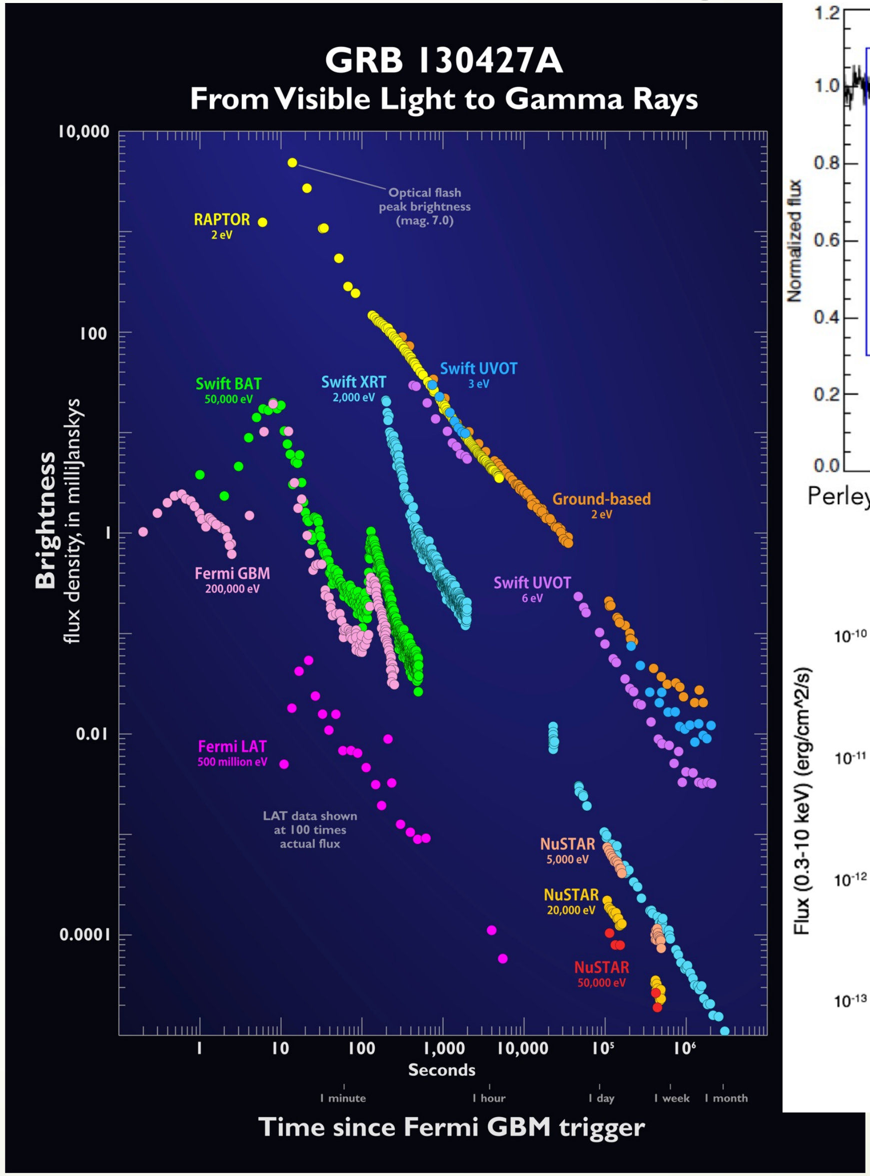
- Major discovery (GRB 970228) by the Italian-Dutch BeppoSAX satellite: GRBs are followed by long term declining X-ray emission; well localized
- This led to the discovery of optical afterglows and finally of GRB host galaxies
- Measured (spectroscopic and photometric) redshifts between ~0.1 and ~9.4
- EISO~10^{50}-10^{54} erg
- GRBs are powerful cosmic explosions

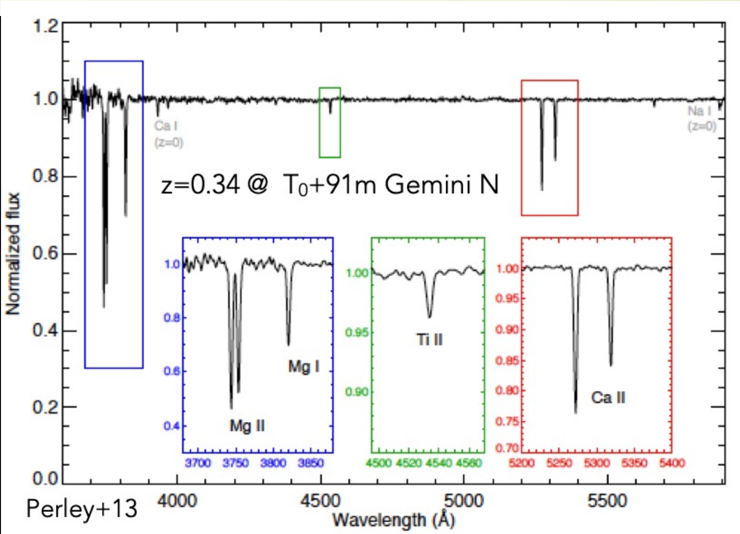


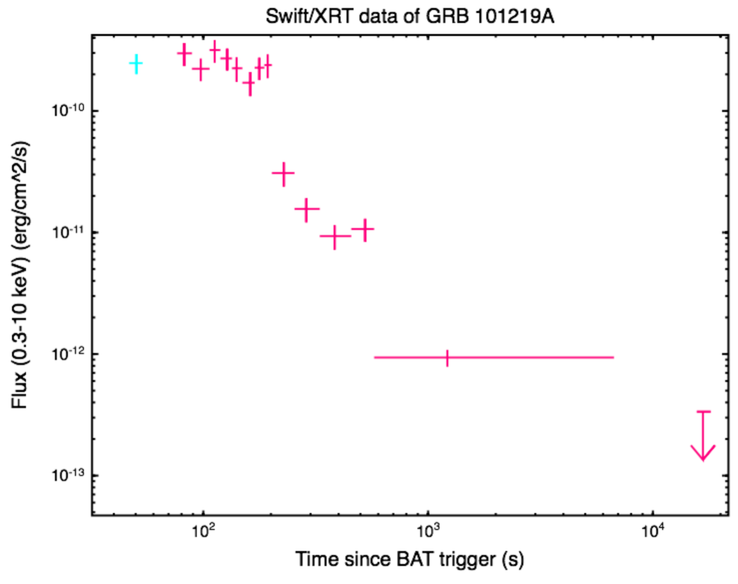


Gamma-Ray Bursts Afterglows

- GRB afterglows are panchromatic events
- They are detected from radio to GeV
- They show fast decline and variability
- Fast reaction is the key!
- Today mainly discovered and localized by Swift, Fermi, and INTEGRAL

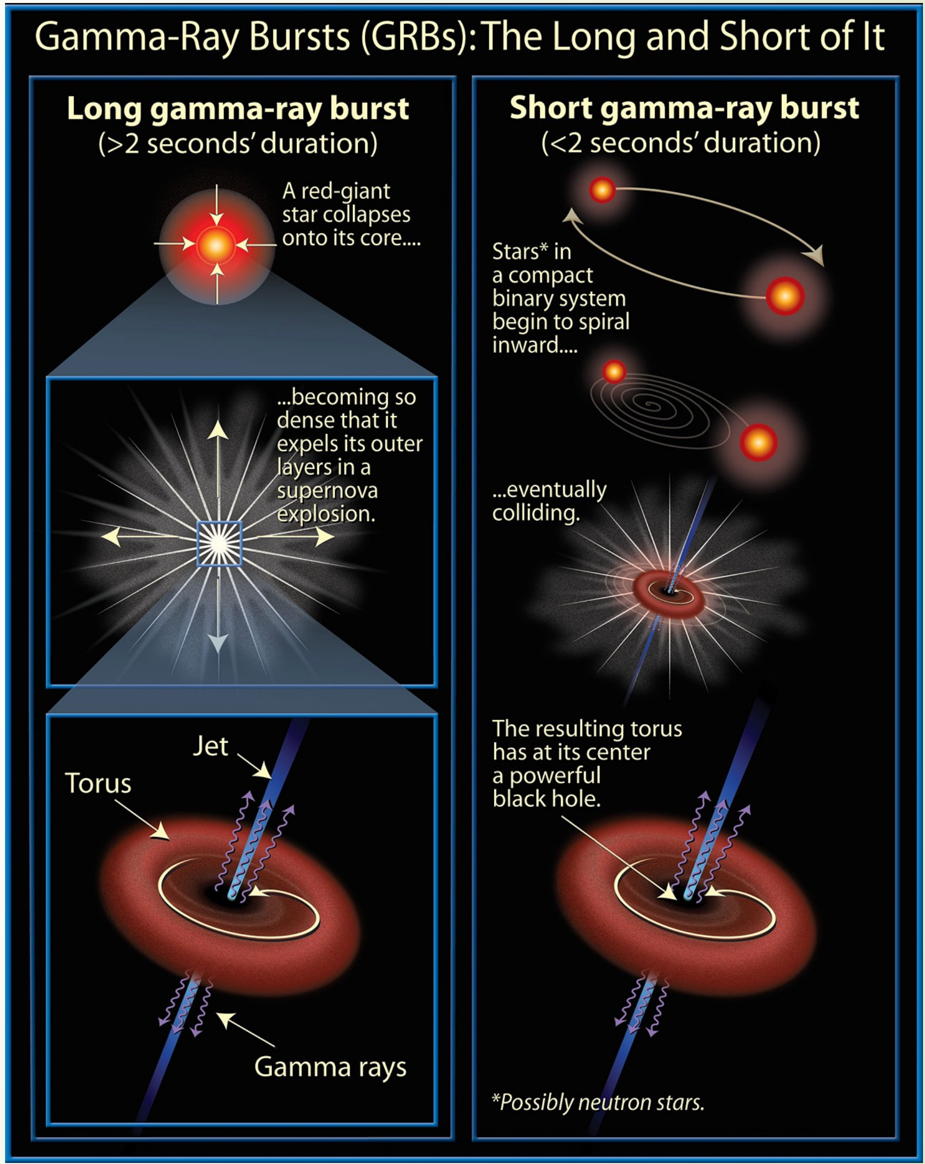




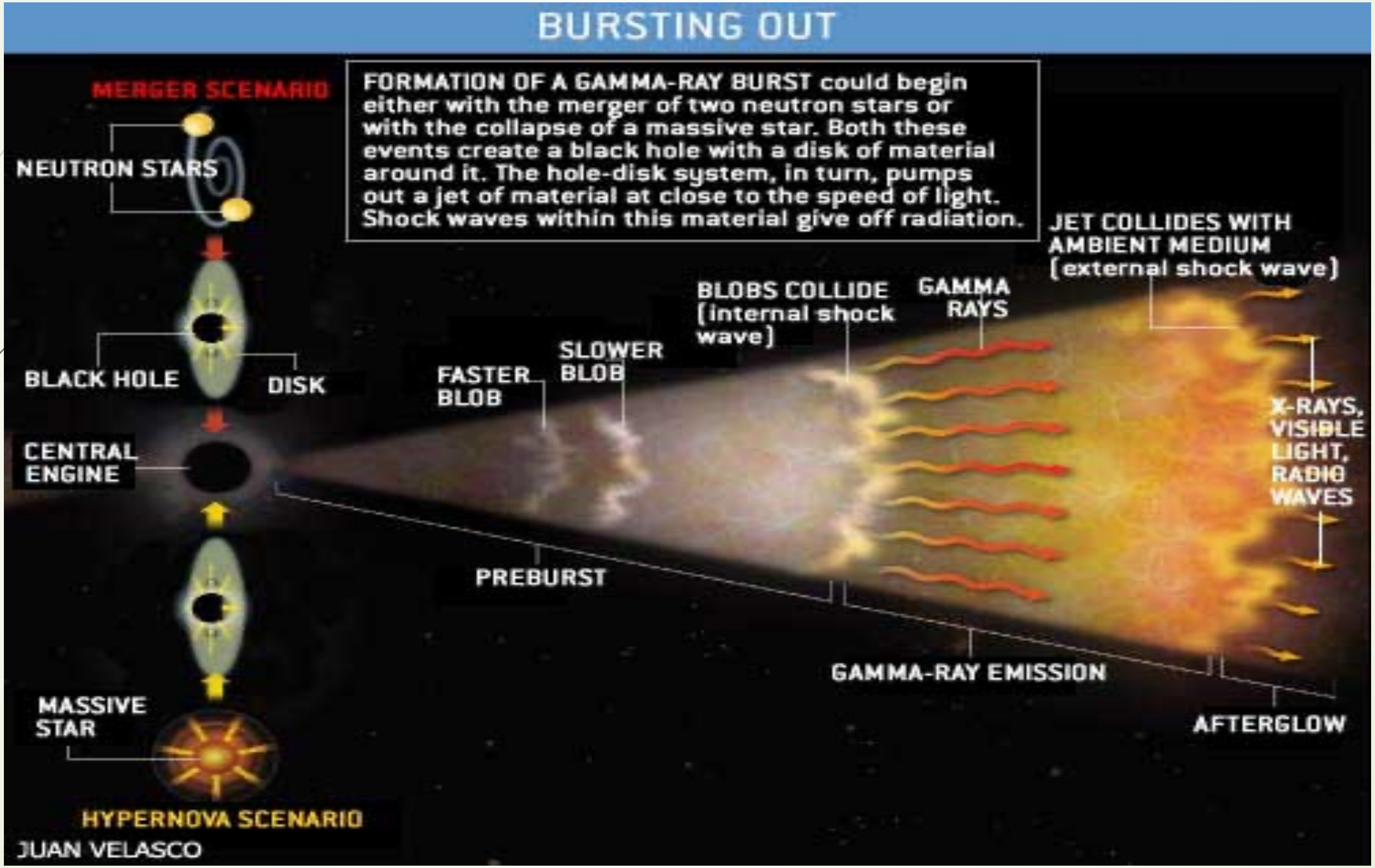


Gamma-Ray Bursts Models

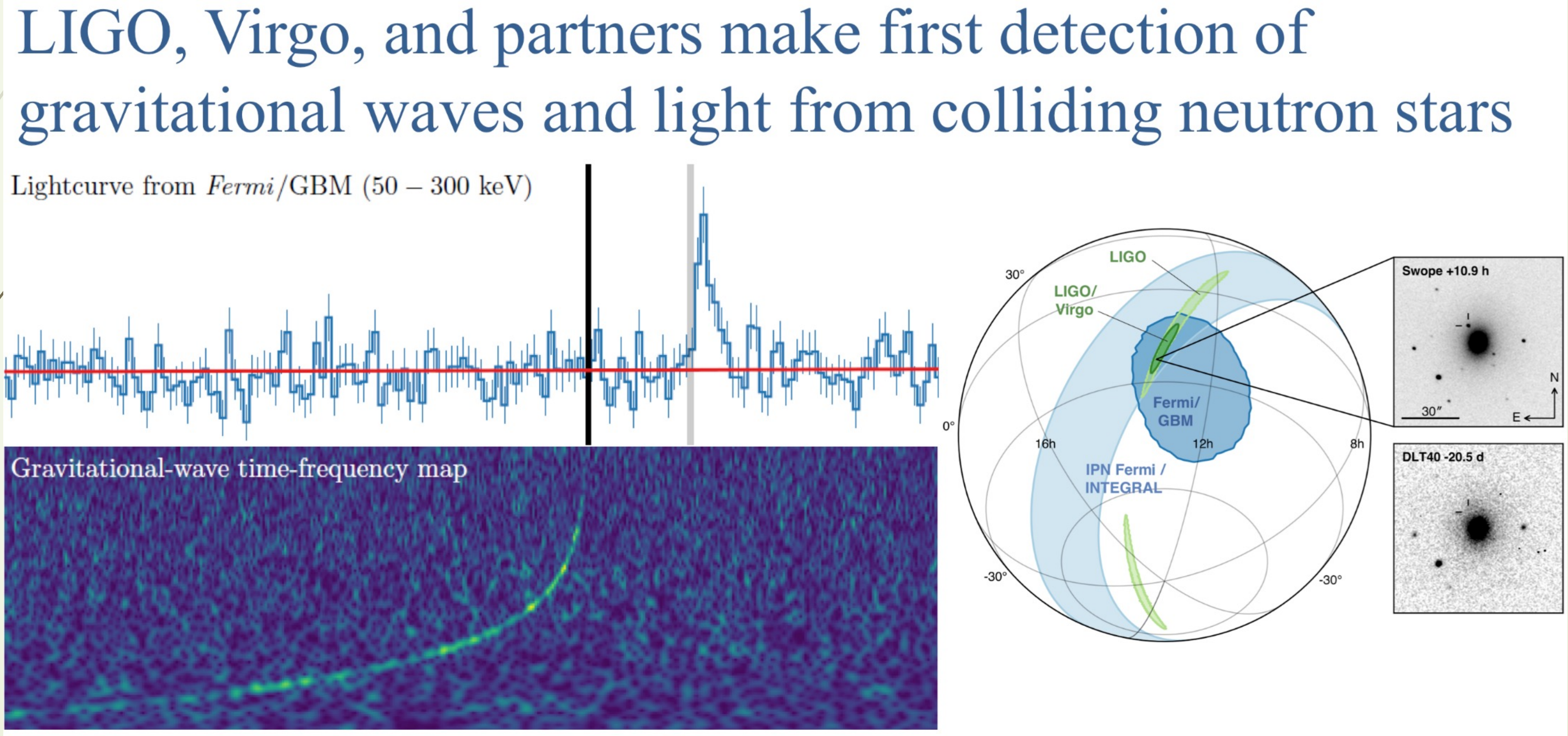
- Two distinct progenitors for the two classes
- Long GRBs are the endpoint of very massive (binary?) stars
  - Association to SN Ib/c for some GRBs confirms this scenario
- Short GRBs are associated with the merger of two compact objects: NS-NS, NS-BH,…
- The production of a relativistic jet is a common feature
- There is no consensus on the central engine: BH or Magnetar?



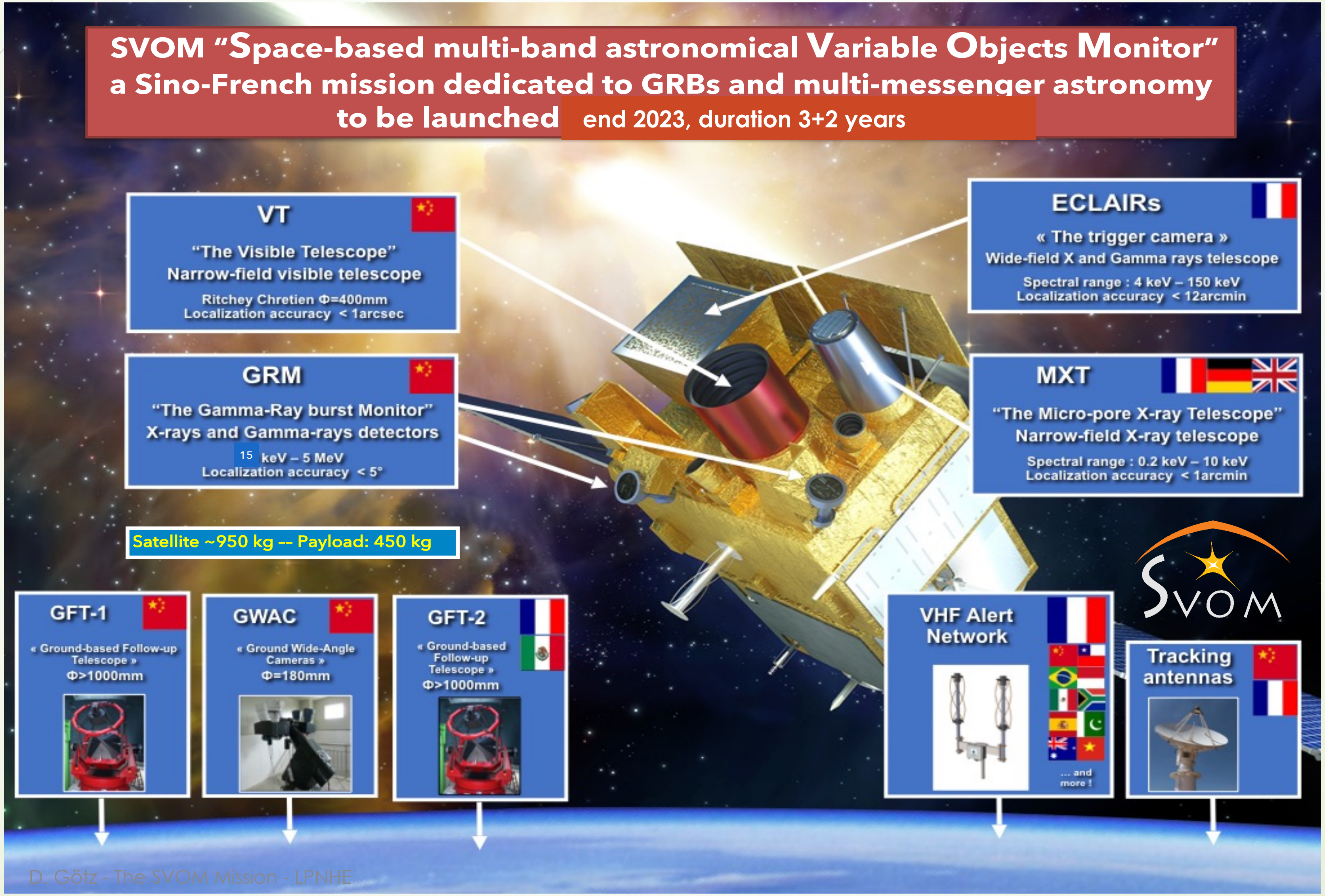
Gamma-Ray Bursts Models



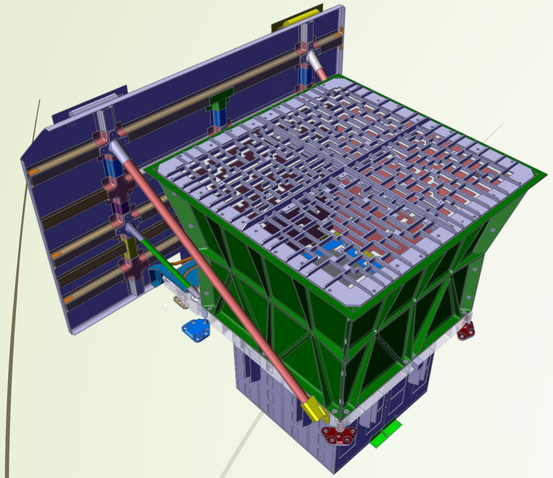
Short GRBs & Gravitational Waves: the 170817 event



Transient Astrophysics in the '20s, the SVOM example



INSTRUMENTS (with LARGE FIELD OF VIEW)

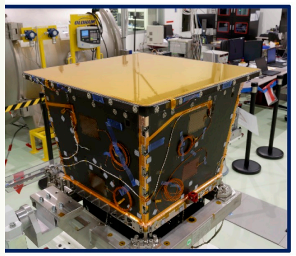


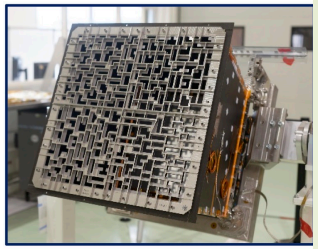
ECLAIRs (CNES, IRAP, CEA, APC)

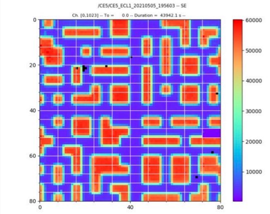
- 40% open fraction
- Detection plane: **1024 cm²**
- 6400 CdTe pixels (4x4x1 mm³)
- FoV**: 2 sr** (zero sensitivity)
- Energy range: **4** - 150 keV
- Localization accuracy **<12 arcmin** for 90% of sources at detection limit
- Onboard trigger and localization: **~65 GRBs/year**

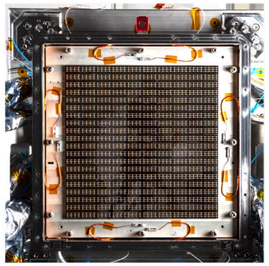
Well adapted for the detection of lGRB with low EPEAK

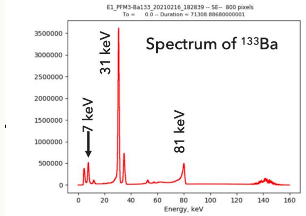
-> See Nicolas Dagoneau talk

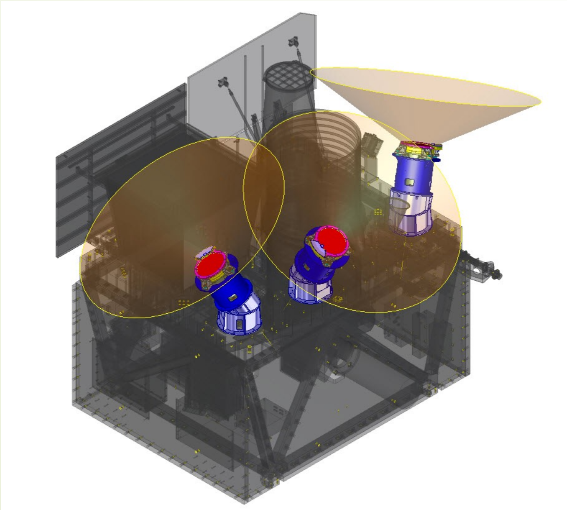










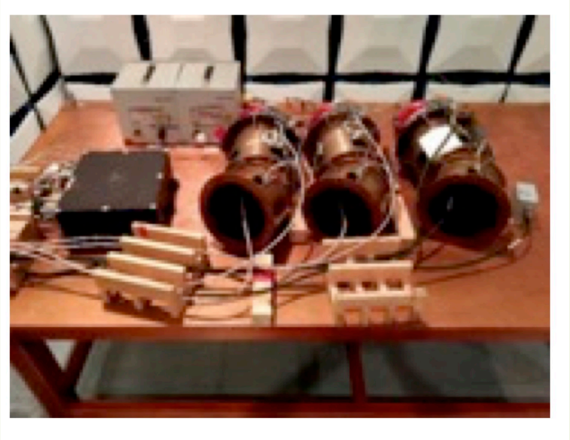


GRM Gamma-Ray Monitor (IHEP)

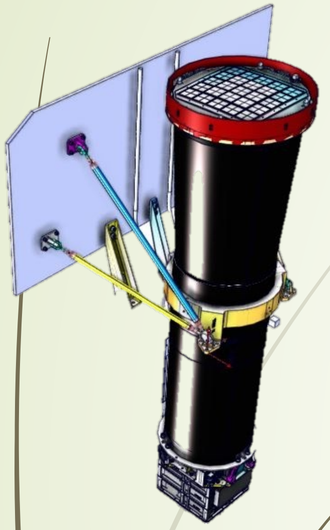
- **3 Gamma-Ray Detectors (GRDs)**
- NaI(Tl) (16 cm Ø, 1.5 cm thick)
- Plastic scintillator (6 mm) to monitor particle flux and reject particle events
- FOV: **5,6 sr** 3 GRDs, **1,0** intersection of 3 GRDs
- Energy range : 30-**5000** keV
- Aeff = **190 cm²** at peak
- Rough localization accuracy
- Expected rate: **~90 GRBs / year**

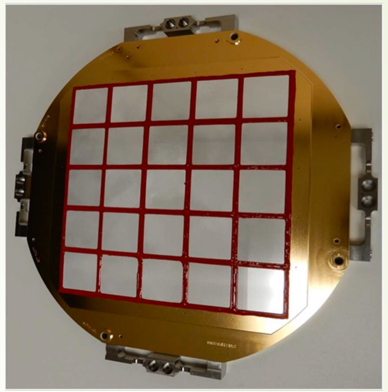
Will provide EPEAK measurements for most ECLAIRs GRBs

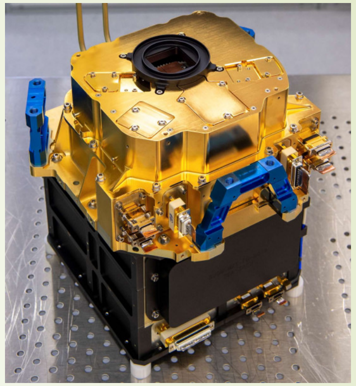
Will detect short GRBs in & out of the ECLAIRs FOV



INSTRUMENTS (with NARROW FIELD OF VIEW)



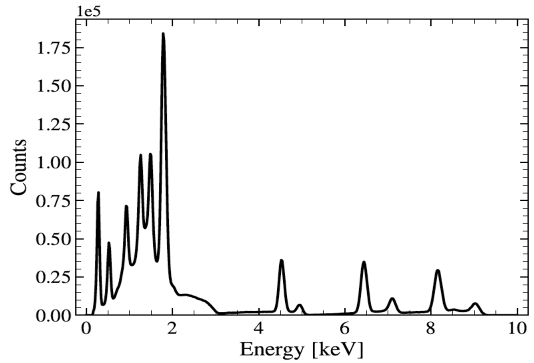


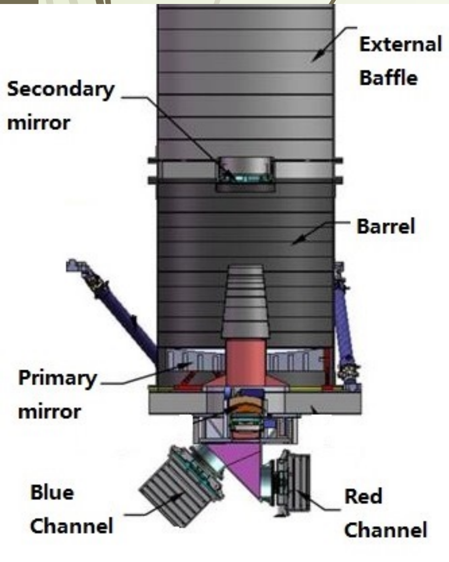


MXT Micro-channel X-ray Telescope (CNES, CEA, UL, MPE, IJClab)

- **Micro-pores optics (Photonis) with 40 µm square pores in a "Lobster Eye" conf. (UL design)**
- pnCCD (MPE) based camera (CEA)
- FoV : **58x58 arcmin²**
- Focal length: 1.15 m
- Energy range : 0.2 – 10 keV
- Aeff = **38 cm² @ 1 keV**
- Energy resolution: ~80 eV @ 1.5 keV
- Localization accuracy **<60 arcsec** within 5 min from trigger for 50% of GRBs (statistical error only)

Implements innovative focusing X-ray optics based on « Lobster-Eye » design
Will reduce the ECLAIRs error box
Will be able to promptly observe the X-ray afterglow

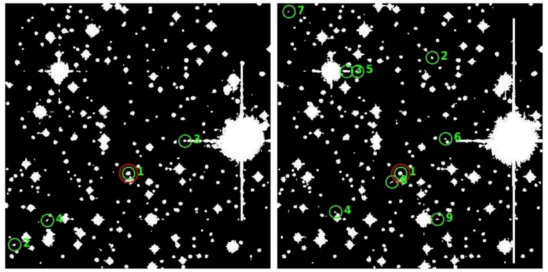




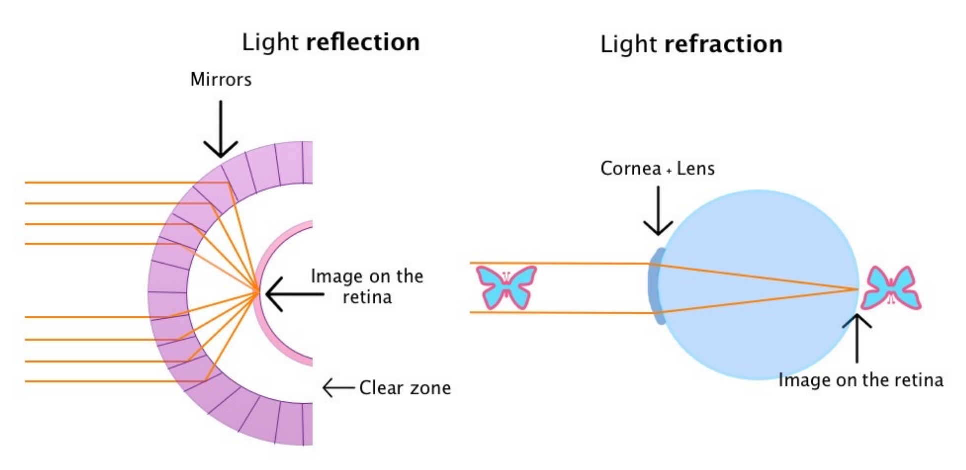
VT Visible Telescope (XIOMP, NAOC)

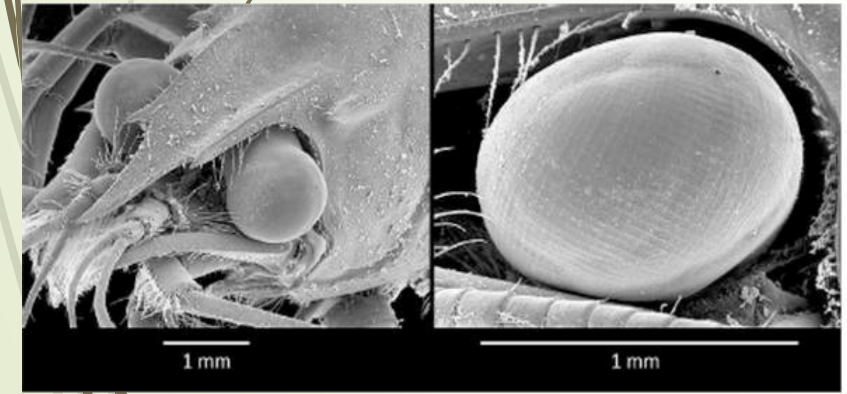
- Ritchey-Chretien telescope, 40 cm Ø, f=9
- FoV: **26x26 arcmin²**, covering ECLAIRs error box in most cases
- **2 channels: blue (400-650 nm) and red (650-1000 nm), 2k * 2k CCD detector each**
- **Sensitivity MV=23 in 300 s**
- Will detect ~80% of ECLAIRs GRBs
- Localization accuracy **<1 arcsec**

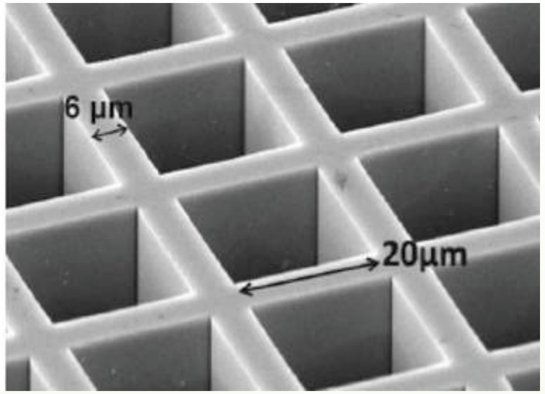
Able to detect high-redshift GRBs up to z~6.5 (sensitivity cutoff around 950 nm)
Can quickly provide redshift indicators due to the presence of two channels

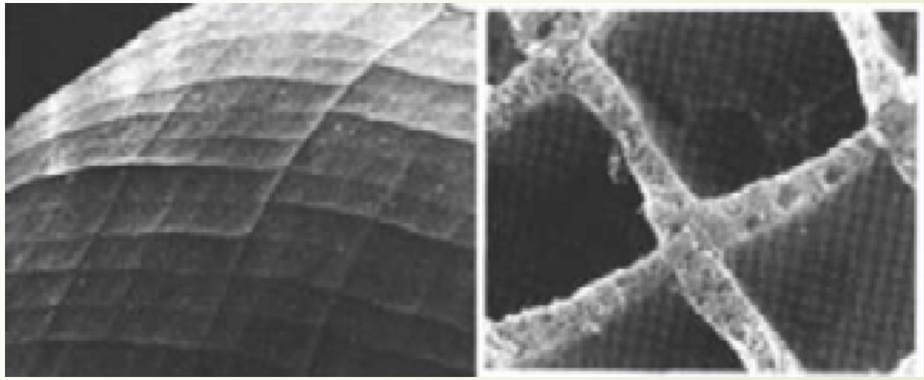


Lobster Eye telescopes









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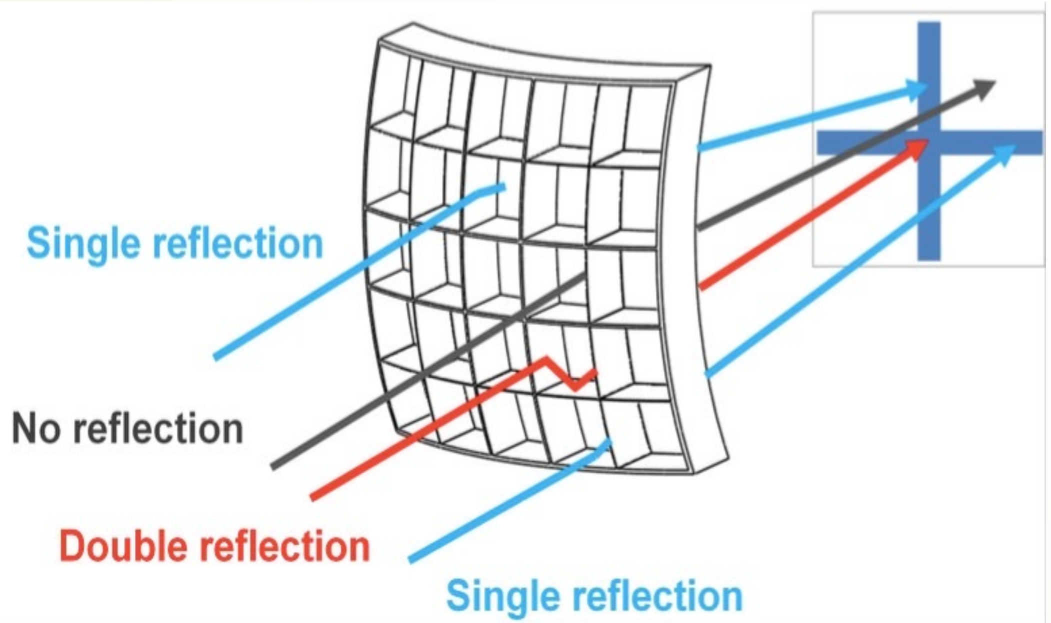

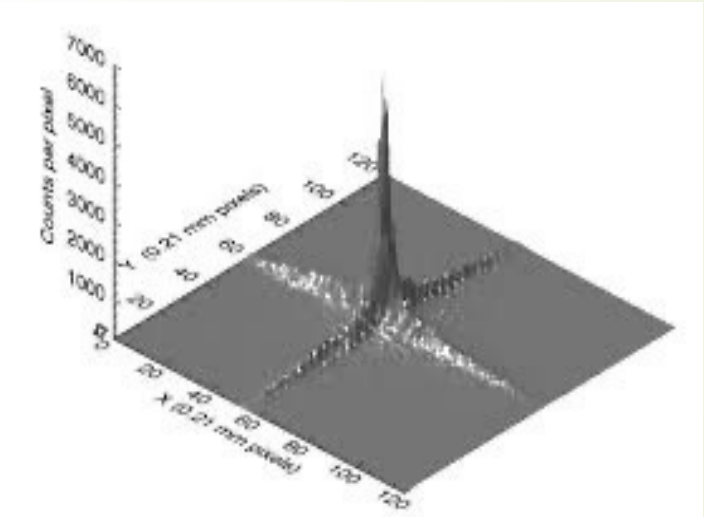

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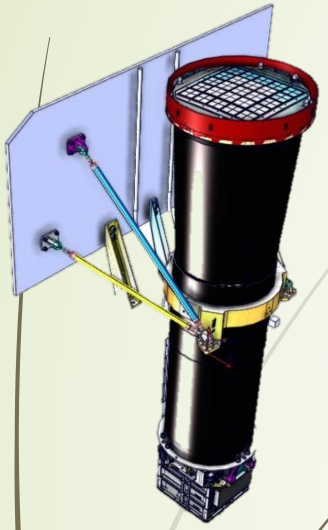

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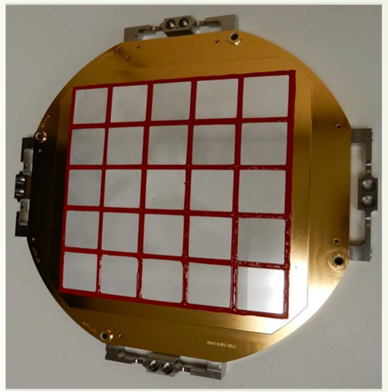

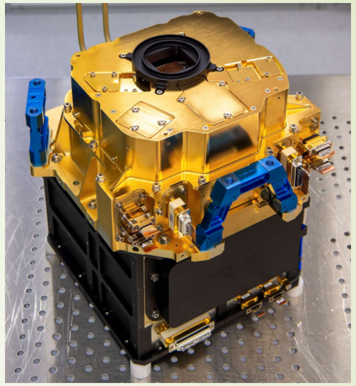

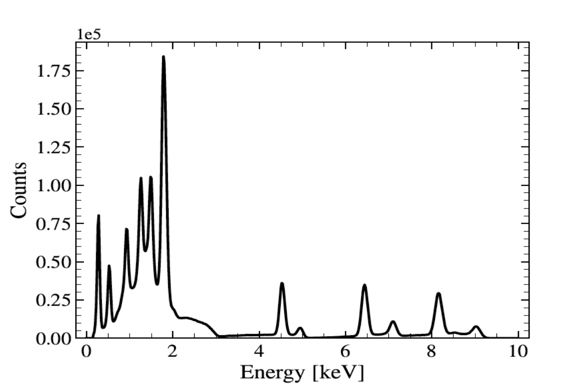

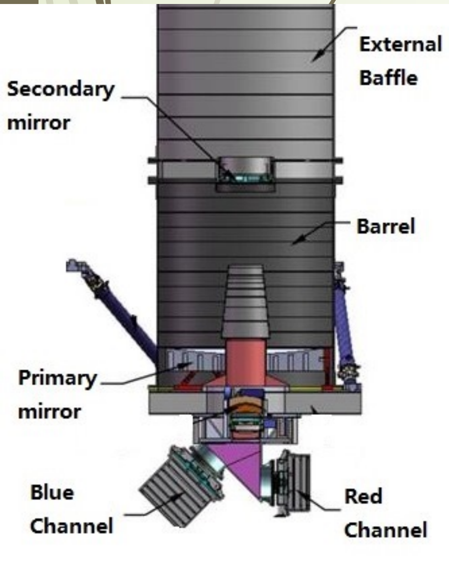

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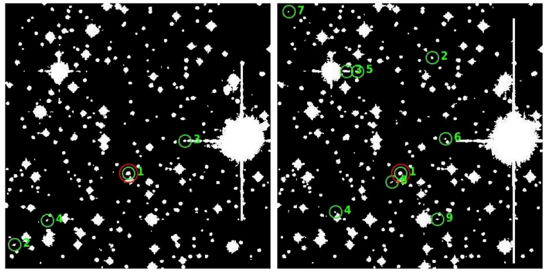


SVOM Ground Segment

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 to the LCOGT network (12x1m+2x2m tel.)

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

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

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

GWAC

GWAC Ground-based Wide Angle Camera

Installed in China at Xinglong & Muztagh Ata observatories

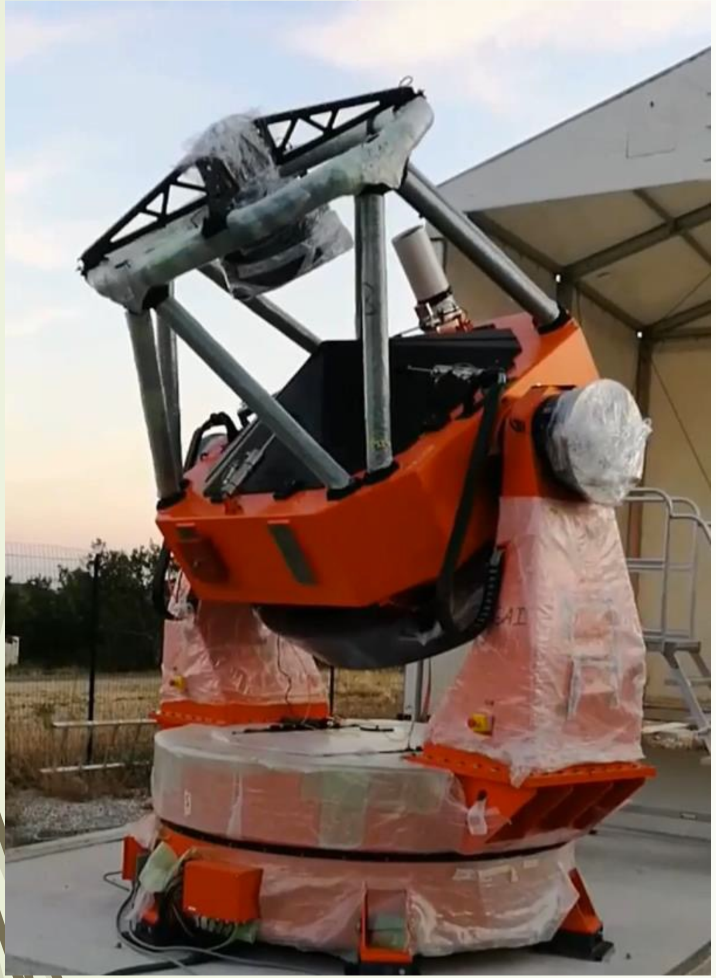
Two sets of **20** cameras of 180 mm diameter

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

Limiting magnitude 16 (V,10s)

- GWAC covers about **75%** of the ECLAIRs FOV when it is observable
- GWAC will scan the entire accesiible sky each night
- Self triggering capabilities: will be able to catch autonomously optical transients
- GWAC is in commissioning phase, shoild be ready to follow-up the LIGO/Virgo 04 run

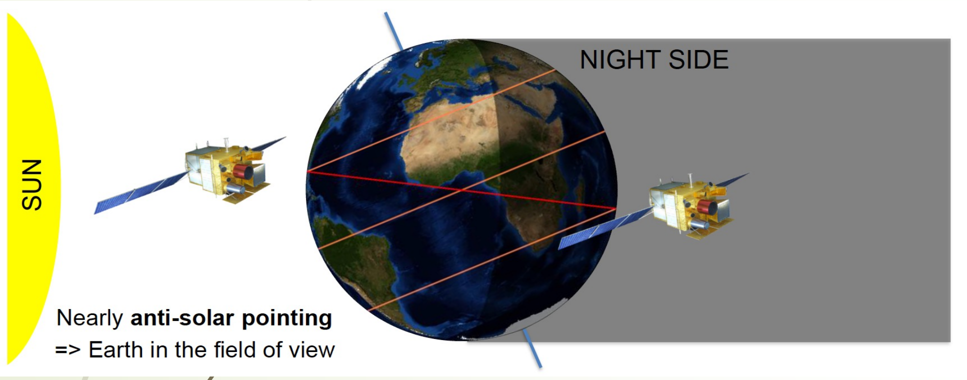
SVOM: the GFTs

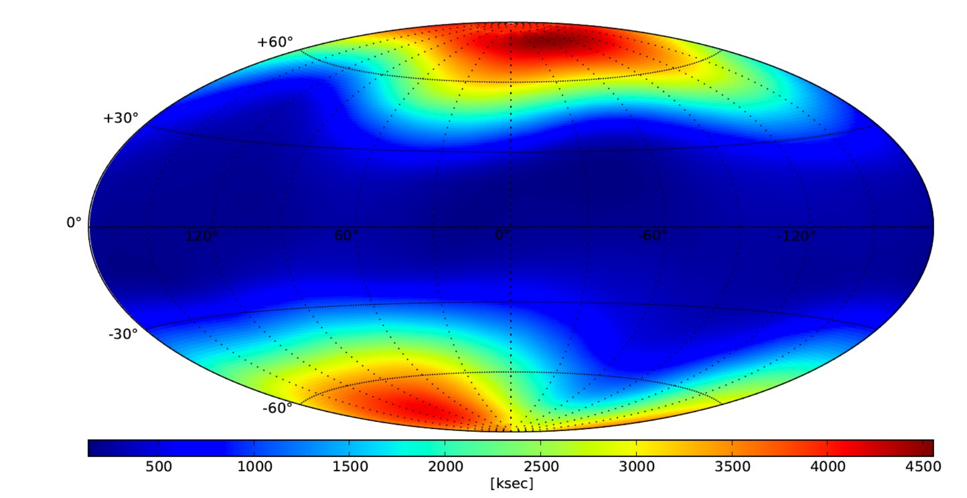


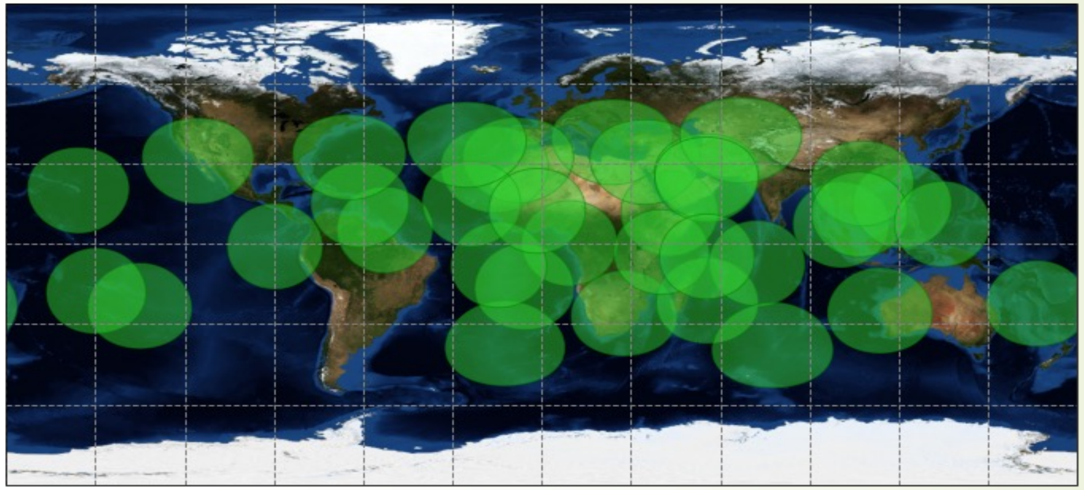
Colibri being tested at Haute-Provence Observatory ←

The Chinese GFT at Jilin Observatory →

SVOM: the pointing strategy and alert dissemination







Fast alert dissemination [VHF + redundancy on Beidou for short messages]

A nice fresco of of the station deployment is visible at:

https://www.svom.eu/#filter=.instrumentsarticle.portfolio219load

SVOM: three observing programmes

- Core Program (CP): GRB & HE transients detected by SVOM

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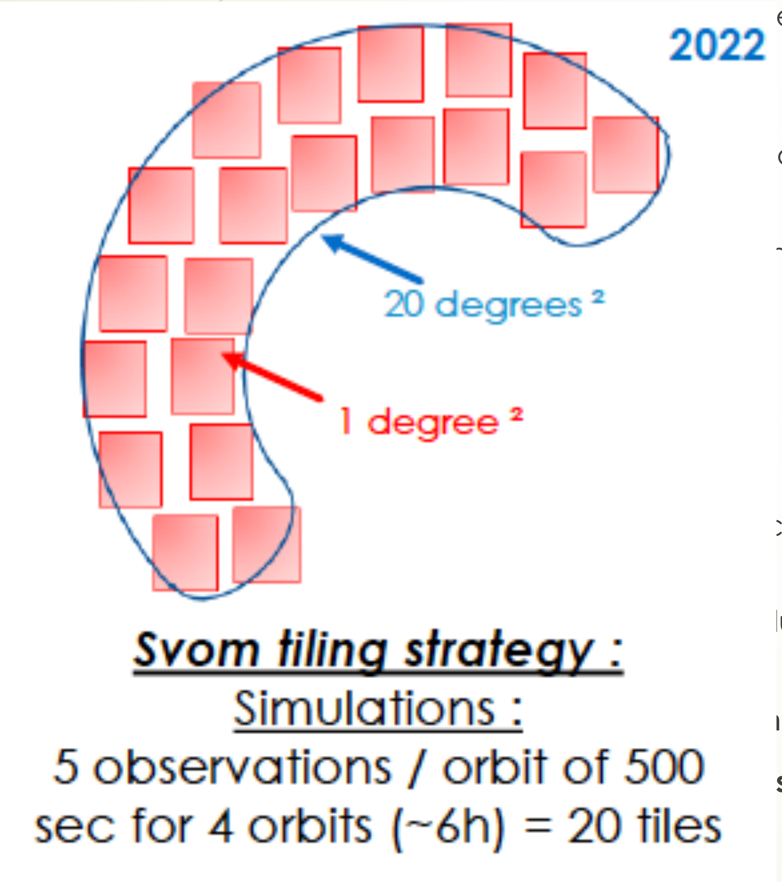
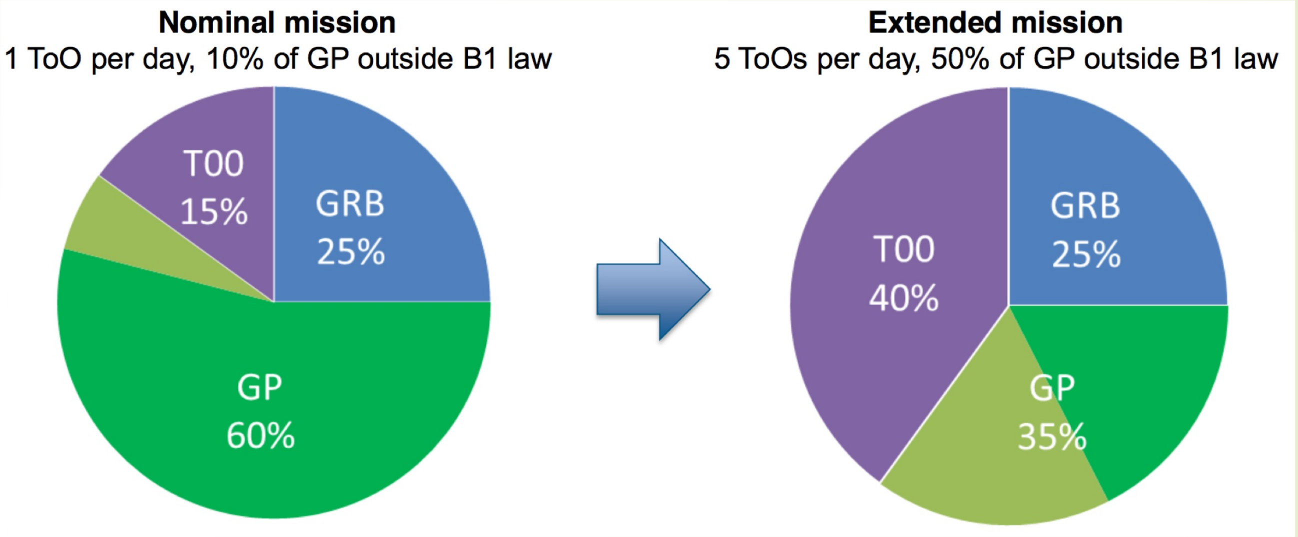
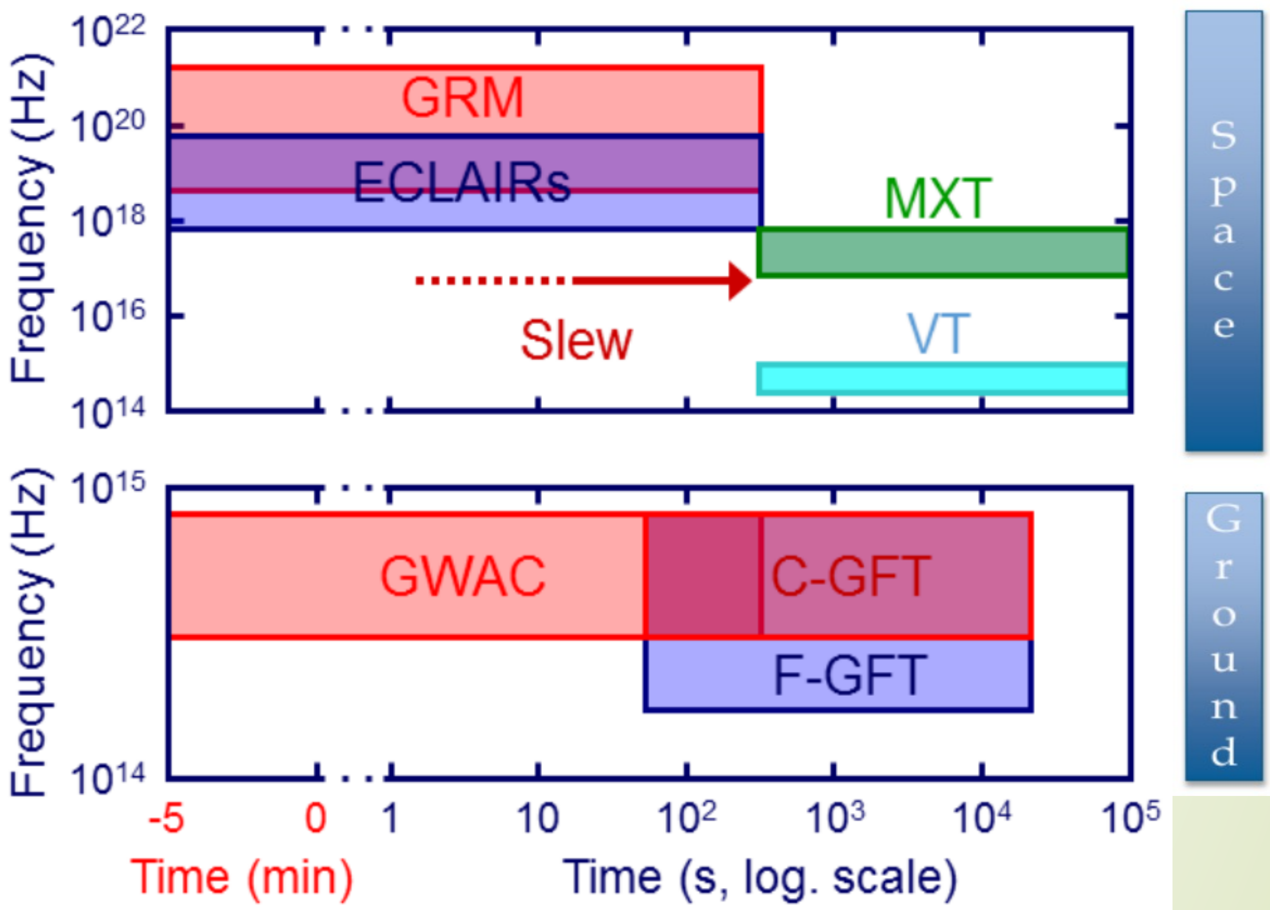




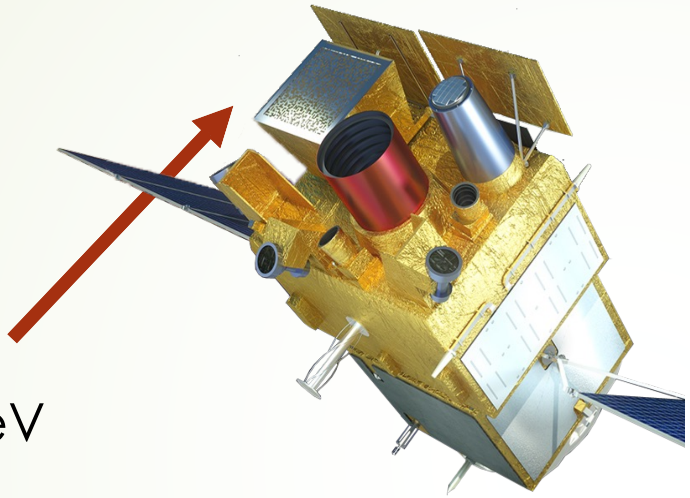
ToO	Approval	From acceptance /trigger	Frequency	Duration
ToO-NOM	ToO Sc.	<48h.	Max 1/day -> 5/day	1 orbit
ToO-EX	PI	<4h	Max 1/month	1-14 orbits
ToO-MM	PI	<4h	Max 1/week	14 orbits

The GRB core program

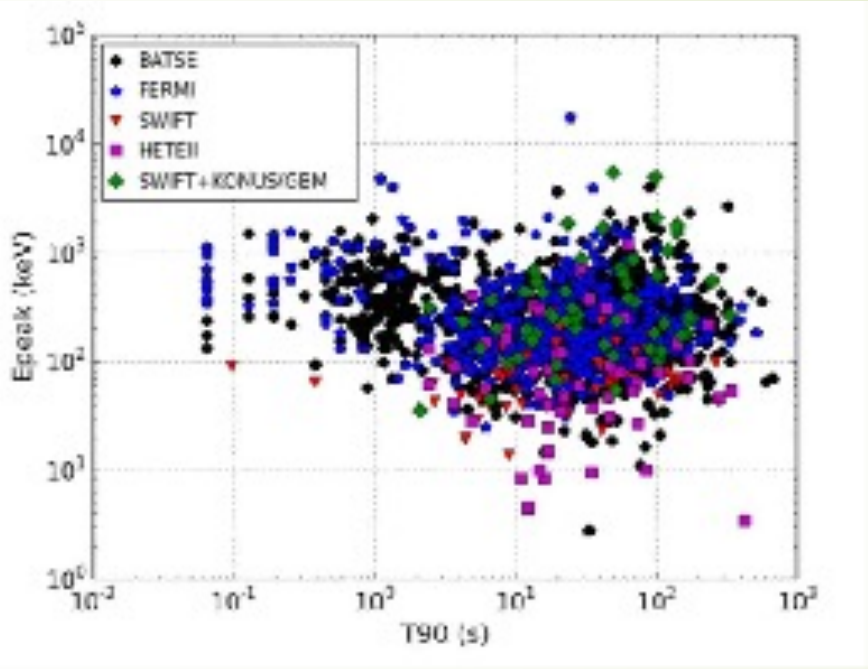
- Trigger and locate GRBs, alerts and localization distributed in real-time
- Optimized pointing strategy for ground-based follow-up
  - Synergy with other space and ground based facilities
  - Larger fraction of GRBs with Redshift
- Synergy btw 7 instruments in space and on ground for a multiwavelength follow-up
- Complete coverage of theG RB emission over 7 decades in energy from the trigger up to the late afterglow phase



The GRB detection

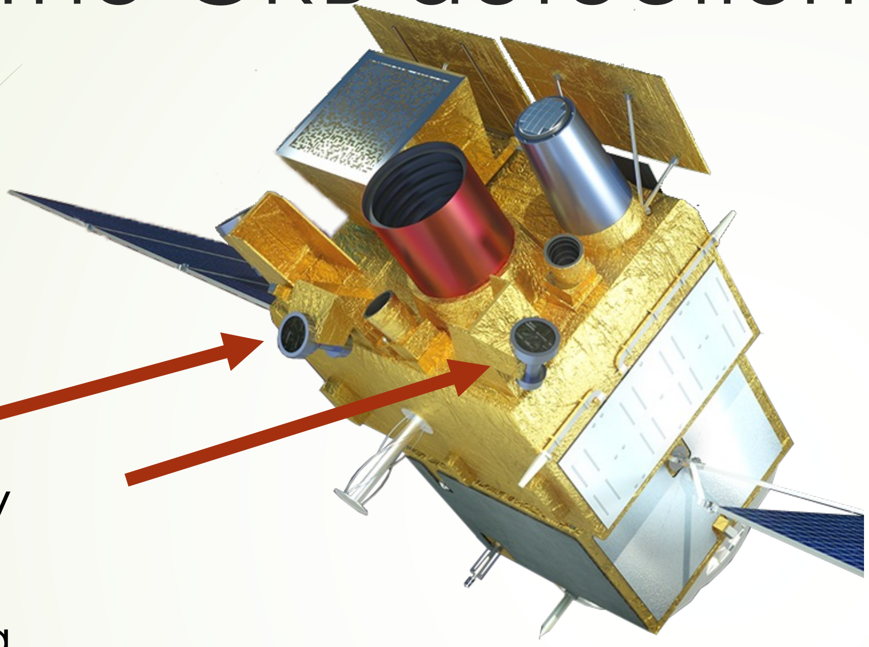


ECLAIRs
- 4-150 keV
- ~ 2 sr
- Loc. < 12'
- 42-80 GRBs/yr



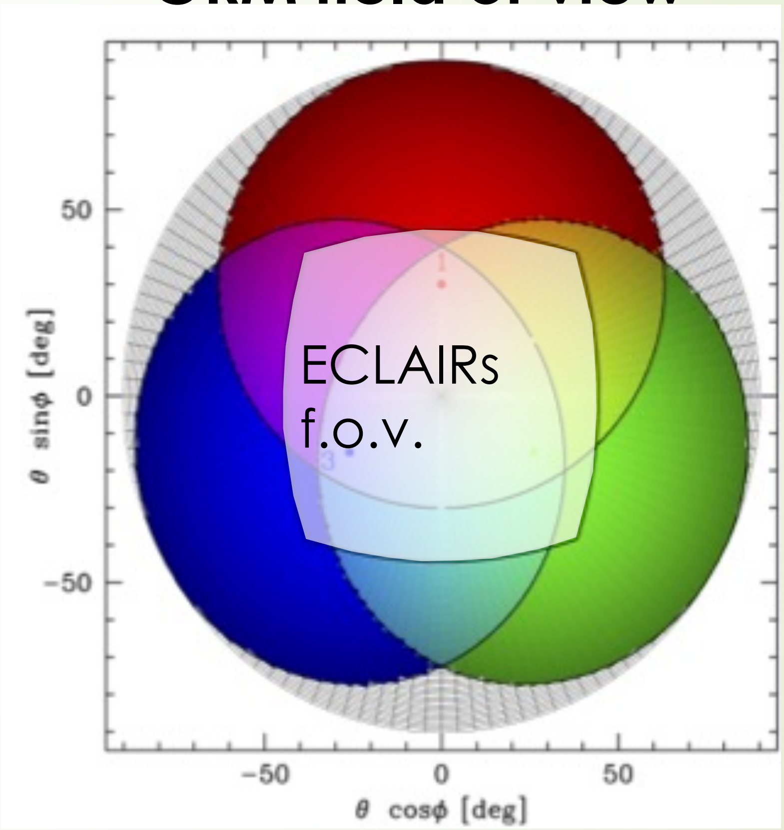
ECLAIRs is sensitive to all classes of GRBs:
- Classical long GRBs
- **Soft GRBs (XRR, XRF)**
- Short GRBs (but with a moderate efficiency)

The GRB detection



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

GRM field of view



GRM has a larger field of view than ECLAIRs
- GRM will have a slightly higher sensitivity to short GRBs than Fermi/GBM
- ECLAIRs sensitivity to short GRBs can be improved by combining ECLAIRs+GRM

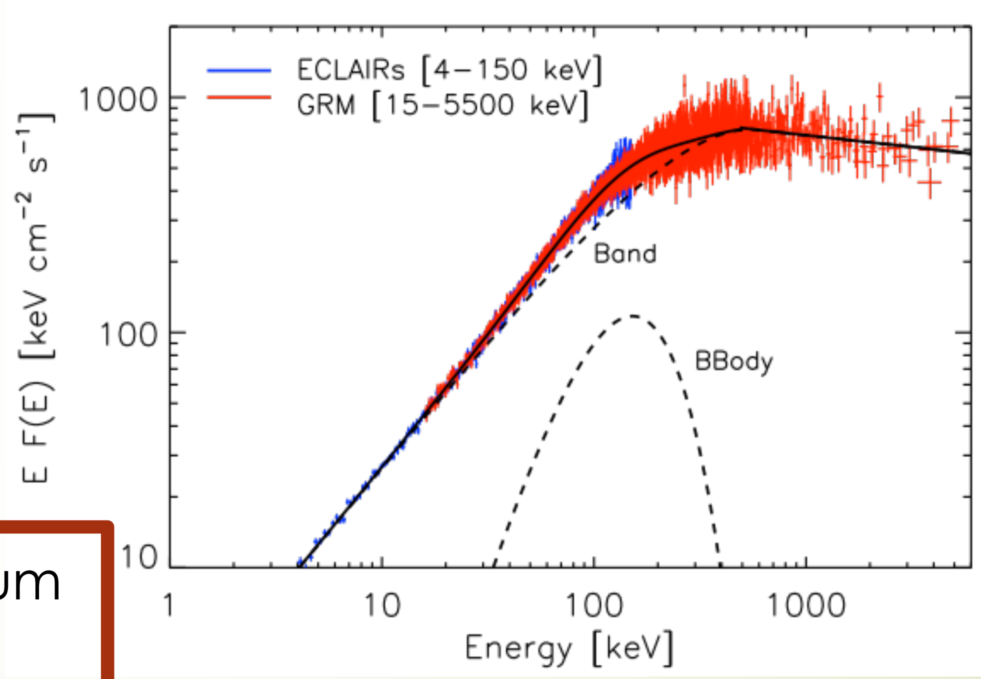
The GRB prompt emission

ECLAIRs+GRM:
- 4 keV - 5 MeV

+

GWAC:
- 2x5000 deg^2
- 500-800 nm
- m_{lim} ~ 16-17 (10s exposure)
- Prompt visible emission in ~16% cases

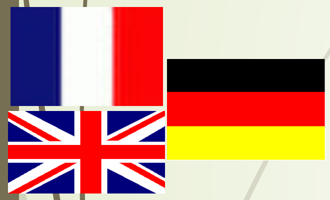
Multi-component spectrum of the Fermi burst GRB 100724B simulated in ECLAIRs+GRM.



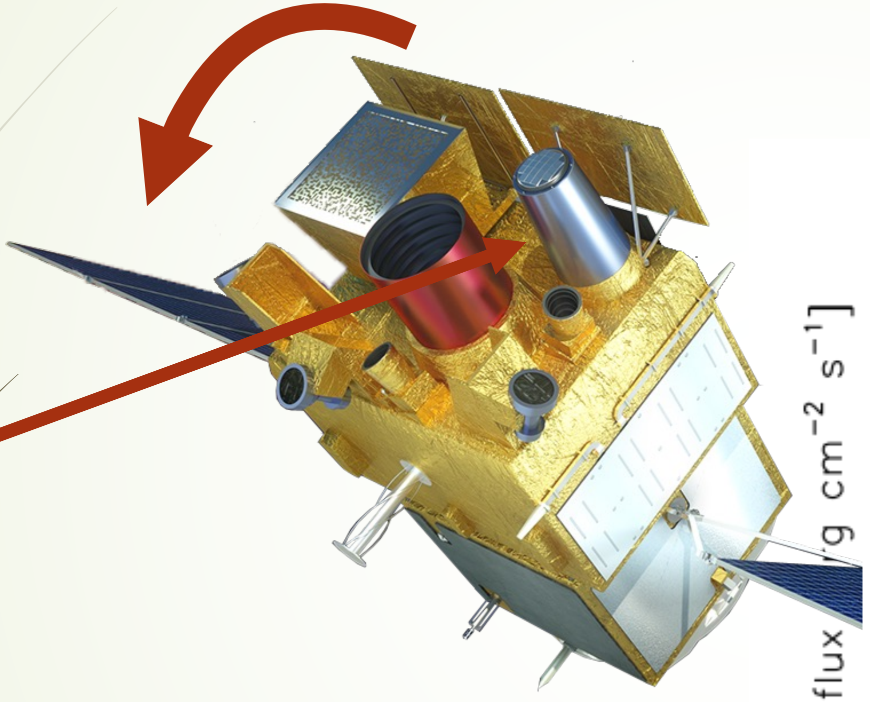
(Bernardini et al., 2017)

- ECLAIRs+GRM can 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.

The GRB follow-up

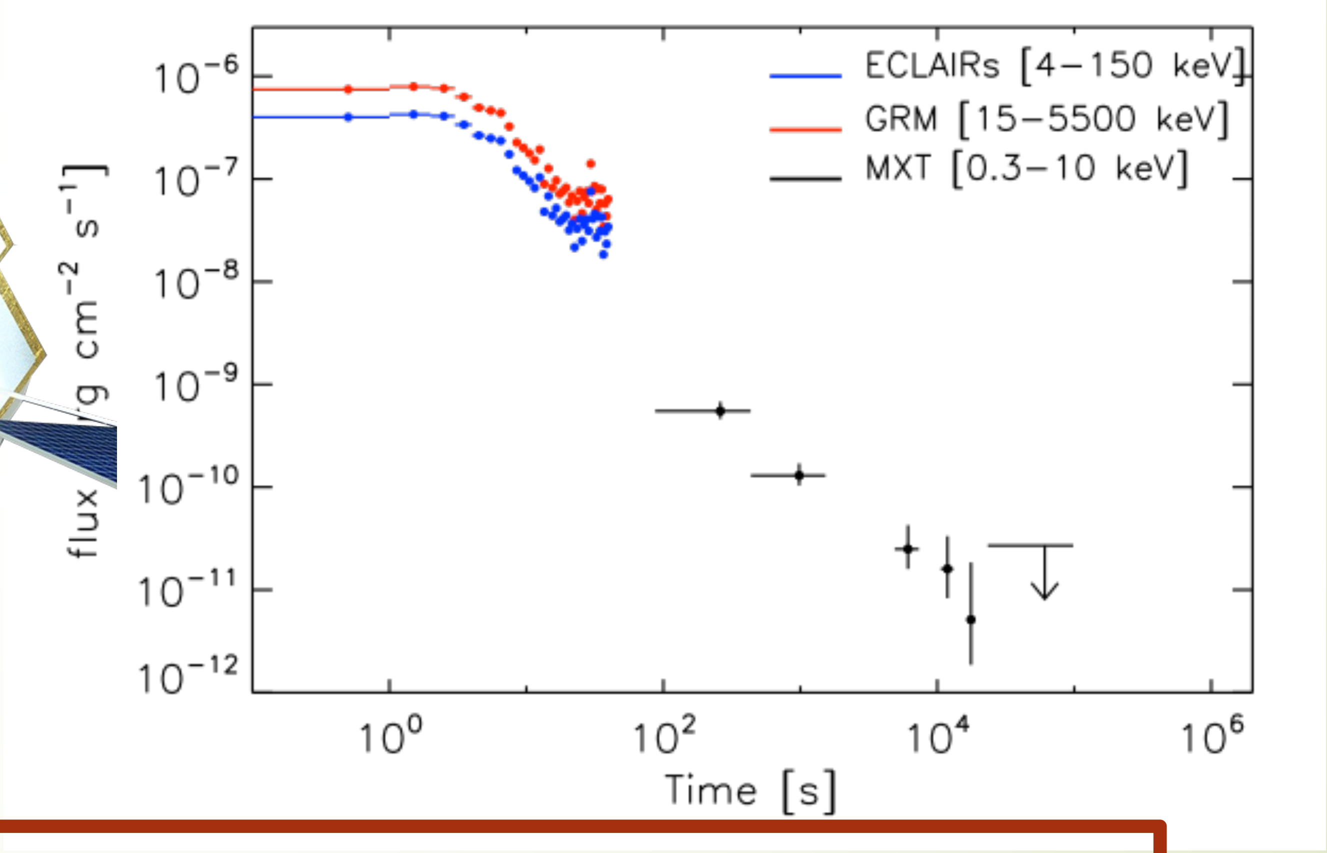


MXT:
- 0.2-10 keV
- 58x58 arcmin^2
- Loc. <60"



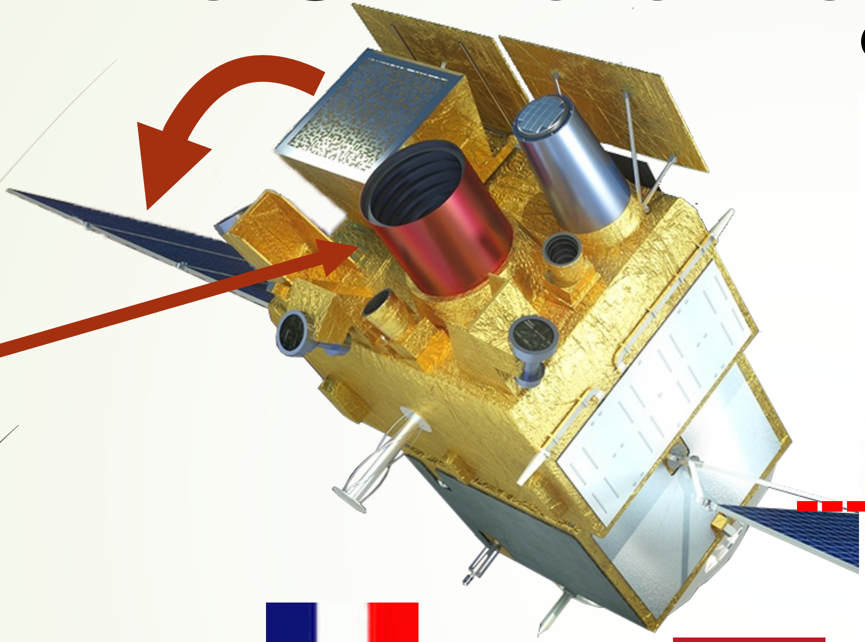
slew request: 36-72 GRB/yr

The X-ray afterglow of the Swift GRB 091020 simulated in MXT



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"

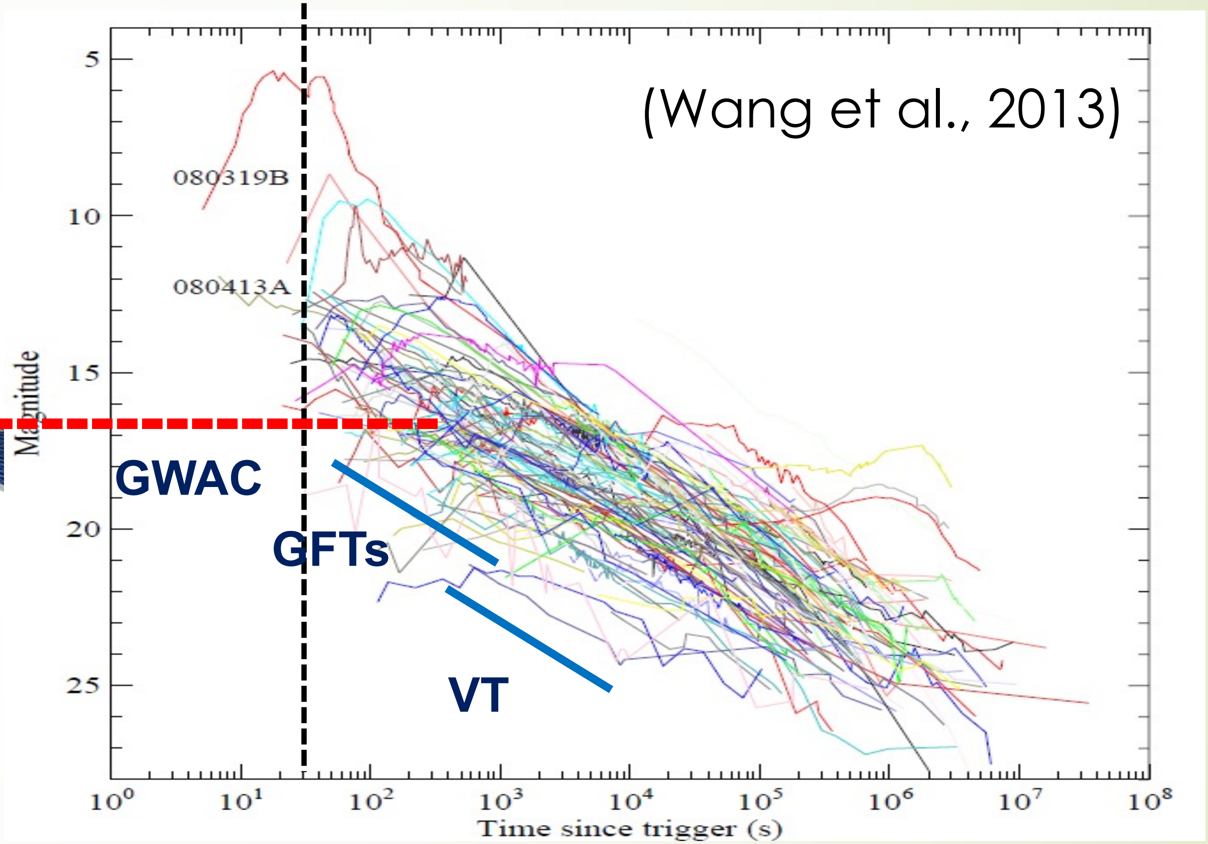
+

GWAC:
- 2x5000 deg²
- 500-800 nm

F-GFT:
- 1.3 m
- 400-1700 nm

C-GFT:
- 1.2 m
- 400-950 nm

Optical Lighcurves of long GRBs



- VT + ground segment will detect, localize and characterize the V-NIR afterglows (lightcurve+photo-z)
- Early observations by large telescopes are favored by pointing strategy
- Redshift measurement is expected in ~2/3 of cases

The SVOM GRB sample

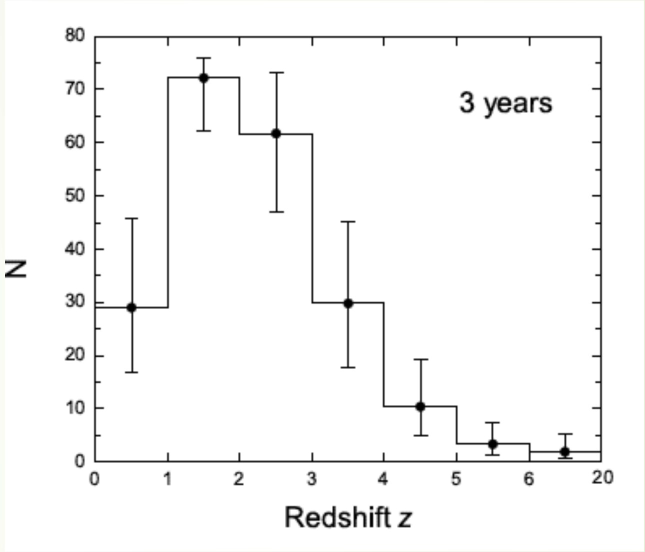
A unique sample of **30-40 GRB/yr** with:
- **prompt emission** over 3 decades (+ optical flux/limit: 16%)
- X-ray and V/NIR **afterglow**
- **redshift**

	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**

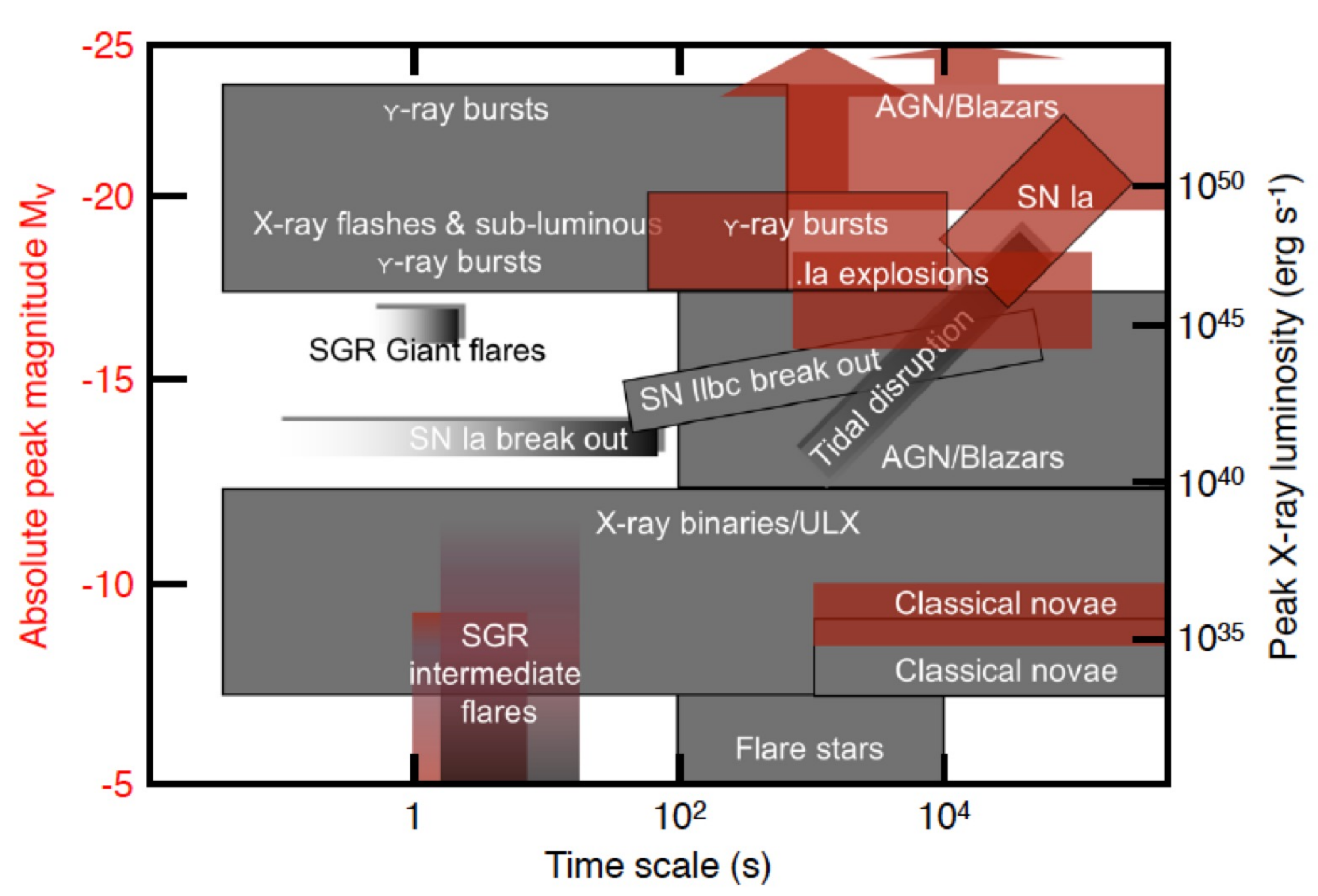
- **Physical mechanisms at work in GRBs**
  - Nature of GRB progenitors and central engines
  - Acceleration & composition of the relativistic ejecta
- **Diversity of GRBs: event continuum following the collapse of a massive star**
  - Low-luminosity GRBs / X-ray rich GRBs / X-ray Flashes and their afterglow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

The SVOM GRB sample

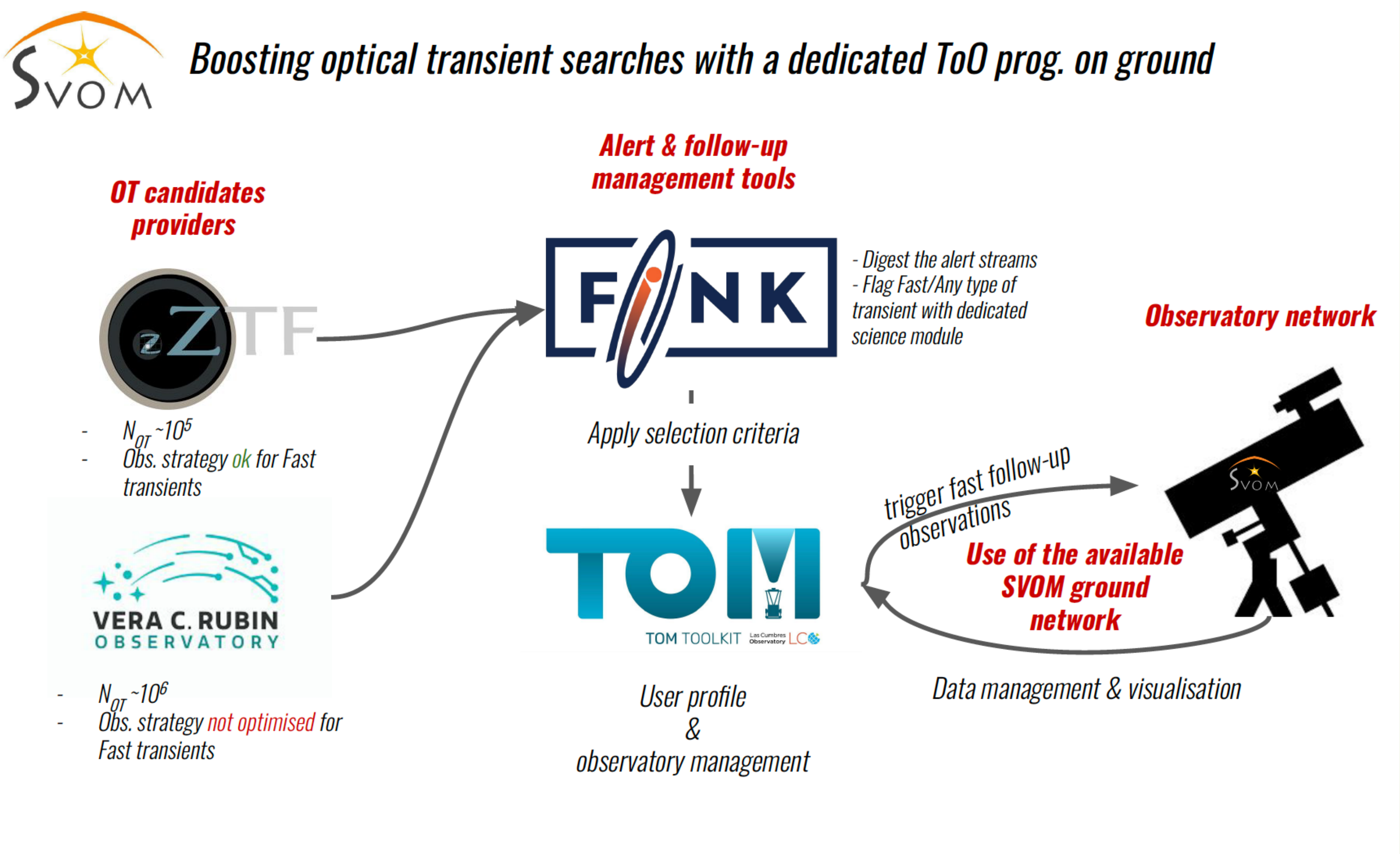
- Over the 3 yr lifetime of the mission, ECLAIRs is expected to be able to detect~200–230 GRBs.
- Nearly 4%–5% of ECLAIRs GRBs are expected to be high redshift GRBs (z >5)
- -> detection rate of about 3–4 GRBs/yr at z >5, including~2–3 GRBs/yr at 5 < z < 6 and~1 GRBs/yr at 6< z <7.
- We expect to rapidly identify candidate high-z bursts (VT non-detections + GTFs photo-z)
  - allow for rapid spectroscopic follow-up with JWST and medium to large ground based telescopes
  - better redshift completeness at high-z than has been possible for the Swift sample
- Thus, in the three year core mission, we expect to roughly double the current known sample of z > 6 GRBs, but, crucially, for most of these also to obtain much more precise measures of host luminosity, column density and metallicities.



Exploring the transient sky with SVOM

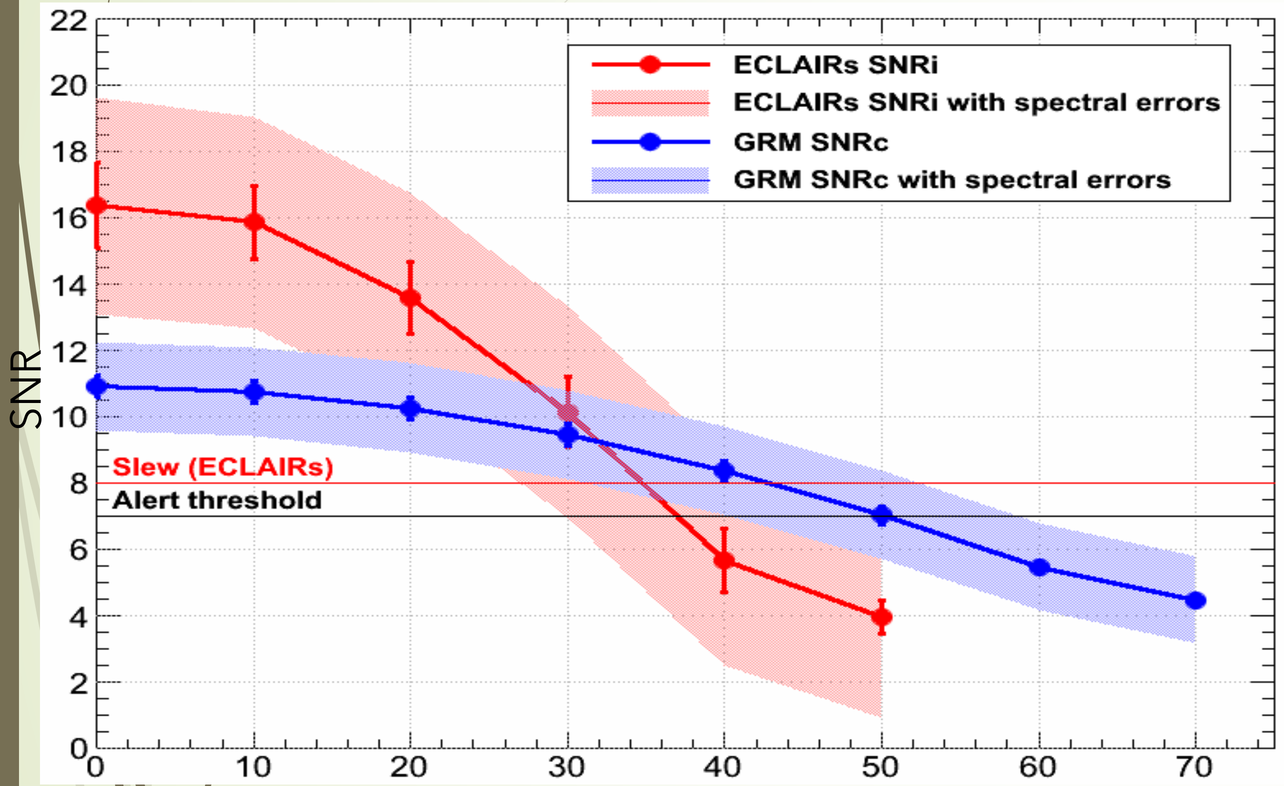


Exploring the transient sky with SVOM

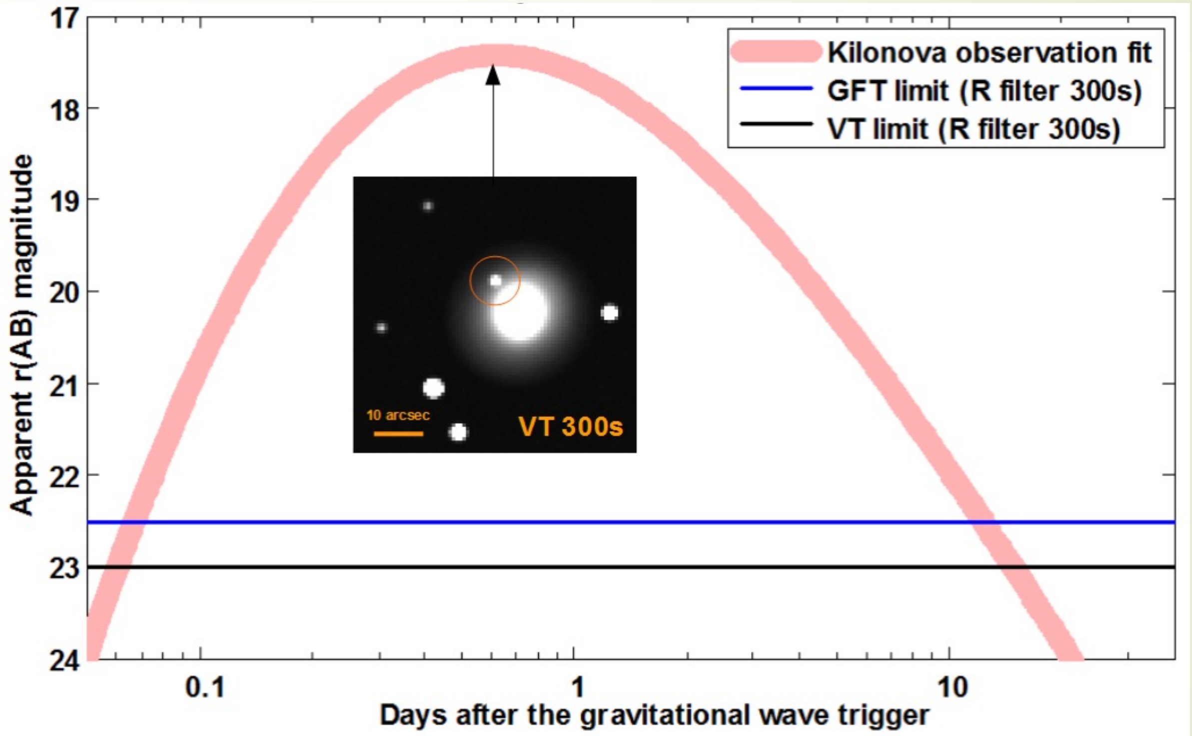


Courtesy D. Turpin

SVOM response to GW170817



Incidence angle θ with respect to ECLAIRs axis (°)



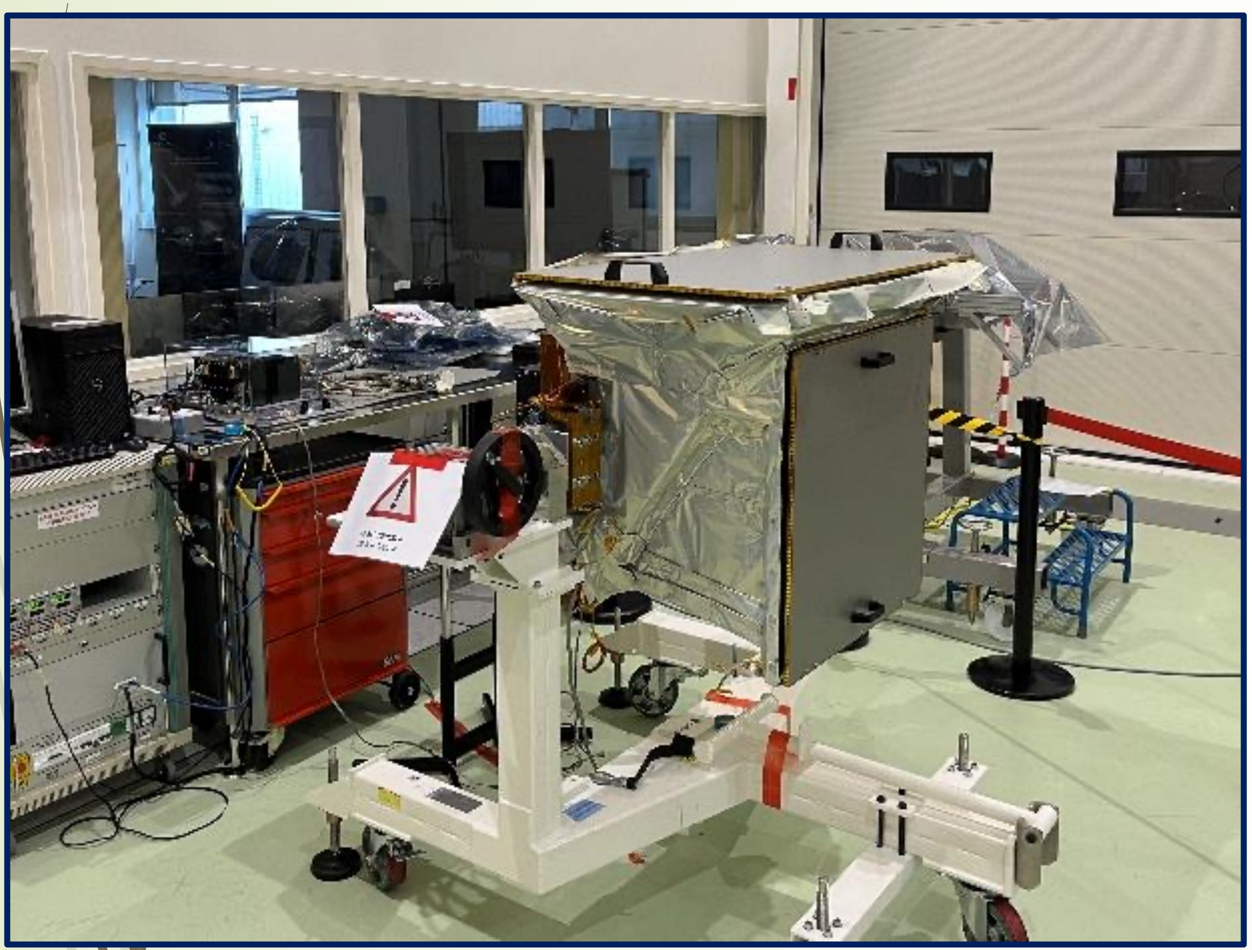
- Up to **35° off axis**: ECLAIRs triggers + alert is sent to the ground + slew is requested
- Up to **50° off-axis**: GRM triggers + alert is sent to the ground (with rough localization)

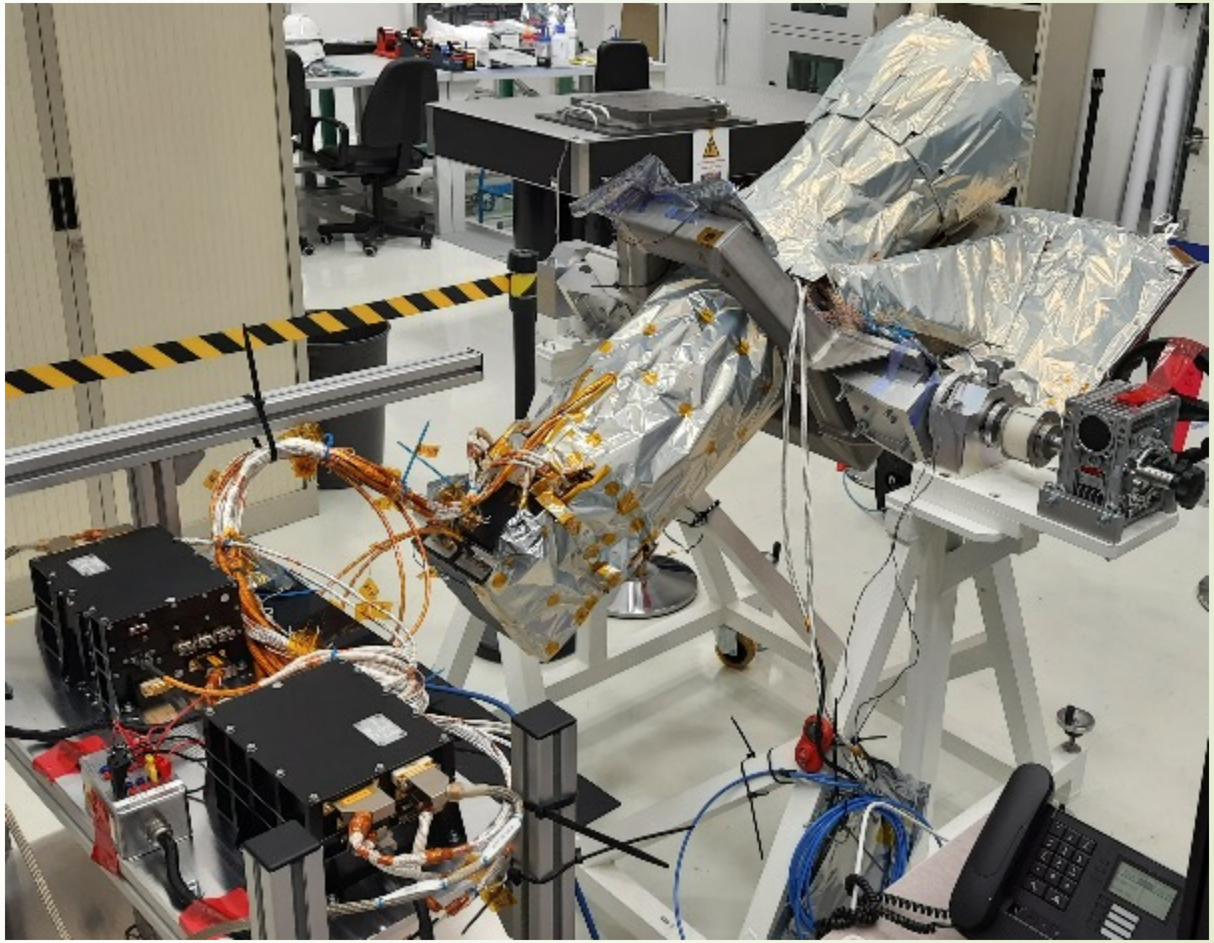
VT and GFTs have the capacity to detect the kilonova since T0+2h and follow it during 10 days

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 :
  - 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

SVOM Hardware status



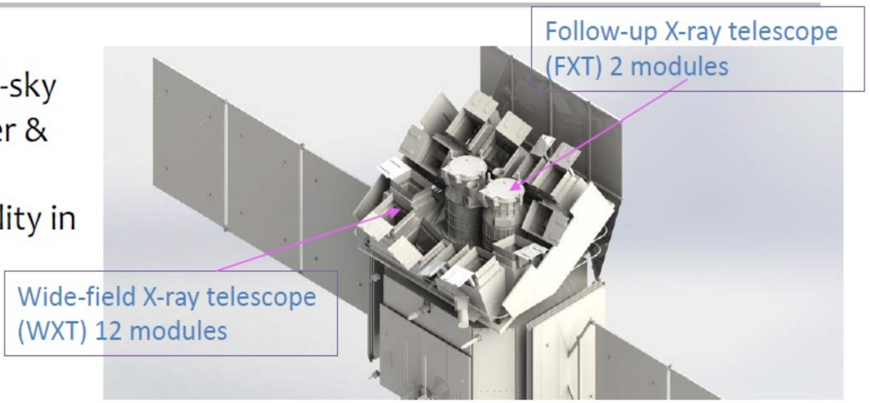


ECLAIRs and MXT flight models are ready to be delivered to China!

Panorama around SVOM: Einstein Probe

Einstein Probe (EP) mission

An observatory for all-sky monitoring to discover & study high-energy transients and variability in soft X-rays



The 1st X-ray monitoring observatory with *all* focusing instruments

- Field of View: 3600 sq. deg.; grasp: ~10,000 deg².cm² — 1 sr FOV
- Monitoring band: soft X-ray 0.5-4 keV
- Sensitivity: > 1 order of magnitude higher than those in orbit
- Good angular resolution: (~5 arcmin) and positioning accuracy (<1 arcmin)
- Autonomous 0.3-10keV X-ray follow-up within < ~ 3min (localisation <10 arcsec)
- Fast alert data downlink and fast uplink (ToO)

EP-WXT Pahtfinder, August 2022

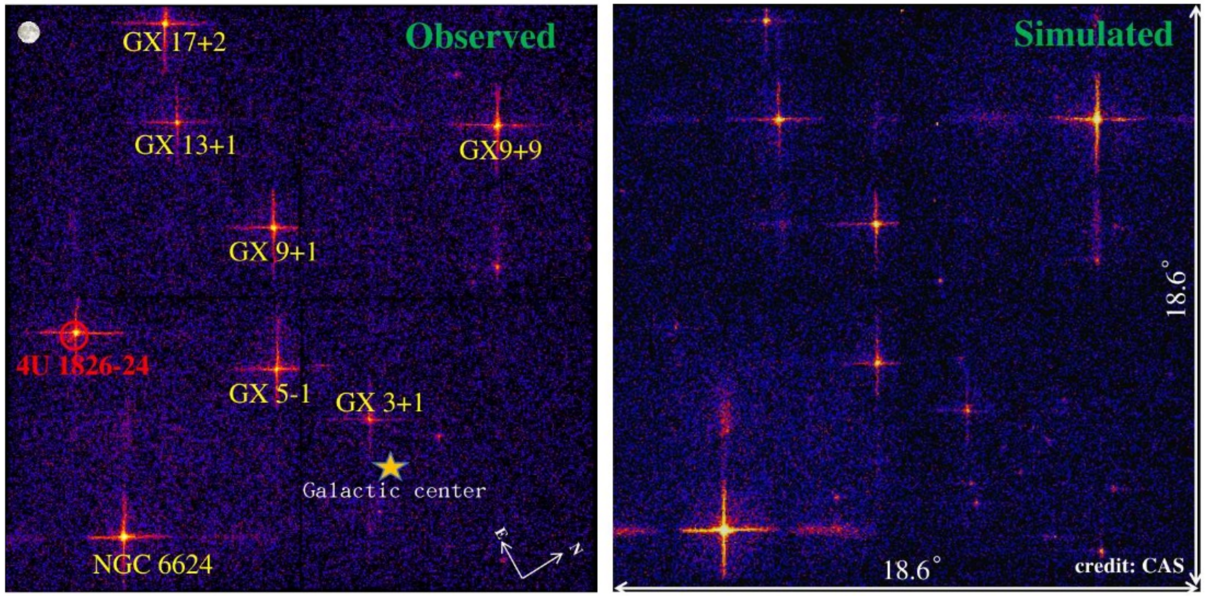
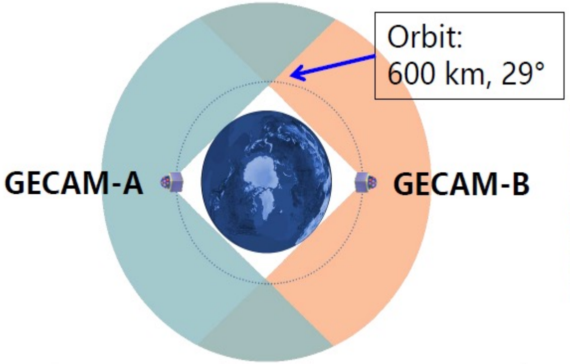


Figure 2: Comparison between the real observation (left) by EP-WXT Pathfinder and the simulated view (right) of the same patch of sky as given in figure 1. The real observation also identifies a source that had bec ome obviously much brighter than viewed at a previous observation, as indicated by the red circle on the left. At the upper-left corner of the left image the size of the full Moon is given for comparison. (Image credi t: CAS)

Panorama around SVOM: GECAM Network

GECAM

Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor



The design of GECAM constellation

- **Characteristics of GECAM**
  - **FOV:** 100% all-sky
  - **Energy band:** 6 keV – 5 MeV
  - **Sensitivity:** <2E-8 erg/cm^2/s
  - **Localization:** <1 deg (1-σ stat., 1E-5 erg/cm^2)
- **Real-time alerts**
  - **Time Latency**: ~ 1 minute
  - **Trigger information**: Trigger time, localization, duration, spectrum, etc.
  - Transmitted by the **BeiDou Navigation Satellite System** (BDS) short message communication

BeiDou Navigation Satellite System (BDS)

http://en.beidou.gov.cn/

GRB missions in IHEP, CAS

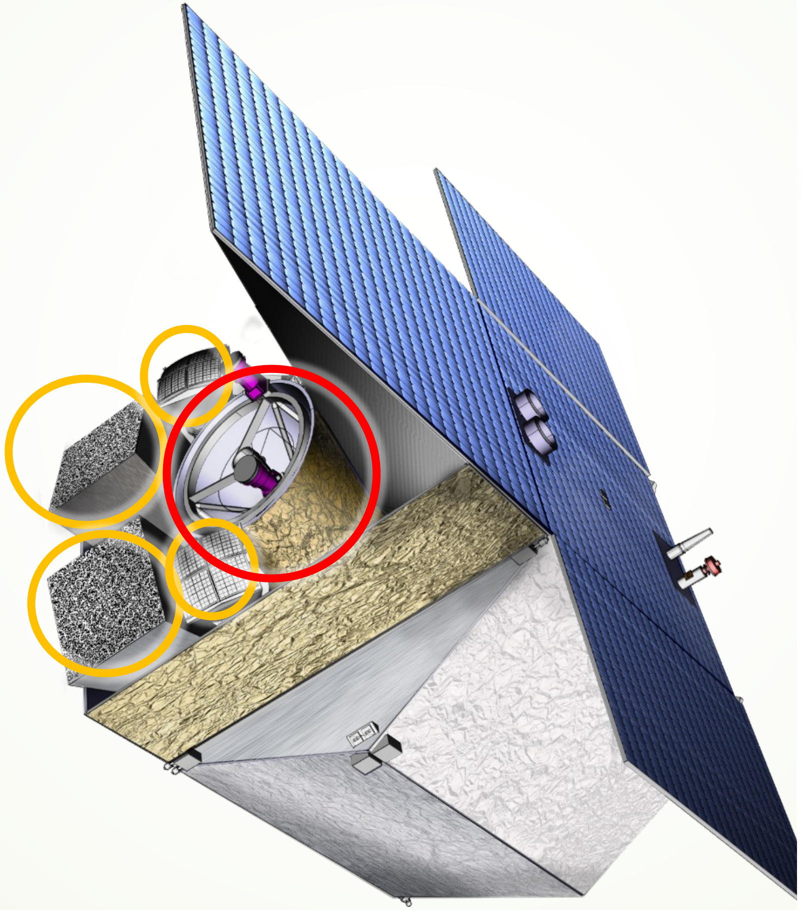
Missions	Launch Time	Energy range	Field of View (all-sky)	Features
Insight-HXMT	2017-06-15	200-3000 keV	~60%	Large effective area in MeV range
GECAM-B	2020-12-09	15-5000 keV	~60%	Real-time alert, wide energy band
GECAM-C	2022-07-27	10-5000 keV	~60%	Real-time alert, wide energy band
GECAM-D	~2023	20-1000 keV	~90%	Deep space, all-sky and all-time coverage Near real-time alert
SVOM/GRM	~2023	15-5000 keV	~60%	Real-time alert. Multi-wavelength. Quick slew
POLAR-2/BSD	~2024	10-5000 keV	~50%	Real-time alert, polarization in 1-800 keV Chinese Space Station.

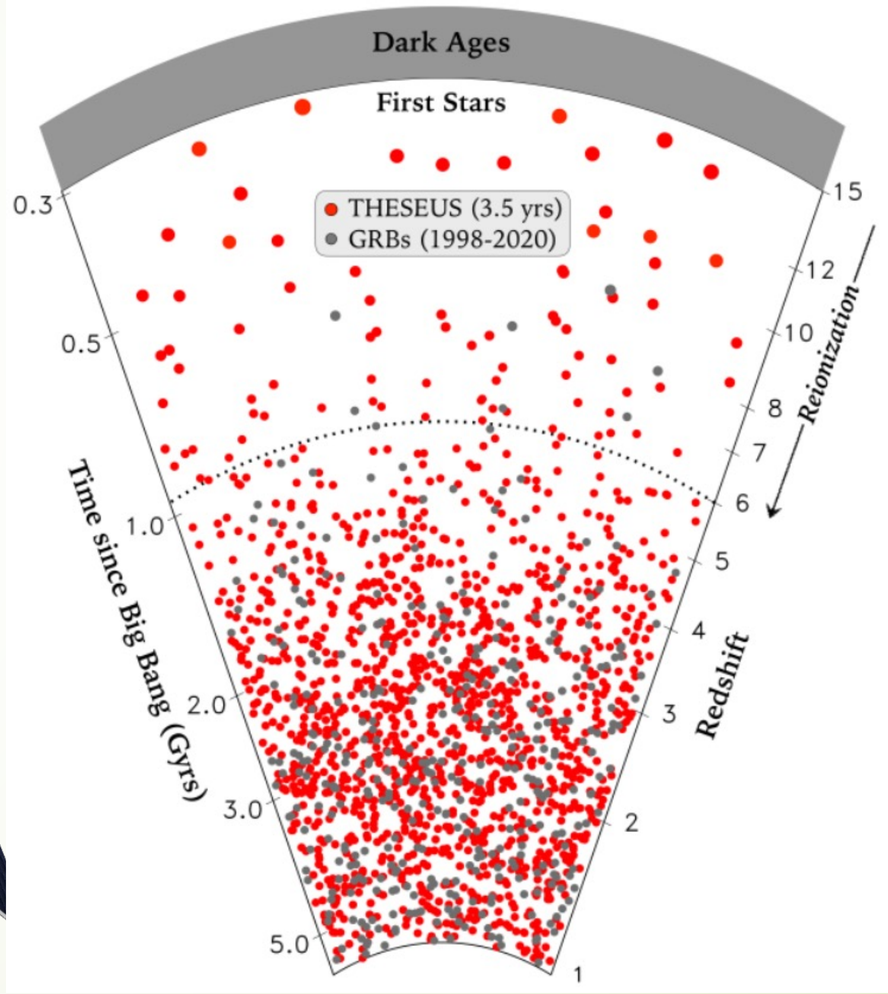
In operation Forthcoming

27

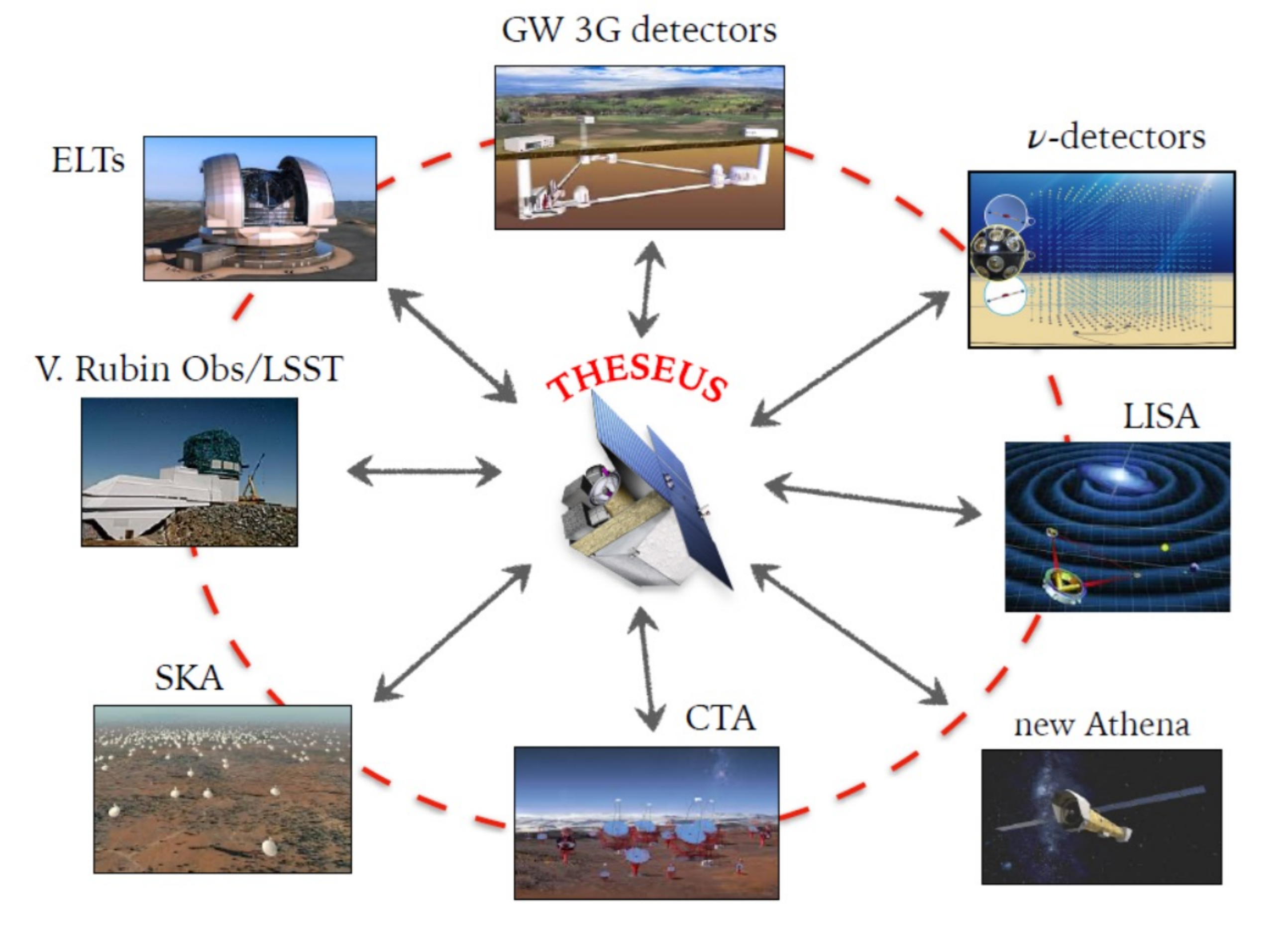
On the longer term: THESEUS M7 candidate

- Set of innovative wide-field monitors with unprecedented combination of broad energy range from gamma-rays down to soft X-rays, FOV and localization accuracy
- On-board autonomous fast follow-up in optical/NIR, arcsec location and redshift measurement of detected GRB/transients
- Will allow for a breakthrough on the use of GRBs as cosmological probes





THESEUS (M7): crucial synergies in the late ’30s



SVOM Generic and specific features

- On-board fast localization [ECLAIRs]
- Automatic satellite slew
- On-board multi-wavelength capabilities
- Accurate localizations in tens of minutes

  [MXT + VT + GFTs]
- Fast alert dissemination [VHF + Beidou]
- ToO observations in few hours (<4 hours) [Beidou + S-band]

- Transients located in the night hemisphere
- Good sensitivity to X-Ray Flashes and highly redshifted GRBs
- Long exposures in the same direction allowing the detection of long transients (e.g. UL-GRBs)
- Broad frequency coverage of GRB prompt emission: vis. to γ-rays
- Good frequency coverage of the afterglow: NIR to X-rays
- Balanced sensitivity between VT & MXT for GRBs afterglows
- Coverage of the prompt-afterglow transition in X-rays
- A potentially large fraction of GRBs with a redshift
- Fast NIR follow-up with good sensitivity
- Quick identification of high-z candidates
- All photons are sent to the ground, allowing delayed off-line trigger

Conclusions

- In the near future transient astrophysics (including the multi-messenger aspects) will be a scientific hot topic
- SVOM is on track to be launched by the end of 2023
  - After the commissioning early 2024 SVOM may participate to the O4 run (May 2023+18 months). The ground segment is partially ready (C-GFT, GWACs)
- SVOM will be part of a more complex satellite system, allowing for synergies with Einstein Probe and GECAM Network
- SVOM is a very good opportunity for the French community to play an important role in time domain astrophysics
  - THESEUS will allow the community to continue along this path