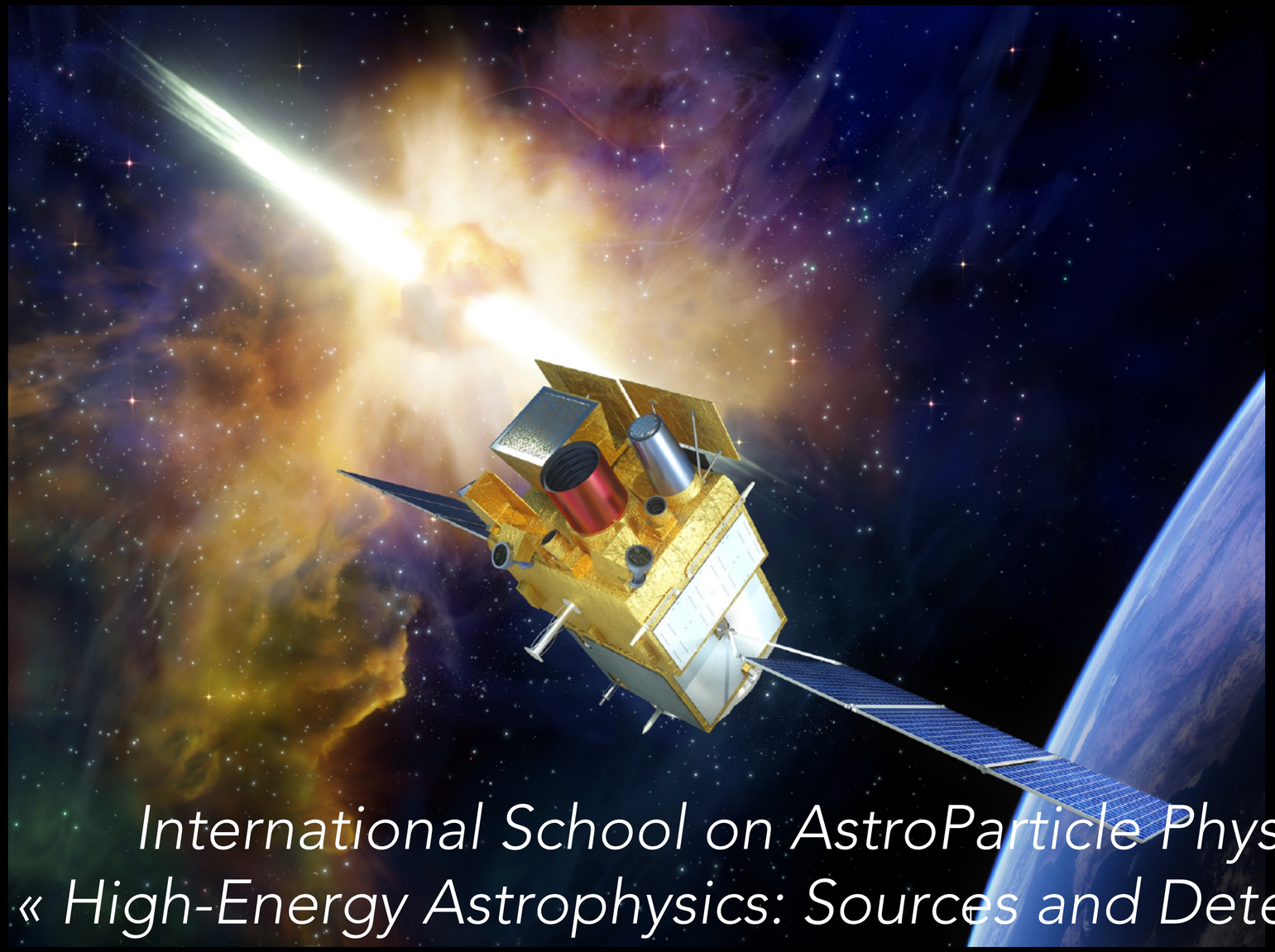
GAMMA-RAY BURST WITH THE SPACE BASED VARIABLE ASTRONOMICAL OBJECT MONITOR



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CEA Irfu/DAp

International School on AstroParticle Physics
« High-Energy Astrophysics: Sources and Detection »

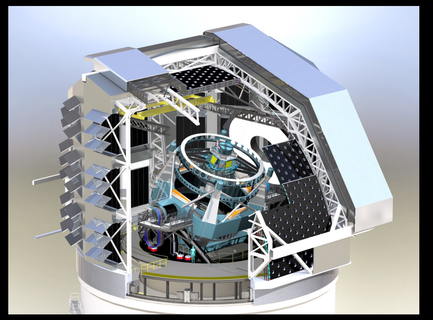
Orsay, June 2026

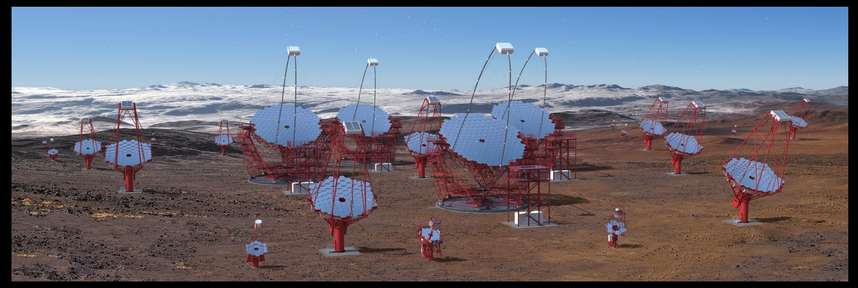
PLAN OF THE LECTURE

- Introduction to Gamma-Ray Bursts
- How do we detect and measure Gamma-Ray Bursts?
  - Focus on X-rays
- Gamma-Ray Bursts origins
- ➢ 5-10 minutes break
- The SVOM mission
- First results from the SVOM mission on GRBs and other HE transients

TIME DOMAIN ASTROPHYSICS (TDA)

- 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, SKA, LOFAR, CTA, etc.) and one of the major connections to astro-particle physics or multi-messenger astronomy (GW, neutrinos, UHECRs, etc.)

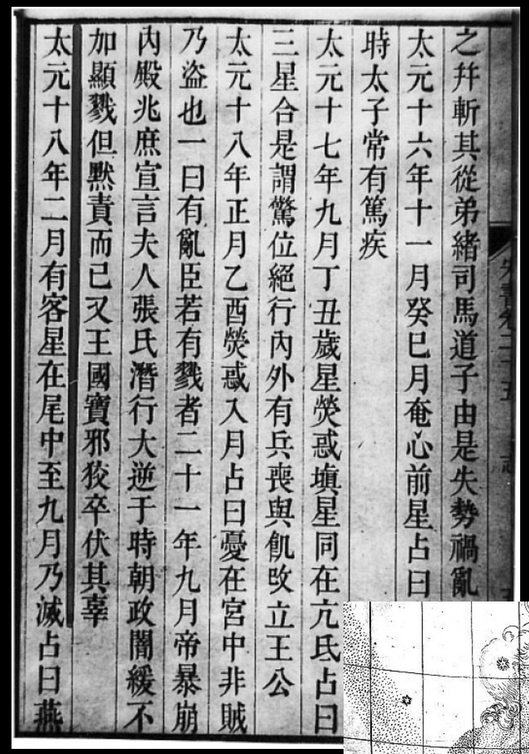




TIME DOMAIN ASTROPHYSICS

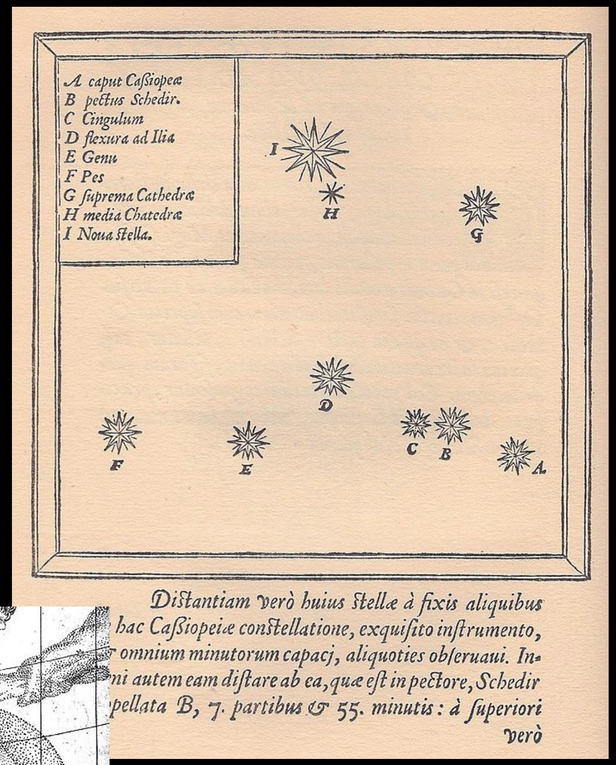
- The study of the time variation of sources is a common practice in astronomy and especially in the X- and gamma-ray domain since the first satellite experiments, but it was made « by hand »

- 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



之幷斬其從弟緒司馬道子由是失勢禍亂
太元十六年十一月癸巳月奄心前星占曰
時太子常有篤疾
太元十七年九月丁丑歲星熒惑填星同在亢氐占曰
三星合是謂驚位絕行內外有兵喪與飢改立王公
太元十八年正月乙酉熒惑入月占曰憂在宮中非賊
乃盜也一曰有亂臣若有戮者二十一年九月帝暴崩
內殿兆庶宣言夫人張氏潛行大逆于時朝政闇緩不
加顯戮但黜責而已又王國寶邪狡卒伏其辜
太元十八年二月有客星在尾中至九月乃滅占曰燕

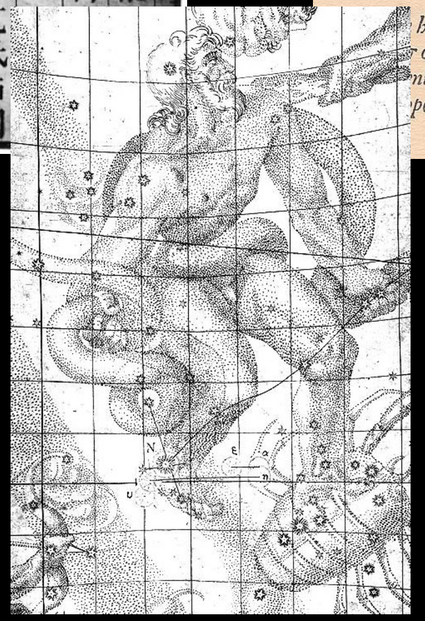
393 Shen
(Sung Dinasty)



A caput Caſsiopeæ
B pectus Schedir.
C Cingulum
D flexura ad Ilia
E Genu
F Pes
G ſuprema Cathedræ
H media Chatedræ
I Noua ſtella.

Diſtantiam verò huius ſtellæ à fixis aliquibus
hac Caſsiopeiæ conſtellatione, exquiſito inſtrumento,
omnium minutorum capacj, aliquoties obſeruaui. In-
ni autem eam diſtare ab ea, quæ eſt in pectore, Schedir
pellata B, 7. partibus & 55. minutis: à ſuperiori
verò

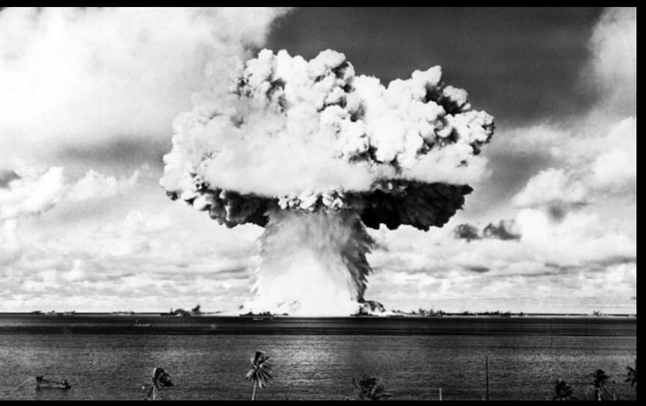
1572 Brahe

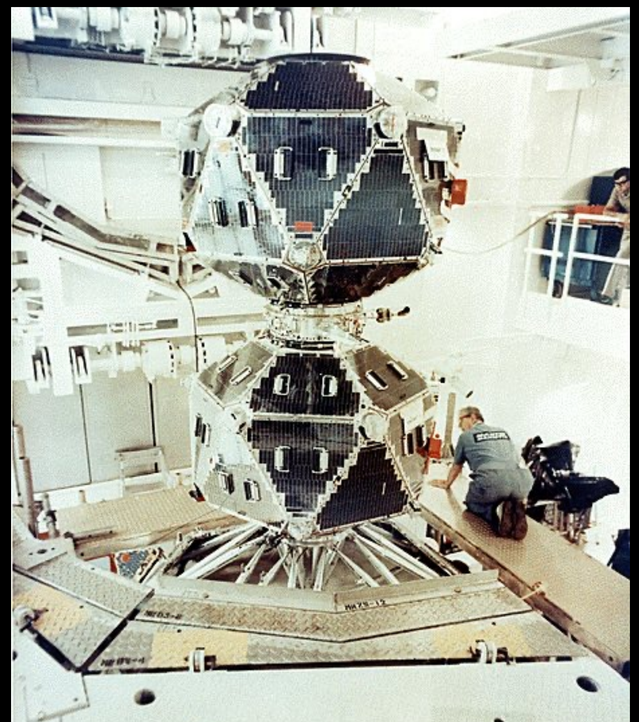


1604 Kepler

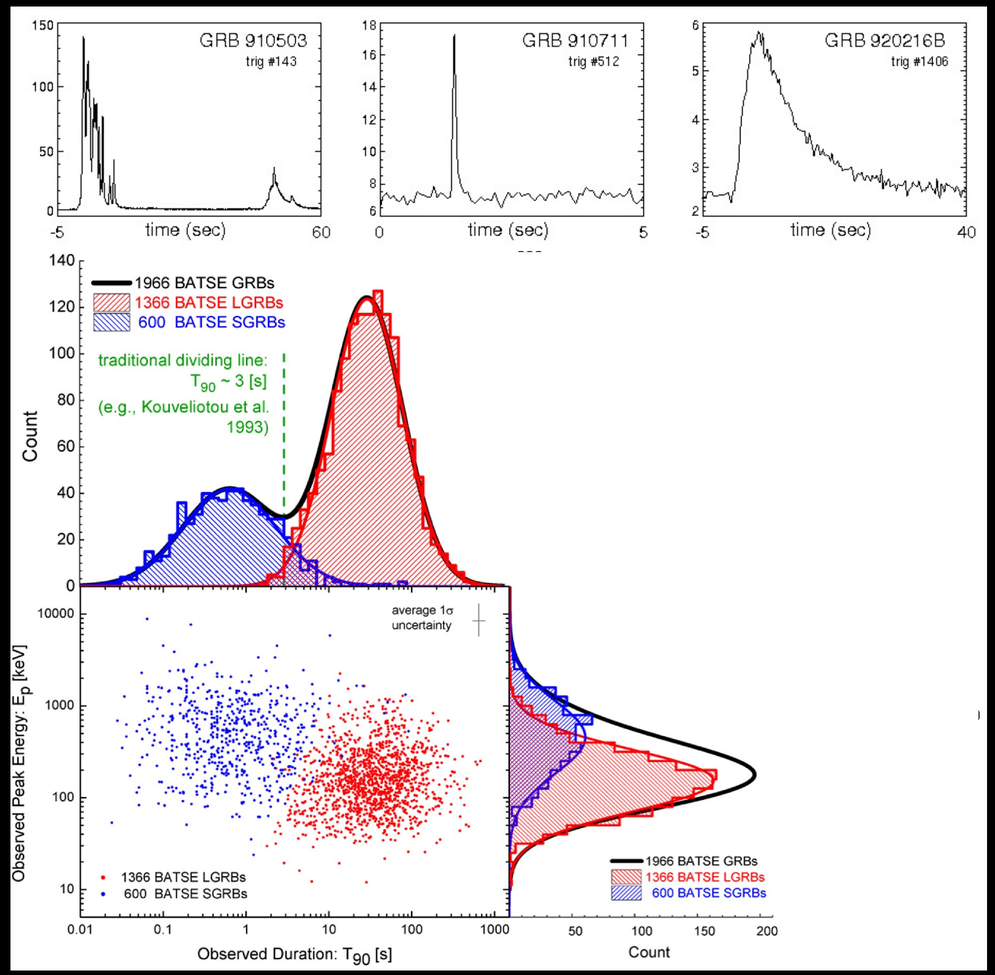
GAMMA-RAY BURSTS

GAMMA-RAY BURSTS

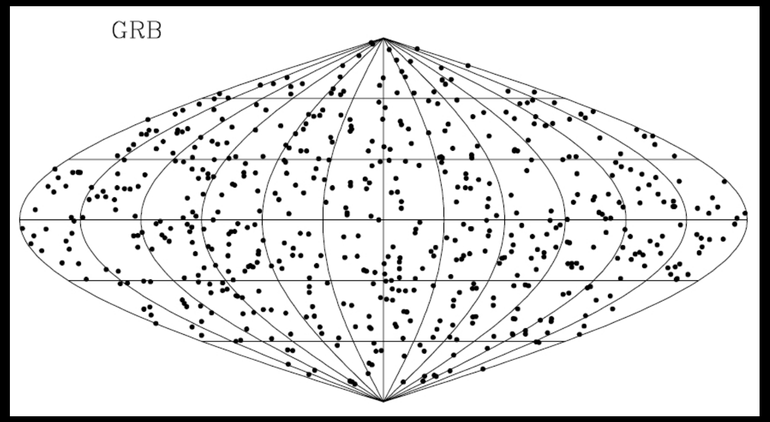


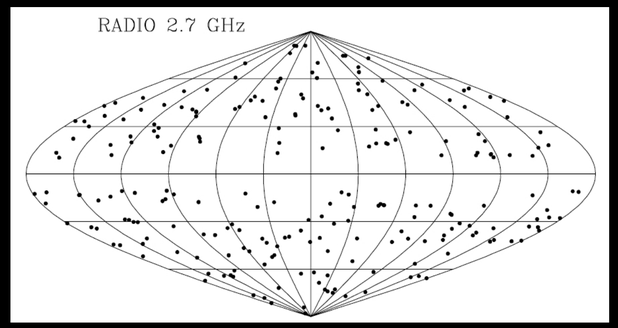


- GRBs are short flashes of gamma-ray radiation with a by-modal time distribution
- They appear randomly over the entire sky
- They spectra are mainly non-thermal
- The variability and the spectra imply a relativistic compact object origin



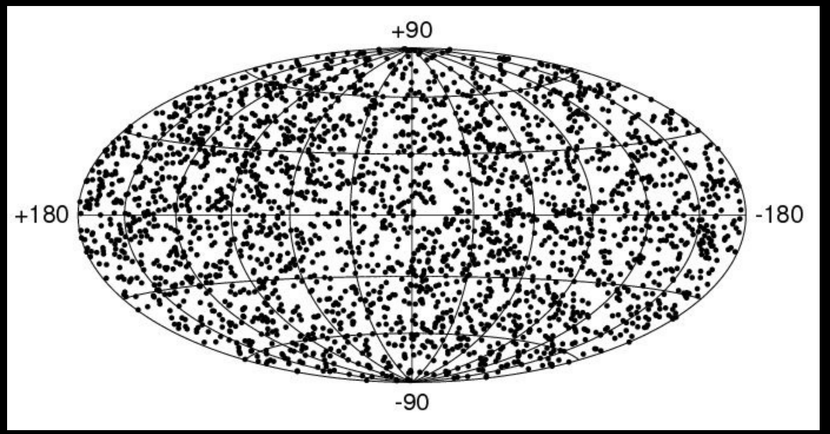
THE BIG DEBATE (CA. 1994)

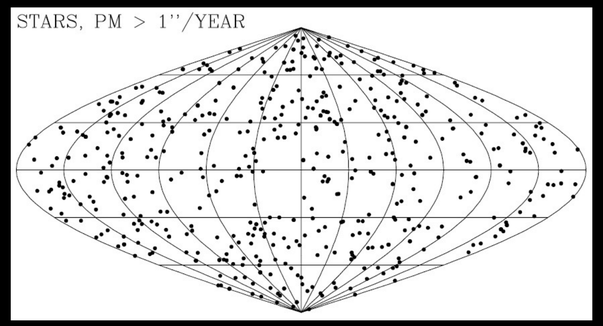




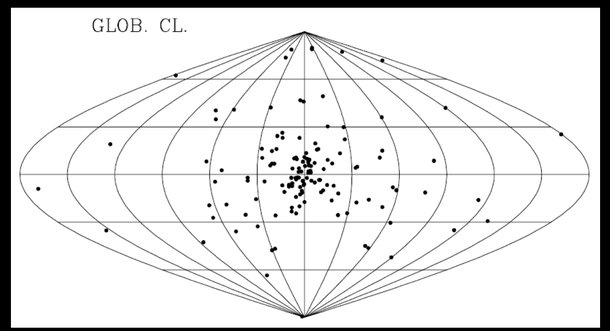
Radio galaxies

Final CGRO/BATSE Catalog

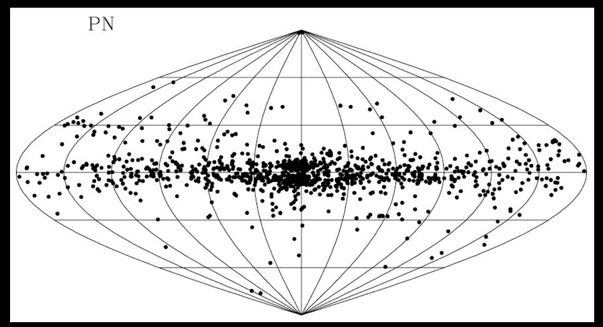




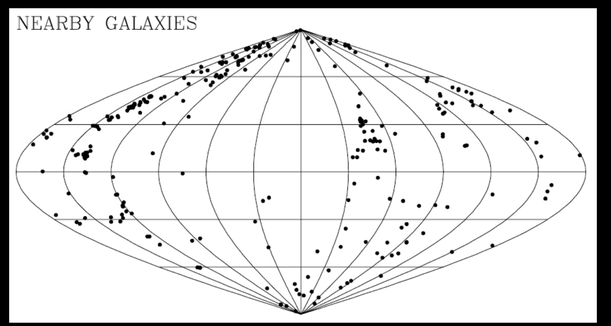
Stars (high PM)



Globular Clusters



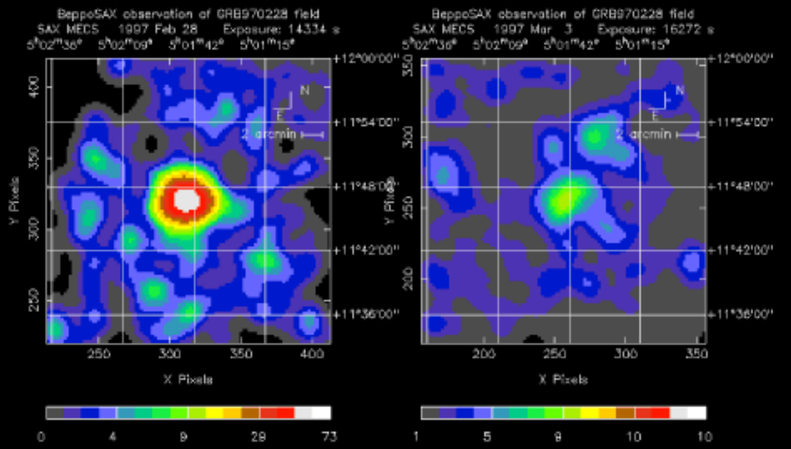
Planetary nebulae

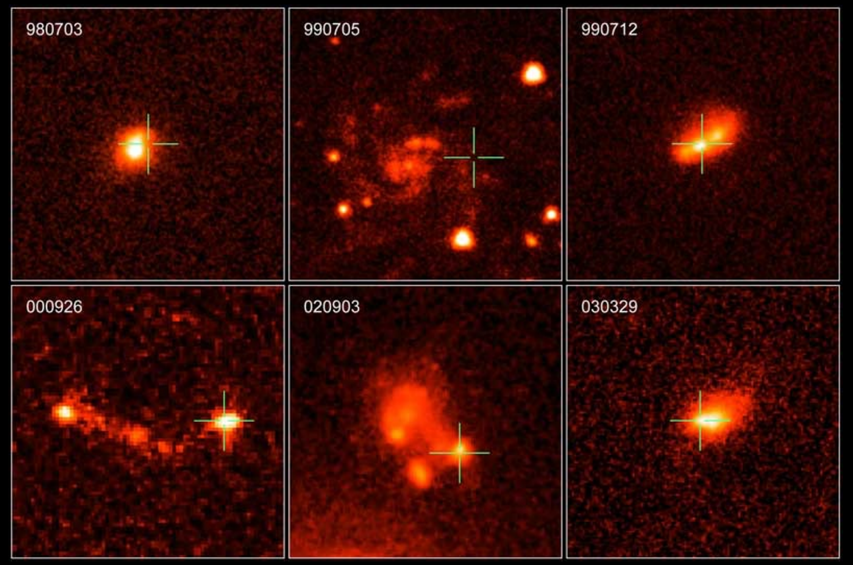


Nearby galaxies

THE GAMMA-RAY BURSTS AFTERGLOW REVOLUTION

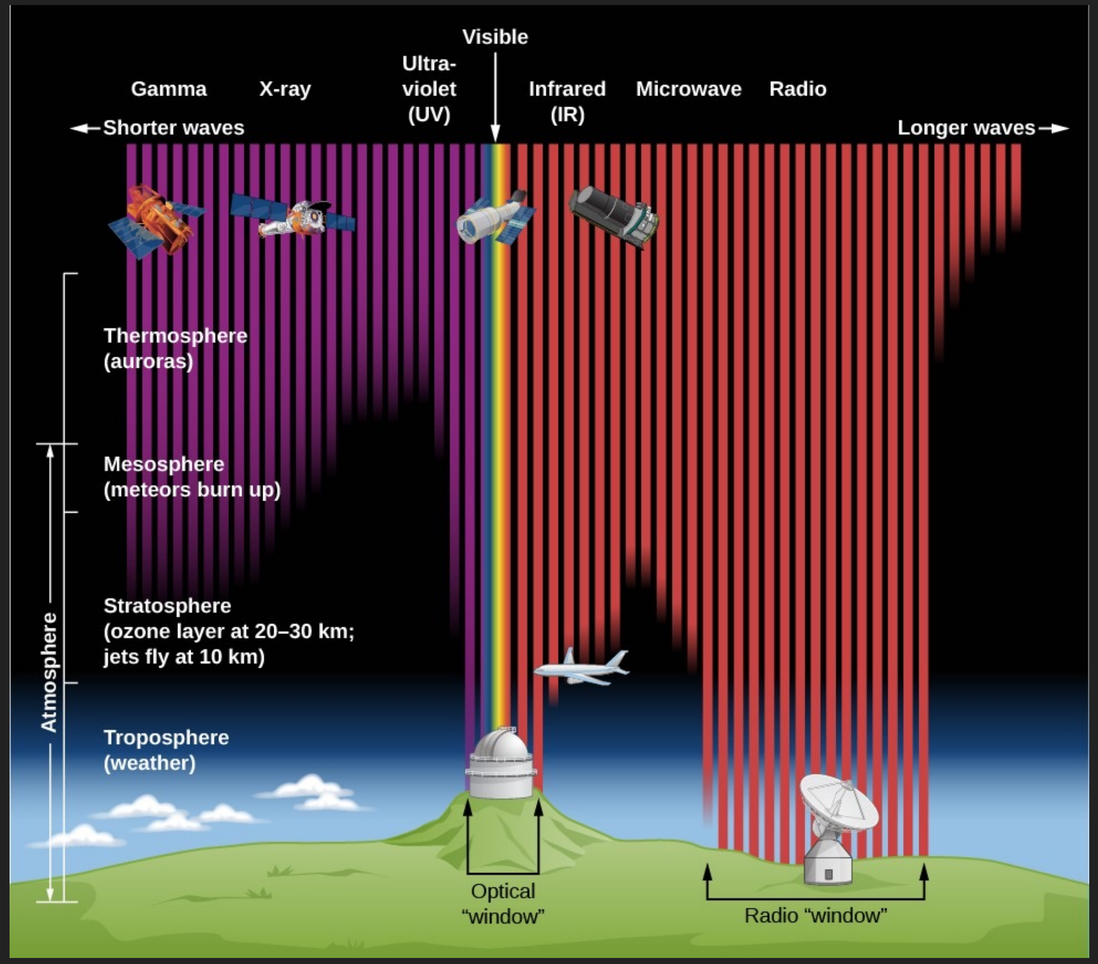
- Major discovery (GRB 970228) by the Italian-Dutch BeppoSAX satellite: GRBs are followed by long term declining X-ray emission; well localized
- This led to the discovery of optical afterglows and finally of GRB host galaxies
- Measured (spectroscopic and photometric) redshifts between ~0.1 and ~9.4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



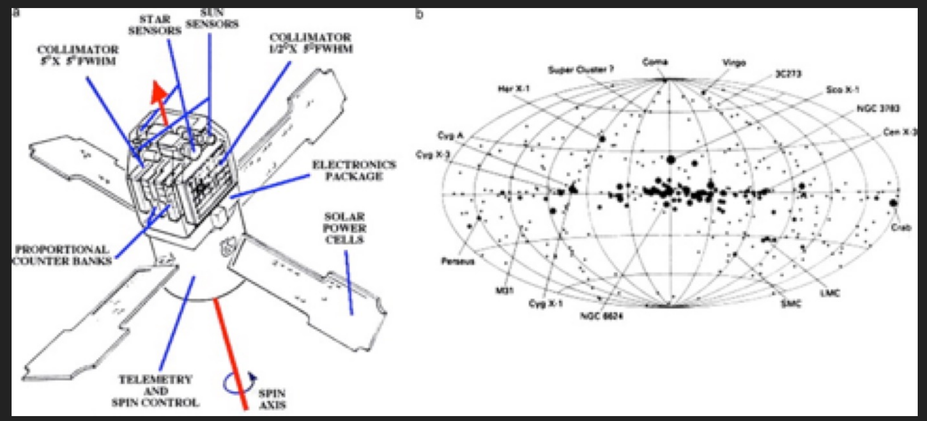


X-RAY ASTRONOMY IS A SPACE BUSINESS….

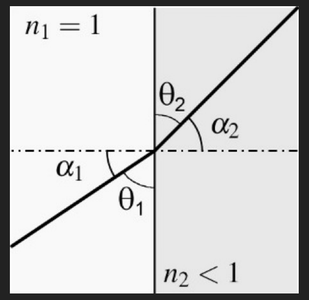
- X-ray astronomy can be performed only at very high altitude due to absorption by the Earth atmosphere
  - Thus it was only after rockets were available to lift payloads above the atmosphere that X-ray astronomy coud be fully developed



- Already after the first rocket flights in 1962 and 1963 lasting just a few minutes it was clear that the sky was full of X-ray sources
  - The team lead by the Nobel Prize winner Riccardo Giacconi (1931-2018) discovered the brightest X-ray source, Sco X-1, while looking for fluorescence X-rays from the Moon surface.
- The first all-sky map in X-rays has been performed using the data from the UHURU satellite
- X-ray allow to test thermal and non-thermal emission processes, both in compact objects (binaries, isolated NS, GRBs,…) and diffuse environments (SNRs, Galaxy Clusters,…)
- X-ray spectroscopy allows e.g. to determine the elemental composition of the observed plasmas



At X-ray energies imaging is only possible for small incidence (grazing) angles



Reflection of X-rays (Snell's law)

$$\frac{\sin\alpha_1}{\sin\alpha_2} = \frac{n_2}{n_1}$$

If α_2 reaches 90° we have a reflection. So if we assume $n_1=1$, the critical angle to have a reflection is

$$\alpha_{critical} = \arcsin n_2$$

As n_2 is slightly below 1 in the X-rays regime (for example for Au for photon energies of 12.4 keV, $n_2 = 1\text{-}1.88\cdot10^{-5}$), the maximum angle for total external reflection to occur is close to 90° (for gold at 12.4 keV $\alpha_{critical} = 89.65° = 90°\text{-}0.351°$).

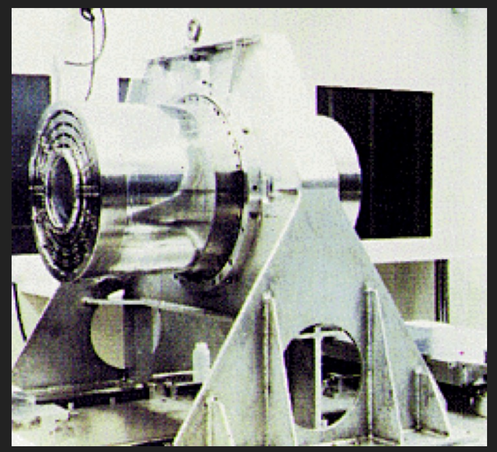
For X-rays total external reflection occurs only under grazing incidence. So the reflection angles α are always close to 90°.

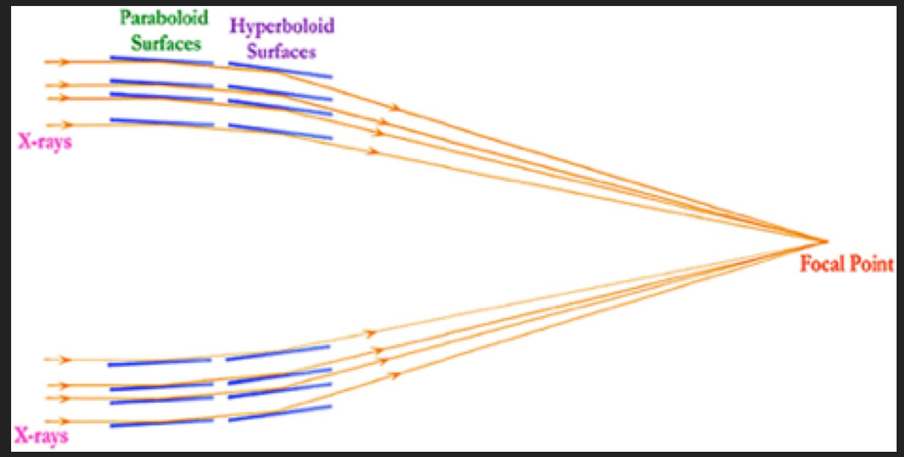
Normally the reflection angles are measured as angles ϑ between the incoming ray and the mirrors surface. The critical angle $\vartheta_{critical}$ is then expressed as

$$\cos\theta_{critical} = n_2$$

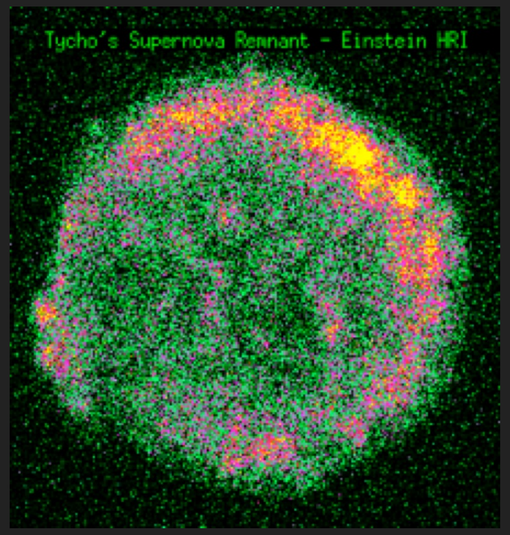
For example $\vartheta_{critical}$ is ~ 1° for 3 keV photons on metals such as Nickel or Gold

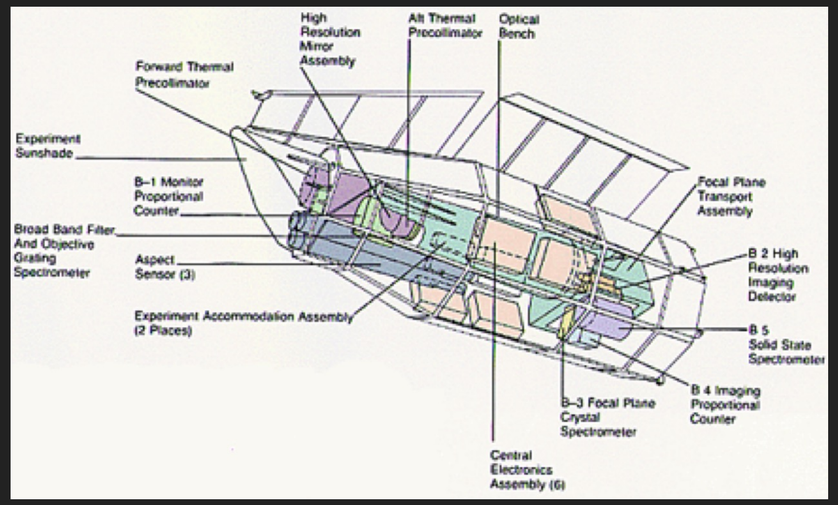
- In 1978 the Einstein X-ray Telescope was launched
- In provided the first high resolution X-ray images of many sources, thanks to the grazing incidence reflection technique (in a Wolter I configuration)

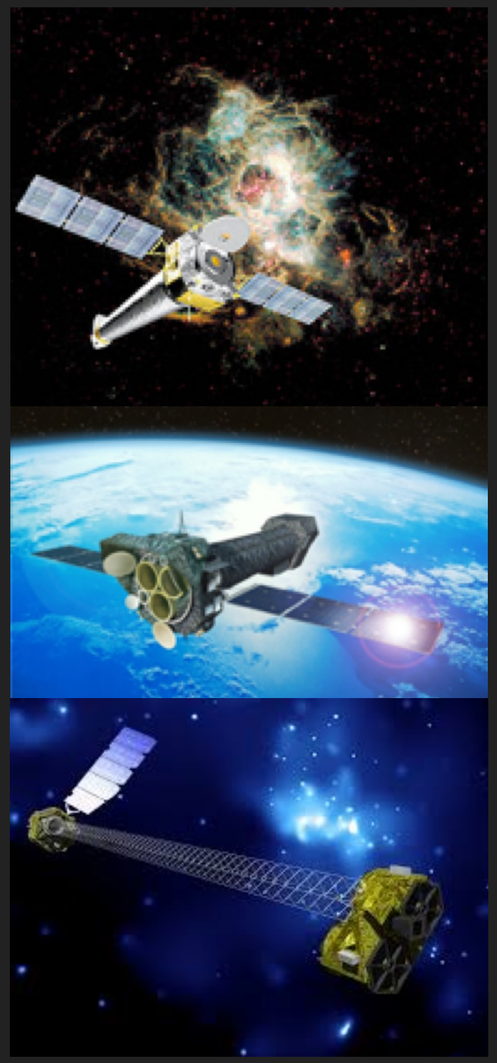




- The sky background radiation was largely reduced wrt UHURU
- This allowed for the first time to image faint and extended sources
- Main result: all the celestial objects are X-ray emitters (stars, galaxies, AGNs, clusters, etc.)





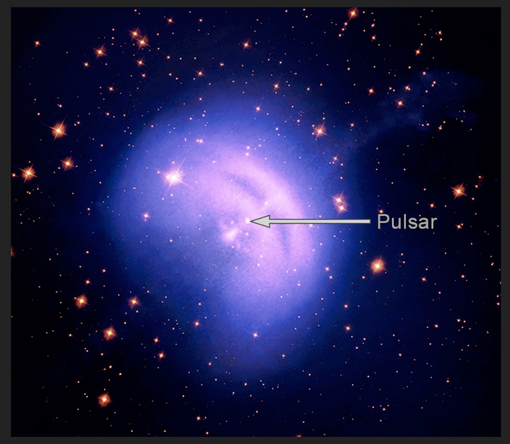


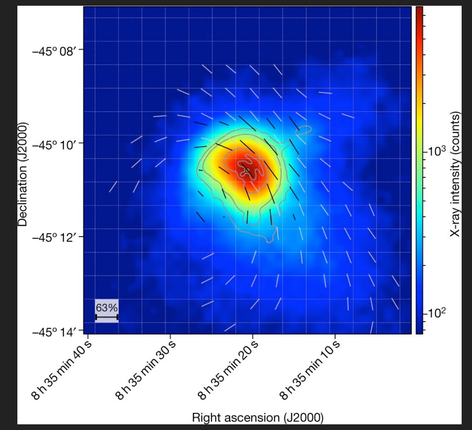
Chandra X-ray Observatory
launched in 1999 by NASA
10 m focal length, 0.1-10 keV
600 cm^2 @ 1.5 keV, PSF: 0.5 arc sec

ESA XMM Newton, launched in 2000
7.5 m focal, length 0.1-12 keV
1500 cm^2 @ 1 keV, PSF: 6 arc sec

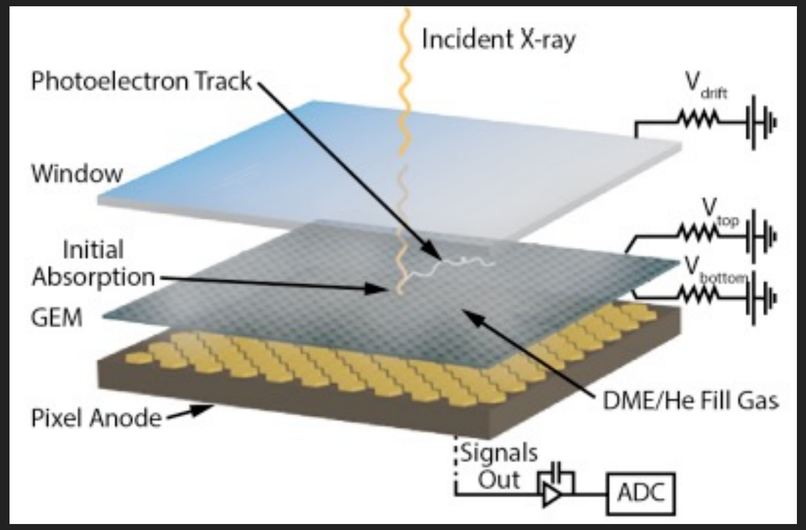
Nustar, launched in 2012 by NASA
10.15 m focal, length 6-79 keV
849 cm^2 @ 9 keV, 60 cm^2 @ 78 keV
PSF: 9.5 arc sec

NASA Explorer mission launched in 2021
Can measure polarization and provide images at the same time!





Combined Chandra (pink), HST (magenta) and IXPE (blue) image of the Vela pulsar and nebula



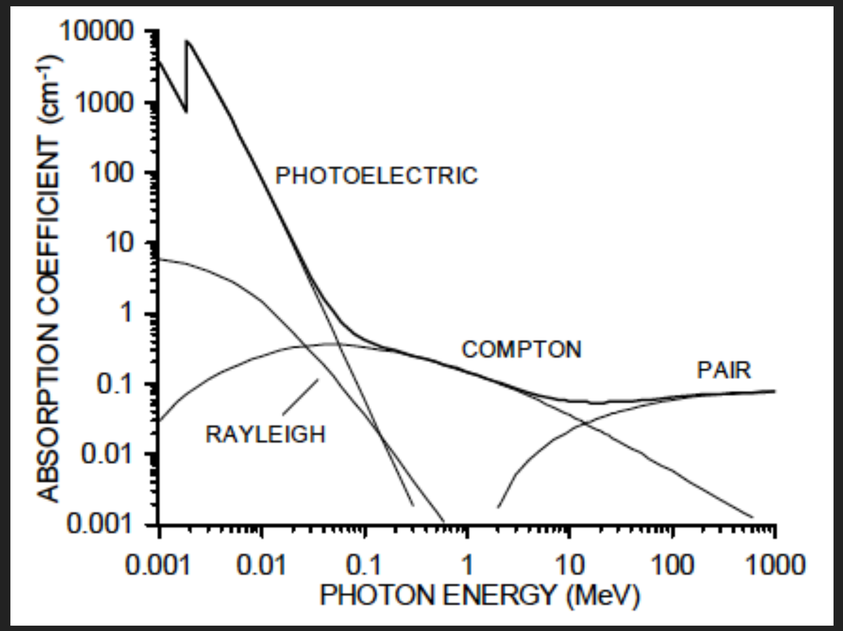
Polarized X rays interacting with a gaseous medium create photoelectons that are preferentially emitted in the polarization direction.
Photoelectron tracks mark the path of the photoelectron from the position of the initial X-ray interaction to its stopping point.
Analysis of the distribution of the initial directions of the tracks gives the degree of polarization and the position angle from the incident X ray.

In passing through a medium, photons will traverse a certain distance unaffected, until depositing its energy either by

a) Photoelectric absorption

b) Compton scattering

c) Pair production

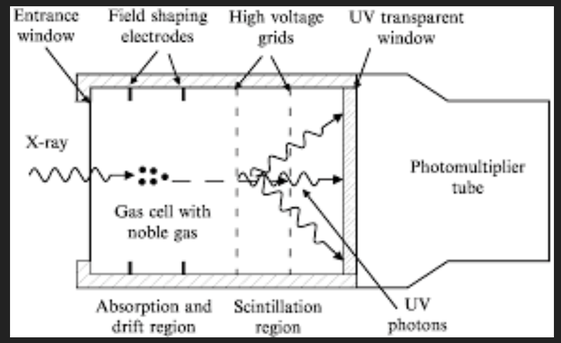


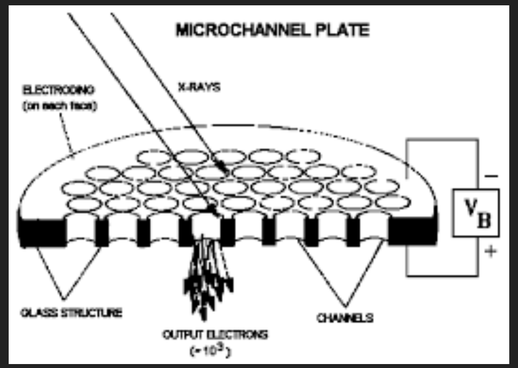
The probability of undergoing an interaction is an exponential function of distance. The fraction of photons that suffered any interaction after traversing a distance x is $f=1-\exp(-\mu x)$, where μ is the total absorption coefficient expressed in cm^{-2}.

We will focus on Photoelectric Absorption

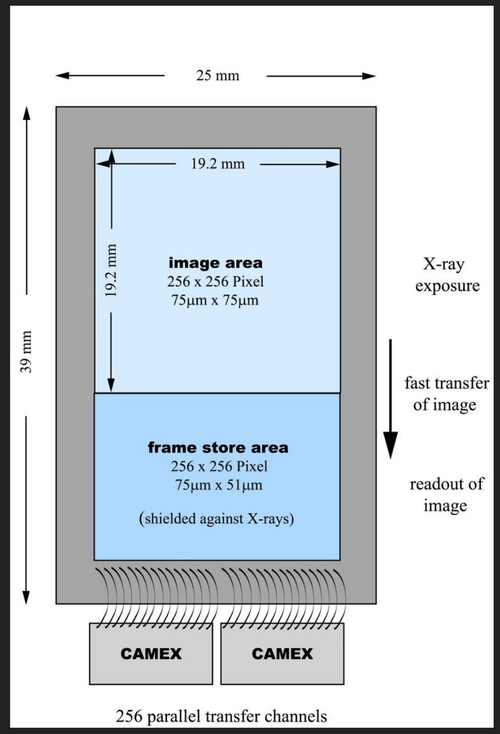
An electron is emitted with the energy $E_{PE}=E_X-E_b$, where E_b is the binding energy of the photo electron and E_X the incident photon energy.

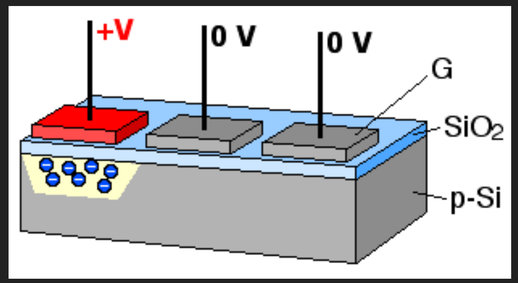
- Generally, X-ray detectors are based on the conversion of X-ray photons into electrical charge through the photoelectric effect
- In the early times gas proportional counters were used to convert X-rays in electrical signals. These detectors had the advantage to be simple in operation, but the drawback of the possibility of leakage and that a relatively large volume of gas is needed to de efficient in the detection. Spectral resolution is moderate
- Microchannel plates (MCPs) are compact electron multipliers of high gain. Channels can be as small as 2 μ providing excellent imaging properties (Chandra HRC). Energy resolution is poor.



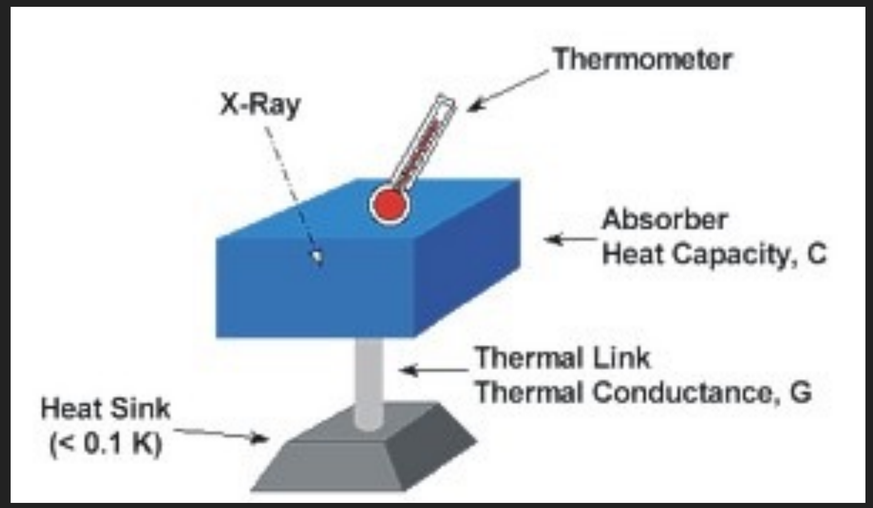


- The most used detectors those days in X-ray astronomy are the ones based on semiconductors (Si, Ge, CdTe,…).
- Such devices are the solid-state analogues of gas-filled ionisation chambers, in the sense that there is no multiplication of the charge within the detecting material, and the generated charges/holes (collected after drifting within the semiconductor) are proportional to the energy of the incident particle. Advantage: can be in principle manufactured in any shape, is denser than gas -> higher efficiency
- In order to have the best performances in terms of spectroscopy these detectors need to be cooled well beyond room temperature (to reduce thermal noise), but they are much more compact than gas filled detectors (which is a huge advantage in space applications)
- In X-ray astronomy Si based CCDs are implemented in all current space missions: they allow for low readout noise and hence good energy resolution (~100 eV) and at the same time they provide a high quantum efficiency.
- The minimum energy required to create a pair/hole is only 3.66 eV

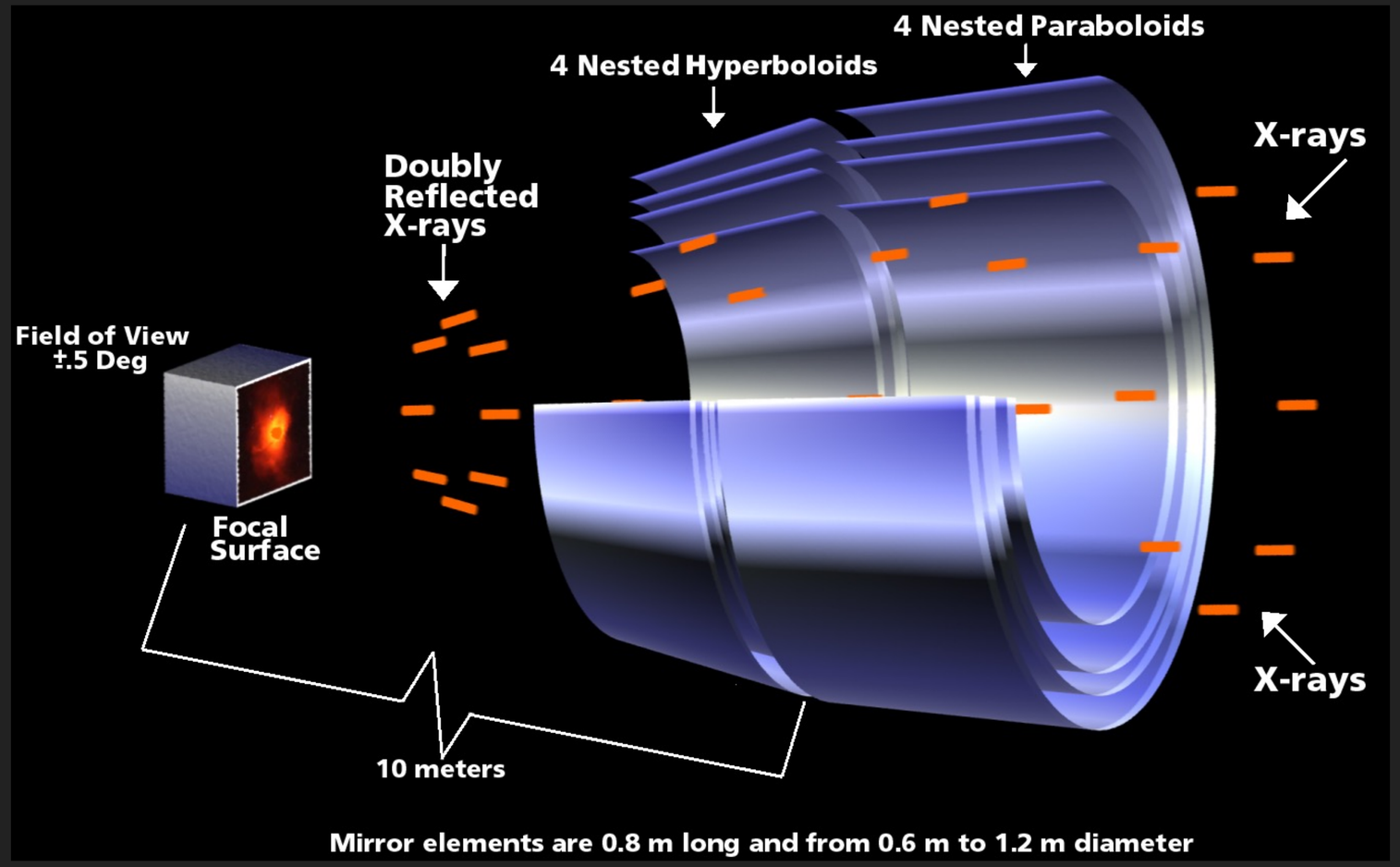




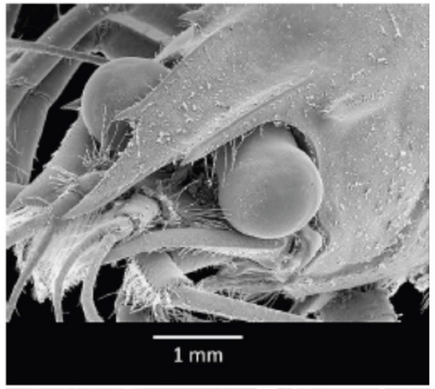
- The future of X-ray detection is nowadays represented by single photon calorimeters in which X-rays are detected via temperature pulses they induce in small absorbers, cooled to a fraction of a degree kelvin.
- Advantage: excellent energy resolution (few eV). Drawback: limited spatial resolution, complex thermal system
- Flying on XRISM (JAXA) and will be on NewATHENA (ESA)



X-RAY TELESCOPE SYSTEMS

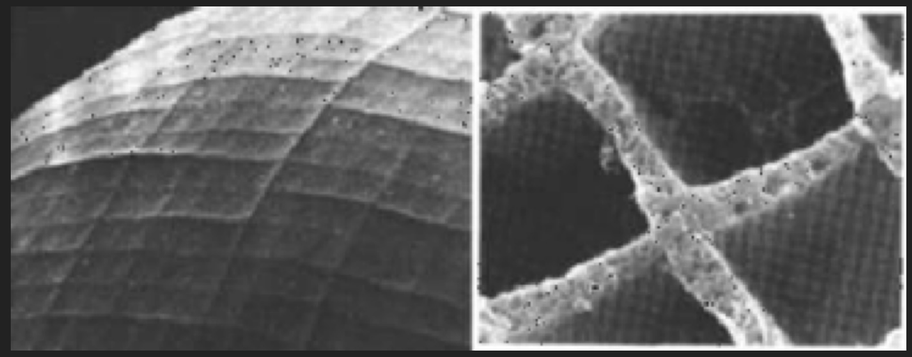


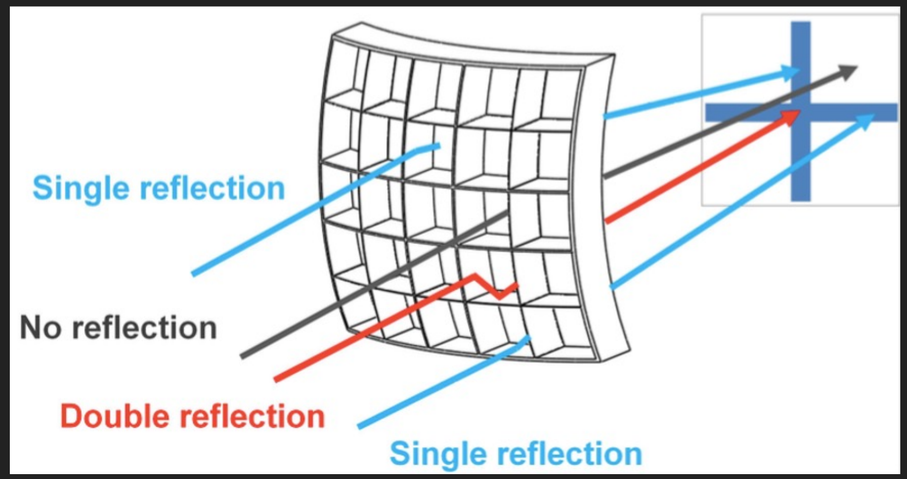
- The observation of a weak point source of X-ray flux F (photons/cm2/s/keV) is always made in the presence of unwanted background B (counts/cm^2/s/keV)
- B is the sum of an intrinsic detector background B_i (arising mainly from the interaction of cosmic rays and the detection medium) and the diffuse X-ray sky background B_d, called CXB, discovered at the same time of Sco X-1.
- If the quantum efficiency of the detector is Q counts/photon and its aperture is Ω in steradians
  - $B_d = Q\,\Omega j_d$ where j_d is the diffuse background flux (ph/cm^2/s/keV/sr)
- If all quantities are constant over the observation time t, then statistical fluctuations in the background B determine the sensitivity of the instrument
- The minimum detectable flux F_{min} for a given signal-to-noise ratio S is that flux that produces a count S standard deviations above B
- Assuming the bandwidth of the instrument δE, the geometric area for the collection of source photons (and diffuse X-ray background) is A_s and A_b the equivalent detector background area then
  - $F_{min} = (S/QA_s)\,[B_iA_b + Q\,\Omega j_d\,A_s)/t\delta E]^{1/2}$

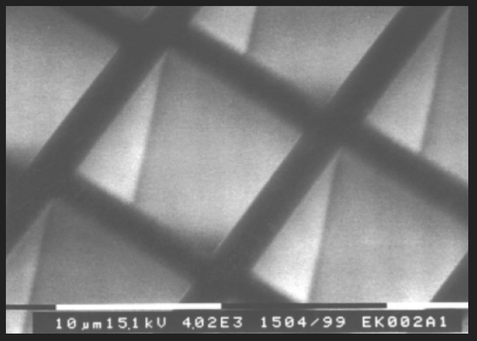


Lobsters and other kind of decapods are a rare example in Nature where the vision is obtained by reflection and not by refraction. This kind of vision is adapted for low-background wide vision (like the dark deep sea).

Can be adapted to X-rays (Angel, 1979)!





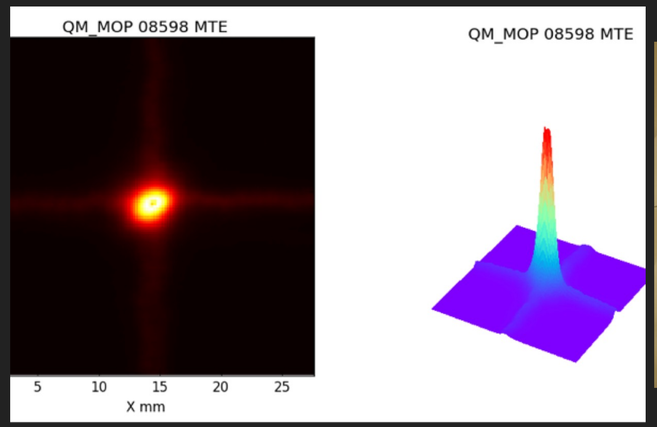


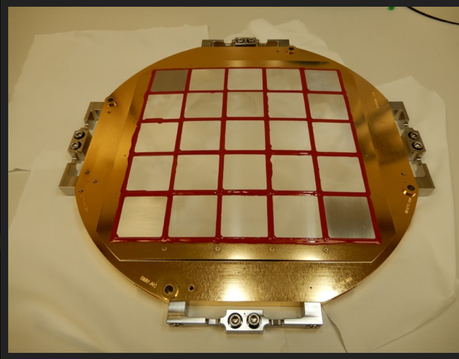
40 microns pitch lead glass MPOs (micro-pore optics) produced by Photonis

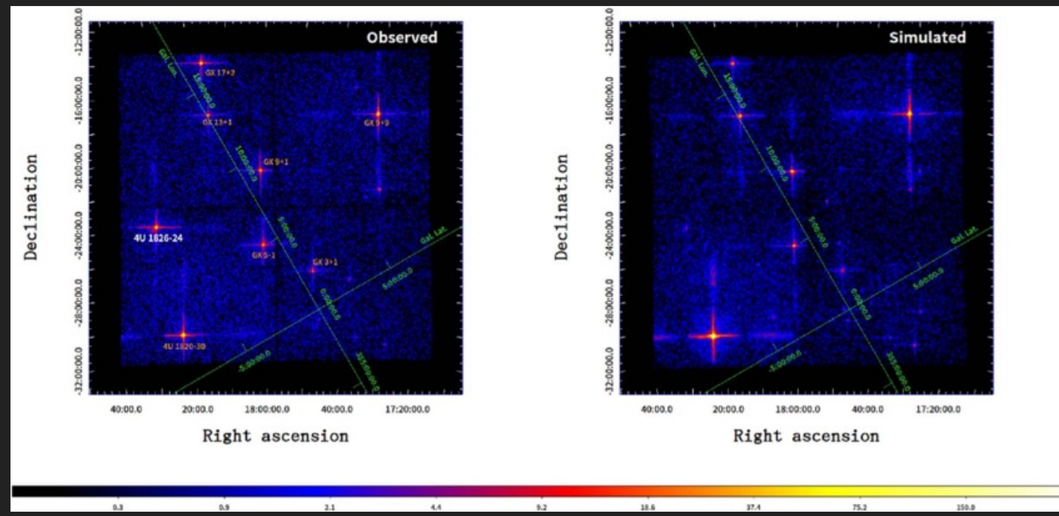
- « Lobster Eyes » are very light (few kg vs. several tens of kg for traditional X-ray optics)
- Hence, they are adapted for relatively small missions like SVOM (total mass ~1000 kg) or SMILE and Einstein Probe (small mission developed jointly by ESA and CAS).

- They have a peculiar Point Spread Function (The one of MXT is shown, small FOV version, to be flown on SVOM)
  - 50% of the flux in the central peak, 22% in each arm, the rest in a diffuse patch, lead glass MPOs

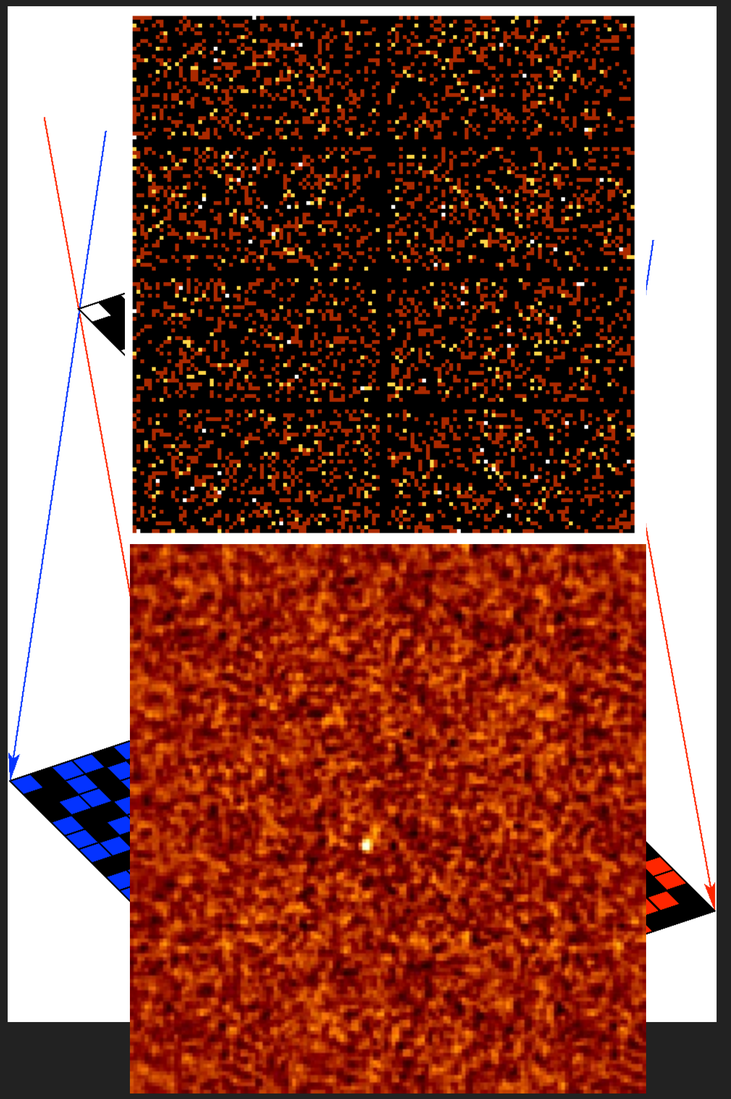
- But micropore optics in general can be used also in a Wolter-I approximation (single peaked PSF, small FOV) as foreseen for the next major X-ray observatory NewATHENA (based on Si)





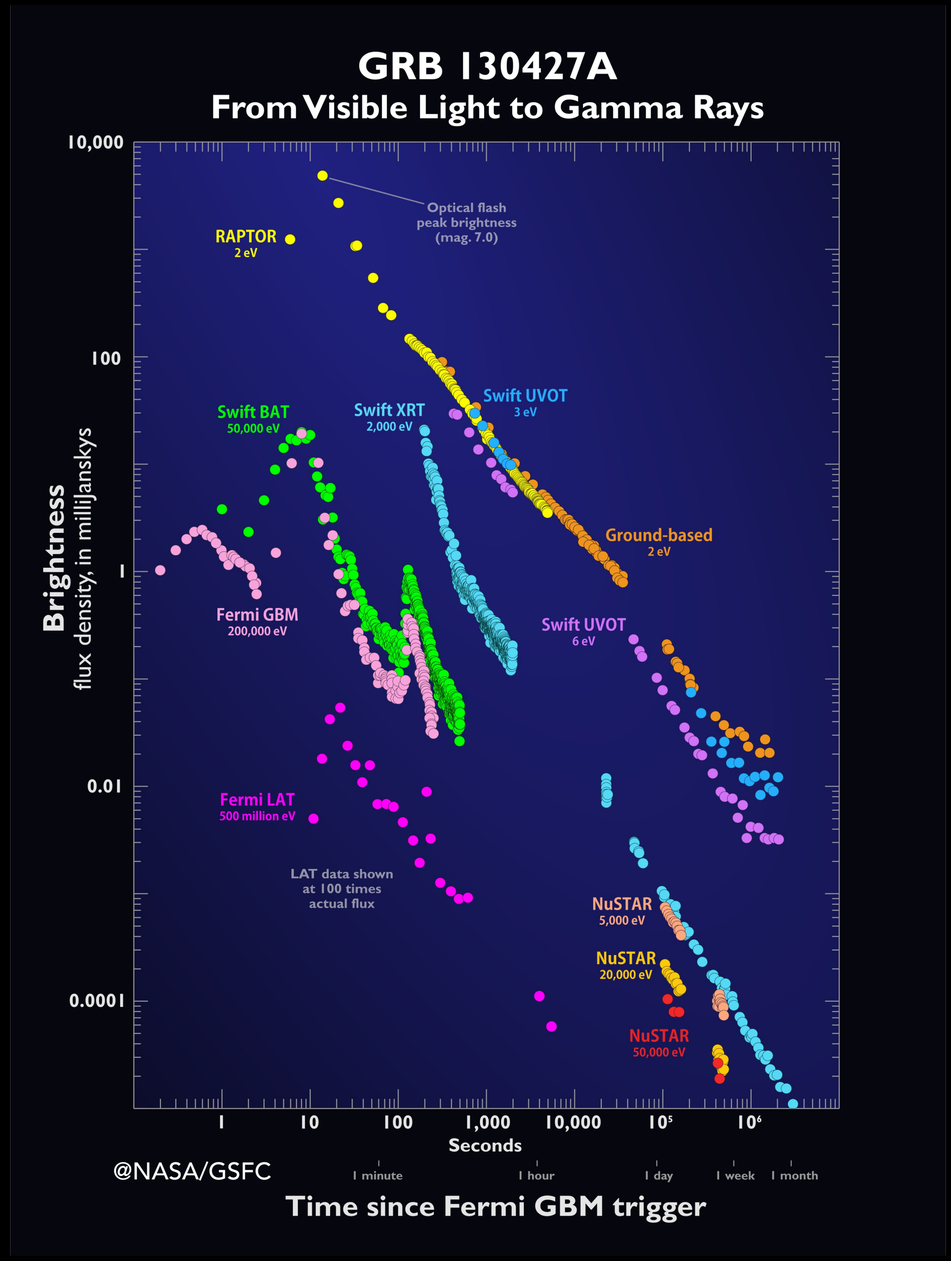


- Above 10 keV it is very difficult to perform direct imaging with mirrors (the maximum energy is proportional to the focal length, see later)
- Coded mask (indirect) imaging is a solution (INTEGRAL/IBIS and SPI, BeppoSAX/WFC, Swift/BAT, GRANAT/SIGMA, etc.) often coupled to pixellated CdTe detectors
- Each pixel records background and possibly source(s) photons
- Image deconvolution techniques are required to reconstruct the sky
- Wide field of view → all-sky monitoring of the transient sky, optimal for Gamma-Ray Burst searches
- State of the art PSF ~ 12 arc min @ 100 keV
- It is difficult to image diffuse sources, and its sensitivity limited (mCrab) due to the high background
- Can be used up to a few MeV



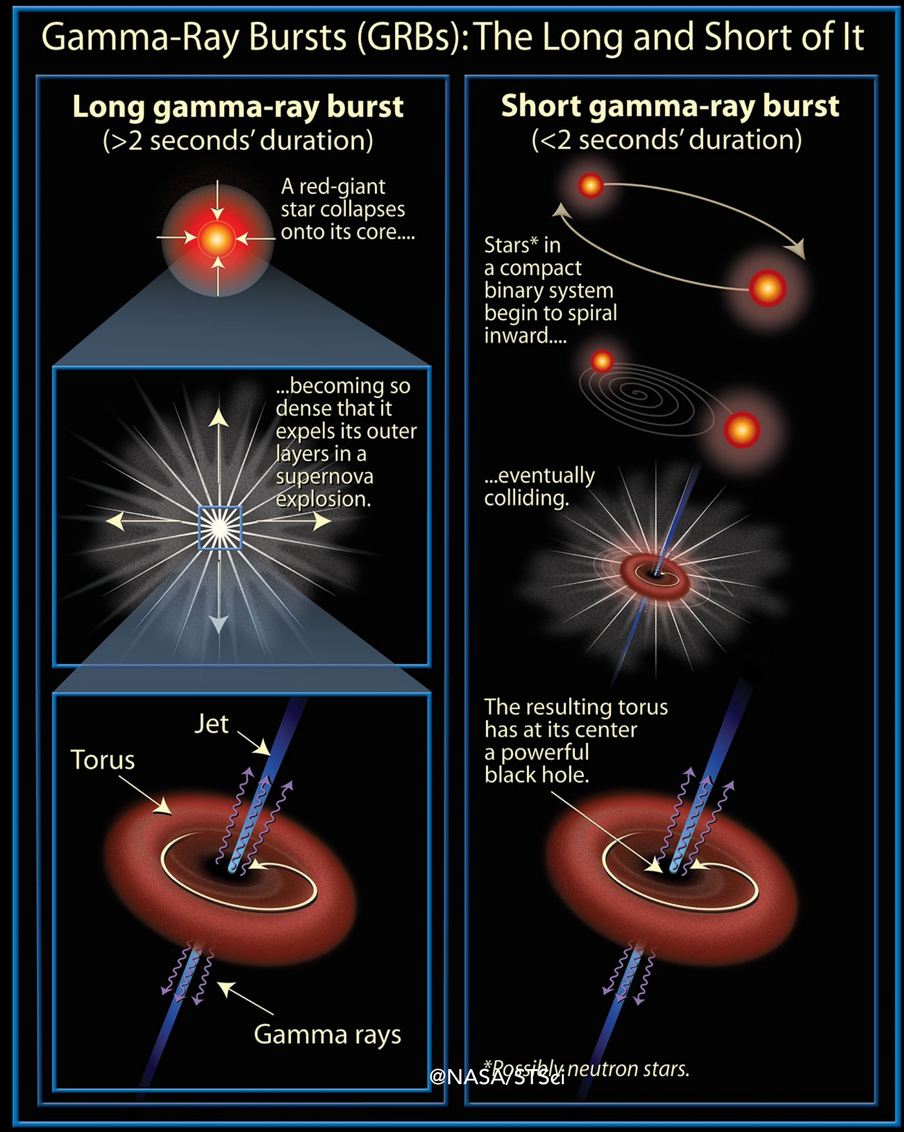
GAMMA-RAY BURSTS AFTERGLOWS

- GRB afterglows are panchromatic events
- They are detected from radio to GeV
- They show fast decline and variability
- Fast reaction is the key!

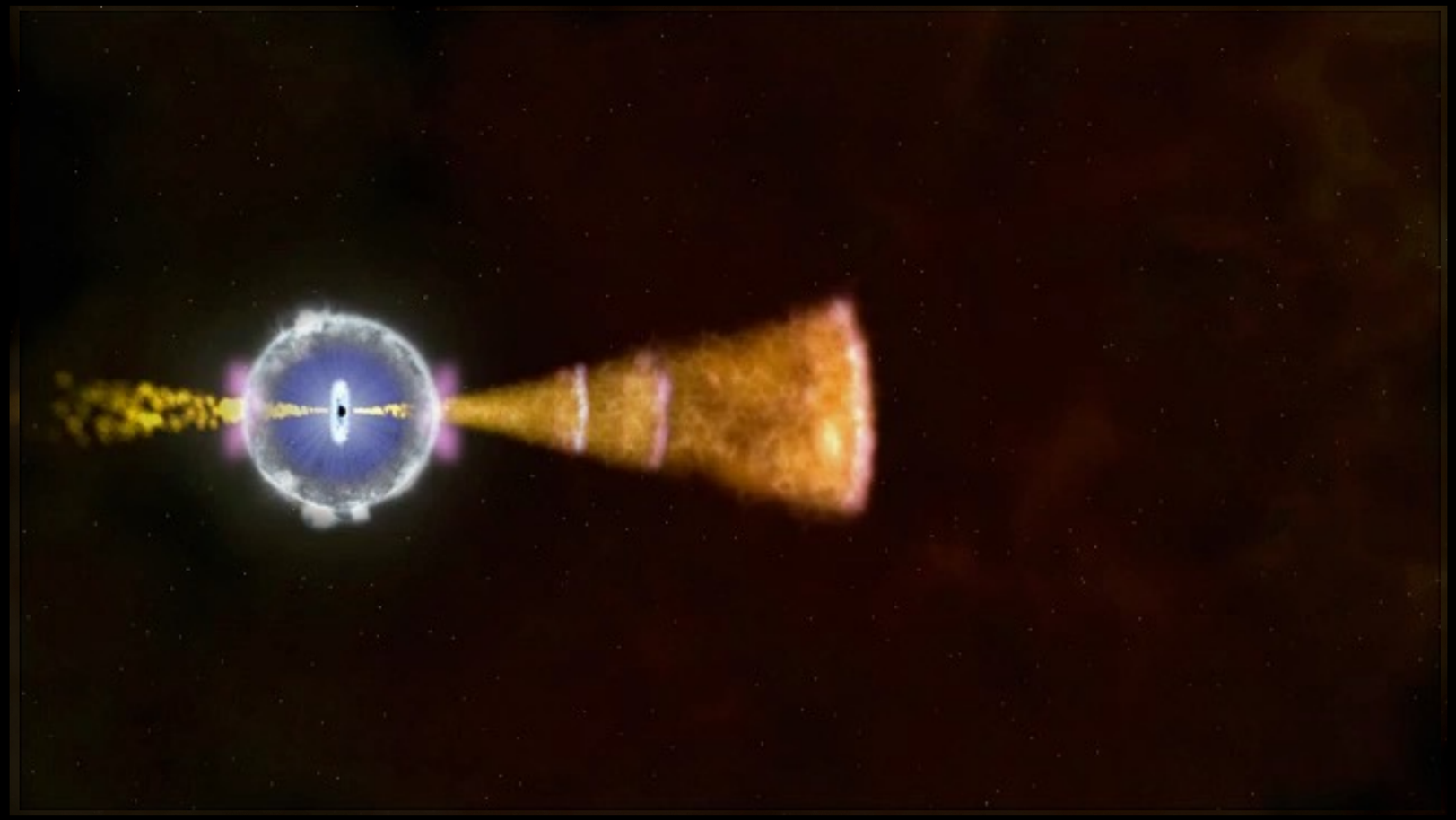


GAMMA-RAY BURSTS MODELS

- 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?



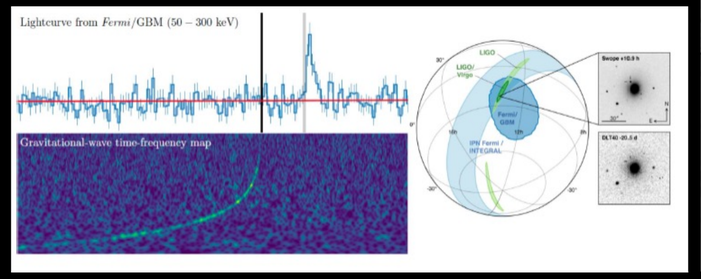
GAMMA-RAY BURSTS MODELS

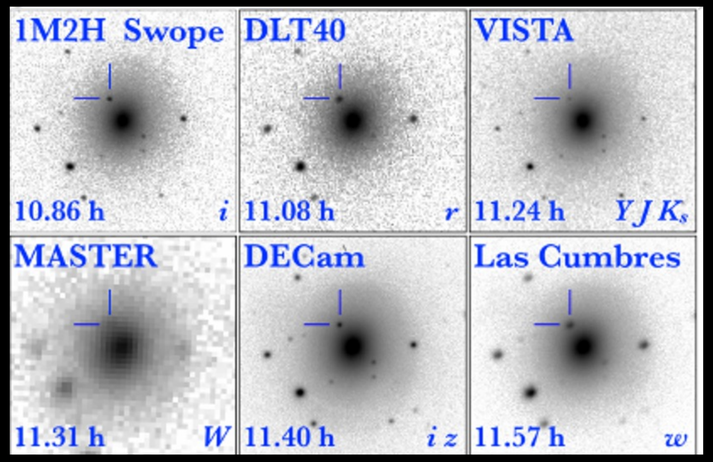


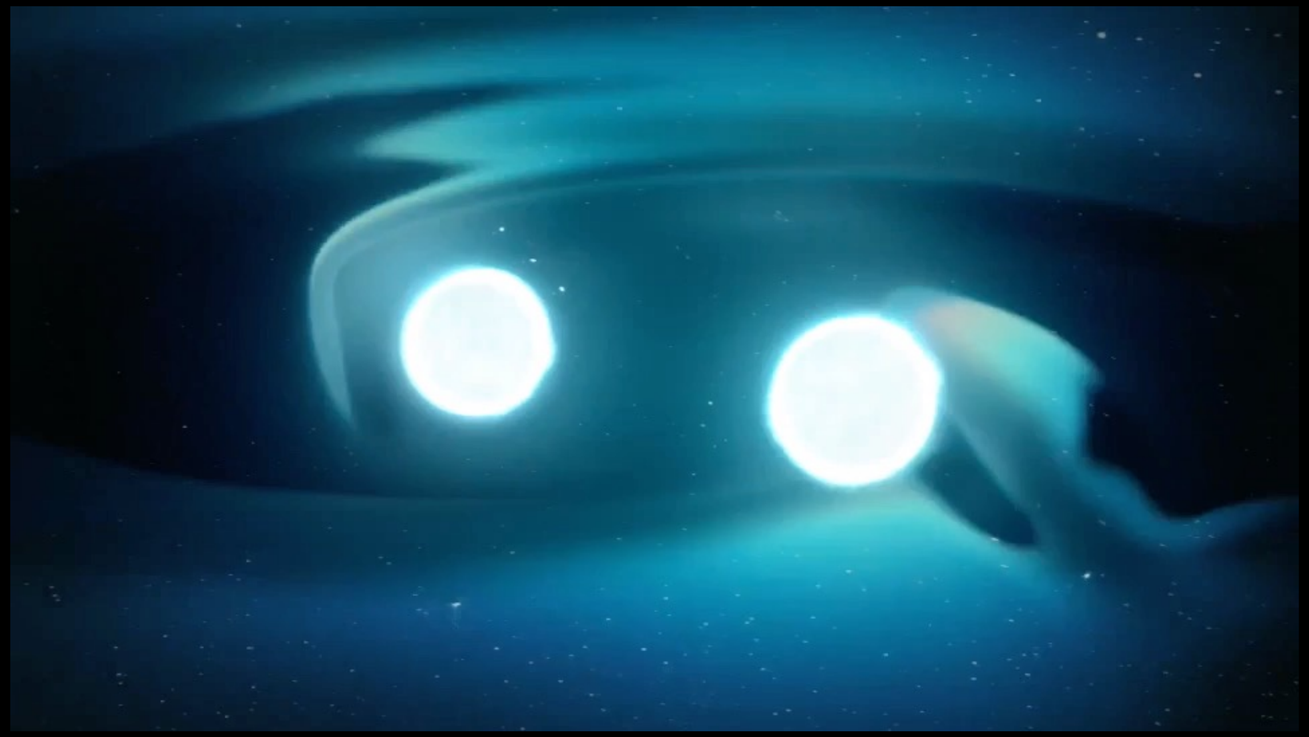
@NASA/GSFC

GAMMA-RAY BURSTS AND GRAVITATIONAL WAVES

- On the 17th of August 2017 the merger of two neutron stars has been detected by LIGO/Virgo
- The first electromagnetic counterpart detected was a short GRB, detected by Fermi/GBM et INTEGRAL/SPI/ACS
- Follow-up from ground (several tens of telescopes) allowed for the detection of a Kilonova, source the heaviest elements in the Universe
- This observation represents the birth of modern multi-messenger astronomy, and Gamma-Ray Bursts are at the hearth of it



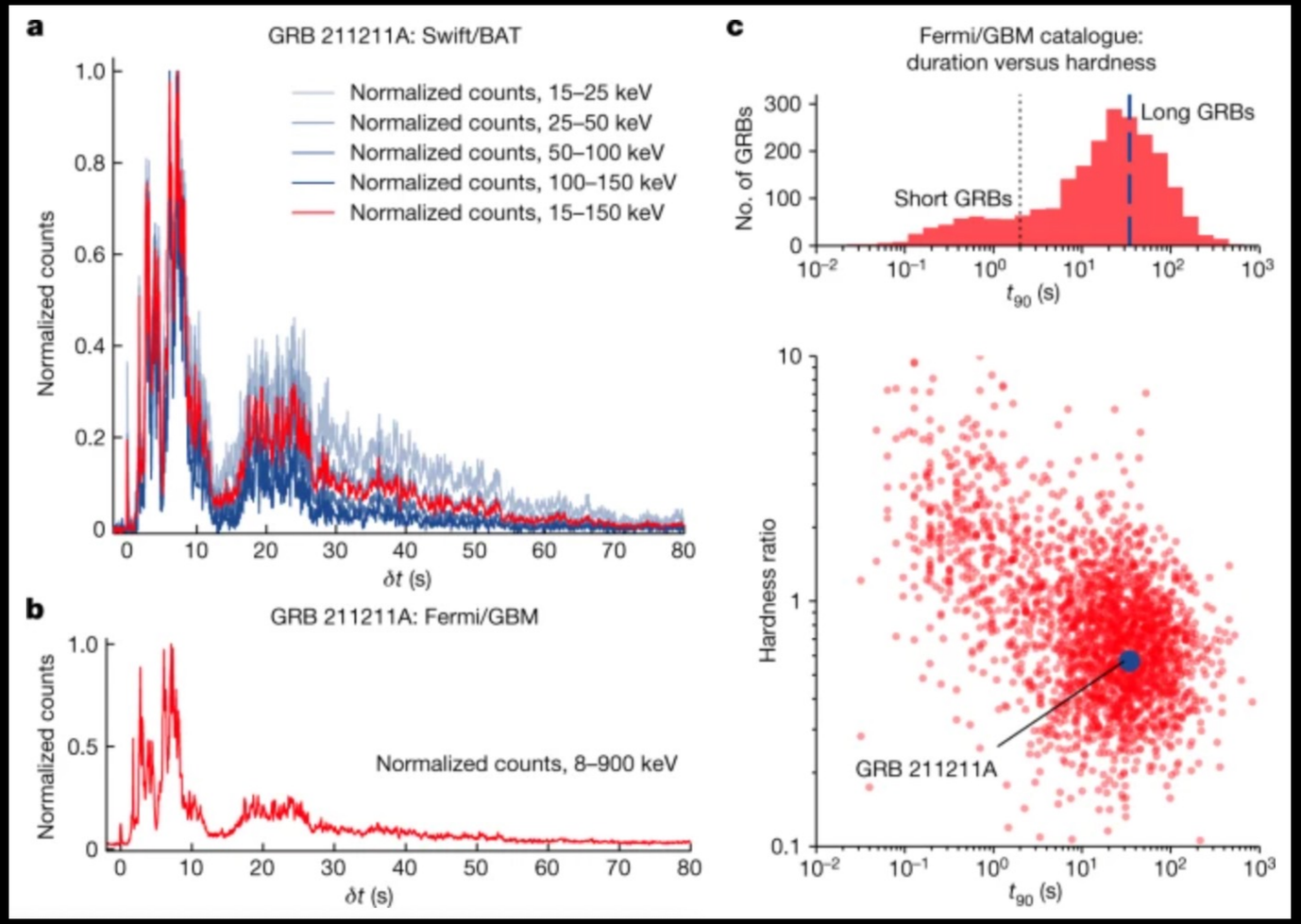




CLASSIFICATION COMPLEXITY: LONG VS SHORT

GRB211211A: A VERY LONG SHORT

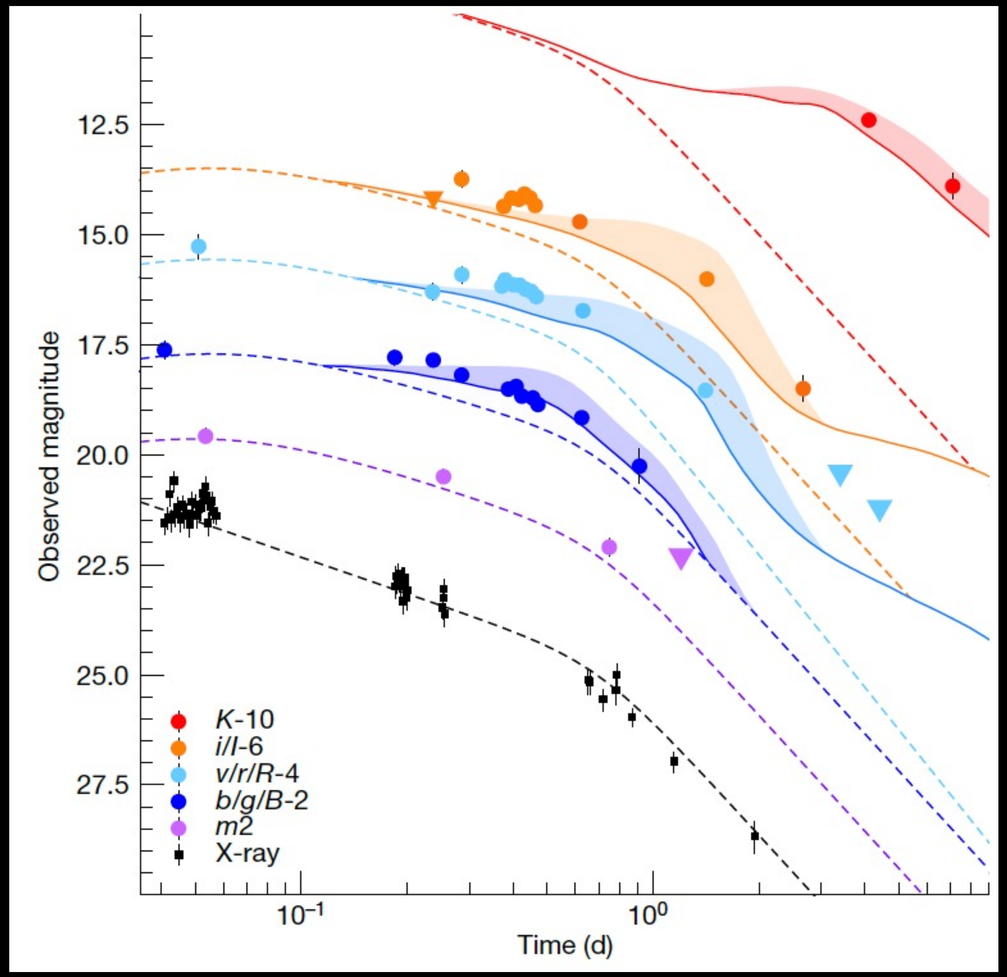
- Duration (t90) = 50 s, and spectral properties consistent with long GRBs
- 8 kpc in projection from a d = 350 Mpc galaxy (no host directly underneath afterglow position)
- No supernova emission at late times (200 x fainter than SN1998bw)



Rastinejad+2022a

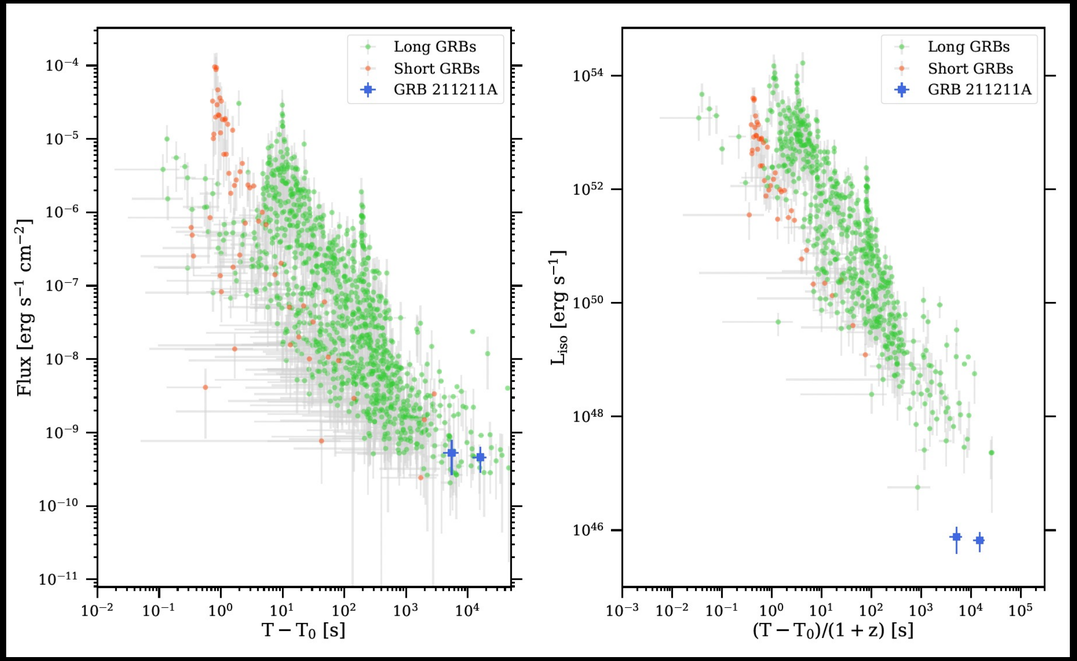
GRB211211A: A VERY LONG SHORT

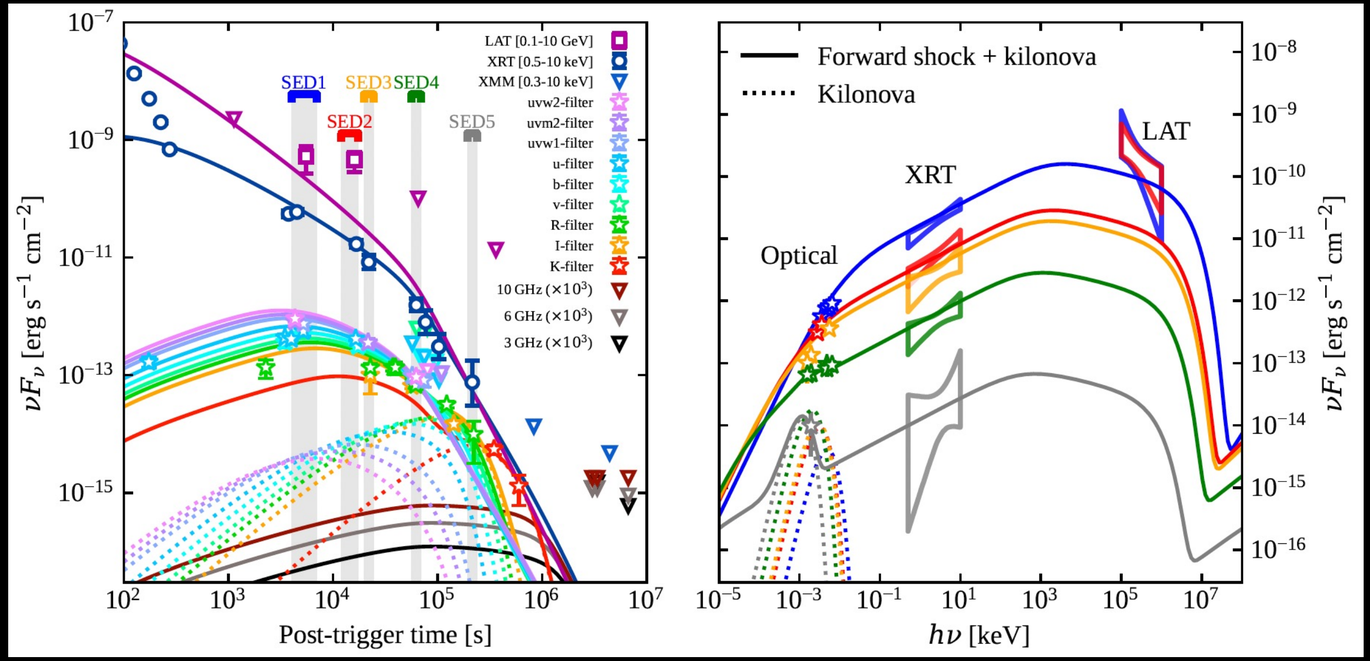
- Optical and (in particular) NIR excess beyond afterglow -> kilonova
- Strong resemblance to AT2017gfo / GW170817
- Challenging to reproduce with only radioactive emission - jet-ejecta interactions may be important?



Troja+2022

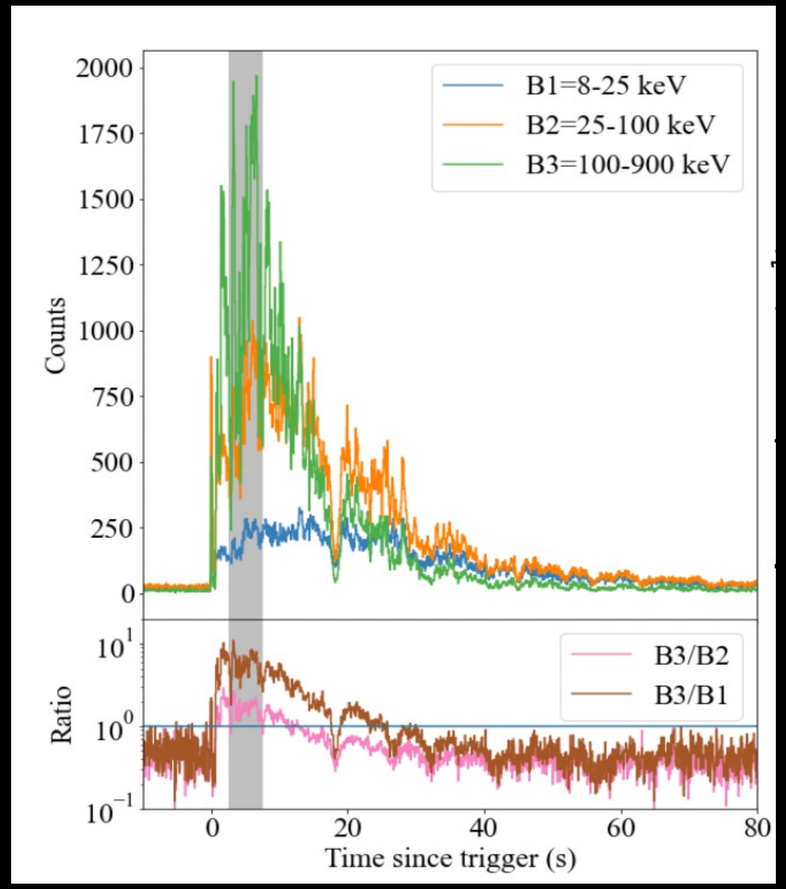
GRB211211A: GEV EMISSION

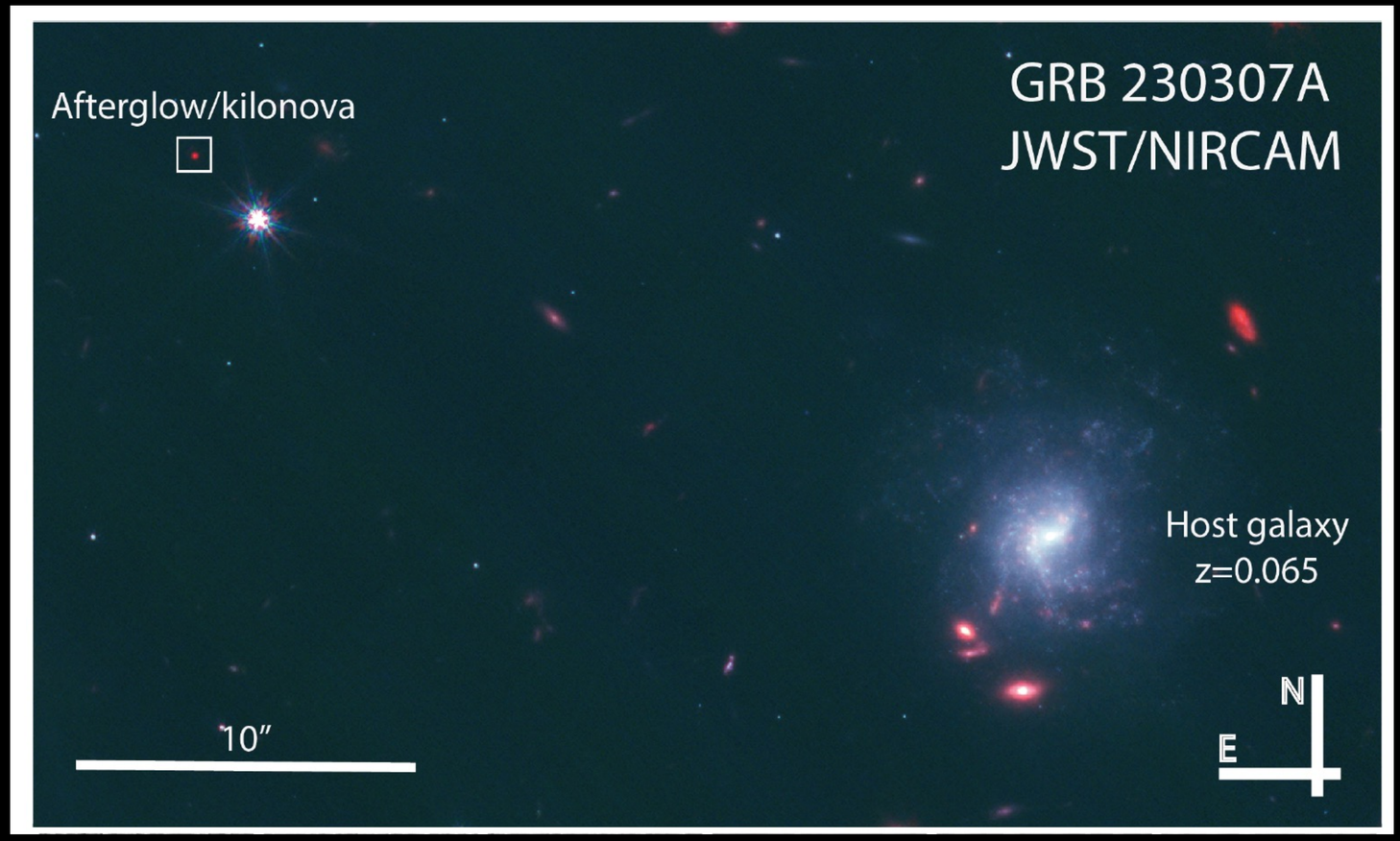




Mei+2022

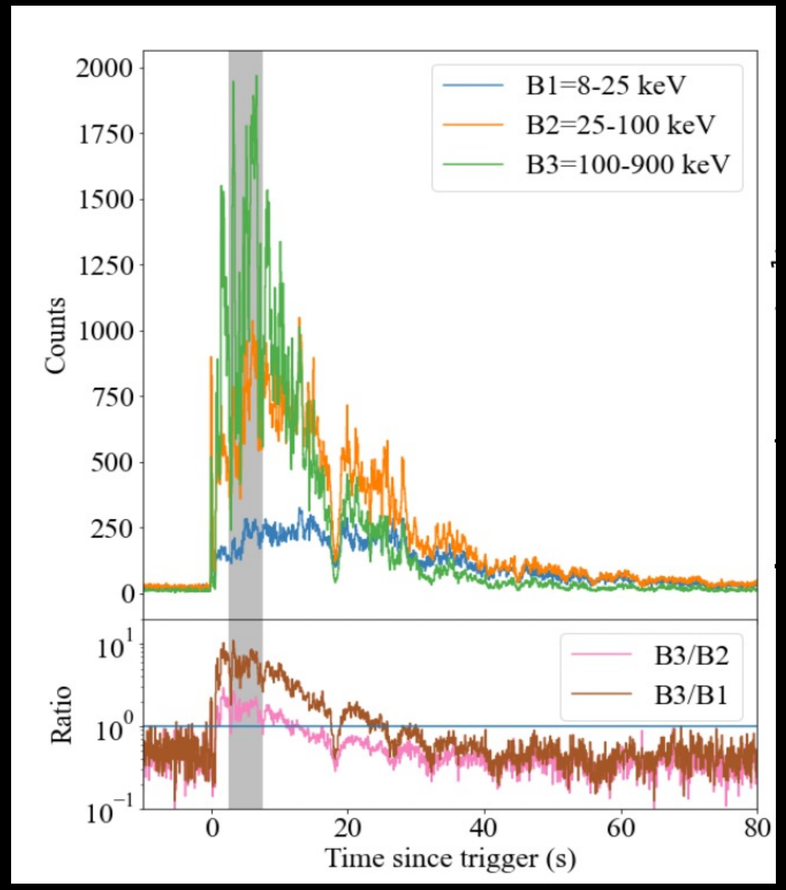
GRB 230307A: ANOTHER SHORT LONG GRB

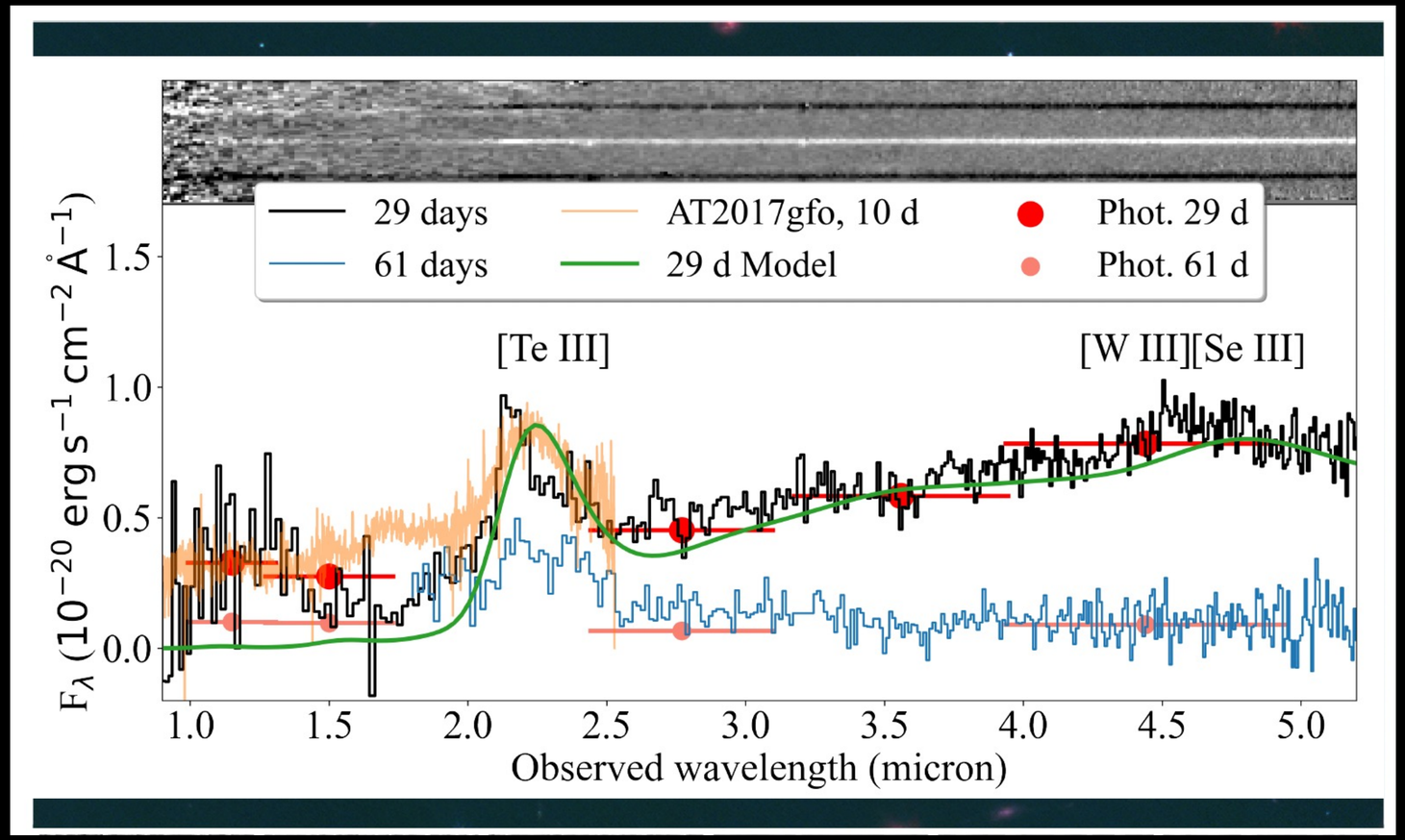




Levan+2023

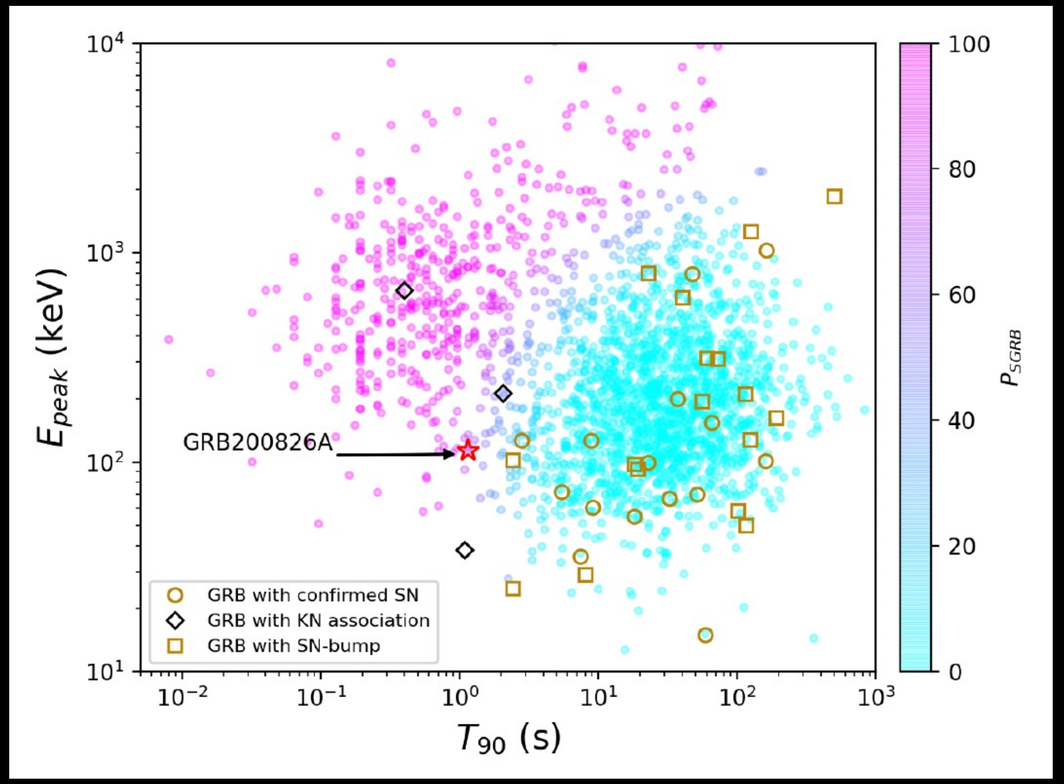
GRB 230307A: ANOTHER SHORT LONG GRB

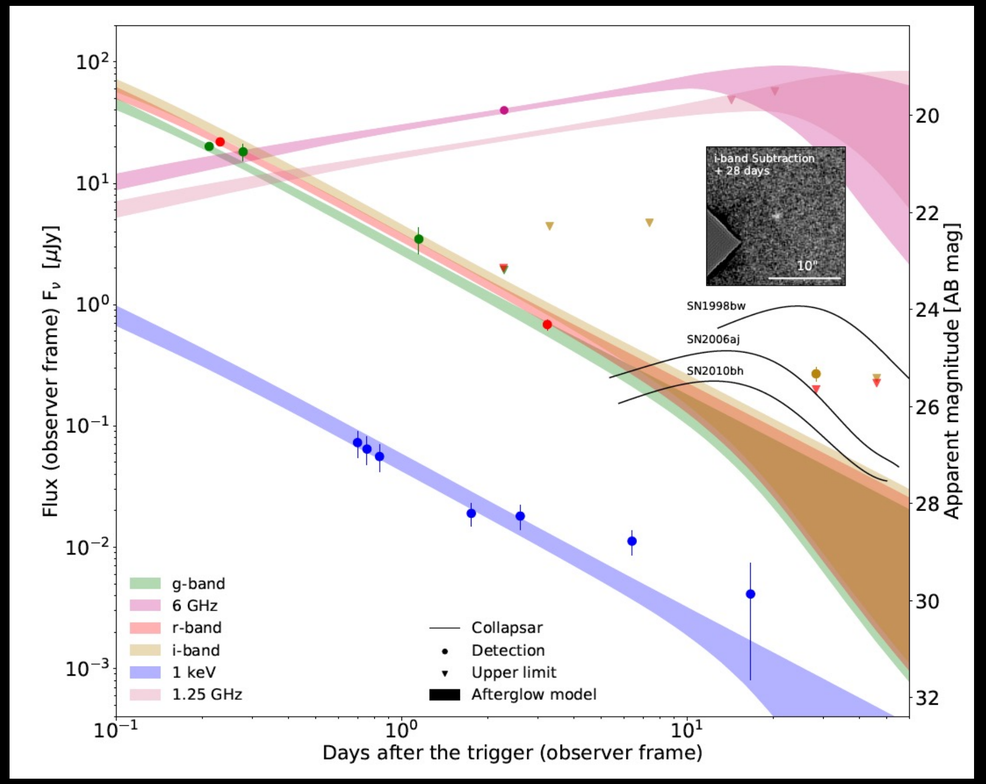




Levan+2023

GRB200826A: A VERY SHORT LONG

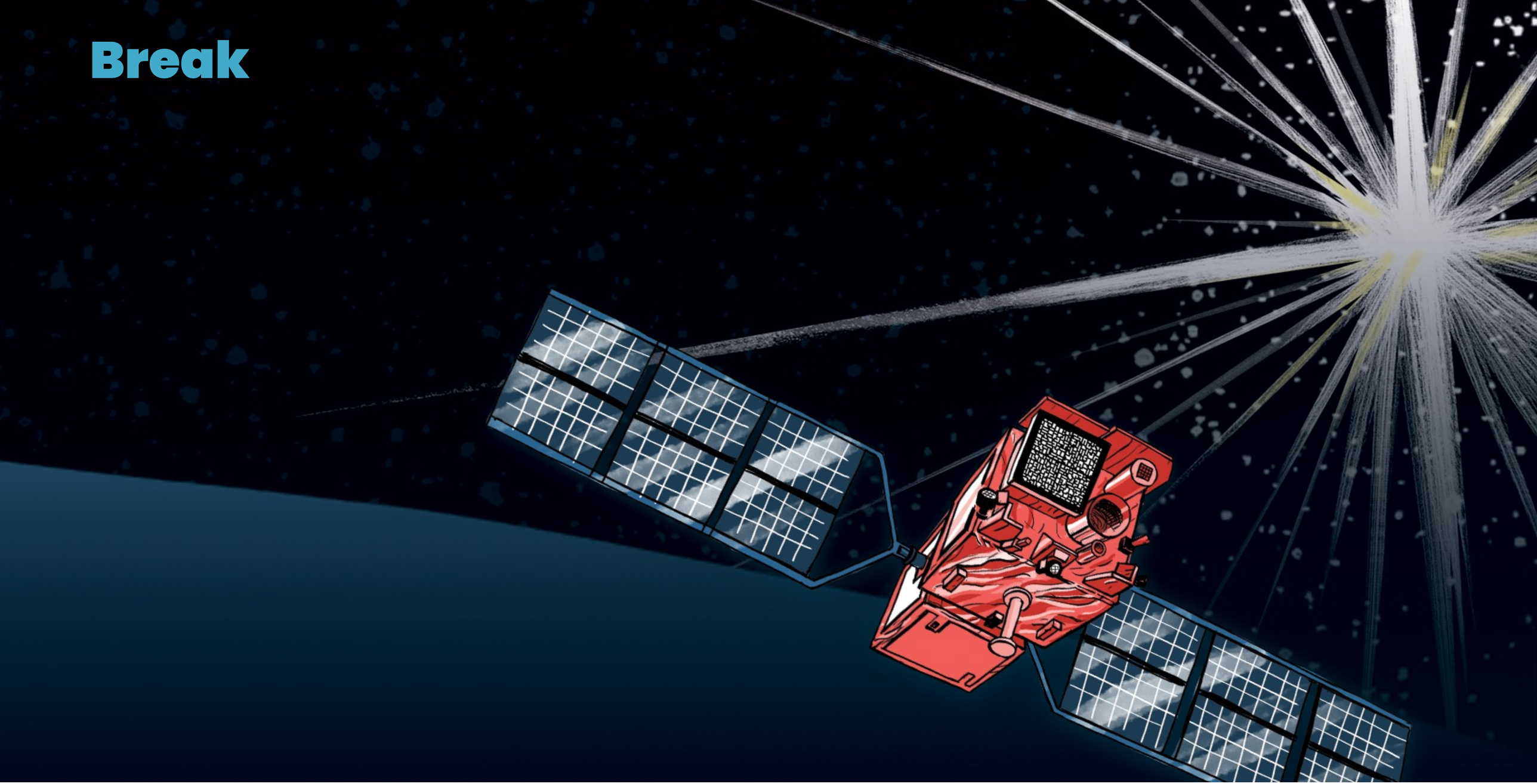




A short GRB with an associated supernova

Ahumada+2022a

Break



First Results from the SVOM mission

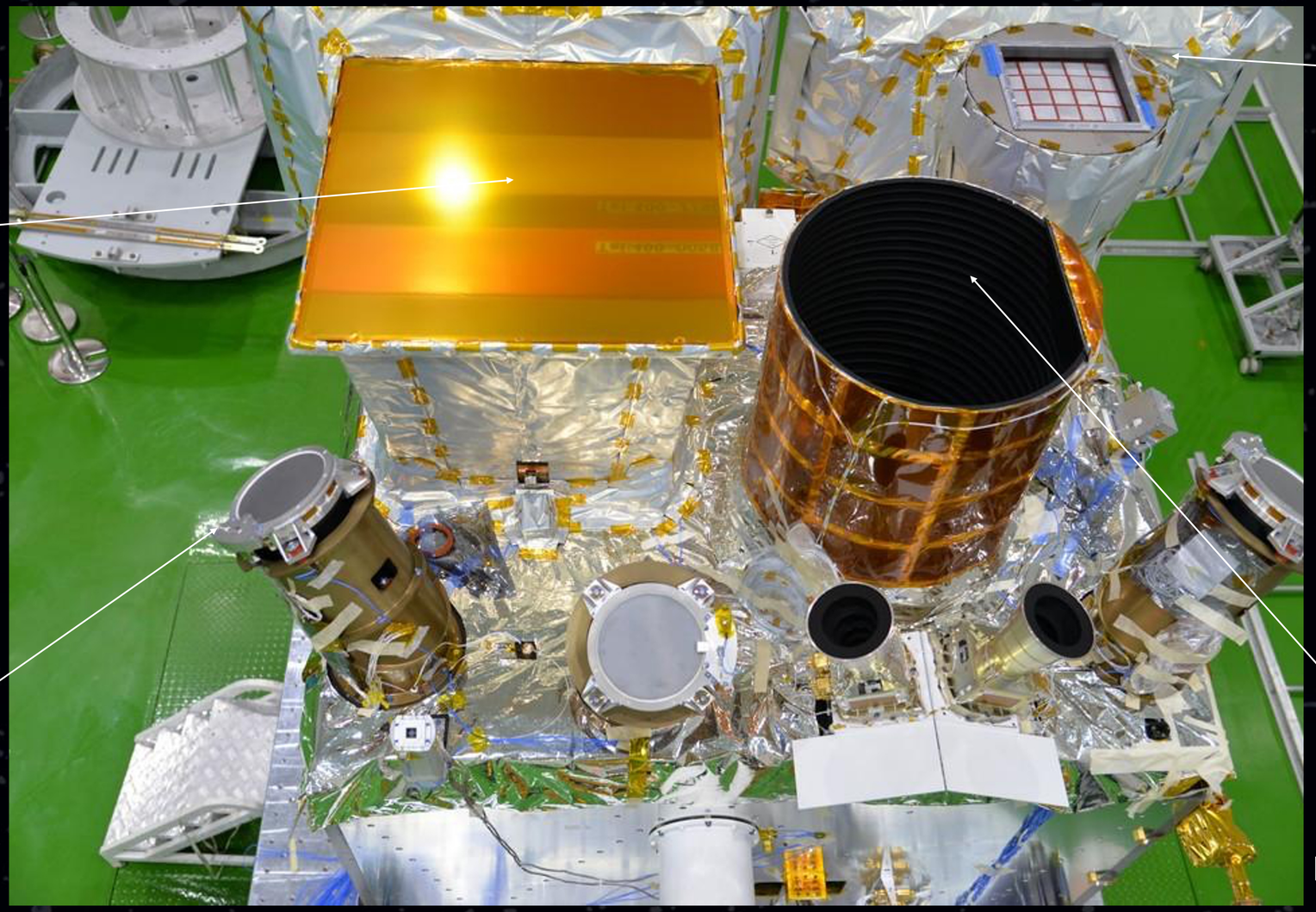
2024 June 22
SVOM
Launch

https://www.svom.eu/

- **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
  - LUX Meudon
  - IAP Paris
  - IRAP Toulouse
  - IJCLab Orsay
  - LAM Marseille
  - LUPM Montpellier
  - OAS Strasbourg
- **UK** University of Leicester
- **Germany**
  - MPE Garching
  - IAAT Tübingen

https://fsc.svom.org/home/collaboration/collaborators



ECLAIRs

Wide field hard X-ray telescope

GRM

Wide field gamma-ray spectrometer

MXT

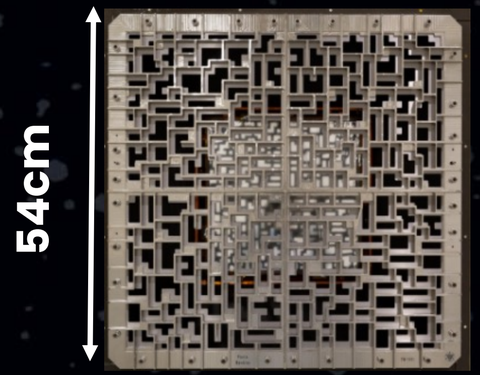
Narrow Field X-ray telescope

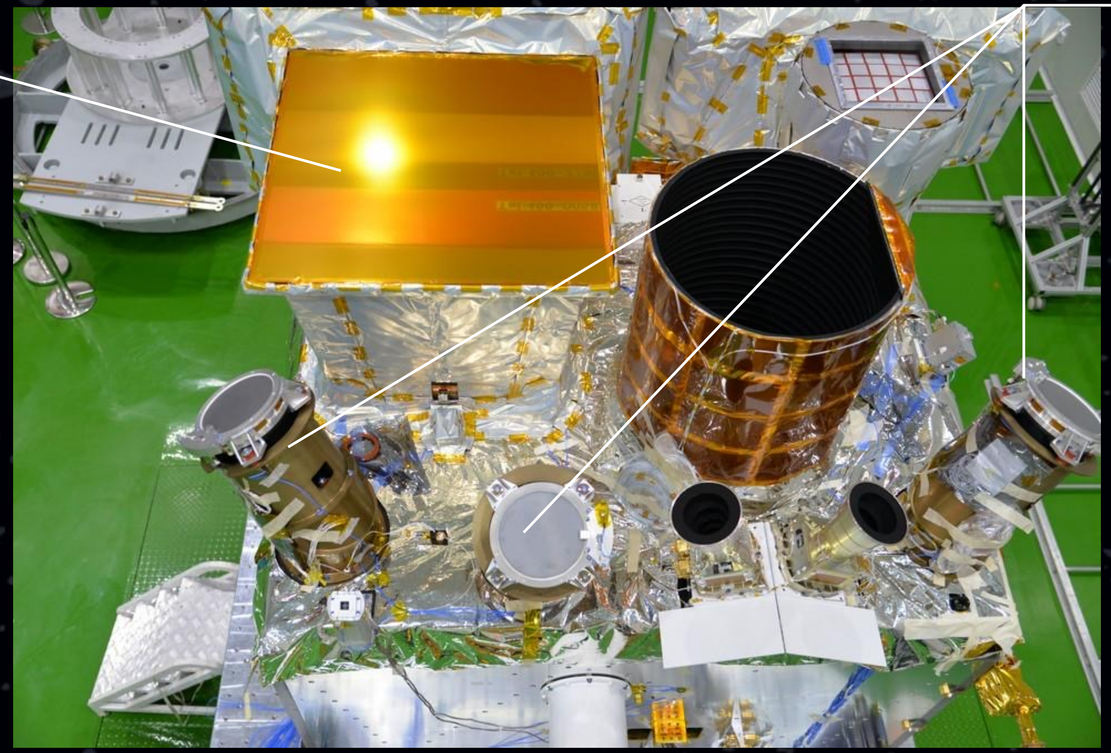
VT

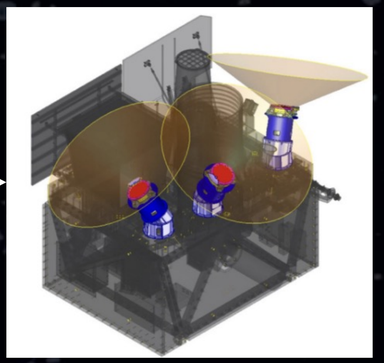
Narrow Field Visible telescope

I- SVOM: a satellite to study the high-energy transient sky

• The SVOM γ-ray monitors







ECLAIRs

A coded-mask with CdTe pixels detection plane
Energy range: **4**-150 keV
FoV = 45° x 45° ~ 2 sr (⅛ of all sky)
A_{eff} = 200cm^2 @6keV

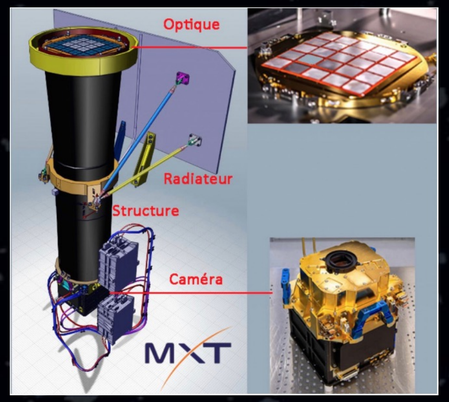
An onboard real-time trigger and localization system (UGTS):
20 ms to 20 min timescales
4 energy bands
<12 arcmin localisation (radius)

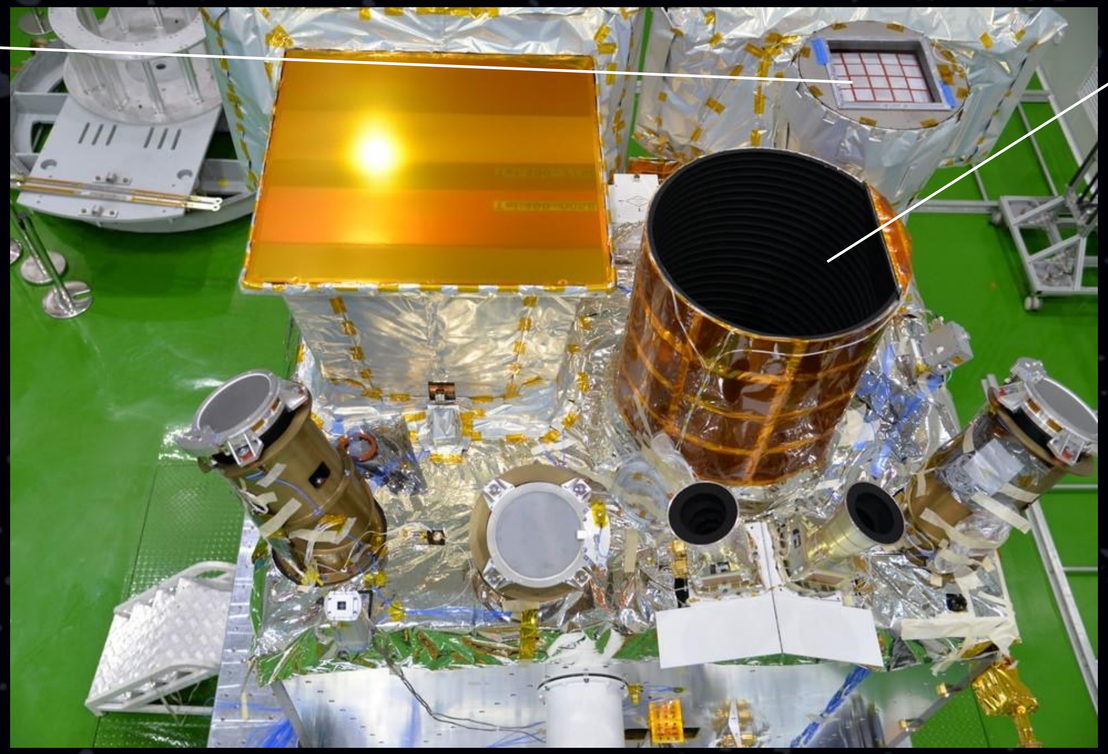
Gamma-Ray Monitor (GRM)

3 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
Energy range: 15-5000 keV
FoV ~ 5.6 sr (~2 sr per GRD)
Aeff = 190 cm² at peak (each unit)
Real-time trigger (2 GRDs)
Rough localization accuracy

I- SVOM: a satellite to study the high-energy transient sky

The SVOM follow-up instruments





Micro-channel X-ray Telescope (MXT)

Micro-channel plate optics

FoV = 58x58 arcmin²
Energy range: 0.2-10 keV
Energy resolution ~80 eV @1.5 keV
Aeff = 27 cm² @1 keV (central spot only)
Localization accuracy <1 arc min

Visible Telescope (VT)

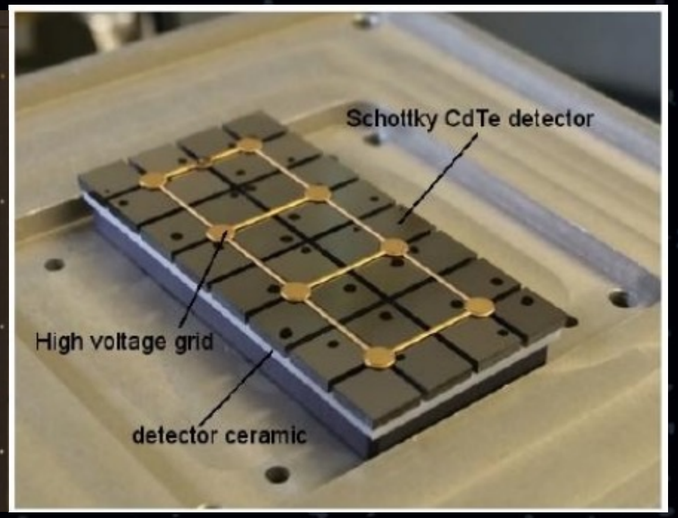
40 cm Ritchey-Chrétien Telescope
2 channels: blue (400-650 nm) and red (650-1000 nm)

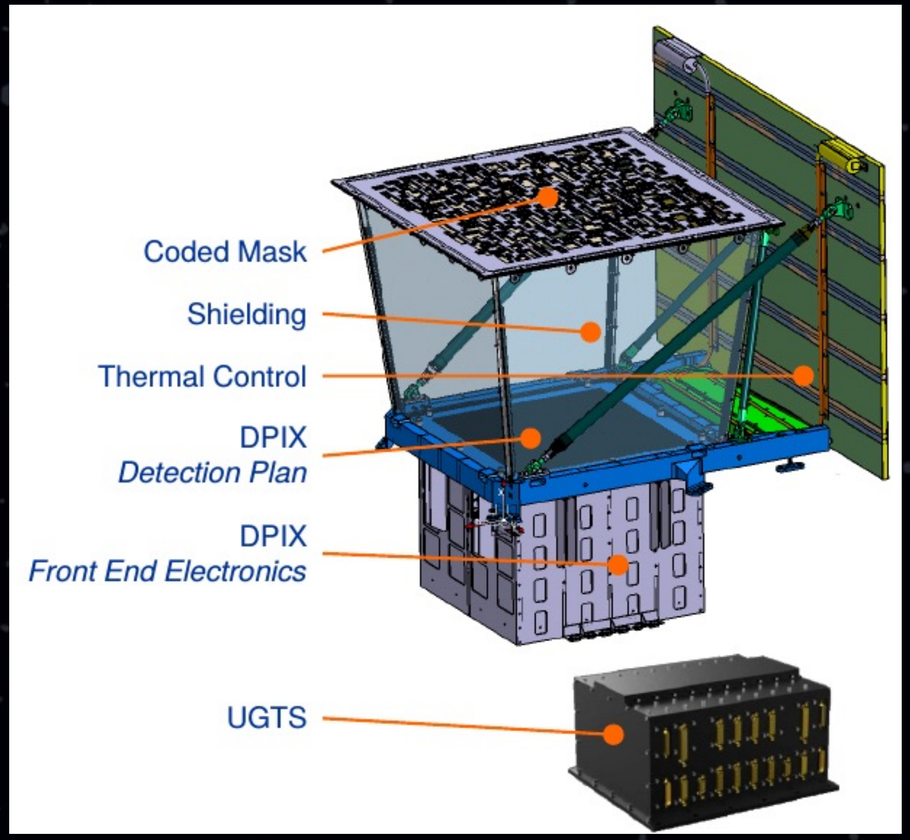
2k x 2k CCD detector each
FoV : 26 x 26 arcmin²
covering ECLAIRs error box in most cases
Sensitivity M_V = 22.5 in 300 s

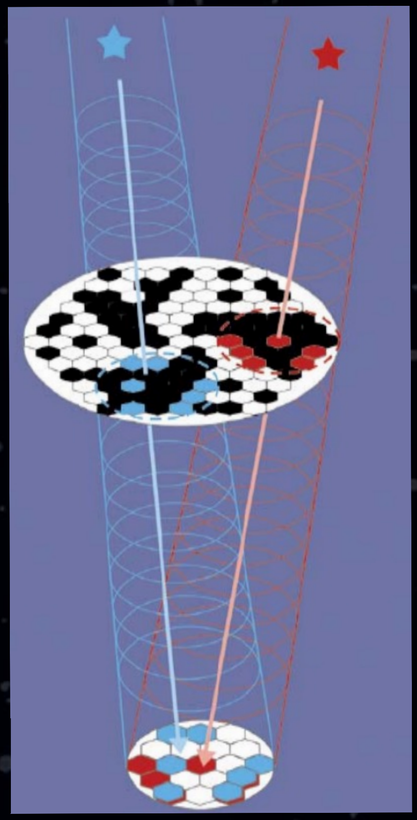
Designed to detect ~80% of ECLAIRs GRBs

Localization accuracy < 1 arcsec

The ECLAIRs gamma-ray camera

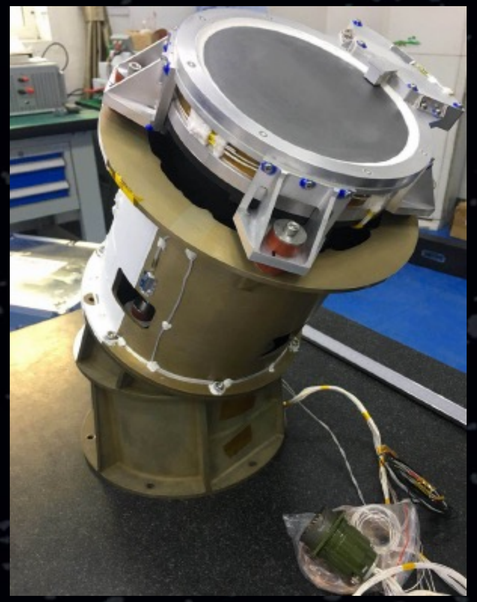


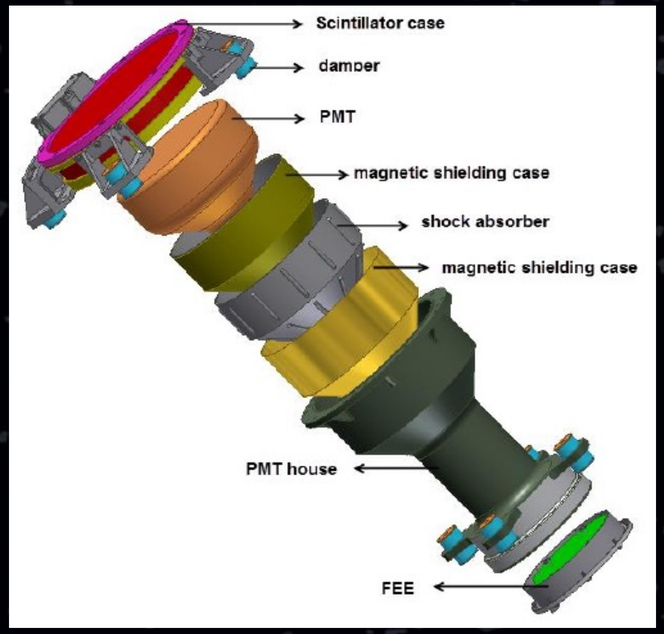


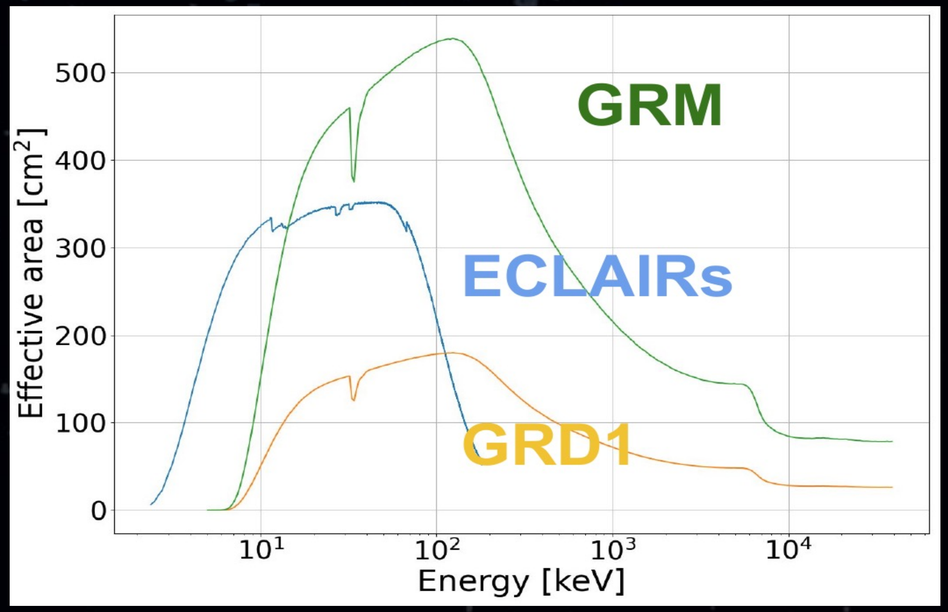


- **Coded mask 54x54 cm², 40% open fraction**
- **Detection plane area 1024 cm² (4-150 keV)**
  - 6400 CdTe pixels (4x4x1 mm3)
- **Onboard real-time trigger and localization (if SNRi>6.5)**
  - Strongly varying background (Earth transit through FoV every orbit)
  - Time scales from 10 ms to 20 min, 4 energy bands, 9 detector zones
  - Count Rate Trigger (CRT, ≤20 s) and Image Trigger (IMT, ≥20 s)
- **Slew request within ~25 s (if SNRi>7)**

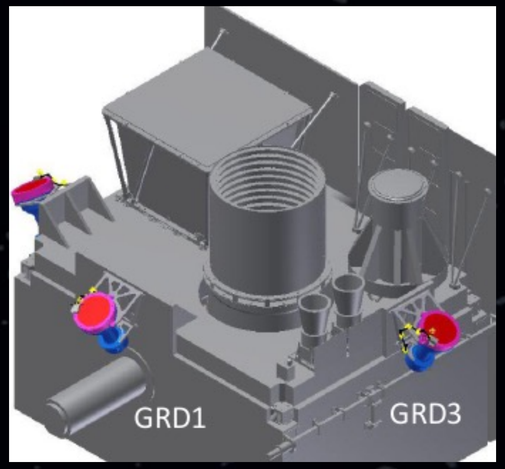
The GRM spectrometer



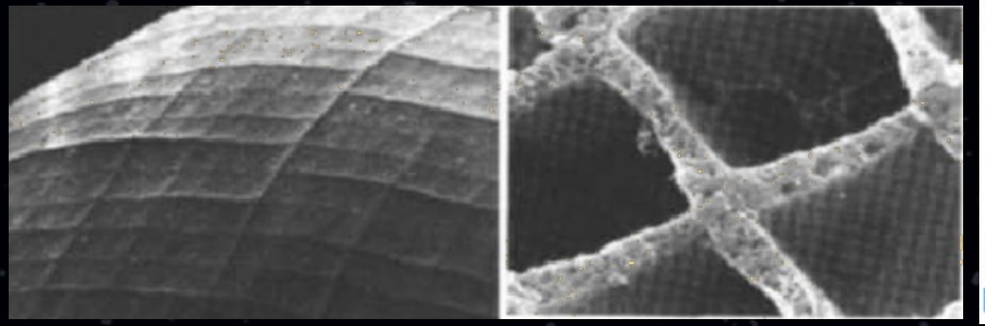


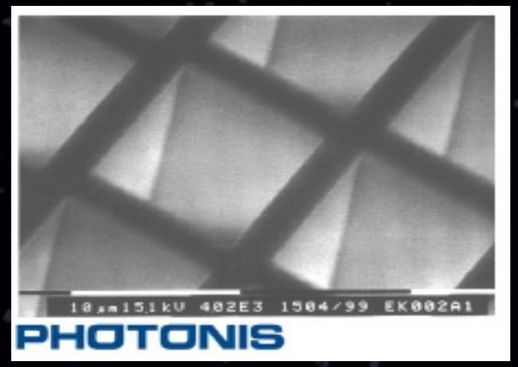


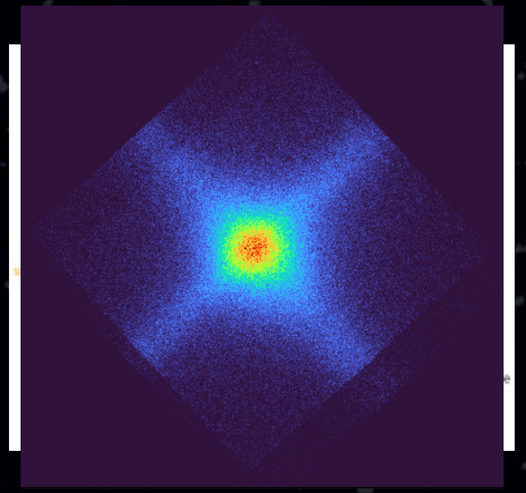
- **3 Gamma-Ray Detectors (GRDs, 15-5000 keV)**
  - NaI(Tl) (16 cm Ø, 1.5 cm thick)
  - 30° inclination w.r.t. ECLAIRs optical axis
- **Count Rate Trigger (2 GRDs above threshold)**
  - Time scales 0.1 to 4 s, 4 energy bands

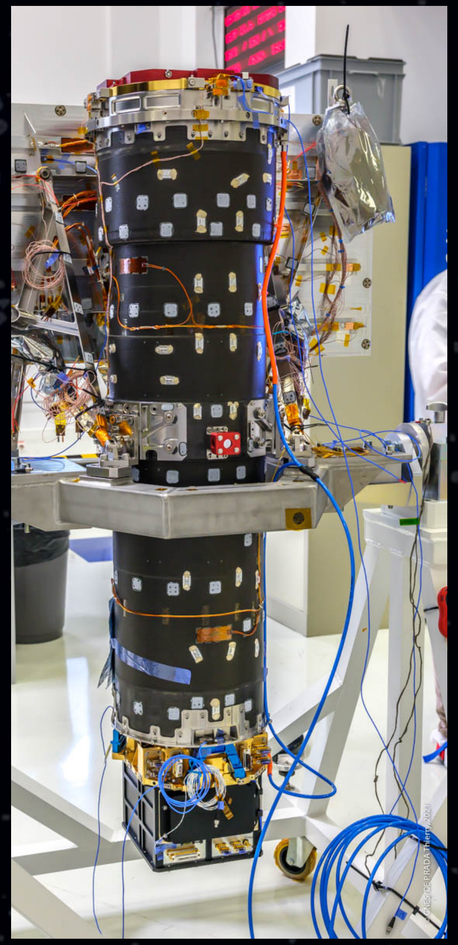


The Microchannel X-ray Telescope

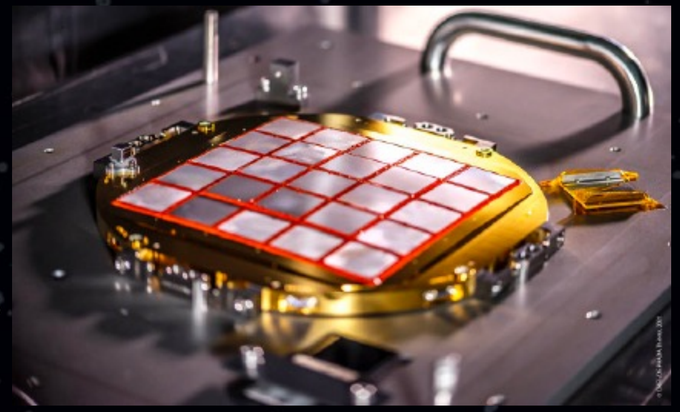




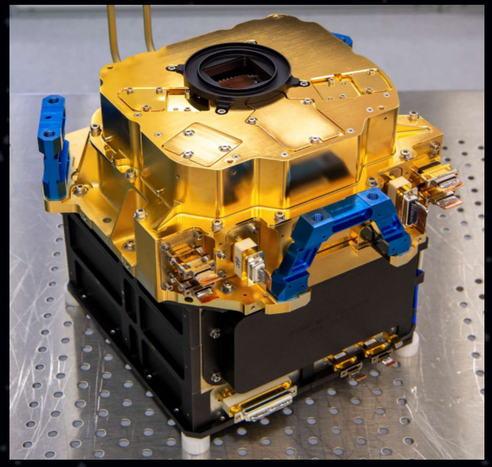




- **Micro-channel plate optics (0.2-10 keV)**
  - 40 micron size pores in a “lobster eye” configuration
  - Focal length: 1.15 m



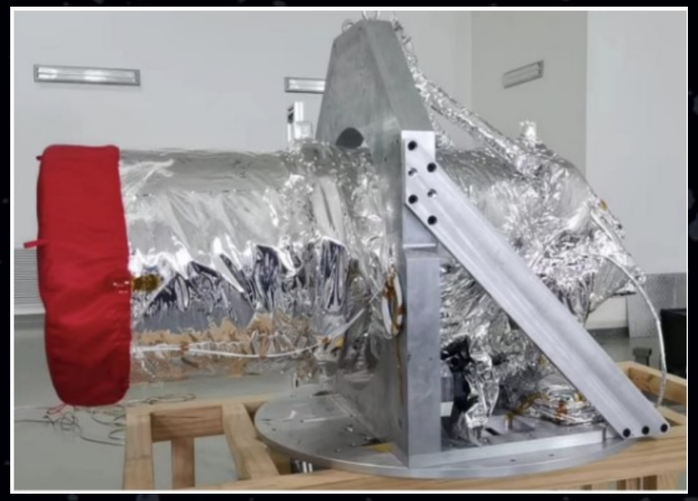
- pnCCD camera (256x256 pixels of 75 microns), cooled at -65°C. State of the art spectral resolution

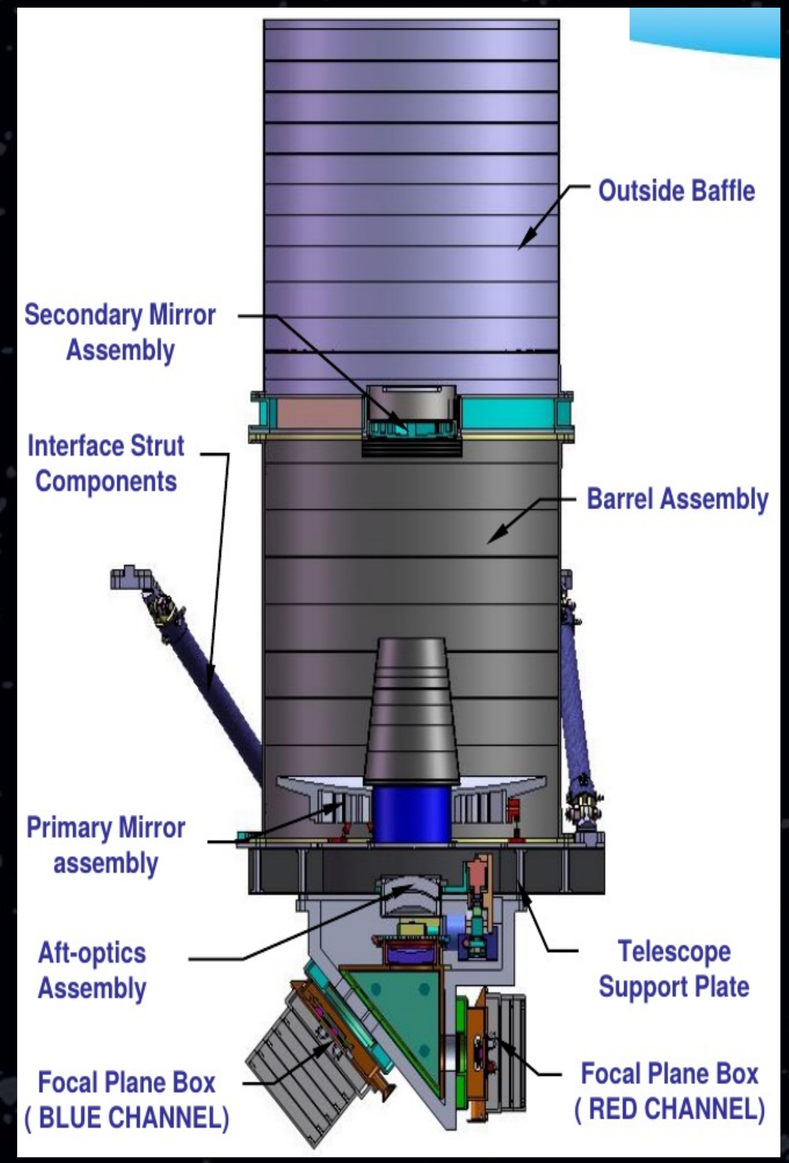


The Visible Telescope

- **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
- **FoV covering ECLAIRs error box in most cases**

Sensitivity $M_V = 22.5$ in 300 s





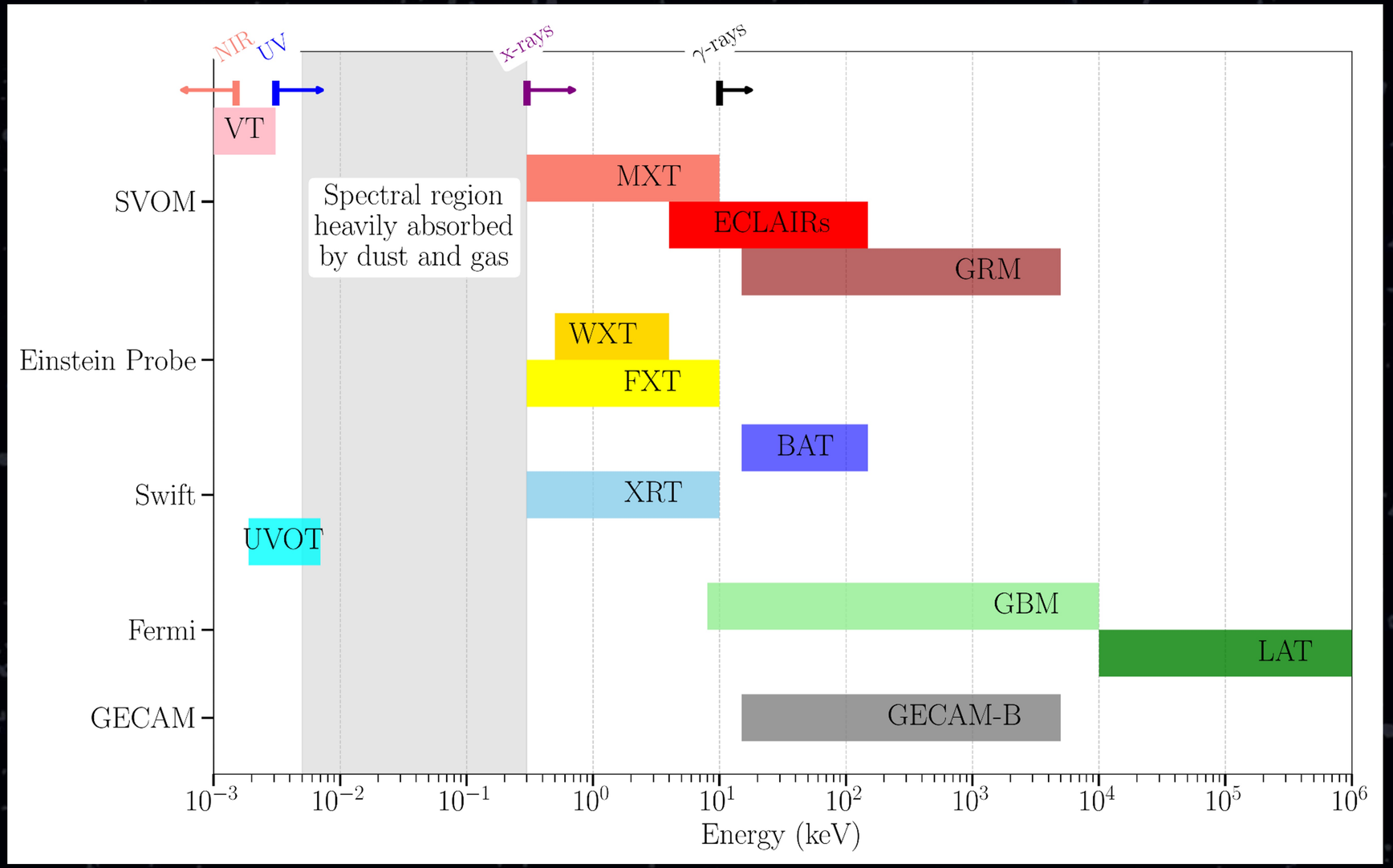
Ground based dedicated Telescopes

- **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
  - **FM-GFT (a.k.a. Colibri)**: 1.3 m, FoV = 26x26 arcmin², multi-band photometry (400-1700 nm, 3 simultaneous bands)
    - A new camera (CAGIRE) to be installed in coming months, allowing observations in J,H bands

- **Accurate GRB localization → observations with large telescopes**

SVOM: a unique spectral range to study the high-energy transients



They (except GRM) localize

(<10 arcmin)

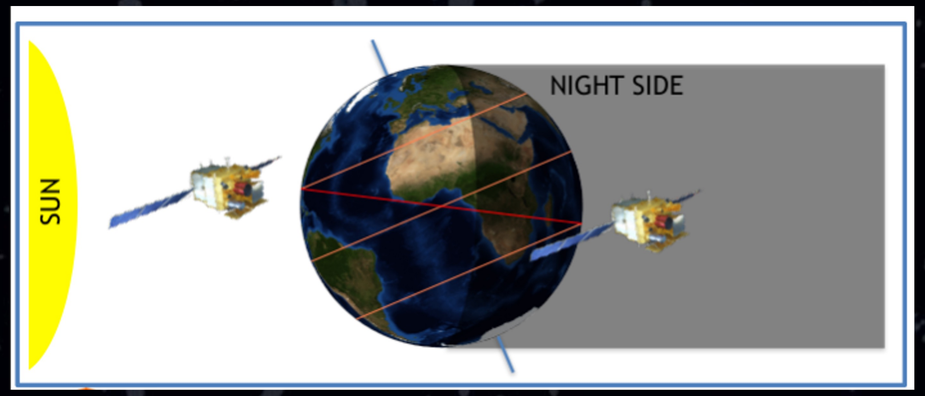
+

onboard auto follow-up of sources

SVOM is placed in a Low Earth Orbit (LEO)

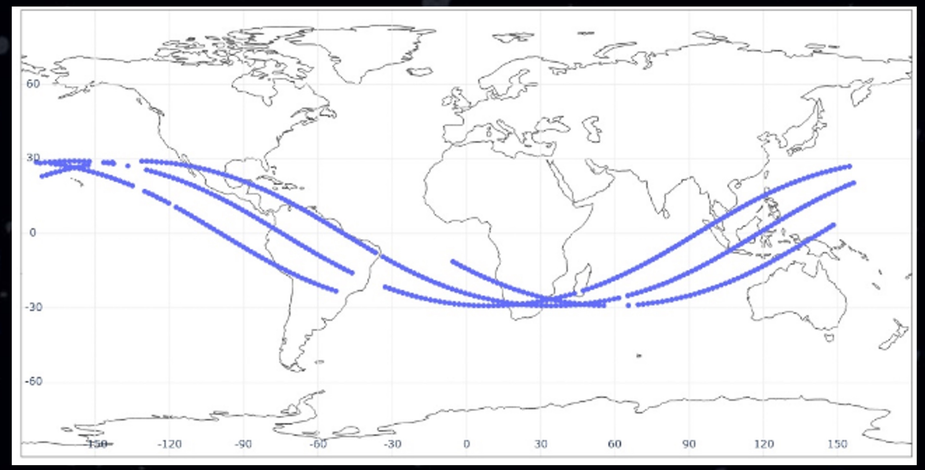
Anti-Solar pointing strategy

~625 km, ~29° inclination angle, 1 orbit ~ 96min



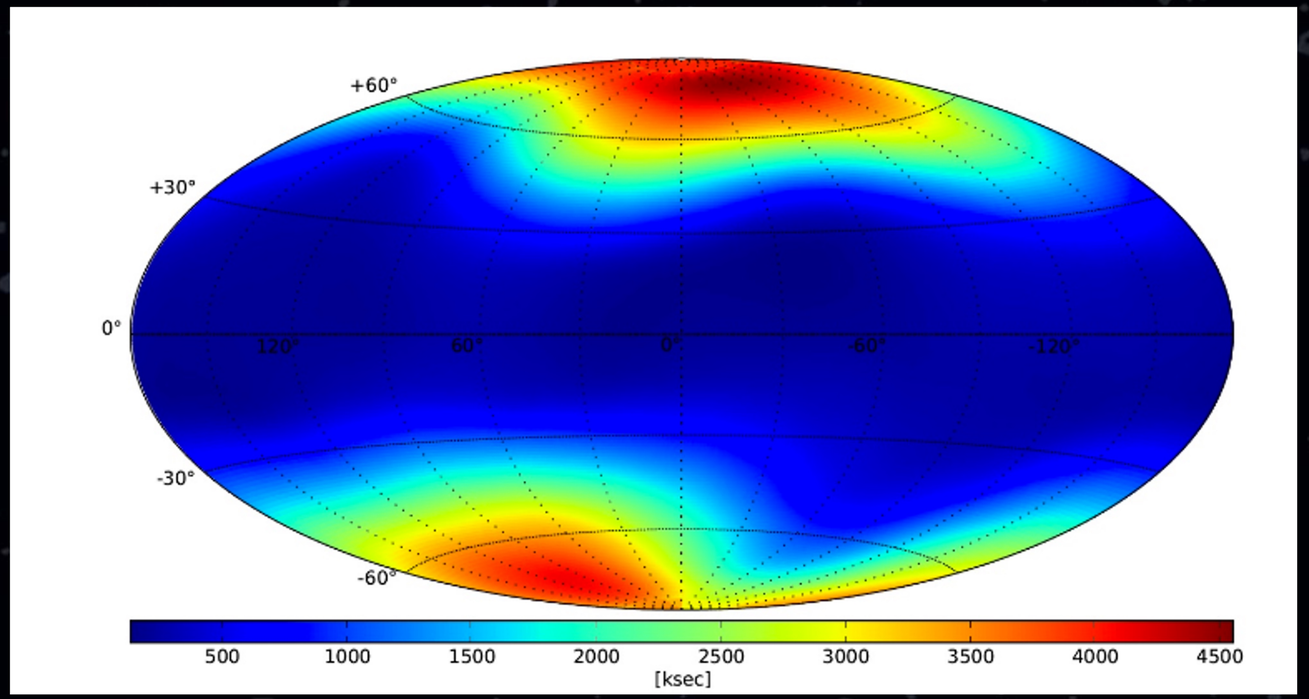
The satellite track on Earth

+/- 30° latitude

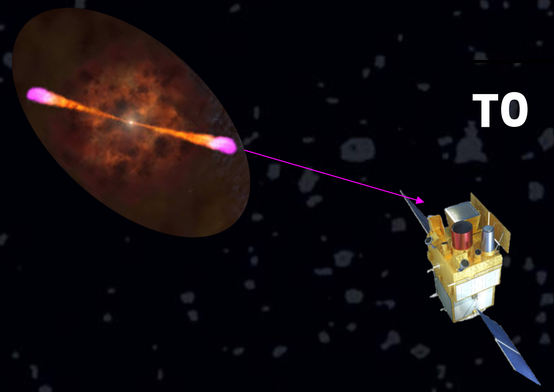


ECLAIRs exposure map simulation (over a year)

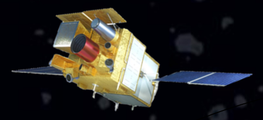
Initial Hypothesis : 65 GRBs/year, 1 ToO per day
- 4 Ms in the direction of the galactic poles
- 500 ks on the galactic plane

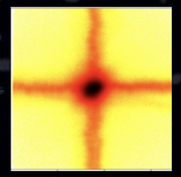


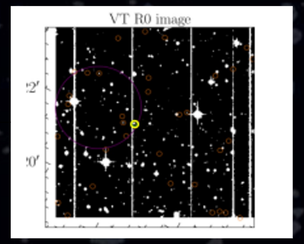
SVOM: a powerful transient detection and alerting machine

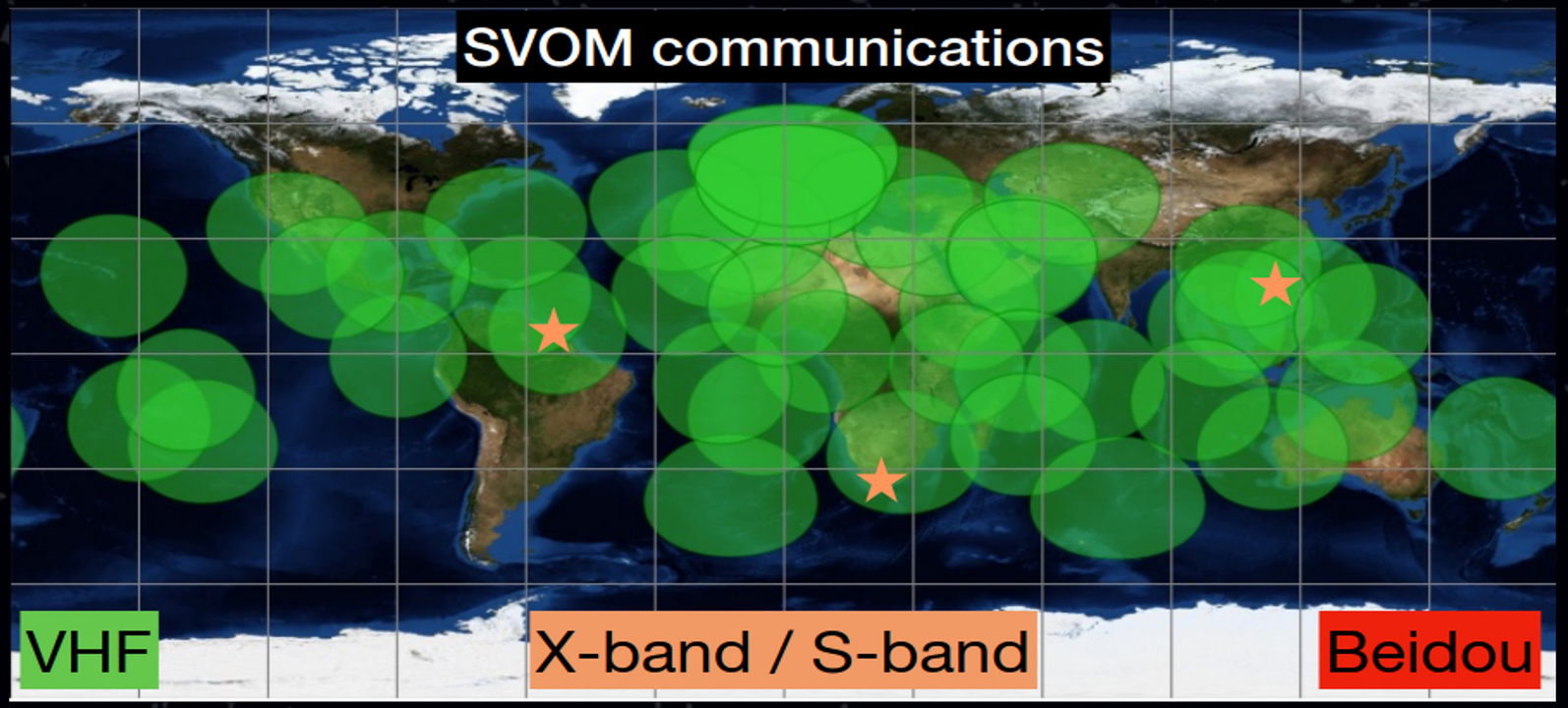


T0	Alert GCN T0 + 15″	slew+stabilization T0+2–3′	First MXT position T0+5′	VT afterglow identification	End of the auto onboard alert sequence T0+8h (5 orbits)









Downgoing links

- **VHF** (fast but few data products)
- **X-band** (slow but complete data)

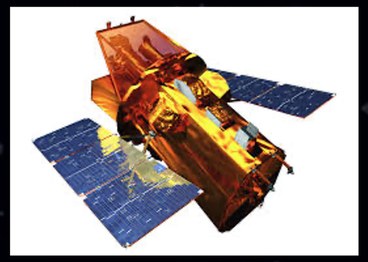
Upgoing links

- **S-band** (slow, few hours)
- **Beidou** (fast, few minutes)

SVOM: Boosting the space and ground-based telescope synergies

A dedicated ground-based follow-up segment
from 25 cm to the 8m class telescopes

Great synergies with Einstein Probe and Swift teams



Automatic follow-up request
EP-FXT
(since April 2025)
and
Swift-XRT
(Feb. 2025 – Feb. 2025)

- **Official Partners**
- **Associate Partners**
- **Bought time (LCO)**
- **Close collaboration**

SVOM: the scientific programs

Gamma-ray bursts

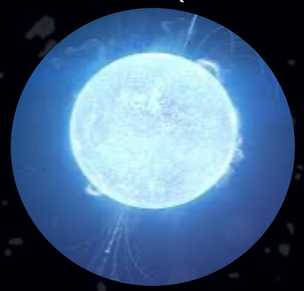
The SVOM Core program
reserved to SVOM Co-Is

Two SVOM science groups :
- GRB science : F. Daigne
- Observatory Science : A. Coleiro

ToO scientist : Cyril Lachaud

The General & ToO programs

GP obs (known sources): Observation proposals awarded by a TAC (your proposal has to include a SVOM co-I).
ToO obs (not anticipated flaring sources): If you want a ToO, please contact the SVOM PIs

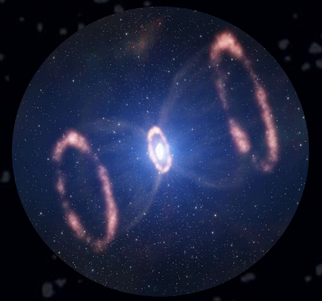


Magnetar Giant flares

CVs, x-ray binaries

Flaring stars

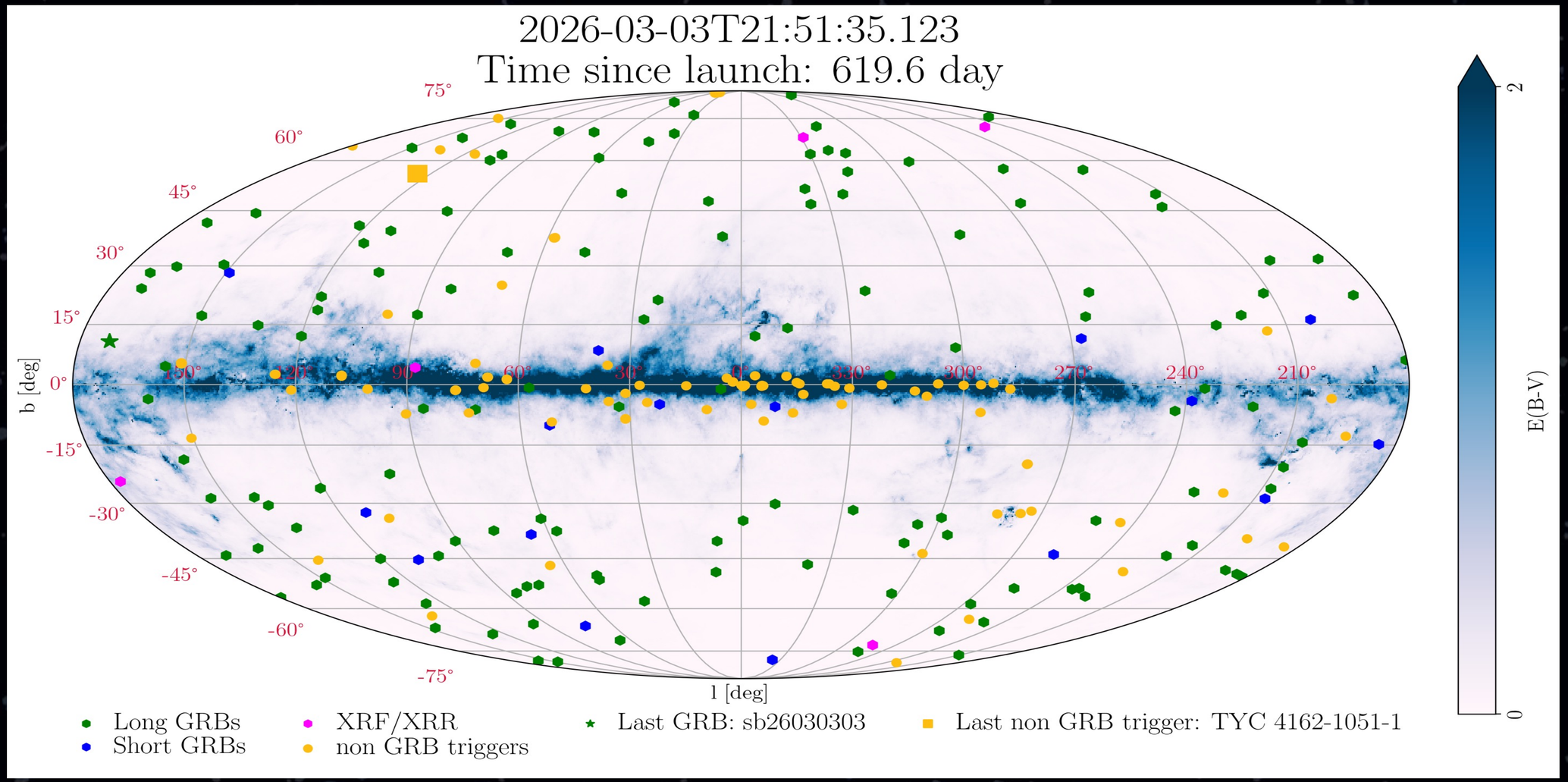
AGNs/Blazars



Supernovae

TDE, FRB, etc.

SVOM transient sources as of March 2026



More than 1700 GCNs related to SVOM since launch

SVOM General Program and ToOs

Serendipitous detections

High-energy source monitoring when present in the ECLAIRs field-of-view by chance

General Program (GP)

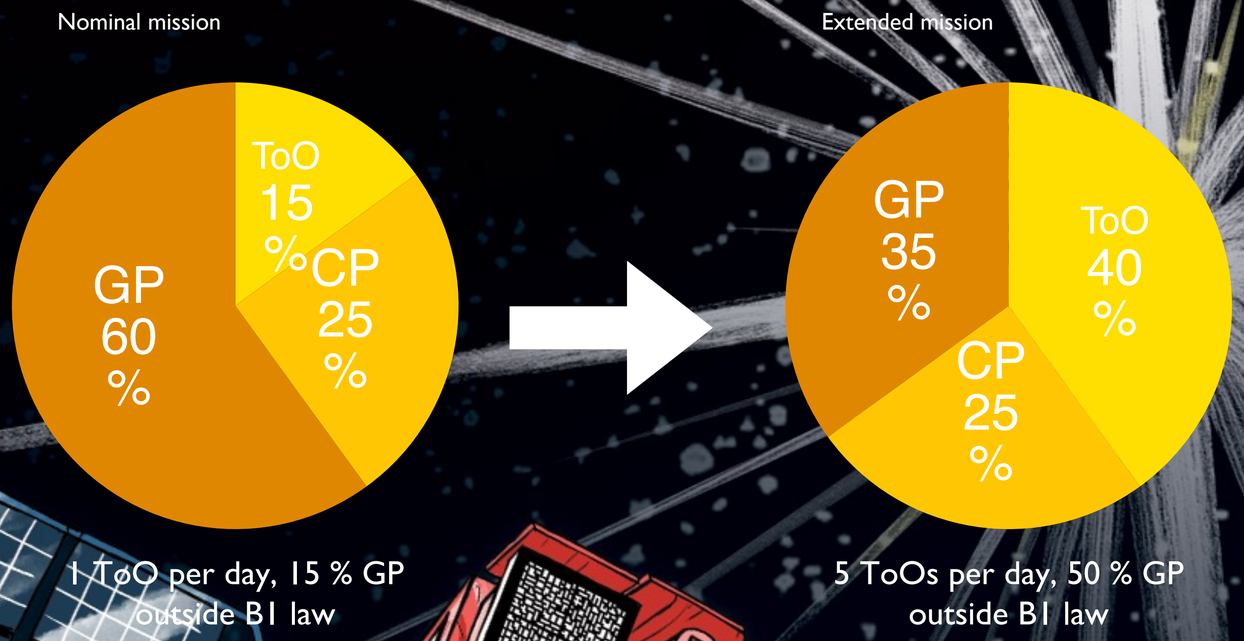
Observation proposals awarded by a TAC (proposals have to include a SVOM Co-I) - Yearly call for proposals (spring/summer 2026)

Targets of Opportunity (ToO)

ToO-NOM — Normal ToO

ToO-Ex — Fast ToO

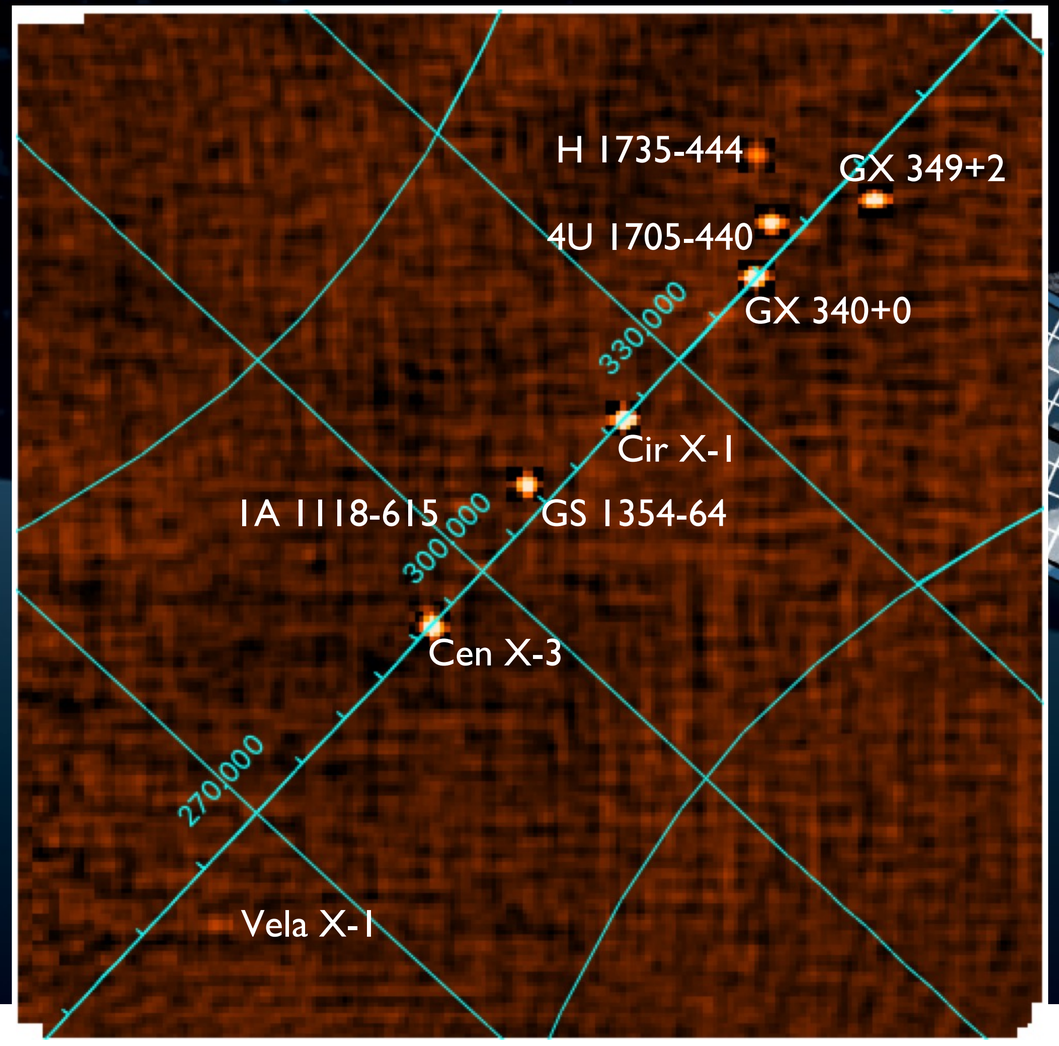
ToO-MM — For large error boxes, with a tiling strategy



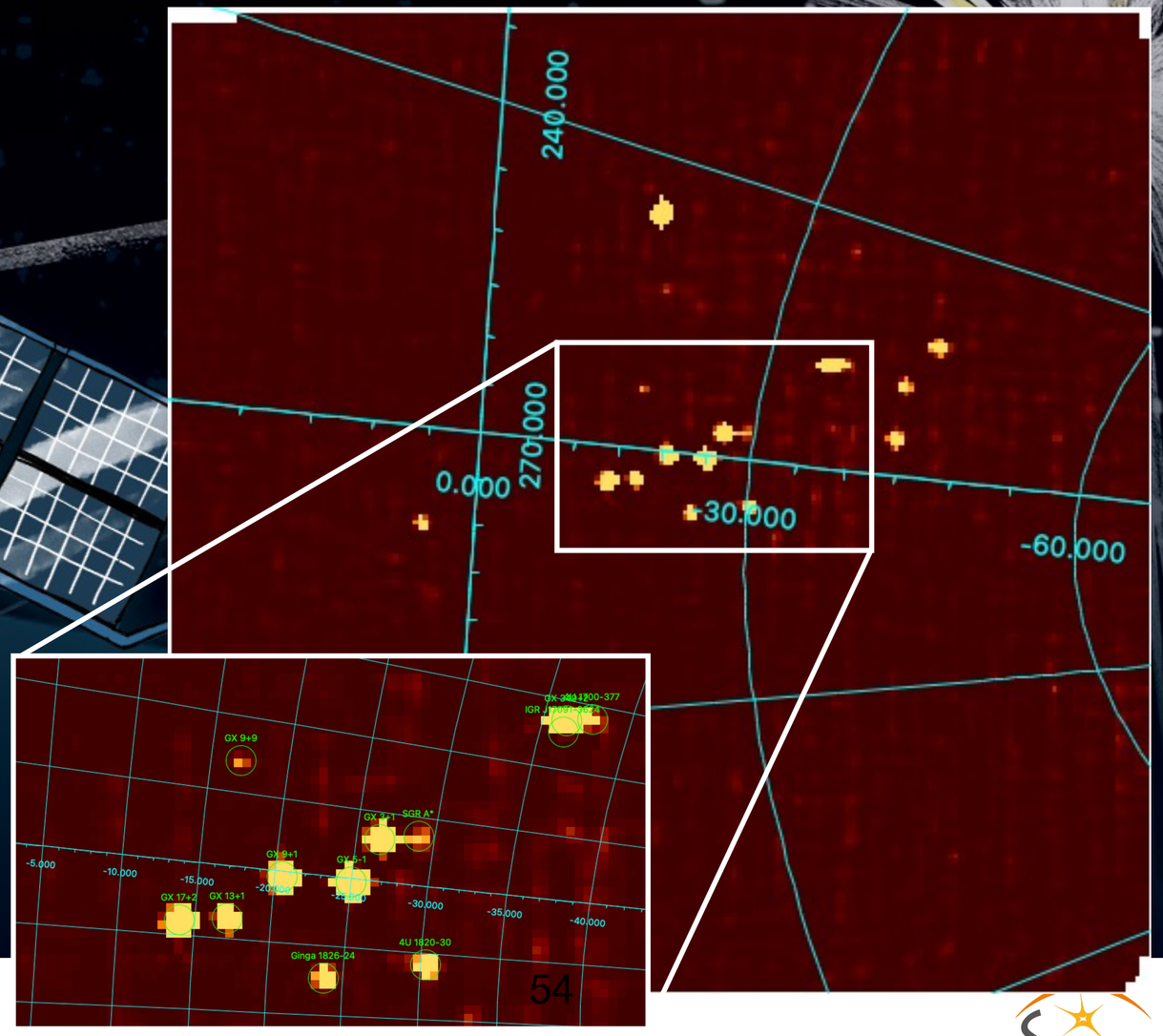
	ToO-NOM	ToO-EX	ToO-MM
Frequency	Nominal mission : 1/day Extended mission : 5/day	1/month => 1/day	1/week
Priority	Low	Highest	Very High
Upload Delays	< 48h (regular X-band)	< 12h (requested X-band)	< 12h (requested X-band)
Duration	Base: 1 orbit => 2.7 ks Max: 14 orbits => 38 ks SAA optimized	Max : 14 orbits => 38ks	Max : 14 orbits => 38ks SAA optimized

ECLAIRs monitoring of the hard X-ray sky

ECLAIRs 4-10 keV view of the Galactic plane

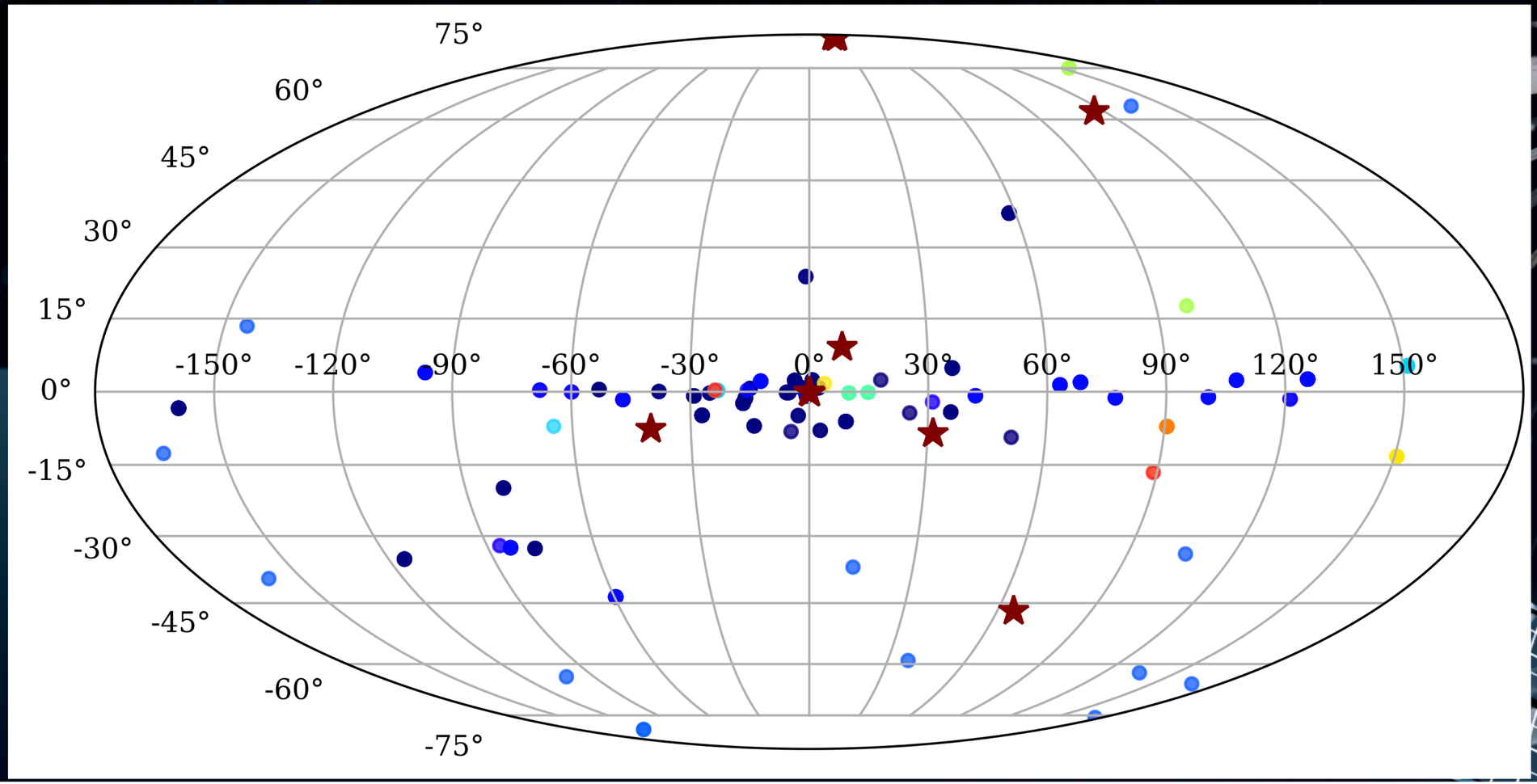


ECLAIRs 4-10 keV view of the Galactic center



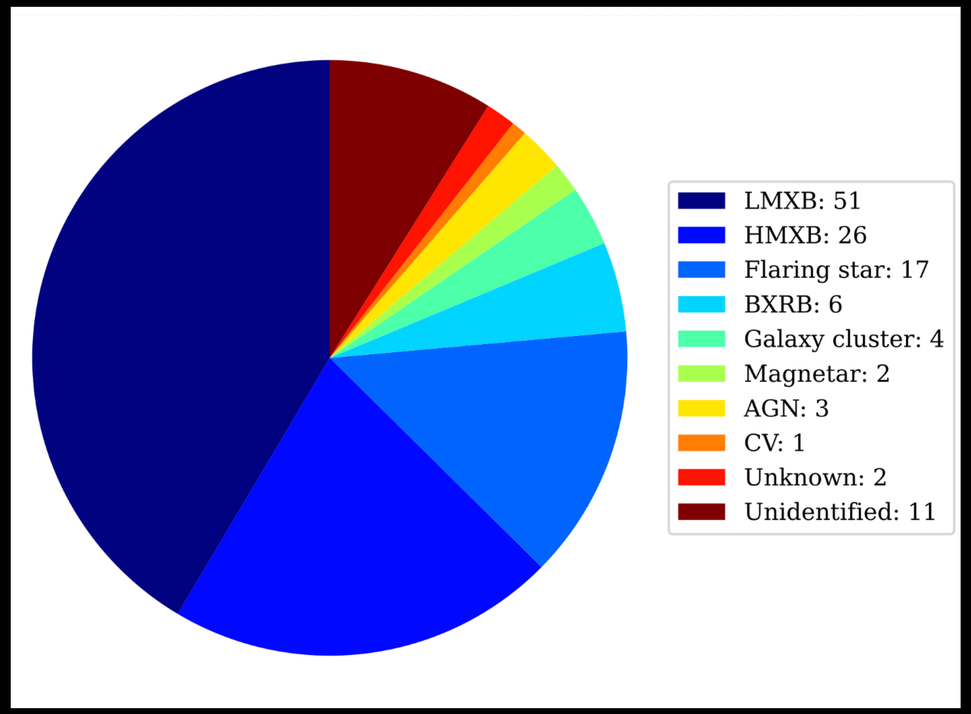
ECLAIRs monitoring of the hard X-ray sky

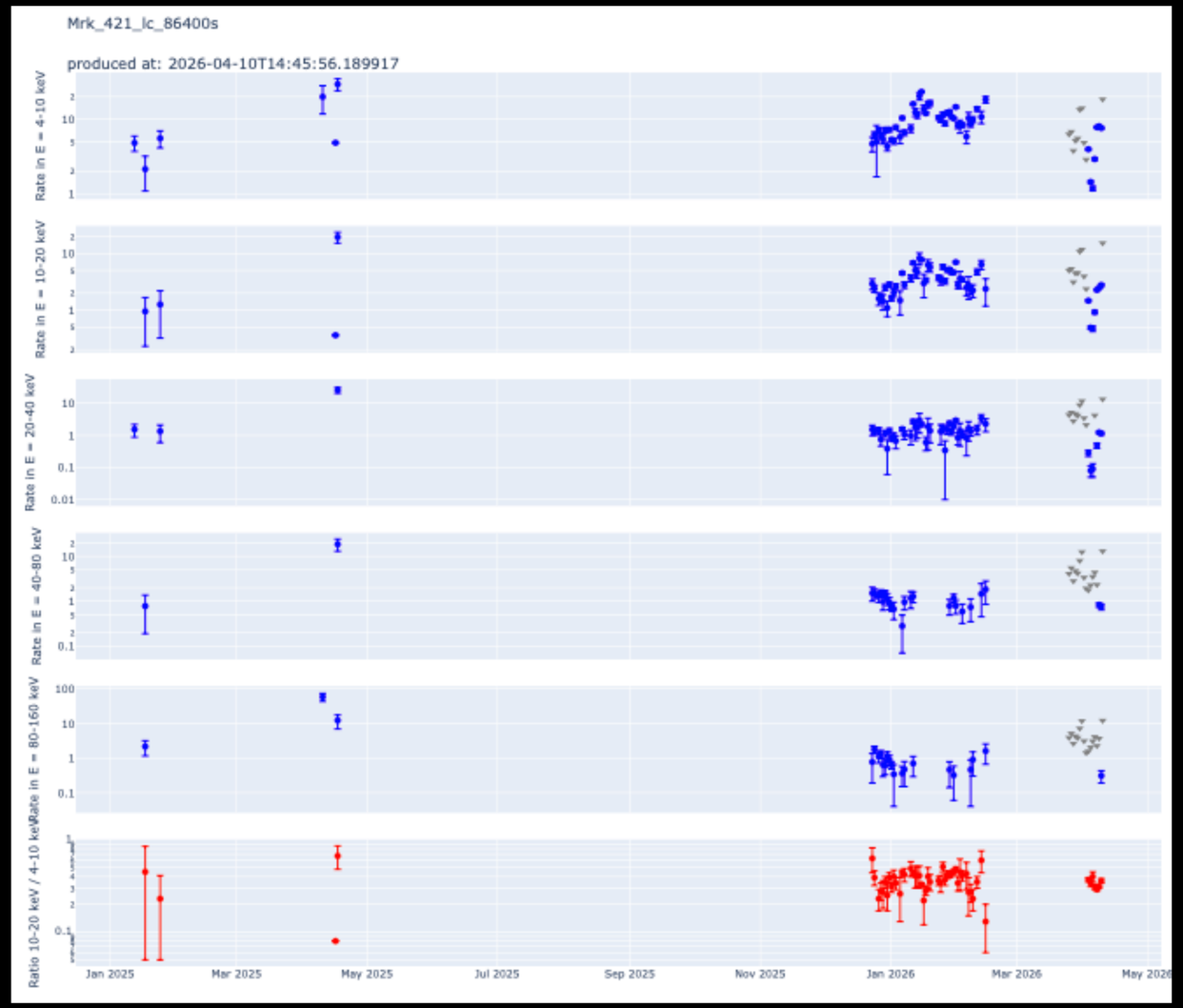
- **General statistics (on 24 March 2026)**



SERENDIPITOUS HIGH-ENERGY SOURCES WORKING GROUP (SHES-WG)

- **453 triggers** (298 onboard, 150 OFT) since the launch
  - **5 sources exhibiting (long-term) spectral state transitions detected with ECPI QLA light curves**
    - **27 ATels** on Type I X-ray bursts, HMXB/LMXB outbursts, AGN outbursts
    - **2 GCNs** on flaring stars



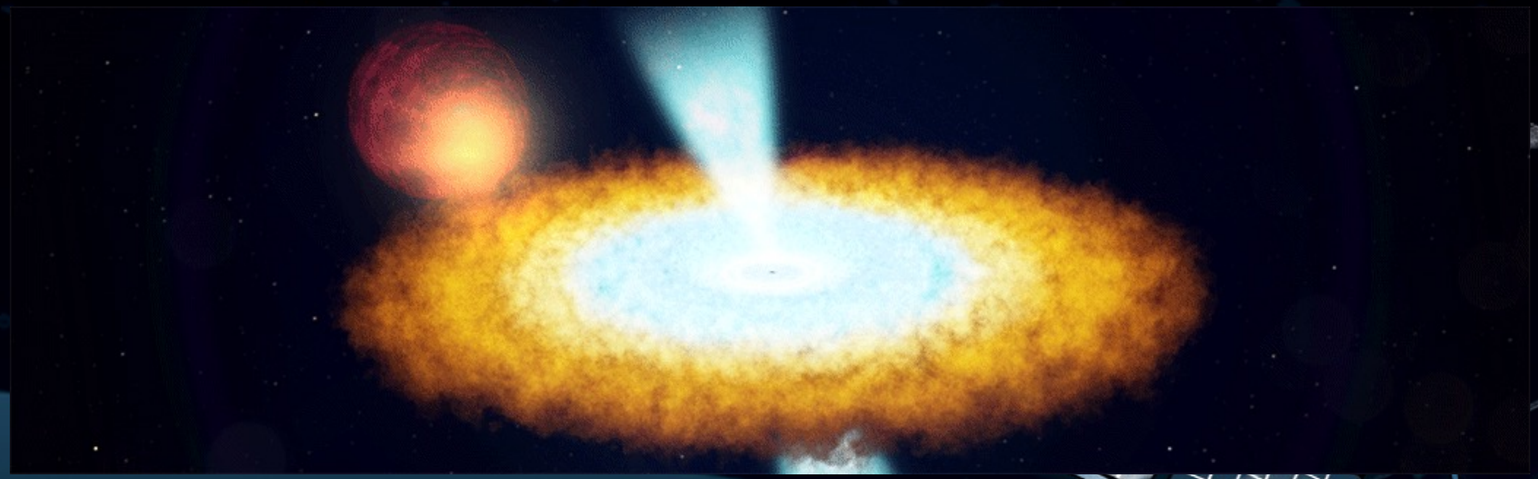


From ECLAIRs X-band Quick-Look Analysis (for longer-timescale variability)

Thermonuclear X-ray bursts

ECLAIRs: a Type I X-ray burst hunter !

~160 bursts from 37 different sources detected so far



Thermonuclear X-ray bursts

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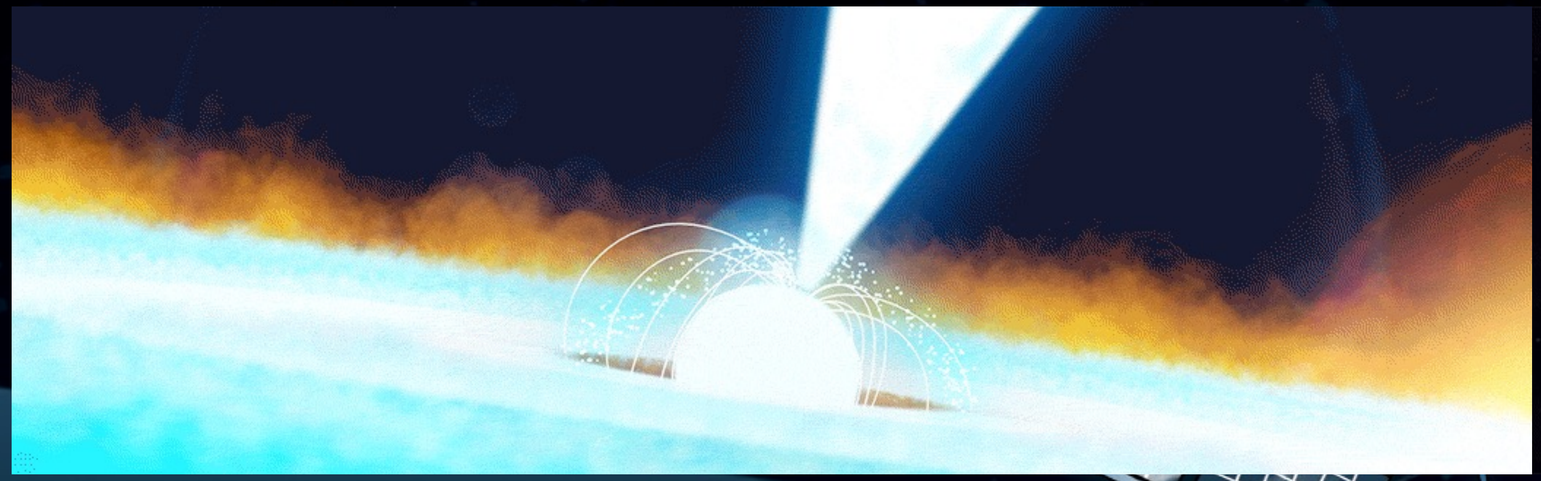

- Gas accumulating at the surface of the neutron star

Thermonuclear X-ray bursts

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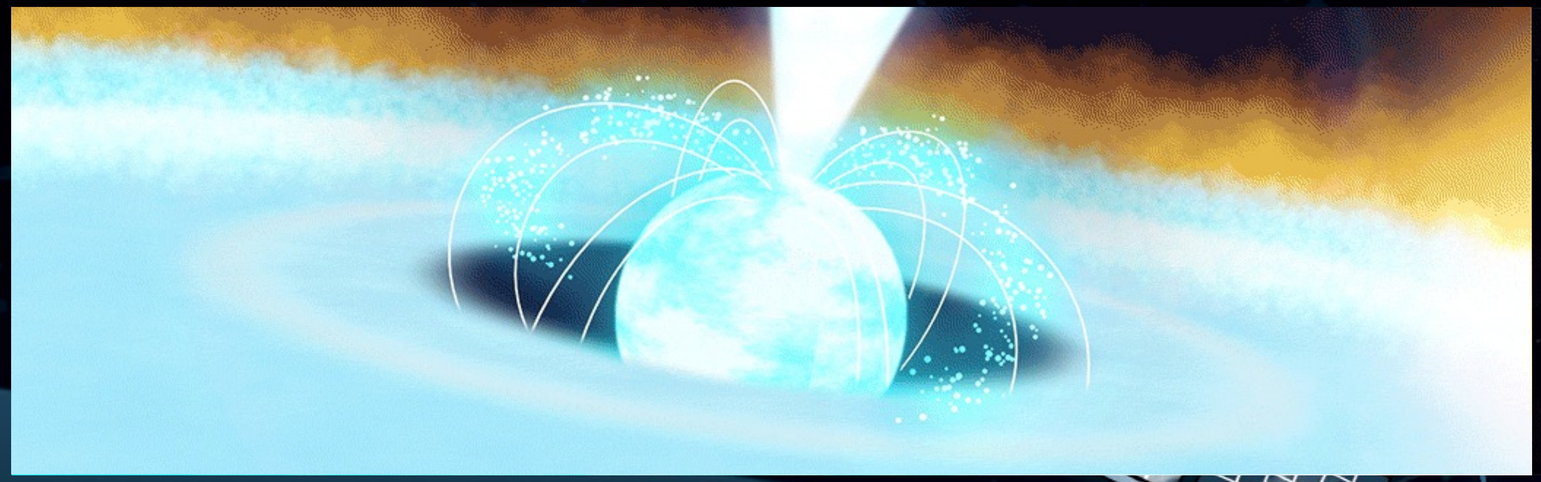

- Gas accumulating at the surface of the neutron star ⇒ **thermonuclear burst**

Thermonuclear X-ray bursts

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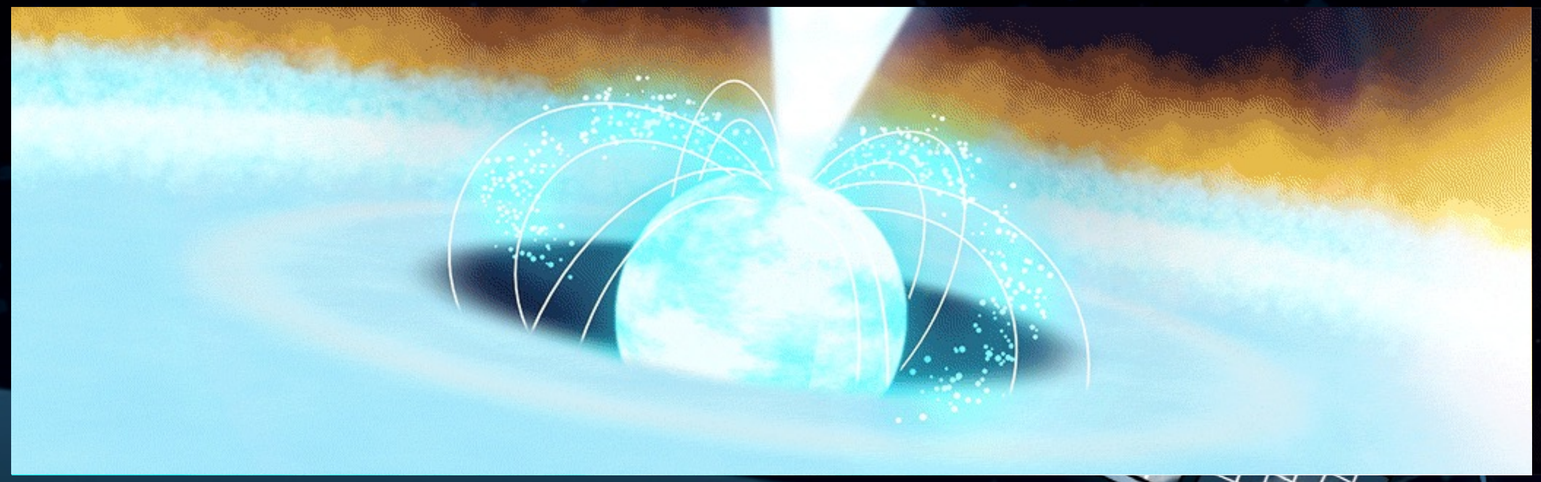
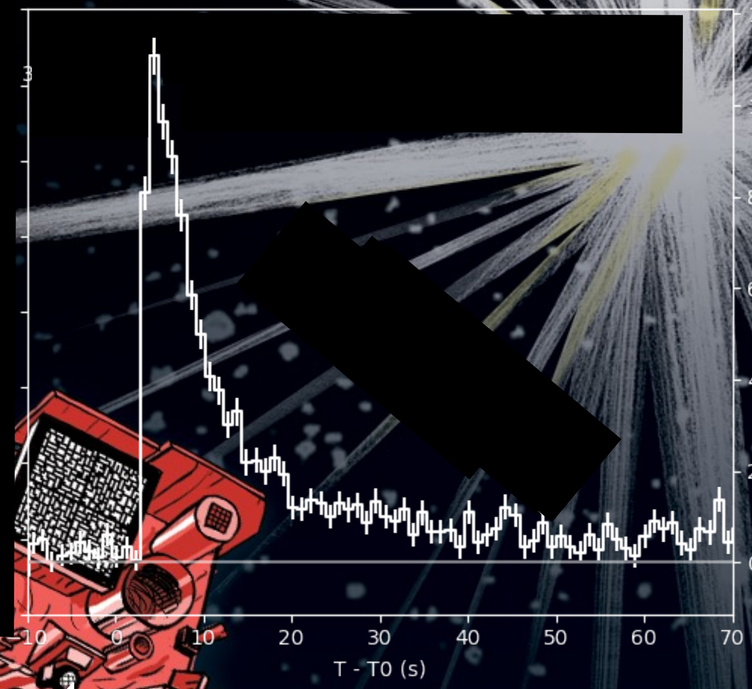


Le Stum et al., 2026

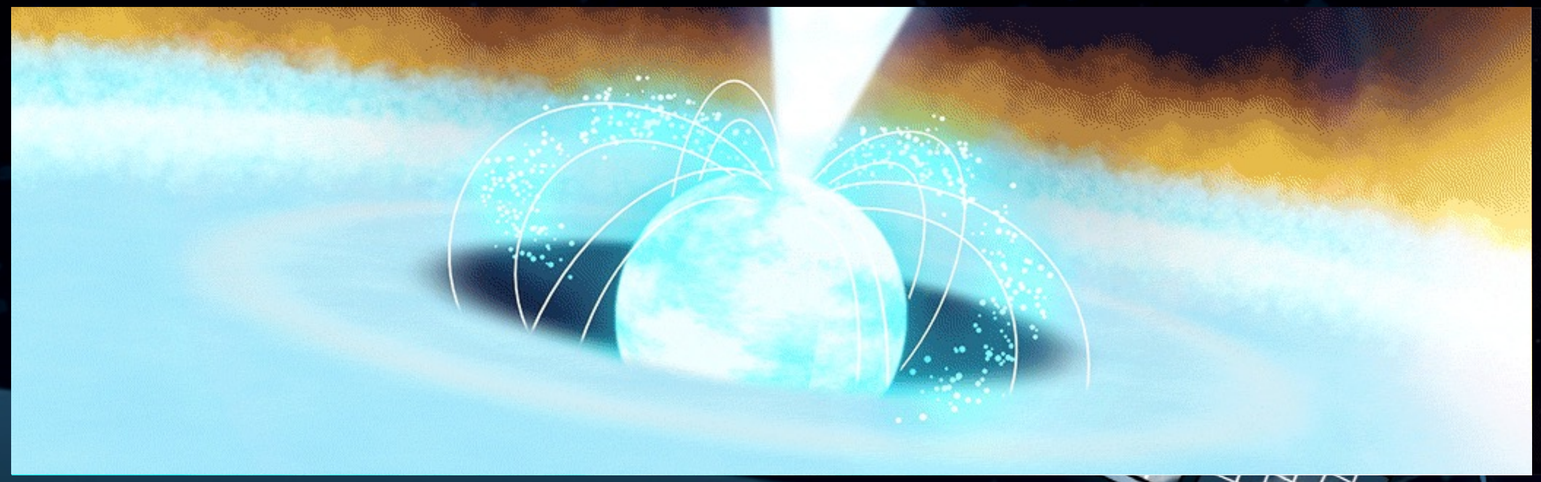


- Gas accumulating at the surface of the neutron star ⇒ **thermonuclear burst**
- ECLAIRs detection of a type I burst of 4U 0614+014 on January 10 2025 at 15:58:02 (UTC) - *Le Stum et al., 2026*

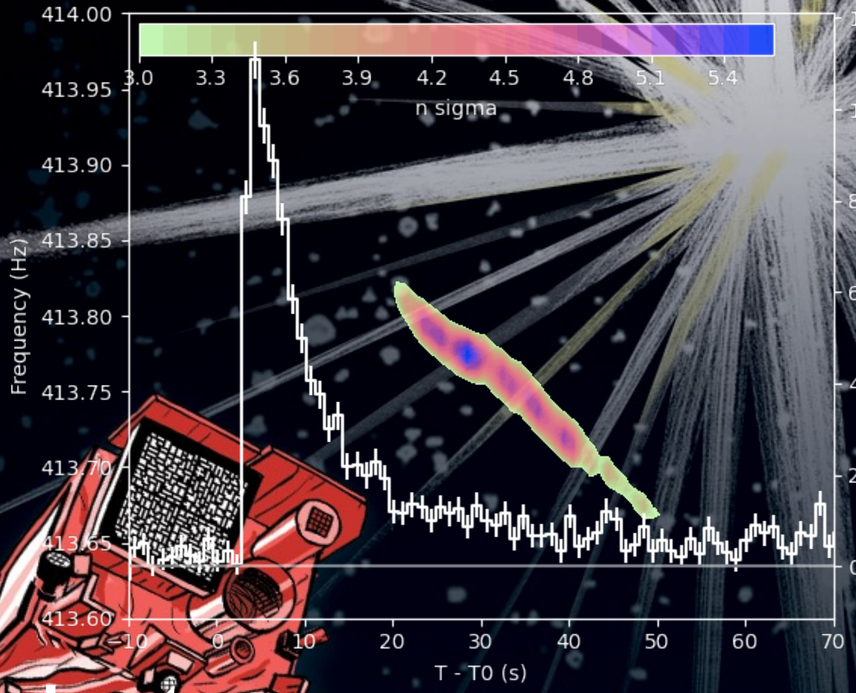
Thermonuclear X-ray bursts

ECLAIRs: a Type I X-ray burst hunter !

~160 bursts from 37 different sources detected so far



Le Stum et al., 2026

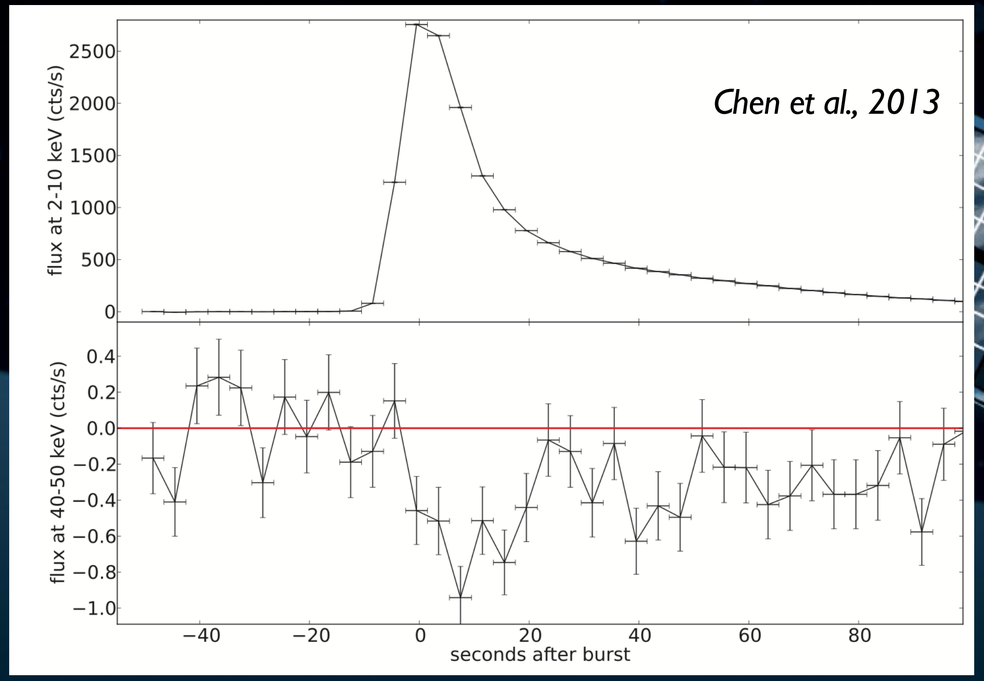


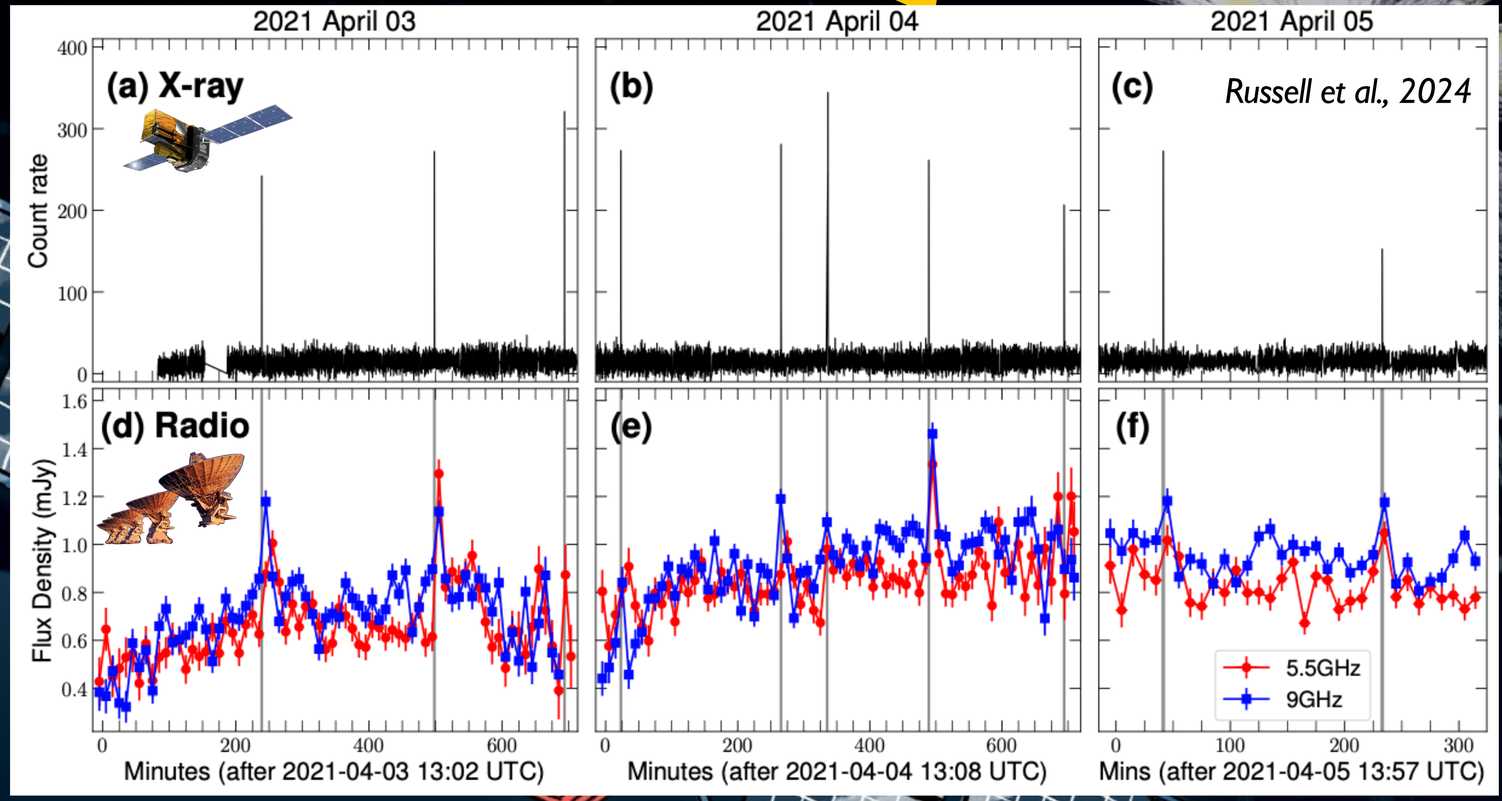
- Gas accumulating at the surface of the neutron star ⇒ **thermonuclear burst**
- ECLAIRs detection of a type I burst of 4U 0614+014 on January 10 2025 at 15:58:02 (UTC) - *Le Stum et al., 2026*
  - Detection of the neutron star pulsation at **413.69 Hz**
  - Decrease of the oscillation frequency observed during the burst (rare behaviour)
  - **If orbital Doppler effect → orbital period < 20 min (verification binary for LISA ?)**

Thermonuclear X-ray bursts

ECLAIRs: a Type I X-ray burst hunter !

~160 bursts from 37 different sources detected so far





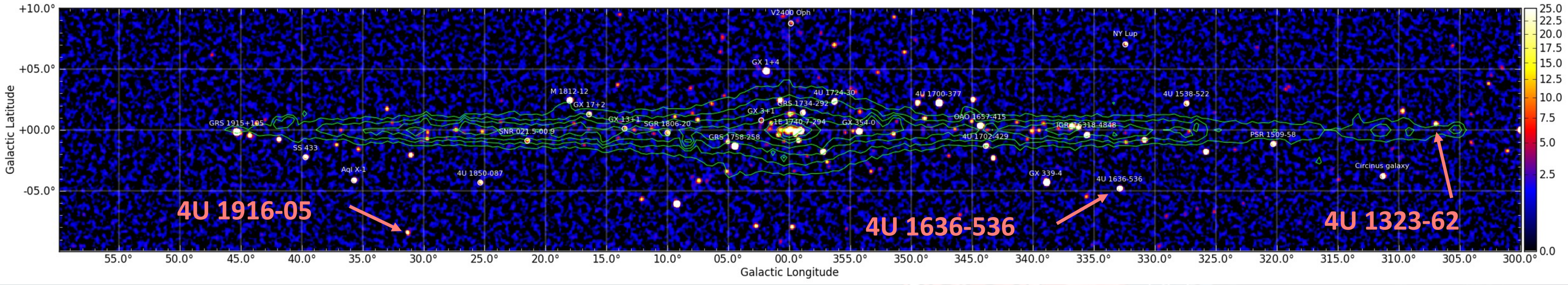
- Type I bursts are known to impact corona + jet ⇒ jet velocity measurement
- Measure jet speed from a population of LMXBs with different spins, masses, … ⇒ opens a new window into the jet launching mechanisms

Thermonuclear X-ray bursts

ECLAIRs: a Type I X-ray burst hunter !

~160 bursts from 37 different sources detected so far

- **300 ks monitoring of the Galactic Plane (accepted program for SVOM General Program 2026)**

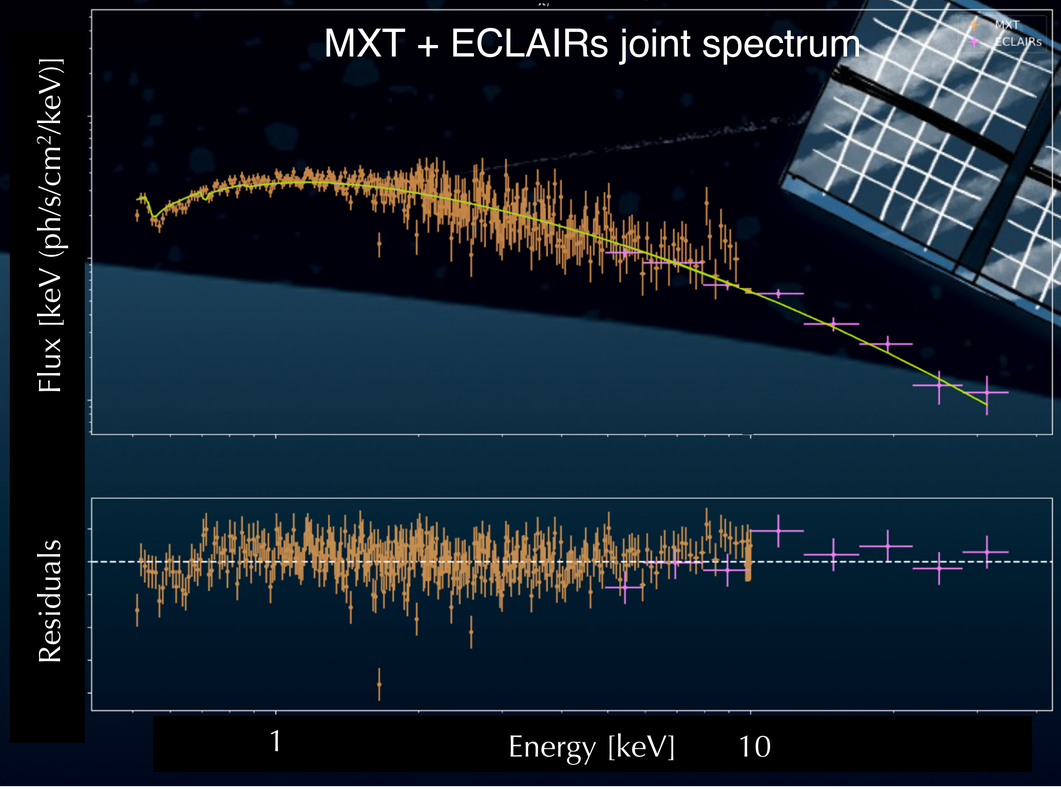


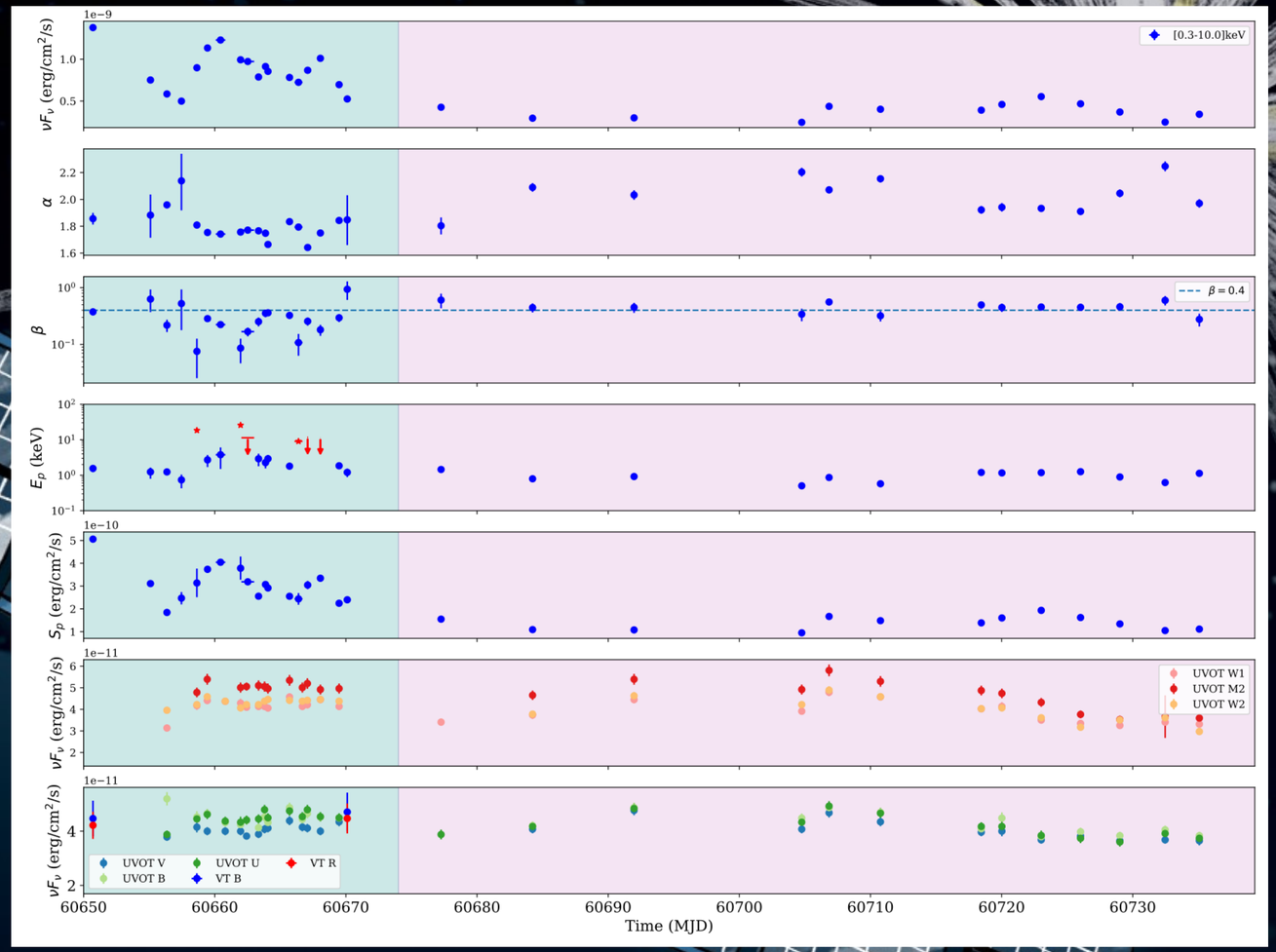
INTEGRAL Galactic Plane survey, Krivonos et al.

- Monitoring of Galactic source variability
- Pointed observations on 3 LMXBs with high type I X-ray burst rate

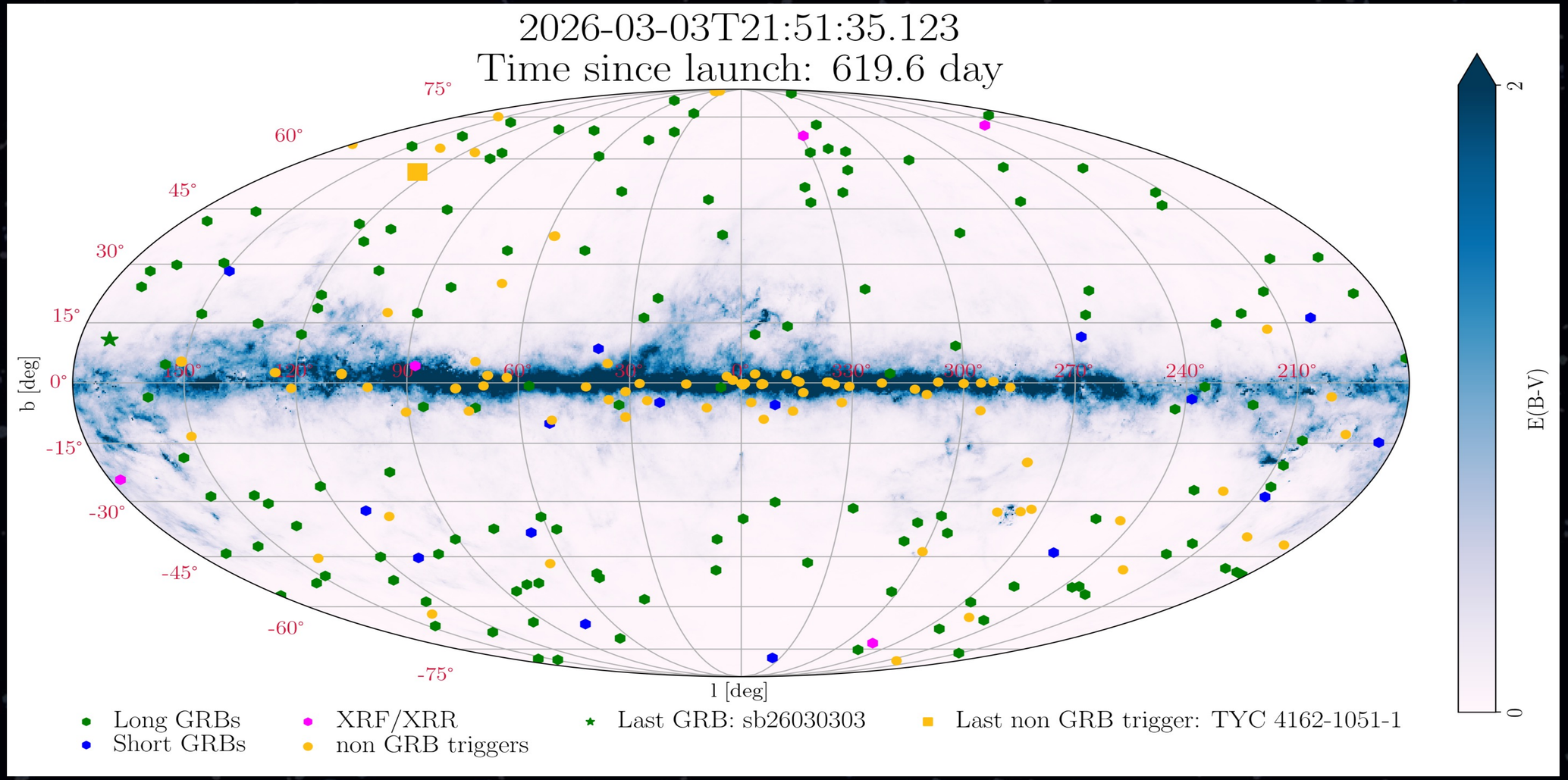
Blazar high-energy outbursts

- **SVOM discovery of an X-ray outburst of 1ES 1959+650**
  - Multi-wavelength follow-up
  - Constrain acceleration processes



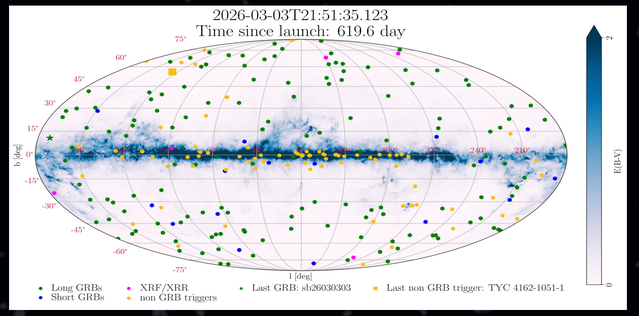


Foisseau et al. (2026)



More than 1700 GCNs related to SVOM since launch

Gamma-ray burst science



Gamma-ray Burst general statistics (on March 2026)

GRM detection	ECL detection	Total ECL+GRM Detection	Jointly detected by Swift/ EP/ Fermi	# z_{GRM}	# z_{ECL}
208	89	250 (47 joint detections) Long (76%), Short (15%), XRF (9%)	68%	18 (9 %)	30 (34%)

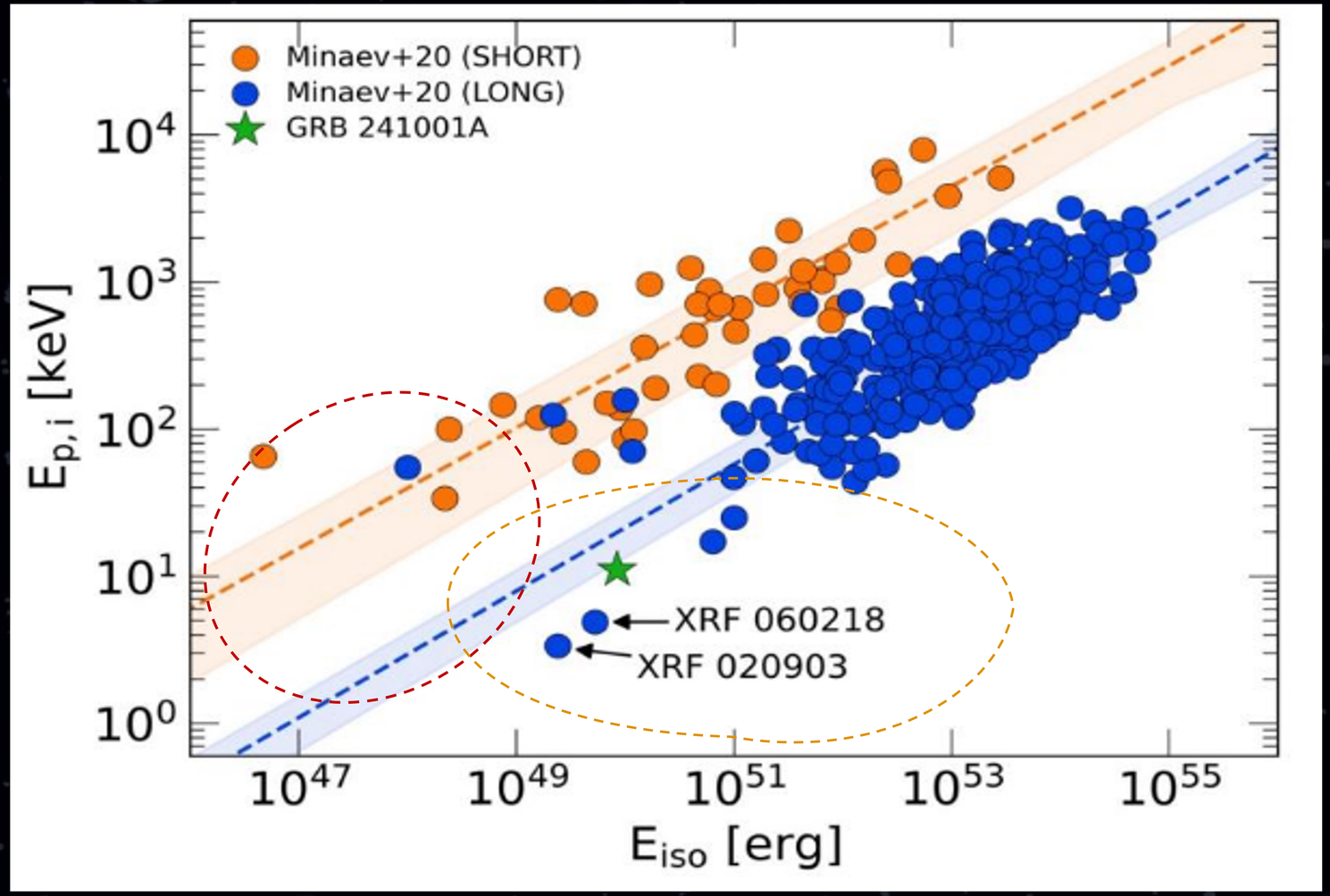
	ECL median loc.	MXT median loc.	x-ray afterglows	Optical afterglows	Radio afterglows	z > 4
	~7′	~40″	67 (88% ECL)	49 (65% ECL)	5	5/41 (12%)

Gamma-ray burst science

SVOM to explore the poorly known XRR/XRF burst population

Our goal: bring a complete physical interpretation of the poorly known population of **very soft x-ray burst**

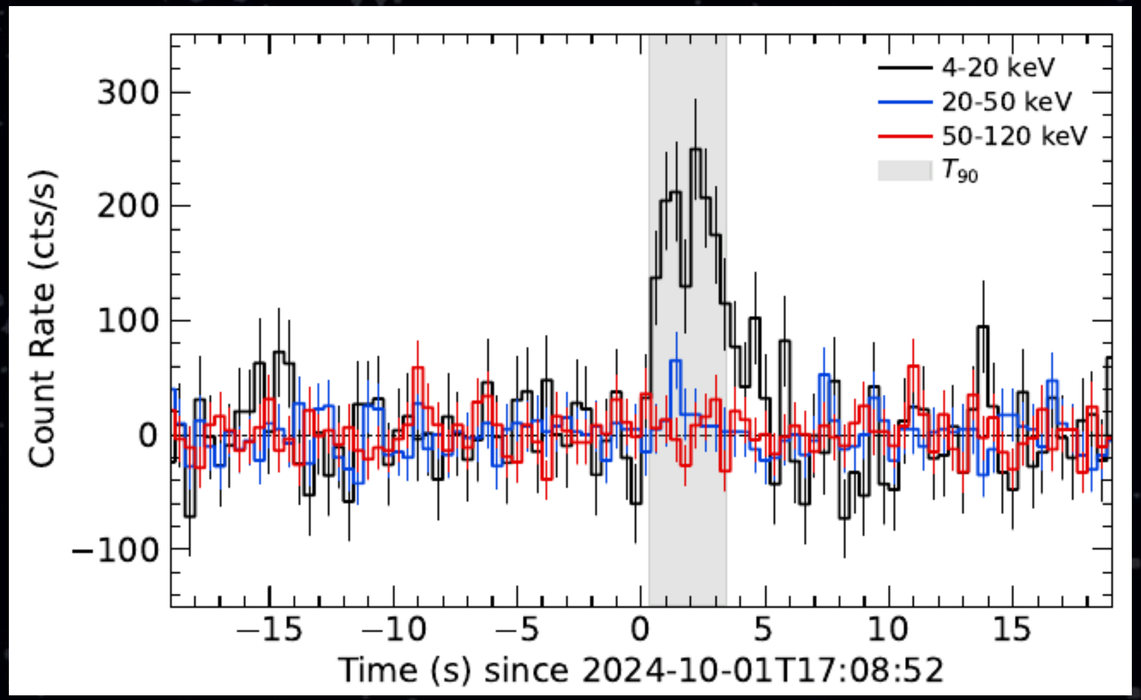
- connection between classical collapsar GRBs and “failed” or low-luminosity GRB collapsars?
- Shock breakout emission?
- geometry effect -> off-axis jet?
- Low Γ jets?
- High-z redshift effect?



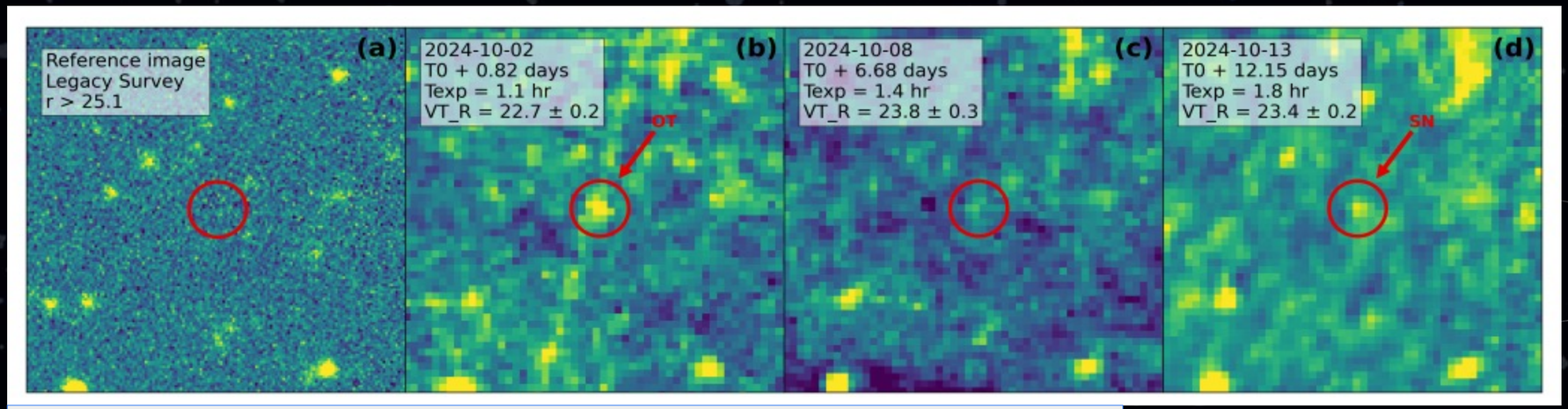
Gamma-ray burst science

GRB 241001A (XRF at z = 0.573)

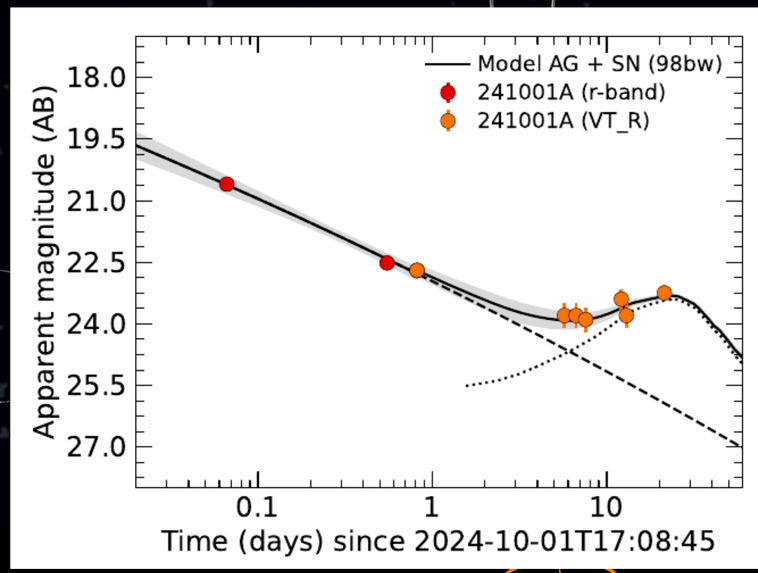
- Weak prompt emission (ECLAIRs, 4-20 keV, **T90=3.1 s**)
  - BB (kT=1.7 keV) but B/CPL OK too (PL rejected)
  - Under-luminous: E_{iso}=7x10^{49} erg
- Faint X-ray afterglow
- Typical GRB visible afterglow evolution (on-axis favoured)
- Associated with a type-Ic broadline SN (SVOM/VT at T0+12d and JWST at T0+24d)
- Collapsar possibly followed by an energetic relativistic ejection with low prompt emission efficiency



Schneider et al. in press.



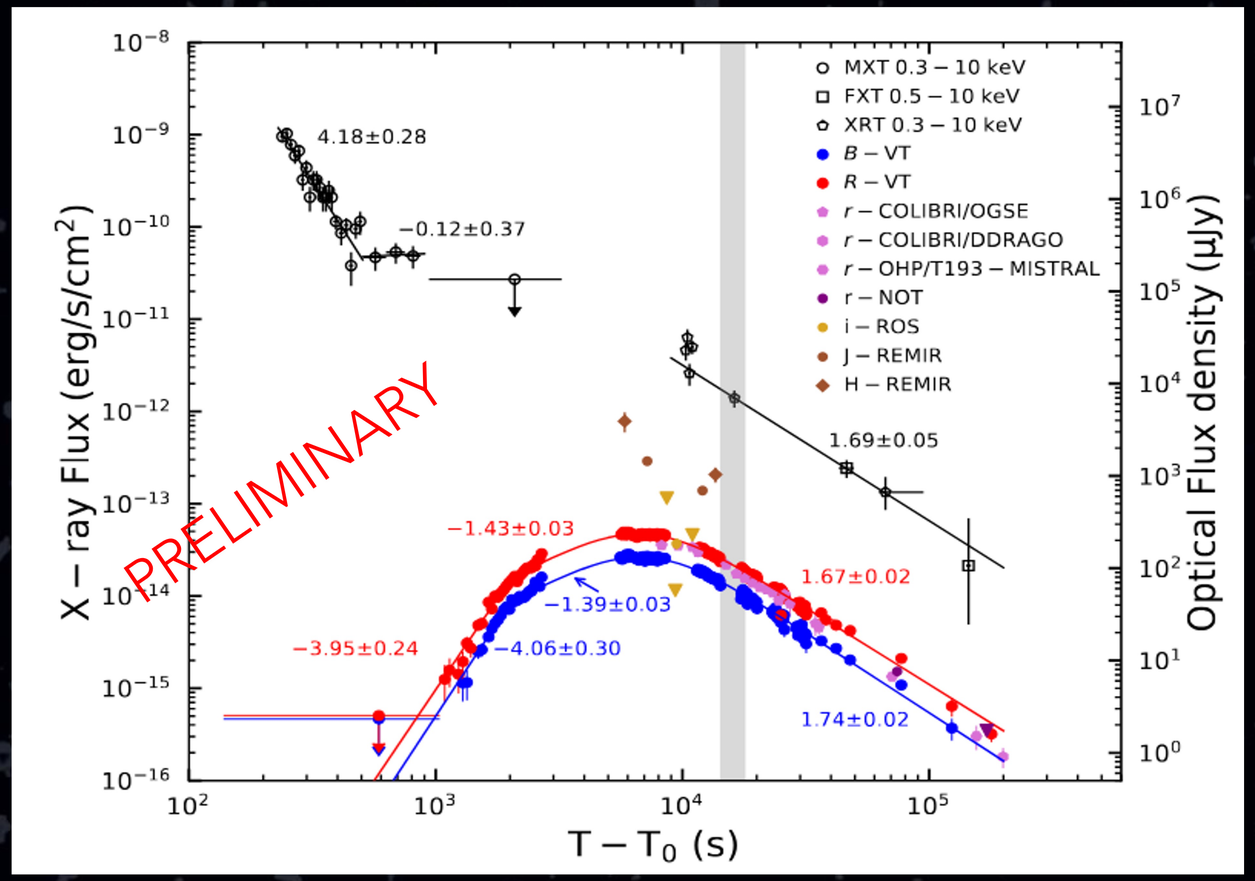
VT observations from T0+0.82d (afterglow) to T0+12.15d (supernova rise)



Gamma-ray burst science

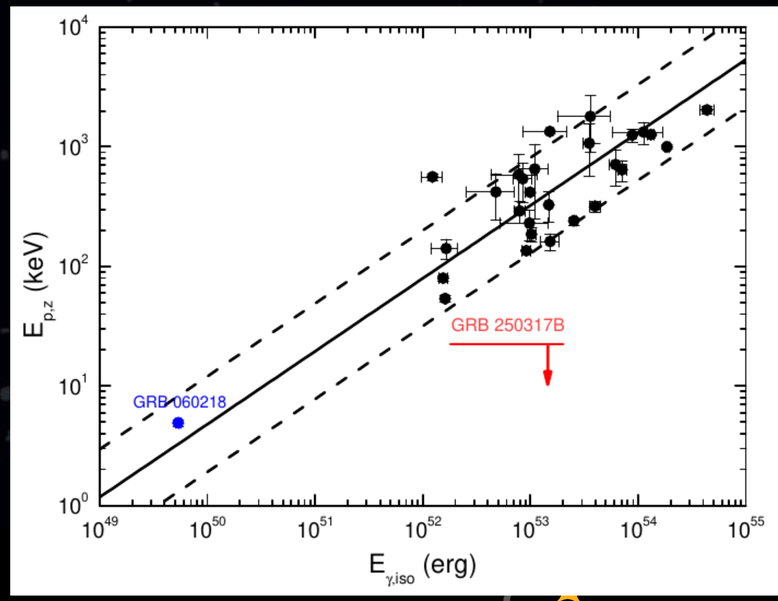
SVOM to explore the poorly known XRR/XRF burst population

GRB 250317B: An X-Ray Flash from Off-Axis Observation to a Magnetar-Driven (?) Gamma-Ray Burst



GRB 250317B (XRF at z=3.448)

- ECLAIRs detection below 20 keV
- Excellent multi-wavelength follow-up, largest XRF redshift (GTC/OSIRIS)
- Steep photon index (-2.9±0.2) → Ep<5 keV
- X-ray afterglow (SVOM, EP, Swift): shallow phase → late activity (magnetar?)
- Optical afterglow rising late and peaking at ~6ks post-trigger → off-axis view



Zhao et al. (submitted)

Gamma-ray burst science

GRB 241217A (z = 1.879)

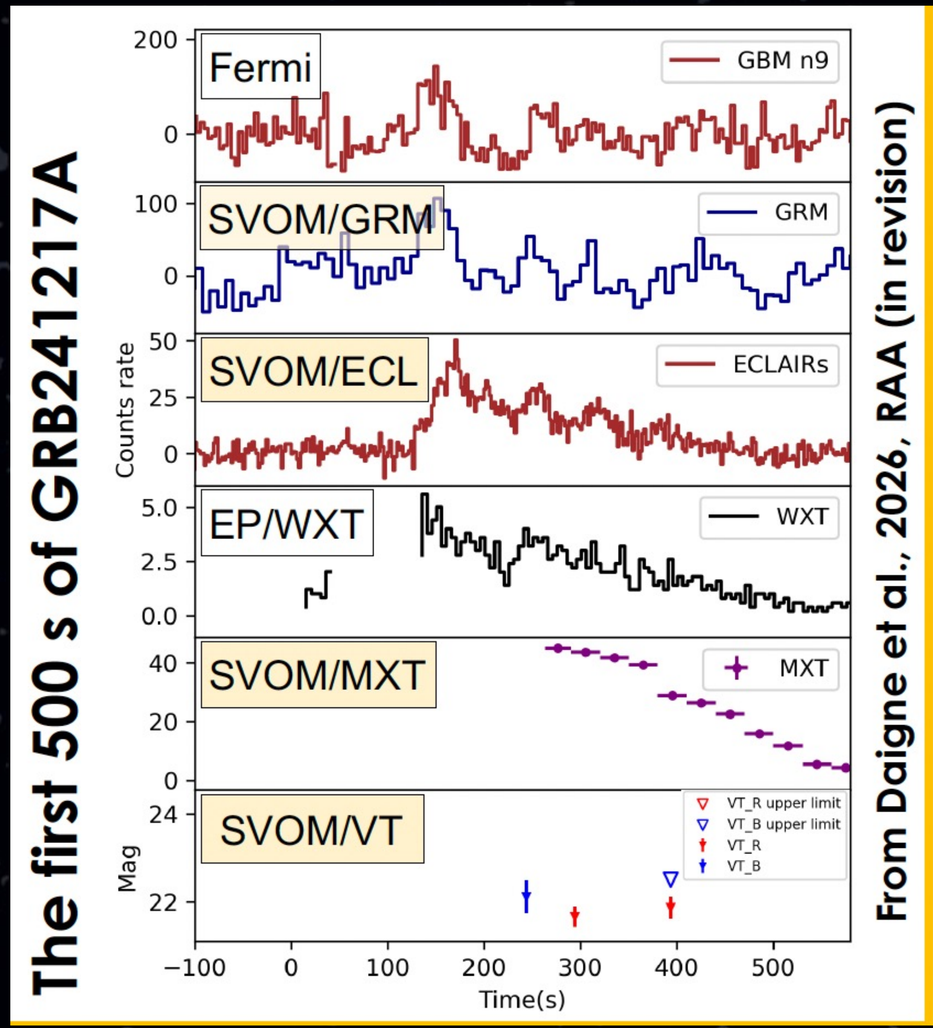
Very long (>500 s) GRB detected by Fermi, SVOM and EP

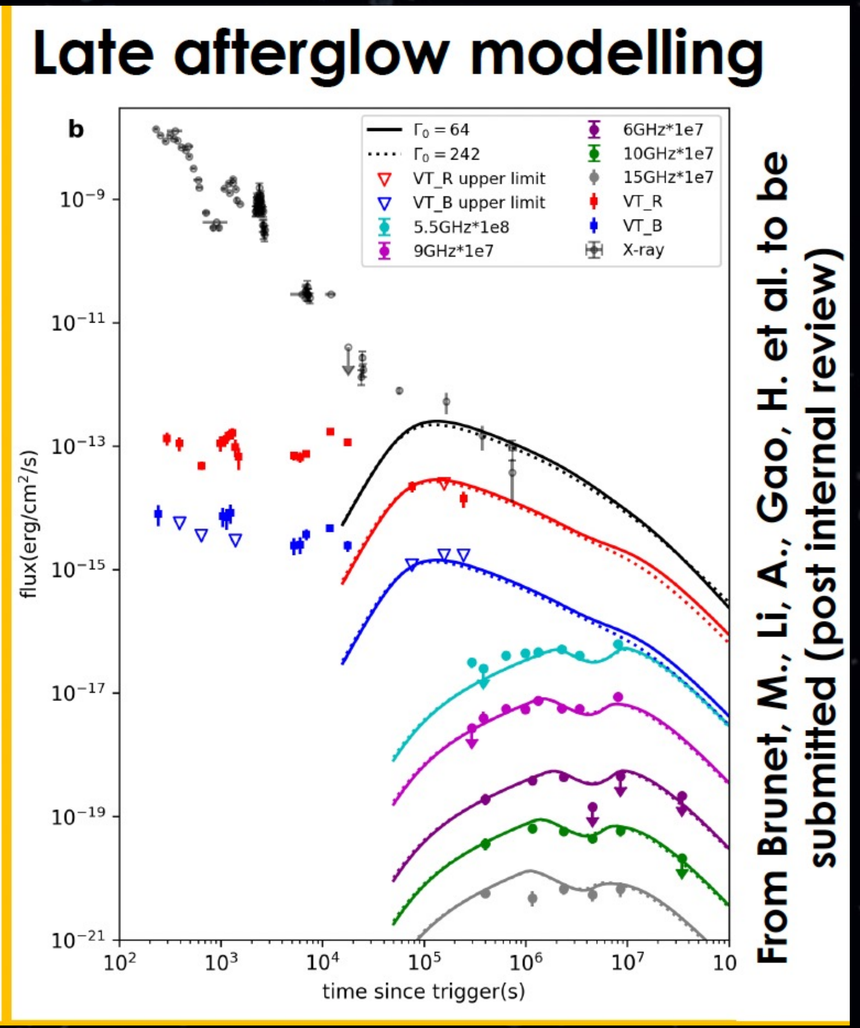
MXT & VT: end of the prompt emission, and transition to the afterglow phase

Peculiar visible afterglow: shallow phase until ~10ks, with possible flares

A long GRB with a collapsar origin in a very low-density external medium?

Progenitor = high-velocity runaway WR star?

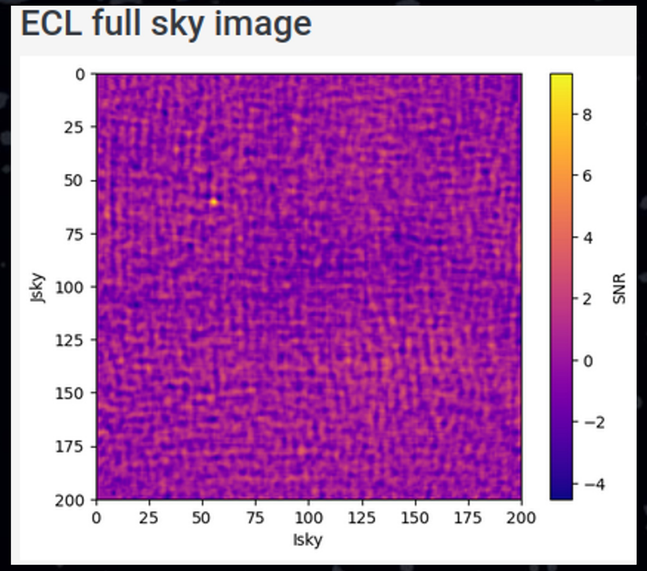




Gamma-ray burst science

SVOM to explore the high-z GRB population

GRB 250314A at z~7.3! : detected by ECLAIRs (T90 ~ 20s) and GRM (T90~10s) (Cordier & Wei et al., accepted)



- **Any afterglow then ?**

- MXT/VT quick follow-up (T_{GRB}+177s)
  - $F_{0.5\text{-}10keV}$ < 5.10^{-11} erg/cm2/s / (T_{GRB}+2.2h) VT_R>23.3 -> GCN#39728
- NIR afterglow discovered by the NOT
  - (T_{GRB}+12.3h) J=20.85 -> GCN#39727
- VLT/X-shooter redshift (T_{GRB}+16.5h) -> GCN#39732

GCN Circular 39732

Subject GRB 250314A: VLT/X-shooter dropout, redshift z ~ 7.3
Date 2025-03-15T12:45:58Z (3 months ago)
Edited On 2025-03-15T20:14:19Z (3 months ago)
From Daniele B. Malesani at IMAPP / Radboud University <d.malesani@astro.ru.nl>
Edited By Vidushi Sharma at NASA GSFC/UMBC <vidushi.sharma@nasa.gov> on behalf of Daniele B. Malesani at IMAPP / Radboud University <d.malesani@astro.ru.nl>
Via Web form

D. B. Malesani (DAWN/NBI and Radboud), G. Pugliese (API-UvA), J. P. U. Fynbo (DAWN/NBI), B. Schneider (LAM), V. D'Elia (SSDC and INAF-OAR), A. de Ugarte Postigo (LAM), L. Izzo (INAF-OACn and DARK/NBI), P. G. Jonker (Radboud), A. J. Levan (Radboud and Warwick), J. T. Palmerio (CEA/Irfu), N. A. Rakotondrainibe (LAM), A. Saccardi (CEA/Irfu), N. R. Tanvir (U. Leicester), A. L. Thakur (INAF-IAPS), S. D. Vergani (CNRS, Obs. Paris/LUX), D. Xu (NAOC), Z.P. Zhu (NAOC) report on behalf of the Stargate collaboration:

We observed the near-infrared candidate counterpart (Malesani et al., GCN 39727) of the long SVOM/ECLAIRs GRB 250314A (Wang et al., GCN 39719) at the ESO VLT, using the HAWK-I near-infrared imager (on UT4, Kueyen) and the X-shooter spectrograph (on UT3, Melipal).

The object is well detected in the Y, J and H filters. HAWK-I observations started on 2025 Mar 15 at 05:23:28 UT (about 16.5 hr after the GRB). We measure preliminary AB magnitudes:

Y = 23.2 +/- 0.15
J = 22.4 +/- 0.1
H = 22.5 +/- 0.1

For the spectra, the observation mid time was 2025 Mar 15.26 UT (about 17.4 hr after the GRB). The data cover the wavelength range 3000-21,000 AA and consist of 4 exposures of 1200 s each.

In a preliminary reduction of the spectra, a faint continuum is confidently detected all across the NIR arm (down to 10,300 AA). Tentative signal is also seen in the very red end of the VIS arm, with a drop around 10,090 AA. While the S/N is too low to confidently identify individual metal absorption features, the break in the VIS is consistent with the onset of the Lyman forest (with possible contribution from damped Lyman-alpha absorption in the GRB host galaxy). The implied redshift is z ~ 7.3.

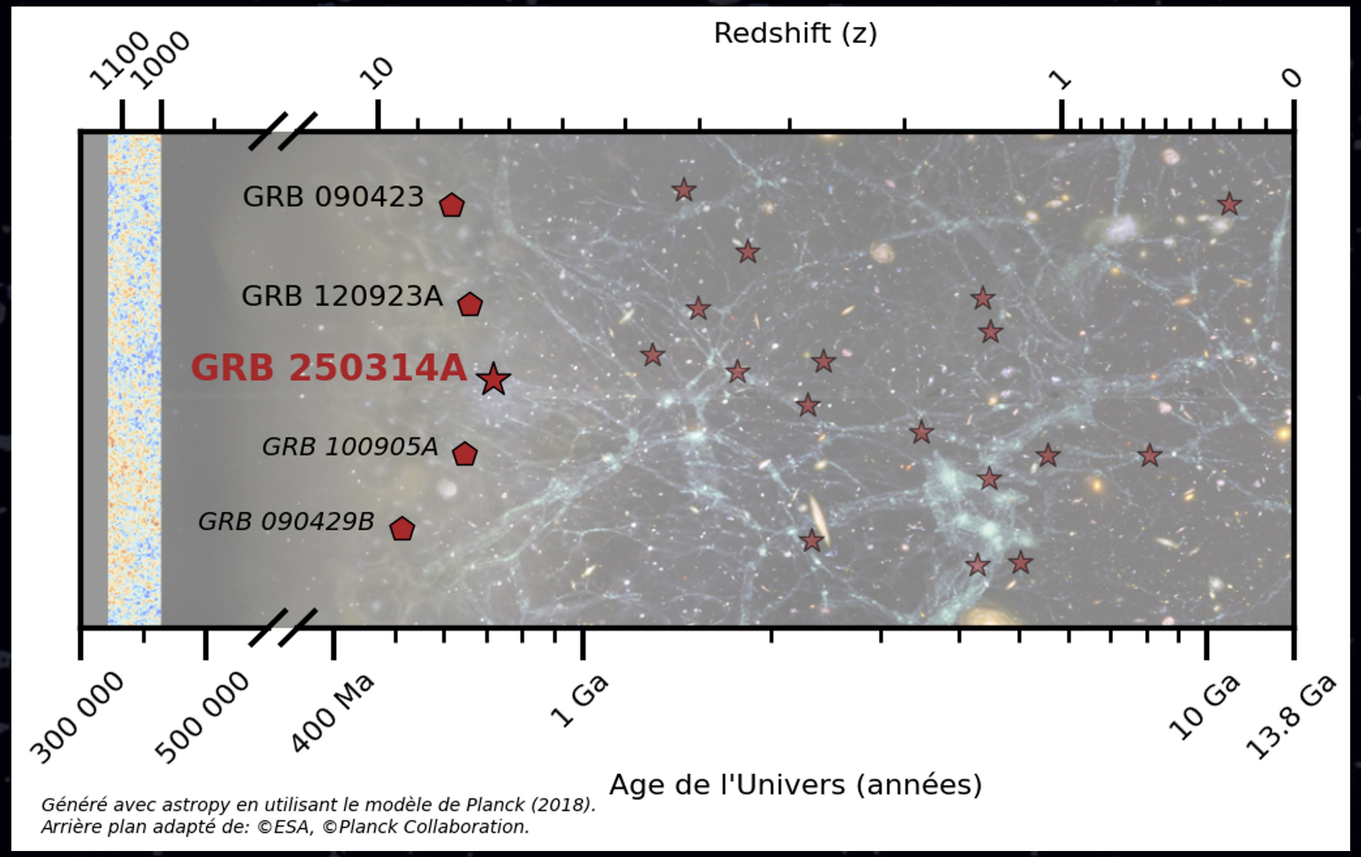
The HAWK-I photometry is consistent with a break, rather than with a generically red shape of the continuum, given the red Y-J vs blue J-H color, consistent with the Y filter being partly dropped out. Assuming a power law model (no dust extinction), a fit to the available photometry provides a redshift z = 7.21 +0.18 -0.38 (1 sigma c.l.), fully consistent with the spectroscopic value.

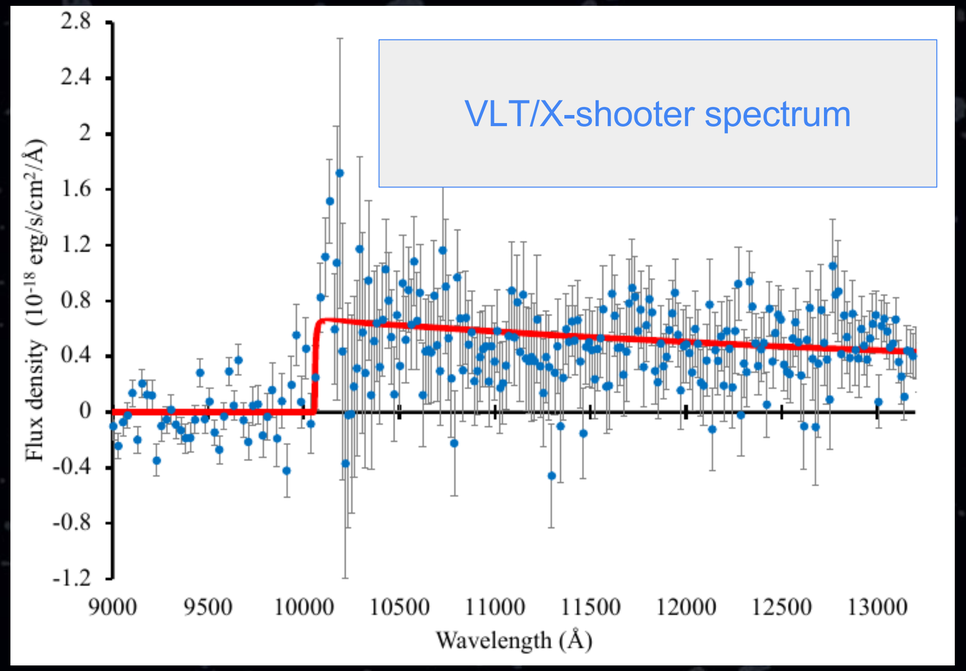
We acknowledge expert support from the ESO staff in Paranal, in particular Cedric Ledoux, Enrico Congiu, Francisco Nogueras-Lara, Pascale Hibon, Rodrigo Romero, and Susana Cerda.

Gamma-ray burst science

SVOM to explore the high-z GRB population

GRB 250314A at z~7.3! : 5th most distant burst, 3rd with a spectroscopic measurement (Cordier et al. 2025)
Follow-up with JWST at T+110 days: most distant Supernova (Levan et al. 2025)





Gamma-ray burst science

- **JWST/NIRCAM observations**
- **SN emission in the redder filters**
  - This SN associated with GRB250314A is by far the most distant supernova ever detected
- **Strong correspondence with the well-known SN 1998bw**
  - associated with GRB 980425 (z = 0.0085).
- **Results suggest that the collapse mechanism of massive stars may be the same in the early Universe as in our local Universe**

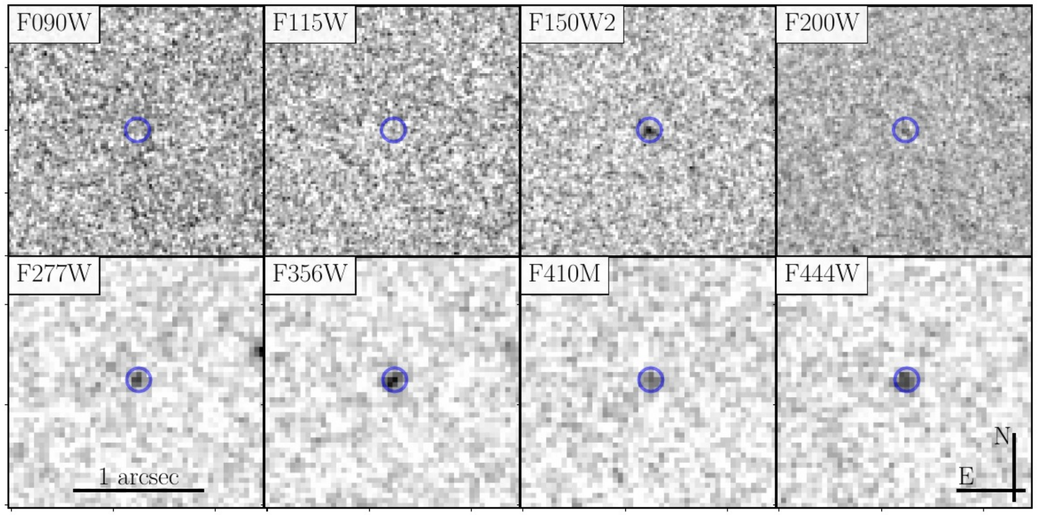


Fig. A.1. Our eight-band NIRCAM images of the location of GRB 250314A. The source is undetected in the bluest F090W band, consistent with the $z > 7$ origin. A clear signature from an extended object is present in the F150W2 observations (with a very broad filter), with a blue colour between F150W2 and F200W. The source is much brighter in the NIRCAM red channel, and brightens consistently between F277W and F444W.

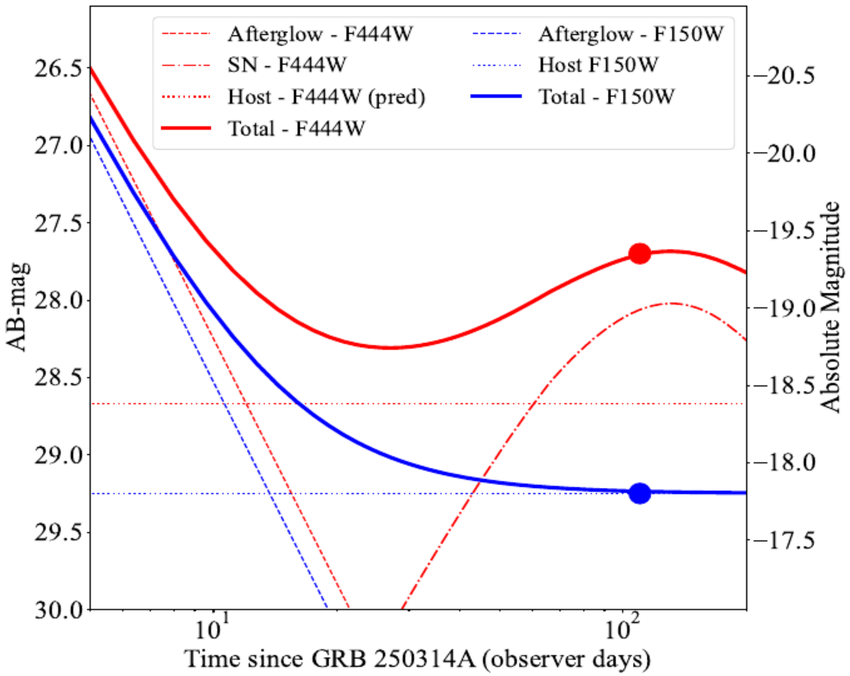
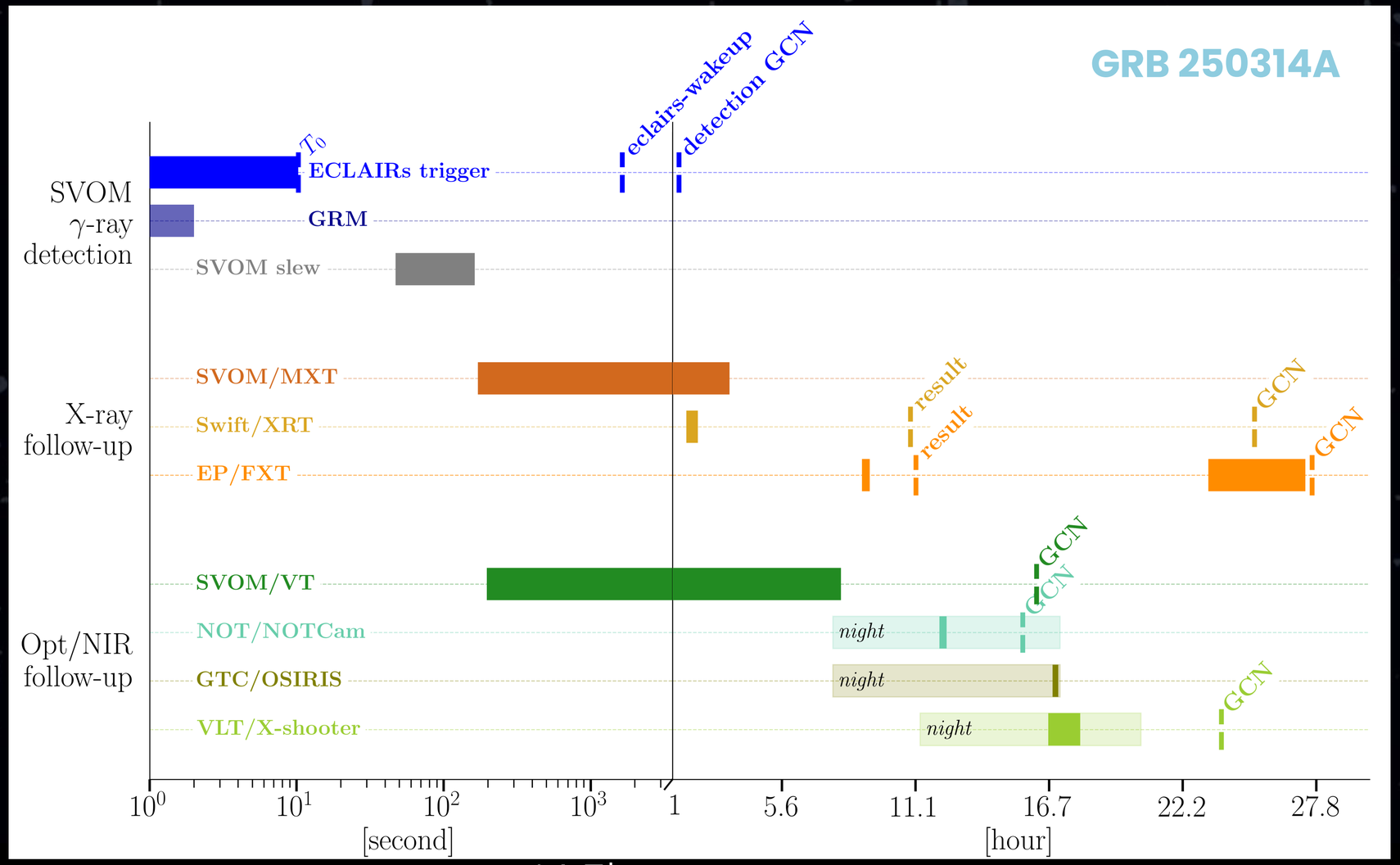


Fig. 1. Light curve of GRB 250314A as expected in the F150W2 and F444W bands. Components from both afterglow, SN, and host galaxy are included. Expectations for the afterglow are based on the ground-based *J* and *H* measurements, extrapolated to F444W based on the measured spectral slope. The host galaxy magnitudes are similarly based on the F150W2 detection (see text) and extrapolated to F444W based on the typical galaxy spectrum at $z \sim 7$. The observed points are also indicated, demonstrating luminosity consistency between observations and a SN 1998bw-like SN (in this case scaled to 70% of the luminosity of SN 1998bw).

Levan+2025

Gamma-ray burst science

SVOM to explore the high-z GRB population
How to optimize the redshift measurement ?



5-10 other bursts for which we suspect a high redshift...but no NIR observation.

Failed to mobilize a large telescope because of the delay between the trigger and the possibility of observation.

The arrival of CAGIRE on COLIBRI and SOXS should increase our efficiency.

Other high-z canidates?

ECLAIRs GRB	Early deep upper limit with VT
GRB 241229A	VT_R > 21.8 @ 1.4 h
GRB 250106A	VT_R > 23.0 @ 0.96 h
GRB 250108A	VT_R > 23.0 @ 3.98 h
GRB 250127A	VT_R > 20.3 @ 2.5 min
GRB 250314A	VT_R > 23.3 @ 2.2 h ⟵
GRB 250507A	VT_R > 22.7 @ 9 min
GRB 250530A	VT_R > 23.1 @ 14 min
GRB 250713A	VT_R > 23.3 @ 20.7 min
GRB 250806A	VT_R > 22.9 @ 6.3 min ⟵
GRB 250912A	VT_R > 23.1 @ 12.8 min
GRB 260228A	VT_R > 23.0 @ 1.1 h
GRB 260307B	VT_R > 22.5 @ 10 min
GRB 260321A	VT_R > 22.5 @ 1.1 h
GRB 260402A	VT_R > 23.0 @ 31 min

14 ECLAIRs GRBs with early deep upper limits with VT

These GRBs are potentially very interesting!

Some may explode in very dusty environment, some other may be at high redshift. (some may be intrinsically faint)

Example 1:
GRB 250806A = heavy extinction
- SVOM/MXT, Swift/XRT & FXT X-ray detection
- Host galaxy in Legacy Survey: r=21.75
- Gemini: host redshift z=0.367

Example 2:
GRB250314A = high redshift GRB!

Take home messages: SVOM first results in a nutshell & lessons learnt

- **A 4 keV low energy band a clear impact to better explore the**
  - The softest GRBs and the XRR/XRF population
  - High-z LGRBs: GRB250314A is the first burst at z>7 for the past 12 years
- **A full spectral coverage of the burst's emission from 4 keV - 5 MeV**
  - Detection (ECL>50/year, GRM~130/year) of all types: ~76% LGRBs, ~15% SGRBs(+EE), ~9% XRRs/XRFs
- **A large FoV (1°x1°) MXT x-ray telescope & a sensitive 40 cm VT telescope**
  - Several well-characterized events during the prompt & early/late afterglow phases
  - Prompt-to-afterglow transition for some bursts
    - Several cases on non detection in VT: dark or high-z bursts? Prompt systematic NIR Follow-up is still missing, but CAGIRE and SOXS will help

- **A pointing strategy optimized to coordinate fast follow-up observations**
  - Already a high rate of optical afterglow detection and redshift measurement, still increasing
- **Already fruitful Collaboration with other missions and groups**
  - Efficient ToO links between SVOM, Einstein Probe and Swift
  - ESO/VLT (Stargate collaboration), GTC and NOT
- **A collaboration open to exchange of data on specific science projects**
  - SVOM is open to jointly publish its data as lead collaboration or as partner
  - All critical SVOM information is publicly available through GCNs
  - SVOM is open for ToOs from the community, provided that one co-I is involved

>40 single GRB papers under review/submitted

A SVOM special issue in press (RAA)

www.svom.eu