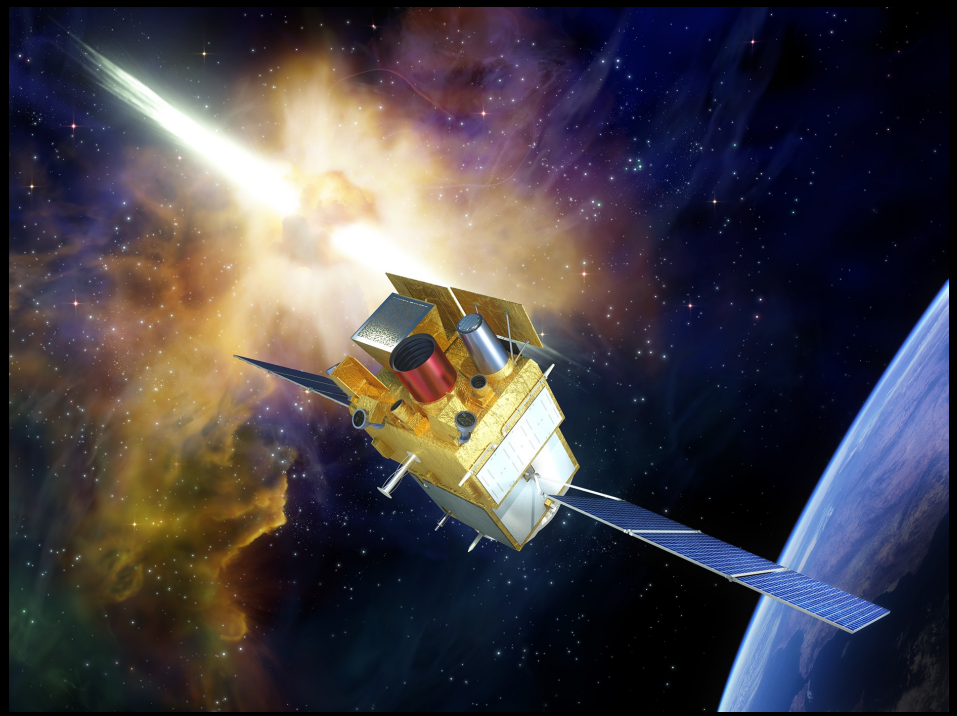
GAMMA-RAY BURST STUDIES WITH SVOM

(AND THE GRB-GW CONNECTION)

Frédéric Daigne



Astroparticle Symposium 2025 "Variability of astrophysical sources across the wavelengths, a tribute to Berrie"

1. Gamma-Ray Bursts

2. The SVOM Mission

3. GRB Studies with SVOM: First Results & Prospects

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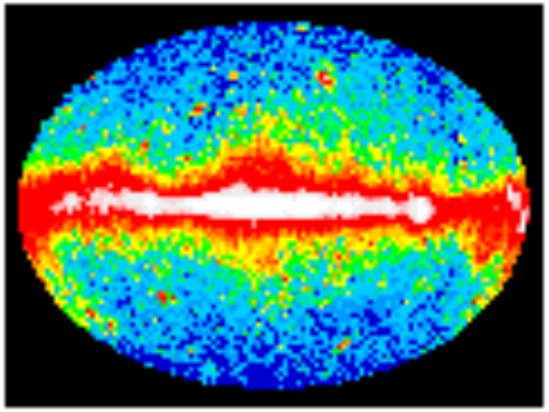
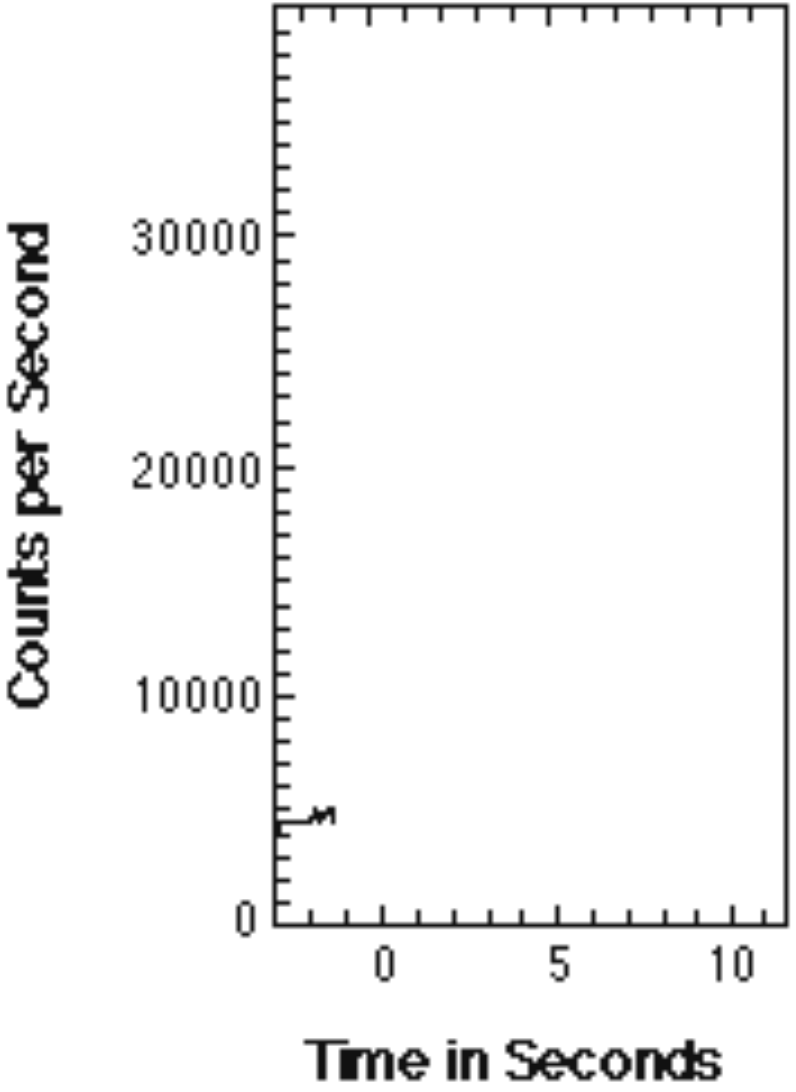
2. The SVOM Mission

3. GRB Studies with SVOM: First Results & Prospects

WHAT IS A GAMMA-RAY BURST?

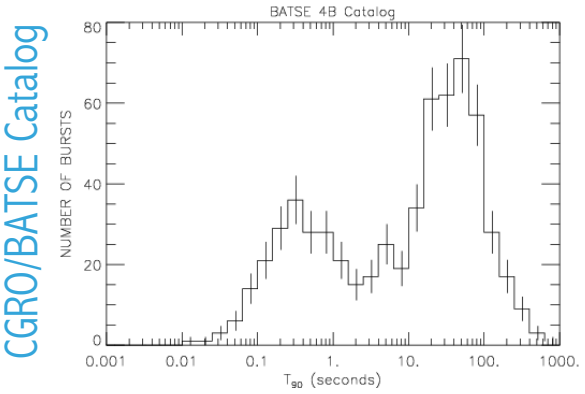




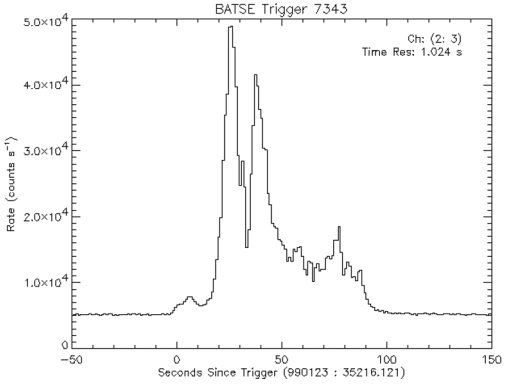
GRB PROMPT EMISSION

- High variability (ms → s)
- Short duration (a few ms → a few min)
- **Two classes: short & long GRBs**

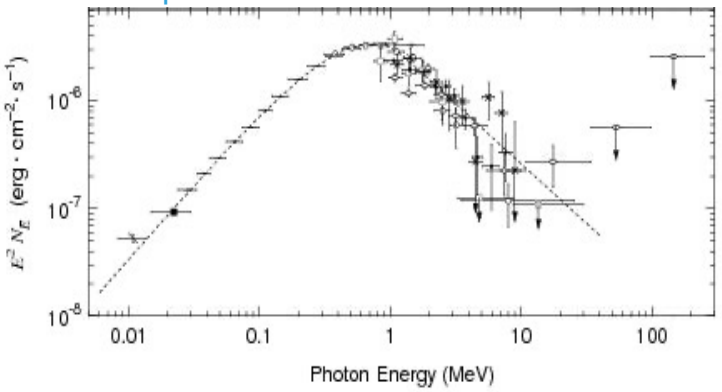
Duration



A lightcurve

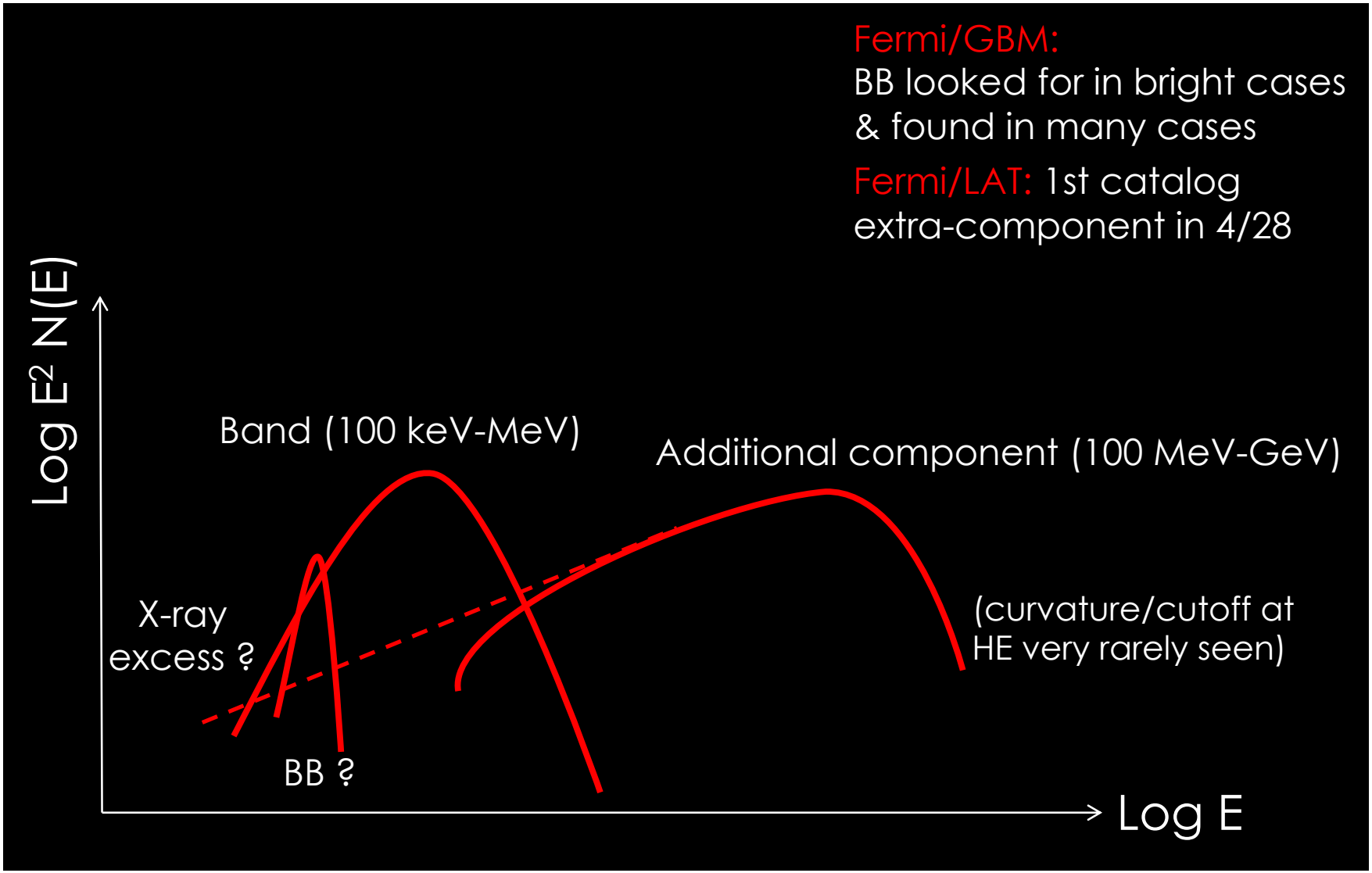


A spectrum



- Great diversity of lightcurves ; Pulses: 100 ms → 10 s
- Non-thermal spect. = **cosmic accelerators**: E_{peak} ~ 100 keV → 1 MeV
- Spectral evolution
- **Spectral diversity: classical GRBs, low-L GRBs, X-ray rich GRBs, X-ray Flashes,** etc.

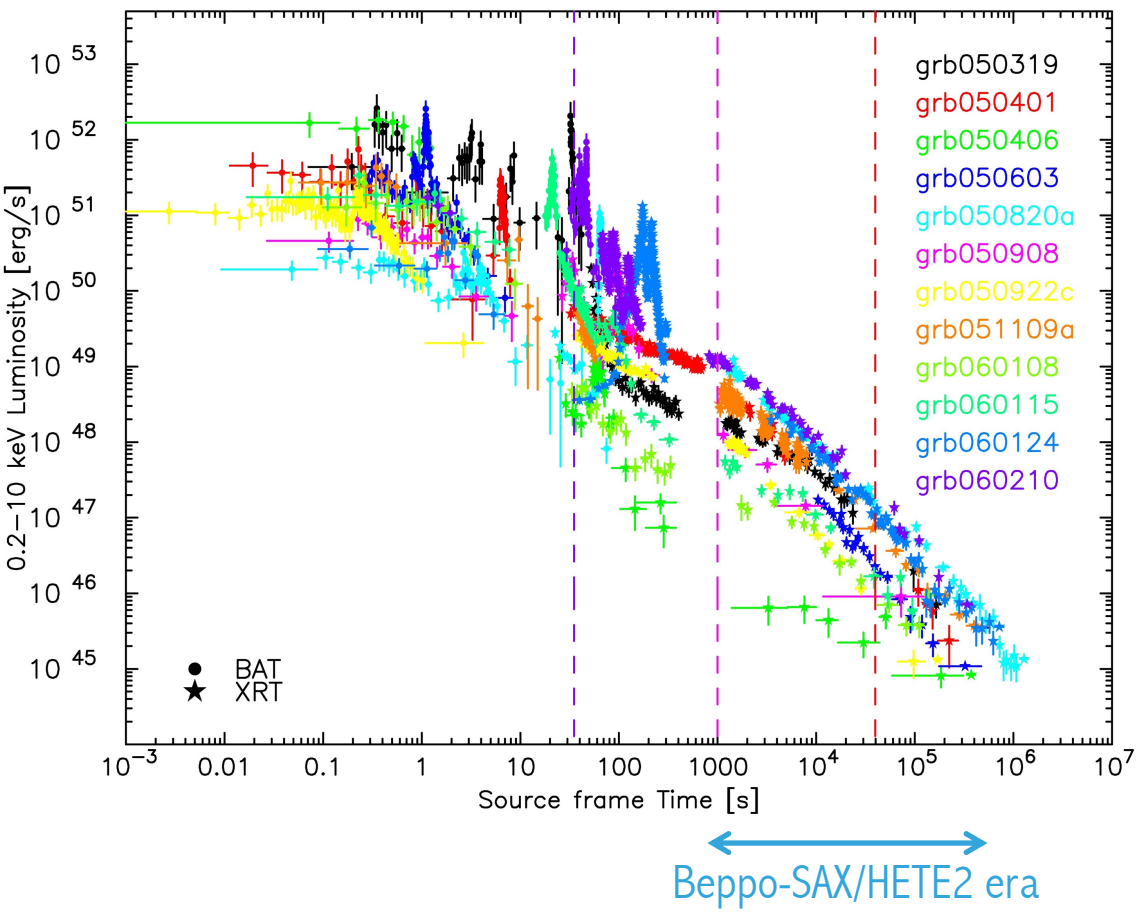
(TYPICAL?) GRB PROMPT SPECTRUM



Also: some cases with a unique component extending up at least 100 MeV?
(Ravasio et al. 2024)

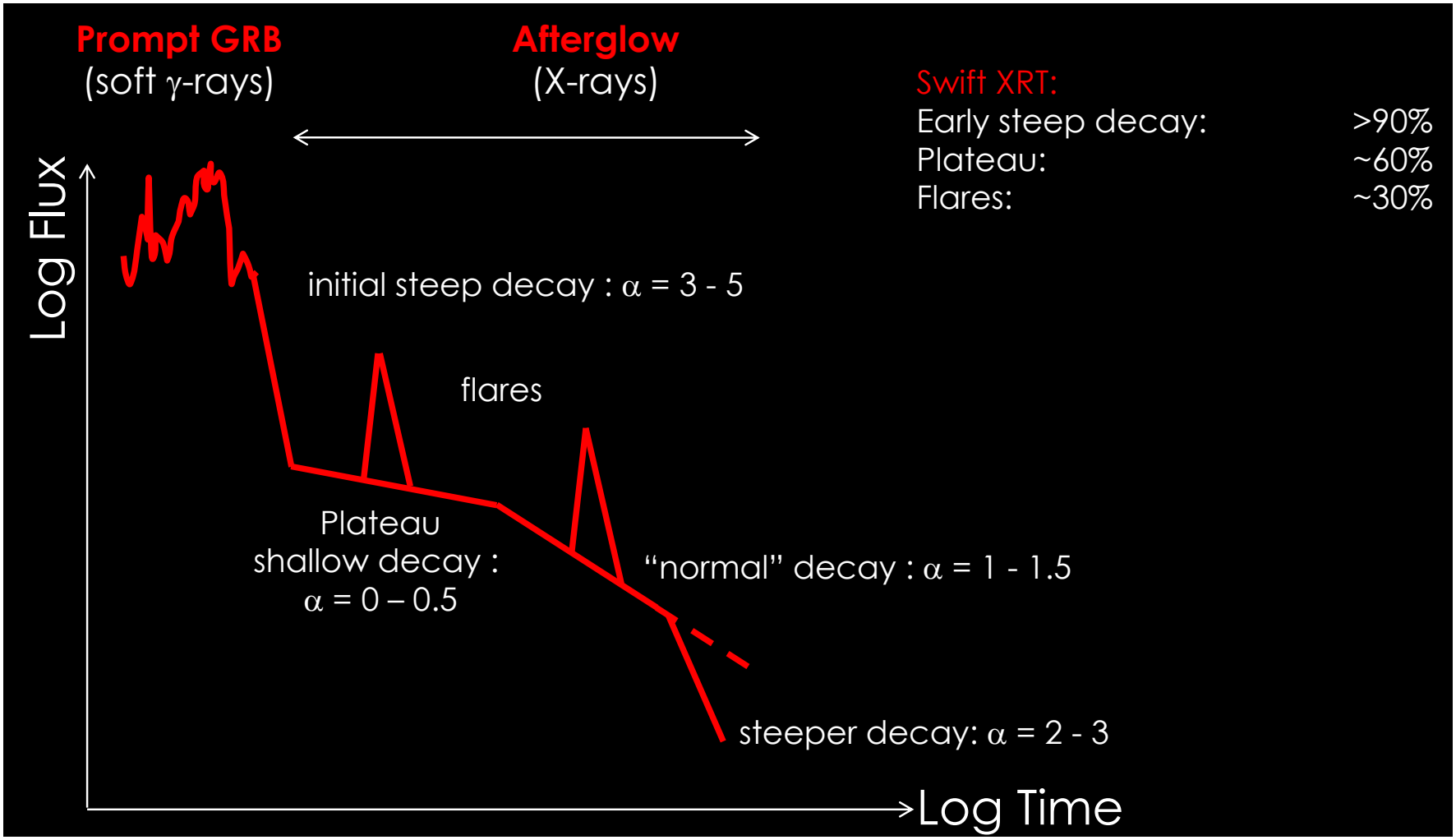
GRB AFTERGLOW EMISSION

- Lightcurves: power-law decay, breaks, flares, plateaus, etc.
- Spectral evolution: X-rays to radio



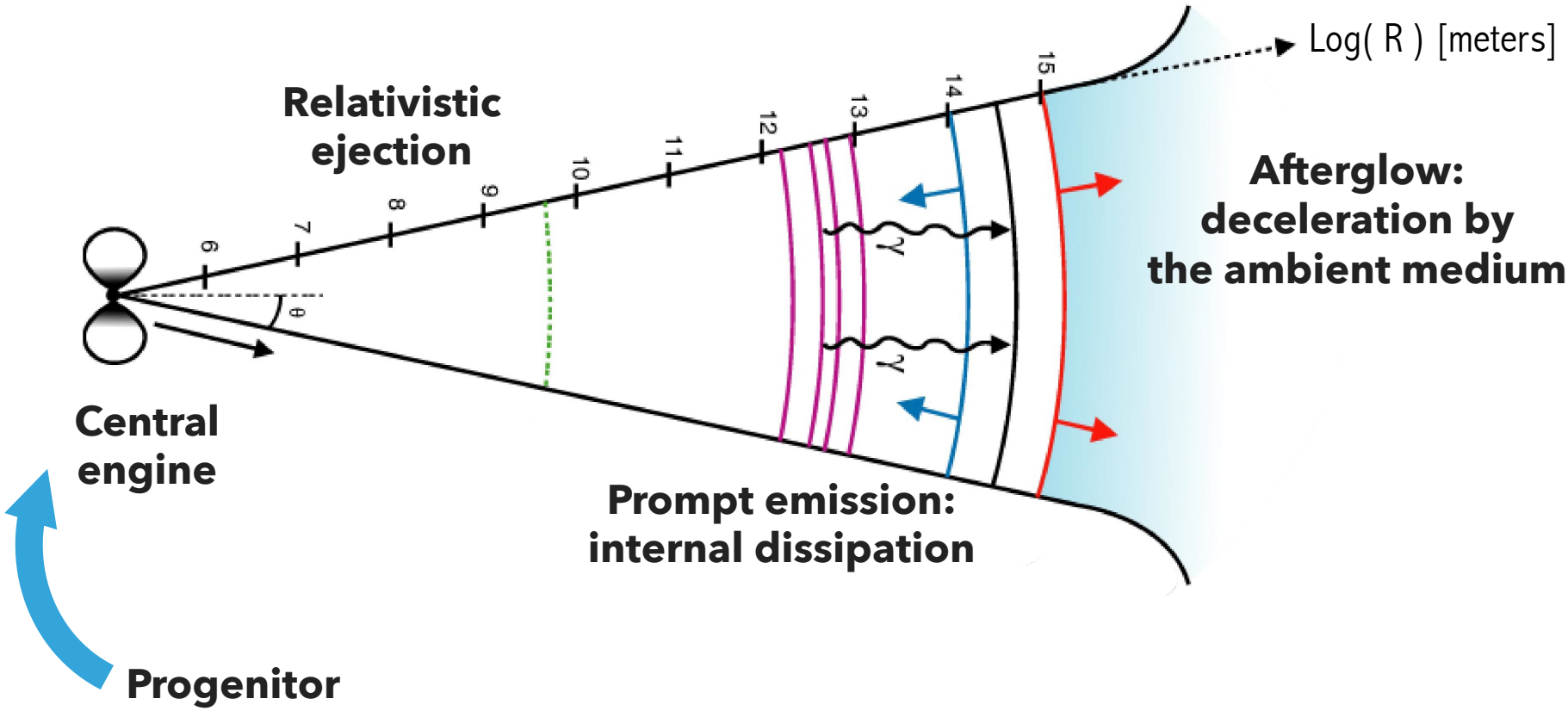
- **Redshift: cosmological distance (Gpc)**
  - Mean redshift above 2 for long GRBs
  - Maximum : GRB 090423 at z = 8.2 (spec.); GRB 090429B at z = 9.3 (phot.)
  - **E_{iso} ~ 10^{51} to 10^{54} erg (some under-luminous ; some monsters…)**

(TYPICAL?) GRB PROMPT-TO-AFTERGLOW LIGHTCURVE



Prompt: rare cases with optical or GeV prompt emission
Afterglow: optical emission detected in many cases. Radio in some cases.
HE in some cases (LAT extended emission)
VHE in rare cases (e.g. GRB190114C, GRB190829A, GRB221009A, etc.)

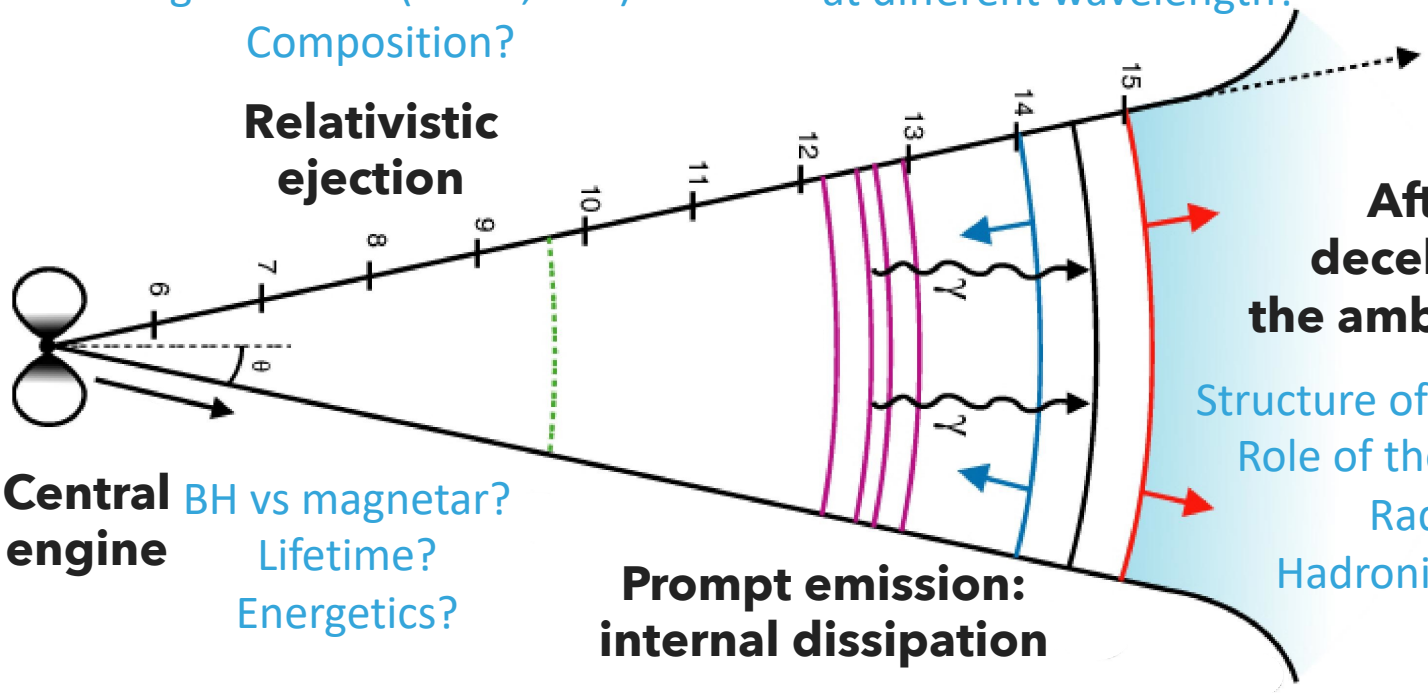
GAMMA-RAY BURSTS PHYSICS



GAMMA-RAY BURSTS PHYSICS: MANY OPEN QUESTIONS

Geometry?
Magnetisation (initial,final)?
Composition?

Prompt to afterglow transition
at different wavelength?



Relativistic ejection

Afterglow: deceleration by the ambient medium

Structure of the environment?
Role of the reverse shock?
Radio? VHE?
Hadronic component?

Central engine

BH vs magnetar?
Lifetime?
Energetics?

Prompt emission: internal dissipation

Shock breakout?
(dissipative) Photosphere?
Internal shocks or reconnection?
Synchrotron + SSC?
Visible? HE/VHE?
Hadronic component?

Progenitor

Collapsars vs Mergers?
Others?
Origin of the GRB diversity?

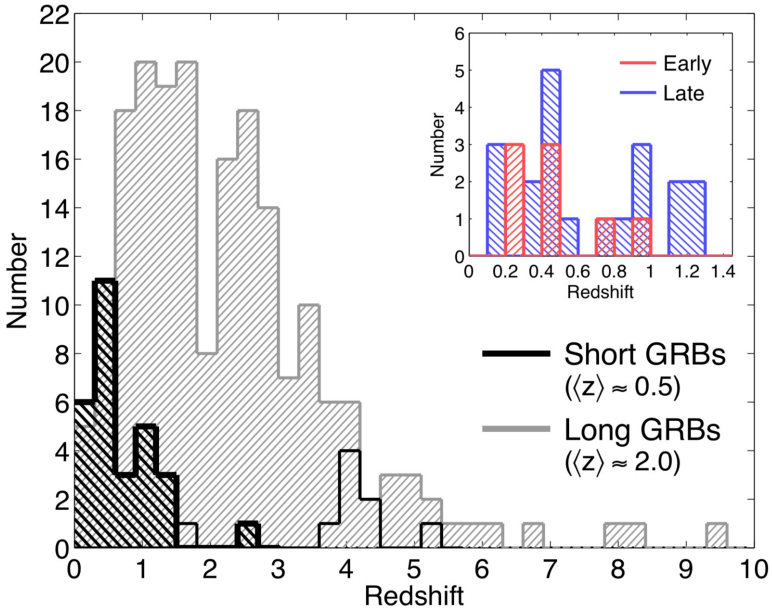
GW/neutrino emission ?

Etc.

ANOTHER CHALLENGE: GRBS AS A TOOL TO PROBE THE DISTANT UNIVERSE

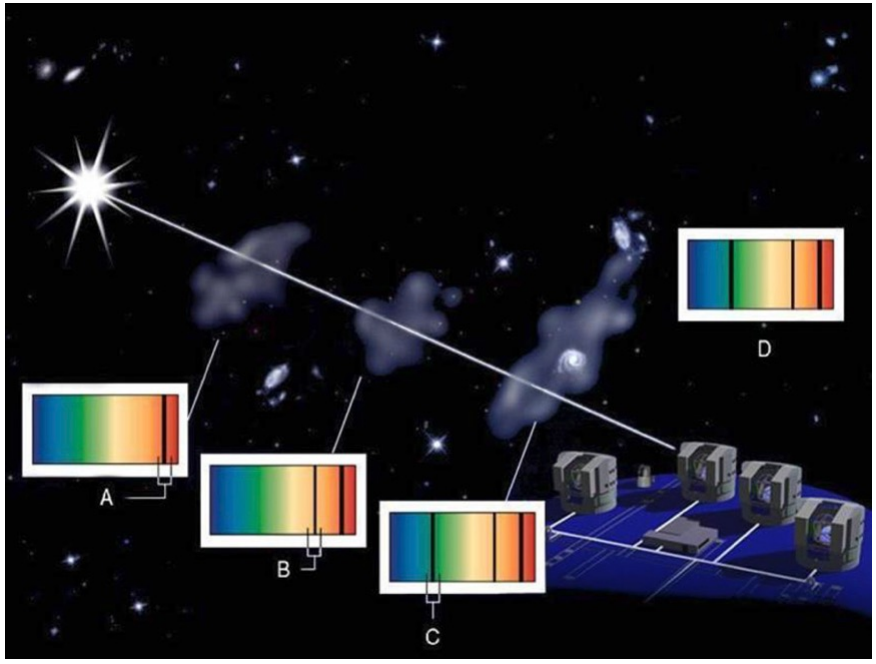
Classical long GRBs can be detected up to high redshifts.

High potential if high-z GRBs can be identified rapidly enough to allow accurate spectroscopy with large telescopes.



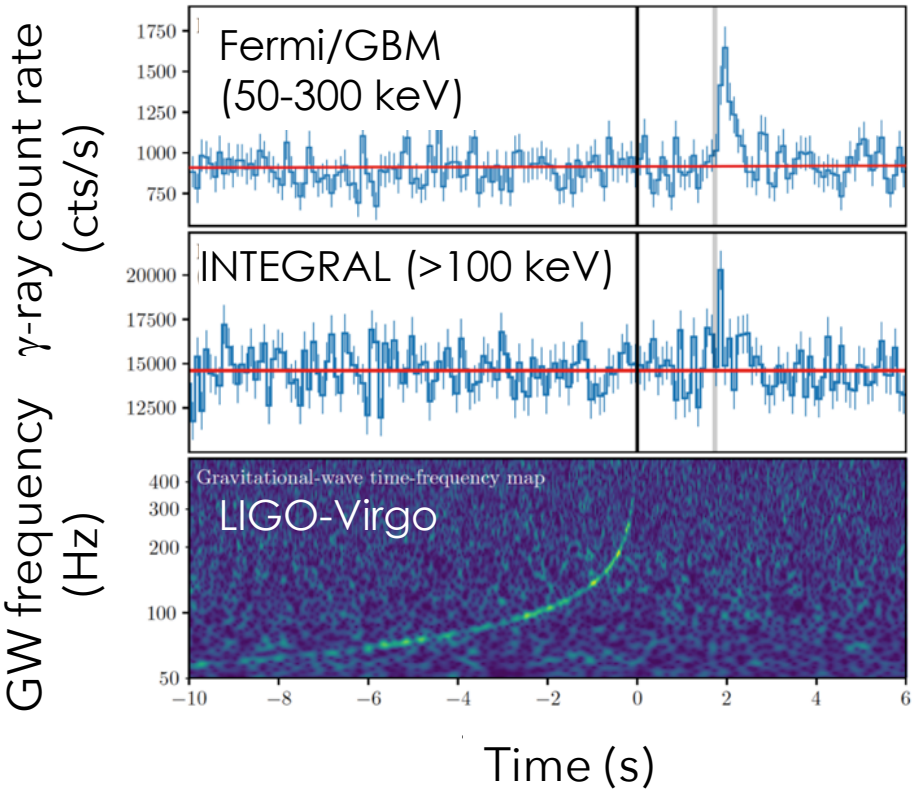
(Berger 2014)

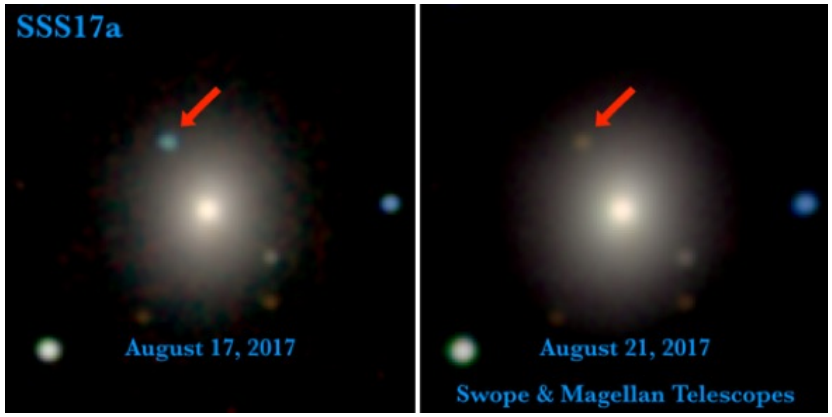
- **Absorption spectroscopy**
  - Host galaxy
  - Metallicity, kinematics, etc.
  - Neutral medium
  - Other absorbers on the l.o.s
- **Emission spectroscopy**
  - New opportunities (MUSE, JWST)
  - Ionized phases



GAMMA-RAY BURST: RECENT OBSERVATIONAL ADVANCES

- **GW170817: a multi-messenger event! (GW+em)**





- **BNS-GRB direct connection**
- **Kilonova!**

GAMMA-RAY BURST: RECENT OBSERVATIONAL ADVANCES

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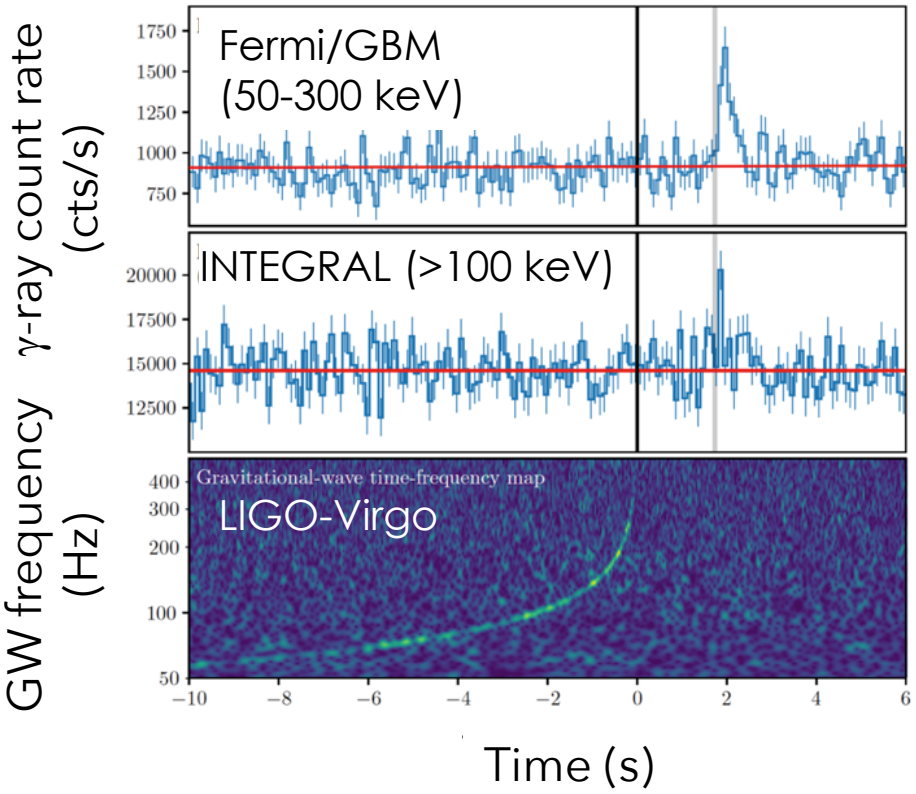
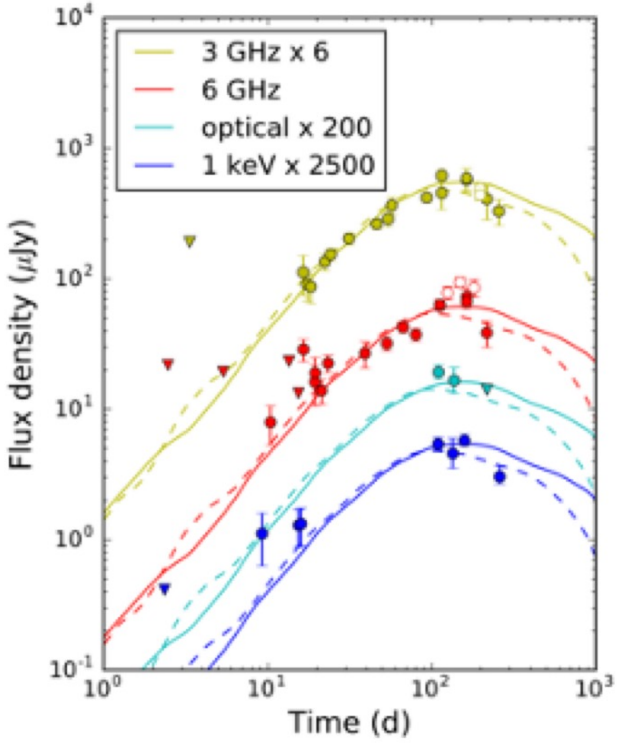
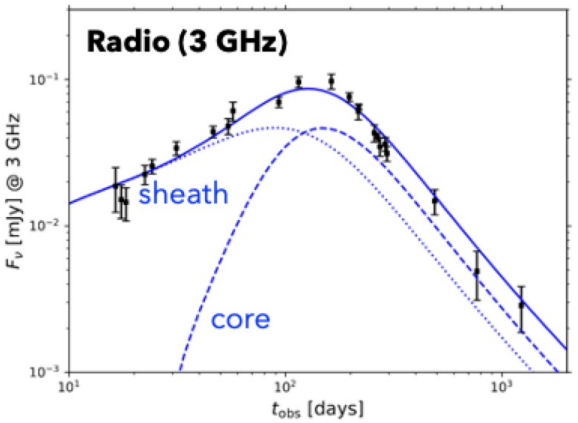




Alexander et al. 2018

- BNS-GRB direct link
- **GRB physics: a first offaxis event!**
  - Direct evidence for relativistic ejection (superluminal motion)
  - Lateral structure of the jet



Pellouin & Daigne 2024

GAMMA-RAY BURST: RECENT OBSERVATIONAL ADVANCES

- **GW170817: a multi-messenger event! (GW+em)**

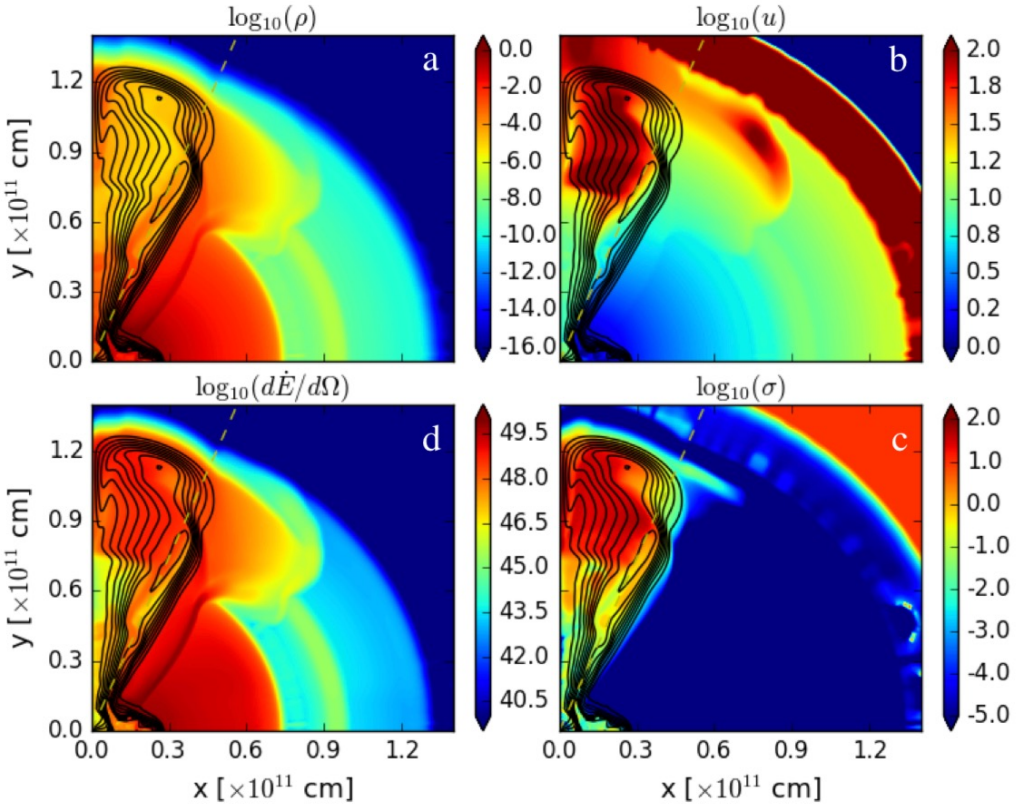
  - **A consistent scenario to explain the weak prompt GRB and the lateral structure revealed by the afterglow?**

  - GRB170817 is very weak despite the very low distance (40 Mpc)

  - Ultra-relativistic jet seen very off-axis?
    → Probably not ($\gamma\gamma$ opacity argument, Matsumoto+ 19)

  - **Much more promising: shock breakout ? (interaction jet + KN ejecta)**
    see e.g. Bromberg+ 18

  - This interaction during the early propagation of the jet naturally leads to the lateral strcuture revealed by the afterglow.

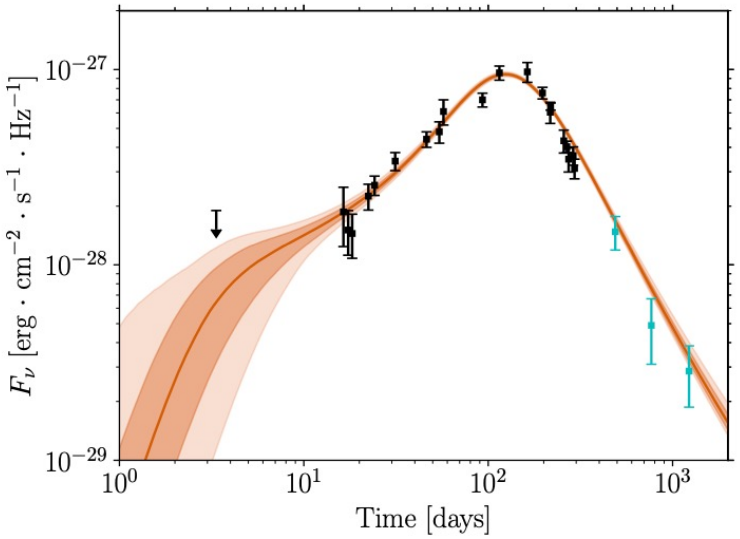


Bromberg+ 18

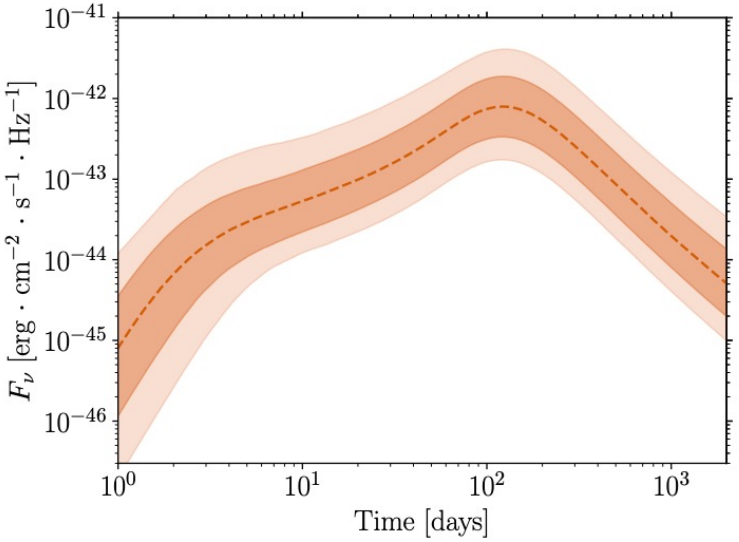
GAMMA-RAY BURST: RECENT OBSERVATIONAL ADVANCES

- **GW170817: a multi-messenger event! (GW+em)**
  - **In this unique case the viewing angle is ideal to probe the jet geometry**
  - **In the future, additional VHE observations would allow to also better constrain particle acceleration/radiative processes at the ultra-relativistic forward shock**
    (see Martin Lemoine's talk this morning)

3 GHz



1 TeV



Pellouin & Daigne 2024

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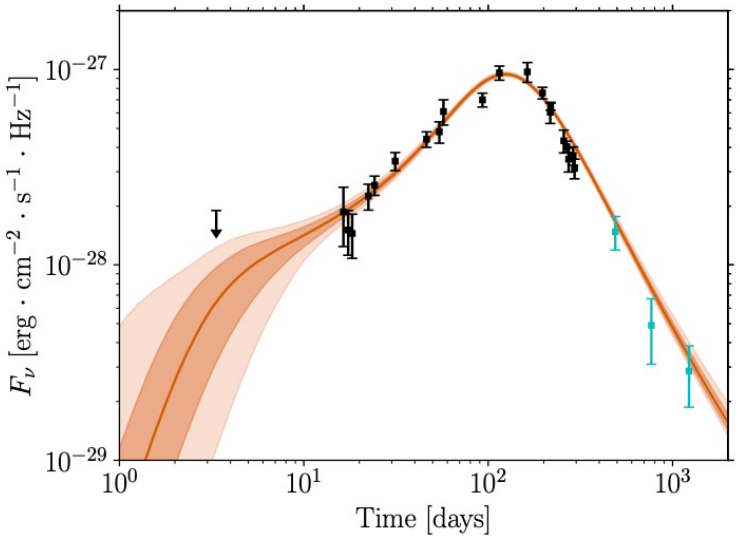
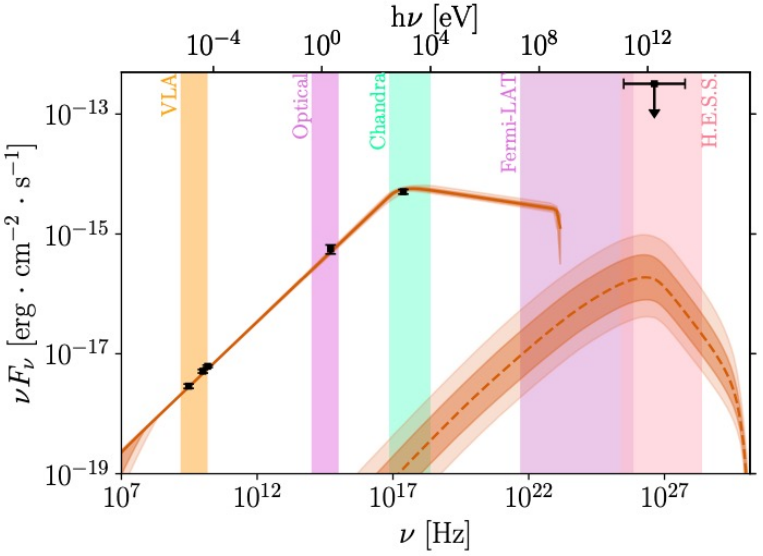


Spectrum@peak



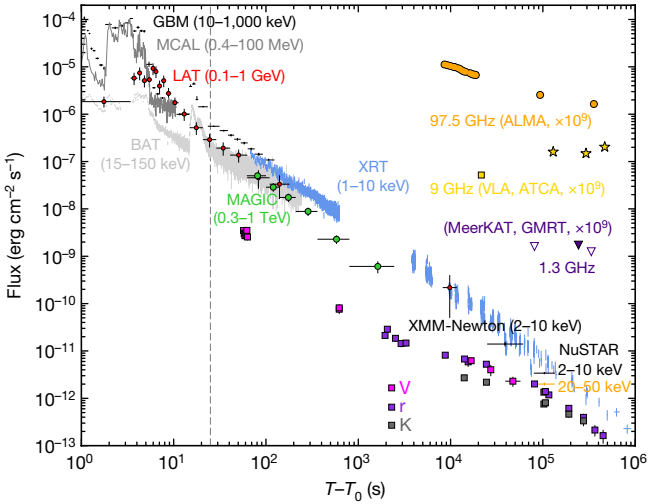
Pellouin & Daigne 2024

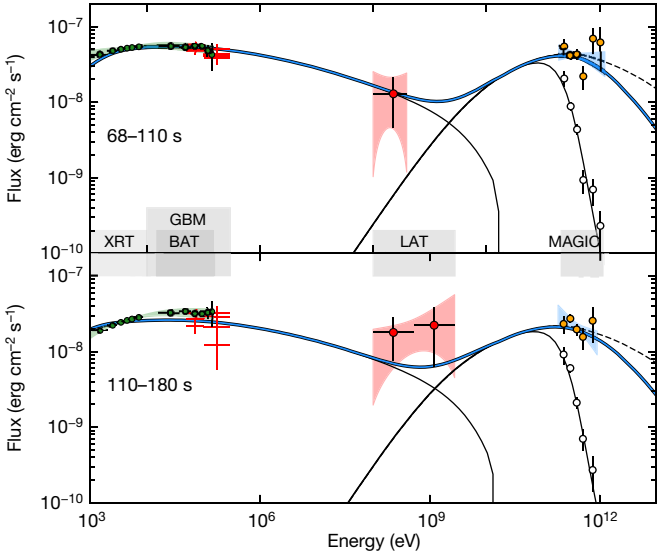
Slightly lower view angle + higher external density: detectable by CTA up to 100 Mpc

GAMMA-RAY BURST: RECENT OBSERVATIONAL ADVANCES

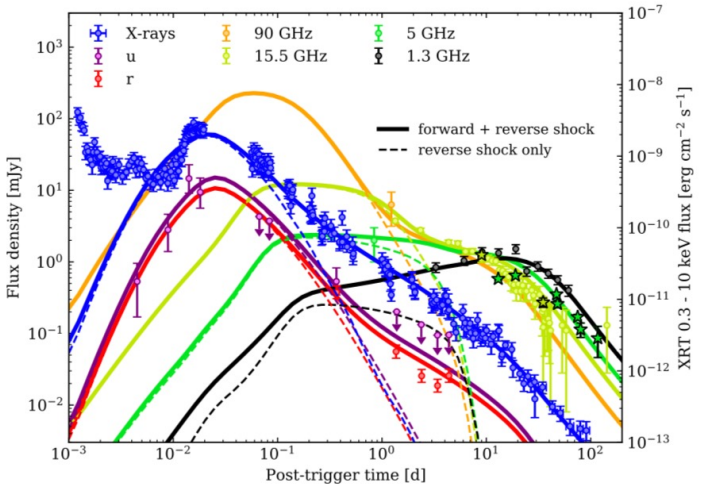
- **First detections in the TeV range ! (afterglow)**

GRB 190114C (MAGIC) @ z=0.14



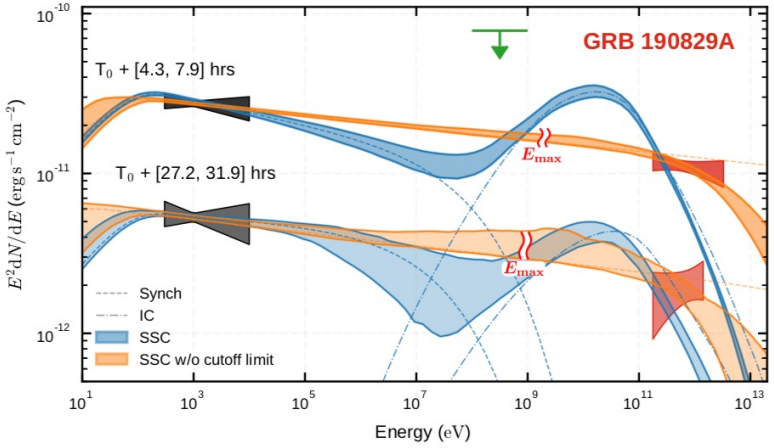


MAGIC collab. 2019a,b



Salafia et al. 2021

GRB 190829A (HESS) @ z = 0.0785
A low-luminosity burst

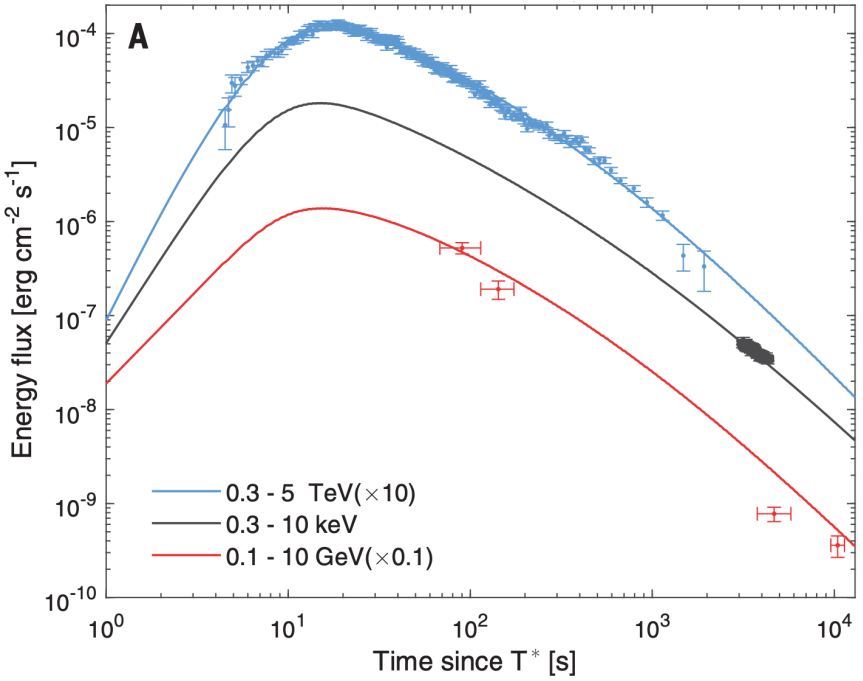


HESS collab. 2021

See Fabian Schüssler's talk tomorrow

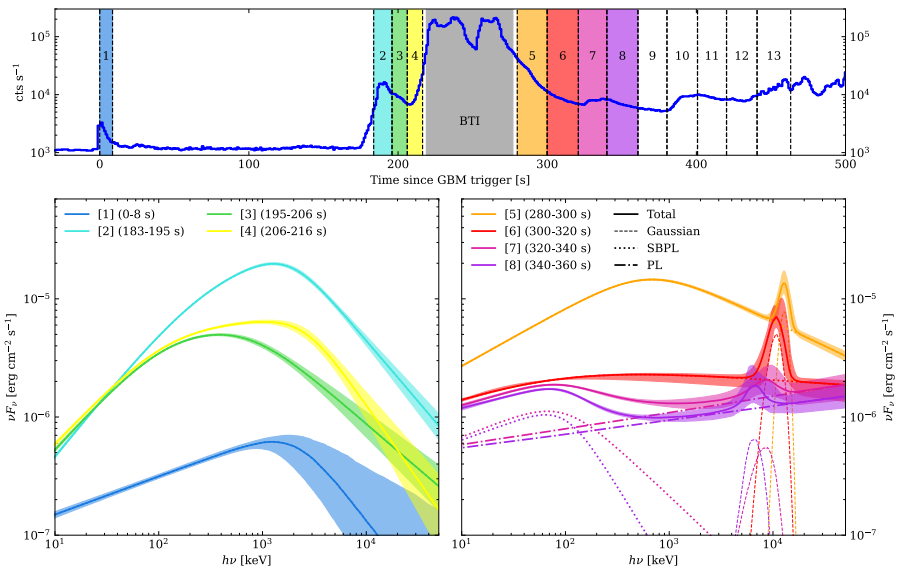
GAMMA-RAY BURST: RECENT OBSERVATIONAL ADVANCES

- **GRB221009A at z = 0.15: the BOAT! ($E_{\gamma,iso}$ ~10^{55} erg!)**
- **Early TeV detection by LHASSO, highest energy photon ~13 TeV**
- Complex prompt lightcurve, Fermi/GBM saturated during the main episod
- Emission line at ~10 MeV!
- Complex afterglow: structured jet?
  (excellent follow-up: radio → TeV)



LHAASO Collab 2023

Rise of the TeV afterglow detected by LHASSO



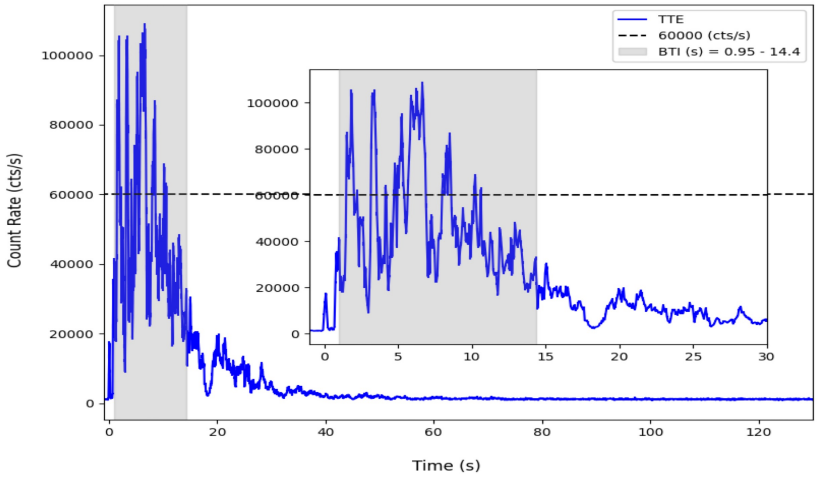
Ravasio et aL. 2023

See Fabian Schüssler's talk tomorrow

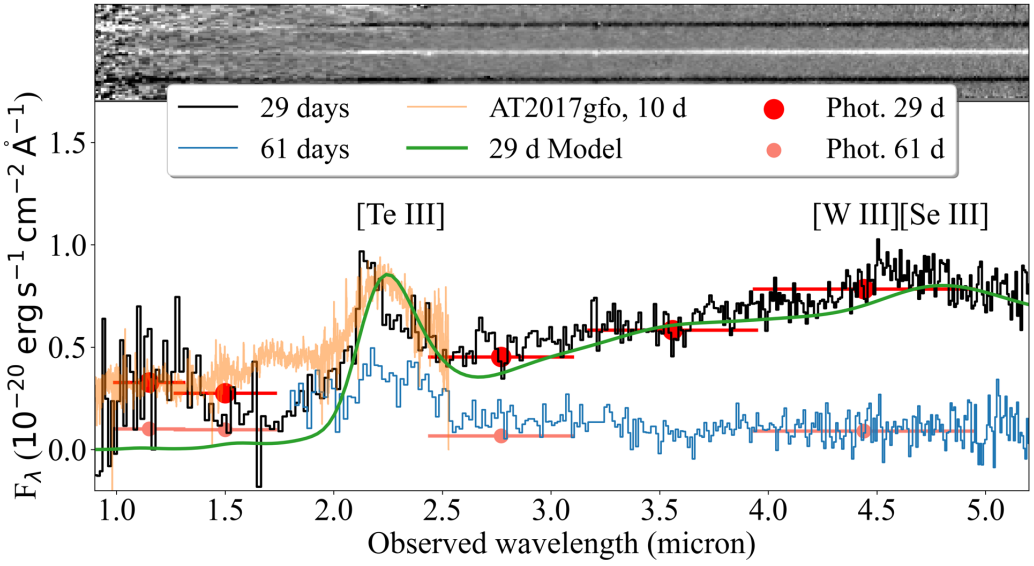
GAMMA-RAY BURST: RECENT OBSERVATIONAL ADVANCES

- **Short GRBs associated to collapsars…**
- **… and long GRBs with a kilonova!**

GRB 230307A @ z=0.065 (very bright!)
A very bright long GRB associated to a kilonova! (JWST spectrum!)



Fermi GBM lightcurve



Levan et al. 2023

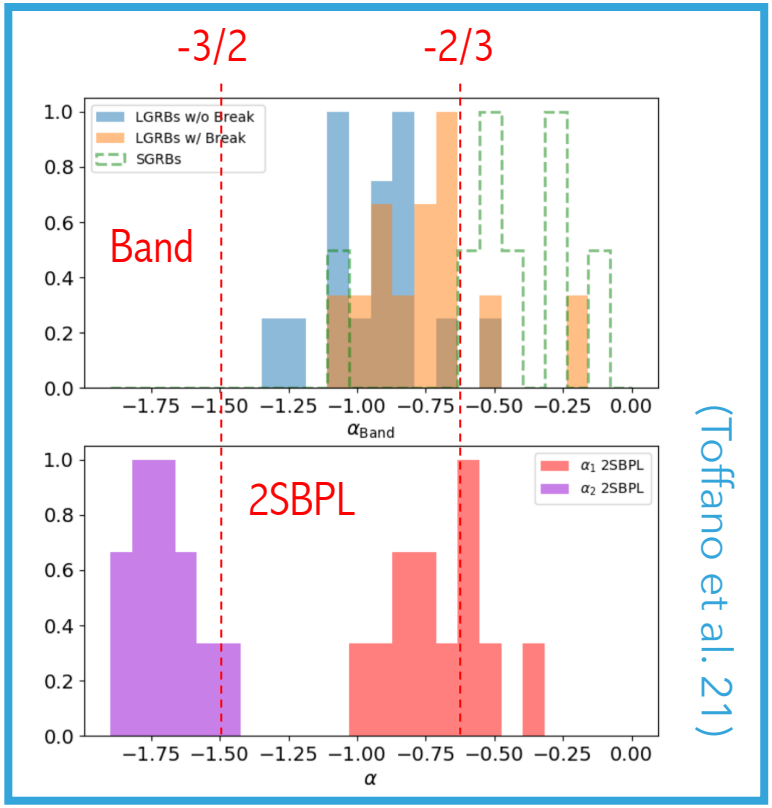
GAMMA-RAY BURST: RECENT OBSERVATIONAL ADVANCES

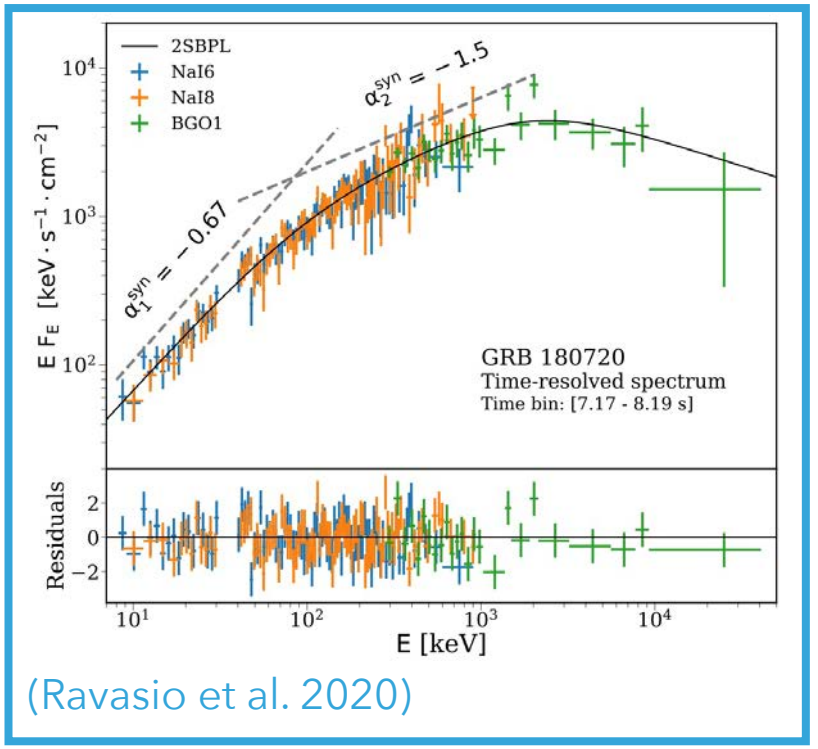
- **The origin of the prompt GRB emission remains puzzling…**

Which spectral shape to fit data?

- Doubly broken power-laws? (Oganesyan et al. 17, 18 ; Ravasio et al. 18, 19 ; Toffano et al. 21)
- ISSM: a new 4-parameters function with a smoothly evolving slope

(Yassine et al. (FD) 20, Scotton et al. (FD) in preparation)





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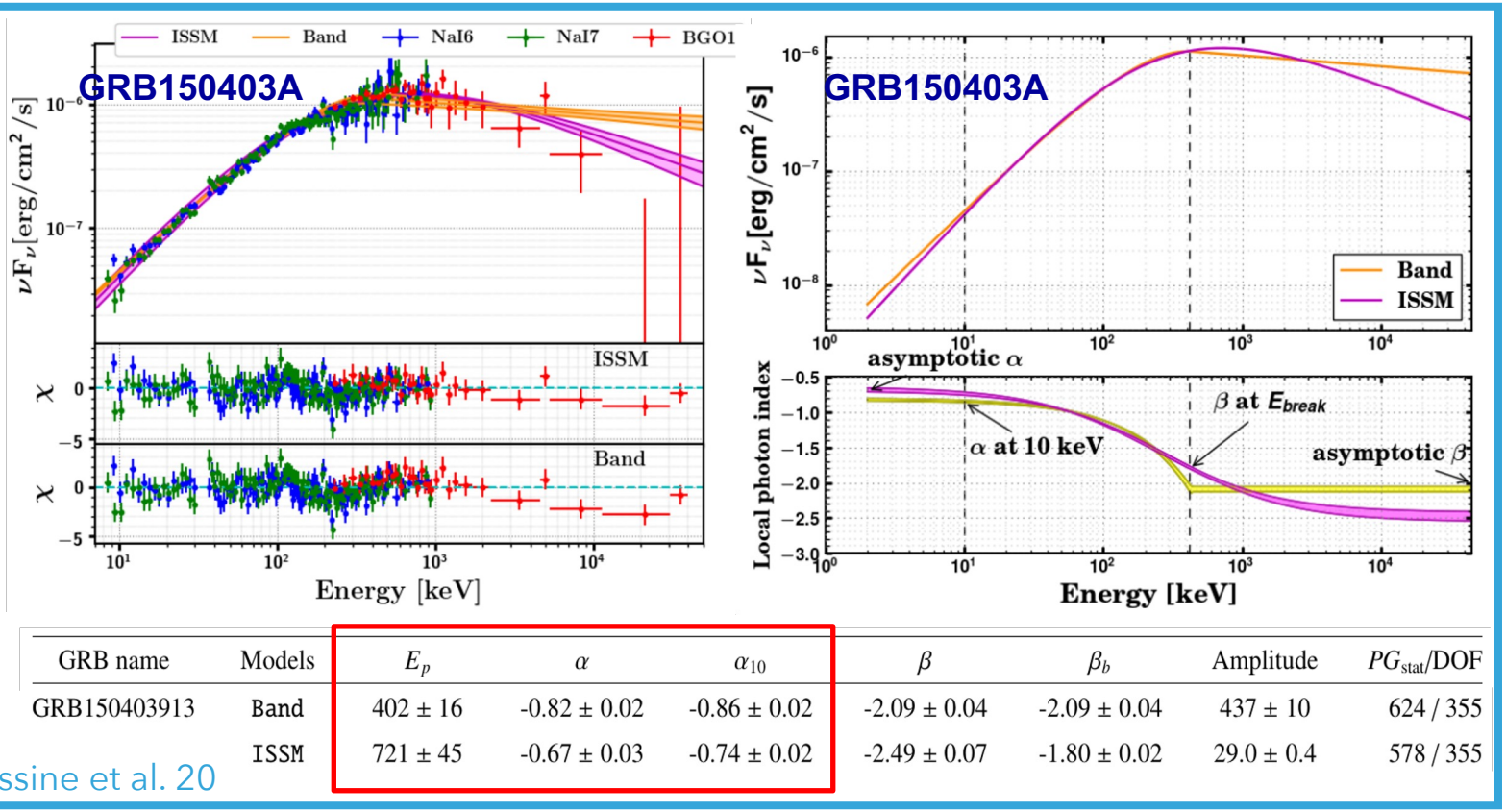


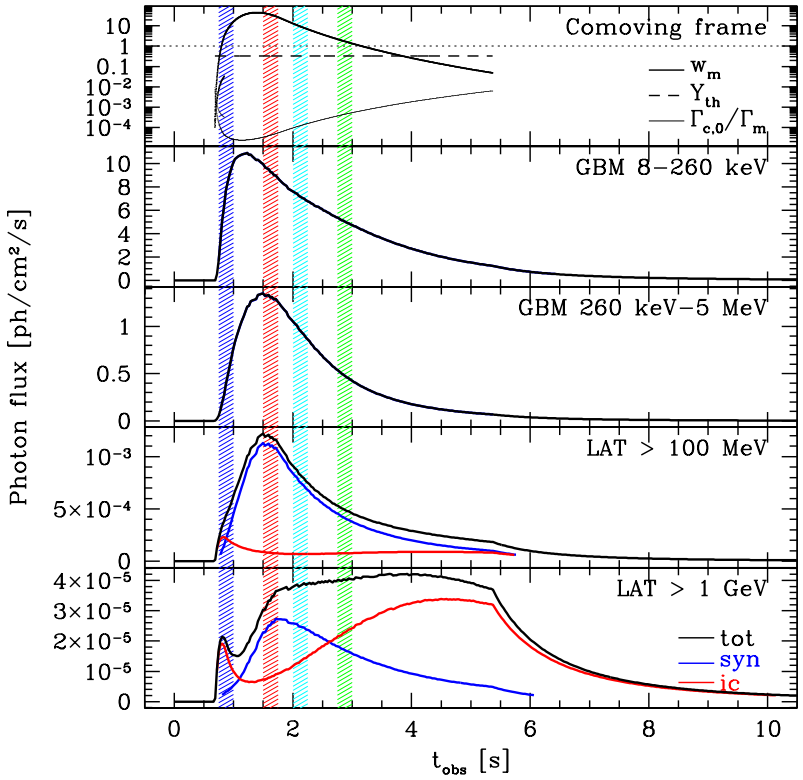
GRB name	Models	E_p	α	α_{10}	β	β_b	Amplitude	PG_{stat}/DOF
GRB150403913	Band	402 ± 16	-0.82 ± 0.02	-0.86 ± 0.02	-2.09 ± 0.04	-2.09 ± 0.04	437 ± 10	624 / 355
	ISSM	721 ± 45	-0.67 ± 0.03	-0.74 ± 0.02	-2.49 ± 0.07	-1.80 ± 0.02	29.0 ± 0.4	578 / 355

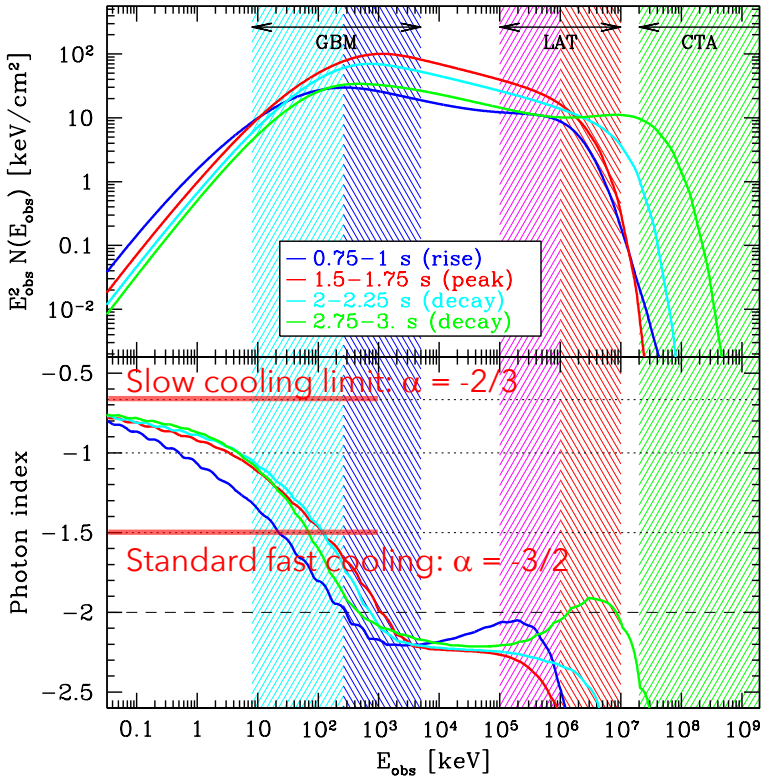
Yassine et al. 20

GAMMA-RAY BURST: RECENT OBSERVATIONAL ADVANCES

- **The origin of the prompt GRB emission remains puzzling…**

Optically thin scenario: (marginally) fast-cooling synchrotron?
(Daigne et al. 11, Beniamini & Piran 13)





Daigne & Bosnjak 2025

This regime may be favored by a decaying magnetic field on a scale intermediate between the radiative timescale of electrons at γ_m and the dynamical timescale.

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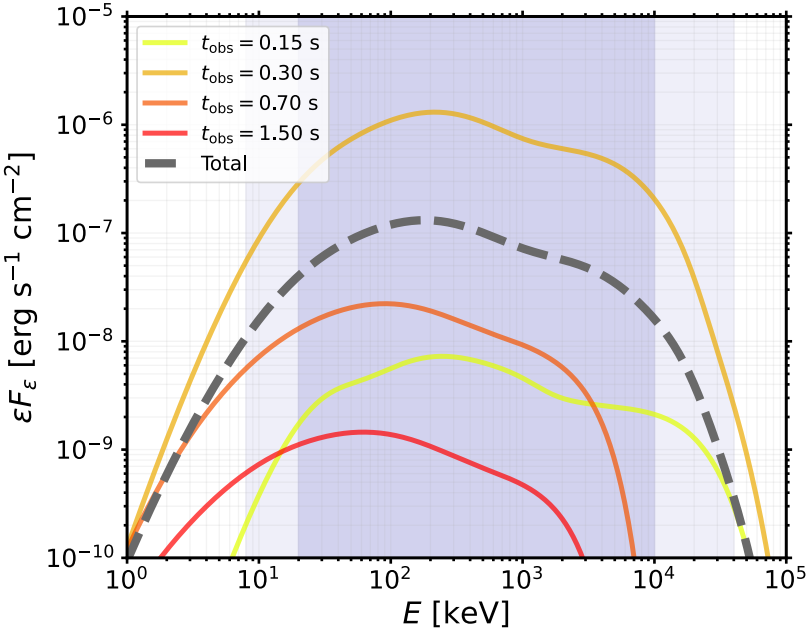
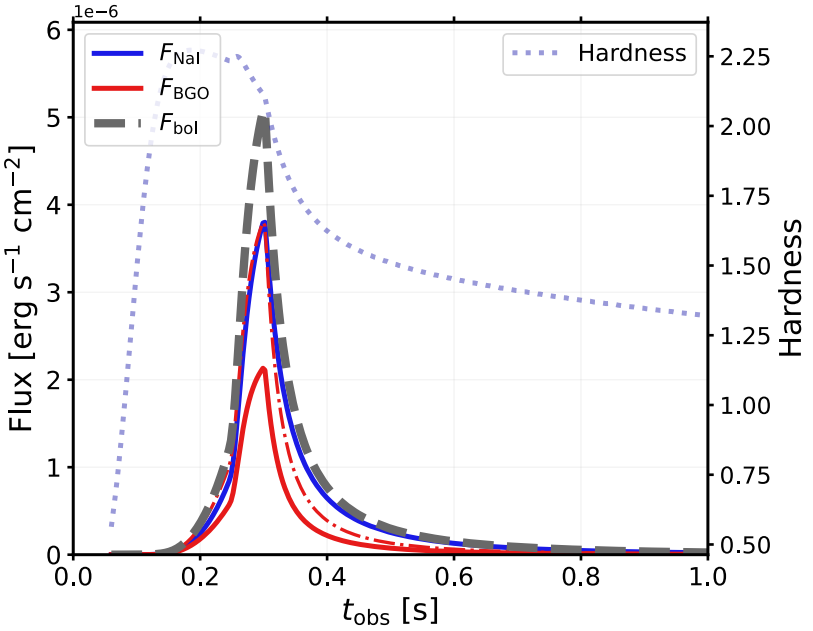
(Daigne et al. 11, Beniamini & Piran 13)

Optically thick scenario (dissipative photosphere)?
(e.g. sub-photospheric radiation mediated shocks)
(e.g. Samuelsson-Alamaa & Ryde 2023)

Non-thermal spectrum: photons crossing the RMS Compton scatter in the velocity gradient.





Alamaa & Daigne, submitted

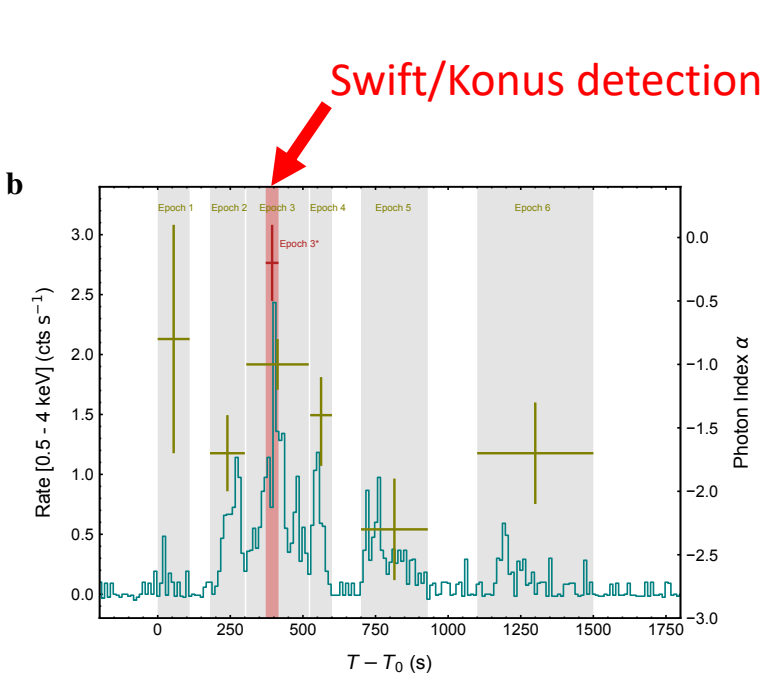
Time-integrated spectrum: $\alpha \sim -0.9$

GAMMA-RAY BURST: RECENT OBSERVATIONAL ADVANCES

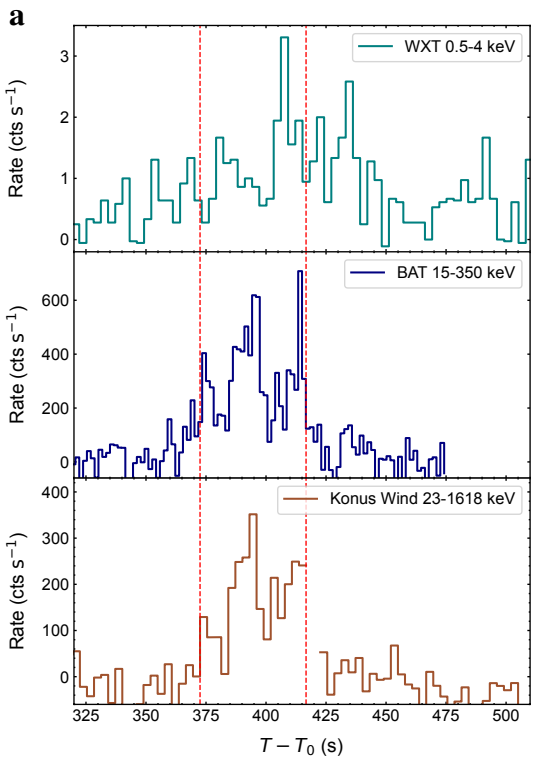
- **X-ray Prompt emission**

EP240315a/GRB230315C

(Liu et al. 24)



EP 0.5-4 keV Lightcurve



z=4.9

« normal » afterglow

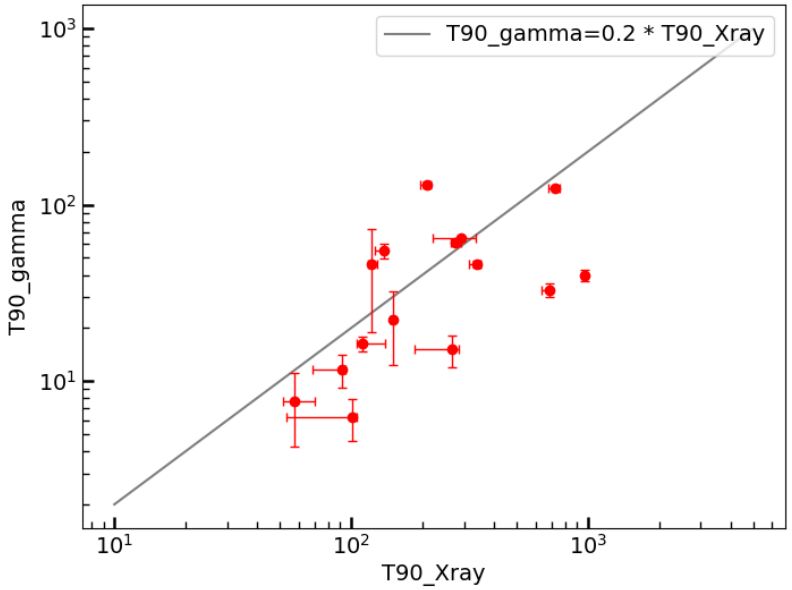
(Levan et al. 24 , Liu et al. 24)

The prompt X-ray emission of classical long GRBs?

GAMMA-RAY BURST: RECENT OBSERVATIONAL ADVANCES

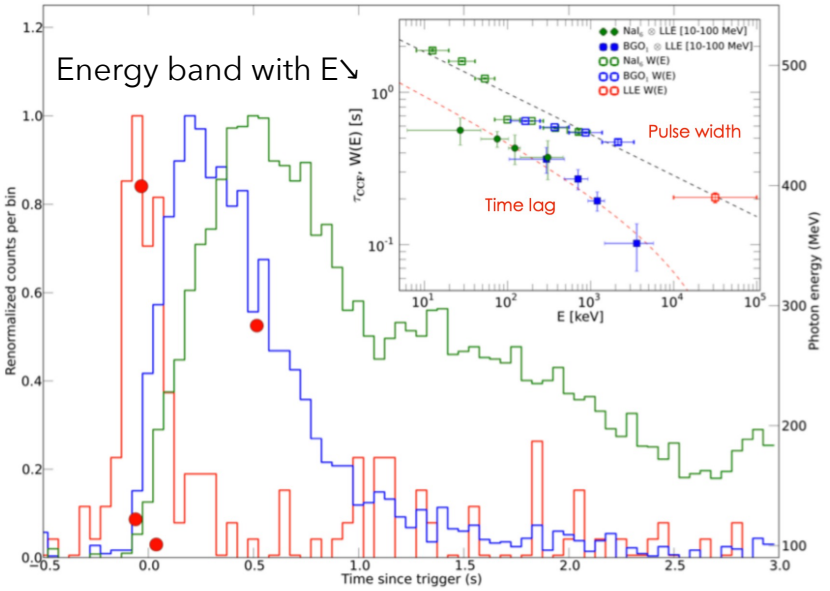
- **X-ray Prompt emission**

GRBs detected with EP/WXT: emission usually longer in X-rays



Liu et al. 2024

Effect stronger than the already known spectral evolution

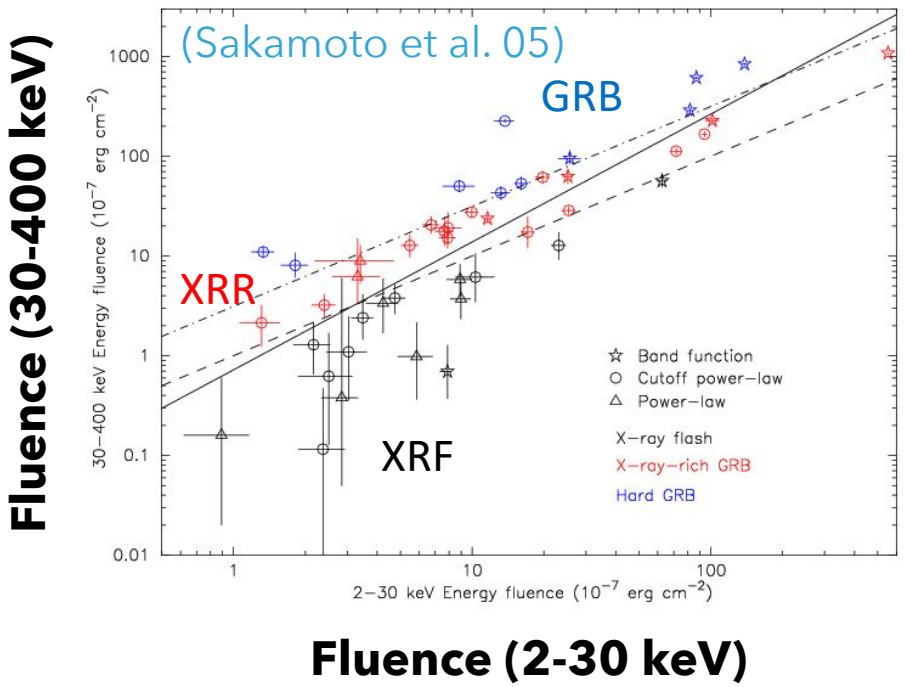


First pulse of the « Fermi monster » GRB 130427A (Preece et al. 14)

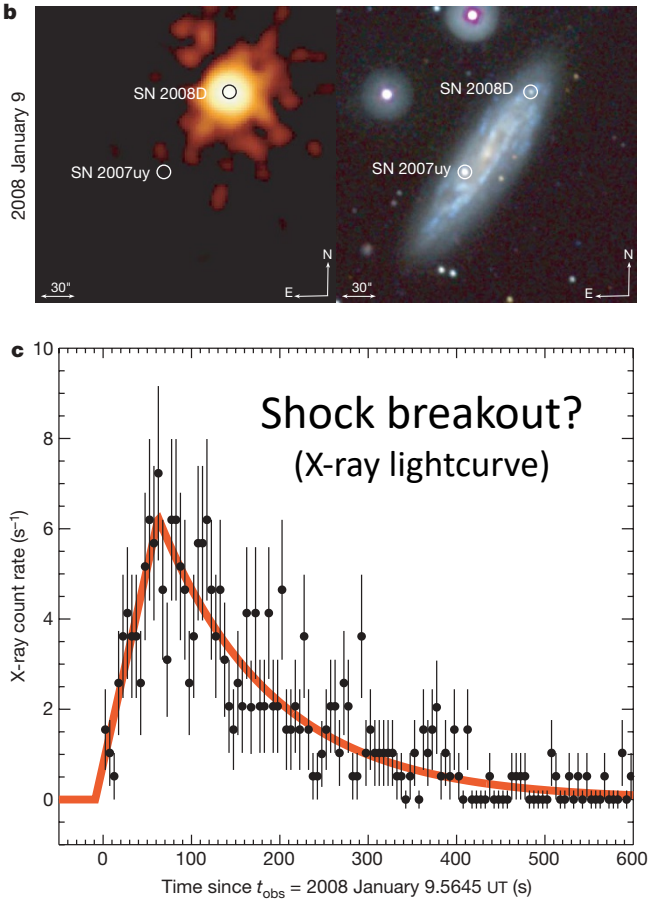
GAMMA-RAY BURST: RECENT OBSERVATIONAL ADVANCES

- **Long GRB diversity: soft events (X-Ray Rich GRBs, X-Ray Flashes, Fast X-ray transients, etc.)**

HETE2 sample



The soft tail of the GRB population?



(Soderberg et al. 08)

Many new FXTs without associated GRB now detected by EP/WXT: to be characterized

Other classes of events?

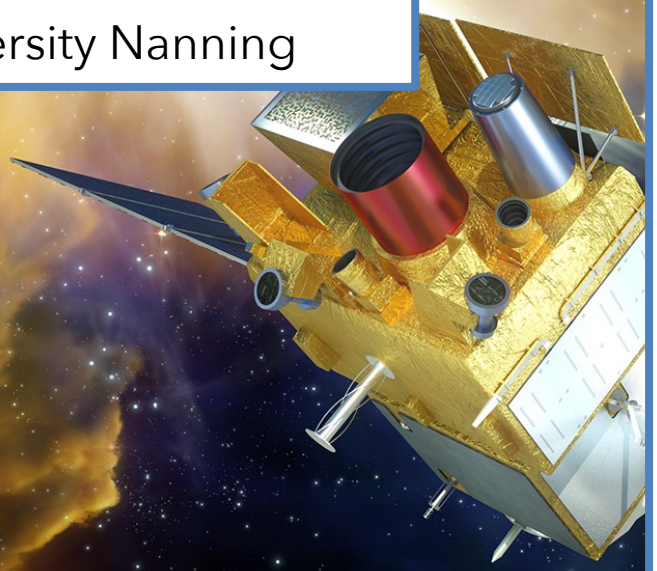
1. Gamma-Ray Bursts

2. The SVOM Mission

3. GRB Studies with SVOM: First Results & Prospects

on behalf of the SVOM consortium

THE SVOM COLLABORATION



China (P.I. J. Wei)
SECM Shangai
NSSC Beijing
NAOC Beijing
IHEP Beijing
GuangXi University Nanning

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

Mexico, UNAM (Colibri)

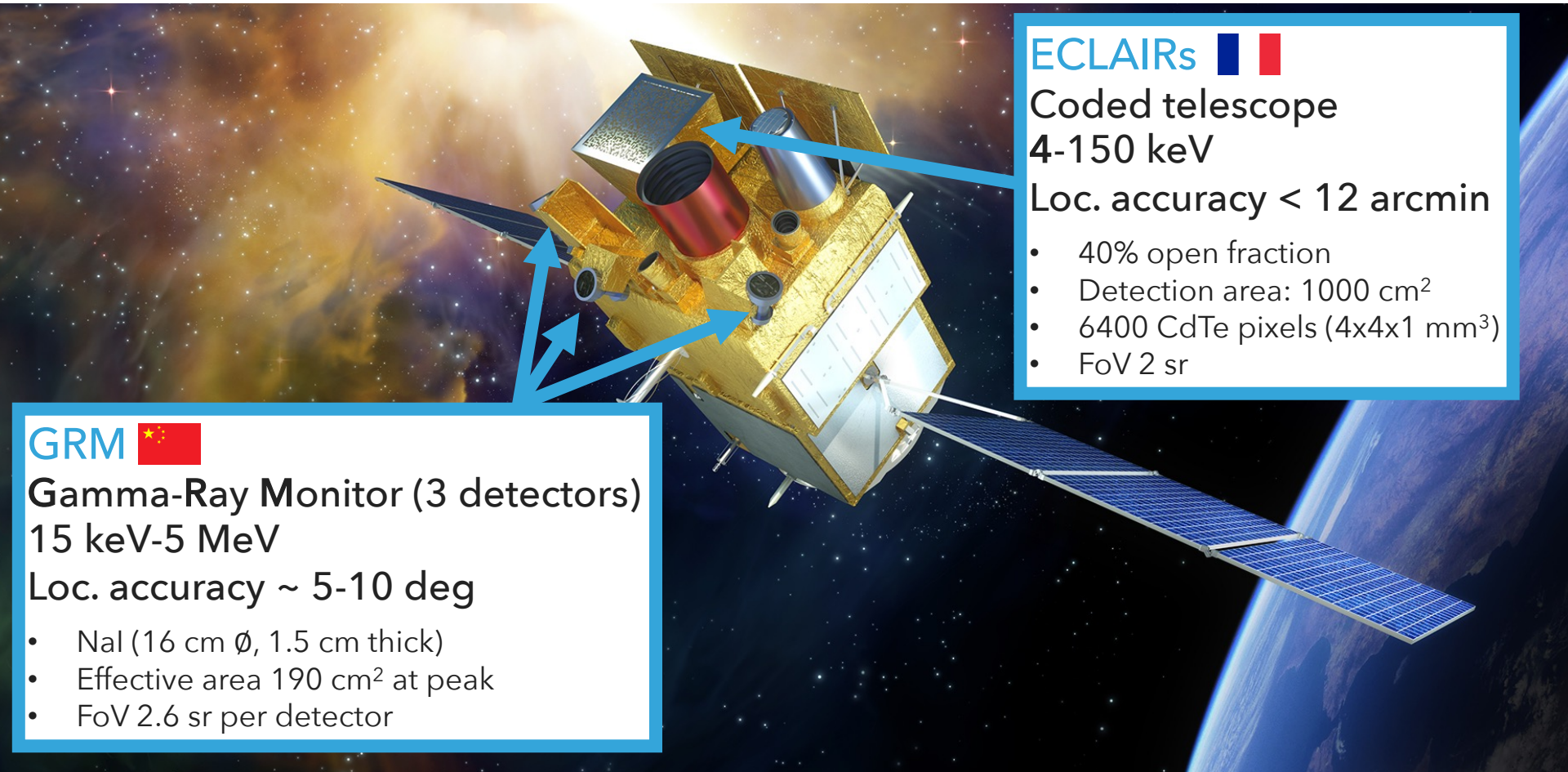
UK, University of Leceister (MXT)

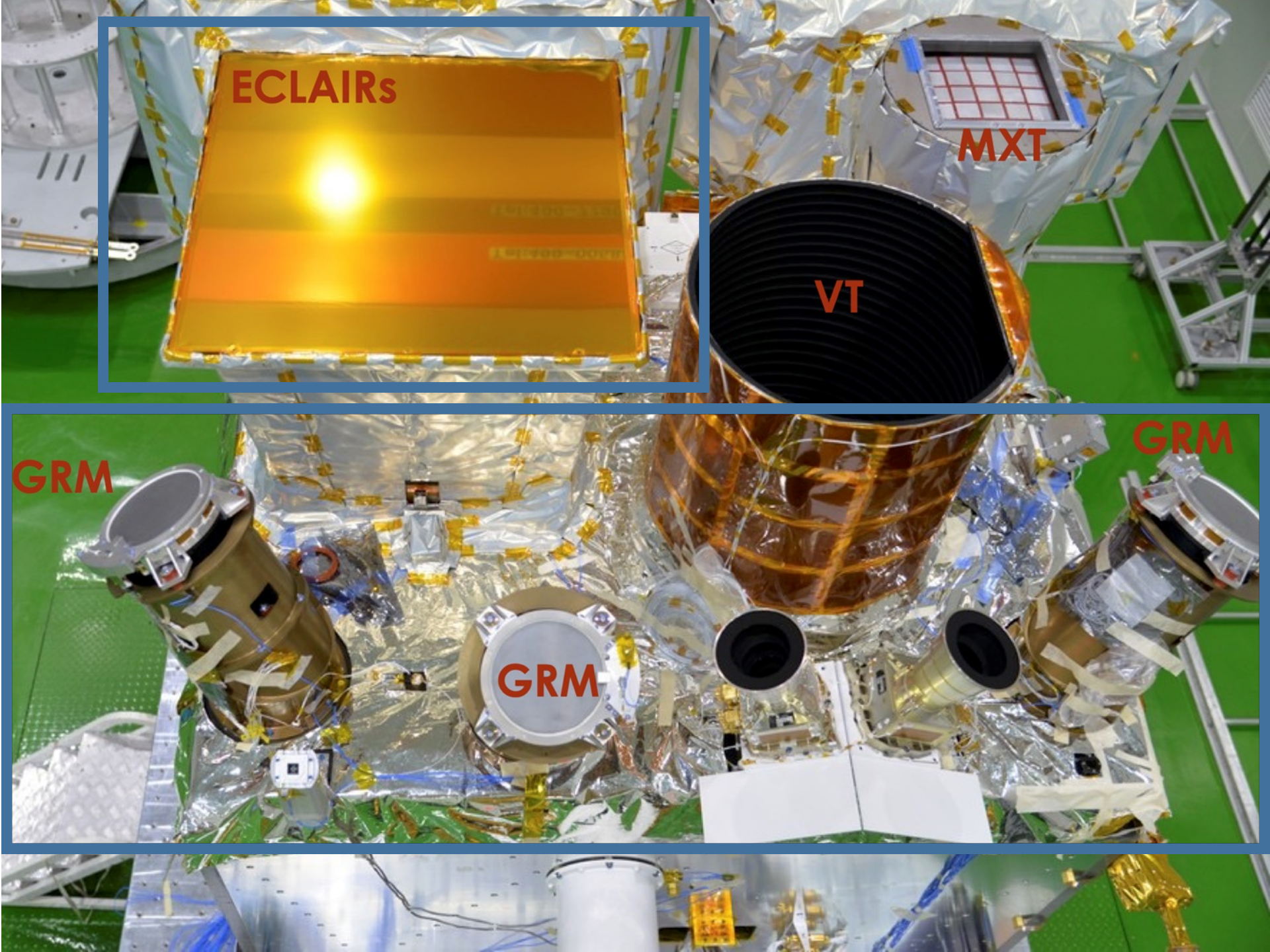
Germany, MPE Garching & IAAT Tübingen (MXT)

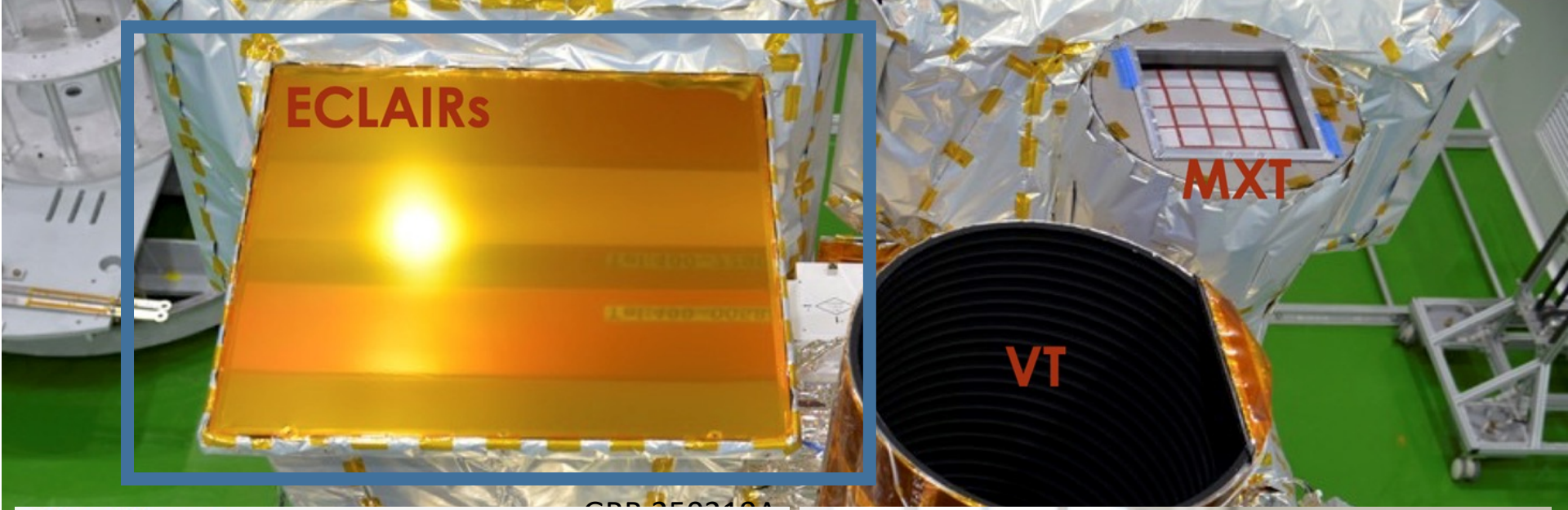
2024 JUNE 22: SVOM LAUNCH!

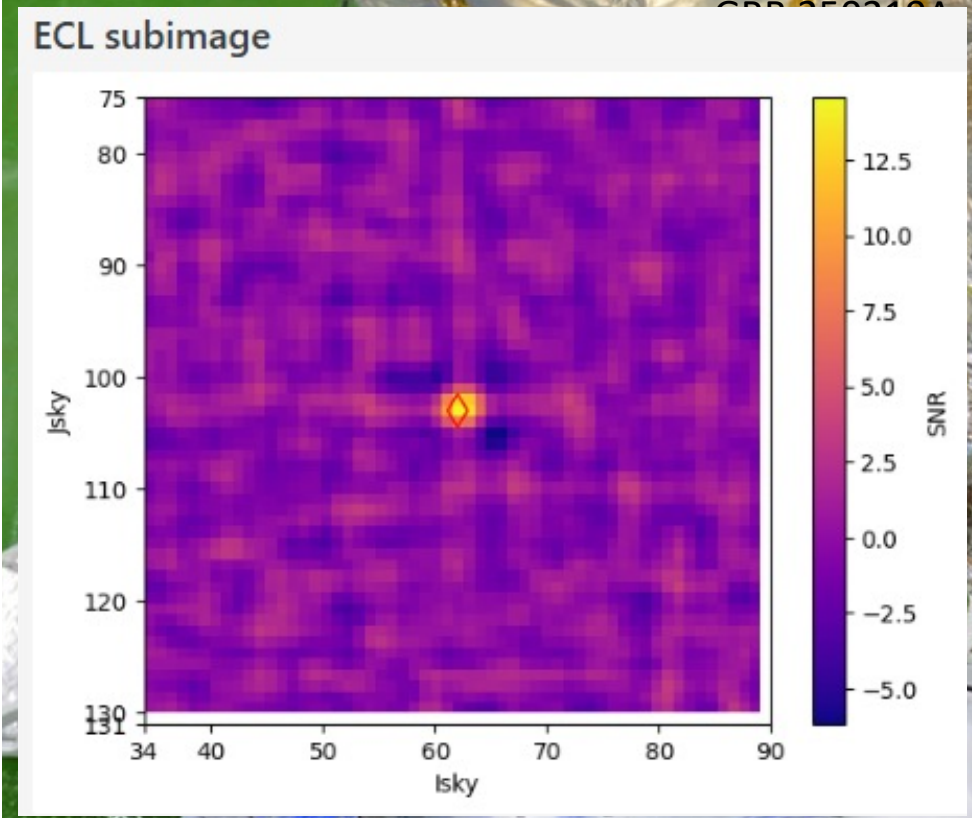
SVOM AT A GLANCE

- **A spacecraft with four instruments + rapid slewing capabilities**
- **Two wide-field instruments (X/γ): ECLAIRs & GRM**




ECLAIRs
MXT
VT
GRM
GRM
GRM


ECLAIRs
MXT
VT


ECL subimage
Jsky
Isky
SNR
75
80
90
100
110
120
130
131
34
40
50
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70
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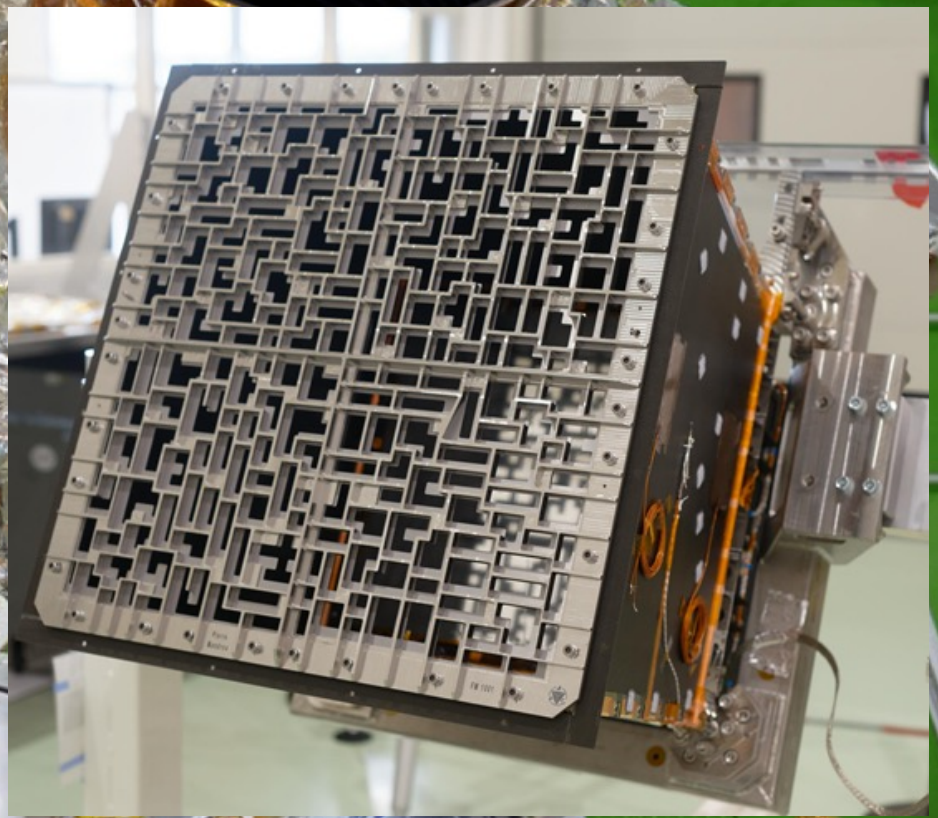
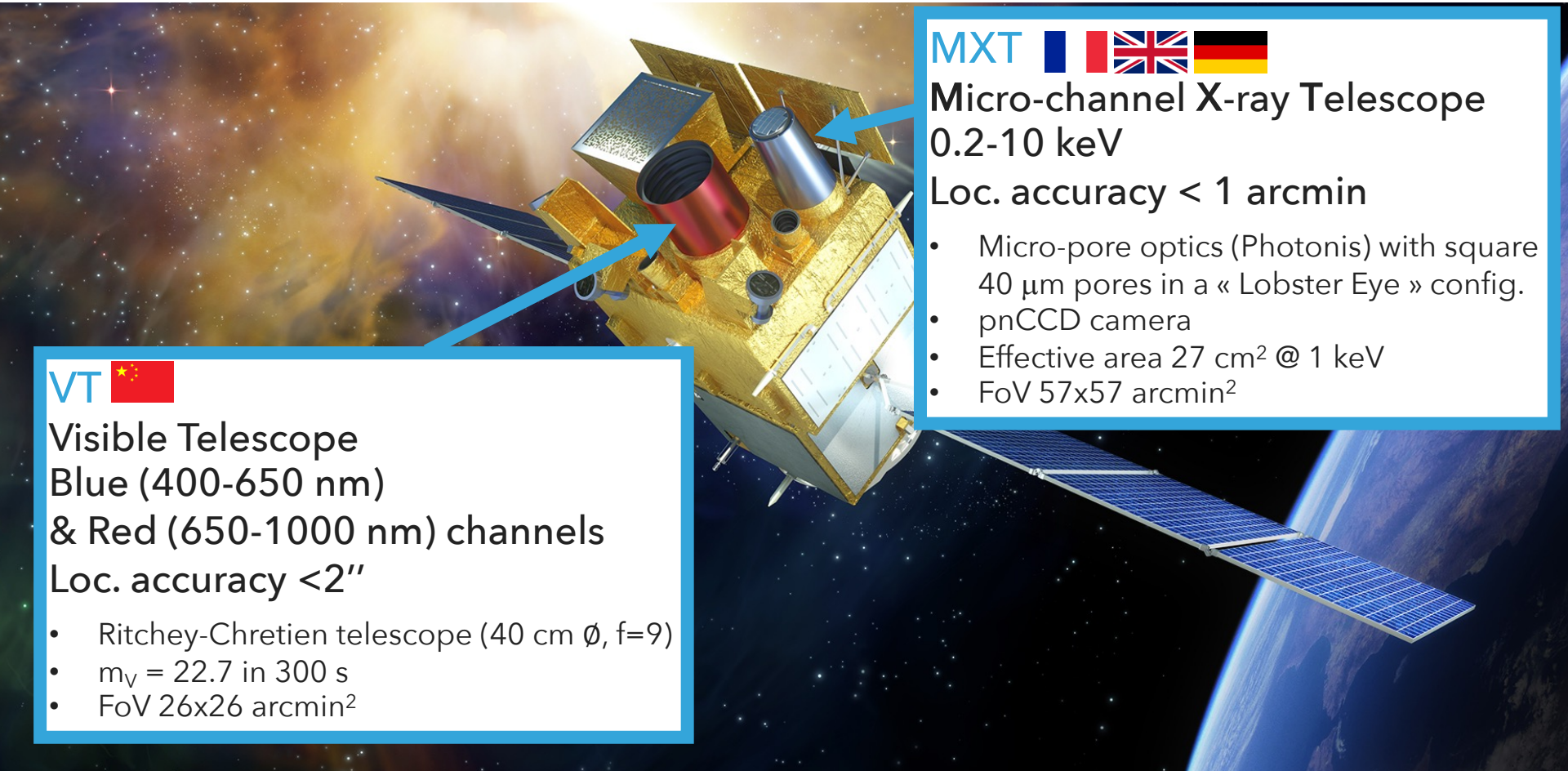
5.0
2.5
0.0
−2.5
−5.0



SVOM AT A GLANCE

- **A spacecraft with four instruments + rapid slewing capabilities**
- **Two wide-field instruments (X/γ): ECLAIRs & GRM**
- **Two narrow-field instruments (X/V): MXT & VT**



MXT

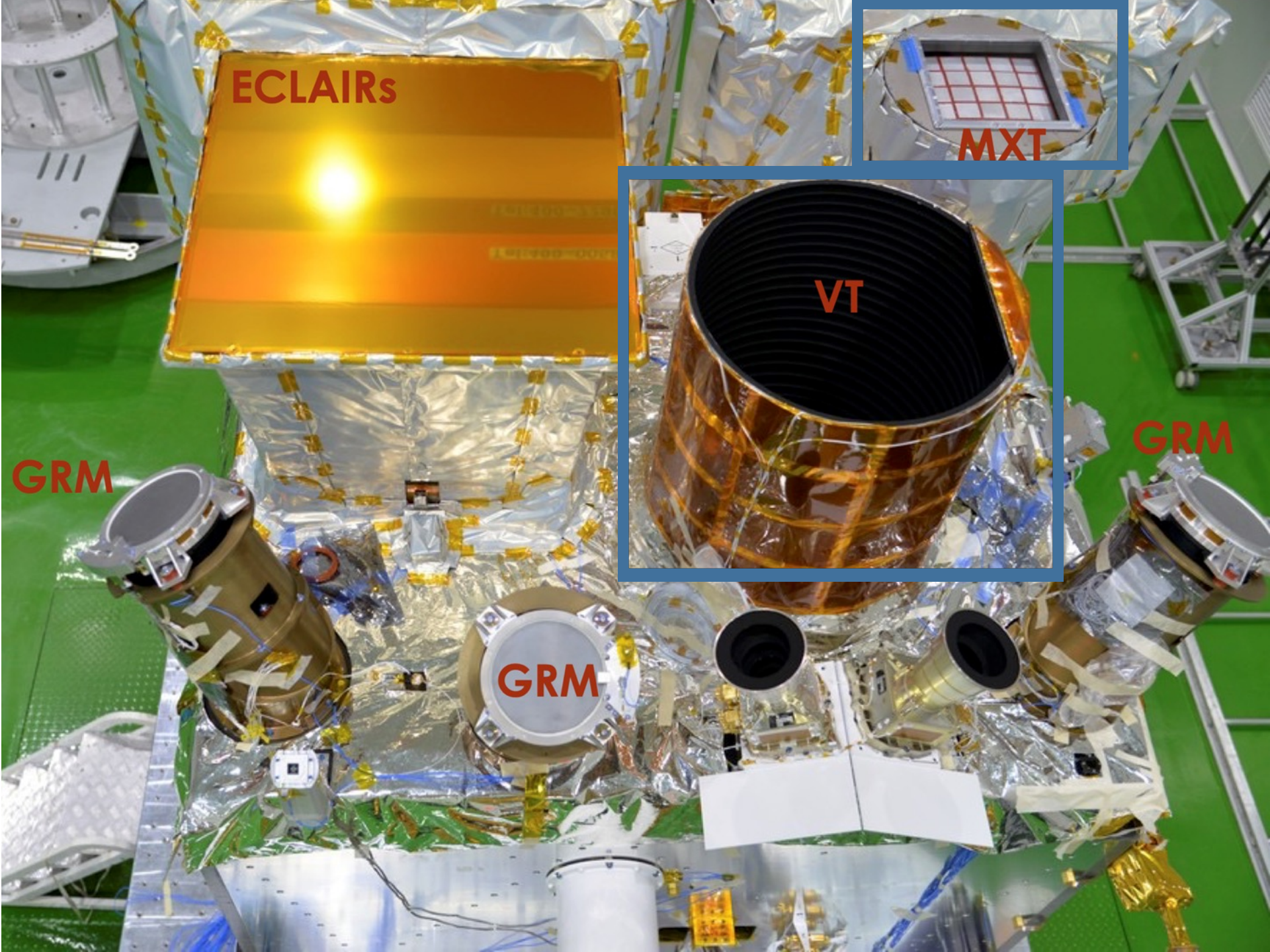
Micro-channel X-ray Telescope
0.2-10 keV
Loc. accuracy < 1 arcmin

- Micro-pore optics (Photonis) with square 40 μm pores in a « Lobster Eye » config.
- pnCCD camera
- Effective area 27 cm^2 @ 1 keV
- FoV 57x57 $arcmin^2$

VT

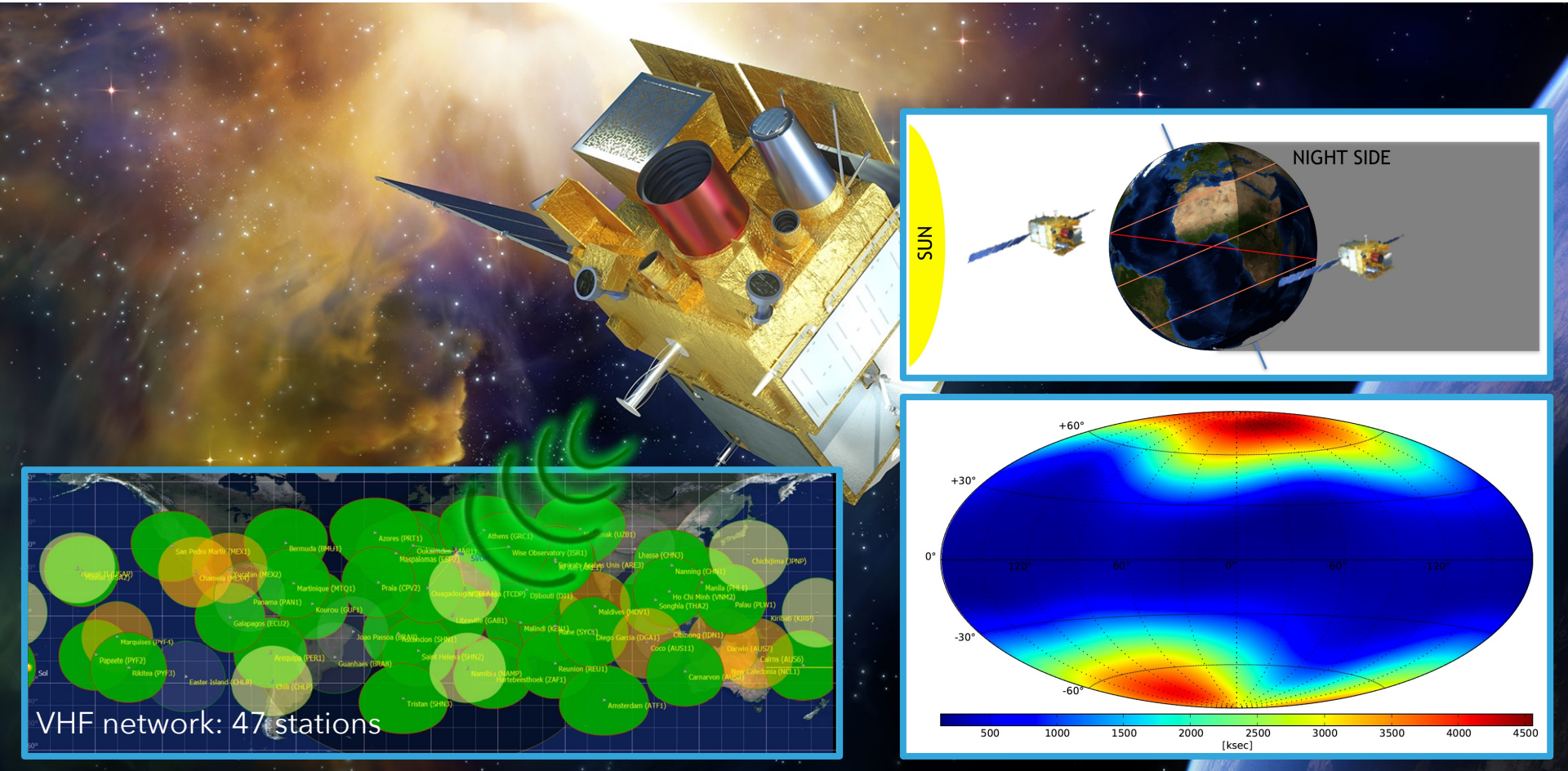
Visible Telescope
Blue (400-650 nm)
& Red (650-1000 nm) channels
Loc. accuracy <2''

- Ritchey-Chretien telescope (40 cm ∅, f=9)
- m_V = 22.7 in 300 s
- FoV 26x26 $arcmin^2$

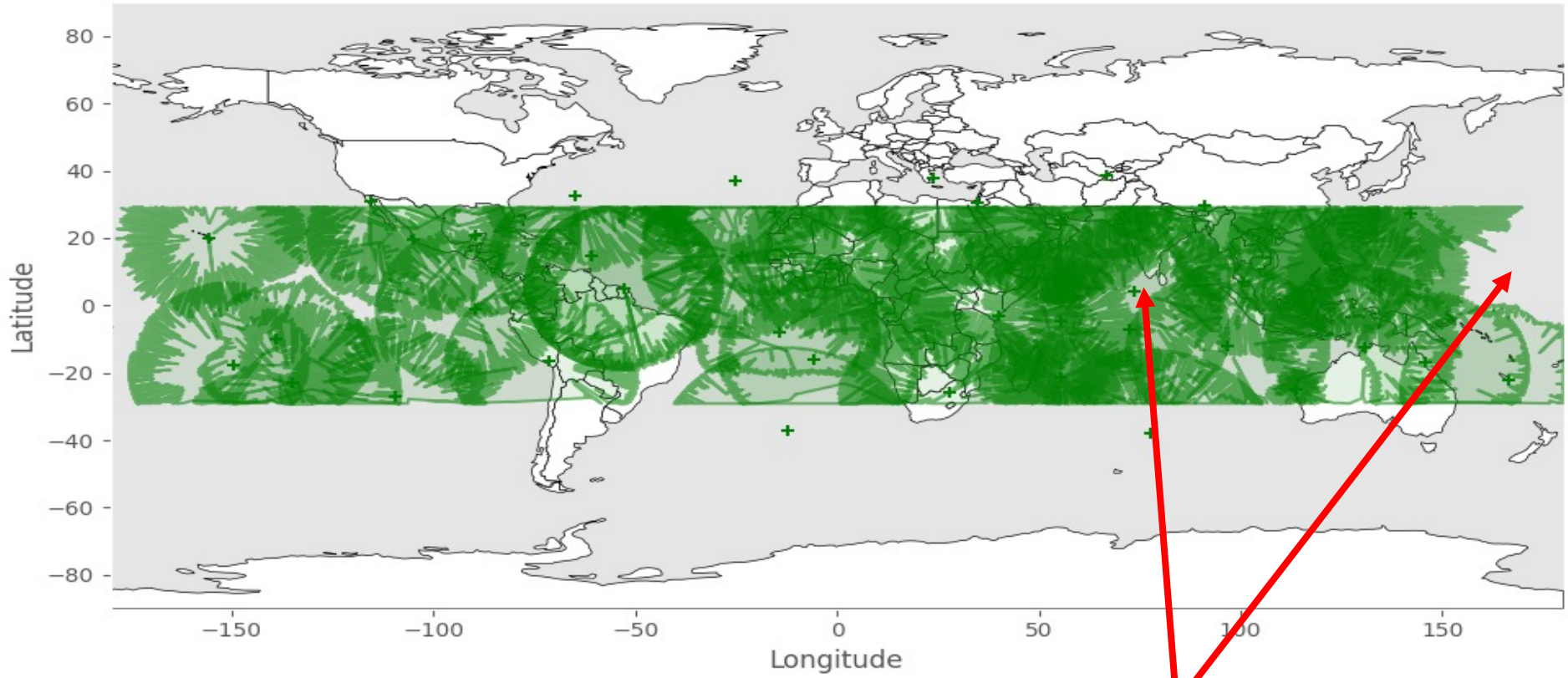

ECLAIRs
MXT
VT
GRM
GRM
GRM

SVOM AT A GLANCE

- **A VHF network for near real-time alerts**
- **A nearly anti-solar pointing for optimizing the follow-up of GRBs and other transients + a pointing law avoiding the Galactic plane**



VHF NETWORK: 47 STATIONS



Two gaps

- On-board transmission → reception at FSC:
  Median ~8 s

- SVOM also uses Beidou
  Median ~ 81 s

SVOM AT A GLANCE

- **A ground segment for a rapid follow-up: GWAC, C-GFT, F-GFT = Colibri**
- **+ Many partners!**

GWAC

Ground-based Wide Angle Camera
Visible

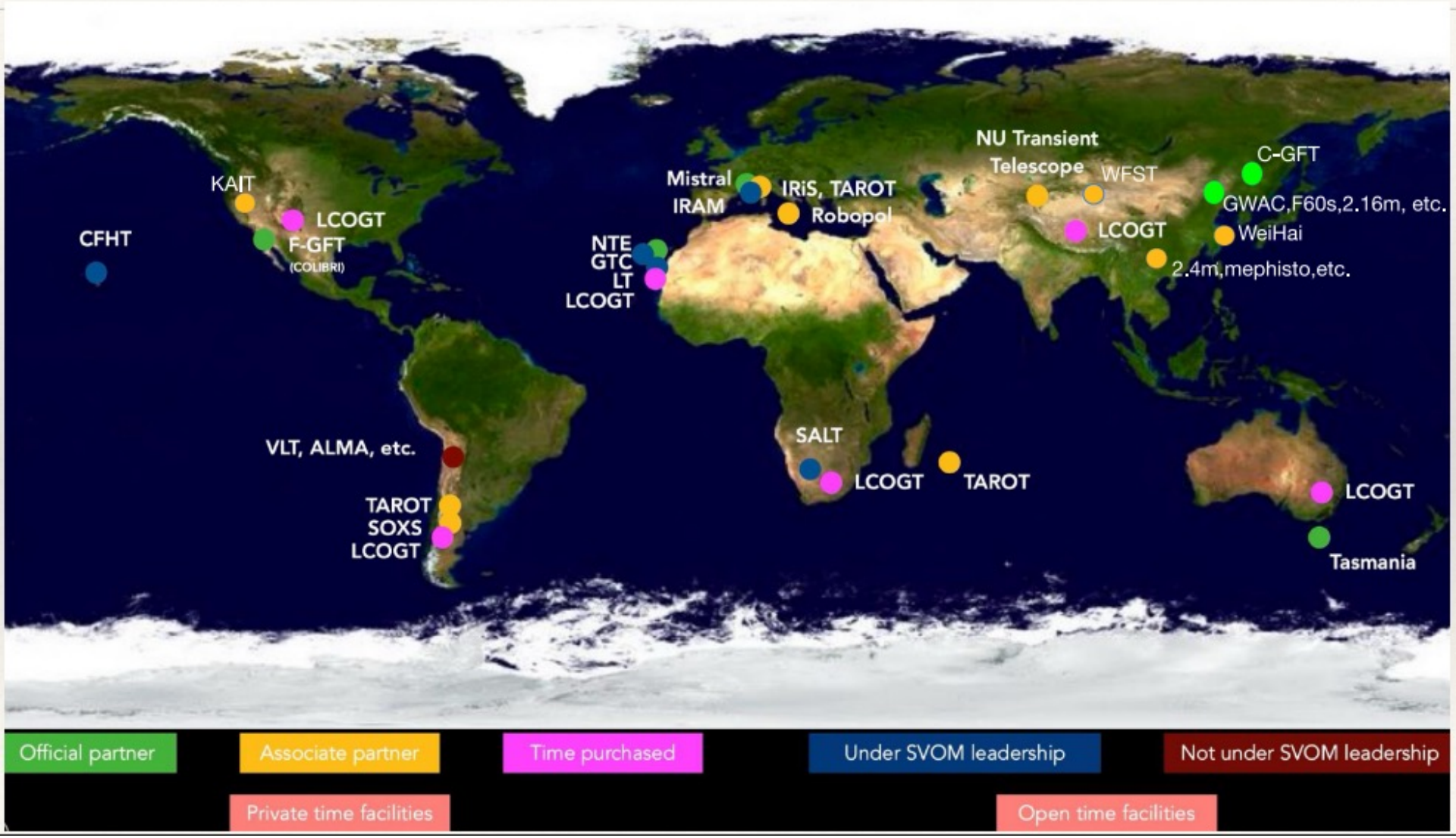
- ~6000 deg^2
- V = 16 (10 s)

GFTs

Ground Follow-up Telescopes
Visible (+NIR for F-GFT)

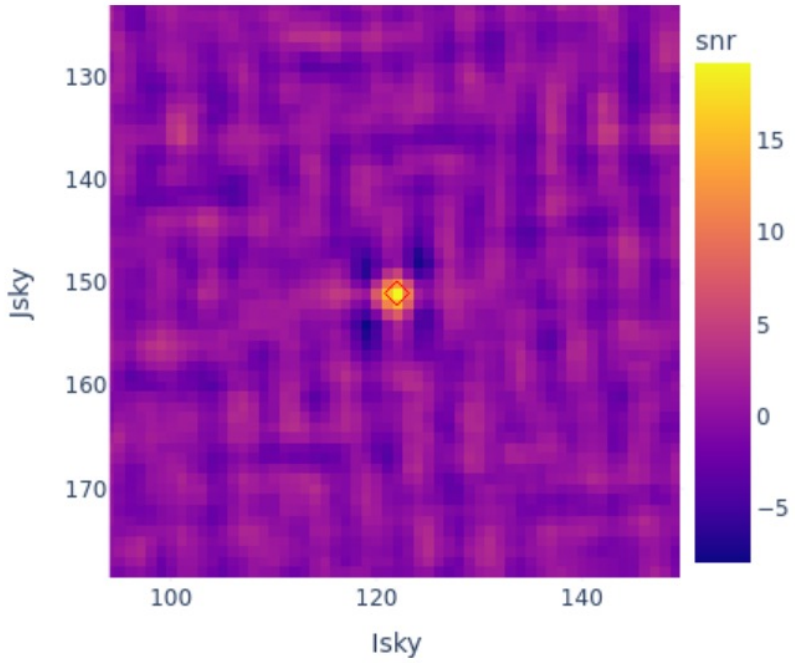
- C-GFT @ Weihai Obs.
  (120 cm, 90x90 arcmin^2, 400-900 nm)
- F-GFT @ OAN San Pedro Mártir
  (130 cm, 26x26 arcmin^2, 400-1700 nm)

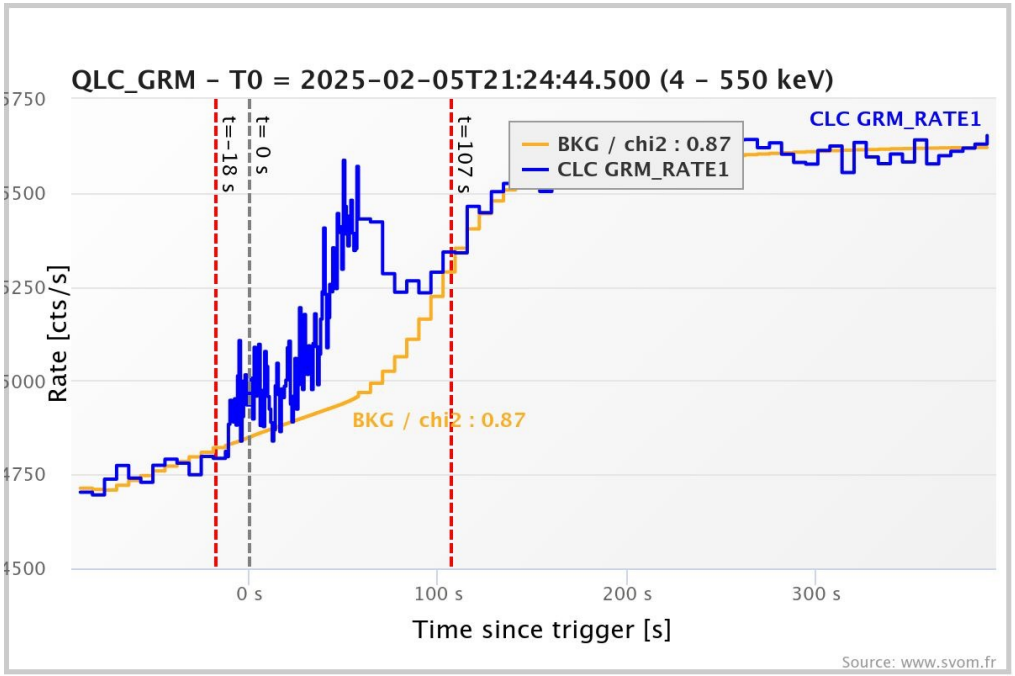
The SVOM follow-up network



A TYPICAL GRB SEQUENCE: GRB 250205A

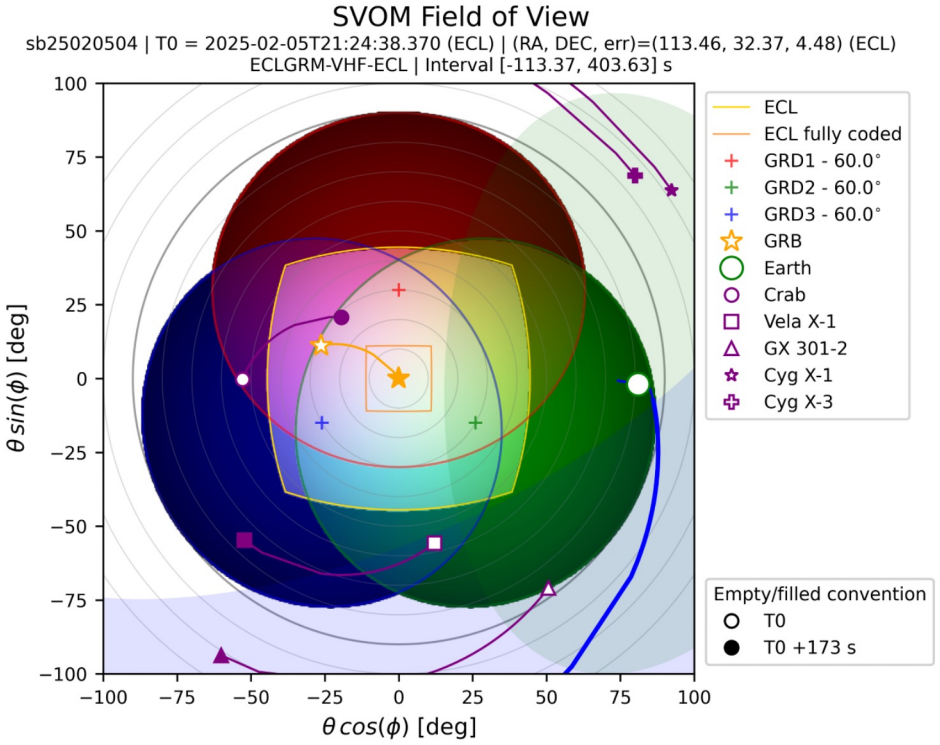
- **ECLAIRs trigger: detection and localization within 4.5 arcmin**
- **At the same time: GRM detection**

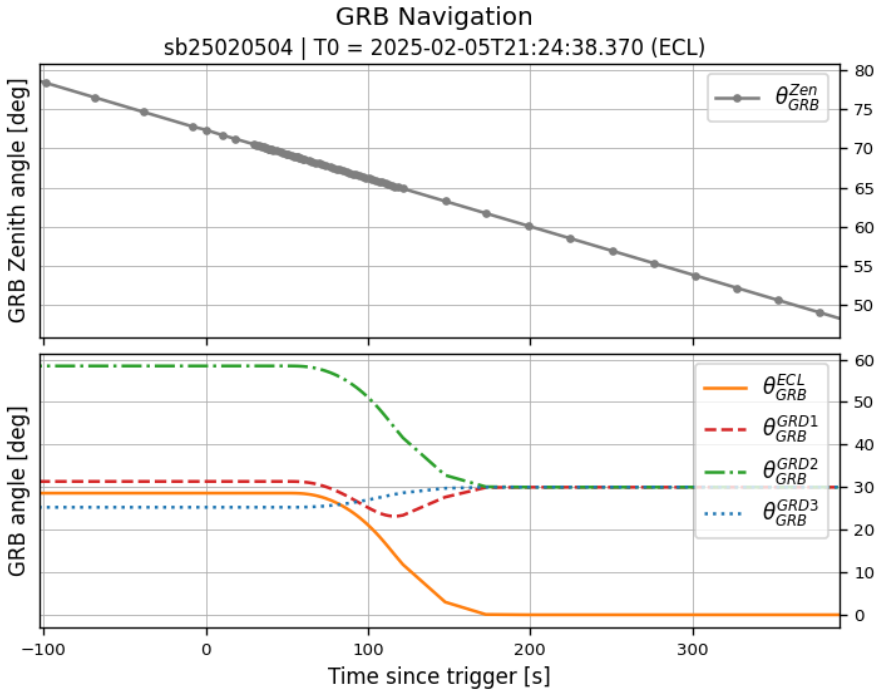




A TYPICAL GRB SEQUENCE: GRB 250205A

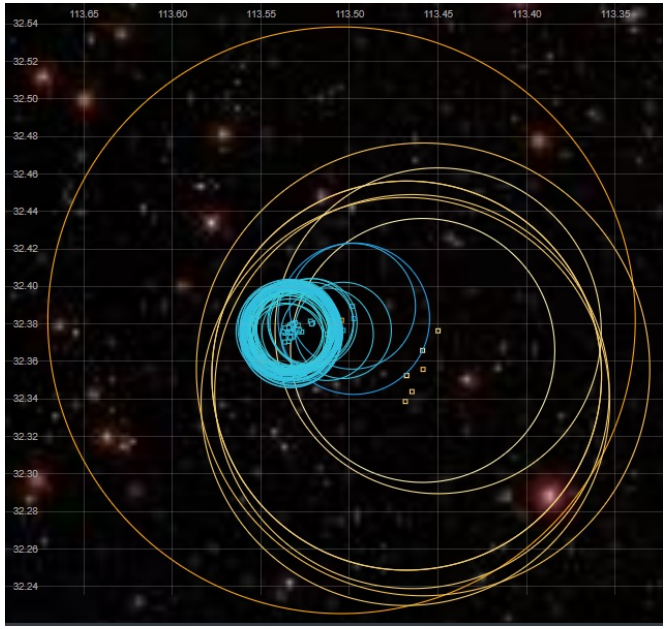
- **ECLAIRs** trigger: detection and localization within 4.5 arcmin
- At the same time: **GRM** detection
- **20 s later: automatic slew starts**
- **132 s later: slew has finished**,
  the burst is in the center of ECLAIRs, MXT and VT fov.



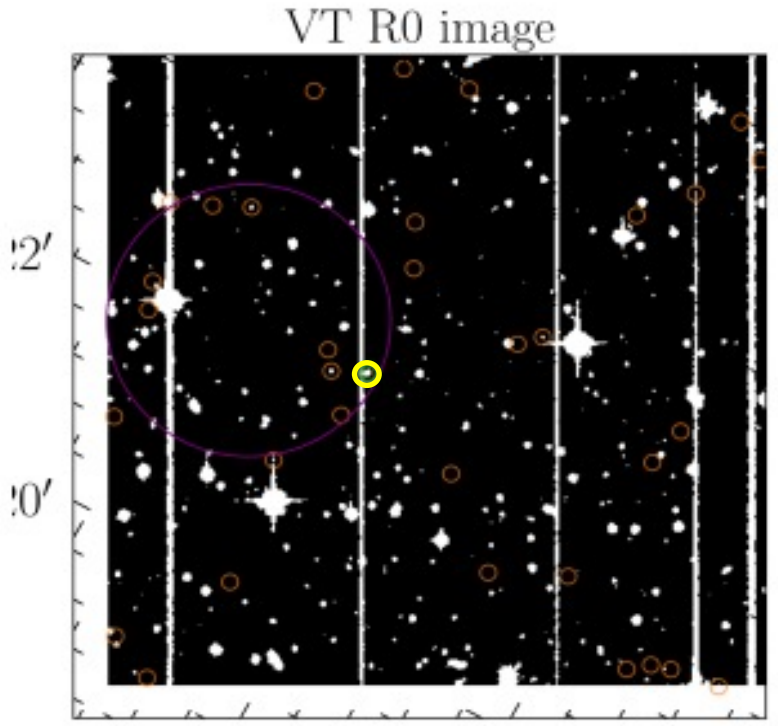


A TYPICAL GRB SEQUENCE: GRB 250205A

- **ECLAIRs** trigger: detection and localization within 4.5 arcmin
- At the same time: **GRM** detection
- 20 s later: automatic slew starts
- 132 s later: slew has finished
- **450s later: first VT observation ends**
  593 s later: first MXT observation ends



MXT: detection and localization within 80 arcsec

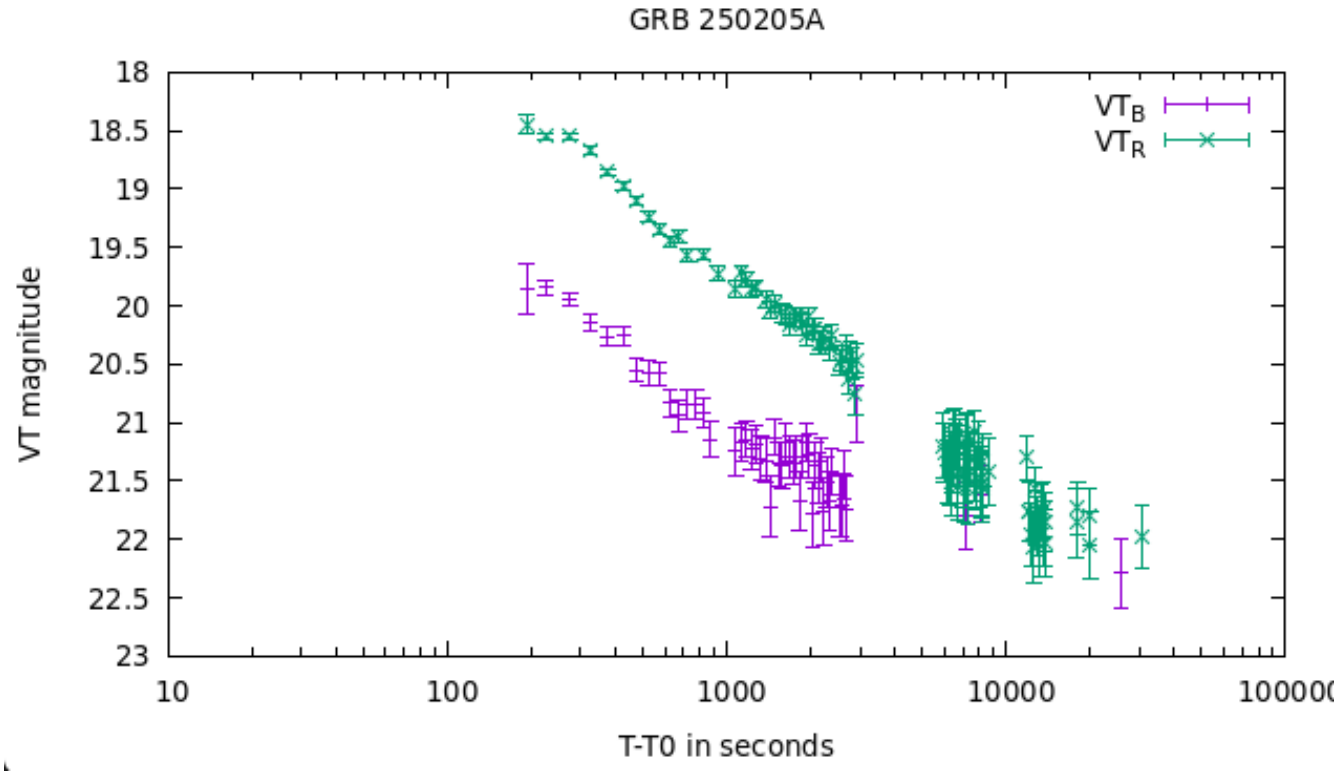


VT: detection and localization within 1 arcsec

1-bit image transmitted via the VHF network
Real images arrive later via the X band stations

A TYPICAL GRB SEQUENCE: GRB 250205A

- **ECLAIRs** trigger: detection and localization within 4.5 arcmin
- At the same time: **GRM** detection
- 20 s later: automatic slew starts
- 132 s later: slew has finished
- 450s later: first **VT** observation ends
  593 s later: first **MXT** observation ends
- **Follow-up with VT for several hours**



A TYPICAL GRB SEQUENCE: GRB 250205A

- **ECLAIRs** trigger: detection and localization within 4.5 arcmin
- At the same time: **GRM** detection
- 20 s later: automatic slew starts
- 132 s later: slew has finished
- 450s later: first **VT** observation ends
  593 s later: first **MXT** observation ends
- Follow-up with VT for several hours

During this sequence on-board SVOM:

- **VHF data are received and processed**
- **Trigger & associated scientific products (early version based on VHF data) are validated**
- **Notices (machine-readable) and Circulars (human-readable) are sent via the GCN Network**

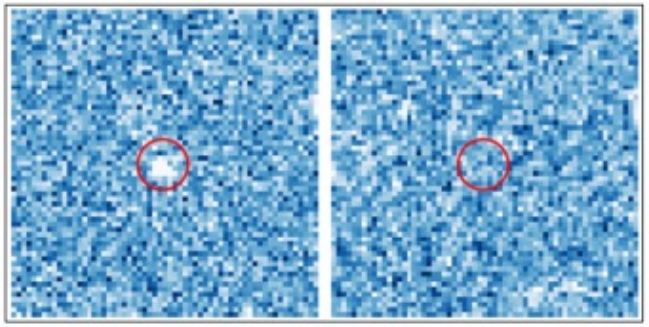
A TYPICAL GRB SEQUENCE: GRB 250205A

- **ECLAIRs** trigger: detection and localization within 4.5 arcmin
- At the same time: **GRM** detection
- 20 s later: automatic slew starts
- 132 s later: slew has finished
- 450s later: first **VT** observation ends
  593 s later: first **MXT** observation ends
- Follow-up with VT for several hours

During this sequence on-board SVOM:

- VHF data are received and processed
- Trigger & associated scientific products are validated
- Notices and Circulars are sent via the GCN Network
- **SVOM on-ground telescopes react as soon as possible**
  GRB250205A: detection by Colibri (F-GFT)
  6.4 hours after the burst

Pan-STARRS DR2



Colibri (F-GFT) 6.4 hours

r = 22.89 ± -0.11

Already a few case with an early follow-up within 1 min
by SVOM/C-GFT or FM-GFT

A TYPICAL GRB SEQUENCE: GRB 250205A

The GRB community (including SVOM partners) reacts to the alert:

GCN Circulars

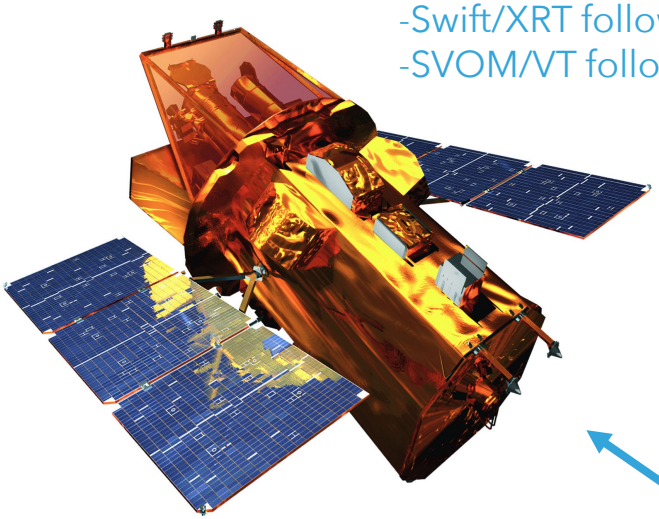
39520. GRB 250205A / EP250205A: further radio observations with the VLA
39315. GRB 250205A: VIRT Optical Upper Limit
39314. GRB 250205A: Leavitt Observatory optical upper limit
39302. GRB 250205A: Calapai Observatory, Massa S. Giorgio (Messina), upper limit
39289. GRB 250205A / EP250205A: radio detection with the VLA
39240. GRB 250205A: 1.3m DFOT optical upper limit
39171. GRB 250205A: Fermi GBM Observation
39170. GRB 250205A: REM NIR upper limit
39169. EP250205a/GRB 250205A: FTW optical and NIR observations of the counterpart
39168. GRB 250205A: Swift/UVOT Upper Limits
39166. EP250205a/GRB 250205A: correction to the source localization
39165. EP250205a/GRB 250205A: Einstein Probe observation
39162. GRB 250205A: COLIBRÍ/DDRAGO Optical Afterglow Detection
39161. GRB 250205A: Swift/XRT detection
39160. GRB 250205A: Redshift from OSIRIS+/GTC z = 3.55
39159. GRB250205A: SVOM/VT optical afterglow detection
39158. GRB 250205A: GOTO optical upper limits
39157. GRB 250205A: OHP/T193 optical counterpart candidate
39156. GRB 250205A: Liverpool Telescope optical counterpart candidate detection
39154. GRB 250205A: SVOM detection of a burst

GRB250205A: redshift z = 3.55 measured with OSIRIS+ at GTC (GCN #39160)

Repeating efficiently this sequence for the majority of SVOM/ECLAIRs GRBs will allow to build a fully characterized GRB sample (prompt, afterglow, redshift + host galaxy, SN, etc.).

SWIFT/FERMI/EP/SVOM SYNERGIES!

-Common triggers
-Swift/XRT follow-up of SVOM GRBs
-SVOM/VT follow-up of Swift GRBs

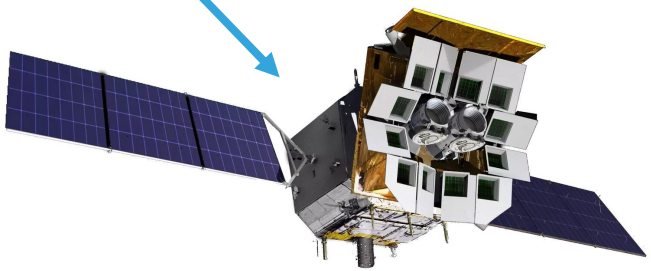


Swift (since 2004)
BAT: 15-150 keV (large fov)
XRT: 0.3-10 keV
UVOT

-Common triggers: spectral range! (LAT)

Fermi (since 2008)
GBM (15 keV-30 MeV) (large fov)
LAT (100 MeV-10 GeV) (large fov)

SVOM (since 2024)



-Common triggers
-SVOM follow-up of WXT triggers
-EP/FXT follow-up of SVOM GRBs

Einstein Probe (since 2024)
WXT (0.5-4 keV) large fov
FXT (0.3-10 keV)

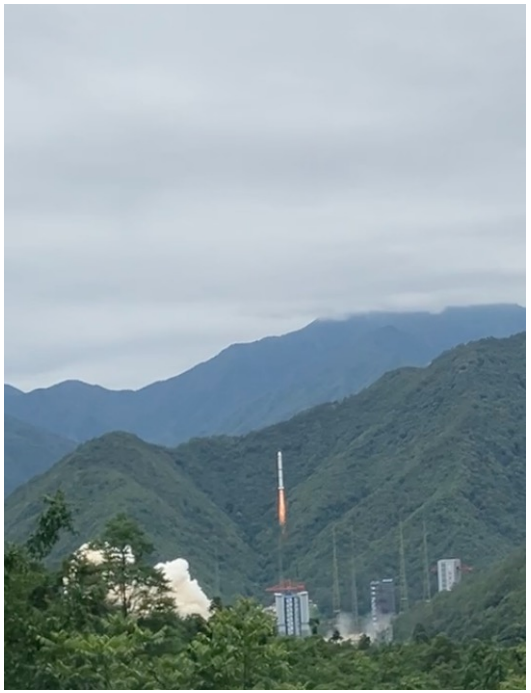
1. Gamma-Ray Bursts

2. The SVOM Mission

3. GRB Studies with SVOM: First Results & Prospects

on behalf of the SVOM consortium

SVOM GRB FIRST DETECTIONS



- **SVOM Launch: 22 June, 2024**
- Since the launch: commissioning and validation phases
- April 2025: beginning of the nominal phase of scientific operations

- **SVOM Core Program: Gamma-Ray Burst Studies**

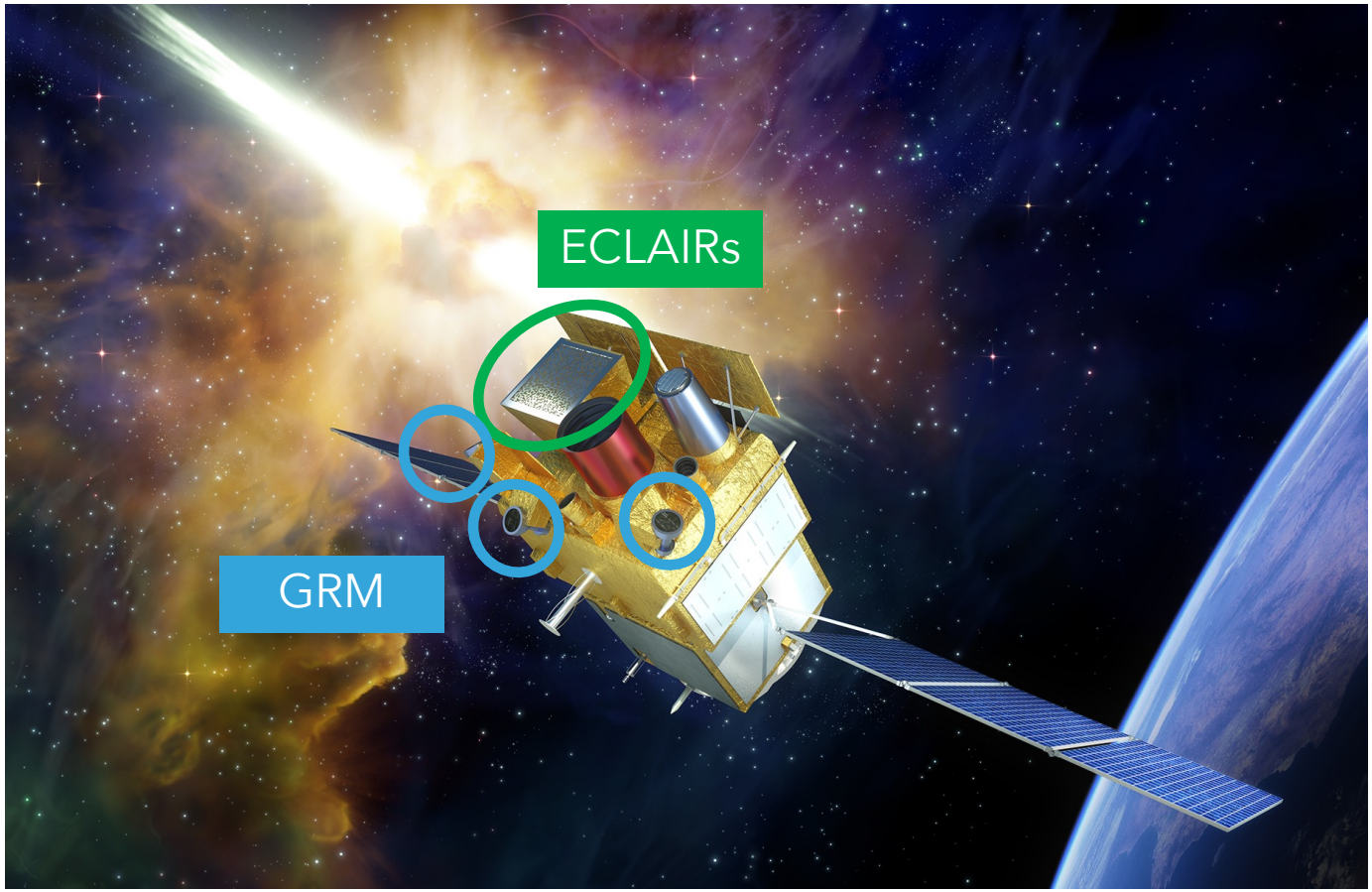
Some stats: from Launch to end of March 2025
= 89 GRBs detected on-board SVOM

including:
36 GRBs also detected by Fermi/GBM
16 GRBs also detected by Swift/BAT
10 GRBs also detected by Konus-WIND
7 GRBs also detected by EP/WXT

1/3 are SVOM-only GRBs

Since April 2025: 80 new GRBs detected on-board SVOM (ECL or ECL+GRM: 37 ; GRM-only: 43)

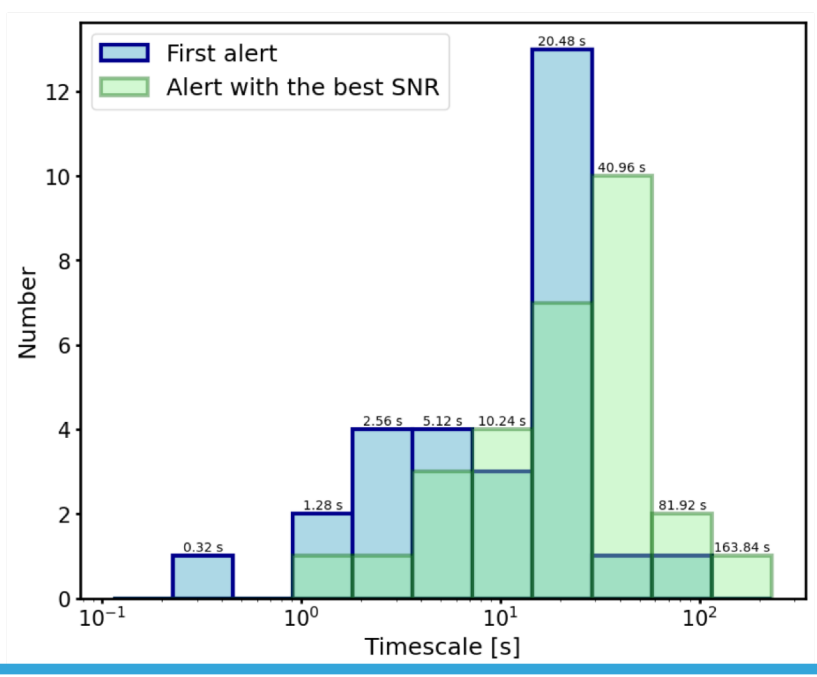
SVOM: TWO TRIGGERING INSTRUMENTS

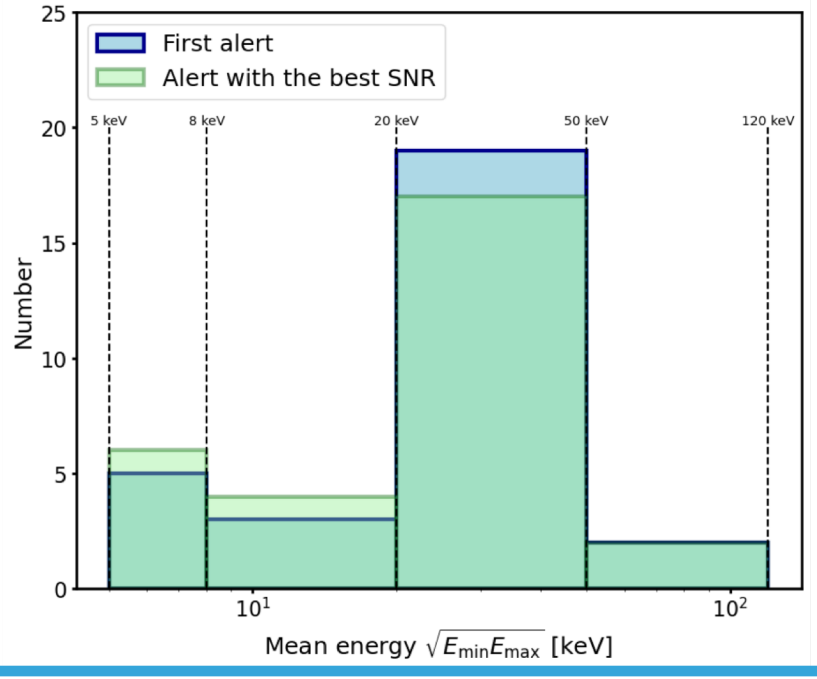


SVOM: TWO TRIGGERING INSTRUMENTS

- **ECLAIRS:**
  - Coded-mask telescope, **4-150 keV**, 2 sr, photon counting mode
  - Can trigger on many combinations of timescales, energy bands and zones in the detector plane, either on the count rate (**CRT**) or on images (**IMT**)

First 29 GRBs (9.3 months) with an on-board detection by ECLAIRs: timescales and energy bands used to trigger

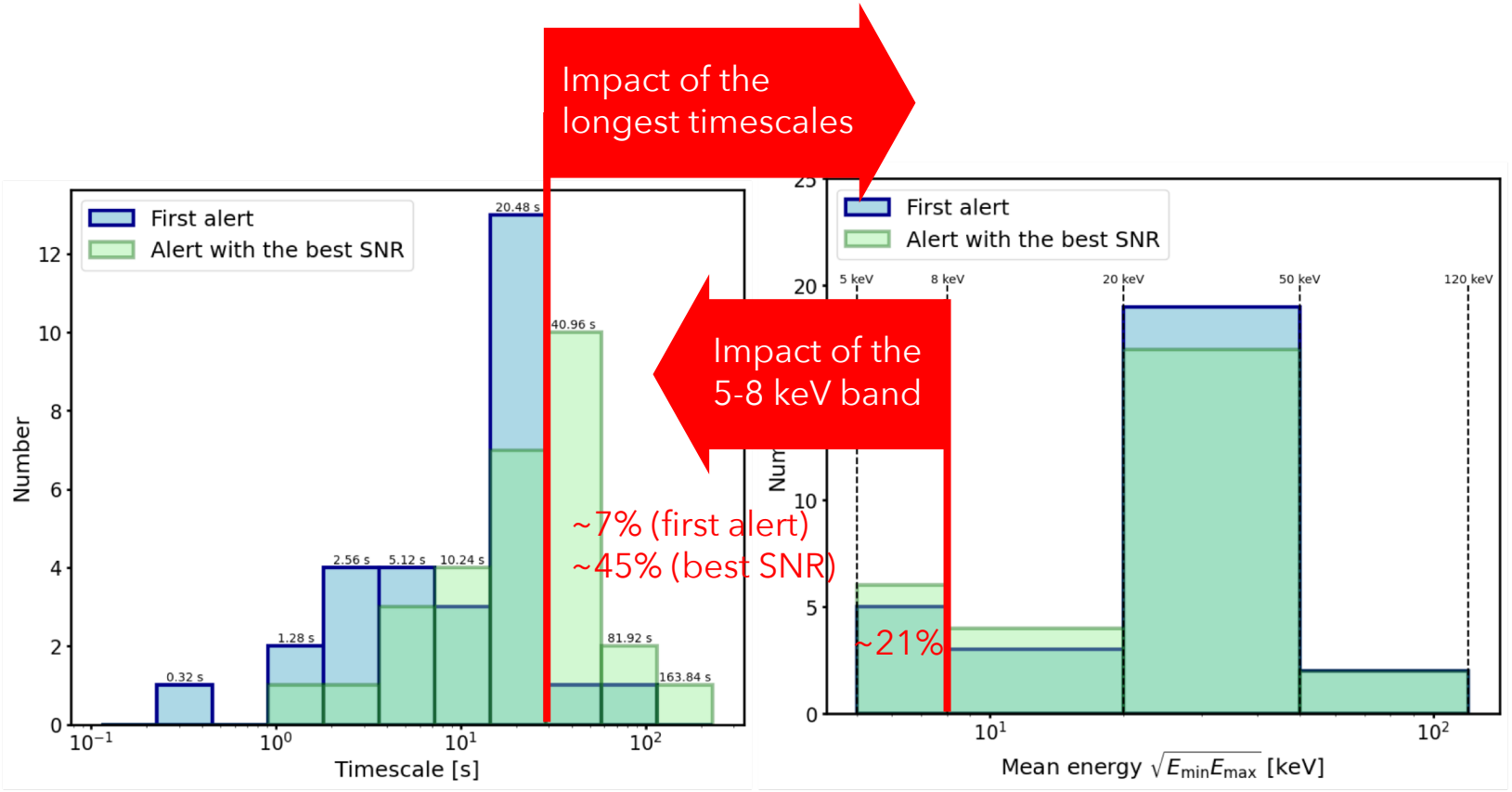




  - IMT: from **20 s to 20 min**
    CRT: from **10 ms to 20 s** (always followed by an image giving the reported SNR)

SVOM: TWO TRIGGERING INSTRUMENTS

First 29 GRBs (9.3 months) with an on-board detection by ECLAIRs: timescales and energy bands used to trigger



Among GRBs detected by ECLAIRs: 62% are SVOM-only GRBs

SVOM: TWO TRIGGERING INSTRUMENTS

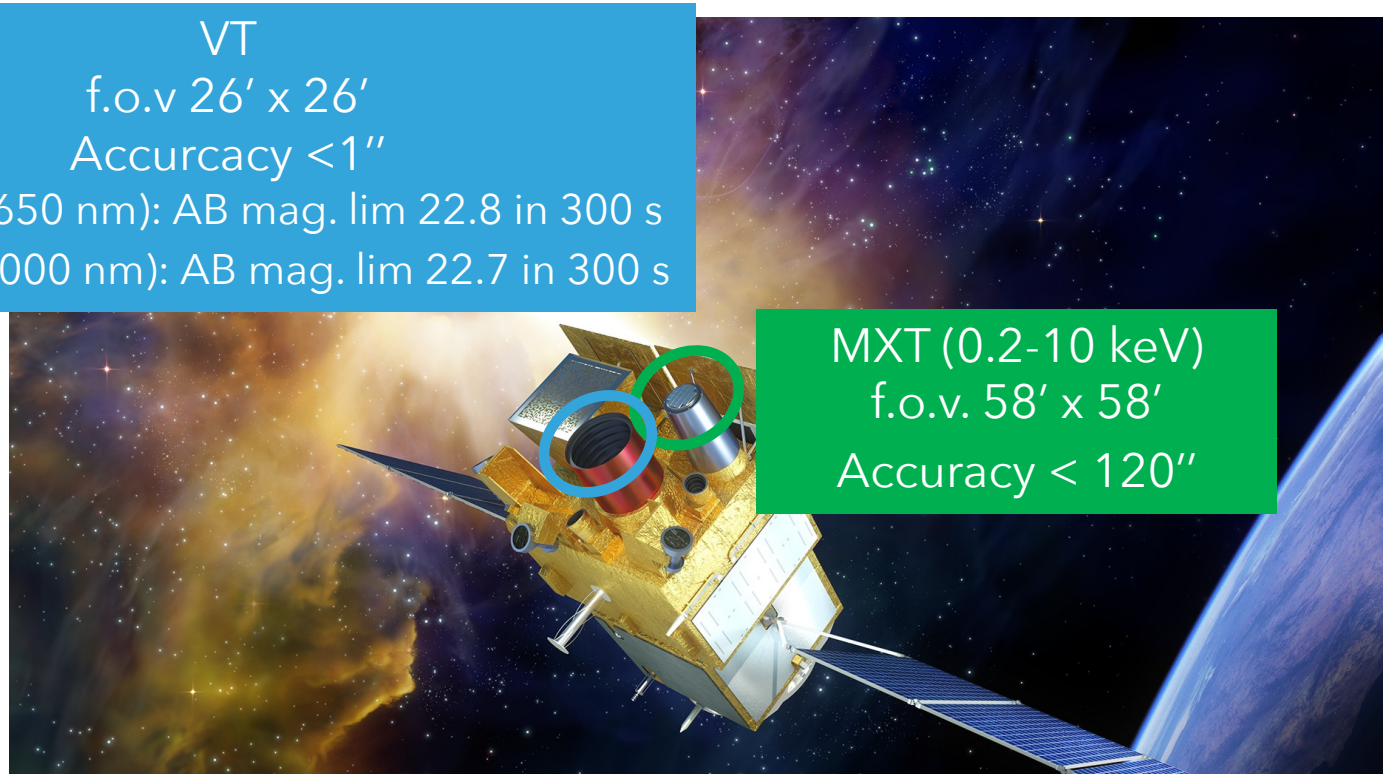
- **ECLAIRS:**
  - 29 GRBs detected on-board in 9.3 months ~ 37 GRB/year
  - % of time with active on-board trigger: 45% (July-Nov. 24) → 76% (Dec. 24-March 25)
  - **Expected rate during scientific operations:**
    at least ~50 GRBs detected and localized on-board per year
  - **Localization in a few arcmin** (current median: 7.1′ (stat) + 2′ (sys))

- **GRM:**
  - **15 keV-5 MeV, three detectors (GRD) with a f.o.v. of 2.6 sr per detector**
  - Can trigger on three timescales: 0.1, 1 and 4 s, only if the signal is above threshold in at least 2 GRDs
  - 77 GRBs detected on-board in 9.3 months (~26% also detected by ECLAIRs):
    at least ~ 100 GRBs/yr det. on board
  - No localization, except on-ground localization
    for bright GRBs seen in the 3 GRDs (within ~5°)

SVOM: AUTOMATIC SLEW & FOLLOW-UP

Automatic slew: ~50% of GRBs since launch ; **~80% since Dec. 24** (lowered thresh.)

VT
f.o.v 26′ x 26′
Accurcacy <1″
Blue (400-650 nm): AB mag. lim 22.8 in 300 s
Red (650-1000 nm): AB mag. lim 22.7 in 300 s



MXT (0.2-10 keV)
f.o.v. 58′ x 58′
Accuracy < 120″

VHF network: alert received on ground with a median delay of 7.6 s

- **GCN: public alert**
  - notice (since early Feb. 2025)
  - first circular (detection, localization for ECLAIRs triggers)
- **SVOM telescopes on ground: GWAC, C-GFT, F-GFT (Colibri) + partners**
- **ECL triggers: automatic ToO request for Swift/XRT** (since mid Feb. 2025)

SVOM GRBS: AFTERGLOW DETECTION & REDSHIFT MEASUREMENT

(since Dec. 24: ~80% of GRBs detected on-board
by ECLAIRs triggered an automatic slew)

First 9.3 months post-Launch	GRM-only on-board-triggers: first 57 GRBs	ECLAIRs on-board triggers: first 29 GRBs	**ECLAIRs on-board triggers: first 16/29 GRBs with auto. slew**
X-ray afterglow	30% (17/57)	97% (28/29)	**100% (16/16)** SVOM/MXT: 8 detections Swift/XRT: 16 ; EP/FXT: 6
Optical/NIR afterglow	21% (12/57)	69% (20/29)	**81% (13/16)** SVOM/VT: 12 det. + 4 early deep UL SVOM/CGFT+FGFT: 4 det. + 3 early UL
Redshift	19% (11/57)	**41% (12/29)**	**56% (9/16)** **Special thanks to SVOM partners: Stargate,NOT, GTC ...**

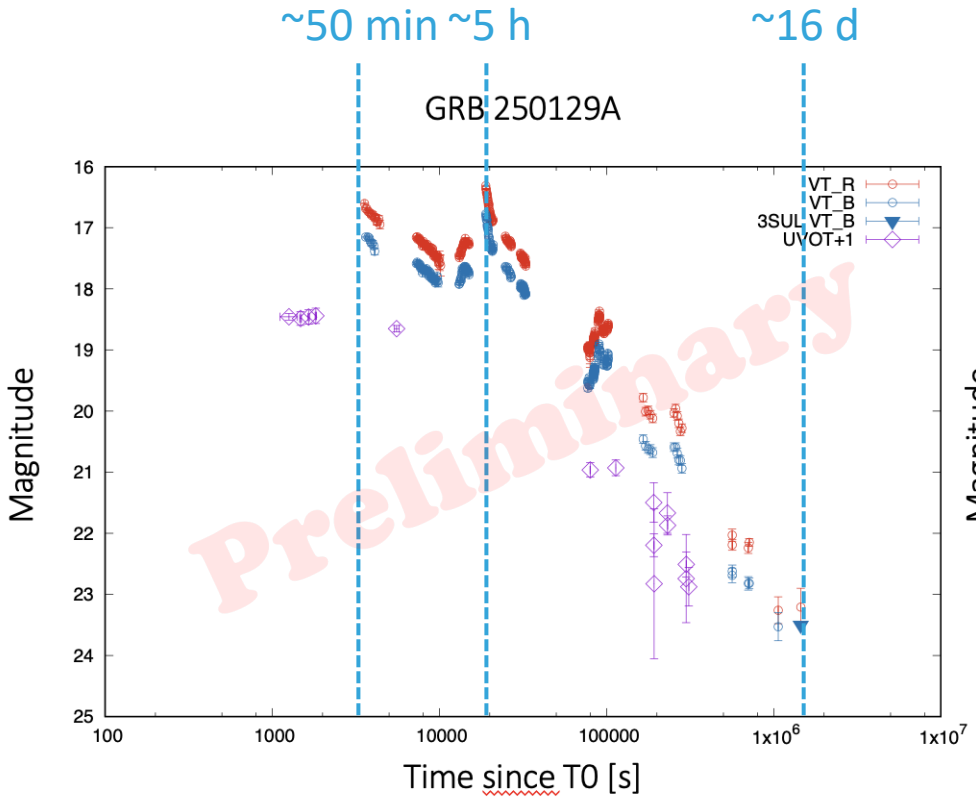
= common triggers
with Swift/BAT (8/11)
or EP/WXT (3/11)

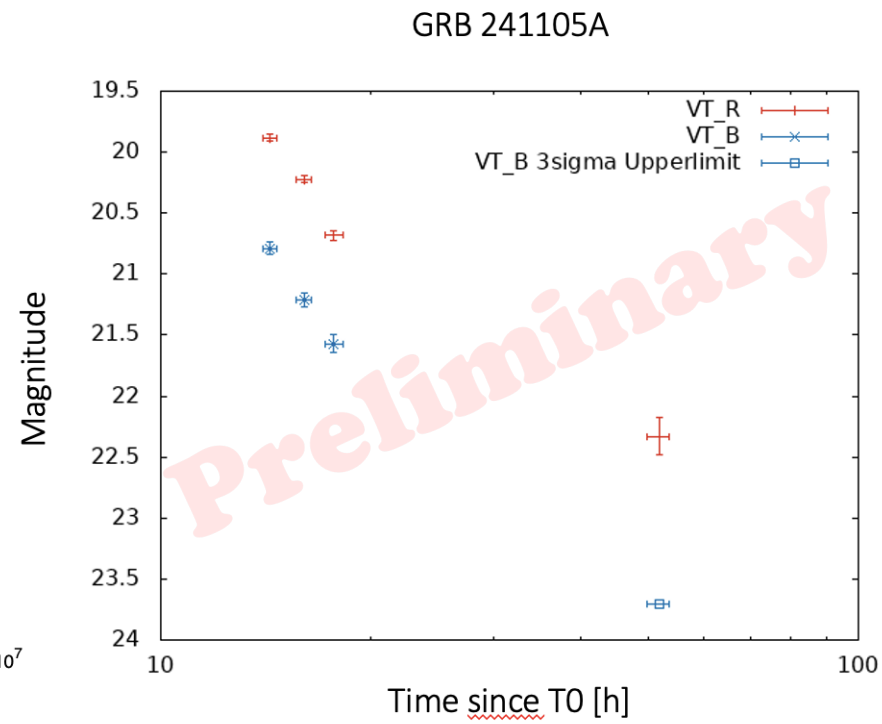
SVOM instruments contribute to the follow-up of these GRBs.

Already an excellent efficiency for the follow-up of GRBs detected on board SVOM with ECLAIRs

SVOM FOLLOW-UP OF SWIFT/BAT GRBS

SVOM/VT follow-up of **Swift/BAT GRB250129A** at z = 2.151 (GCN#39071)
and **Fermi/GBM Swift/BAT GRB241105A** at z = 2.702





A puzzling flare at ~5 hours

A rapidly decaying afterglow detected up to 2.2 days (see also Dimple et al. 25)

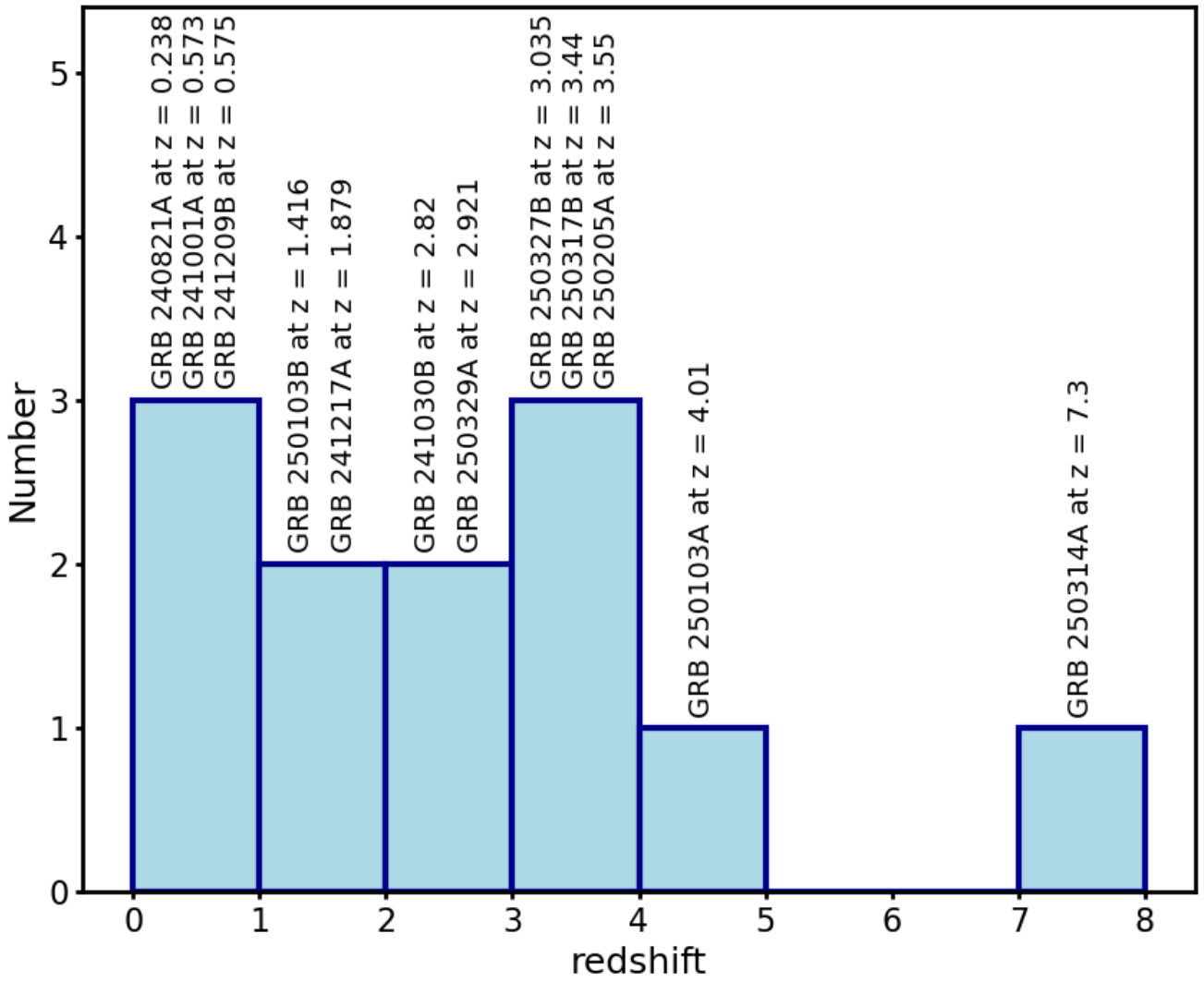
Physics of the deceleration of the GRB relativistic ejecta by the ambient medium.

SVOM GRBS: AFTERGLOW DETECTION & REDSHIFT MEASUREMENT

- **Already more than 40% of ECLAIRs GRBs with a measured redshift !**
- **The efficiency of the redshift measurement should still increase:**
  - SVOM still on a learning curve…
  - The nominal pointing law avoiding the Galactic plane was not followed for most of the time during the first months.
  - Since Dec. 2024, increased fraction of automatic slew following ECLAIRs triggers
  - Since Feb. 2025: automatic Swift/XRT ToO request following ECLAIRs triggers, Since April 2025: automatic EP/FXT ToO request
  - Ratio #redshift/#opt. afterglow ~ 70%: some additional redshifts may be measured via late host galaxy spectroscopic observations.
  - Delay to identify optical candidates in early VT images may be reduced. (more X band stations to get full images sooner ?)
  - A new camera (CAGIRE) will be installed in coming months, allowing observations in J,H bands with SVOM/F-GFT (Colibri).

SVOM ECLAIRS GRBS: REDSHIFT DISTRIBUTION

- **First 12 ECLAIRs GRBs with a measured redshift:** ECL+GRM = 10 ; ECL-only = 2
- **z = 0.238 to 7.3!**

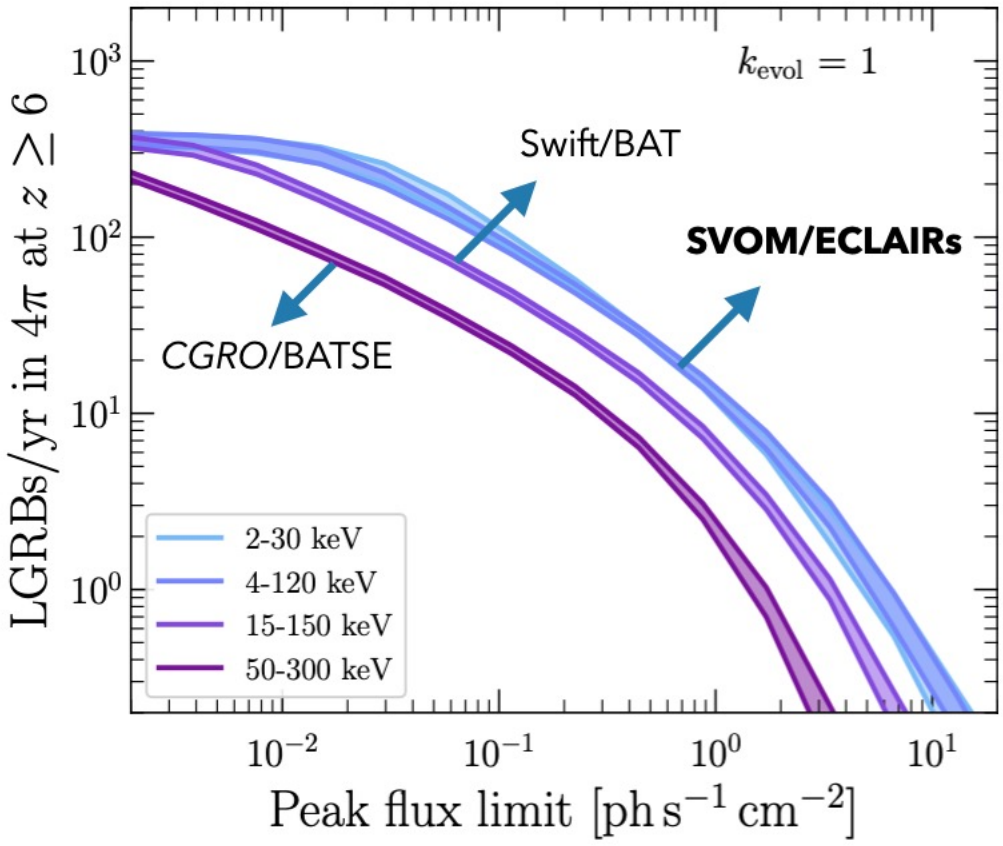


SVOM ECLAIRS GRBS: REDSHIFT DISTRIBUTION

- **Impact of the 4 keV low-energy threshold?**

Pop. model: all-sky rate above z=6 as a function of the peak flux limit

(Palmerio & Daigne 2021)



Effect of the energy channel on the detected rate:

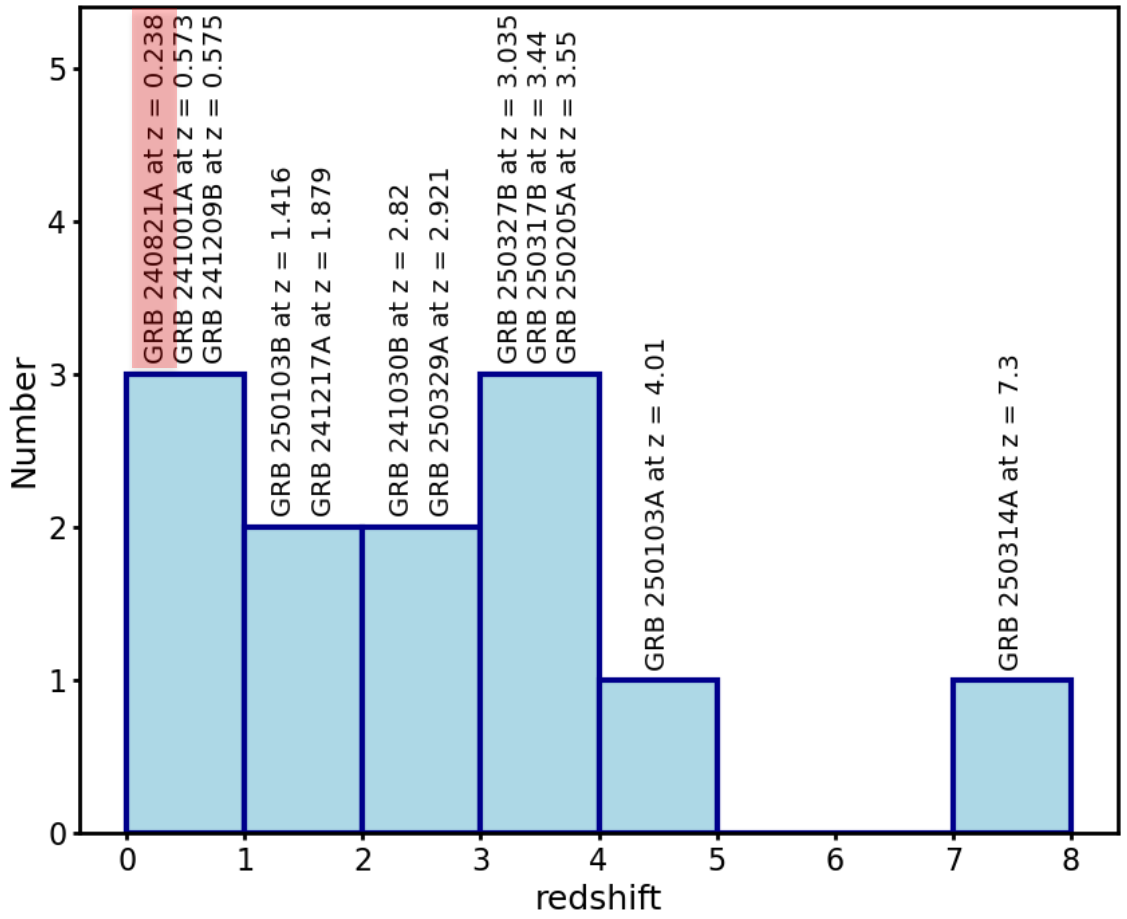
Color: energy band

From 50-300 keV (violet) to 2-30 keV (blue)

SVOM ECLAIRS GRBS: REDSHIFT DISTRIBUTION

Better understanding the **short GRB-merger connection** and the **physics of ejection/emission in the post-merger phase**: SVOM can contribute to build a sample of fully characterized short GRBs, including the properties of the host galaxy.

GRB 240821A = a short GRB with extended soft emission



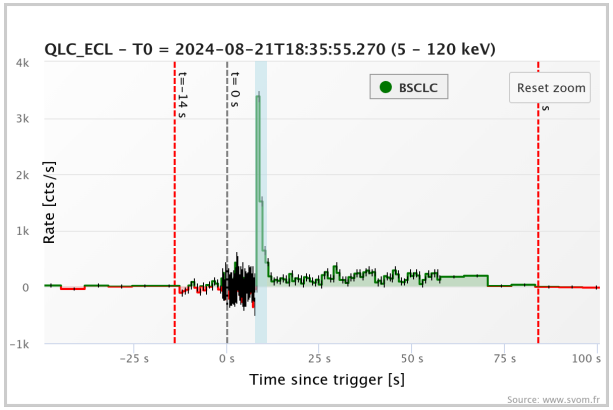
SHORT GRBS & THE MERGER SCENARIO: GRB240821A

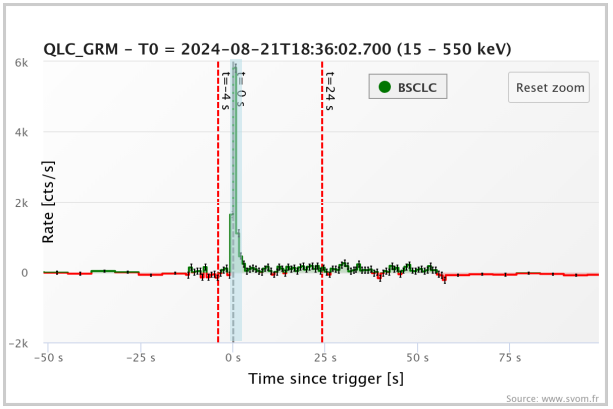
- **A first example: GRB240821A** (during SVOM commissioning phase)

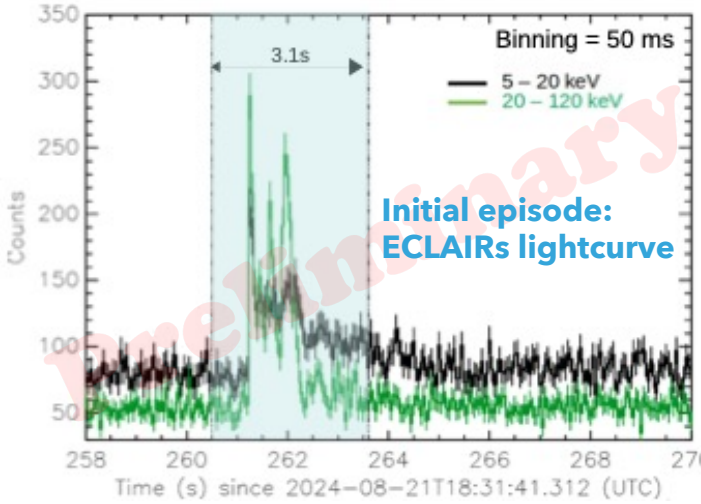
ECLAIRs (5-120 keV) **GRM (15-550 keV, 3 GRDs combined)**

GRB240821A
ECLAIRs and GRM lightcurves:
T90 = 52.2 ± 0.2 s (4-120 keV)

Short spike + ext. emission

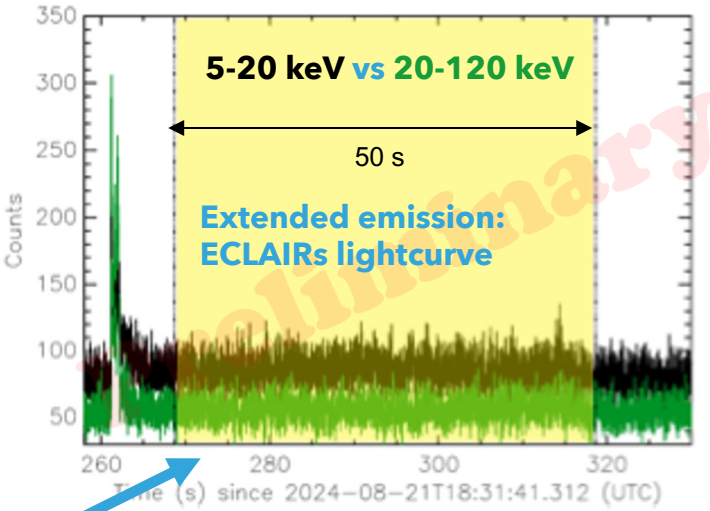






Initial episode

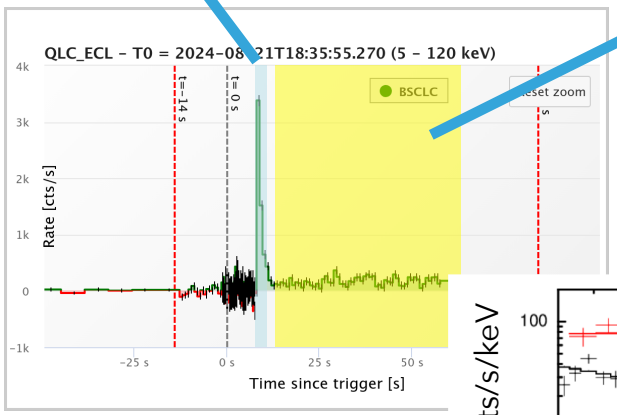
= short hard spike (variable) detected by ECLAIRS+GRM

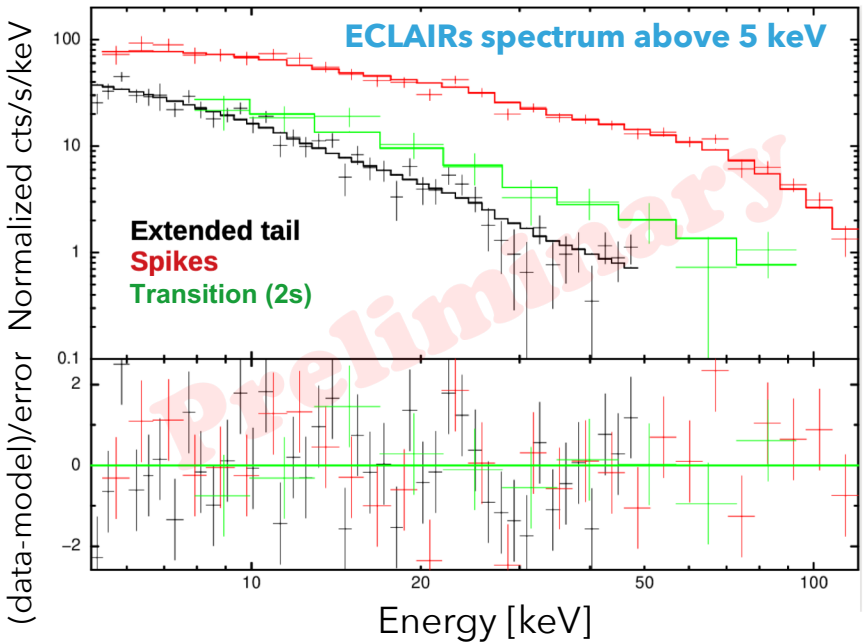


GRB240821A ECLAIRs lightcurve:

T90 = 52.2 ± 0.2 s (4-120 keV)

Short spike + ext. emission





Extended emission

- **plateau-like emission**
- **softer = not detected above 50 keV**
- **non-thermal emission**

(to be compared to the analysis by Chang+24 of a Fermi/GBM sample of 36 SGRB+EE)

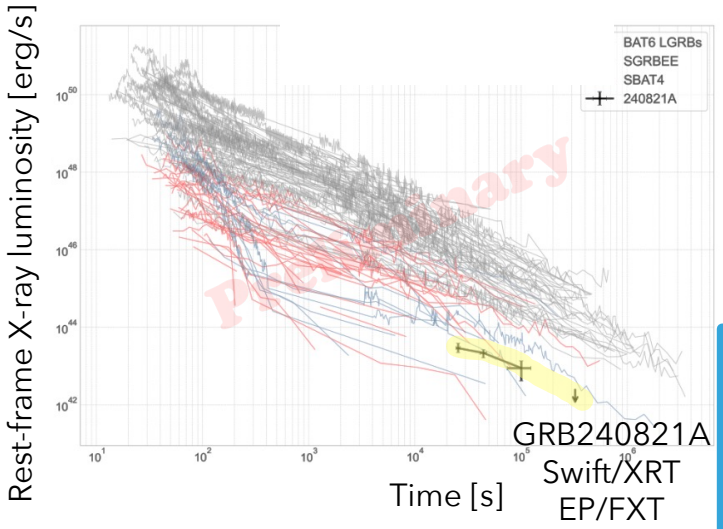
- **no strong spectral evolution**

SHORT GRBS & THE MERGER SCENARIO: GRB240821A

- **A first example: GRB240821A**

Red: short GRBs without extended emission / Blue: short GRBs with extended emission / Black: GRB240821A

X-ray afterglow = consistent with other sGRBs with EE but faint in X-rays



BAT6, Salvaterra+12
S-BAT4, d'Avanzo+14, see Riccardo Brivio yesterday's talk
with a sub-sample of SGRB-EE, see poster by M.M. Dinatolo

- Optical AG detected by Gemini and GRANDMA/SOAR
- **Host galaxy: phot. & spectr. (GTC, VLT, Keck)**
- Preliminary analysis (spectroscopy only): z = 0.237
  Metallicity: 12 + log(O/H) = 9.1 +/- 0.1
  SFR = 0.05 +0.05/-0.02 M⊙/yr (to be updated with phot.)
- **Host gal. properties would be very unusual for a LGRB host but are consistent with SGRB hosts**

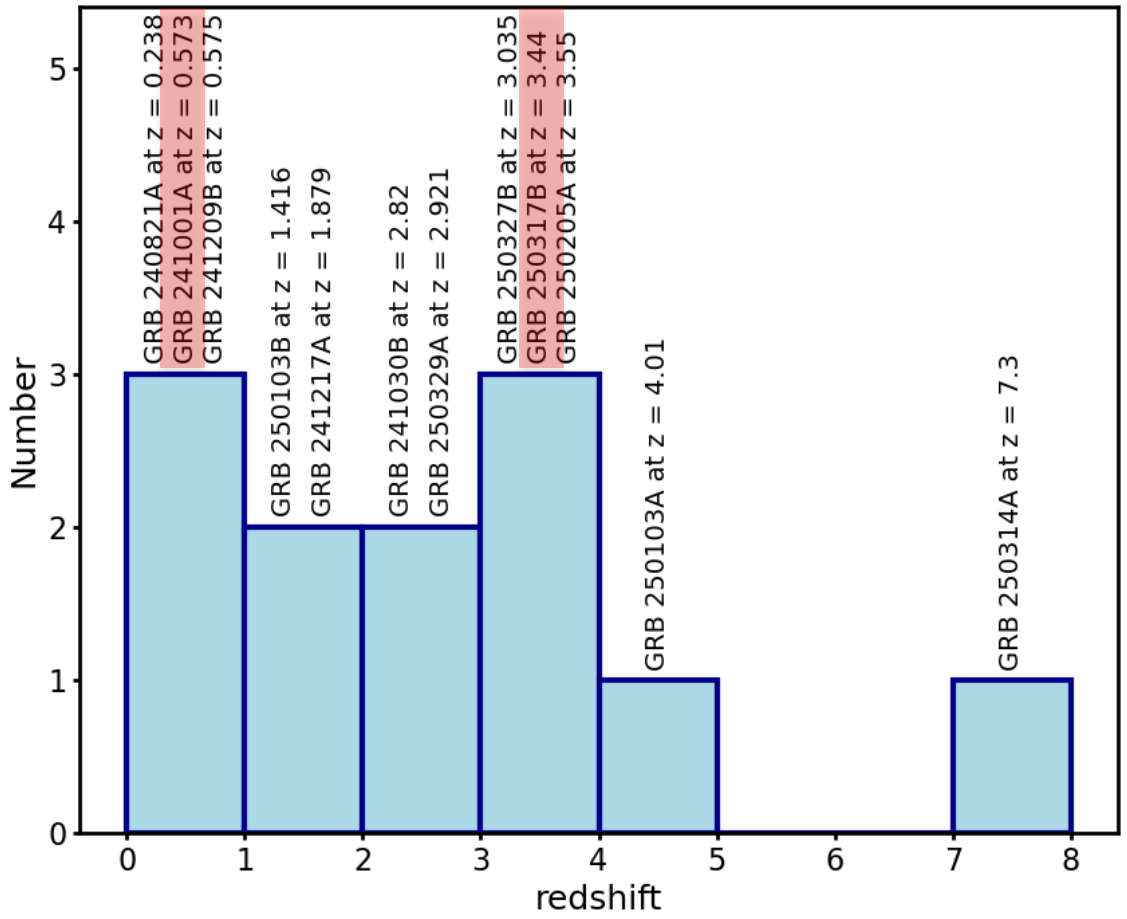
- **The low-energy threshold of ECLAIRs (4 keV) should help in the future to constrain the fraction of SGRBs with EE** (see also Kisaka+17)
- **Origin of the extended emission highly debated: post-merger physics!**

Daigne, Zhang + SVOM collab & partners, in prep.

SVOM ECLAIRS GRBS: REDSHIFT DISTRIBUTION

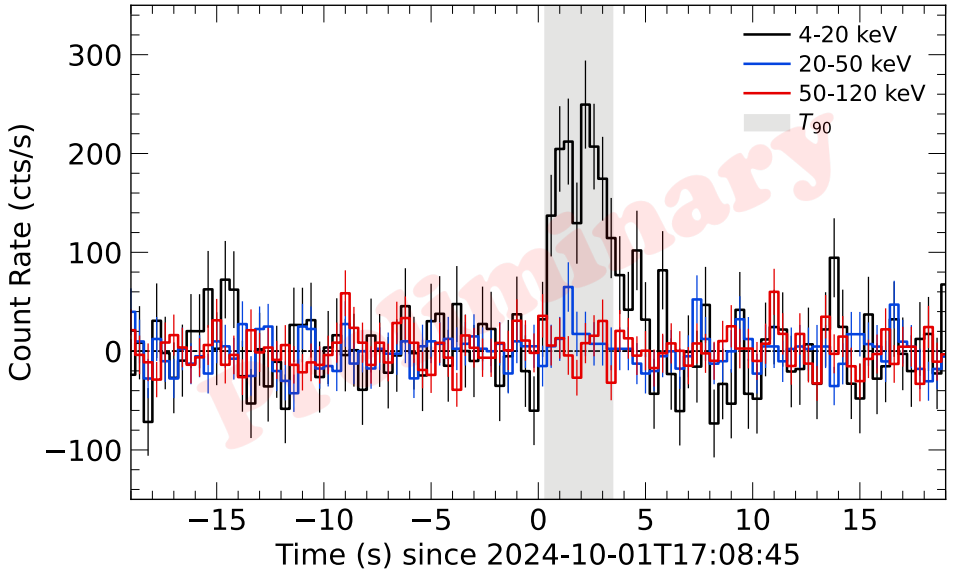
SVOM/ECLAIRs detect many soft or very soft events. The characterization of these events (AG, redshift, host) allows to explore the **underlying diversity.**

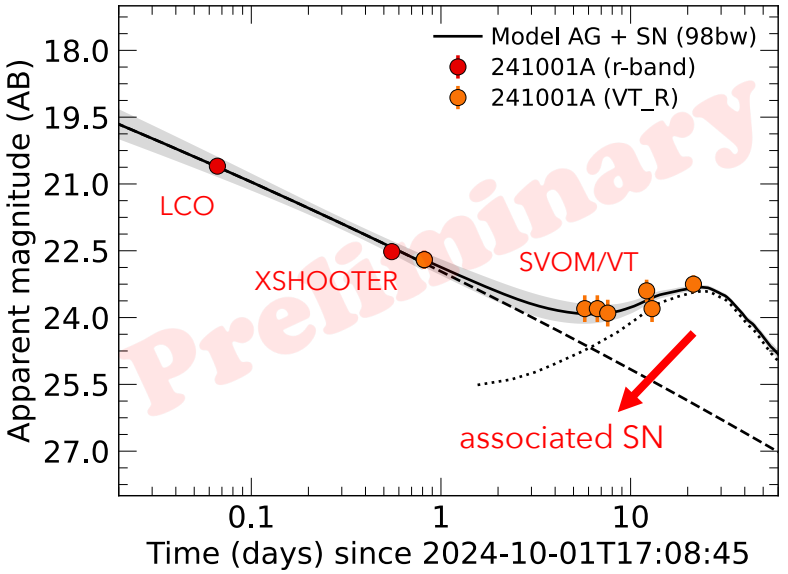
GRB 241001A and GRB 250317B
= two very soft events detected only by ECLAIRs



SOFT GAMMA-RAY BURSTS: EXPLORING THE DIVERSITY

GRB241001A = A fully characterized X-ray flash



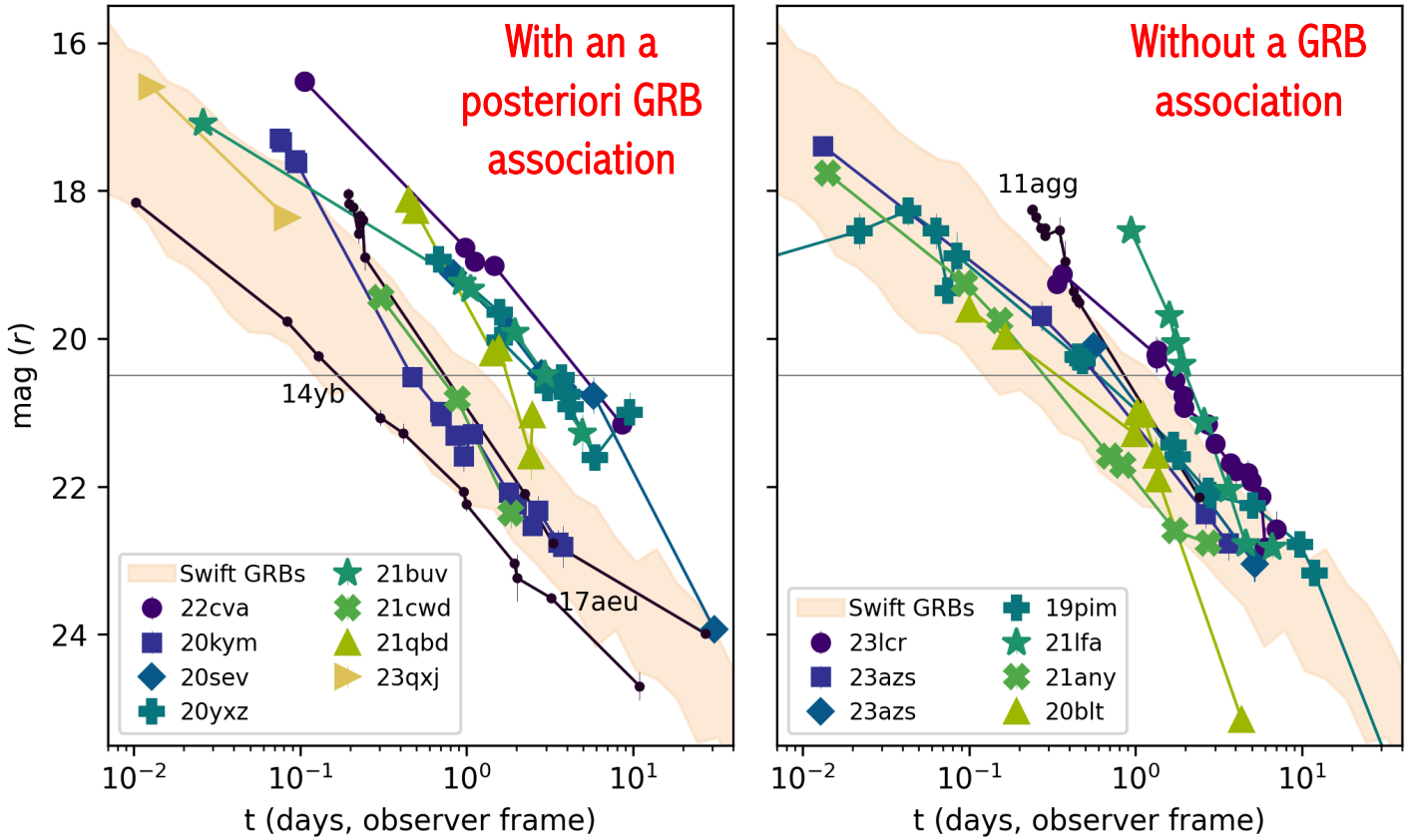


- ECLAIRs spectrum well fitted with BB, also consistent with BPL, but PL rejected
  E_{iso} = 8.4 10^{49} erg ; E_p = 7.1 keV (kT = 1.9 keV) ; **subluminous at its redshift**
- **Prompt emission would most probably be un-detectable in Swift/BAT**
- Faint X-ray afterglow (Swift/XRT & EP/FXT)
- **Optical afterglow weak but would still be detectable up to z~1**
- **Redshift z = 0.573** by VLT/XSHOOTER (GCN#37677)

JWST follow-up: detection of an associated Ic bl supernova
(NIRSpec spectrum @21.5 days; GCN#37867)

Schneider + SVOM collab & partners, in prep.

SOFT GAMMA-RAY BURSTS & FAST X-RAY TRANSIENTS



Ho et al. 2022

Physical origin of FXTs?

- **On-axis GRBs instrinscally soft?**
- **Off-axis GRBs?**
- GRB-related events events with different dominant dissipative mechanisms (e.g. shock breakout)
- Etc.

Another new constraint: first orphan afterglow detections with ZTF!

SOFT GAMMA-RAY BURSTS & FAST X-RAY TRANSIENTS

Einstein Probe / SVOM synergy

- EP (launched in January 2024) detects many Fast X-Ray Transients
- First EP catalog of extragalactic FXTs:
  - 72 FXTs (January 2024-February 2025) = EP/WXT (0.5-4 keV, 1.1 sr)
  - 53 with X-ray AG candidates = EP/FXT (0.3-10 keV, 1 deg^2)
  - 29 with optical AG candidates = follow-up
  - 17 with redshift
- **Many of these FXTs appear as soft or very soft GRBs = X-Ray Rich GRBs / X-Ray Flashes** (e.g. Jiang et al. 2025)

Preliminary results taken from Qinyu Wu's talk at the Swift20 conference

- **SVOM will contribute to the follow-up of EP FXTs**
- **SVOM already detects and characterize X-Ray Rich GRBs and X-Ray Flashes**

- **Towards a sample of well characterized FXTs!**

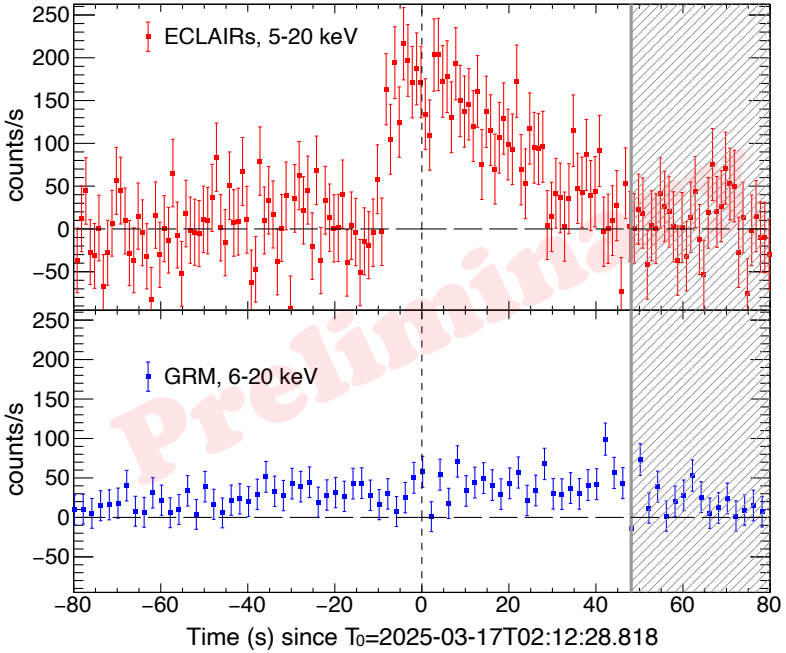
Physical origin of FXTs?

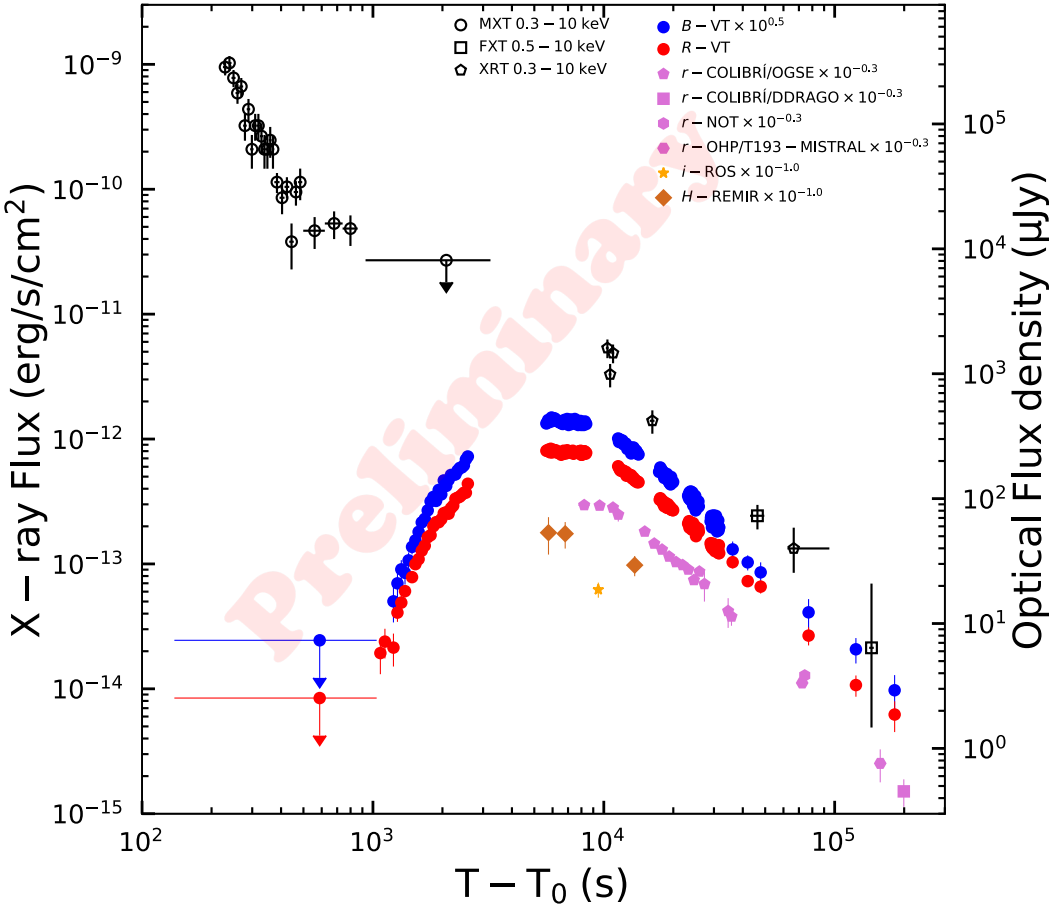
- On-axis GRBs instrinscally soft?
- Off-axis GRBs?
- GRB-related events events with different dominant dissipative mechanisms (e.g. shock breakout)
- Etc.

SOFT GAMMA-RAY BURSTS: EXPLORING THE DIVERSITY

GRB250317B at z=3.44 (GTC, GCN#39769)

- **Probably the most distant XRF?**
- **Possibly a classical long GRB seen off-axis?**
- X-ray AG detected by SVOM/MXT / Follow-up with Swift/XRT and EP/FXT
- Optical AG detected by SVOM/VT Follow-up by many telescopes, including SVOM/VT and SVOM/F-GFT (Colibri)



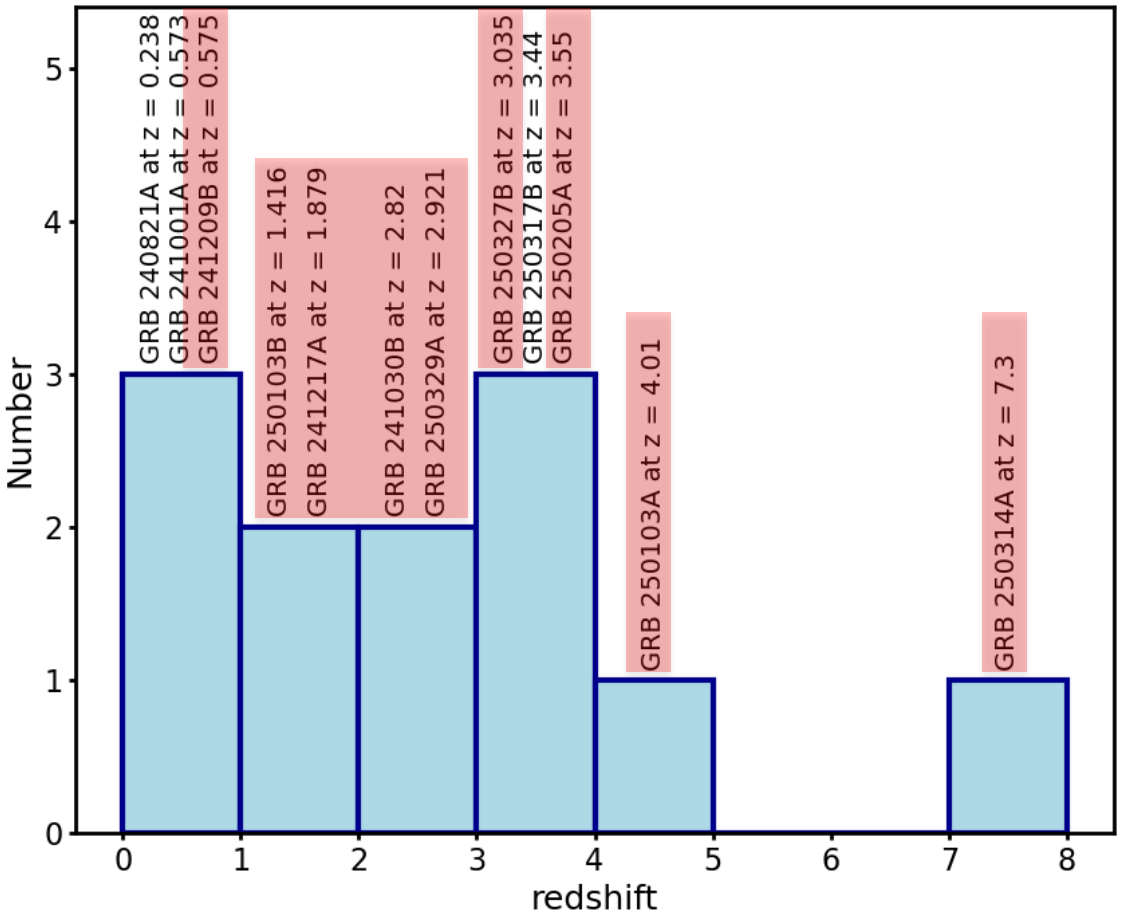


Dong-Hua ZHao + SVOM collab & partners, in prep.

SVOM ECLAIRS GRBS: REDSHIFT DISTRIBUTION

The population of long GRBs is already better understood but SVOM can build a sample of well characterized long GRBs (prompt, AG, z, host) and especially better constrain the prompt spectrum (ECLAIRs+GRM), the early afterglow (MXT,VT,GFTs), or the population at high redshift.

9 long GRBs with z = 0.575 to 7.3

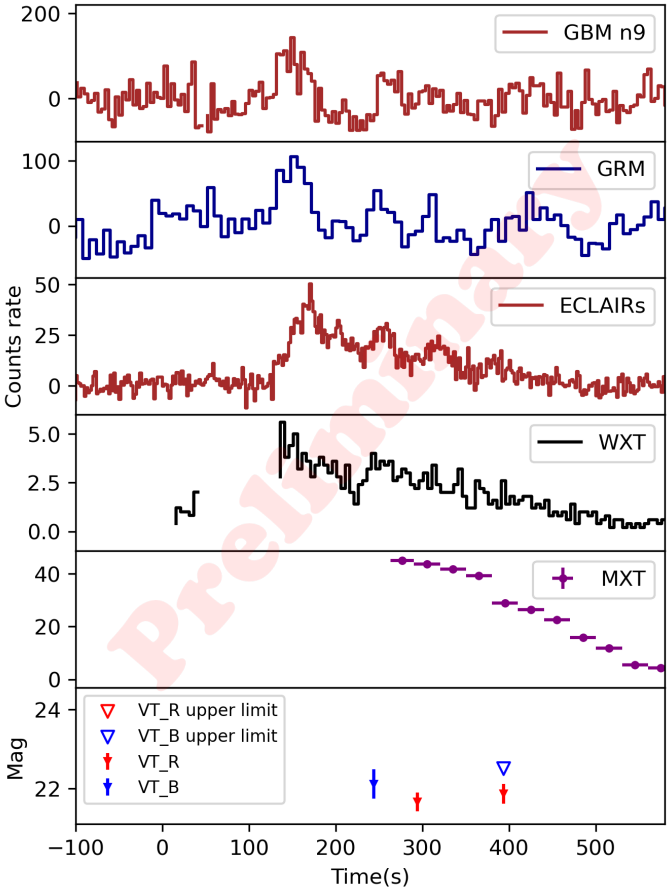


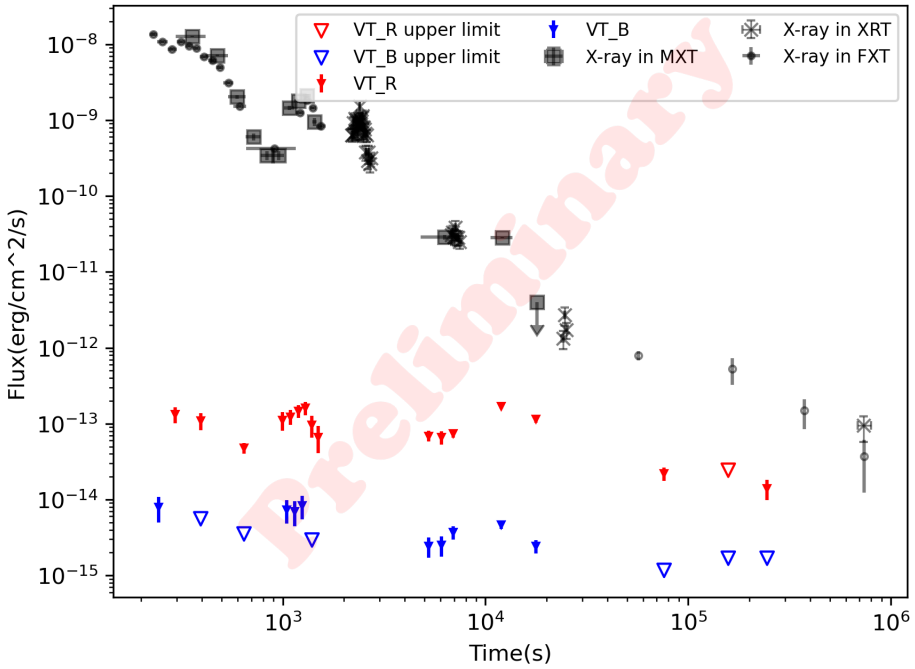
LONG GRBS: LATE PROMPT & EARLY AFTERGLOW (V,X,γ)

GRB241217A at z = 1.879 Physics of the prompt-to-AG transition

- **A very long GRB detected by the four instruments on board SVOM**
  - a precursor detected by SVOM/ECLAIRs, triggering a slew (also detected by GRM)
  - main episode detected by the four instruments on-board SVOM
- **MXT and VT start observing before the end of the prompt emission**
  (also detected by EP/WXT)

Marius Brunet, An Li, He Gao + SVOM collab. & partners, in prep.





LONG GRBS AT HIGH REDSHIFT

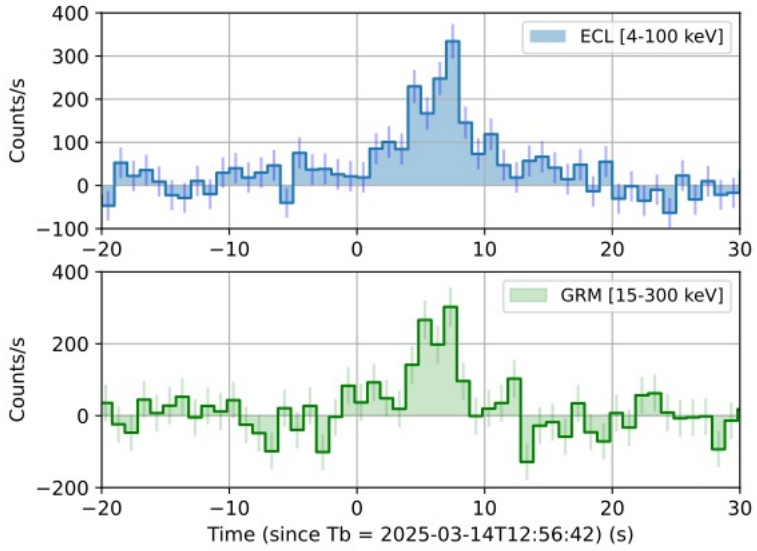
GRB250314A at z = 7.3

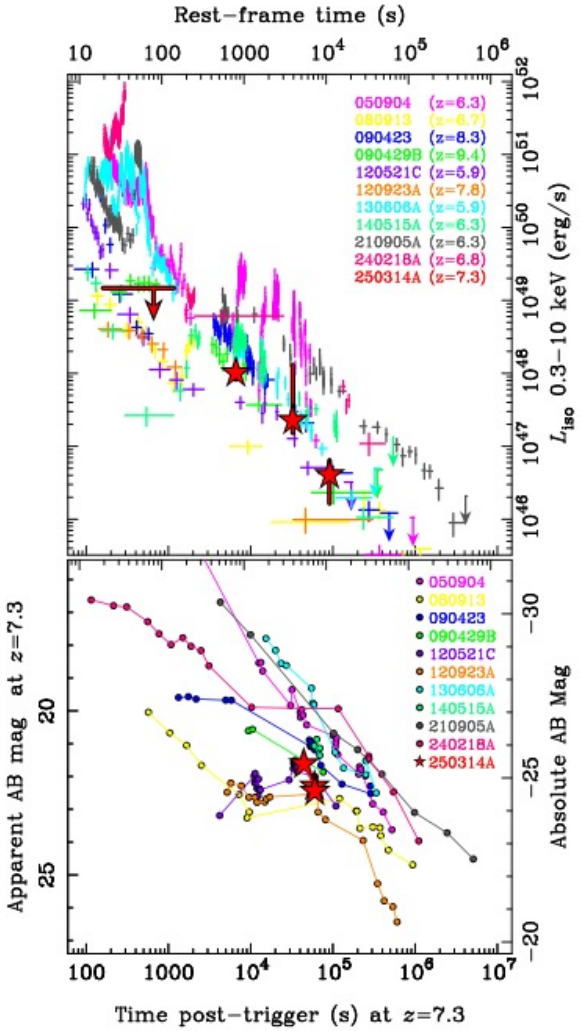
- **A long GRB detected by ECLAIRs** (T90 ~20 s) **and GRM** (T90 ~10 s) **on-board SVOM**
- **Deep early upper limit with VT - NIR AG detected by NOT – Xshooter spectrum**

SVOM GRB 250314A at $z \simeq 7.3$: an exploding star in the era of reionization

B. Cordier[1,*], J. Y. Wei[2,3,**], N. R. Tanvir[4,***], S. D. Vergani[5,6], D. B. Malesani[7,8,9], J. P. U. Fynbo[7,8], A. de Ugarte Postigo[10], A. Saccardi[11], F. Daigne[6], J.-L. Atteia[12], O. Godet[12], D. Götz[11], Y. L. Qiu[2], S. Schanne[1], L. P. Xin[2], B. Zhang[13,14], S. N. Zhang[15], A. J. Nayana[16], L. Piro[17], B. Schneider[10], A. J. Levan[9,18], A. L. Thakur[17], Z. P. Zhu[2], G. Corcoran[19], N. A. Rakotondrainibe[10], V. D'Elia[20], D. Turpin[11] et al.

(Full list of authors and affiliations can be found after the references)





LONG GRBS AT HIGH REDSHIFT

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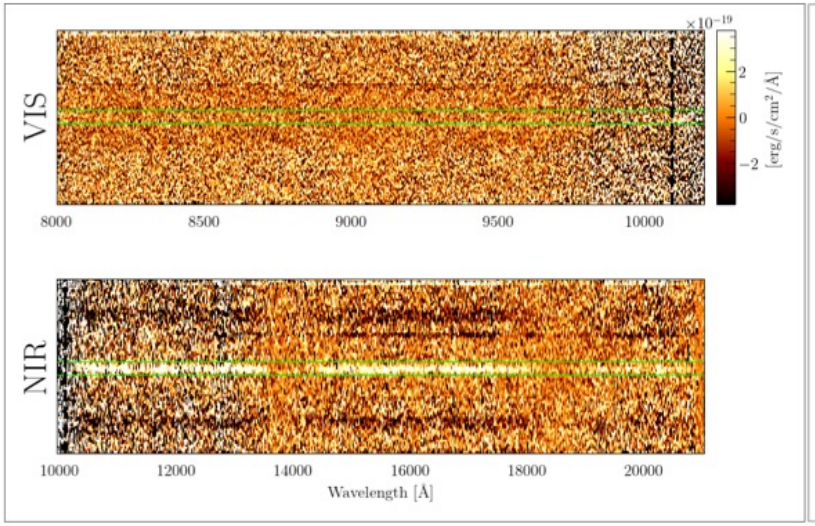
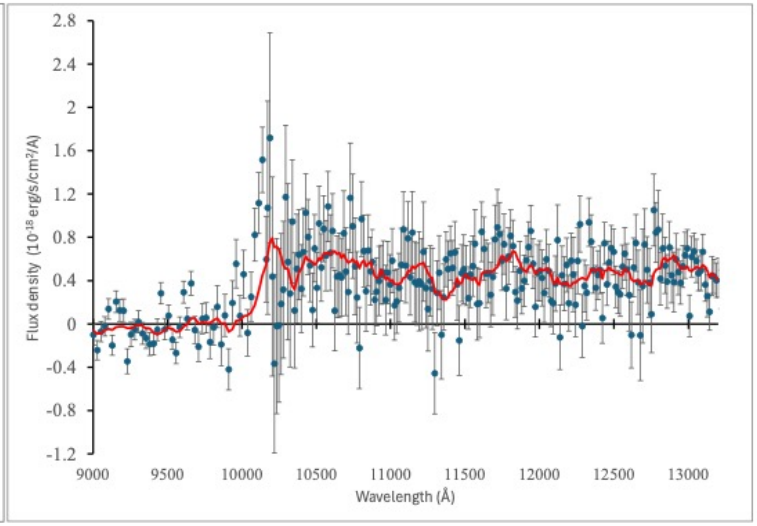




X-Shooter Spectrum: Lyman alpha break at ~ 10090 Å

(Cordier et al. 25)

LONG GRBS AT HIGH REDSHIFT

GRB250314A at z = 7.3

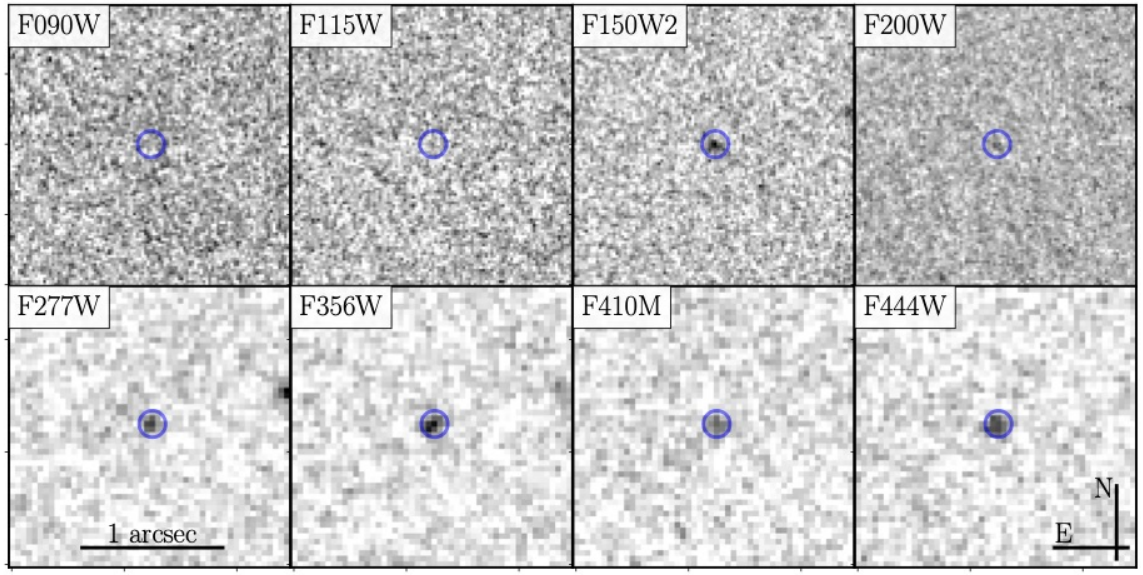
- **JWST Follow-up: probable detection of the associated supernova!**

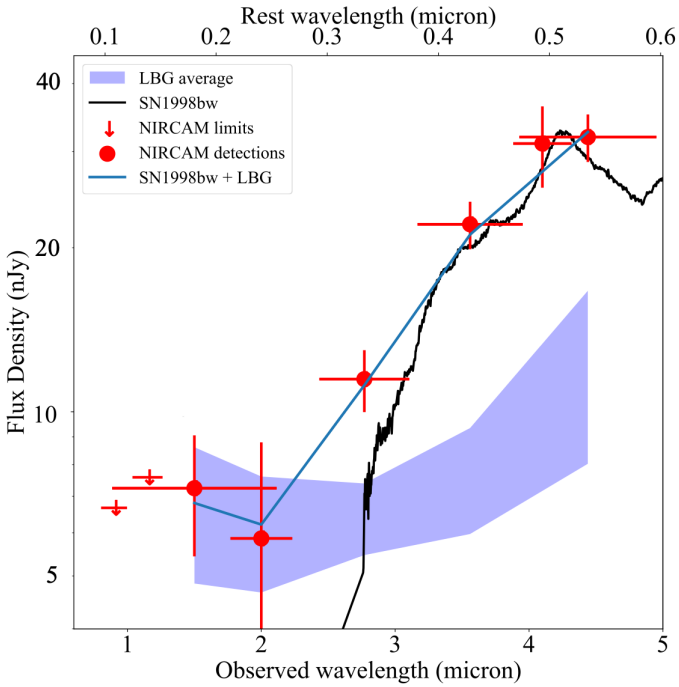
JWST reveals a supernova following a gamma-ray burst at z ≃ 7.3

A. J. Levan[1,2,⋆], B. Schneider[3], E. Le Floc'h[4], G. Brammer[5,6], N. R. Tanvir[7], D. B. Malesani[5,6], A. Martin-Carrillo[8], A. Rossi[9], A. Saccardi[4], A. Sneppen[5,6], S. D. Vergani[10,11,12], J. An[13], J.-L. Atteia[14], F. E. Bauer[15], V. Buat[3], S. Campana[12], A. Chrimes[16], B. Cordier[17], L. Cotter[8], F. Daigne[18], V. D'Elia[19], M. De Pasquale[20], A. de Ugarte Postigo[3], G. Corcoran[8], R. A. J. Eyles-Ferris[7], H. Fausey[21], A. S. Fruchter[22], O. Godet[14], B. P. Gompertz[23], D. Götz[4], N. Habeeb[7], D. H. Hartmann[24], L. Izzo[25,26], P. Jakobsson[27], T. Laskar[28], A. Melandri[29], P. T. O'Brien[7], J. T. Palmerio[4], L. Piro[30], G. Pugliese[31], Y. L. Qiu[13], B. C. Rayson[7], R. Salvaterra[32], S. Schanne[14], A. L. Thakur[30], C. C. Thöne[33], D. Watson[5,6], J. Y. Wei[13], K. Wiersema[34], R. A. M. J. Wijers[31], L. P. Xin[13], D. Xu[13], S. N. Zhang[35]

(Affiliations can be found after the references)

JWST/NIRCAm

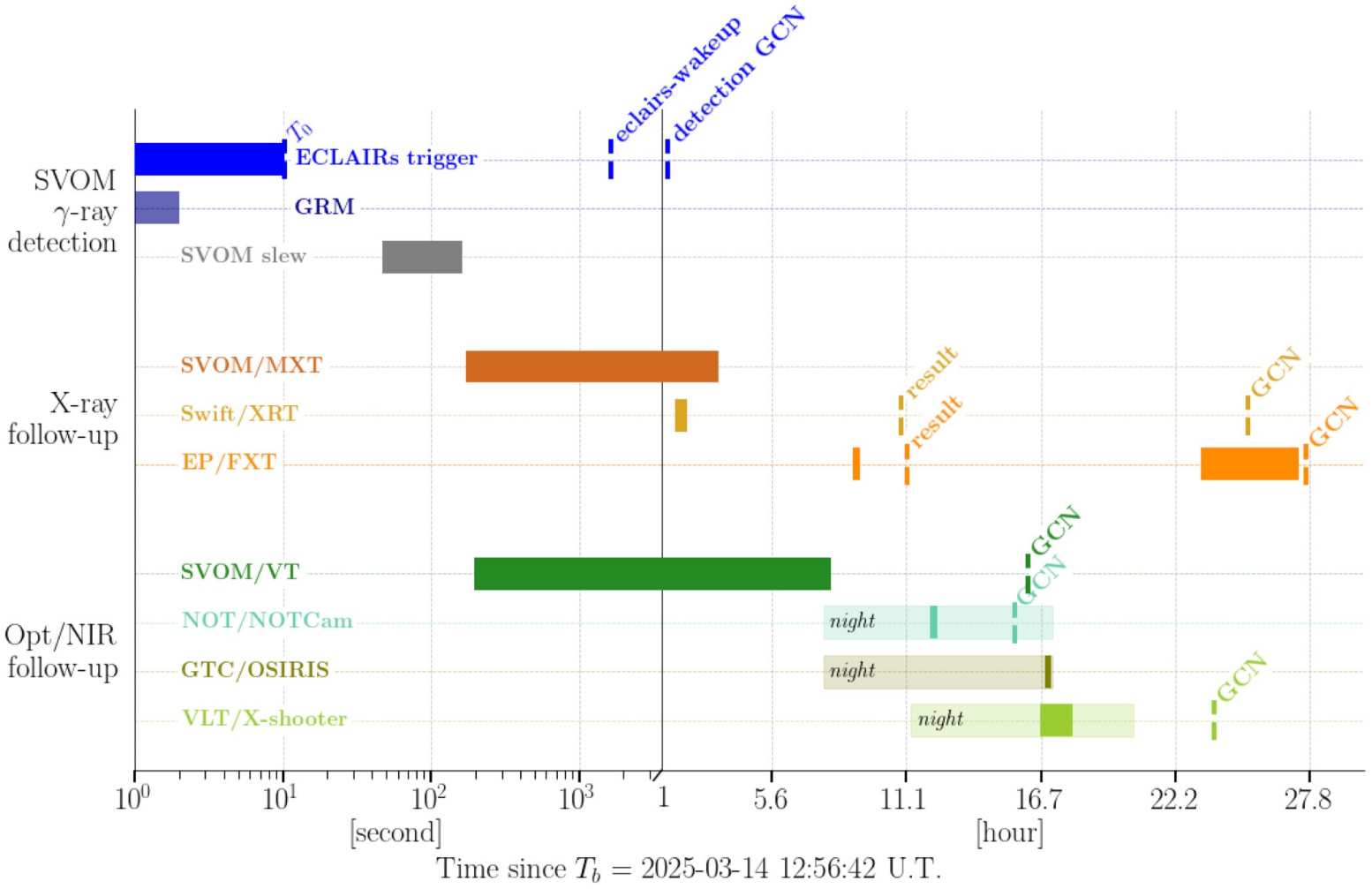




LONG GRBS AT HIGH REDSHIFT

GRB250314A at z = 7.3

- **Timeline: optimization is still possible!**



GRB Studies with SVOM: Conclusions & Prospects

CONCLUSIONS & PROSPECTS

- **SVOM has started to explore the GRB diversity** with a clear impact
  - of the **4 keV low-energy threshold of ECLAIRs**:
    - **soft GRBs**
    - **long GRBs at high redshift**
    - **to come: characterization of the soft γ-ray spectrum by ECLAIRs+GRM**
  - of the optimization of the follow-up sequence (especially: **anti-solar pointing**, **VT sensitivity, GFTs, partners**):
    - crucial role of **Swift/XRT** and **EP/FXT** for the observation of the X-ray AG
    - already **high Opt. AG detection/redshift measurement rate** (still increasing, to come in a few month: JH filters on F-GFT)
    - **several cases of well characterized events at the prompt/early afterglow transition in X-rays and optical with MXT and VT**

- **Several papers on the first detected GRBs to be submitted soon.**
  (coordination: SVOM GRB-Science Working Group co-chaired by F. Daigne & B. Zhang)

- **Still on a learning curve, but SVOM works already very well, with a strong support of SVOM partners and the whole GRB community!**

- **Stay tuned!**