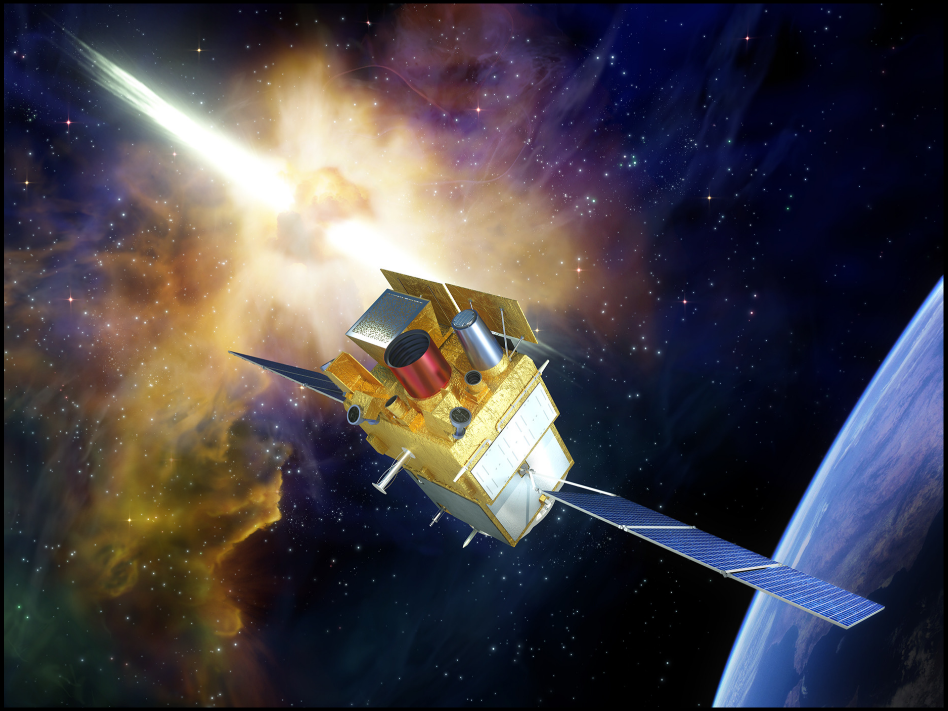
Institut d'Astrophysique de Paris

SORBONNE UNIVERSITÉ

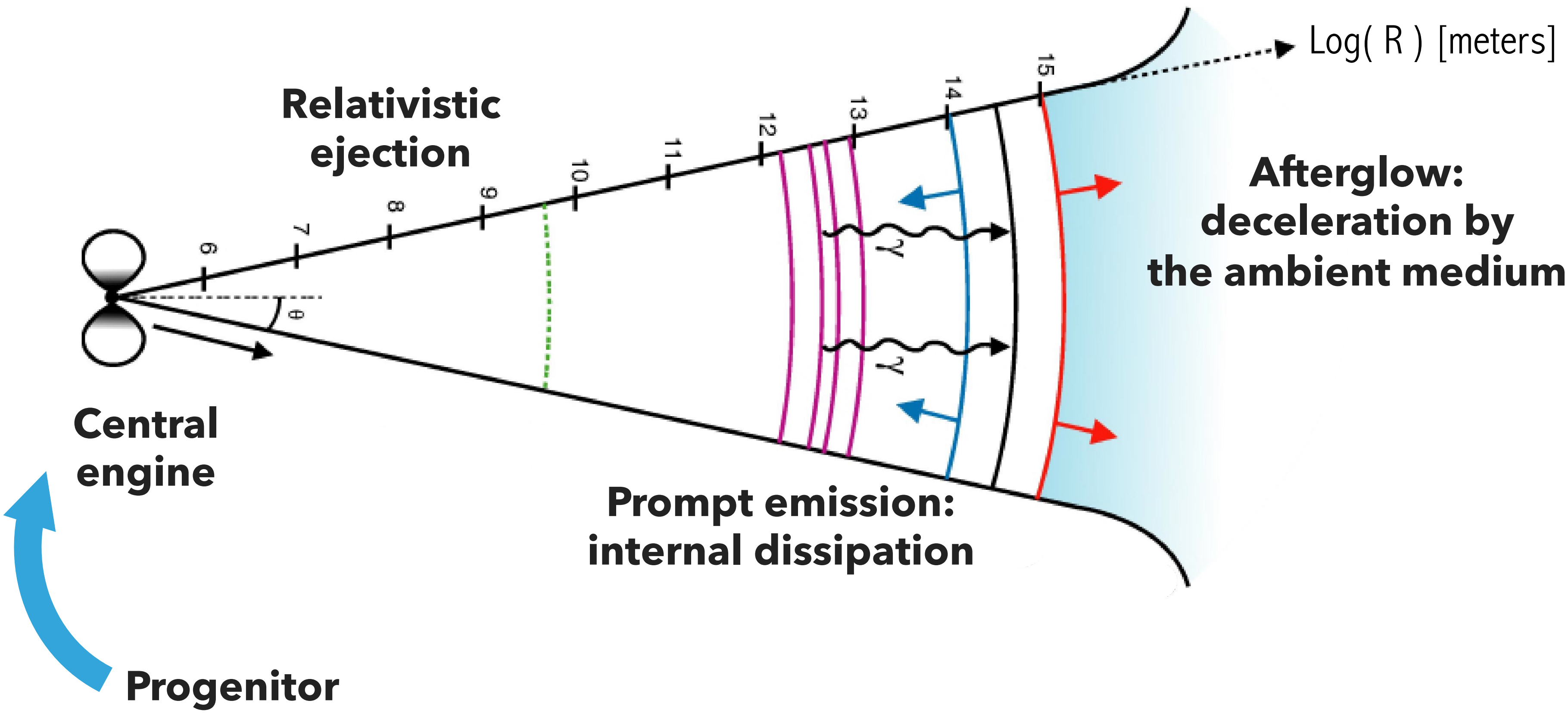
WHAT CAN WE EXPECT FROM THE SVOM MISSION FOR GRB SCIENCE?

Frédéric Daigne



SVOM Scientific Workshop, Xichang, 23 June 2024

GAMMA-RAY BURSTS PHYSICS



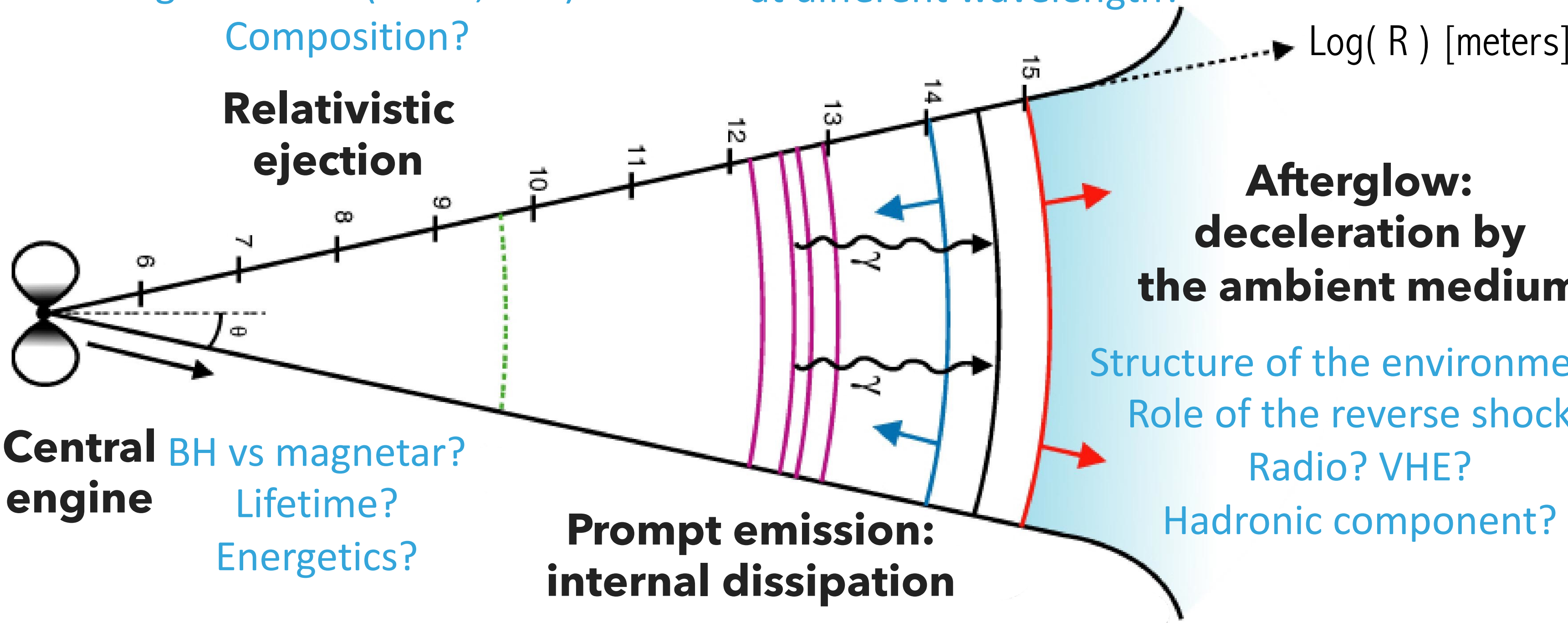
GAMMA-RAY BURSTS PHYSICS: MANY OPEN QUESTIONS

See B. Zhang's talk this morning

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?

See B.B. Zhang's talk this morning

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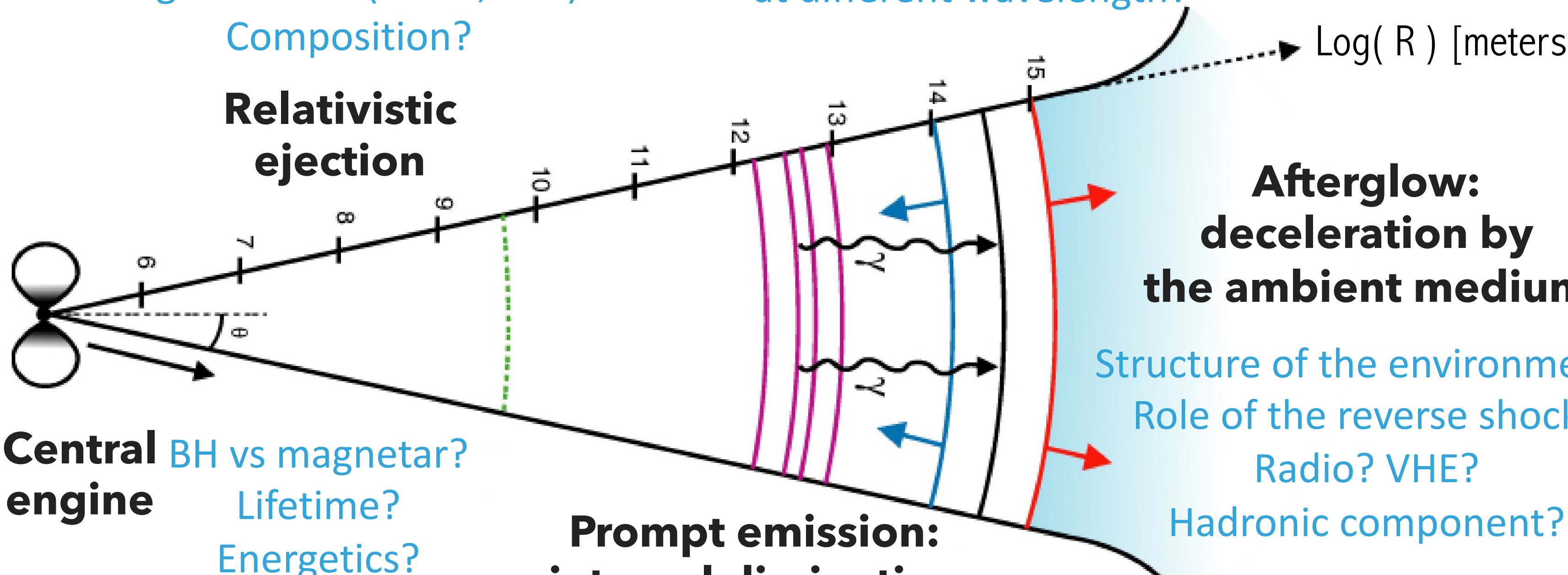

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Relativistic ejection

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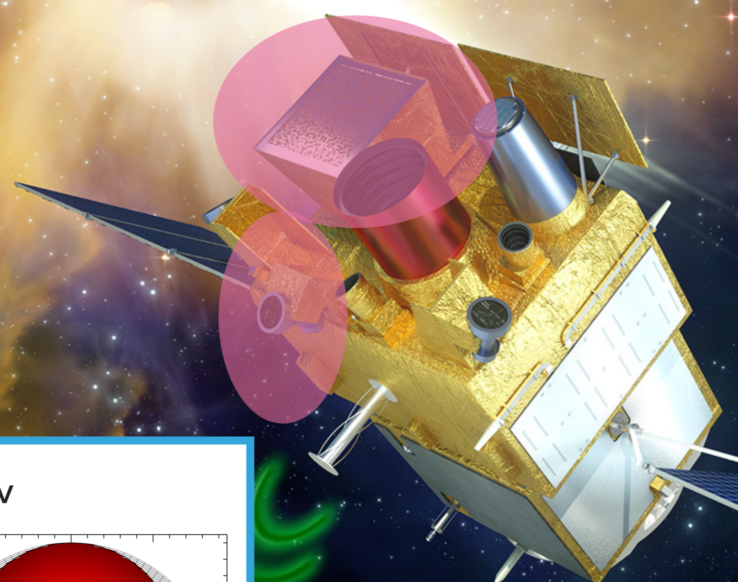
See B.B. Zhang's talk this morning

SVOM observations will allow progress on most of these question

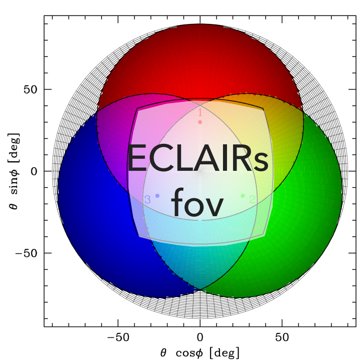
SVOM CORE PROGRAM: THE TYPICAL GRB SEQUENCE

- **Trigger: ECLAIRs** (4 -150 keV ; ~ 2 sr ; Loc. < 12′)
- **Expected rate: 42-80 GRB/yr**
- **GRM** (15 keV-5 MeV ; ~ 5.6 sr ; Loc.: 5-10° if 3 detectors)**: ~90 GRB/yr**

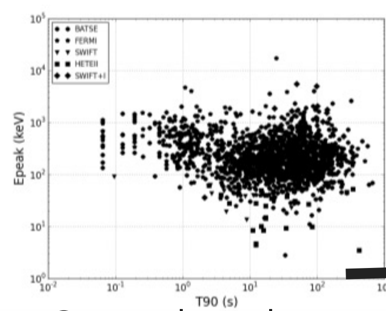
(but poor localization: no slew for GRM-only triggers)



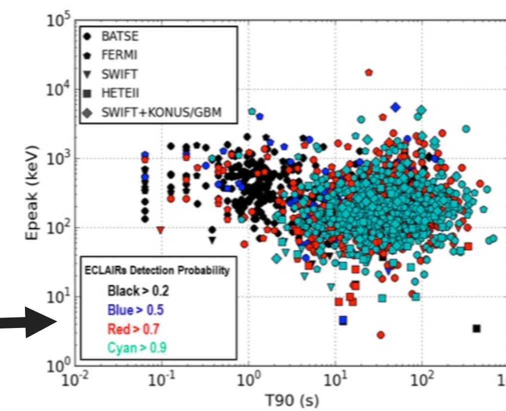
GRM fov



ECLAIRs sensitive to all GRB classes:
Classical long GRBs / Soft GRBs (XRR, XRF)
Short GRBs (but with a moderate efficiency)
ECLAIRs+GRM: improves sensitivity to short GRBs



Original catalogs

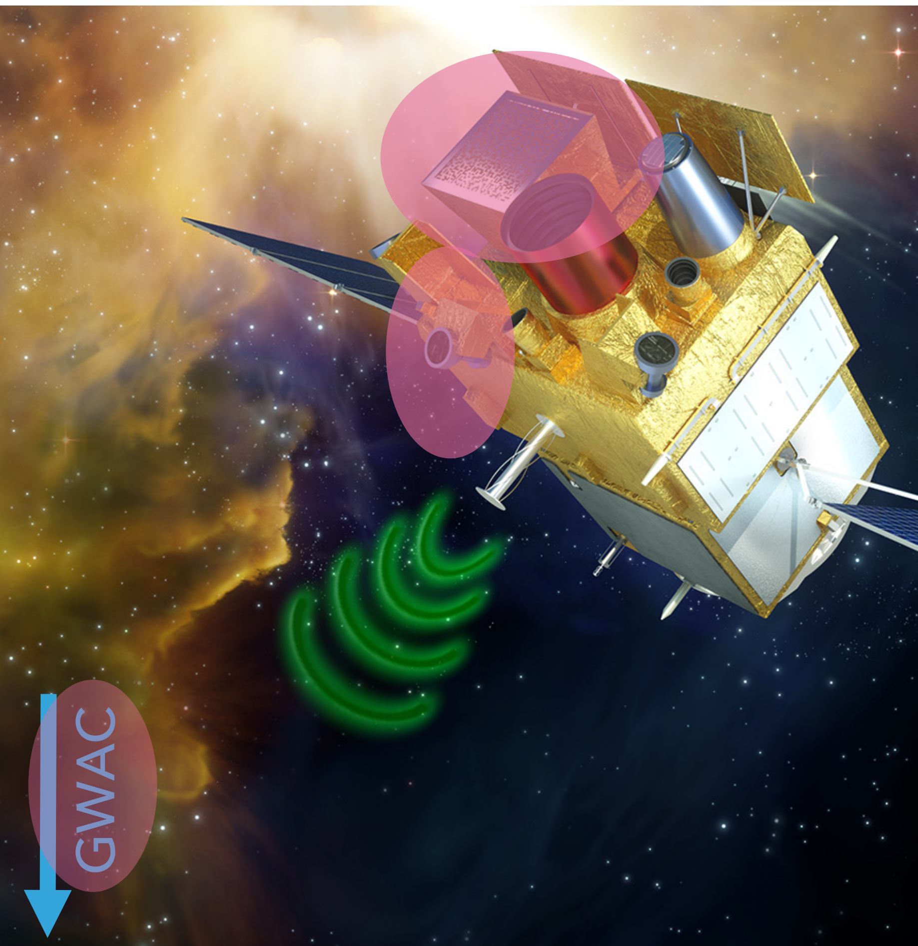


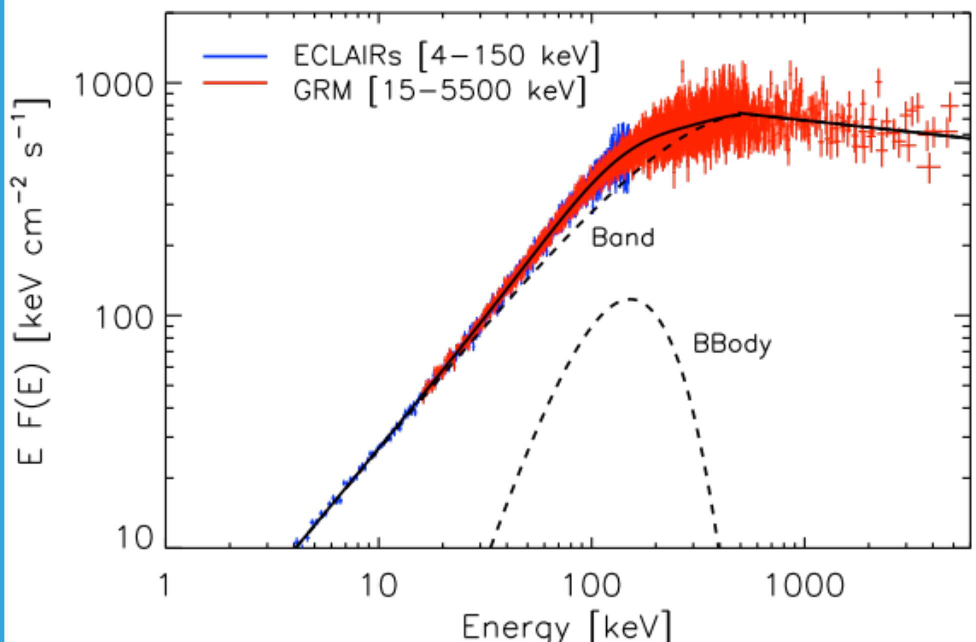
(arXiv:1610.06892)

Simulation in ECLAIRs

SVOM CORE PROGRAM: THE TYPICAL GRB SEQUENCE

- **Prompt emission from 4 keV to 5 MeV with ECLAIRs and GRM**
- **Visible detection/upper limit in ~10-15% of cases with GWAC**

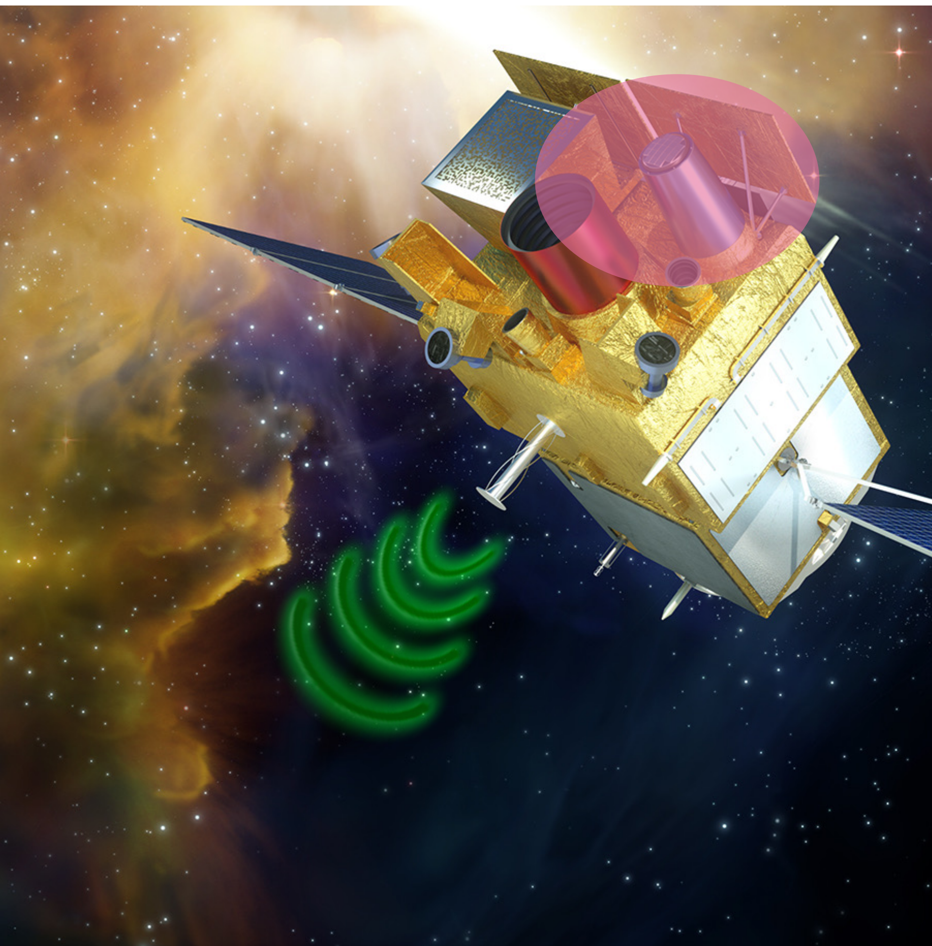


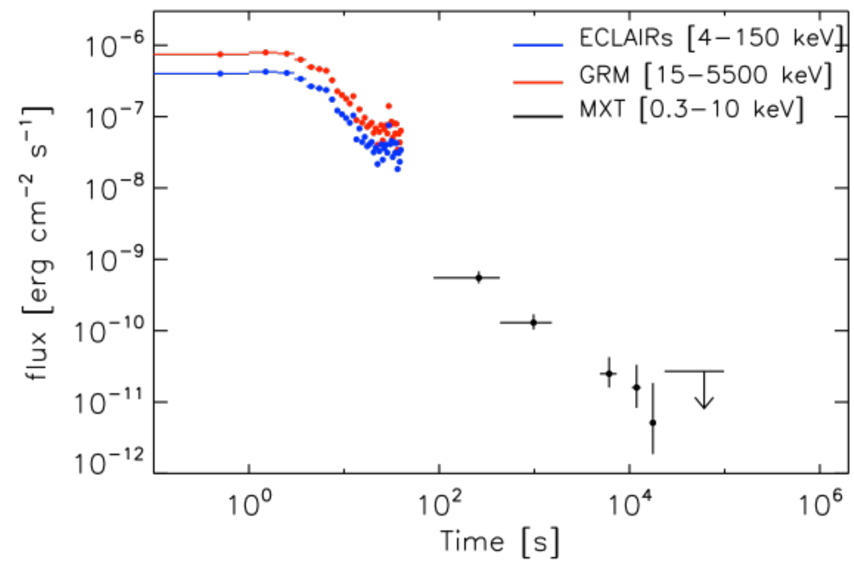


Multi-component spectrum of the Fermi burst GRB 100724B simulated in ECLAIRs+GRM. (Bernardini et al. 2017)

SVOM CORE PROGRAM: THE TYPICAL GRB SEQUENCE

- **Slew: ~36-72 GRB/yr**
- **Follow-up: detection and localization by MXT in >90% of cases (0.2-10 keV)**

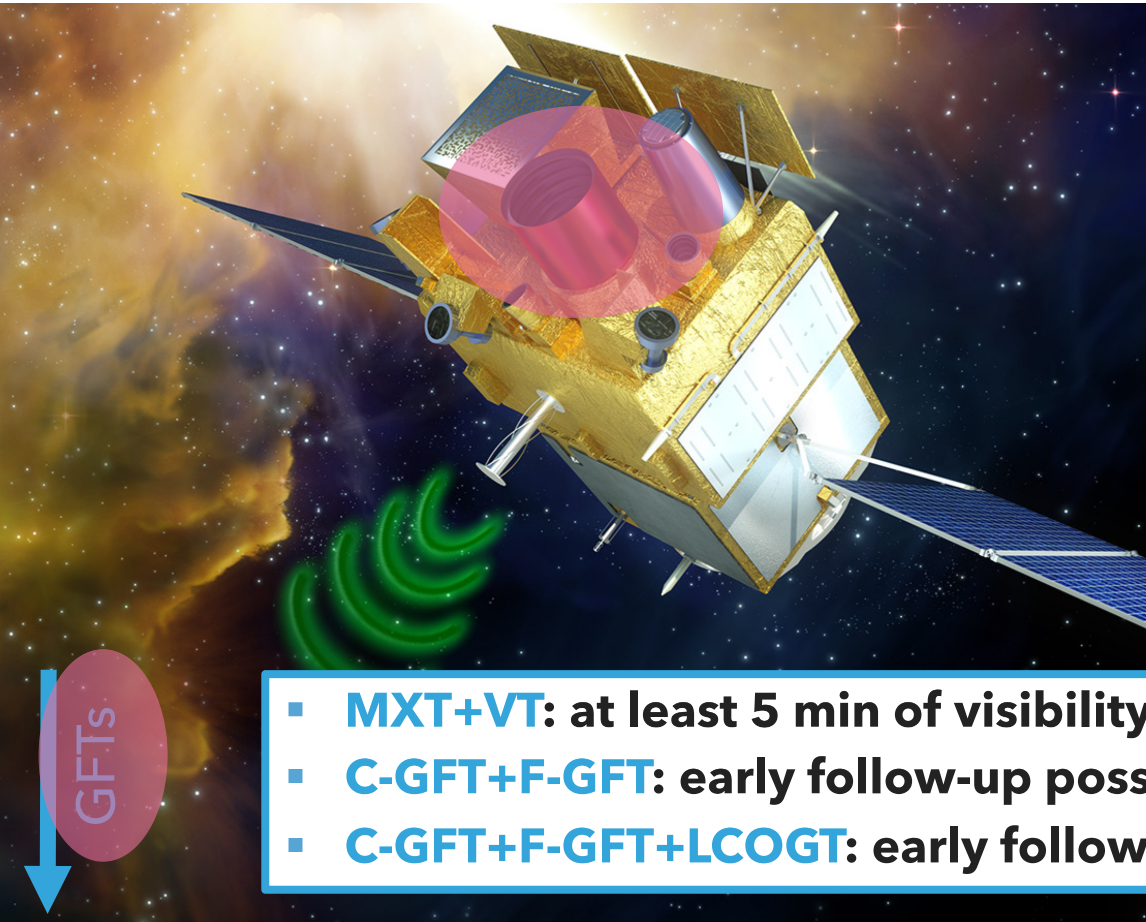


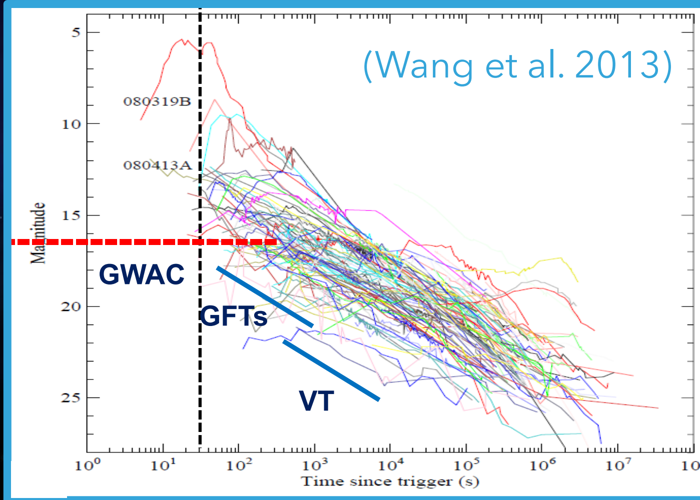


The X-ray afterglow of the Swift burst GRB 091020 simulated in MXT. (arXiv:1610.06892)

SVOM CORE PROGRAM: THE TYPICAL GRB SEQUENCE

- **Visible/NIR early follow-up : VT/GWAC/C-GFT/F-GFT (lightcurve/photo-z)**
- **Pointing strategy favors a rapid follow-up by ground-based instruments (long-term afterglow, spectro-z, SN/KN association, host galaxy, …)**
- **Objective: redshift in ~2/3 of cases**





- **MXT+VT: at least 5 min of visibility in ~66% of cases**
- **C-GFT+F-GFT: early follow-up possible in ~37% of cases**
- **C-GFT+F-GFT+LCOGT: early follow-up possible in ~75% of cases**

A GRB SAMPLE WITH A COMPLETE DESCRIPTION

A unique sample of ~30-40 GRB/yr with

- **prompt GRB over 3 decades (4-5000 keV) + V flux/limit in ~10-15 % of cases**
- **X/V/NIR early afterglow**
- **redshift**

Physical mechanisms at work in GRBs

Nature of GRB progenitors and central engines
Acceleration, composition, dissipation & radiation process of the relativistic ejecta

Diversity of GRBs: event continuum following the collapse of a massive star

Low-luminosity GRBs / X-ray rich GRBs / X-ray Flashes and their afterglow
GRB/SN connection

Short GRBs and the merger model

GW association / Short GRBs with extended soft emission

GRBs as a tool to study the distant Universe

Host galaxies
Rate of very high-z GRBs similar to Swift,
better fraction of redshift measurements expected

GAMMA-RAY BURSTS PHYSICS

SOFT GRBS

SVOM unique sample of ~30-40 GRB/yr with
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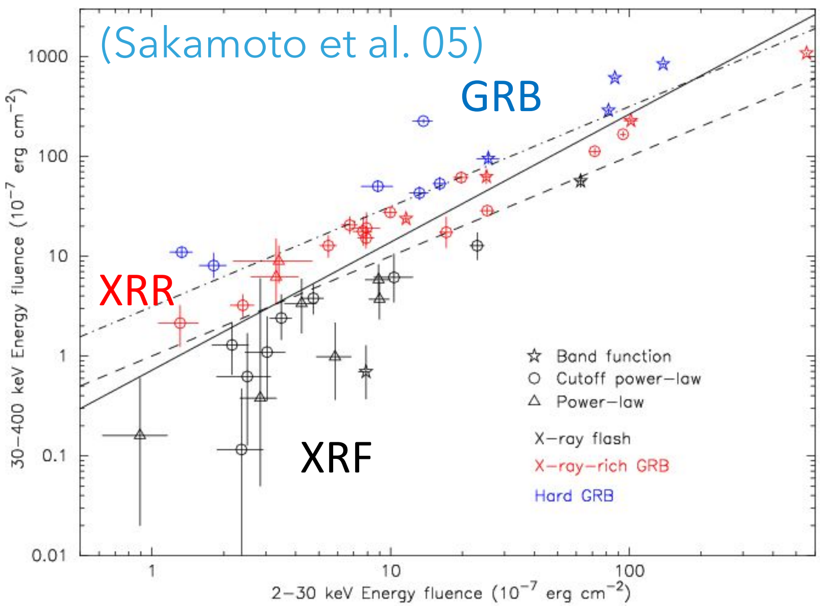
- Early afterglow(X/V/NIR)
- Long-term afterglow in many cases
- Redshift

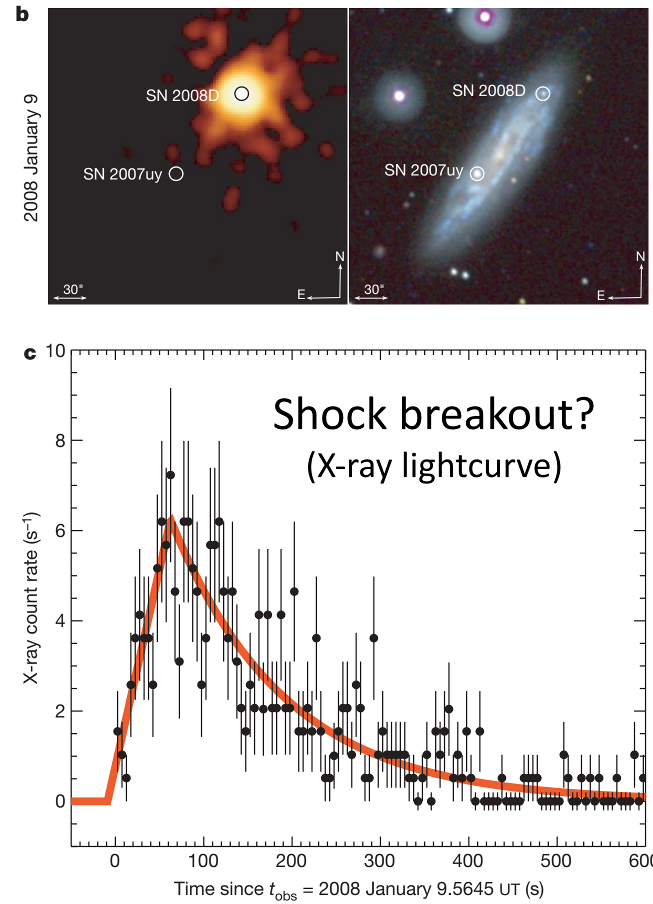
Sensitivity to soft events thanks to the 4 keV threshold of ECLAIRs: nature of Fast X-ray Transients/X-Ray Rich GRBs/X-Ray Flashes/Low-L GRBs…

HETE2 sample

Fluence (30-400 keV)



Fluence (2-30 keV)



(Soderberg et al. 08)

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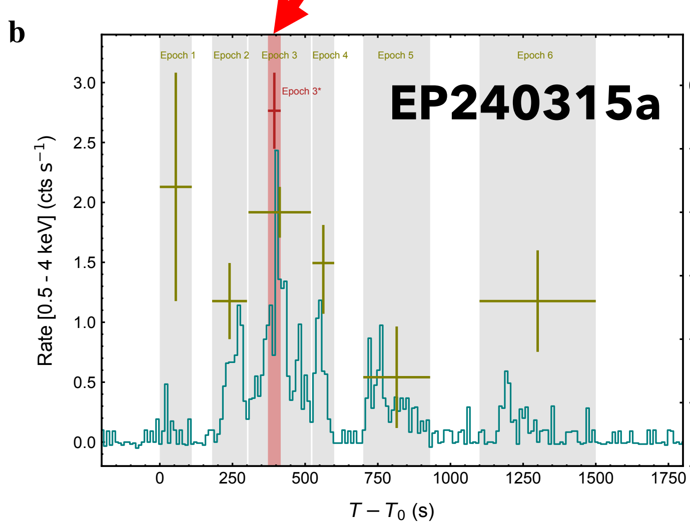
Sensitivity to soft events thanks to the 4 keV threshold of ECLAIRs: nature of Fast X-ray Transients/X-Ray Rich GRBs/X-Ray Flashes/Low-L GRBs…

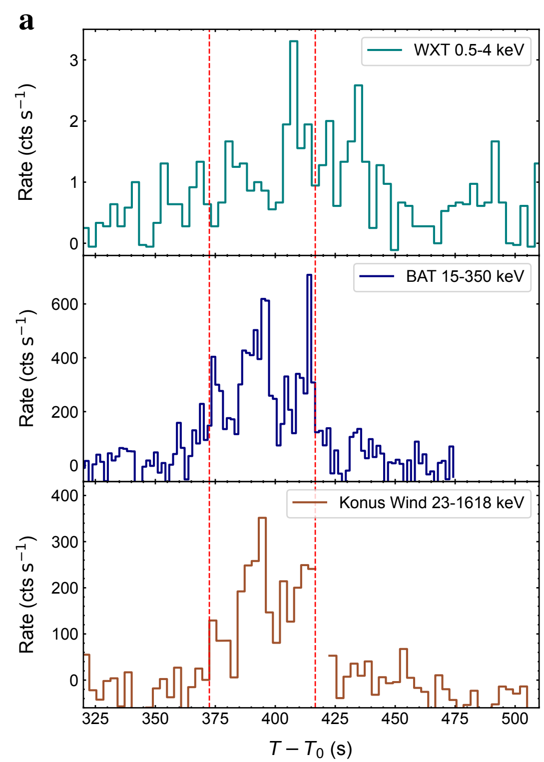
- **Strong synergy with Einstein Probe:**
  - characterization prompt+afterglow+host/environment
  - diversity?

Swift/Konus detection

(Liu et al. 24)



EP 0.5-4 keV Lightcurve



z=4.9
« normal » afterglow
(Levan et al. 24 , Liu et al. 24)

See W. Yuan's talk

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Sensitivity to soft events thanks to the 4 keV threshold of ECLAIRs: nature of Fast X-ray Transients/X-Ray Rich GRBs/X-Ray Flashes/Low-L GRBs…

- **Strong synergy with Einstein Probe:**
  - characterization prompt+afterglow+host/environment
  - diversity?
- **Which of these events are classical GRBs?**
  What do we learn on the X-ray prompt emission? (Prompt emission physics)
- **Which of these events do belong to the soft tail of the GRB population?**
  Conditions for low peak energies? (Prompt emission physics)
- **Which of these events are connected to GRBs but with a different dominant process for the prompt emission? Or different viewing conditions?**
  Choked jets/shock breakout emission? Off-axis jets? … (Progenitors/Jet physics)
- Which of these events are not connected to GRBs? New transients?

GAMMA-RAY BURSTS PHYSICS

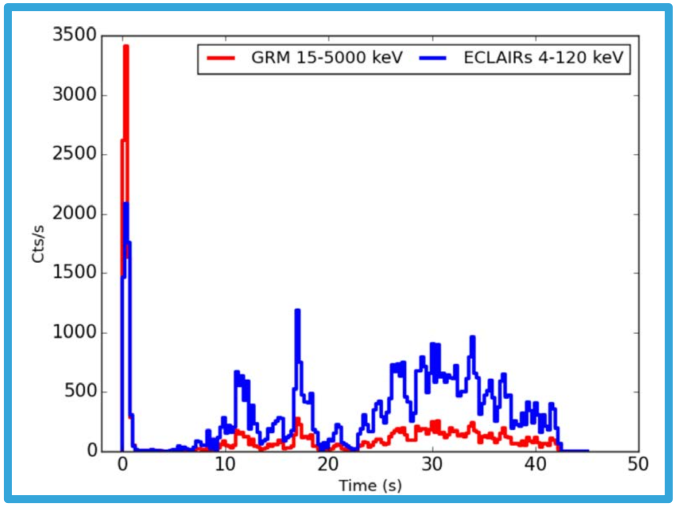
SHORT GRBS

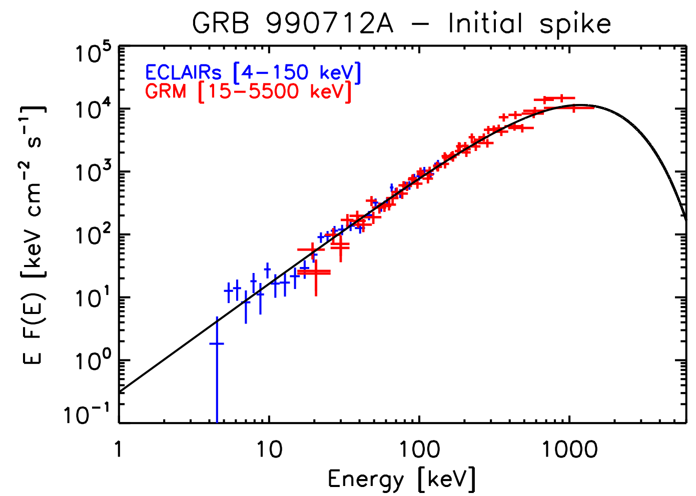
SVOM unique sample of ~30-40 GRB/yr with
- Prompt emission (4-5000 keV + V flux/limit: ~10-15 % of cases)
- Early afterglow(X/V/NIR)
- Long-term afterglow in many cases
- Redshift

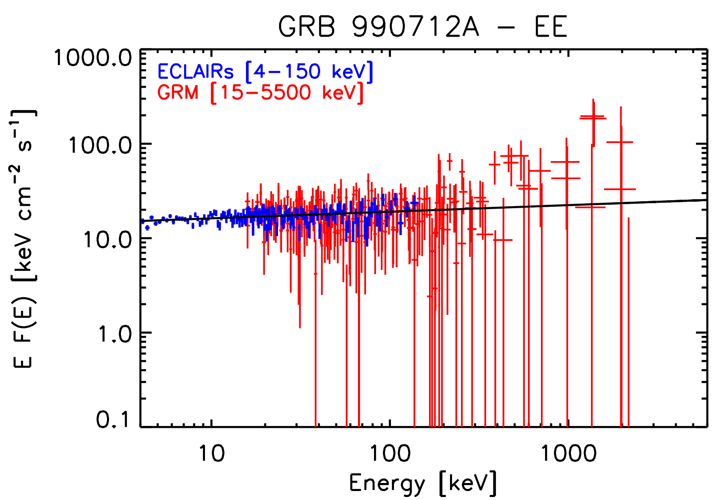
The combination of ECLAIRs & GRM provides good performances for the detection, localization and spectral characterization of short GRBs.

- **Characterization: spectrum? Soft tail?**
- **Early afterglow? (MXT/VT/GFTs)**
- **Diversity?** (Central engine, Progenitors)
- **GW association?**

Simulation of a short GRB with a soft tail in ECLAIRs+GRM: GRB 990712A. (arXiv: 1610.06892)







GAMMA-RAY BURSTS PHYSICS

LOCAL GRBS

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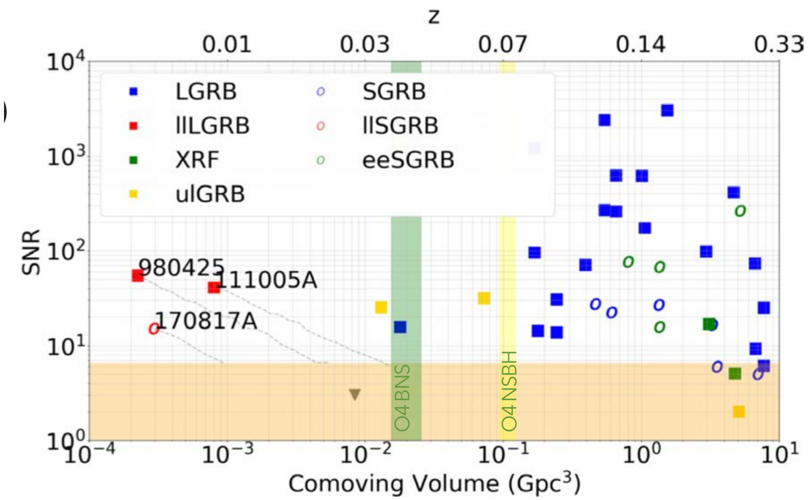
- Redshift

GRBs in the local Universe are an excellent target for a complete characterization

- **SVOM instruments + early follow-up strategy allows to explore the diversity of the GRB population in the local Universe**

Simulation of 34 nearby GRBs (z<0.3): detection by ECLAIRs.

- **22/24 long GRBs**, including
  3 ultra-long
  2 low-luminosity
  2 X-Ray Flashes
- **8/10 short GRBs**
  (including the simulated 170817)



(Arcier et al. 2020)

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GRBs in the local Universe are an excellent target for a complete characterization

- **SVOM instruments + early follow-up strategy allows to explore the diversity of the GRB population in the local Universe**
- **Best targets for the search for SN/KN associations** (Progenitors)
  Explore diversity: e.g. GRB211211A/KN (Emission mechanisms)
- **Best targets for VHE counterparts**

Associated SN/KN can be searched with VT/GFTs for these local events.

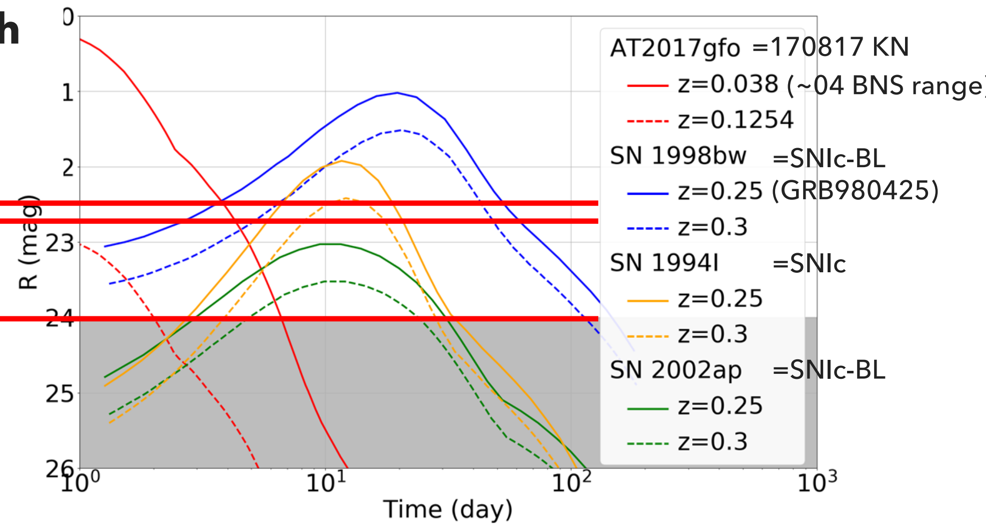
(Arcier et al. 2020)

SVOM limit R-mag

VT (300 s) 22.5

GFT (300 s) 22.8

VT (4800 s) 24



GAMMA-RAY BURSTS PHYSICS

HIGH-REDSHIFT GRBS

GRBs are a tool to probe the distant Universe

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- **Low-energy threshold of ECLAIRs: favors the detection of high-z GRBs at z>6.**

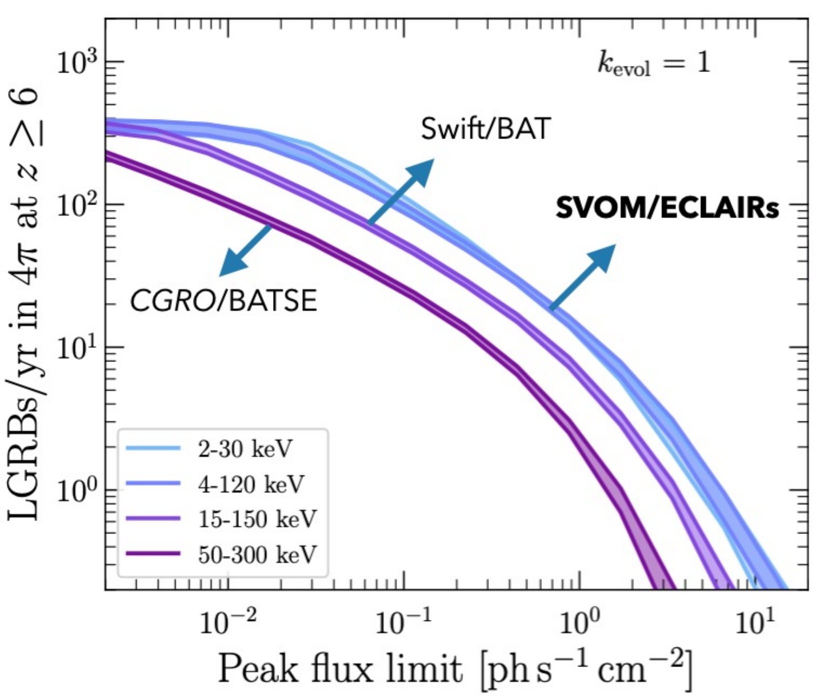
Pop. model: all-sky rate above z=6 as a function of the peak flux limit

(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)



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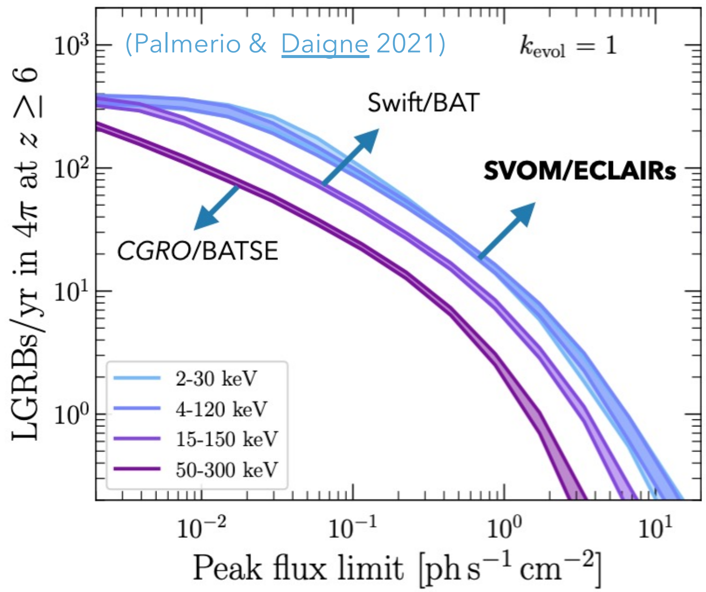
- **Low-energy threshold of ECLAIRs: favors the detection of high-z GRBs at z>6.**
- **Pointing strategy: favors a rapid follow-up (GRB is in the night hemisphere).**
- **VT/GFTs: allow a rapid identification of high z candidates.**
- **A challenge: rapid spectroscopic follow-up with very large telescopes**

(GRB progenitors)

(Host galaxies/IGM at high z)



GAMMA-RAY BURSTS PHYSICS

PROMPT

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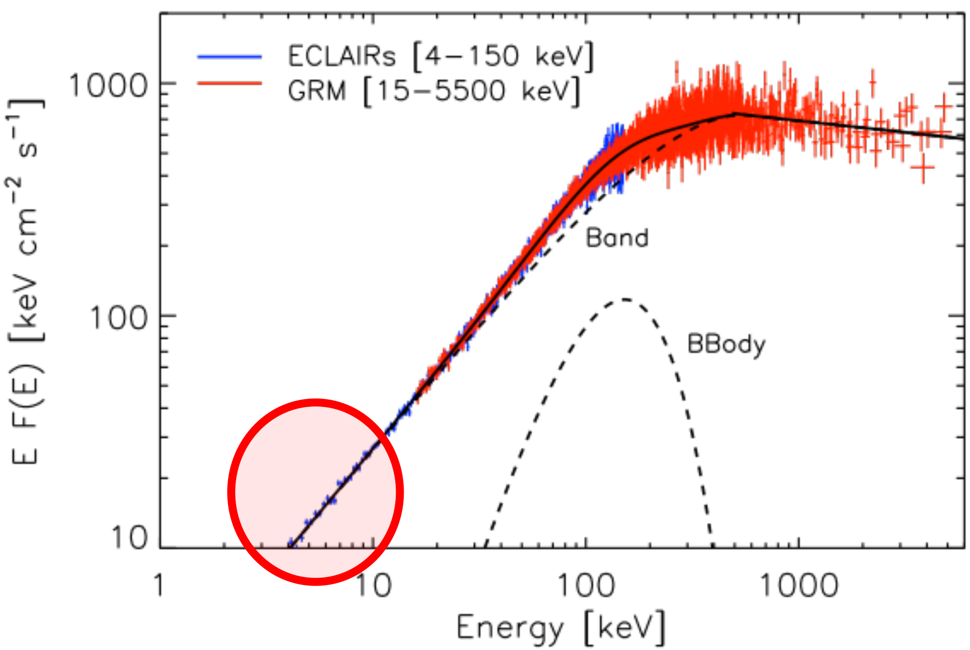
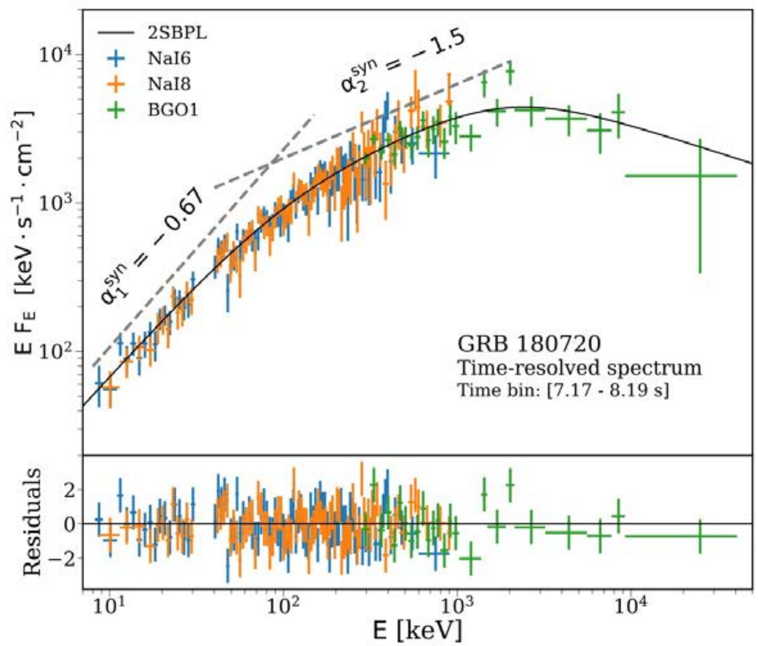
- **The spectral range of ECLAIRs+GRM (4 keV-5 MeV) is well adapted to test some of the debated scenarios for the prompt emission mechanism.**



Multi-component spectrum of the Fermi burst GRB 100724B simulated in ECLAIRs+GRM. (Bernardini et al. 2017)



(Ravasio et al. 2020)

The low-energy threshold at 4 keV of ECLAIRs will allow to further test such complex spectral shapes.

see Frédéric Piron's talk this morning

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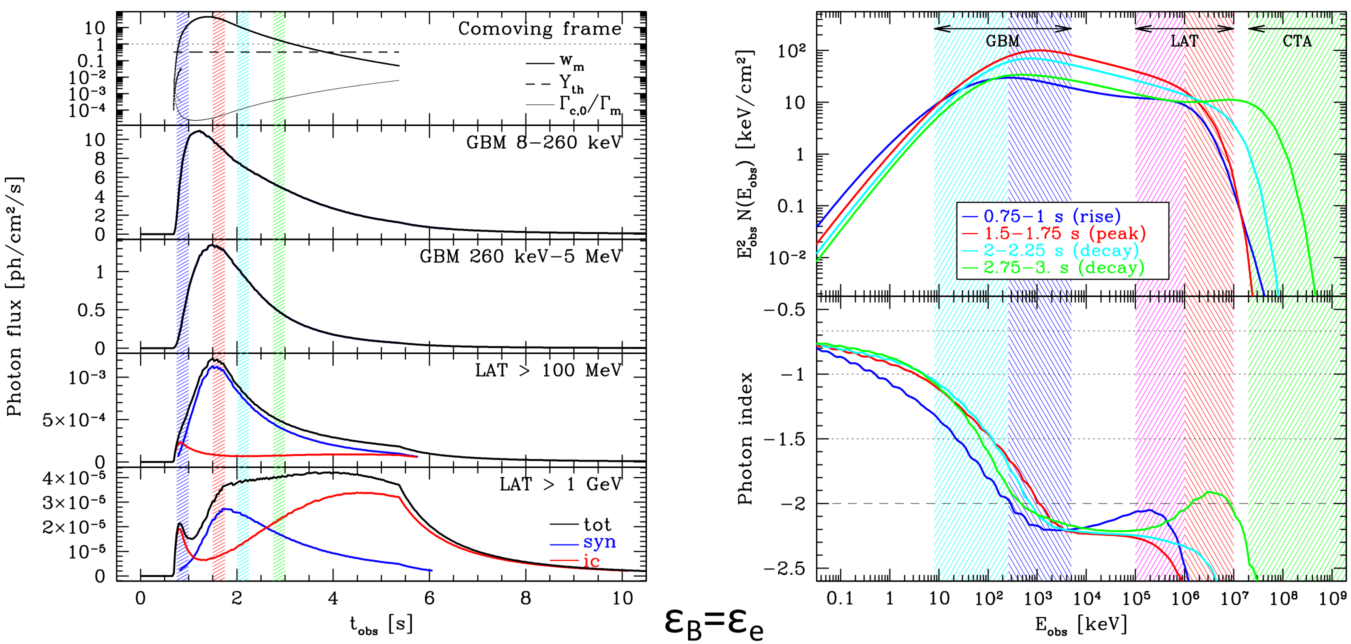
Direct: prompt emission physics (dissipation/particle acceleration/radiation proc.)
Indirect: jet properties (magnetization?)

Model of a GRB pulse (internal shock scenario)
keV-GeV range
marginally fast cooling synchrotron+SSC
(rapid B decay)

Daigne & Bosnjak
submitted



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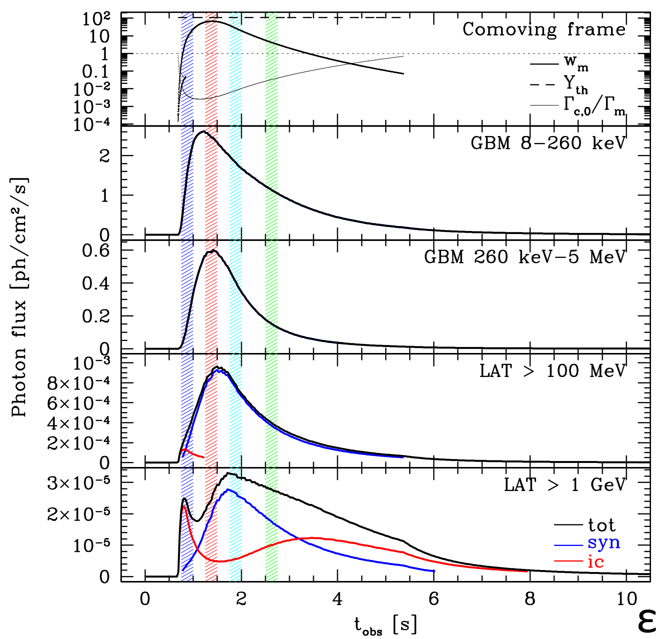
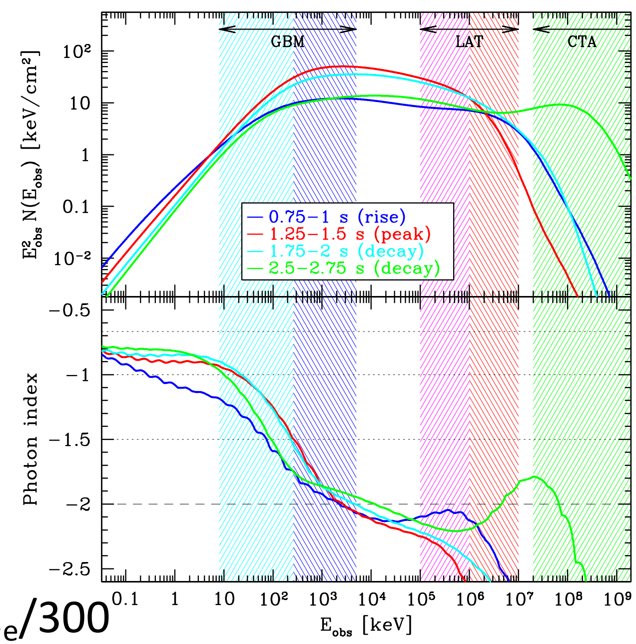


$\varepsilon_B = \varepsilon_e/300$



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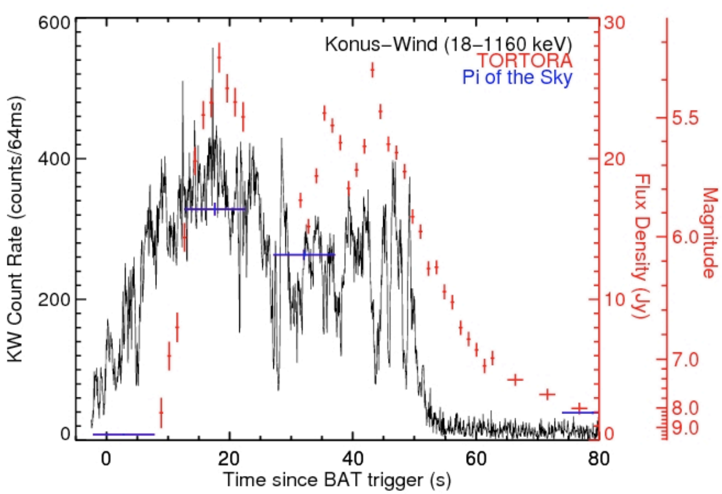
- **The spectral range of ECLAIRs+GRM (4 keV-5 MeV) is well adapted to test some of the debated scenarios for the prompt emission mechanism.**
- **GWAC will bring additional constraints on the visible prompt emission** (+MXT for the longest bursts?)

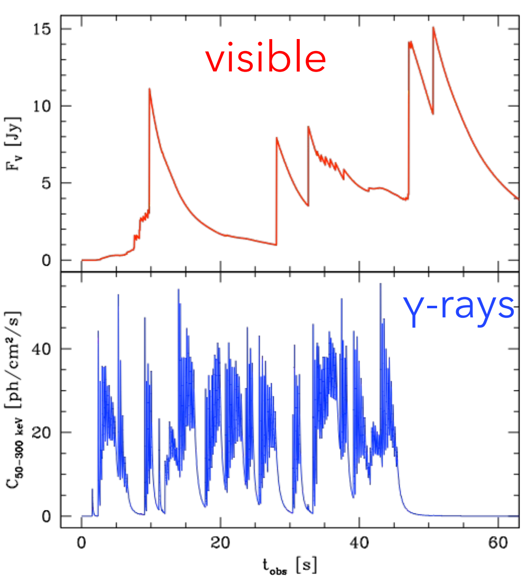
Same internal dissipation mechanism than for the prompt soft gamma-rays vs effect of the deceleration by the ambient medium (reverse shock) ?
Prompt-to-afterglow transition ? (cf. GWAC obs of GRB 201223A, Xin et al. 23)



Naked eye burst, Racusin et al. 08

Prompt optical emission from internal shocks (Hascoet, Daigne et al. 08)

GRB080319B is an extreme case. In other cases the prompt visible emission is very weak: effect of syn. self-abs. ? Constraint on radius ?



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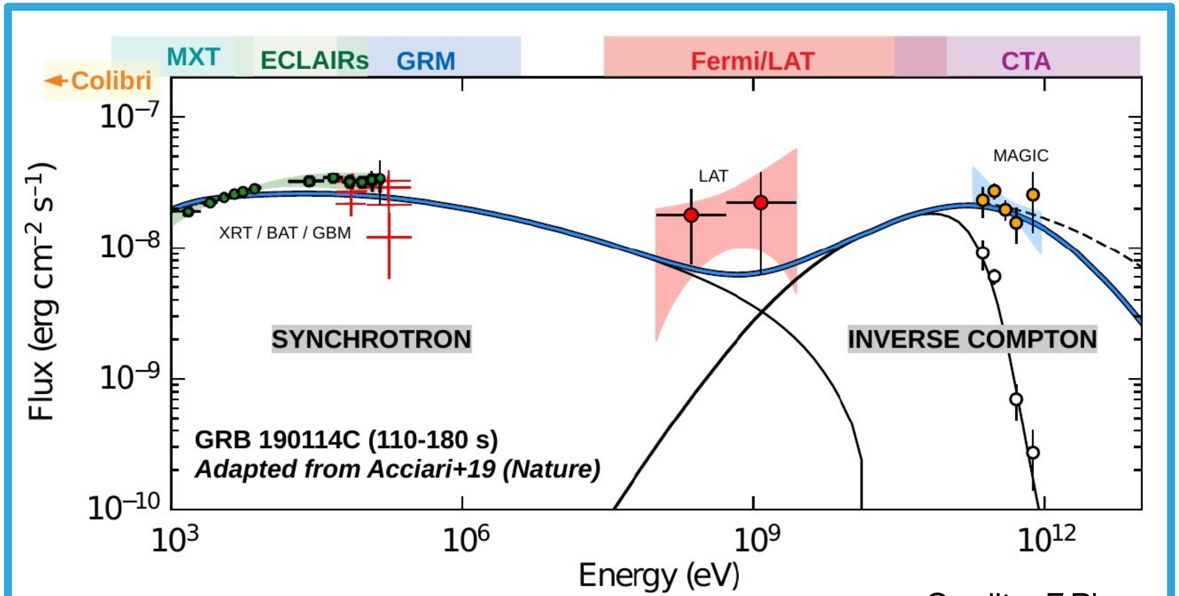
- **Synergies with Einstein Probe (X-rays) / Fermi/VHE instruments (HE/VHE)**

see Frédéric Piron's talk this morning



Credits: F. Piron

GAMMA-RAY BURSTS PHYSICS

PROMPT TO AG TRANSITION

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- **SVOM instruments + pointing strategy is well suited to study the prompt-to-afterglow transition in X-rays/visible**
- **This is one of the most puzzling phase in GRBs, with a lot of features (early steep decay, plateaus, flares, etc.), and many competitive models with very different implications for the central engine (nature, lifetime, etc.) and/or the jet radial or lateral structure.**

  See B. Zhang's and E.W. Liang's talks this morning

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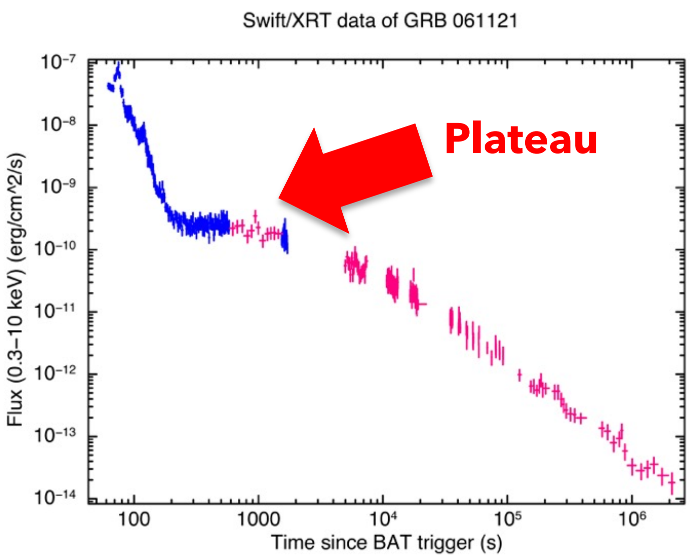
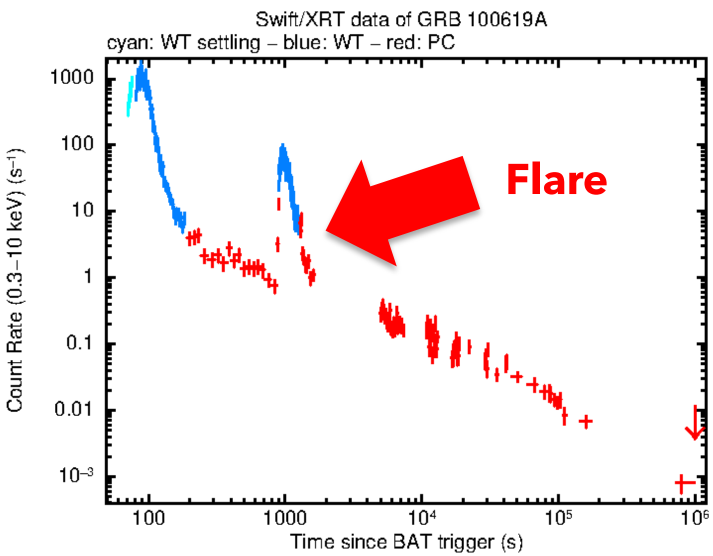
- **SVOM instruments + pointing strategy is well suited to study the prompt-to-afterglow transition in X-rays/visible**
- **Example: the case of plateaus and flares in X-rays**
  = SVOM MXT + EP FXT on long term?)
  SVOM bonus: simultaneous visible observations in more cases?

Swift/XRT afterglows:



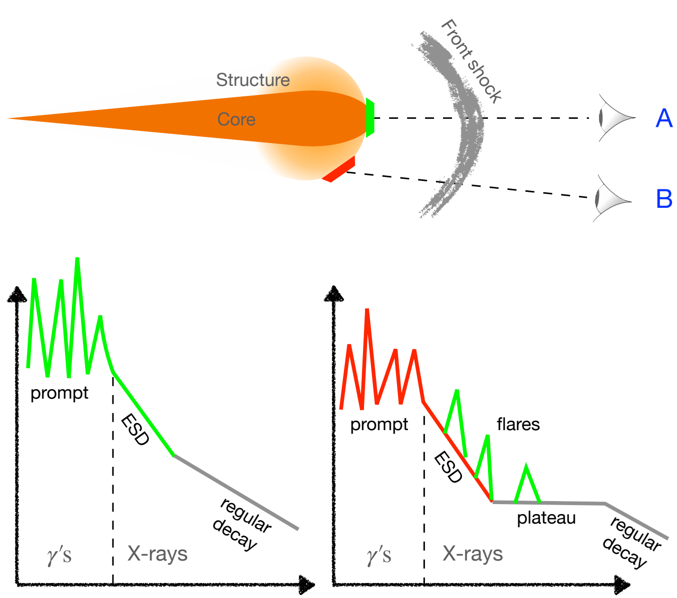


GAMMA-RAY BURSTS PHYSICS

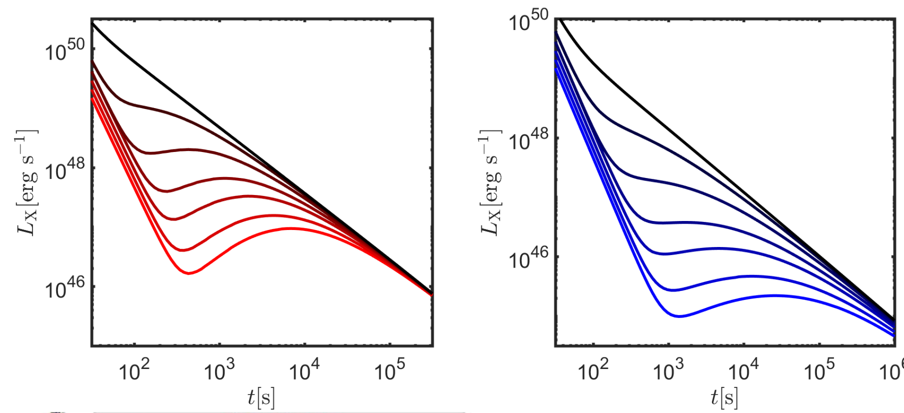
PROMPT TO AG TRANSITION

SVOM unique sample of ~30-40 GRB/yr with
- Prompt emission
  (4-5000 keV + V flux/limit: ~10-15 % of cases)
- Early afterglow(X/V/NIR)
- Long-term afterglow in many cases
- Redshift

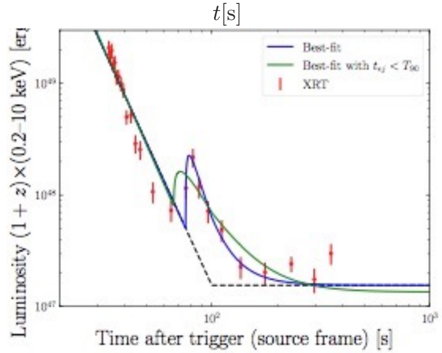
- **The case of plateaus and flares in X-rays**
  = SVOM MXT + EP FXT on long term?)
  SVOM bonus: simultaneous visible observations in more cases?
- **An example of a physical model with implications for the jet structure rather than the central engine activity: slightly off-axis structured jets**



A (aligned)   B (misaligned)



Beniamini et al. 20



Beniamini, Duque, Daigne, Mochkovitch

Duque et al. 22

GAMMA-RAY BURSTS PHYSICS

PROMPT+AG+REDSHIFT

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- Redshift

The sample of SVOM GRBs with a detailed characterization (prompt+afterglow+redshift) will allow to probe in details the physics of GRB ejecta.

Many physical diagnostics: **see E.W. Liang's, Z. Jin's and B.B. Zhang's talks this morning**

- **Prompt spectrum:** non-thermal/thermal ratio ; magnetization at large distance
  Tests of dissipation/acceleration/radiation models
- **Early afterglow:** Lorentz factor at the end of the prompt phase
  Magnetization at the end of the prompt phase (reverse shock)
- **Afterglow:** energetics, environment, opening angle/lateral structure
- **Prompt+afterglow+redshift:** prompt efficiency
  (see recent detections of on-axis orphan afterglows by ZTF, Ho, Perley et al. 22,24)
- **Local GRBs:** fraction of associated SN/KN, VHE emission
- **Host/environment:** GRB-star formation delay, progenitors, …
- Etc.

SVOM sample should make it possible to perform such diagnostics on GRBs belonging to many sub-classes of GRBs and should help to develop a consistent physical picture of the whole population.

GAMMA-RAY BURSTS PHYSICS

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Main challenge: follow-up!

- **SVOM instruments (MXT/VT/GWAC/GFTs): mostly the early afterglow**
- **Also needed: long-term afterglow**
  - X-rays, visible + radio is also important!
  - spectroscopic redshift
  - deep photometry: search for KN/SN associations
  - host galaxy/environment

GAMMA-RAY BURSTS PHYSICS

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Main challenge: follow-up!
- **SVOM instruments (MXT/VT/GWAC/GFTs): mostly the early afterglow**
- **Also needed: long-term afterglow**
- **With luck: HE (Fermi-LAT) and/or VHE (HESS/MAGIC/LHAASO/CTA)**
- **With even more luck: GW association? Neutrino association?**
  See N. Leroy's talk
- **Even a few of these rare events are of the greatest interest.**
  For instance VHE data allow to much better constraints emission model
  See X. Wang's talk

GAMMA-RAY BURSTS PHYSICS

PROMPT+AG+REDSHIFT

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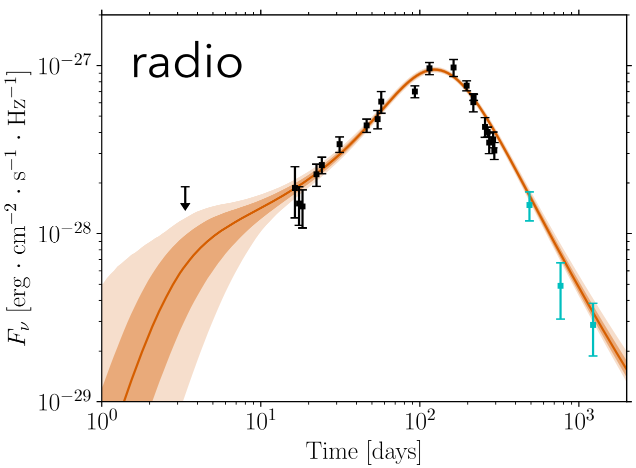
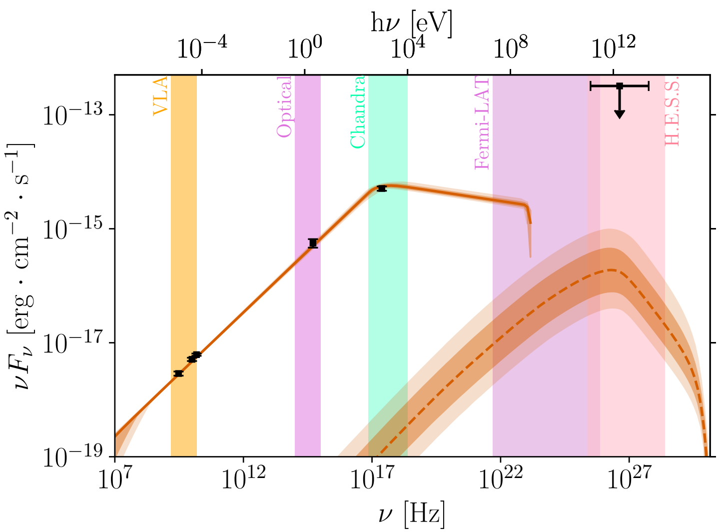
Many physical diagnostics

Example: 170817

spectrum at 110 days





VHE AG of 170817 becomes detectable by CTA above 100 Mpc for
- slightly less off-axis obs.
- higher external density (fast mergers?)

Pellouin & Daigne 24

SVOM will bring many new observations to explore the exciting physics of Gamma-Ray Bursts: let's wait for the first detections!