SVOM White Paper

SVOM ADVANCES ON GRB SCIENCE (*SVOM CORE PROGRAM)*

The population of classical long GRBs: physical mechanisms

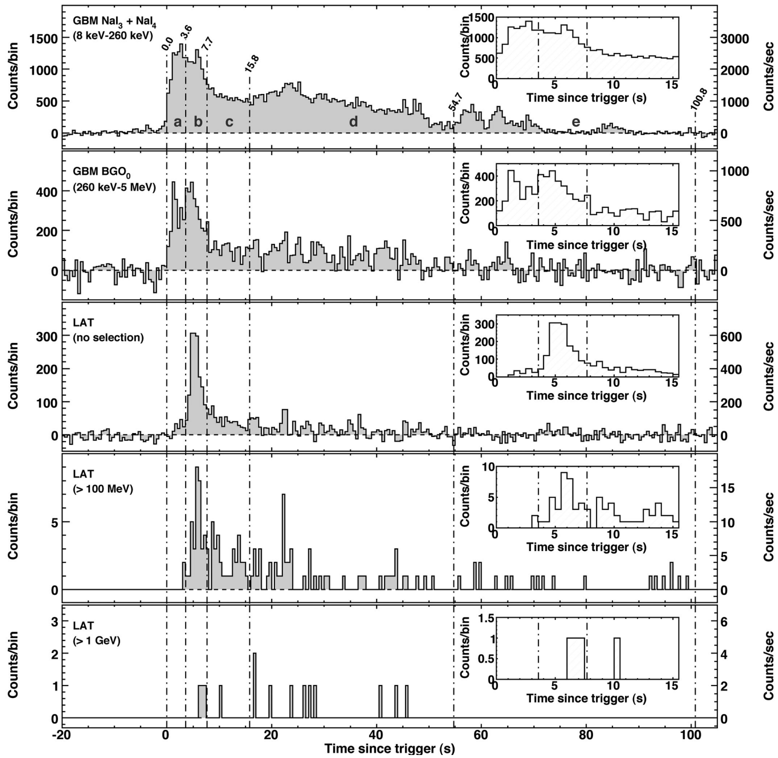
Frédéric Daigne (IAP) & Yongfeng Huang (Nanjing U.)

The diversity of stellar explosions

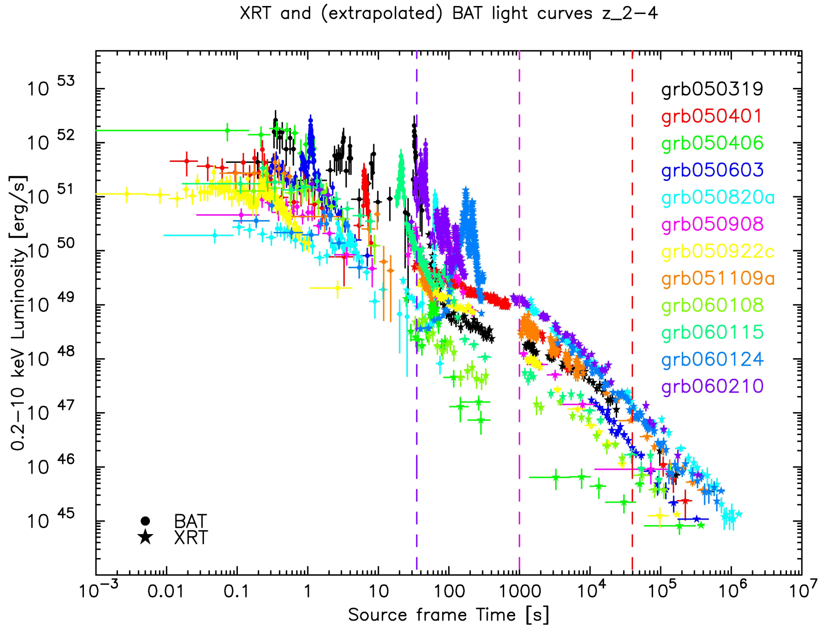
Robert Mochkovitch (IAP) & Bing Zhang (UNLV)

Context/Scientific issues

GRB observed emission

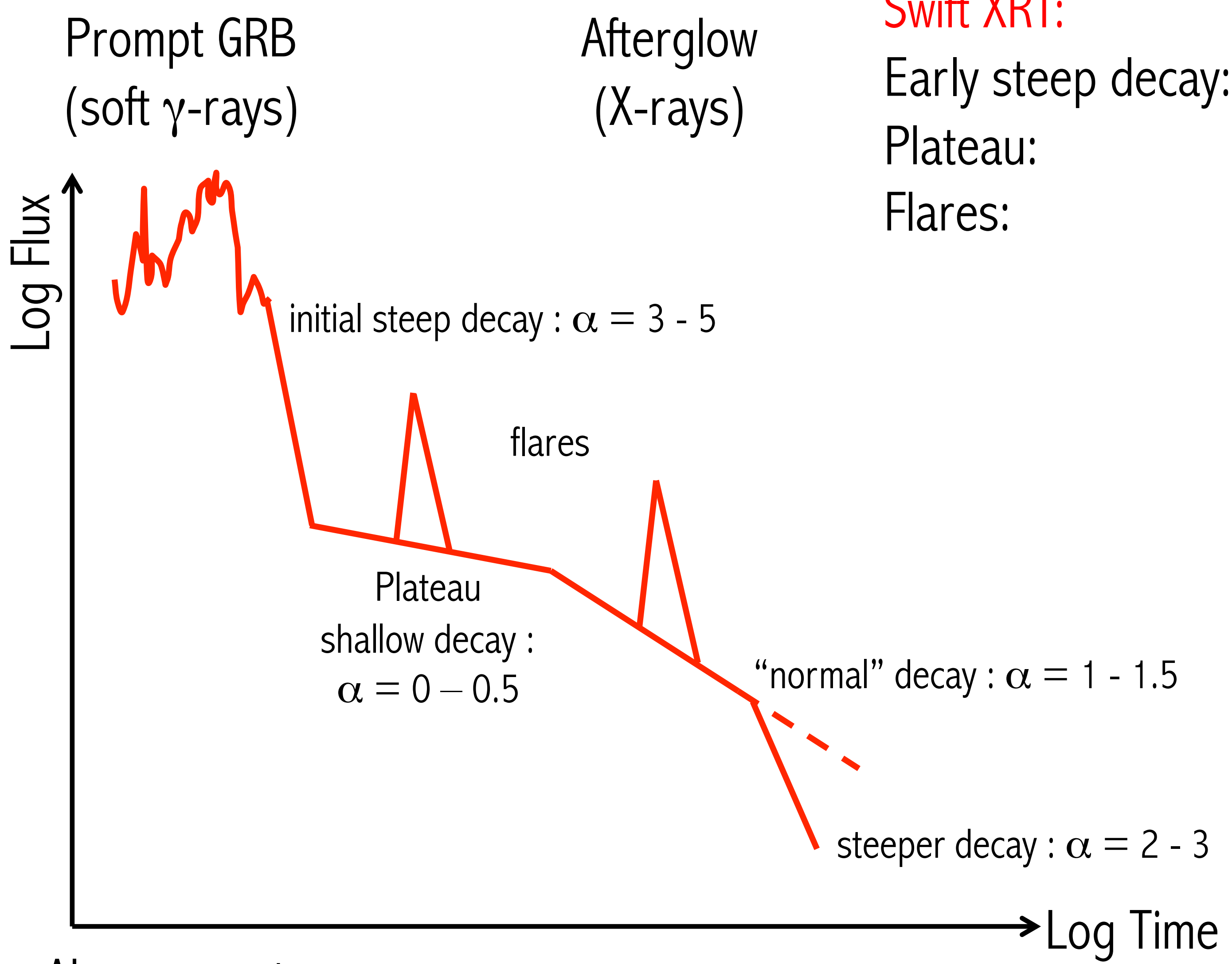


Prompt emission keV ➞ GeV (Fermi)



X-ray afterglow (Swift)

GRB observed emission: prompt+afterglow light curve



Swift XRT:

Early steep decay:	>90%
Plateau:	~60%
Flares:	~30%

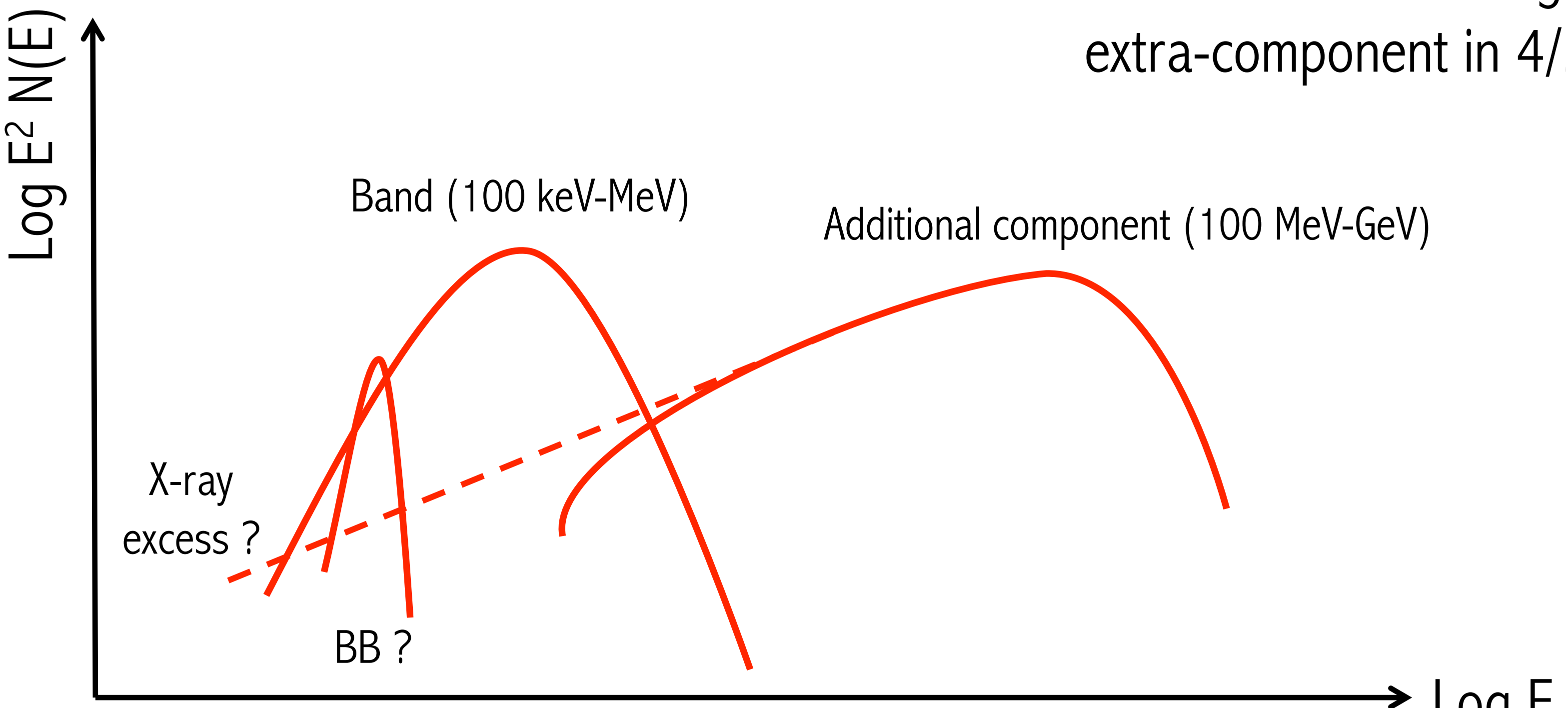
Also: prompt optical=very rare, >100 MeV=rare (LAT)

Also: optical, radio afterglow long-lasting Fermi/LAT emission

GRB observed emission: prompt spectrum

Fermi/GBM:
BB looked for in bright cases
& found in many cases

Fermi/LAT: 1st catalog
extra-component in 4/28



The physical origin of GRBs

Deceleration of the jet by the external medium

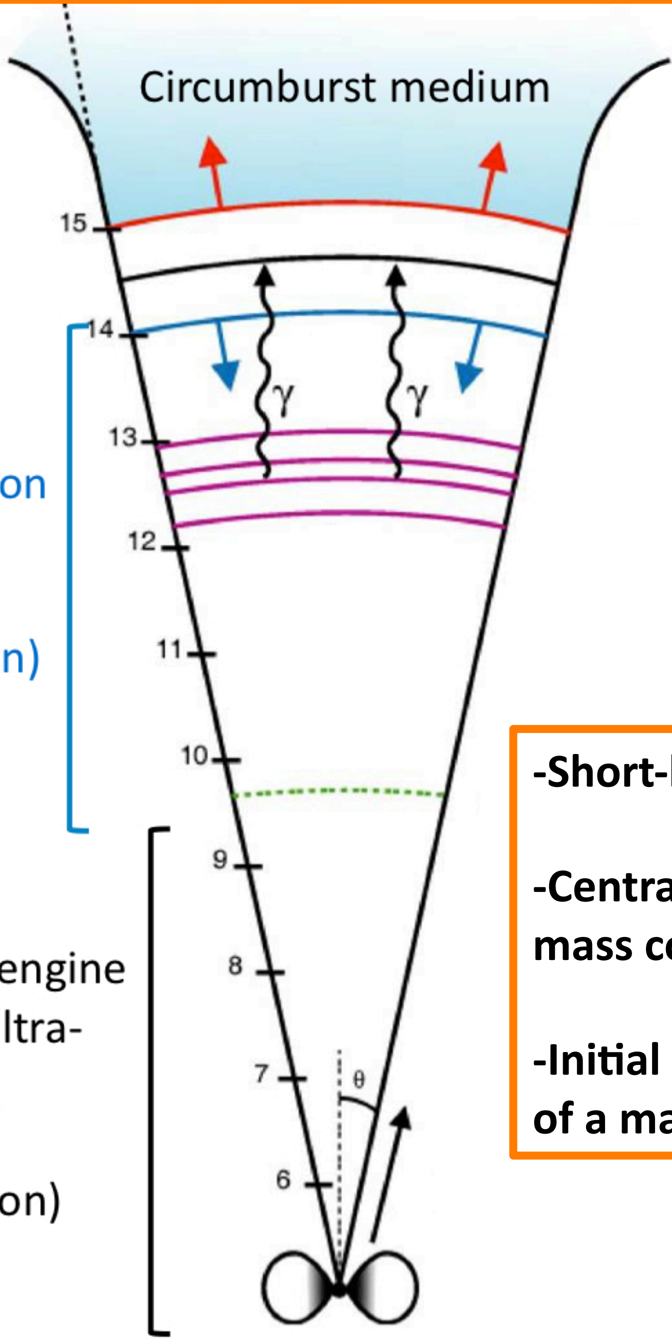
(afterglow emission)

Internal dissipation in the jet

(prompt emission)

Ejection by the central engine and acceleration to ultra-relativistic speed

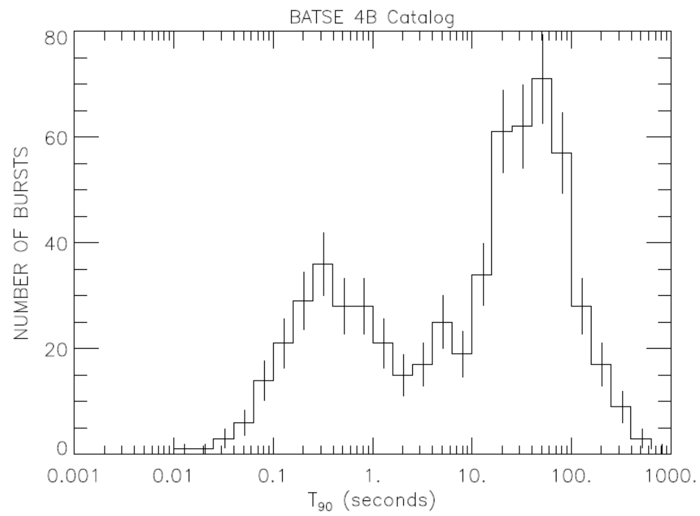
(no photonic emission)



- **-Short-lived ultra-relativistic ejecta**
- **-Central engine: newborn stellar-mass compact object**
- **-Initial event: gravitational collapse of a massive star or merger**

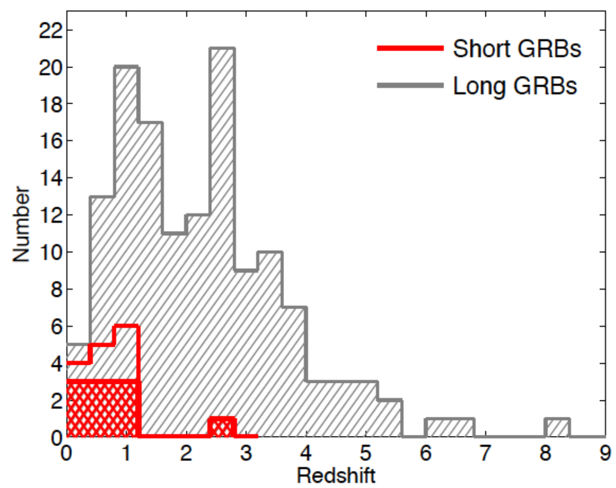
The nature of GRB progenitors and central engines
The different classes of GRBs

Short vs long GRBs : duration



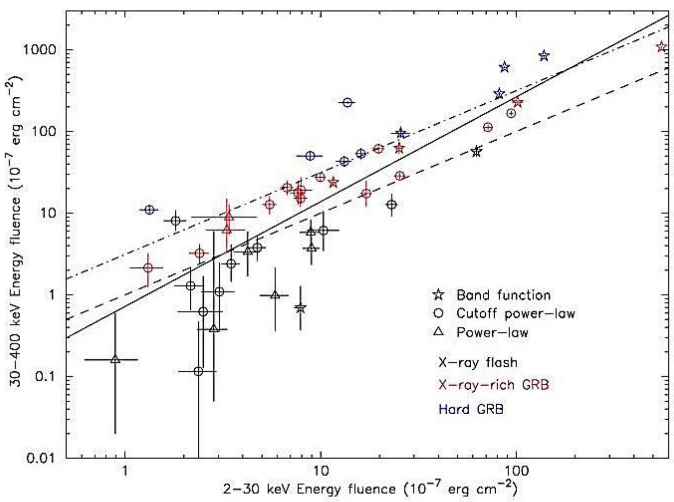
BATSE catalog

Short vs long GRBs : redshift



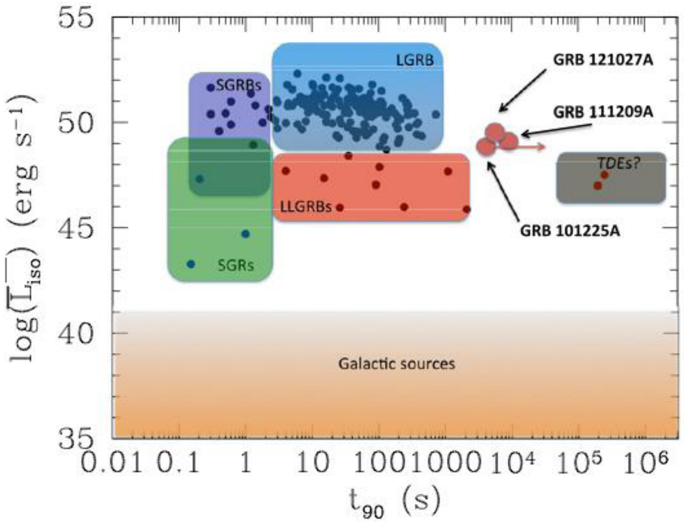
Berger et al. 2011

XRR and XRF (HETE2 catalog)



HETE2 catalog

More diversity: low-L, ultra-long, etc.



Levan et al. 2014

The nature of GRB progenitors and central engines
The different classes of GRBs

- **Long GRBs:** clear link with the end of life of some massive stars
  [star forming galaxies, afterglow in star-forming regions, SN-GRB associations]

  - Type Ibc SNae/classical GRBs ~ 10-100
    Type Ibc Snae/sub-luminous GRBs > 10
    (e.g. Soderberg et al. 2006, assume beaming factor ~100)
  - GRB/SN association: there are some exceptions (e.g. GRB 060614)
  - cosmic GRB rate does not follow cosmic SFR (e.g. Daigne et al. 2006)

  Which special conditions for the production of a GRB?
  Which conditions to have (or not) an associated SN?
  (mass? rotation? metallicity? binarity?)

  Continuum of explosive events
  from classical SNae to classical long GRBs?

- **Short GRBs:**
  observations point towards a different class of progenitors = mergers?

The nature of GRB progenitors and central engines
The different classes of GRBs

- **How to investigate the nature of long GRB progenitors?**
  - Search for SN (low-z)
  - Properties of host galaxy (evolution with z ?)
  - Circum burst medium
  - Non-photonic emission (neutrinos, GW)

  - Good statistical description of the whole population (including soft, low-luminosity, ultra-long, …)

  - **Needs:** **- a sample of GRBs of all classes**
    - with a rapid and accurate localization
    - a rapid follow-up: z, high-resolution afterglow spectrum
    [fraction with z as high as possible to reduce a complex bias]
    - once the afterglow has faded: host galaxy

    - capacity to search counterparts to neutrino/GW alerts

Acceleration and composition of the relativistic ejecta
Physical origin of the prompt emission

- **Many questions:** -energy content (thermal/kinetic/magnetic)
  -dissipation region (photosphere/shocks/reconnection)
  -particle acceleration/radiative processes

- **Answering (even partially) to these questions can help to**
  - understand the physics of ultra-relativistic outflows
  - constrain the relativistic ejection mechanism
  -constrain the nature of the central engine
  (and then the nature of the progenitors)

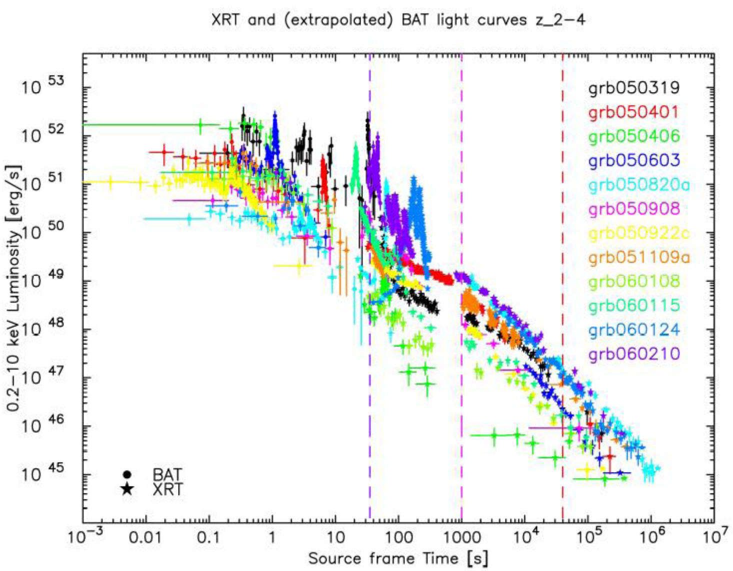
- **Recent progress:**
  - from Fermi, we know that the spectrum is complex
  See M.G. Bernardini's talk yesterday
  - from Swift, we know that the prompt to afterglow transition is complex
  - the prompt emission at low frequency (optical) is poorly known.

- **Needs:** **- a sample of GRBs with**
  - redshift (energetics)
  - good temporal and spectral coverage of the prompt emission (optical to gamma-rays)
  - good description of the early afterglow

  - extend to GeV/TeV? Polarization? HE neutrinos?

Interaction of the ejecta with the circumburst medium
Physical origin of the afterglow

- **Many questions:**
  -unexpected diversity/variability revealed by Swift
  -dissipation region : FS/RS/late IS ?
  -constraints on central engine (energetics? Lifetime?)
  -interaction prompt/afterglow ?



Sub-sample of XRT lightcurves

- **Needs:**
  - a sample of GRBs with
  - redshift (energetics)
  - good temporal and spectral coverage of the afterglow emission (following immediately the prompt emission)
  - good description of the prompt emission

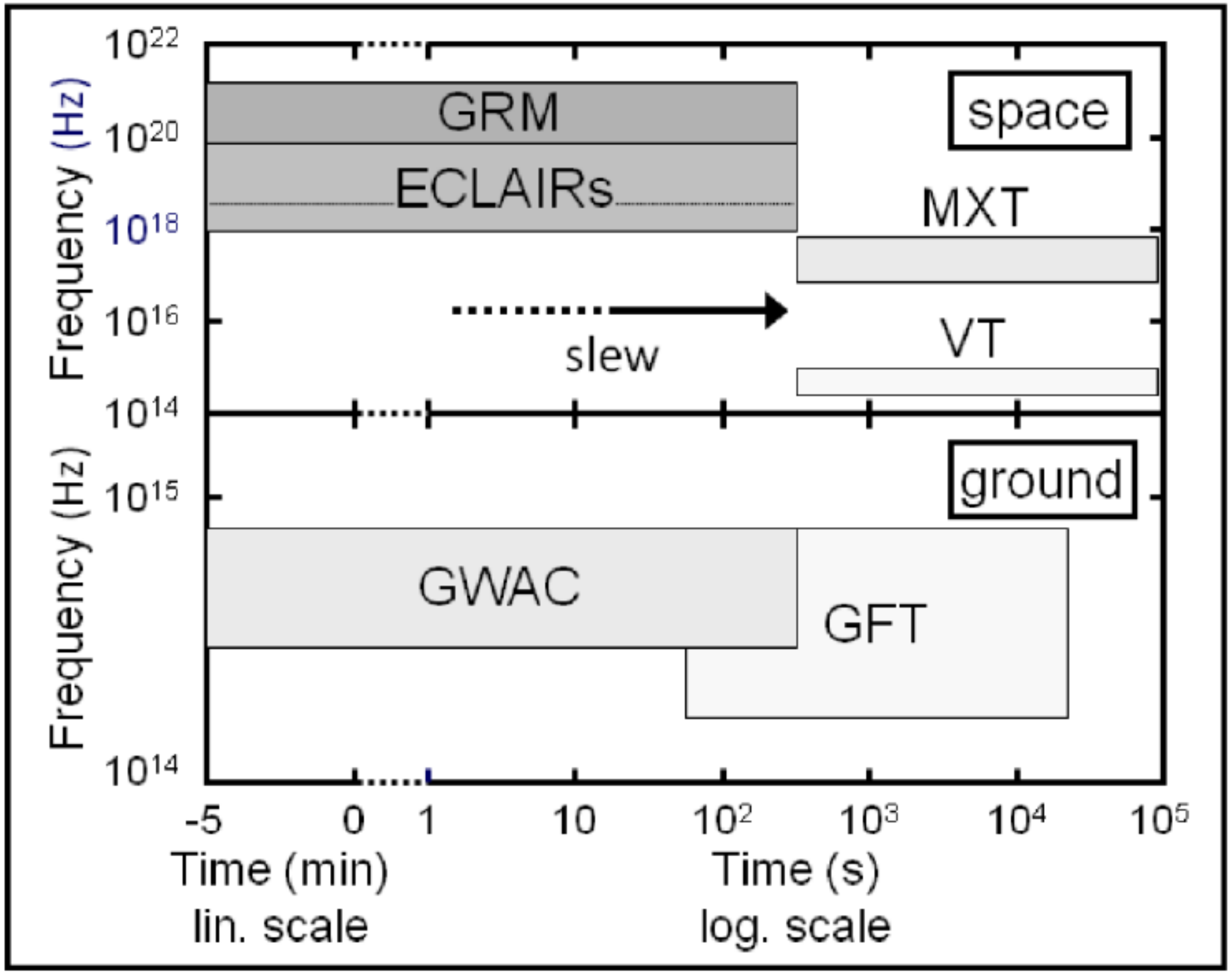
Summary

- **What is the nature of GRB progenitors and central engines?**
- **What is the origin of the GRB diversity?**
- **Physics of the relativistic outflow:**
  -composition?
  -dissipation process?
  -radiation mechanisms?
- **Interaction of the ejecta with the environment:**
  -prompt-to-afterglow transition?
  -emission regions?
  -nature of the circumburst medium?
  -ejecta geometry? True energetics?

Contributions of SVOM

We need a sample of GRBs:
-With a good spectral and temporal coverage
of the prompt AND afterglow emission (later: host)
-With a redshift measurement
-Describing the whole GRB diversity

Temporal and spectral coverage / redshift

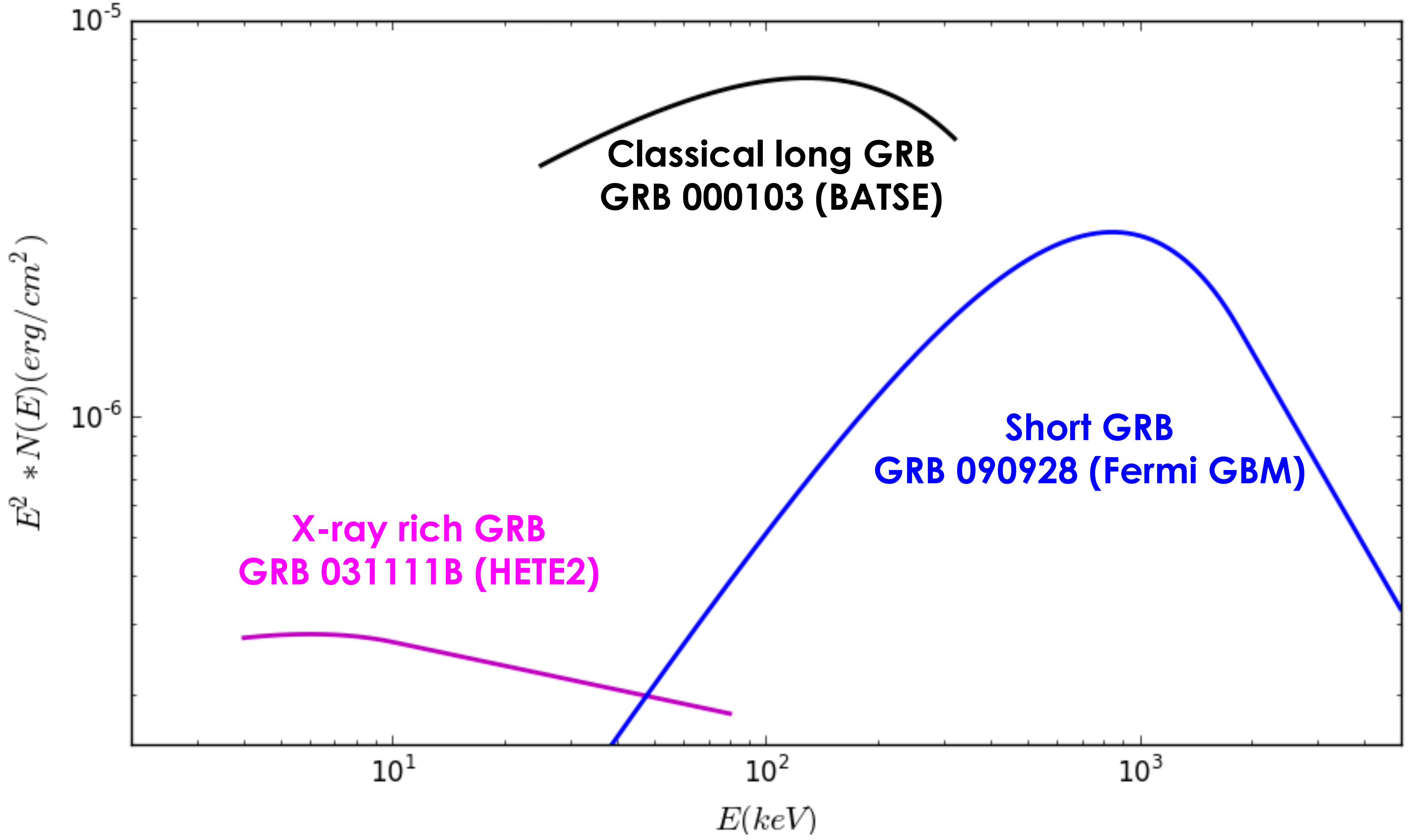


- Prompt: ECLAIRs+GRM=spectral measurement *(cf. M.G. Bernardini's talk)*
  GWAC = prompt optical emission
- Afterglow : pointing law+MXT+VT+GFT
  = optimized follow-up & high efficiency in z measurement

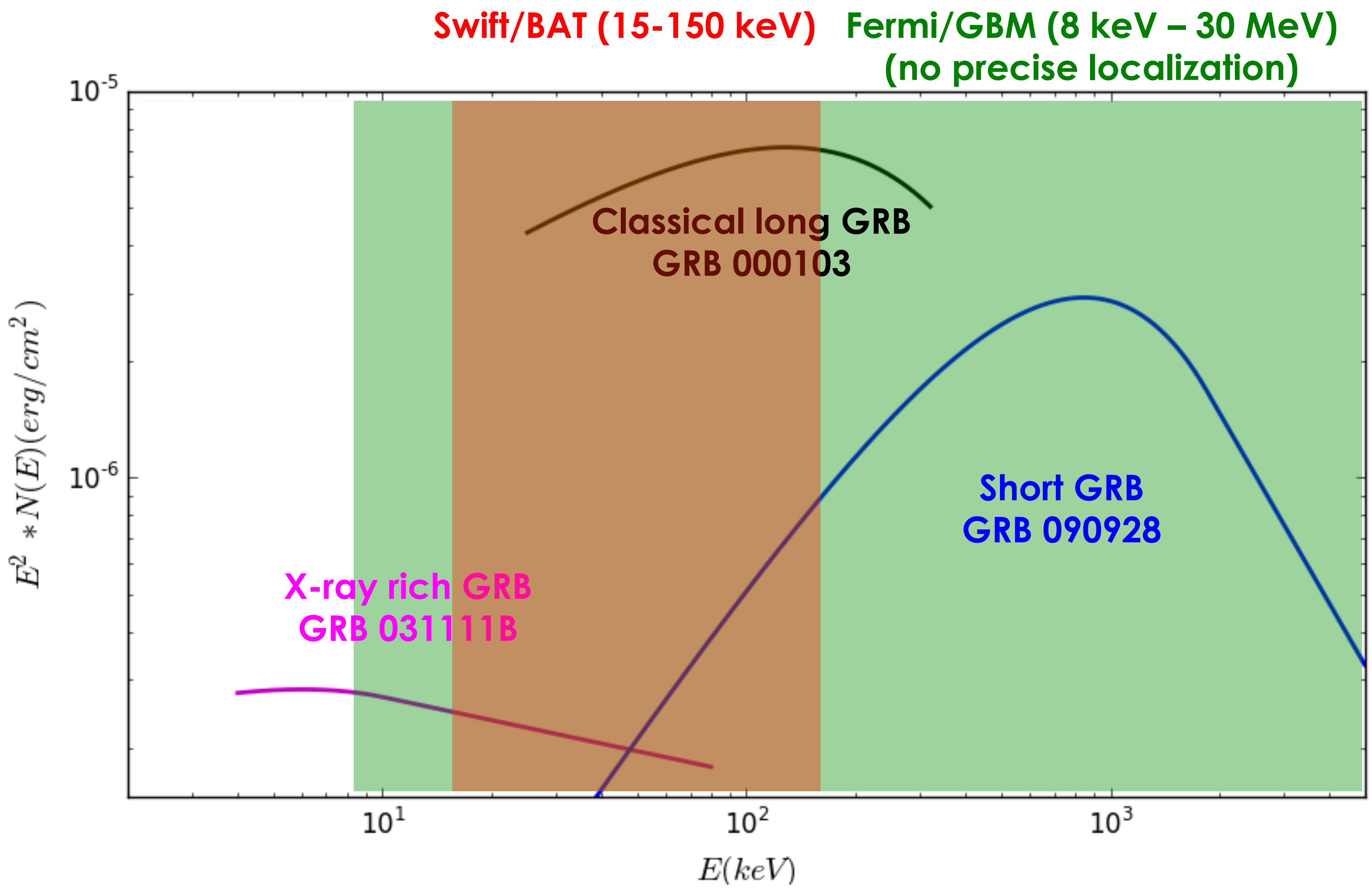
Exploring the diversity of the GRB population

- ECLAIRs 4 keV threshold: XRF, XRR
- ECLAIRs imaging trigger capability: long/weak/soft GRBs
- ECLAIRs + GRM : better sensitivity to short GRBs / ECLAIRs: soft tail ?
- GWAC : explore the very poorly known prompt optical emission
- MXT+VT+GFT : fast detection of long/short GRB afterglows
- VT: good sensitivity to faint and soft events – allow the search for associated SN

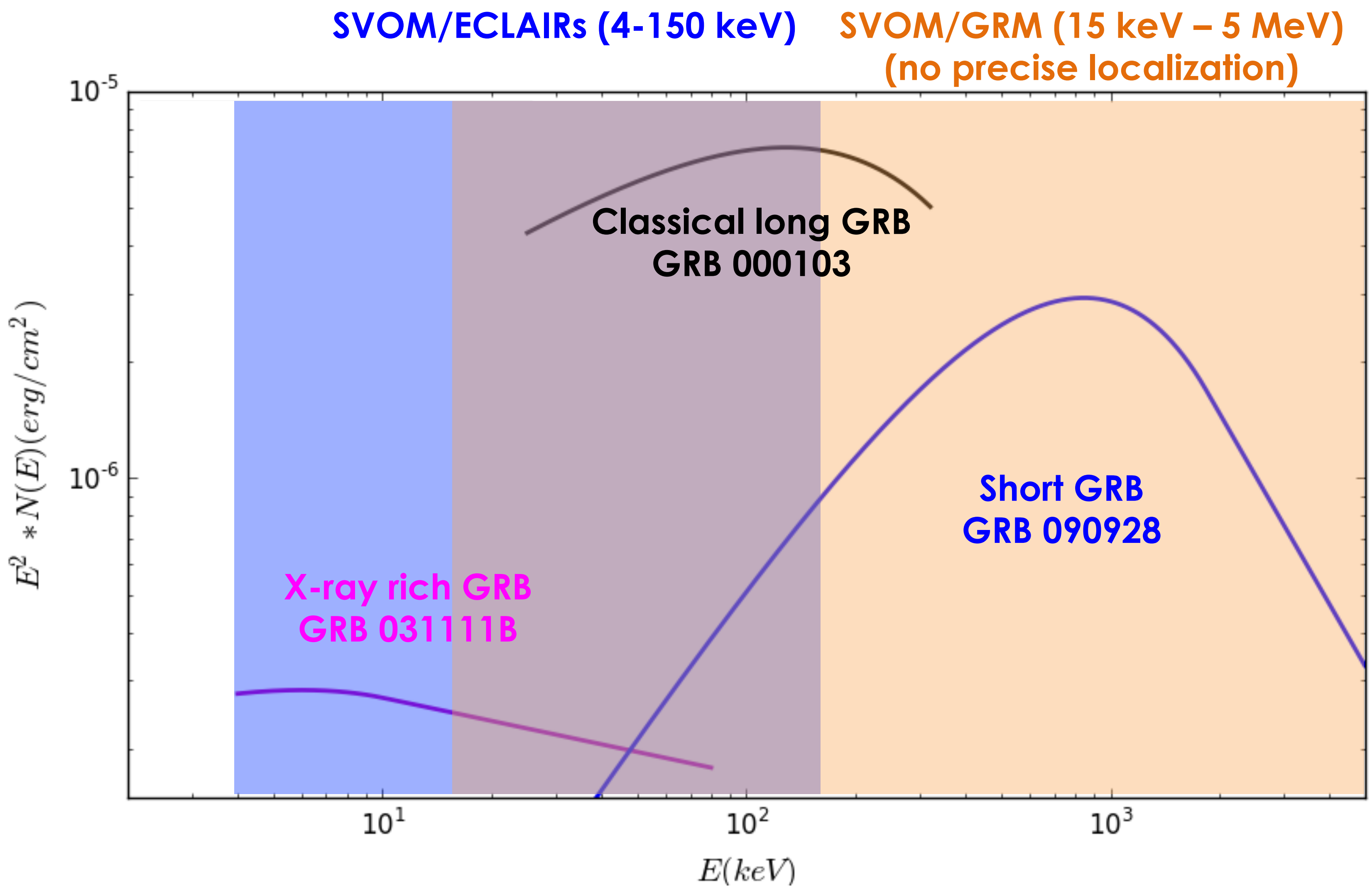
SVOM spectral coverage and GRB diversity



SVOM spectral coverage and GRB diversity



SVOM spectral coverage and GRB diversity



On-going studies

- ECLAIRs detection efficiency: check the capacity to explore the whole GRB population.

Sarah Antier's PhD work:

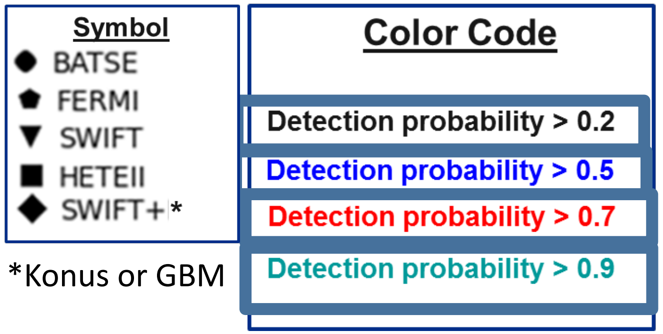
GRB catalog	size	C-Rate Trigger (%)	Image Trigger (%)	Detection efficiency ECLAIRS (%)
Batse	2030	73.0	61.1	73.6
HeteII	58	82.4	78.5	83.9
Fermi/GBM	783	75.6	67.7	76.3
Swift/BAT	391	70.12	71.85	76.56
Swift + Konus or GBM	84	79.5	80.3	81.1

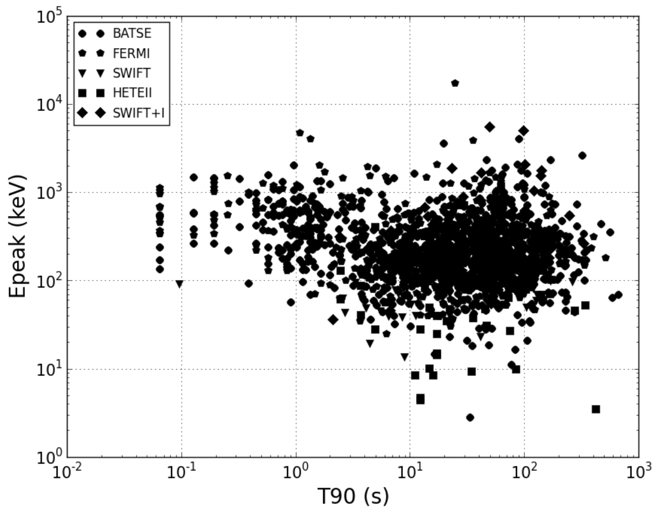
Still needs to be converted in trigger rates for ECLAIRs

On-going studies

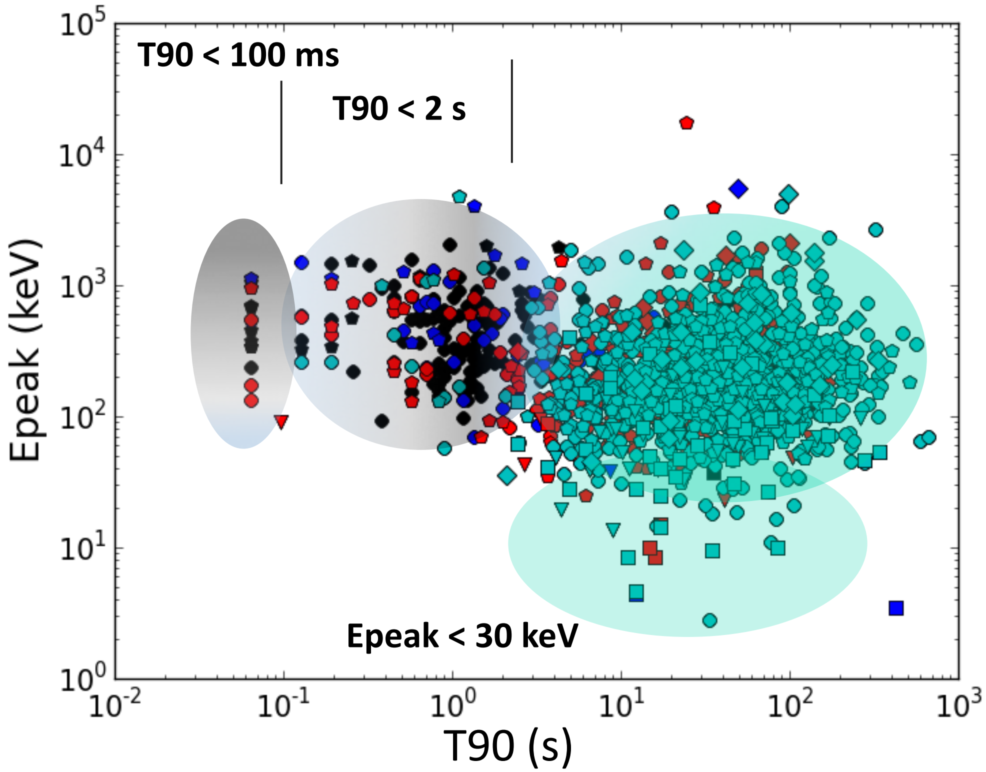
- ECLAIRs detection efficiency: check the capacity to explore the whole GRB population.

Sarah Antier's PhD work:





Input catalogs



On-going studies

- ECLAIRs detection efficiency:
  - -check the capacity to explore the whole GRB population: yes!
  - -still needs to be converted in trigger rates for ECLAIRs: in progress

  S. Antier's PhD work

- Propagation to other SVOM instruments:
  - -ECLAIRs + GRM : *see M.G. Bernardini's talk*
  - -GWAC?
  - -MXT, VT,GFT ?

  (GWAC, MXT, VT, GFT) Present: estimates independent of ECLAIRs trigger

Based on existing catalogs (« garanteed GRBs ») but another approach will also be applied
(population models, *J. Palmerio's PhD work at IAP*, still at early stage)

- Simulations of GRBs: capacity to measure light curve, spectrum, etc.
  - - first simulations ECLAIRs + GRM at LUPM
  - - needs to improve the instrument models

White Paper: discussion

WHITE PAPER : SVOM ADVANCES ON GRB SCIENCE

SVOM ADVANCES ON GRB SCIENCE (*SVOM CORE PROGRAM*)

The population of classical long GRBs: physical mechanisms	F. Daigne	Y.F. Huang
The population of classical long GRBs: characterization of the population	S. Vergani	E.W. Liang / Y.W. Yu
The population of short GRBs (includes the synergy with GWs)	J. Osborne	G. He / L.X. Li
The diversity of stellar explosions (soft GRBs, ultra-soft GRBs, sub luminous GRBs, etc.)	R. Mochkovitch	B. Zhang
GRBs as particle accelerator (link with CR and neutrinos)	D. Dornic	Z. Li / X.Y. Wang
GRBs at high redshift	S. Basa	E.W. Liang / X.F. Wu
GRBs to study the evolution of star formation	S. Boissier	F.Y. Wang
GRBs to study galaxies	E. le Floch	Y. Li ??
Absorption spectroscopy on the line of sight of GRBs (IGM reionization, etc.)	P. Petitjean	J. Wang
GRB as standard rulers	S. Basa	Z.G. Dai

WHITE PAPER : SVOM ADVANCES ON GRB SCIENCE

We need to clarify the frontiers between different chapters:

- **Two chapters focus on classical long GRBs, with two different approaches:**
  - **The population of classical long GRBs: physical mechanism**
    [-progenitors/central engine]
    -physics of the relativistic outflow
    -constraints from lightcurves, spectra, … *This talk*
  - **The population of classical long GRBs: characterization of the population**
    -progenitors/central engine
    [-physics of the relativistic outflow]
    -constraints from luminosity function/comoving rate/host galaxies/etc.
    See talk by S. Vergani

- **Two chapters explore the diversity of the GRB population**
  - **The population of short GRBs**
    - Short GRBs
    - Link with GW *See talk by J. Osborne*
  - **The diversity of stellar explosions**
    -Discuss the diversity of long GRBs
    (diversity in luminosity, temporal and spectral properties) *This talk*

We probably also need a header for the whole chapter on GRB science.

The population of classical long GRBs: physical mechanisms (Daigne/Huang)

- **Context:**
  - **progenitors/central engine of classical long GRBs**

    Collapsar → accreting BH → ultra-relativistic jet escapes the star

    Alternatives (e.g. magnetars)?

    Quantify GRB-SN association
  - **jet physics: composition/dissipation mechanism/emission**

    Photosphere+shocks/reconnection? Magnetization?
    Dissipative photosphere?
  - **interaction with circumburst medium**

    Nature of the environment
    Emission regions? Origin of the afterglow diversity/variability?

- **SVOM contribution: a sample of long GRBs with well measured properties**
  - **good temporal/spectral coverage prompt+afterglow**
  - **redshift**

The diversity of stellar explosions (Mochkovitch/Zhang)

Context

GRBs exhibit a great diversity in **luminosity**, **temporal** and **spectral** properties

- wide range of isotropic luminosity: from 10^{47} (under-luminous GRBs) to 10^{54} $erg.s^{-1}$
- ultra-short / short / long / ultra-long
  a few ms   0.1 – 2 s   2 – 100 s   100 – 1000 s
- smooth / highly variable light curve
- X-ray Flashes / X-ray rich GRBs / regular GRBs
  $E_p < 30$ keV $30 < E_p < 50$ keV $E_p > 50$ keV
- prompt optical emission
  (un)correlated to prompt gamma-rays
  bright (naked eye burst) or dim

→ A diversity of progenitors, of dissipation mechanisms, of radiation processes ?

The diversity of stellar explosions (Mochkovitch/Zhang)

Scientific issues

Progenitors

long/short GRBs: collapsars/compact objects mergers

What else ? blue supergiants for ultra-long GRBs ?
unsuccessful chocked jets for under-luminous GRBs ?

Dissipation mechanisms

Where? above/below the photosphere
How ?   shocks/magnetic reconnection/np collisions
Same for all GRBs?

Radiation processes

Synchrotron + IC ?
Comptonization at the photosphere ?
Same for all GRBs?

GRB diversity: a source of complexity

but can also provide clues to decipher the mechanisms at work during the prompt phase

The diversity of stellar explosions (Mochkovitch/Zhang)

SVOM contributions

Spectral diversity

• X-ray rich GRBs and X-Ray Flashes
Swift and *Fermi* are not very efficient to detect XRR GRBs and XRFs
(poor prompt spectral coverage for *Swift*, trigger starting at 50 keV for *Fermi*)

→ **SVOM will obtain redshifts and a detailed spectral information on soft events**

• Prompt optical emission
just a bunch of events observed showing very diverse behaviors

→ **SVOM: moving from a case by case approach to population studies**

• Spectral components
Good coverage of the prompt spectrum with Fermi GBM
(thermal component, additional power law) but few redshifts

→ **SVOM will extend the prompt coverage to optical and provide redshifts**

Original new data for comparison to models (IS, reconnection, photospheric)
→ new constraints on dissipation mechanisms, radiation processes

The diversity of stellar explosions (Mochkovitch/Zhang)

SVOM contributions

<u>Temporal diversity</u>

• Short GRBs

SVOM will operate when advanced LIGO/Virgo will reach its full sensitivity

Simultaneous GW + GRB detection

→ confirmation of the merger scenario for short GRBs
→ the delay between the GW signal and the GRB can constrain the GRB mechanism
→ if GRB redshift is known, independent measure of H_0

• Ultra-long GRBs

Best observed in image mode

SVOM will offer a broad spectral coverage to study ultra-long GRBs

→ constrain the nature of the progenitors (BSG, magnetar?)

The diversity of stellar explosions (Mochkovitch/Zhang)

Conclusion

By offering a broad spectral coverage and localization on one single platform SVOM combines several of Swift and Fermi capabilities

… and offers new ones: continuous monitoring of ECLAIRs FOV in optical

SVOM is well designed to explore the GRB diversity and will fly timely when GW observatories and new facilities (e.g. NGST, LSST) will be fully operational