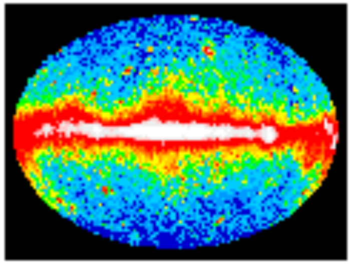
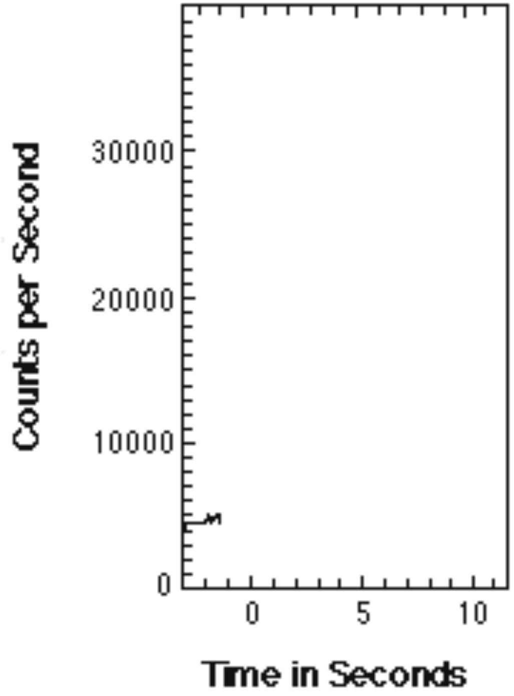
Cosmic gamma-ray bursts

Frédéric Daigne (Institut d'Astrophysique de Paris – Sorbonne Université)



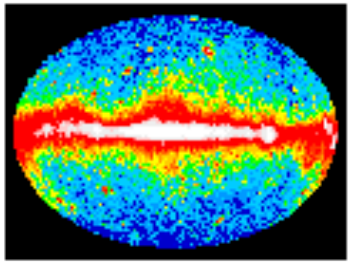


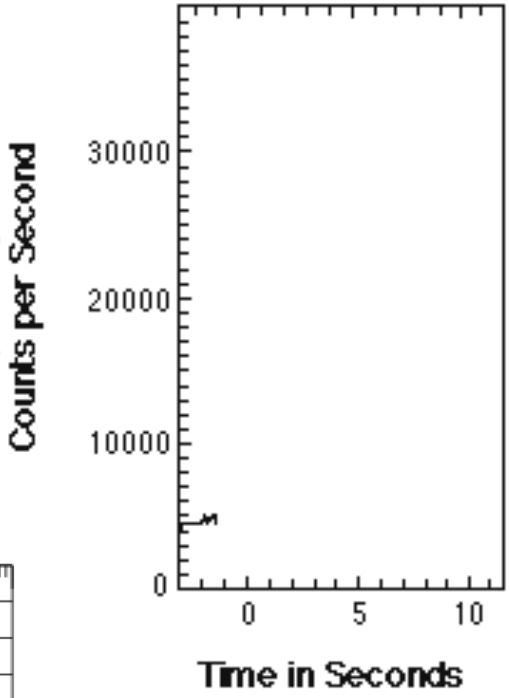
Journée THESEUS France – Paris – 23 septembre 2019

GRB observations

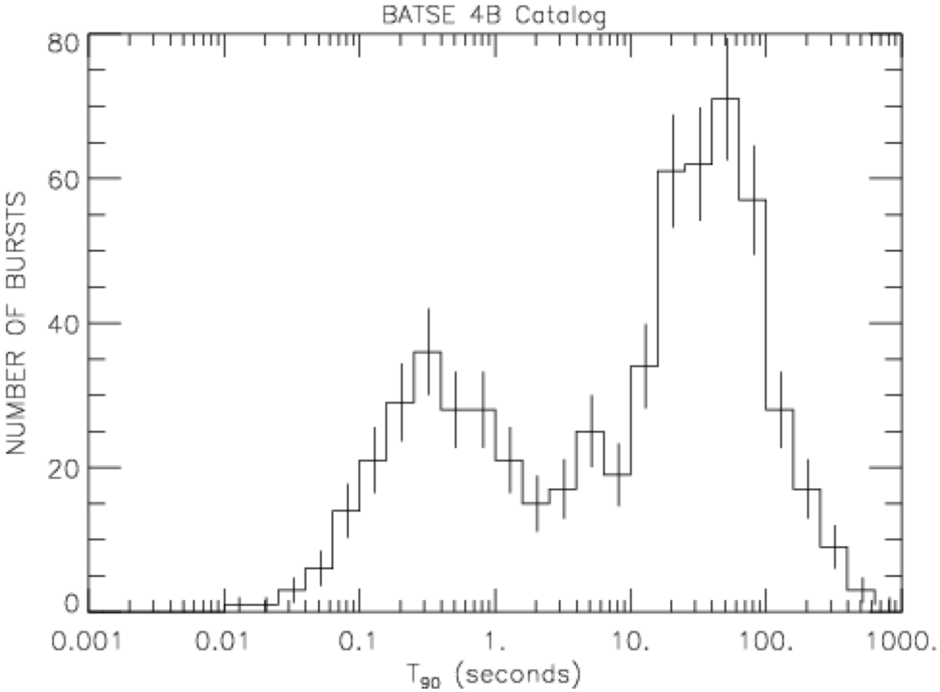
Gamma-ray bursts

- **Short duration:**
  a few ms to a few min





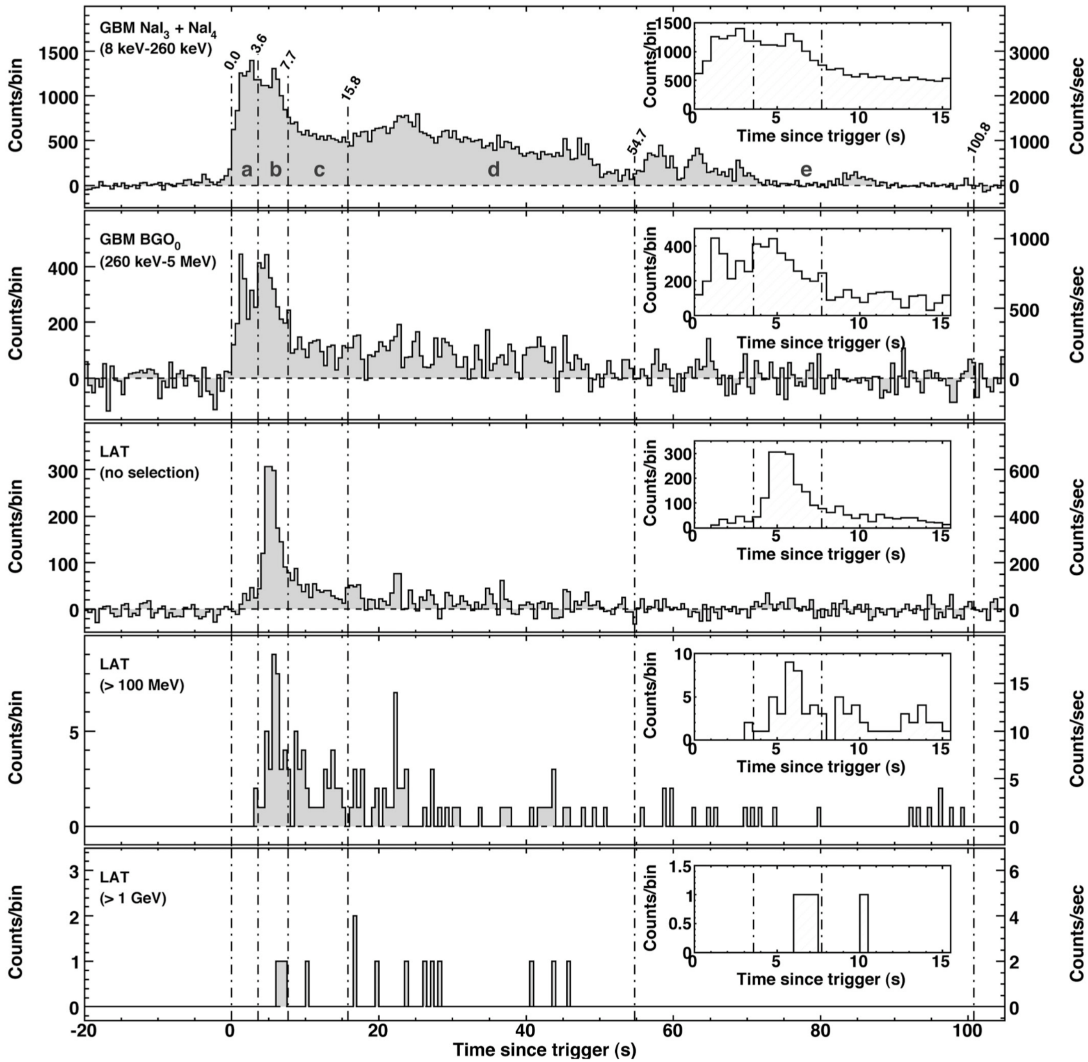
- **Two classes:**



- **Cosmological distance**

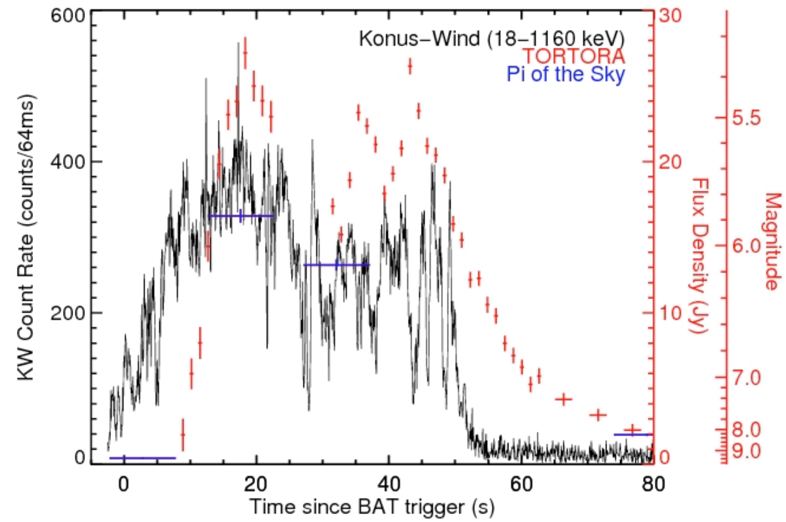
Gamma-ray bursts: prompt emission (opt. → GeV)

Fermi GBM+LAT



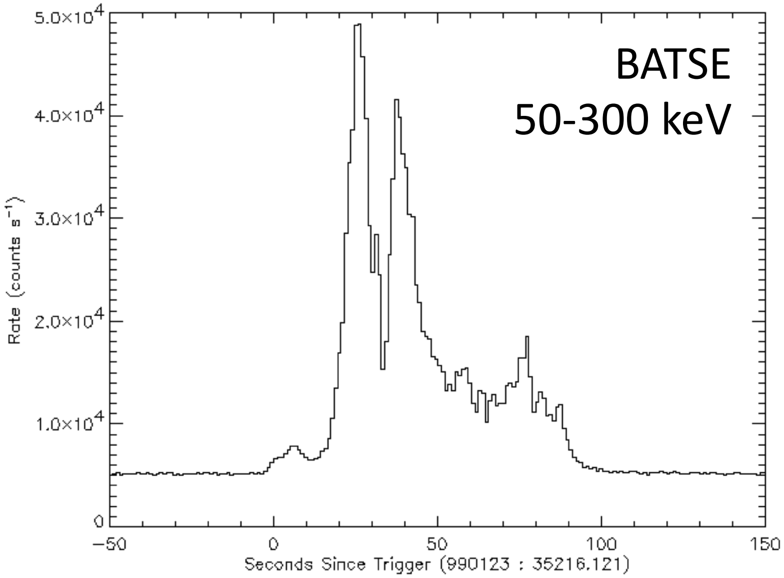
Abdo et al. 2009

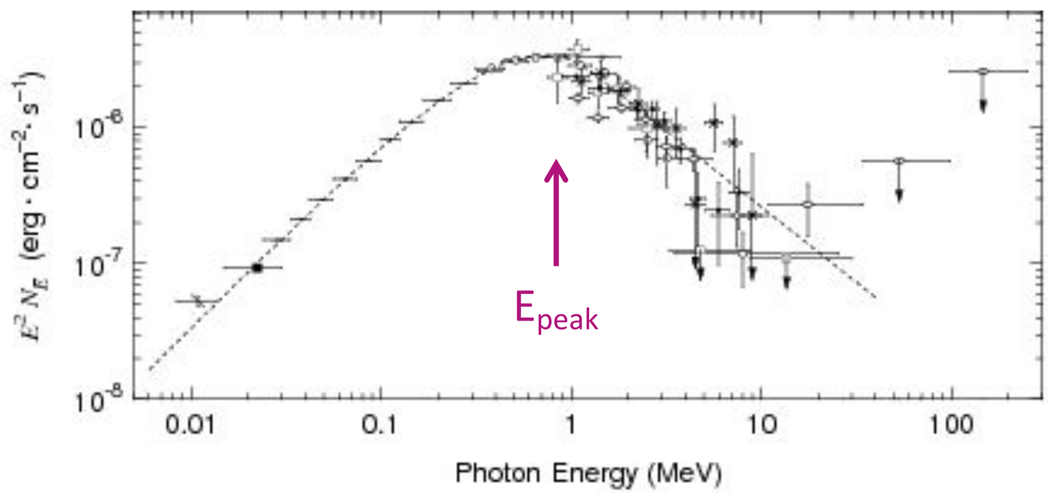
Swift+robotic



Racusin et al. 2008

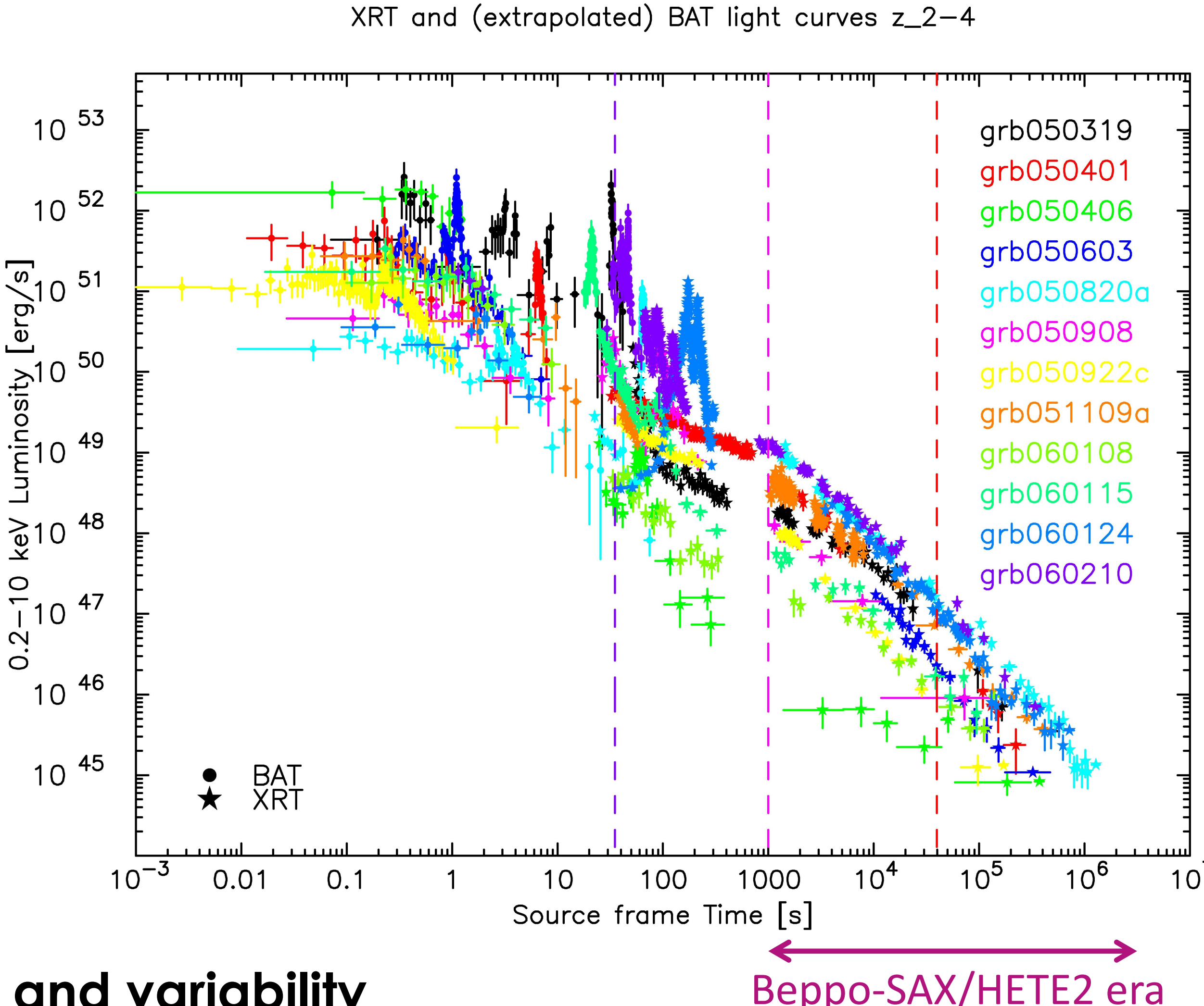
Gamma-ray bursts: prompt emission





- **Peak energy : 100 keV – 1 MeV**
- **Short timescale variability : ms → 100 ms**
- **Pulses : 100 ms → 10 ms**

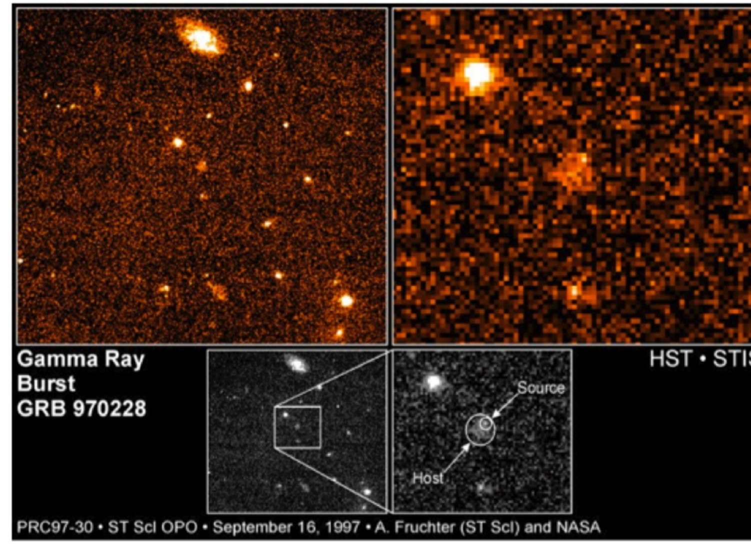
Gamma-ray bursts: afterglow (X, opt, radio)



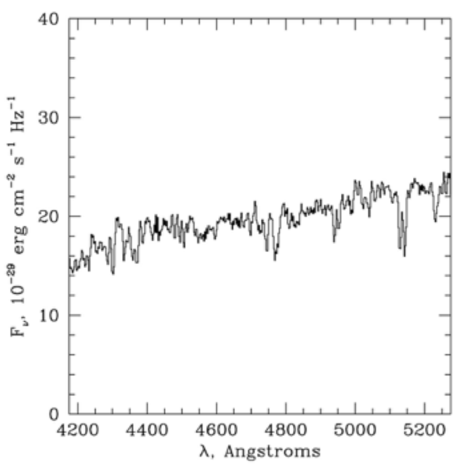
- **Diversity and variability**
- **Plateaus, flares, …**

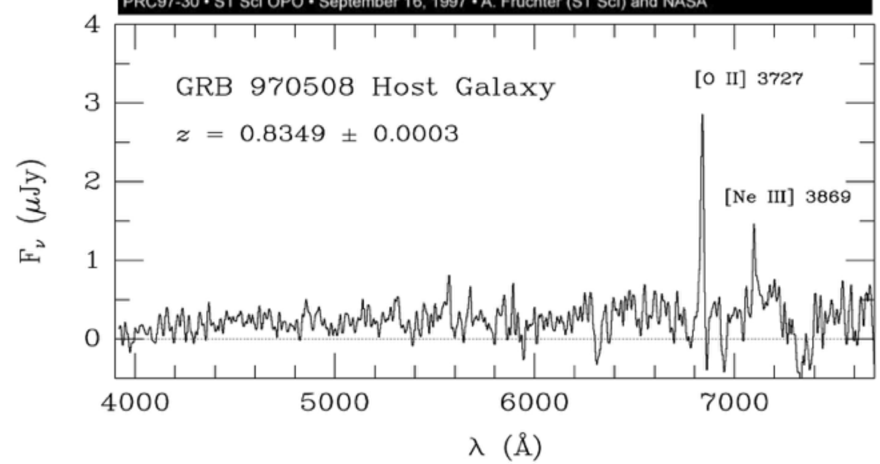
Gamma-ray bursts: redshift & host galaxy

- GRB 970228



- GRB 970508





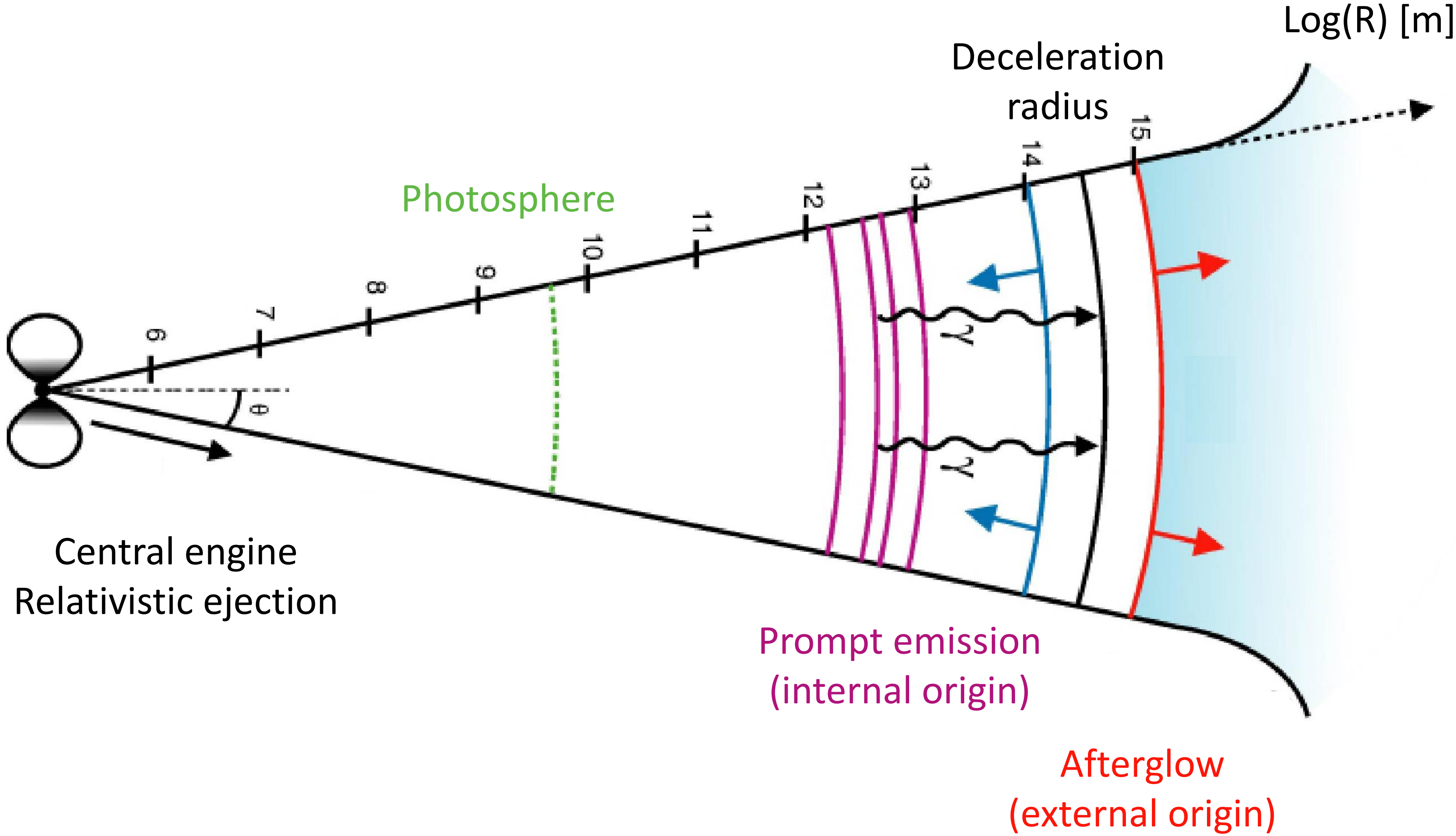
- Present: >400 GRBs with redshift

Maximum : GRB 090423 at z = 8.2
GRB 090429B at z = 9.3

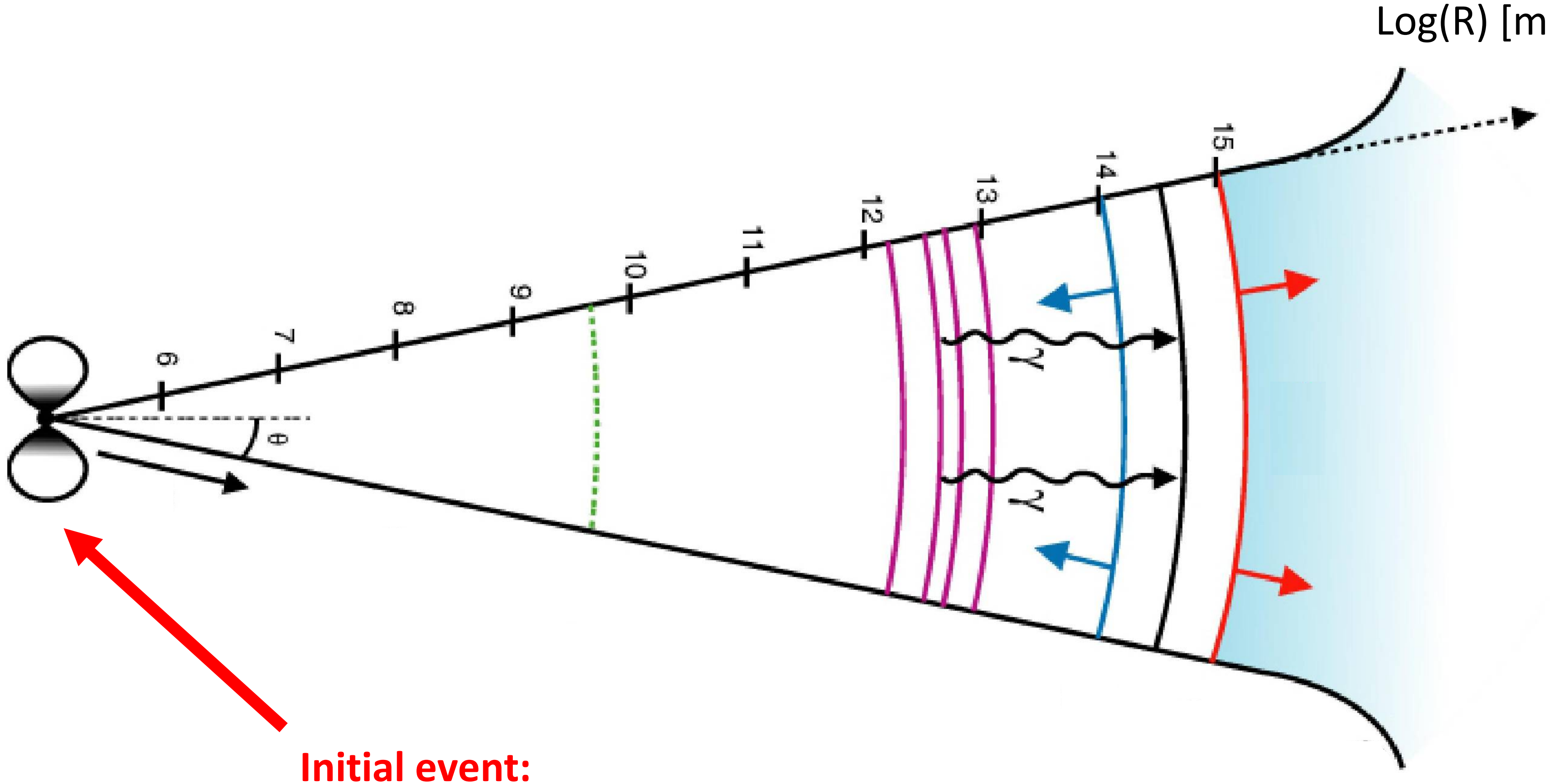
E_{iso} ~ 10^{51} to 10^{54} erg (some under-luminous ; some monsters…)

GRB Theory

Gamma-ray bursts : model(s ?)



Gamma-ray bursts : model(s ?)



Initial event:

- long GRBs = grav. collapse of some massive stars
- Short GRBs =NS+NS mergers (NSBH ?)

GRB Populations/Progenitors

GRB Populations/Progenitors: observations

- **Trigger = prompt GRB**

-different classes have different spectral properties
-possible hardness-luminosity correlation

Different GRB missions do not necessarily probe the same GRB populations

- Main identified populations: short vs long ; XRF/XRR/low-L ; ultra-long ; …

- **To identify the intrinsic populations and possibly the progenitors, a lot of observations are needed:**
  - prompt (good coverage of the spectrum)
  - afterglow (sometimes difficult: short GRBs, XRF/XRR, …)
  - redshift
  - host galaxy (a lot of information: see short vs long GRBs)
  - in some cases: MMA observations (e.g. short GRBs)

- **Probing all classes of GRBs in a efficient way is very demanding for a GRB mission**

- **It would be interesting to have other triggers (i.e. orphan science)**

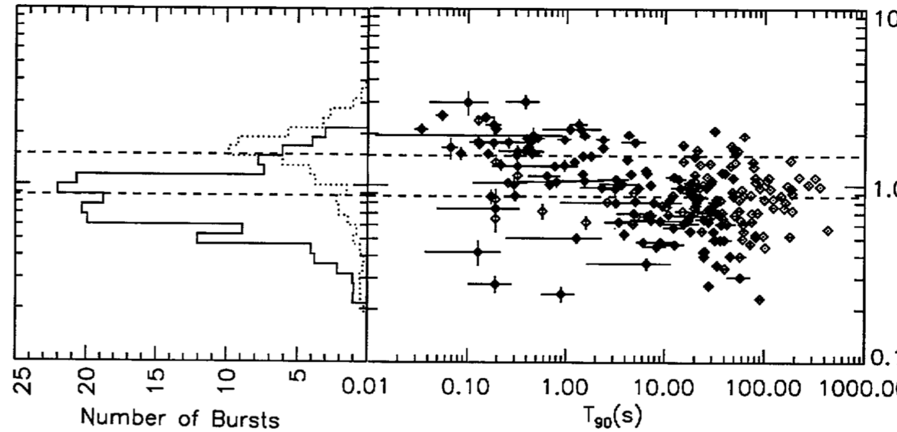
GRB Populations/Progenitors: theory

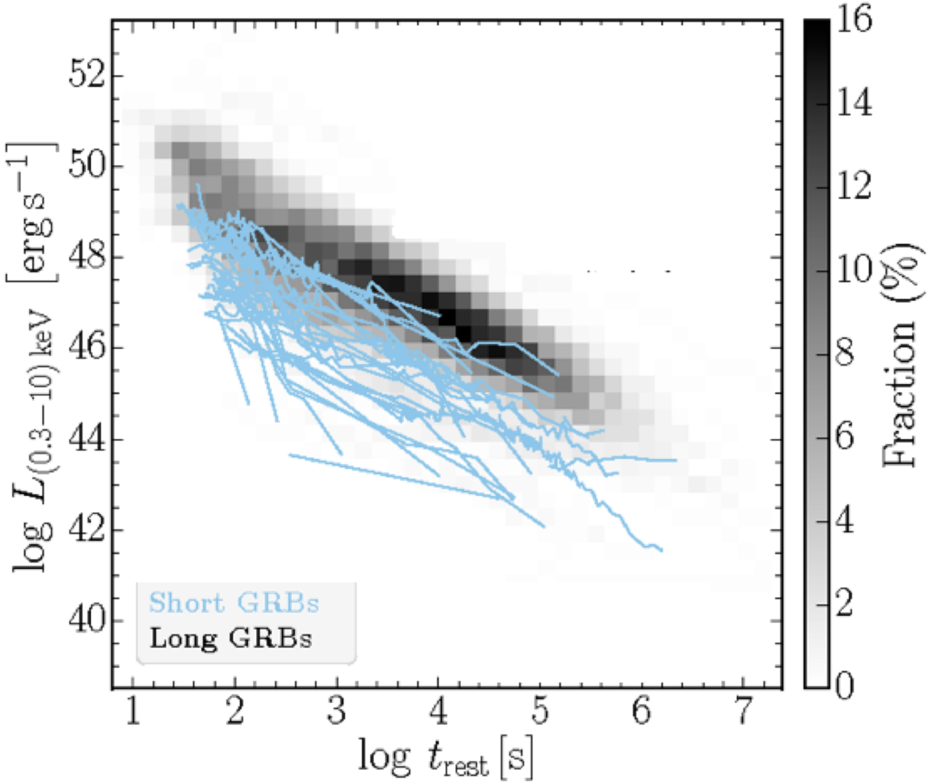
- Different progenitors may imply
  - different central engines (BH, magnetar, …)
  - different properties for the relativistic ejecta (geometry, energy, Lorentz factor, magnetization, …)
  - different circumburst environement

- **A fundamental question: is there a unique physical mechanism for the prompt+afterglow emission or is there also some diversity in the physics at work?**

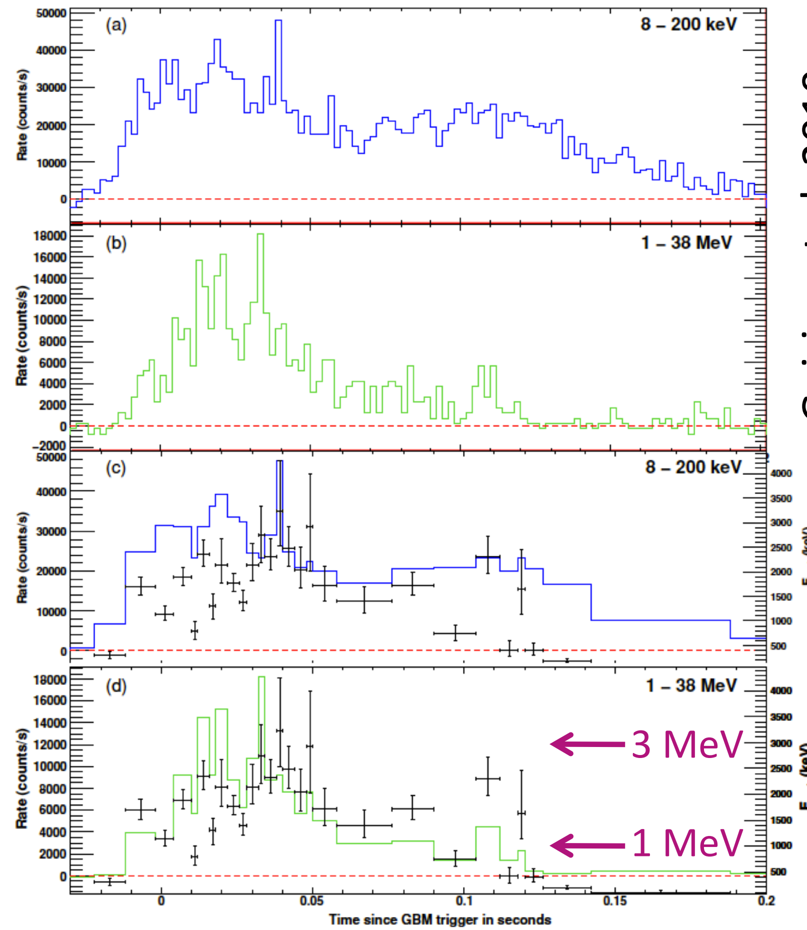
Example: short GRBs

- **Prompt**
  - hardness-duration correlation
  - large peak energies
- **Afterglow**
  - small sample
  - weaker / fast decay in many cases





Swift short GRB sample



Guiriec et al. 2010

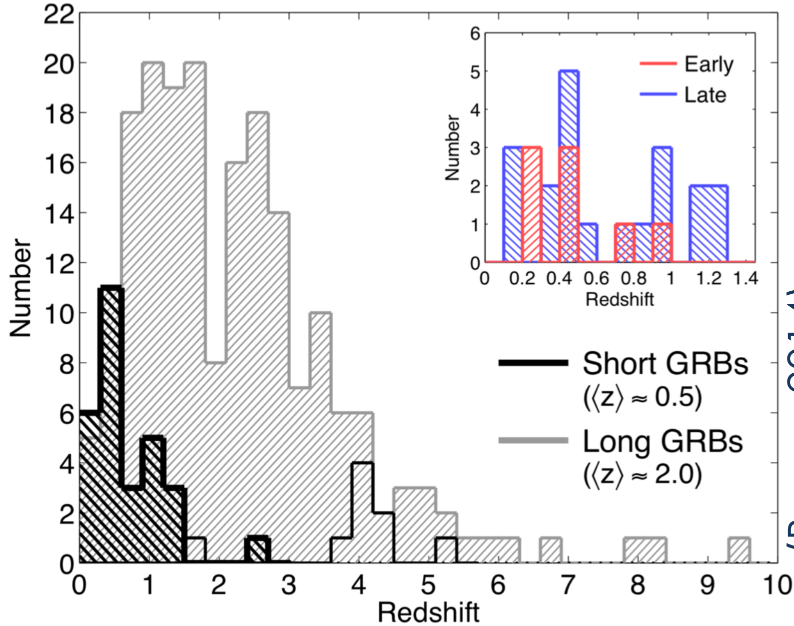
GRB 090227B (*Fermi*/GBM) T_{90} ~ 0.15 s

Example: short GRBs

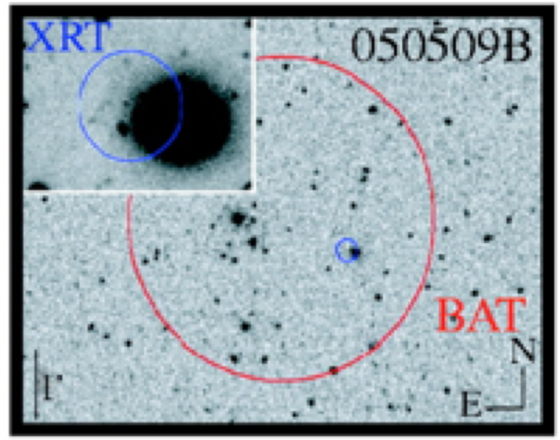
- **Host galaxies**
  - -all morphologies
  - -no correlation with star formation
  - -offsets

Long:
star forming host / SN association

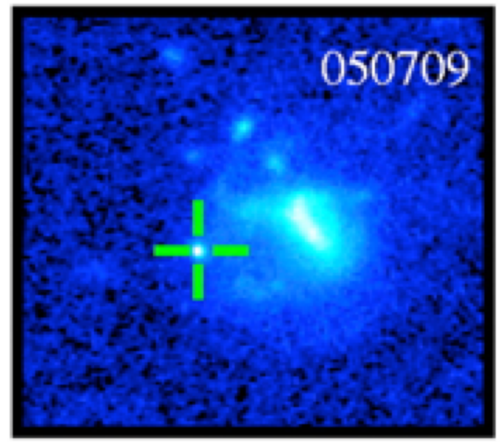
- **Redshift**



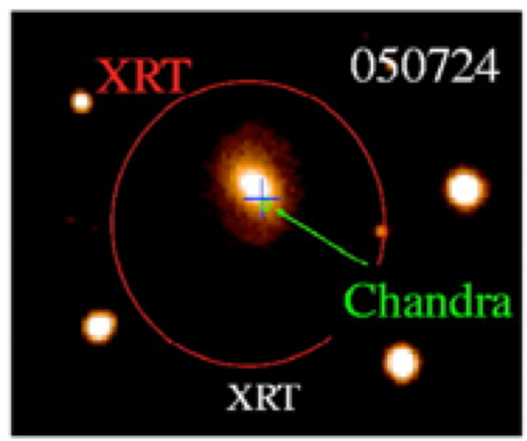
(Berger 2014)



cD elliptical
SFR < 0.2 $M_\odot\ yr^{-1}$
Swift



SF galaxy
with offset
HETE-2

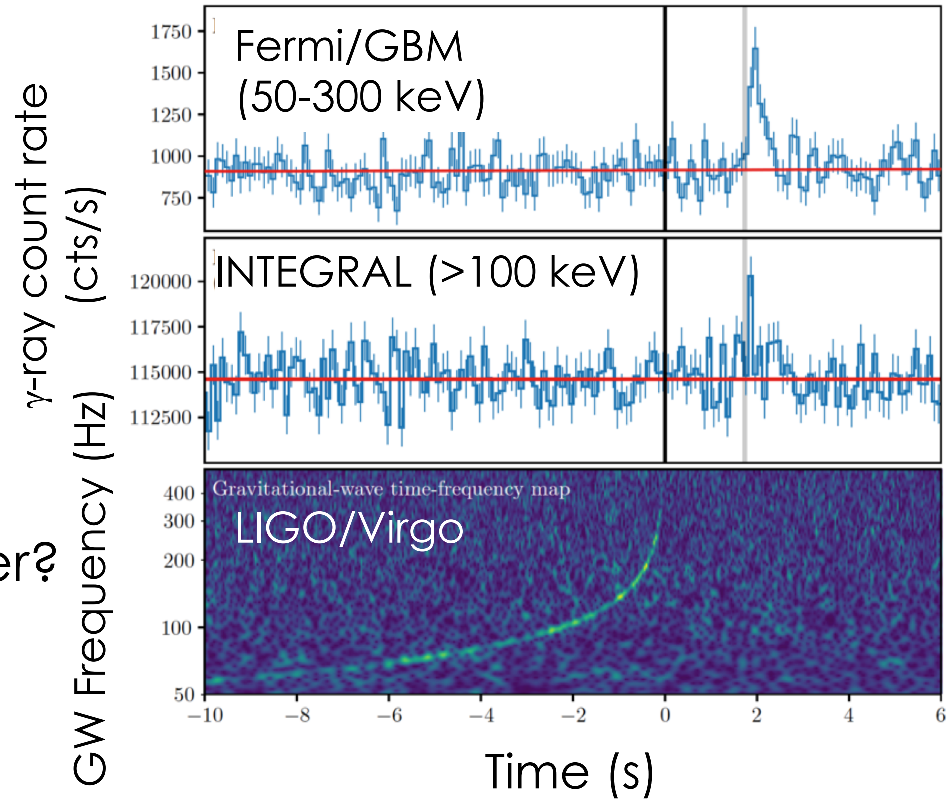


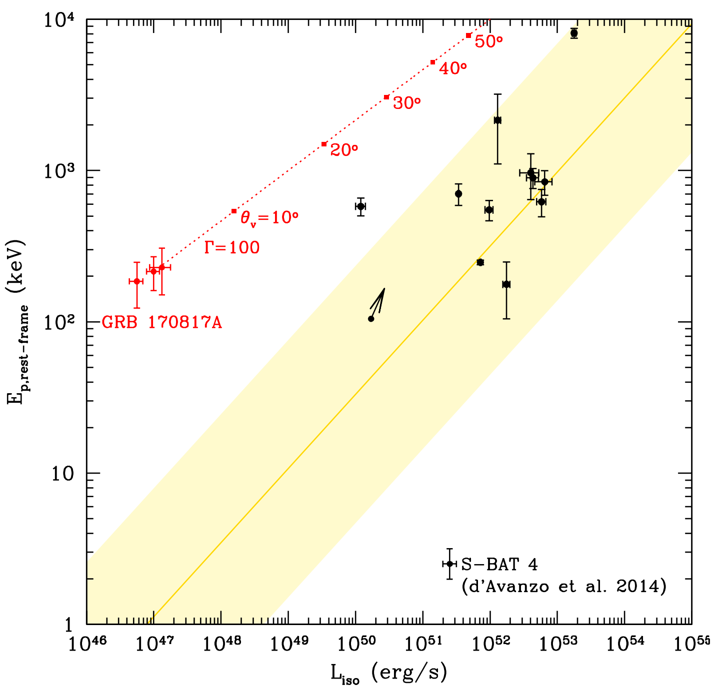
elliptical
SFR < 0.02 $M_\odot\ yr^{-1}$
Swift

Figure prepared by Suzanna Vergani

Example: short GRBs

- **Gravitational waves**
  - -only one case: GW170817
  - -GRB170817A is short (<2s) but under-luminous
  - -good evidence in favor of a core relativistic jet: bright short GRB for an on-axis observer?





$L \propto \mathcal{D}^3(\Gamma, \theta_v)$ $E_p \propto \mathcal{D}(\Gamma, \theta_v)$

- **Connecting short GRB population with BNS mergers:** needs BNS horizon at z~0.5 + good sensitivity to short hard bursts

GRB Populations/Progenitors: predictions for GRB rates

- **Predictions of detection rates:**

A fundamental ingredient is the redshift distribution and the luminosity function. Both are poorly known for most classes of GRBs.

- best known: long GRBs (but still: highly uncertain above z ~6)
- short GRBs: some attempt of modelling based on small samples
- other: difficult

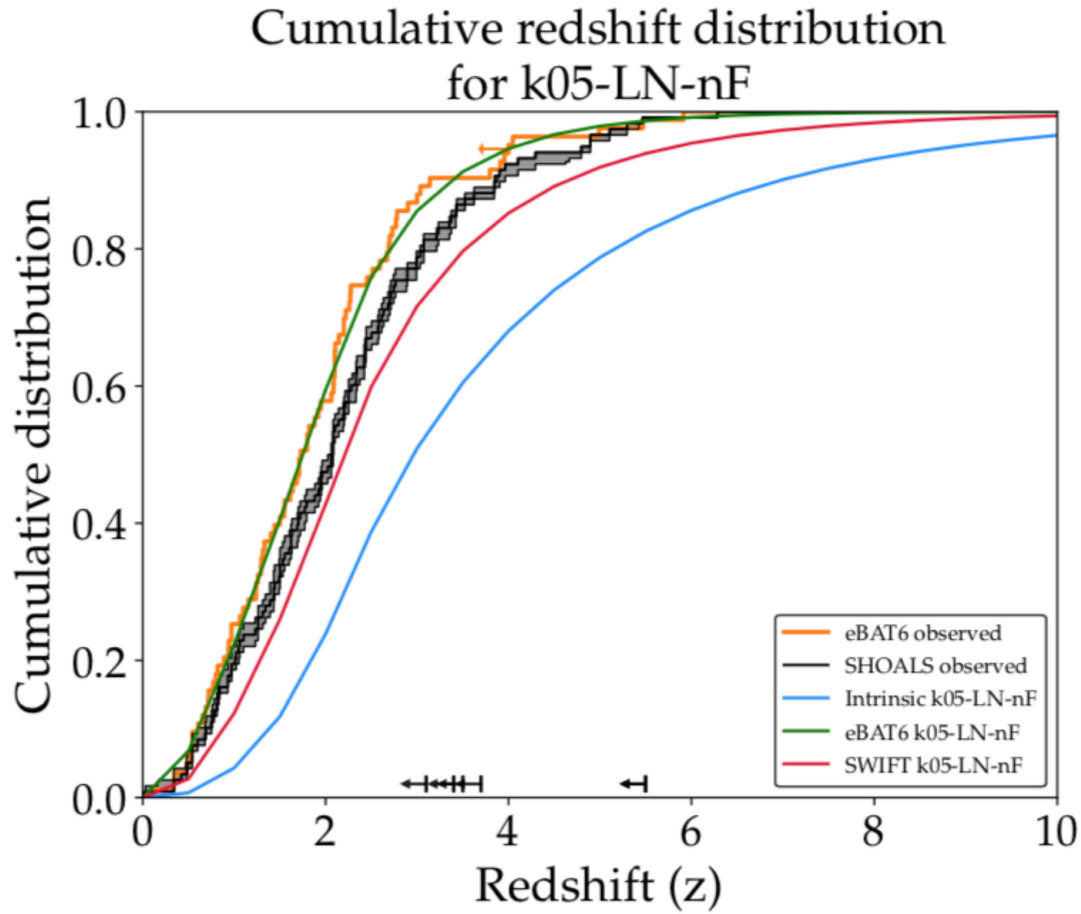
Example: long GRBs

- **Constraints:**

Intensity: LogN-LogP BATSE
Spectrum: GBM catalog (flux cut)
Redshift: eBAT6 (Swift, flux cut)

- **A posteriori tests:**

Ep-L plane (eBAT6)
SHOALS redhsift distribution



- **Population model allows for**

- Luminosity evolution with z
- Production efficiency evolution with z

J. Palmerio's thesis

•No evolution (L, efficiency): does not fit observations

- **Several models fit:**
  difficult to distinguish between L and efficiency evolution

GRB Physics:
central engine and relativistic ejection

GRB Physics – central engine & relativistic ejection

- **A very complex physics**
  (GR+MHD+high density/strong radiative fields/ huge B/ …)
- **No direct signal except with GW (and possibly neutrinos)**
  = importance of MMA observations
- **A lot of discussions based on indirect arguments**
  (example: magnetar signatures in X-ray afterglow?)

GRB Physics:
prompt and afterglow emission

GRB Physics – prompt & afterglow emission

- **Internal dissipation + deceleration by the circumburst medium**

- **Several possible emission sites:**
  - **photosphere:** spectrum/luminosity depends strongly on jet magnetization + complex (micro-)physics (i.e. sub-photospheric dissipation)
  - **internal shocks/reverse shock:** if jet magnetization is low at large distance
  - **magnetic reconnection:** if jet magnetization is still large at large distance
  - **external (forward) shock:** robust feature; details can be complex…

- **In all cases: difficult microphysics:**
  - shock acceleration in mildly/ultra relativistic regime
  - reconnection in relativistic regime

- **Frontier between internal/external origin is not always clear** (e.g. X-ray flares)

- **Key: time+spectral coverage**

Example: impact of Swift+Fermi

Swift XRT:

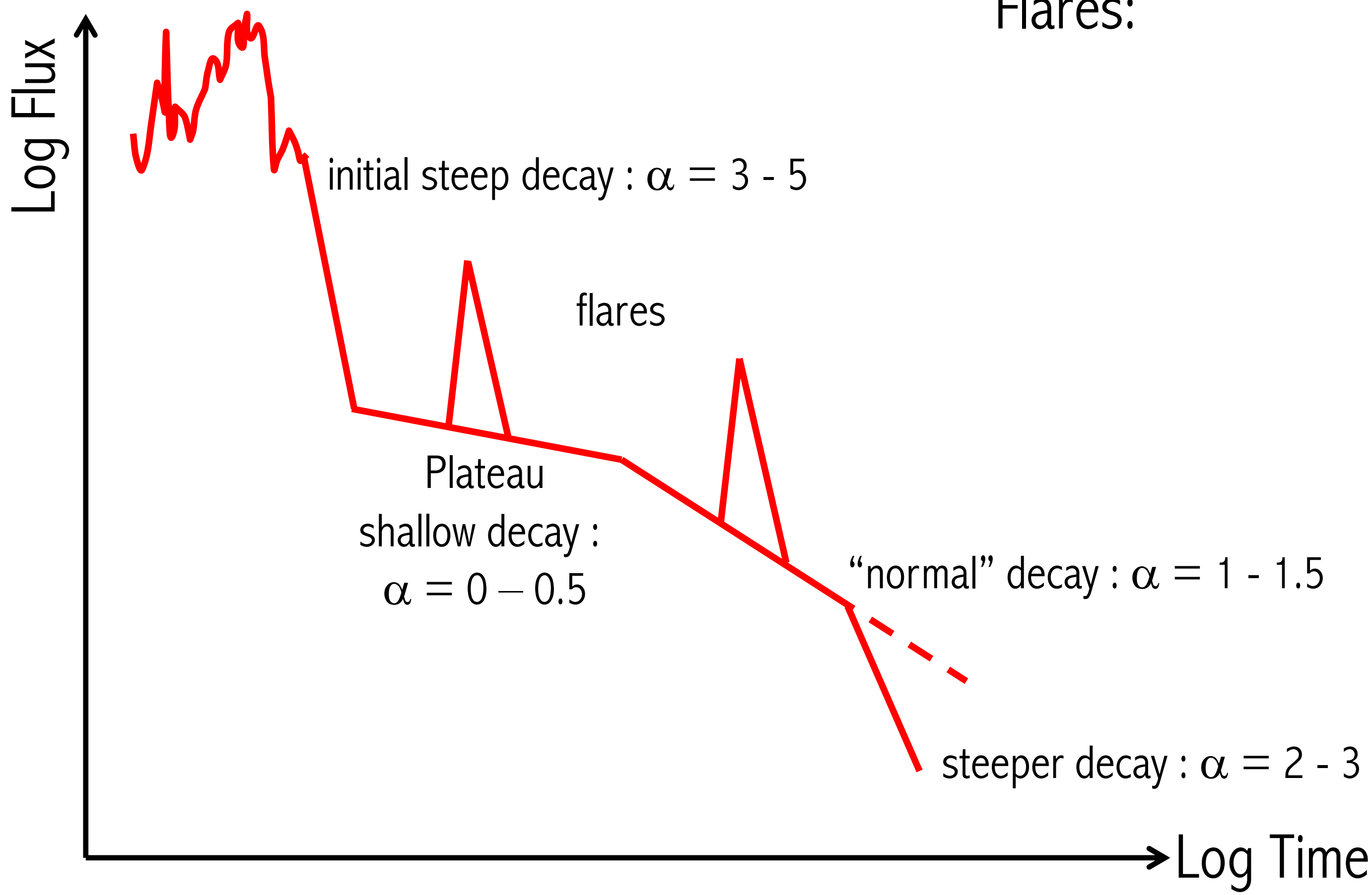
Early steep decay: >9

Plateau:

Flares:

Prompt GRB
(soft γ-rays)

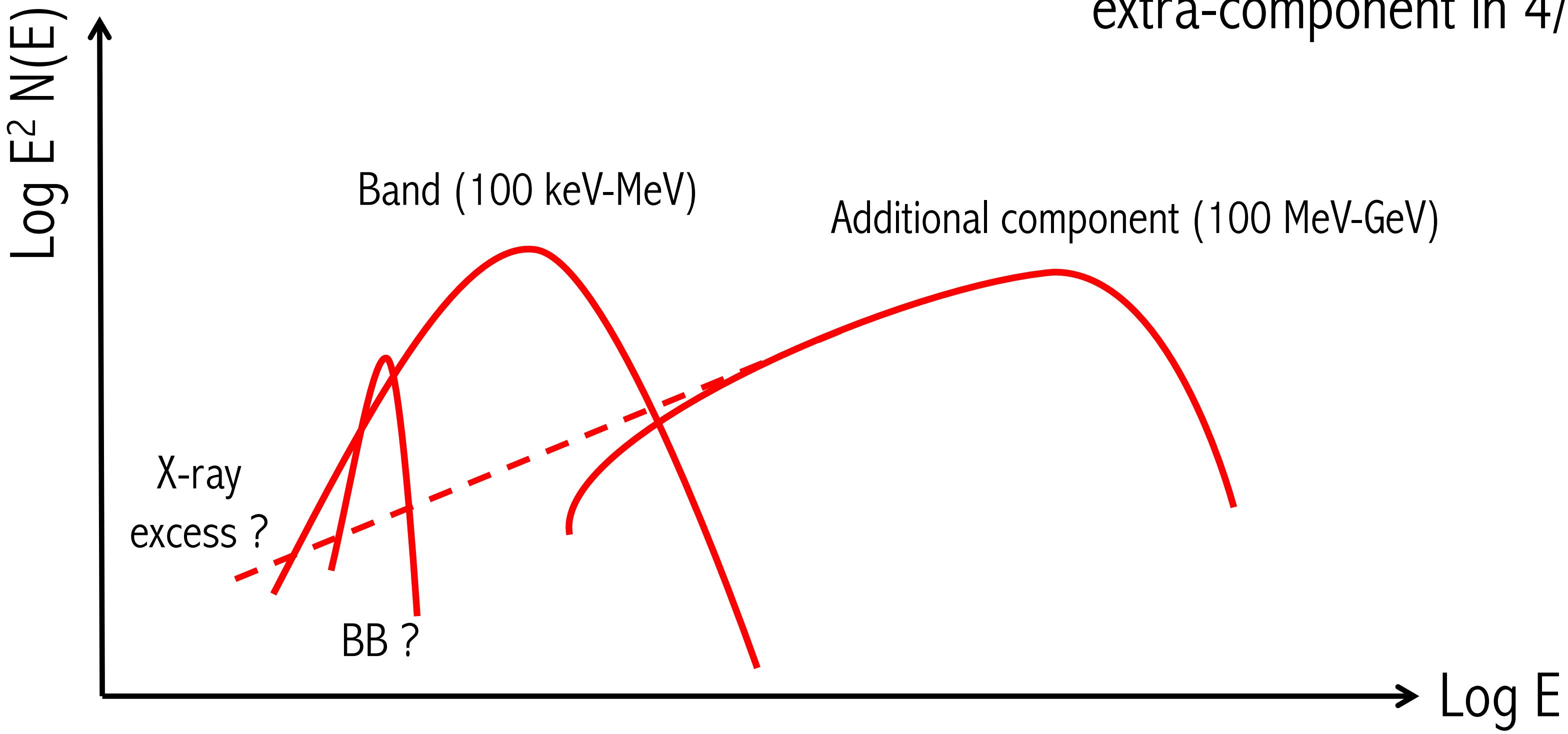
Afterglow
(X-rays)



Also: prompt optical, GeV

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

Example: impact of Swift+Fermi



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

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

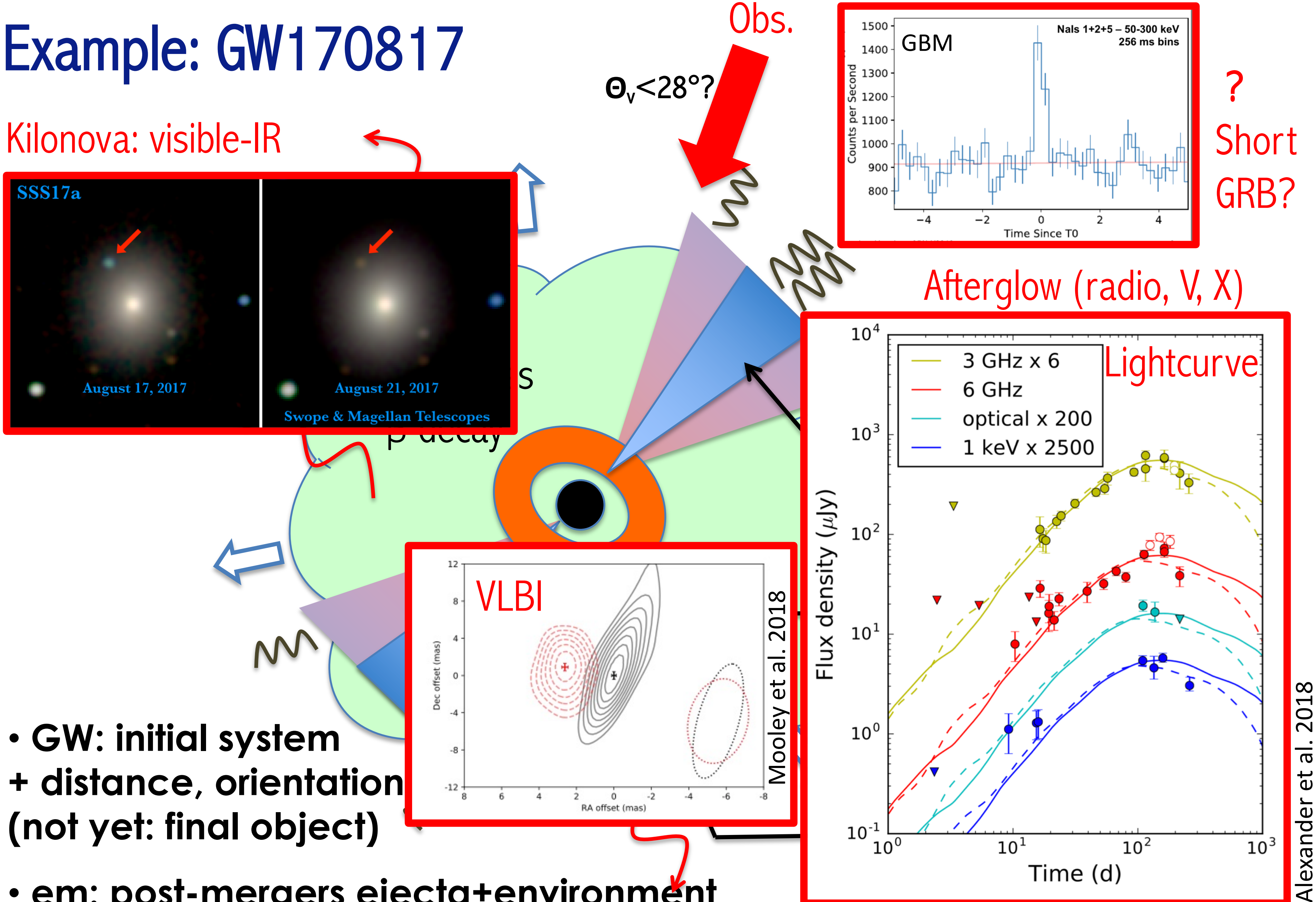
- **Afterglow: long lasting emission in LAT**
  + recent TeV detections (MAGIC, HESS)
  = new constraints on the afterglow physics

Gamma-ray bursts
in the multi-messenger era

GRBs in the multi-messenger era

- **Best case: short GRBs and GW**
- **GW in association with other classes of GRBs?**
- **High-energy neutrinos? Importance of low-L GRBs? (choked jets?)**

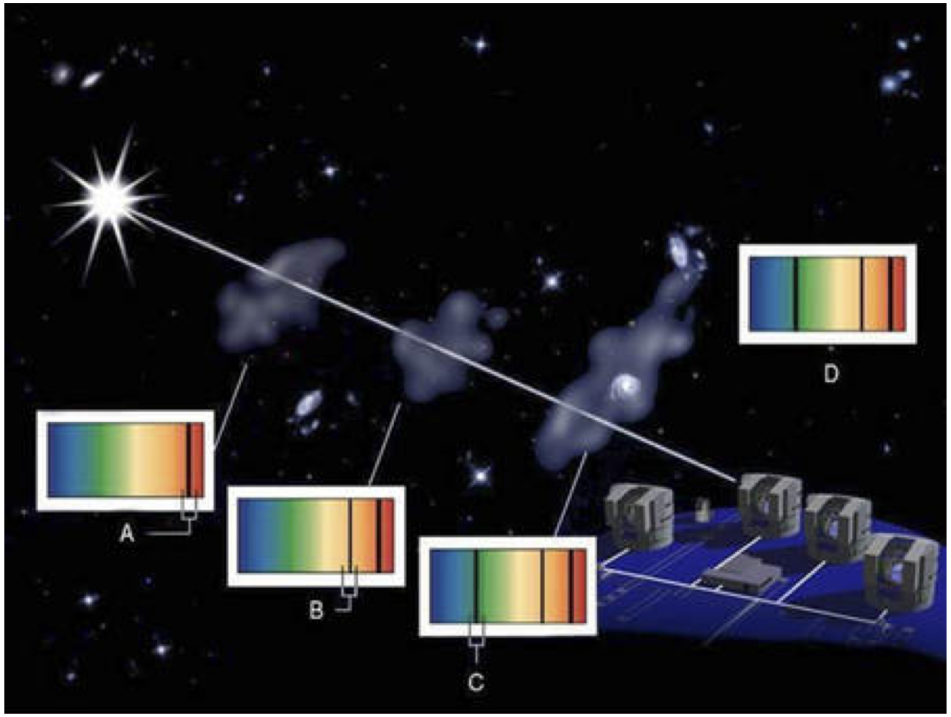
Example: GW170817



- **GW: initial system + distance, orientation (not yet: final object)**
- **em: post-mergers ejecta+environment**
- **GW+em: fundamental physics, cosmology (Hubble)**

Gamma-ray bursts
as a tool for cosmology

GRBs as a tool for cosmology



- **Host galaxies:**
  study ISM at high redshift
  absorption spectroscopy (AG)
  + emission spectroscopy (host)

  Selection is done only on GRB.
  Includes weak galaxies
  that are not found in surveys.

- **Study IGM**
  (absorption spectrosocopy: AG)

- **Distant GRBs:**
  access to reionization epoch, f(esc), first stars, …

- **Cosmological parameters: difficult…**

- **Needs large samples of GRBs at high redshift (above z=6: difficult)**
  with rapid accurate localization (for AG spectroscopy)
  and ideally rapid redshift measurements
  and GRB classification

Conclusion

Requirements for a GRB mission

- **Be sensitive to all classes of GRBs**

- **For each class of GRBs, be able to build a sample with prompt (including spectrum) + afterglow + redshift + host galaxy** (polarization ?)

- **For cosmology:**
  - **be able to detect a significant number of long GRBs at high z**
  - **provide rapidly accurate positions** (e.g. for high-res AG spectro.)

- **For MMA observations:**
  - **γ-rays:**
    - **have a good sensitivity to short GRBs**
    - **cover a very large f.o.v.**
  - **X-rays:**
    - **ideally cover a very large f.o.v with a good sensitivity**
    - **otherwise: strategy is more complexe to define**
  - **other wavelength: limit magnitude/flux + sky coverage**

- **Orphans ?**