Using GRBs to test LIV…

Testing LIV with signals from the end of the Universe

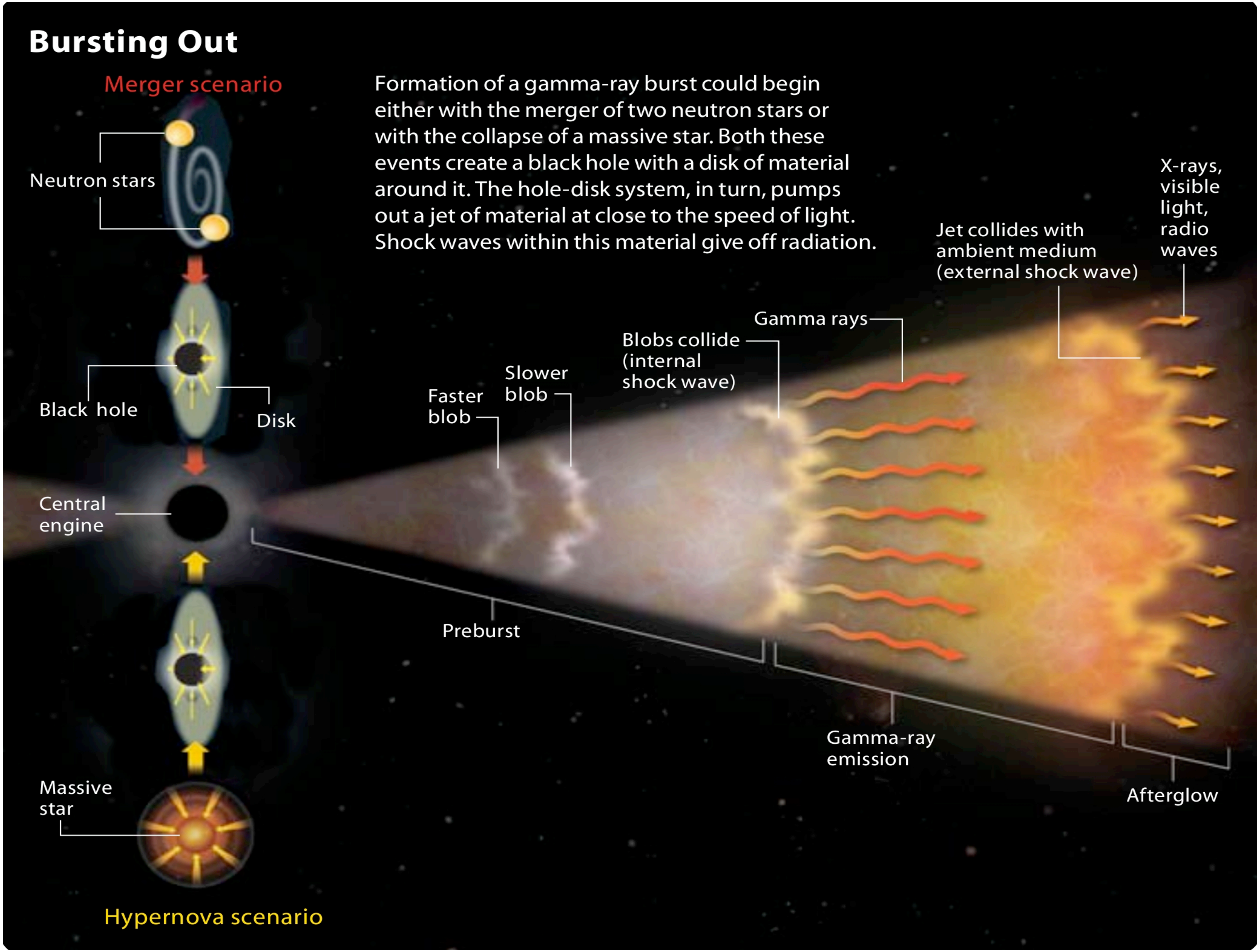
- I'll not talk about LIV !

- At 1st order LIV modifies the speed of the photons:

$$c' = c\left(1 \pm \xi \frac{E}{E_P}\right) \quad ; \quad \Delta t = \boxed{\Delta t_0} + \frac{(E_2 - E_1)}{E_P}\frac{\xi}{H_0}\int_0^z dz' \frac{(1+z')}{\sqrt{\Omega_m(1+z')^3 + \Omega_\Lambda}}$$

  - E is the energy of the photons
  - $E_P \sim 10^{19}$ GeV → Importance of high energies !
  - Observations are used to constrain ξ
  - Δt is usually called the « spectral lag »

- LIV can be constrained with signals at different energies travelling a significant fraction of the size of the universe
  - → Use GRBs and measure time lag between photons of different energies
  - → Need to know Δt_0 !


Bursting Out
Merger scenario
Formation of a gamma-ray burst could begin either with the merger of two neutron stars or with the collapse of a massive star. Both these events create a black hole with a disk of material around it. The hole-disk system, in turn, pumps out a jet of material at close to the speed of light. Shock waves within this material give off radiation.
Neutron stars
Black hole
Disk
Central engine
Massive star
Hypernova scenario
Faster blob
Slower blob
Blobs collide (internal shock wave)
Gamma rays
Jet collides with ambient medium (external shock wave)
X-rays, visible light, radio waves
Preburst
Gamma-ray emission
Afterglow

Testing LIV with GRBs

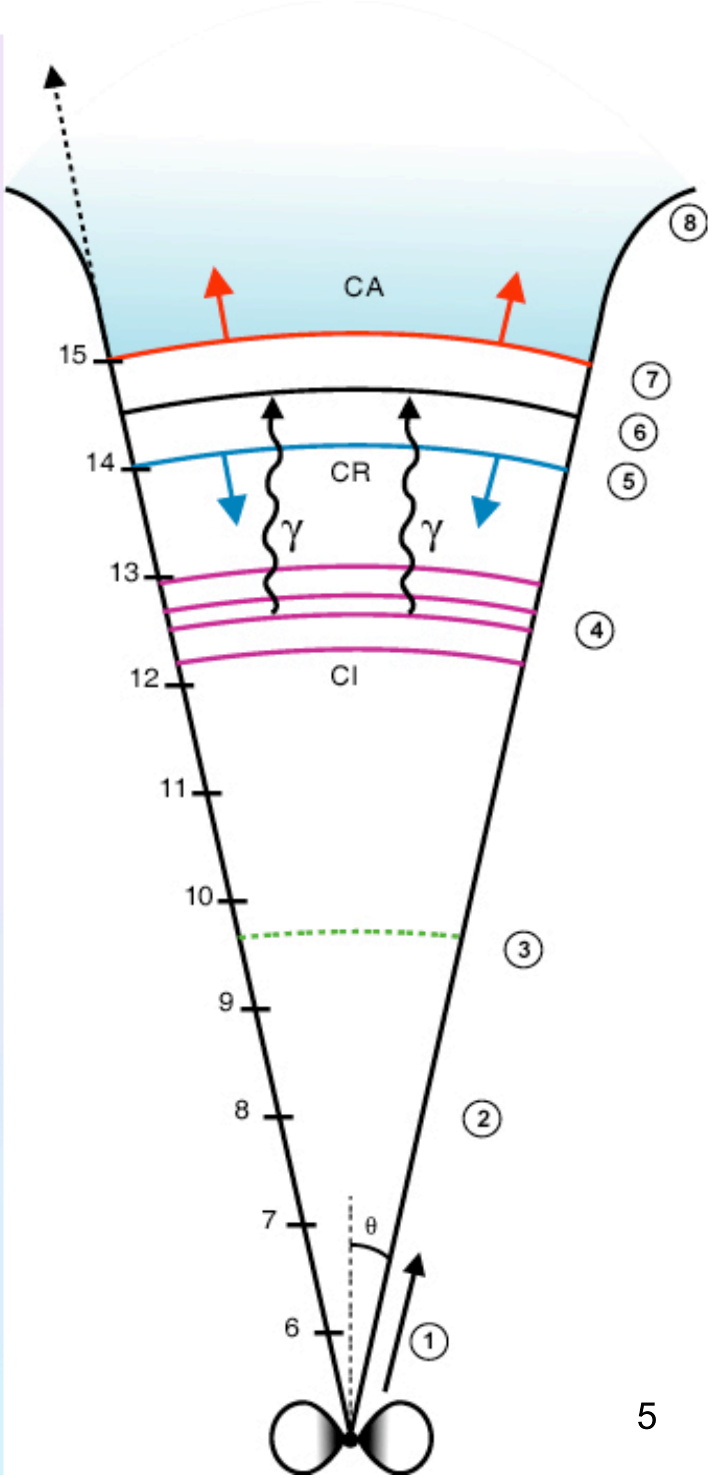
- I only discuss the use of the prompt emission, which is bright & short
  - The « standard sketch »
  - Global properties of GRB prompt emission in the 'historic' keV range:
    - Duration
    - E_{peak}
    - Redshift
  - Prompt optical emission
  - Prompt High energy emission (GeV)
  - SVOM

The « standard sketch »

1) Acceleration
2) End of acceleration: Γ > 100

3) Transparency → photospheric emission?
4) Internal shocks (CI) → γ-ray emission
5) Reverse shock (CR) → early afterglow?

6) Shock discontinuity
7) Forward shock (CA) → classical afterglow
8) $1/\Gamma > \theta$ → break in afterglow lightcurve



The physics of prompt emission is complex
(see F. Daigne presentation)

- If we concentrate on the prompt emission, the physics is not well understood. Crucial questions remain concerning the nature of the jet (magnetic or baryon dominated), the acceleration of the radiating particles, the microphysics, the regions of emission

  → Difficulty to interpret the observed emission(s)

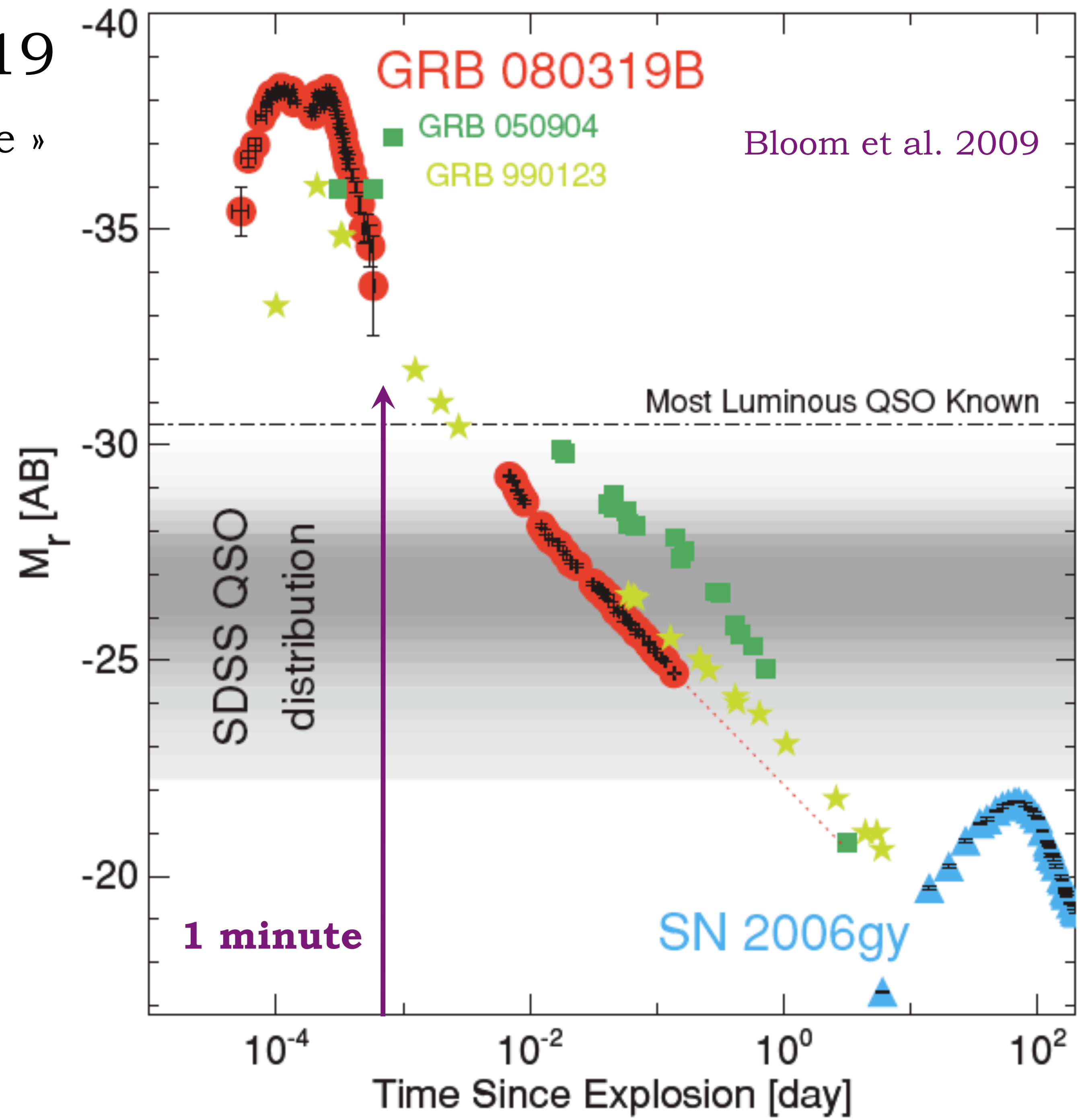
- GRBs are very broadband emitters : the prompt emission is detected from NIR to HE γ-rays, it is most often the superposition of various radiating components

- The relativistic motion complicates the interpretation of the observed radiation

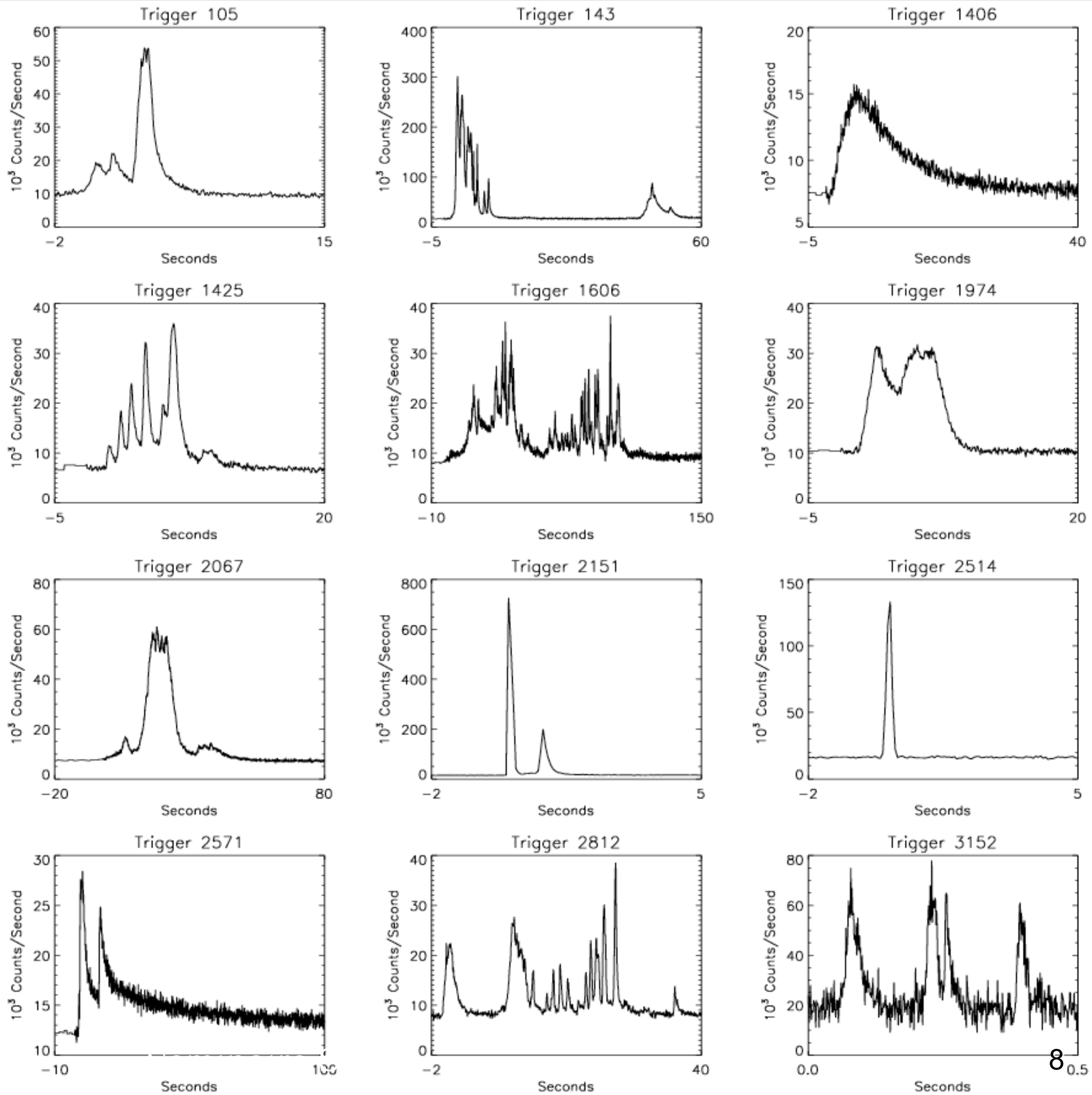
- This makes difficult the interpretation of the observed lags and the search for LIV evidence

GRB 080319

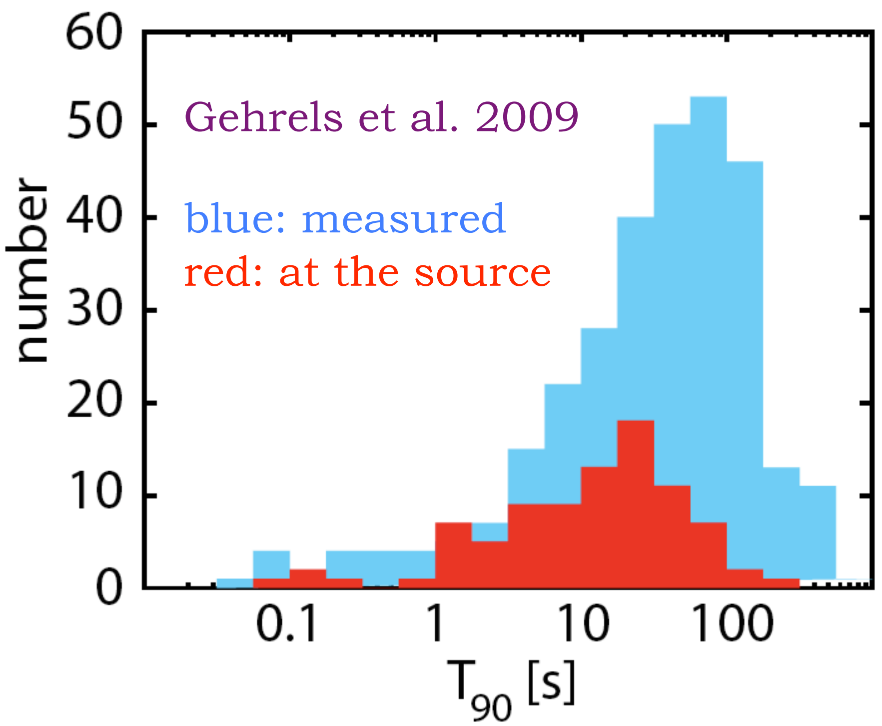
The « naked eye » burst !



Typical GRB light-curves at ~100 keV

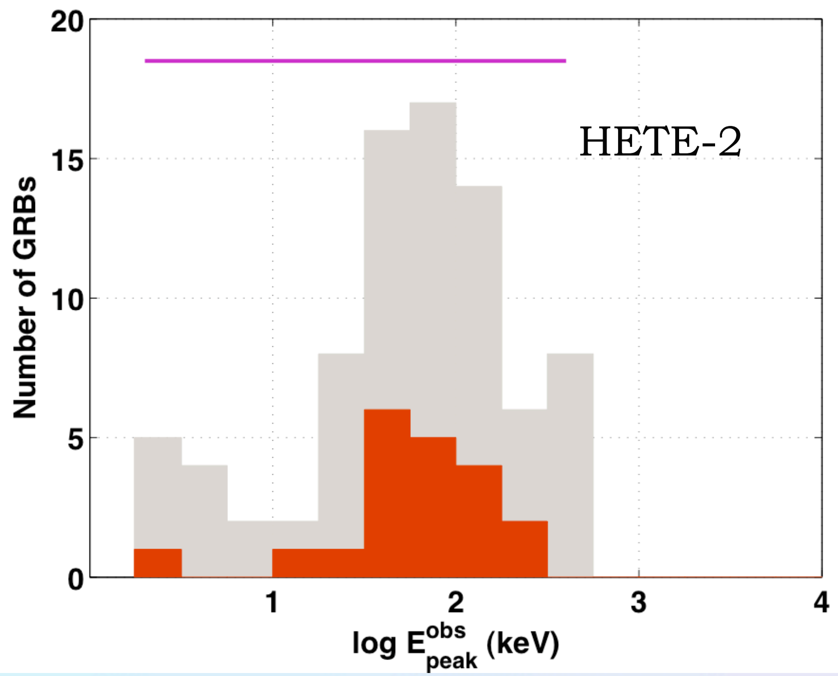


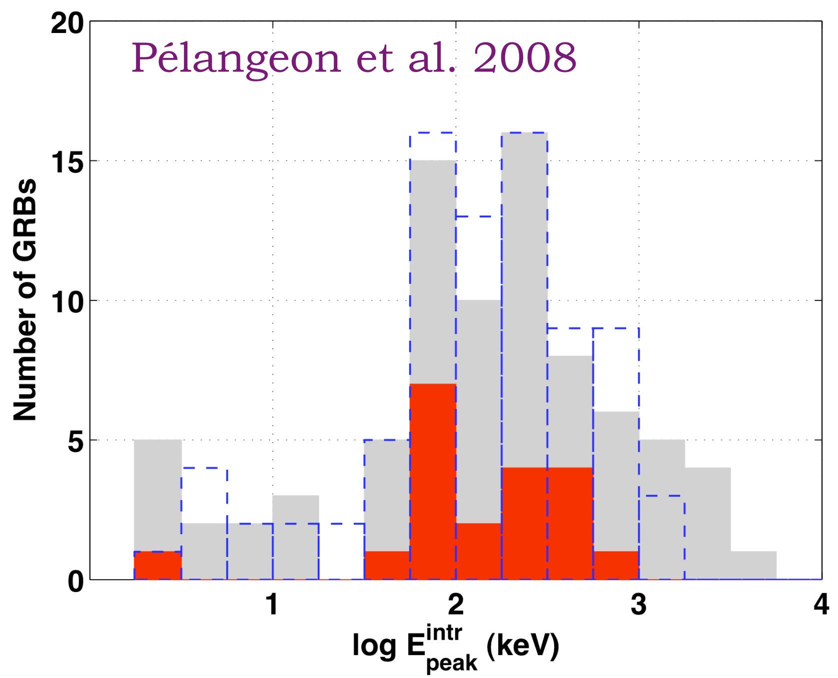
Duration distribution



In the range 1-1000 keV

- Most GRBs are made of several spikes
- There are two classes of GRBs: long & short
- ~2 sec in the observer's frame
- GRBs last longer at low energies





E_{peak} distribution

In the range 1-1000 keV

- Epeak ranges from few keV to ~MeV. The observed range is strongly biased by the detectors.
- There are strong selection effects against the detection of faint soft GRBs (XRFs) and sub-luminous GRBs
- Some GRBs emit HE (GeV) radiation
- Some GRBs emit optical radiation

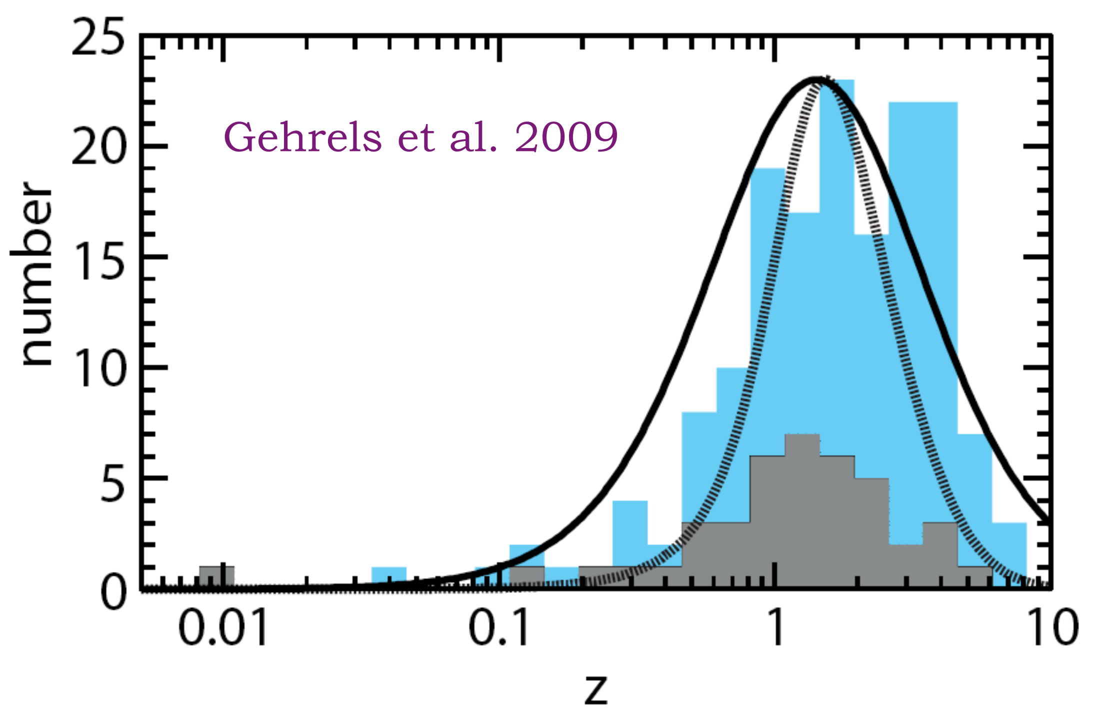
Redshift distribution

The redshift is absolutely required!

The observed distribution is strongly biased: measuring the redshift is complex (the GRB is detected in space and the redshift is measured from the ground with large telescopes).

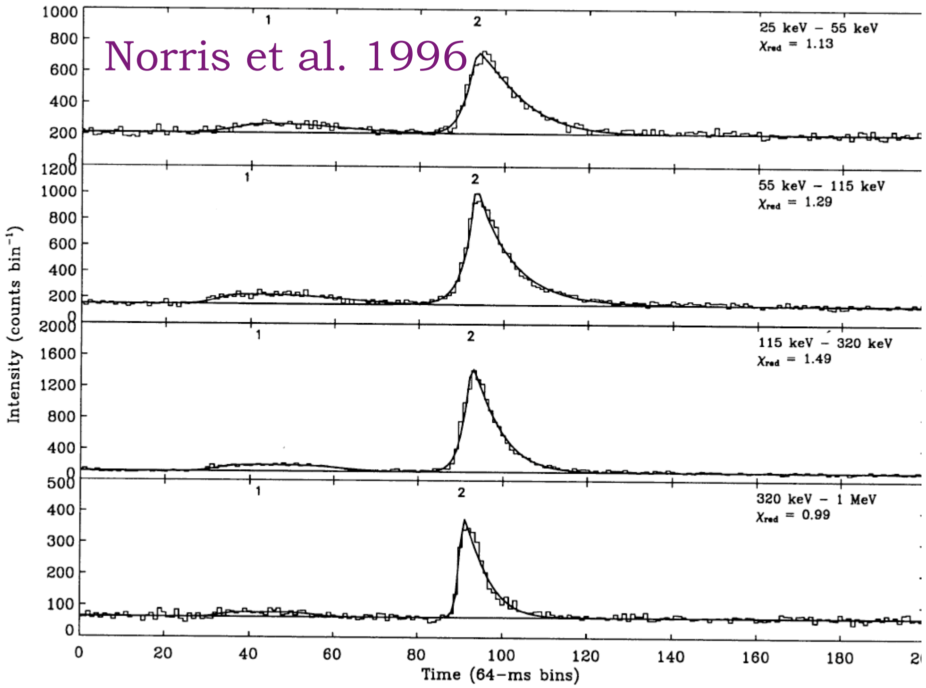
Swift has permitted a giant step:
GRBs with z, pre-Swift: **32**
GRBs with z, with Swift: **176**

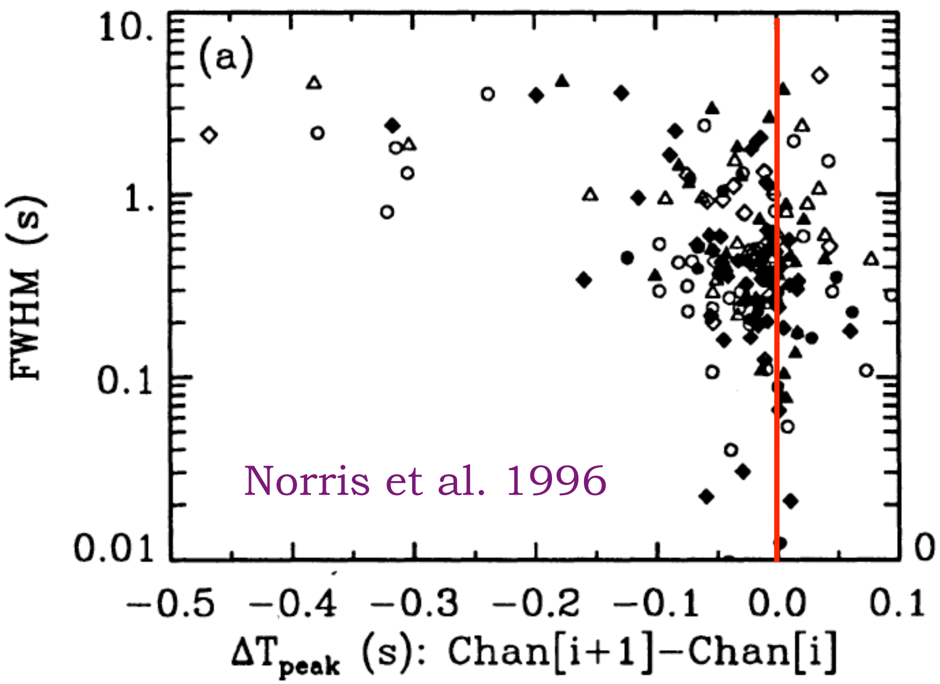
The observed « spectral lag » depends on the redshift:
- The intrinsic lag is ×(1+z)
- The energies are ÷(1+z)
- Evolution effects might be important. This would make high-z GRBs different, with distinct properties (e.g. « spectral lags »).



Spectral lags at keV-MeV energies

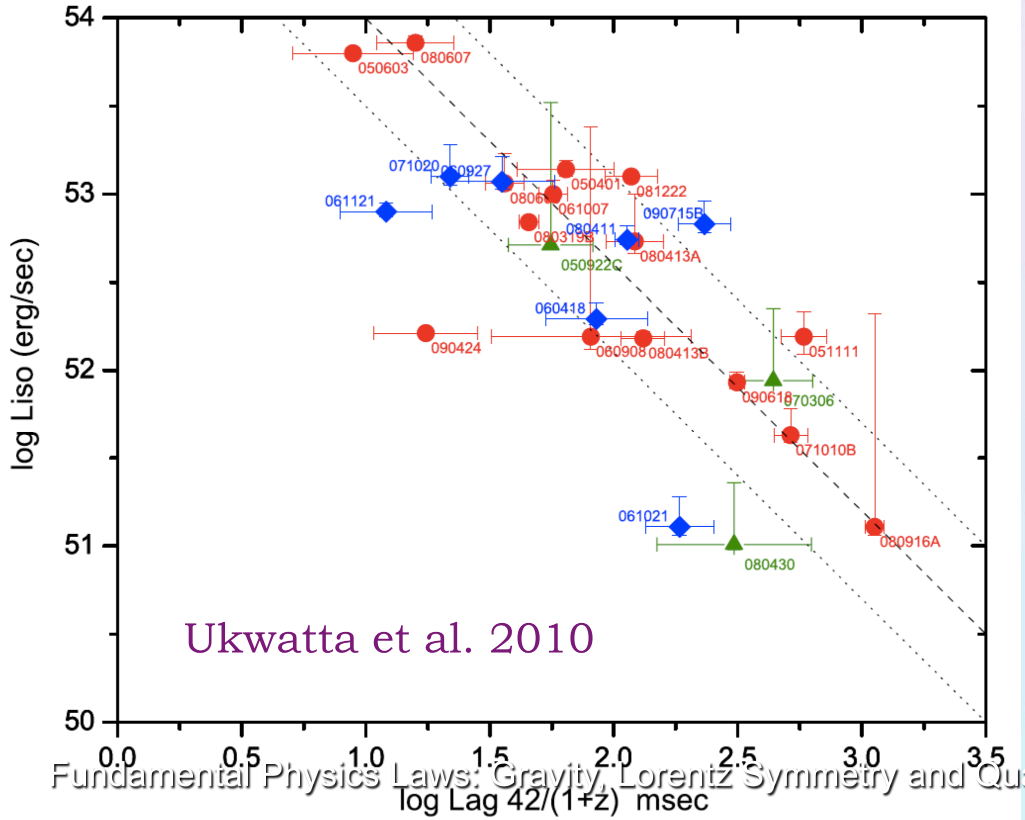
- Spectral lags have been observed very early in long GRBs (e.g. Norris et al. 1996)
- Spectral lags depend on the energy range
- Spectral lags depend on the luminosity

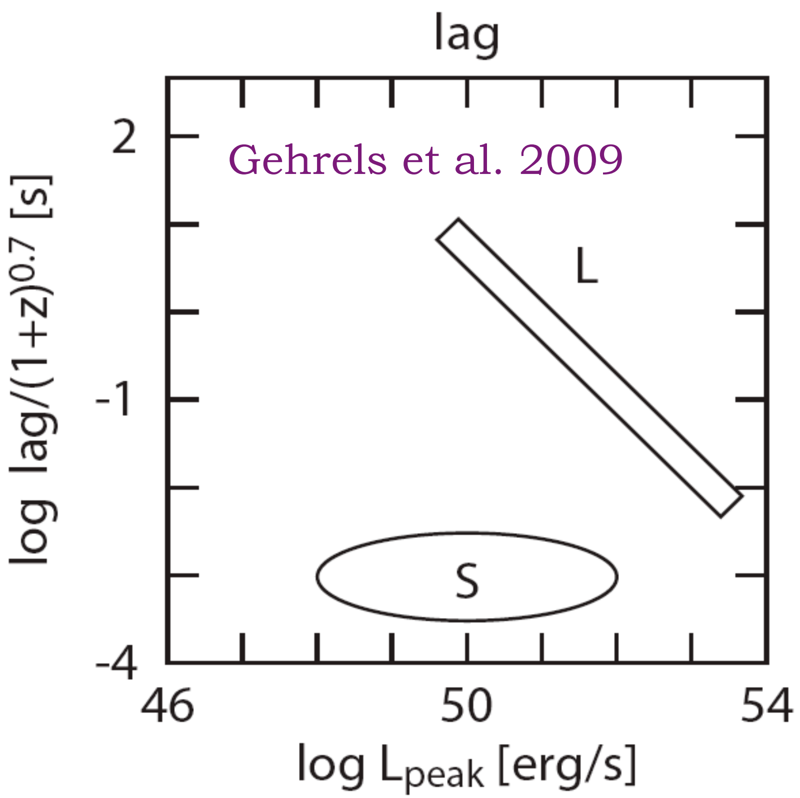




Spectral lags at keV-MeV energies

- Spectral lags are very different for short and long GRBs
- Short GRBs and long luminous GRBs are more interesting for LIV as they exhibit smaller lags and they can be detected to large distances



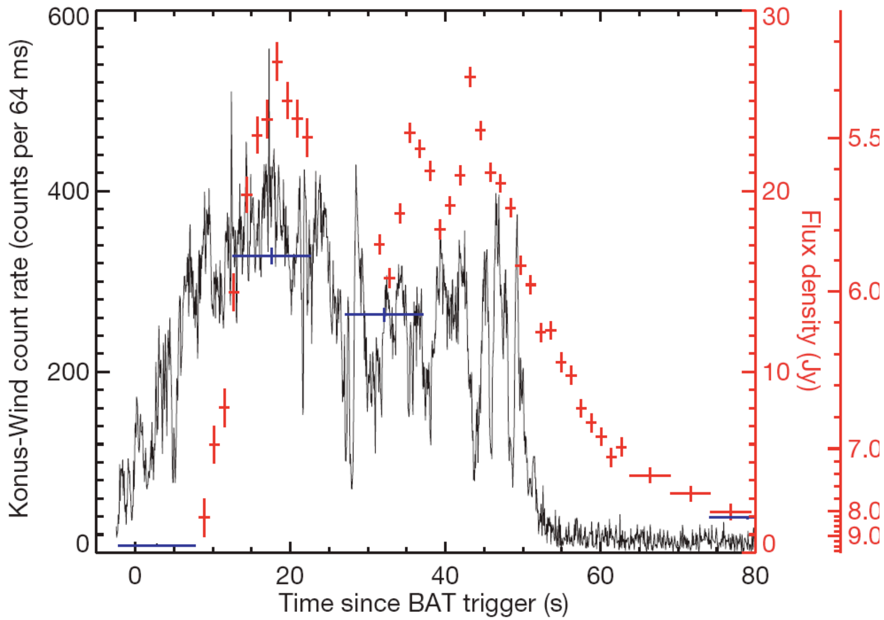


Spectral lags at keV-MeV energies

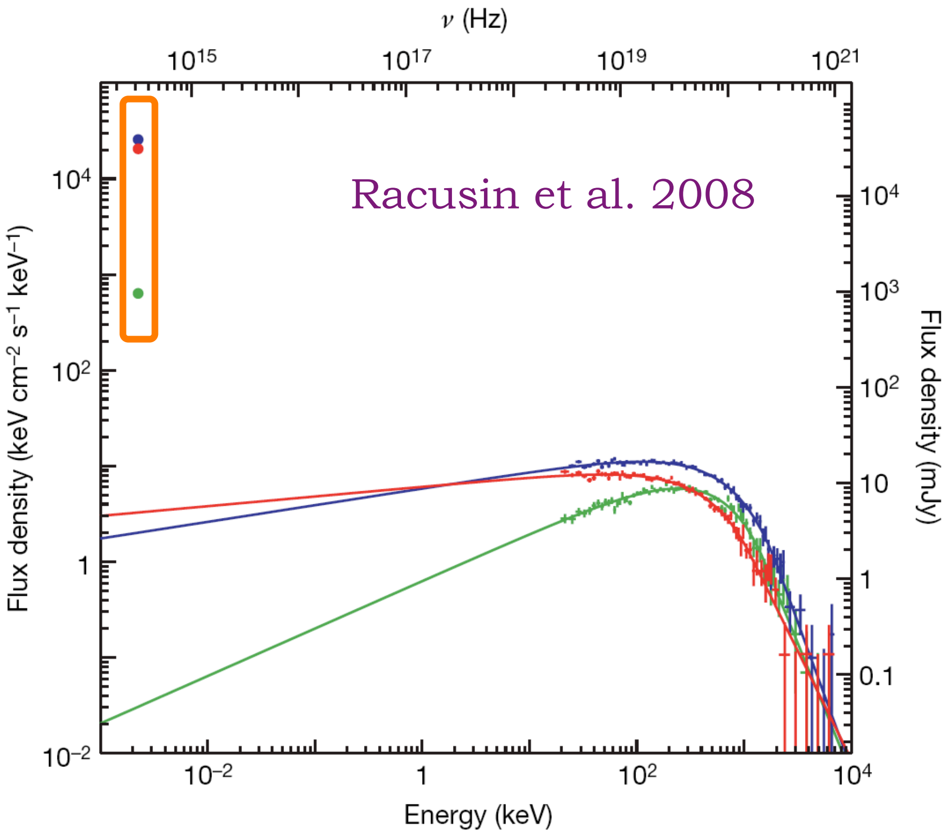
- $E \sim 10^5$ eV
- A single component?
- The prompt emission is often bright and spiky, allowing the measure of 1-100 ms lags
- Spectral lags have been measured and studied in details
- Hundreds of GRBs with redshift, allowing statistical studies
- Remains a promising way of detecting/measuring LIV
- Studies of LIV currently limited by:
  - Our understanding of the prompt emission
  - The statistics of the GRB signal
  - The difficulty to obtain redshifts

The prompt optical emission

The prompt emission of GRB 080319B extends from eV to MeV…
The prompt optical emission is correlated with the prompt keV emission, and lags it by several seconds

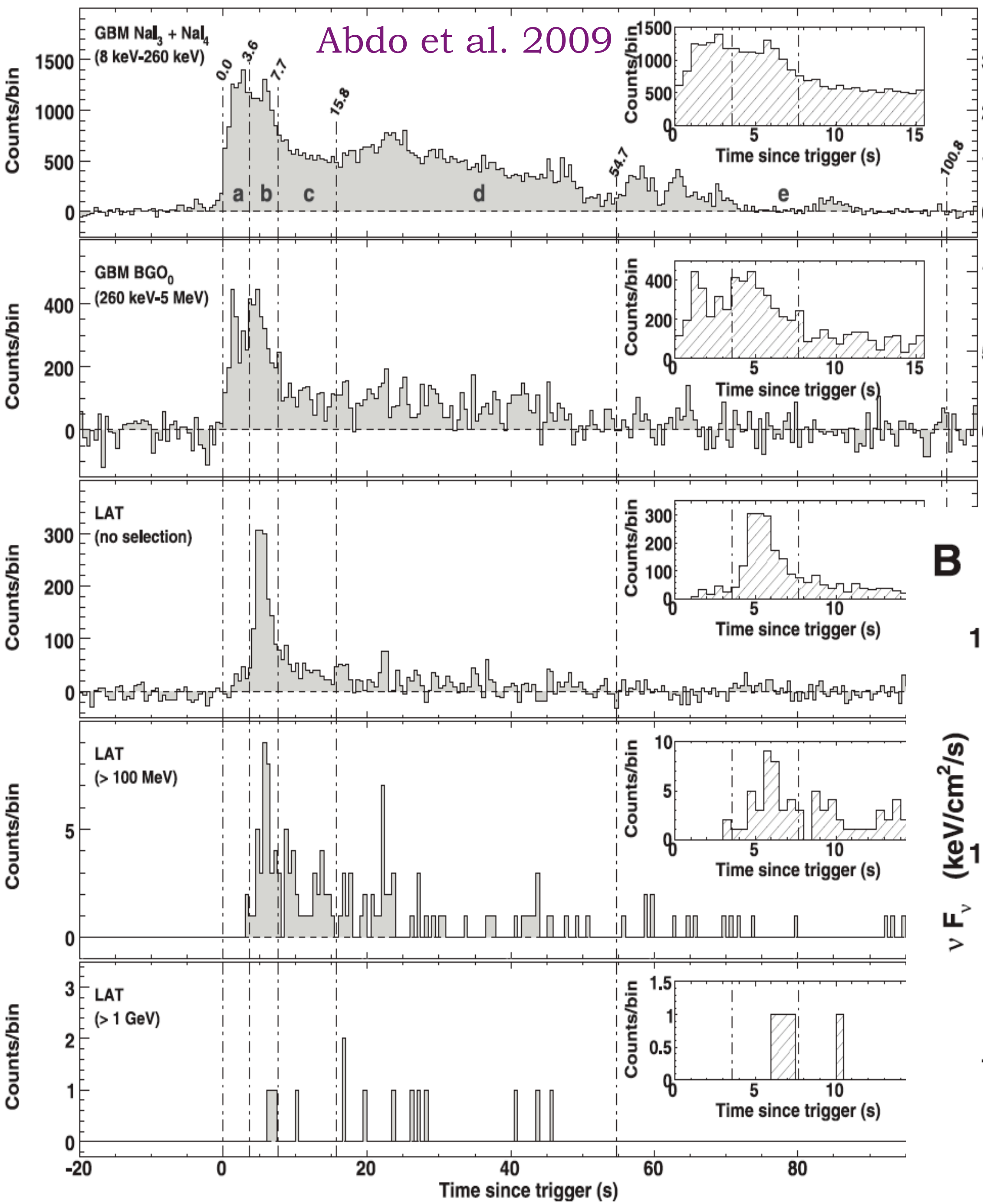


Racusin et al. 2008



The prompt optical emission

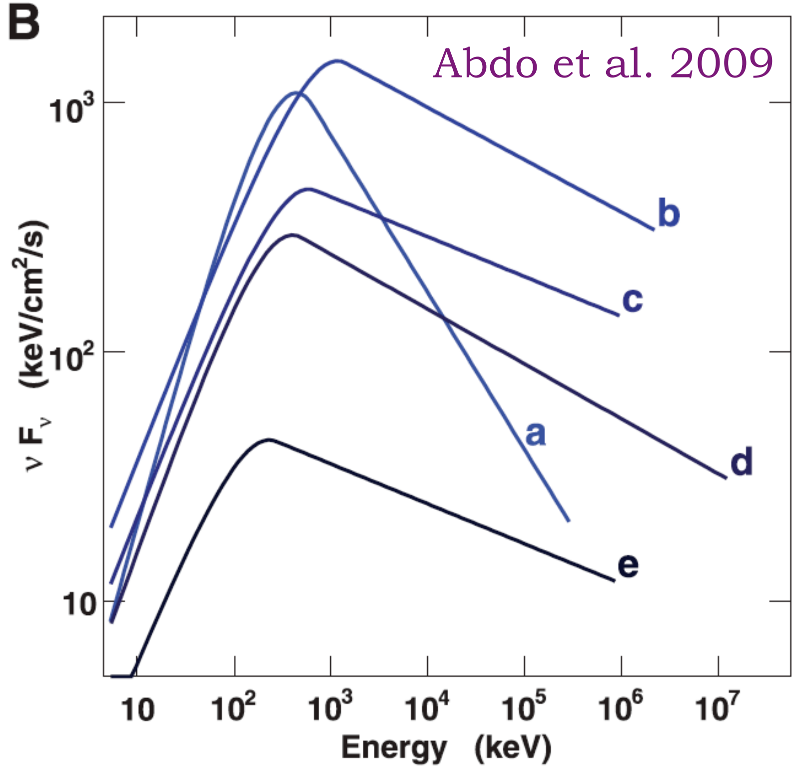
- Prompt optical emission correlated with the gamma-ray emission has been detected in several GRBs
- The prompt optical emission is difficult to detect (requires very wide field instruments or GRBs with precursors)
- Origin?
- Not very promising for LIV…



GRB 080916C

The prompt emission of GRB 08916C extends from keV to GeV…

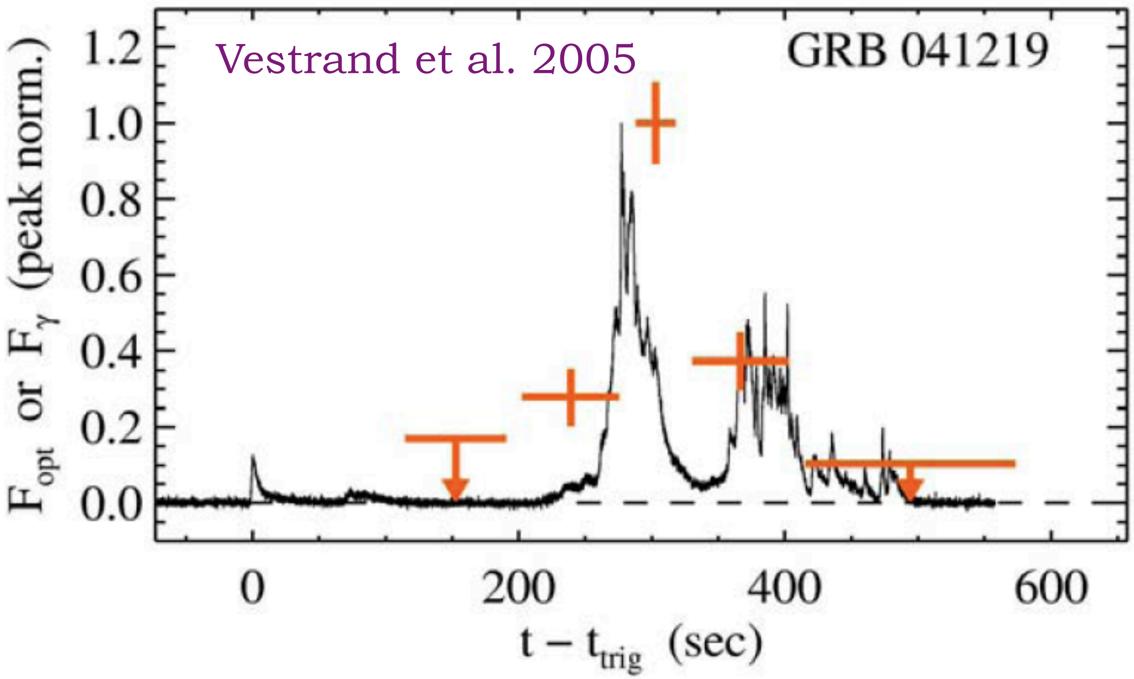
Do keV and GeV emissions have the same origin?



Spectral lags at GeV energies

- $E \sim 10^9$ eV
- Prompt GeV emission is present in short and long GRBs
- Fermi provides invaluable data
- Some difficulties are :
  - What is the origin of GeV radiation: prompt or afterglow?
  - Photon statistics is low (compared with the keV range!)
  - Few GRBs exhibit GeV emission
- GeV emission has led to the best constraints brought by GRBs
- , it may be more difficult to use it to detect/measure LIV
- It may be difficult to do better than GRB 090510…

At TeV energies…



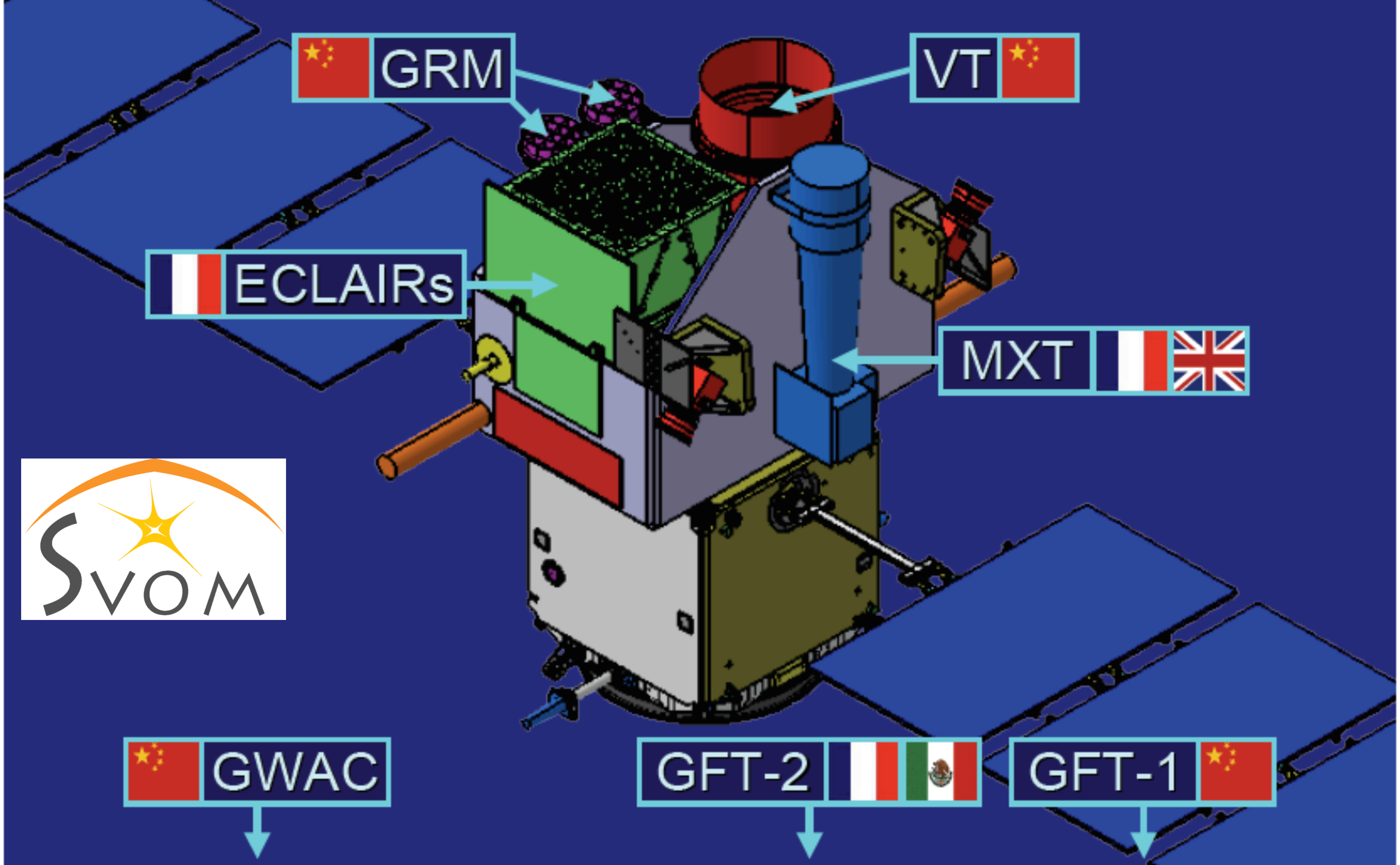
- E ~ 10^{12} eV
- Prompt TeV emission has not yet been observed, but…
- Exciting new data are expected from the High Altitude Water Cerenkov (HAWC) wide field detector, and…
- Fast Pointing TeV telescopes (e.g. MAGIC) can look for TeV emission from long GRBs with precursor activity (like GRB 041219 above, observed in gamma-rays and NIR).

- The interaction with background IR photons may be problematic, if local subluminous GRBs do not emit TeV radiation!

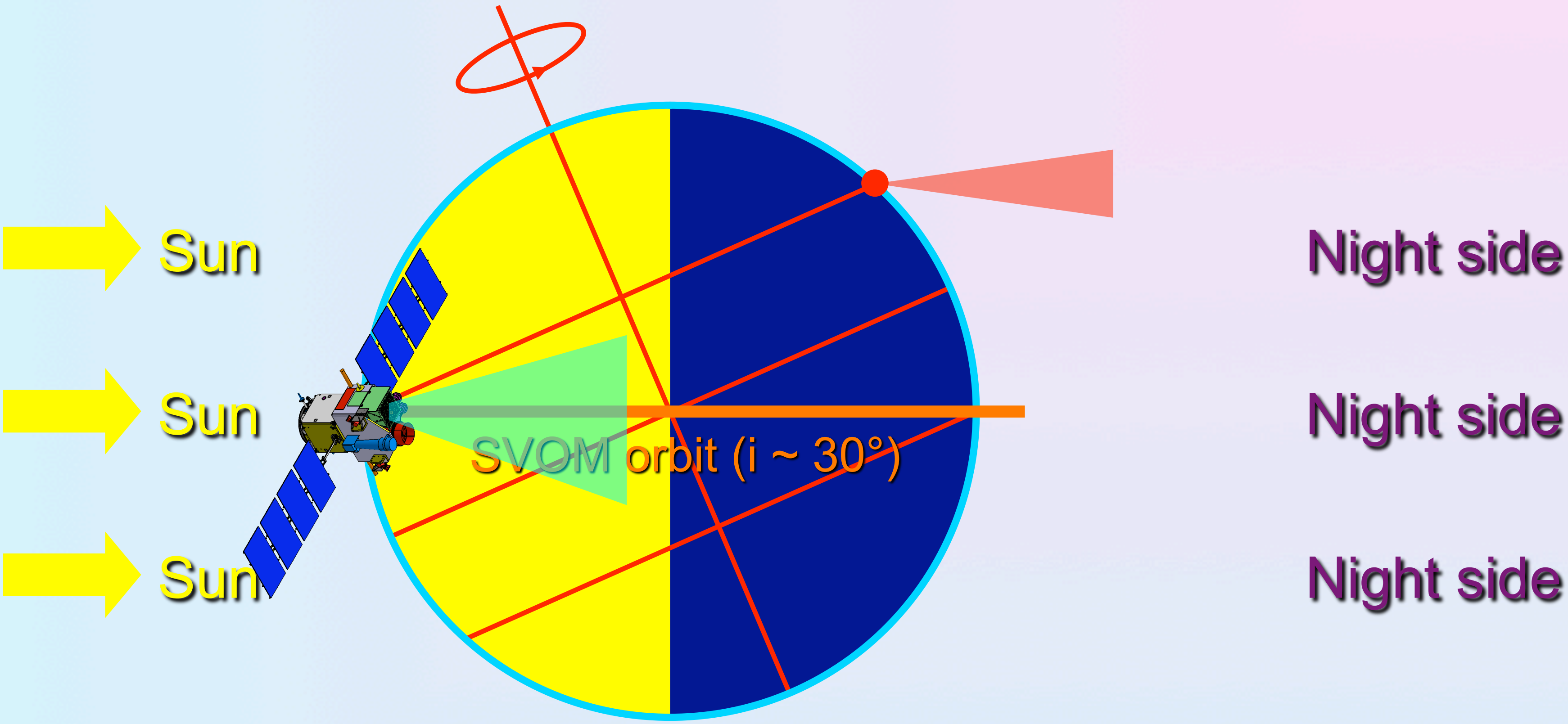
SVOM science goals

- Permit the detection of all know types of GRBs, with a special care on high-z GRBs and low-z, sub-luminous GRBs
- Provide fast, reliable and accurate GRB positions
- Measure the broadband spectral shape of the prompt emission (from visible to MeV)
- Measure the temporal properties of the prompt emission
- Quickly identify the afterglows of detected GRBs, including those which are highly redshifted (z>6)
- Quickly provide (sub-) arcsec positions of detected afterglows
- Quickly provide redshift indicators of detected GRBs

SVOM configuration at the starting of phase B

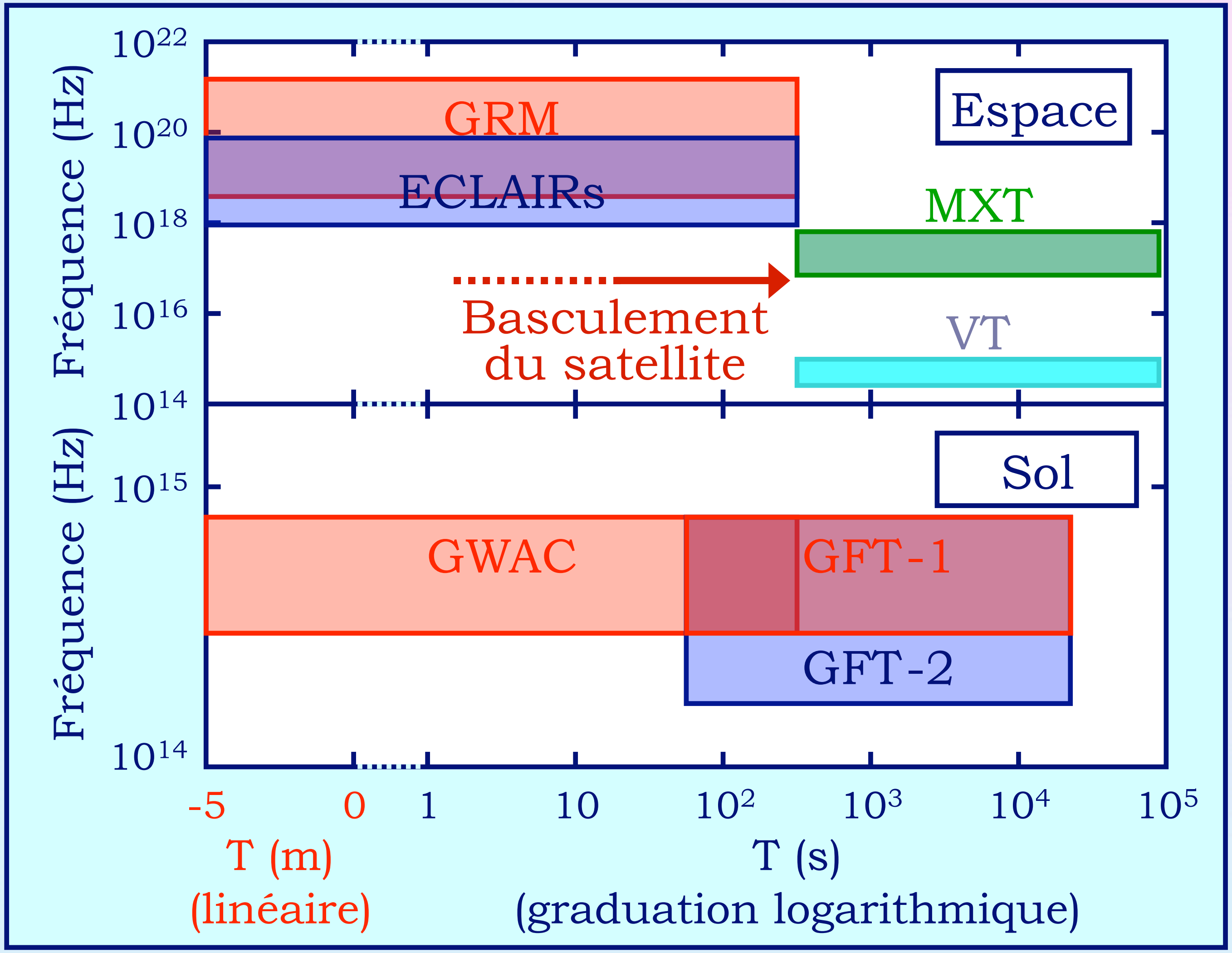


SVOM observing strategy



Most SVOM GRBs will be in the dark hemisphere,
and immediately observable by large telescopes on Earth

Capacités multi-longueurs d'onde



Instruments embarqués et au sol : couverture spectrale inégalée

C’est fini !