Gamma-Ray Bursts: recent advances and open issues

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Five Years of INTEGRAL

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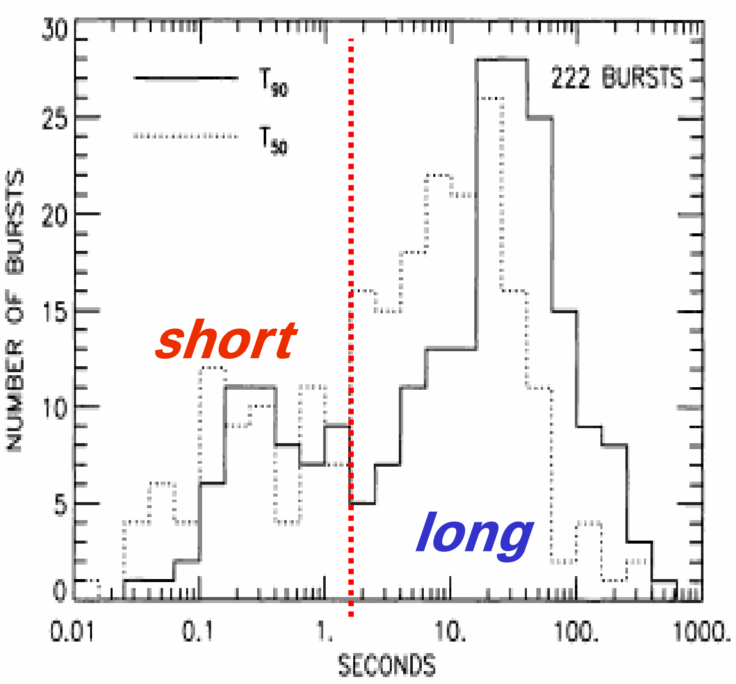
Outline

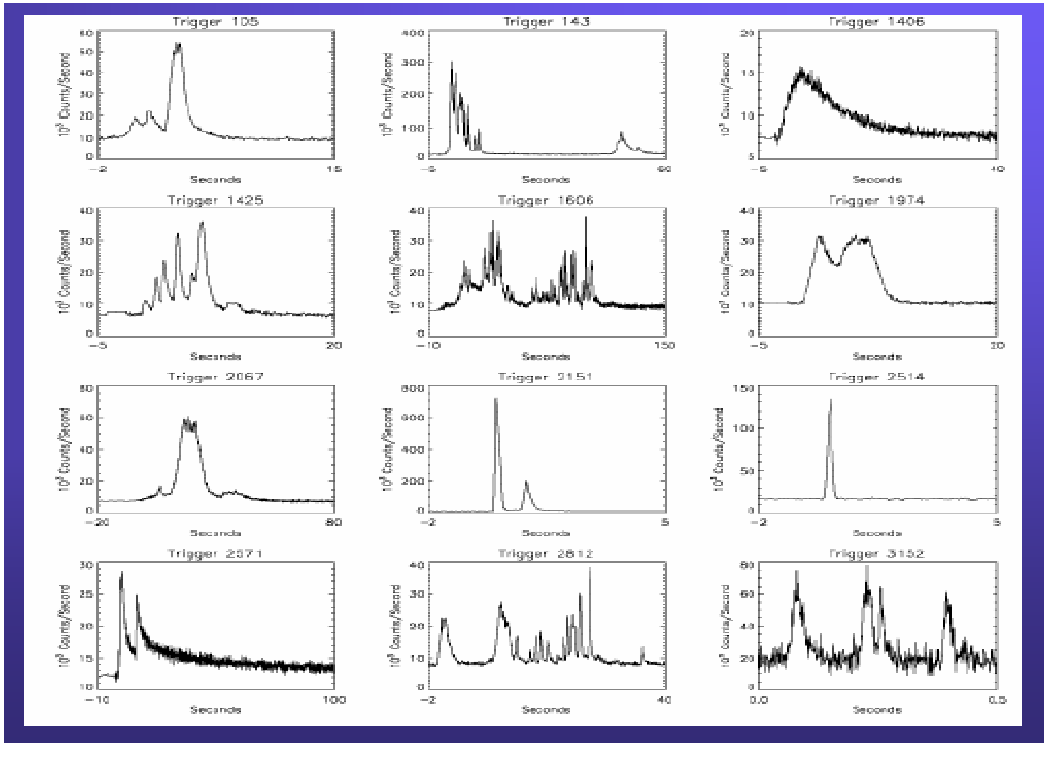
- A brief summary of observations
- Open issues
- Future perspectives

Brief summary of observations

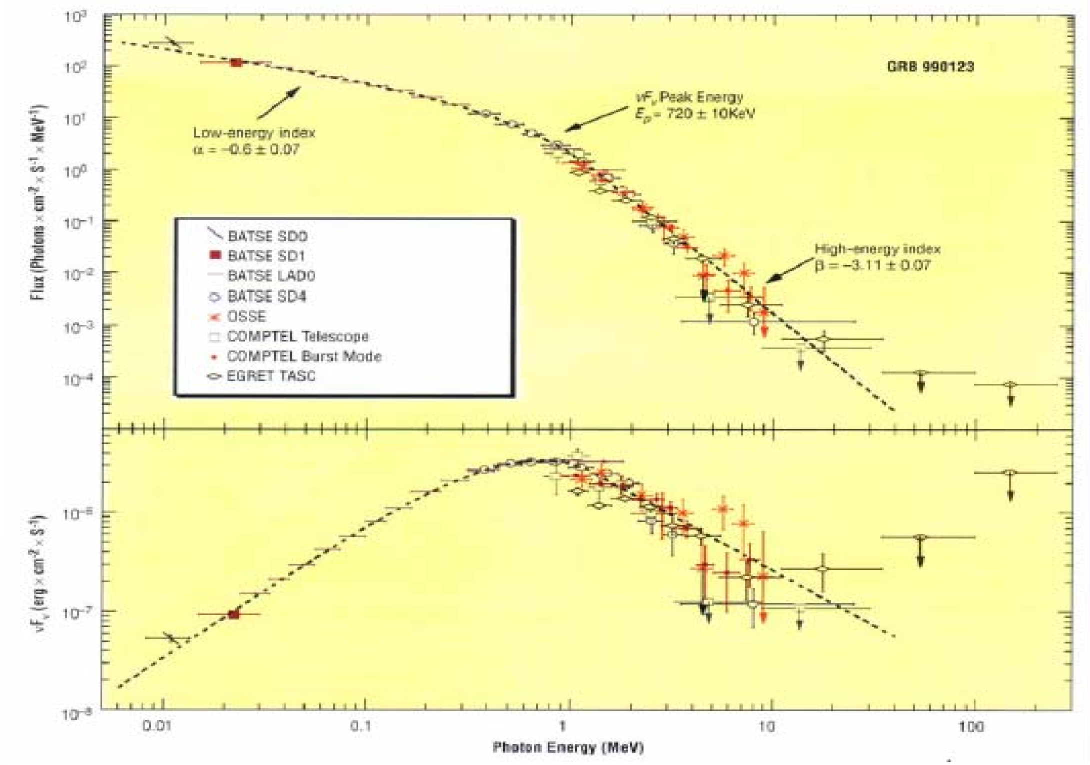
➢ *prompt emission (late '60s, main contribution by CGRO/BATSE in90s)*

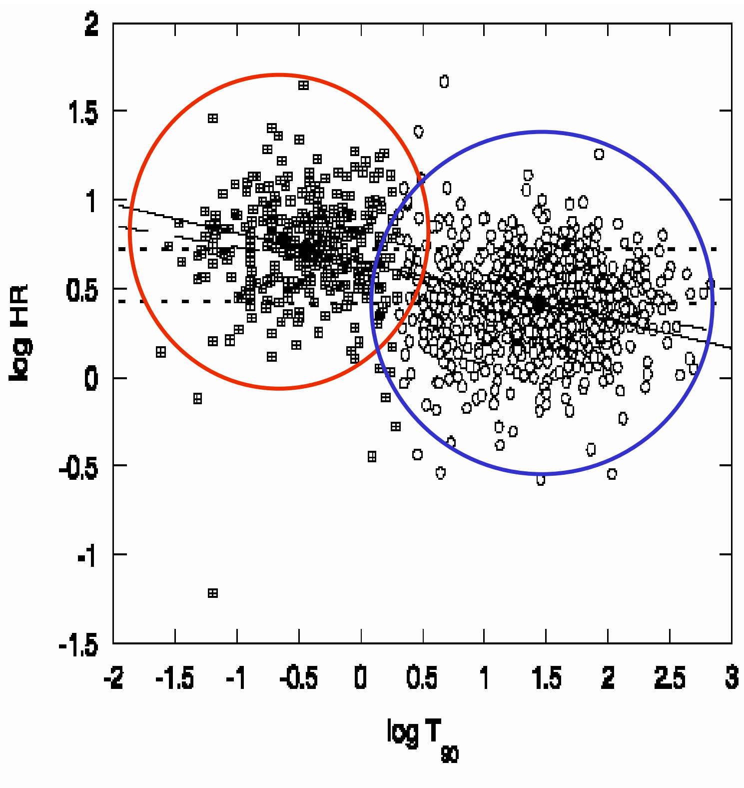
- ❑ complex and unclassifiable light curves
- ❑ bimodal distribution of durations
- ❑ ~0.8 GRB/day measured by ASM in LEO (e.g., CGRO/BATSE)

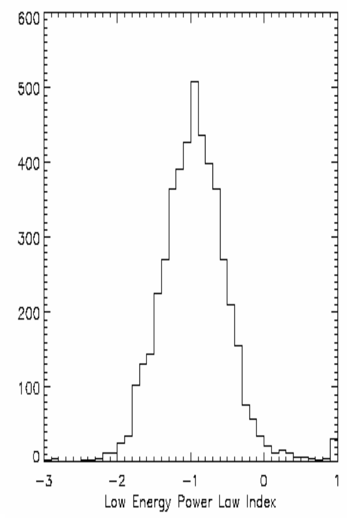


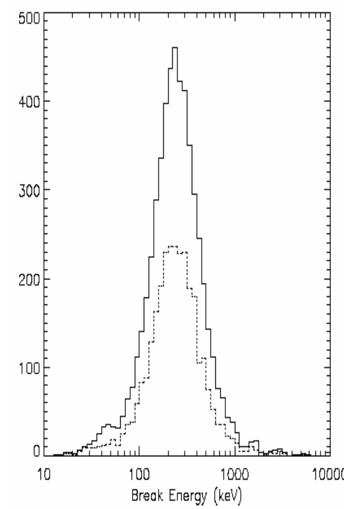


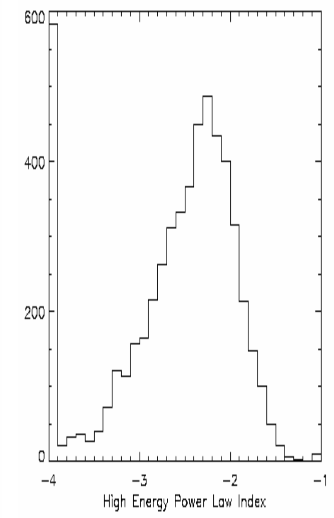
- non thermal spectra
- duration – hardness correlations



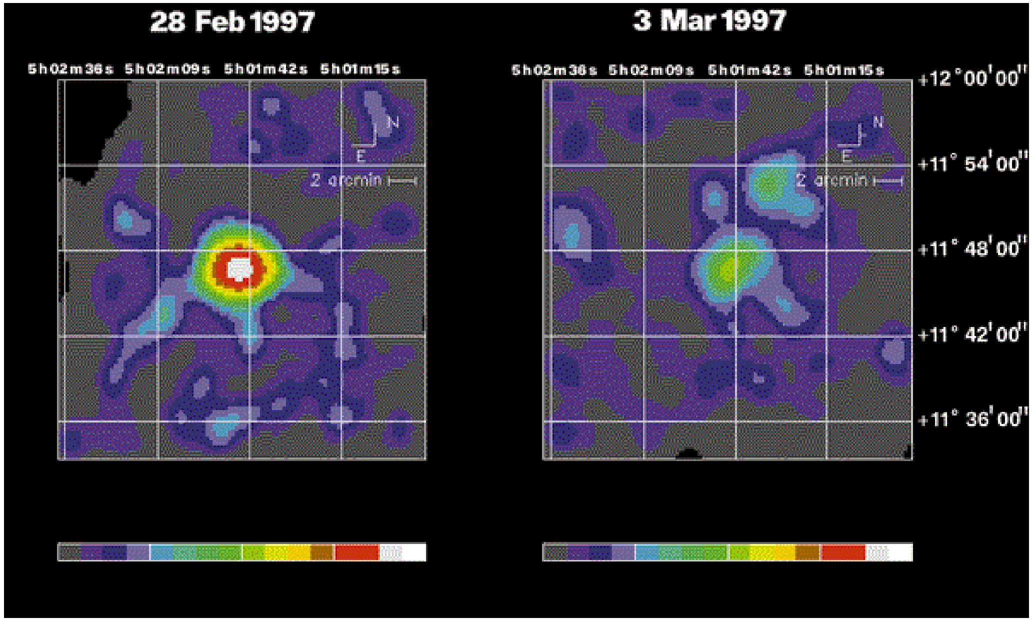


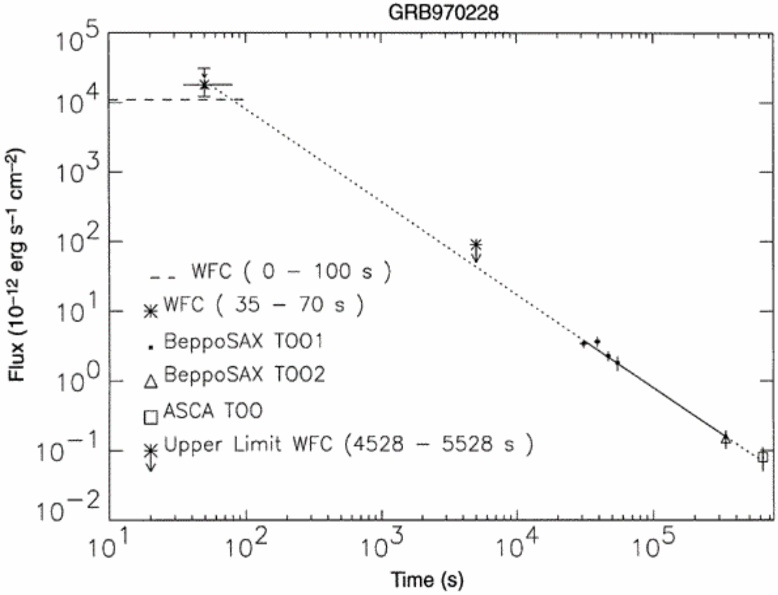


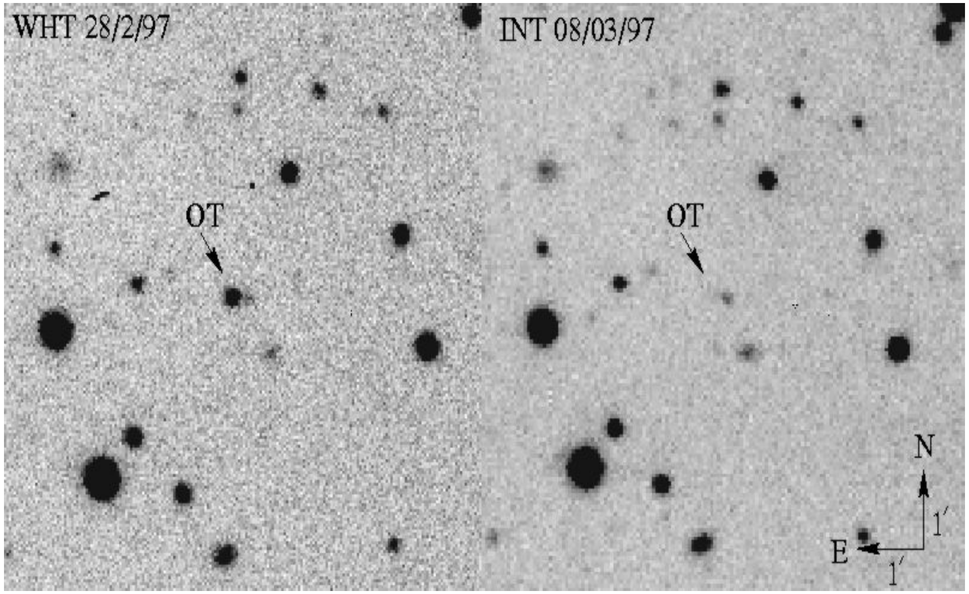


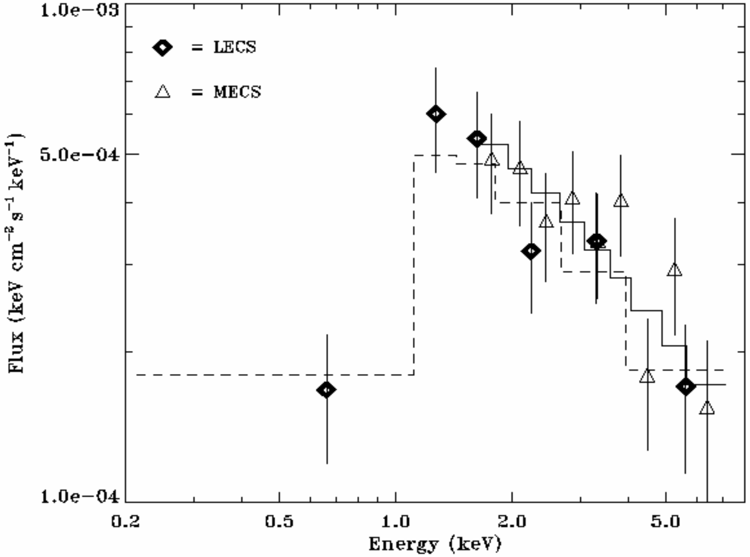


➢ *afterglow emission (late '90s, BeppoSAX + XMM, Chandra + opt/IR/radio telescopes):* power-law decay and spectrum (with exceptions)







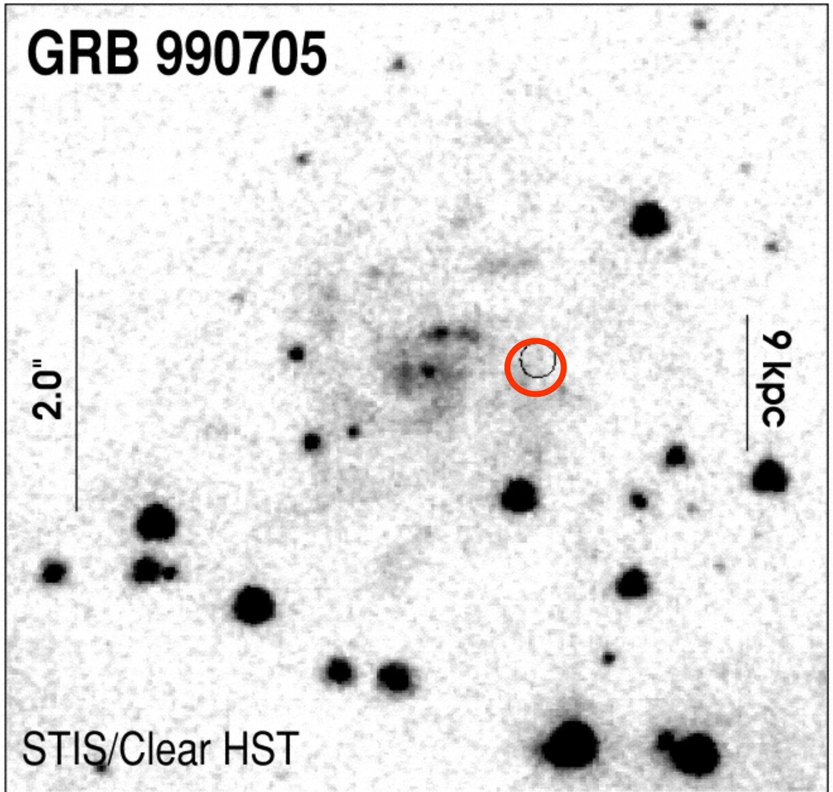


➢ *host galaxies (>1997, X-ray loc. + optical follow-up)*

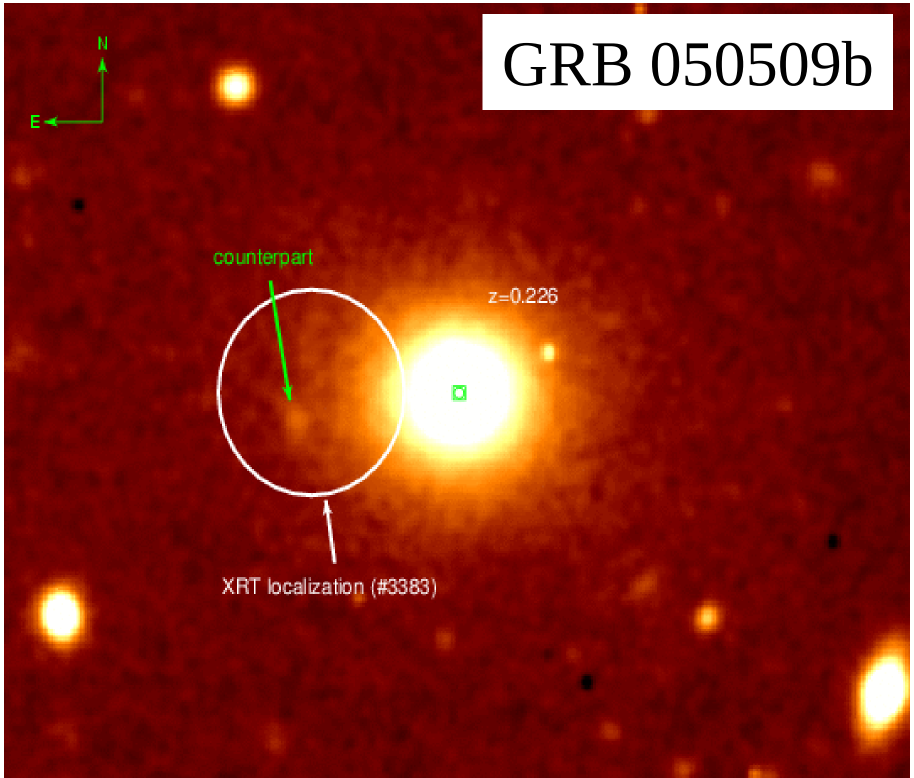
❑ host galaxies long GRBs: blue, usually regular and high star forming, GRB located in star forming regions

❑ host galaxies of short GRBs (very recent): elliptical, irregular galaxies, away from star forming region (but still unclear)

Long

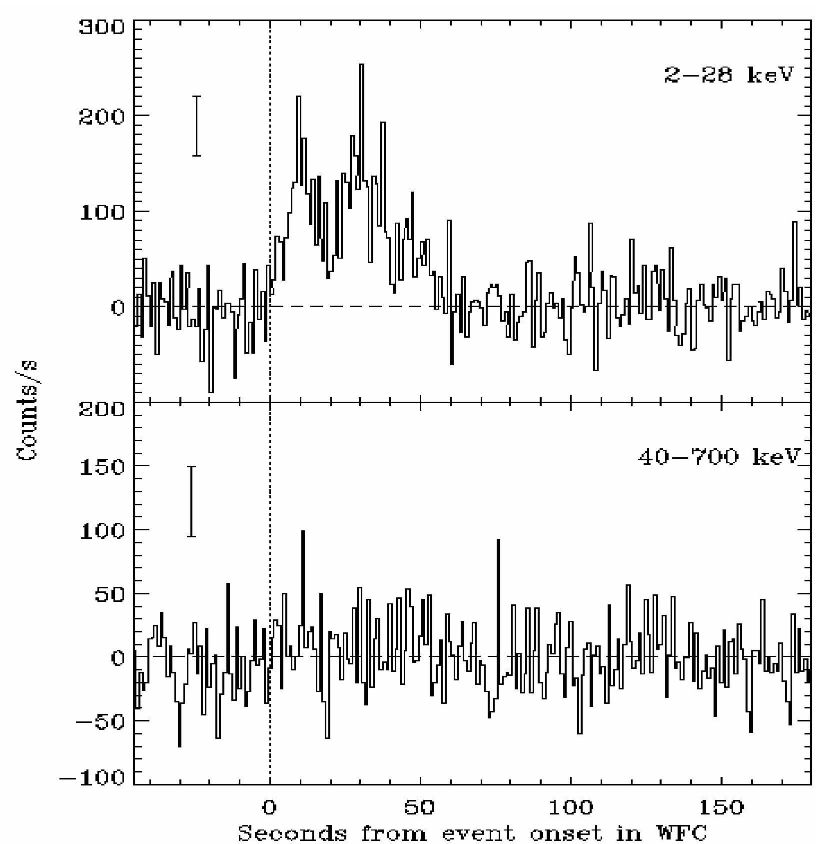


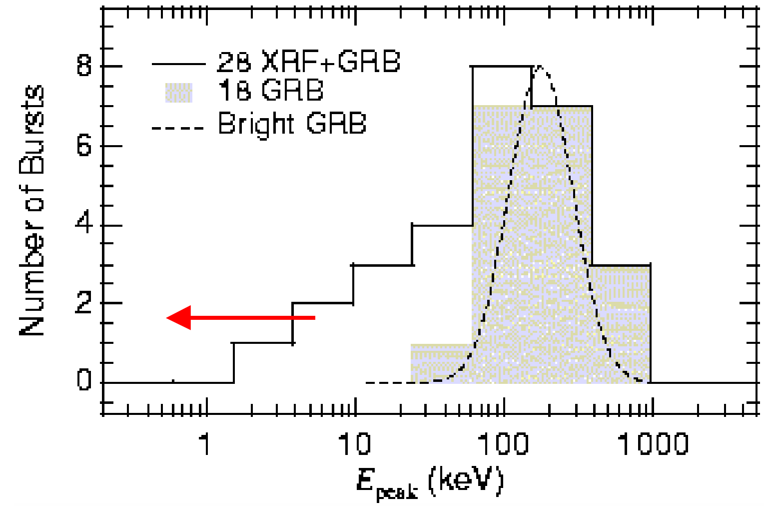
Short

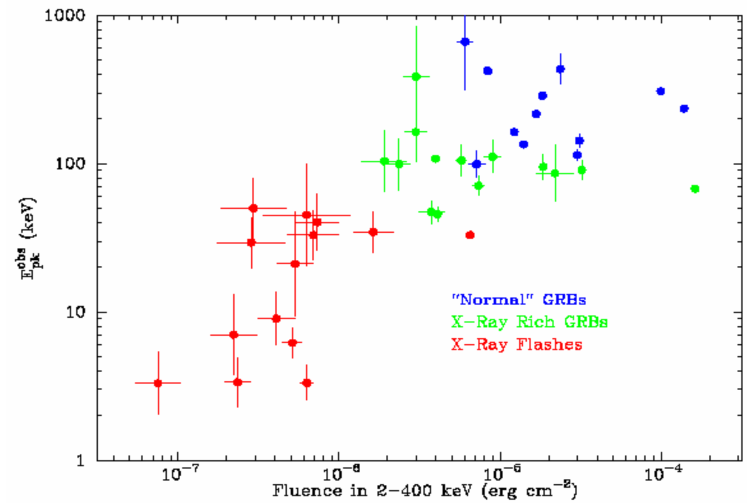


➢ *X-Ray Flashes (late '90s, main contribution by BeppoSAX and HETE-2)*

- ❑ GRBs with only X-ray emission (BeppoSAX, HETE-2)
- ❑ distribution of spectral peak energies has a low energy tails

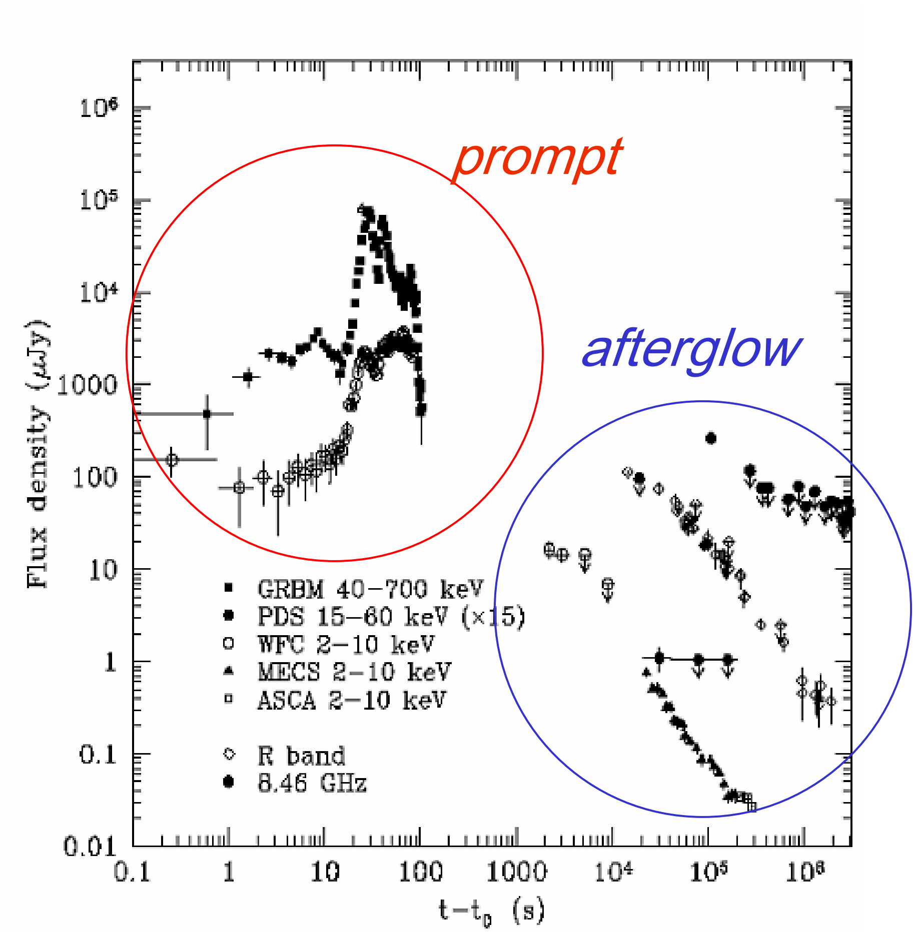




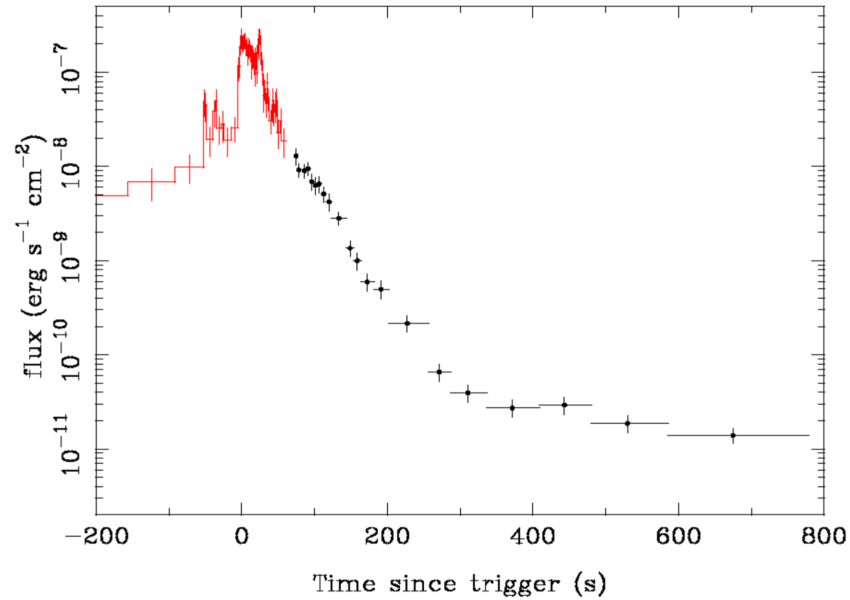


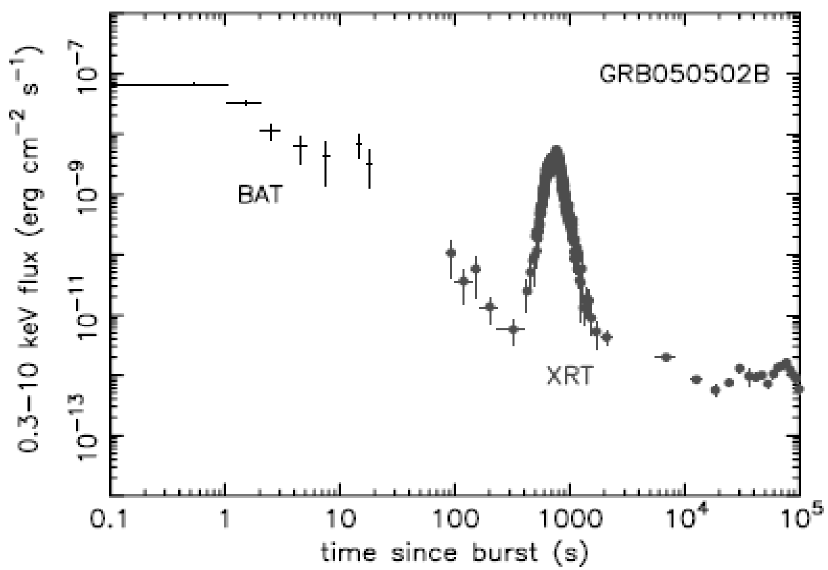
➢ *transition from prompt to afterglow (Swift, >2005)*

❑ BeppoSAX era



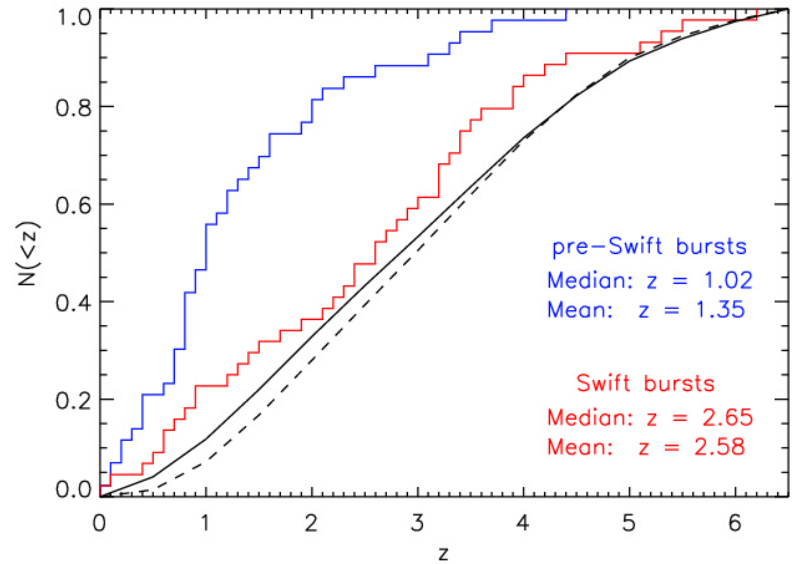
❑ Swift era

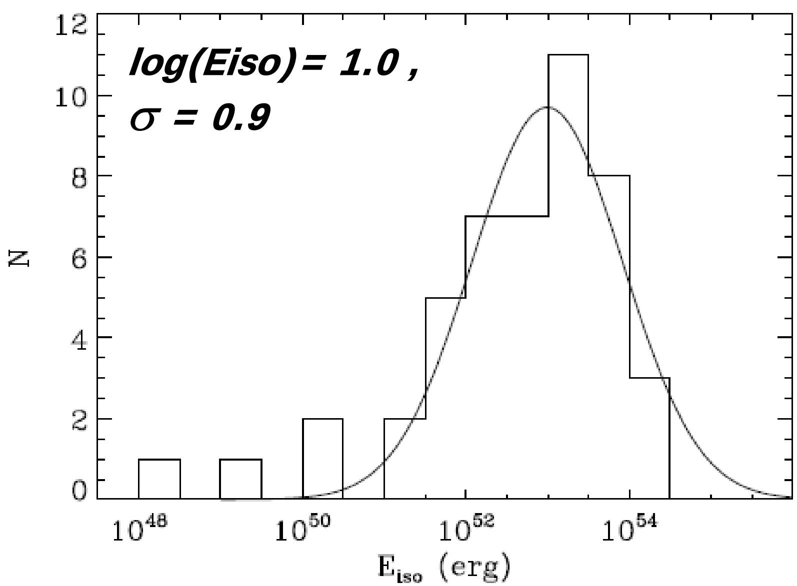




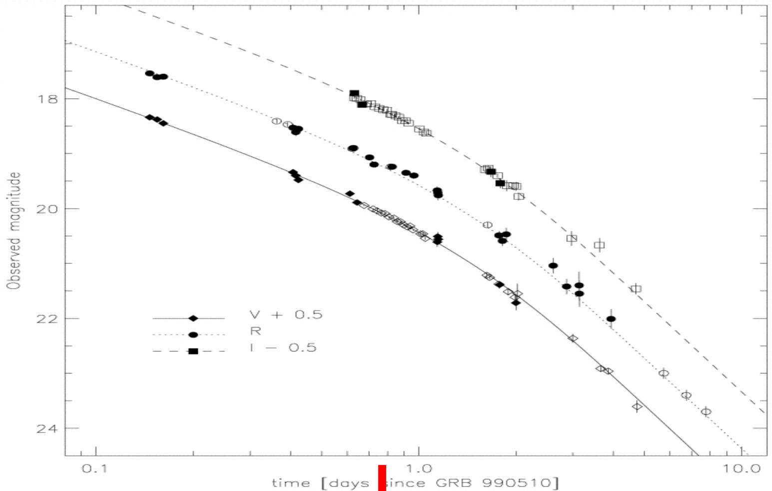
➢ *Distance and luminosity (>1997, X-ray loc. + opt. follow-up)*

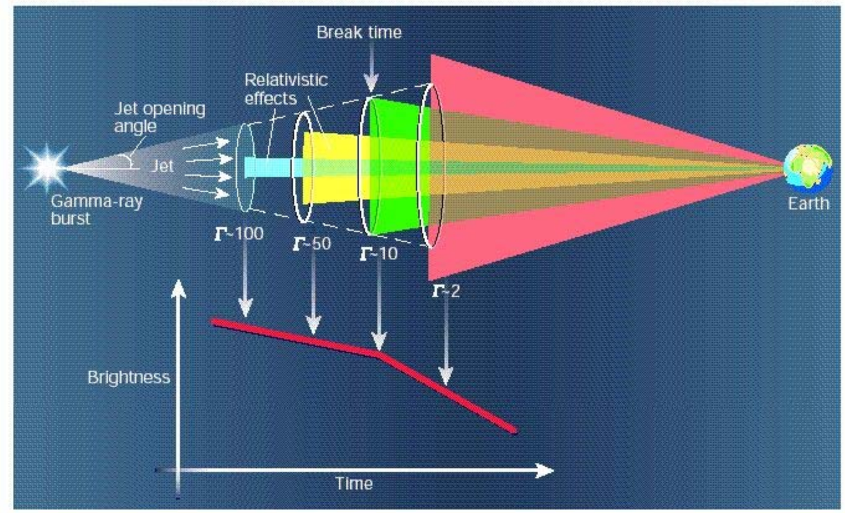
- from optical spectroscopy (OT or HG) -> redshift estimates
- all GRBs with measured redshift (~100) lie at cosmological distances (z = 0.033 – 6.3) (except for the peculiar GRB980425, z=0.0085)
- isotropic equivalent radiated energies can be as high as > 10^{54} erg
- short GRB lie at lower redshifts (<~1) and are less luminous (Eiso < ~10^{52} erg)





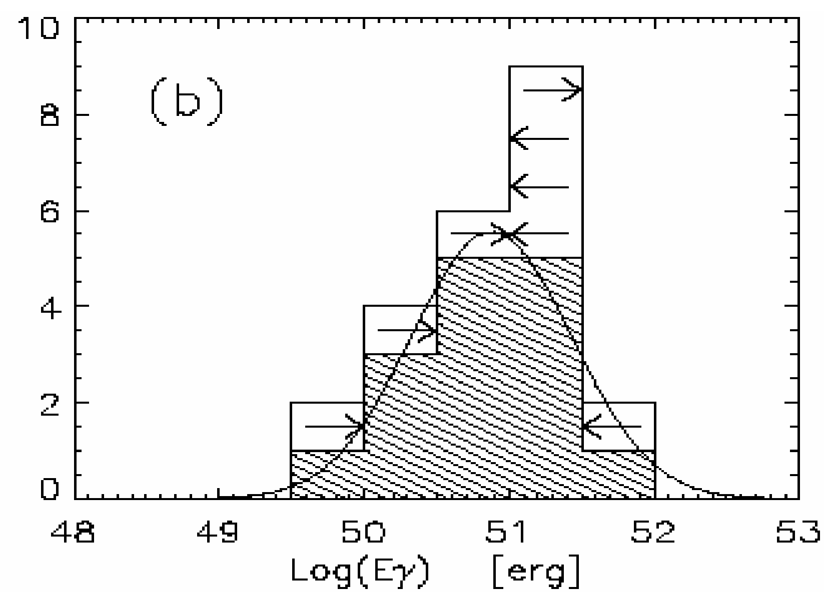
- jet angles derived from the achromatic break time, are of the order of few degrees
- the collimation-corrected radiated energy spans the range $\sim 10^{50} - 10^{52}$ erg





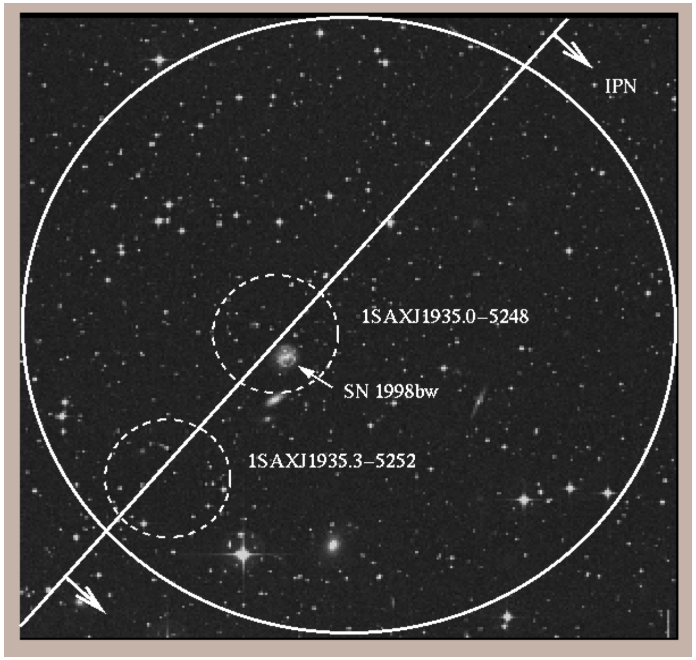
$$\theta = 0.09 \left(\frac{t_{jet,d}}{1+z}\right)^{3/8} \left(\frac{n\,\eta_\gamma}{E_{\gamma,iso,52}}\right)^{1/8}$$

$$E_\gamma = (1-\cos\theta)E_{\gamma,iso}.$$

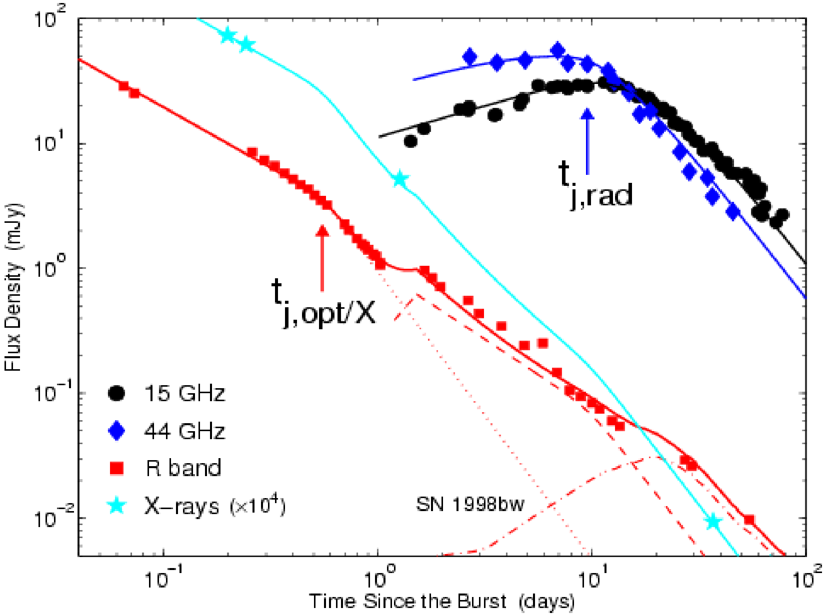


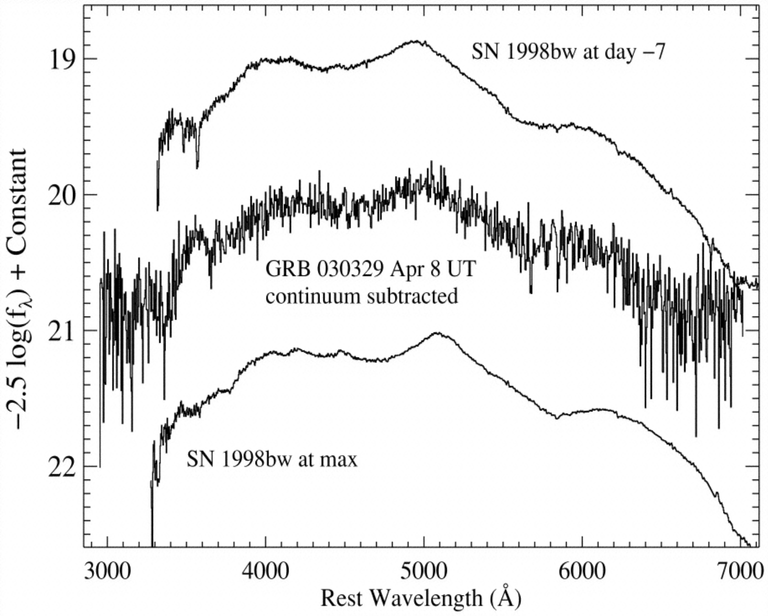
➢ *GRB/SN connection*

➢ GRB 980425, a normal GRB detected and localized by WFC and NFI, but in temporal/spatial coincidence with a type Ib/c SN at z = 0.008 (chance prob. 0.0001)

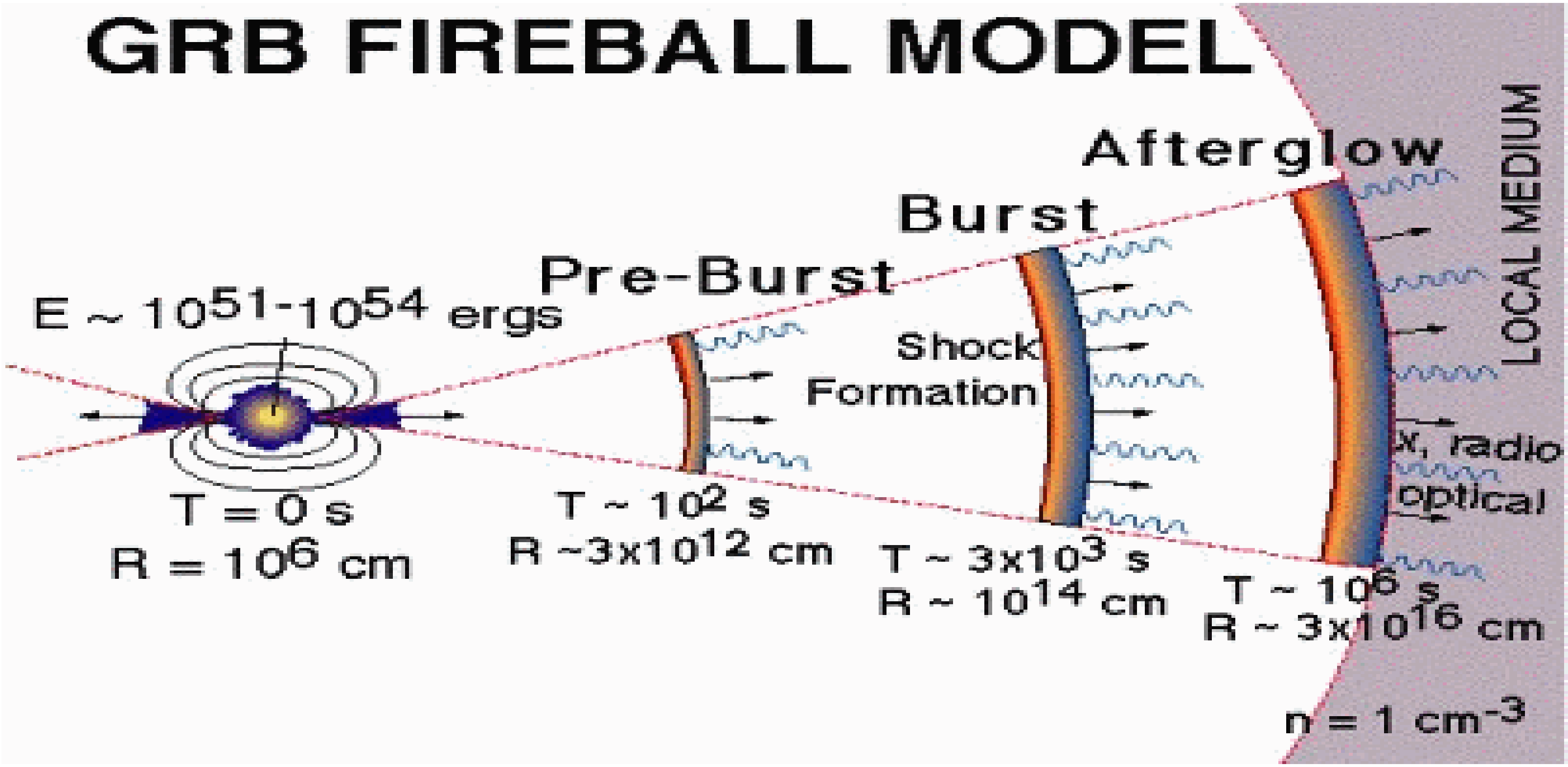


➢ further evidences of a GRB/SN connection: bumps in optical afterglow light curves and optical spectra resembling that of GRB980425 (e.g., GRB 030329)





➢ *Standard scenarios for GRB emission*

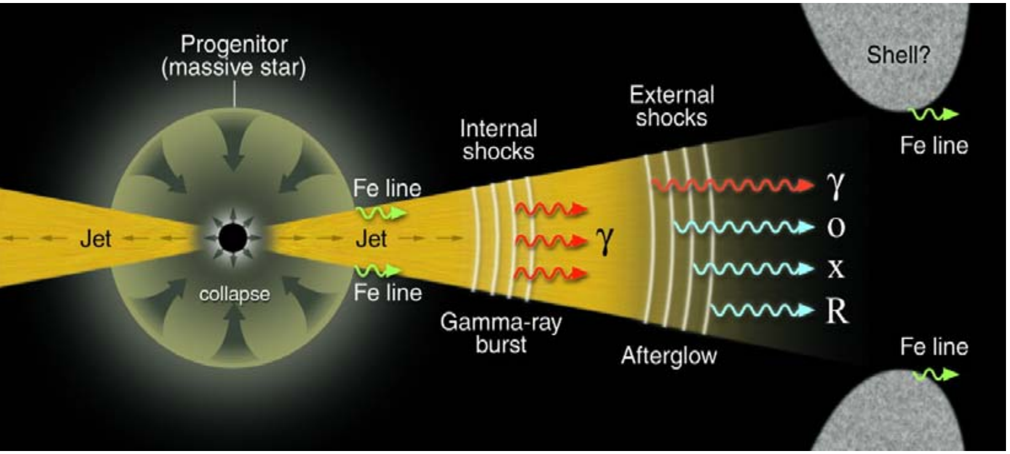


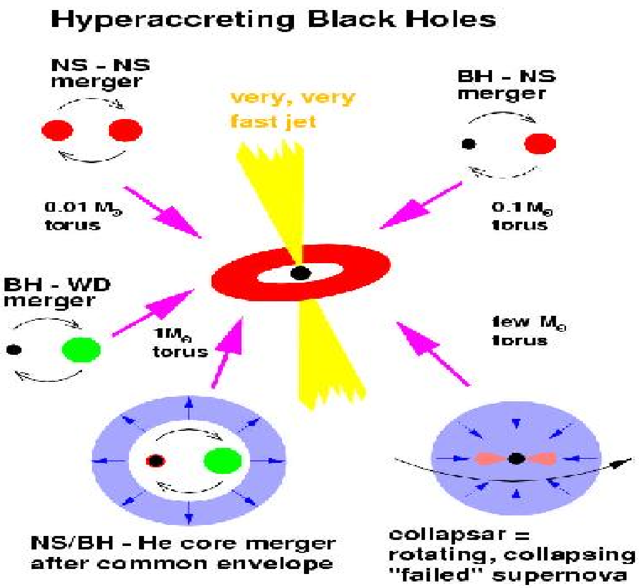
- ❑ ms time variability + huge energy + detection of GeV photons -> plasma occurring ultra-relativistic (Γ > 100) expansion (fireball)
- ❑ non thermal spectra -> shocks synchrotron emission (SSM)
- ❑ fireball internal shocks -> prompt emission
- ❑ fireball external shock with ISM -> afterglow emission

➢ *Standard scenarios for progenitors*

SHORT

LONG





- ➢ energy budget up to >10^{54} erg
- ➢ long duration GRBs
- ➢ metal rich (Fe, Ni, Co) circum-burst environment
- ➢ GRBs occur in star forming regions
- ➢ GRBs are associated with SNe
- ➢ naturally explained collimated emission

- ➢ energy budget up to 10^{51} - 10^{52} erg
- ➢ short duration GRBs (< 5 s)
- ➢ clean circum-burst environment
- ➢ GRBs in the outer regions of the host galaxy

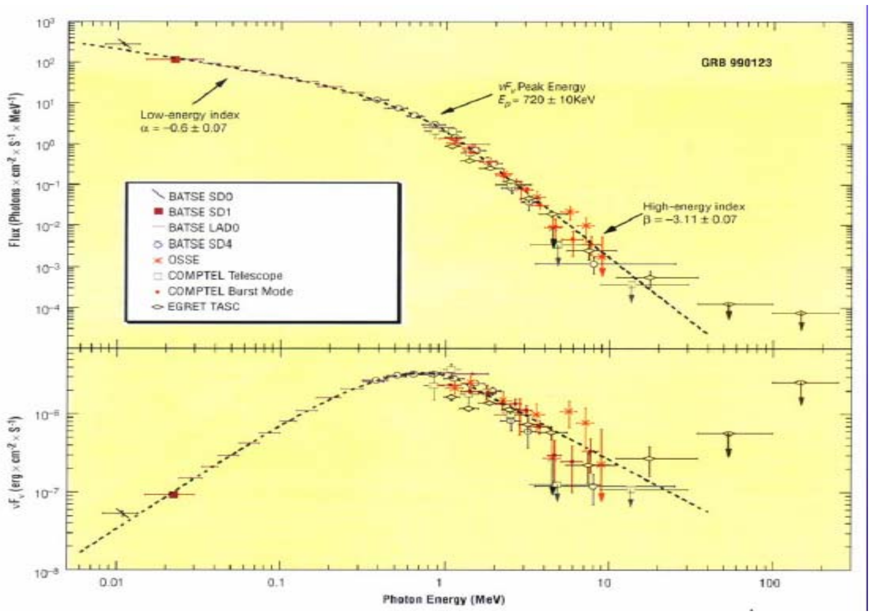
Open issues (several, despite recent huge observational advancements)

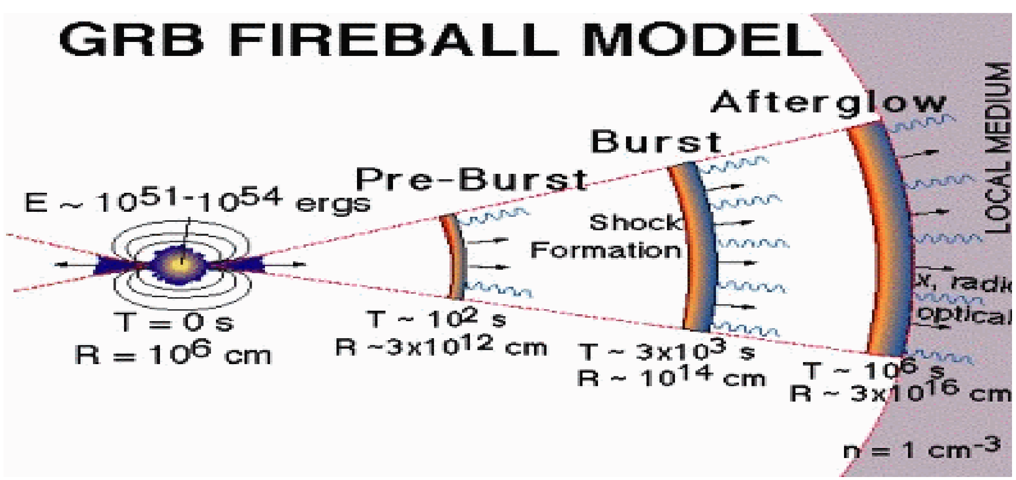
- Prompt and afterglow emission mechanisms: still to be settled
- early afterglow (steep decay, flat decay, flares): to be understood
- GeV / TeV emission: need for new measurements to test models
- X/gamma-ray polarization: need of measurements to test models
- short vs. long events: emission mech. and GRB/SN connection
- sub-energetic GRB and GRB rate: to be investigated -> SFR evolution
- collimated emission: yes or no ?
- spectrum-energy correlations and GRB cosmology: explanations and test

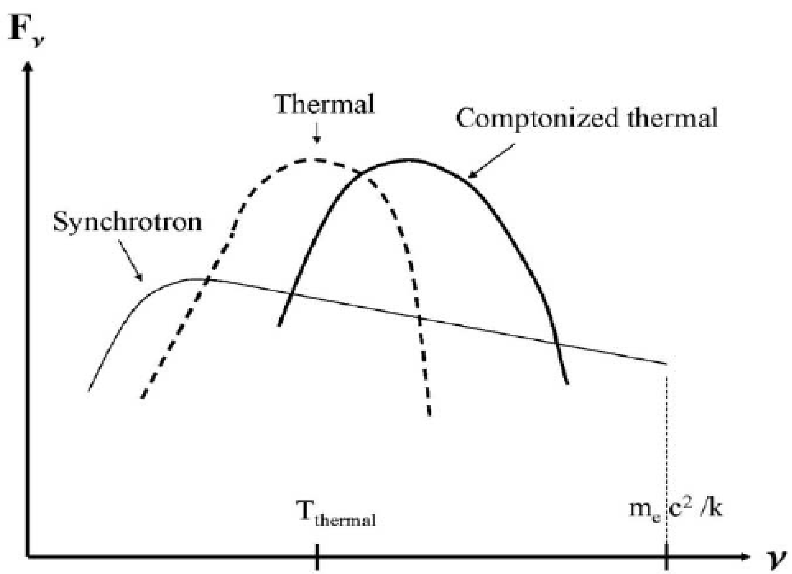
... and more !

➢ *GRB prompt emission physics*

❑ physics of prompt emission still not settled, various scenarios: SSM internal shocks, IC-dominated internal shocks, external shocks, photospheric emission dominated models, kinetic energy dominated fireball , poynting flux dominated fireball)

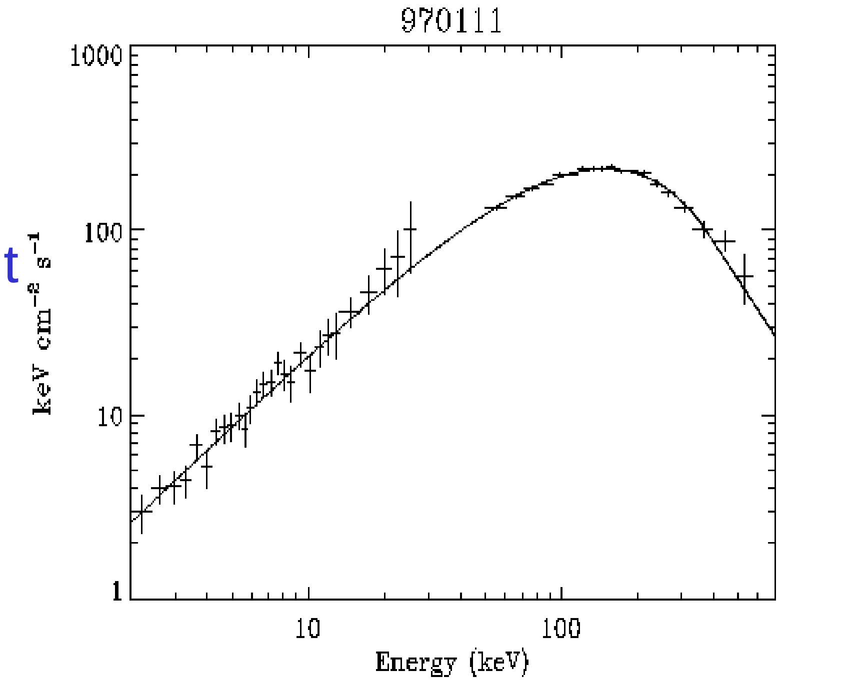


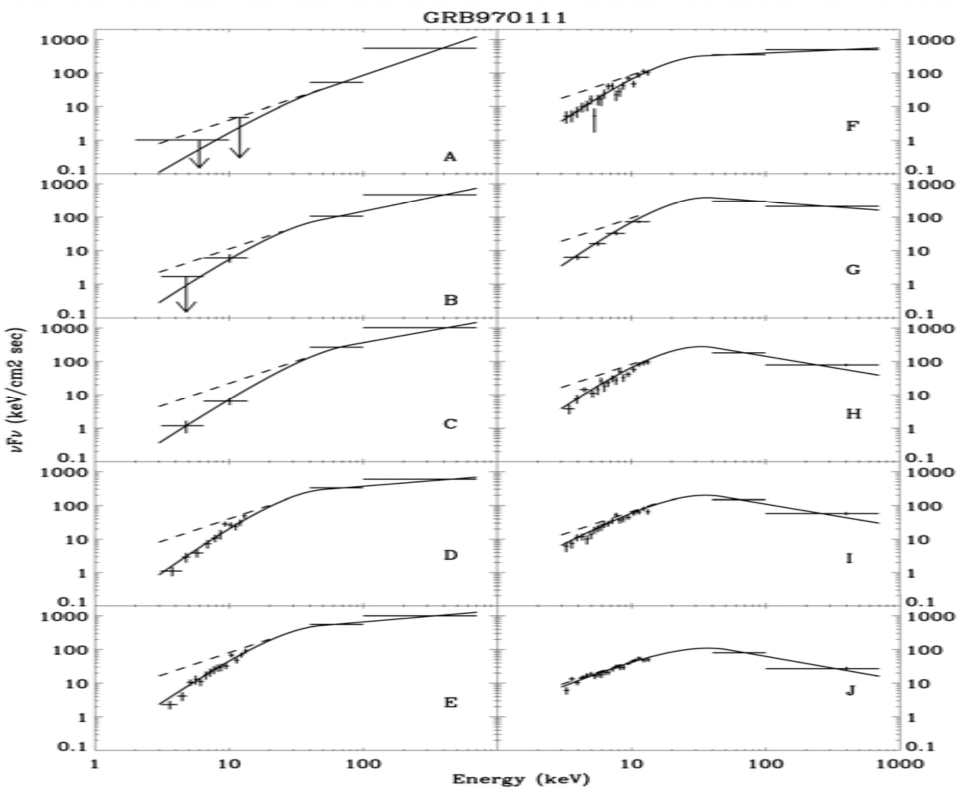




- ❑ most time averaged spectra of GRBs are well fit by synchrotron shock model

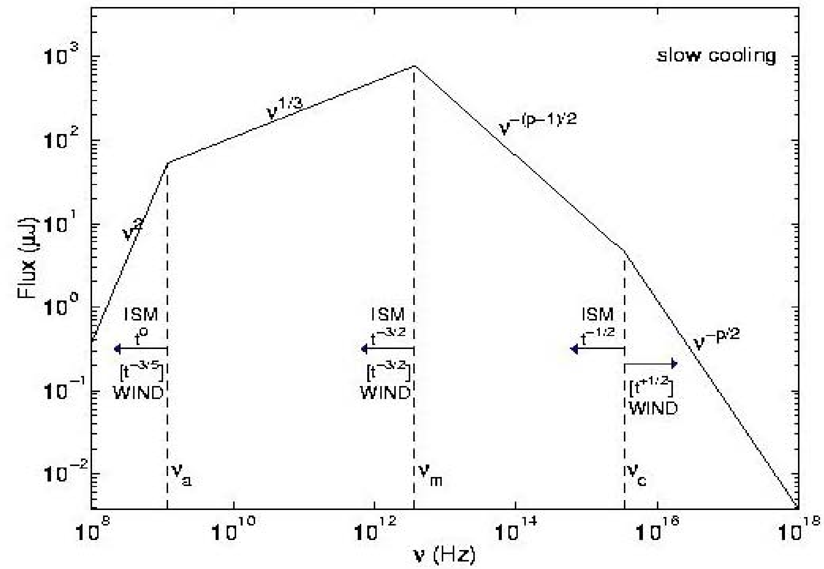
- ❑ at early times, some spectra inconsistent with optically thin synchrotron: possible contribution of an Inverse Compton component and/or thermal emission from the fireball photosphere



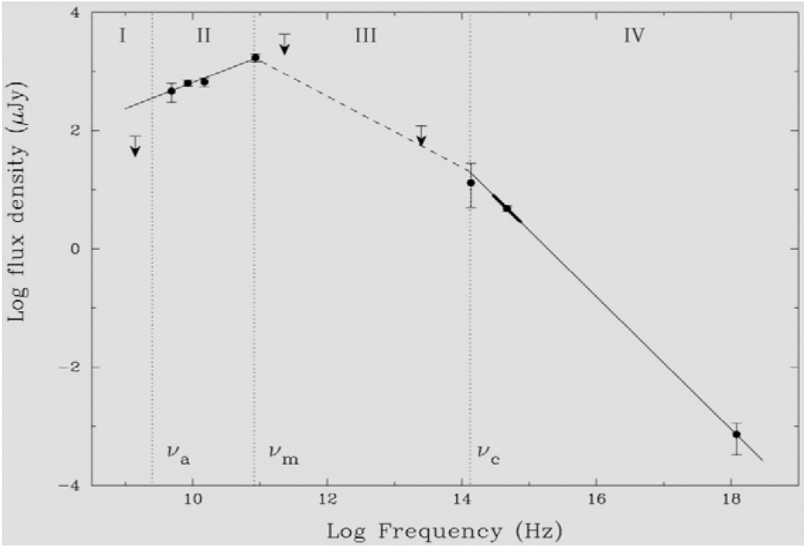


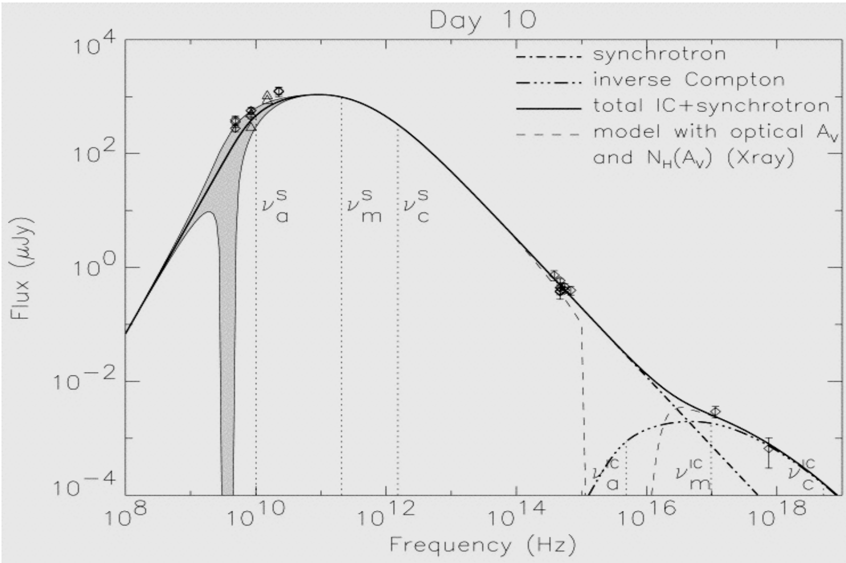
α $N(E)$	$\alpha+1$ $F(E)$	$\alpha+2$ EF_E	model/spectrum
-3/2	-1/2	1/2	Synchrotron emission with cooling
-1	0	1	Quasi–saturated Comptonization
-2/3	1/3	4/3	Instantaneous synchrotron
0	1	2	Small pitch angle/jitter inverse Compton by single e^-
1	2	3	Black Body
2	3	4	Wien

➢ *Afterglow emission physics*



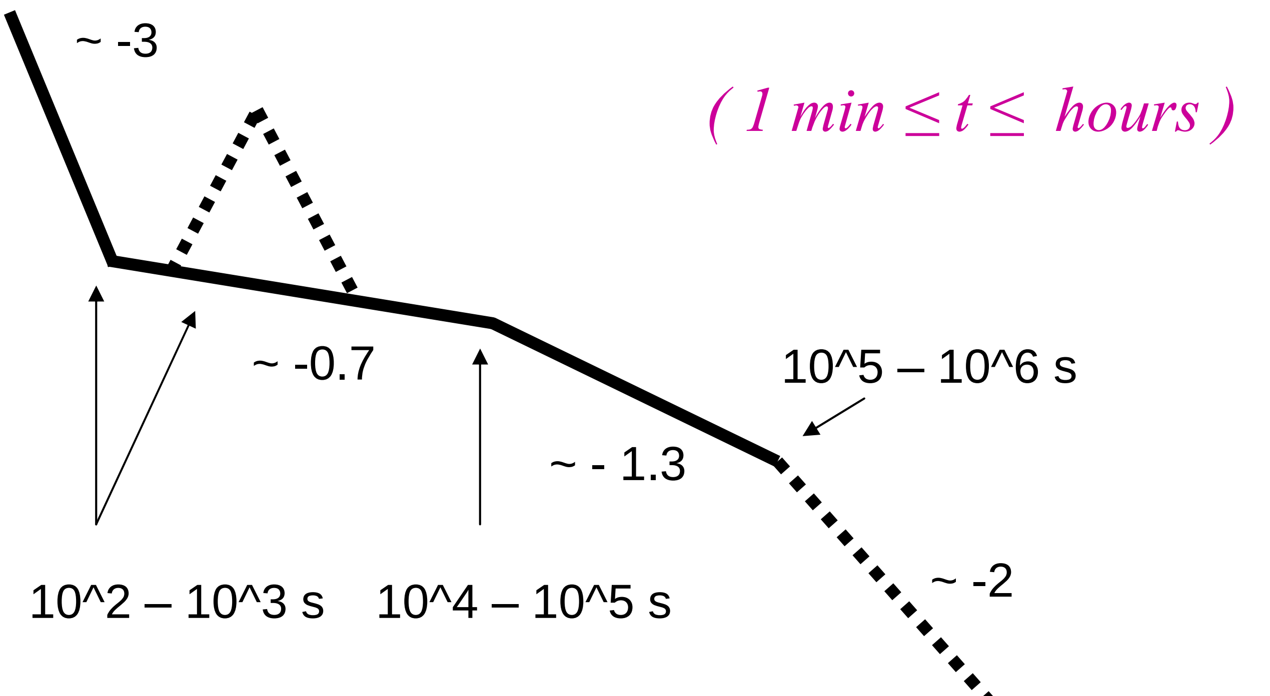
- consistency with synchrotron predictions found e.g. for GRB 970508
- deviations in the X-ray band from synchrotron: found for GRB000926 (Harrison et al. 2001) and GRB010222 (in 't Zand et al. 2001).
- they are consistent with relevant Inverse Compton on the low energy photons





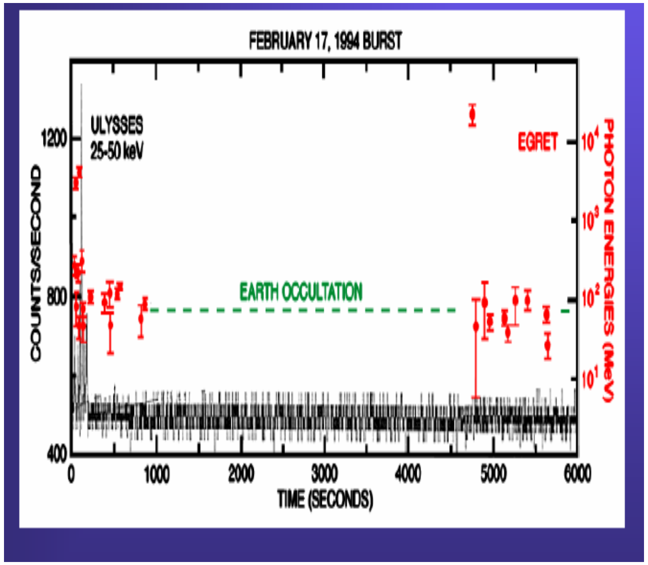
➢ *Early afterglow*

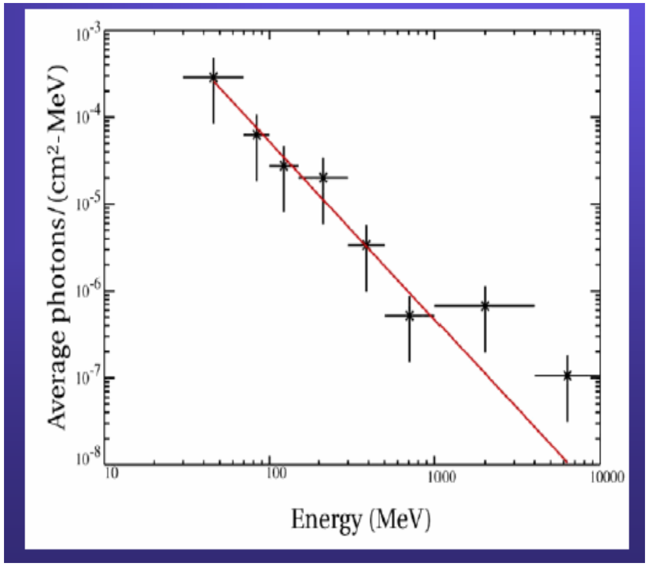
- new features seen by Swift in X-ray early afterglow light curves (initial very steep decay, early breaks, flares) mostly unpredicted and unexplained
- initial steep decay: continuation of prompt emission, mini break due to patchy shell, IC up-scatter of the reverse shock sinchrotron emission ?
- flat decay: probably “refreshed shocks” (due either to long duration ejection or short ejection but with wide range of Γ) ?
- flares: could be due to: refreshed shocks, IC from reverse shock, external density bumps, continued central engine activity, late internal shocks...

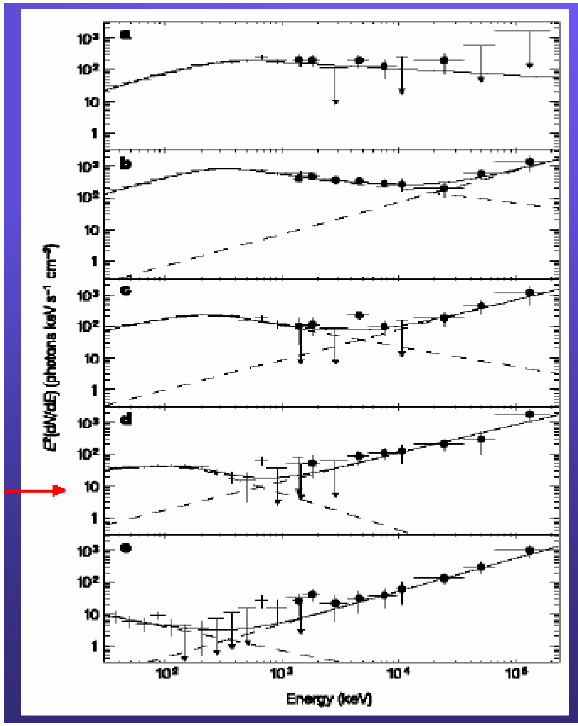


➢ GeV emission

- ❑ CGRO/EGRET detected VHE (from 30 MeV up to 18 GeV) photons for a few GRBs
- ❑ VHE emission can last up to thousends of s after GRB onset
- ❑ average spectrum of 4 events well described by a simple power-law with index ~2 , consistent with extension of low energy spectra
- ❑ GRB 941017,measured by EGRET-TASC shows a high energy component inconsistent with synchrotron shock model
- ❑ GeV emission produced by X-ray flares ?





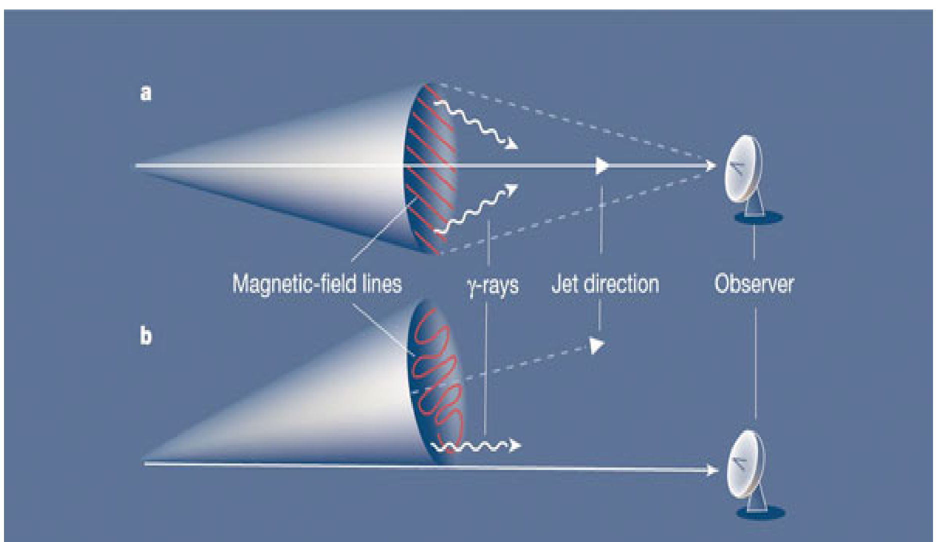


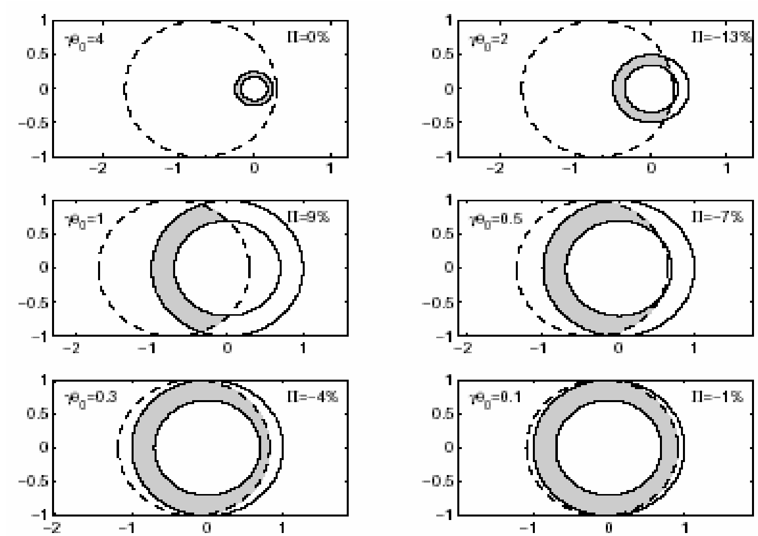
➢ *Polarization*

- ❑ no secure detection of polarization of prompt emission (some information from INTEGRAL?); polarization of a few % for some optical / radio afterglows

- ❑ radiation from synchrotron and IC is polarized, but a high degree of polarization can be detected only if magnetic field is uniform and perpendicular to line of sight

- ❑ small degree of polarization detectable if magnetic field is random, emission is collimated (jet) and we are observing only a (particular) portion of the jet or its edge



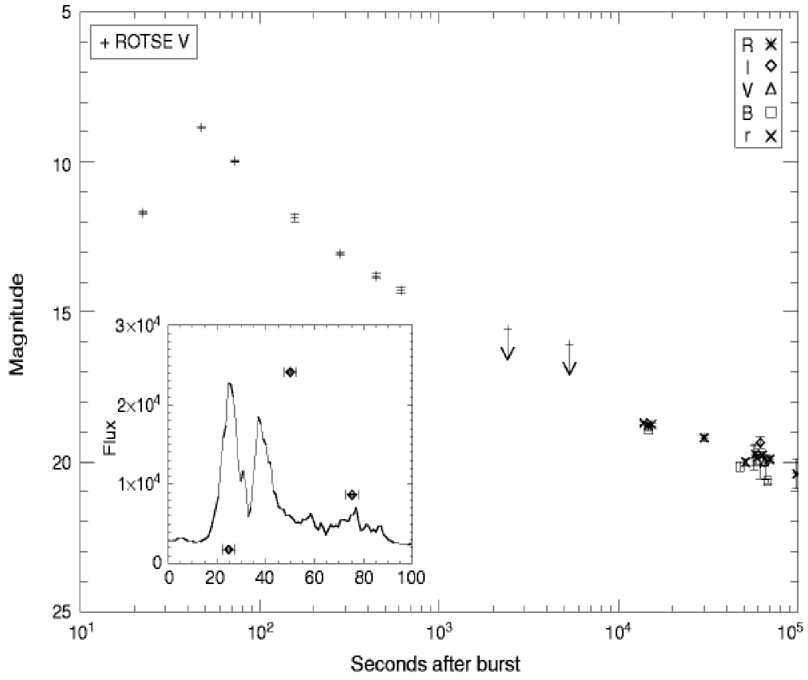


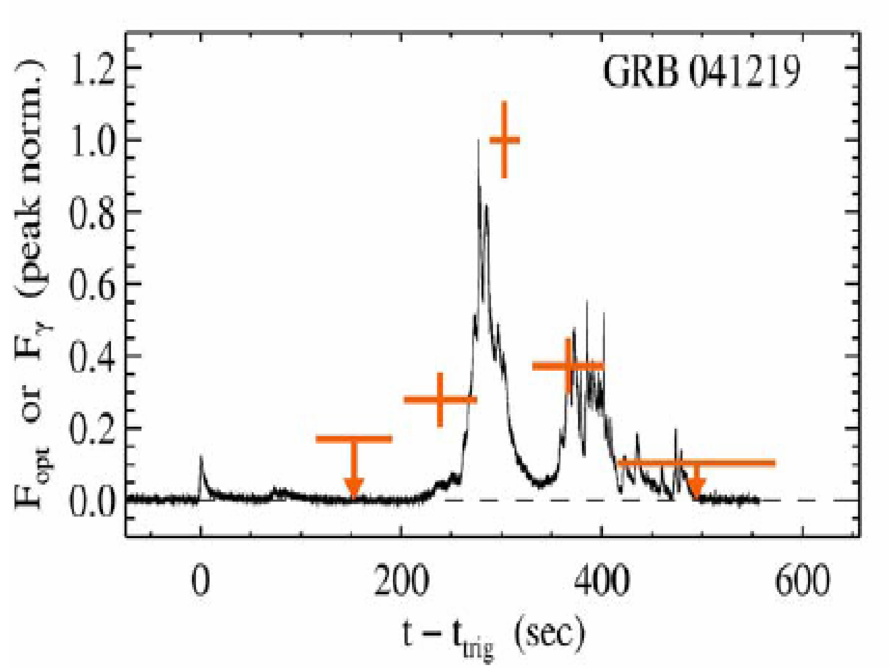
➢ *Prompt optical emission (thanks to robotic telescopes)*

- ❑ GRB990123: first detection (by ROTSE) of optical emission simultaneous to a GRB

- ❑ optical light curve does not follow high energy light curve: evidence for a different origin (reverse shock ?)

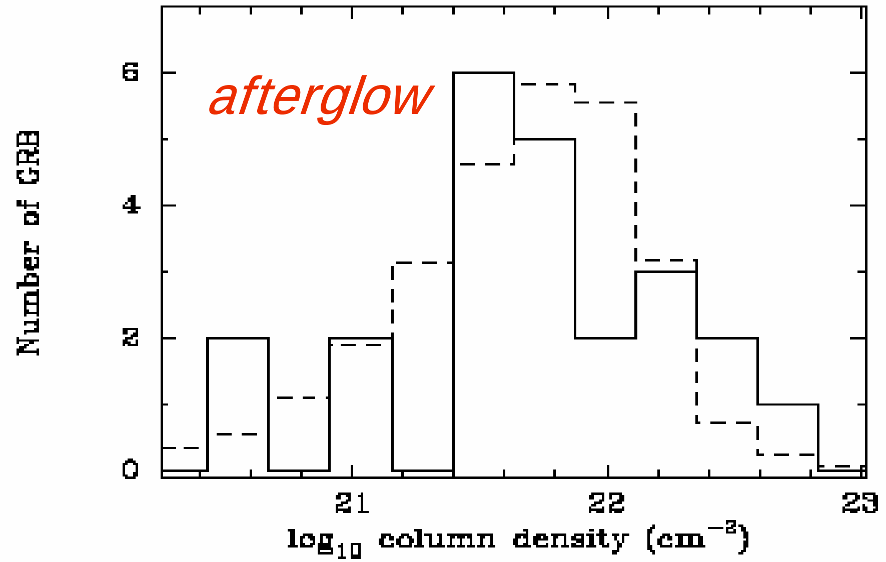
- ❑ GRB041219 (RAPTOR) contrary to GRB990123, the optical light curve follows the high energy light curve: evidence for same origin (internal shocks ?)

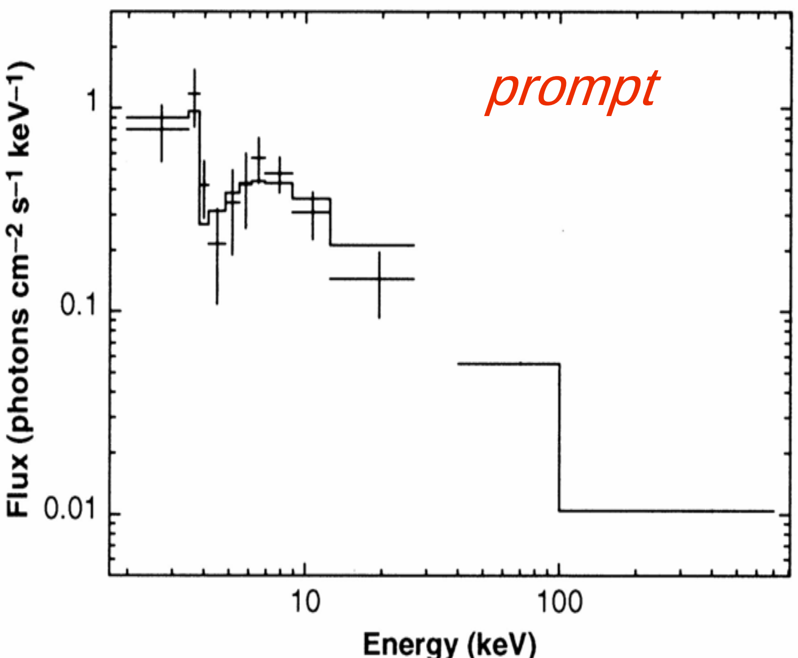


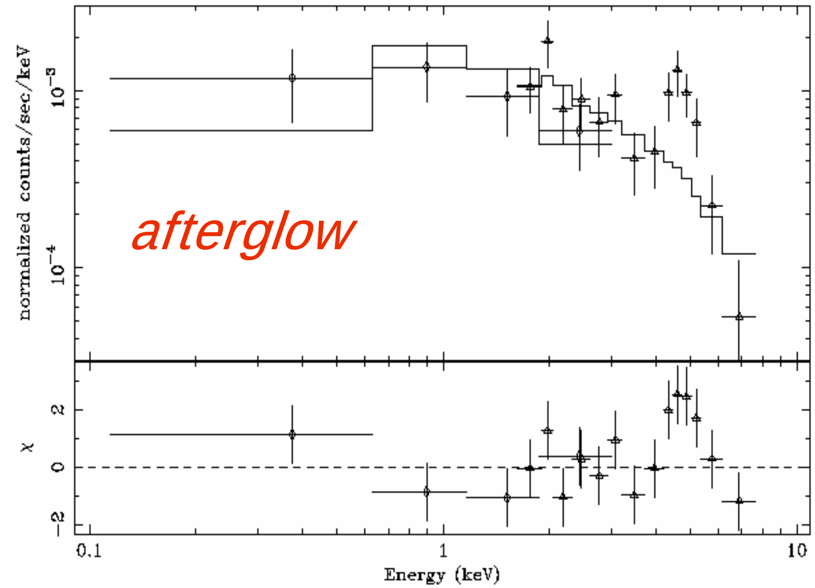


➢ *Circum-burst environment*

- evidence of overdense and metal enriched circum-burst environment fror absorption and emission features
- emission lines in afterglow spectrum detected by BeppoSAX but not by Swift
- Swift detects intrinsic NH for many GRB afterglows
- optical (Lyα) vs. X-ray NH



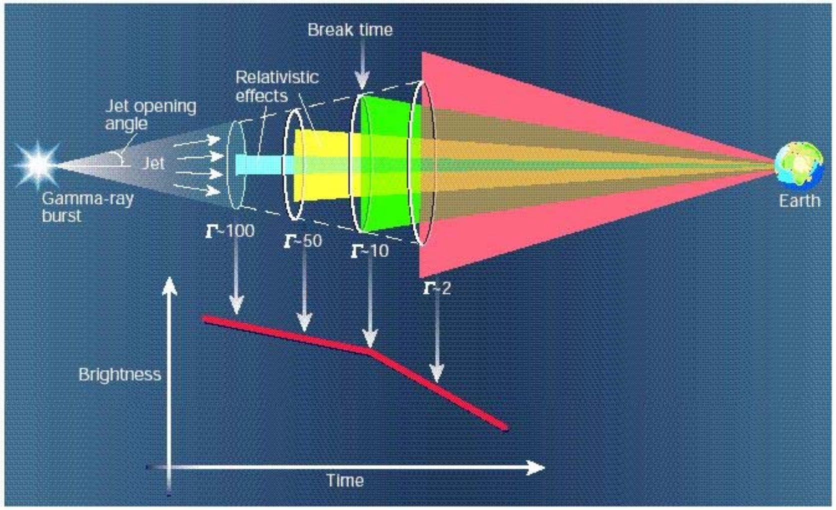


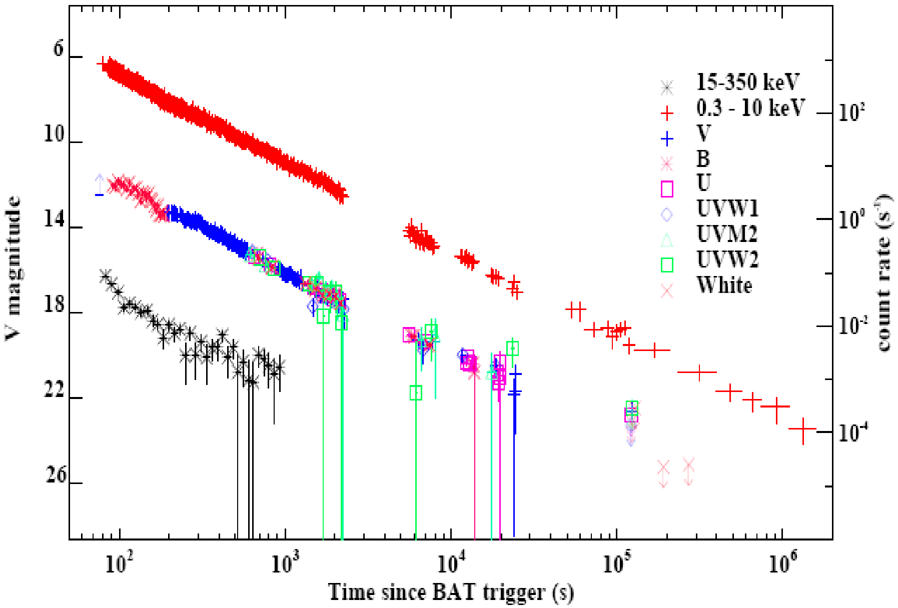


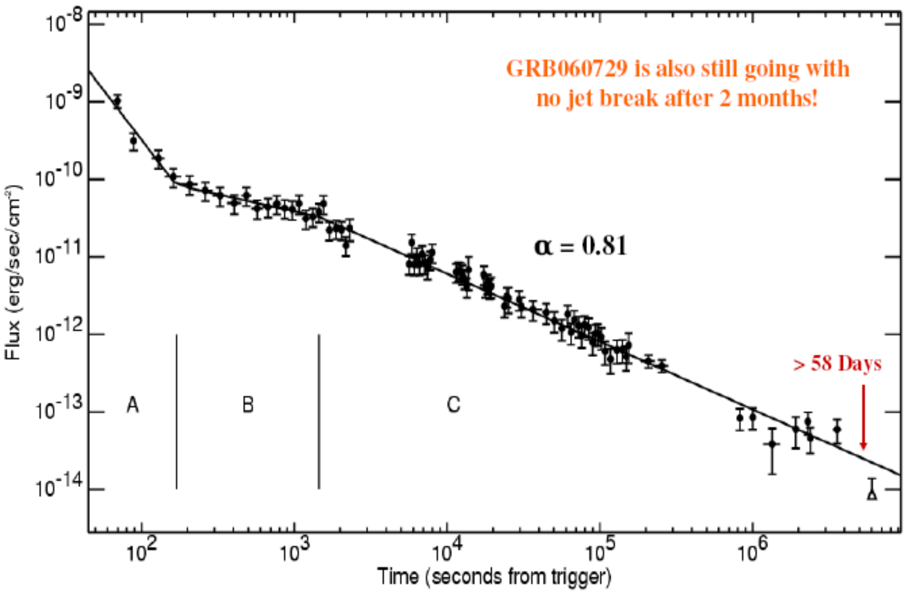
➢ *Collimated or isotropic ?*

- ❑ lack of jet breaks in several Swift X-ray afterglow light curves, in some cases, evidence of achromatic break

- ❑ challenging evidences for Jet interpretation of break in afterglow light curves or due to present inadequate sampling of optical light curves w/r to X-ray ones and to lack of satisfactory modeling of jets ?

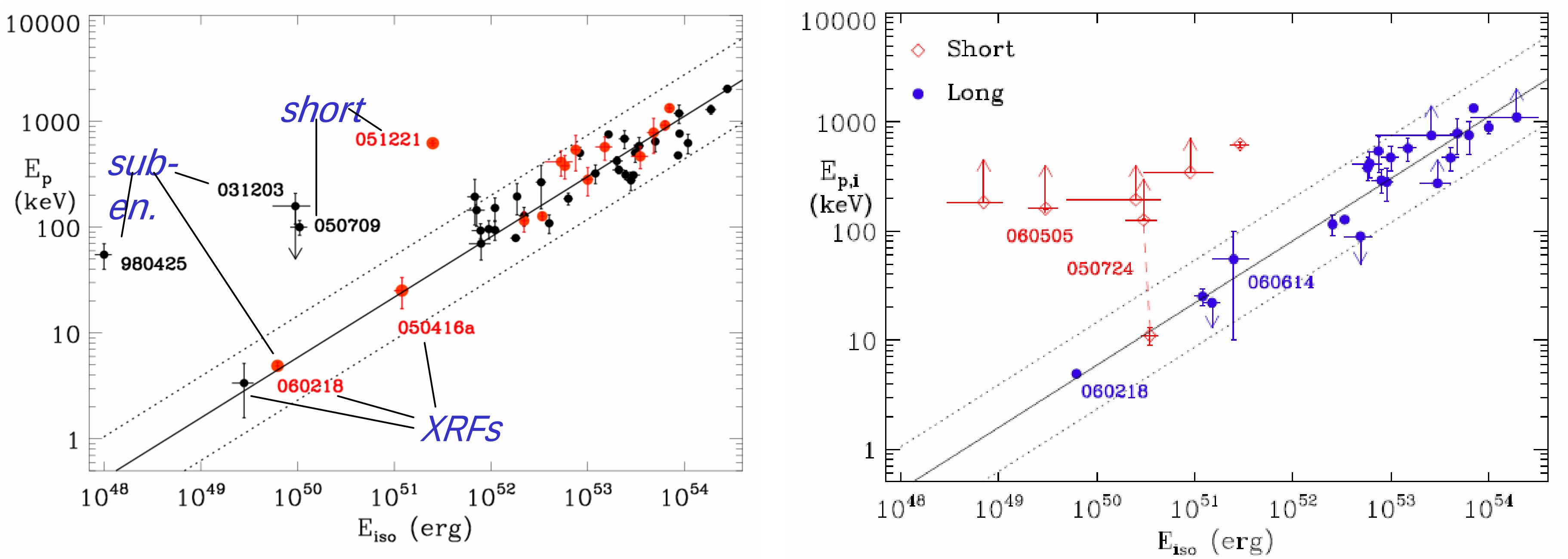




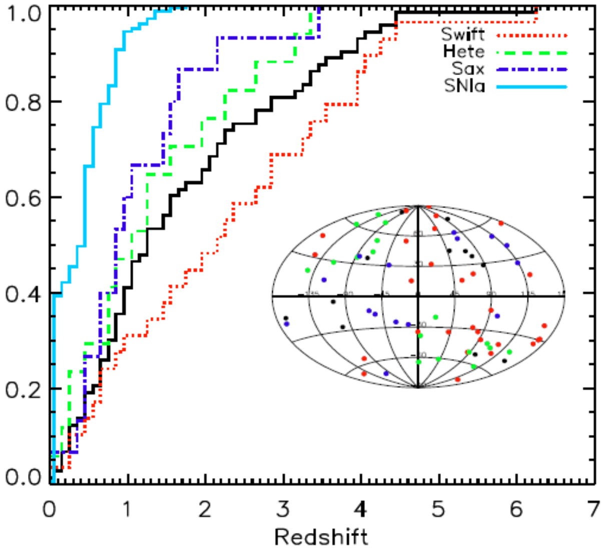


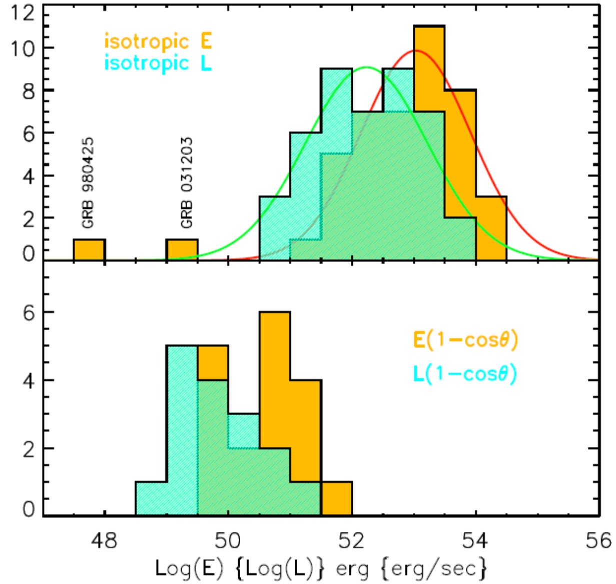
➢ *Spectrum-energy correlations: GRB physics (and cosmology ?)*

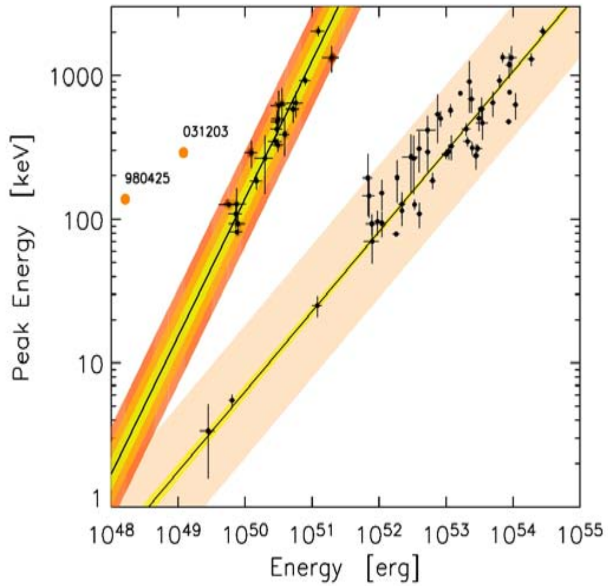
- ❑ Strong correlation between Ep,i and Eiso for long GRBs: test for prompt emission models (physics, geometry, GRB/XRF unification models)
- ❑ short GRB do not follow the correlation: clues to difference in emission mechanism (soft tail of short GRB 050724 consistent with Ep,i-Eiso)
- ❑ only outliers: GRB 980425 (very peculiar) and, possibly, INTEGRAL GRB 031203 -> sub-class of GRBs ?
- ❑ confirmed by Swift: limited impact of selection effects (if any)

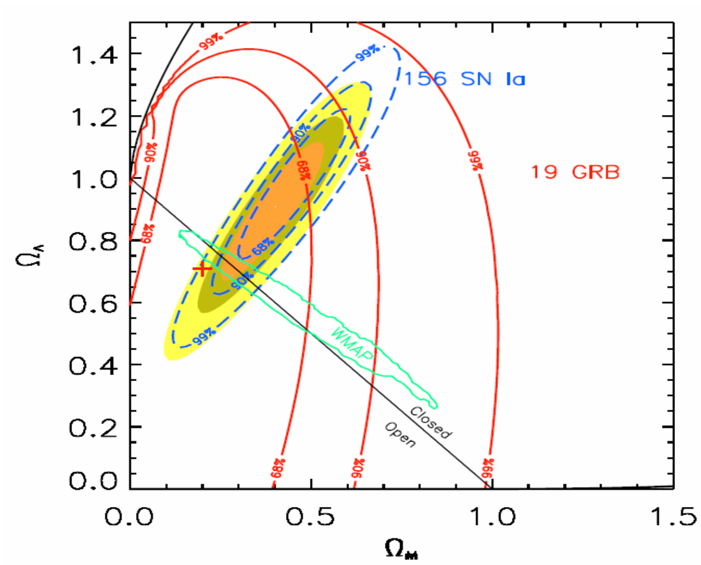


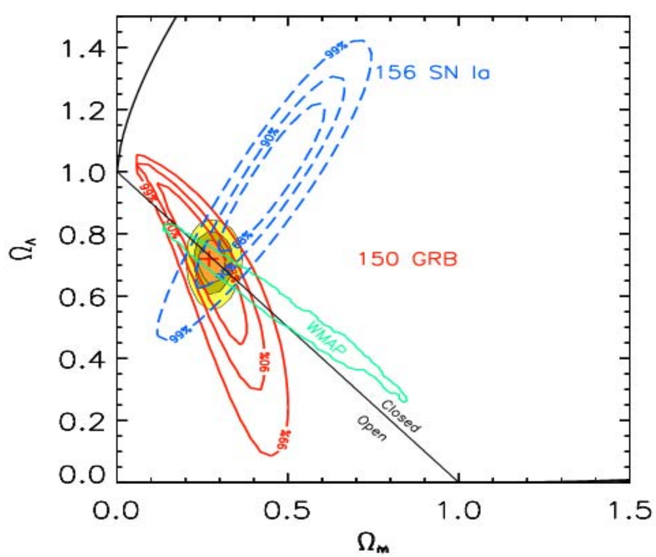
- GRB have huge luminosity, a redshift distribution extending far beyond SN Ia; high energy emission -> no extinction problems
- not standard candles, but can they be standardized with spec-en. corr. ?









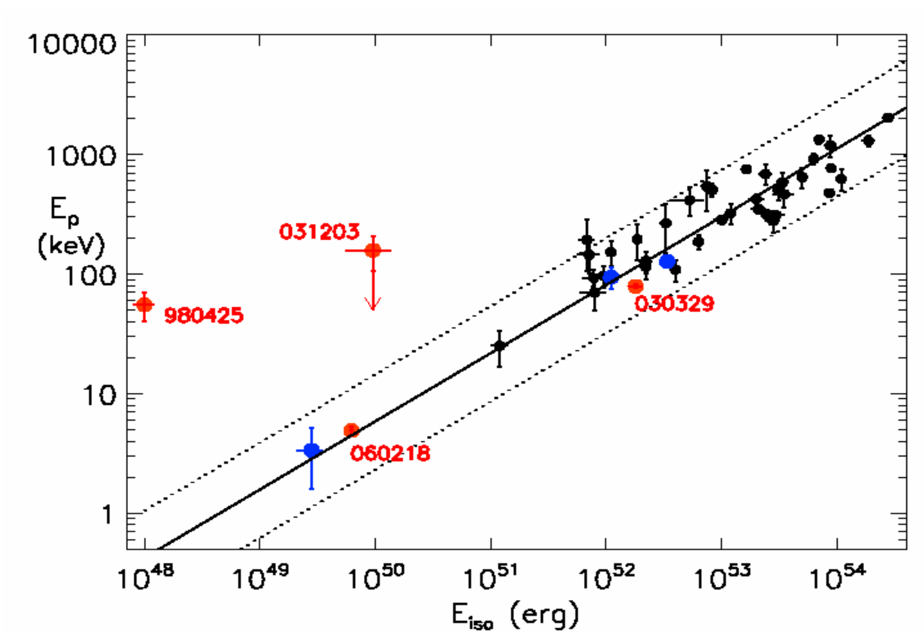


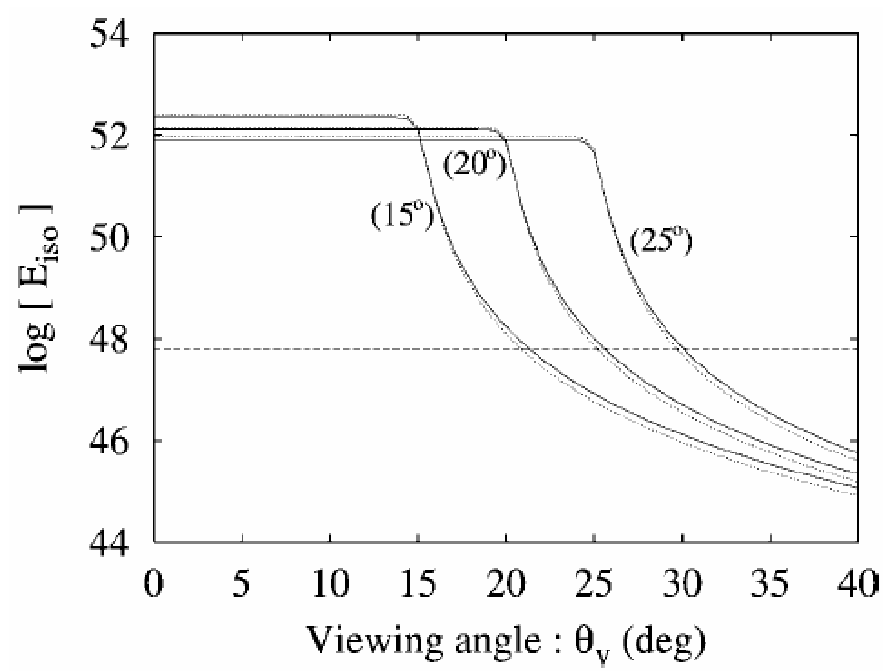
➢ *sub-energetic GRBs*

- ❑ GRB980425 not only prototype event of GRB/SN connection but closest GRB (z = 0.0085) and sub-energetic event (Eiso ~ 10^{48} erg, Ek,aft ~ 10^{50} erg), outlier to $E_{p,i}$-E_{iso} correlation

- ❑ GRB031203 (by INTEGRAL): the most similar case to GRB980425/SN1998bw: very close (z = 0.105), SN2003lw, sub-energetic

- ❑ normal GRBs seen off-axis or truly sub-energetic ? GRB 060218 on-axis -> truly sub-en.?





➢ *GRB/SN connection and short/long classification*

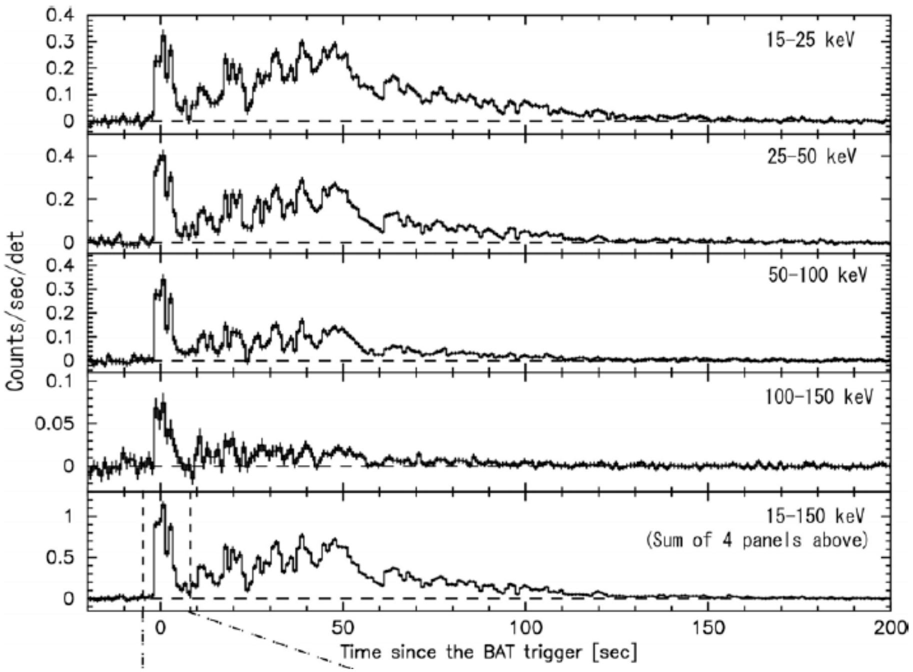
❑ GRB 060614: very low upper limits to the magnitude of an associated SN wich exclude at least its association with a hypernova

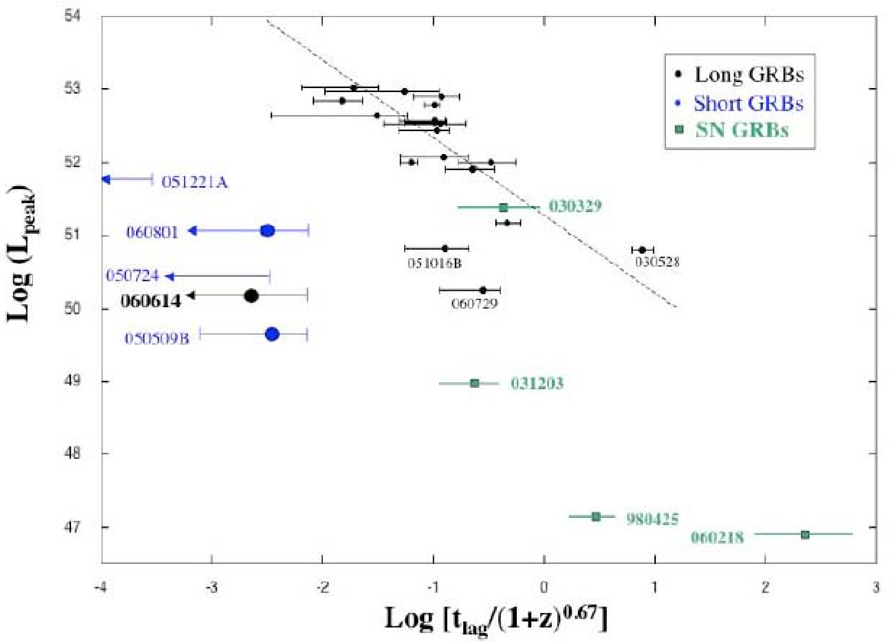
❑ other two events (XRF040701 and, in particular, GRB060505) show very low upper limits too

❑ new sub-class of long GRBs ? (e.g. produced by faint type II SNe or type Ib/c Nichel fall-back SNe or even binary systems mergers)

GRB/SN	z	$E_{p,i}$ (keV)	E^{iso}_{prompt} (10^{50} erg)	θ_{jet} (deg)	E^{jet}_{prompt} (10^{50} erg)	SN $E^{iso(a)}_{K}$ (10^{50} erg)	SN peak mag
980425/SN 1998bw	0.0085	55±21	0.01±0.002	-	<0.012	200-500	$M_V=-19.2\pm0.1$
060218/SN 2006aj	0.033	4.9±0.3	0.62±0.03	>57	0.05–0.65	20–40	$M_V=-18.8\pm0.1$
031203/SN 2003lw	0.105	<200	1.0±0.4	–	<1.4	500-700	$M_V=-19.5\pm0.3$
030329/SN 2003dh	0.17	100±23	170±30	5.7±0.5	0.80±0.16	~400	$M_V=-19.1\pm0.2$
020903/BL-SNIb/c	0.25	3.4±1.8	0.28±0.07	–	<0.35	–	$M_V\sim-18.9$
050525A/SN 2005nc	0.606	127±10	339±17	4.0±0.8	0.57±0.23	–.	$M_B=-18.9^{+0.1}_{-0.5}$
021211/SN 2002lt	1.01	127±52	130±15	8.8±1.3	1.07±0.13	–	$M_U\sim-18.9$
060505	0.089	>160	0.3±0.1	–	–	–	$M_R>-13.5$
060614	0.125	10–100	25±10	~12	0.45±0.20	–	$M_V>\sim-13$
040701	0.215	<6.	0.8±0.2	–	–	–	$M_V>-16$

- In the spectral lag – peak luminosity plane, GRB060614 lies in the short GRBs region
- Based on this, Gehrels et al. propose that GRB 060614 has similar properties to short GRBs and propose a new GRB classification scheme
- they also report that the first pulse (Ep,i from Konus-Wind) does not follow the Ep.i-Eiso correlation, further supporting the similarity with short GRBs (but when considering the whole event it is consistent)





Present and next future

➢ *Prompt emission*

❑ GRB prompt emission localizations (down to a few arcmin) come mostly from Swift/BAT (15-150 keV) and, to a less extent, INTEGRAL/ISGRI, the IPN and very recently, SUPER-AGILE

❑ spectral parameters (in particular, Ep) provided mostly by Konus/WIND (15-10000 keV) and, for fewer events by Suzaku/WAM and RHESSI; Ep for ~30% of Swift GRBs

❑ advances in the study of X and gamma ray prompt emission still from the exploitment of BATSE (25-2000 keV), BeppoSAX (2-700 keV) and HETE-2 (2-700 keV) archival data

❑ prompt emission below ~15 keV is presently unobservable (JEM-X ?)

❑ very recent improvements in detection and study of optical prompt emission thanks to increased number and quality of robotic telescopes and

❑ search for GeV emission now possible with AGILE/GRID

❑ search for TeV emission (HESS, MAGIC, VERITAS...)

➢ *Afterglow emission*

❑ Swift is greatly performing: discover of prompt-afterglow connection (steep decay, flat decay, breaks, X-ray flares); precise localizations by Swift -> increase of z estimates (~25/year) and reduction of selection effects in sample of GRB with known z

❑ X-ray afterglow of a few GRBs still studied by Chandra, XMM, Suzaku

❑ optical follow-up programs by large international collaborations (e.g. GRACE) with the largest telescopes (VLT, GEMINI, NTT, HST, ...)

❑ active radio follow up programs (NRAO, VLA, ...)

➢ *What is needed ?*

➢ need to combine the Swift capabilities with a sensitive prompt emission detector operating in a broad few keV – 1-2 MeV) energy band (emission mechanisms, features, spectral-energy correlations, GRB cosmology, ...)

➢ need to study soft X-ray (down to ~0.1 keV) prompt emission: variable absorption / emission features -> GRB physics and environmente, X-ray redshift, properties and evolution of ISM and IGM

➢ X/gamma-ray polarimetry (can something be done by ISGRI ?); GeV, TeV...

➢ *Future experiments*

- GLAST (2008->) : GBM (broad FOV, prompt spectra from ~10 keV up to several MeV) + LAT (emission from hundreds of MeV to hundreds of GeV + few arcmin localization)

- SVOM (> 2012) : few arcmin localization + spectral study of prompt emission from ~3 keV to several MeV + fast follow-up with optical and X-ray telescopes

- GRB experiments under study

a) EDGE (proposed for ESA cosmic vision, >2015): accurate (arcmin) localization + broad band study of prompt emission (from a few keV to a few MeV) + fast follow-up and 0.1-10 keV high res. spectroscopy (absorption/emission features, use of GRB as cosmological beacons)

b) GRIPS (proposed to ESA for cosmic vision, > 2015): X/gamma-ray spectroscopy and polarimetry

c) Lobster (LWFT+GRBM, >2011, on-board Spectrum-RG) : arcmin localization + spectral study of GRB prompt and afterglow emission in the ~0.1-600 keV enegy band

END OF THE TALK