GRB science with LOFT

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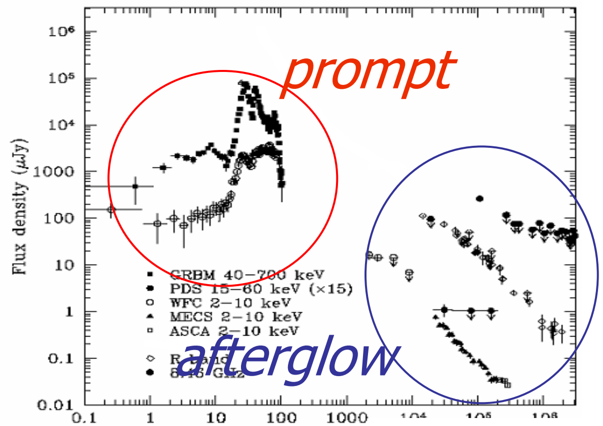
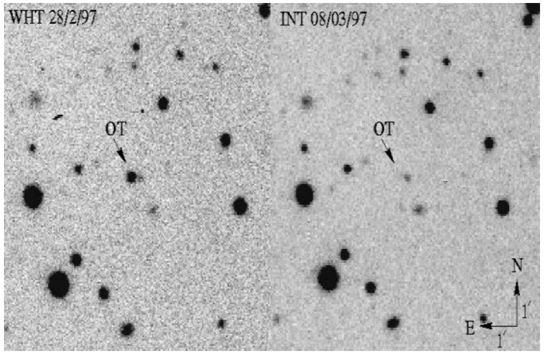
On behalf of the LOFT/GRB Working Group, with main contributions by E. Del Monte, B. Gendre, V. D'Elia, L. Izzo, R. Salvaterra, G. Stratta, A. Penacchioni & M. Feroci

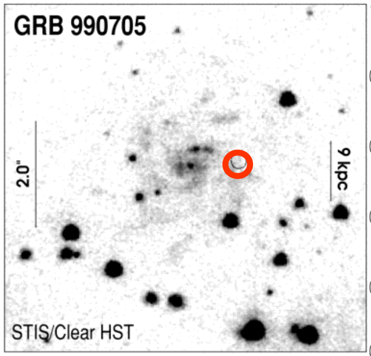
The GRB phenomenon: a puzzle still to be solved

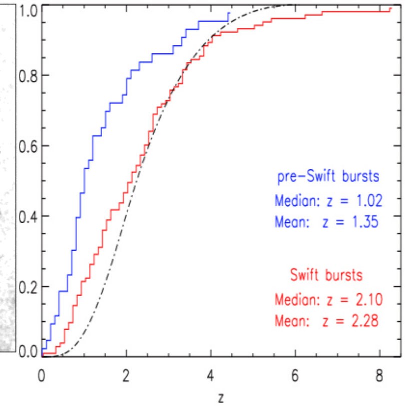
- Despite the huge advances occurred in the last years, the GRB phenomenon is still far to be fully understood

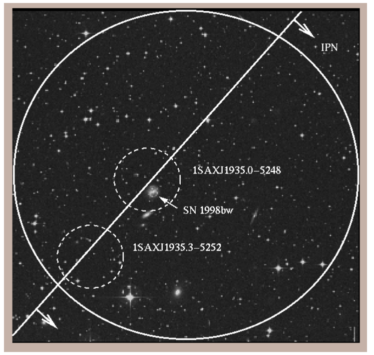
- **Open issues include**: physics and geometry of the prompt emission, unexpected early afterglow phenomenology (plateau, flares, …), identification and understanding of sub-classes of GRBs (short/long, XRFs, sub-energetic), GRB/SN connection, VHE emission, nature of the inner engine, cosmological use of GRBs, … and more !

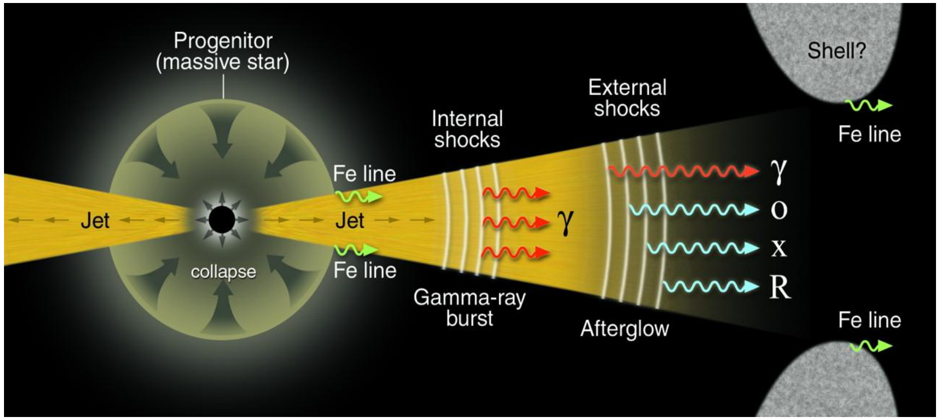










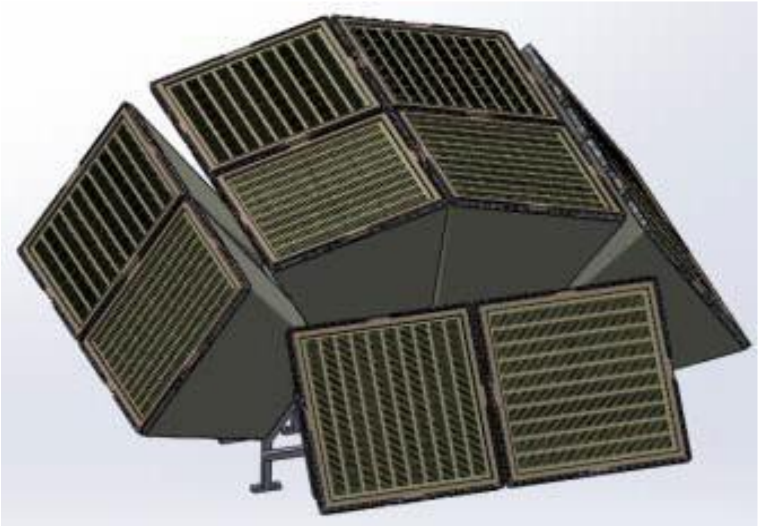


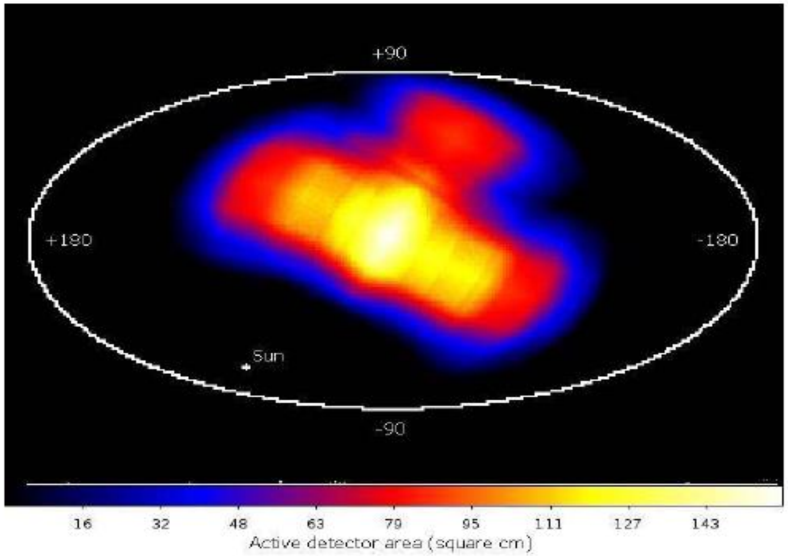
What LOFT can do for GRB science ?

❑ LOFT, possibly in combination with other GRB experiments flying at the same epoch, can give us useful clues to some of the still open issues through:

1) **Detection, accurate location and characterization of GRB prompt emission down to ~2 keV with the WFM (+ fast dissemination of ~arcmin position !)**

2) Measurements of the afterglow emission up to **~40 keV** with the LAD ?





GRB X-ray prompt emission with LOFT/WFM

- Main LOFT/WFM characteristics

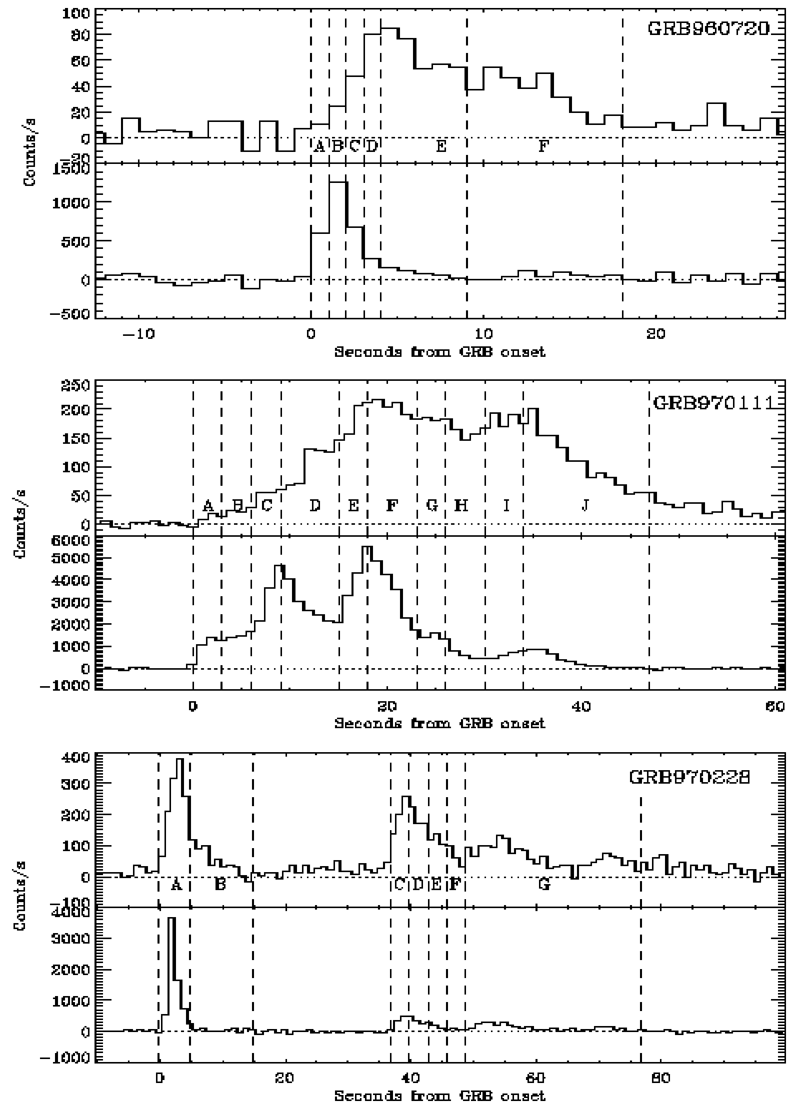
Parameter	Requirement	Goal
Point Source Location Accuracy	<1 arcmin	<0.5 arcmin
Angular Resolution	<5 arcmin	<3 arcmin
Sensitivity (5σ, on-axis)	1 s: 1 Crab 3×10^{-8} erg/cm^2/s 50 ks: 5 mCrab 1.5×10^{-10} erg/cm^2/s	1 s: 0.2 Crab 6×10^{-9} erg/cm^2/s 50 ks: 2 mCrab 6×10^{-11} erg/cm^2/s
Field of View	π sr around the LAD pointing	1.5π sr around the LAD pointing
Energy Range	2 – 30 keV (primary); 30 – 80 keV (extended)	1.5 – 30 keV (primary); 30 – 80 keV (extended)
Energy Resolution	500 eV	300 eV

- It is recognized that the GRB phenomenon can be understood only going back to the study of the Prompt Emission

- **An energy band extending down to soft X-rays is needed.**

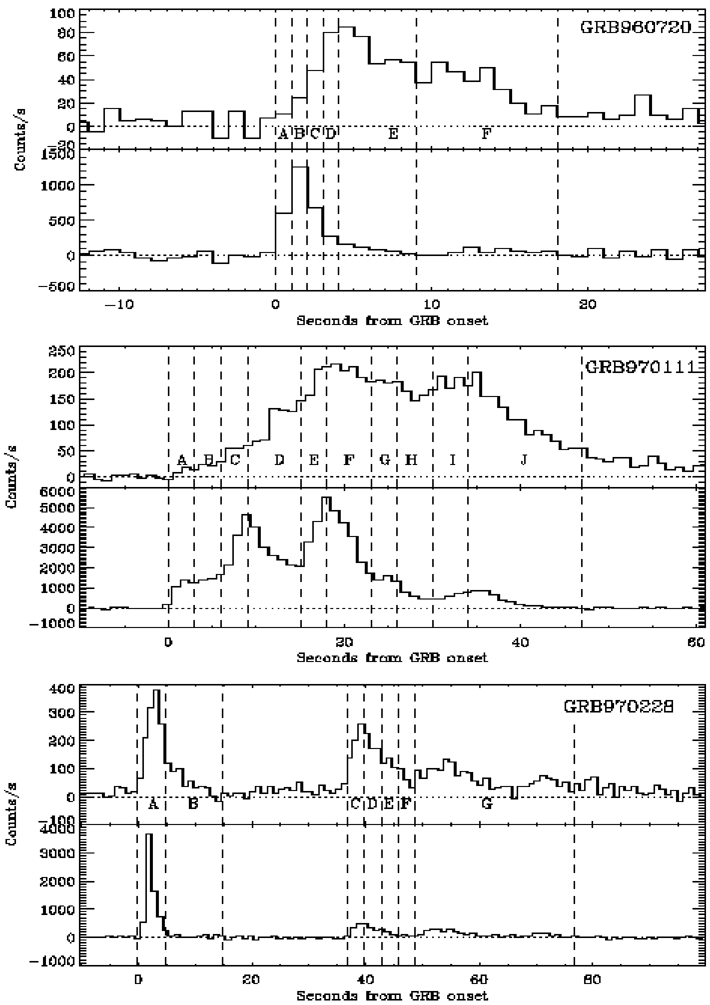
- Measurements down to a few keV were provided in the past by BeppoSAX and HETE-2, but better sensitivity and energy resolution are required to make a step forward

- Present GRB experiments are limited to prompt emission > ~10 keV; near future (SVOM ?, UFFO?) > ~ 5 keV; proposed / under study (JANUS, LOBSTER, ASTAR, GAME) aim at going down to 1 keV or below

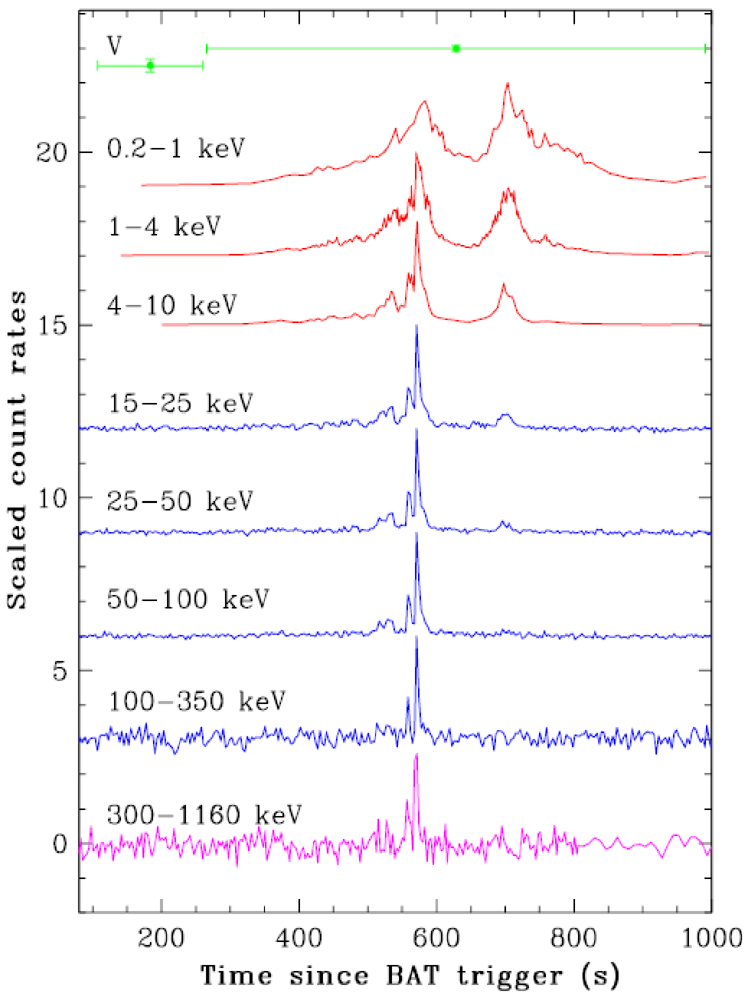


BeppoSAX (top: 2-28 keV, bottom: 40-700 keV)

❑ Relevance of GRB prompt low energy (<15 keV) X-ray emission



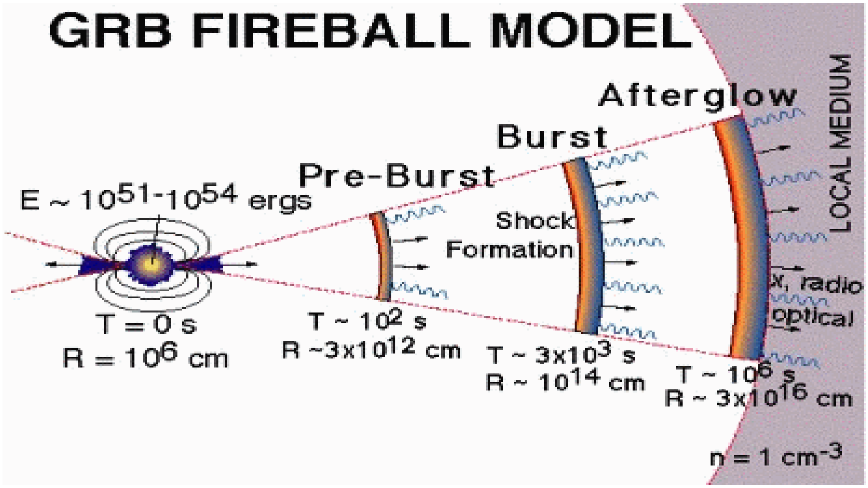
BeppoSAX (top: 2-28 keV, bottom: 40-700 keV) Frontera et al. 2000

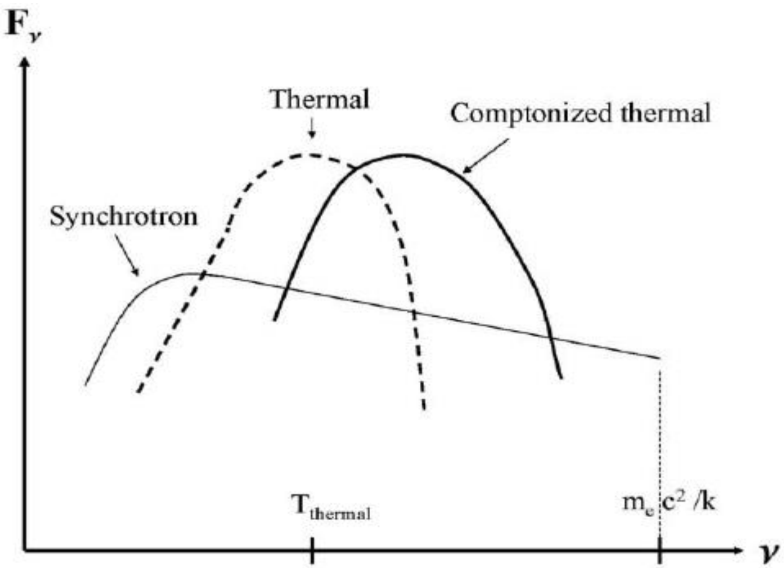


Swift XRT (rare / unique case) + Swift/BAT + konus/WIND. Romano et al. 2006

❑ Testing prompt emission mechanisms with X-ray spectra

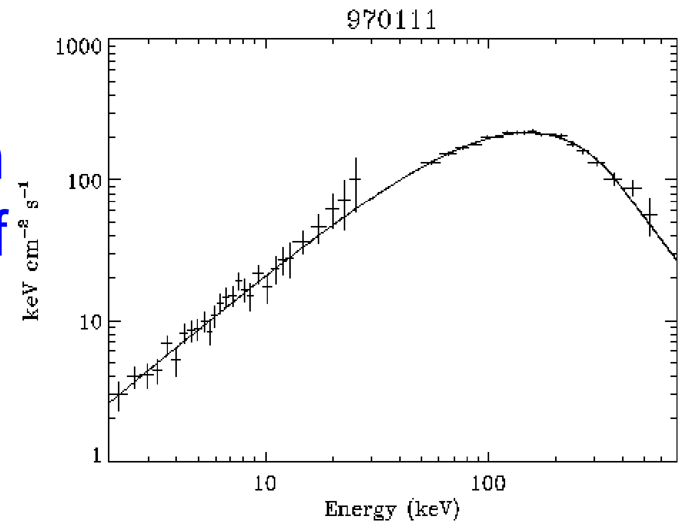
❑ physics of prompt emission still not settled, various scenarios: SSM internal shocks, IC-dominated internal shocks, external shocks, photospheric emission dominated models, kinetic energy dominated fireball , Poynting flux dominated fireball

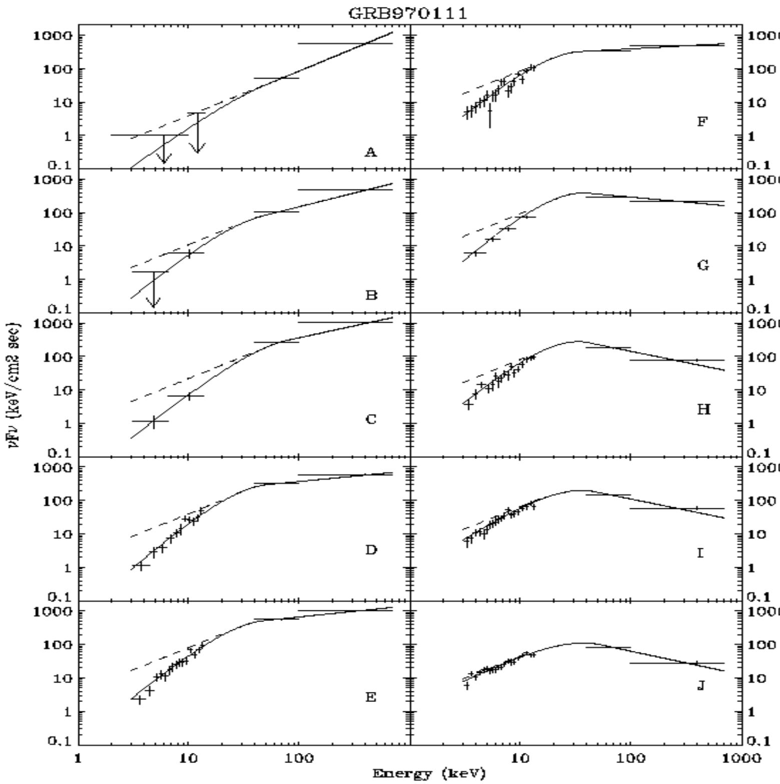


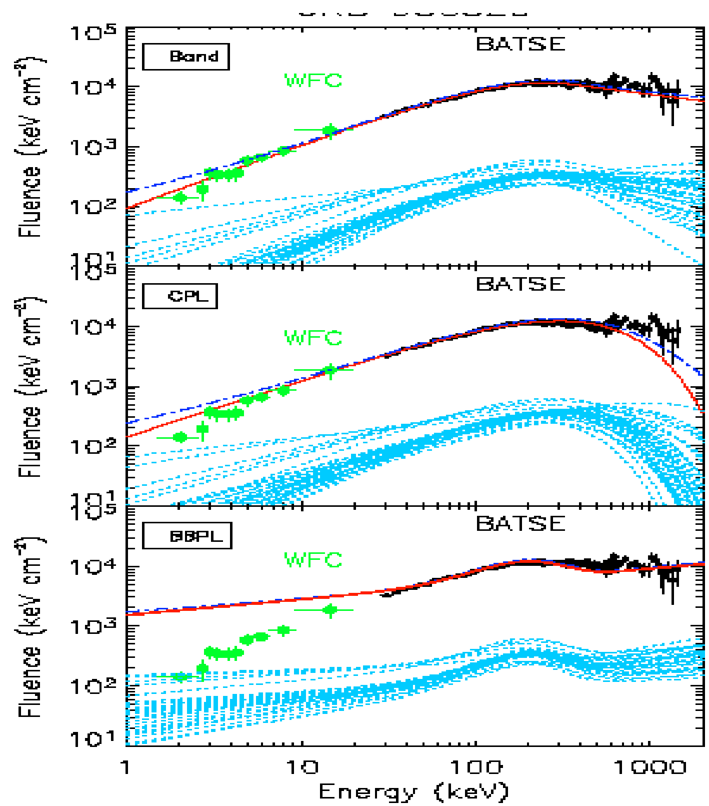


α $N(E)$	$\alpha+1$ $F(E)$	$\alpha+2$ EF_E	model/spectrum
-3/2	-1/2	1/2	Synchrotron emission with cooling
-1	0	1	Quasi–saturated Comptonization
-2/3	1/3	4/3	Instantaneous synchrotron
0	1	2	Small pitch angle/jitter
			inverse Compton by single e^-
1	2	3	Black Body
2	3	4	Wien

- most time averaged spectra of GRBs are well fit by synchrotron shock models
- at early times, some spectra inconsistent with optically thin synchrotron: possible contribution of IC component and/or thermal emission from the fireball photosphere
- thermal models challenged by X-ray spectra



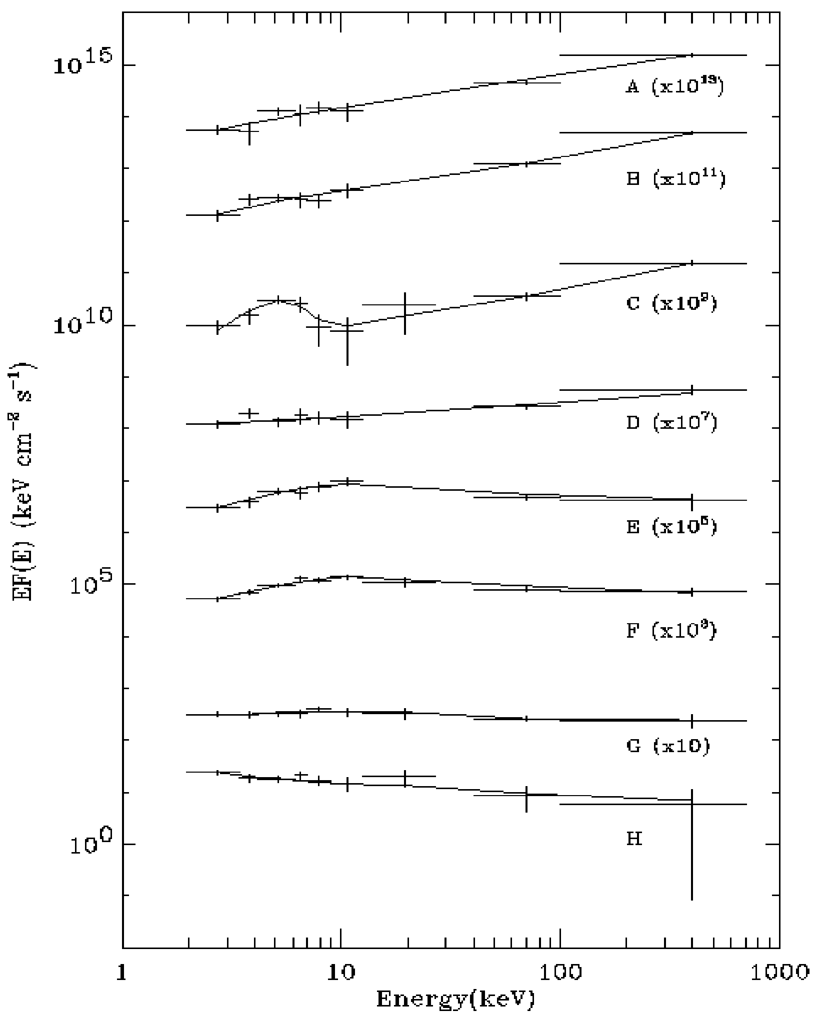




Amati et al. 2001, Frontera et al. 2000, Ghirlanda et al. 2007

❑ Tansient bump, consistent with a 2 keV blackbody, observed in the low energy band with BeppoSAX WFC

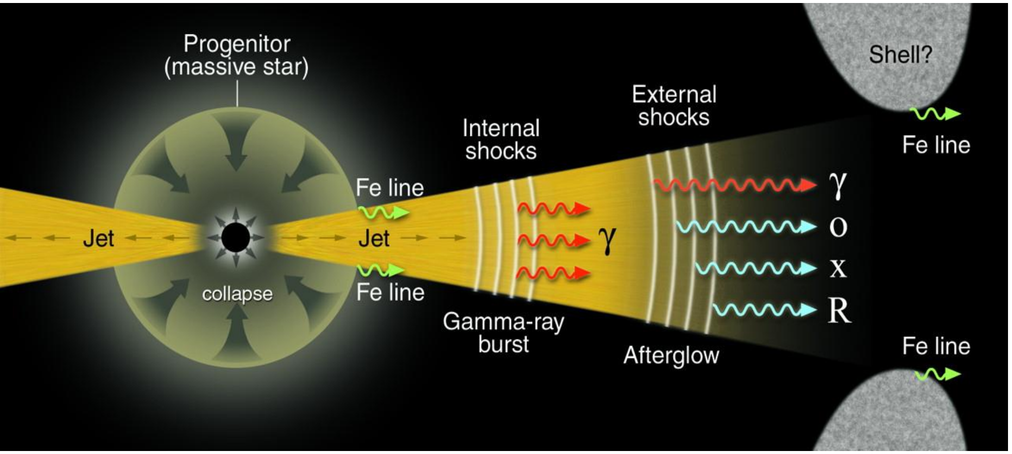
GRB 990712



Frontera et al. 2001

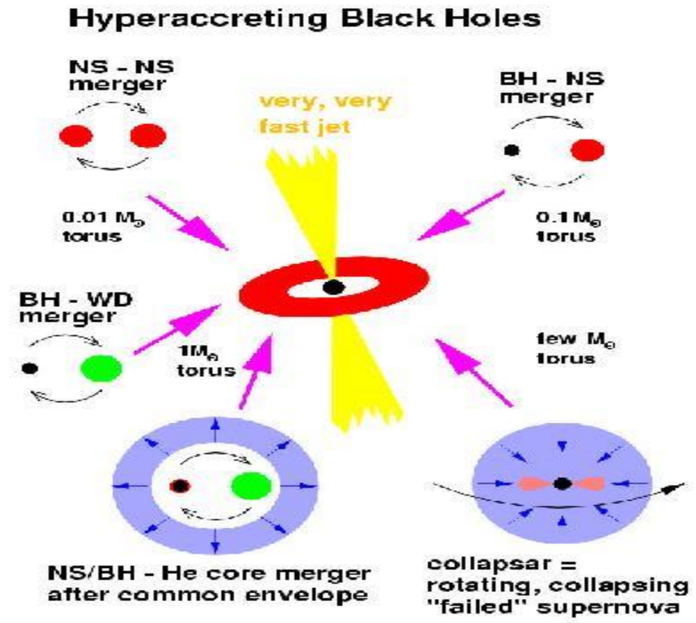
❑ Probing the circum-burst environment with X-ray spectra

LONG



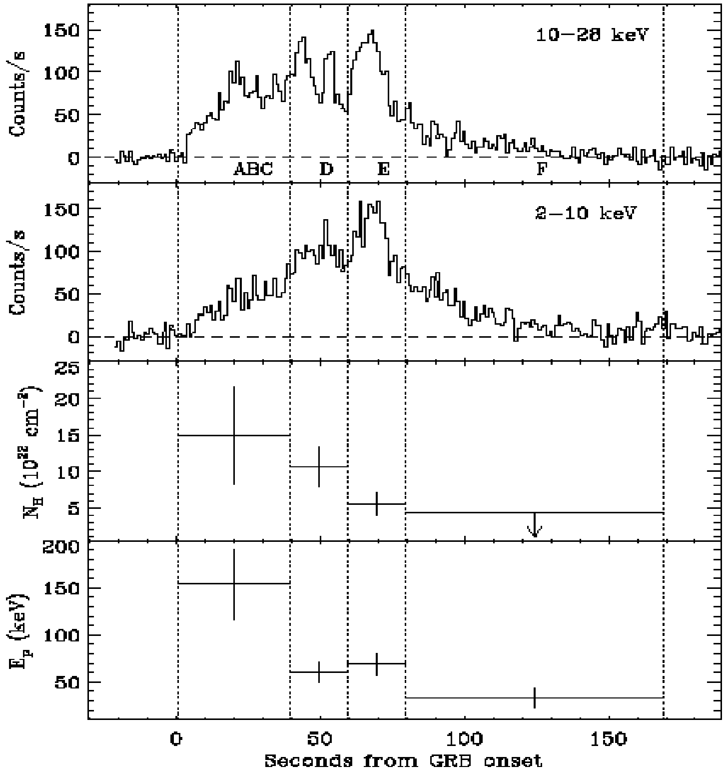
- energy budget up to >10^{54} erg
- long duration GRBs
- metal rich (Fe, Ni, Co) circum-burst environment
- GRBs occur in star forming regions
- GRBs are associated with SNe
- likely collimated emission

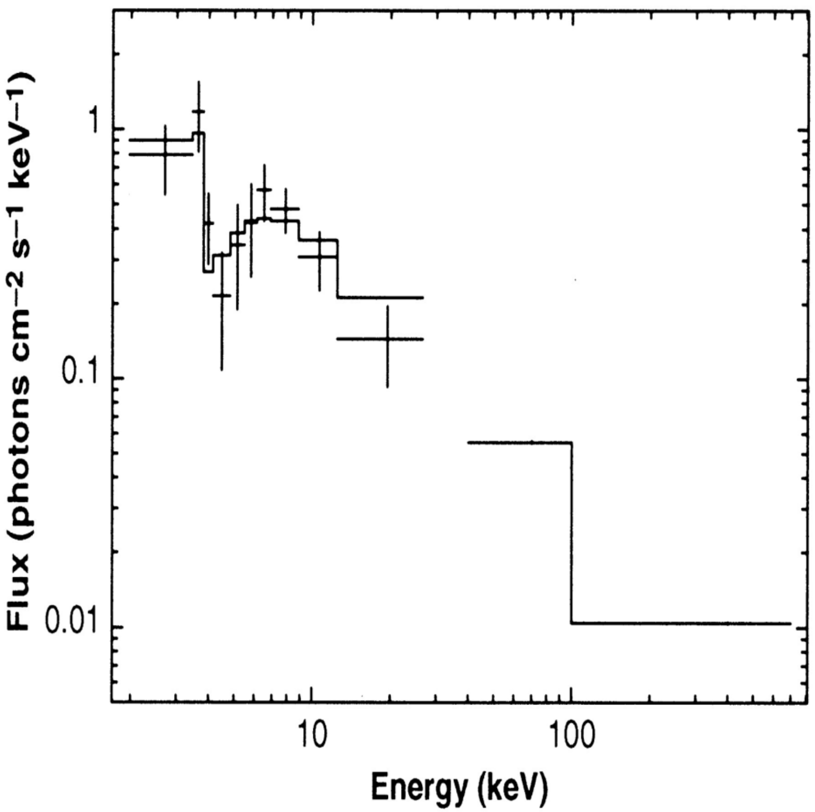
SHORT



- energy budget up to 10^{51} - 10^{52} erg
- short duration (< 5 s)
- clean circum-burst environment
- old stellar population

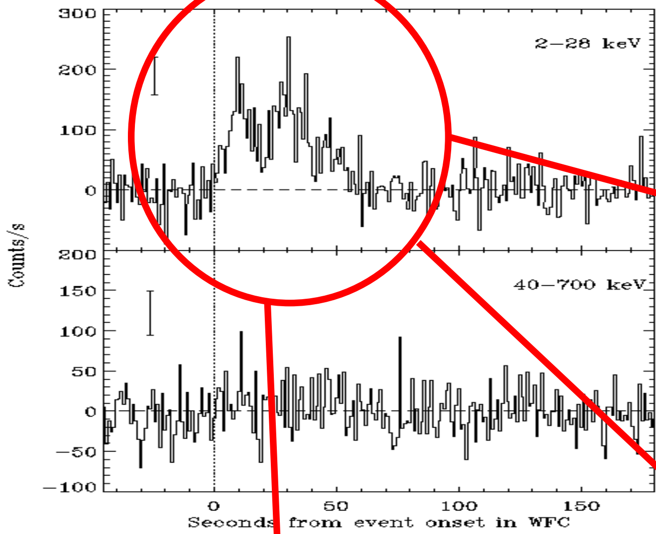
❑ X-ray features: properties (density profile, composition) of circum-burst environment (progenitors, X-ray redshift)

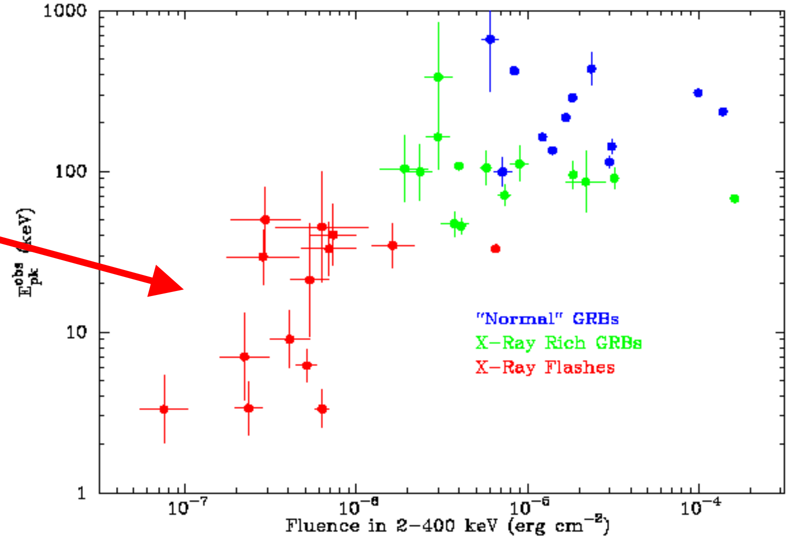




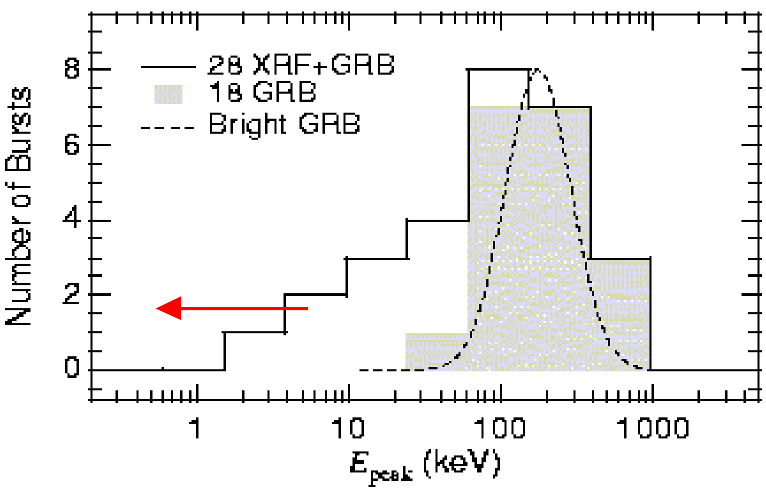
Frontera et al., ApJ, 2004, Amati et al, Science, 2000

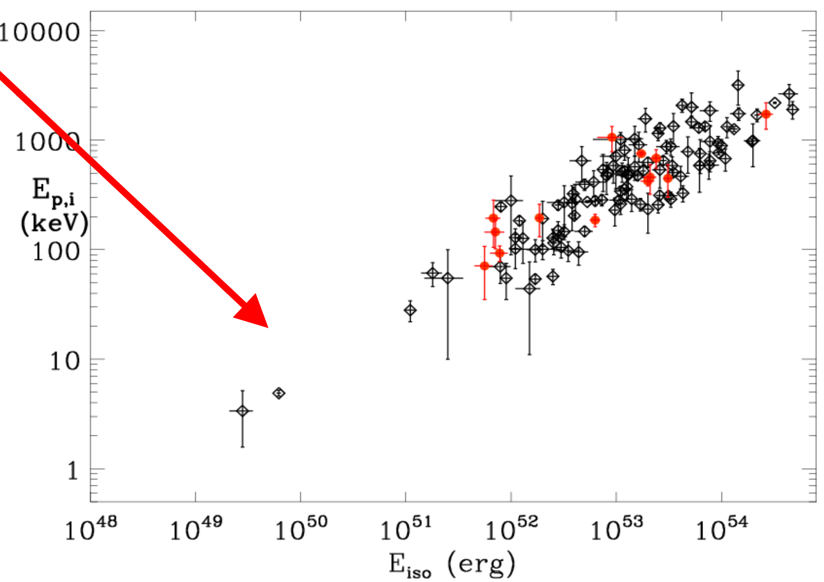
❑ X-Ray Flashes: origin, population size, link with GRB





(Amati et al. 2004, Sakamoto et al. 2005

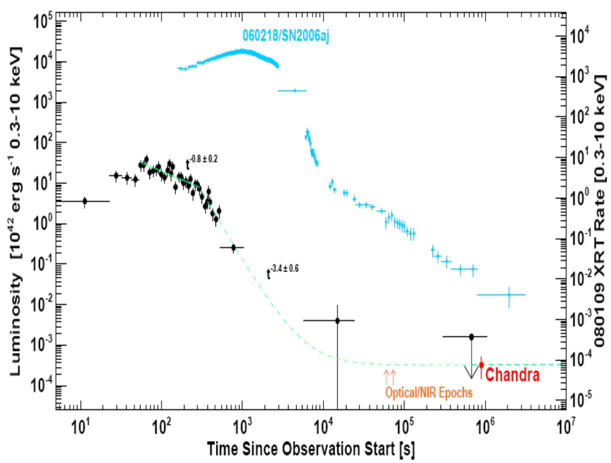




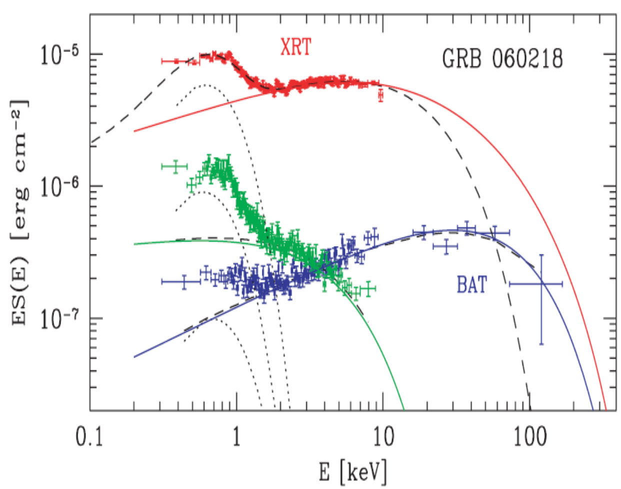
Kippen et al. 2001,Amati 2012

❑ Soft/long X-ray transients (GRB 060218 and XRF 080109 associated with SN 2006aj (at z = 0.038) and SN 2008D at z = 0.0064

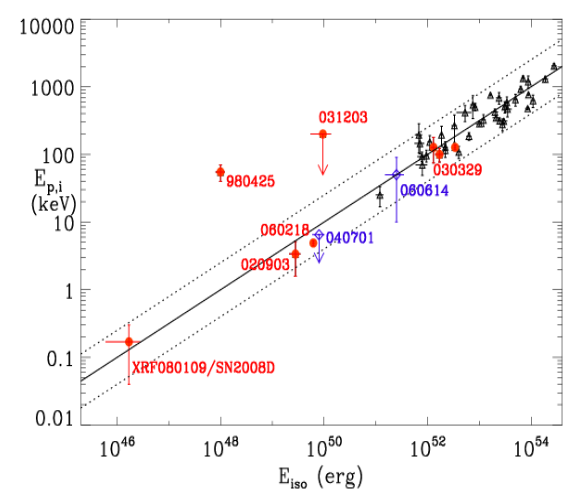
- Debate: very soft/weak XRF or SN shock break-out ?
- Peak energy limits and energetics consistent with a very-low energy extension of the Ep,i-Eiso correlation holding for normal GRBs and XRFs: Evidence that these transients may be very soft and weak GRBs, thus confirming the existence of a population of sub-energetic GRB ?



Modjaz et al., ApJ, 2008

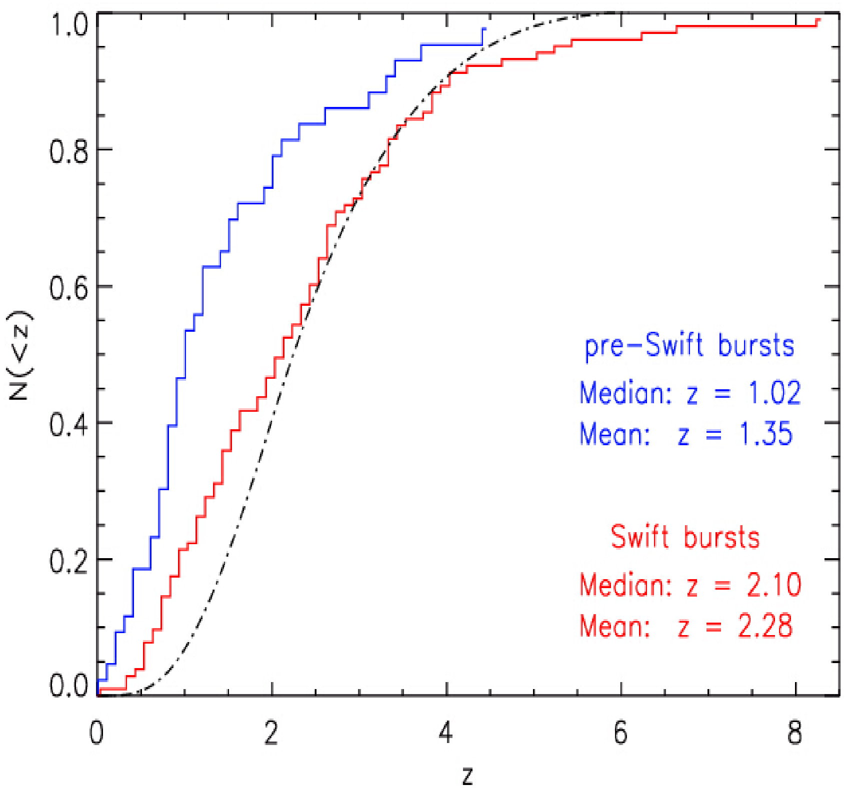


Ghisellini et al. 2006

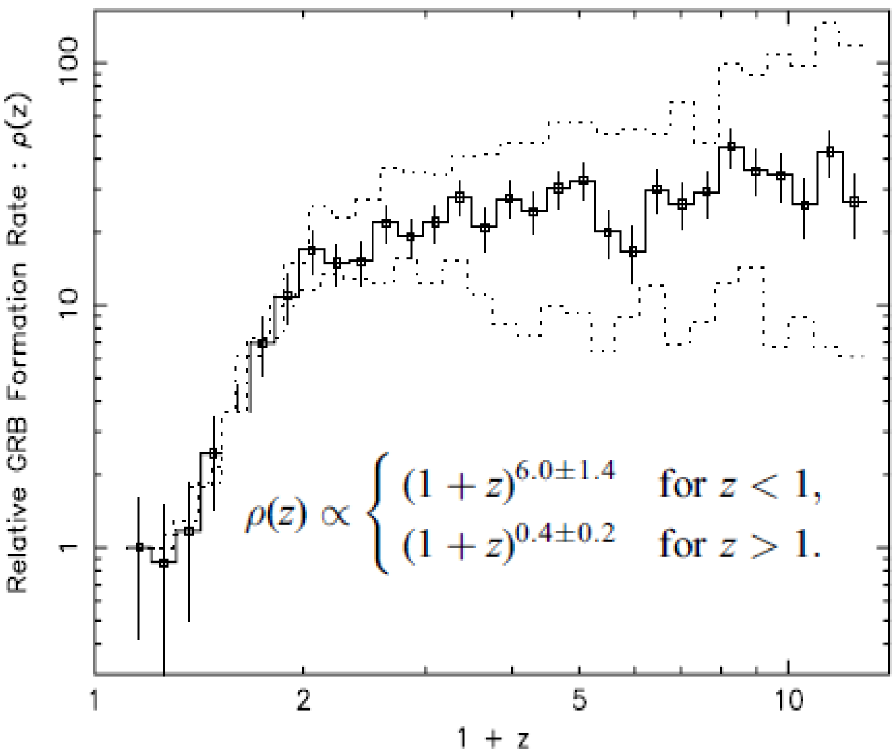


Amati, 2009

❑ **Increasing the detection rate of high-z GRB with low energy threshold: SFR up to dark ages, pop III stars, …**

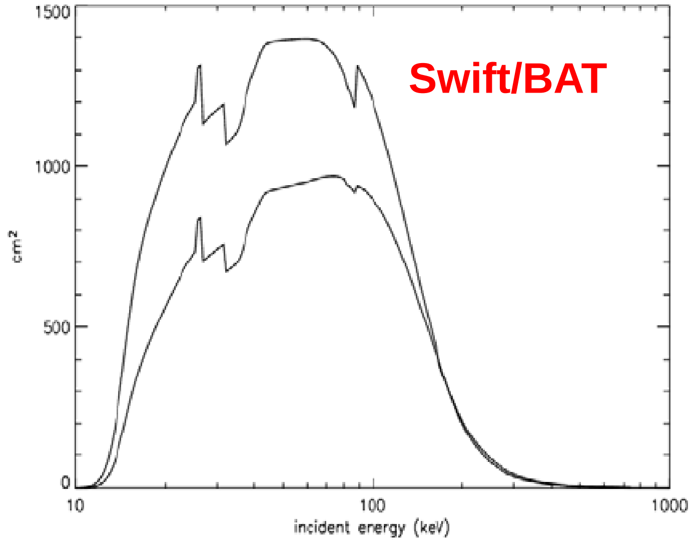


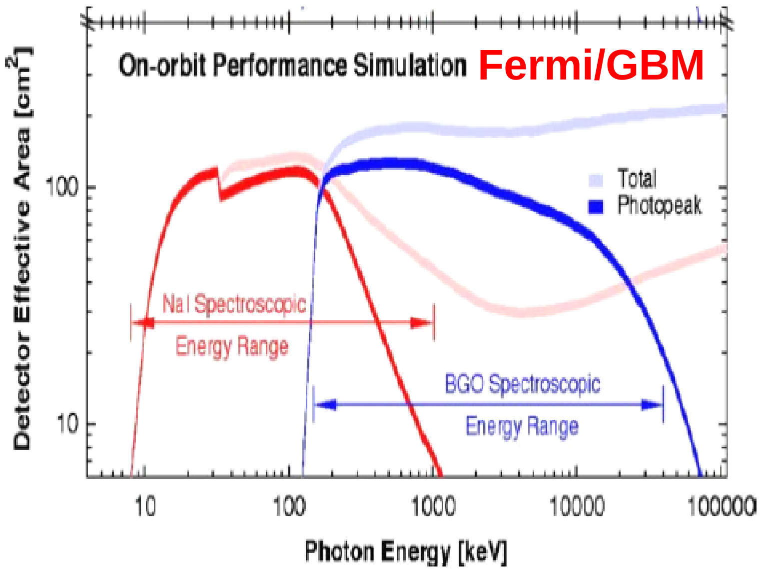
Stanek et al. 2010

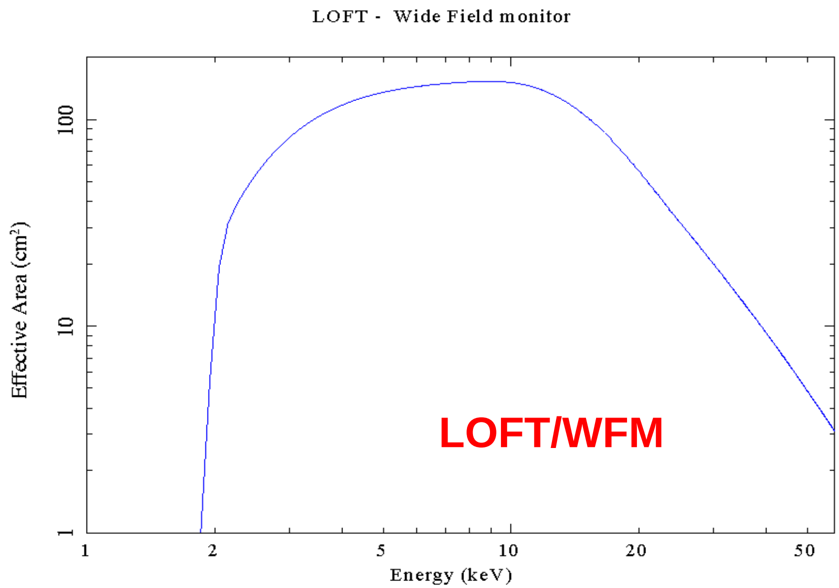


Yonetoku et al. 2004

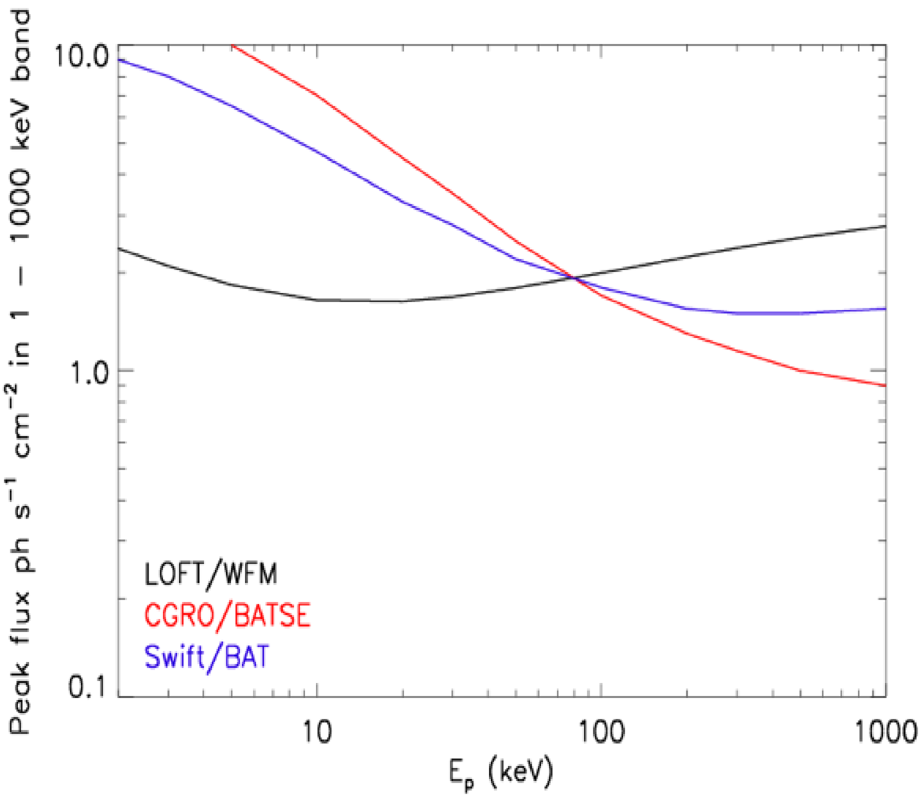
❑ Eff. Area and GRB sensitivity of the LOFT/WFM w/r to present GRB detectors

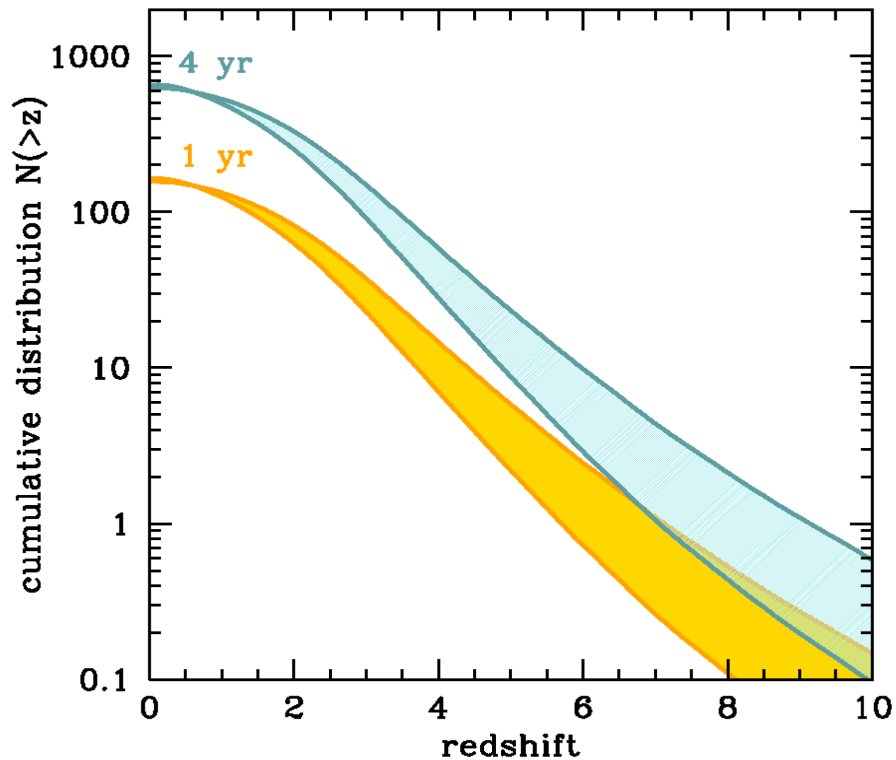




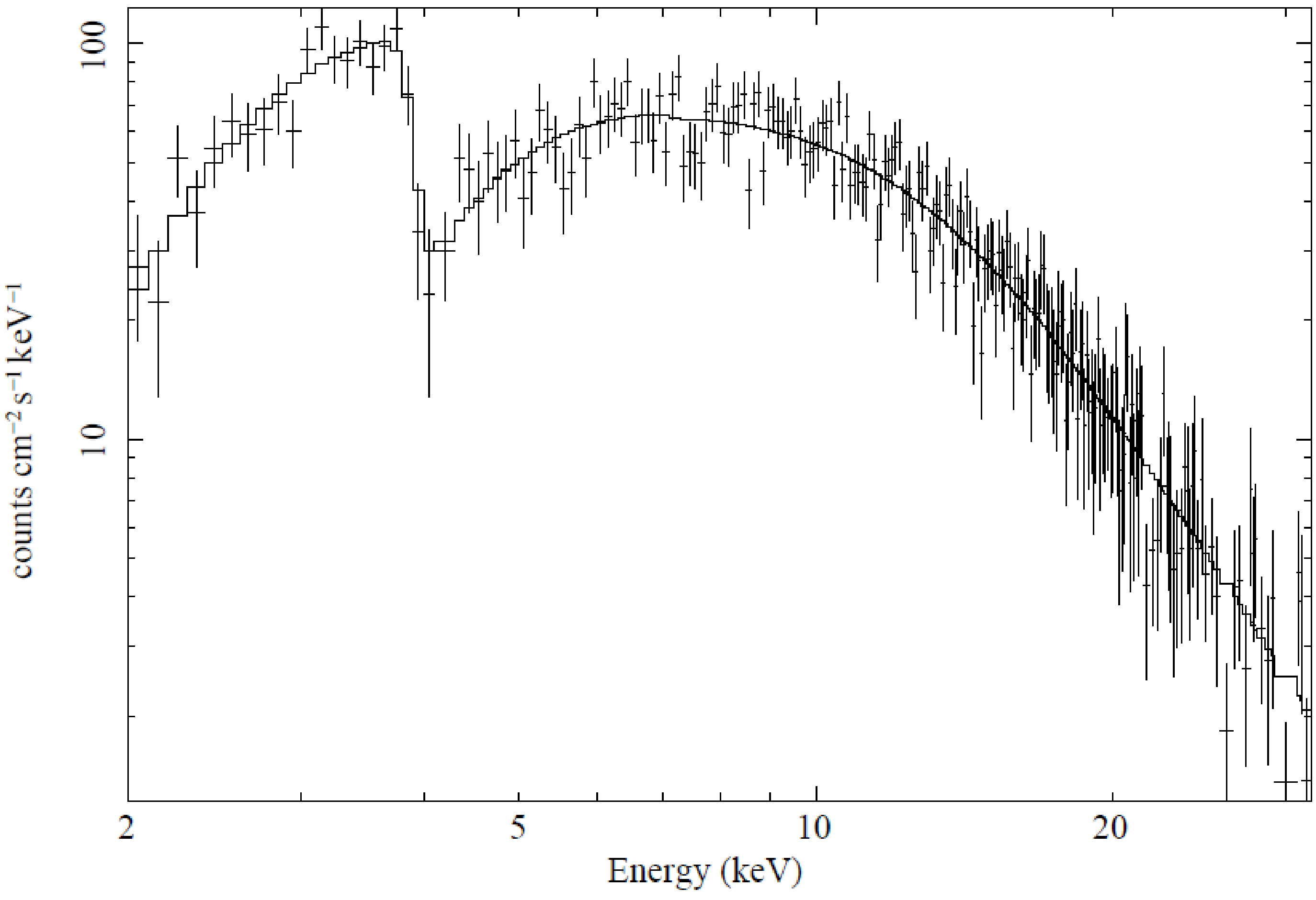


❑ Improvement in detection of soft and high-z GRBs w/r to present and next future experiments



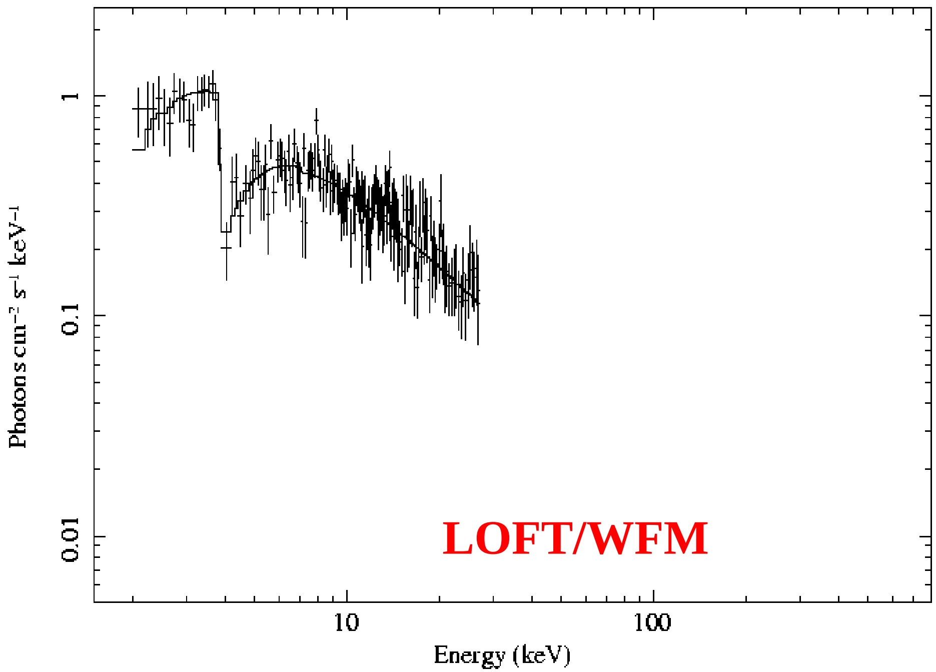


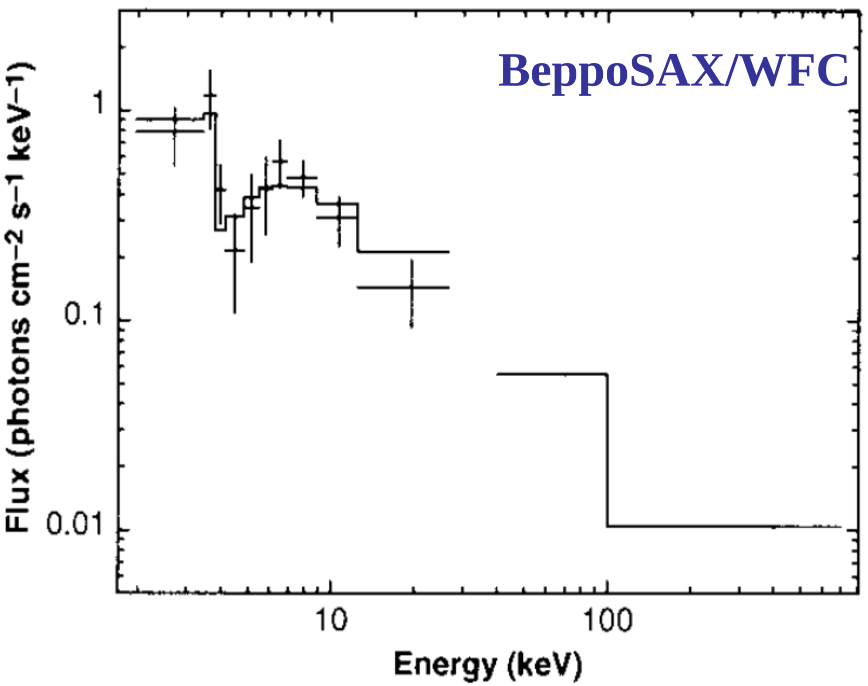
❑ Expected spectrum with LOFT/WFM assuming the K-edge observed from GRB990705 with BeppoSAX/WFC



E = 3.8 keV, τ = 1.4, exp: 13s, fl (40-700 keV) = 3.8x10^{-5} erg)

❑ **Expected spectrum with LOFT/WFM assuming the K-edge observed from GRB990705 with BeppoSAX/WFC:** higher significance (thanks to better en. res) and higher detection rate (thanks to much broader FOV)

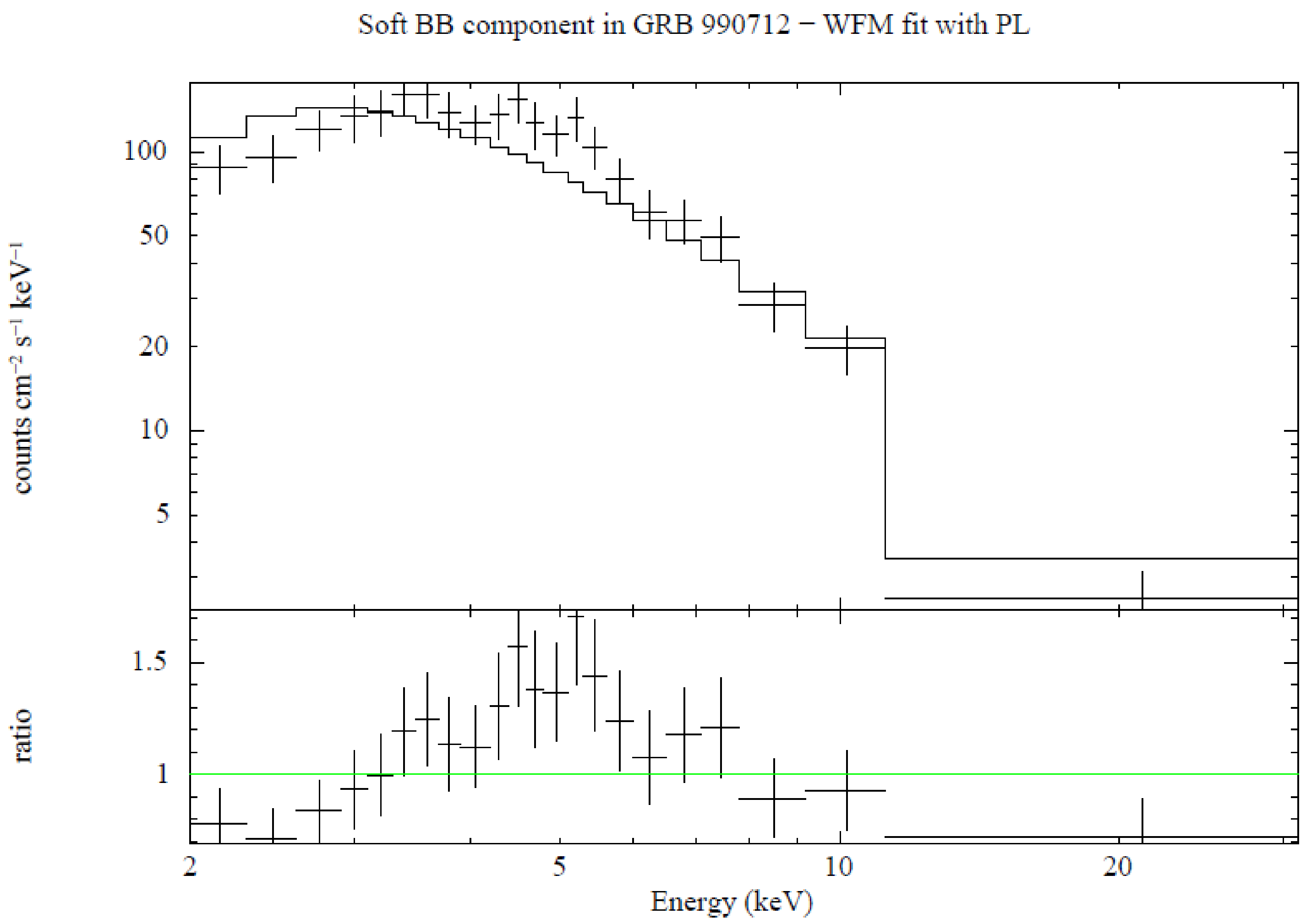




LOFT/WFM

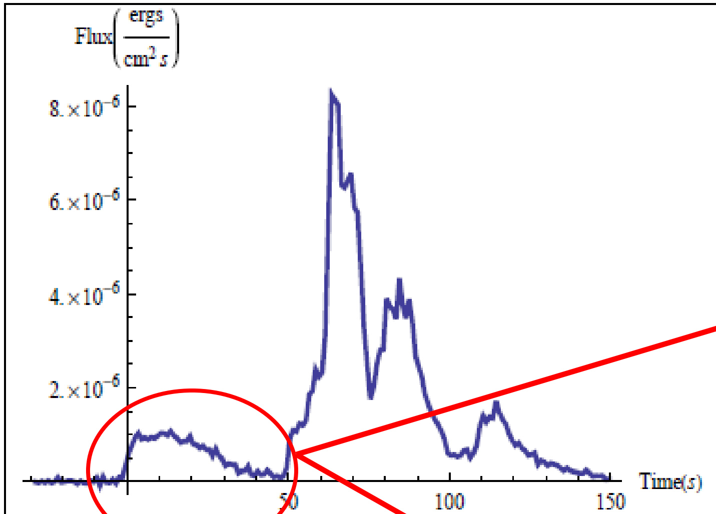
BeppoSAX WFC+ GRBM

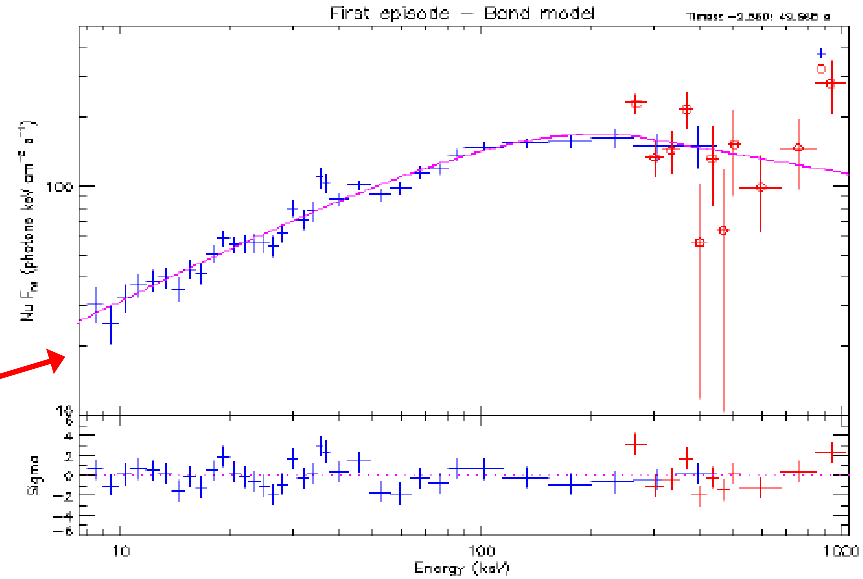
❑ Expected spectrum with LOFT/WFM assuming the transient Black-body feature observed from GRB990712 with BeppoSAX/WFC

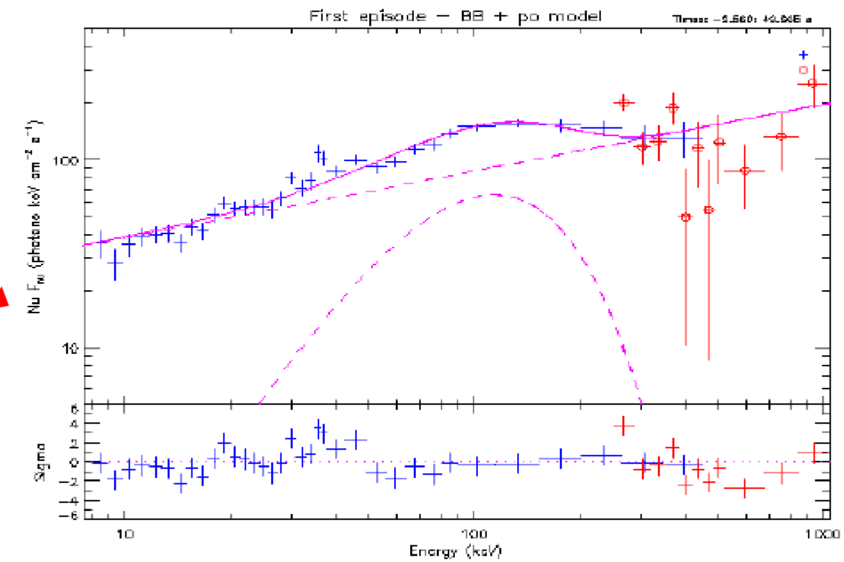


BB + PL simulated spectrum fit with a simple PL

❑ Discriminating among different models- The case of GRB 090618





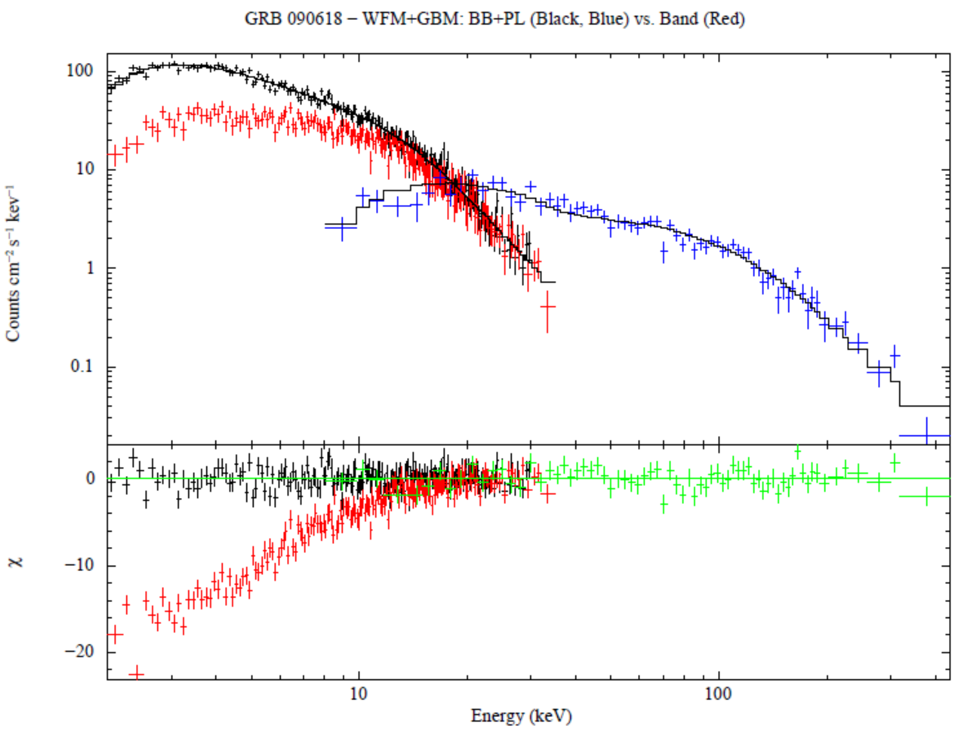


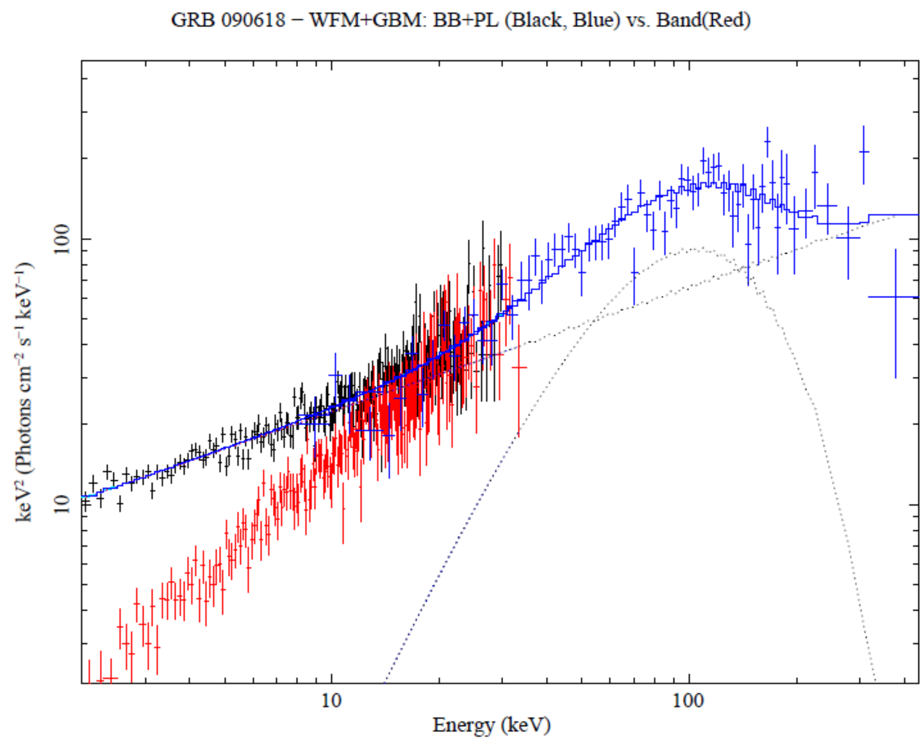
Fermi GBM (10 – 1000 keV) cannot distinguish among BB + PL and standard GRB Band function (Izzo et al. 2012)

Time Interval (s)	α	β	$E_0(keV)$	$\tilde{\chi}^2_{BAND}$	$kT(keV)$	γ	$\tilde{\chi}^2_{BB+po}$
0 - 50	-0.74 ± 0.10	-2.32 ± 0.16	118.99 ± 21.71	1.12	32.07 ± 1.85	1.75 ± 0.04	1.21

❑ Discriminating among different models - The case of GRB 090618:

LOFT/WFM will be capable of discriminating among Band and BB+PL thanks to its energy band extending below 10 keV



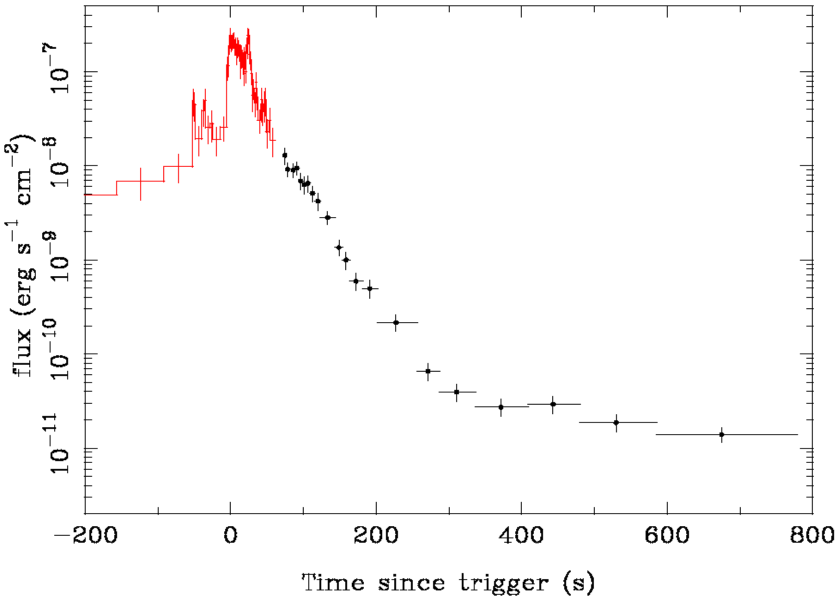


Fermi/GBM LOF/WFM (BB+PL) LOFT/WFM(Band)

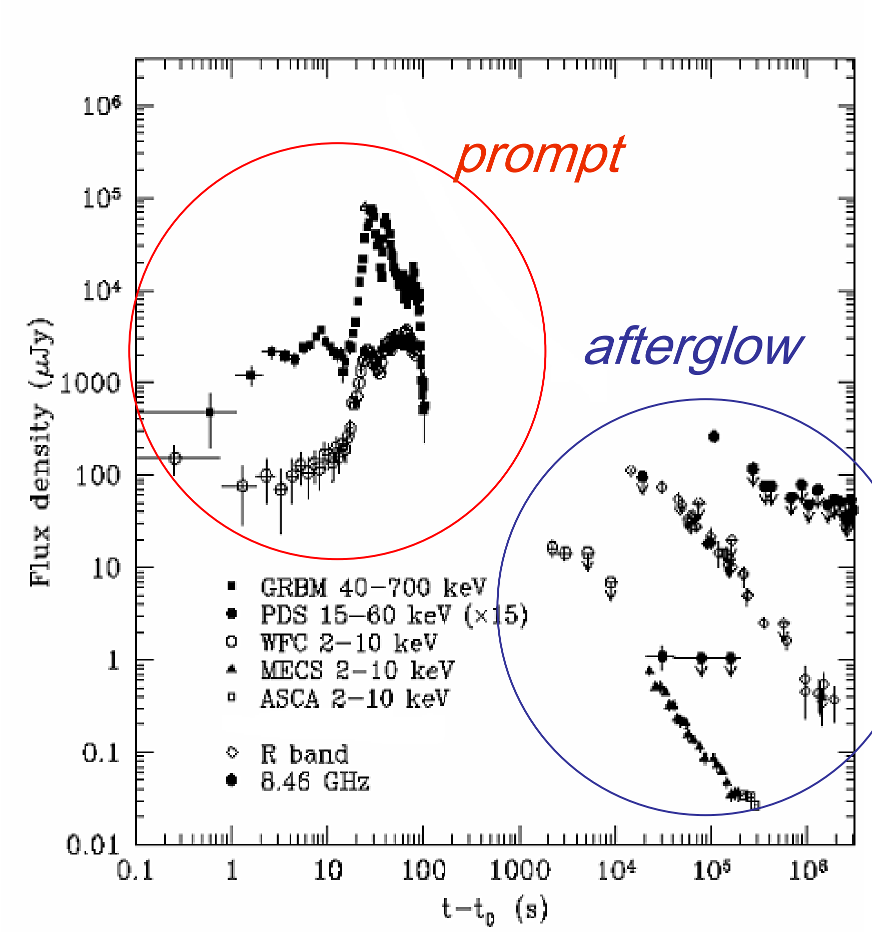
GRB X-ray early afterglow with LOFT/LAD

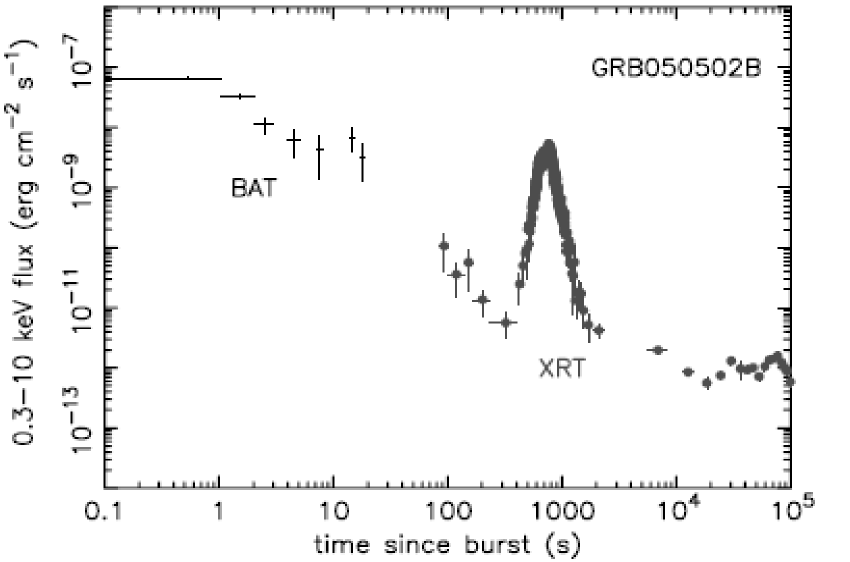
❑ Swift: transition from prompt to afterglow (>2005)

Swift era



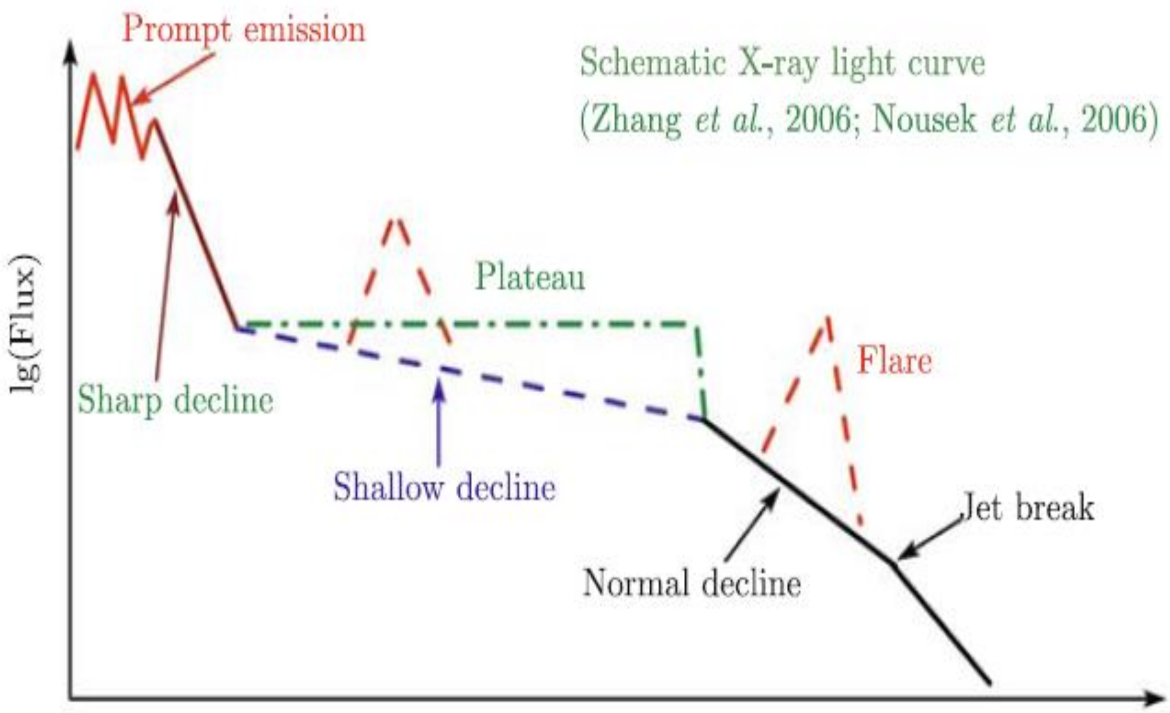
BeppoSAX era (1997-2002)





❑ *The complex Early X-ray Afterglow phenomenology*

- 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…

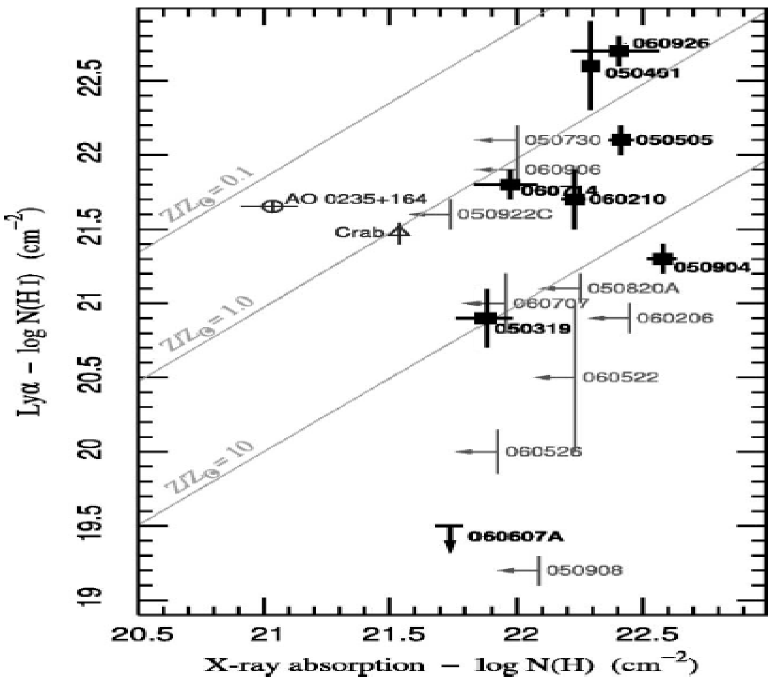


❑ Absorption column and emission lines

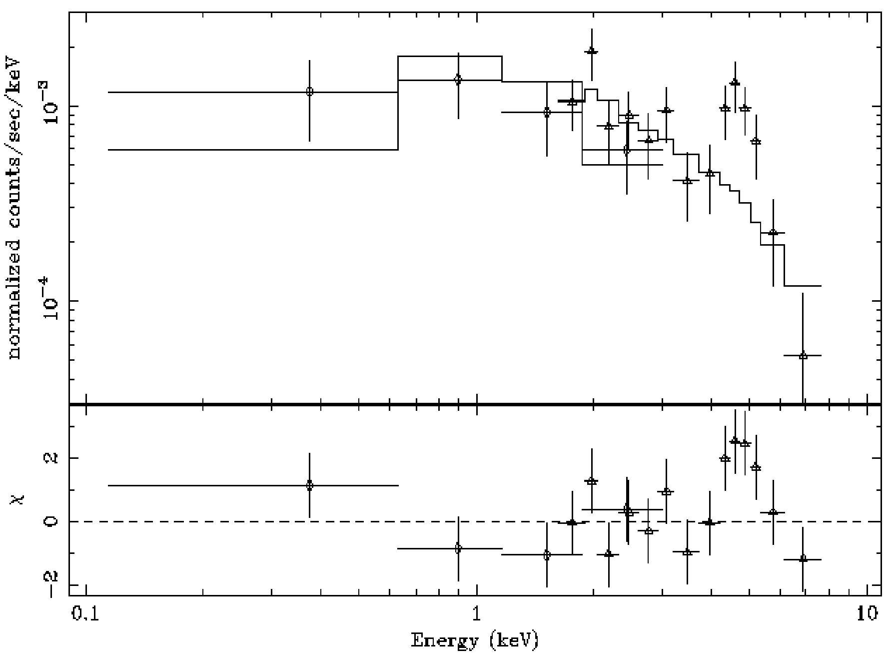
➢ emission lines in afterglow spectrum detected by BeppoSAX and Chandra for a few events, but not by Swift

➢ Swift detects intrinsic NH for many GRB afterglows, often inconsistent with NH from optical (Lyα)

➢ exploit large area and good spectral resolution of the LAD to solve the line issue and characterize with accuracy NH variation ?



Watson et al. 2007

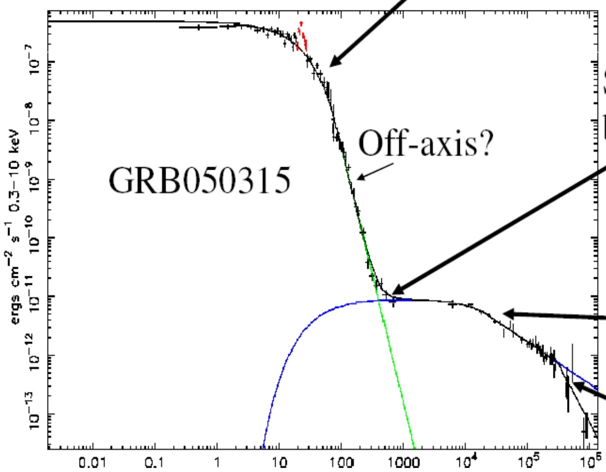


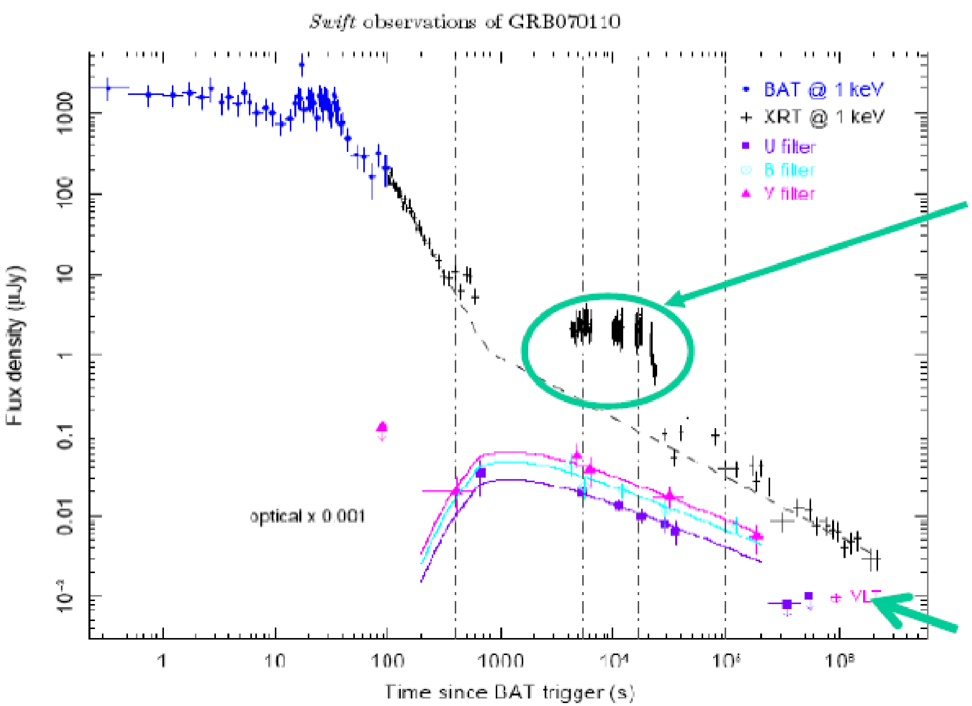
Antonelli et al. 2000

❑ Signatures of NS-magnetar progenitor ?

➢ in a fraction of GRB, an excess during the plateau phase was detected by Swift/XRT, inconsistent with externeal shock models, interpreted as a possible NS progenitor (Troja et al. 2007, O'Brien 2010, Lyons et al. 2010)

➢ Timing with the LAD could provide unique information (if on target within ~2-3 h)





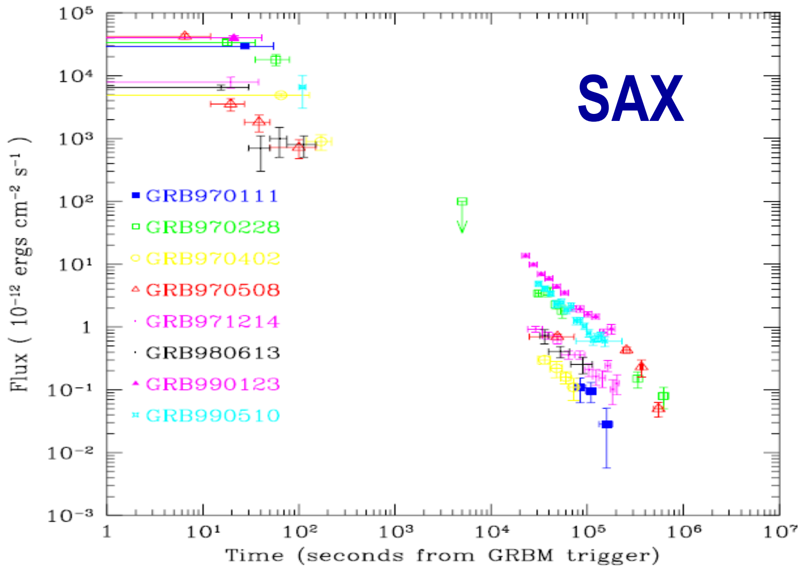
After the initial (impulsive event) see a late excess or "internal plateau" followed by a very steep decay.

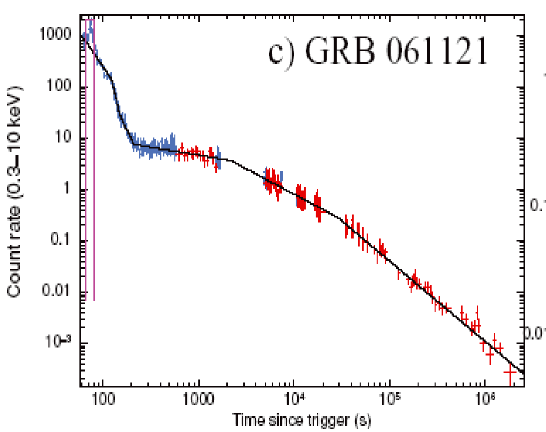
Propose "internal plateau" due to the spin-down of a magnetar which thencollapses.

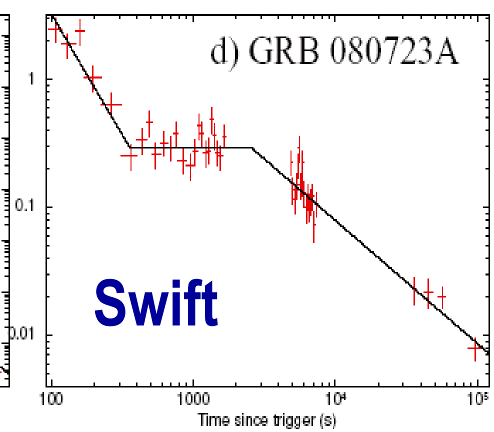
Not seen in the optical which appears to show a fairly "standard" afterglow.

Late afterglow emission: less complex …

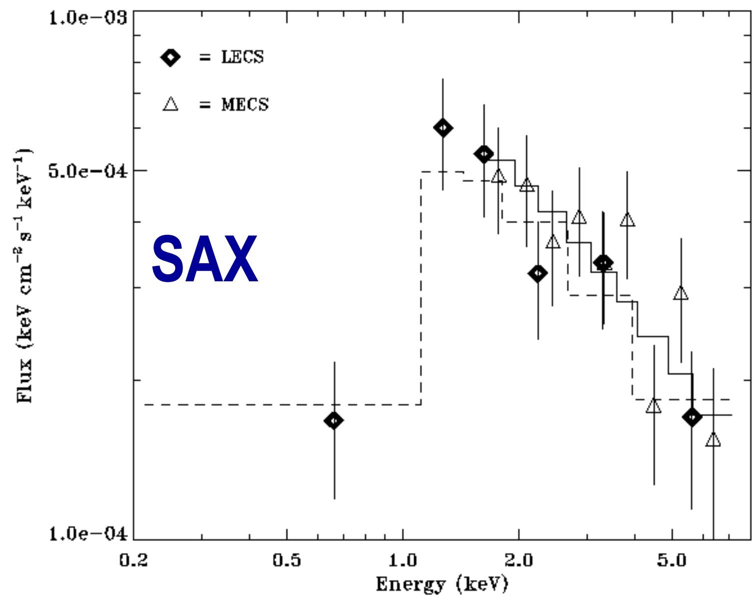
- ~power-law decay





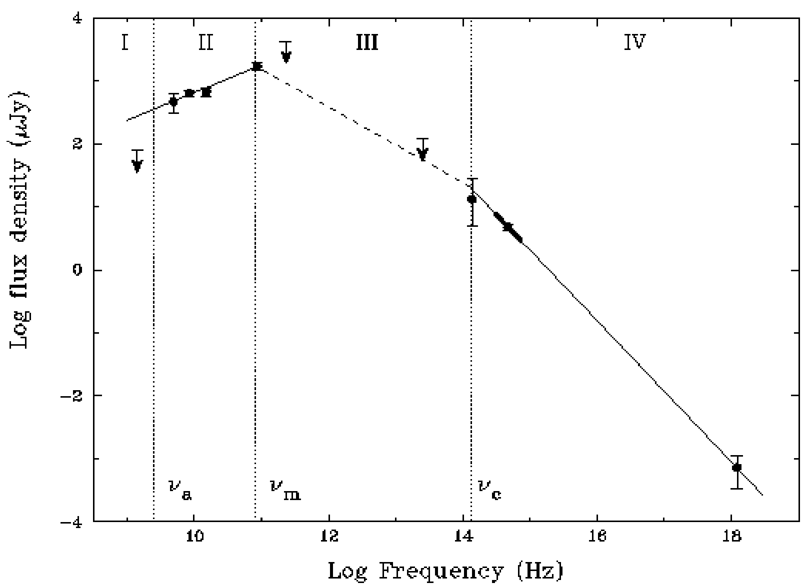


- ~power-law spectra

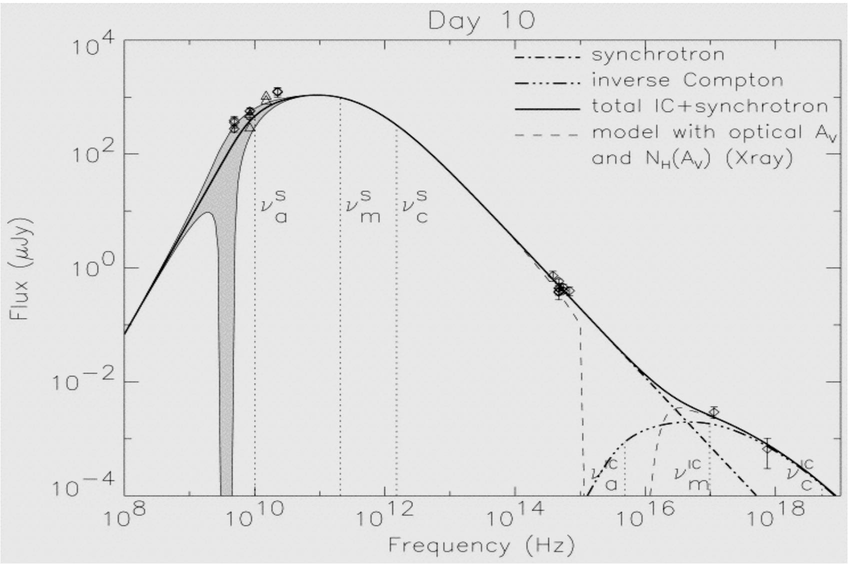


…but standard model not always works !

- SED of GRB 970508: fit with standard synchrotron shock model in slow cooling regime is OK
- SED of GRB 000926: excess of X-ray emission with respect to synchrotron prediction: IC component ?



Galama et al. (1997)

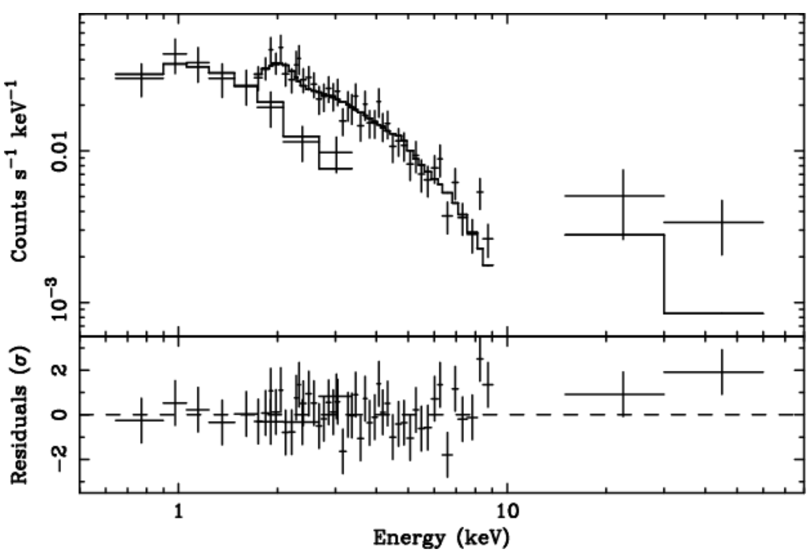


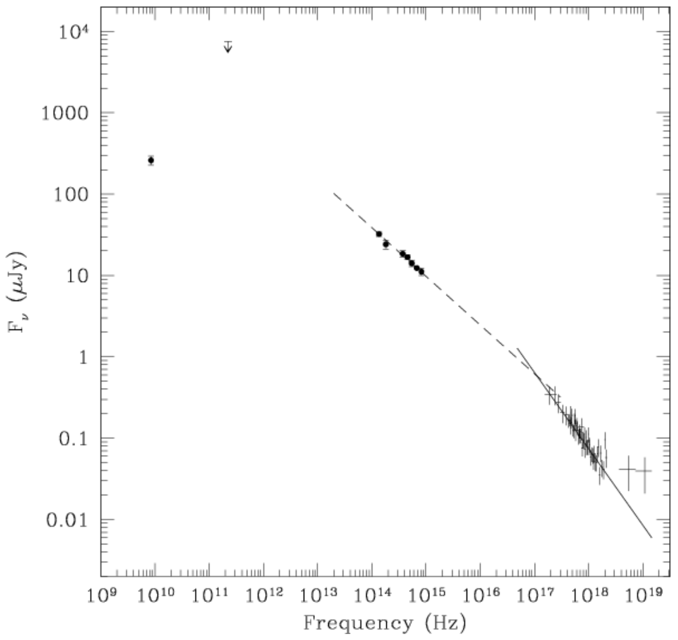
Harison et al. (2001)

The puzzling case of GRB990123

- Only one case of afterglow emission clear detection at energies > 10 keV: the bright GRB 990123 by BeppoSAX/PDS

- The 15-60 keV flux is inconsistent with the lower energy spectrum and synchrotron emission models predictions

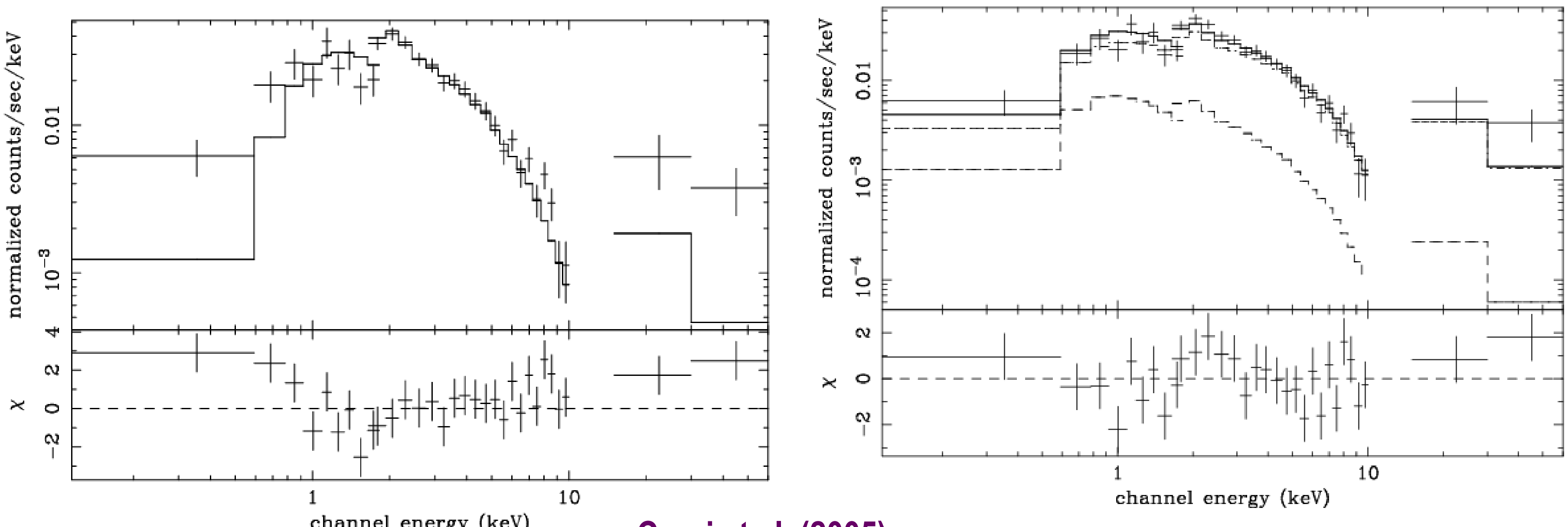




Maiorano et al. (2005)

The puzzling case of GRB990123

- the fit with a synchrotron + IC component is more satisfactory, but still problems with the "closure relationships" between spectral and decay indices
- alternative explanations include peculiar circum-burst properties and/or peculiar shock physics
- this shows the relevance of sensitive measurements of GRB hard X-ray afterglow emission

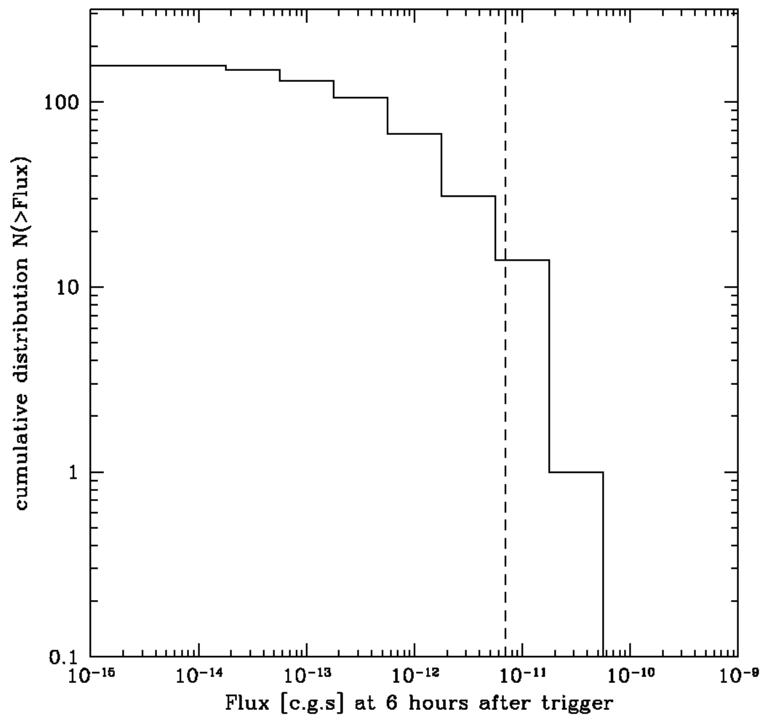


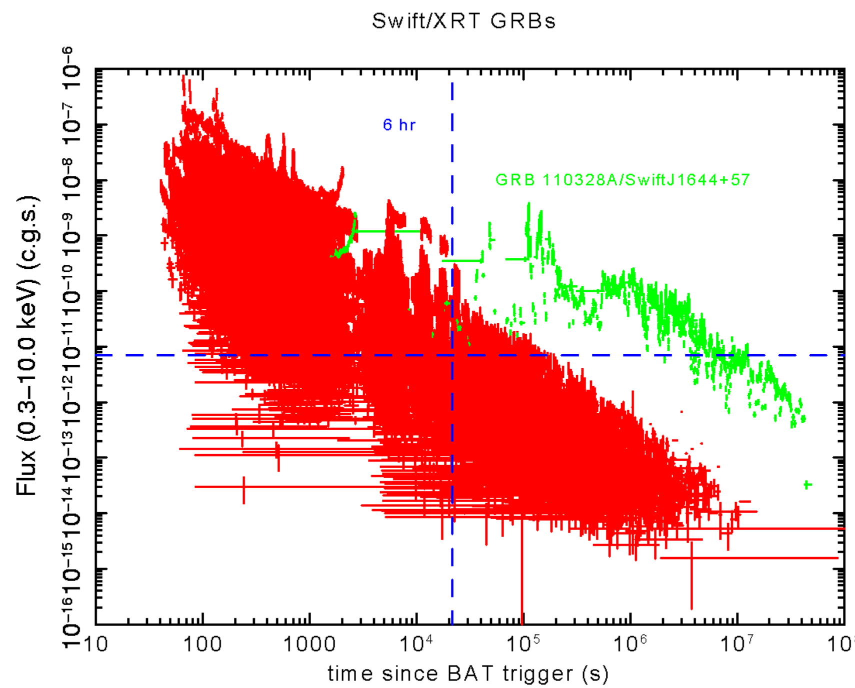
Corsi et al. (2005)

❑ Sensitivity of the LOFT/LAD to GRB X-ray afterglow emission as a function of observation time

- ➢ strongly dependent on the time required to slew to the GRB position

- ➢ may provide sensitive measurements (comparable to or even better than Swift/XRT) if pointed to GRB position at max 6-8 hr after GRB trigger





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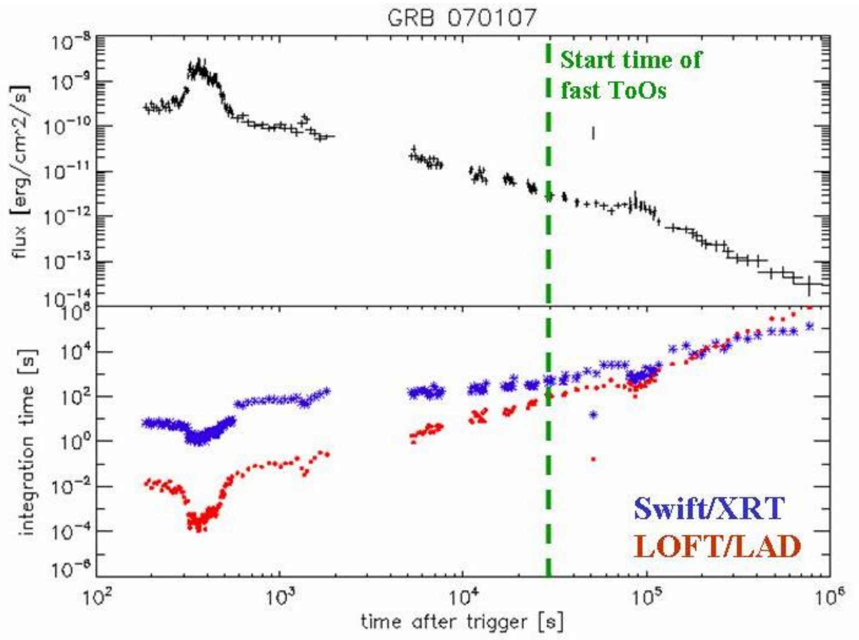

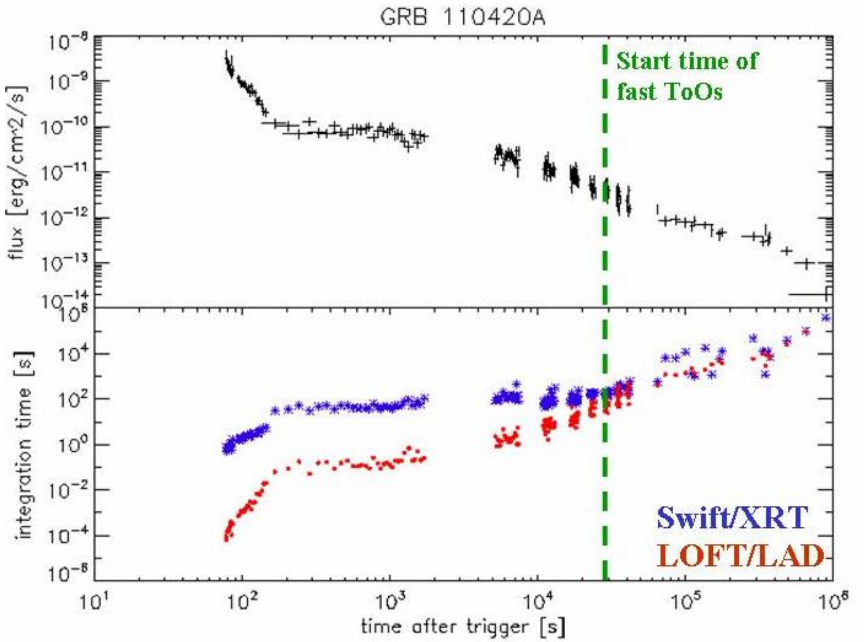

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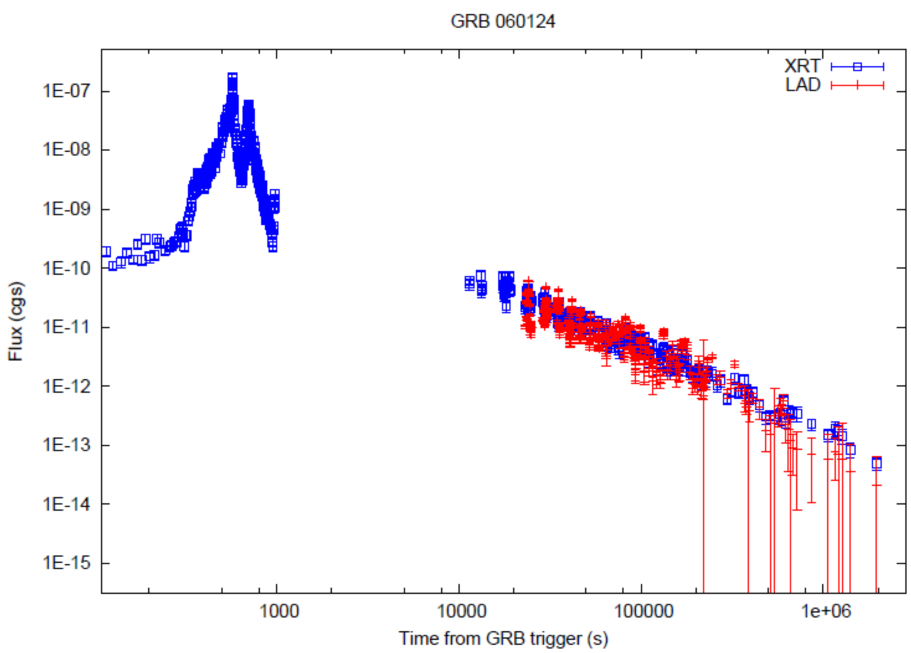
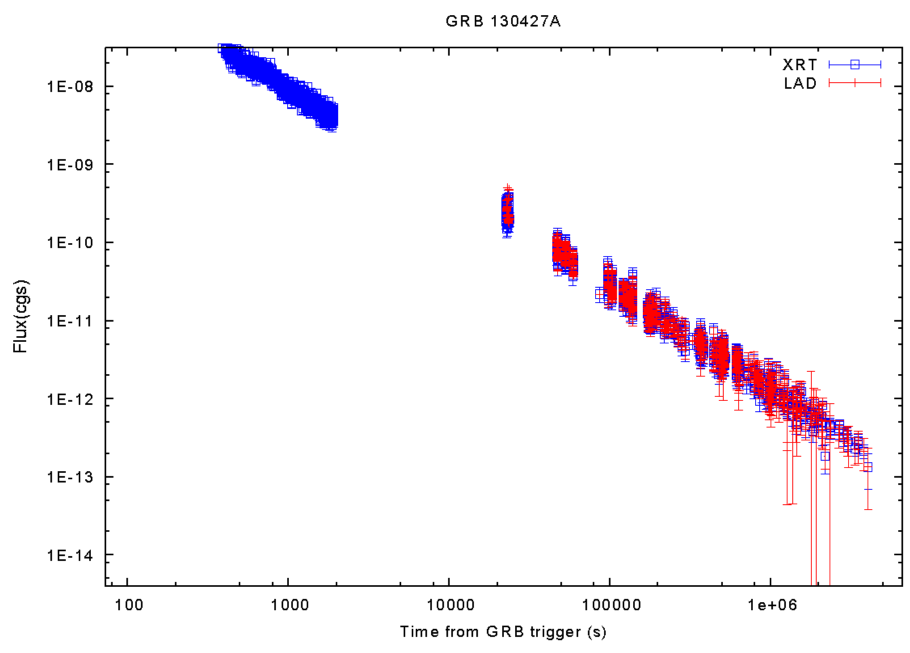
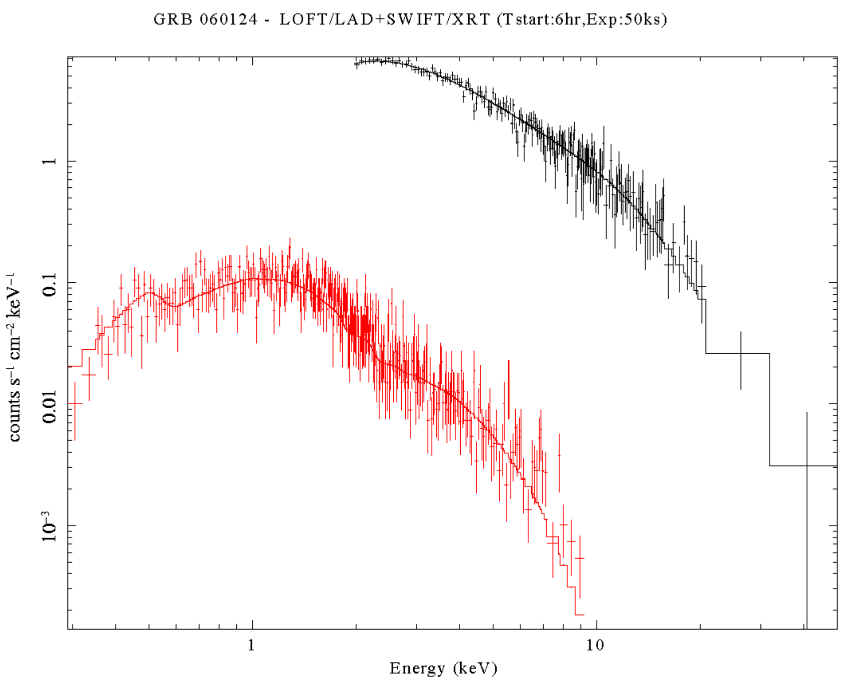
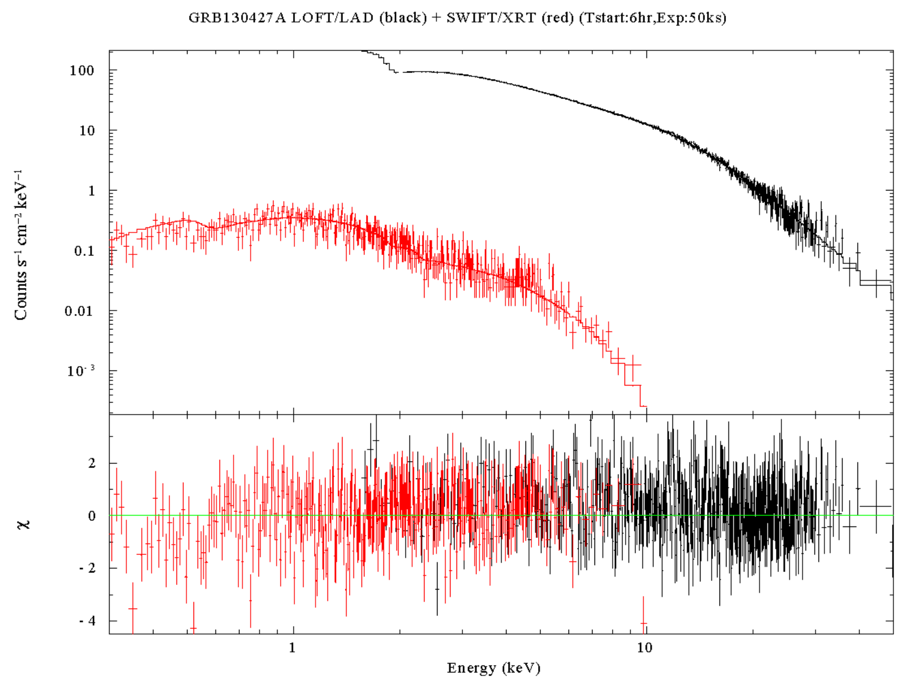




❑ LOFT/LAD measurement of hard X_ray (> 10 keV) afterglow emission for the brightest GRBs





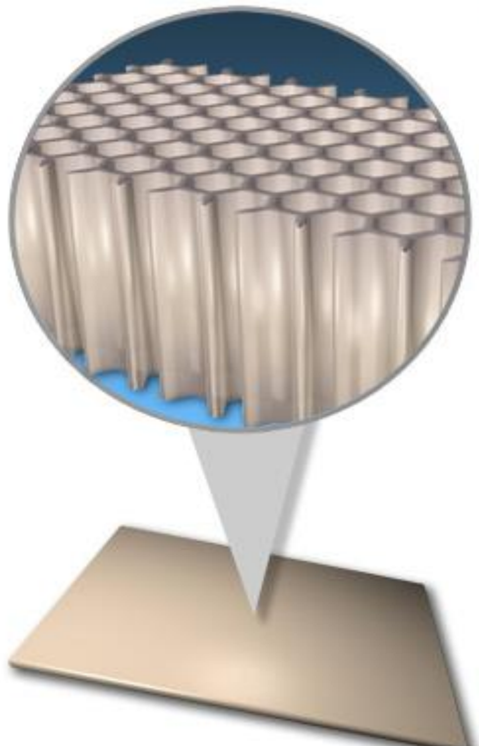
50 ks observation starting 6hr from GRB onset (Swift/XRT and LOFT/LAD)

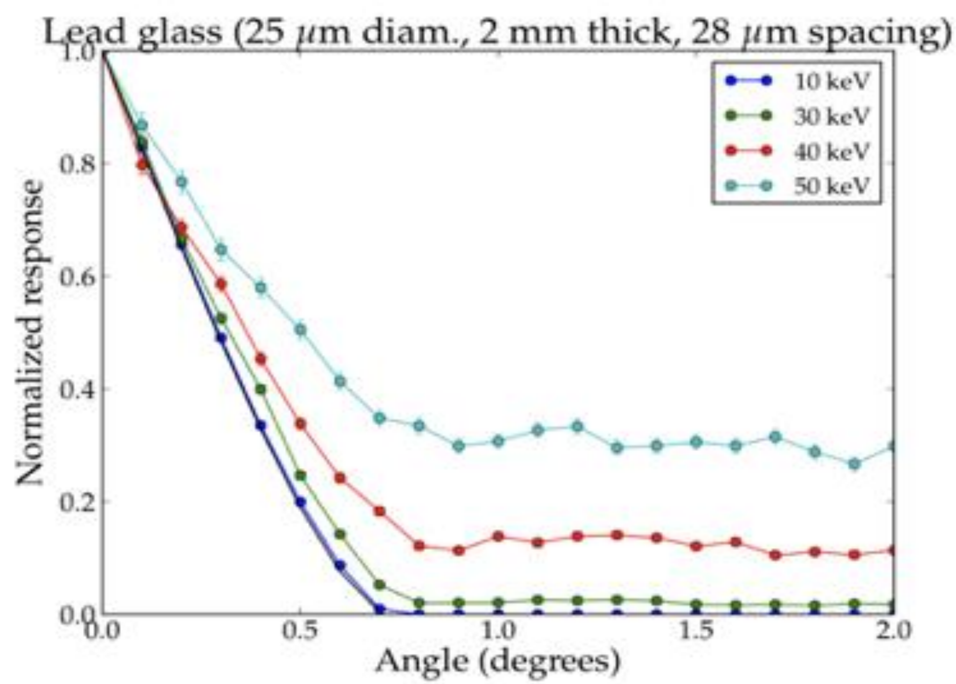
❑ Prompt emission at > 40 keV with the LAD ?

➢ the huge area of the LAD combined with the lead glass collimator transparency as a function of off-axis and energy could allow detection of > 40 keV GRB prompt emission with several hundreds cm2 eff. area

➢ if metal collimator, the possibility of leaving a small fraction of the LAD uncollimated will be considered

➢ **complement measurements of prompt emission by the WFM**





- **Updated mission profile and instruments design in the last year are mostly positive for GRB science !**

  - **broadcast of WFM trigger time and onboard computed position within 20-30s through HETE2(SVOM)-like network of VHF stations**

  - improved FOV (more than 4 sr) of the WFM, with a pair of cameras pointing to the anti-solar direction

  - extended energy range (up to 80 keV) for both WFM and LAD

  - trigger photon by photon mode for the WFM (300s)

  - reliability of the LAD detection of prompt emission (transparency of glass collimator at > 40 keV or, if metal collimator, uncollimated panel)

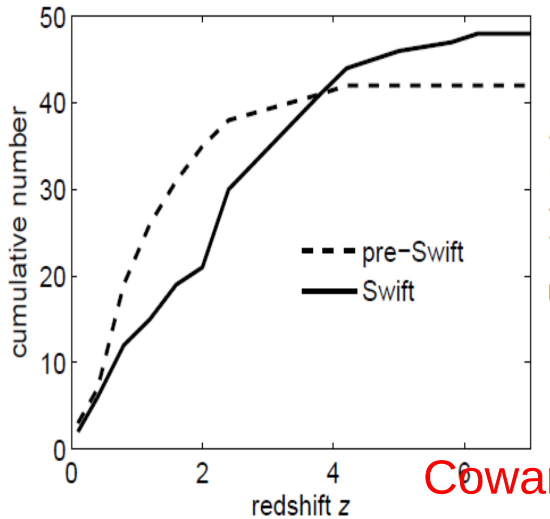
  - TOO pointings with the LAD within 8 (can be pushed down to a few ?) hours from trigger

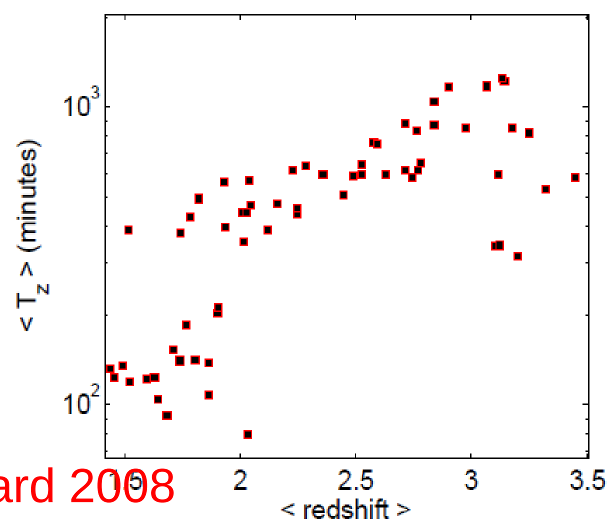
❑ Prompt dissemination of ~arcmin GRB positions provided by WFM

➢ VHF+ ground stations (HETE-2 like): < 30s, possibly within a few s

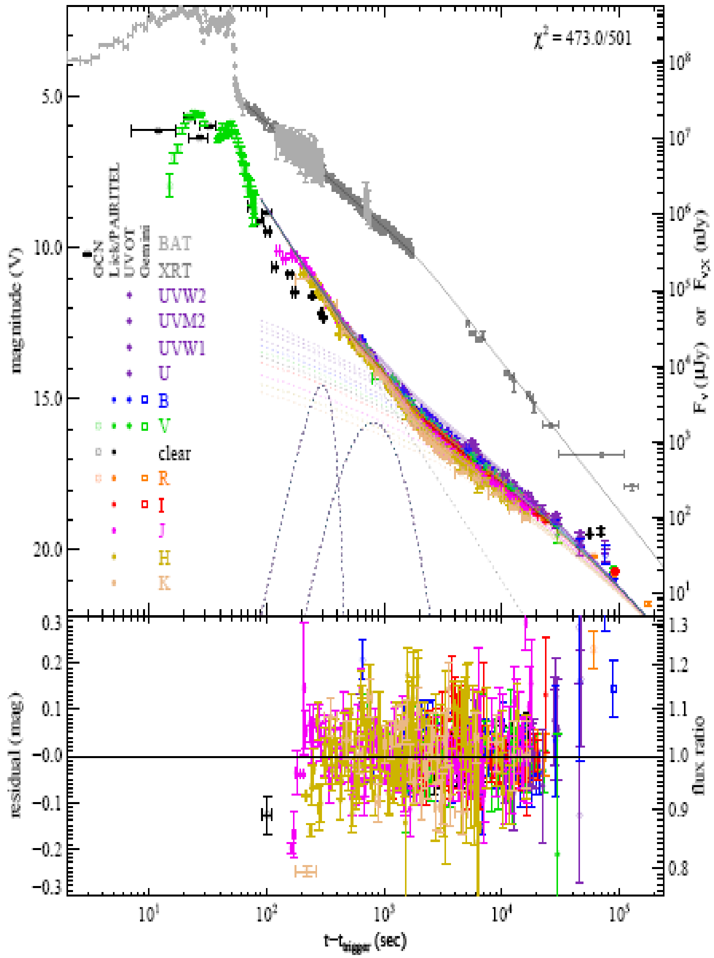
➢ will be a fundamental service to the GRB community, given that neither Swift or SVOM may be operative in the > 2024 time frame

➢ increase rate and reduce bias of redshift estimates; allow broad-band study of GRBs starting from prompt emission; provide trigger for GW detectors





Coward 2008



Bloom et al. 2008

LOFT GRB Science in the >2022 context

- **No past, present or future (e.g., SVOM) GRB experiment has such a combination of low energy threshold, high energy resolution and wide FOV**, which will make the LOFT/WFM unique for GRB science.

- For instance, the BeppoSAX/WFC or the HETE-2/WXM had a low energy threshold around 2 keV, but with much worse energy resolution and smaller FOV). SVOM and UFFO (>2018 ?) will have a low energy threshold of 4-5 keV, but with significantly worse energy resolution and eff.area at low energies.

- With its capability of computing and promptly transmitting the GRB position to ground LOFT will: a) continue a fundamental "service" work for the astrophysical community, carried out presently by Swift (and, maybe, in the 2018-2022 time frame by SVOM) of allowing GRB follow-up and multi-wavelength studies with the best telescopes operating in the > 2022 time line (e.g., i.e., LSST, SKA, CTA, eROSITA; maybe XMM, Chandra, etc.); b) complement simultaneous observations by GRB experiments flying on other satellites by providing low energy extension and GRB position, in a way similar to what is presently done, e.g., by joining data from Swift, Fermi and Konus/WIND.

Conclusions

❑ Loft can do significant GRB science by:

✓ exploiting the broad FOV, low energy threshod, excellent energy resolution and good effective area / sensitivity of the WFM to investigate the physics of prompt emission, absorption features by circum-burst material, the population of XRFs and high-z GRBs

✓ complementing simultaneous observations by GRB experiments flying on other satellites (e.g., Swift + Fermi, Swift + KW)

✓ performing timing and spectroscopy of the afterglow emission up to 30 keV with the LAD for the 3-4 brightest GRBs/year

❑ onboard computation and prompt dissemination of GRB (~arcmin) position will be a fundamental service to the GRB (and not only) community in the > 2022 time frame

❑ **GRB science is of high interest to the broad astrophysical (cosm.) community**

❑ Further and refined investigations of the LOFT capabilities for GRB science will be performed within the Observatory Science / GRB working group
http://www.iasfbo.inaf.it/~amati/loftgrb , amati@iasfbo.inaf.it