Strumentazione per lo studio dell'emissione X dei GRB (e X-ray all-sky monitoring)

L. Amati, M. Feroci, F. Frontera, C. Labanti

on behalf of
a large collaboration

Riunione Nazionale sull'Astronomia X
(Roma 16 Novembre 2012)

Interest for the wide astrophysical (cosm.) community

- the study of GRBs, because of their complex phenomenology and extreme energetics, the association of at least a fraction of them with core-collapse SNe, their redshift distribution extending up to at least z~8-9, is relevant to different fields of astrophysics, ranging from plasma and black-hole physics, evolution of the star forming rate and of the galactic ISM up to the epoch of re-ionization, the first generation (pop III) stars, the understanding of the diversity and rate of core-collapse SNe, the measurement of cosmological parameters

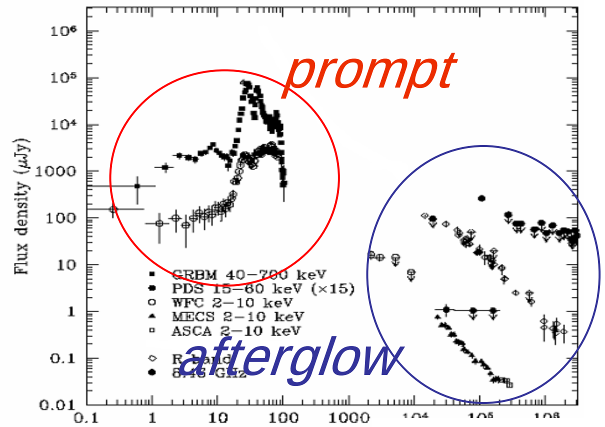
- In addition, the GRB science already involves, and will continue to involve, observers and instrumentation from different communities: optical/IR robotic telescopes (prompt detections and localization of the optical counterparts), major optical/IR telescopes like VLT, Gemini, Hubble (identification, redshift and ISM of the host galaxies, optical afterglow decay and jet signatures), radio telescopes like VLA (afterglow modelling and energetics) observations in the TeV range by Cherenkov telescopes (challenging emission models)

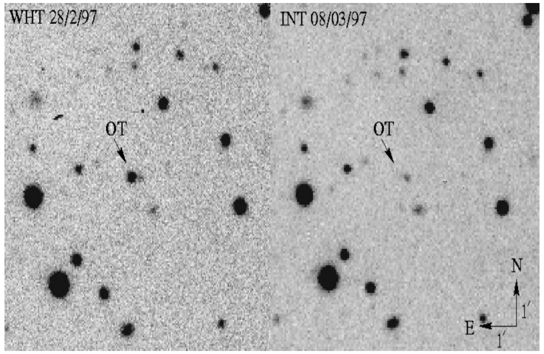
- Italian community at top level in the field:BeppoSAX, Swift, Fermi…

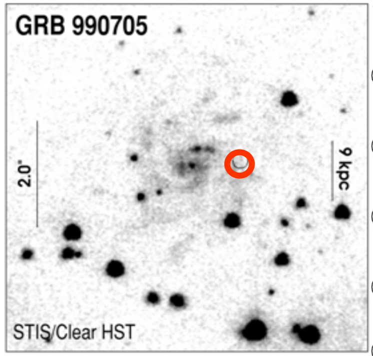
The GRB phenomenon: a puzzle still to be solved

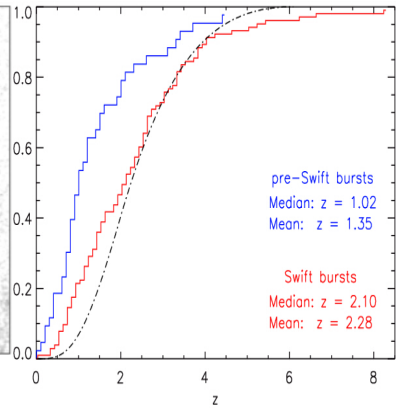
- Despite the huge advances occurred in the last years, the GRB phenomenon is still far to be fully understood

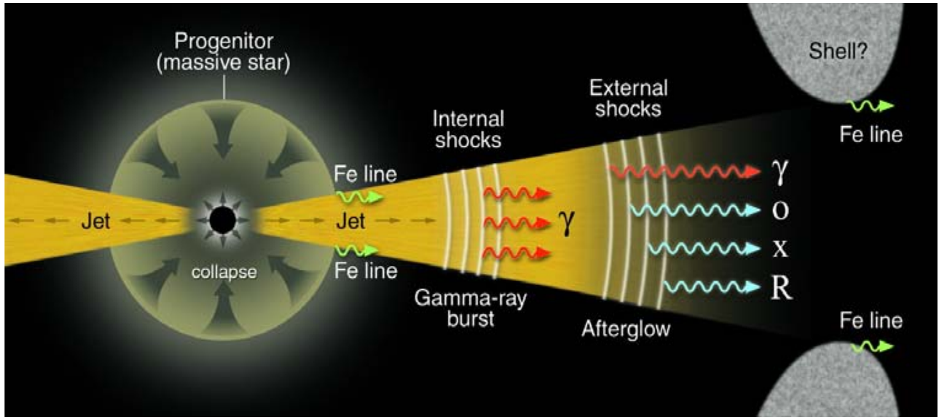
- Open issues include: physics and geometry of the prompt emission, unexpected early afterglow phenomenology (plateau, flares, …), identification and understanding of sub-classes of GRBs (short/long, XRFs, sub-energetic), GRB/SN connection, VHE emission, nature of the inner engine, cosmological use of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









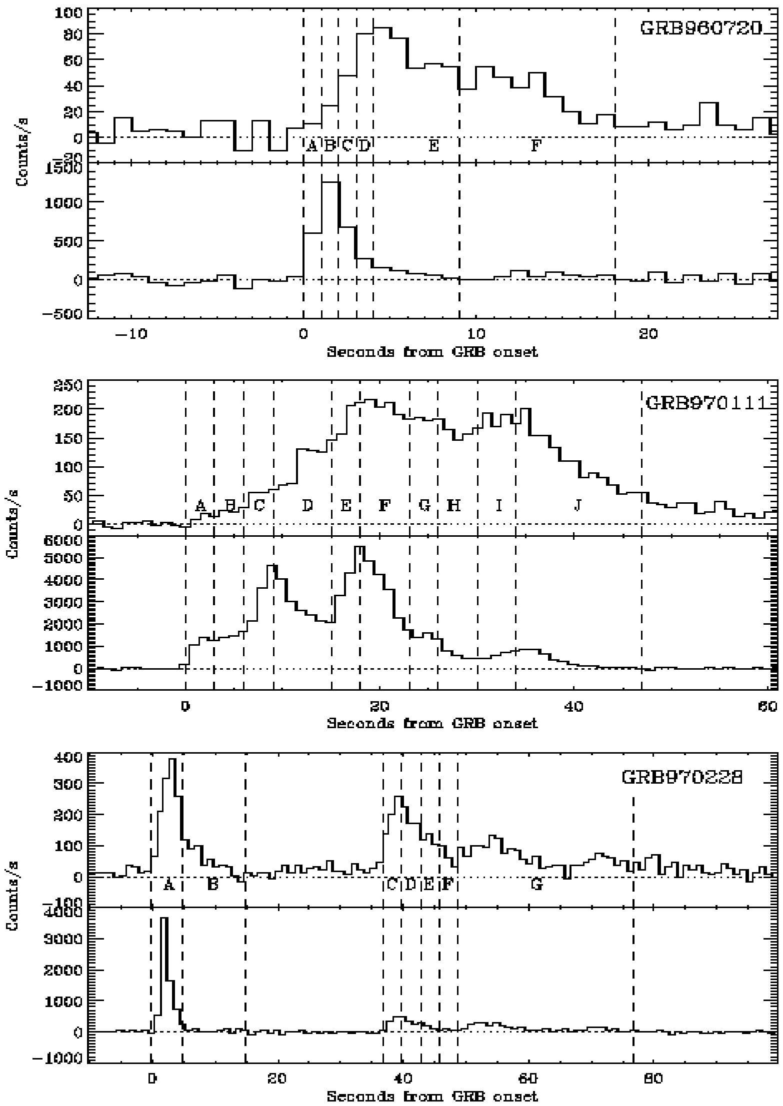


- It is recognized that the GRB phenomenon can be understood only going back to the study of the Prompt Emission

- <u>An energy band extending down to soft X-rays is needed.</u>

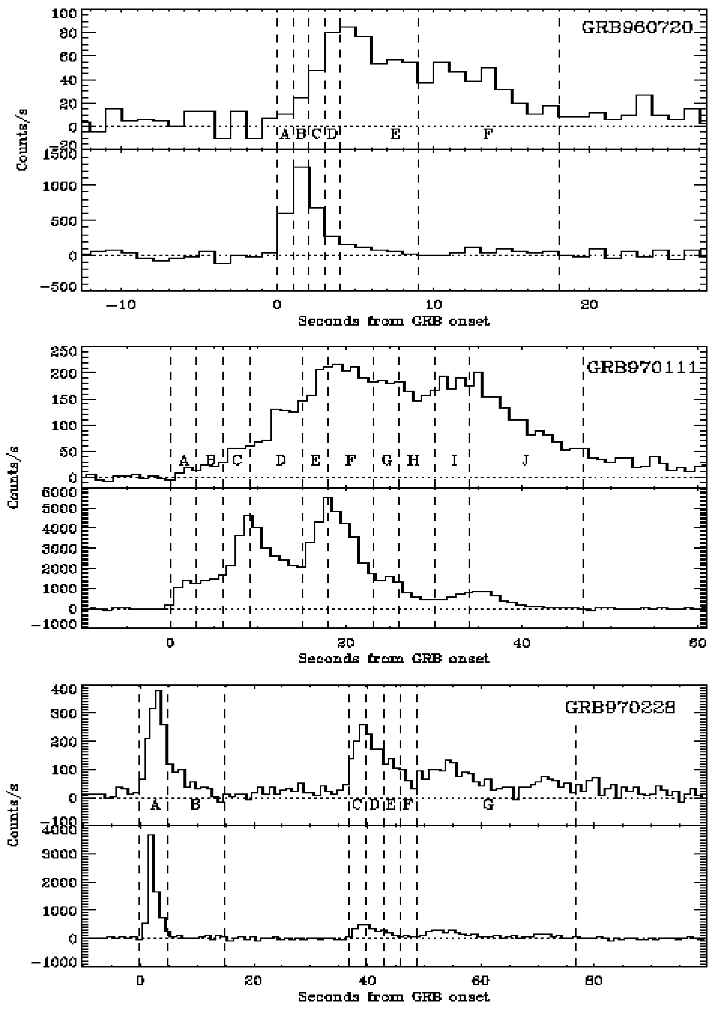
- Measurements down to a few keV were provided in the past by BeppoSAX and HETE-2, but better sensitivity and energy resolution are required to make a step forward

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

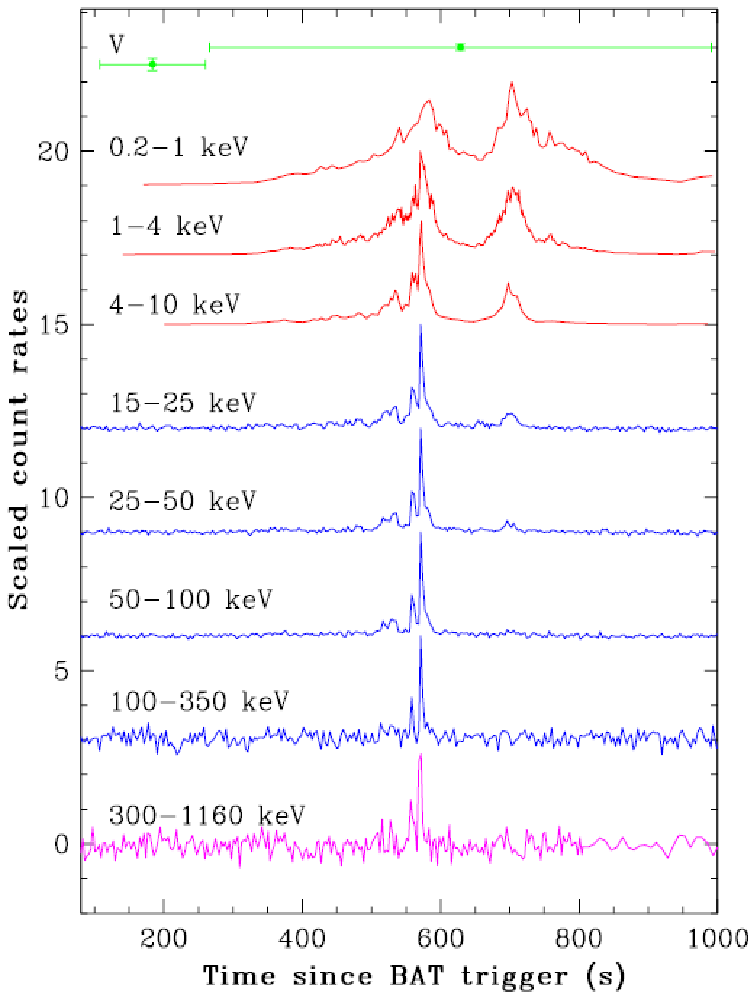


BeppoSAX (top: 2-28 keV, bottom: 40-700 keV)

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



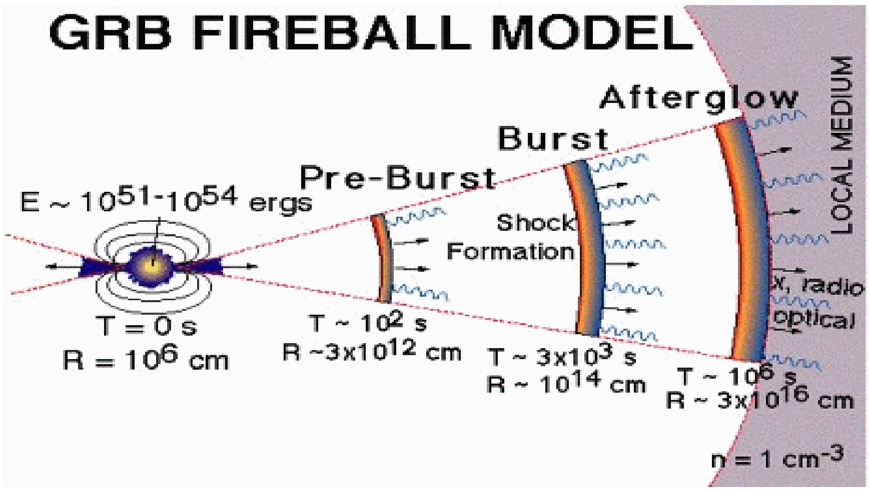
BeppoSAX (top: 2-28 keV, bottom: 40-700 keV) Frontera et al. 2000

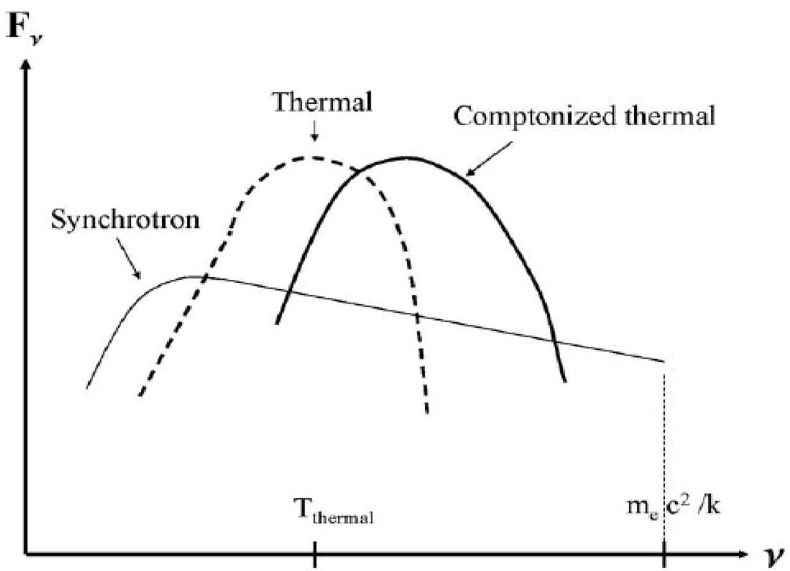


Swift XRT (rare / unique case) + Swift/BAT + konus/WIND. Romano et al. 2006

❑ Testing prompt emission mechanisms with X-ray spectra

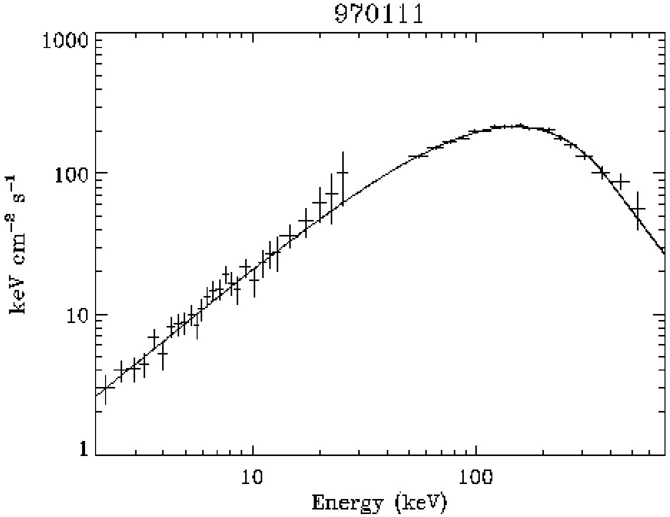
❑ physics of prompt emission still not settled, various scenarios: SSM internal shocks, IC-dominated internal shocks, external shocks, photospheric emission dominated models, kinetic energy dominated fireball , Poynting flux dominated fireball

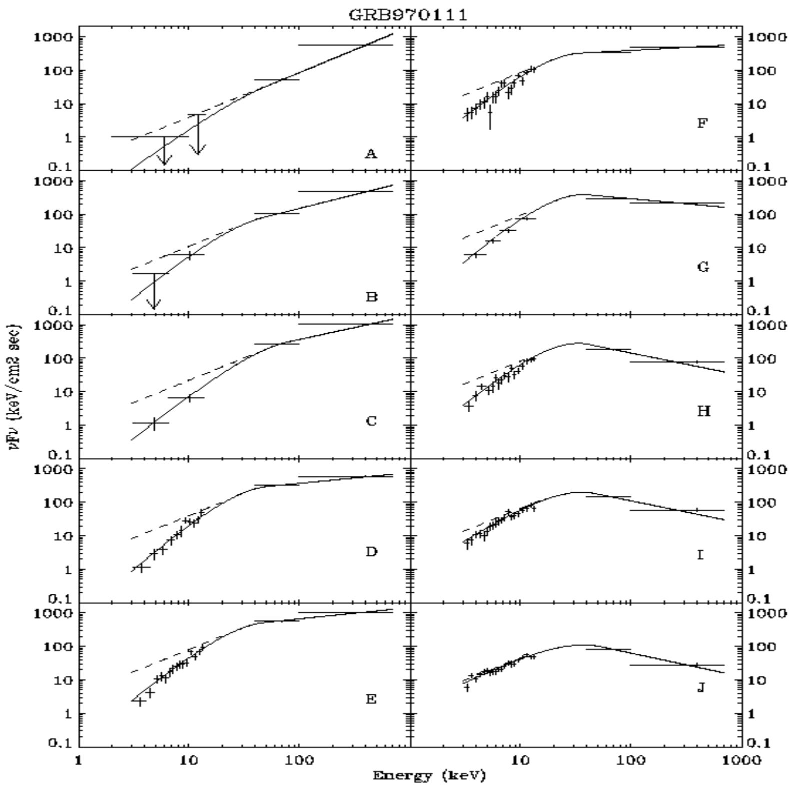


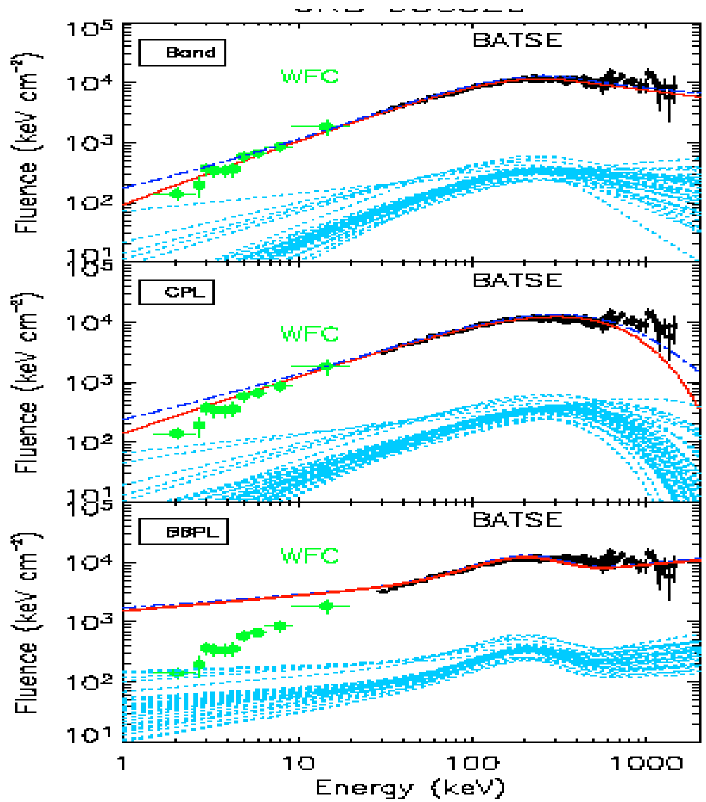


α $N(E)$	$\alpha+1$ $F(E)$	$\alpha+2$ EF_E	model/spectrum
-3/2	-1/2	1/2	Synchrotron emission with cooling
-1	0	1	Quasi–saturated Comptonization
-2/3	1/3	4/3	Instantaneous synchrotron
0	1	2	Small pitch angle/jitter
			inverse Compton by single e^-
1	2	3	Black Body
2	3	4	Wien

- 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



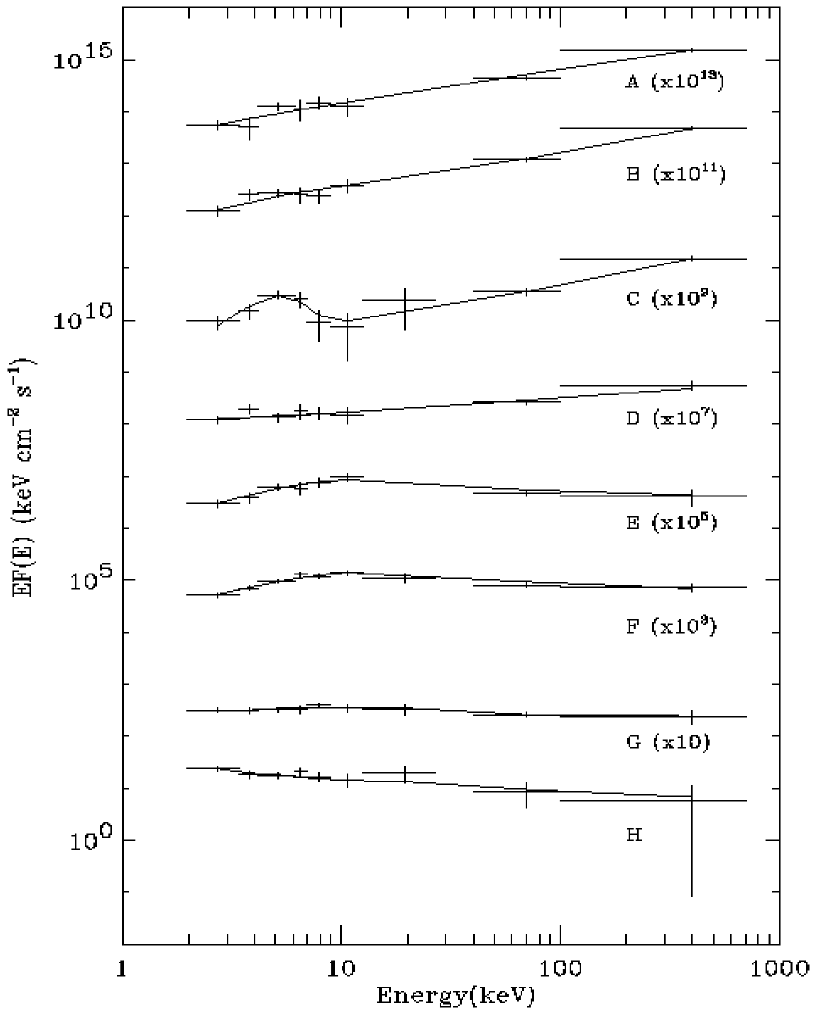




Amati et al. 2001, Frontera et al. 2000, Ghirlanda et al. 2007

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

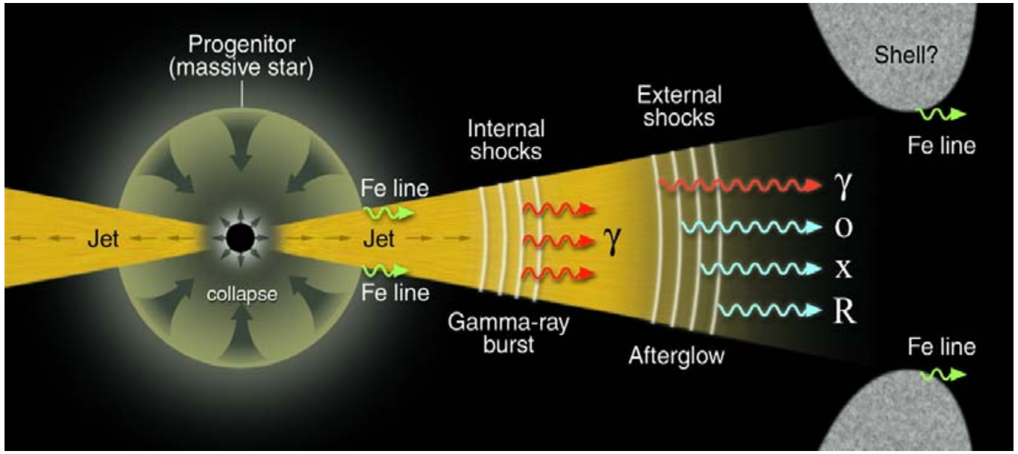
GRB 990712



Frontera et al. 2001

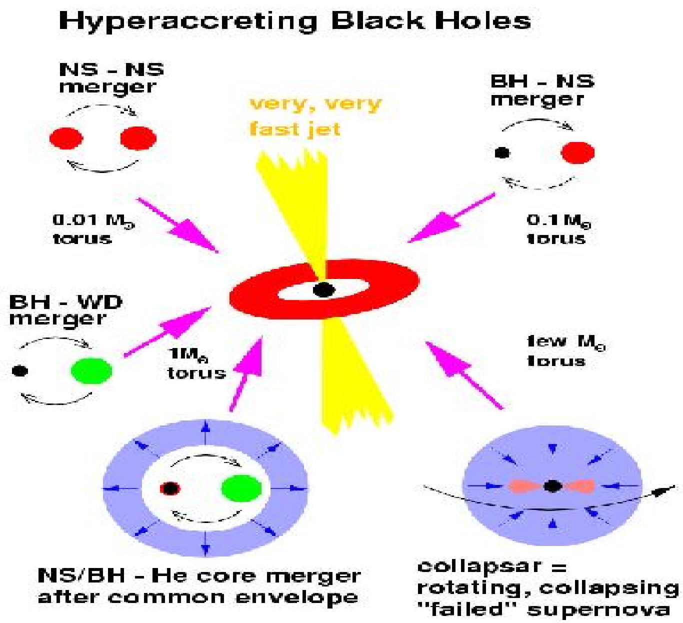
❑ Probing the circum-burst environment with X-ray spectra

LONG



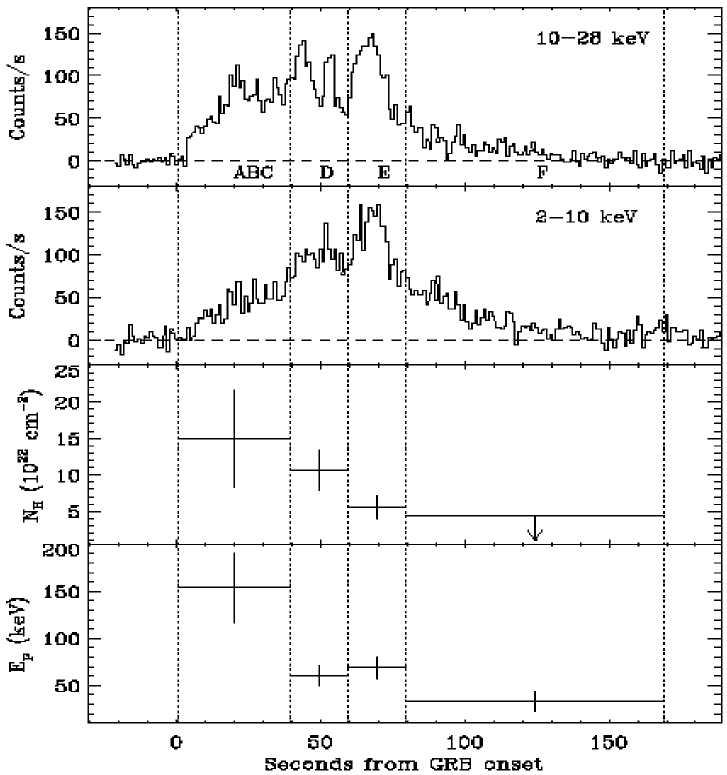
- ➢ energy budget up to $>10^{54}$ erg
- ➢ long duration GRBs
- ➢ metal rich (Fe, Ni, Co) circum-burst environment
- ➢ GRBs occur in star forming regions
- ➢ GRBs are associated with SNe
- ➢ likely collimated emission

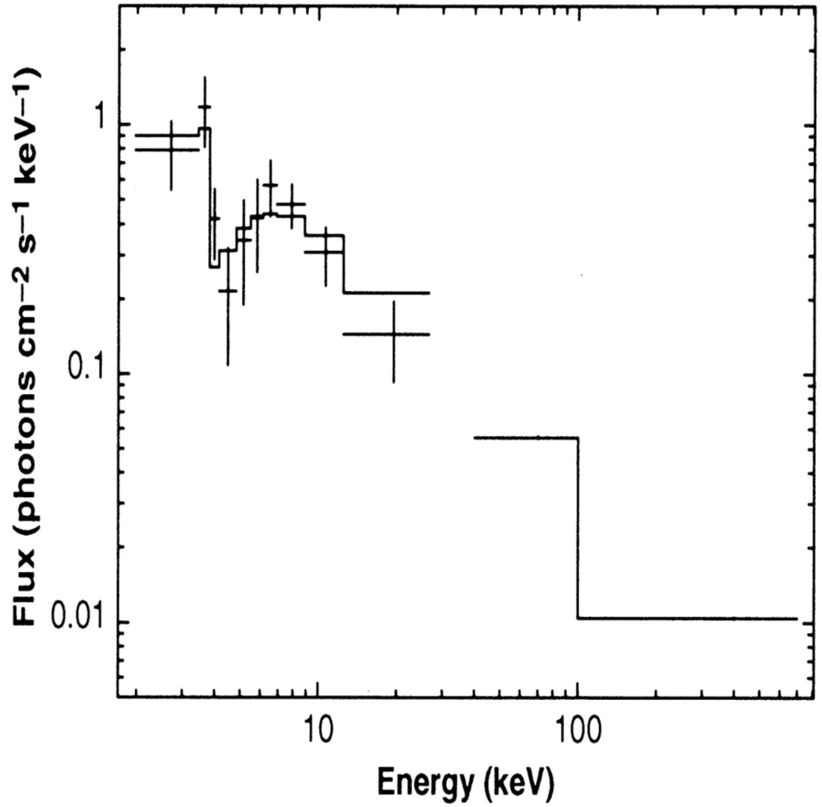
SHORT



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

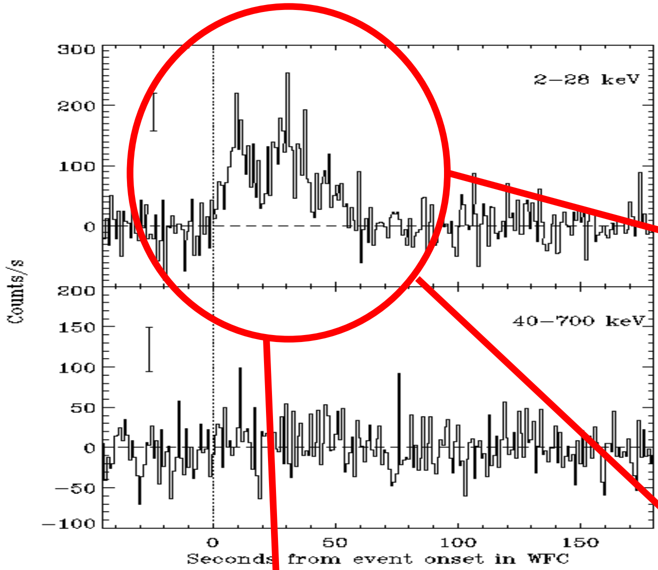
❑ X-ray features: properties (density profile, composition) of circum-burst environment (progenitors, X-ray redshift)

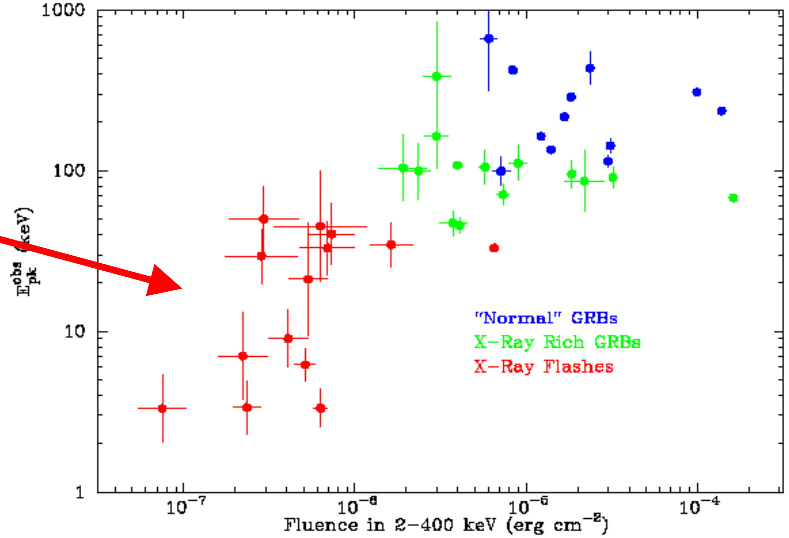




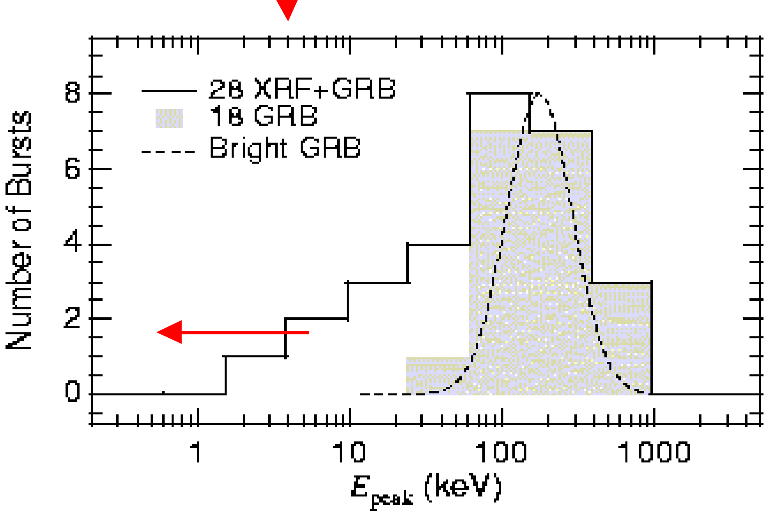
Frontera et al., ApJ, 2004, Amati et al, Science, 2000

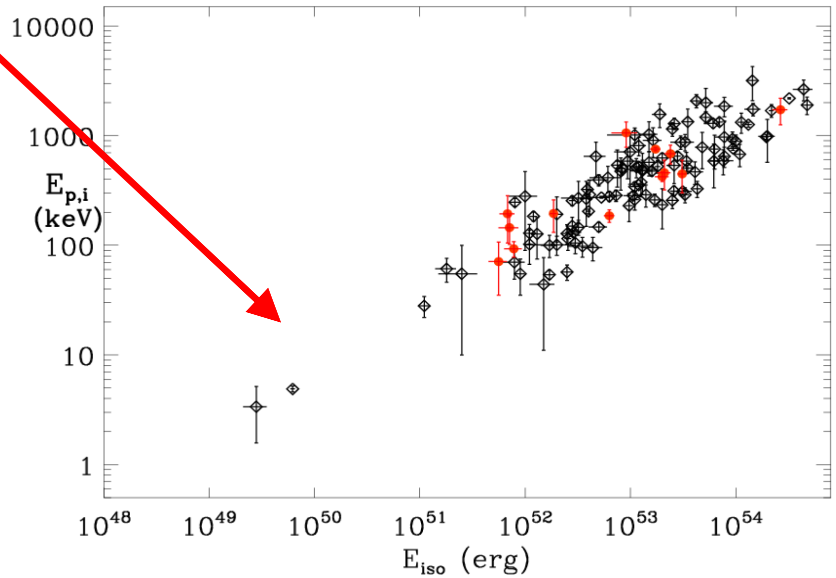
❑ X-Ray Flashes: origin, population size, link with GRB





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

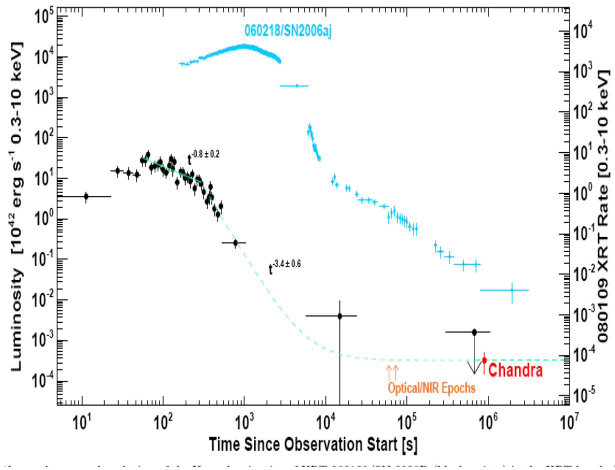




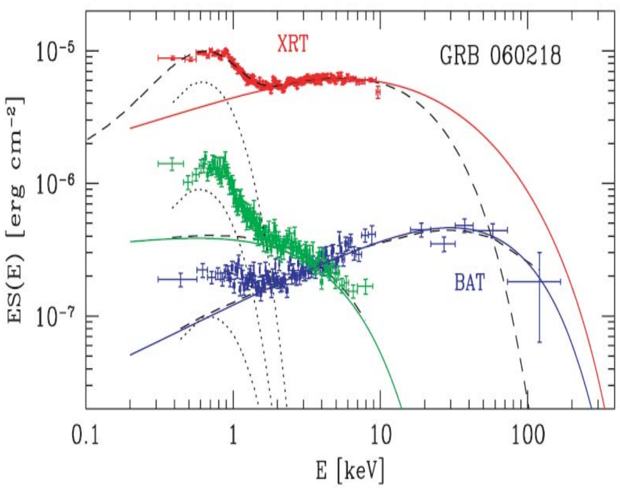
Kippen et al. 2001,Amati 2012

- 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

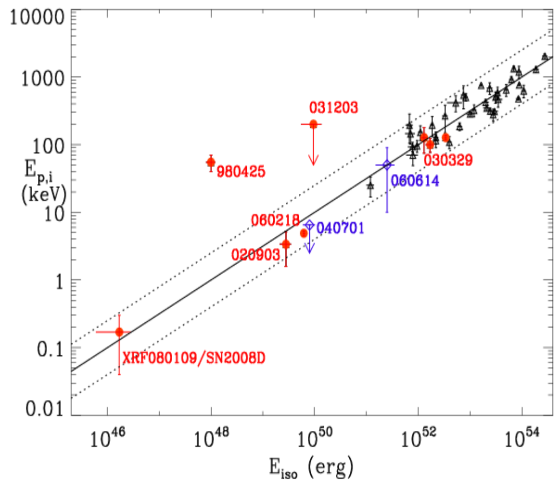
- Debate: very soft/weak XRF or SN shock break-out ?
- Peak energy limits and energetics consistent with a very-low energy extension of the Ep,i-Eiso correlation holding for normal GRBs and XRFs: Evidence that these transients may be very soft and weak GRBs, thus confirming the existence of a population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



Modjaz et al., ApJ, 2008

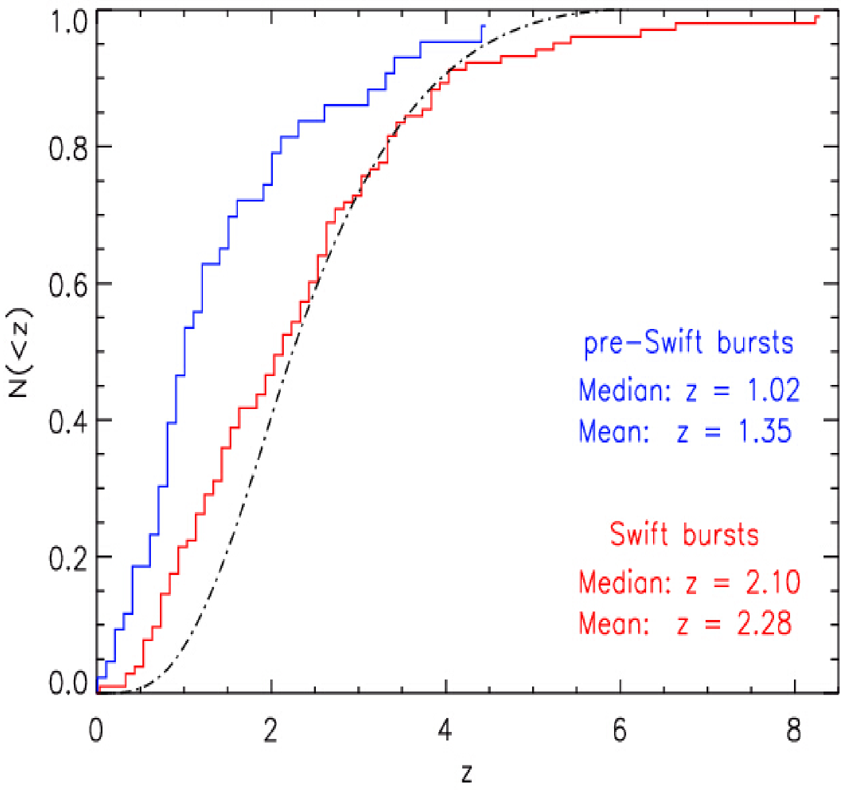


Ghisellini et al. 2006

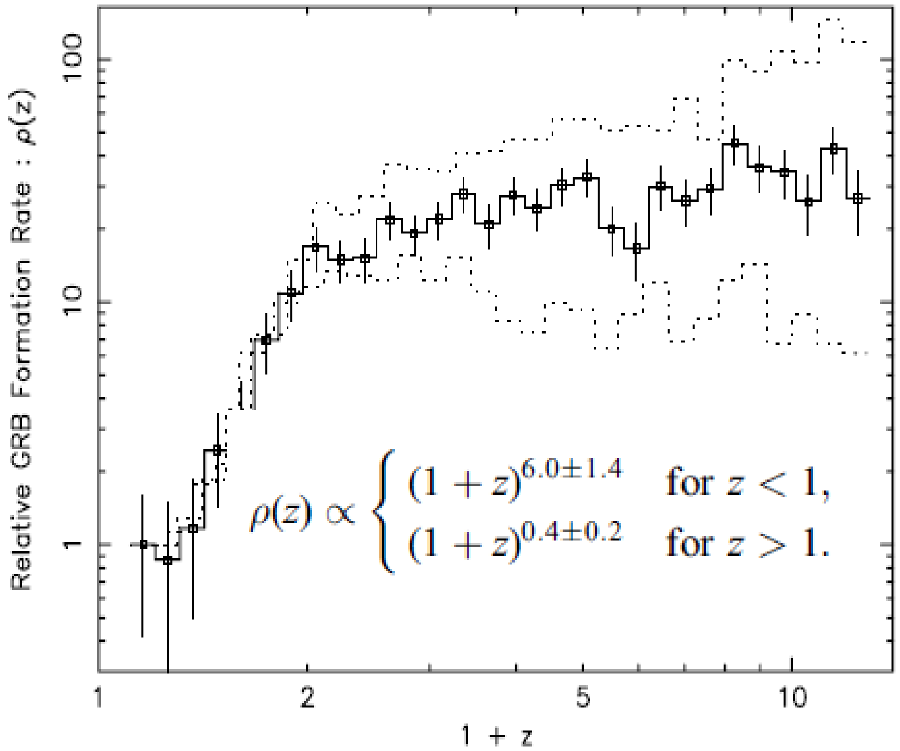


Amati, 2009

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

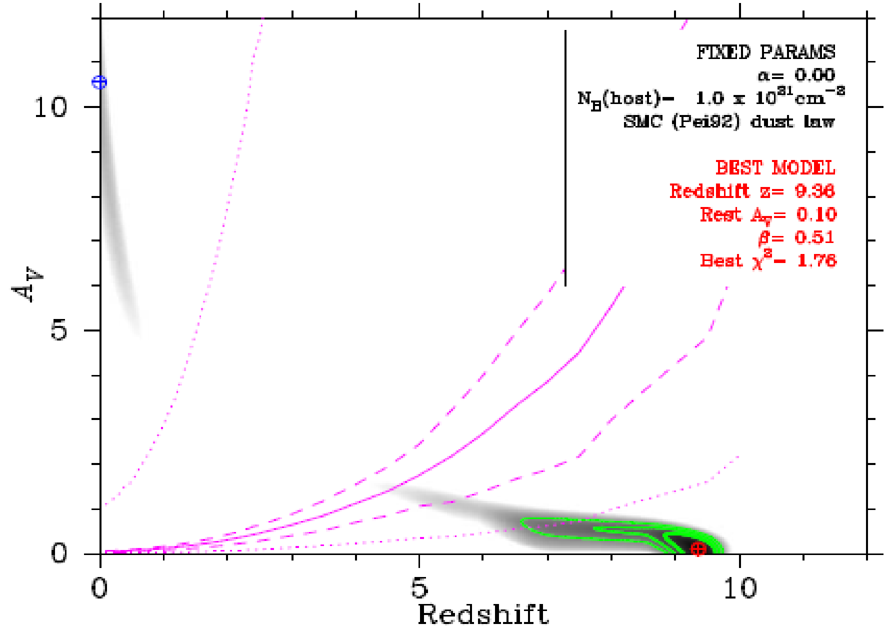


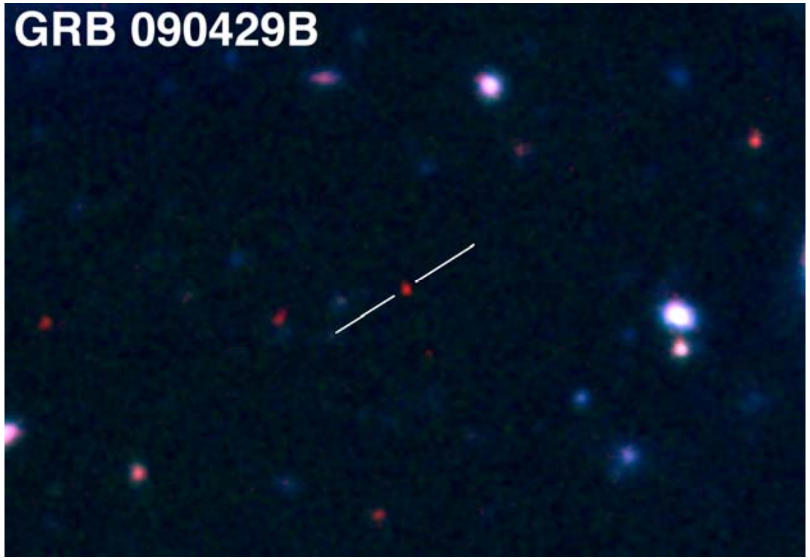
Stanek et al. 2010

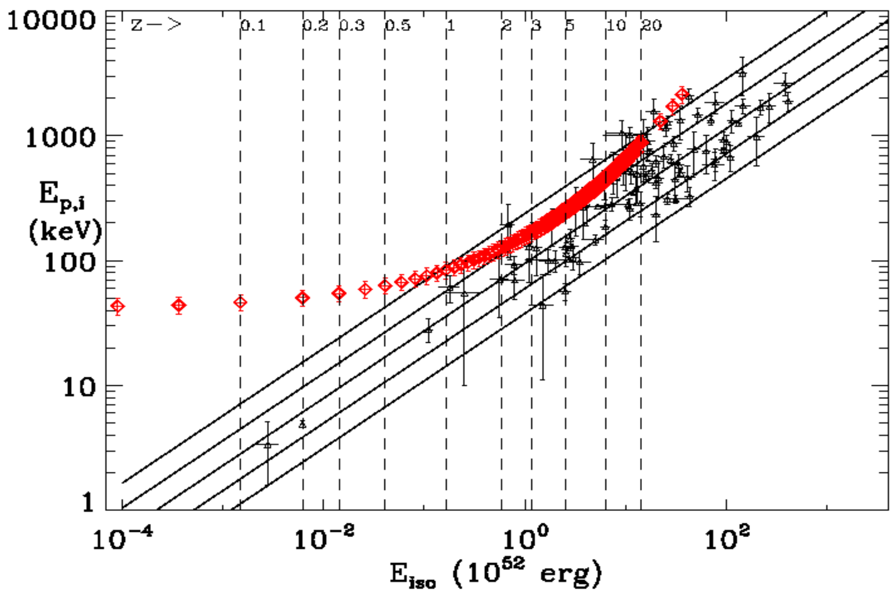


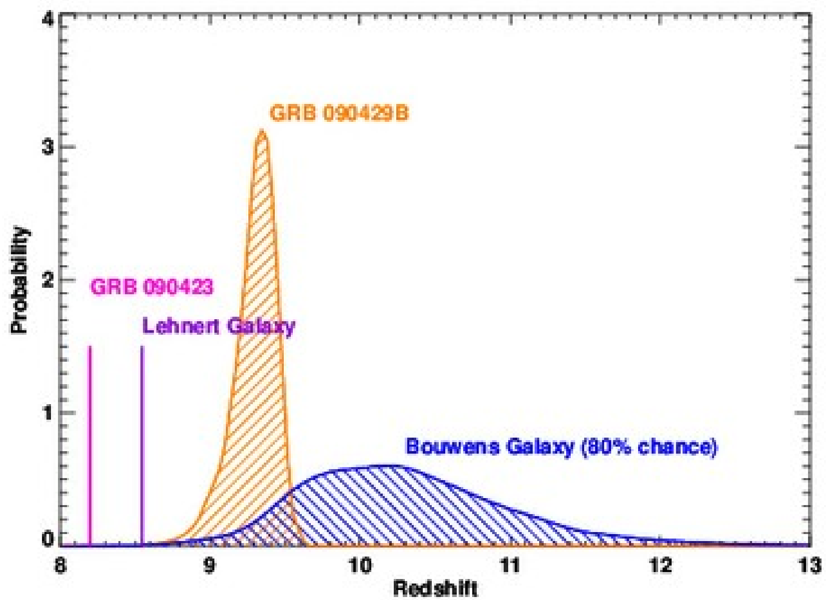
Yonetoku et al. 2004

❑ The case of GRB 090429B at a photometric redshift of ~9.4 ! (Cucchiara et al. 2011): a (pop III ?) star exploded at only 500 millions years since big-bang







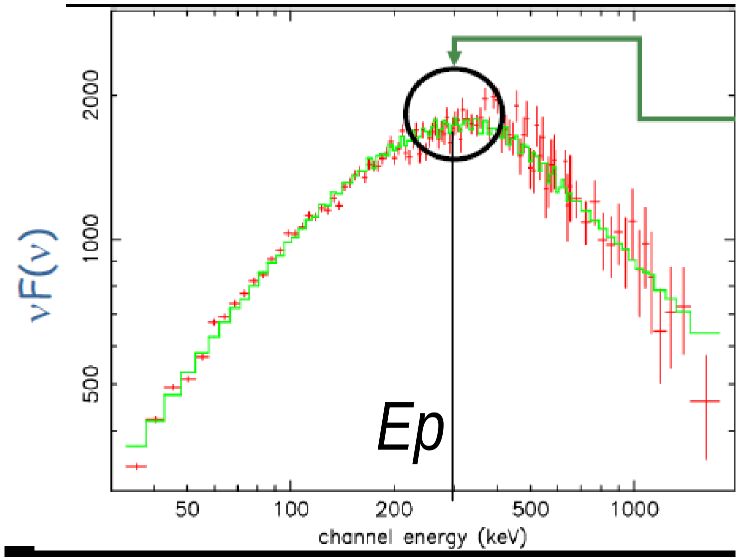


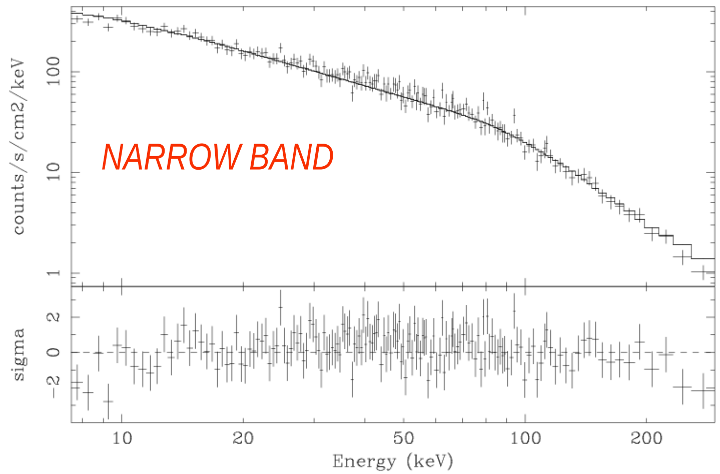
❑ GRB broad band prompt emission: peak energy estimate

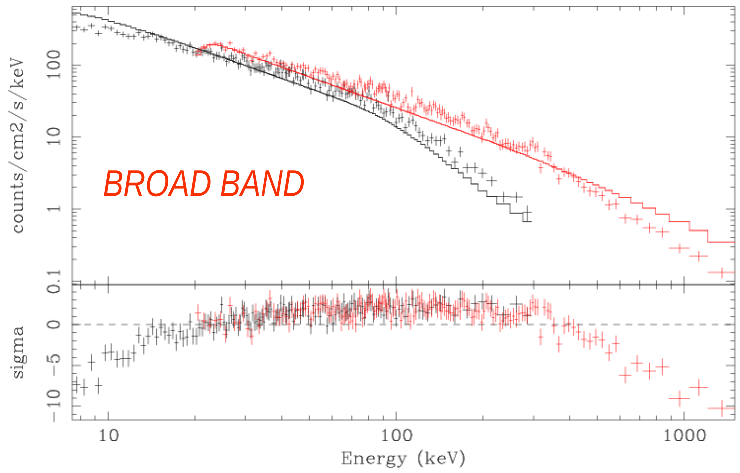
- ❑ the accurate measurement of the spectral parameters of GRB prompt emission is fundamental to test the emission models and, in particular, to test and use Ep-Eiso correlation

- ❑ Swift cannot provide a high number of firm Ep estimates, due to BAT 'narrow' energy band (sensitive spectral analysis only from 15 up to ~200 keV) -> a broad energy band is needed

- ❑ in last years, Ep estimates for some Swift GRBs from Konus/WIND, SUZAKU, Fermi/GBM







❑ investigation of the Ep,i – Intensity correlation

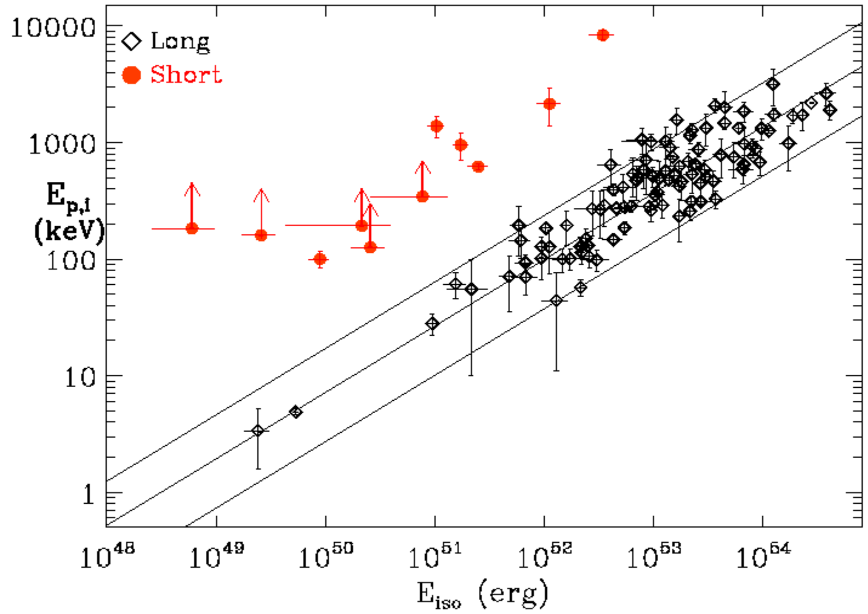
- ➢ Ep,i – Eiso (Liso) relation can give crucial information on the physics of GRBs, like:

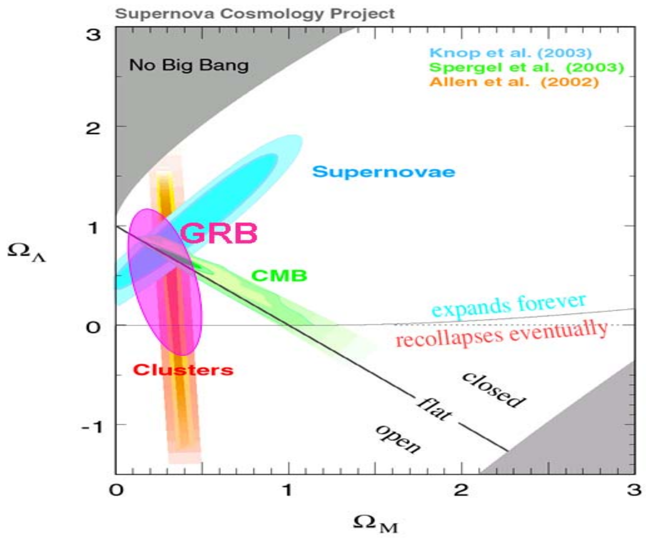
- ➢ Study of the GRB explosion origin and process;

- ➢ Radiation production/emission mechanisms.

- ➢ Ep,i - Eiso relation can also be a powerful instrument for cosmology

- ➢ A much larger sample of GRBs with known Ep and z is needed.





Our scientific motivation for GRB studies: broad band spectroscopy (down to 1 keV) of the prompt emission

- **Physics of the GRB continuum prompt emission:**
  - Broad spectrum from 10 MeV down to 1 keV
  - Transient spectral components (e.g. BB);
- **Establishing the GRB progenitors and their distance from the properties of circumburst environment:**
  - Column density NH and its time behaviour;
  - Absorption edges;
- **X-Ray Flashes: origin, population size, link with GRB**
- **Increasing the detection rate of high-z GRB with low energy threshold: SFR up to dark ages, pop III stars, etc**
- **Physical origin of spectral-energy correlations and their exploitation for cosmology.**

Background and context

- **2002-2004:** we participated to the ESA phase A study of LOBSTER-ISS with the goal of extending the energy band of the lobster-eye (MCP based) wide field telescope from 0.1 – 5 keV up to at last 1 MeV in order to allow deteciton and study of GRBs soft X-ray emission

- **2005**: LOBSTER-ISS phase A study successfully concluded, mission approved to phase B, but ESA program suspended following shuttle Columbia accident

ARTICLE IN PRESS

ELSEVIER

Available online at www.sciencedirect.com

SCIENCE DIRECT®

Advances in Space Research xxx (2005) xxx–xxx

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

The gamma-ray burst monitor for Lobster-ISS

L. Amati [a,*], F. Frontera [a,b], N. Auricchio [a], E. Caroli [a], A. Basili [a], A. Bogliolo [c], G. Di Domenico [b], T. Franceschini [a], C. Guidorzi [b,d], G. Landini [a], N. Masetti [a], E. Montanari [b], M. Orlandini [a], E. Palazzi [a], S. Silvestri [a], J.B. Stephen [a], G. Ventura [a]

[a] *CNR-IASF, Sez. Bologna, via P. Gobetti 101, 40129 Bologna, Italy*
[b] *Universitá di Ferrara, Via Paradiso 12, 44100 Ferrara, Italy*
[c] *STI, Universitá di Urbino, Piazza della Repubblica, 13, 61029 Urbino, Italy*
[d] *Liverpool John Moores University, Egerton Wharf Birkenhead CH41 1LD, UK*

Received 11 December 2004; received in revised form 1 June 2005; accepted 2 June 2005

- **2006-2009:** Within an ASI-INAF contract for AAE studies, science goals and instrument requirements defined for:

  a) broad band spectroscopy (1 keV – 10 MeV) of the GRB prompt emission;

  b) X- ray Sky Monitoring in 1 – 50 keV

- In parallel, R&D activities performed at INAF/IASF institutes in Rome and Bologna (supported by ASI and PRIN INAF) and in collaboration with INFN (Trieste, Bologna, Rome)

- **June 2010:** Invited to join by MIRAX PI, science case and a payload proposal presented, discussed and accepted at INPE (Brazil)

- **July 2010:** Brazilian Space Agency (AEB) invites ASI to discuss the possible Italian contribution to MIRAX, based also on AEB-ASI cooperation agreements.

- **May 2011:** INAF evaluation (positive) of the scientific merit of our proposed payload for MIRAX following a solicitation by ASI

The Italian MIRAX Collaboration as of May 2011

INAF	IASF Roma	M. Feroci**, A. Argan, R. Campana**, I. Donnarumma, Y. Evangelista**, E. Del Monte**, S. Di Cosimo, G. Di Persio, F. Lazzarotto, M. Mastropietro, E. Morelli, F. Muleri, E. Costa, L. Pacciani**, M. Rapisarda, A. Rubini, P. Soffitta
	IASF Bologna	Lorenzo Amati, Claudio Labanti, Martino Marisaldi, Fabio Fuschino, Mauro Orlandini, Alessandro Traci
	OAB, Merate	Gabriele Ghisellini, Giancarlo Ghirlanda
INFN	Sez. Trieste	Andrea Vacchi, Gianluigi Zampa, Nicola Zampa, Alexander Rashevski, Valter Bonvicini
	Sez. Bologna	Giuseppe Baldazzi
	LNGS	Francesco Vissani, Giulia Pagliaro
University	Ferrara	Filippo Frontera*, **, Alessandro Drago**, Cristiano Guidorzi*, Ruben Farinelli*, Lev Titarchuk
	Como	Ruben Salvaterra*
	L'Aquila	Francesco Villante**
	Pavia	Piero Malcovati, Luca Picolli, Marco Grassi
	Pisa	Ignazio Bombaci**
	SNS, Pisa	Mario Vietri*, E. Pian
ICRANET	Pescara	Remo Ruffini and his team

IL NUOVO CIMENTO Online First
DOI 10.1393/ncc/i2011-10867-0

COLLOQUIA: Scineghe2010

A proposed Italian contribution to the MIRAX Scientific Payload

L. AMATI(1), M. FEROCI(2), F. FRONTERA(3), C. LABANTI(1), A. VACCHI(4), A. ARGAN(5), R. CAMPANA(2), E. COSTA(2), R. RUFFINI(6), I. BOMBACI(7), E. DEL MONTE(2), I. DONNARUMMA(2), A. DRAGO(3), Y. EVANGELISTA(2), R. FARINELLI(3), G. GHIRLANDA(8), G. GHISELLINI(8), C. GUIDORZI(3), F. FUSCHINO(1), F. LAZZAROTTO(2), D. LAZZATI(9), P. MALCOVATI(10), M. MARISALDI(1), E. MORELLI(1), F. MULERI(2), M. ORLANDINI(1), L. PACCIANI(2), E. PIAN(11), M. RAPISARDA(2), A. RUBINI(2), R. SALVATERRA(12), P. SOFFITTA(2), L. TITARCHUK(3), A. TRACI(1), A. RASHEVSKY(4), G. ZAMPA(4), N. ZAMPA(4), N. AURICCHIO(1), A. BASILI(1), E. CAROLI(1), E. MAIORANO(1), N. MASETTI(1), L. NICASTRO(1), E. PALAZZI(1), S. SILVESTRI(1), J. B. STEPHEN(1) and J. BRAGA(13)

(1) *INAF, Istituto di Astrofisica Spaziale e Fisica Cosmica - Bologna, Italy*
(2) *INAF, Istituto di Astrofisica Spaziale e Fisica Cosmica, Rome, Italy*
(3) *Università di Ferrara - Ferrara, Italy*
(4) *INFN, Sezione di Trieste, Trieste, Italy*
(5) *INAF, sede centrale - Rome, Italy*
(6) *International Center for Relativistic Astrophysics Network (ICRANet) - Pescara, Italy*
(7) *Università di Pisa - Pisa, Italy*
(8) *INAF, Osservatorio Astronomico di Brera - Merate, Italy*
(9) *North Carolina State University - Raleigh, NC, USA*
(10) *Università di Pavia - Pavia, Italy*
(11) *INAF, Osservatorio Astronomico di Trieste - Trieste, Italy*
(12) *Università dell'Insubria - Como, Italy*
(13) *Instituto Nacional de Pesquisas Espaciais (INPE) - Sao Josè dos Campos, Brazil*

(ricevuto il 25 Febbraio 2011; pubblicato online il 12 Maggio 2011)

Available at: http://prometeo.sif.it/papers/?pid=ncc9894

- **2006-2009:** Within an ASI-INAF contract for AAE studies, science goals and instrument requirements defined for:

  a) broad band spectroscopy (1 keV – 10 MeV) of the GRB prompt emission;

  b) X- ray Sky Monitoring in 1 – 50 keV

- In parallel, R&D activities performed at INAF/IASF institutes in Rome and Bologna (supported by ASI and PRIN INAF) and in collaboration with INFN (Trieste, Bologna, Rome)

- **June 2010:** Invited to join by MIRAX PI, science case and a payload proposal presented, discussed and accepted at INPE (Brazil)

- **July 2010:** Brazilian Space Agency (AEB) invites ASI to discuss the possible Italian contribution to MIRAX, based also on AEB-ASI cooperation agreements.

- **May 2011:** INAF evaluation (positive) of the scientific merit of our proposed payload for MIRAX following a solicitation by ASI

- **June 2012:** GAME (GRB and All-sky Monitor Experiment) proposal to ESA small mission based on same science case and payload concept of MIRAX

The proposed payload for GAME

Science Drivers:

1. Wide-band spectroscopy of the prompt emission of GRBs down to 1 keV (and up to a few MeVs) + accurate (1-2 arcmin) determination and prompt dissemination of GRB position
2. All-sky monitoring of Galactic and Extragalactic X-ray sources in 1-50 keV with a 1-2 arcmin location accuracy and high sensitivity (a few mCrab in 1 day)

Proposed instrumentation:

- X-ray Monitor (XRM): 1-50 keV, 6 units, Imaging, Silicon Drift Detectors with Coded Mask, large FOV (3 sr FC)
- Soft Gamma-ray Spectrometer (SGS):
  15 keV – 10 MeV NaI(Tl)/CsI(Na) phoswich detector, 8 units
- Xard X-rays Imager (HXI): 10-200 keV, Imaging, CZT detectors, wide FOV (20°x20° FWHM)

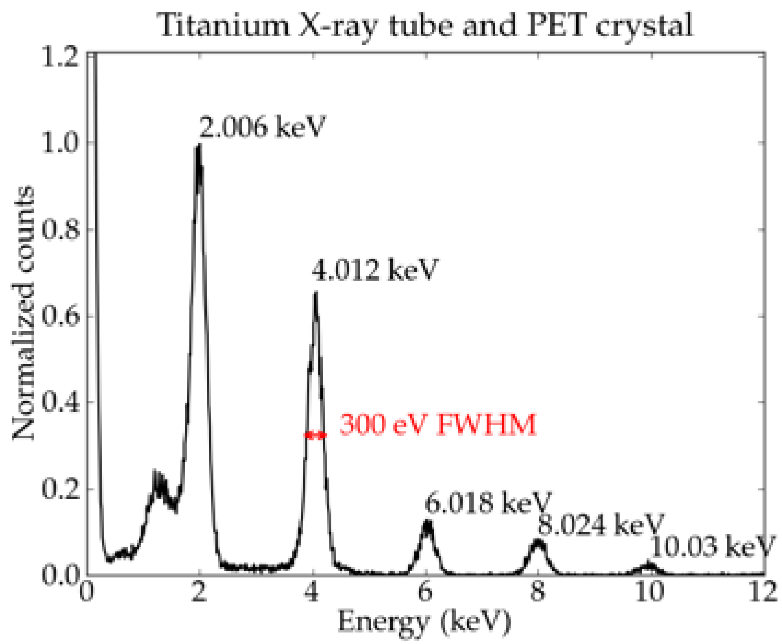
The X-Ray Monitor

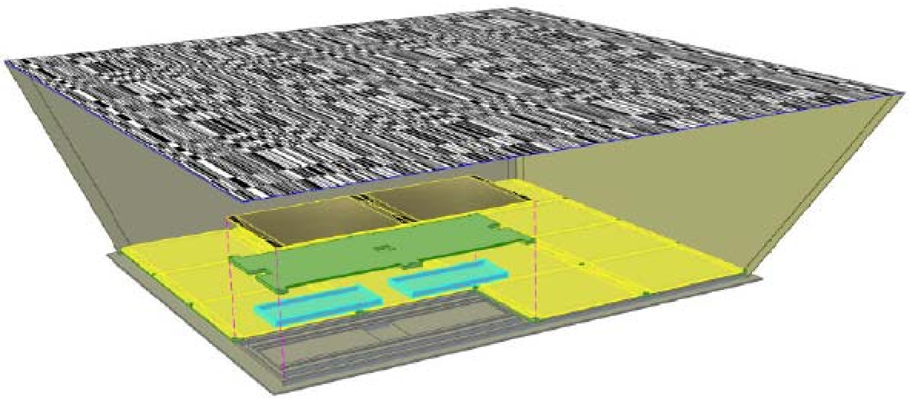
- Use of Silicon Drift Detectors (SDC) heritage of the LHC/Alice experiment at CERN with excellent performances (energy resolution 200-300 eV, low energy threshold < 2 keV, time res. < 10μs) can be used to build large area detectors)

- The SDC detector has asymmetric position resolution: ≤100μm in one direction and ~2-3 mm in the orthogonal direction.

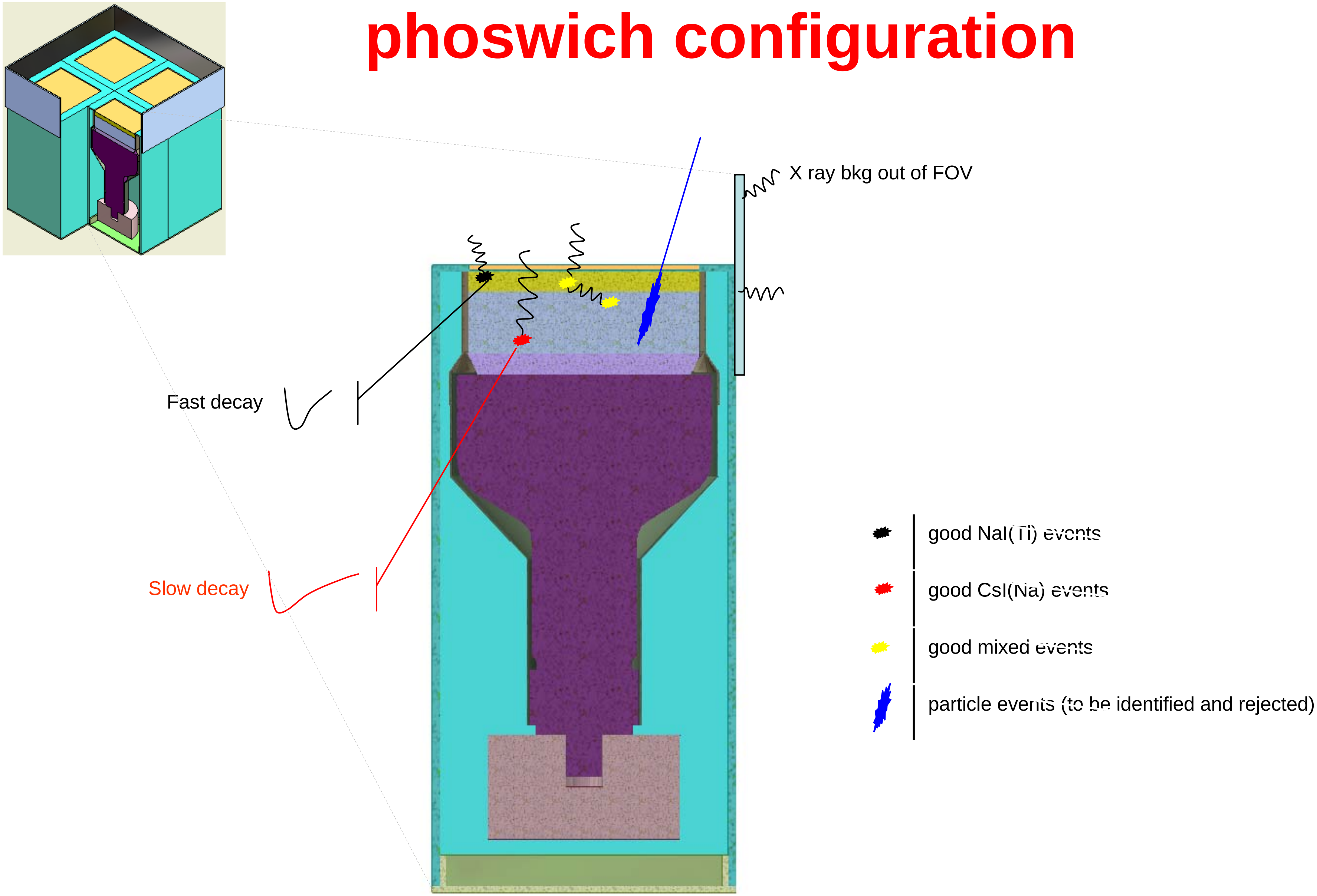
  ⇒ Asymmetric 2D coded mask

  ⇒ 2 orthogonal units always looking at the same FoV to guarantee arcmin prompt localization of Gamma Ray Bursts

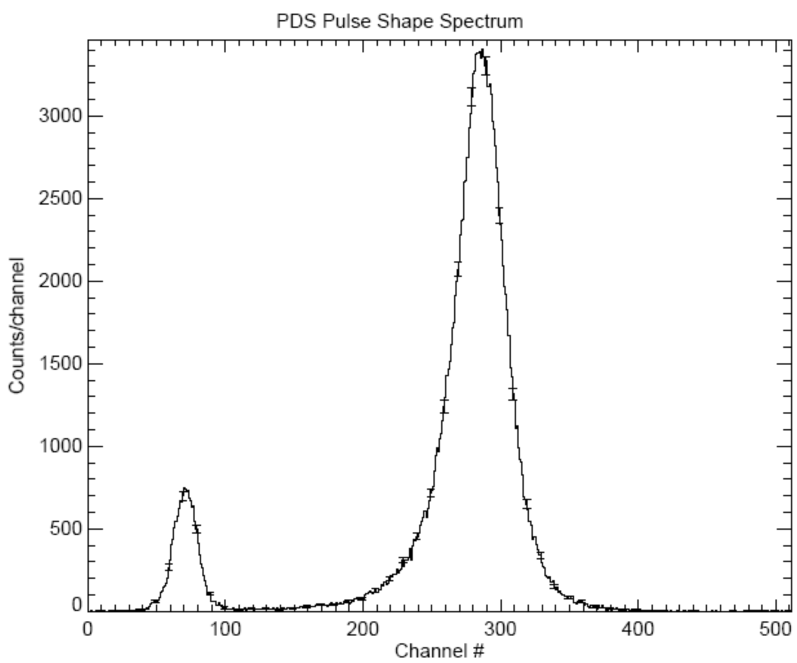


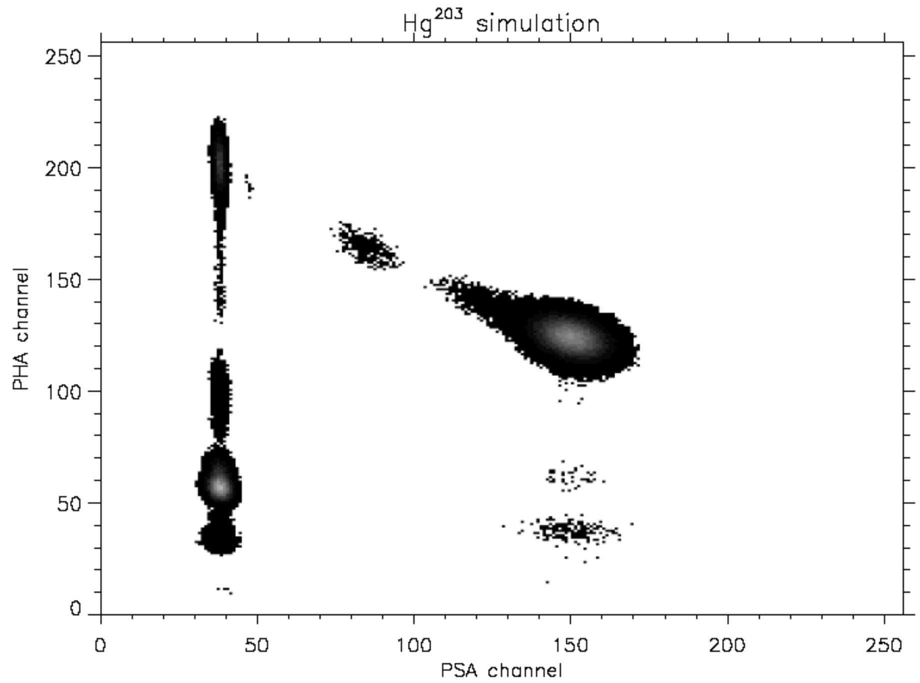


The Soft Gamma-Ray Spectrometer: phoswich configuration



Effectiveness of phoswich technique





Effectiveness of the Pulse Shape Analysis (PSA) for the phoswich detectors of the BeppoSAX/PDS instrument

PSA parameter is a measure of the duration in time of a fraction of the signal (typically from 20% to 90% of the maximum)

PHA is Pulse Hight Amplitude of the signal

Mission profile and Payload configuration

Table 1: *Main characteristics of the whole satellite.*

Parameter	Value
Mass	~500 kg (PMM total), ~250 kg (GAME payload)
Power	~240 W (total), ~150 W (GAME payload)
Telemetry budget	~4.8 Gb/orbit
Telemetry Downlink	X-band, ~4.0 Mbps for 15 passes/day/station (10 min transmission/pass)
Ground Stations	Alcantara, Malindi

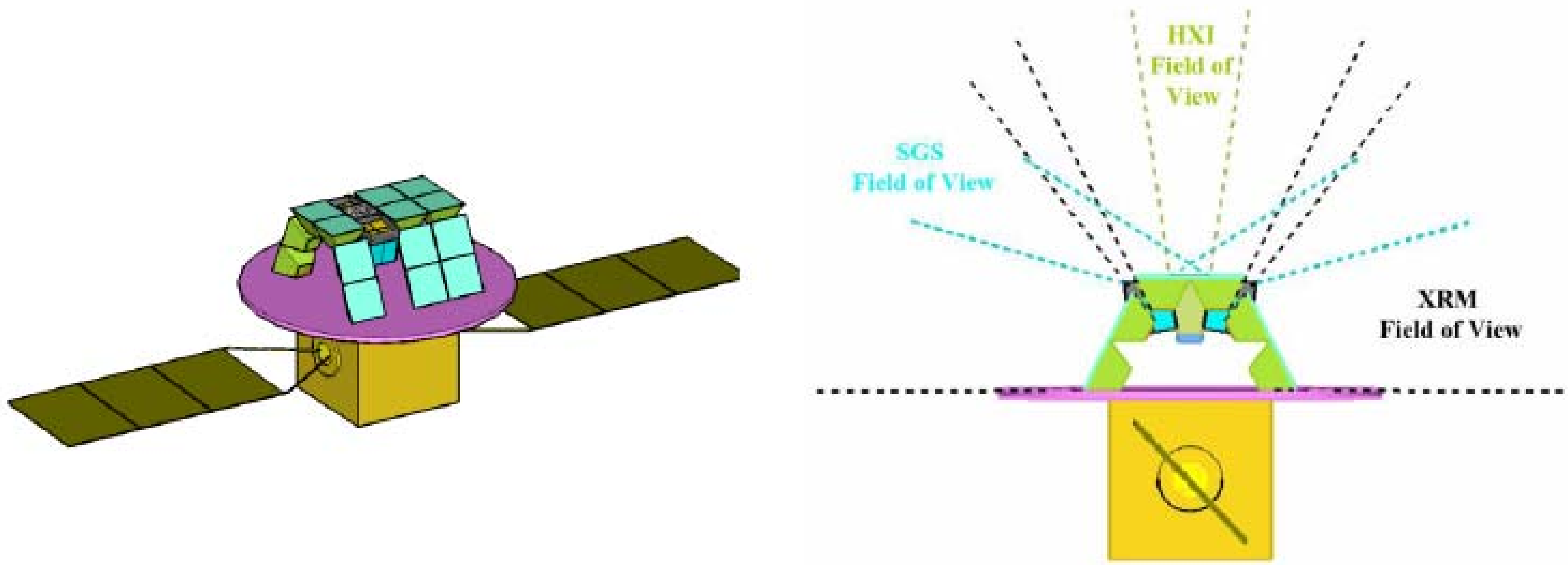


Figure 5. *An hypothesis of allocation of XRM, HXI and SGS. The dimensions of the bus are ~1 m^3.*

Table 2: *Main characteristics and resources of the GAME instruments*

	XRM	HXI	SGS
Energy Range [keV]	1-50	10-200	20-20000
Energy Resolution FWHM	250 [eV]	5 keV@60 keV	15% @60 keV
Time Resolution [μs]	~10	~10	~1
Effective Area [cm²]	>550 in FCFoV (through mask)	~170	~1500 @ 300keV
Angular Resolution	5 arcmin	~1.5°	-
Point Source Location Accuracy	<1 arcmin	~30 arcmin	-
Field of View	~3.0 sr FCFoV ~5.4 sr PCFoV	20° x 20°FWHM	~2.5 sr (FWHM)
Sensitivity (5-σ)	300 mCrab or ~2.5 ph/cm²/s in 1s, FCFOV ~ 2 mCrab (50 ks) (FCFOV)	~ 10 mCrab (1 day)	~ 1 Crab in 1s
Mass plus 20% contingency [kg]	140	30	80
Volume [mm³]	1307 x 1316 x 700 (whole)	375x375x550	283 x 283 x 320 (1 unit)
Power plus 20% contingency [w]	100	20	30
Data rate (orbit average) kbit/s	~750	3.2	~40

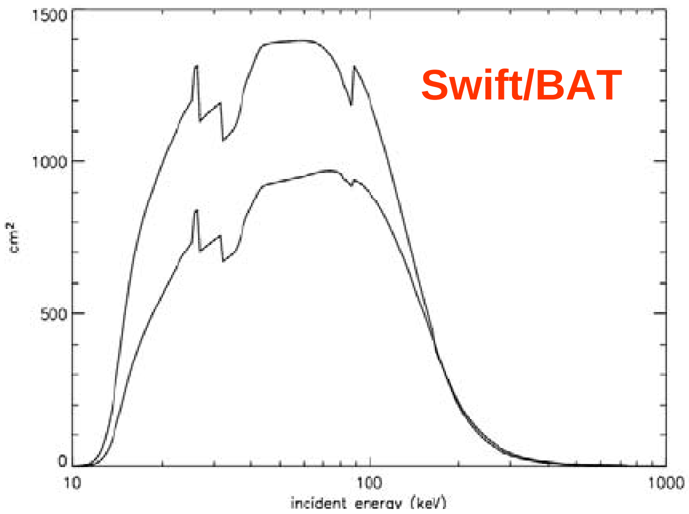
GAME collaboration / funding scheme

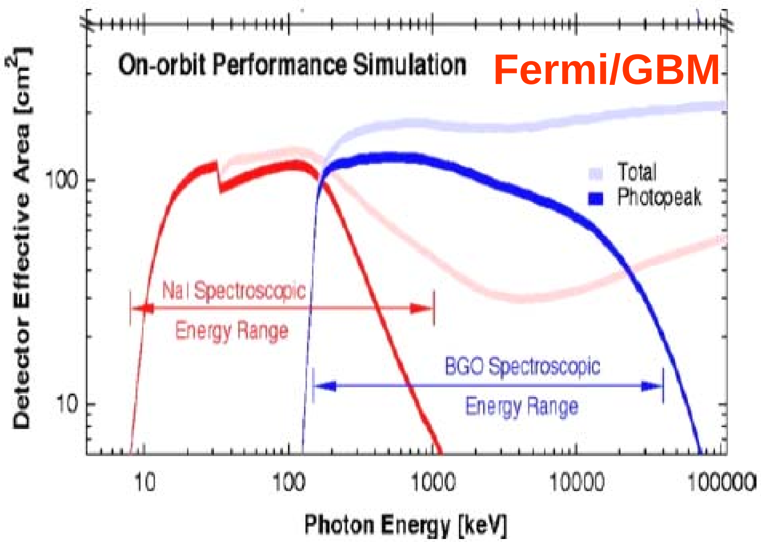
Table 4*- Proposed distribution of contributions*

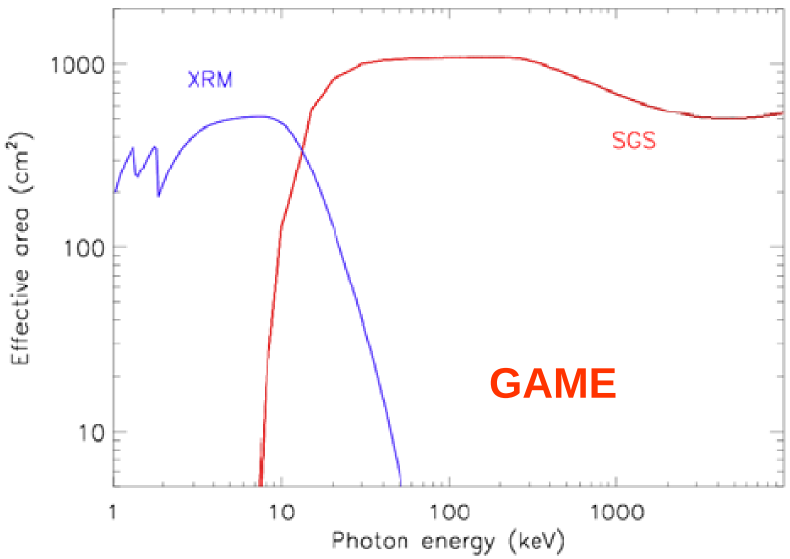
	Respons.	Note
Mission Architect	ESA	
Spacecraft Launch	ESA	VEGA
Spacecraft Architect	ESA	Industry (including spacecraft AIV)
Spacecraft Platform	Brazil Slovenia	PMM: Brazil (eventual X-band transponder SLO)
Science Payload	Italy Brazil Germany Czech Rep.	XRM: Italy ASI-INAF + Czech Rep. HXI: Brazil SGS: Italy ASI-INAF DH: Germany Tübingen Mech. Structure: Czech Rep. ?
Mission Operations	ESA Italy Brazil	MOC: ESA Ground station Malindi ASI Ground station Alcantara INPE
Science Operations	Italy	GAME SDC: ASI

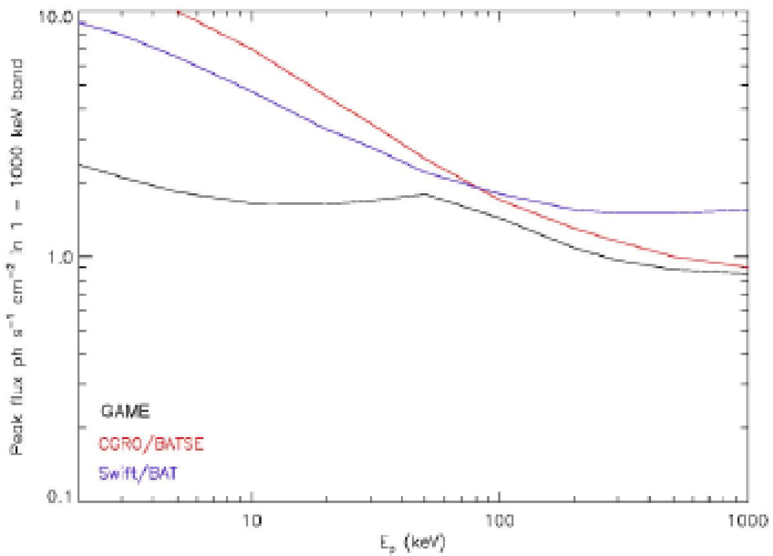
❑ The collaboration includes scientist from INAF, INFN, Italian Universities, Sweden, Czech Republic, Poland, Germany, Slovenia, USA, Brazil

❑ Eff. Area and GRB sensitivity of MIRAX w/r to present / next future GRB detectors

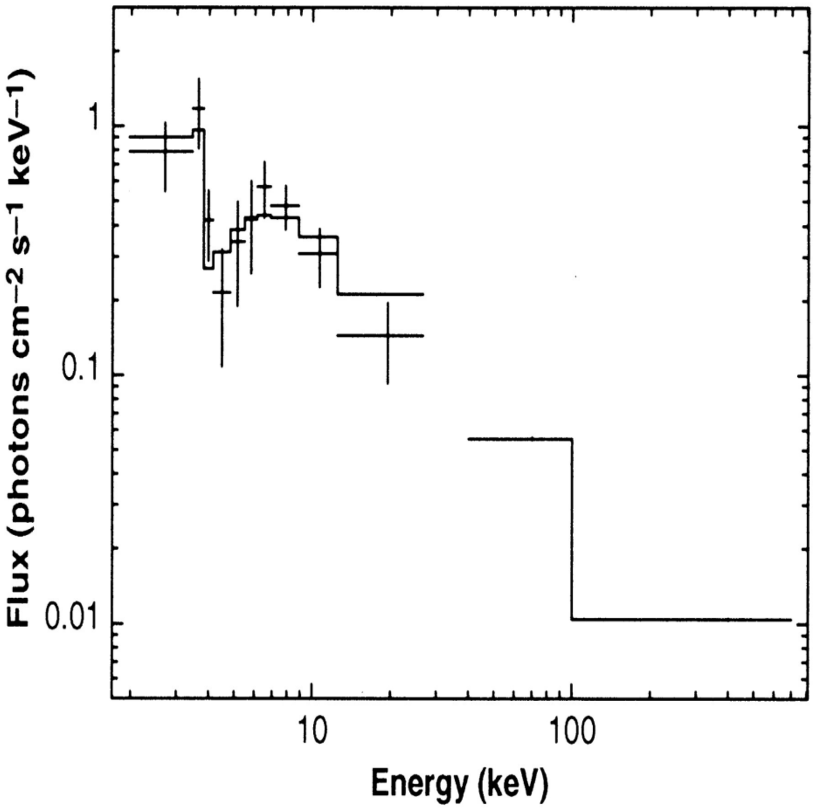




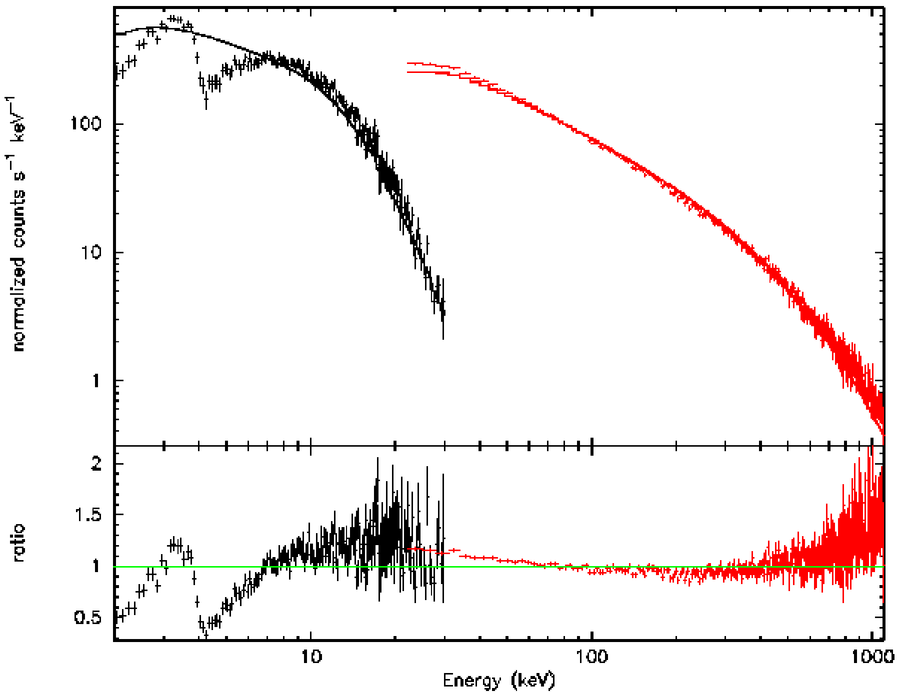




❑ The k-edge from GRB990705 as would be detected by XRM+SGS

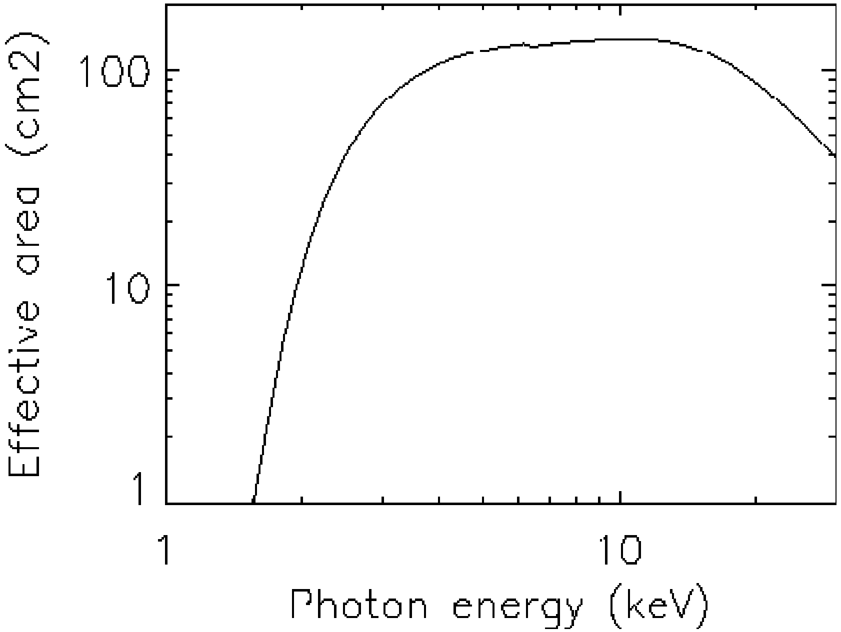


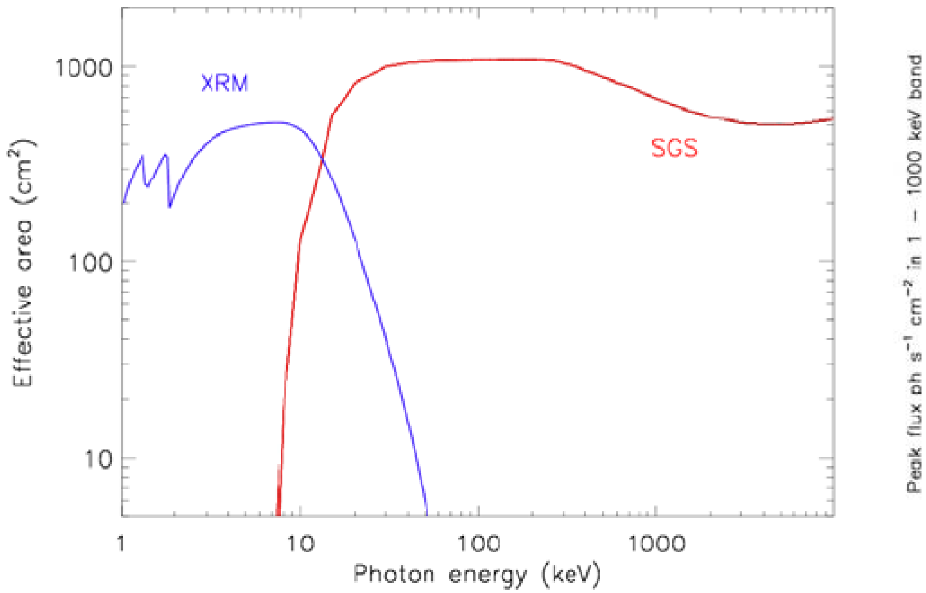
BeppoSAX WFC+ GRBM



GAME XRM + SGS

❑ Low energy efficiency of GAME vs.BeppoSAX WFC

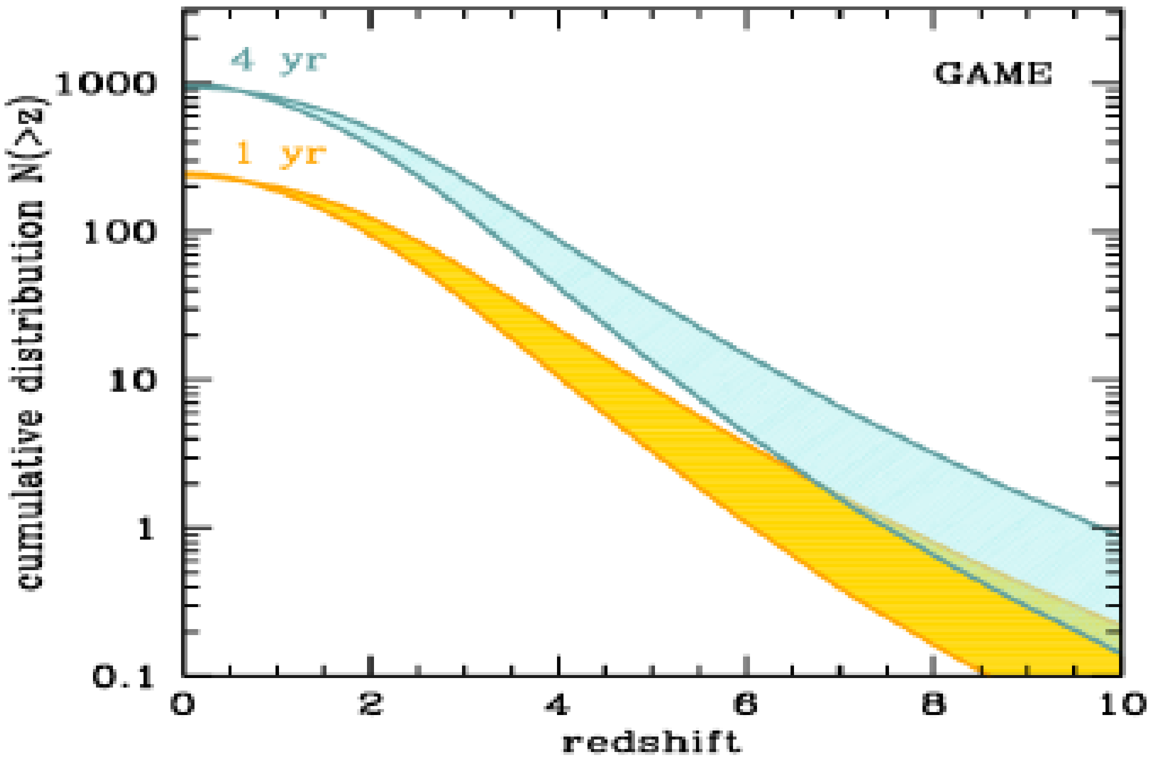




BeppoSAX WFC
(10 keV eff. Area 140 cm2, en. res. > 1 keV)

GAME
(10 keV eff.Area 500 cm2, en. Res. 250 eV)

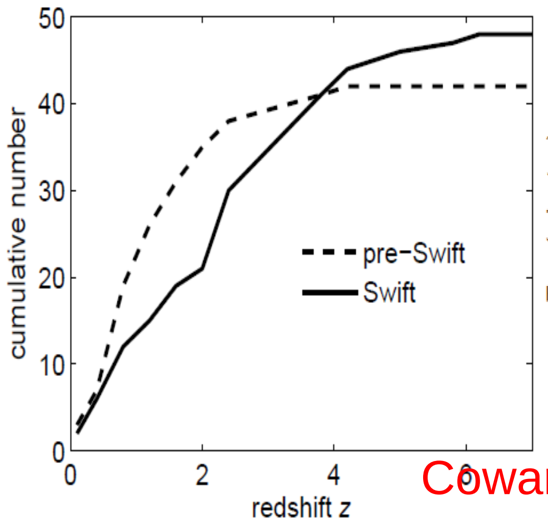
❑ Improvement in detection of high-z GRBs w/r to present and next future experiments

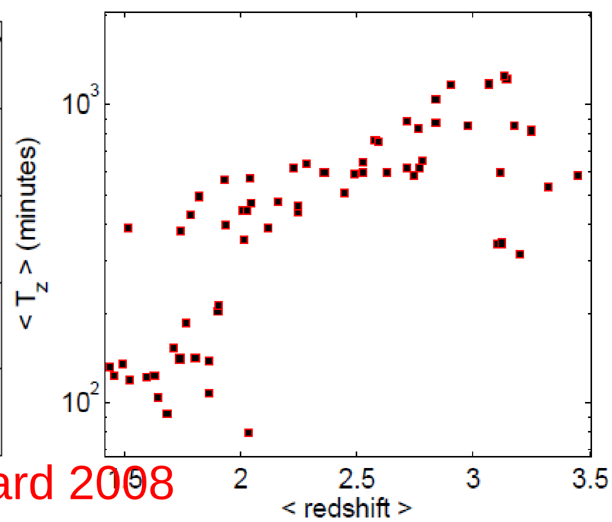


❑ Prompt dissemination of ~arcmin GRB positions provided by GAME/XRM

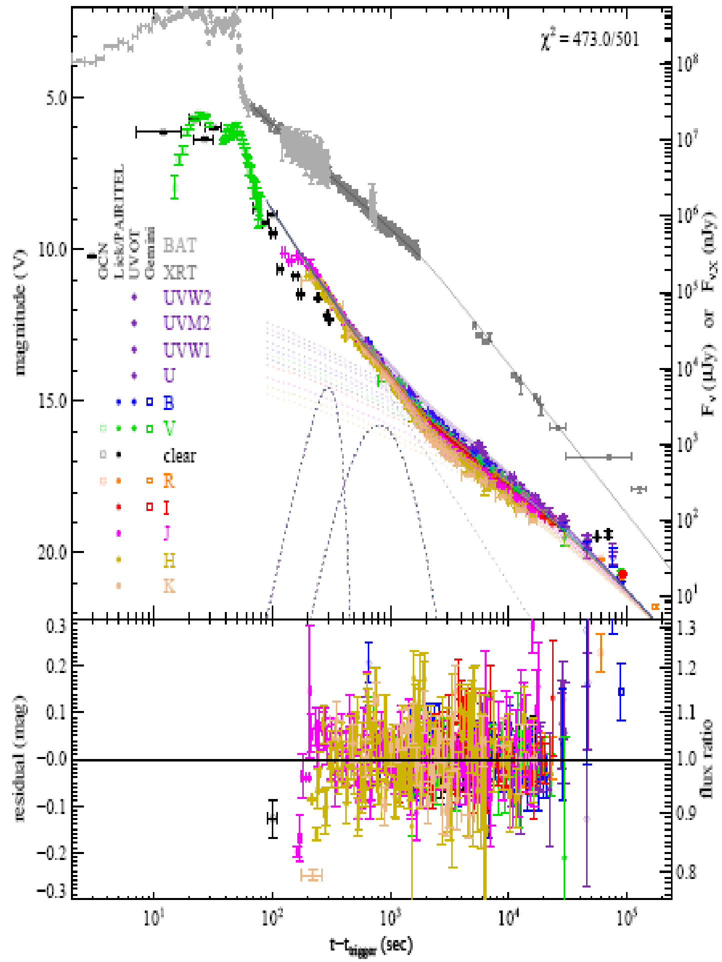
- ➢ XRM trigger and location to ground within 30s, possibly within a few s

- ➢ will be a fundamental service to the GRB community, after Swift 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

❑ X-ray all-sky monitoring and survey

Science objectives opened by continuous All Sky Monitoring are extremely wide-spectrum, numerous and general. Long-term, continuous monitoring of Galactic sources allows the study of source/class properties not easily or unaccessible to specific, short observations, although more sensitive.

Examples are:

- discovery of new transient sources;
- discovery and long-term evolution of orbital, superorbital and spin periodicities, period derivatives and quasi-periodicities (QPOs);
- intensity and spectral state changes in BHC;
- multi-frequency correlation between timing, spectral and intensity parameters;
- discovery and monitoring of bursting behaviour (bursters, SGRs, AXPs, ...);
- a complete all sky survey.

❑The ASM Science: “Service”

The most sensitive observatories of any generation carry state-of-the-art detectors and experiments, allowing to perform unprecedented studies of individual sources, over a narrow field of view (~1º or less).

A monitoring experiment is then needed to trigger ToOs, to catch the most interesting states of the sources, often unpredictable. Also, specific observations can be put in the context of the history or evolution of the source (or class of sources) if monitoring is continuously available.

Several X-ray missions have put wide field experiments in their baseline requirements (e.g., RXTE, BSAX, INTEGRAL, Suzaku, ...). Over the last decade, the RXTE/ASM - and now Swift/BAT, ISS/MAXI and INTEGRAL/IBIS - have made All Sky Monitoring a task “taken for granted” by our Community. But these experiments will not be up there forever ...

A larger GRB mission

(Amati,Frontera, Ghisellini,Tagliaferri, et al.)

- A substantial increase of the high-energy (20 keV – 10 MeV) scintillators-based instrument would allow furhter unprecedented measurements of high importance for the physics of the GRB prompt emission and GRB cosmology through:

  a) time-resolved spectroscopy down to the time scales (a few ms) closer to those of the emission process;

  b) sensitive timing analysis (power-spectra) up to high frequencies

- e.g., a “superGAME” with 8 SGS modules, for a total of 70x140 (10000) cm2 area and 320 kg, together with an enhanced XRM 3 camera pairs 60x60x40 cm and 60 kg
- e.g., an even larger SGS (ton weigth) for a long-duration balloon flight

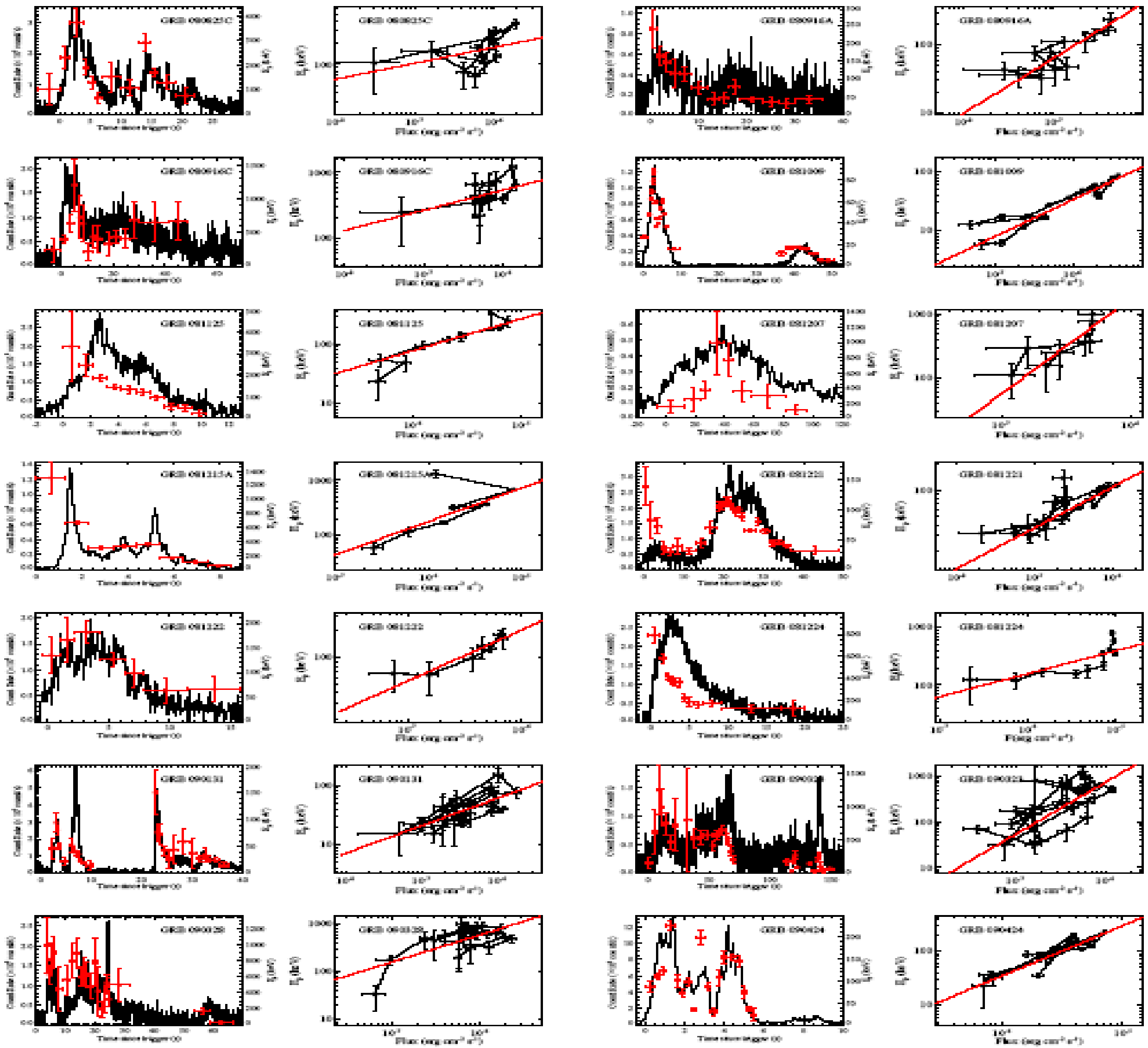


Fig. 2.— *Left:* Light curves (connected lines) along with $E_{\rm p}$ evolution (circles with error bars) of long GRBs in our sample; *Right:* Time-resolved $E_{\rm p}$ as a function of flux, along with the best fit line for the $E_{\rm p} - F$ correlation for the long GRBs in our sample.

Li et al. 2012

Conclusions

- ❑ GAME is an important opportunity for the Italian high-energy astrophysics community (INAF, INFN, Univ.), allowing to:

  - achieve primary scientific goals on GRBs and galactic sources and provide a fundamental service to the world-wide community (prompt emission of GRBs from 10 MeV down to 1 keV, X-Ray all-sky monitoring in 2-50 keV with unprecedented FOV and sensitivity).

  - provide a scientific outcome for R&D activities supported by INAF, INFN, ASI and Universities (Ferrara, Pavia, …)

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

- ❑ Future mission opportunities include the Brazilian program for small scientific satellites, future ESA call for small mission,…