X-ray afterglows of GRB

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Summary

• X-ray afterglows (some History) and the fireball
• X-ray line features, massive progenitors and SN connection
• GHOSTS/dark GRBs and the link with star-formation
• Observational Perspectives of High resolution X-ray spectroscopy of GRB as a probe of the Early Universe
BeppoSAX

- Named after Giuseppe (Beppo) Occhialini
- Italian satellite with Dutch participation
- Launched April 30, 1996
- Switched-off April 30, 2002
- 56 fast (<few hrs) localizations of GRB, 35 fast (5-16 hrs) follow-up observations with NFI
- First and last observation of a GRB: July 20, 1996 and April 30, 2002
BeppoSAX instruments

GB960720: the 1st GRB by BeppoSAX

Piro et al. 1997
A&A
GRB970228: the 1st X-ray and O afterglow

- Triggered by GRBM and localized by WFC
- Fast follow up with NFI in 8 hrs: a bright unknown X-ray source
- A second pointing 3 days after the GRB: fading X-ray counterpart (Costa et al 1997)
- Optical fading source (van Paradijs et al 1997)
GB970508: the 1\textsuperscript{st} redshift

- Images in the 2-10 keV range by the BSAX WFC (10-200 sec after the GRB) and by the BSAX MECS (6 hrs and 3 days). The BSAX observation led the Caltech group to the measurement of the redshift and Frail et al. to the discovery of the 1\textsuperscript{st} radio afterglow and direct measurement of relativistic expansion.
The progenitors of GRB

The nature of the progenitor can be inferred from the environment:

- **NS-NS (BH-NS & BH-WD)** travel far from their formation sites before producing GRB’s (Fryer et al 2000) => “clean environment”; no lines
- **Hypernovae/collapsar** evolve much faster, going off in their formation site => “mass-rich environment” => lines

- NS-NS merging
- Hypernova
X-ray Fe features

- Ubiquitous feature in several classes of X-ray sources
- Diagnostics of the environment nearby the central engine
- Independent and direct redshift determination
Iron features

- GB991216 (Piro et al 2000)
- GB000214 (Antonelli et al 2000)
- GB970508 (Piro et al 1999)
- GB991216 (Piro et al 2000)
- GB990705 (Amati et al 2000)
- GB980828 (Yoshida et al 1999)
Iron features in GRB’s

- Energies consistent with that expected from the optical redshift (GB991216 Fe line and recombination edge observed at 3.4 keV and 4.5 keV corresponding exactly to the energy of the Fe line redshifted with $z=1.00\pm0.02$; GB970508, $z=0.84$, GB970828, $z=0.9$). Note also that in GB990705 the predicted X-ray redshift is consistent with that found later by optical spectroscopy.

- The energy of Fe features in the afterglow indicate highly ionized atoms (ionization parameter $>10^3$). This is consistent with a medium being ionized by a strongly variable radiation field (ionization vs recombination).

- The mass of Fe ($N_{Fe}=L_L t_{rec}$, where $t_{rec}=30 T_7^{1/2} n_{10}^{-1}$ is the recombination time) ($M_{Fe}\approx0.1 M_{sun}$) and high density and line width in 991216 $=0.1c$) suggests a SN explosion by a massive progenitor, possibly preceding the GRB like in the Supranova model (Vietri & Stella).

Alternatively the jet/bubble model of (Meszaros & Rees 2001) needs less iron but still requires a massive progenitor.
Low-energy lines in the X-ray afterglow of GRB011211

Localized by BeppoSAX, follow-up by XMM

The afterglow spectrum shows 3 $\sigma$ evidence of lines from He/H-like Mg, Si, S, Ar, Ca blueshifted at $v/c=0.1$ (Reeves et al 02, but see Borodzin & Trudolybov 02). They argued for a thermal origin.

The lines disappear in the second part of the observation (timescale about 30000 s) = size of $10^{15}$ cm. From the velocity => SN explosion few days before the GRB.

Consistent with the absence of Iron line (upper limit about 400 eV): $^{56}\text{Fe}$ is produced by $\beta$-decay via the reaction $^{56}\text{Ni} \rightarrow ^{56}\text{Co} \rightarrow ^{56}\text{Fe}$, the reactions having half-lives of 6 and 78 days.

However, the lines are consistent with a photoionization scenario, that requires a ionization parameter of about 100-200. In such a case Fe is lowly ionized and the expected line intensity is low (Lazzati et al 02)
GRB localized and observed in X-rays

- BeppoSAX detected:

32 X-ray afterglow candidates out of 35 GRB follow up observations in X-rays

- X-ray afterglows > 90%
- Optical afterglows ~ 40% - 50%
- Radio afterglows ~ 35% - 40%
GHOST’s in the sky

- Grb Hiding Optical Source-Transient: GRB with X-ray but no O afterglow aka dark GRB
- Optical searches with same sensitivity & reaction times as in the cases with OT (Reichert, Ghisellini, Fruchter, Andersen,..)
- OT heavily absorbed by star forming region? Or located at $z>5$ (such that intragalactic gas will absorb photons below Lyman limit)
- How to disclose GHOST’s:
  - arcsec X-ray or/and radio positioning
  - X-ray spectroscopy => $z$
  - IR observations
GRB000210: BeppoSAX & Chandra

- GRB localized by BeppoSAX. The brightest ever observed in $\gamma$-ray peak flux
- Simultaneous obs of the X-ray afterglow with Chandra.
The host of GB000210?

- Obs at NOT, 1.54D, NT T, 2.2mESO starting 12 hrs after the GRB: no OT down to R=23.5
- A galaxy in the CXO error box
- VLA: radio transient
- (Piro, Frail, Gorosabel et al, 2002)
The redshift of the galaxy

• VLT spectrum and photometry (no B or V dropout) \( z = 0.85 \)

• The probability of a field galaxy with \( R > 23.5 \) in the Chandra/radio (1” error box is \( 10^{-2} \))

• However, there is at least another dark GRB associated with a galaxy at \( z < 5 \) (GB970828, Djorgovski et al 01)
Dark GRB in star-forming GMC

- Significant absorption above the galactic in X-rays. At $z=0.85$, $N_H=(5 \pm 1) \times 10^{21} \text{ cm}^{-2}$
- Typical of a GMC
- Distribution of distances of optical afterglows vs host galaxy connects long GRB with star-formation sites and massive progenitors (Bloom et al 2002)
The origin of the obscuring medium in GHOST’s

- Giant Molecular Clouds (d:20-60pc, NH=10^{21}-10^{22} \text{ cm}^{-2}) are large enough to keep a substantial fraction of dust in effectively extinguish optical (dust is sublimated up to 10pc, Reichert 2001)
- The gas column density and optical extinction are nicely consistent with those of GB000210
- BUT: the gas of the GMC should be ionized by the GRB photons over a substantial volume (e.g. Boettcher et al 1999)
- The X-ray absorber is NOT ionized (\xi<1)
- To reconcile obs. with the GMC scenario: high dense (n>10^9 \text{ cm}^{-3}) clouds
- Alternatively: absorption due to ISM in the host galaxy.
GRB: probes of star-formation in the far Universe

- The brightest ($L_{iso}=10^{53-54}$ erg/s) and most distant sources in the Universe ($z=0.3-4.5$)
- They can be detected at farthest distances (in fact some of the constituents of mysterious classes of GRB can be high-z GRB)
- Associated with star-formation
- They can pinpoint obscured star-forming galaxies (X-rays and gamma-rays pierce through)
High Resolution Cryogenic Spectrometer for X-ray Sky Survey on the International Space Station

• X-ray bolometer (R=300-1000) in the 0.1-10 keV on ISS

• It will an all-sky survey with an unprecedented spectroscopic resolution with a beam of 10°
Spectroscopy of GRB with IMBOSS

- The spectrum of a bright GRB at $z=4$ (about 2 per year in a FOV of 60°) with a FOV of 60°) with 1.5 cm$^2$: narrow/broad iron line with EW = 0.3/4 keV and edge like GB970508 (Piro et al) GB990705 (Amati et al)
High resolution X-ray spectroscopy of GRB with XEUS

• The Fe line in a GRB like GB970508 but at z=5

• Study of the metallicity of the host galaxies of a GRB at z=5 through X-ray edges