

X-ray spectroscopy of Gamma-Ray Bursts

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The Brightest Explosions in the Universe

Every time a gamma-ray burst goes off, a black hole is born

By Neil Gehrels, Luigi Piro and Peter J. T. Leonard

Early in the morning of January 23, 1999, a robotic telescope in New Mexico picked up a faint flash of light in the constellation Corona Borealis. Though just barely visible through binoculars, it turned out to be the most brilliant explosion ever witnessed by humanity. We could see it nine billion light-years away, more than halfway across the observable universe. If the event had instead taken place a few thousand light-years away, it would have been as bright as the midday sun, and it would have dosed Earth with enough radiation to kill off nearly every living thing.

The flash was another of the famous gamma-ray bursts, which in recent decades have been one of astronomy's most intriguing mysteries. The first sighting of a gamma-ray burst (GRB) came on July 2, 1967, from military satellites watching for nuclear tests in space. These cosmic explosions proved to be rather different from the man-made explosions that the

A PICTURE LIKE THIS could not have been drawn with any confidence a decade ago, because no one had yet figured out what causes gamma-ray bursts—flashes of high-energy radiation that light up the sky a couple of times a day. Now astronomers think of them as the ultimate stellar swan song. A black hole, created by the implosion of a giant star, sucks in debris and sprays out some of it. A series of shock waves emits radiation.

Outline



- Gamma-Ray Bursts: recent developments and new frontiers
- X-ray features: the only narrow features in the broad-band spectrum produced by the GRB
- Motivations for high resolution X-ray spectroscopy:
 - The nature of Progenitors of GRB
 - GRB as cosmological probes:
 - identify obscure primordial galaxies and measure their redshift by X-ray spectroscopy (not possible in the optical range)
 - tracing the evolution of metals in the Universe
 - Tracing the dark matter structures in the $z < 2$ universe by measuring the WHIM (Warm Hot Intragalactic Medium)

BeppoSAX: GRB in the afterglow Era

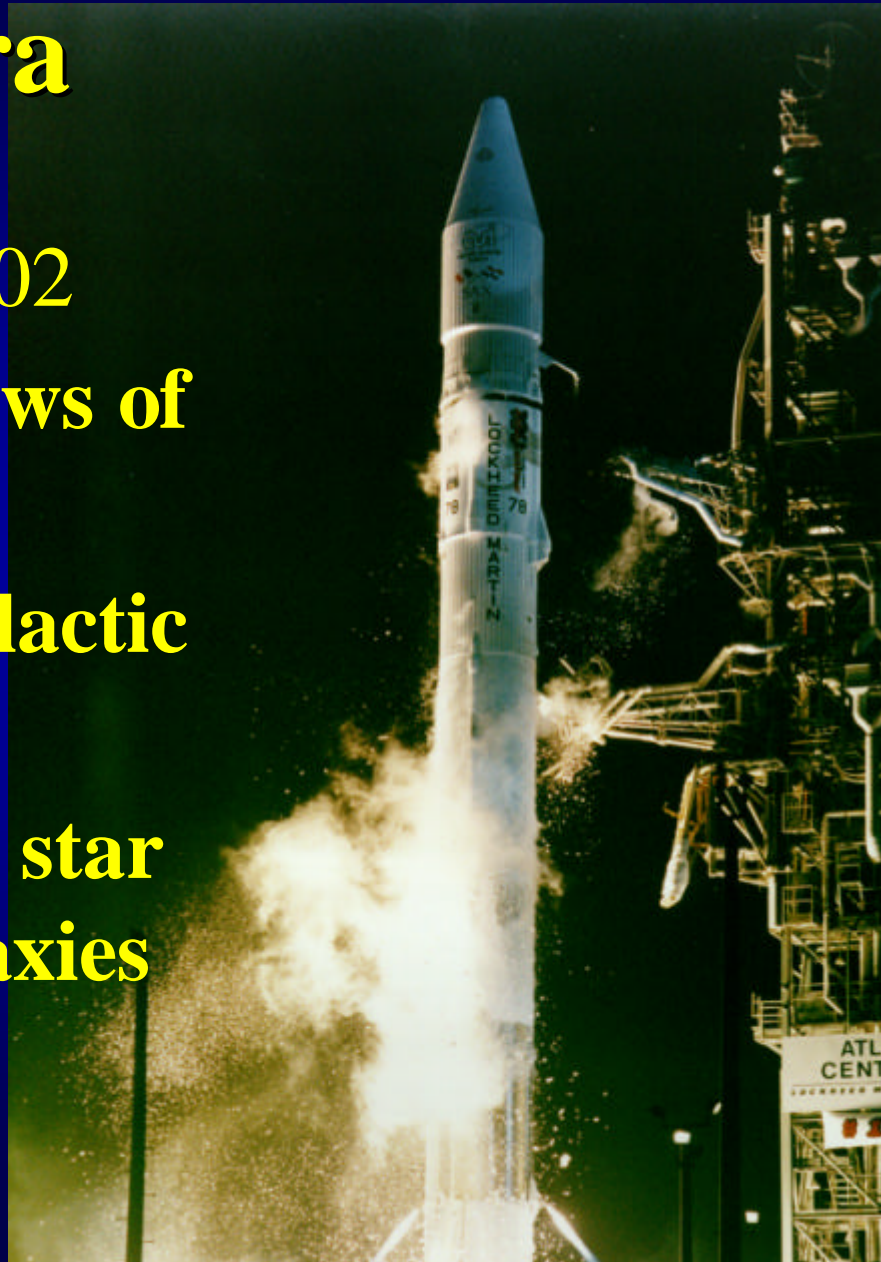
Launched April 30, 1996

Switched-off April 30, 2002

Discovery of the afterglows of GRB

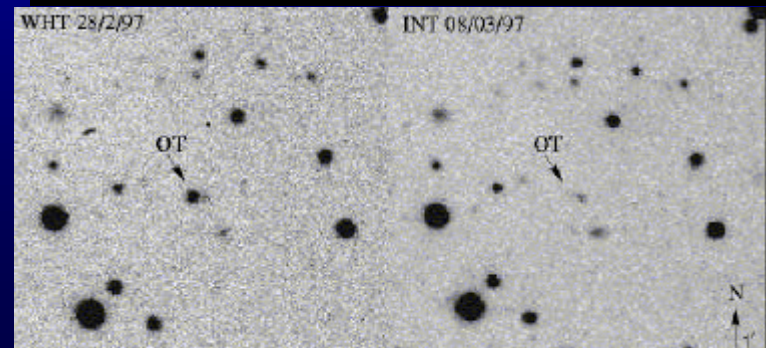
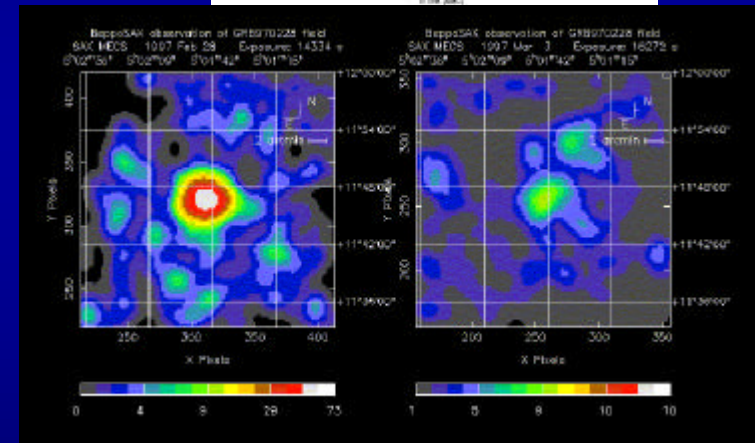
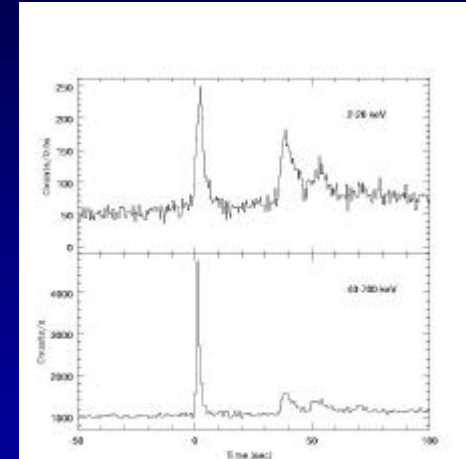
Discovery of the extragalactic distances

Association with SN and star formation in distant galaxies



GRB970228: the 1st X-ray and O afterglow

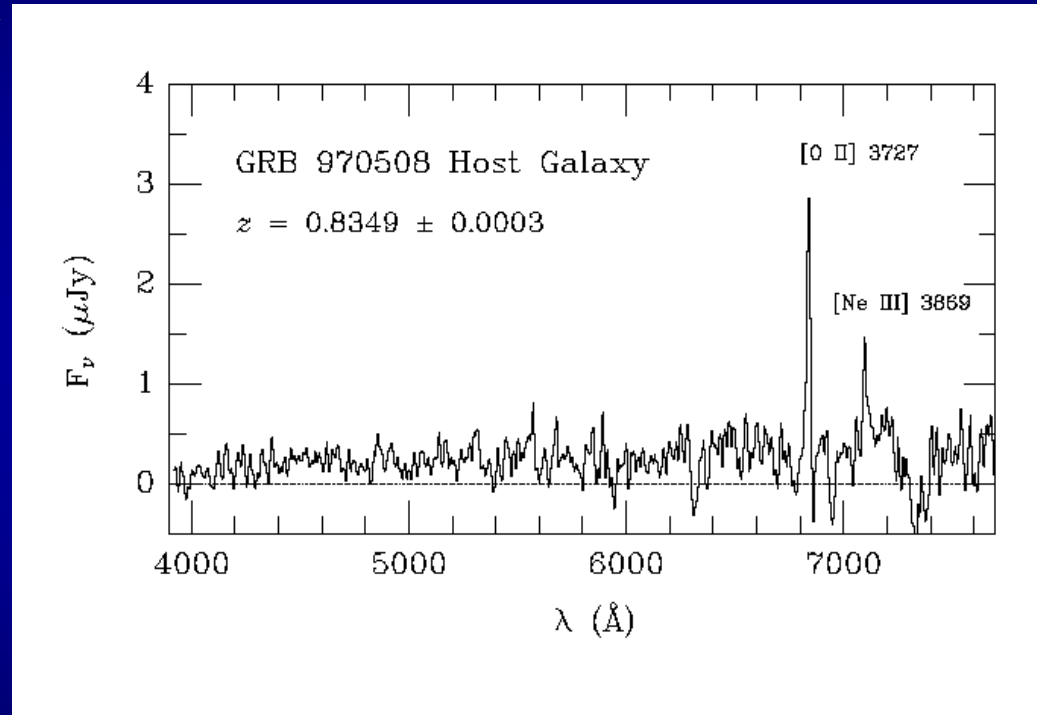
- Triggered by GRBM and localized by WFC
- Fast follow up with NFI in 8 hrs: a bright unknown X-ray source
 - A second pointing 3 days after the GRB: fading X-ray counterpart (Costa et al 1997)
- Optical fading source (van Paradijs et al 1997)



GB970508: the 1st redshift

- The spectrum of the optical transient at Keck by Metzger et al showed lines at $z=0.83$.

- GRB are extragalactic !



- So far, the distance of about 40 GRB has been measured by optical lines produced in the host galaxies and the redshift ranges from 0.16 to 4.5

X-ray Fe features and the progenitors

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



The progenitors of GRB



The nature of the progenitor can be inferred from the environment

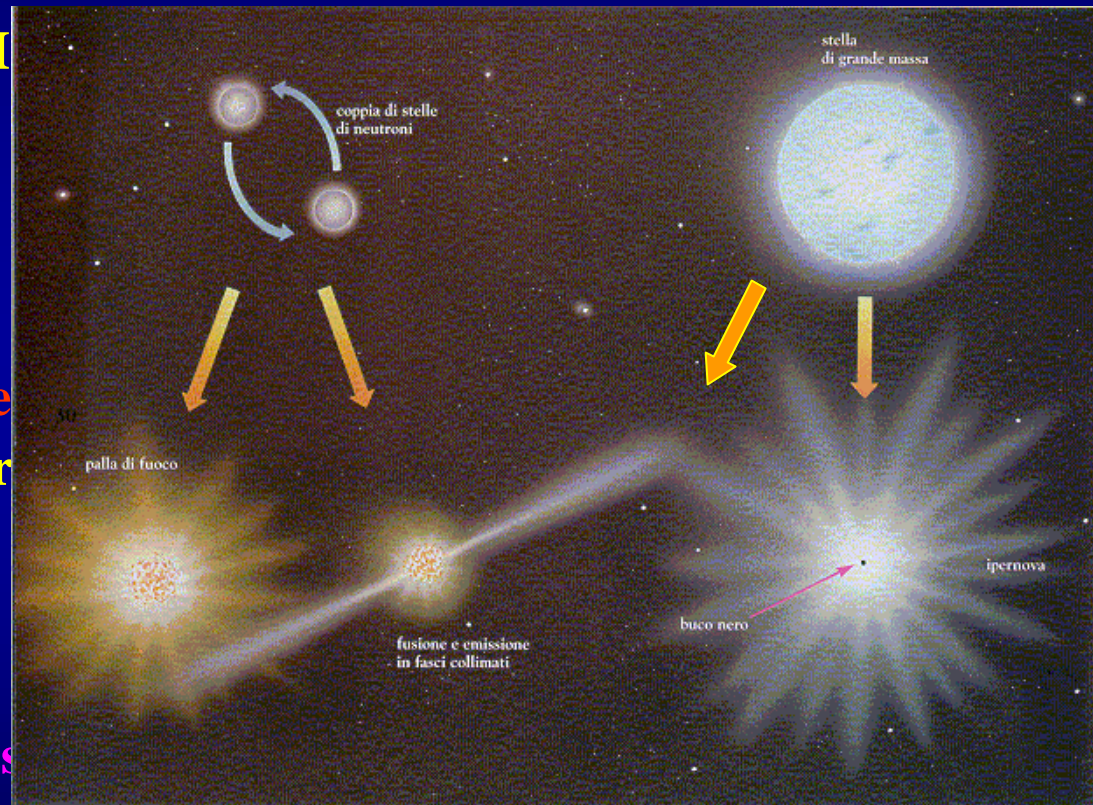


**NS-NS (BH-NS & BH
WD)** travel far from
their formation sites
before producing
GRB's (Fryer et al 2000)

=> “clean
environment”: no line

Hypernovae/collapsar
evolve much faster,
going off in their
formation site =>

“mass-rich
environment” => lines



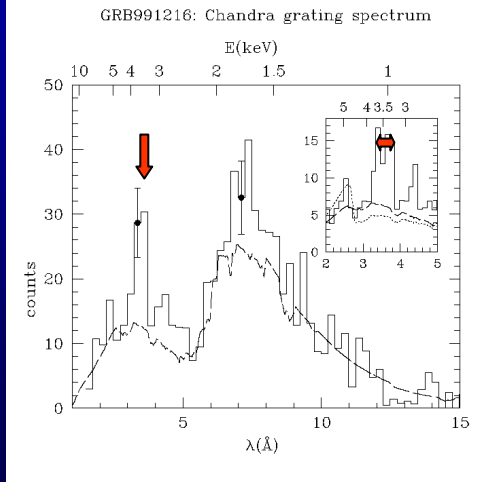
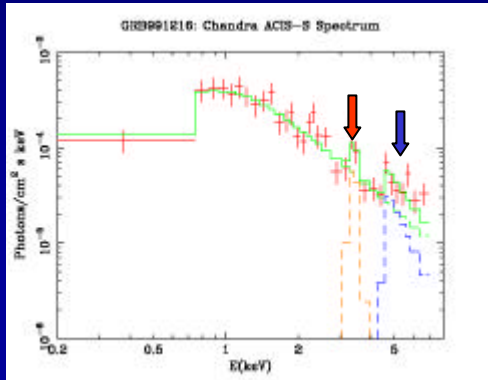
•  **NS- NS merging**

 **Hypernova**

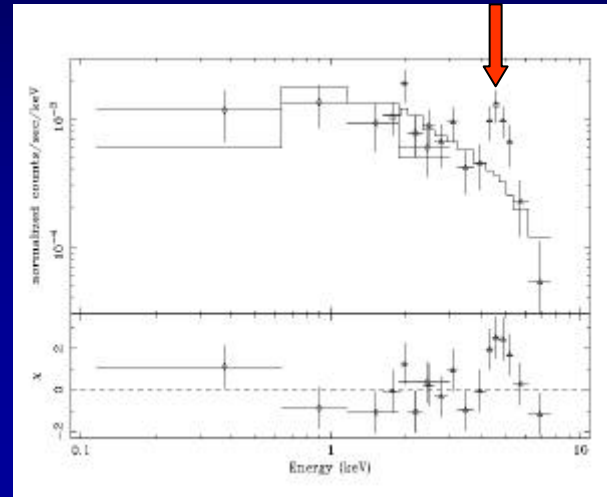


X-ray Iron features

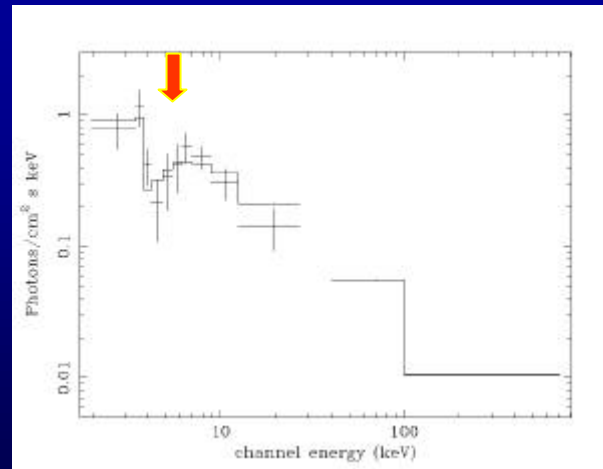
•GB991216 (Piro et al 2000)



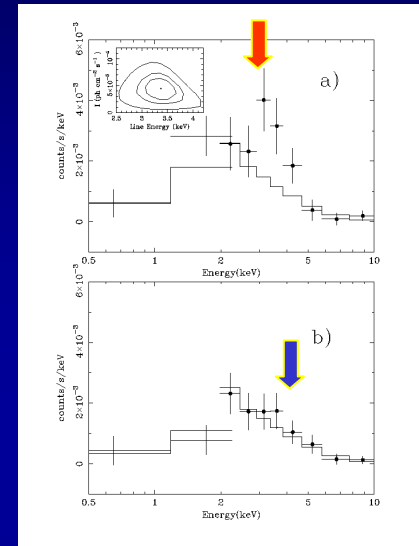
•GB000214 (Antonelli et al 2000)



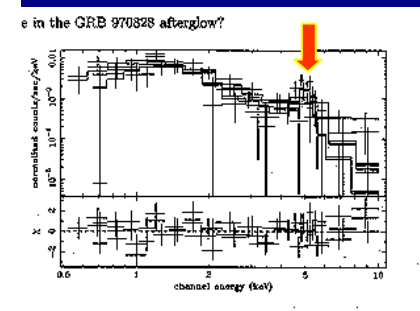
•GB990705 (Amati et al 2000)



•GB970508 (Piro et al 1999)



•GB980828 (Yoshida et al 1999)



Iron features in GRB's

Energies consistent with that expected from the optical redshift

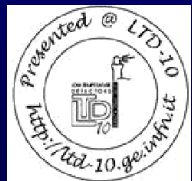
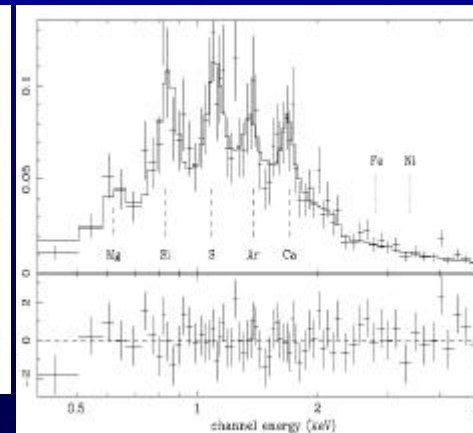
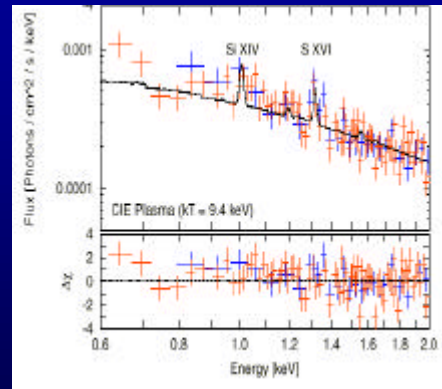
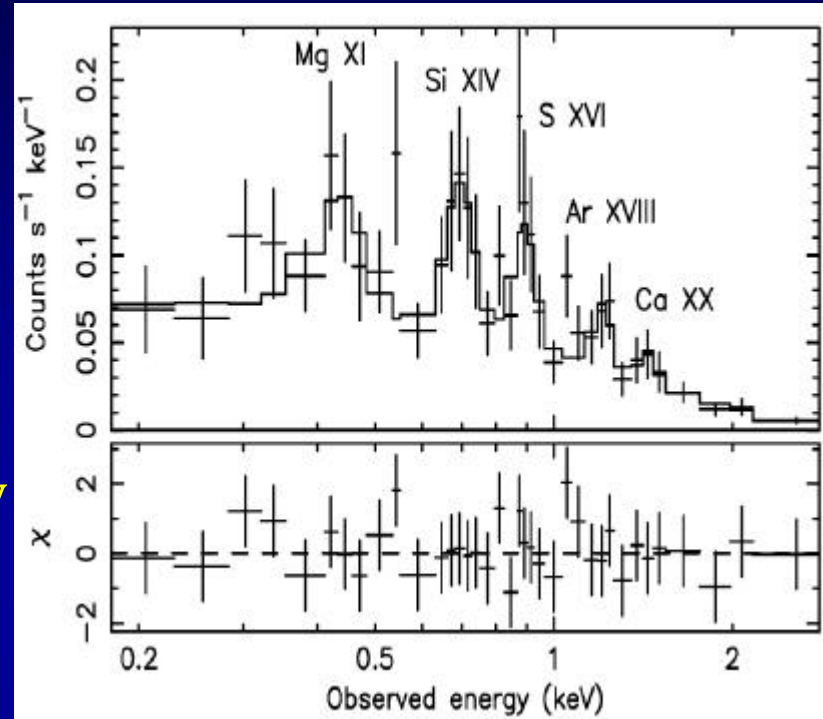
The energy of Fe features in the afterglow indicate highly ionized atoms This is consistent with a medium being ionized by GRB photons

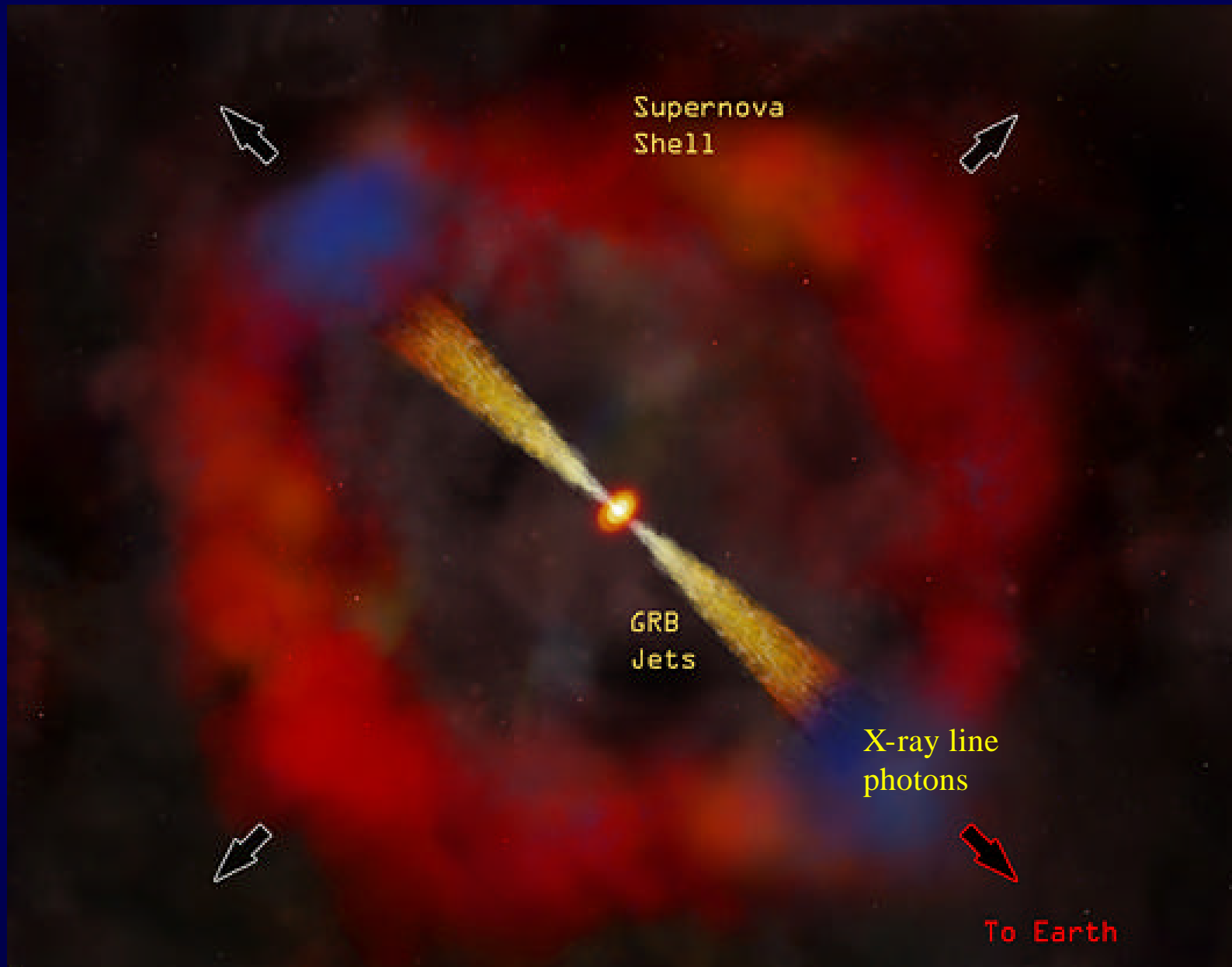
The mass of Fe ($N_{\text{Fe}} = L_L t_{\text{rec}}$, where $t_{\text{rec}} = 30 T_7^{1/2} n_{10}^{-1}$ is the recombination time) ($M_{\text{Fe}} \gg 0.1 M_{\text{sun}}$) and **high density** and line width in 991216 ($v=0.1c$, Piro et al 2000) suggests that the line emitting medium was ejected by **SN explosion by a massive progenitor**,



The GRB-SN connection
 furtherly confirmed by the
 detection of **He/H-like Mg, Si,**
S, Ar metal lines **blueshifted at**
 $z/c=0.1$ in the afterglow spectra
 of GRB011211 (by XMM,
 Reeves et al 02), GRB020813 (by
 Chandra, Butler et al 03) and
 GRB030227 (by XMM, Watson
 et al 03)

Soft X-ray lines





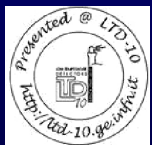
GRB and Cosmology: probes of star-formation in the early Universe

- The brightest ($L_{\text{iso}}=10^{53-54}$ erg/s) and most distant sources in the Universe ($z=0.16-4.5$)
- They are **bright enough to be visible out to much larger distances than those of the most luminous galaxies & quasars**(in fact some of the constituents of mysterious classes of GRB can be high- z GRB)
- Associated with star-formation (Iron lines, GRB-SN connection, fireball evolution, OT in host galaxies)
- They can pinpoint obscured star-forming galaxies (X-rays and gamma-rays pierce through) and probe the region $z=10-20$ where the first stars & galaxies formed (current record holder is a qso at $z=6.2$)
- The only way of measuring distance for $z>5$: X-ray redshift



The quest for high- z GRB

- Events at $z > 5$ will not be visible in the optical range, (Ly α forest absorption): they have to be “dark”
- About 50% of GRB that are optically dark
- High- z GRB should hide in this population



High resolution ($E/DE=1000$) X-ray spectroscopy of GRB

GRB:

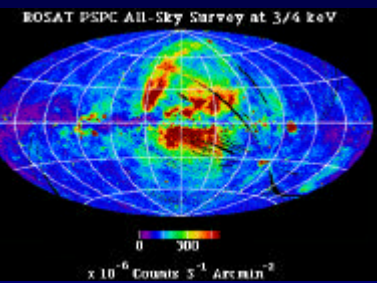
- Understand the nature of the GRB progenitor



Cosmology:

- Spot the protogalaxies at $z>5$ and probe the star forming region in the early Universe (the first stars?) with GRB
- the evolution of metal enrichment upto distant galaxies ($z>5$) with GRB

**Missions: IMBOSS (see poster by Colasanti, LP et al),
NG-GRBO, XEUS**

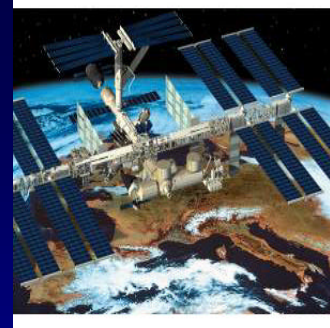


IM-BOSS

Interstellar & Intergalactic Medium

GRB Observatory & Spectroscopy Survey

High Resolution Cryogenic Spectrometer for X-ray Sky Survey on
the International Space Station



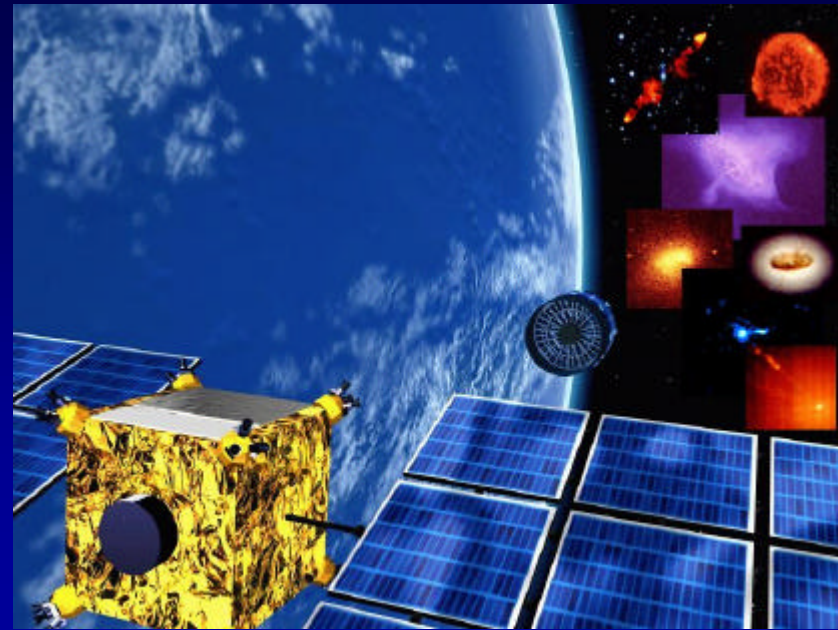
- X-ray bolometer ($R=300-1000$) in the 0.1-10 keV to be flown on ISS
- It will an all-sky survey with an unprecedented spectroscopic resolution with a beam of 10°
- See poster by Colasanti, L.P. et al





XEUS

ESA mission is under study
for the end of the decade
within the Space Station
Utilization Programme



XEUS will be around 250 times more sensitive
than XMM-NEWTON.

6 m² of collecting area at 1 keV, 30 m² after
refurbishment from ISS

Spectral resolution of between 1 and 10 eV over
the energy range 0.05 to 30 keV with TES and StJ

Next Generation GRB Observatory

- Cosmology with GRB and X-ray spectroscopy with TES microcalorimeter (need TES for high count rate)
- Localize GRB and perform very fast (<1 min) follow-up observations with X-ray telescope+microcalorimeter
- Similar results of XEUS on GRB and WHIM with a much smaller area but at much higher flux (because the GRB afterglow is observed at much earlier times, when it is much brighter)

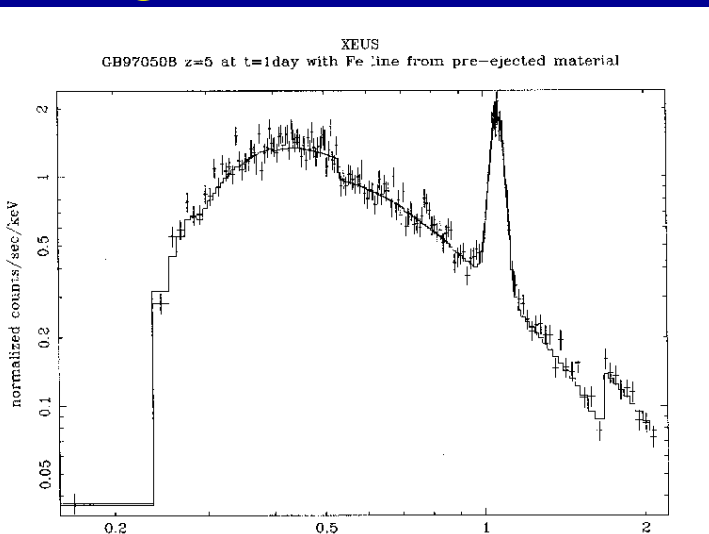


High resolution X-ray spectroscopy of GRB afterglows

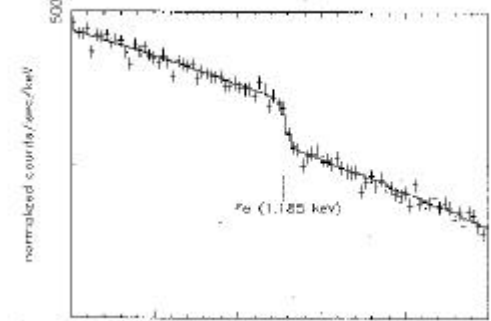
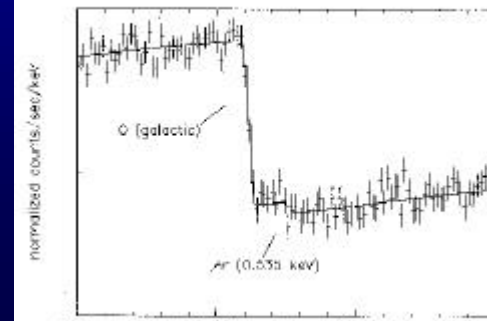
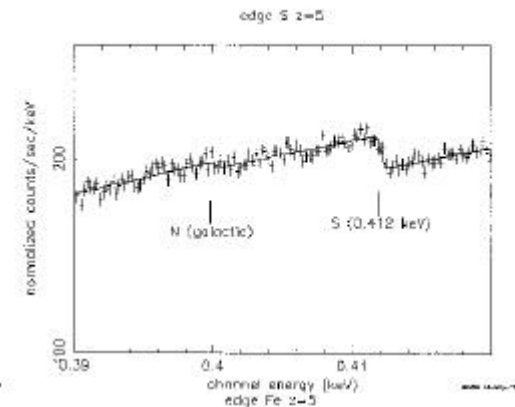
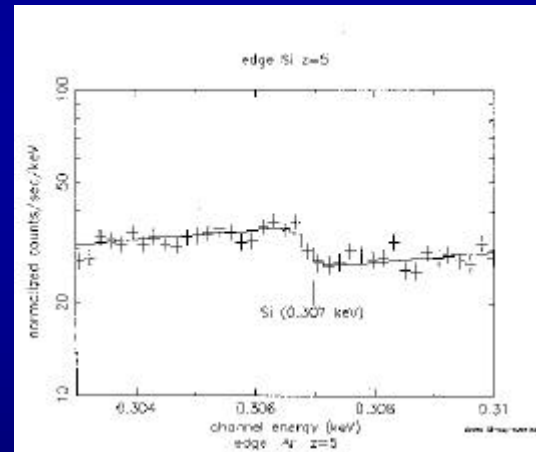


XEUS @ 1 day or NG-GRBO @ 1 minute

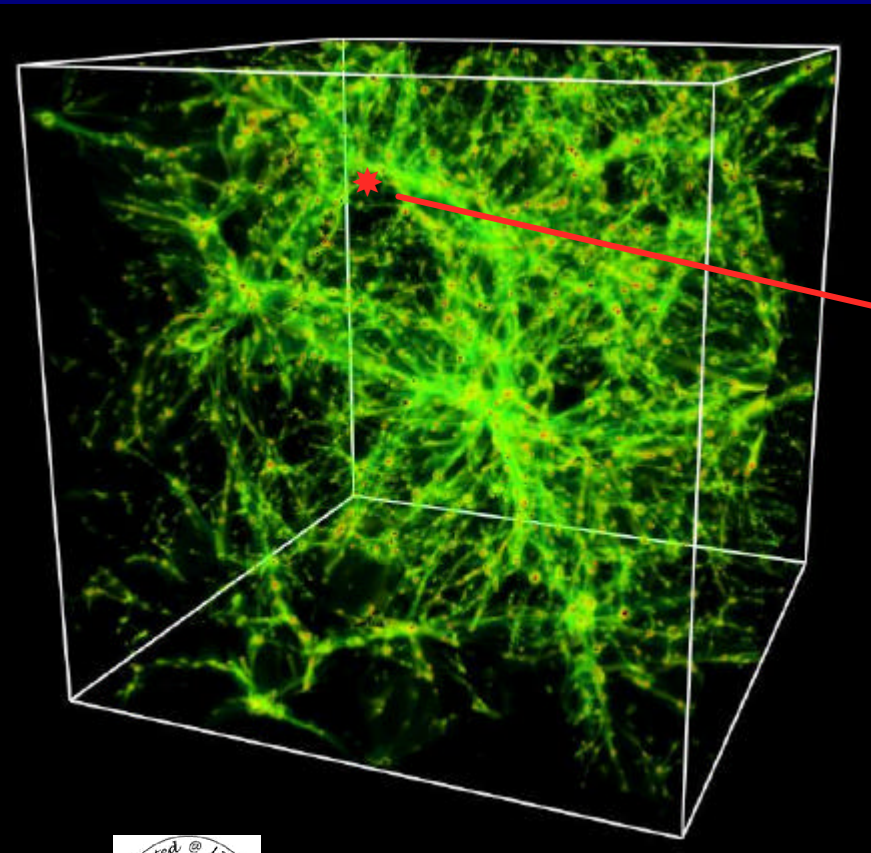
- The Fe line in a GRB like GB970508 but at $z=5$



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



XEUS & NG-GRBO - Studying Large Scale Structure: X-ray forest



Structure simulation from Cen & Ostriker (1999)

