X-ray observations of Gamma-Ray Bursts

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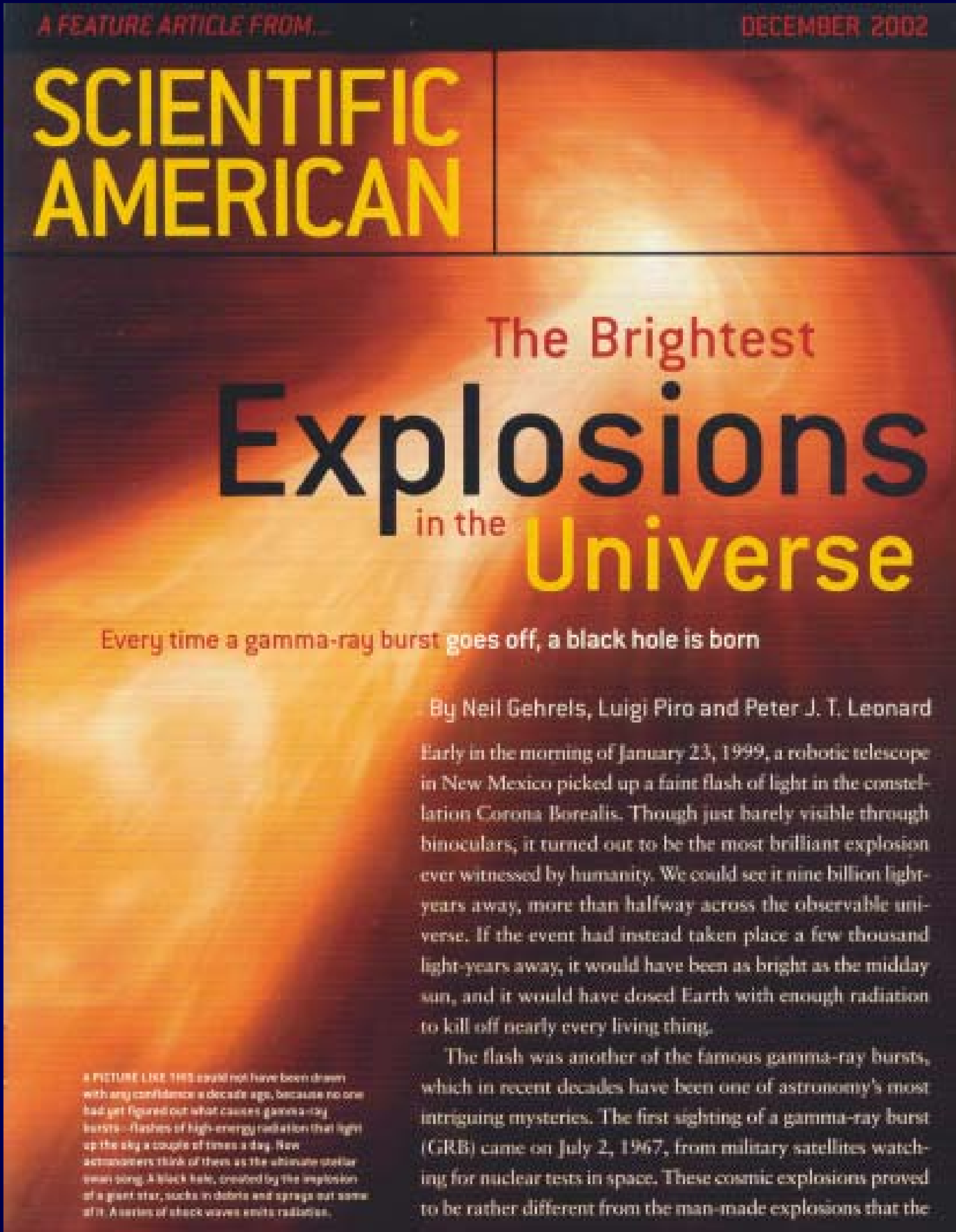

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The Brightest Explosions in the Universe

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.

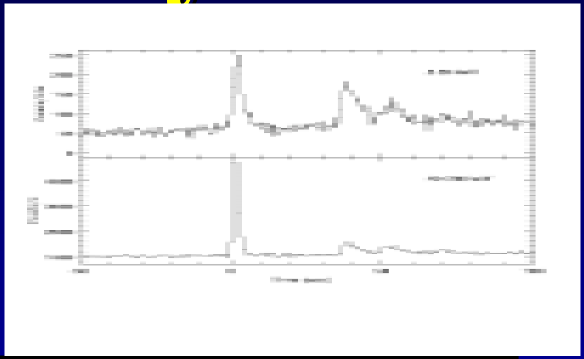
The flash was another of the famous gamma-ray bursts, which in recent decades have been one of astronomy's most intriguing mysteries. The first sighting of a gamma-ray burst (GRB) came on July 2, 1967, from military satellites watching for nuclear tests in space. These cosmic explosions proved to be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

BeppoSAX: GRB in the afterglow Era

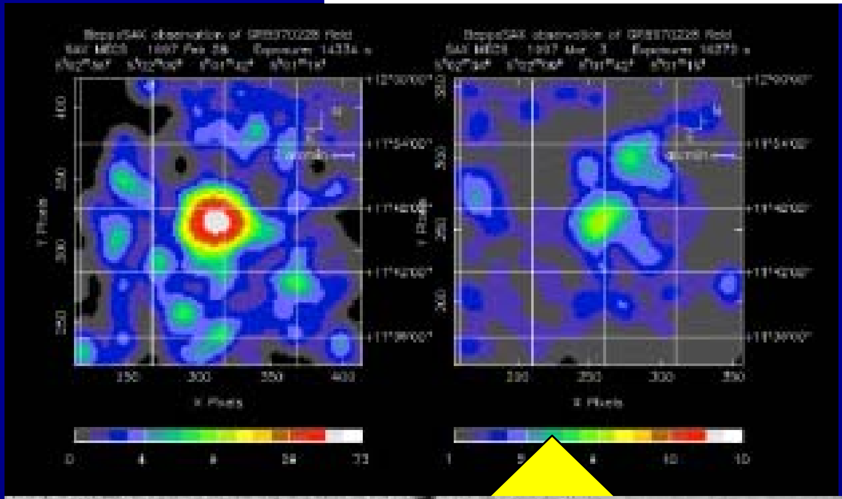
- Launched April 30, 1996
  Switched-off April 30, 2002
- **Discovery of the afterglows of GRB**
- **Discovery of the extragalactic distances**
- **Progenitor: Association with SN and star formation in distant galaxies**
- **Dark GRB's and X-ray flashes**
- **Cosmology with GRB**

GRB970228: the 1st X-ray and O afterglow



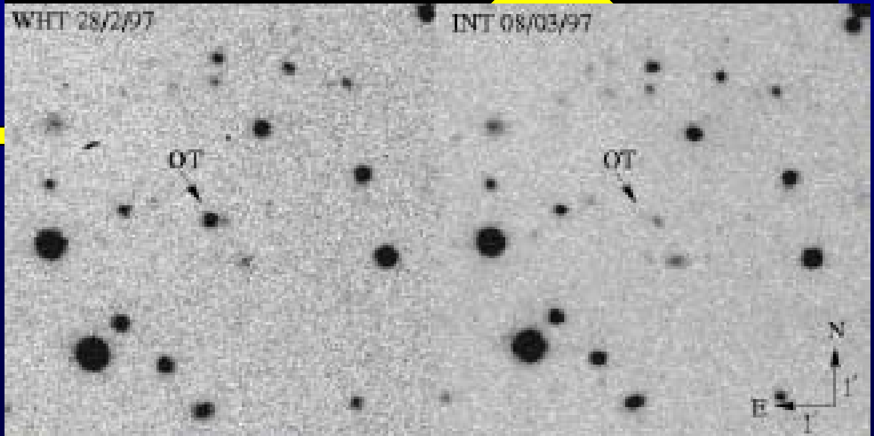
- Triggered by GRBM and localized by WFC

•Fast follow up with NFI in 8 hrs: a bright unknown X-ray source



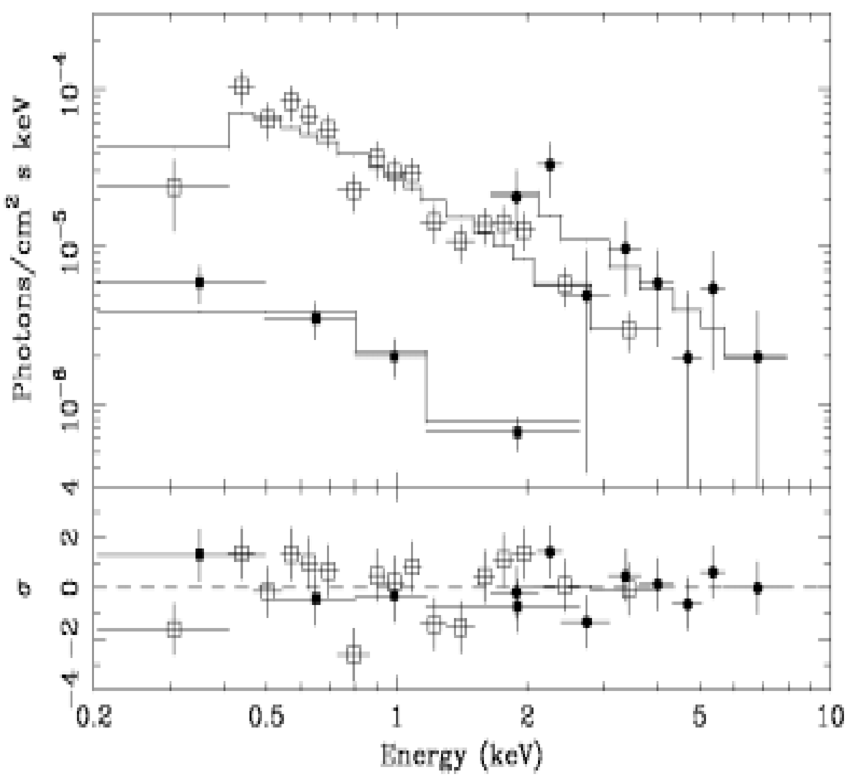
•A second pointing 3 days after the GRB: fading X-ray counterpart (Costa et al 1997)

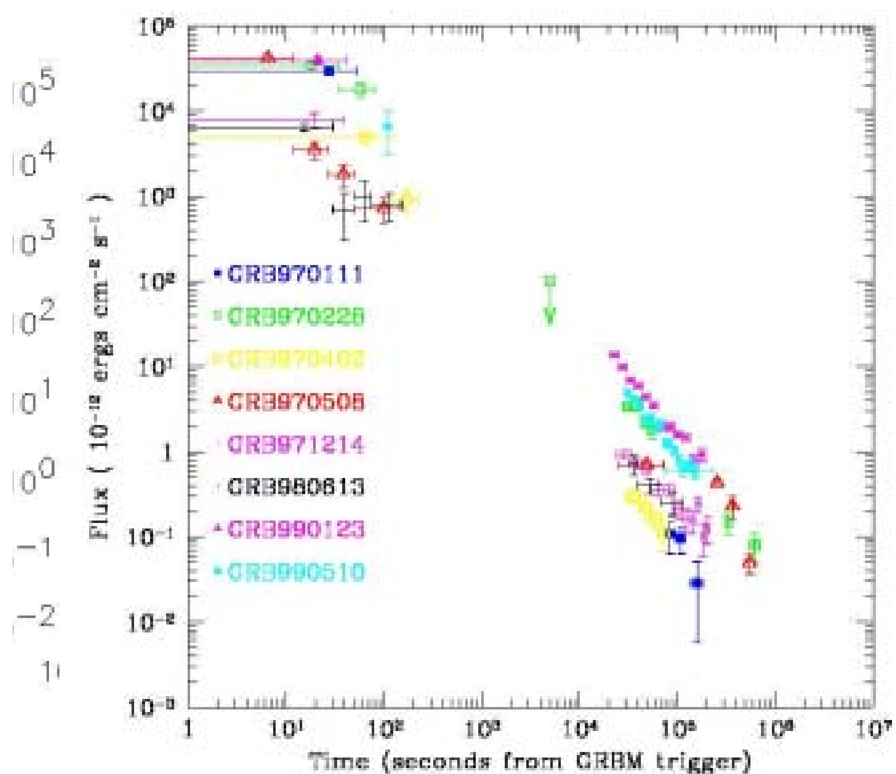
- Optical fading source (van Paradijs et al 1997)



Power laws: the hallmark of afterglows

- $F \approx t^{-\delta} \nu^{-\alpha}$ $\delta_x \approx 1.4$; $\alpha_x \approx 1.0$



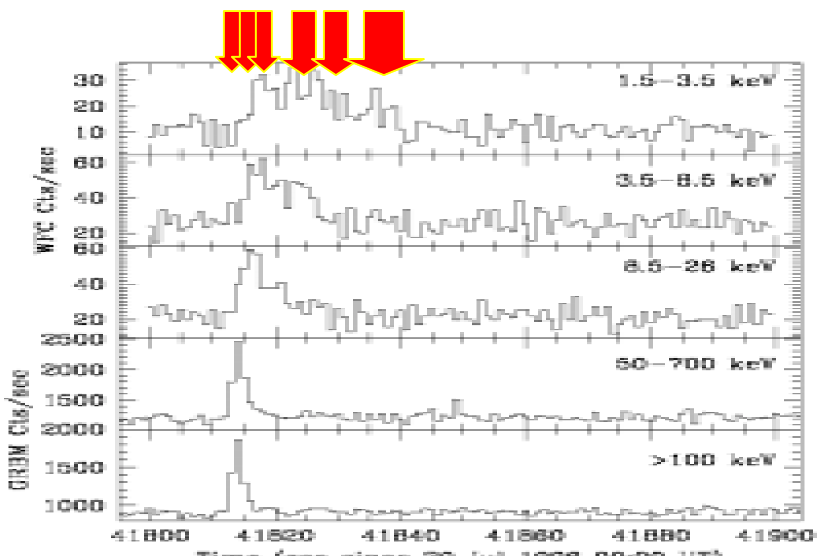


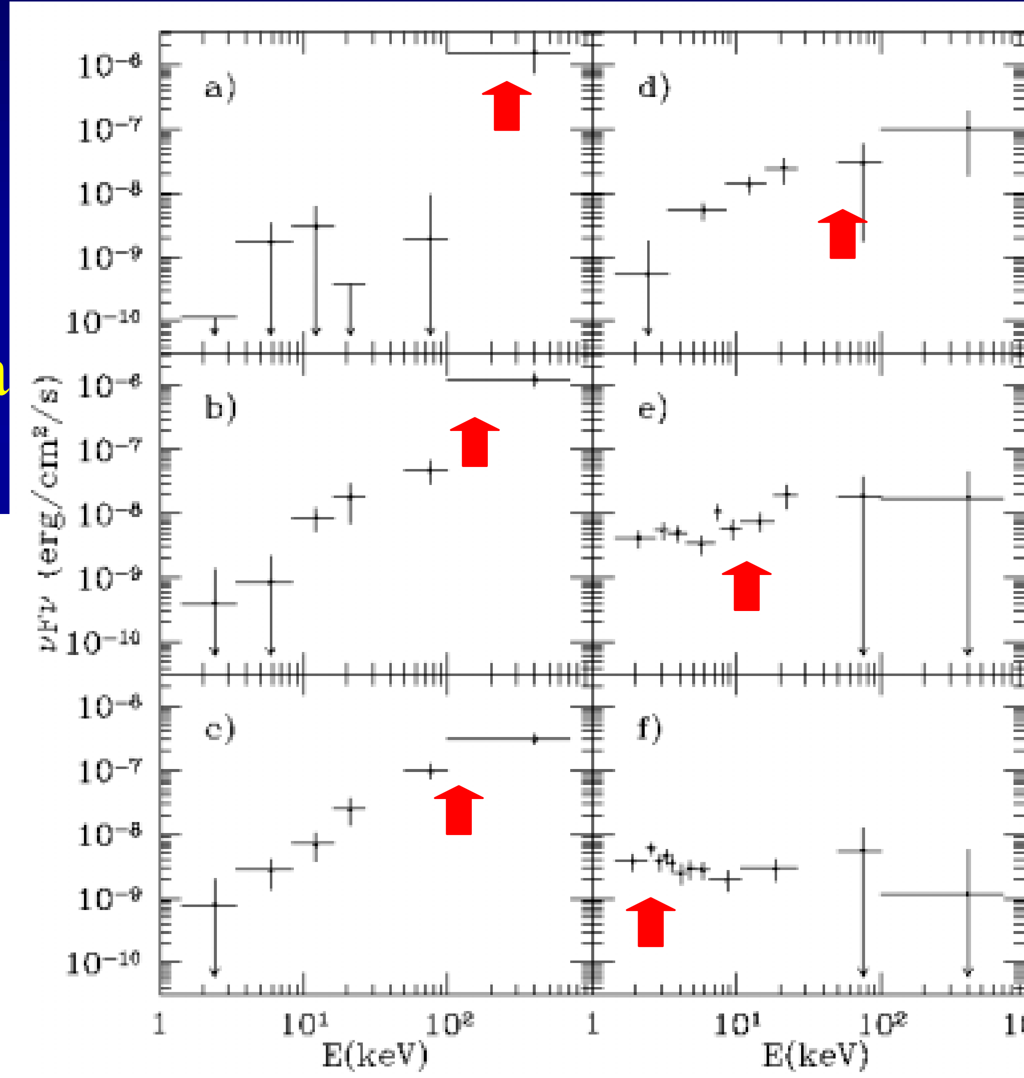
GB000926:Piro et al, 01

Costa et al 97
Piro et al 99

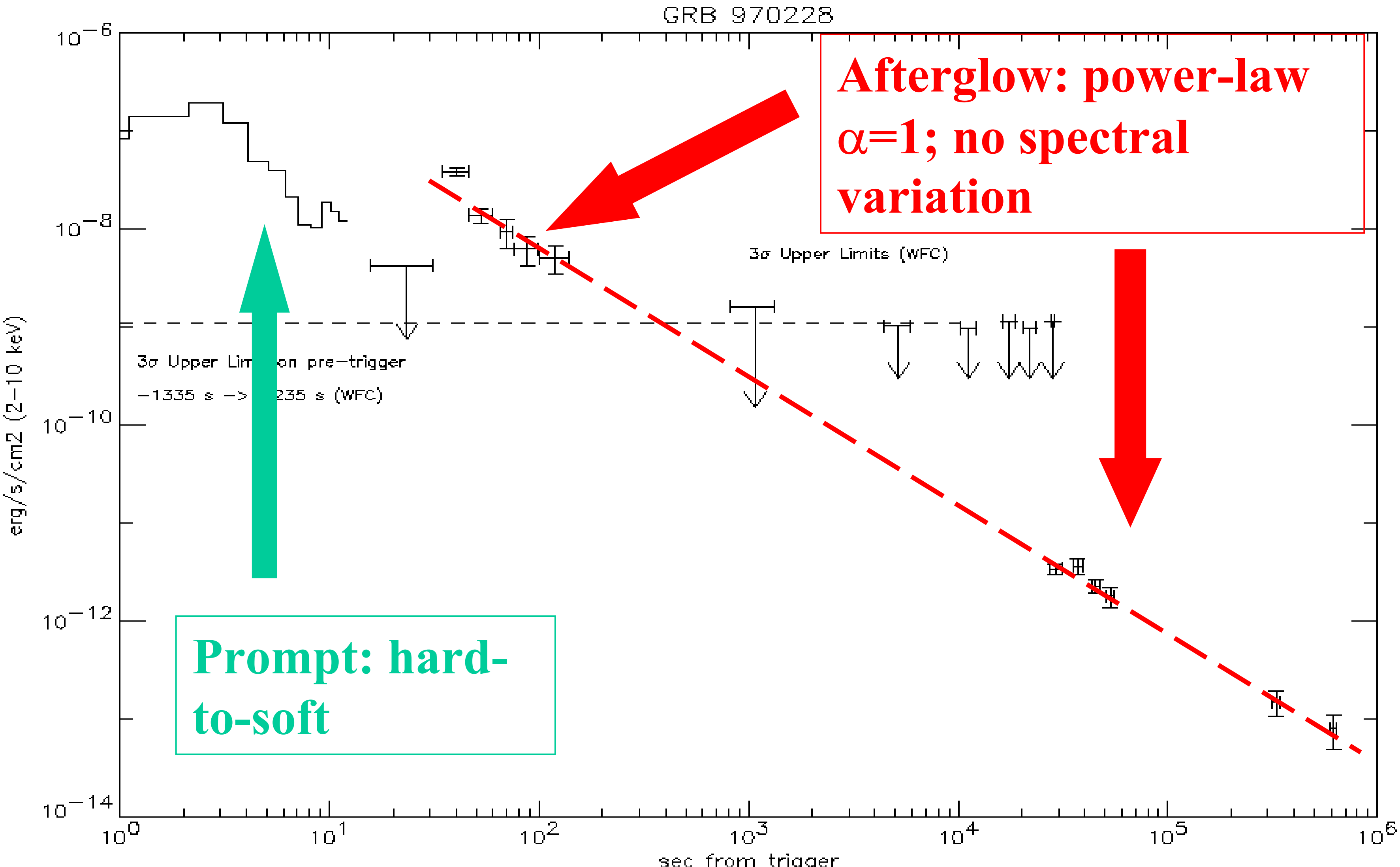
Internal vs external shock: prompt & afterglow emission (I)

In contrast with the afterglow, the prompt emission is characterized by strong hard-to-soft spectral evolution from X- to Gamma rays (e.g. GRB960720 Piro et al 1997)

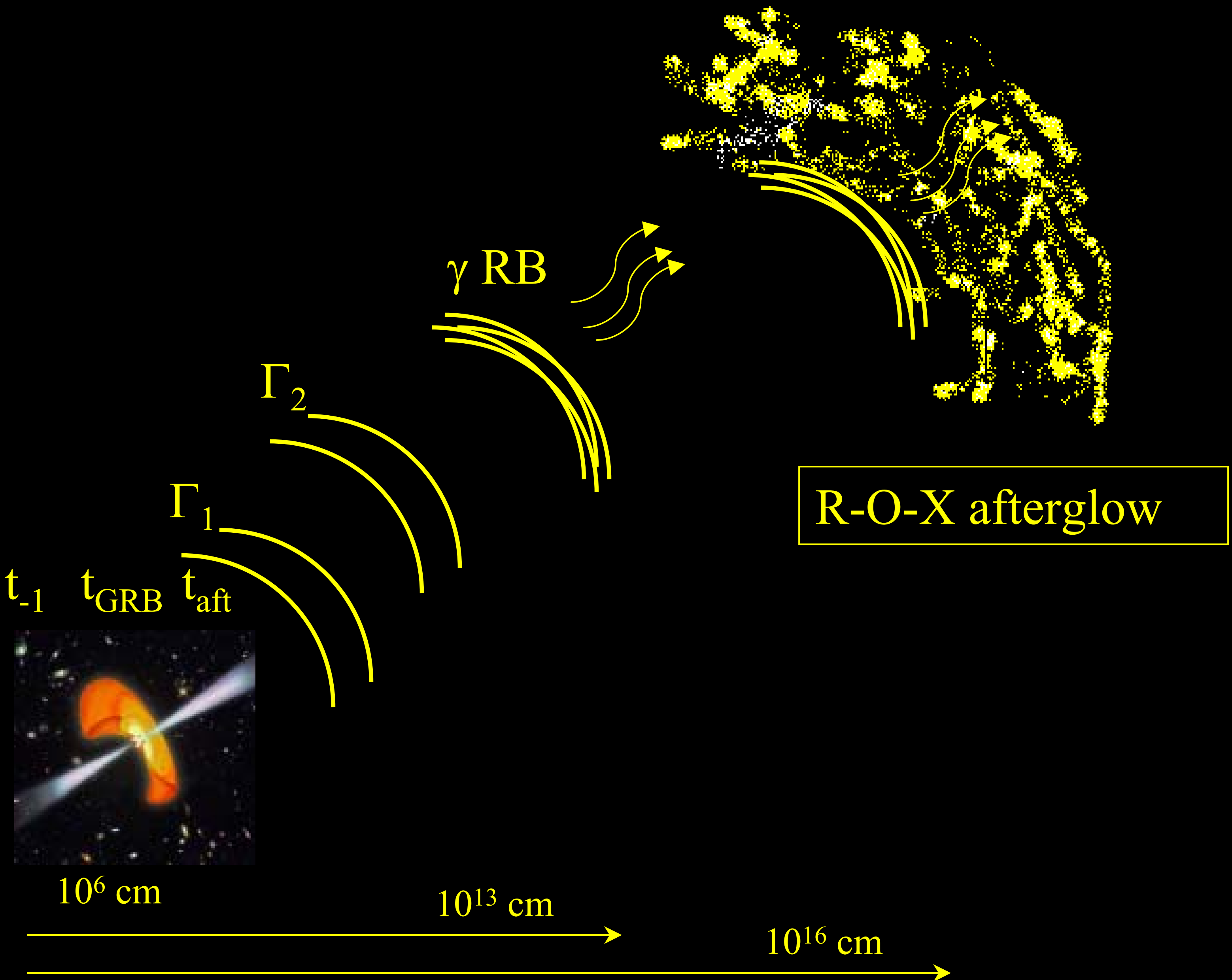




Prompt and afterglow emission Internal and external shocks?



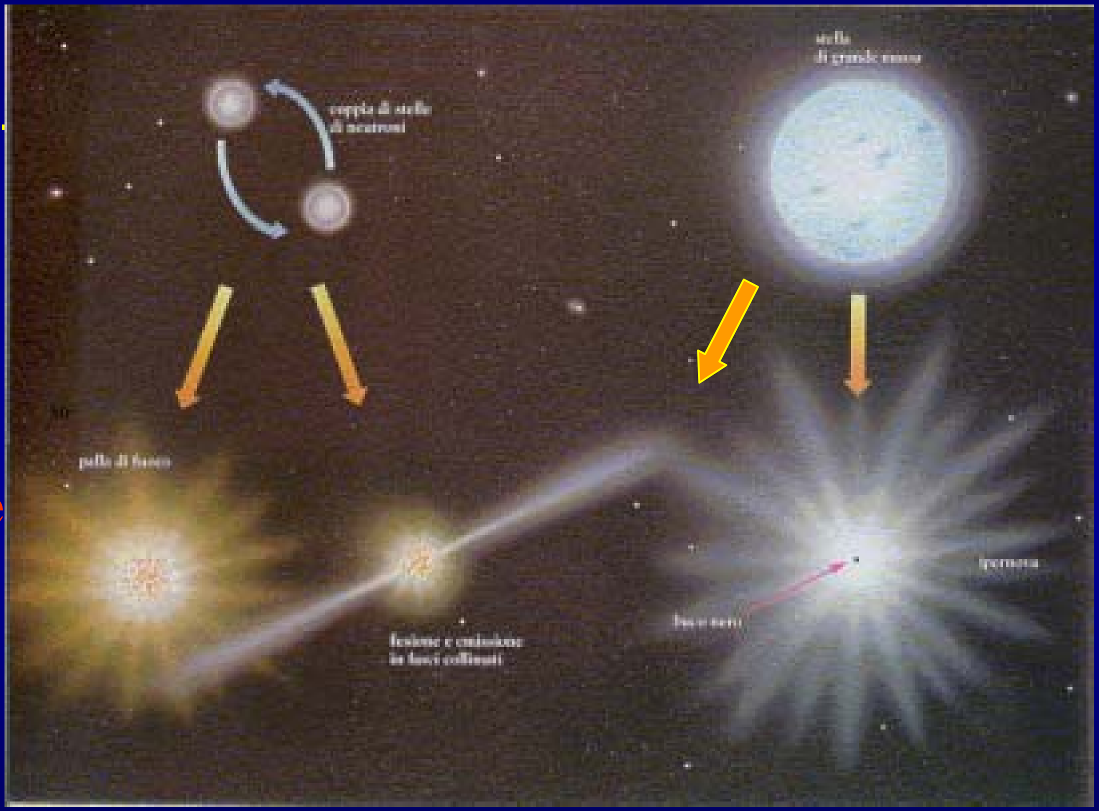
The fireball scenario



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

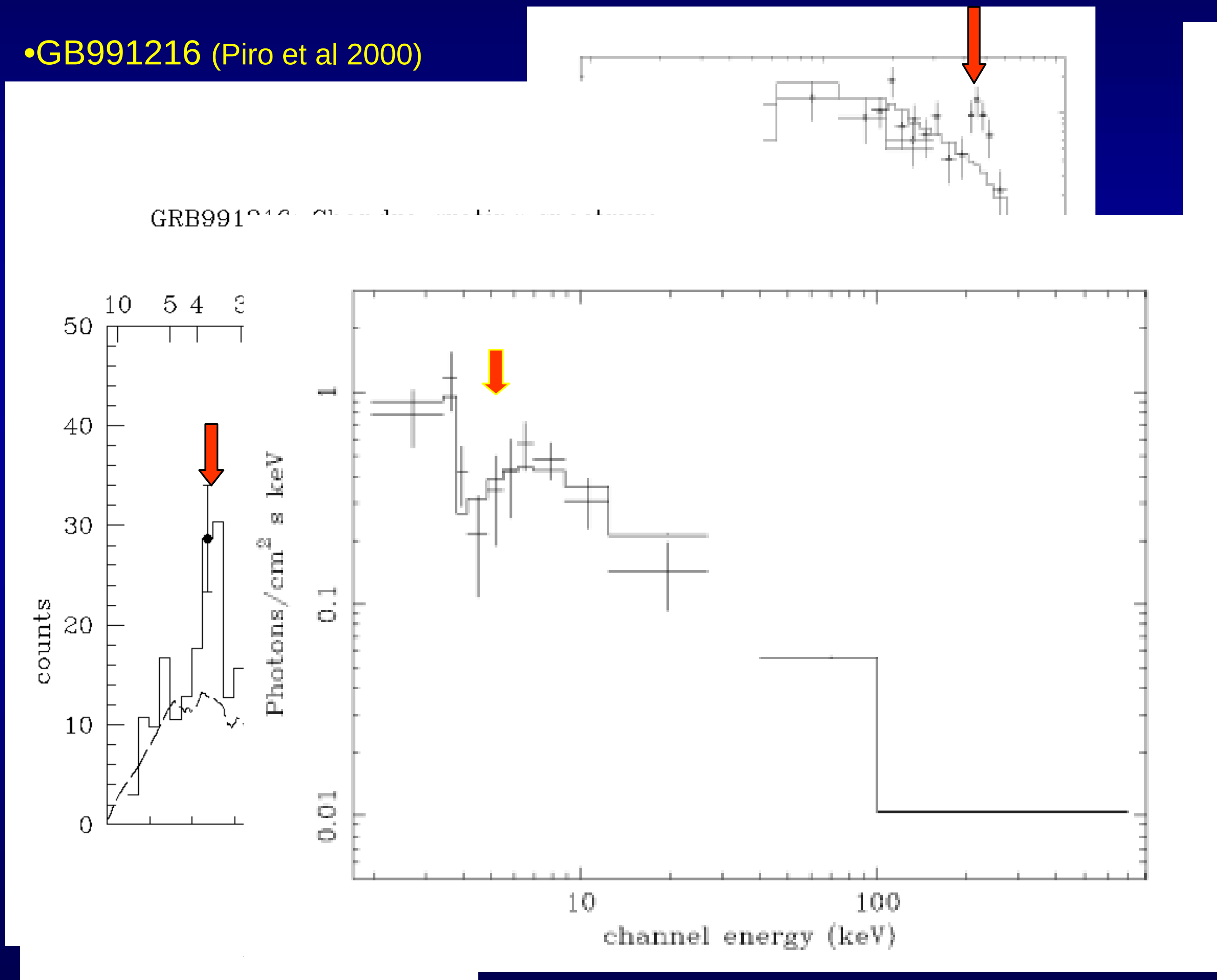
Hypernova

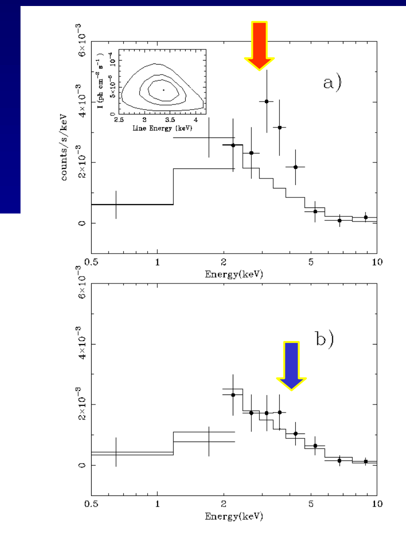
Iron features

•GB000214 (Antonelli et al 2000)

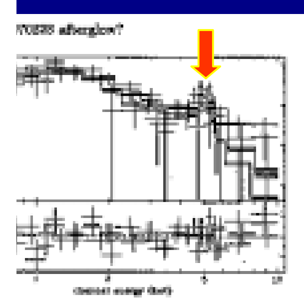
•GB970508 (Piro et al 1999)

•GB991216 (Piro et al 2000)





980828 (Yoshida et al 1999)



Summary of Fe features obs.

- Detections from 4 satellites and 6 instruments (no systematics)
- 3 detections at 3 sigma and 2 above 4 sigmas
- Emission features (in the afterglow phase) at rest frame E= 7.0±0.1 keV and 9 ± 0.4 keV, consistent with H-like Fe Kα (6.9 keV) and recombination edge (9.3 keV)
- Transient behaviour in 2 observations
- Not ubiquitous: there are some upper limits below fluxes of detections
- Transient absorption feature during prompt phase (0-15 s) at 7 keV, consistent with cold Fe edge (7.1 keV)

Features in GRB's: models

- Distant reprocessor scenario. Line produced by medium photoionized by GRB photons. Time scale= size of the medium. The mass of Fe (M_{Fe}≈0.1Msun) and high density and line width in 991216 (v=0.1c) require a SN explosion by a massive progenitor, preceding the GRB by a few weeks-months like in the Supranova model(Vietri &Stella).

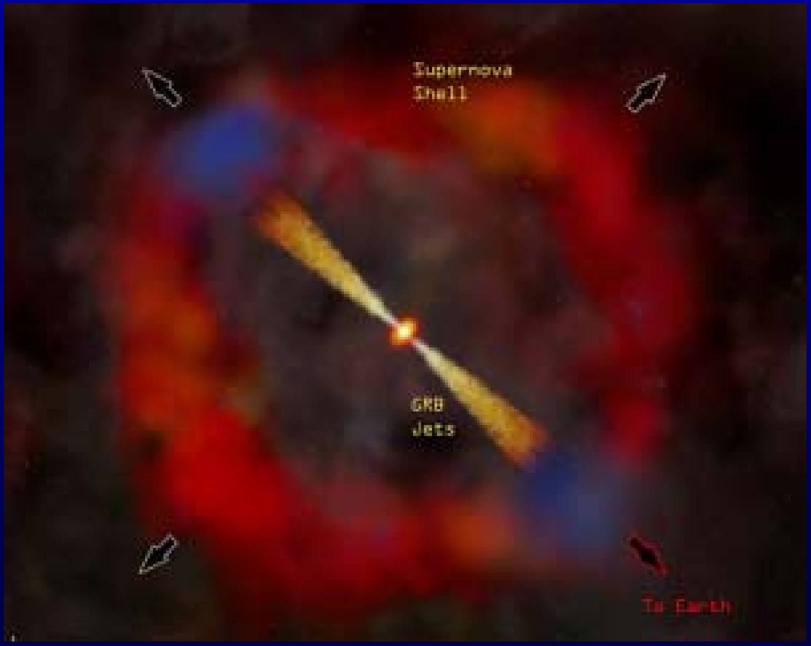
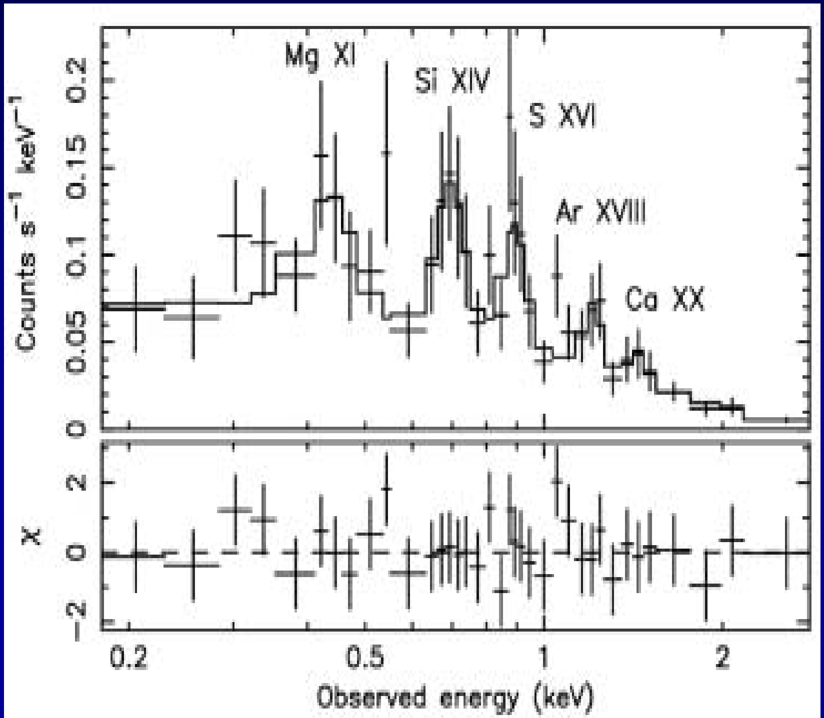


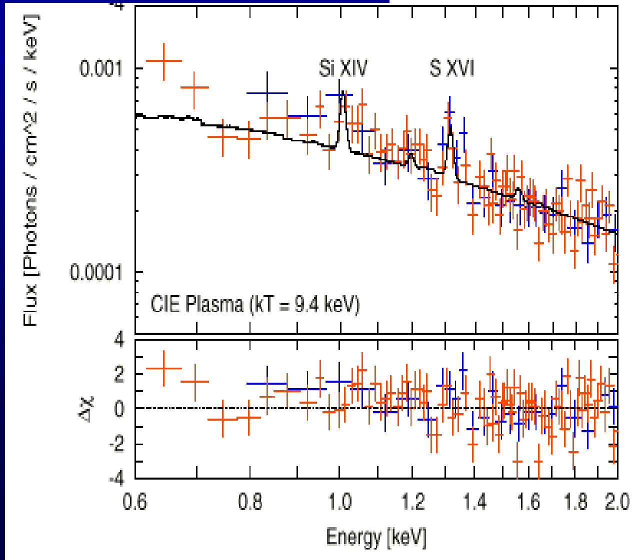
Image from HETE2 team & NASA

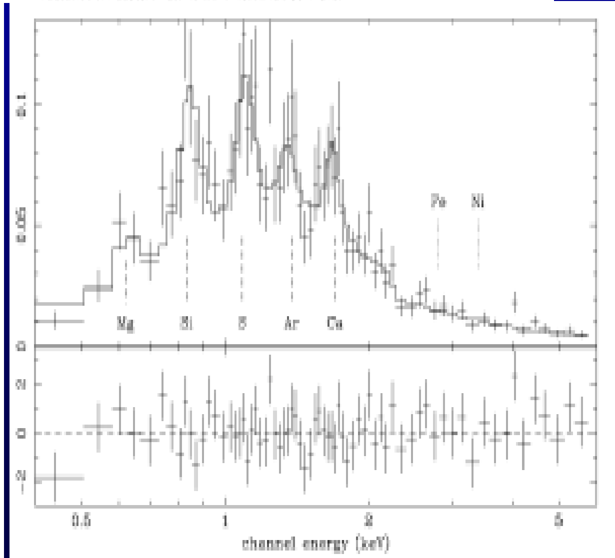
Soft X-ray lines

The GRB-SN connection furtherly confirmed by the detection of **He/H-like Mg, Si, S, Ar** metal lines **blueshifted at v/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)

See Schartel talk



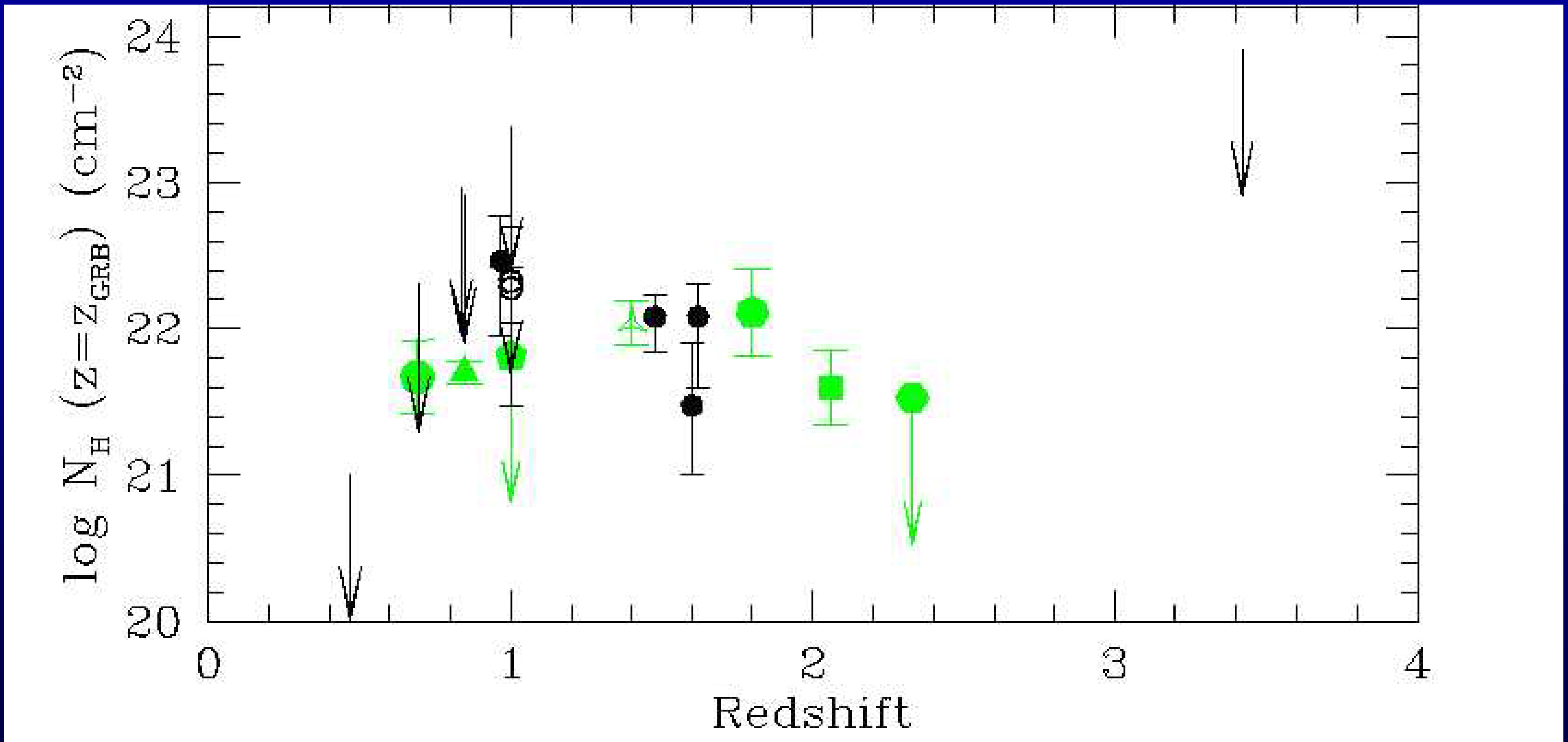




X-ray absorption

X-ray absorption column densities in the afterglow: NH=10^{21-22} cm-2 (Stratta et al, ApJ, subm)

Consistent with NH in Giant Molecular clouds



GRB-SN connection

- GB980425: in the BeppoSAX error box: SN1998bw (Pian et al. 99,Kulkarni et al, Galama et al al 98). Exploded within 1 day from the GRB. Chance P=1E-4
- HETE-2 GRB030329=typeIc SN2003dh >Ricker's talk

SN 1998bw in Spiral Galaxy ESO184-G82

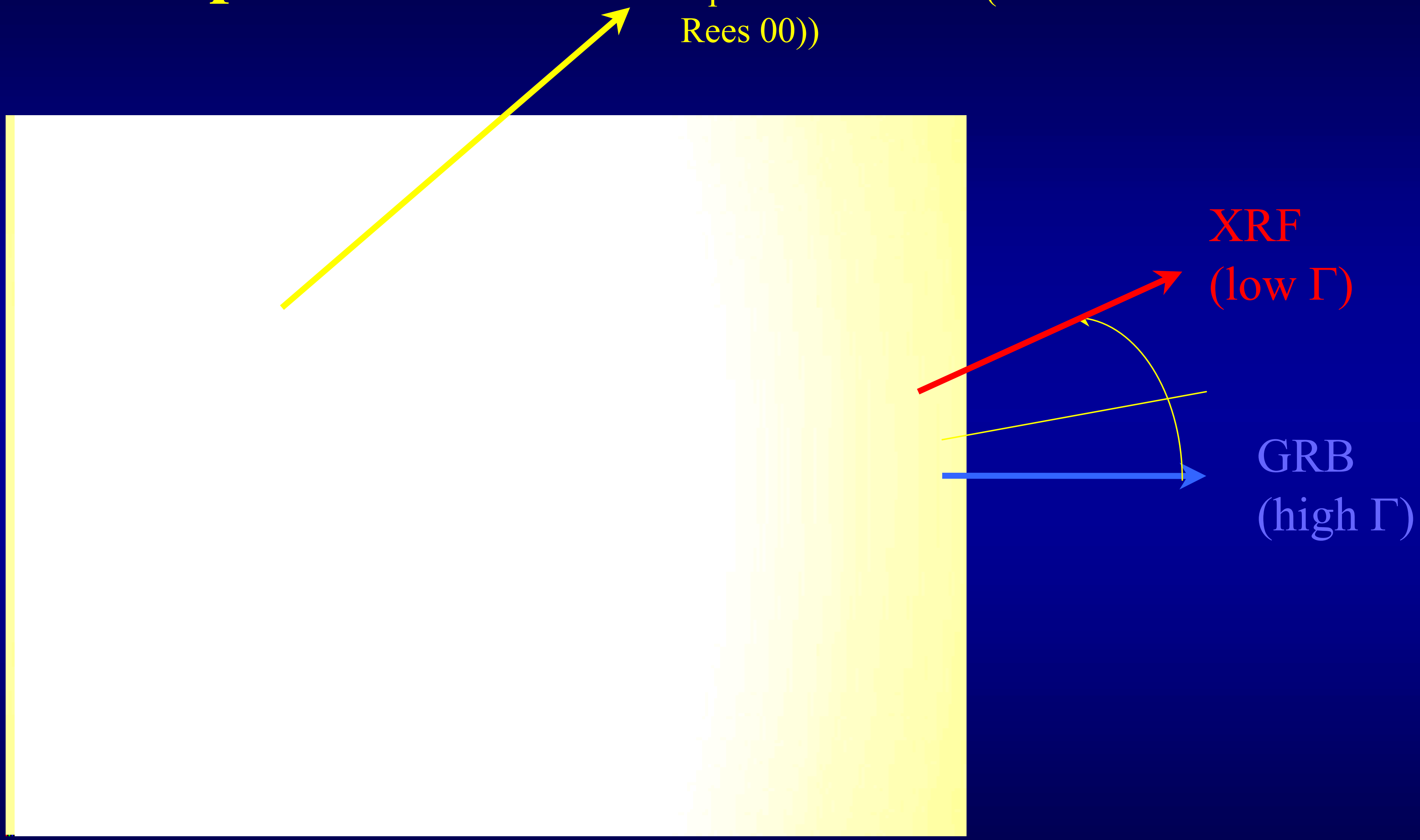
ESO PR Photo 39a/98 (15 October 1998)

Collapsar model

- Massive (>40 Msun) rotating star that has lost H envelope (WR) (Woosley et al. 98,00,03)
- In the core-collapse a BH+AD is formed, energy is tapped out of the system and propagates along the evacuated rotation axis (jet)
- The jet breaks out of the stellar surface with Gamma about 100 (collimated fireball=>GRB, consistent with "observed" jet opening angles of 5-10 deg and total energy from GRB= a few 10^{51}erg, Frail et al 02, Berger et al 03)
- A substantial fraction of the energy is produced at wider angles with lower Gamma
- SN-like star explosion almost simultaneous with the GRB
- In this phase, depending on the n/p content, Ni56 or Fe54 are produced. Ni56 => optical SN while if Fe54 no SN and X-ray Fe lines

Collapsar model

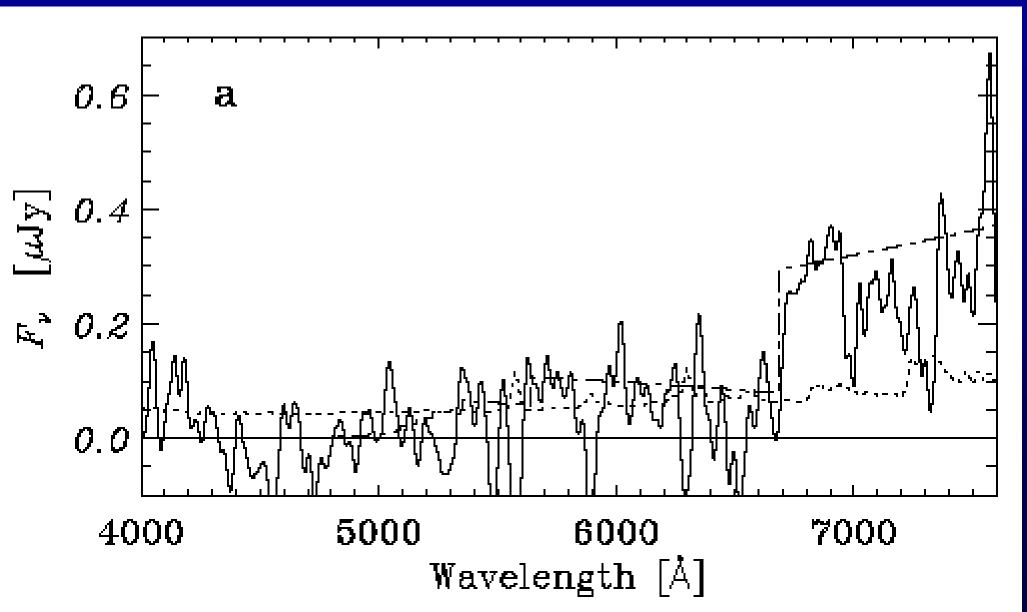
X-ray lines (local reprocessor scenario (Mesaros & Rees 00))



Woosley et al

The quest for high-z GRB

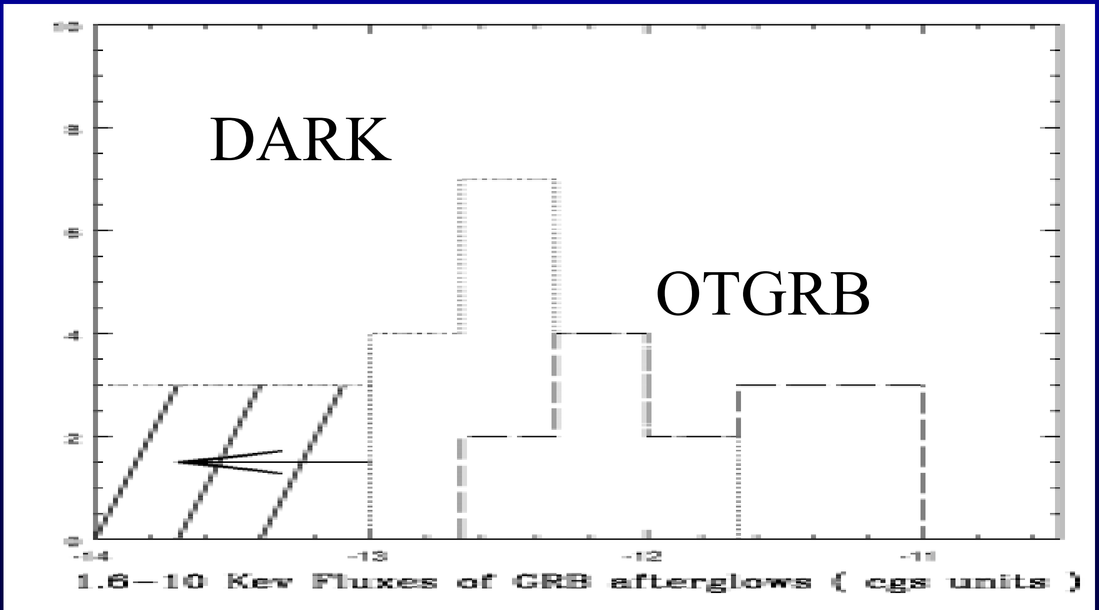
- If GRB=SFR, about 20% of them at z>5 (Bromm & Loeb 03
- Events at z>5 will not be visible in the optical range, (Lyalpha forest absorption): they have to be "dark"
- Most of the redshift are now derived from optical obs => strong bias against high-z GRB
- X-ray redshift or IR photometric/spectroscopy z



GRB00013C: z=4.5
(Andersen et al 01)

Are there really dark GRB?

- From the BSAX sample we find (De Pasquale, LP etal 03, ApJ)
- **About 90% GRB have X-ray afterglows, only 40% an optical afterglow (dark GRB)**
- **Dark GRB are on average 6 times fainter in X-rays than OTGRB (explaining why HETE2 SXC localization lead to OTGRB, Ricker's talk)**

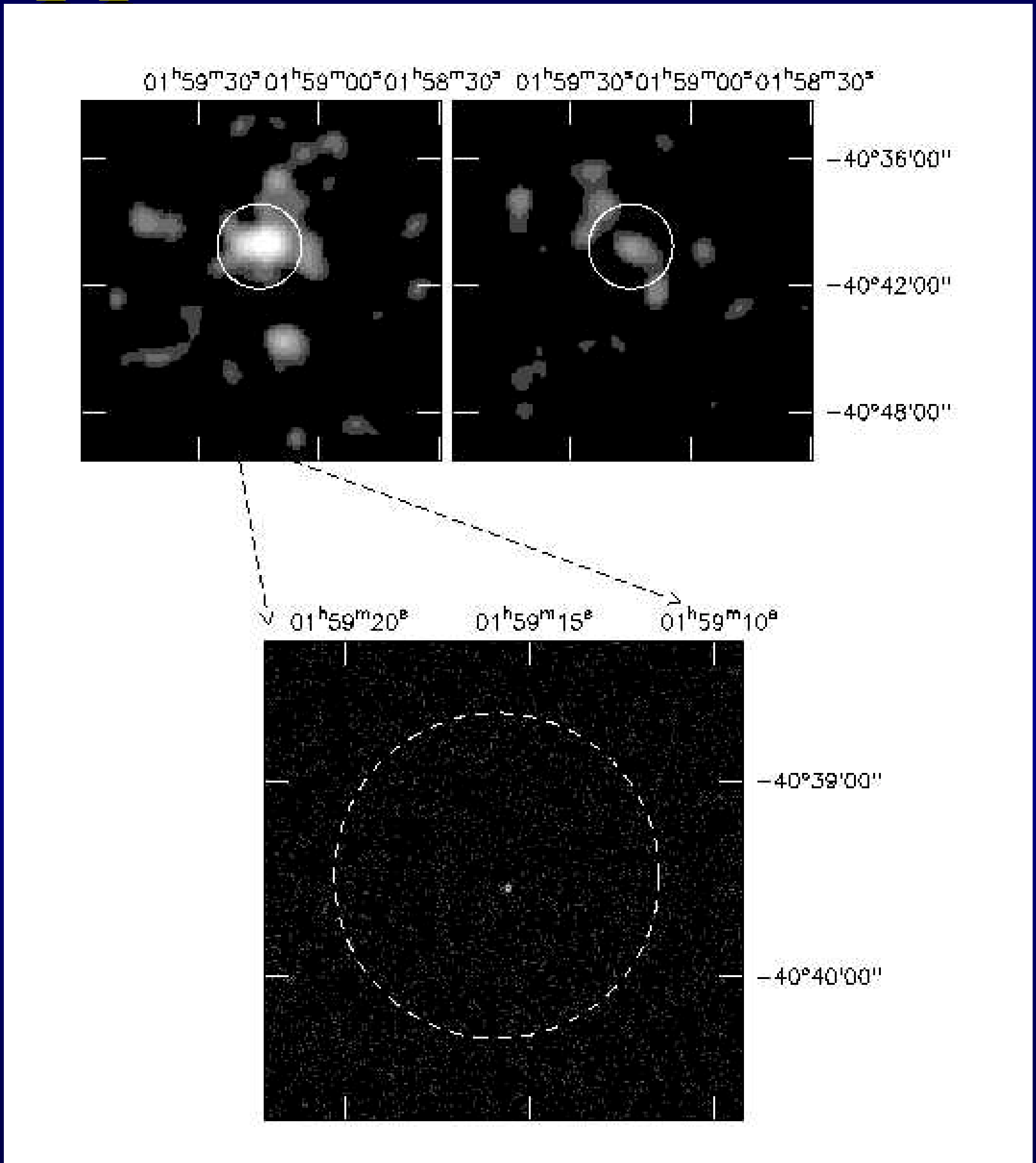


Are there really dark GRB? YES

- **about 20% of dark GRB are "truly dark", being their ratio of optical-to-X-ray fluxes smaller by a factor of about 6 compared to OTGRB**
- **Not consistent with the fireball model unless:**
- **OT heavily absorbed by star forming region ?**
- **Or located at z>5 (such that intragalactic gas will absorb photons below Lyman limit)**

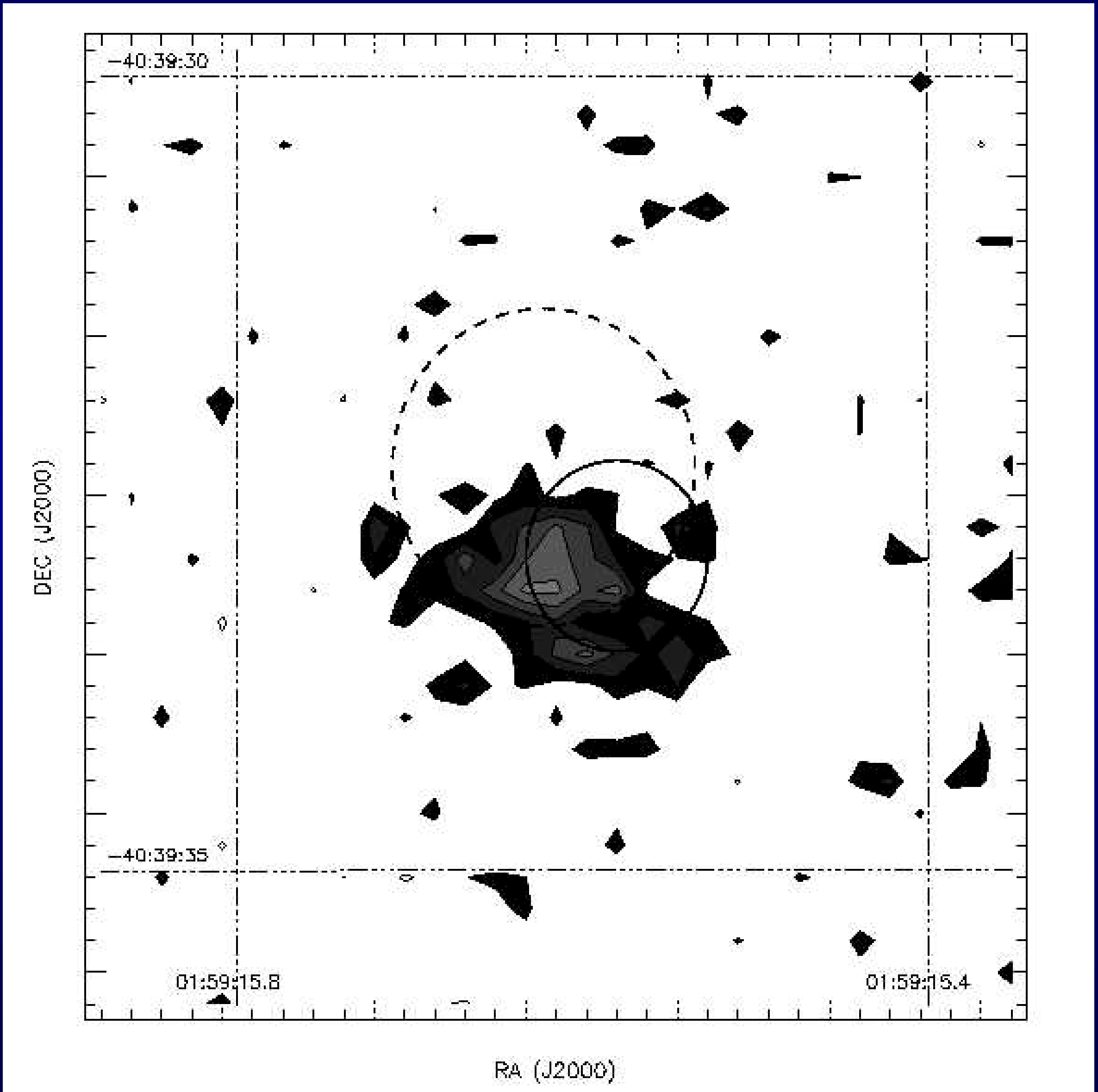
GRB000210: BeppoSAX & Chandra

- GRB localized by BeppoSAX. The brightest ever observed in γ-ray peak flux
- Simultaneous obs of the X-ray afterglow with Chandra.
- No OT >23.5



The host of GB000210?

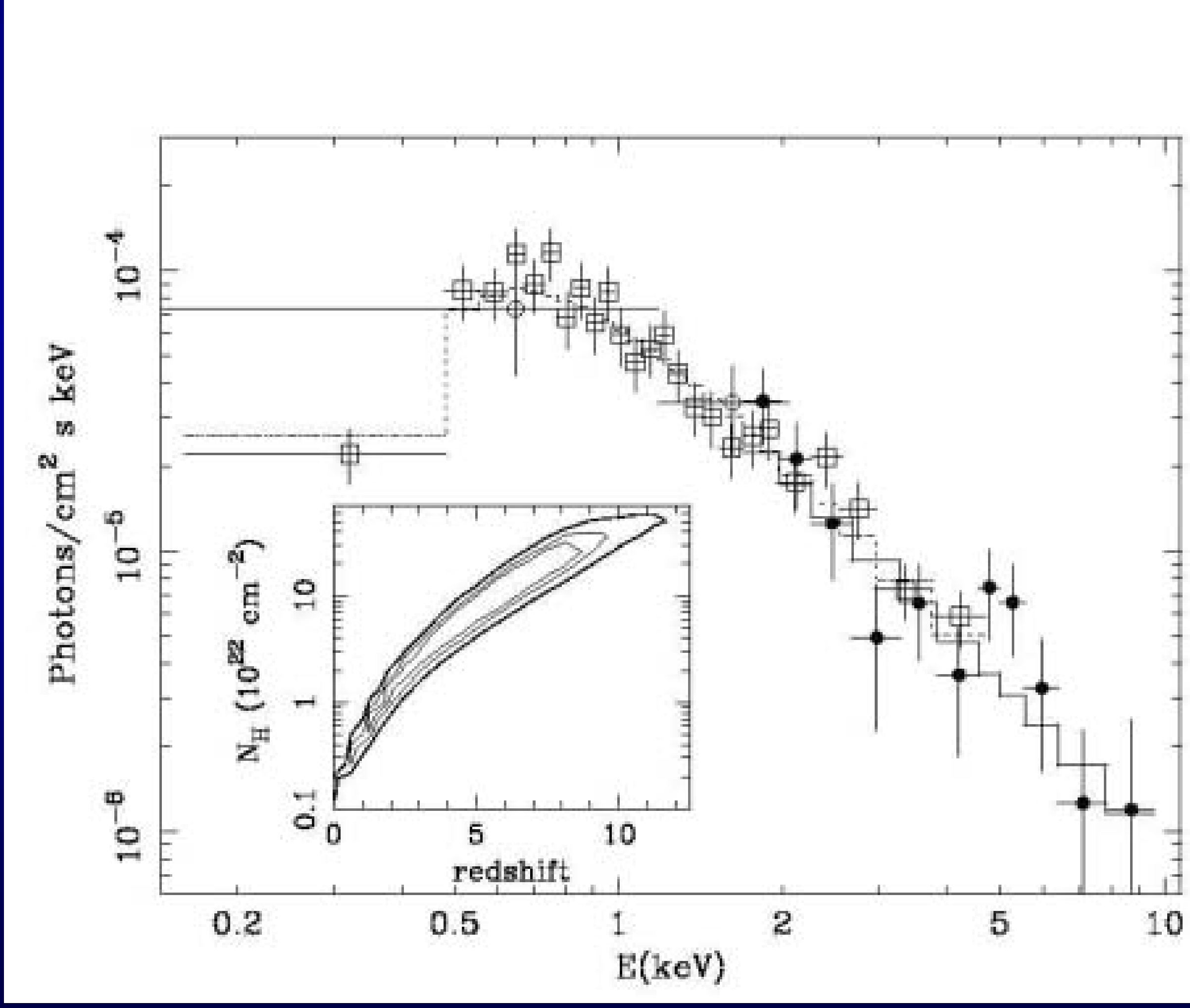
- VLT: A galaxy in the CXO error box
- VLA: radio transient
- VLT spectrum: Host galaxy at z=0.83 (Piro et al 2002)
- there is at least another dark GRB associated with a galaxy at z<5 (GB970828, Djorgovski et al 01)



Dark GRB in star-forming GMC: GRB000210

- Significant absorption above the galactic in X-rays. At z=0.85 NH=(5 ± 1) 10^{21} cm^{-2}
- The optical spectrum is depleted by about 2 mag compared to the fireball model prediction based on the X-ray flux
- Consistent with the X-ray column density with a dust-to-gas ratio similar ot the galactic one
- Typical of a GMC

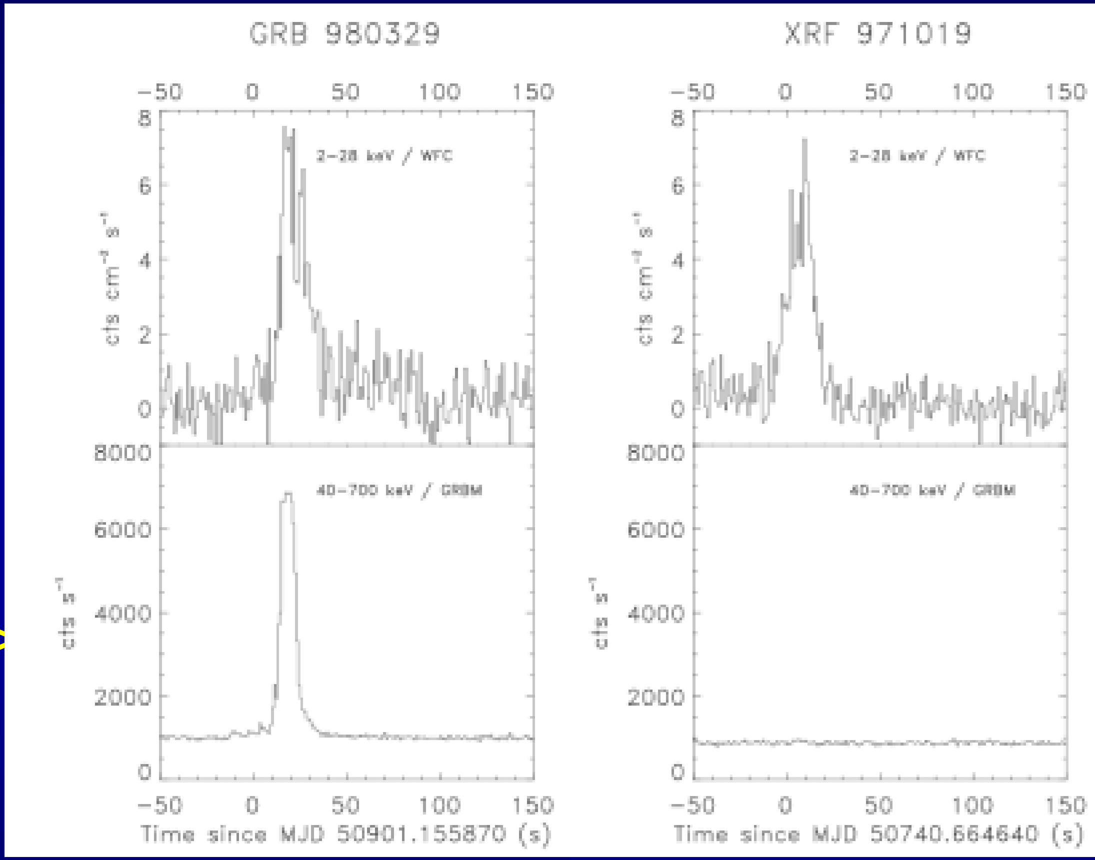
Piro et al (2002)



X-ray flashes

X-ray rich GRB/ X-Ray Flash: a new class discovered by BSAX: about 30% GRB's with no or very faint or gamma-ray emission ($S_x/S_\gamma>1$).

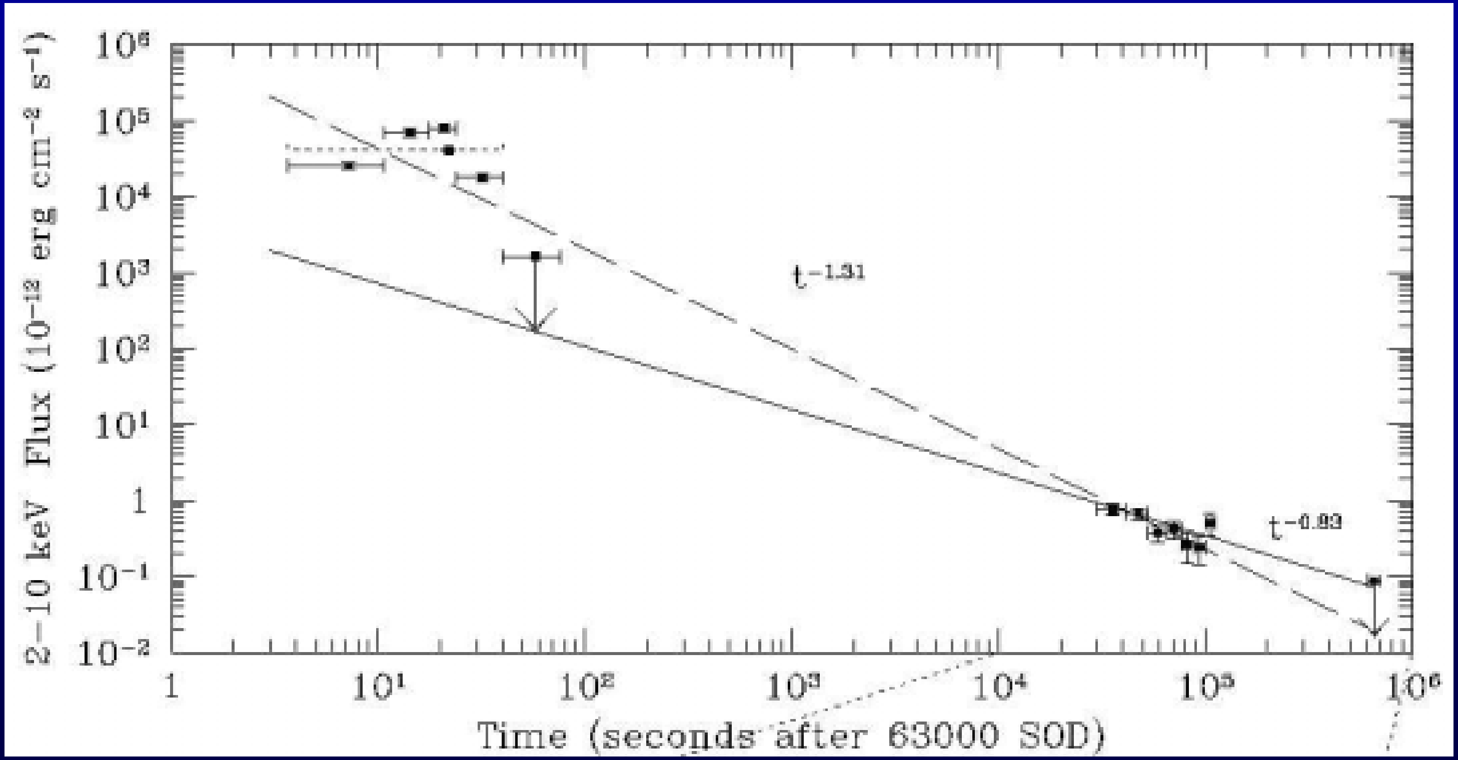
GRB's in high dense medium (dirty fireball => smaller Lorentz factor (Dermer et al) or normal GRB seen at large angles (Berger et al, Woosley et al., ..) or events at z>5-10?



Heise et al 2001

X-ray afterglows of XRF

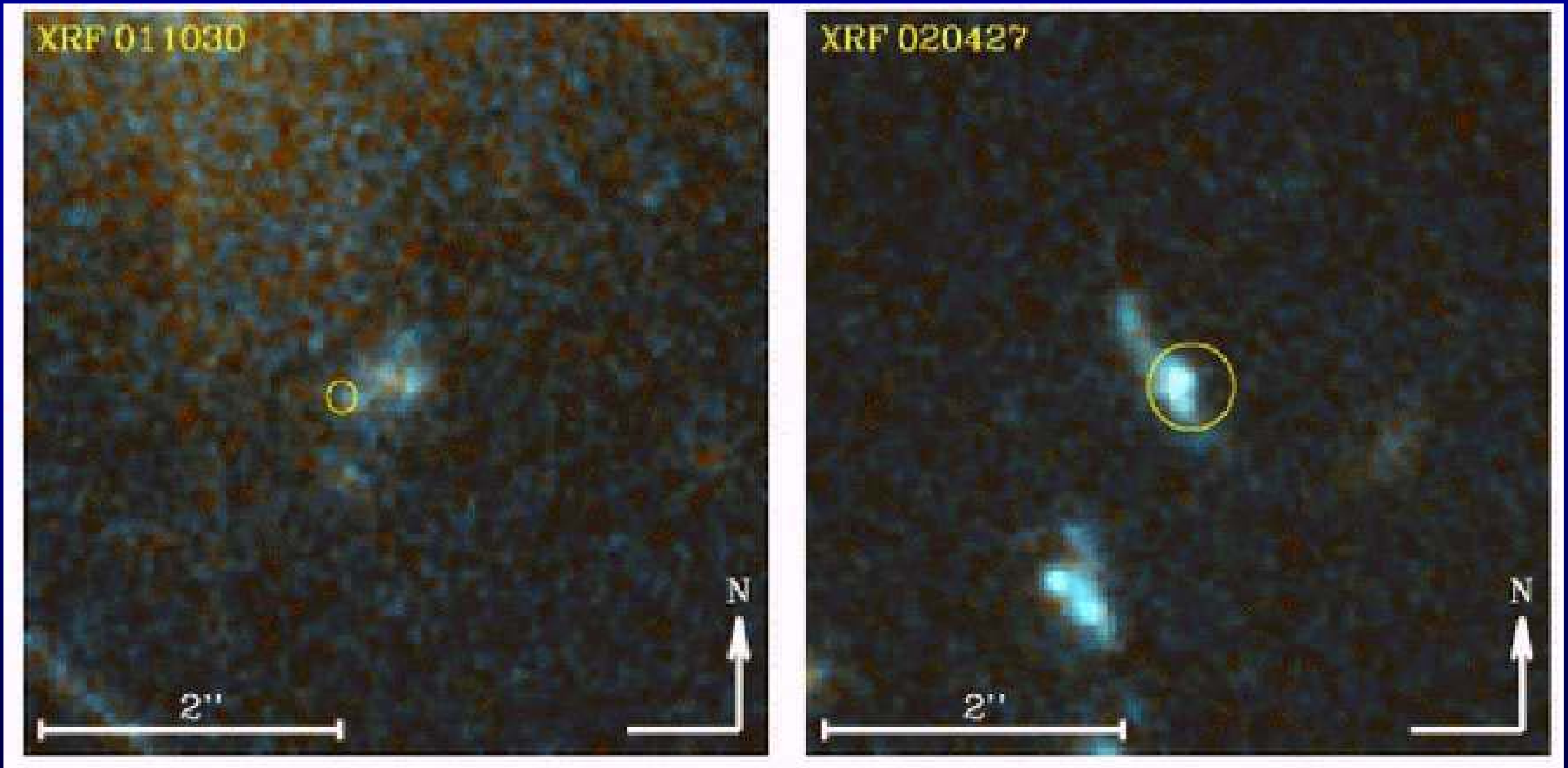
- 5 fast follow-up obs of X-ray rich/XRF localized by BSAX (see al Ricker's talk on HETE2): 3 by BSAX, 1 by BSAX+Chandra, 1 by XMM
- X-ray afterglows similar to normal GRB



990704, Feroci et al,00

XRF host galaxies

- 2 of XRF localized by BSAX and followed up by Chandra (1”position) show a faint blue host galaxy (z<2) (Bloom et al 03)



GRB and Cosmology

- The brightest ($L_{iso}=10^{53-54}$ 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)
- trace the evolution of metals is the Universe
- Trace the dark matter structures in the z<2 universe by measuring the WHIM (Warm Hot Intragalactic Medium)
- 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)
- Probing the reionization epoch (no proximity effect as in QSO's)