Story of a Discovery
25 years later: GRB Afterglow with BeppoSAX

Lesson Learned

By

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GRB-V

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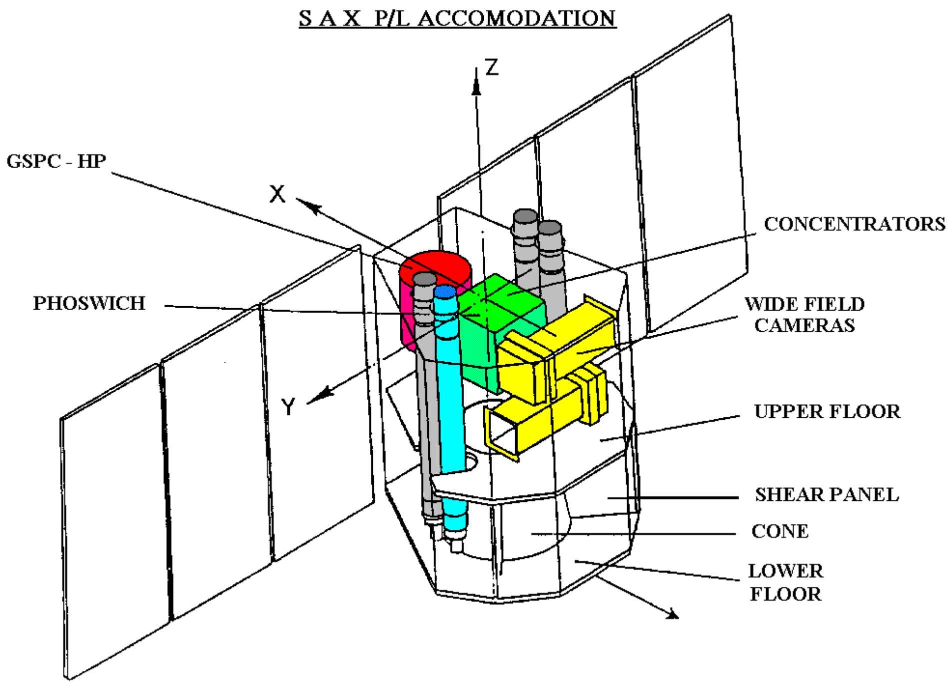
BeppoSAX
an ASI mission led by L. Scarsi

Payload

- **Narrow Field Instruments:**
  - 4 focusing telescopes LECS+MECS (0.2-10 keV), PI G. Boella
  - HPGSPC (4-60 keV), PI G. Manzo
  - PDS (15-200 keV), PI FF (Deputies: EC, D. Dal Fiume)



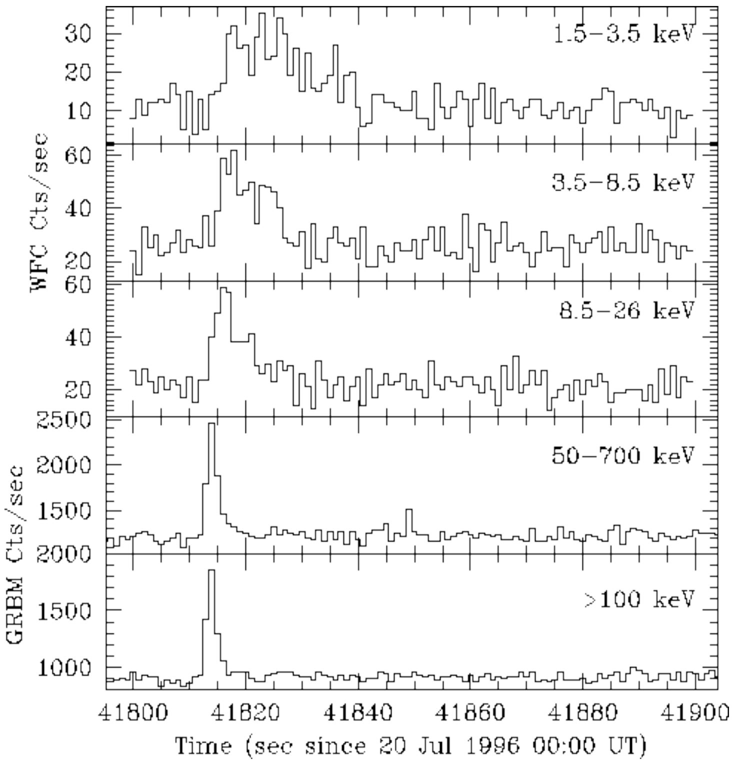
- **WFCs (2-28 keV, PI R. Jager):**
  - 2 units in opposite directions,
  - proportional counters + coded mask, ang. res. 3′-4′
  - FOV 20°x20° (fwhm)

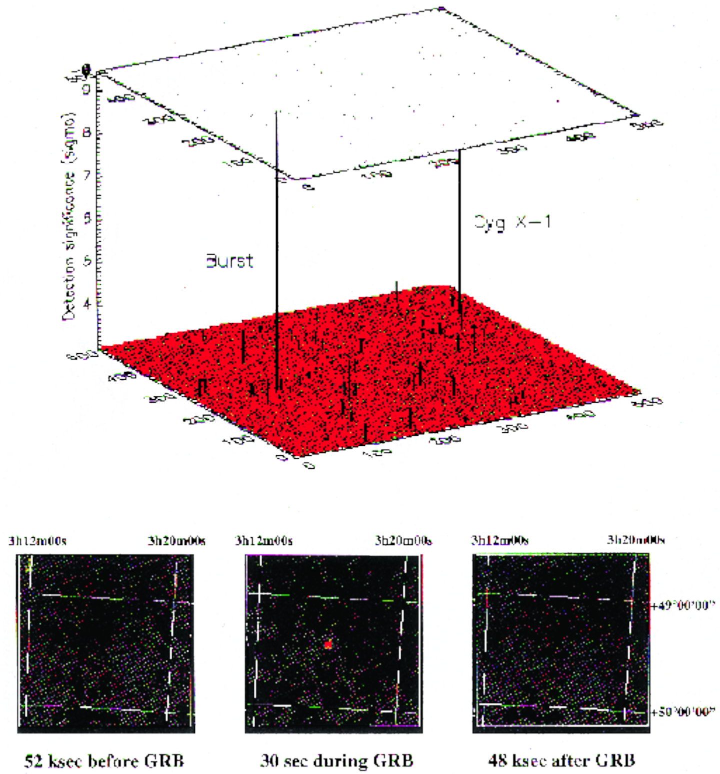
The first GRBs

During SVP, several GRBs detected in off-line analysis with GRBM.
On july 20 1996 we learned that BATSE had detected a GRB960720 with localization in the center of a BSAX WFC.
But no burst was there in the GRBM. A burst was present 10s after.
WFC counting rate was perfectly flat.
The GRBM burst was identical to the BATSE burst (kindly sent to FF by Jerry Fishman) but for the time.
We (Mauro Orlandini) found a bug (tens of minutes) in the time decoding software. After debugging SAX and BATSE perfectlty coincided.
We found a bug in the decoding S/W of WFC. The burst showed up in the data.

•WFC data were imaged during, before and after the burst time. A bright source was present that was not present before and was no more present after and the event. The localization was at the time of the order of 5 arcminutes.

• A pointing of the NFIs toward the GRB direction was performed, but no X-ray counterpart found.

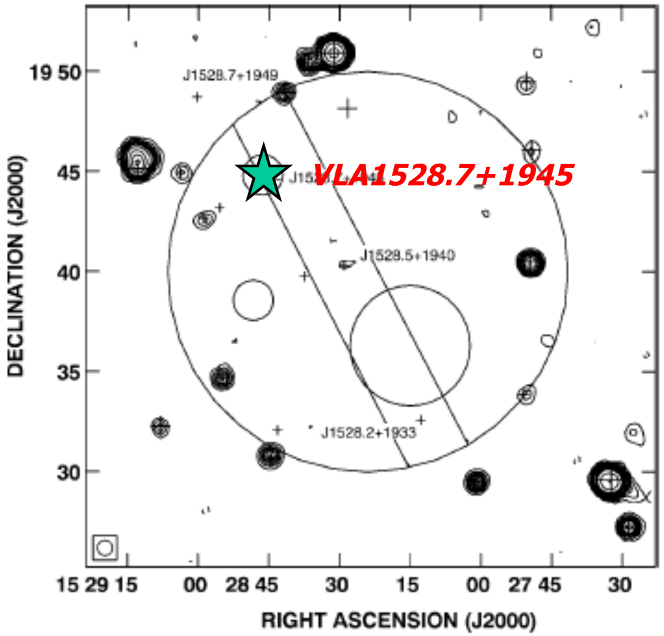




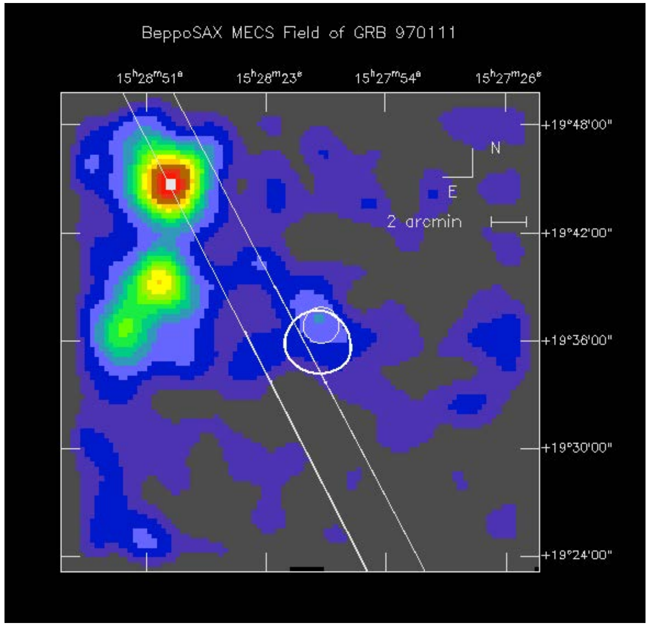
Observation strategy set up

- **From GRB960720 experience , two alternatives:**
  - **No X-ray residual radiation at all;**
  - **A rapidly fading X-ray source.**
- **A prompt follow up would be the next attack.**
- **Observation strategy devised:**
  - **Prompt analysis of the GRBM data and validation of real bursts.**
  - **WFC data analysis in coincidence with detected GRBs;**
  - **In the case of a positive detection/localization with WFC, follow-up with NFIs.**
- **This observation strategy became operative in Jan 1997.**

970111: the first GRB promptly followed up



Radio image of March 1995 with superposed earliest and latest WFC error boxes (Frail + 1997)

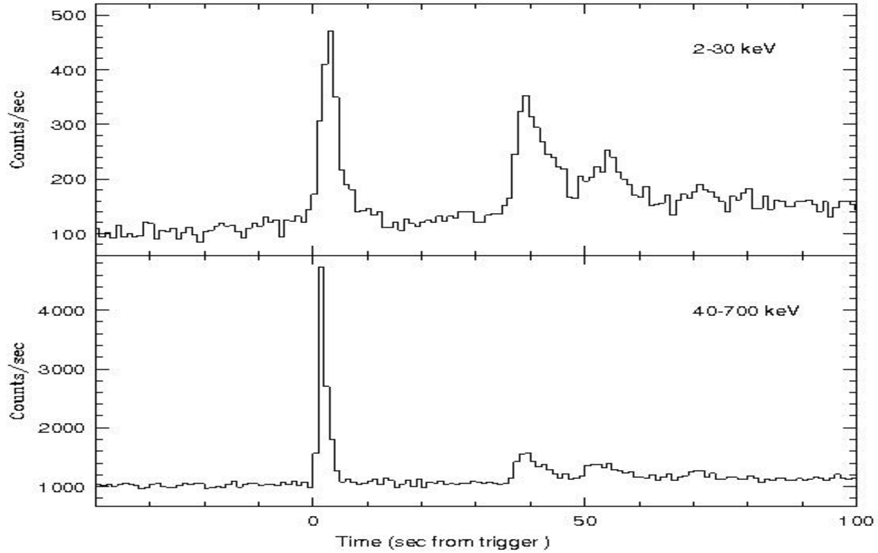


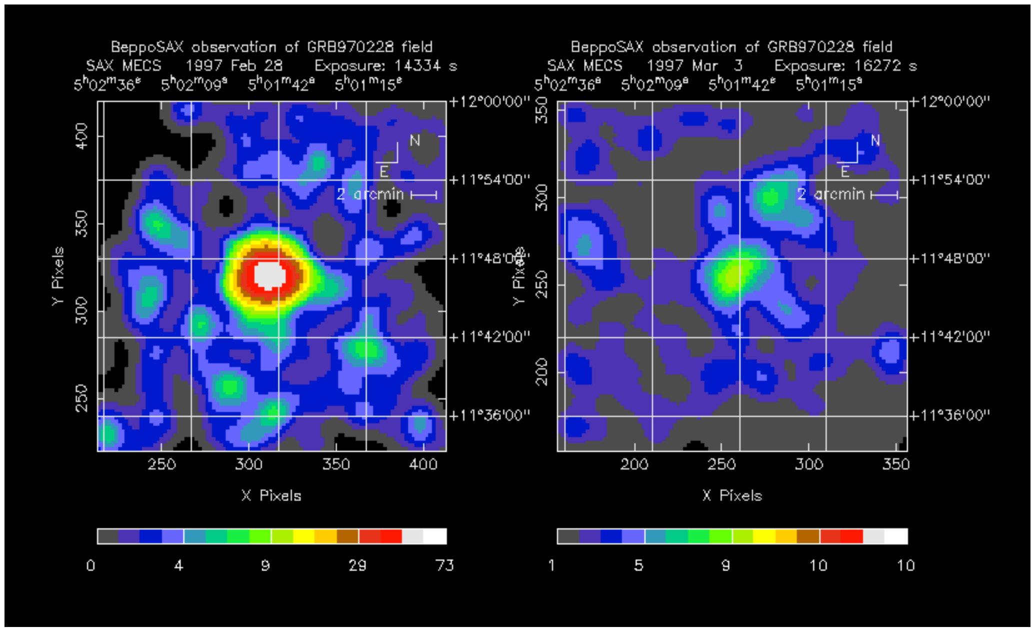
Feroci et al. 1997

GRB afterglow discovery

Unsuccessful search with GRB GRB970111.

- **Second GRB promptly identified and well localized: GRB970228**
- **Follow up after 8 hrs: afterglow emission discovered.**

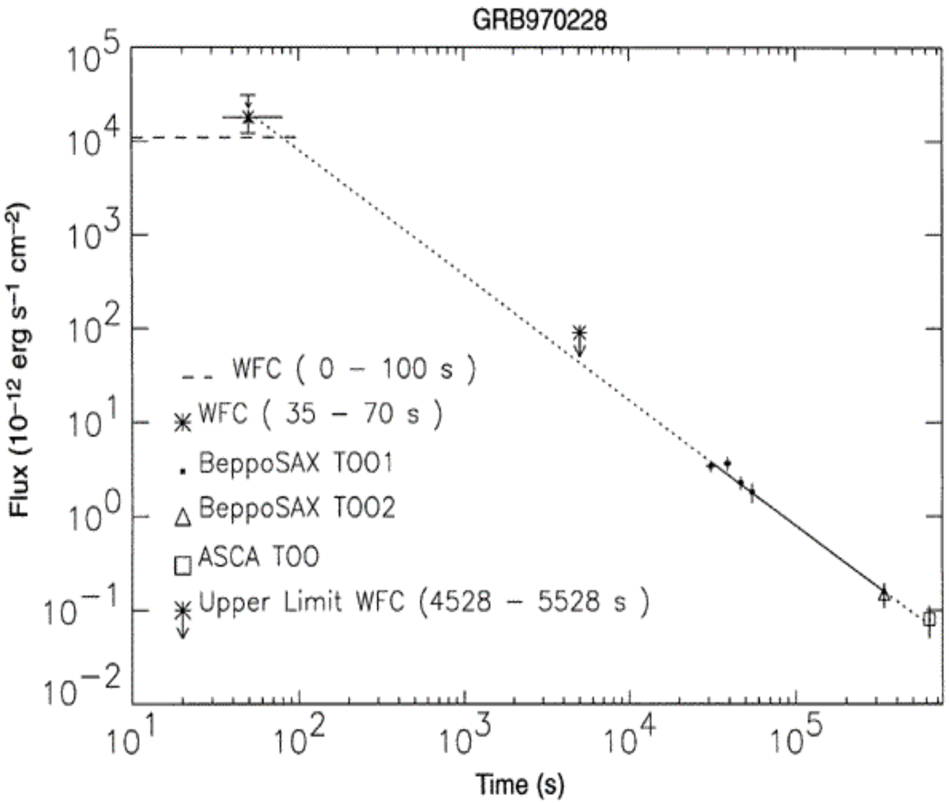


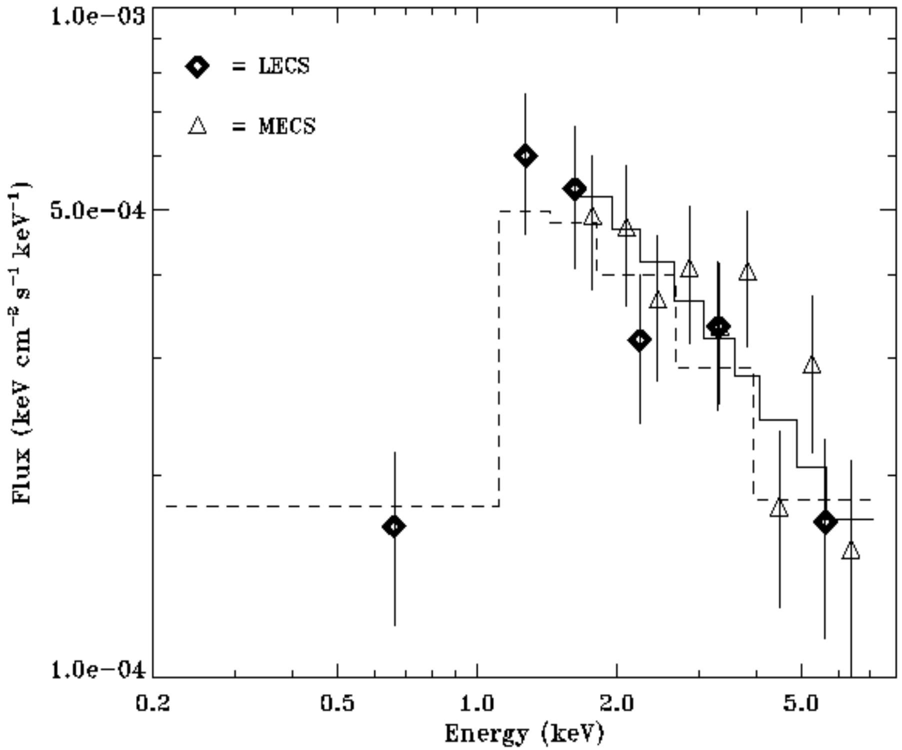


Costa, Frontera et al. 1997

X-ray Afterglow emission properties of GRB970228

Power- law decay and power-law spectrum





$\boldsymbol{F} \sim t^{1.3}$

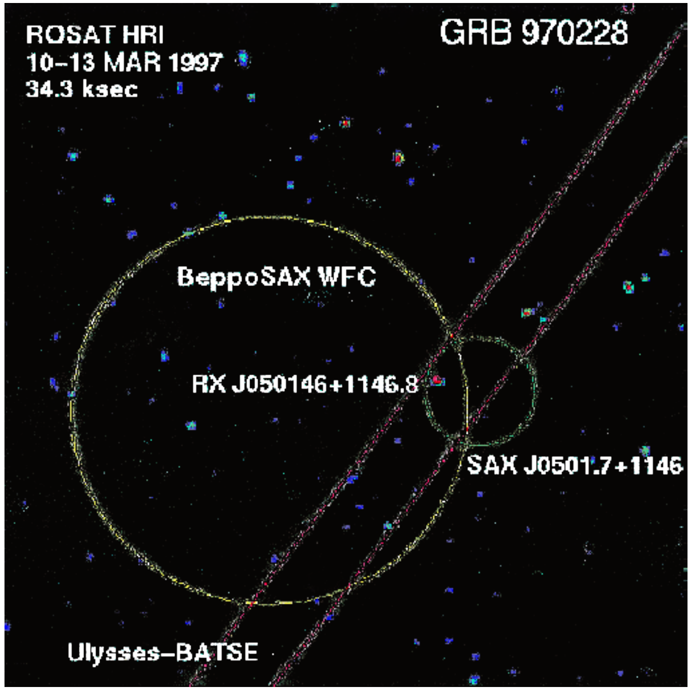
Costa, Frontera et al. 1997

$\boldsymbol{F} \sim E^{-2.1}$

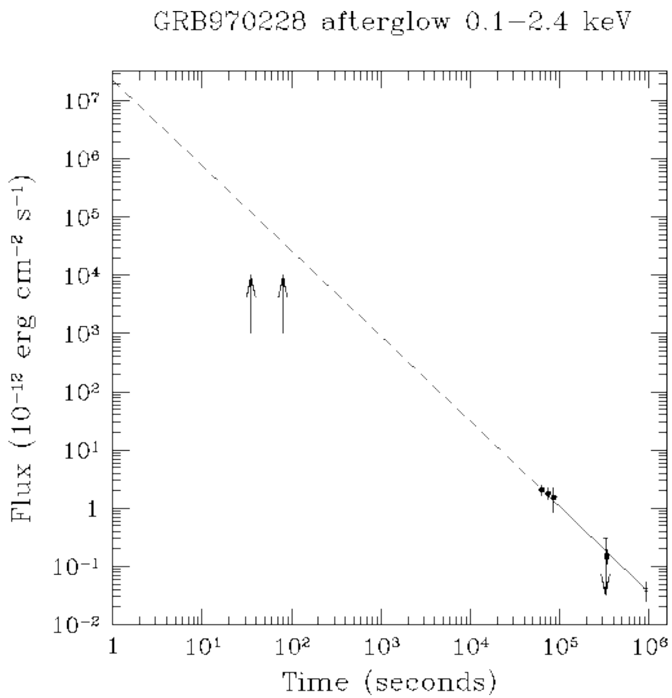
Frontera, Costa et al. 1998

GRB970228 afterglow observation with ROSAT

- ROSAT was the most sensitive Soft X-ray telescope at the epoch. We asked for a pointing in the direction of the burst. After 10 days (a anthropology case) the afterglow was still there.



Frontera et al. 1998



But the error box had shrinked down to 5 arcseconds

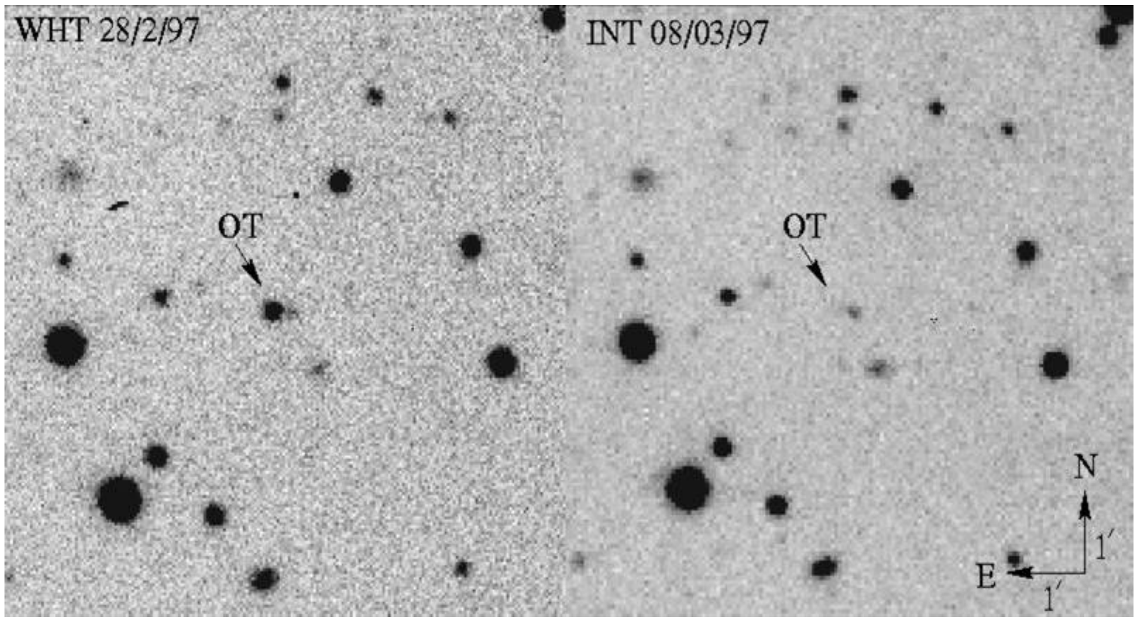
First discovery of the optical afterglow from GRB970228

The error box given by BeppoSAX was at last compatible with a search in optical images within a reasonable small field.

Various teams observed the field at the BeppoSAX coordinates distributed by a telegram to the International Astronomical Union (Costa et.al 1997)

Van Paradjis, Groot, Galama et al. 1997

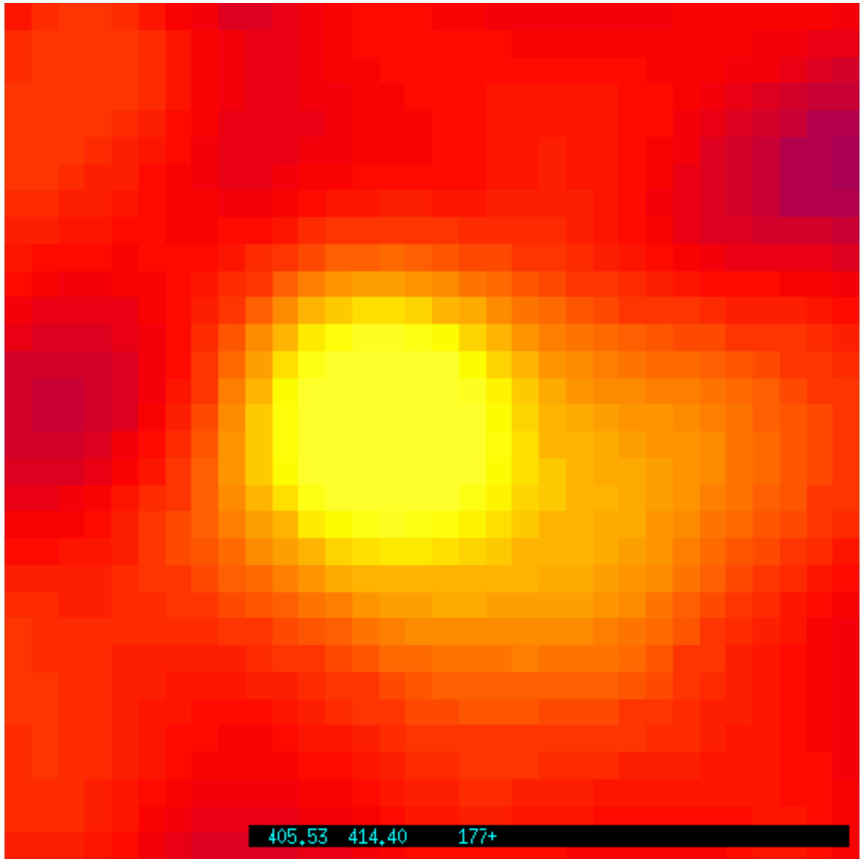
Paul Groot of the team of Ian Van Paradijs was the first to observe twice the field with William Herschel Telescope and to detect the optical afterglow decaying with the same power-law index of X-ray afterglow.



GRB970228 afterglow observation with HST

The AG was observed with HST. A decaying point source was included within a faint nebulosity, possibly a far galaxy (or a SNR?).

A peculiar authorship for an Observatory TOO (everybody but Italians of BepoSAX)



The ladder

SAX – GRBM		**~ 45°**	**(0-)100 m**
SAX – WFC	↓	**5-3 arcmin**	**3h**
SAX – NFI	↓	**1 arcmin**	**8h**
ROSAT	↓	**10 arcsec**	**10 d**
Optical Telescopes		**1 arcsec**	**2-10 d**
	↓		
Hubble		**0.2 arcsec**	**1 month**

- ***Every improved error box is included in the previous and has a transient object.***
- ***All detected transients decay with the same power-law.***

It is the same object

Why was the ladder needed?

A posteriori we know that:

- **Even if GRBs are outstanding, namely stronger than any source (but Solar flares) at 100 keV-1MeV, the instrument s have a coarse angular resolution (≥2°): almost any astrophysical object can be associated!**

- **In the optical band, both the GRB afterglow and its host galaxy are in general quite weak:**
  - **afterglow magnitude of about >20 (most GRB)**
  - **Host galaxy magnitude of 23-25**

- **Thus the association is only possible with very large instruments and arcsecond angular resolution.**

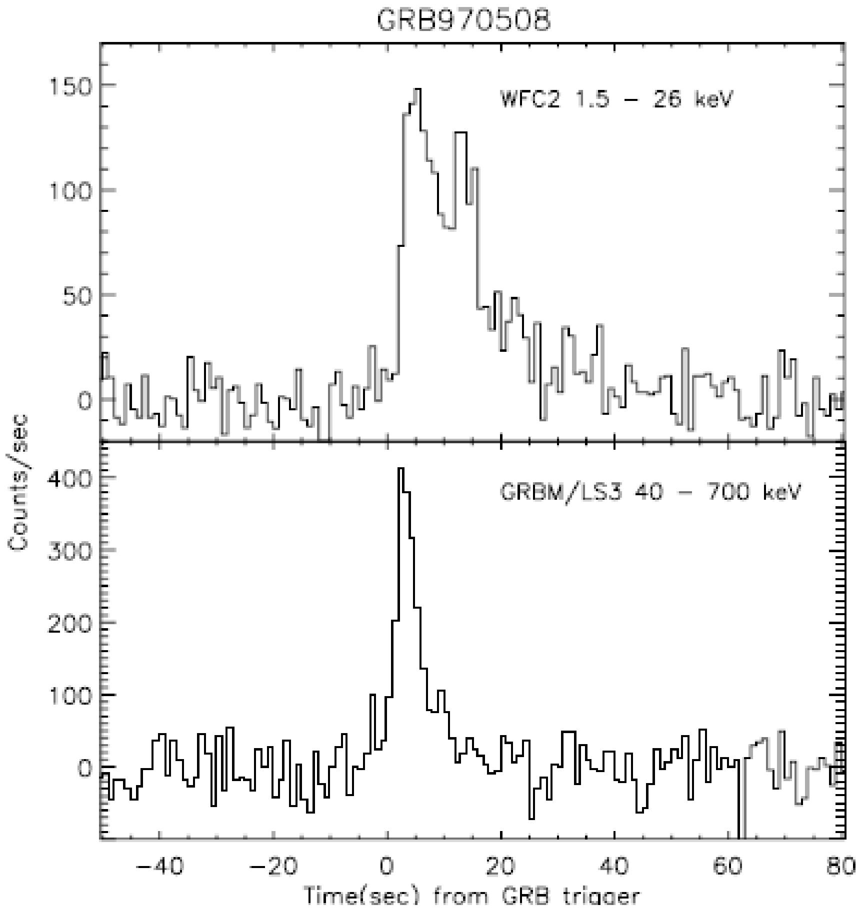
Could any step of the ladder be jumped?

ROSAT was important to convince skeptics but it was switched off after a few weeks.

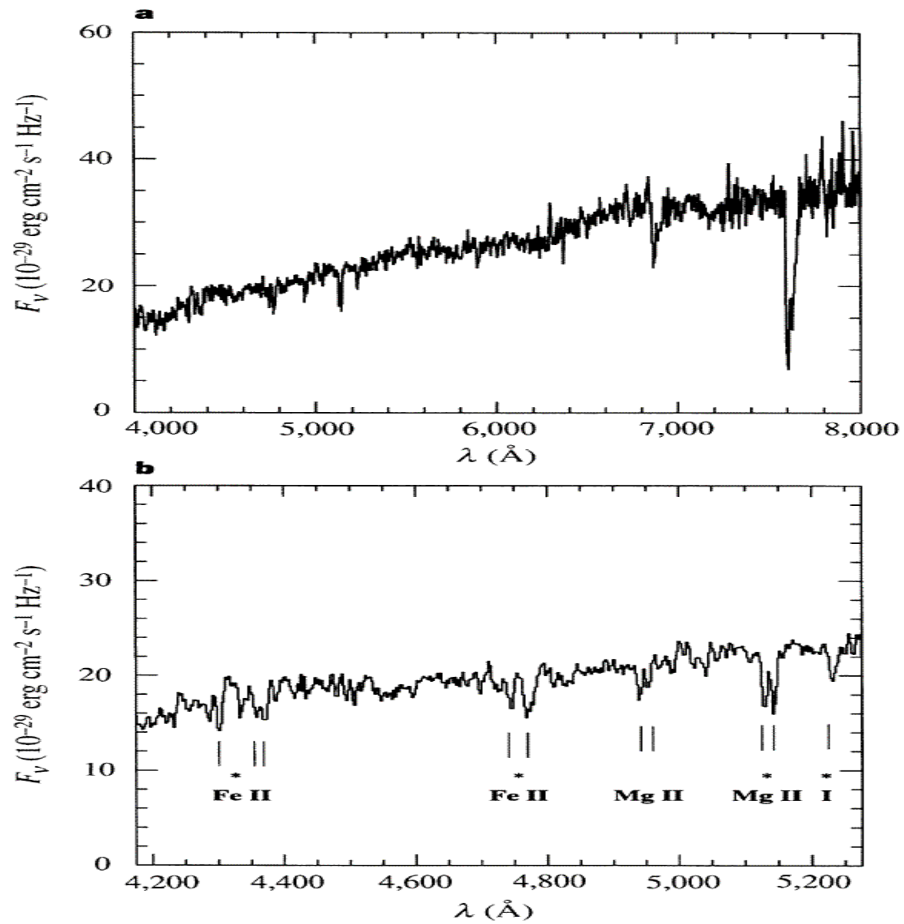
A f.a.q.
Was GRBM really needed? Could WFC only do the work?
Images of WFC were the key. With SAX an image of the sky in one orbit would include tens of fake sources. An image of the sky each 10 – 20 s seconds would not be viable (20 m was the typical analysis time).
Timing of WFC data could be the trigger instead of GRBM.

The GRB is oustanding (brighter than ny steady or transient source) in the GRBM range. In the WFC range they are comparable with strong sources. In the X range GRB970402 was 0.3 Crab. CirX-1 de-occultation (star rise) was brighter than the burst. False triggers from de-occultations of brigt sources or from XRB would be tens at each orbit.

➢First measurement of GRB redshift: GRB970508 **(z = 0.835)**



Metzger et al 1997



Consequences of the redshift measurement

- From the distance we derived the energetics of GRB970508. Assuming isotropy:

$$E_{iso} = (0.61 \pm 0.13) \times 10^{52} \text{ ergs}$$

- On December 14, 1997 the redshift of another BeppoSAX GRB (971214) was determined: $z = 3.42$.

- The corresponding energetics was $E_{iso} = (2.45 \pm .28) \times 10^{53}$ ergs $\rightarrow 0.14\ m_{\odot} \times c^2$

Main results from following missions (HETE-2, SWIFT, AGILE, Fermi)

Short Bursts

Plateau and flares in the early afterglow light curve

High Energy (>50 MeV) emission

Z up to 8.1

$\mathbf{E_{iso} \approx m_{\odot} \times c^2}$

Tighter connection GRB/SN

A tool to test fundamental physics

The collapse

Search for evidence of a double collapse to proof an intermediate state of Quark Gluon Plasma.

Propagation

Search for LIV with delays as a function of the energy and of the distance as evidence of string Quantum Gravity Theories.

Search for LIV with the rotation of the polarization angle as a function of the square of the energy and of the distance as evidence of Loop Quantum Gravity Theories.

Comparison of speed of e.m. radiation with GW.

More Discoveries (after 2010)

AG up to Z ≈ 10
GRB at VHE
Short GRB associated to GW and kilonova
GRB associated to FRB (and SGR)
[no neutrinos]

More Questions

Things still to understand (a lot)

I single out three questions directly deriving from our experience

1. Which is the energy of the AG? No data on the AG above 10 keV (maybe 40keV)

2. Is the HE GRB a part of the prompt or the AG?

3. Is absorption feature in the prompt real?

Questions 1. and 2 have a straigtforward instrumental impact

The Lesson I

Approach to a mission

- Solid experimental groups to test and verify every choice and to control the activity of industry
- Be maniacal with possible problems with the radiation environment
- Do not save on telemetry
- Be ready with software. Be Confucian and include in the Team somebody with experience of previous missions. You cannot image how much software is needed unless you experience it. Start Software ≥3years before the launch not 3 months before. Use as possible public software. Do not start debugging with real mission data. New buga will arrive anyway.
- Do not save on the ground segment: 24 hours is ≥ 3 shifts. Quick science is done by people who unfortunately pretends to be payed

The lesson II

Sociology of science

- Difficult things can be done: think big
- Each Community has a wealth of experience: Recombine Communities.
- Complications give opportunities: resist to pressure for simplifications. But do not do things that you will not have time to test.
- Every experiment, even producing breakthrough data, is only giving a piece of the puzzle. Think in advance to a network. Define in detail data right before the observation.
- A science revolution is accompanied by a certain level of change of personality and newcomers arrive. Do not be too Confucian!

The lesson III

Approach to Science

- A complex phenomenology can hide very different things: the difference from one burst to the other was also hiding a crowd of other transient families
- The Occam razor is not for every beard: sometime the most exotic hypothesis is the true one
- Even if you will be always asked to focus on the core science fight to preserve discovery space

Which New Experiments

High Z

THESEUS ....

Energetics

Extend the measurement of the AG to higher energies with MultiLayer Optics (such as a NHXM with fast pointing) or possibly with Laue Lenses

Polarimetry

Two phase polarimeters (scatterer + total absorber)

High Energy: Compton Telescopes

Low Energy: Photoelectric