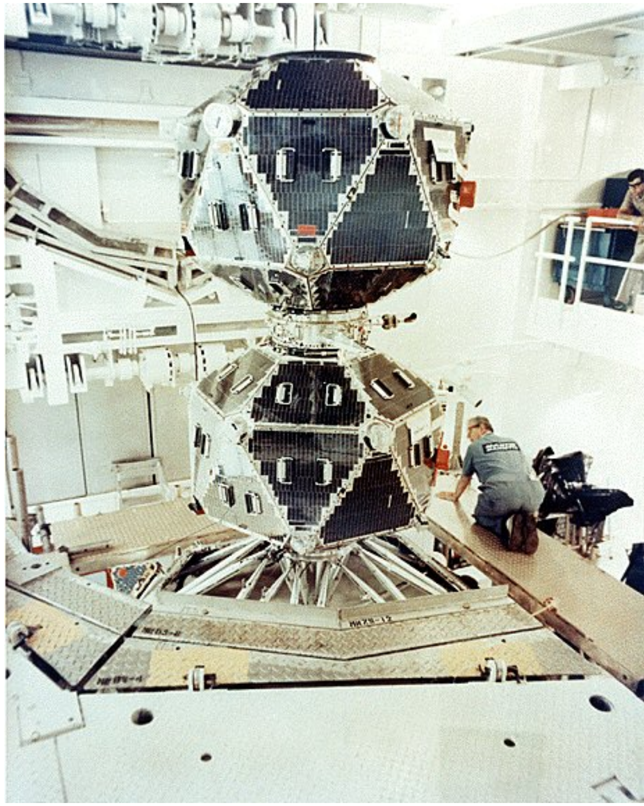
Gamma-Ray Bursts

- Detectors for 20 keV to 10 MeV
- Discovery
- The early years
- BATSE
- Fast versus slow bursts
- Uniformity and log N – log S relation
- BeppoSAX and discovery of afterglows
- Redshift measurements

Discovery

Vela 5 a/b (launched in 1969) and Vela 6 a/b were each pairs on opposite sides of a circular orbit 250,000 kilometers in diameter. Gamma-ray detector 60 cm^3 of CsI. Events could be timed to an accuracy ~ 0.2 s, sometimes as good as 0.05 s.



The direction angle to the event with respect to the line between a pair of satellites could thus be determined to about 1/5th of a radian based on the difference in trigger times for the two satellites.

In 1973, Klebesadel, Strong, and Olsen published a paper describing 16 cosmic gamma-ray bursts observed in 1969-72.

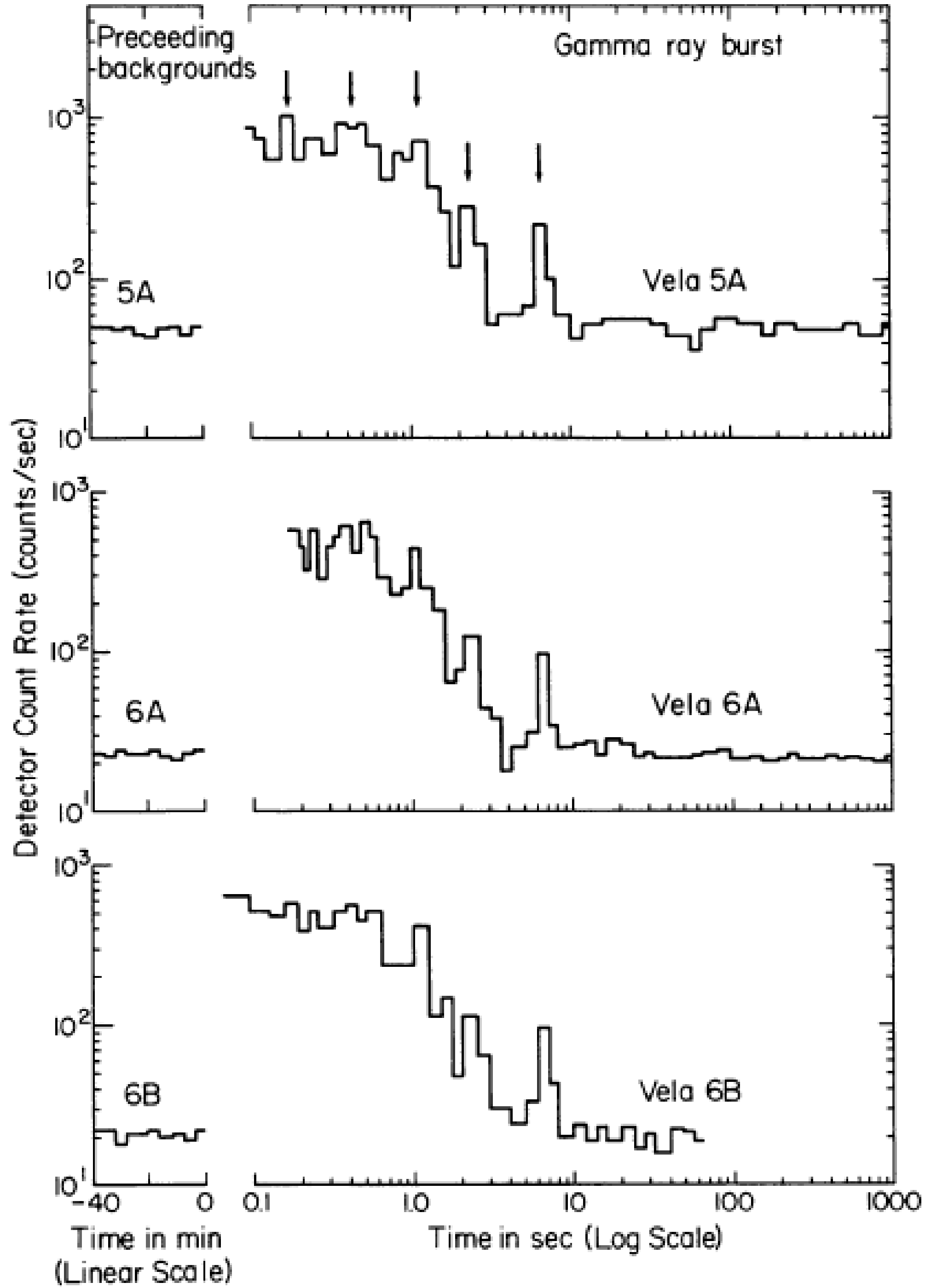
Discovery

1970 August 22 burst from Klebesadel et al. (1973).

Burst durations ranged from 0.1 s to 30 s.

Burst fluences ranged from 10^{-5} erg cm^{-2} to 2×10^{-3} erg cm^{-2}.

Peak of spectrum above 10 keV maybe up to 10 MeV.



Interpretation of Early Bursts

Main question was Galactic or extra-Galactic.

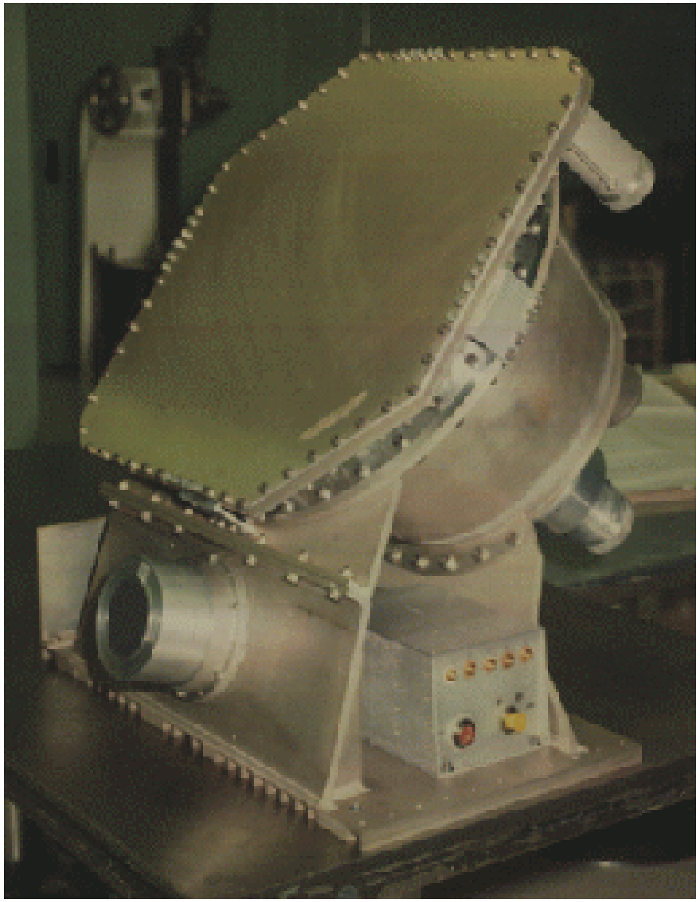
Galactic: distance ~ 10 kpc, total energy ~ $10^{41} - 10^{43}$ erg

Extragalactic: distance ~ 10 Mpc, total energy ~ $10^{47} - 10^{49}$ erg

BATSE

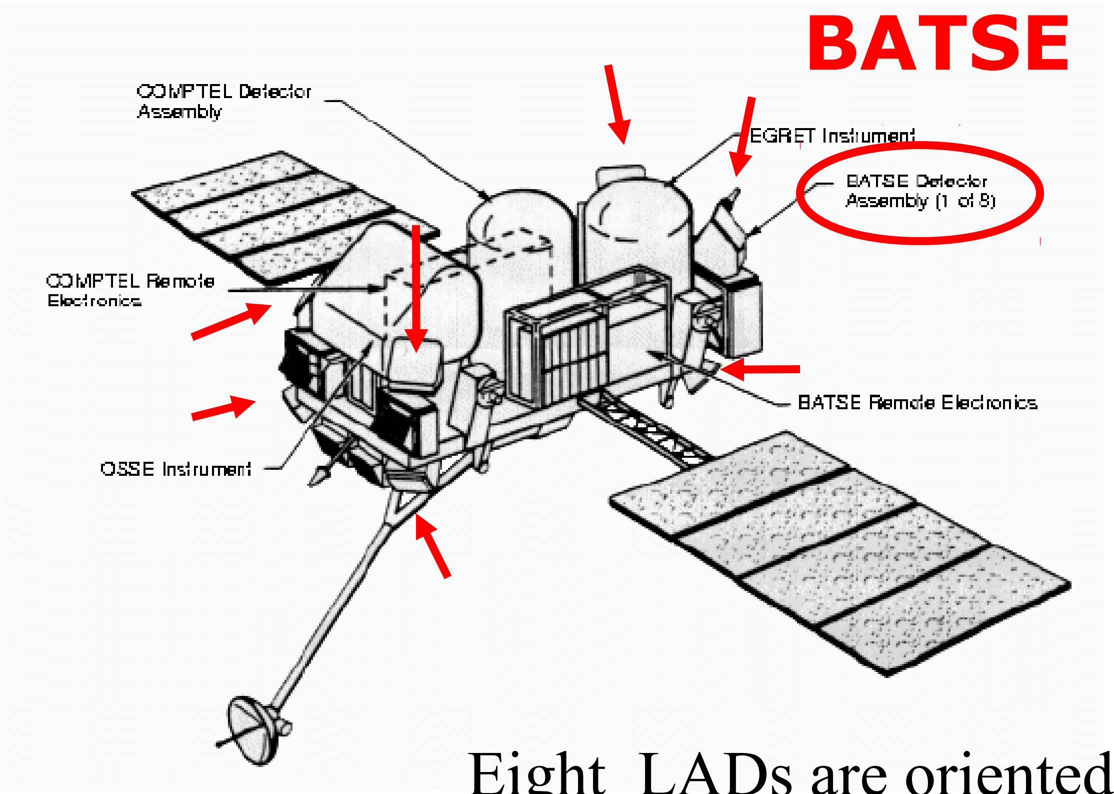
Large Area Detector - disk of NaI scintillation crystal 20 inches in diameter and 0.5 inch thick read out with three 5-inch photomultiplier tubes. Quarter-inch plastic scintillation detector in front of the LAD for anticoincidence. Sensitive from 25 keV to 2 MeV.

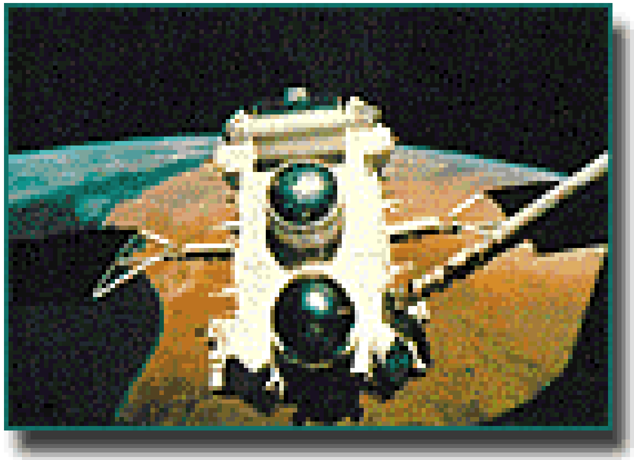
Spectroscopy Detector - NaI(Tl) 5 inches in diameter and 3 inches thick. Single 5 inch PMT.



BATSE

BATSE on CGRO





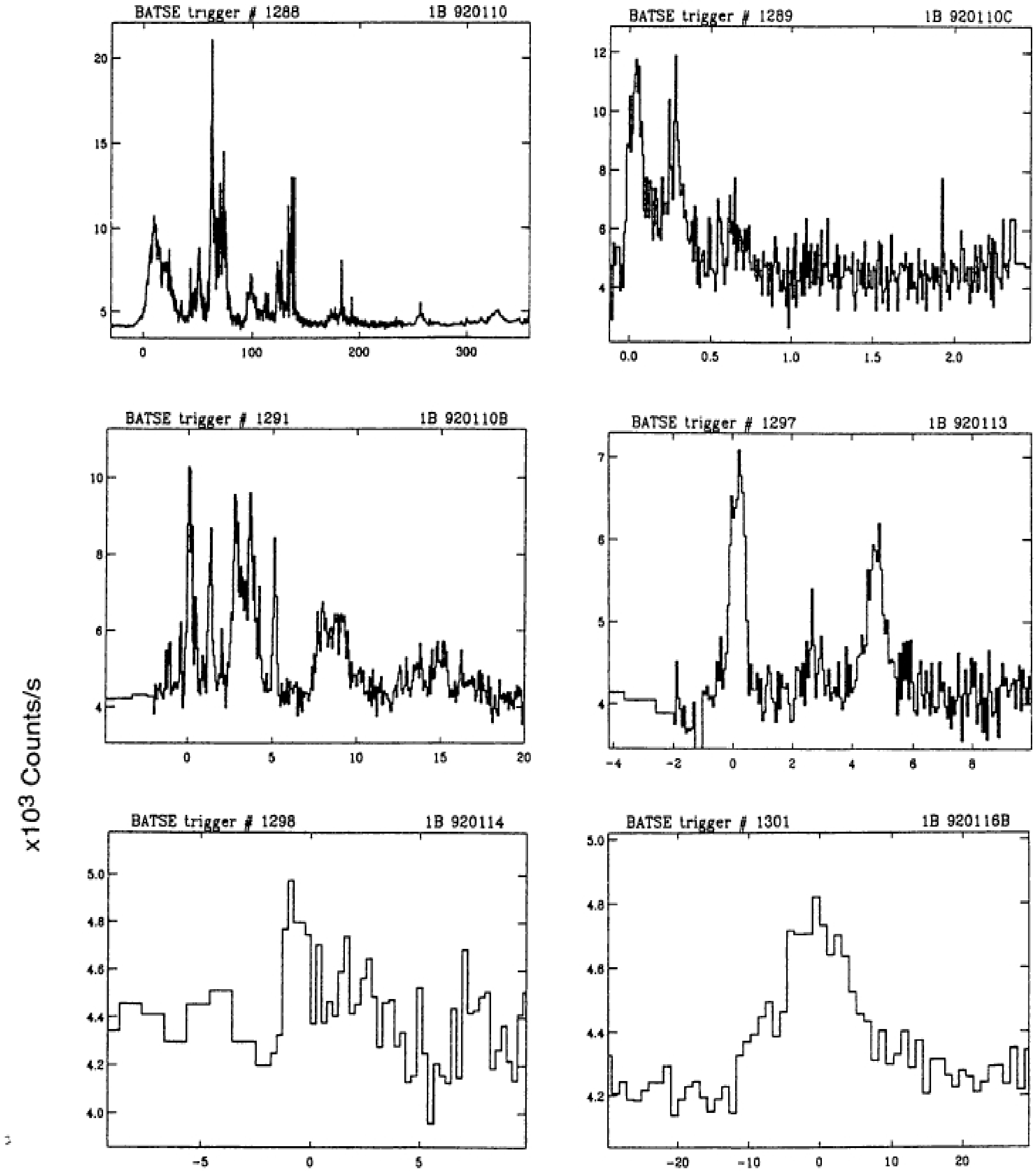
Eight LADs are oriented like the eight faces of an octahedron. Position of burst determined by relative counts in different detectors.

BATSE Bursts

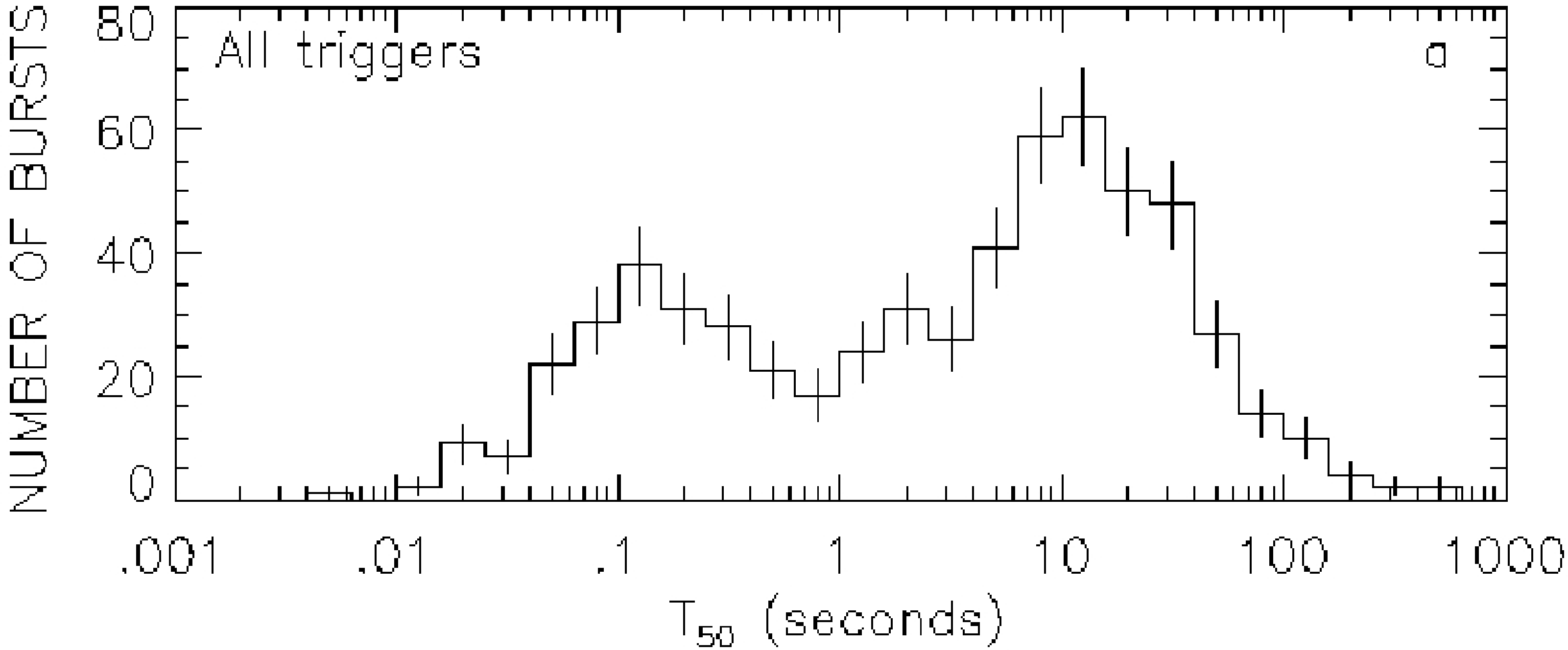
BATSE operated for 9 years and detected 2704 bursts.

Huge variety of GRBs varying on time scales from 10^{-3} to 10^{3} seconds.

Bright bursts were localized to an accuracy of 2° dim ones to 10°. This prevented identifying X-ray or optical counterparts.



Long vs Short GRBs



Characterize burst durations by T_{50} and T_{90}. These are the minimum time intervals in which 50% or 90% of the burst fluence is contained.

GRB Spectra

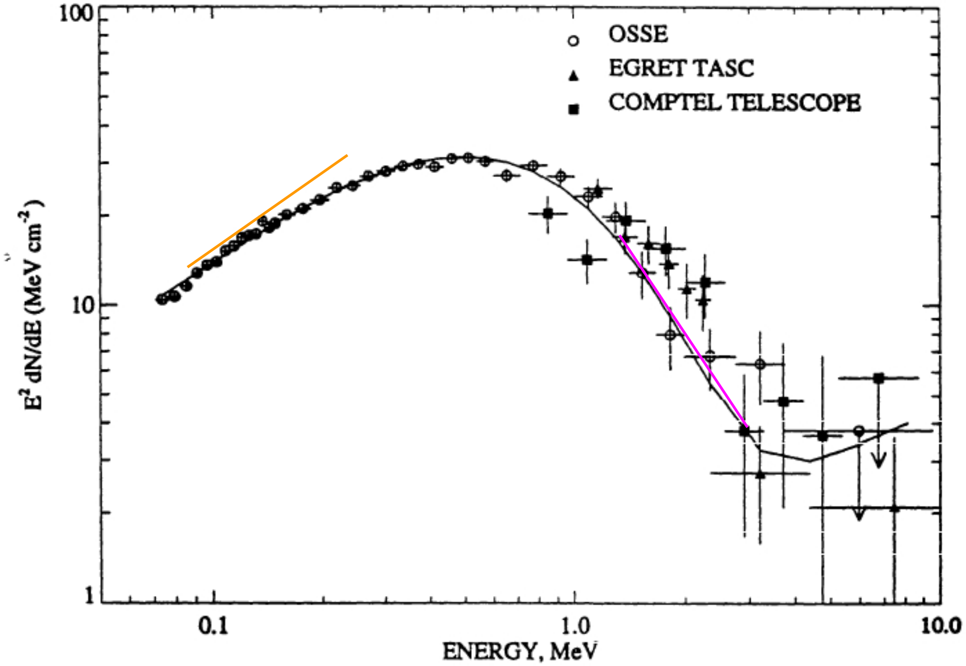
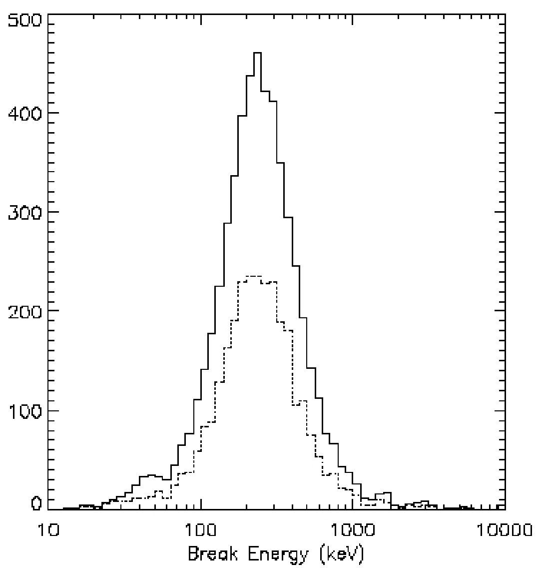


Figure 9 The spectrum of GB 910601 observed over a wide energy range, as measured by three experiments on *CGRO* (Share et al 1994). A typical broad spectrum with a peak power at about 600 keV is seen. (The fitted spectral up-turn above 4 MeV is not significant.)



PREECE ET AL.

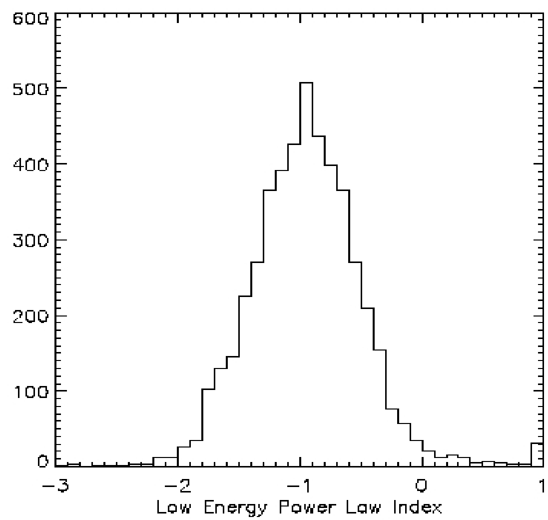
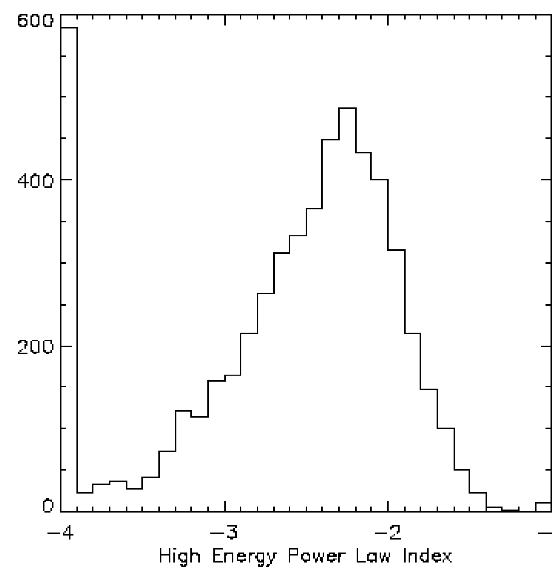
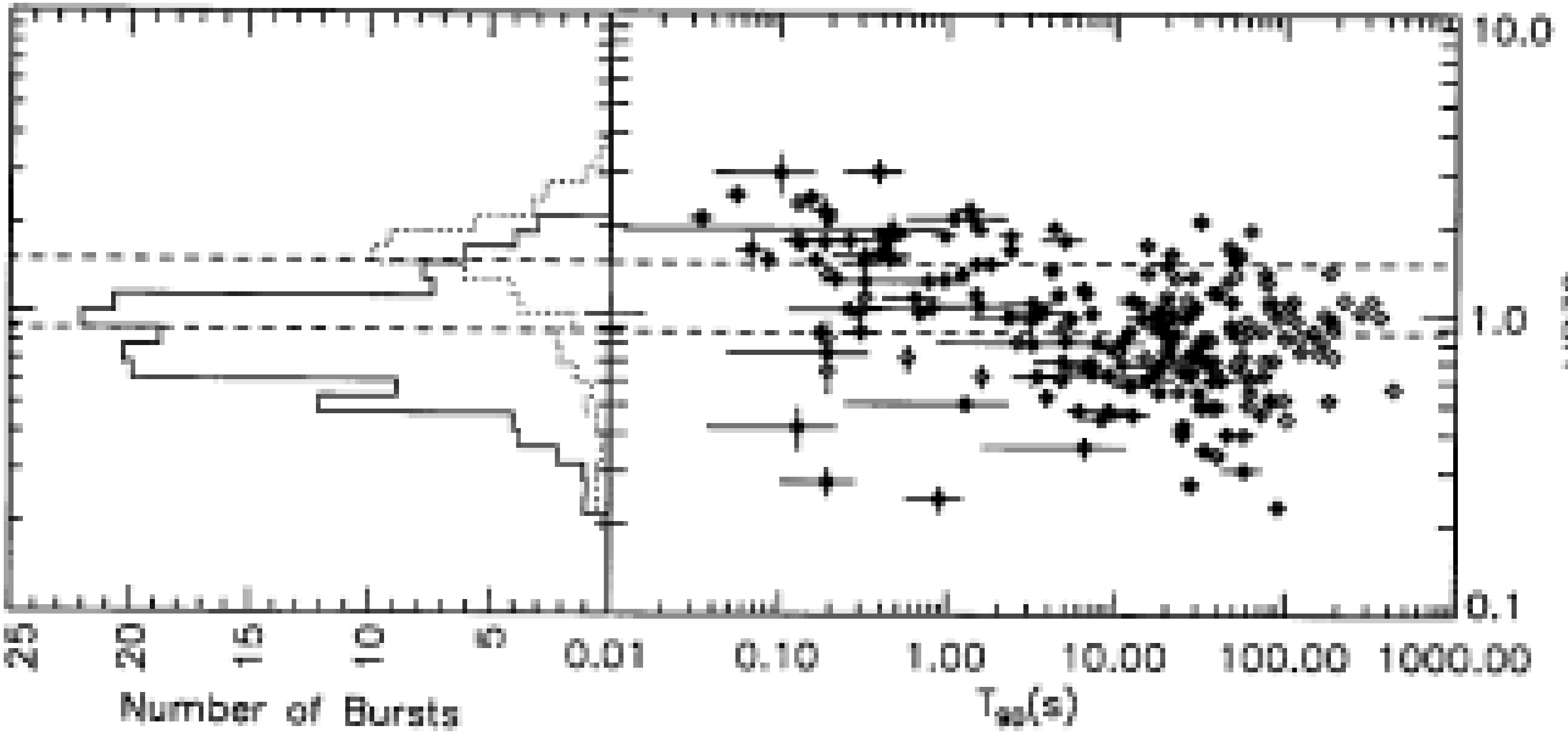


FIG. 7.—Low-energy power-law index distribution for the entire sample

BATSE SPECTROSCOPY CATALOG

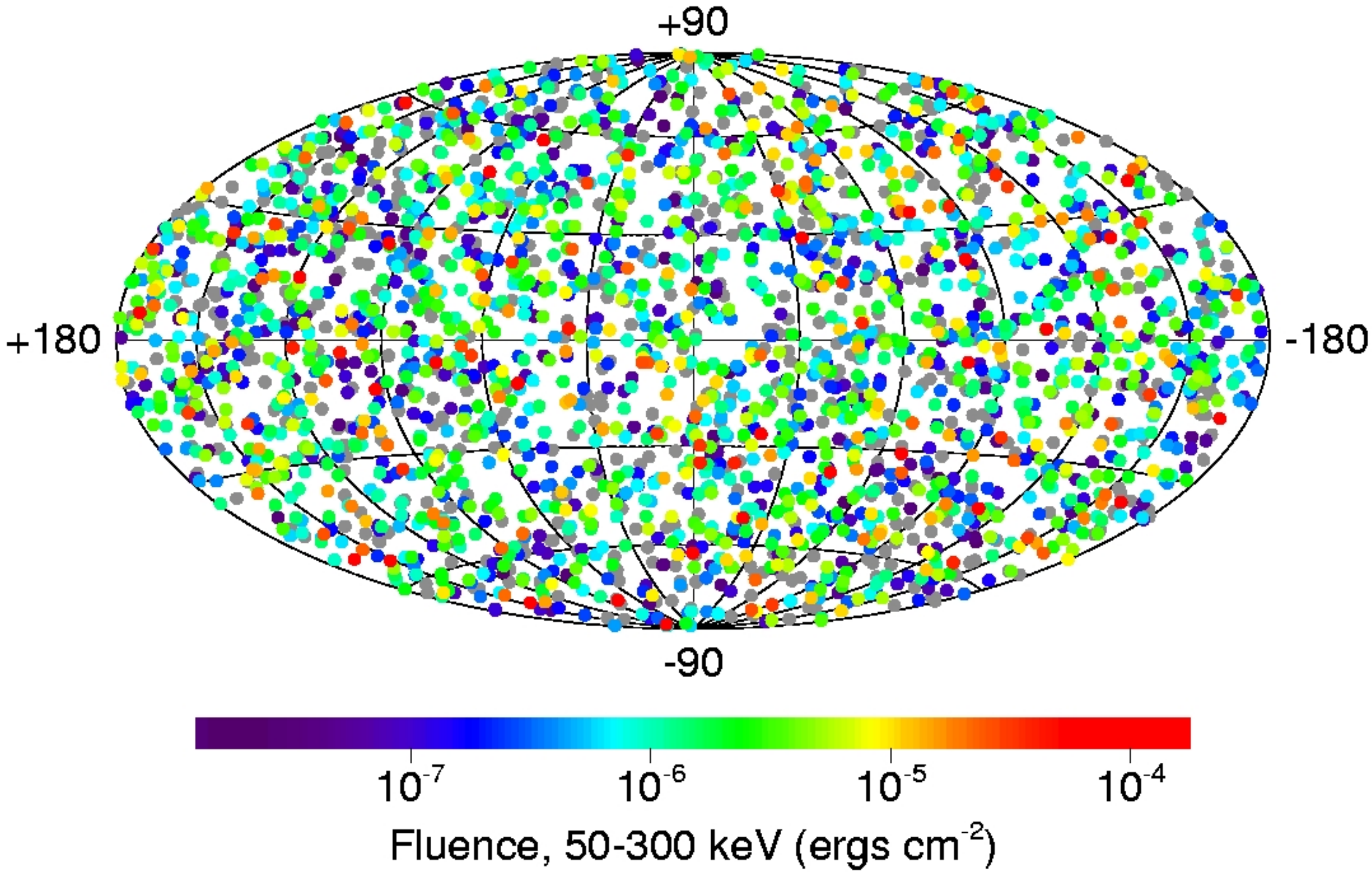


Long vs Short GRBs



HR32 is ratio of counts in 100-300 keV band versus counts in 50-100 keV band. Short bursts appear to be harder than long ones.

2704 BATSE Gamma-Ray Bursts



First 153 bursts: $\langle\cos\theta\rangle = -0.002 \pm 0.006$, $\langle\sin^2 b\rangle = 0.310 \pm 0.006$

For isotropic: $\langle\cos\theta\rangle = 0.0$, $\langle\sin^2 b\rangle = 0.333$

Flux distribution

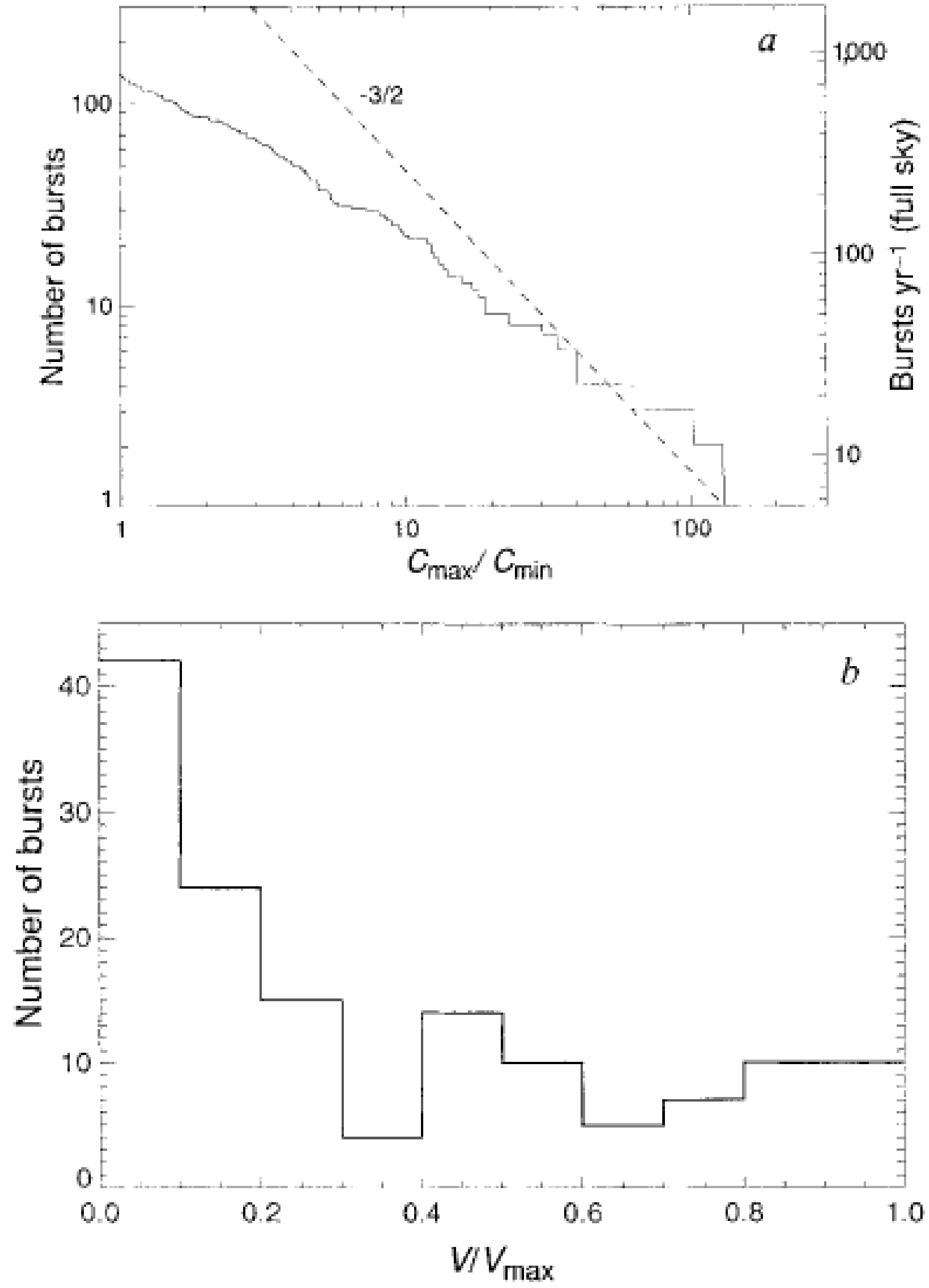
C_{max} is burst maximum count rate, C_{min} is trigger threshold.

$V/V_{max} = (C_{max}/C_{min})^{-3/2}$

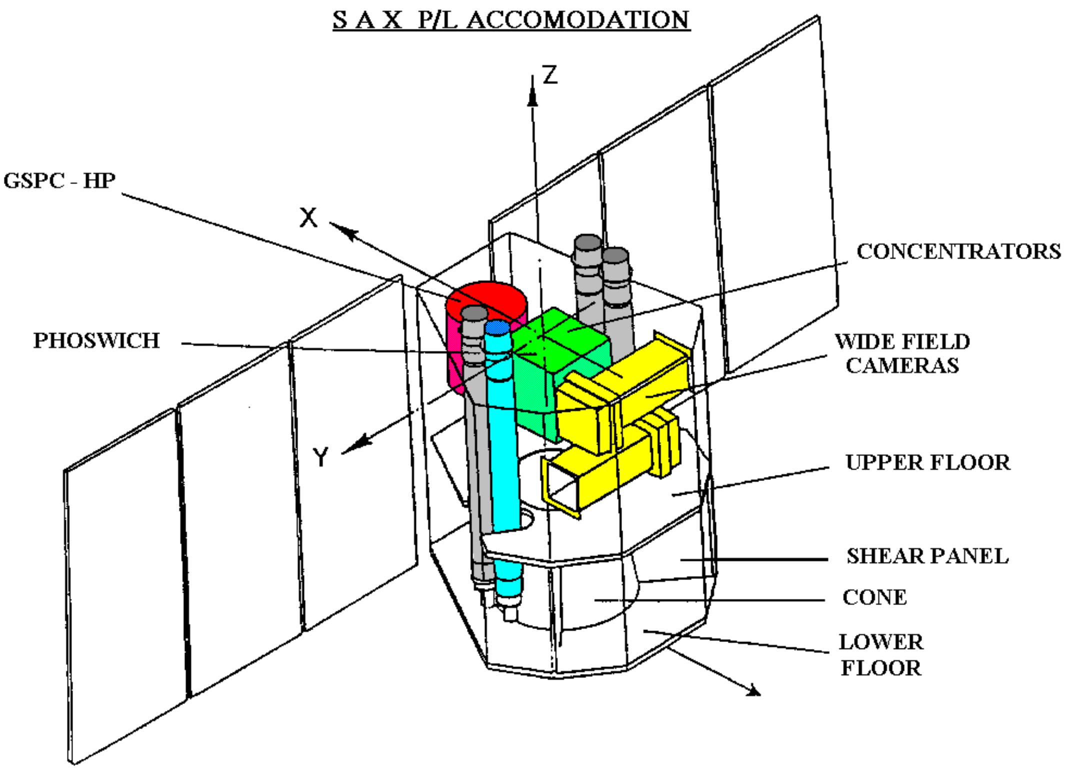
For homogeneous distribution, expect $\log(N>S)$ vs $\log(S)$ to follow –3/2 power law and $\langle V/V_{max} \rangle = 0.5$.

Find $\langle V/V_{max} \rangle = 0.35 \pm 0.02$ and deviations from -3/2 power law.

Conclude GRBs are isotropic, but not homogeneous.



BeppoSAX



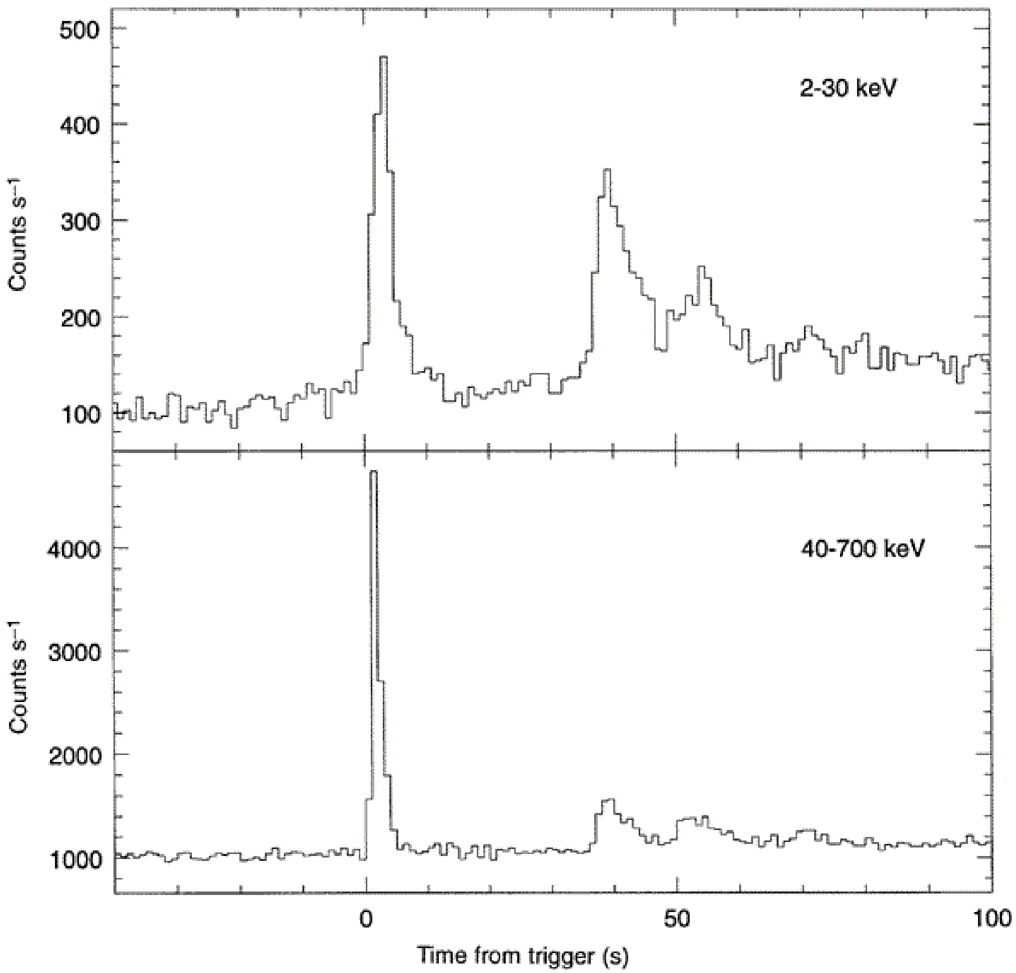
Italian-Dutch X-ray astronomy satellite.

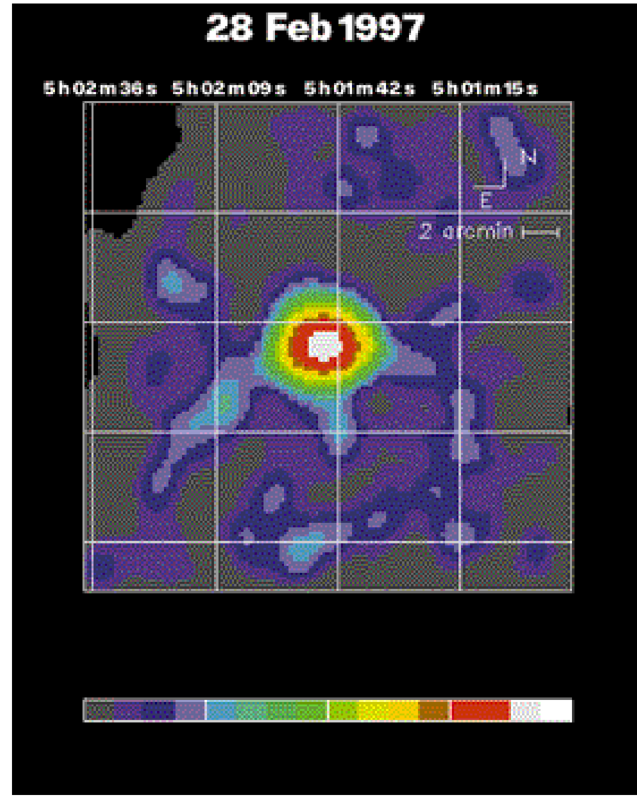
Launched 1996.

Carried several X-ray instruments.

For GRBs, the critical instrument turned out to be the Wide Field Cameras: Proportional counters with effective area of 140 cm^2 and a coded aperture mask covering 2-30 keV with a field of view 20° × 20°.

First BeppoSAX WFC Burst



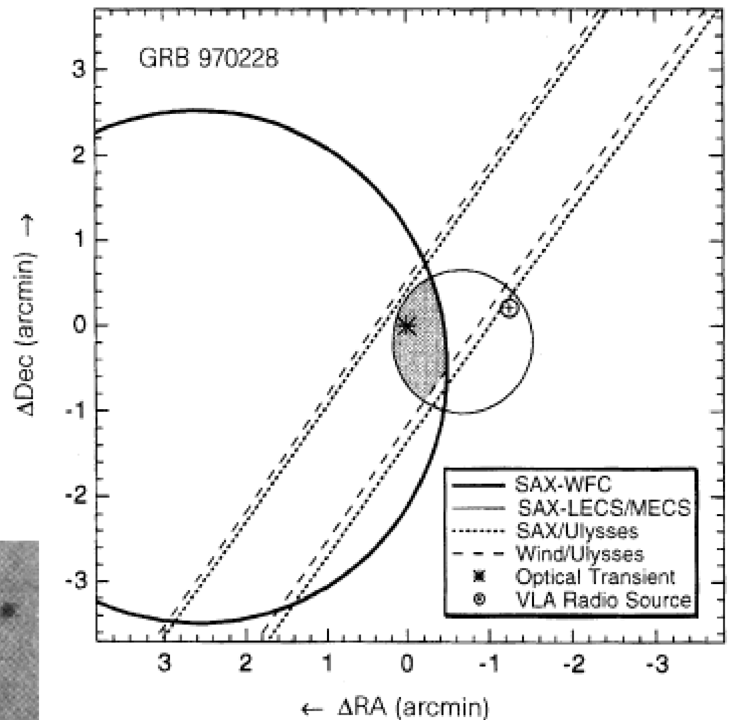


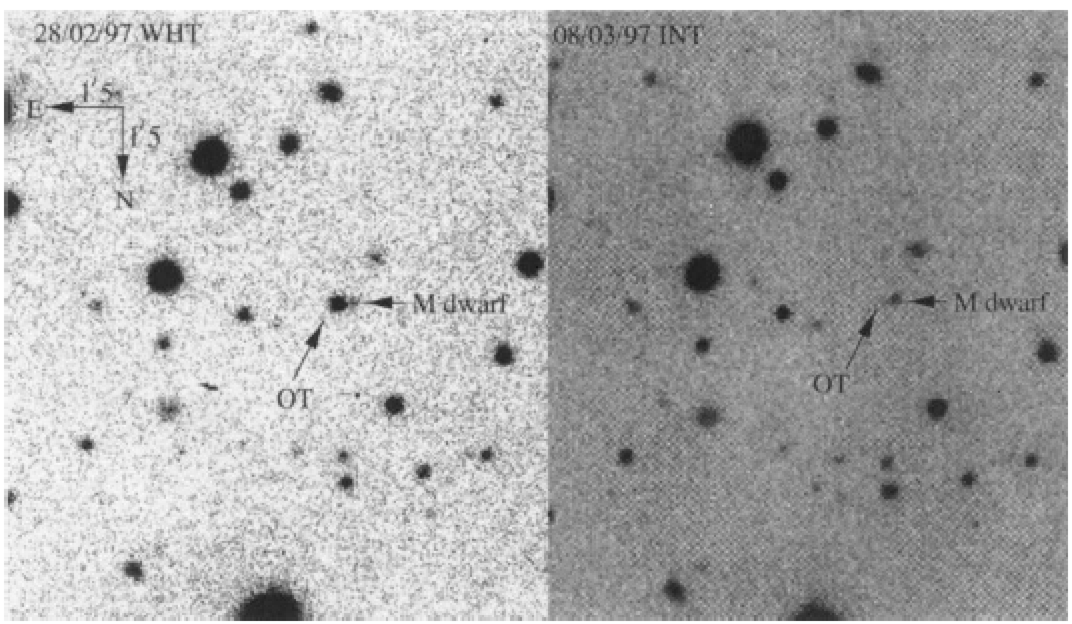
WFC light curve (top), GRB monitor light curve (bottom), narrow field instrument image (right) from Costa et al. 1997.

First GRB Optical Counterpart

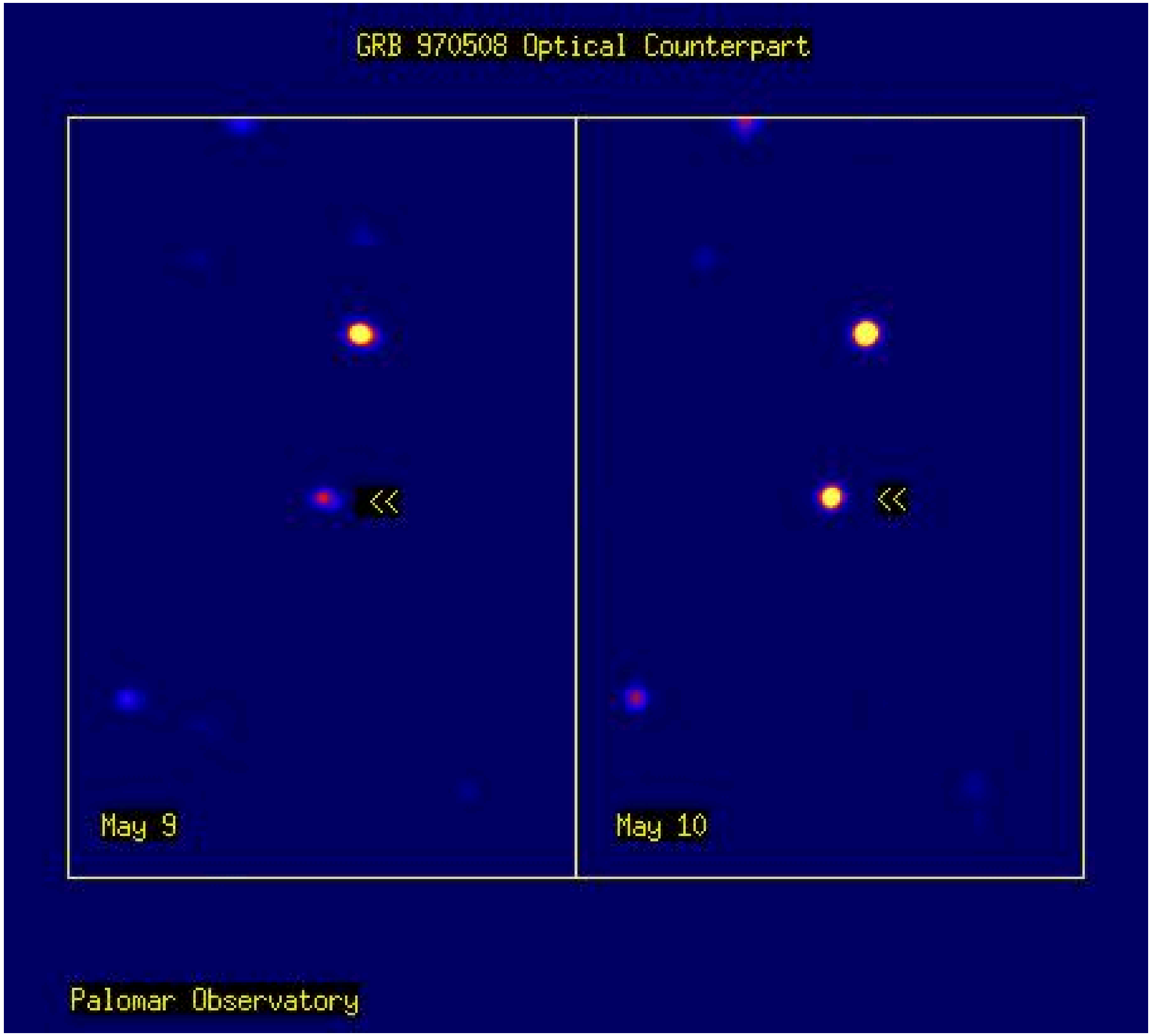
Found decaying optical source inside BeppoSAX NFI error circle.

Found to lie near a faint and distant galaxy.



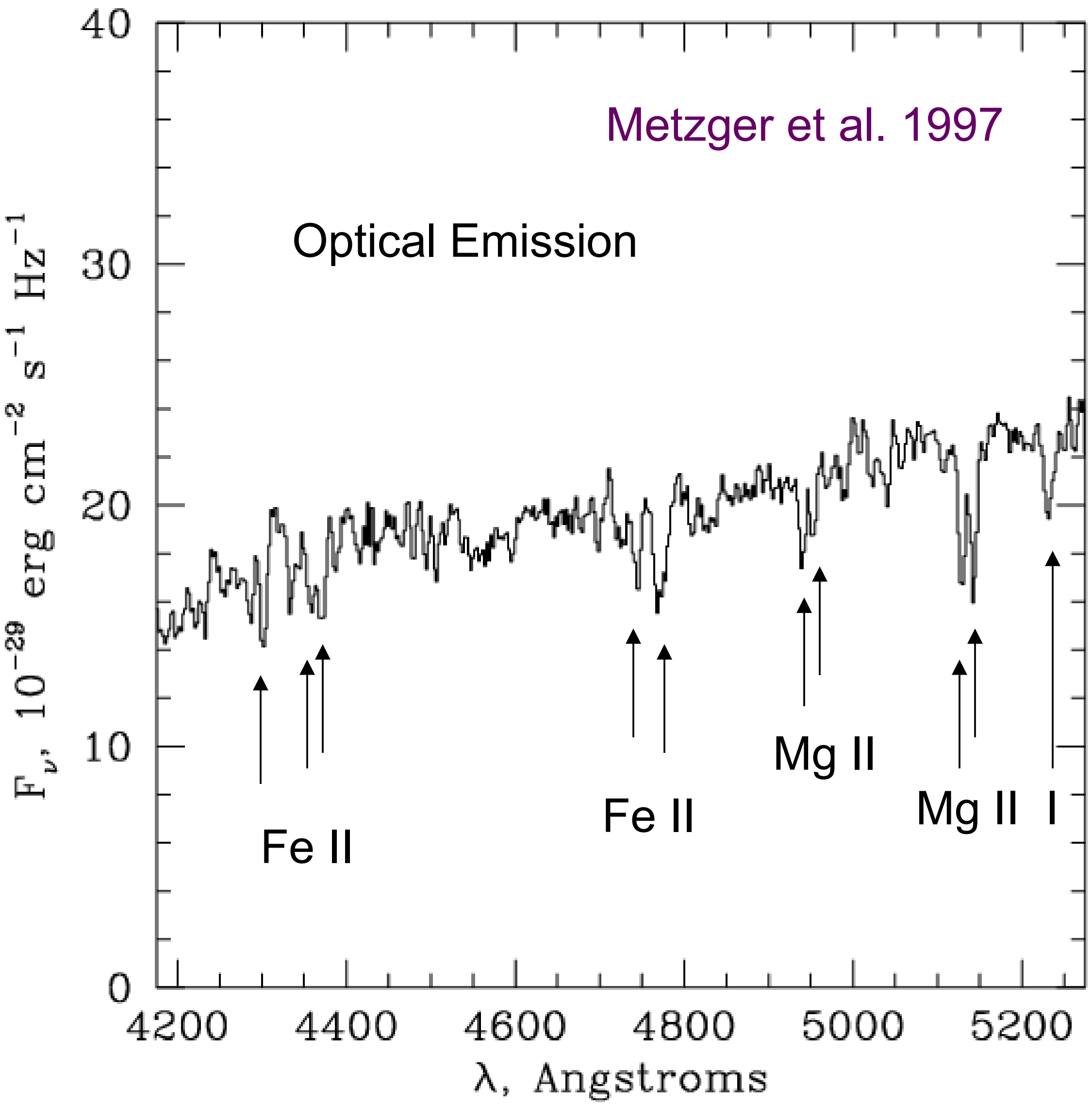


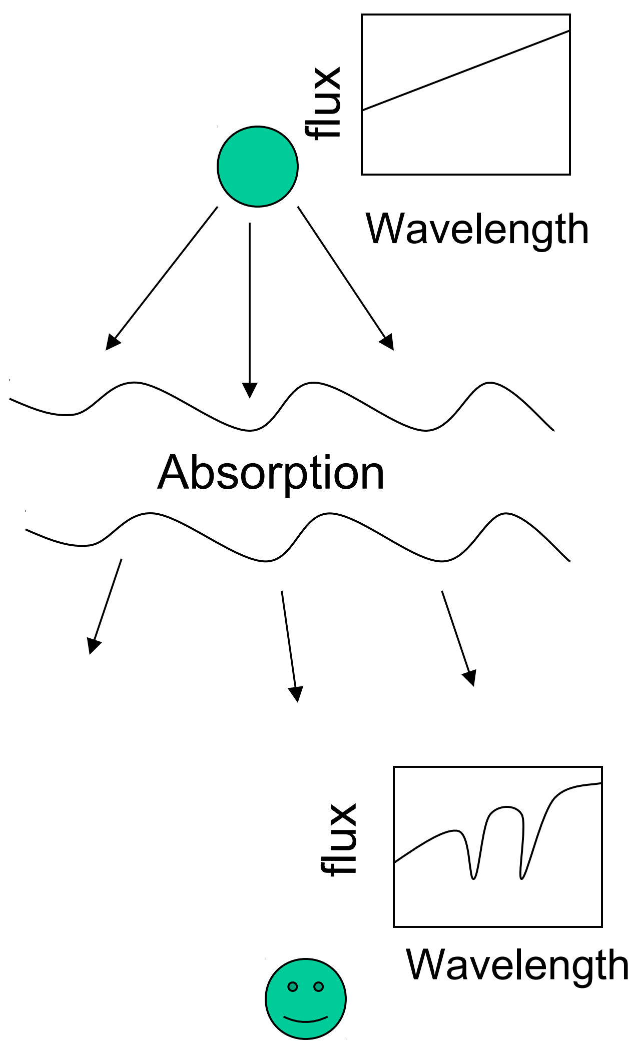
GRB 970508 – Optical Counterpart



BeppoSAX X-ray localization enabled detection of an optical transient.
It was then possible to obtain an optical spectrum.

GRB970508 – Absorption Lines: z=0.835





Host Galaxy Detected for GRB970508

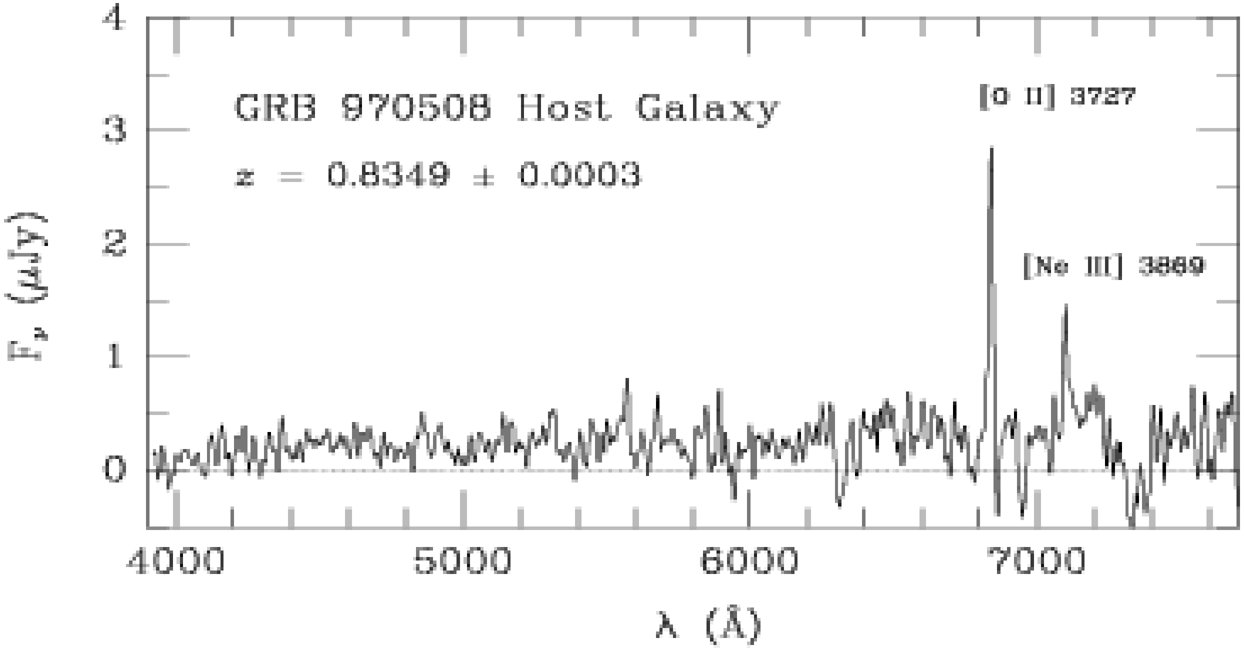


FIG. 2.— The weighted average spectrum of the host galaxy of GRB 970508, obtained at the Keck telescope. The spectra were smoothed with a Gaussian with a $\sigma = 5$ Å, roughly corresponding to the instrumental resolution. Prominent emission lines are labeled.

Peak Photon Fluxes and Isotropic Luminosities for GRBs with Secure Redshifts

GRB	Redshift	P (photons cm^{-2} s^{-1})[a]	L_p (photons s^{-1})[b]	Redshift Reference
970228	0.695	3.5	5.1×10^{57}	1
970508	0.835	1.2	2.5×10^{57}	2, 3
971214	3.418	2.3	6.4×10^{58}	4
980613	1.096	0.63	2.3×10^{57}	5
980703	0.967	2.6	7.4×10^{57}	6
990123	1.600	16.4	1.2×10^{59}	7
990510	1.619	8.16	6.2×10^{58}	8
990712[c]	0.430	...	...	9

Redshifts either measured for host galaxy after burst, or from absorption lines in optical after glow of the burst itself.

Clearly most bursts are at cosmological distances.

In BeppoSAX era, all bursts with afterglows and optical counterparts were long bursts.

Long-duration GRBs are cosmological