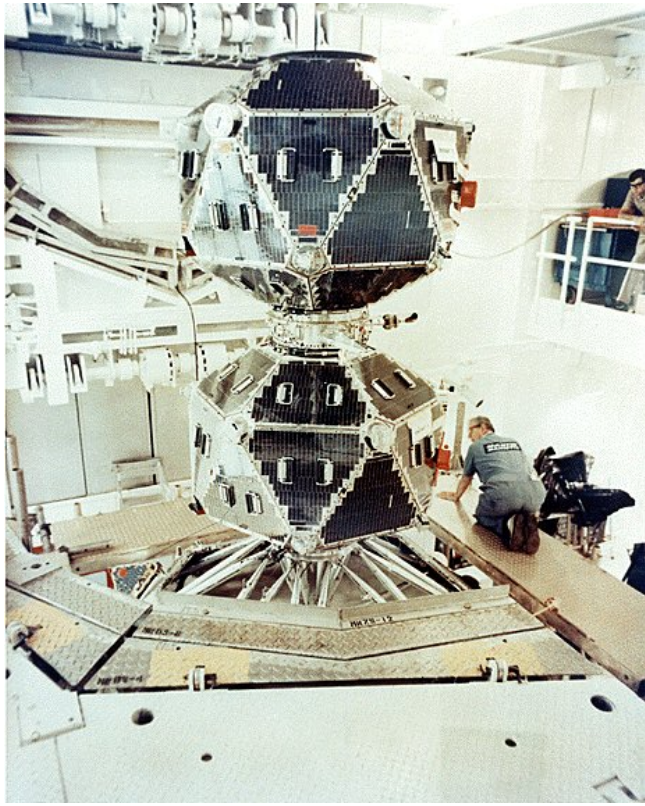
Gamma-Ray Bursts

- Discovery
- The early years
- BATSE
- Fast versus slow bursts
- Uniformity and log N – log S relation
- BeppoSAX and discovery of afterglows
- Redshift measurements
- Connection of long GRBs to supernovae

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.

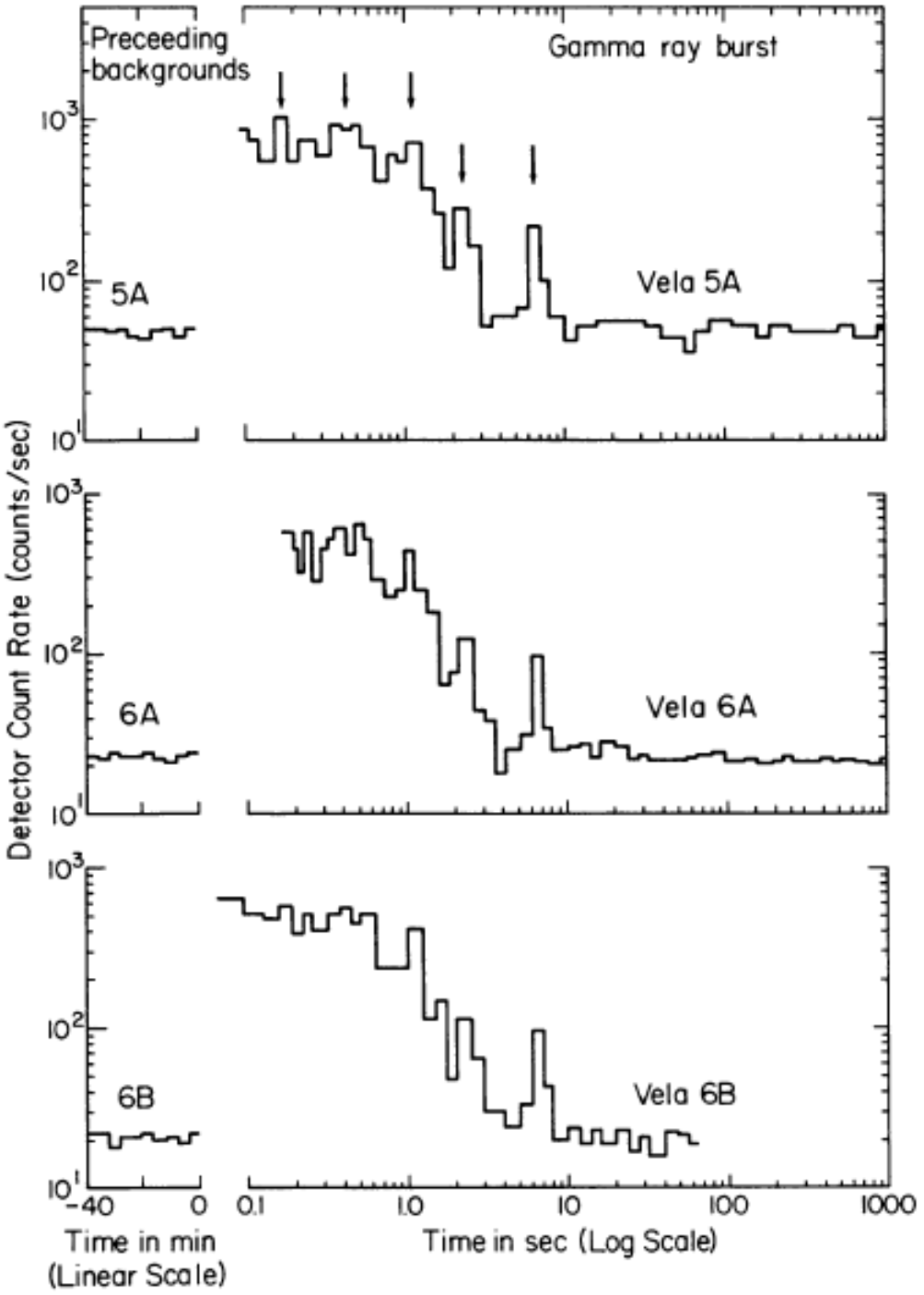
Discovery

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

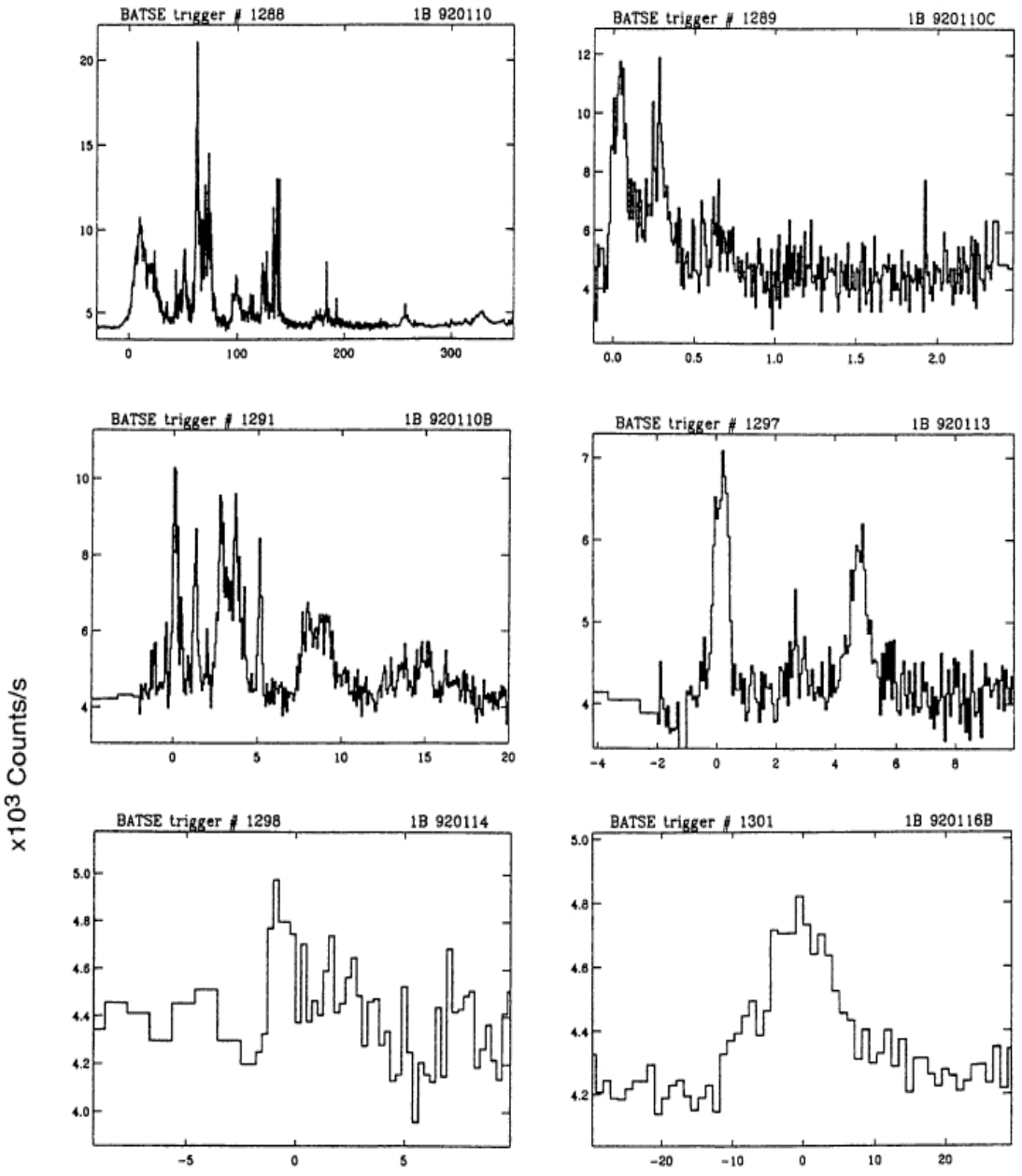
Extragalactic: distance ~ 10 Mpc, total energy ~ 10^{47} – 10^{49} erg

BATSE Bursts

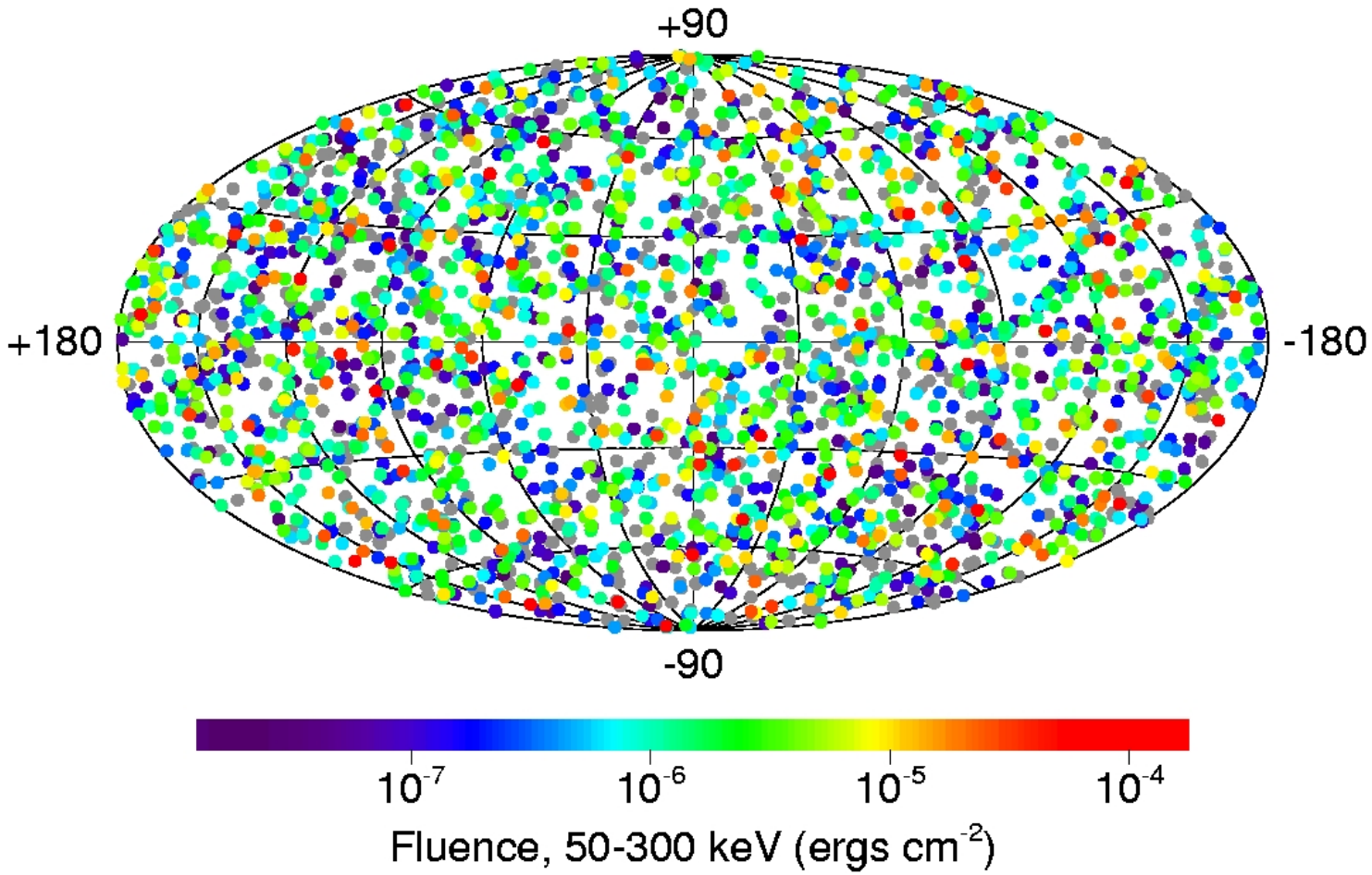
BATSE operated for 9 years and detected 2704 bursts.

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.



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

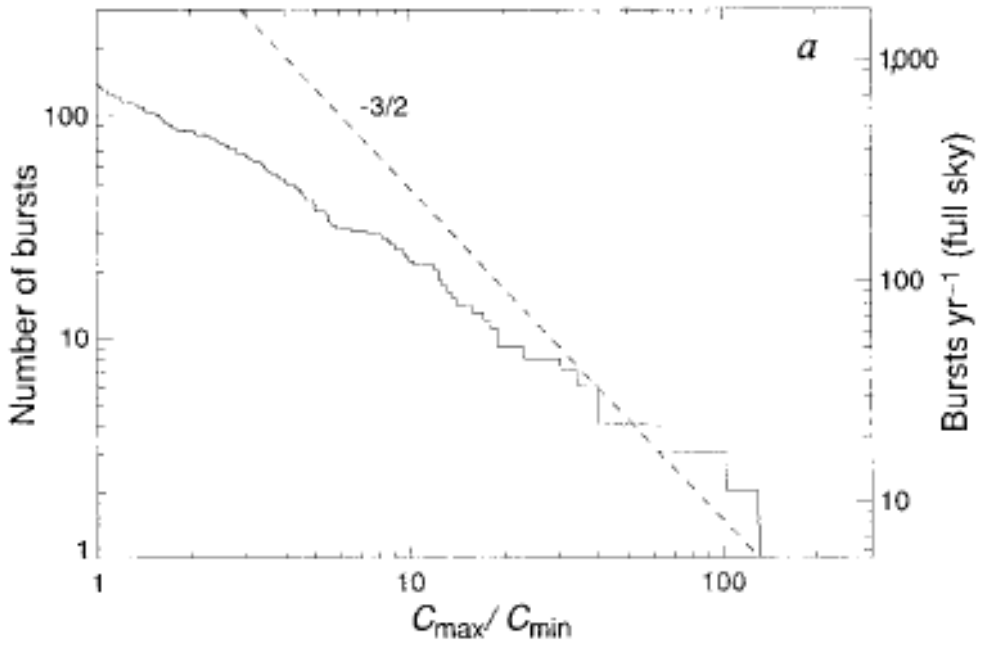
C_{max} is burst maximum count rate, C_{min} is trigger threshold.

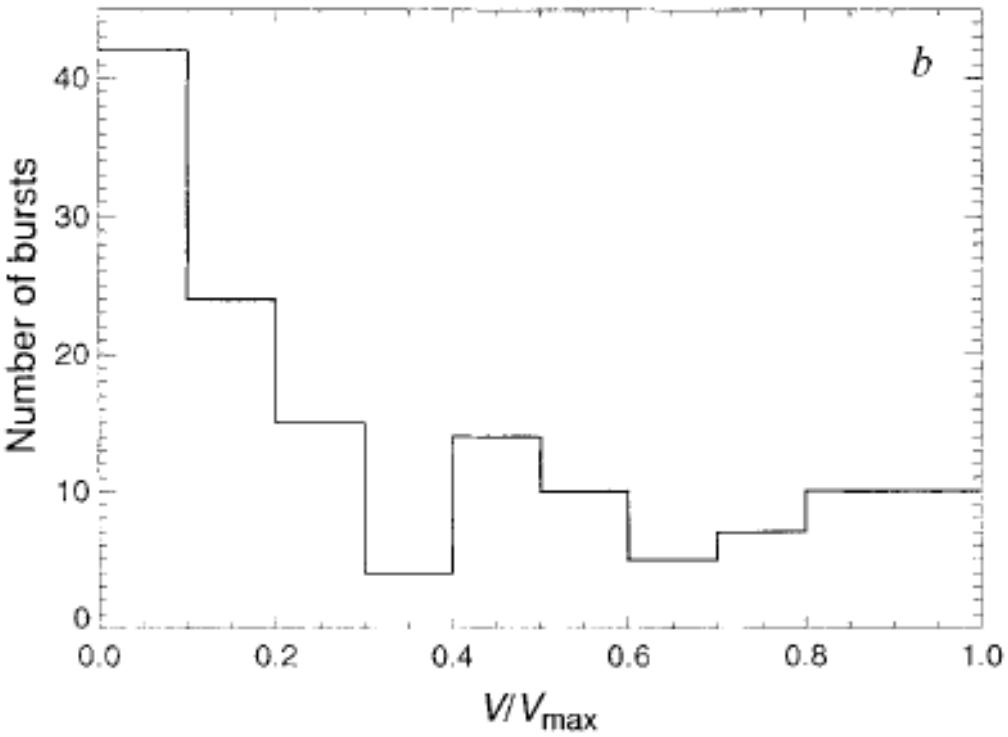
$V/V_{max} = (C_{max}/C_{min})^{-3/2}$

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

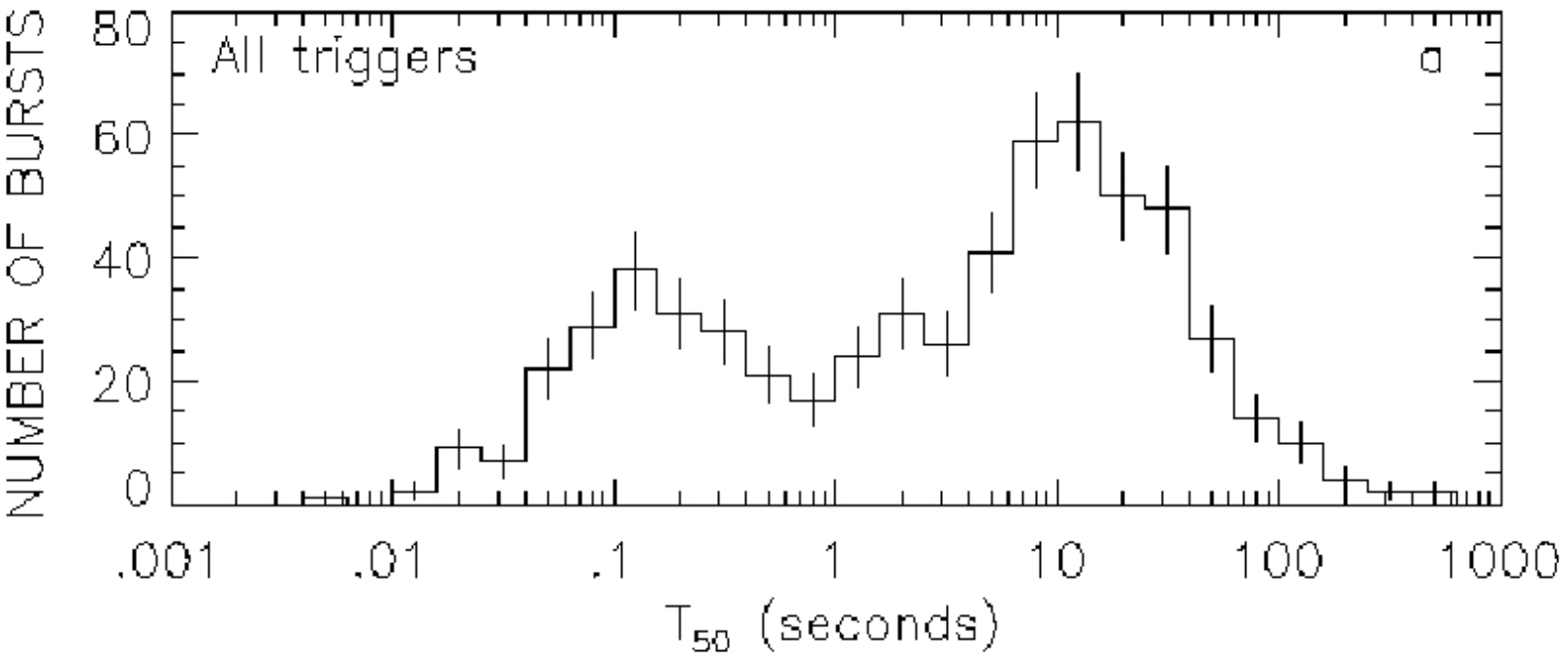
Find $\langle V/V_{max} \rangle = 0.35 \pm 0.02$ and deviations from -3/2 power law.

Conclude GRBs are isotropic, but not homogeneous.



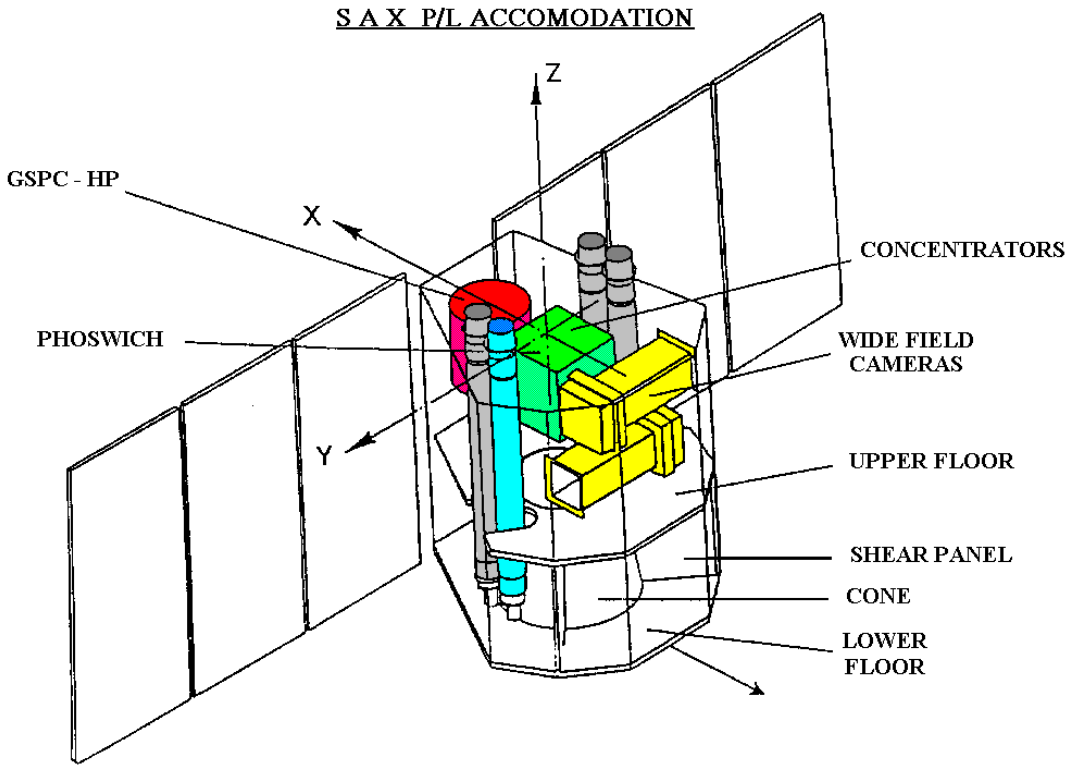


Long vs Short GRBs



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.

BeppoSAX



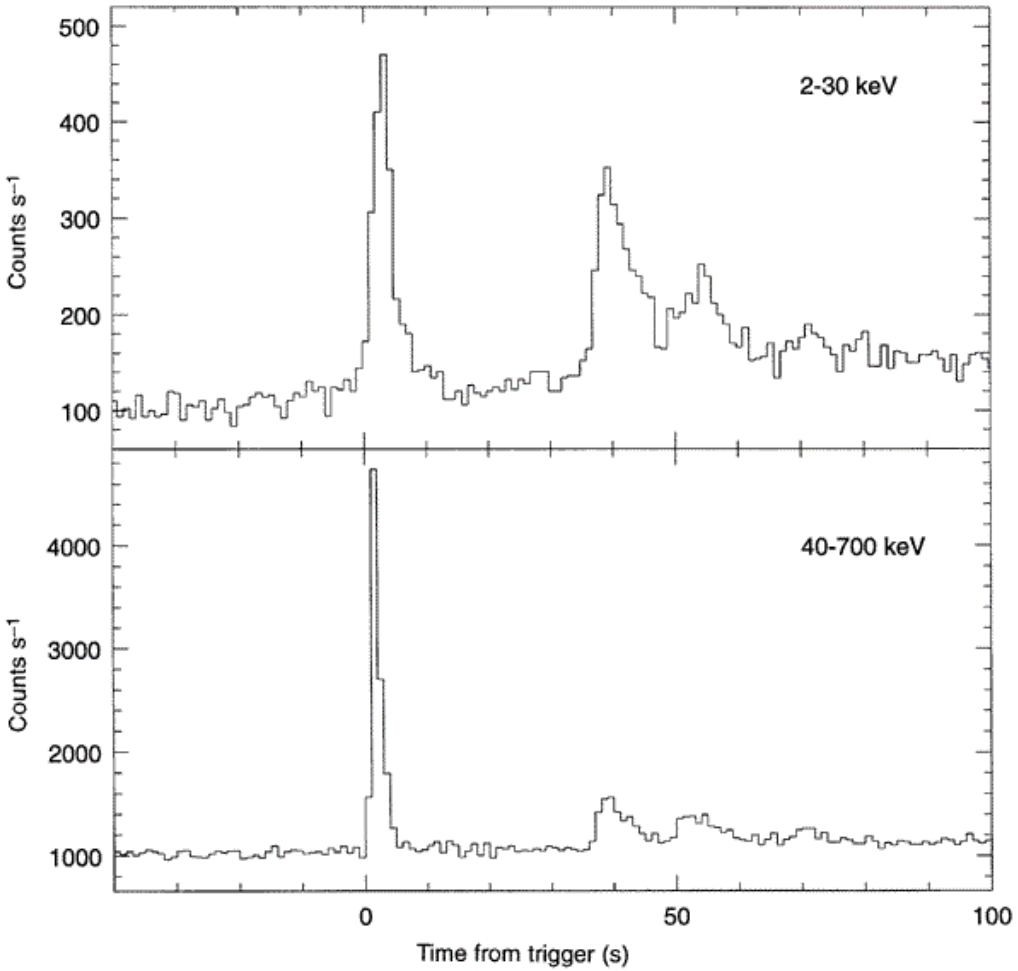
Italian-Dutch X-ray astronomy satellite.

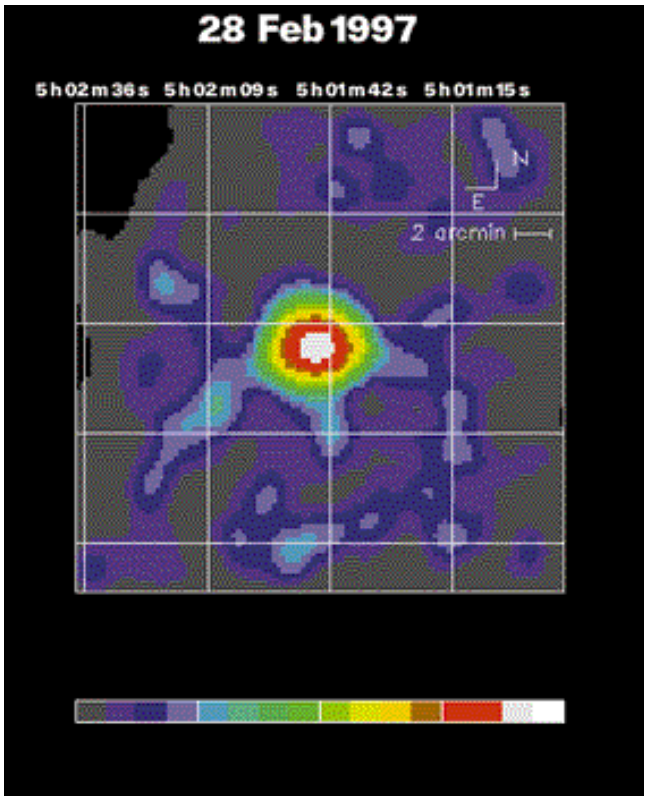
Launched 1996.

Carried several X-ray instruments.

For GRBs, the critical instrument turned out to be the Wide Field Cameras: X-ray detectors sensitive over 2-30 keV with a field of view $20° \times 20°$ source location accuracy of ~1'.

First BeppoSAX WFC Burst



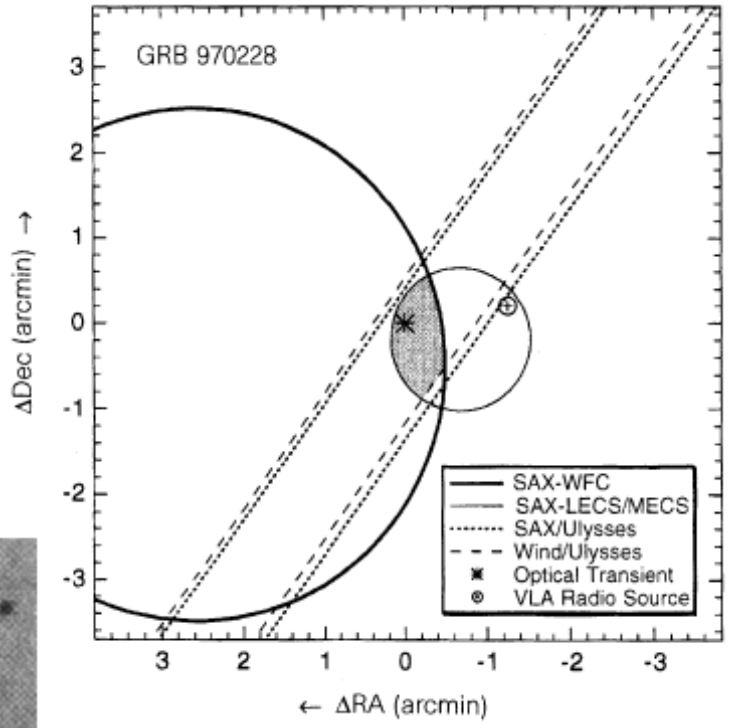


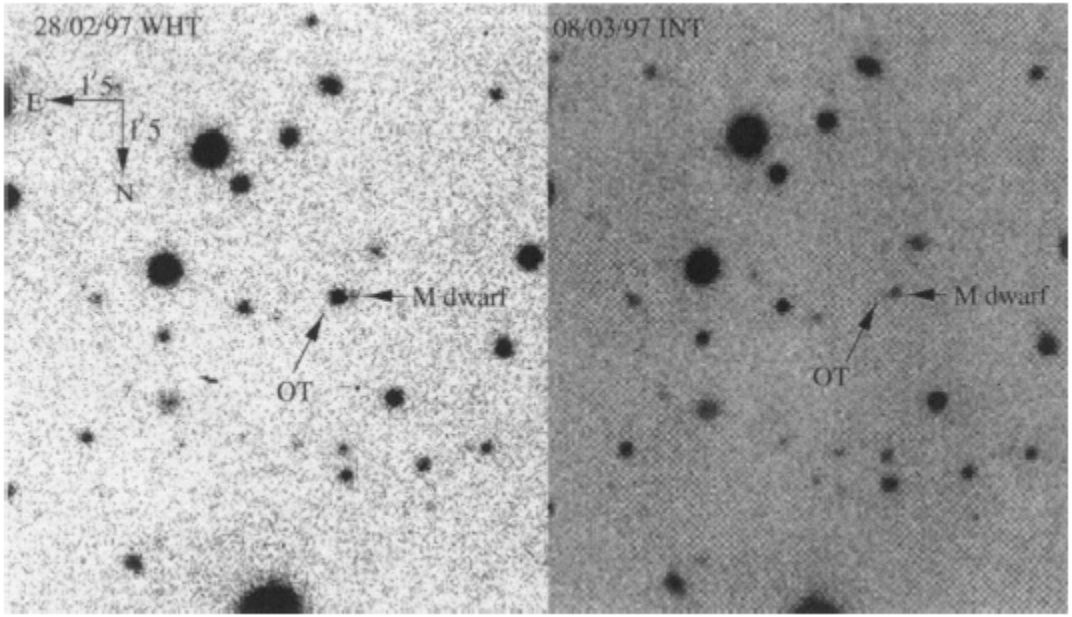
WFC light curve (top), GRB monitor light curve (bottom), narrow field instrument image (right) from Costa et al. 1997.

First GRB Optical Counterpart

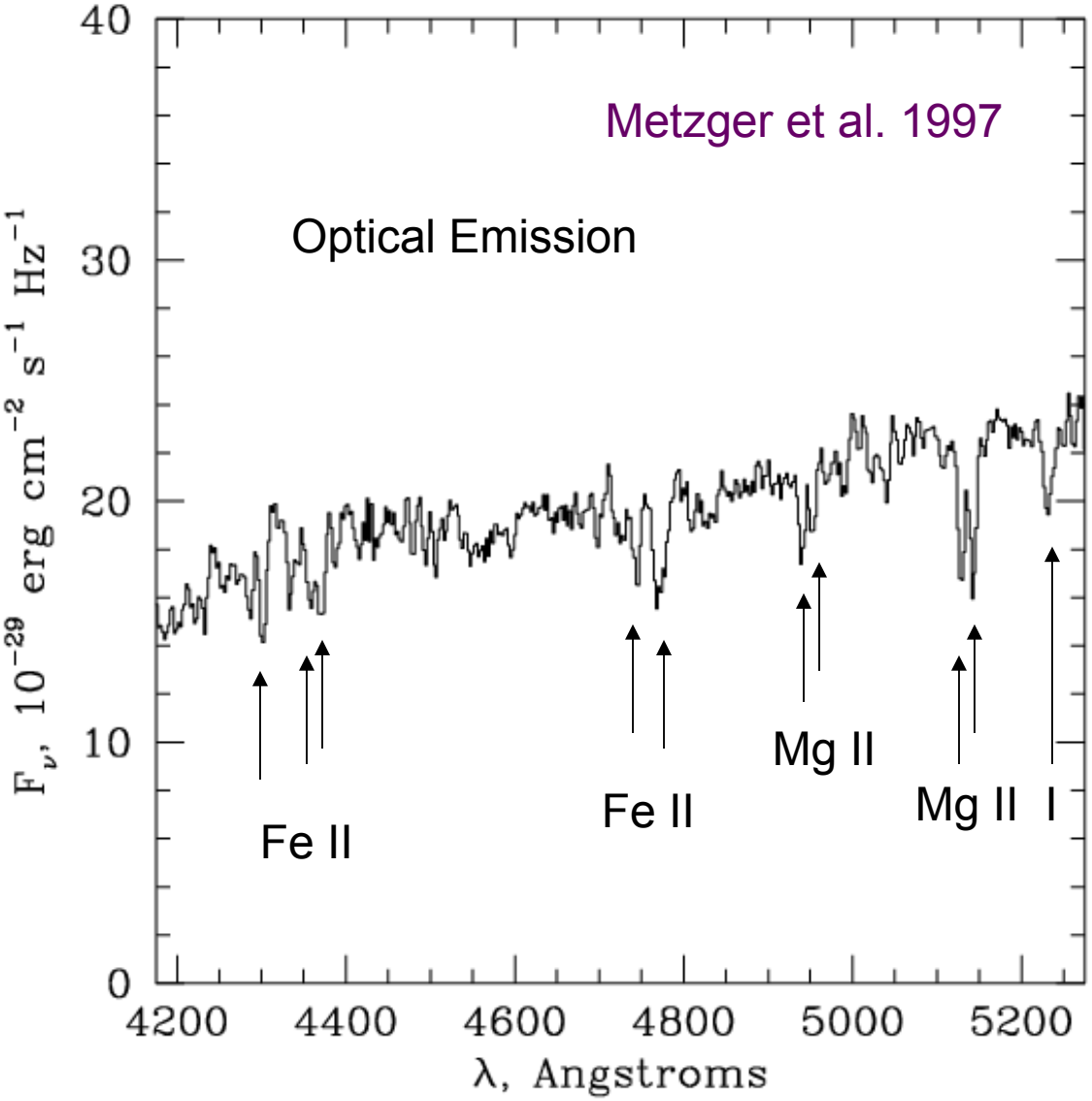
Found decaying optical source inside BeppoSAX NFI error circle.

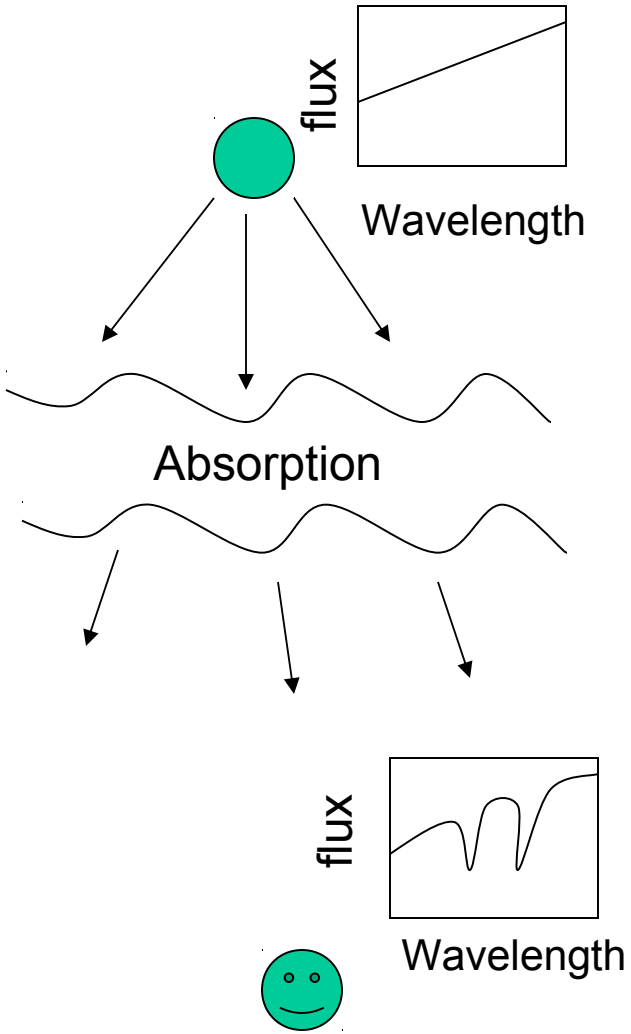
Found to lie near a faint and distant galaxy.





GRB970508 – Absorption Lines: z=0.835





Host Galaxy Detected for GRB970508

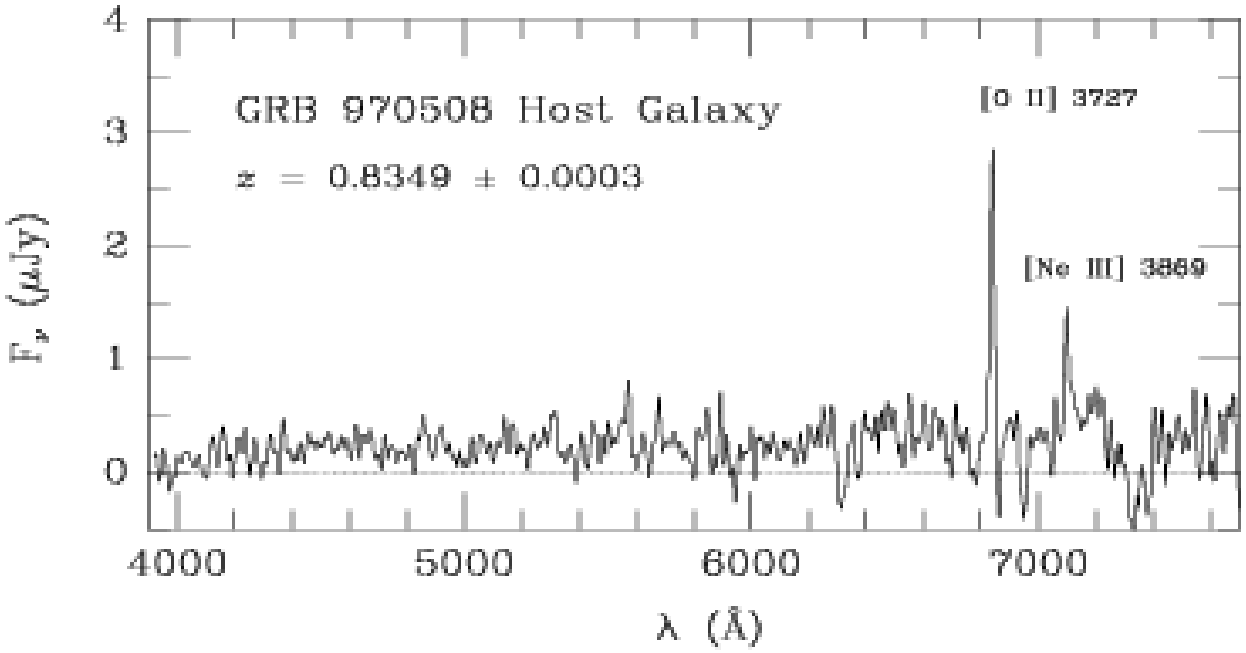


FIG. 2.— The weighted average spectrum of the host galaxy of GRB 970508, obtained at the Keck telescope. The spectra were smoothed with a Gaussian with a $\sigma = 5$ Å, roughly corresponding to the instrumental resolution. Prominent emission lines are labeled.

PEAK PHOTON FLUXES AND ISOTROPIC LUMINOSITIES FOR GRBS WITH SECURE REDSHIFTS

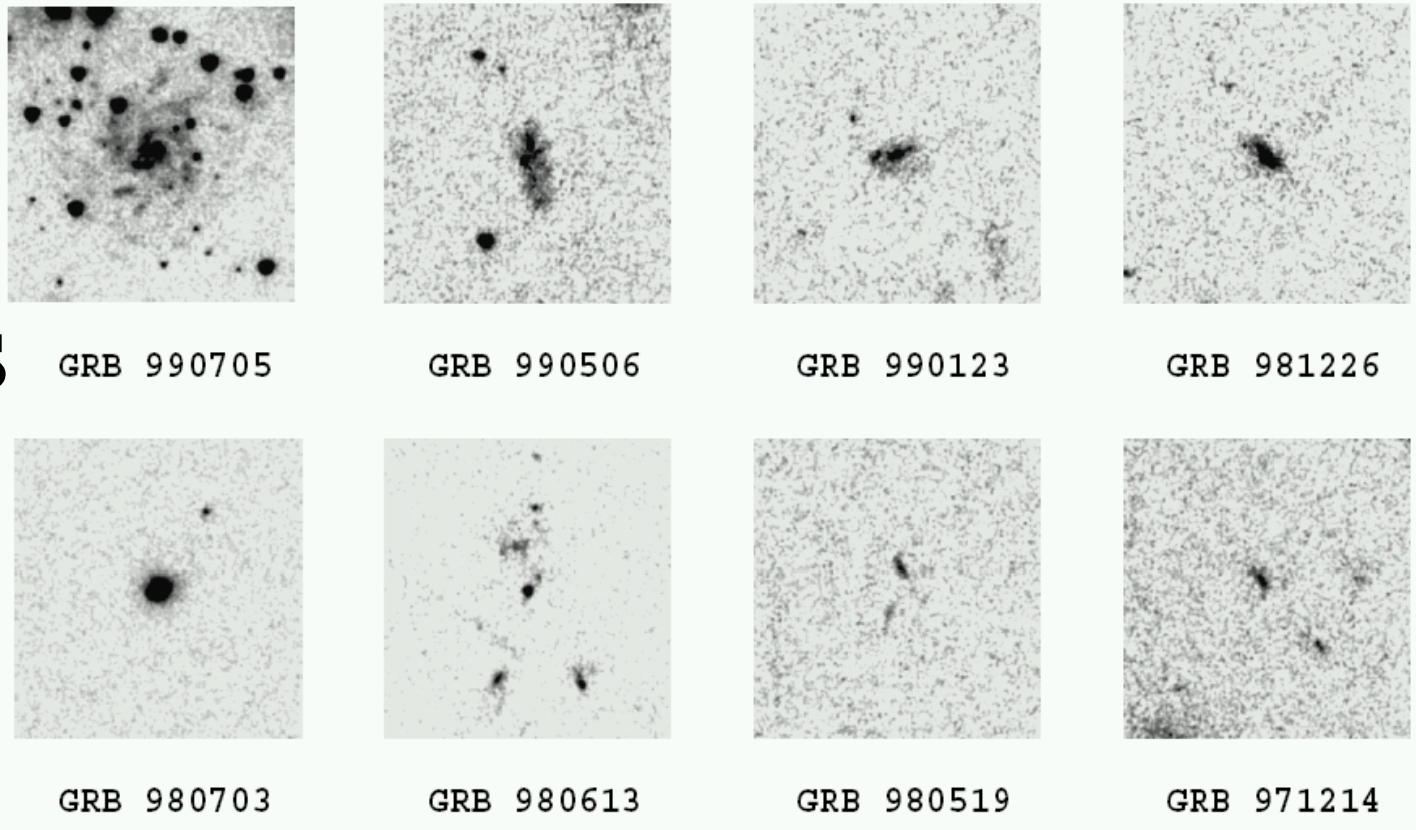
GRB	Redshift	P (photons cm^{-2} s^{-1})[a]	L_P (photons s^{-1})[b]	Redshift Reference
970228	0.695	3.5	5.1×10^{57}	1
970508	0.835	1.2	2.5×10^{57}	2, 3
971214	3.418	2.3	6.4×10^{58}	4
980613	1.096	0.63	2.3×10^{57}	5
980703	0.967	2.6	7.4×10^{57}	6
990123	1.600	16.4	1.2×10^{59}	7
990510	1.619	8.16	6.2×10^{58}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

Host Galaxies



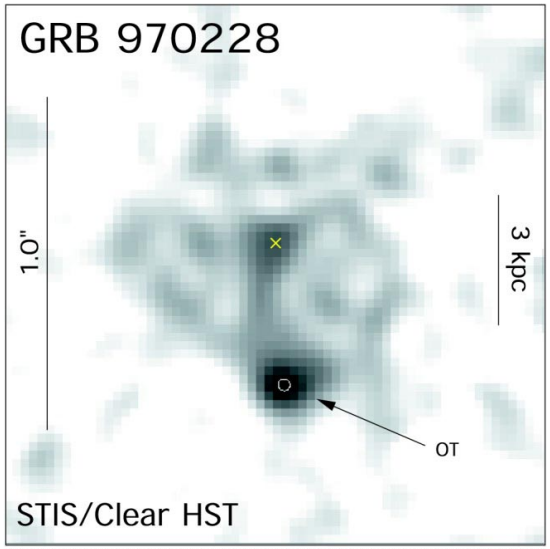
Holland 2001

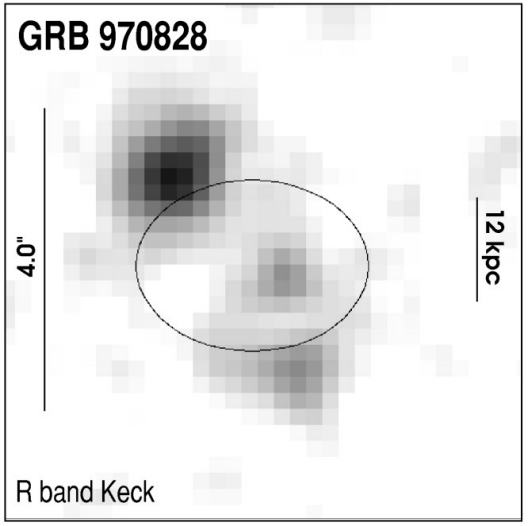
TABLE 1. Specific star-formation rates for several GRB host galaxies.

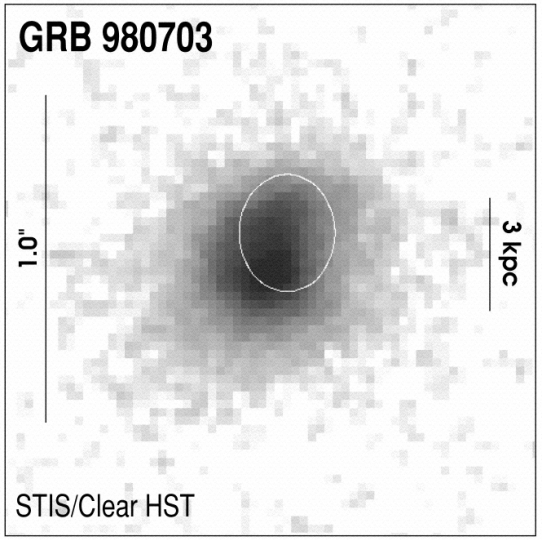
GRB	z	$R_{\rm host}$	$\mathcal{M}_{\odot}{\rm yr}^{-1}L_B^{*\,-1}$
970508	0.835	25.20	11.0
980613	1.096	24.56	20.0
980703	0.966	22.57	6.5
990123	1.600	24.07	11.0
990712	0.434	21.91	4.4

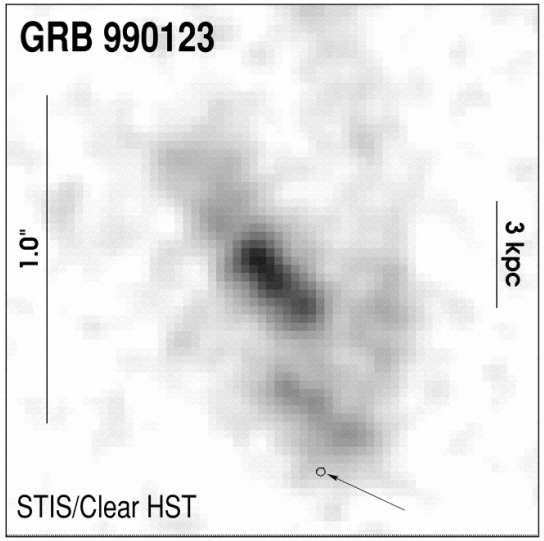
Hosts have high star formation rates and are generally similar to other star-forming galaxies at these redshifts.

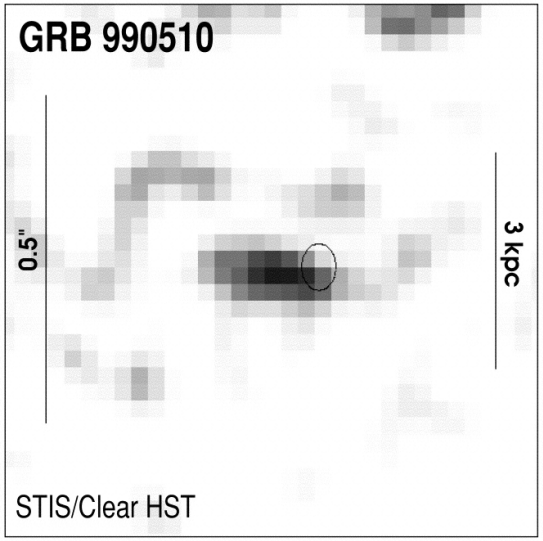
Location of GRB within Host

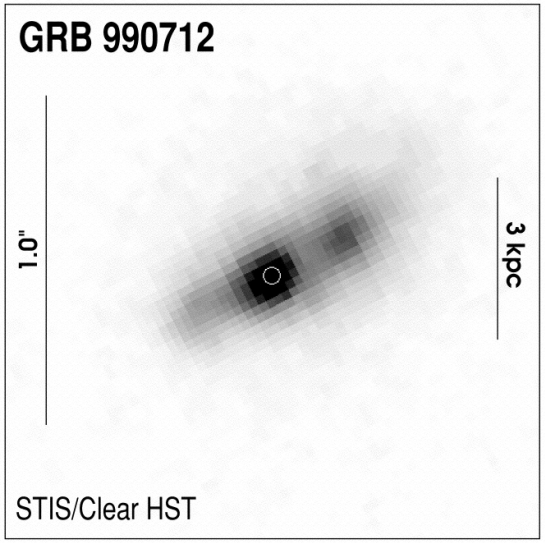








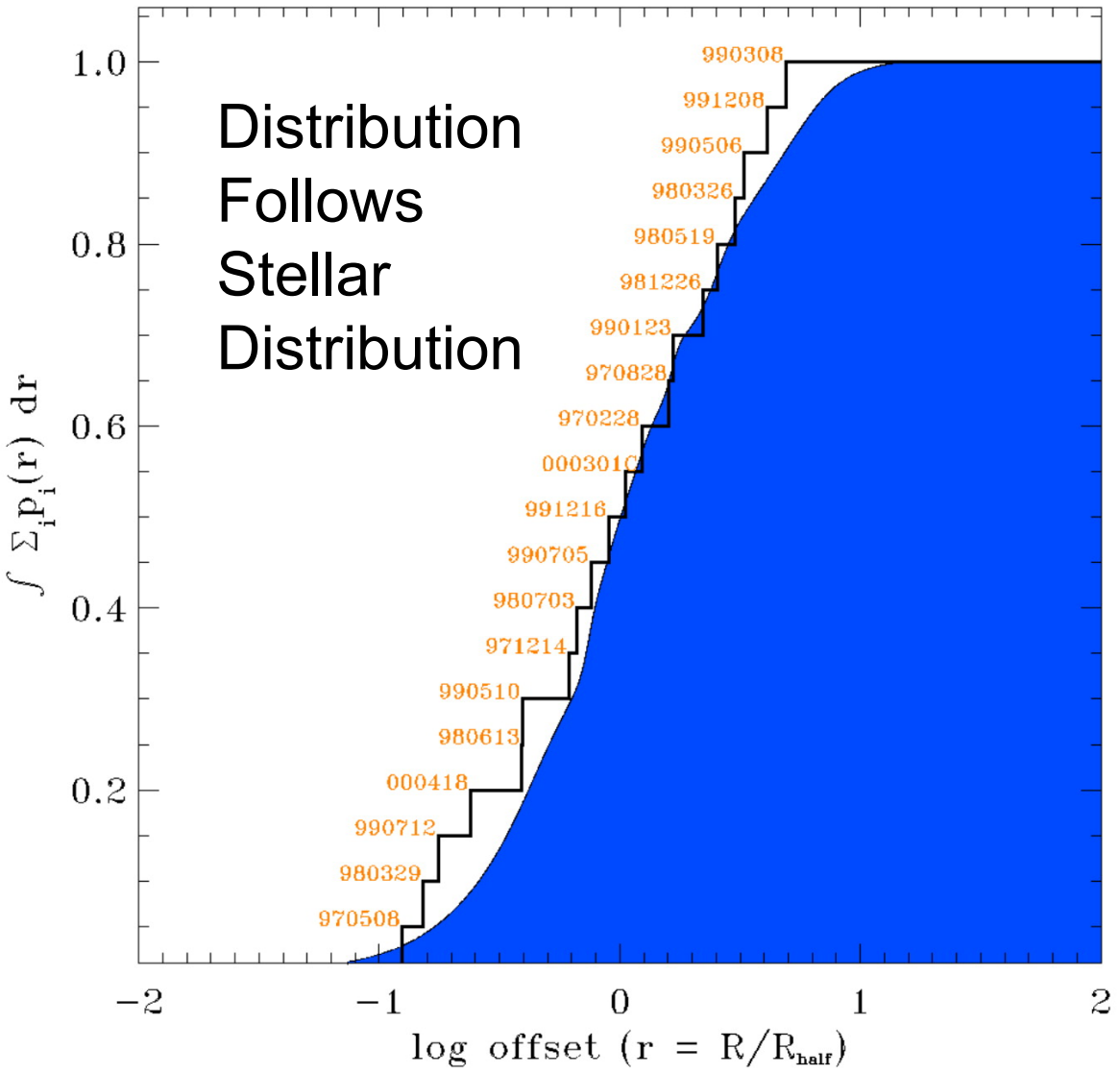




Location of GRB within Host

The environments of GRBs show higher gas densities, higher metallicities, and higher dust content than random locations in host galaxies.

Suggests that GRBs occur in star forming regions.



GRB Locations

- GRB hosts are star-forming galaxies
- GRBs trace the stellar distribution (in distance from galaxy center)
- GRBs occur in dense environments (probably star forming regions)

- Suggests long GRBs are associated with star formation and occur promptly after star formation

Connection of GRBs to Supernovae

SN 1998bw was found in the 8' error circle of GRB 980425 in observations made 2.5 days after the burst.

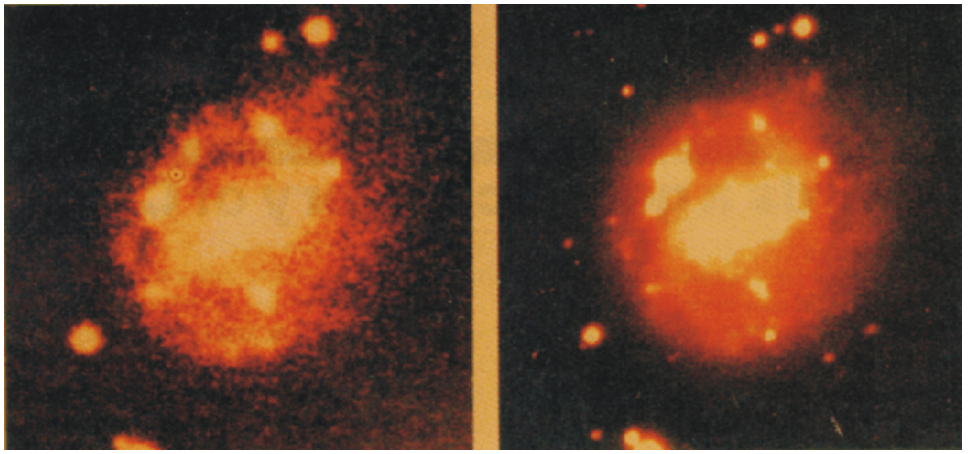
A slowly decaying X-ray source was subsequently found in the same galaxy (z = 0.0085) and identified with the GRB.

However, the GRB was very underluminous and the SN was very usual with parculiar line emission (no H, no He, no Si at 615 nm.

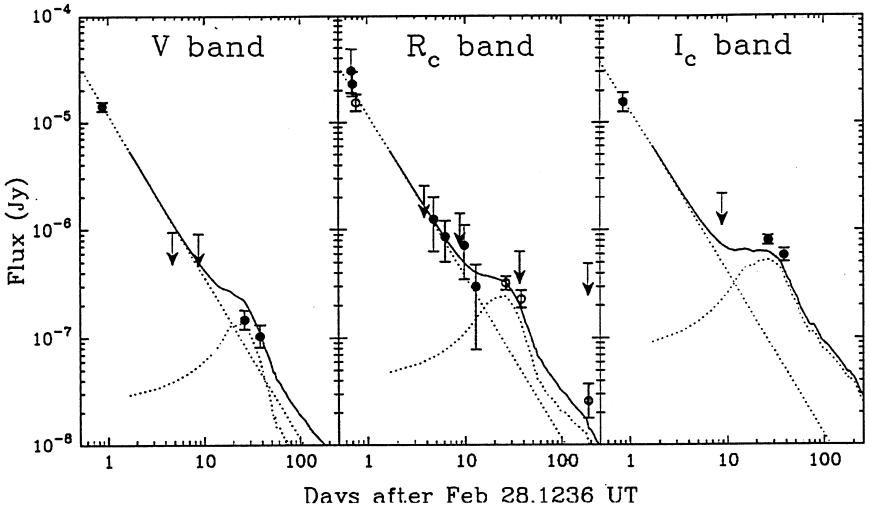
Radio emission a few days after GRB indicated relativistic outflow with energy ~ 3×10^{50} erg.

Thought to be oddball GRB and SN.

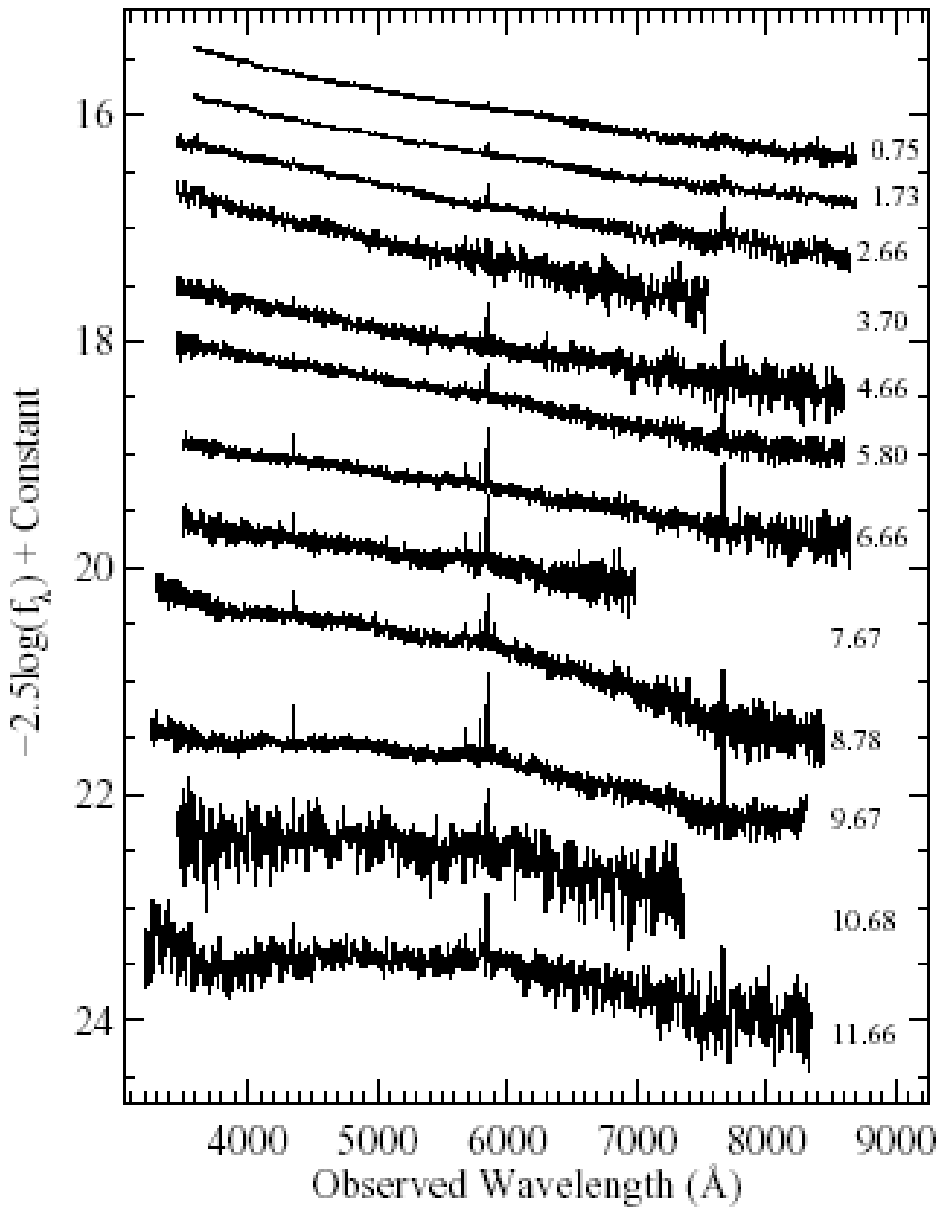
Host galaxy of SN 1998bw



light curves of GRB 970228



GRB030329 and SN 2003dh



Clear spectroscopic signature of a SN, broad emission lines, found after decay of afterglow of GRB030329.

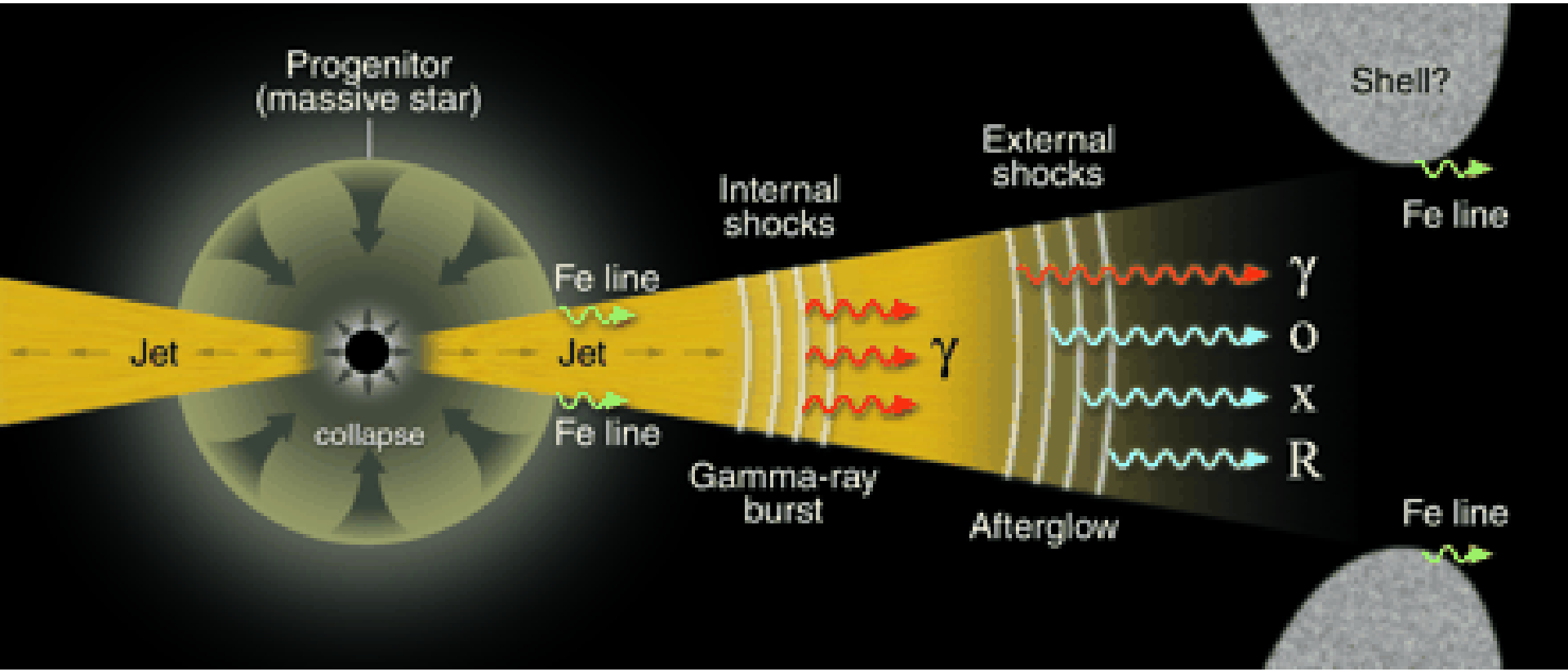
"Smoking gun" linking GRBs and SNe.

GRB - Supernova

Name Burst/SN	z	Peak [mag]	$T^{a}_{\rm peak}$ [day]	SN likeness/ designation
GRB 980425/1998bw	0.0085	$M_V = -19.16 \pm 0.05$	17	Ic-BL
GRB 030329/2003dh	0.1685	$M_V = -18.8$ to -19.6	10 - 13	Ic-BL
GRB 031203/2003lw	0.1005	$M_V = -19.0$ to -19.7	18 - 25	Ibc-BL
XRF 020903	0.25	$M_V = -18.6 \pm 0.5$	$\sim$15	Ic-BL
GRB 011121/2001dk	0.365	$M_V = -18.5$ to -19.6	$12 - 14$	I (IIn?)
GRB 050525a	0.606	$M_V \approx -18.8$	12	I
GRB 021211/2002lt	1.00	$M_U = -18.4$ to -19.2	$\sim$14	Ic
GRB 970228	0.695	$M_V \sim -19.2$	$\sim$17	I
XRR 041006	0.716	$M_V = -18.8$ to -19.5	$16 - 20$	I
XRR 040924	0.859	$M_V = -17.6$	$\sim$11	?
GRB 020405	0.695	$M_V \sim -18.7$	$\sim$17	I

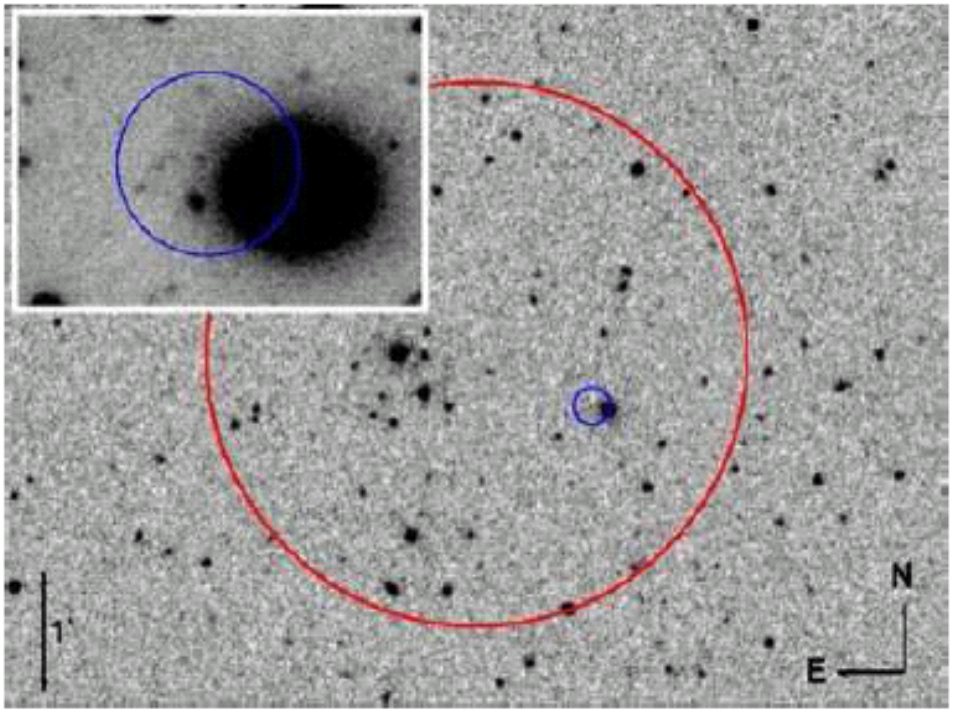
Only a tiny fraction of SN are observed to be GRBs

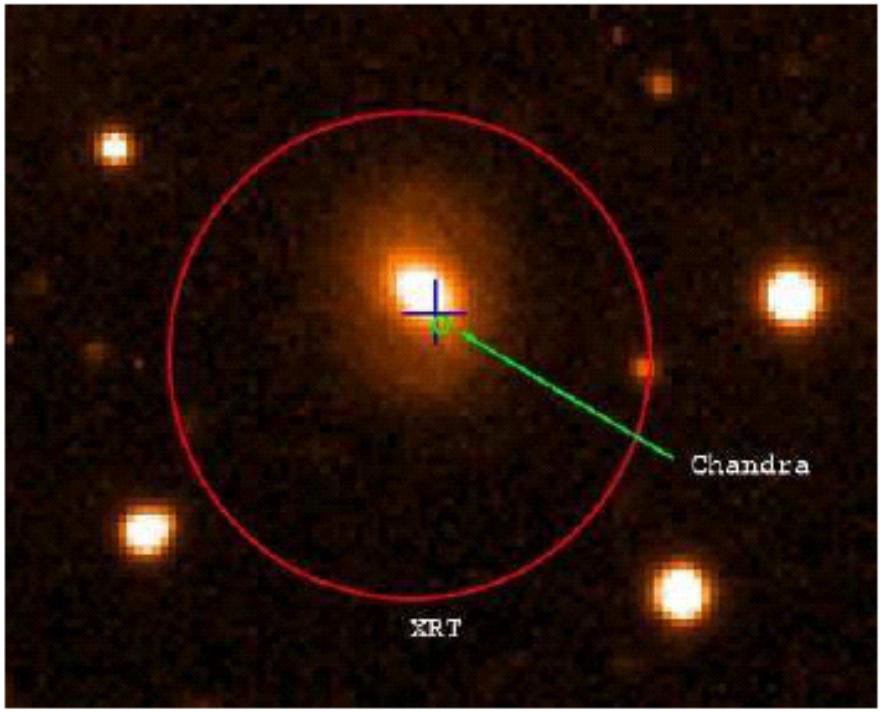
Massive Star Collapse



- Massive star collapses, forming NS or BH
- Matter briefly forms accretion disk around compact object
- Accretion disk produces collimated relativistic outflow
- Beamed outflow makes GRB, supernova explosion accompanies

Short GRBs

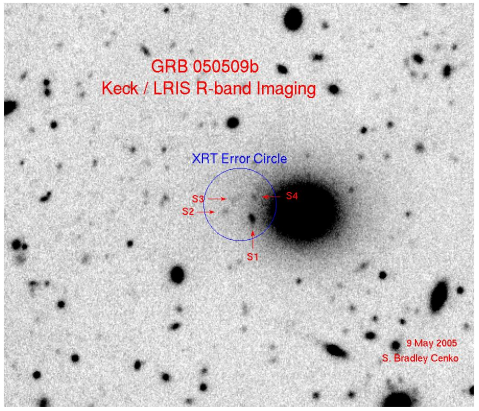




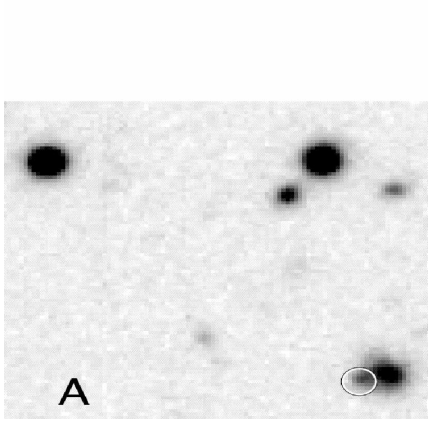
Short GRBs associated with elliptical galaxies. *left:* GRB 050509B; z=0.226 (Gehrels et al. 2005; Bloom et al. 2006a), the red and blue circles are BAT and XRT error boxes, respectively; *Right:* GRB 050724; z=0.257 (Barthelmy et al. 2005b; Berger et al. 2005a)

Host Galaxies of Short GRBs

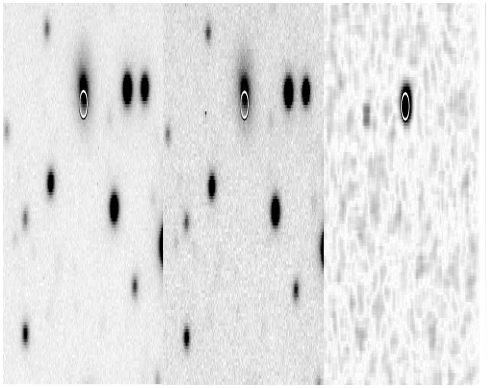
GRB050509



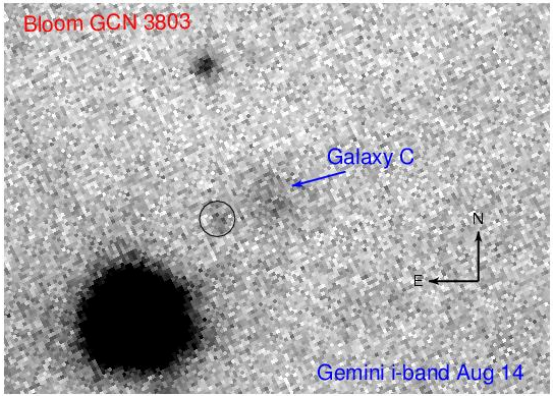
GRB050709



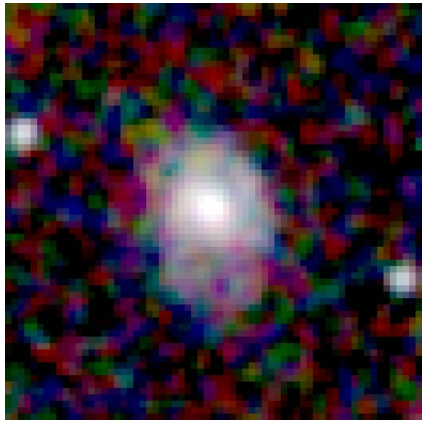
GRB050724



GRB050813



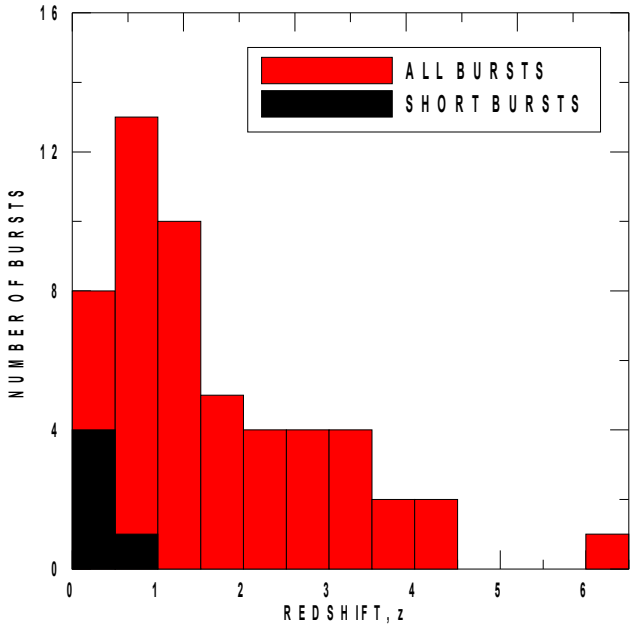
GRB050906



Properties of Short GRBs

GRB	X-RAY?	OPTICAL?	RADIO?	REDSHIFT	GALAXY	ENERGY erg
050509	YES	NO	NO	0.225?	ELLIPTICAL?	1.1×10^{48}?
050709	YES	YES	NO	0.1606	EARLY	2.8×10^{49}
050724	YES	YES	YES	0.257	ELLIPTICAL	9.9×10^{49}
050813	YES	NO	NO	0.722?	?	1.7×10^{50}?
050906	NO	NO	NO	0.03?	BLUE, SPIRAL	1.2×10^{47}?

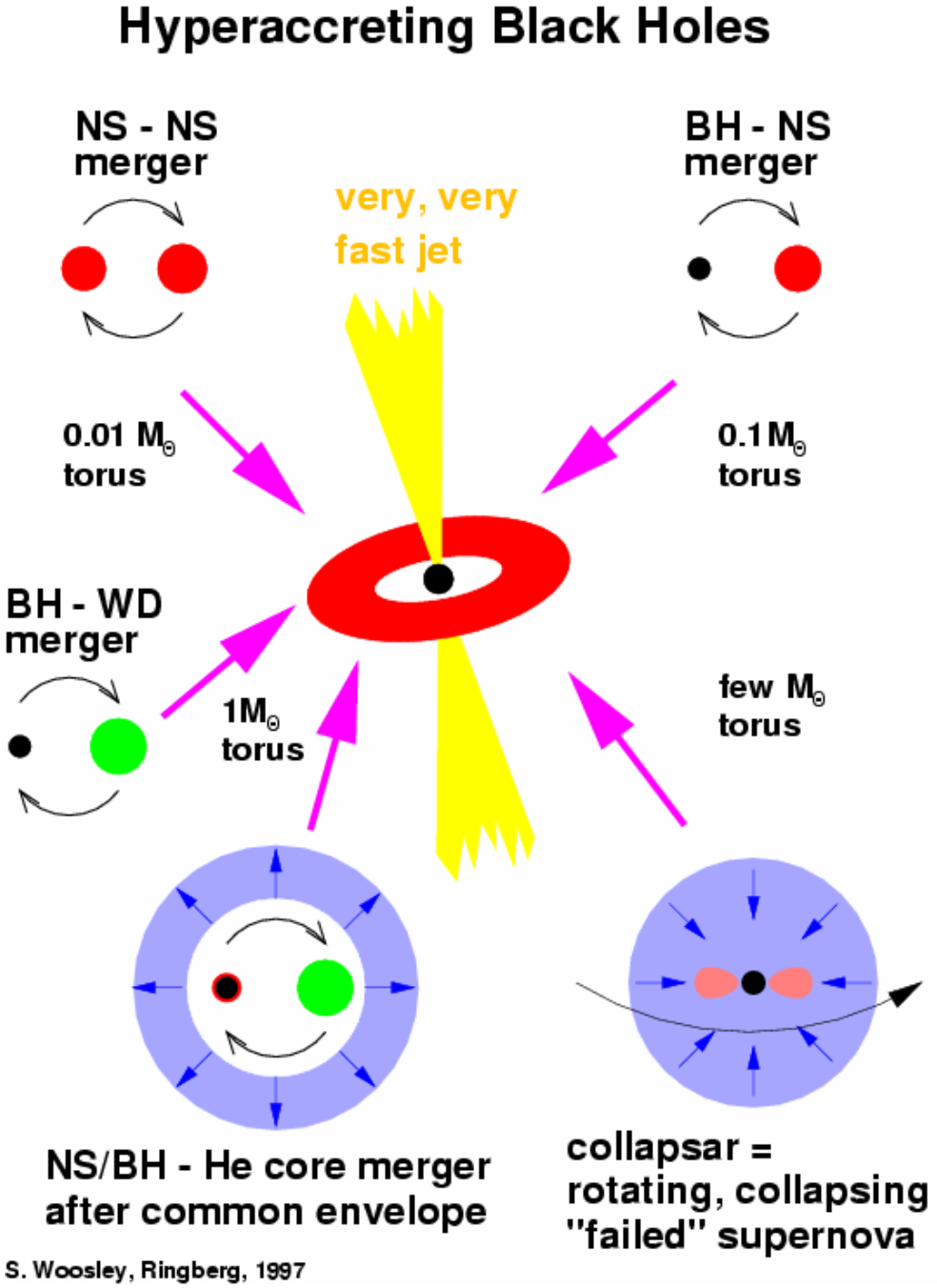
- Found in both elliptical and star forming galaxies
- No evidence for supernova emissions
- Offset from host galaxy



Mergers

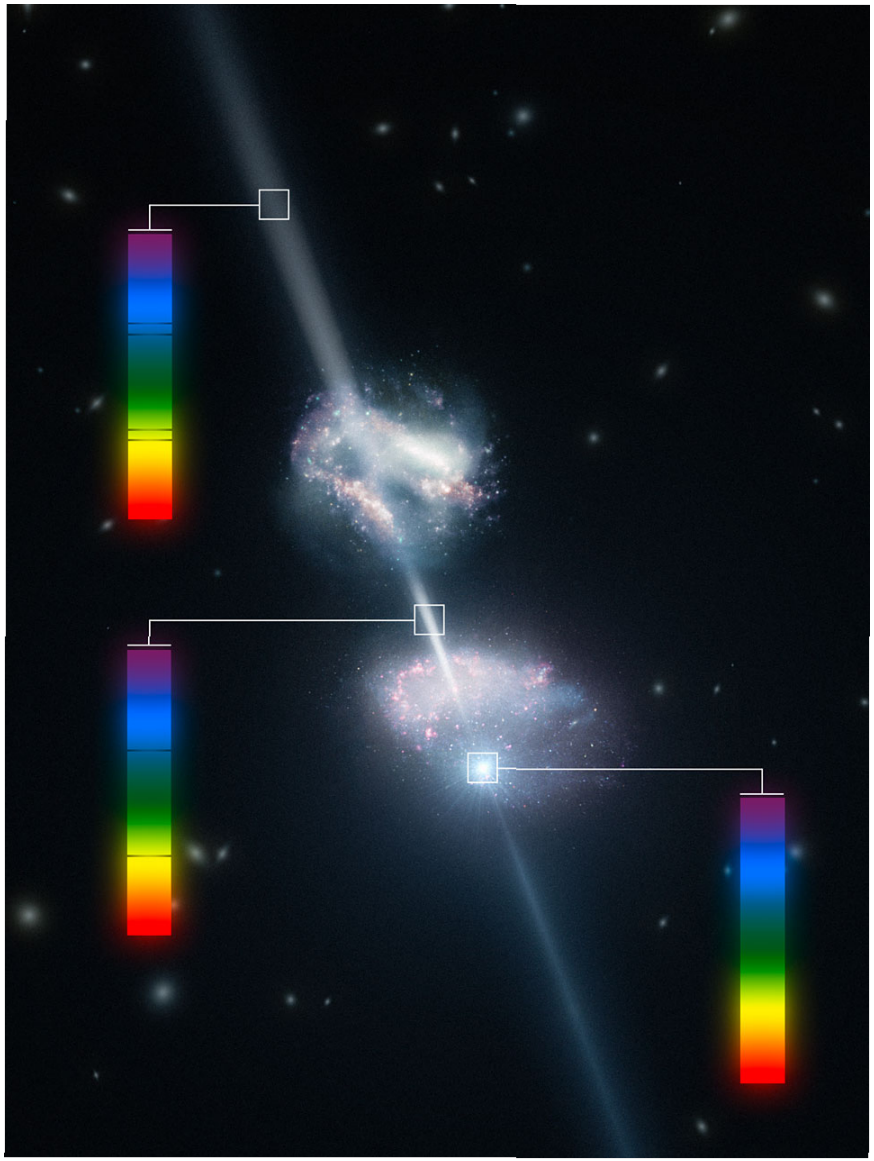
Binaries must evolve before merger and binaries have non-zero speeds due to kicks in compact object formation.

Thus, GRBs can occur in outskirts of or even far from host galaxy.



High *z* GRBs

- Highest *z* from GRB is 8.26.
- GRB is briefly bright in optical/IR as well as gamma-rays due to afterglow.
- Can use spectroscopy of GRB to study properties of host galaxy and any intervening galaxies (like QSO absorption lines).



Next week

- No class on Monday, December 3
- Project final draft on December 5 (one week from Wednesday)
- Project presentations on December 5
  - 1:30 pm Brorby and Griffiths
  - 2:00 pm McCoy and Scheiner
  - 2:30 pm Allured and Marlowe
  - 3:00 pm De Pascuale and DeRoo
  - 3:30 pm Butterfield and Savage
  - 4:00 pm Lodvici and Toomey