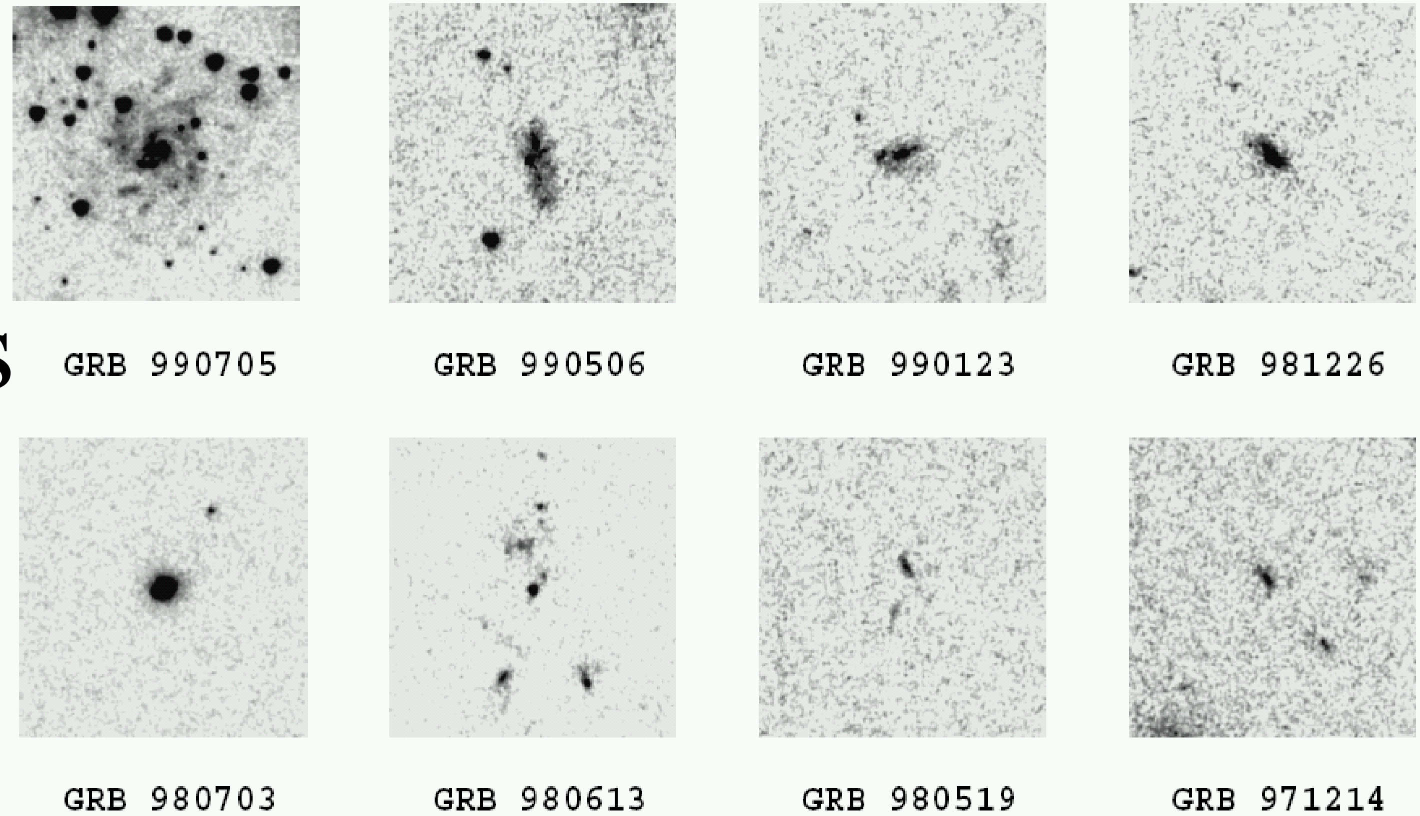
Gamma-Ray Bursts

- Connection of long GRBs to supernovae
- Swift
- Long GRBs, SN, collapsars
- Short GRBs and mergers
- Low luminosity GRBs and soft gamma repeaters

Host Galaxies



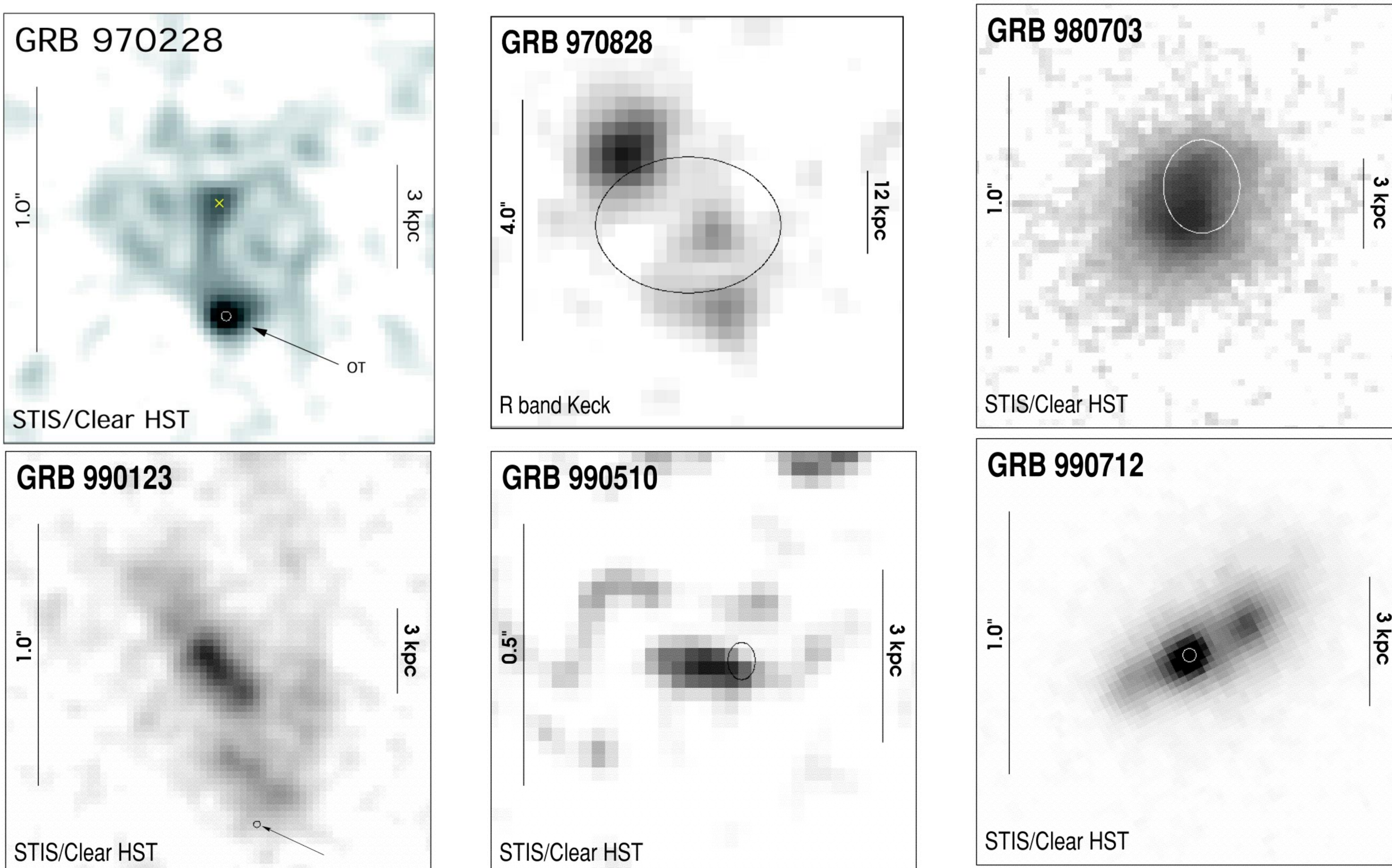
Holland 2001

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

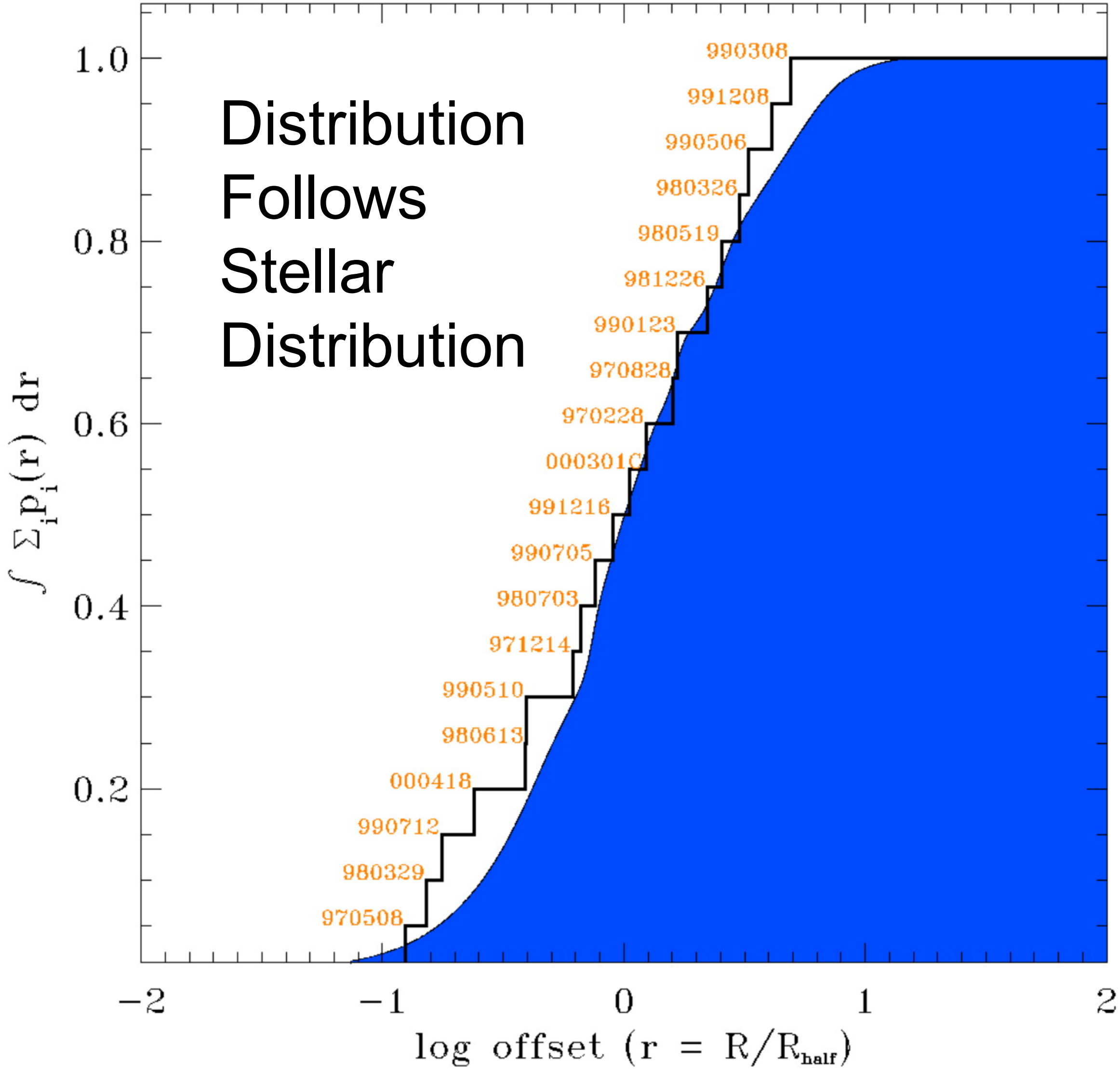
GRB	z	$R_{\rm host}$	$\mathcal{M}_\odot {\rm yr}^{-1} L_B^{*\,-1}$
970508	0.835	25.20	11.0
980613	1.096	24.56	20.0
980703	0.966	22.57	6.5
990123	1.600	24.07	11.0
990712	0.434	21.91	4.4

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.

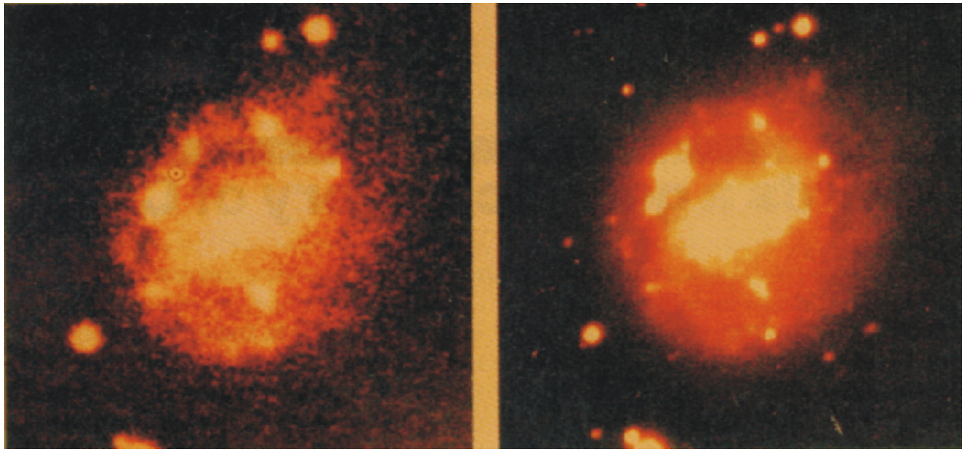
A slowly decaying X-ray source was subsequently found in the same galaxy (z = 0.0085) and identified with the GRB.

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.

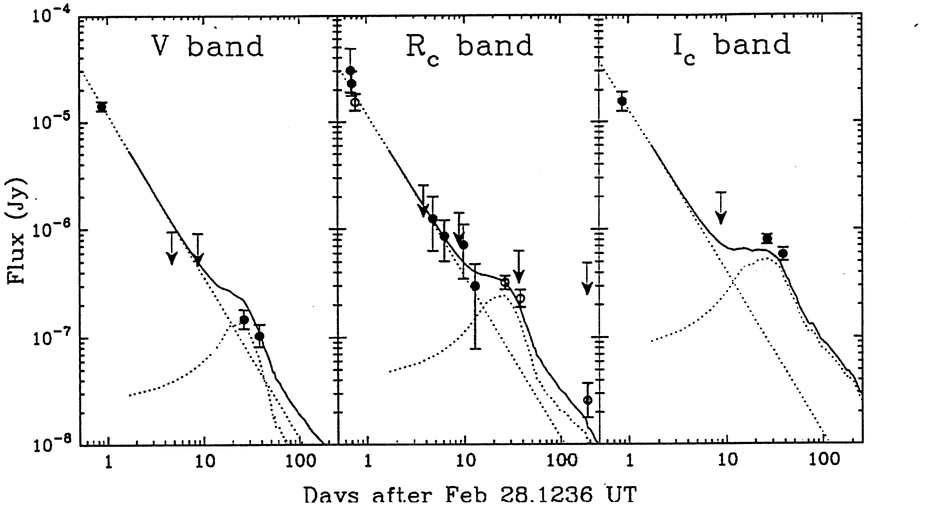
Radio emission a few days after GRB indicated relativistic outflow with energy ~ 3×10^{50} erg.

Thought to be oddball GRB and SN.

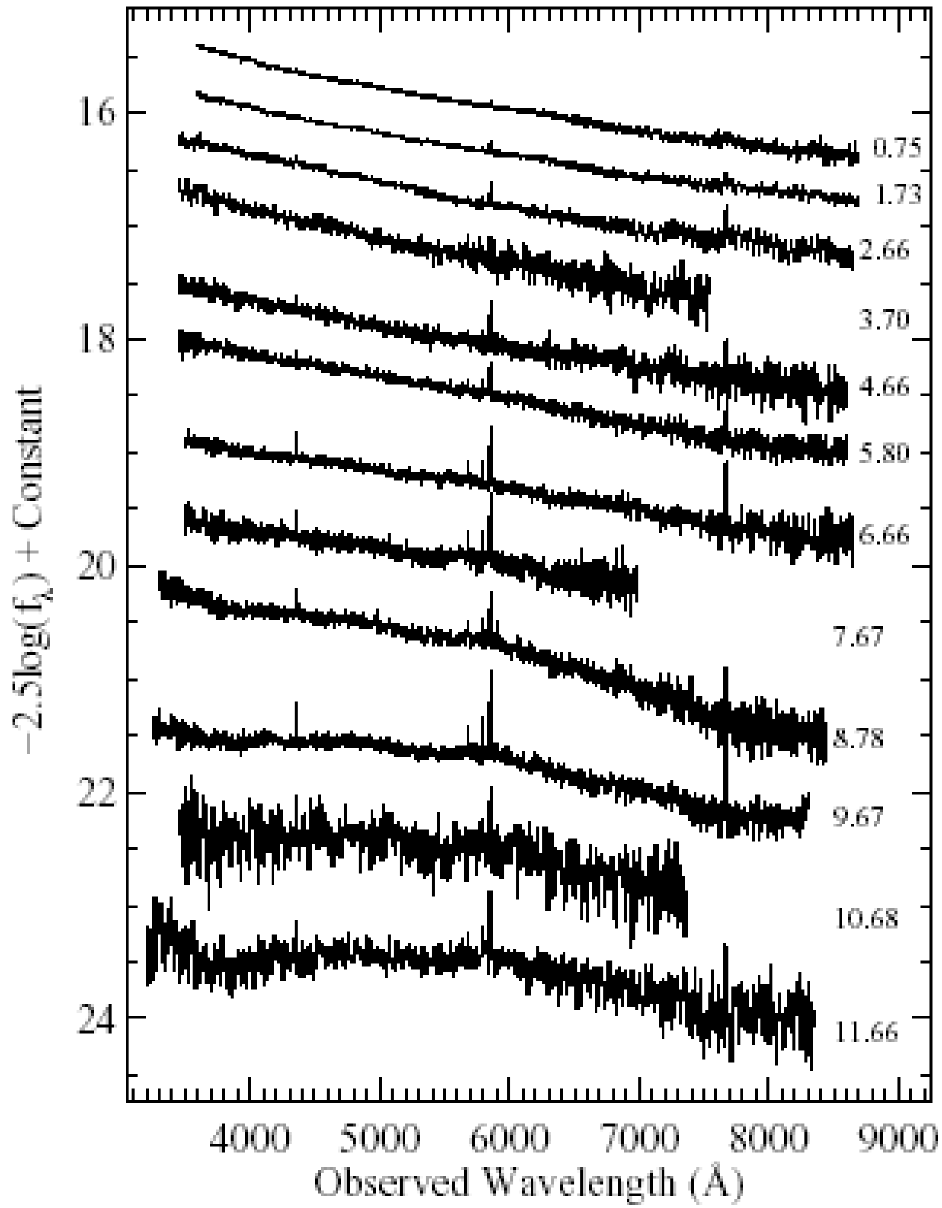
Host galaxy of SN 1998bw



light curves of GRB 970228



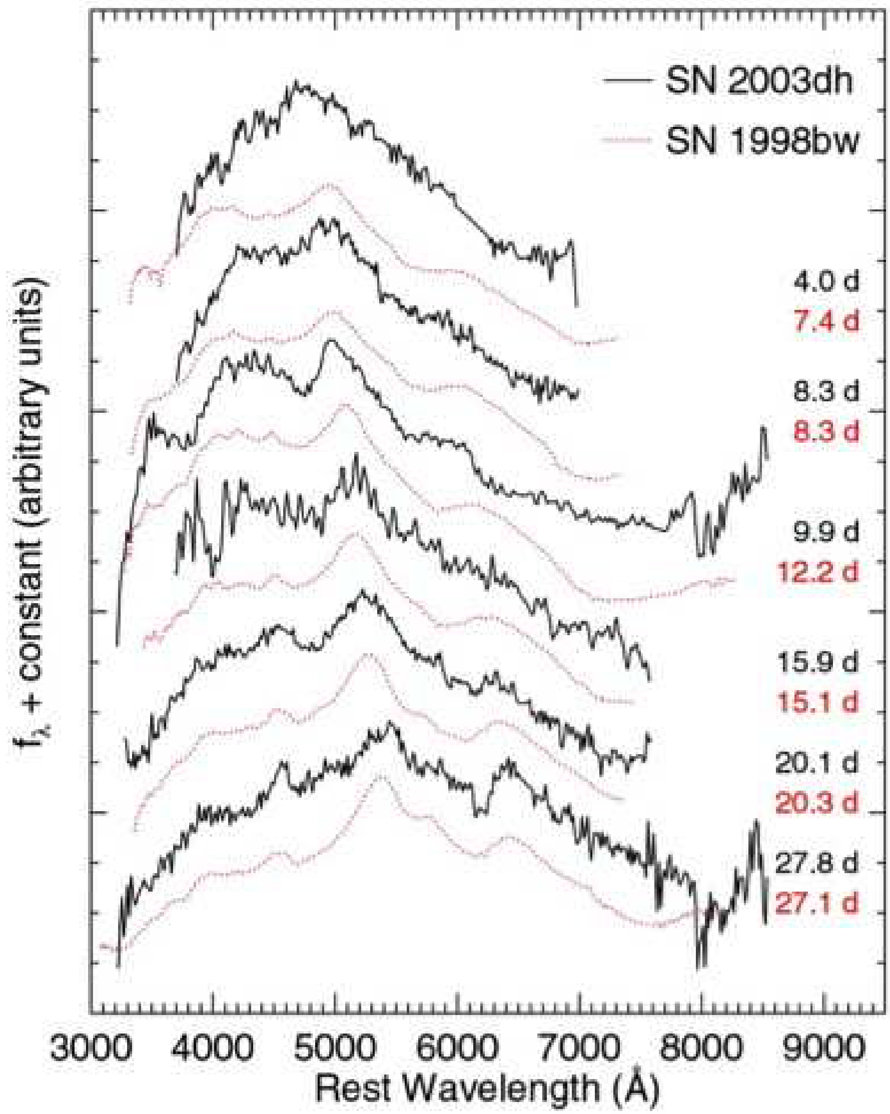
GRB030329 and SN 2003dh



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

"Smoking gun" linking GRBs and SNe.

SN 2003dh versus SN 1998bw



SN Bumps

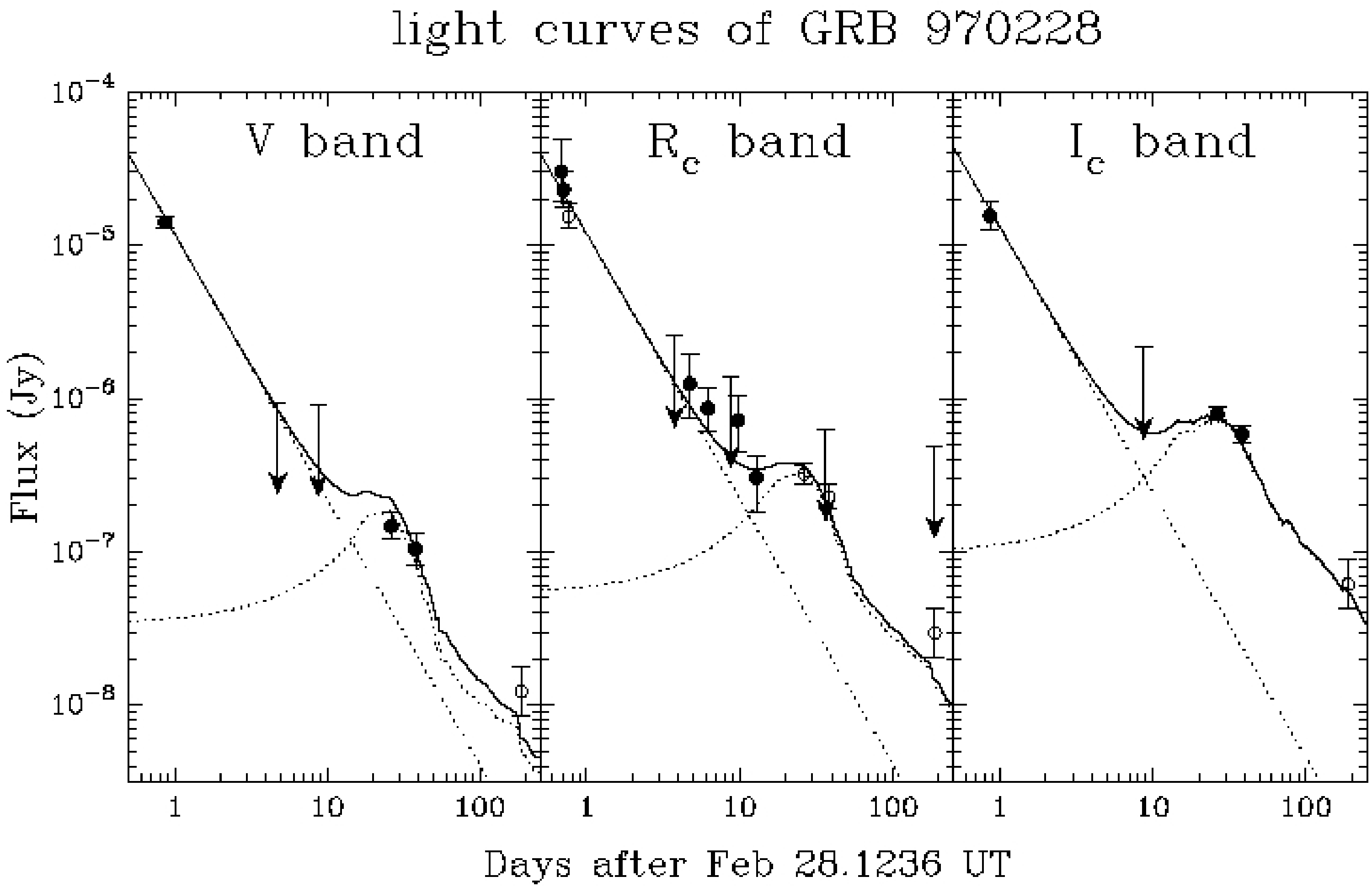
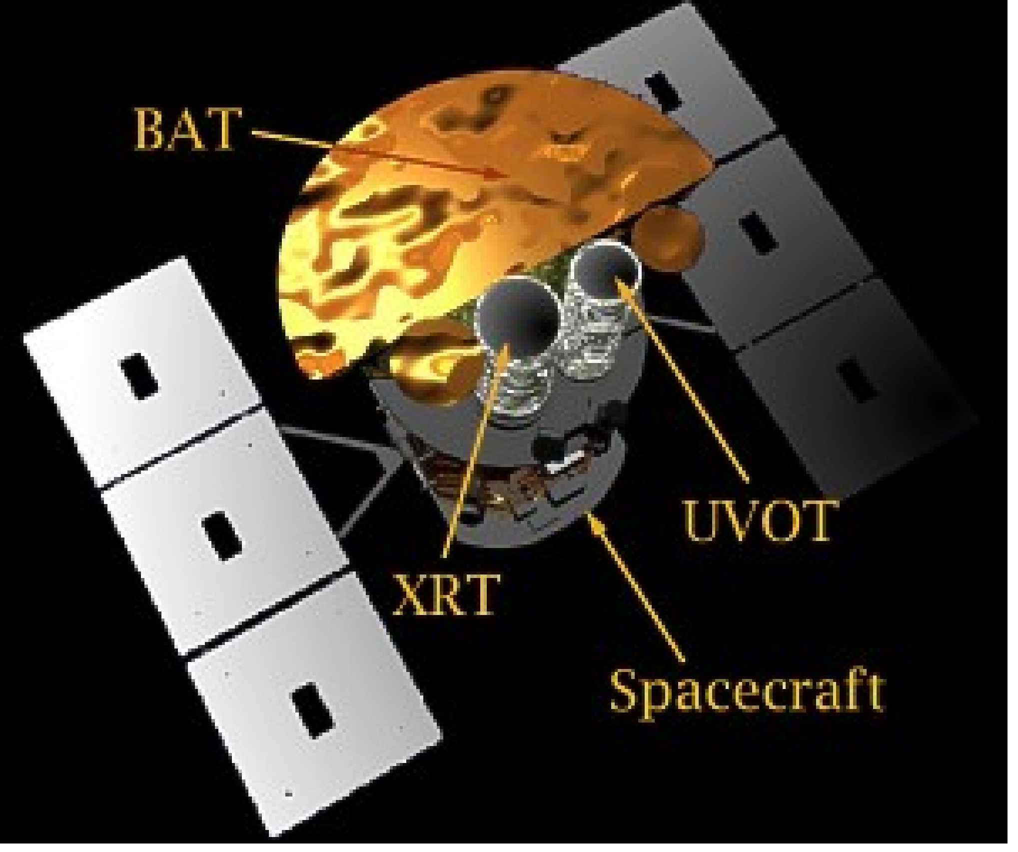


FIG. 3.— The V-, R_c-, and I_c-band lightcurves of GRB 970228 (fluxes versus time). The dotted curves indicate power-law decays with $\alpha = -1.73$, and redshifted SN 1998bw light curves. The thick line is the resulting sum of SN and power-law decay light curves.

GRB - Supernova

Name Burst/SN	z	Peak [mag]	T^a_{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	$M_V = -18.6 \pm 0.5$	~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	~14	Ic
GRB 970228	0.695	$M_V \sim -19.2$	~17	I
XRR 041006	0.716	$M_V = -18.8$ to -19.5	16 − 20	I
XRR 040924	0.859	$M_V = -17.6$	~11	?
GRB 020405	0.695	$M_V \sim -18.7$	~17	I

Only a tiny fraction of SN are observed to be GRBs



Swift

BAT – CZT detector with 5200 cm^2 area sensitive in 15-150 keV band.

Coded aperture imaging of 1.4 steradian field with 4 arcmin resolution suing 32768 pixels.

After detecting a burst, Swift autonomously repoints bringing the burst into view of the XRT and UVOT, often within 90 seconds.

XRT – focusing X-ray telescope in 0.5-6 keV band, 2.5 arcsecond source location accuracy.

UVOT – focusing UV/optical telescope.

Swift Results

- Launched in 2004, detects about 100 bursts/year
- Increased red shift range

  GRB 090423 with $z = 8.2$, Swift $\langle z \rangle = 2.7$ versus pre-Swift $\langle z \rangle = 1.2$

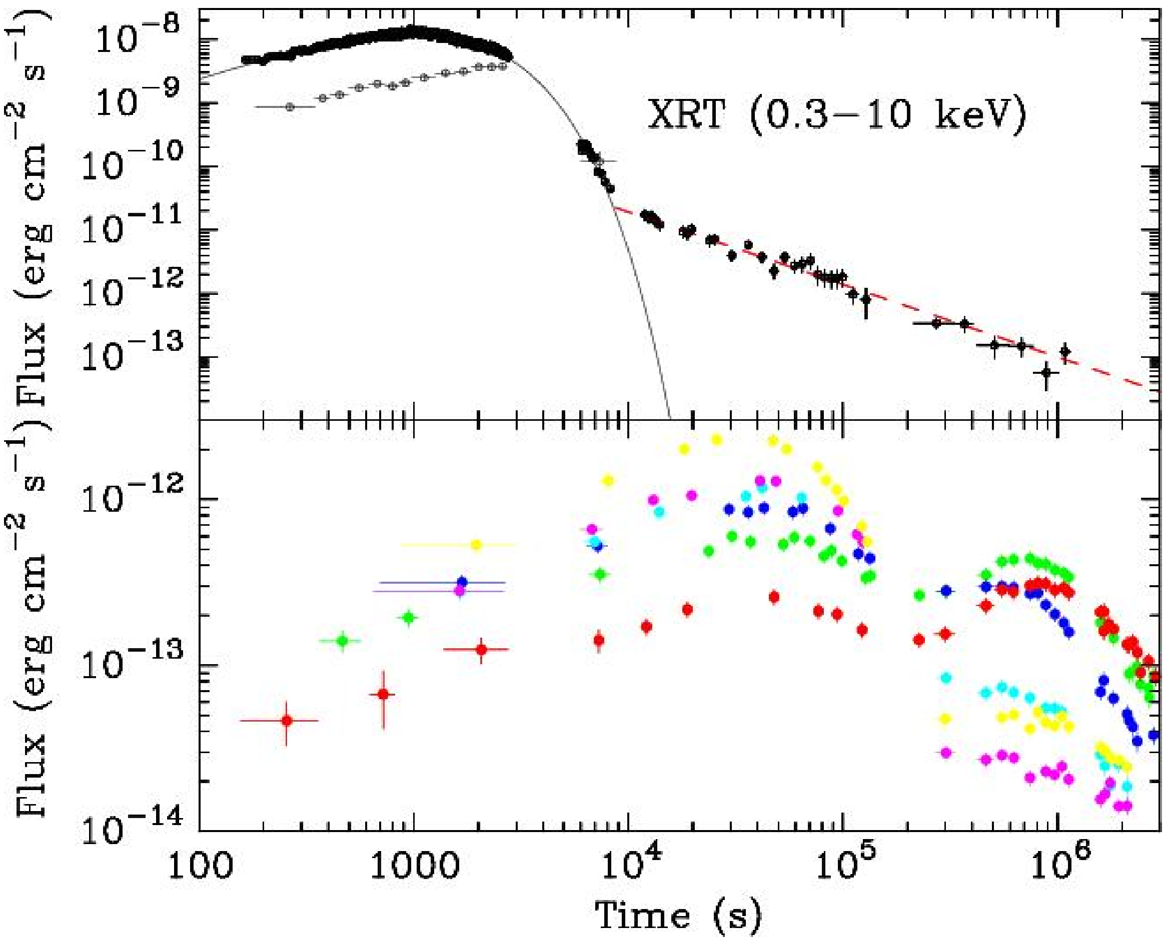
- Huge sample of afterglow X-ray/optical light curves with excellent coverage

  Afterglow light curves far more complex than anticipated.

  Jet breaks in only 20% of GRBs (coverage for 40% incomplete)

- More data on long GRB/SN connection
- Afterglow of short GRB
- Low luminosity GRBs

GRB 060218 = SN 2006aj



- Clear type SN Ic

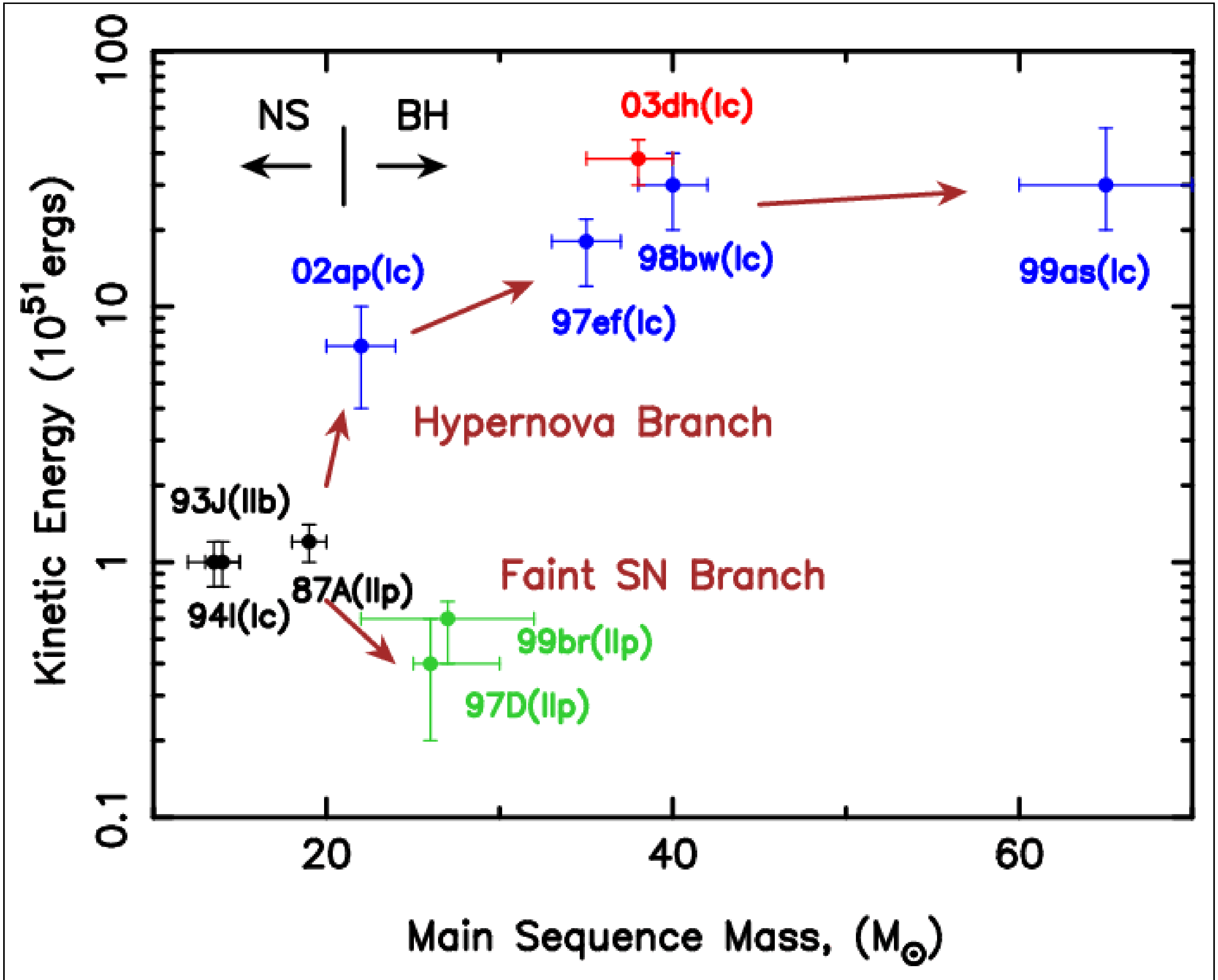
Compared to usual GRB-SN:
- SN was 100x less powerful
- More frequent events
- Less ejected mass
- Thought to have NS at core

More on GRB/SN connection

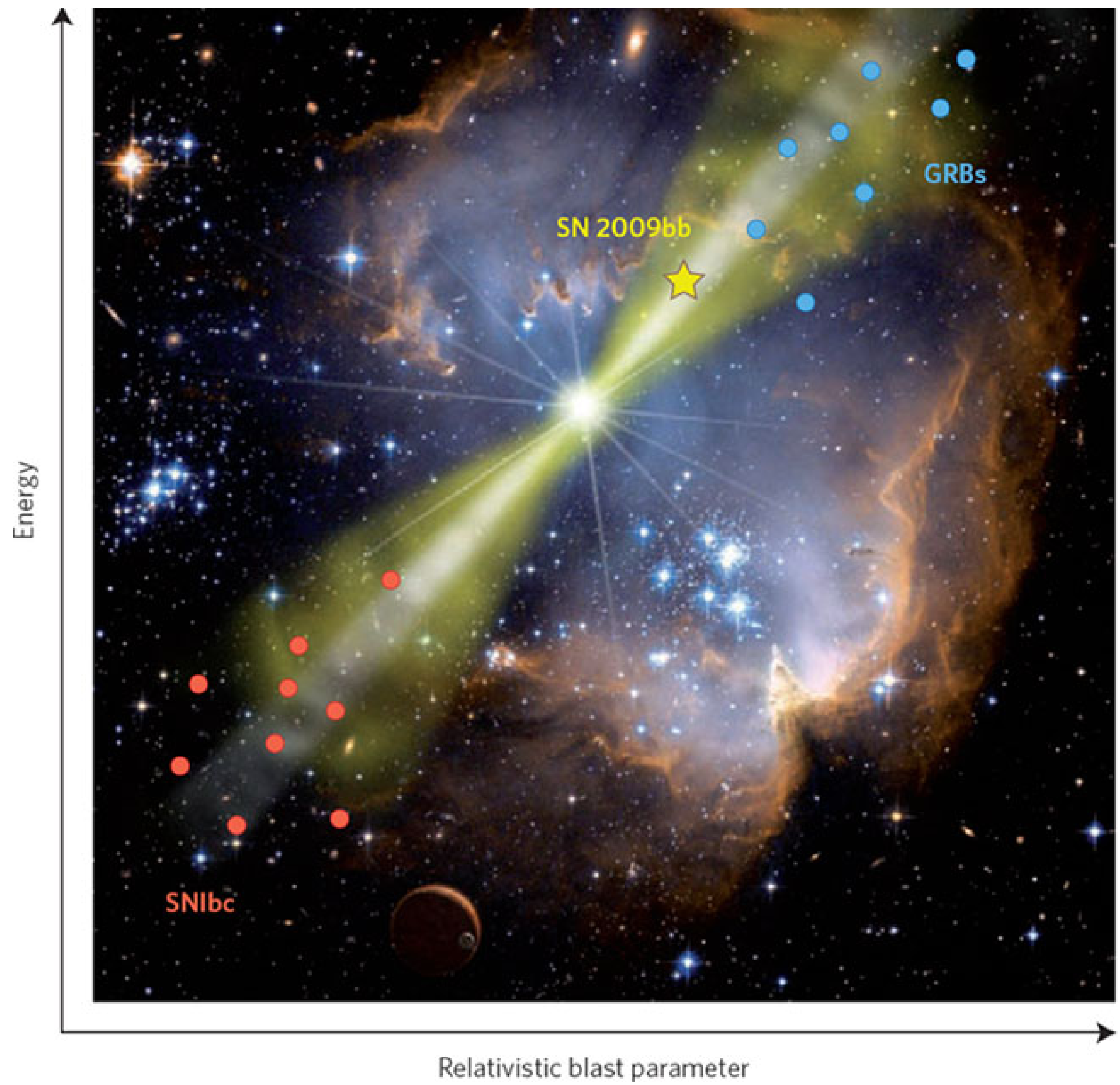
- Type of SN associated with GRBs established as SN Ic – core collapse SN with absence of H, He, Si absorption lines
- SNR-SNe also show high speed (v ~ 0.1c) outflows

- Do all SN Ic make GRBs?
- At late times, fire ball should produce unbeamed radio emission. Radio survey of SN Ic shows that not every (or even most) SN Ic harbors a GRB
  - Most SN Ic have no relativistic ouflows
  - Some have mildly relativistic outflows (SN 2009bb), but no gamma-rays
  - Some have highly relativistic outflows

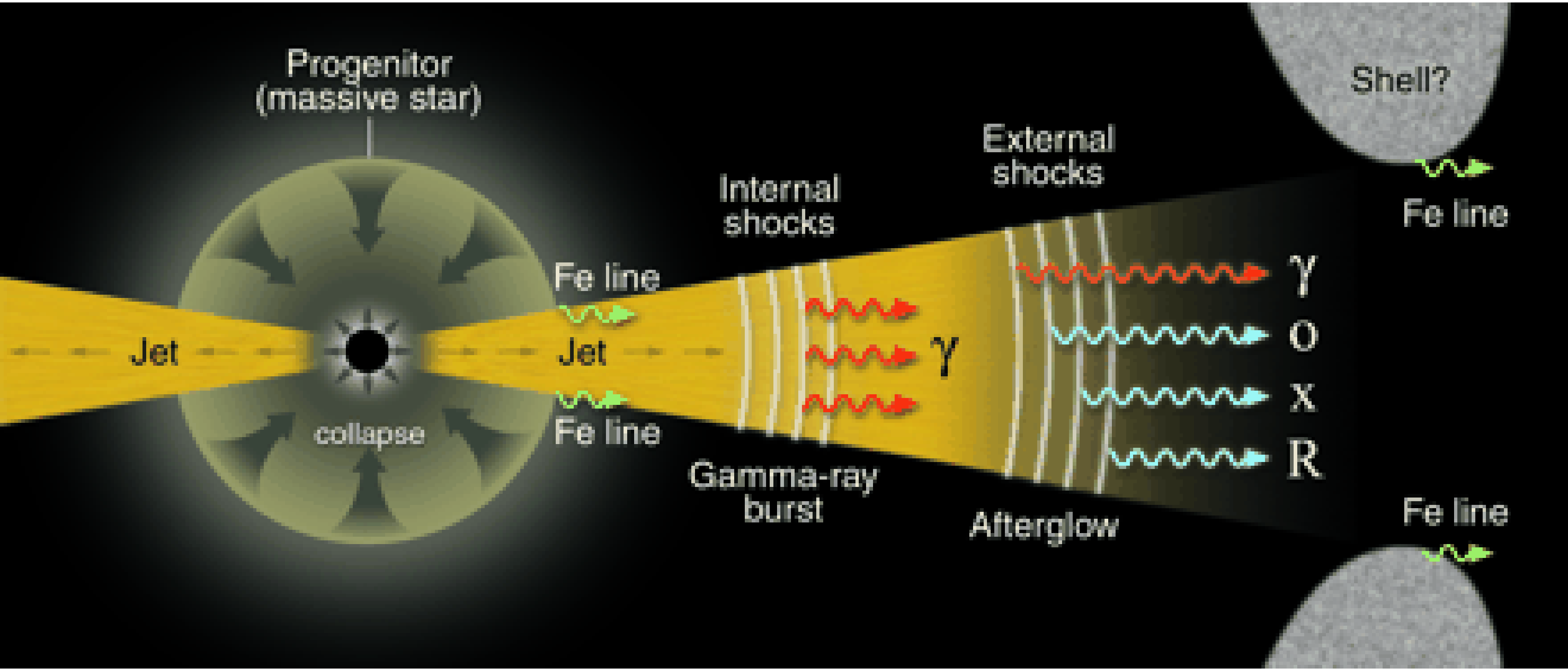
Supernovae/GRB connection



Supernovae/GRB connection

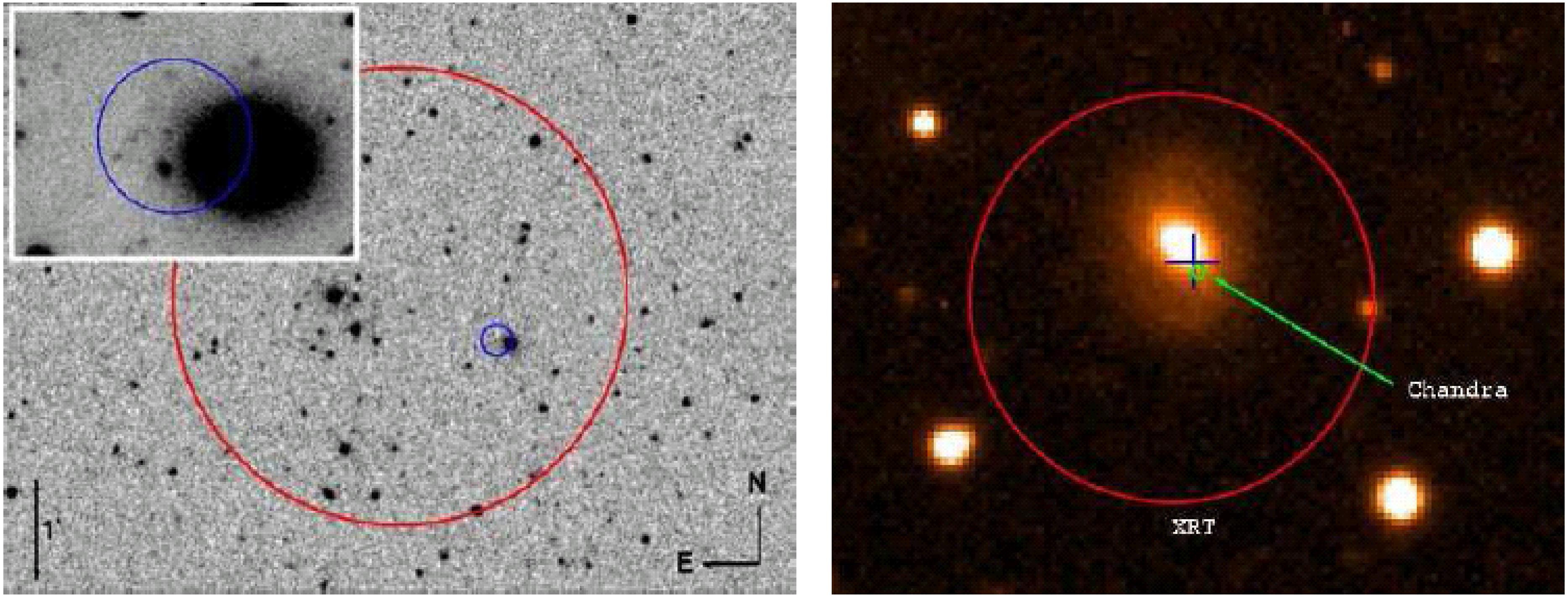


Massive Star Collapse



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

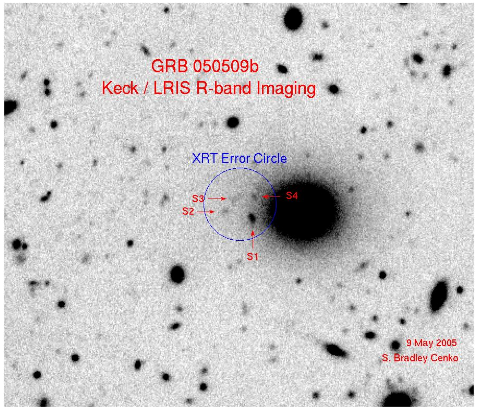
Short GRBs



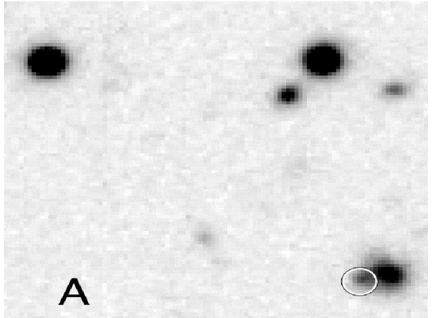
Short GRBs associated with elliptical galaxies. *left:* GRB 050509B; z=0.226 (Gehrels et al. 2005; Bloom et al. 2006a), the red and blue circles are BAT and XRT error boxes, respectively; *Right:* GRB 050724; z=0.257 (Barthelmy et al. 2005b; Berger et al. 2005a)

Host Galaxies of Short GRBs

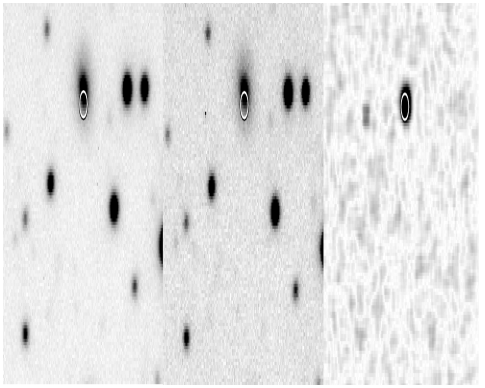
GRB050509



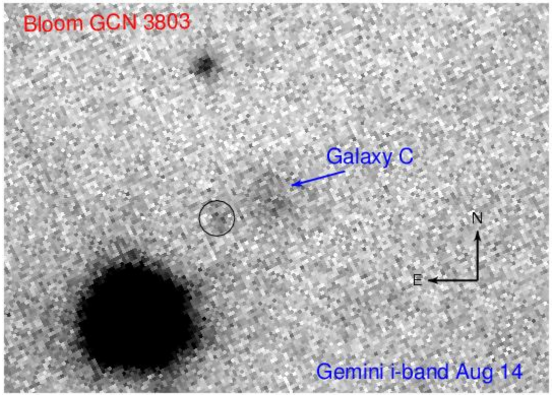
GRB050709



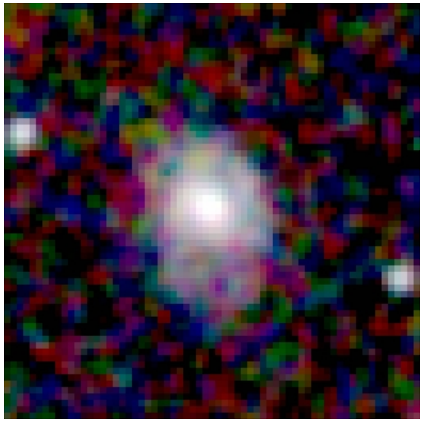
GRB050724



GRB050813



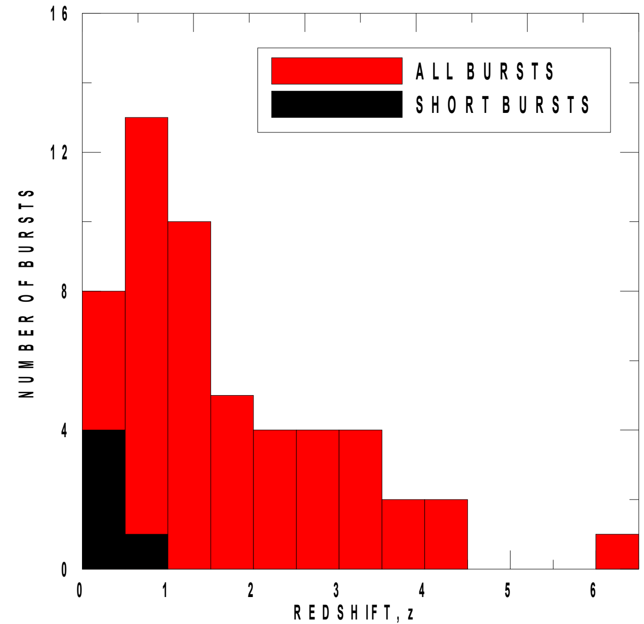
GRB050906



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



Properties of Short GRBs

GRB	Mission	T_{90}(s)	z	Host galaxy	Location	Refs
050509B	Swift	0.04 ± 0.004	0.226	elliptical	outskirts?	[1, 2]
050709	HETE	0.07 ± 0.01	0.1606	irregular	outskirts	[3–5]
050724	Swift	3.0 ± 1.0	0.257	elliptical	outskirts	[6–9]
050813	Swift	0.6 ± 0.1	–	–	–	[10]
050911*	Swift	~ 16	0.1646?	galaxy cluster?	–	[11, 12]
051210	Swift	1.4 ± 0.2	–	–	–	[13]
051221A	Swift	1.4 ± 0.2	0.5465	star forming galaxy	slightly off-center	[14, 15]
051227∗	Swift	8.0 ± 0.2	–	–	–	[16, 17]
060121	HETE	4.25 ± 0.56	1.7? or 4.6?	early-type?	outskirts?	[18–20]
060313	Swift	0.7 ± 0.1	–	–	–	[21]
060502B	Swift	0.09 ± 0.02	0.287?	early-type?	outskirts?	[22, 23]
060505	Swift	4.0 ± 1.0	0.089?	star-forming galaxy	–	[24–26]
060614*	Swift	102 ± 5	0.125	star-forming galaxy	off-center	[27, 28]
060801	Swift	~ 0.50	1.1304??	–	–	[29, 30]
061006	Swift	~ 0.42	–	–	–	[31, 30]

Short hard GRBs are different class than Long-duration GRBs on the basis of:

Host galaxies

Energies

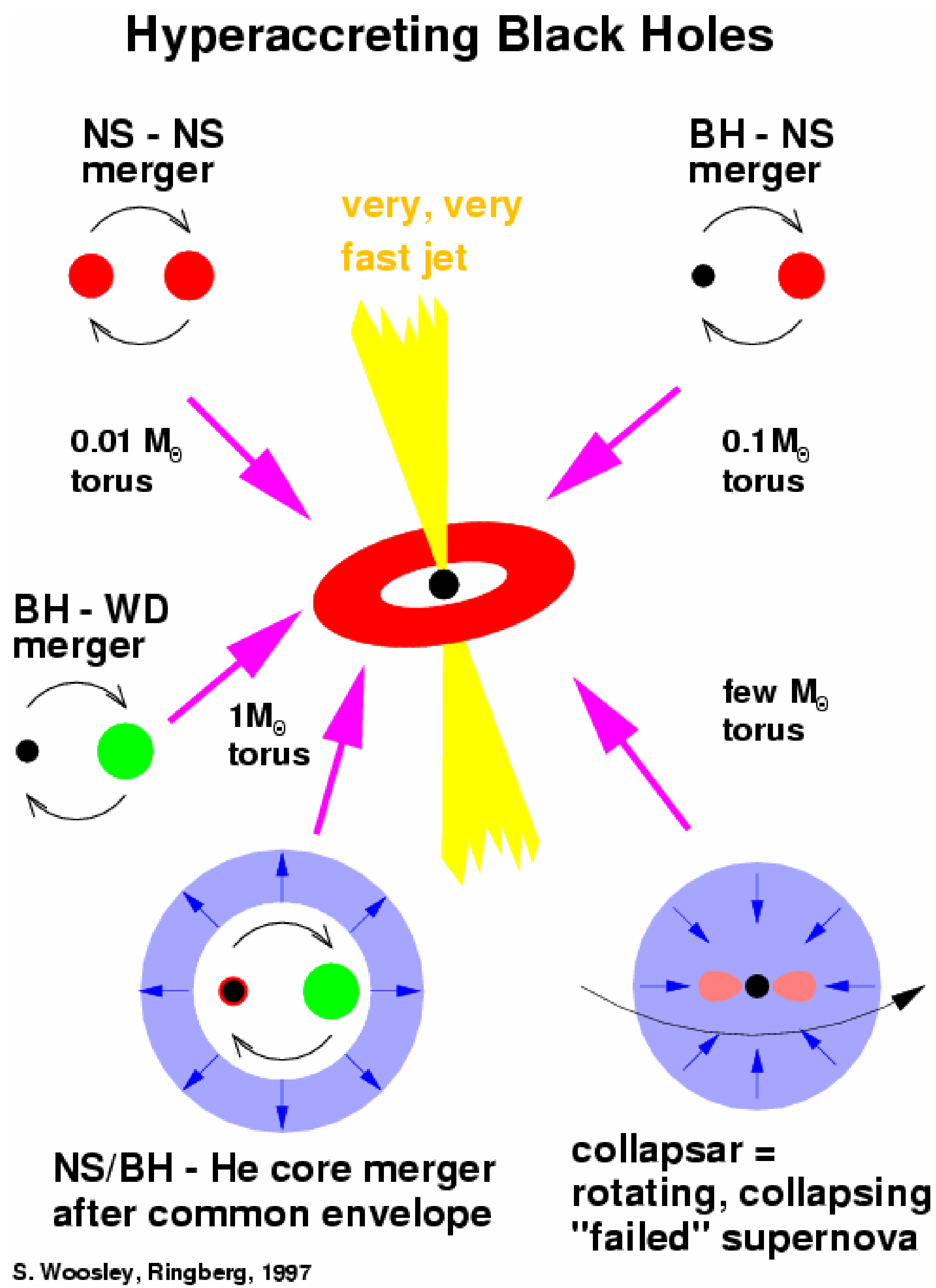
Redshift distribution

Lag-luminosity relation

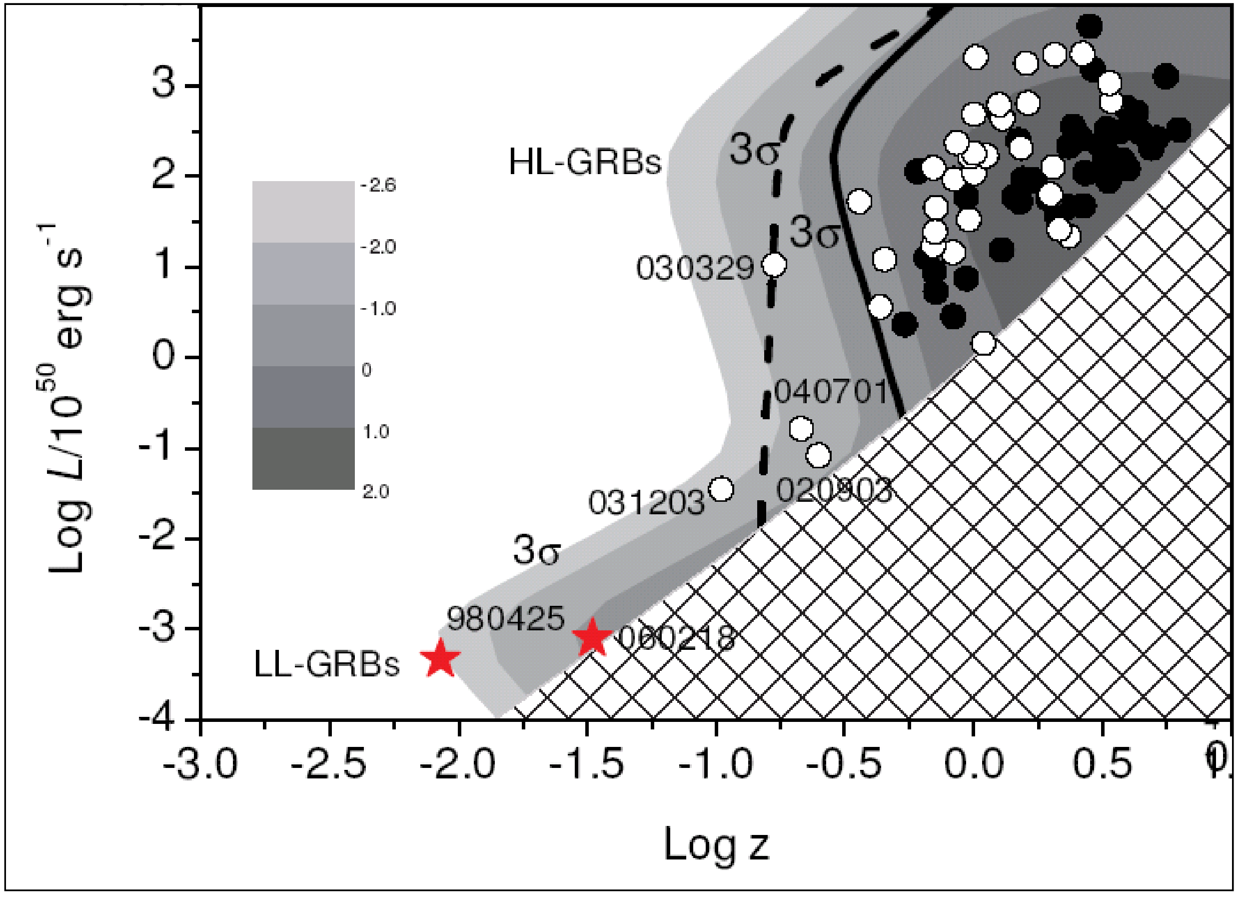
Mergers

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.



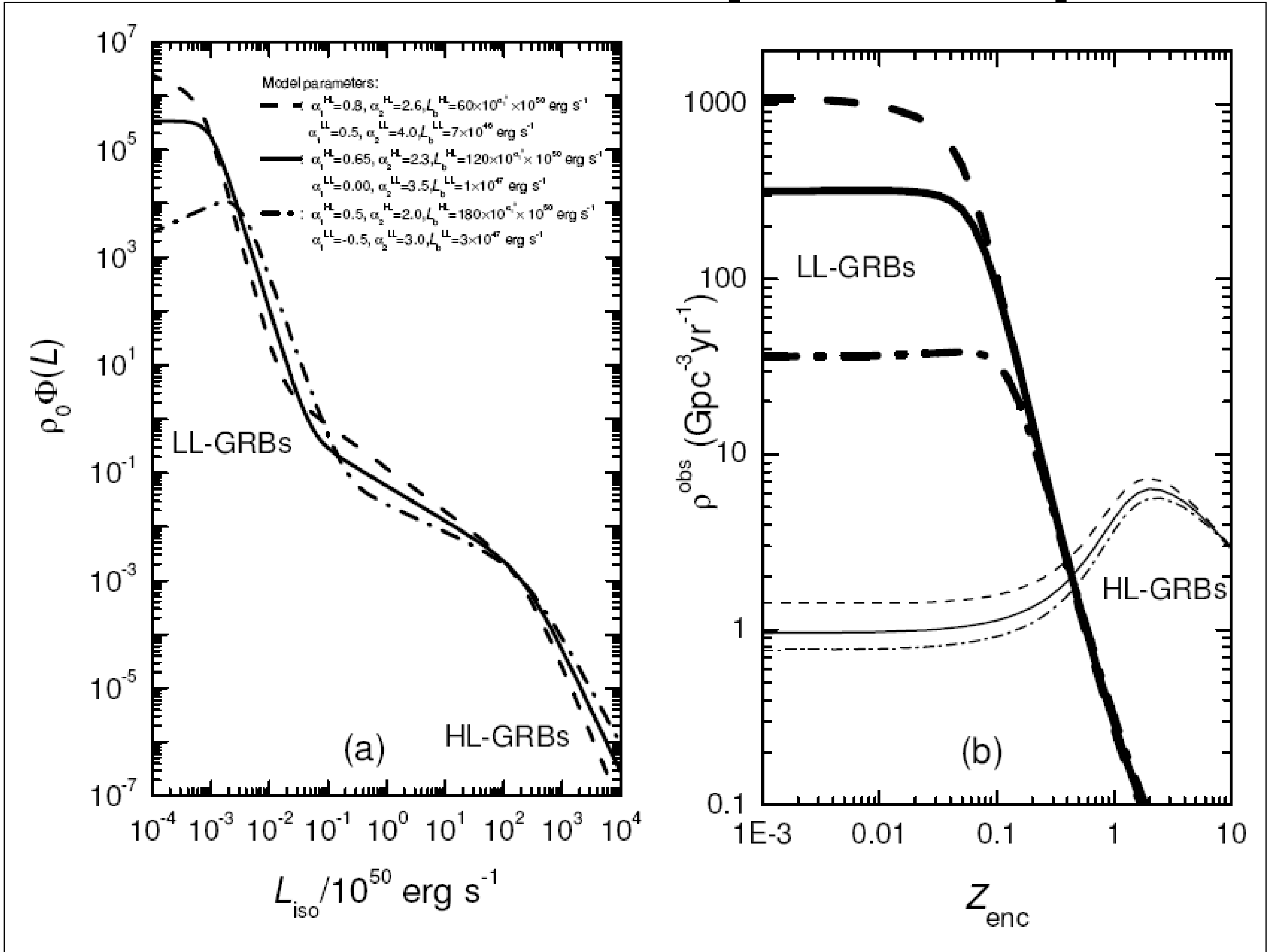
Low Luminosity GRBs



GRB 980425: z = 0.0085
GRB 060218: z = 0.0331

Zhang (2007)

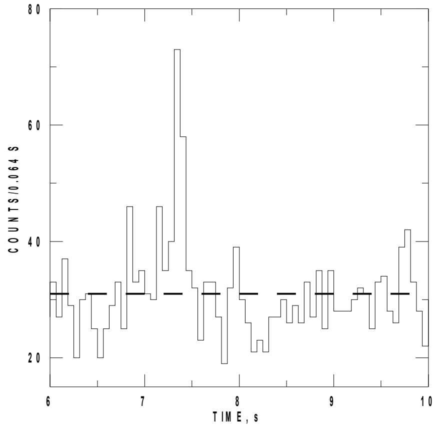
LLGRBs as a Separate Population

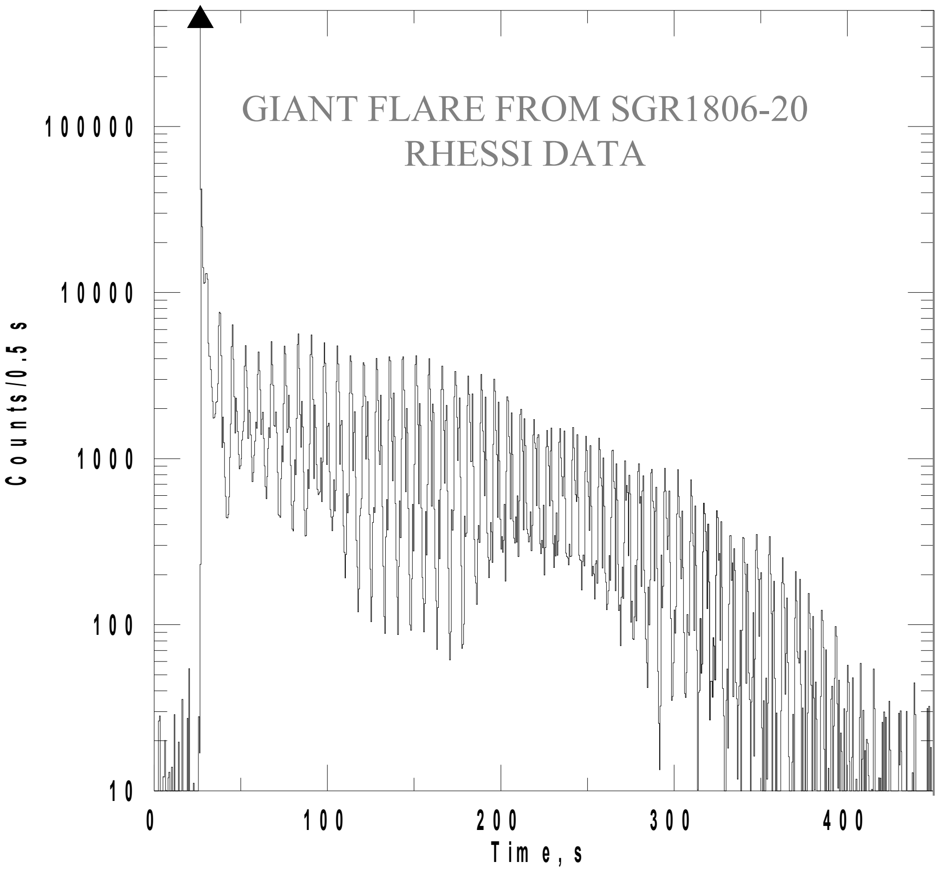


Event rate density: long GRBs ~ 1/Gpc^3-yr versus LLGRBs: ~ 800/Gpc^3-yr

Redshift and luminosity distribution suggest a separate population

Soft Gamma Repeaters





Extraordinary SGR event of Dec. 27, 2004

Begin with ~0.2 s long, hard spectrum spikes with E~10^{46}-10^{47} erg

The spike is followed by a pulsating tail with ~1/1000th of the energy

Viewed from a large distance, only the initial spike would be visible

It would resemble a short GRB

It could be detected out to 100 Mpc

GRB050906 at z=0.03 could be a magnetar flare