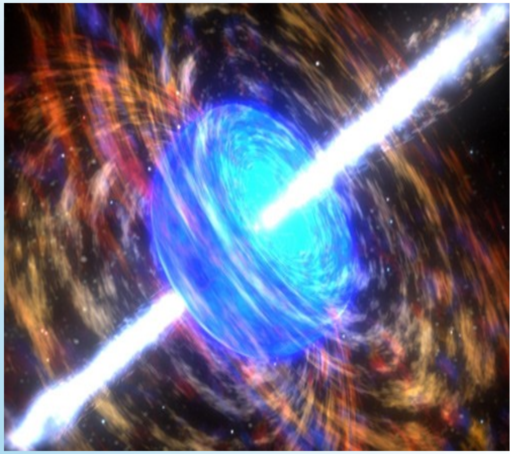
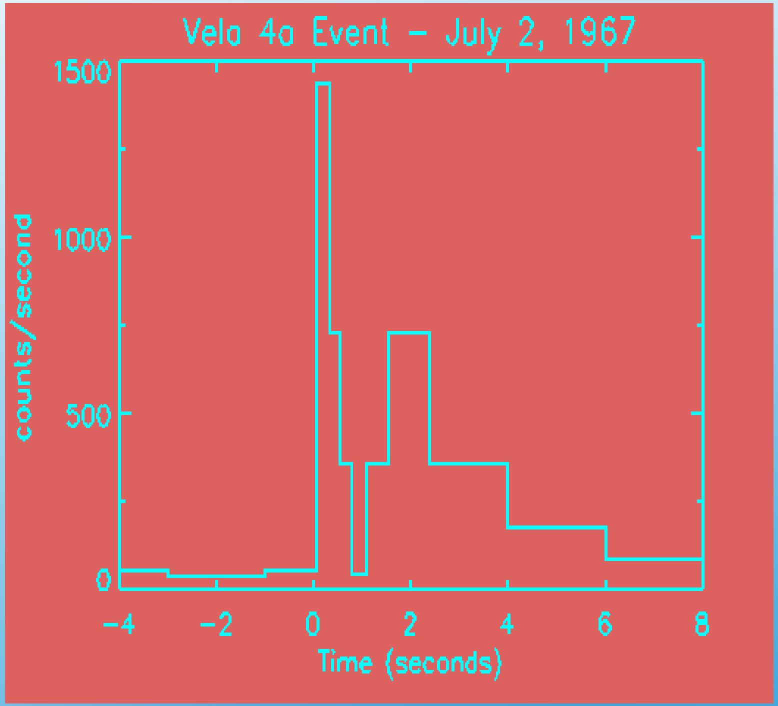
The Supernova – Gamma-Ray Burst Connection



Jesper Sollerman, Stockholm University
Department of Astronomy & The Oskar Klein centre

Explosive ideas About Massive Stars – from observations to Modeling, Stockholm Aug. 10-13 2011



Vela 4a Event - July 2, 1967
1500
1000
500
0
counts/second
-4
-2
0
2
4
6
8
Time (seconds)

around 6.5 s. For each record this peak is statistically significant to about 6 standard deviations. It represents integrated flux densities of 10^{-5} ergs cm^{-2} and 4×10^{-6} ergs cm^{-2} in the lower and higher energy ranges, respectively. The spectrum is clearly softer than that of the initial part of the burst.

IV. DISCUSSION

A search was made for reports of a nova or supernova within a reasonable time ($\sim$ several weeks) of each gamma-ray burst. No reported novae were related in time or direction to any of the bursts. Only two reported supernovae reached maximum apparent magnitude within a few days of an observed burst. In both cases, however, reports of prediscovery observations were later made which preceded the gamma-ray burst by at least several days. In addition, the source positions derived from preliminary timing data are inconsistent with the locations of the supernovae.

The lack of correlation between gamma-ray bursts and reported supernovae does not conclusively argue against such an association, since it is possible that there are supernovae, not necessarily bright in the optical region ("theoreticians' supernovae"), whose rate of occurrence may exceed those which are optically visible (see, e.g., Thorne 1969). A source at a distance of 1 Mpc would need to emit $\sim 10^{46}$ ergs in the form of electromagnetic radiation between 0.2 and 1.5 MeV in order to produce the level of response observed here. Since this represents only a small fraction ($< 10^{-3}$) of the energy usually associated with supernovae, the energy observed is not inconsistent with a supernova as a source.

The authors wish to acknowledge the interest shown in the past by Edward Teller, Stirling Colgate, and A. G. W. Cameron who have on a number of occasions encouraged us to look for bursts of energetic photons.

We also wish to thank J. H. Coon and all of our colleagues in the Space Science Group at Los Alamos who have helped with this work. The detector electronics were the responsibility of the Space Electronics section at Los Alamos, under the direction of J. P. Glore. Logics were developed by the Satellite Systems Division at Sandia Laboratories; in particular we wish to mention R. E. Spalding, G. J. Dodrill, and J. G. Mitchell.

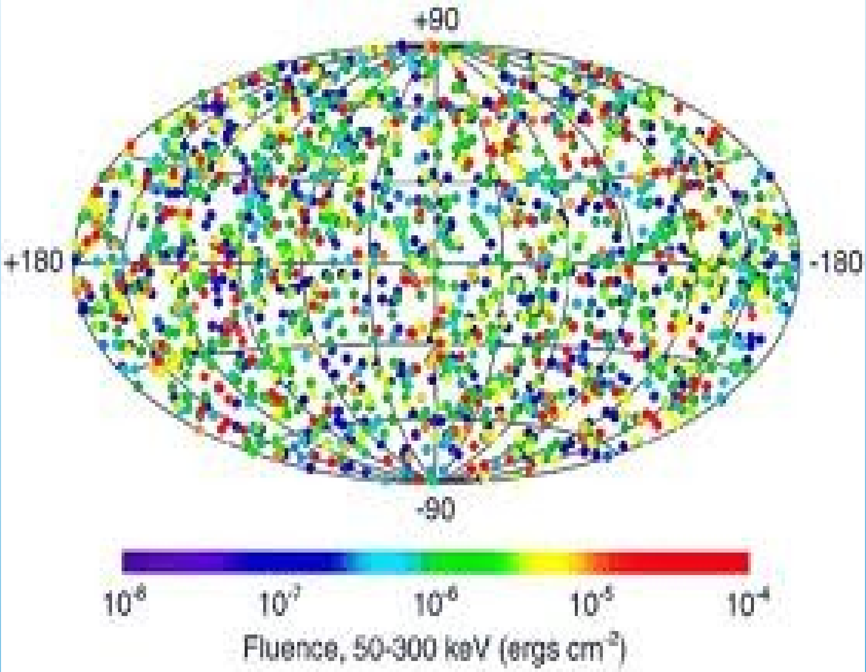
This research was performed as part of the Vela Satellite Program, which is jointly sponsored by the U.S. Department of Defense and the U.S. Atomic Energy Commission. The program is managed by the U.S. Air Force, and satellite operation activities are under the jurisdiction of the Air Force Satellite Control Facility, Sunnyvale, California.

REFERENCES

Colgate, S. A. 1968, *Canadian J. Phys.*, **46**, S476.
Thorne, K. S. 1969, in *Supernovae and Their Remnants*, ed. Peter J. Brancazio and A. G. W. Cameron (New York: Gordon & Breach).

($\sim$ several weeks) of each gamma-ray burst. No reported novae were related in time or direction to any of the bursts. Only two reported supernovae reached maximum apparent magnitude within a few days of an observed burst. In both cases, however, reports of prediscovery observations were later made which preceded the gamma-ray burst by at least several days. In addition, the source positions derived from preliminary timing data are inconsistent with the locations of the supernovae.
The lack of correlation between gamma-ray bursts and reported supernovae does not conclusively argue against such an association, since it is possible that there are supernovae, not necessarily bright in the optical region ("theoreticians' supernovae"), whose rate of occurrence may exceed those which are optically visible (see, e.g., Thorne 1969). A source at a distance of 1 Mpc would need to emit $\sim 10^{46}$ ergs in

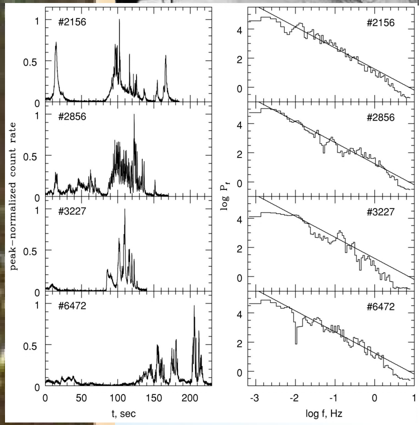
Klebesadel, Strong & Olson, 1973, ApJ



BATSE

#	Author	Year Pub	Reference	Main Body	2nd Body	Place	Description
1.	Colgate	1968	CJPhys, 46, S476	ST		COS	SN shocks stellar surface in distant galaxy
2.	Colgate	1974	ApJ, 187, 333	ST		COS	Type II SN shock brem, inv Comp scat at stellar surface
3.	Stecker et al.	1973	Nature, 245, PS70	ST		DISK	Stellar superflare from nearby star
4.	Stecker et al.	1973	Nature, 245, PS70	WD		DISK	Superflare from nearby WD
5.	Harwit et al.	1973	ApJ, 186, L37	NS	COM	DISK	Relic comet perturbed to collide with old galactic NS
6.	Lamb et al.	1973	Nature, 246, PS52	WD	ST	DISK	Accretion onto WD from flare in companion
7.	Lamb et al.	1973	Nature, 246, PS52	NS	ST	DISK	Accretion onto NS from flare in companion
8.	Lamb et al.	1973	Nature, 246, PS52	BH	ST	DISK	Accretion onto BH from flare in companion
9.	Zwicky	1974	Ap & SS, 28, 111	NS		HALO	NS chunk contained by external pressure escapes, explodes
10.	Grindlay et al.	1974	ApJ, 187, L93	DG		SOL	Relativistic iron dust grain up-scatters solar radiation
11.	Brecher et al.	1974	ApJ, 187, L97	ST		DISK	Directed stellar flare on nearby star
12.	Schlovskii	1974	SovAstron, 18, 390	WD	COM	DISK	Comet from system's cloud strikes WD
13.	Schlovskii	1974	SovAstron, 18, 390	NS	COM	DISK	Comet from system's cloud strikes NS
14.	Bisnovatyi- et al.	1975	Ap & SS, 35, 23	ST		COS	Absorption of neutrino emission from SN in stellar envelope
15.	Bisnovatyi- et al.	1975	Ap & SS, 35, 23	ST	SN	COS	Thermal emission when small star heated by SN shock wave
16.	Bisnovatyi- et al.	1975	Ap & SS, 35, 23	NS		COS	Ejected matter from NS explodes
17.	Pacini et al.	1974	Nature, 251, 399	NS		DISK	NS crustal starquake glitch; should time coincide with GRB
18.	Narlikar et al.	1974	Nature, 251, 590	WH		COS	White hole emits spectrum that softens with time
19.	Tsygan	1975	A&A, 44, 21	NS		HALO	NS corequake excites vibrations, changing E & B fields
20.	Chanmugam	1974	ApJ, 193, L75	WD		DISK	Convection inside WD with high B field produces flare
21.	Prilutski et al.	1975	Ap & SS, 34, 395	AGN	ST	COS	Collapse of supermassive body in nucleus of active galaxy
22.	Narlikar et al.	1975	Ap & SS, 35, 321	WH		COS	WH excites synchrotron emission, inverse Compton scattering
23.	Piran et al.	1975	Nature, 256, 112	BH		DISK	Inv Comp scat deep in ergosphere of fast rotating, accreting BH
24.	Fabian et al.	1976	Ap & SS, 42, 77	NS		DISK	NS crustquake shocks NS surface
25.	Chanmugam	1976	Ap & SS, 42, 83	WD		DISK	Magnetic WD suffers MHD instabilities, flares
26.	Mullan	1976	ApJ, 208, 199	WD		DISK	Thermal radiation from flare near magnetic WD
27.	Woosley et al.	1976	Nature, 263, 101	NS		DISK	Carbon detonation from accreted matter onto NS
28.	Lamb et al.	1977	ApJ, 217, 197	NS		DISK	Mag grating of accret disk around NS causes sudden accretion
29.	Piran et al.	1977	ApJ, 214, 268	BH		DISK	Instability in accretion onto rapidly rotating BH
30.	Dasgupta	1979	Ap & SS, 63, 517	DG		SOL	Charged intergal rel dust grain enters sol sys, breaks up
31.	Tsygan	1980	A&A, 87, 224	WD		DISK	WD surface nuclear burst causes chromospheric flares
32.	Tsygan	1980	A&A, 87, 224	NS		DISK	NS surface nuclear burst causes chromospheric flares
33.	Ramaty et al.	1981	Ap & SS, 75, 193	NS		DISK	NS vibrations heat atm to pair produce, annihilate, synch cool
34.	Newman et al.	1980	ApJ, 242, 319	NS	AST	DISK	Asteroid from interstellar medium hits NS
35.	Ramaty et al.	1980	Nature, 287, 122	NS		HALO	NS core quake caused by phase transition, vibrations
36.	Howard et al.	1981	ApJ, 249, 302	NS	AST	DISK	Asteroid hits NS, B-field confines mass, creates high temp
37.	Mitrofanov et al.	1981	Ap & SS, 77, 469	NS		DISK	Helium flash cooled by MHD waves in NS outer layers
38.	Colgate et al.	1981	ApJ, 248, 771	NS	AST	DISK	Asteroid hits NS, tidally disrupts, heated, expelled along B lines
39.	van Buren	1981	ApJ, 249, 297	NS	AST	DISK	Asteroid enters NS B field, dragged to surface collision
40.	Kuznetsov	1982	CosRes, 20, 72	MG		SOL	Magnetic reconnection at heliopause
41.	Katz	1982	ApJ, 260, 371	NS		DISK	NS flares from pair plasma confined in NS magnetosphere
42.	Woosley et al.	1982	ApJ, 258, 716	NS		DISK	Magnetic reconnection after NS surface He flash
43.	Fryxell et al.	1982	ApJ, 258, 733	NS		DISK	He fusion runaway on NS B-pole helium lake
44.	Hameury et al.	1982	A&A, 111, 242	NS		DISK	e- capture triggers H flash triggers He flash on NS surface
45.	Mitrofanov et al	1982	MNRAS, 200, 1033	NS		DISK	B induced cyclo res in rad absorp giving rel e-s, inv C scat
46.	Fenimore et al.	1982	Nature, 297, 665	NS		DISK	BB X-rays inv Comp scat by hotter overlying plasma
47.	Lipunov et al.	1982	Ap & SS, 85, 459	NS	ISM	DISK	ISM matter accum at NS magnetopause then suddenly accretes
48.	Baan	1982	ApJ, 261, L71	WD		HALO	Nonexplosive collapse of WD into rotating, cooling NS
49.	Ventura et al.	1983	Nature, 301, 491	NS	ST	DISK	NS accretion from low mass binary companion
50.	Bisnovatyi- et al.	1983	Ap & SS, 89, 447	NS		DISK	Neutron rich elements to NS surface with quake, undergo fission
51.	Bisnovatyi- et al.	1984	SovAstron, 28, 62	NS		DISK	Thermonuclear explosion beneath NS surface
52.	Ellison et al.	1983	A&A, 128, 102	NS		HALO	NS corequake + uneven heating yield SGR pulsations
53.	Hameury et al.	1983	A&A, 128, 369	NS		DISK	B field contains matter on NS cap allowing fusion
54.	Bonazzola et al.	1984	A&A, 136, 89	NS		DISK	NS surface nuc explosion causes small scale B reconnection
55.	Michel	1985	ApJ, 290, 721	NS		DISK	Remnant disk ionization instability causes sudden accretion

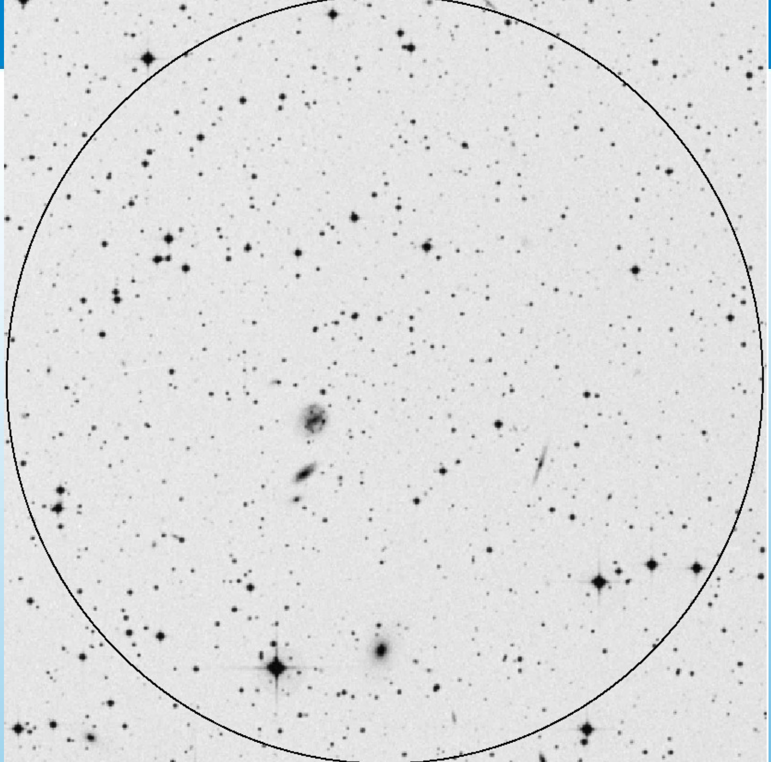
Nemiroff 1993



Jesper Sollerman, Supernovae and Gamma-Ray Bursts:
Stockholm Aug. 10 2011

Jesper Sollerman, **Supernovae and Gamma-Ray Bursts:**

Stockholm Aug. 10 2011



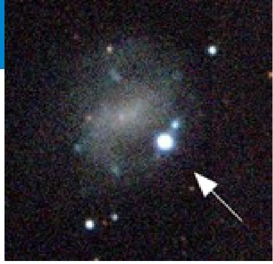
supernova community has bought this identification hook, line, and sinker, based on the odd properties of the supernova. The γ-ray burst community remains substantially suspicious despite the low *a priori* probability, $\sim 10^{-4}$ (Galama et al. 1998), of an

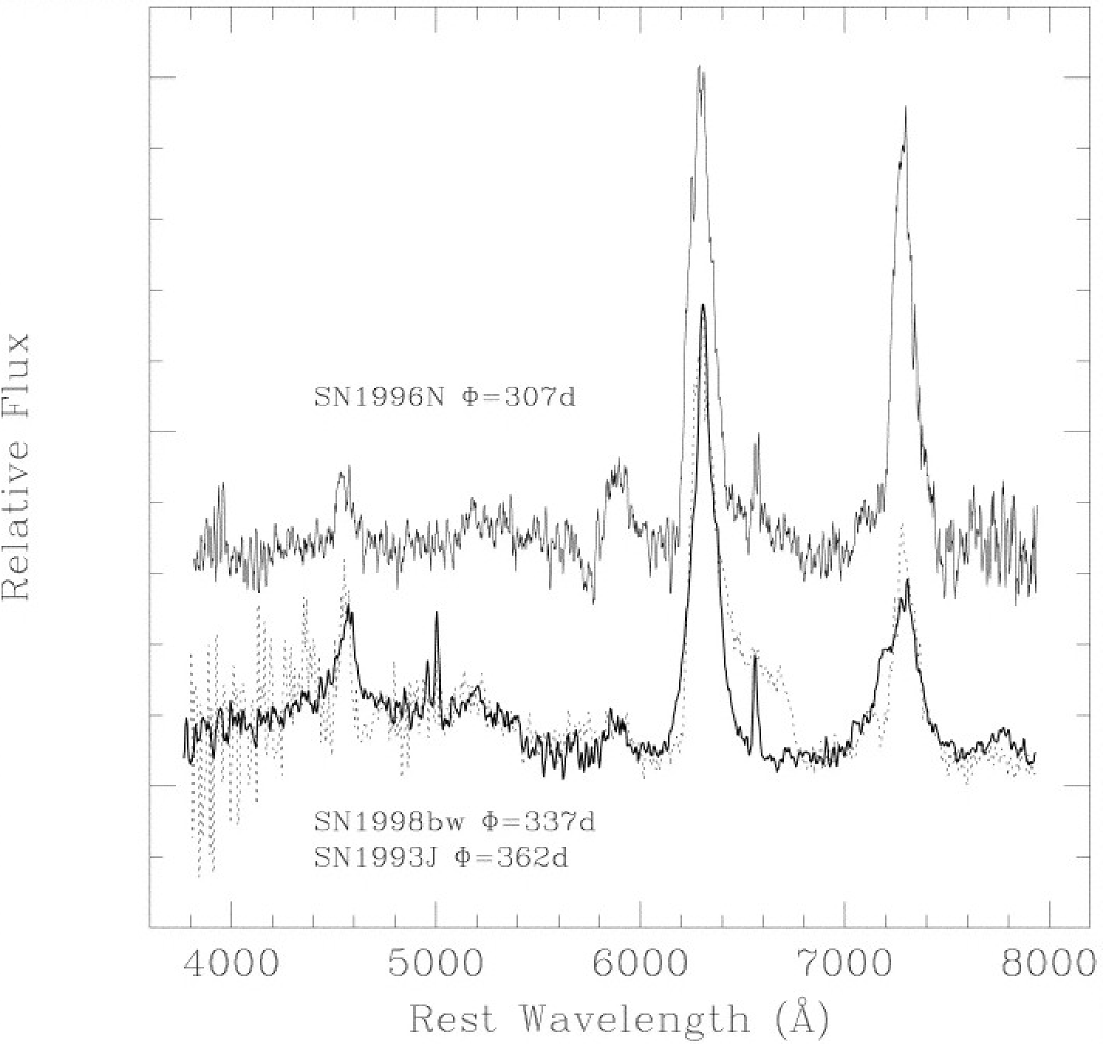
J.C. Wheeler, 1999

GRB 980425
=
SN 1998bw

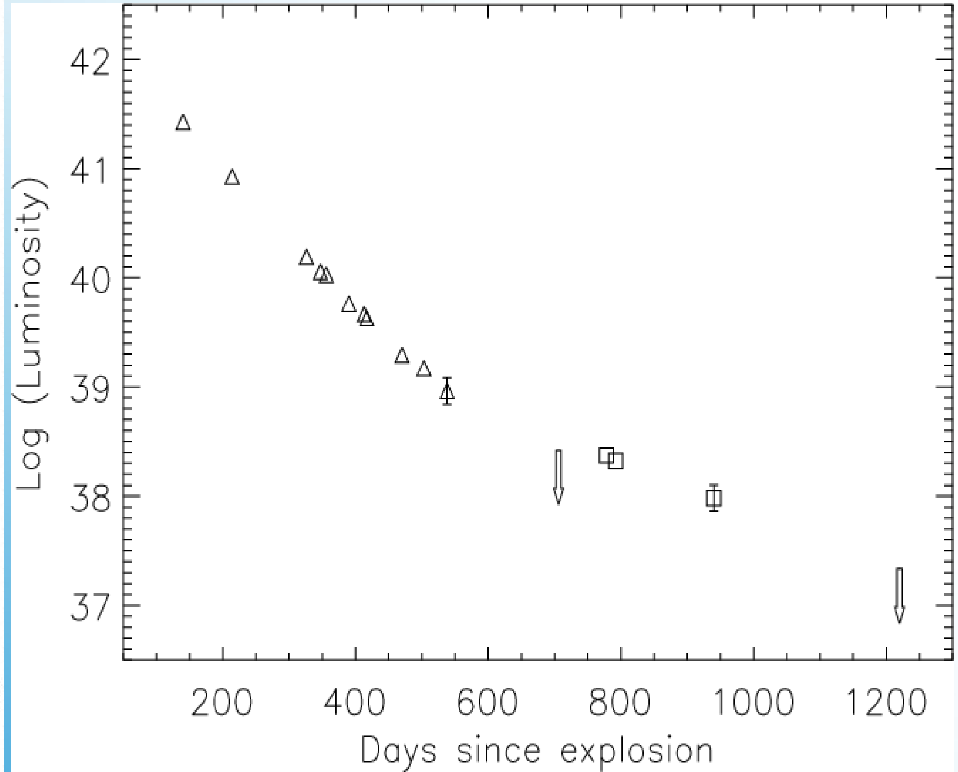
Jesper Sollerman, **Supernovae and Gamma-Ray Bursts:**
Stockholm Aug. 10 2011

SN 1998bw





Patat, Cappellaro, Danziger, Mazzali, Sollerman, et al. 2001, ApJ

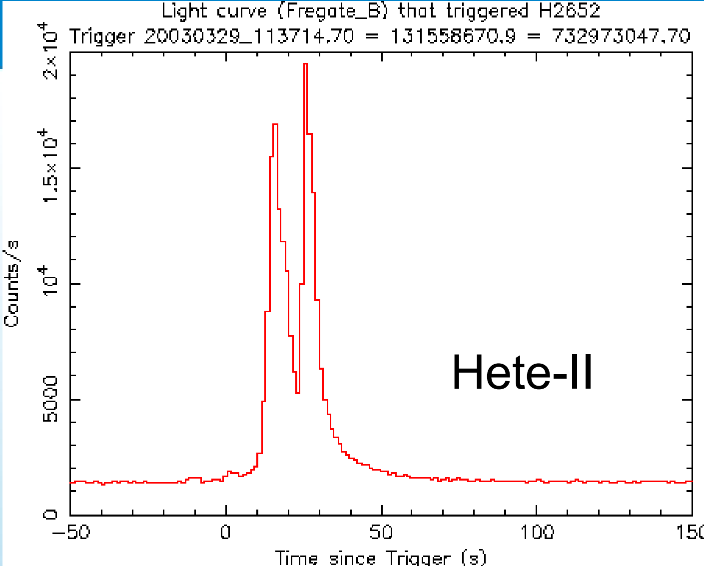


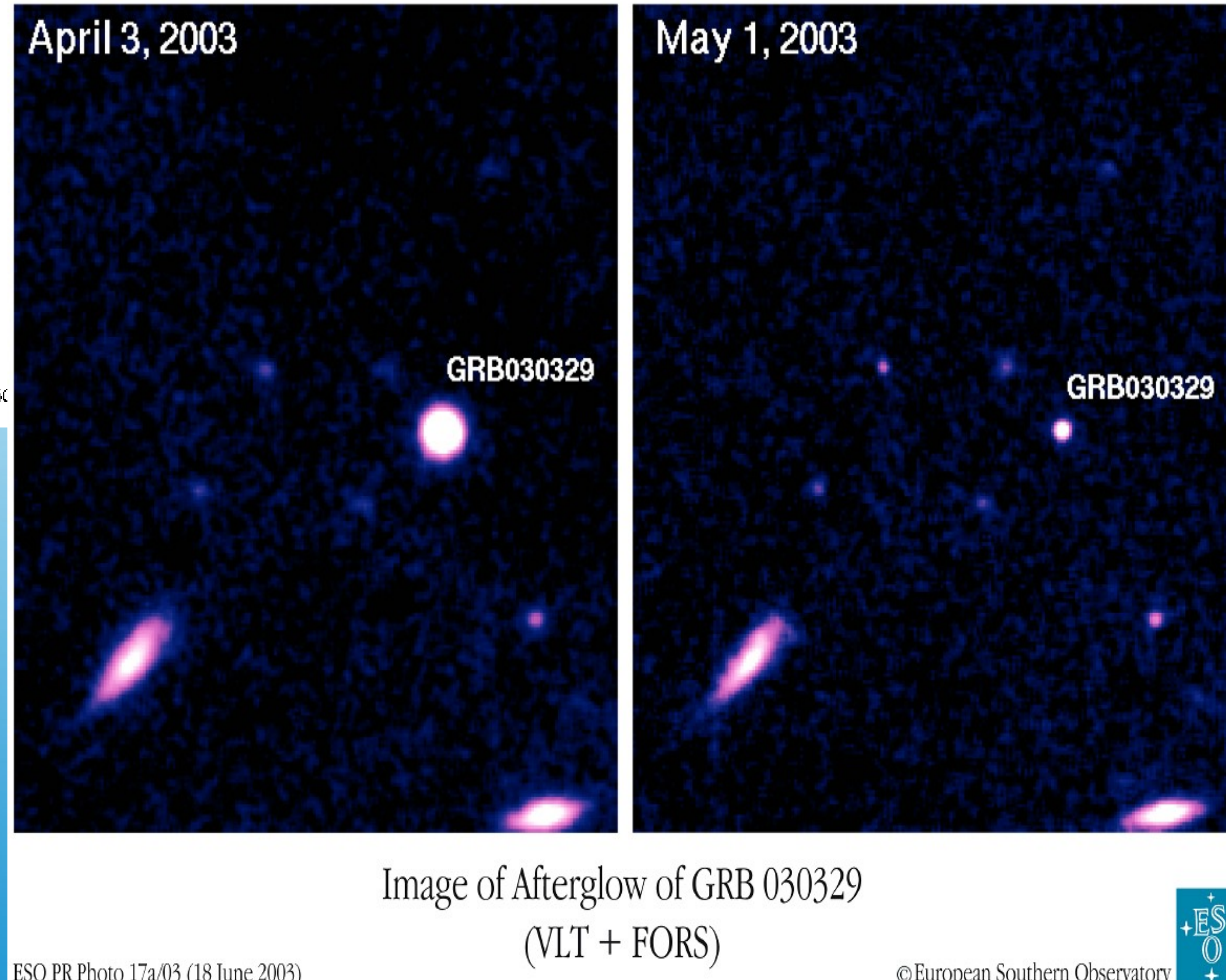
Sollerman, Holland, Challis, Fransson, et al. 2002, A&A

Bumps and Humps, Host galaxies, Speculations...

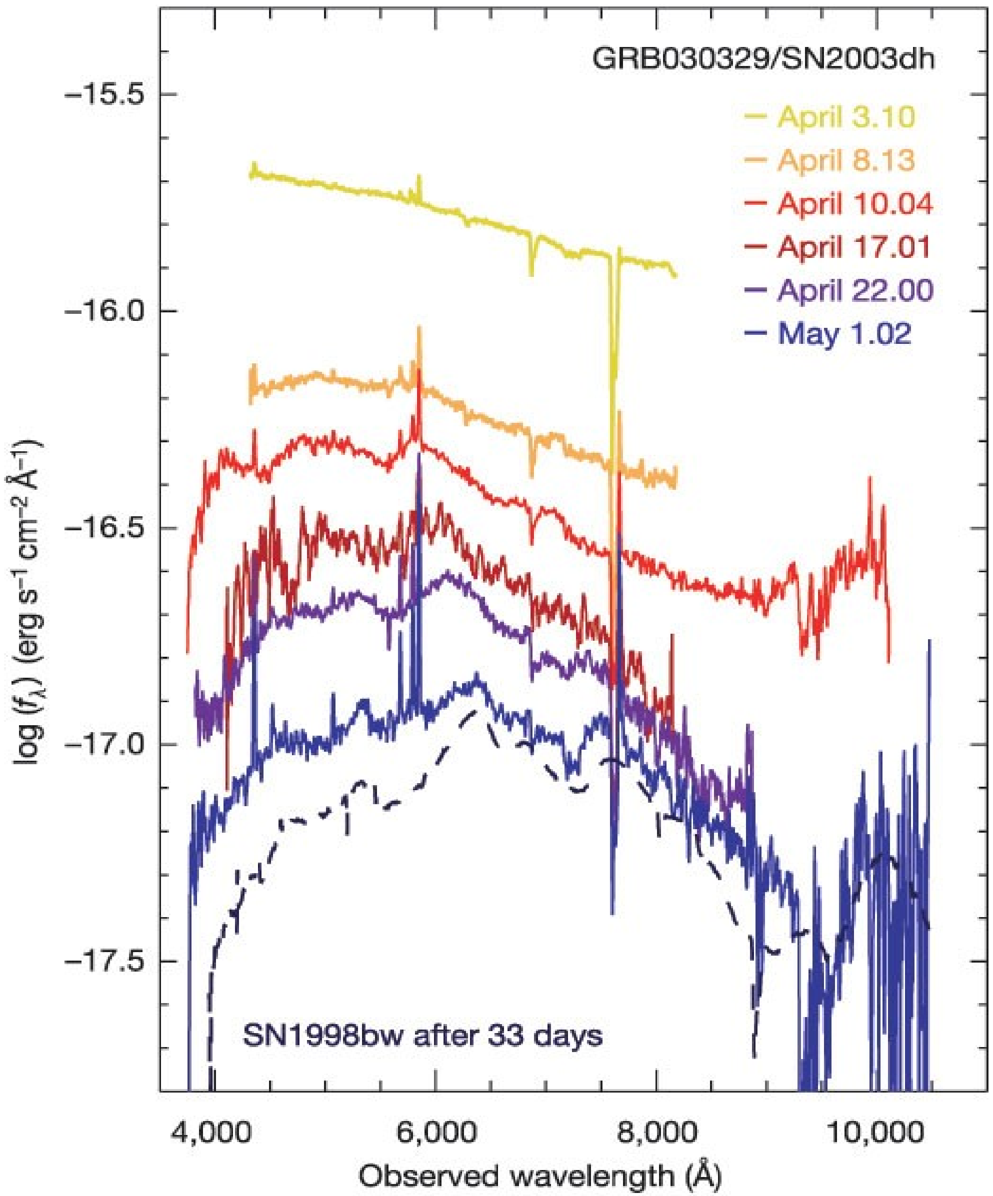
Jesper Sollerman, Supernovae and Gamma-Ray Bursts:

Stockholm   Aug. 10 2011


Light curve (Fregate_B) that triggered H2652
Trigger 20030329_113714.70 = 131558670.9 = 732973047.70
Counts/s
0
5000
10^4
1.5×10^4
2×10^4
−50
0
50
100
150
Time since Trigger (s)
Hete-II

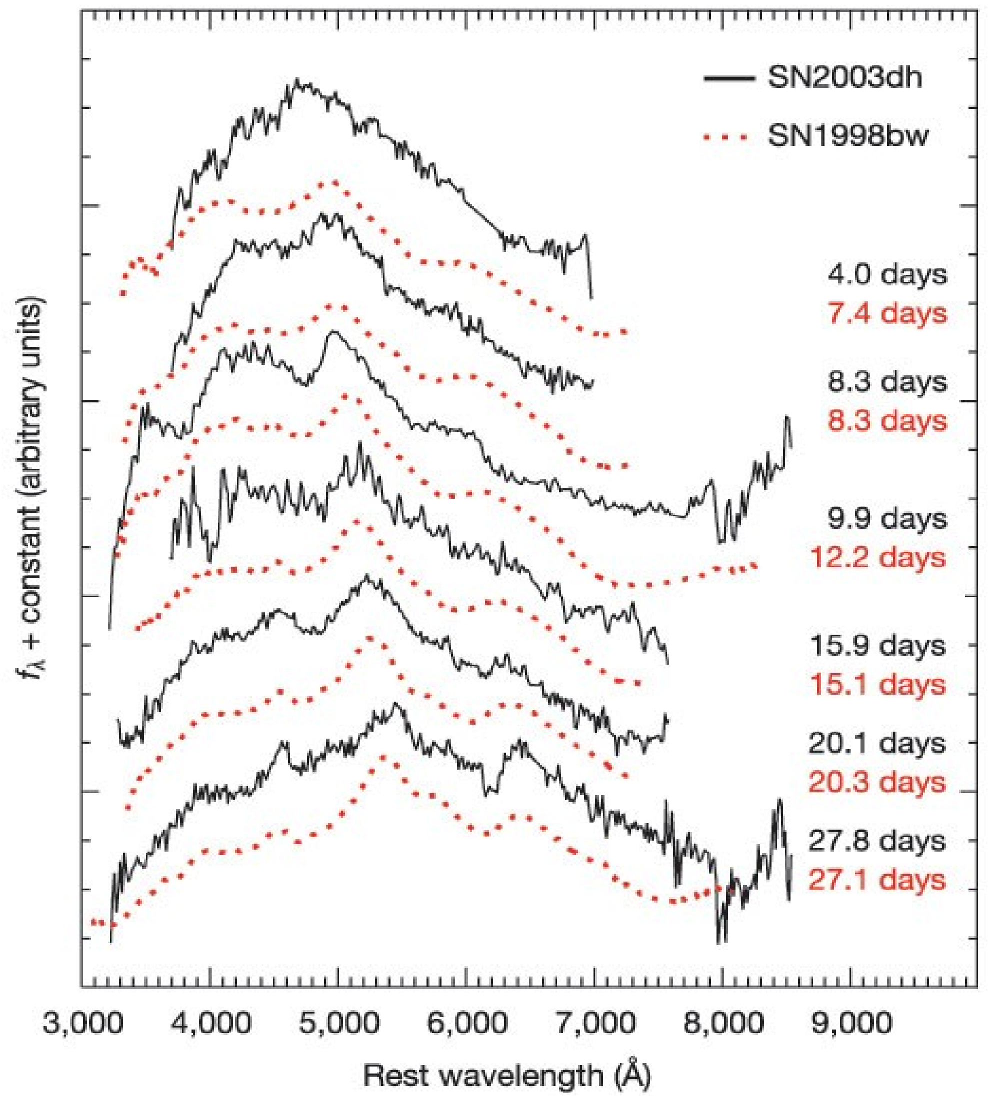

April 3, 2003
May 1, 2003
GRB030329
GRB030329
Image of Afterglow of GRB 030329
(VLT + FORS)
ESO PR Photo 17a/03 (18 June 2003)
©European Southern Observatory
ESO

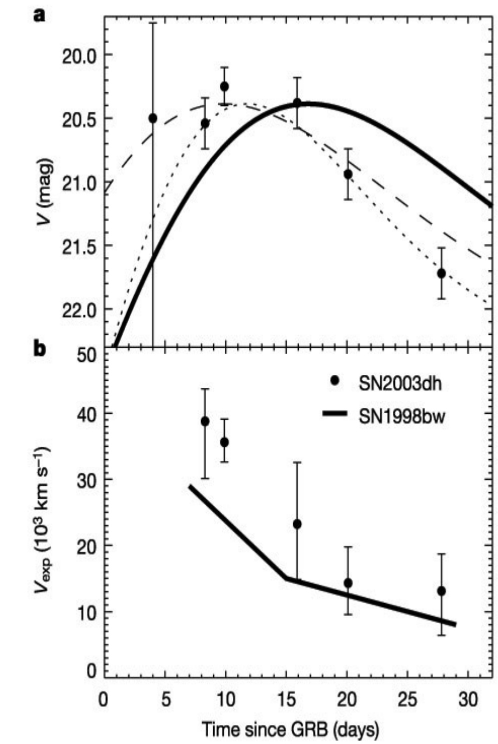
GRB 030329



GRB 030329
=
SN 2003dh

Hjorth, Sollerman, Moller et al. 2003, Nature



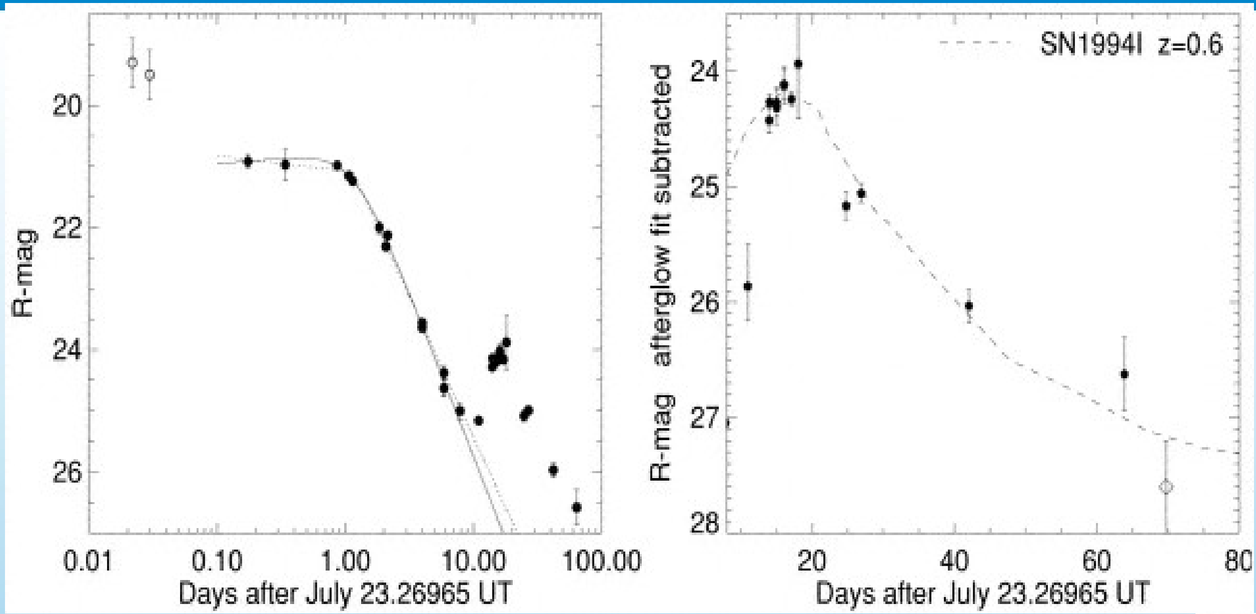


Hjorth, Sollerman, Moller et al. 2003, Nature

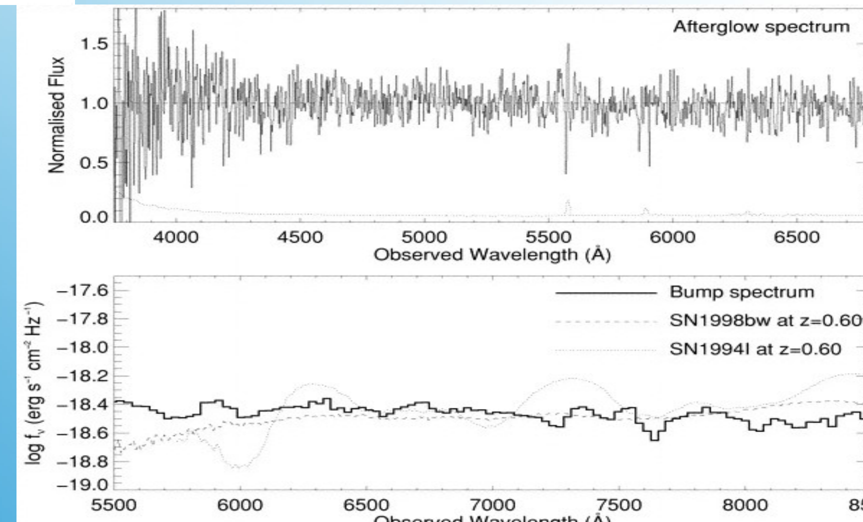
Table 9.1. *Evidence for GRB-SNe.*

GRB/XRF	SN Designation	z	Evidence	Comments	Refs.
970228		0.695	C		1,2
980326			D	red bump	3,4
980425	1998bw	0.0085	A	spectroscopic SN	5
990712		0.433	C		6
991208		0.706	E	low significance	7
000911		1.058	E	low significance	8,9
011121	2001ke	0.362	B	spectral features	10,11,12
020305			E	not fitted by GRB-SNe	13
020405		0.691	C	red bump	14,15
020410			D	discovered via bump	16
020903		0.251	B	spectral features	17,18
021211	2002lt	1.006	B	spectral features	19
030329	2003dh	0.1685	A	spectroscopic SN	20,21,22
030723			D	red bump, X-ray excess	23,24
031203	2003lw	0.1055	A	spectroscopic SN	25
040924		0.859	C		26,27
041006		0.716	C		26,28
050416A		0.654	D	poor sampling	29
050525A	2005nc	0.606	B	spectral features	30
050824		0.828	E	low significance	31
060218	2006aj	0.0334	A	spectroscopic SN	32,33,34
060729		0.543	E	afterglow dominated	35,36
070419A		0.971	D	poor sampling	35,37,38
080319B		0.938	C	multiple color bump	35,39,40,41
081007	2008hw	0.530	B	spectral features	42,43,44
090618		0.54	C		36,45
091127	2009nz	0.490	C		46
100316D	2010bh	0.0591	A	spectroscopic SN	47,48
100418A		0.624	D		49
101219B		0.552	B	spectral features	50,51,52

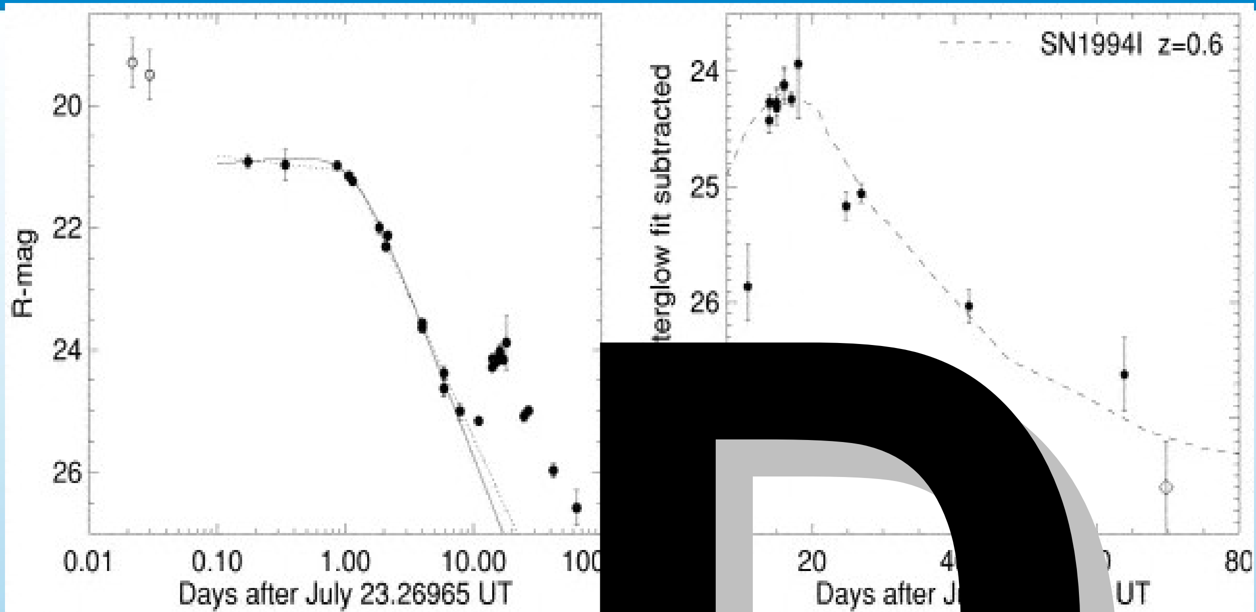
The evidence according to the authors for a SN associated with a GRB is listed in column (4) according to the following scale: A: Strong spectroscopic evidence. B: A clear light curve bump as well as some spectroscopic evidence resembling a GRB-SN. C: A clear bump consistent with other GRB-SNe at the spectroscopic



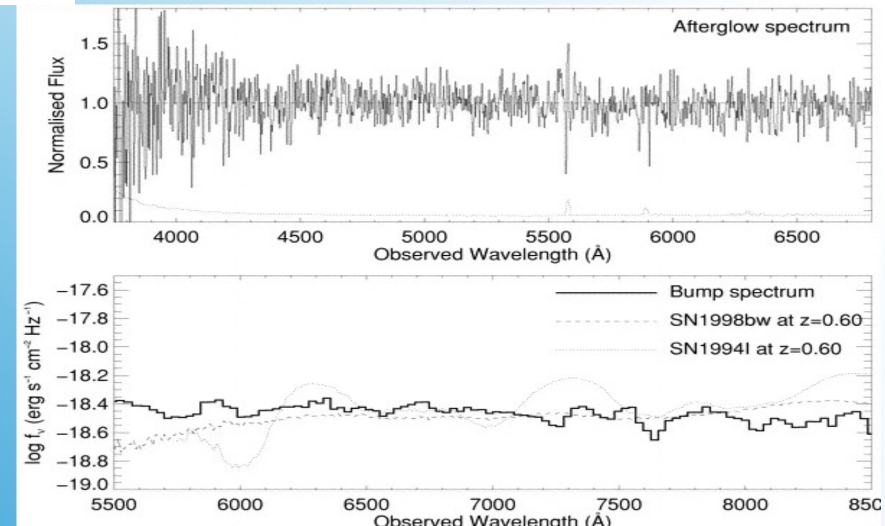
XRF 030723



Fynbo, Sollerman, Hjorth et al. 2004, ApJ

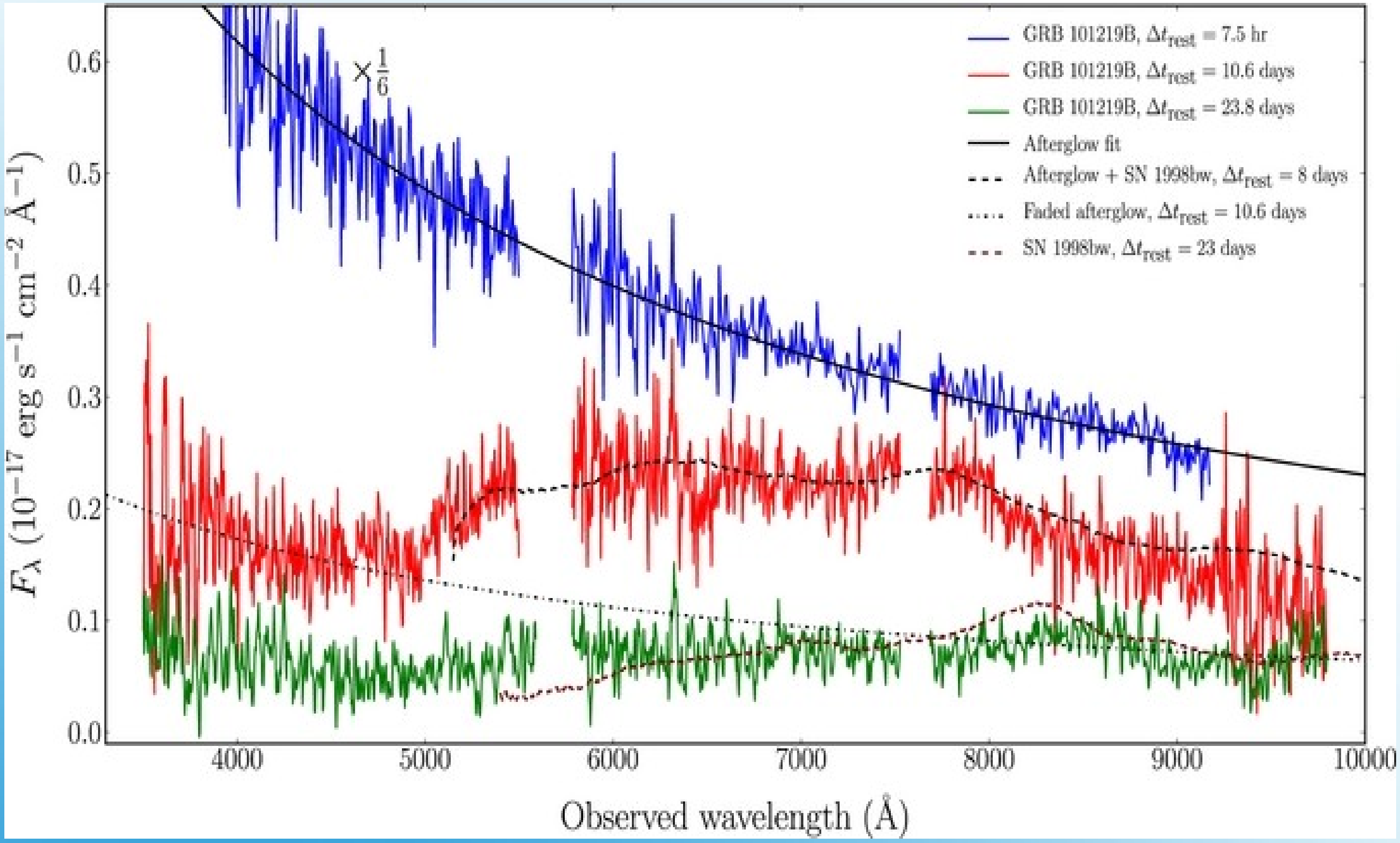


XRF 030723



Fynbo, Sollerman, Hjorth et al. 2004, ApJ

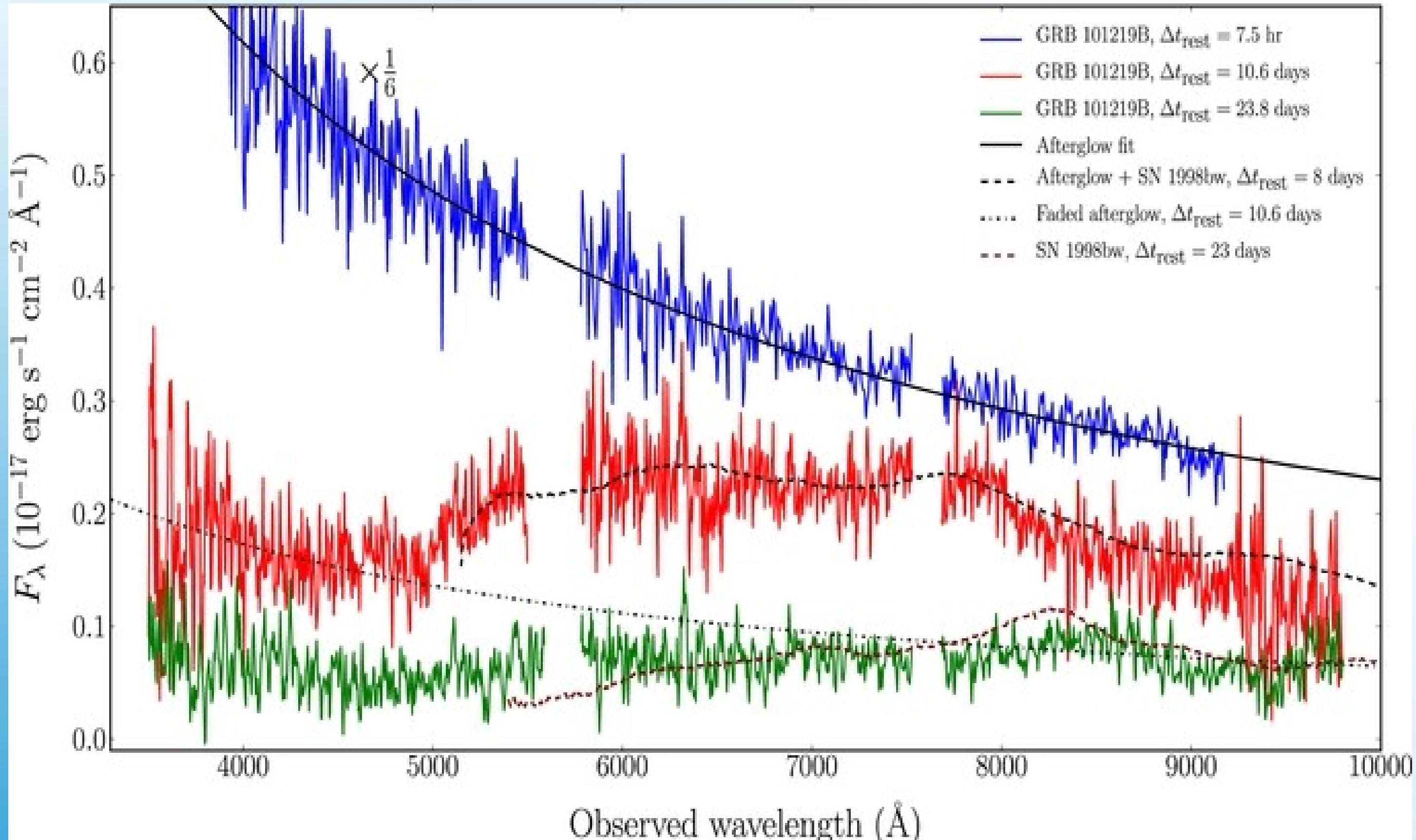
GRB 101219B
=
SN 2010ma



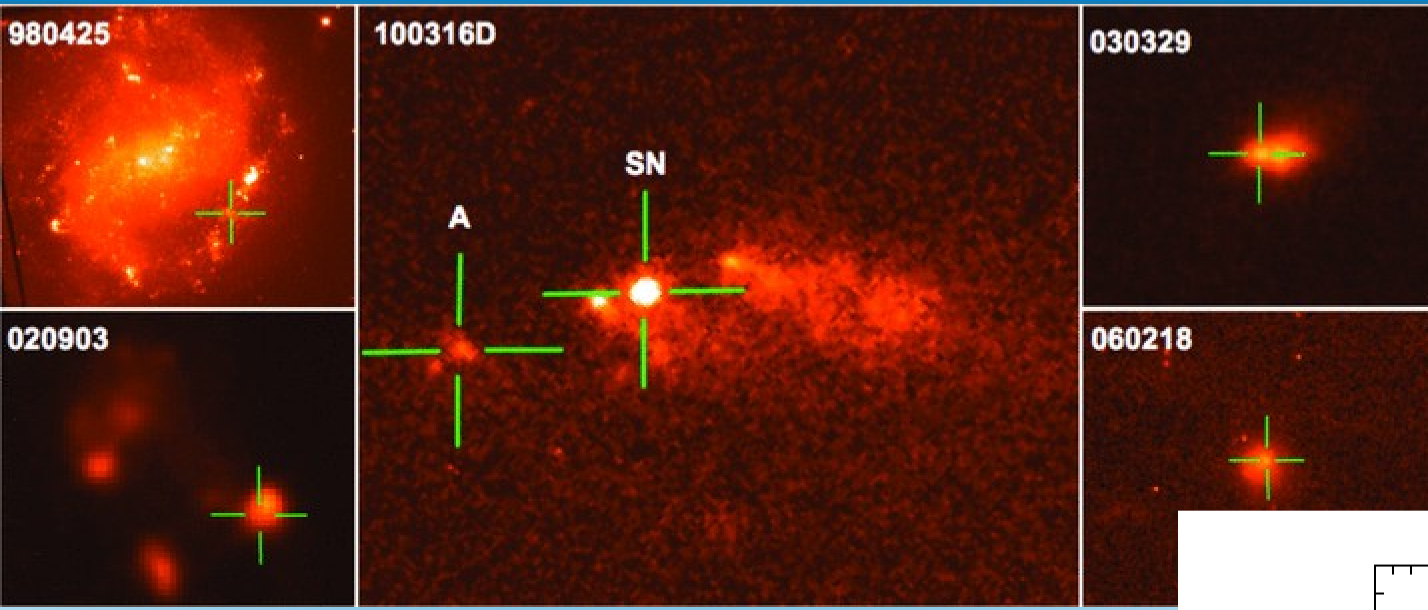
Sparre, Sollerman, Fynbo et al. 2011, ApJ

Z=0.55

$E_{iso} = 4.2\times10^{51}$erg



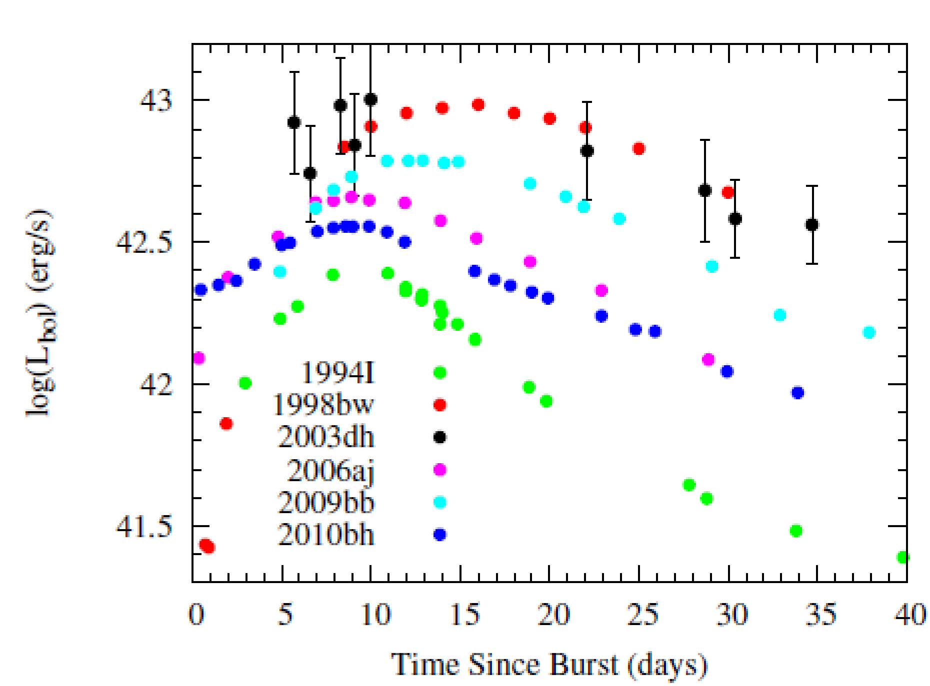
Sparre, Sollerman, Fynbo et al. 2011, ApJ



Starling, Wiersema, Levan, et al. 2011, MNRAS

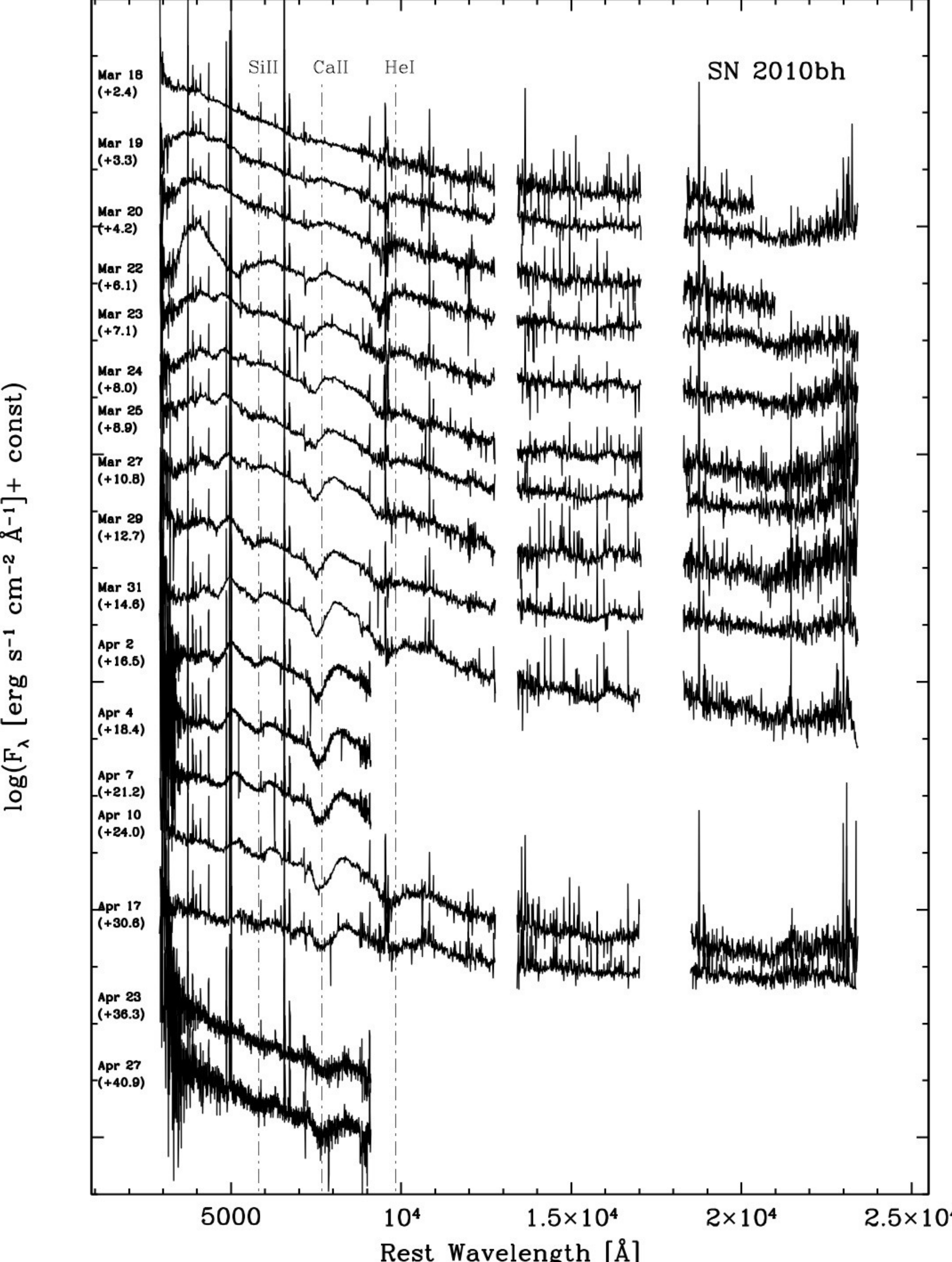
GRB 100316D = SN 2010bh

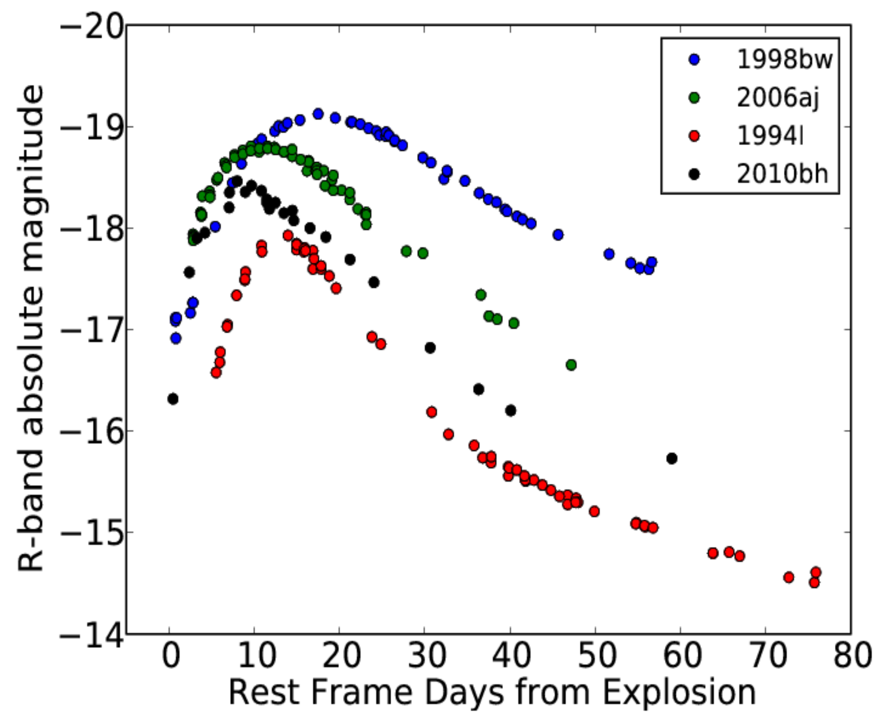
Cano, Bersier, Guidorzi, et al. 2011, ArXiv
\+ POSTER!

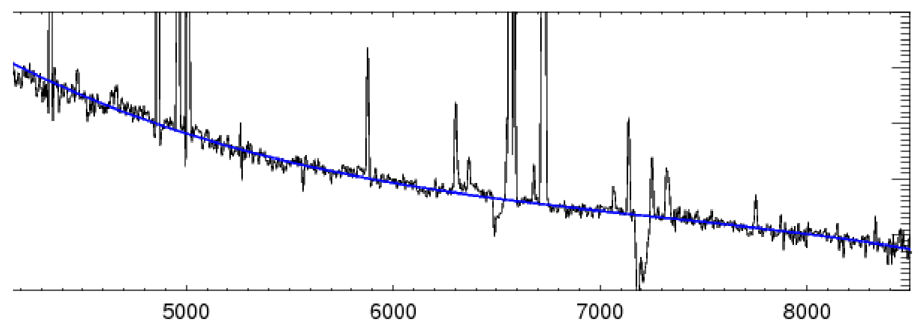


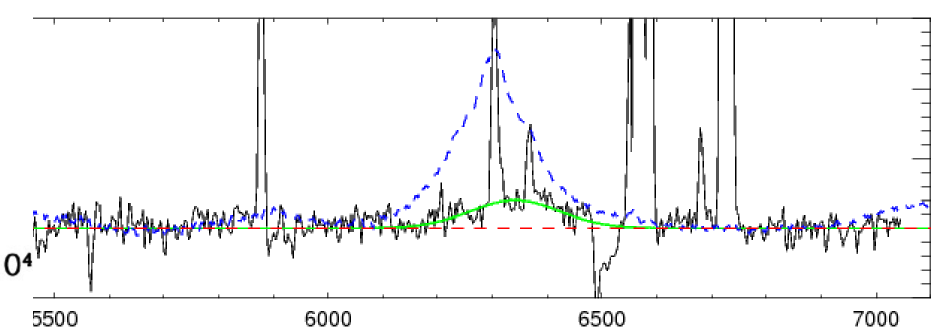
Jesper Sollerman, **Supernovae and Gamma-Ray Bursts:**
Stockholm Aug. 10 2011

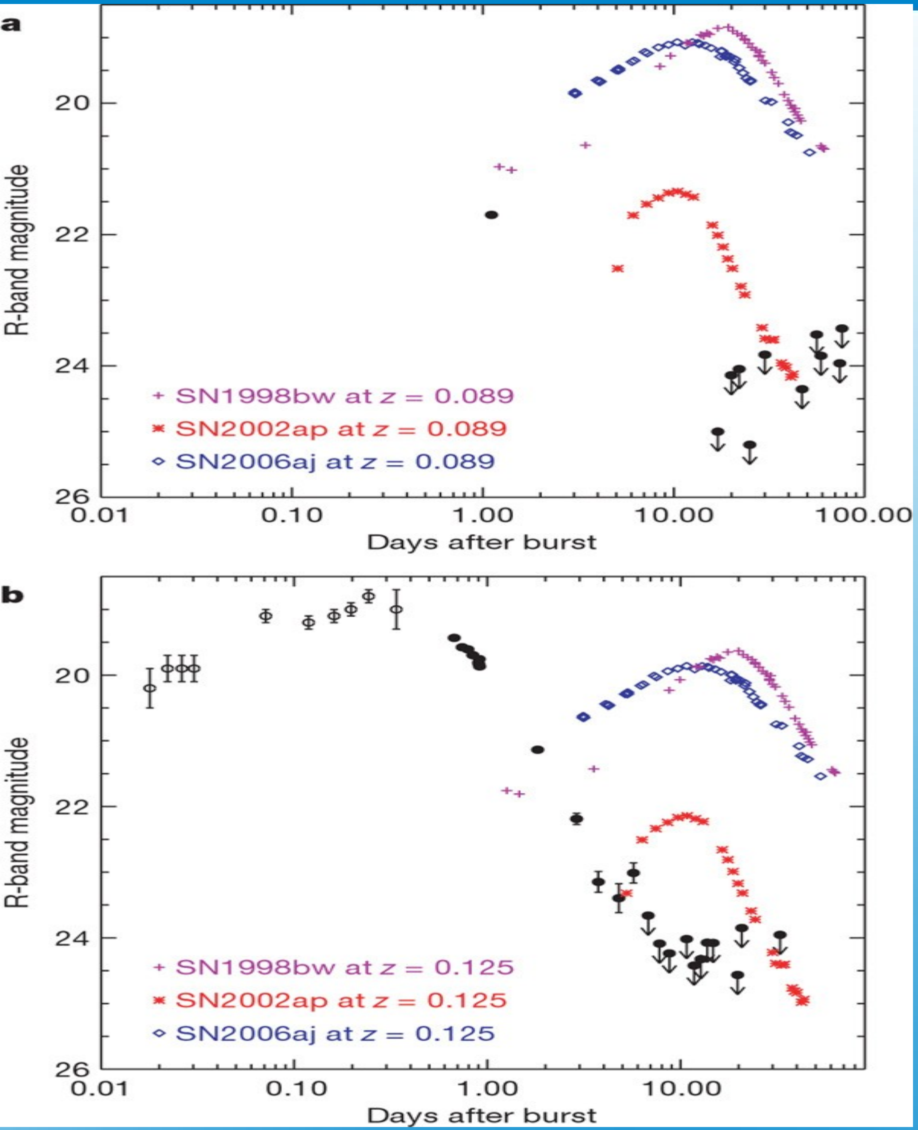
Bufano, Pian, Sollerman, et al. 2011 ???

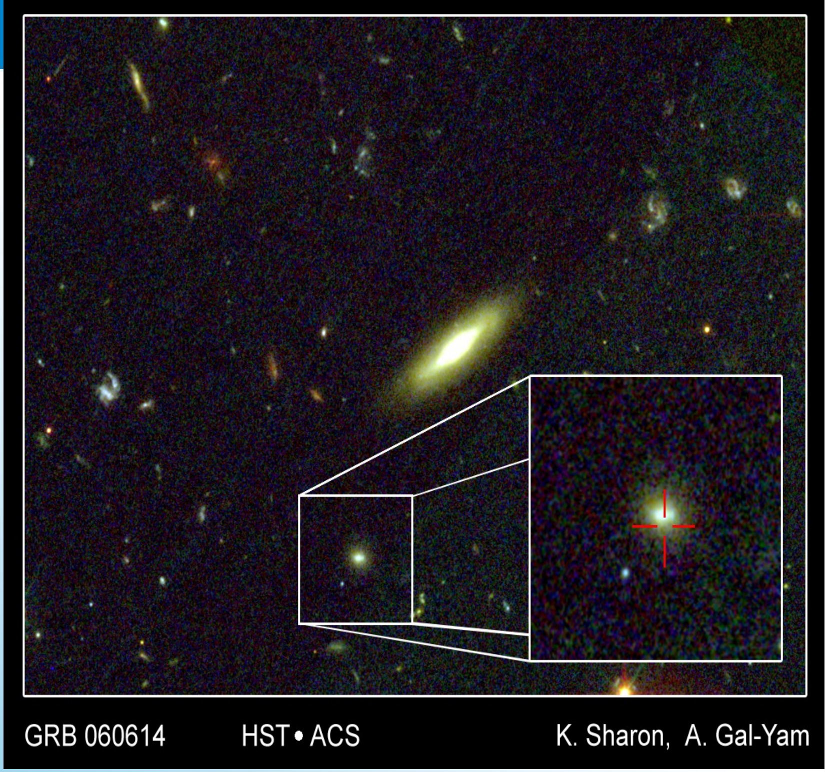






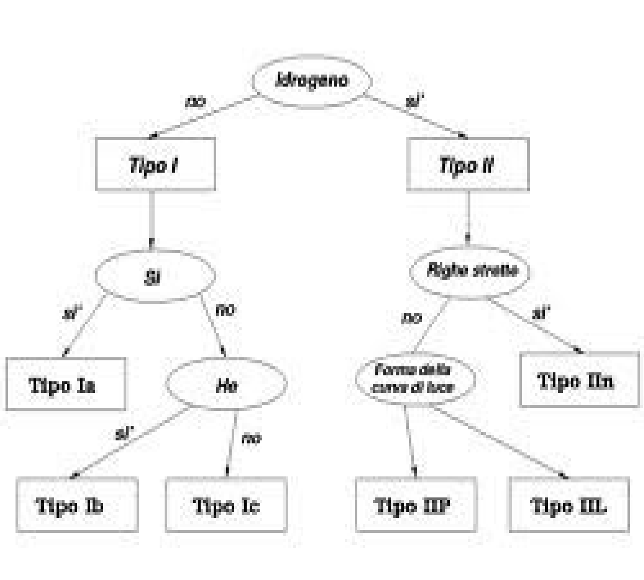


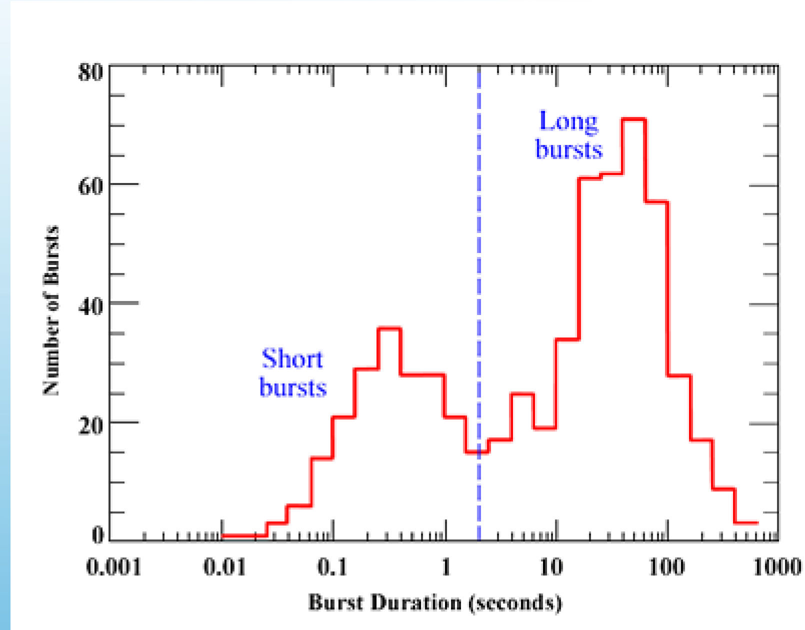


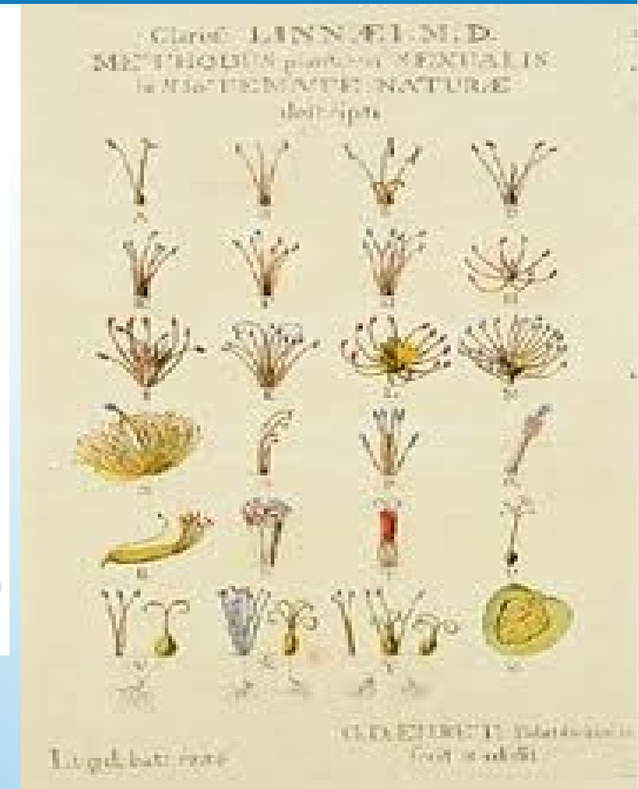


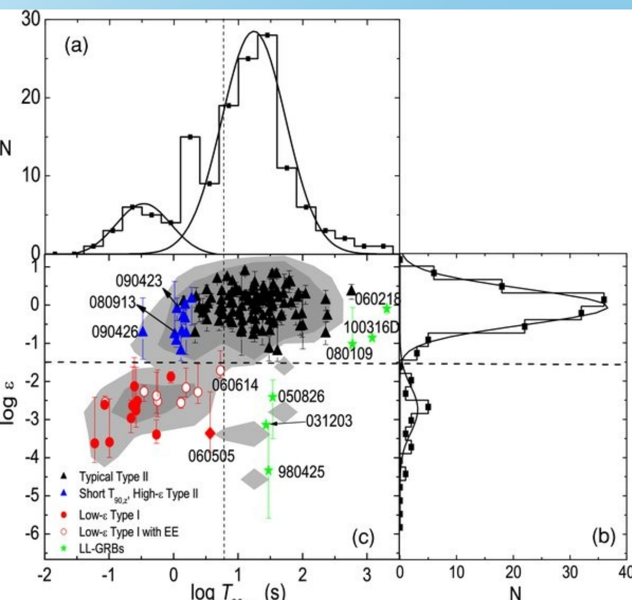
GRBs 060505
& 060414

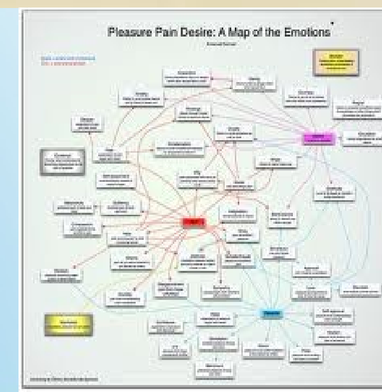
e.g., Fynbo, Watson, Thone, Sollerman, et al. 2006, Nature



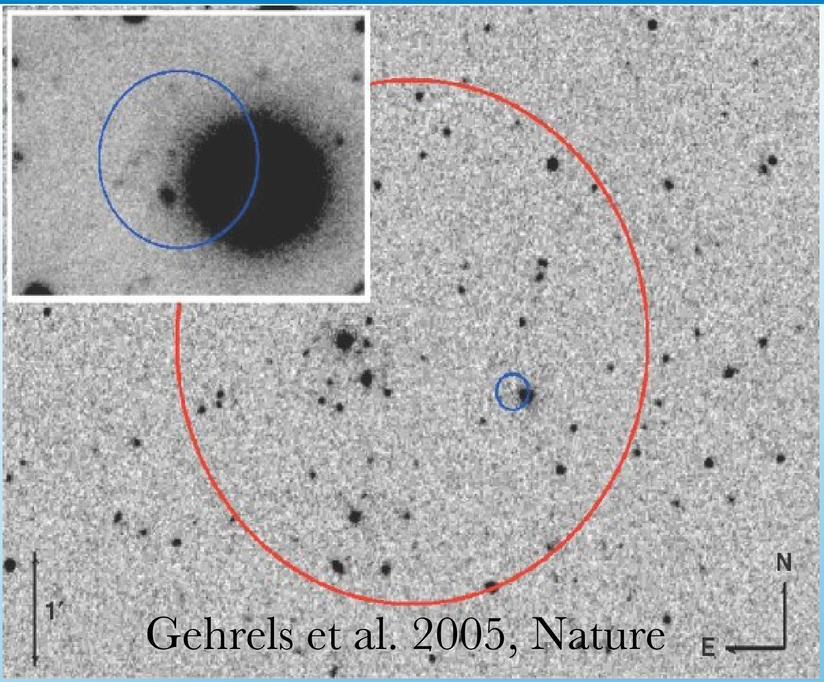








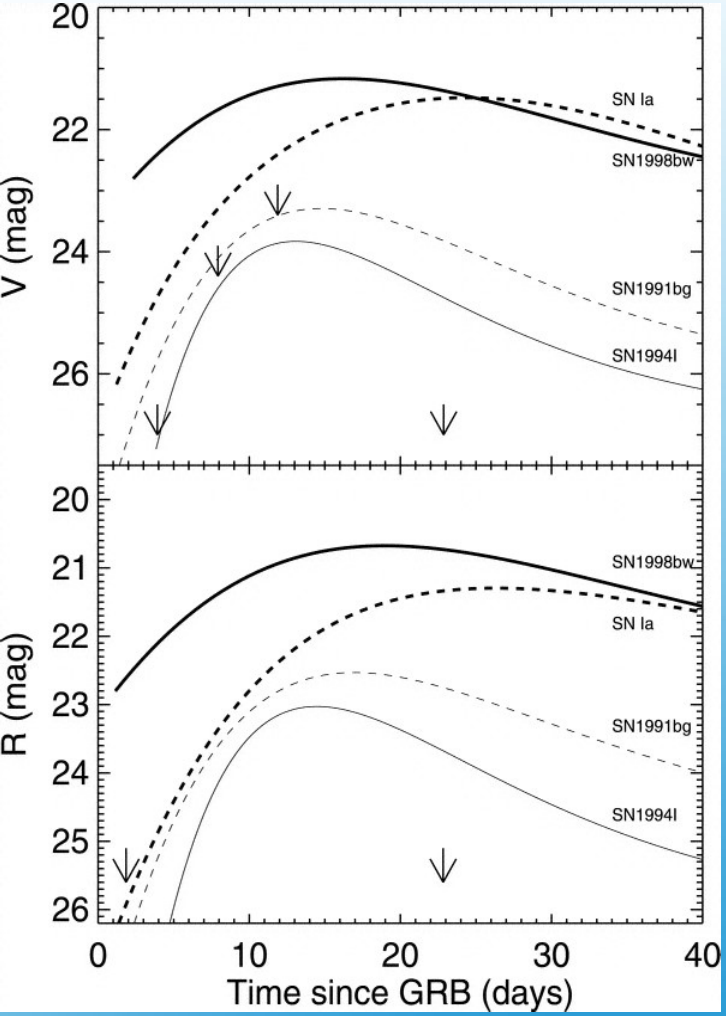
Jesper Sollerman, **Supernovae and Gamma-Ray Bursts:**
Stockholm Aug. 10 2011



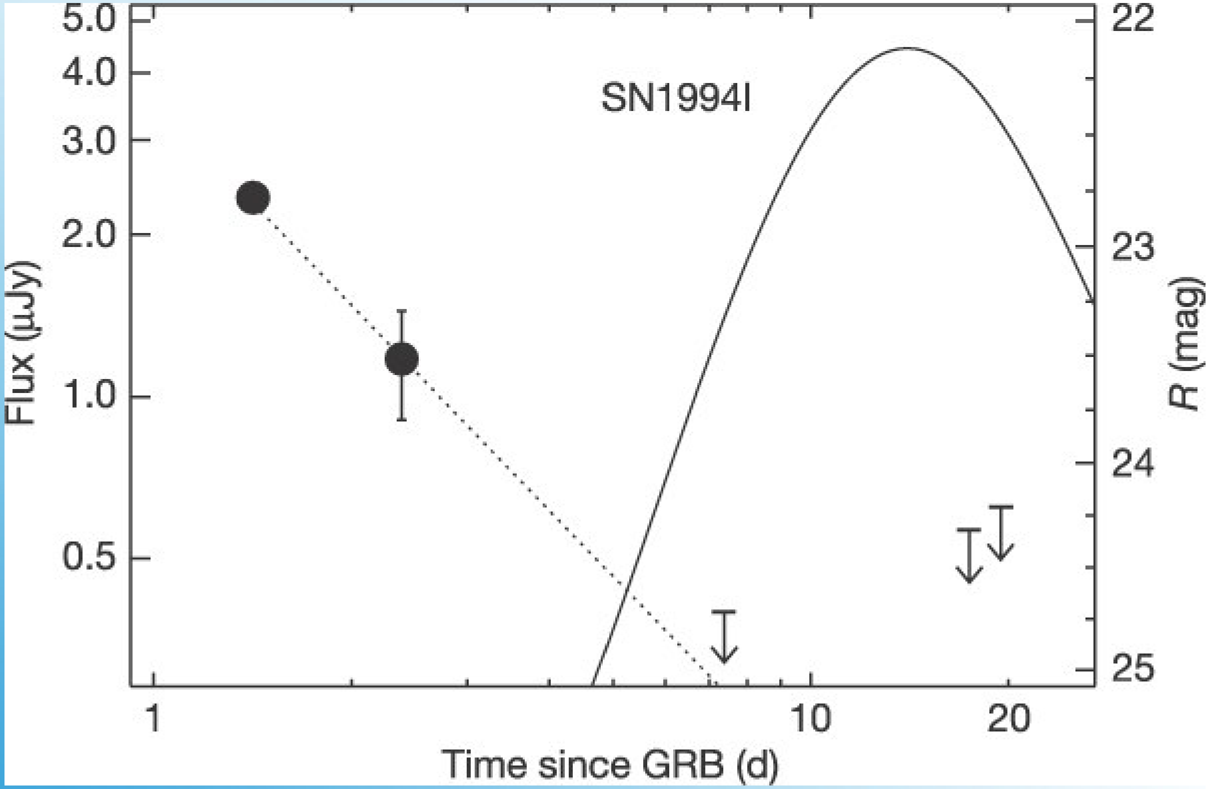
A SHORT detour

GRB 050509B

GRB 050509B



GRB 050709



Hjorth, Sollerman, Gorosabel, et al. 2005, ApJ

Hjorth, Watson, Fynbo, et al. 2005, Nature

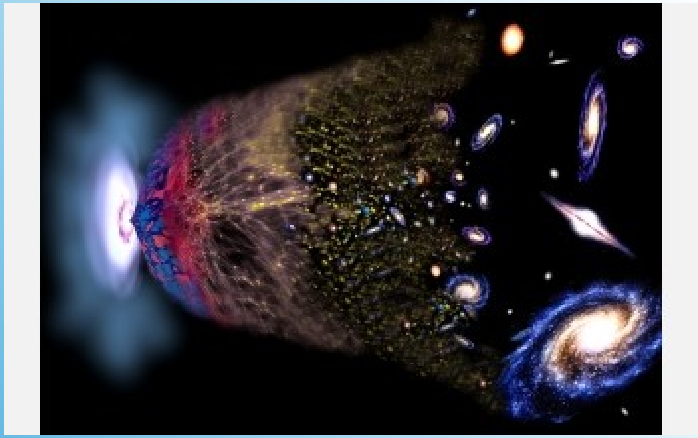
Alert

Hosts

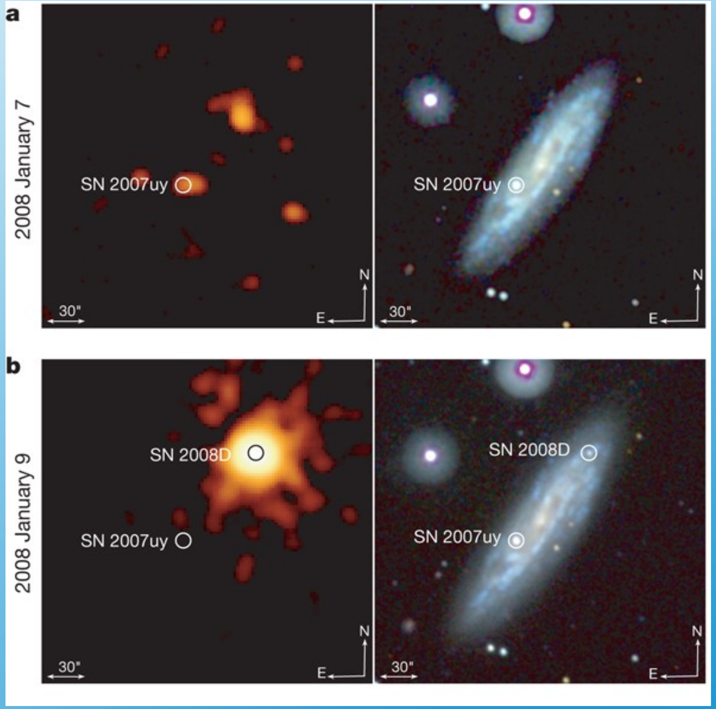
Multiwavelenght - Panchromatic

Explosion mechanism and supernova Diversity

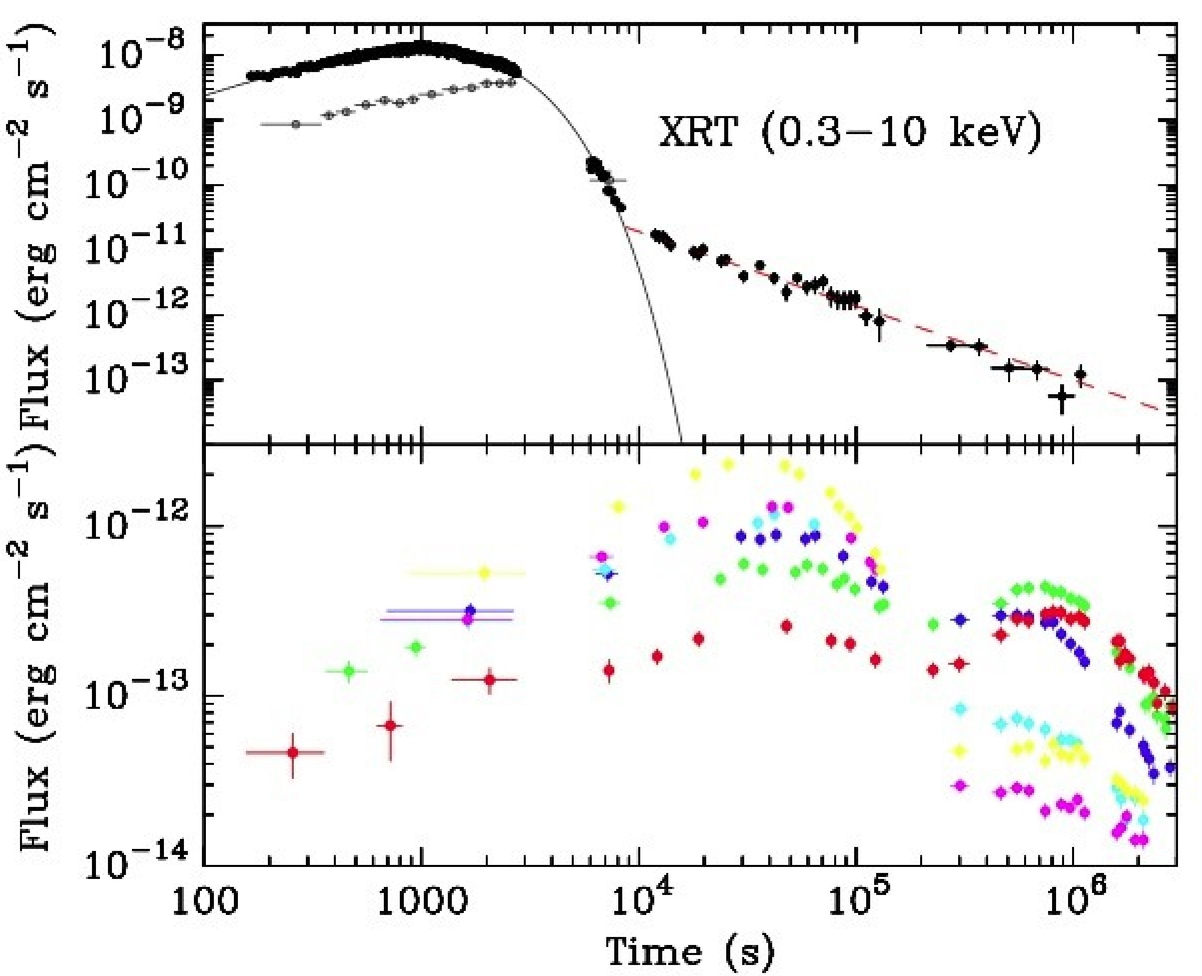
High-z cosmology



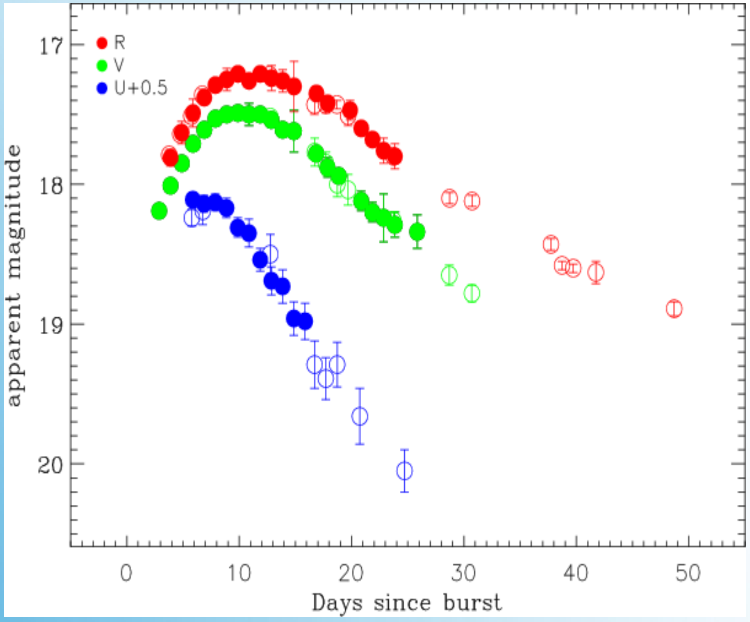
Jesper Sollerman, **Supernovae and Gamma-Ray Bursts:**
Stockholm Aug. 10 2011

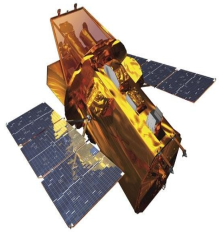


Jesper Sollerman, **Supernovae and Gamma-Ray Bursts:**
Stockholm Aug. 10 2011



Sollerman, Jaunsen, Fynbo,et al. 2006, A&A

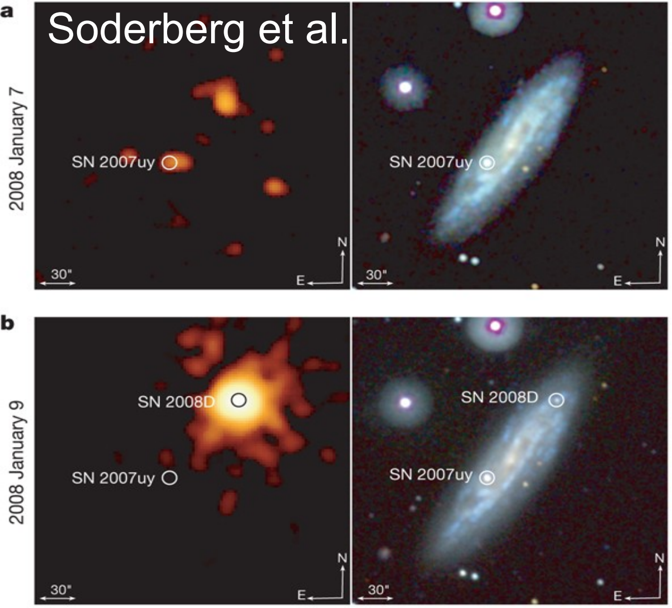




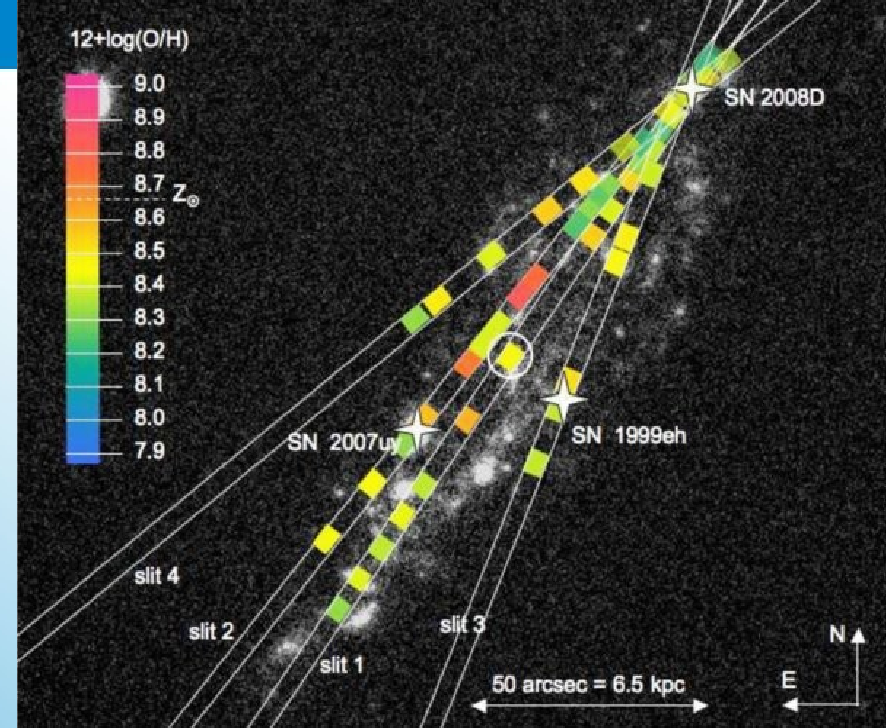
Campana, Mangana, Blustin et al. 2006, Nature

SN 2006aj = XRF 060218

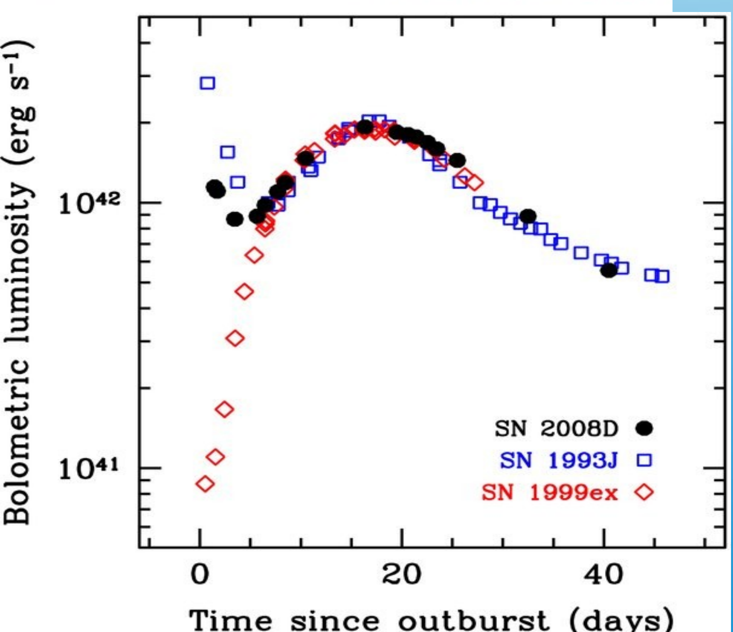
Jesper Sollerman, **Supernovae and Gamma-Ray Bursts:**
Stockholm Aug. 10 2011



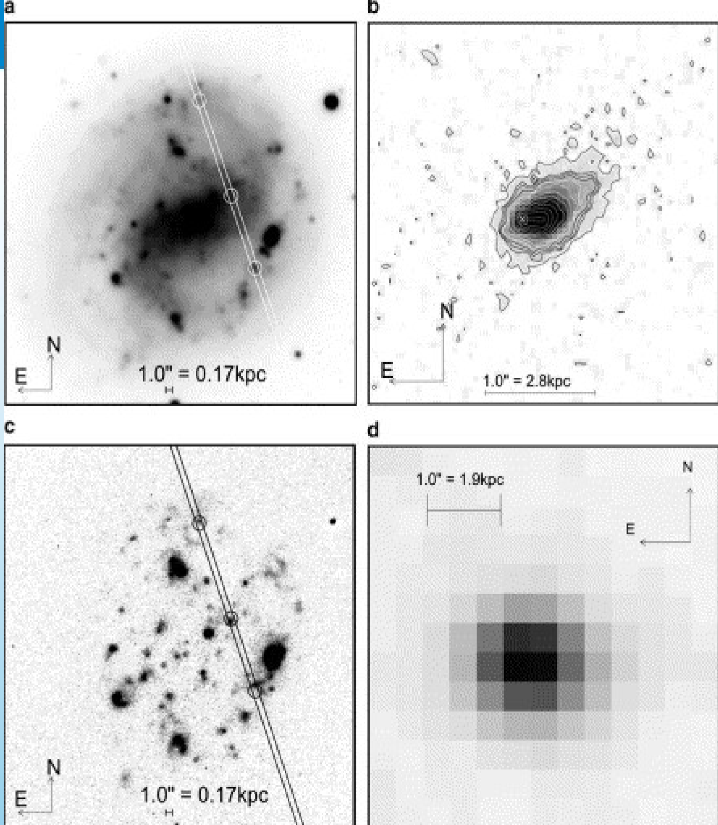
SN 2008D



Thoene, Michalowski, Leloudas, et al. 2009, ApJ

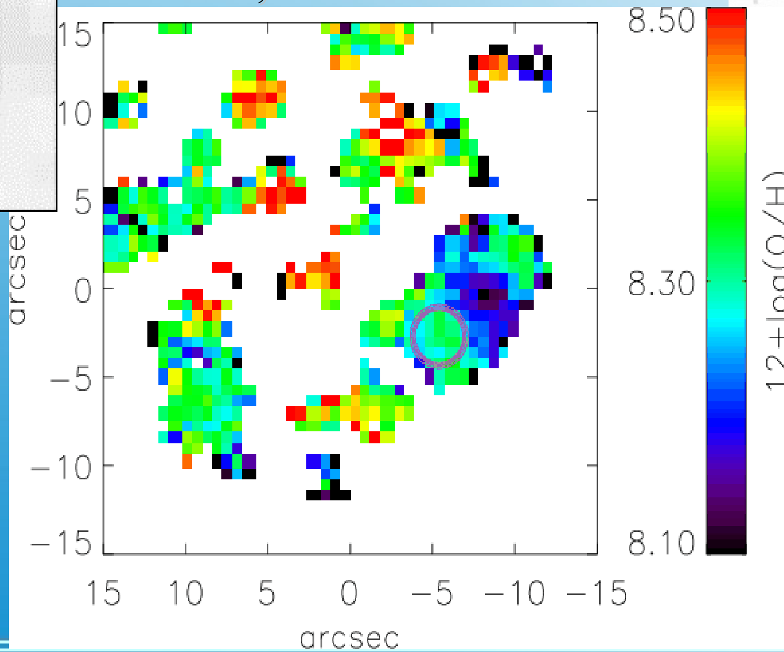


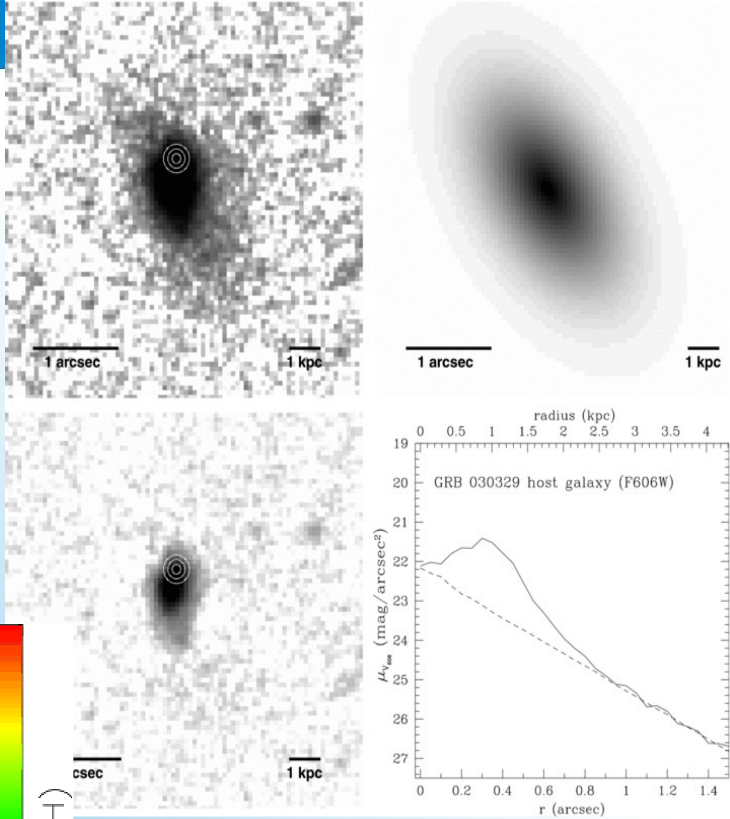
Malesani, Fynbo, Hjorth, Leloudas, Sollerman, et al. 2009, ApJ



Sollerman, Östlin, Fynbo et al. 2005, New Astronomy

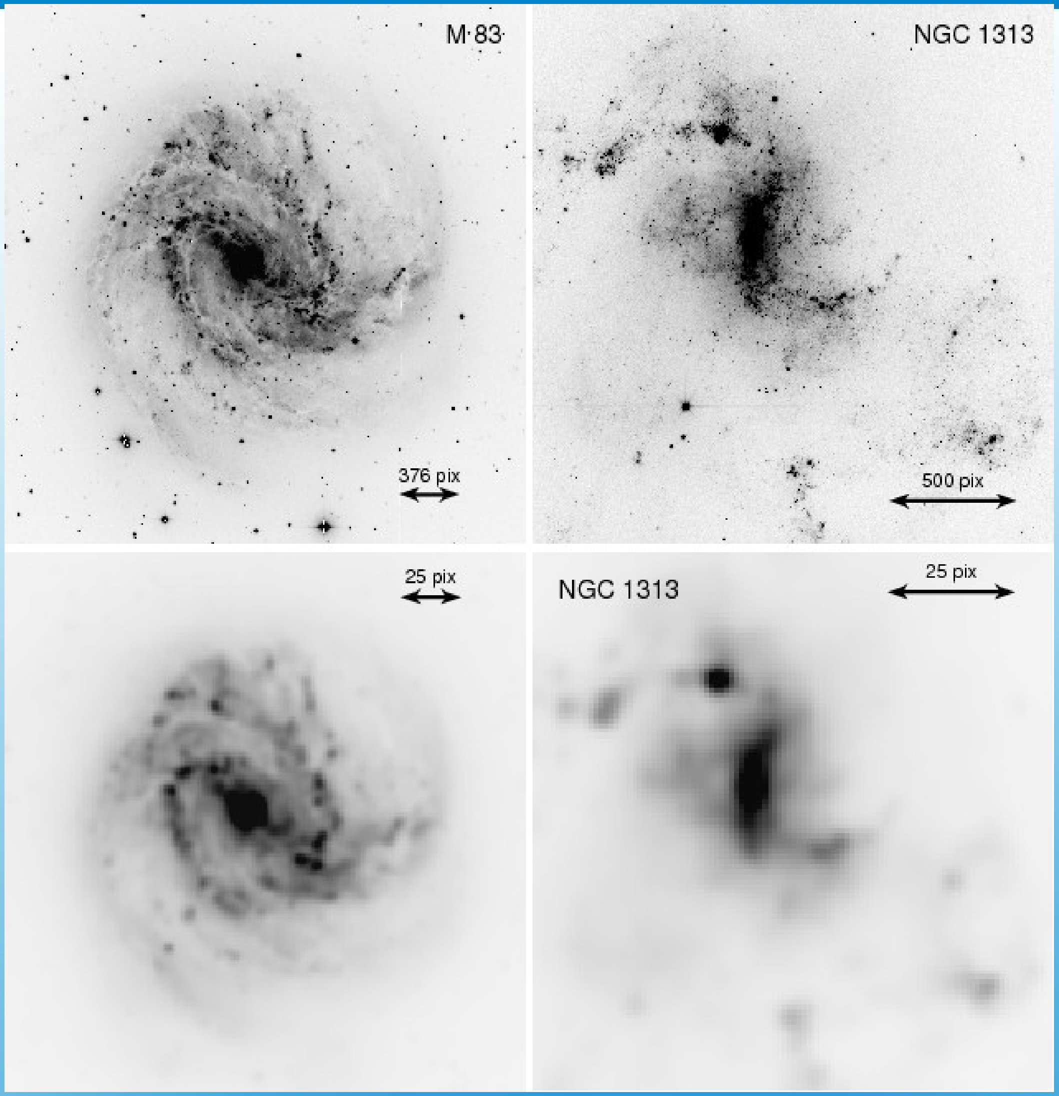
Christensen,Wreesvijk, Sollerman, et al. 2008, MNRAS





Östlin, Zackrisson, Sollerman, et al. 2008, MNRAS

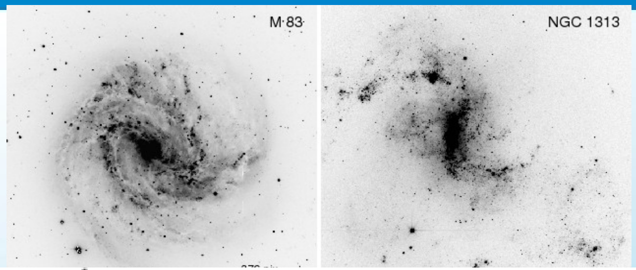
Jesper Sollerman, Supernovae and Gamma-Ray Bursts: Stockholm Aug. 10 2011

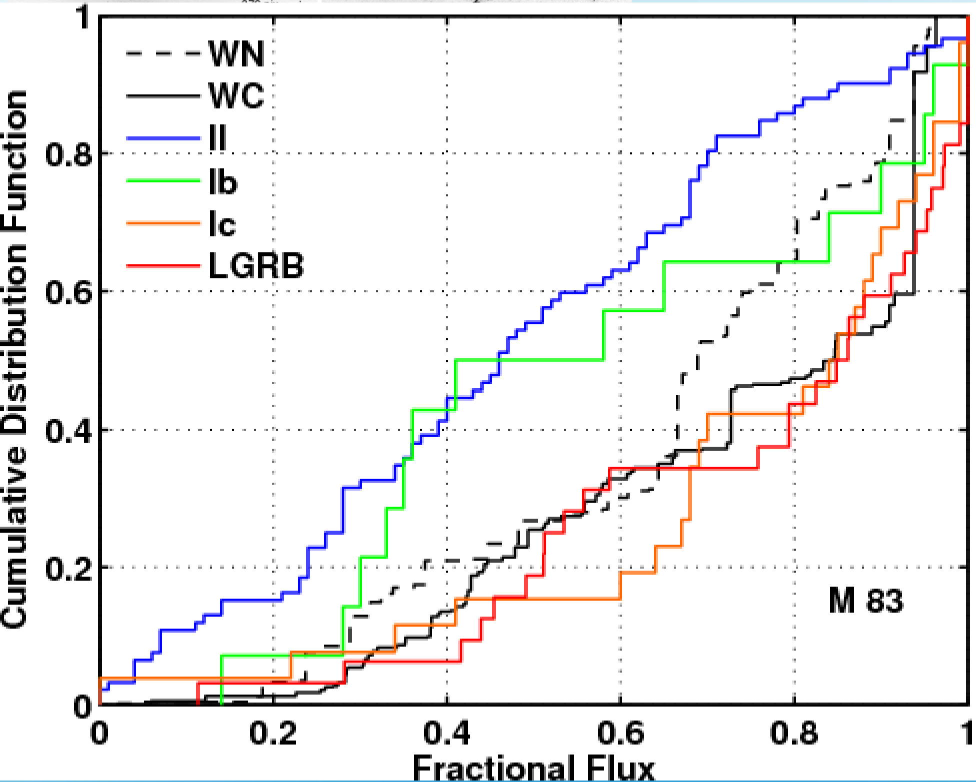


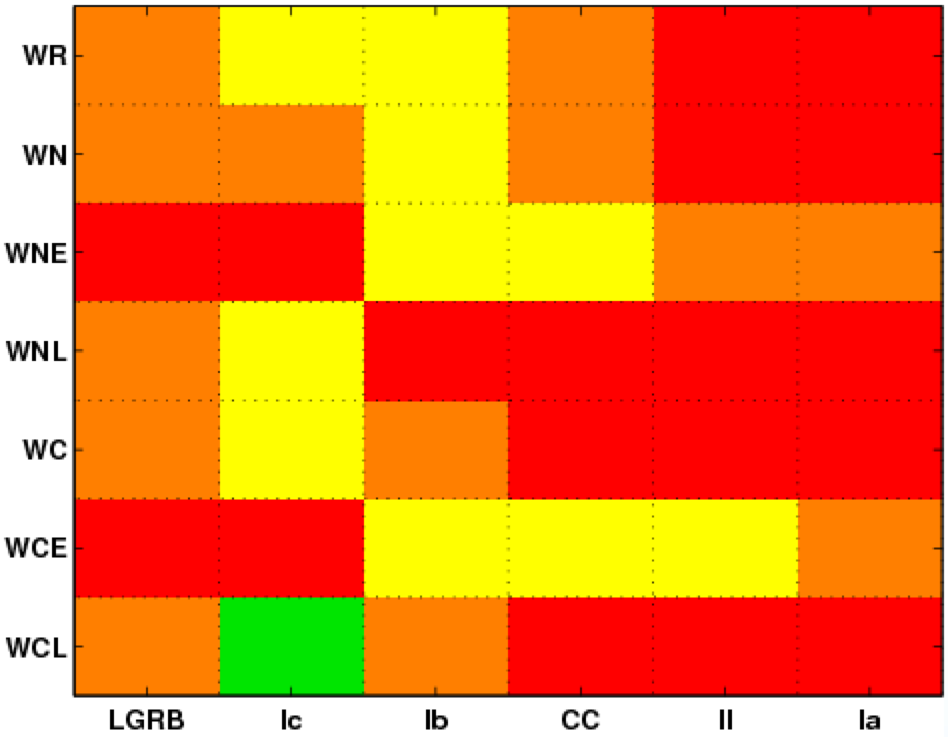
Do Wolf-Rayet stars have similar locations in hosts as type Ib/c supernovae and long gamma-ray bursts?

Leloudas, Sollerman, Levan et al. 2010, A&A

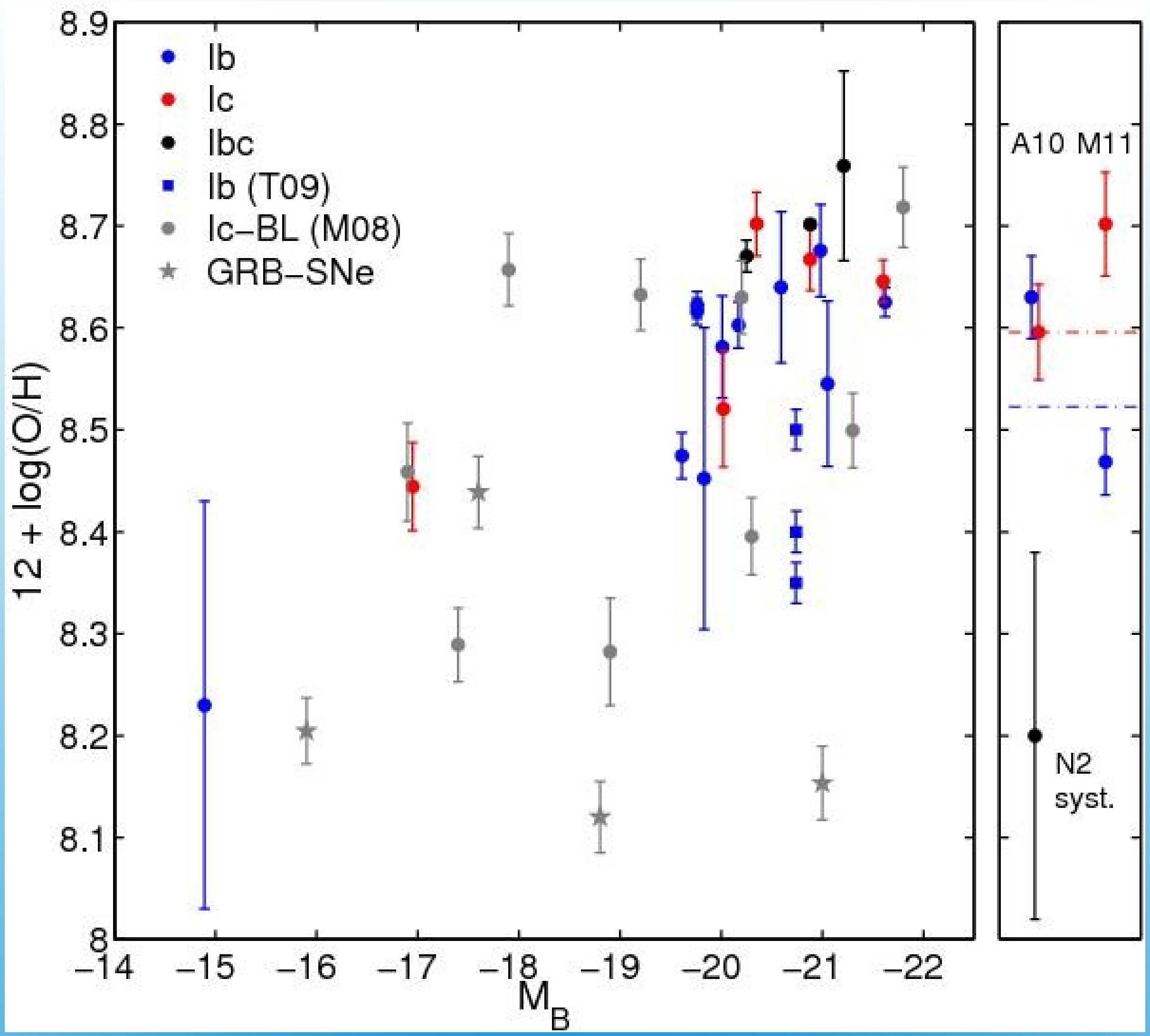
+ POSTER!



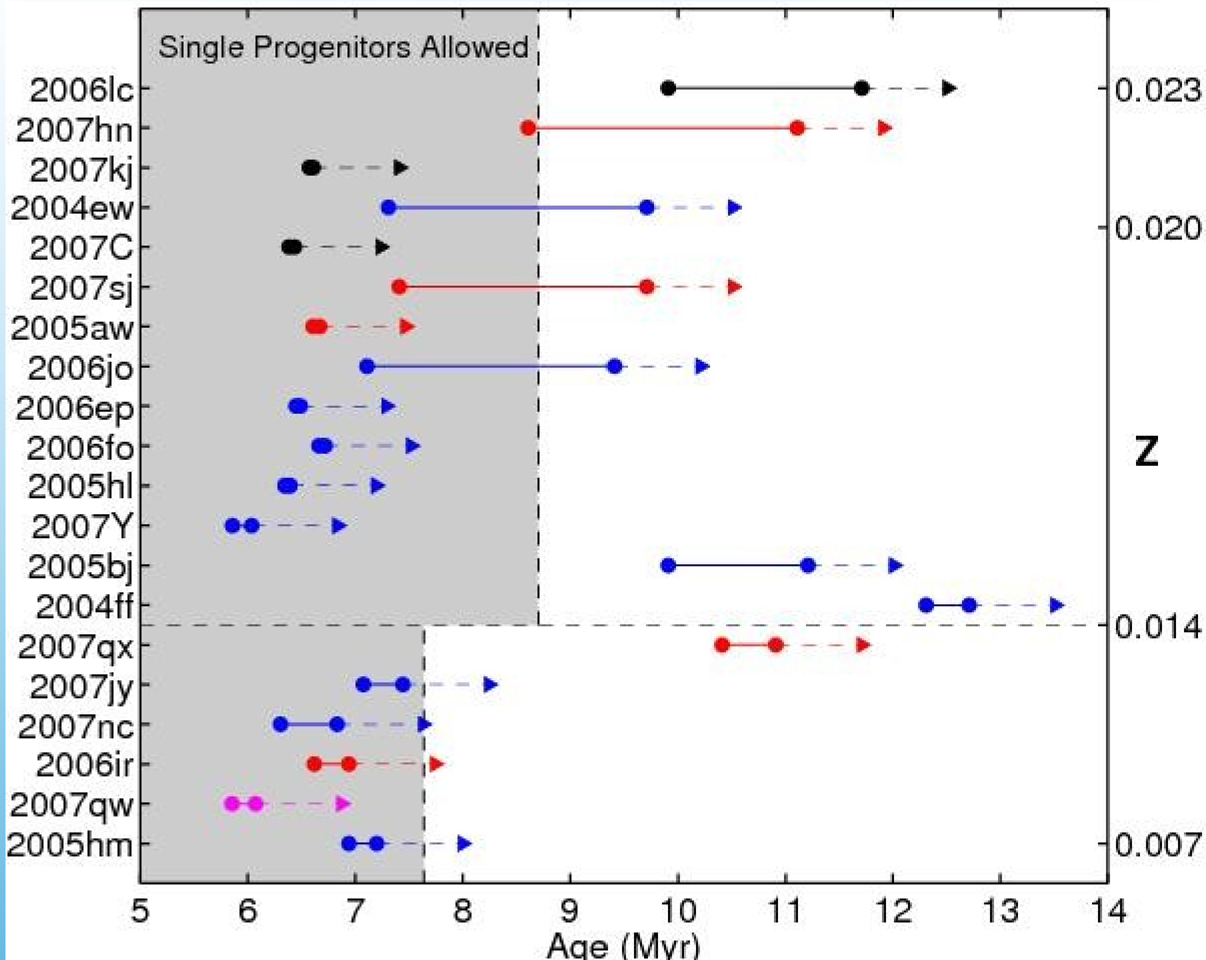




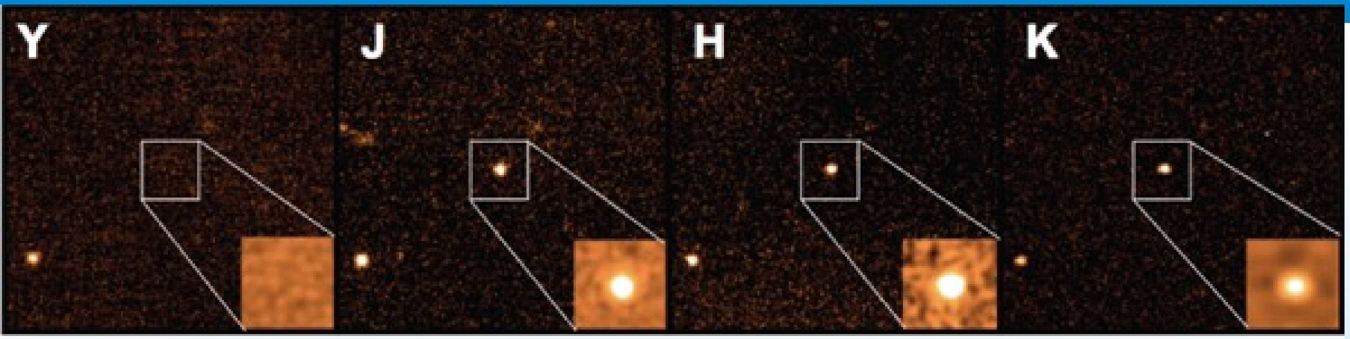
Leloudas, Sollerman, Levan et al. 2010, A&A

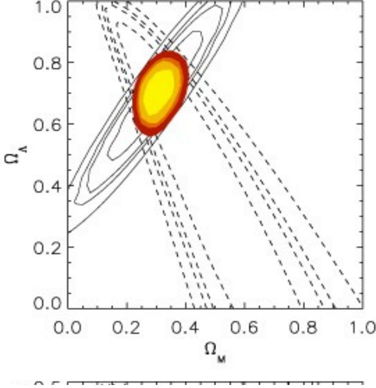


Leloudas, Gazzali, Sollerman et al. 2011, A&A



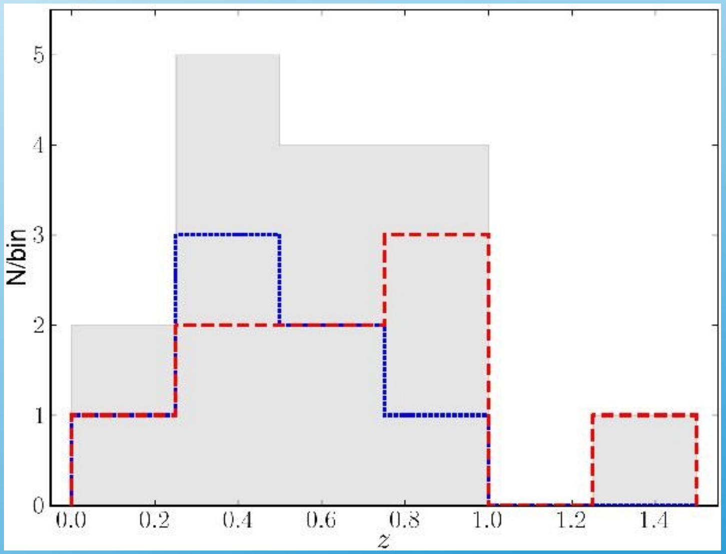
Leloudas, Gazzali, Sollerman et al. 2011, A&A

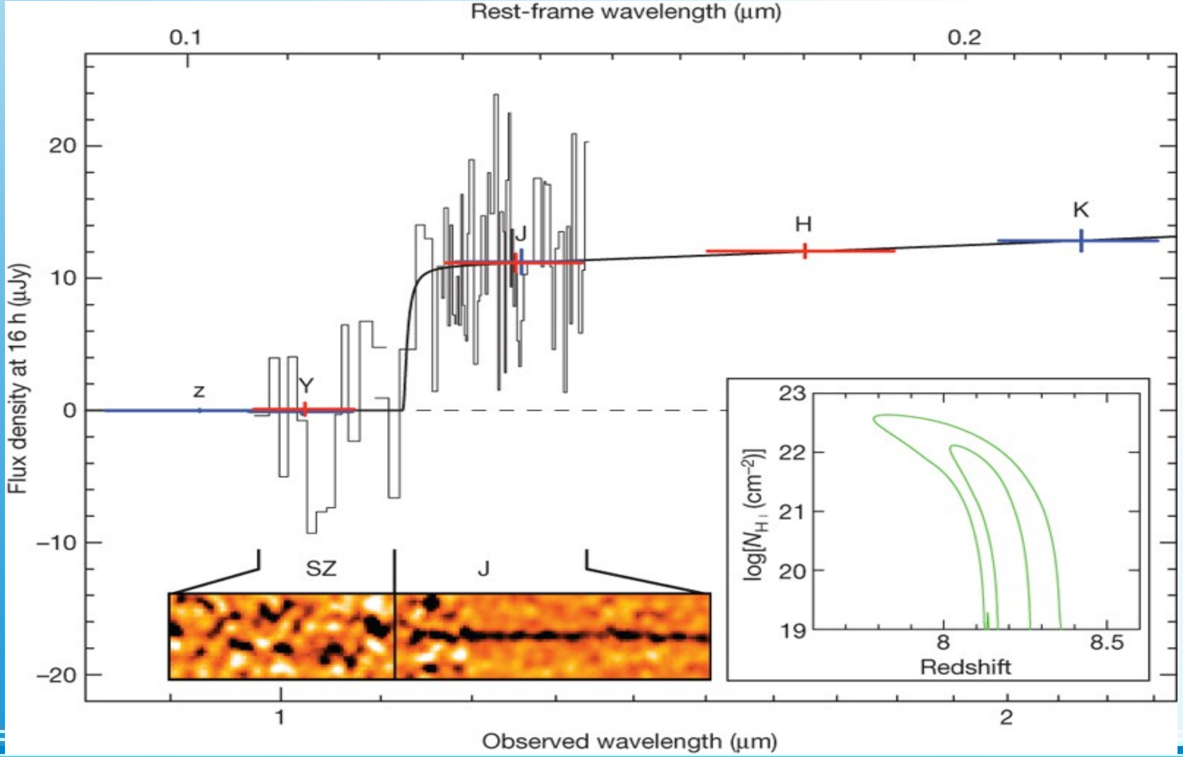




Mörtsell & Sollerman, 2005, JCAP

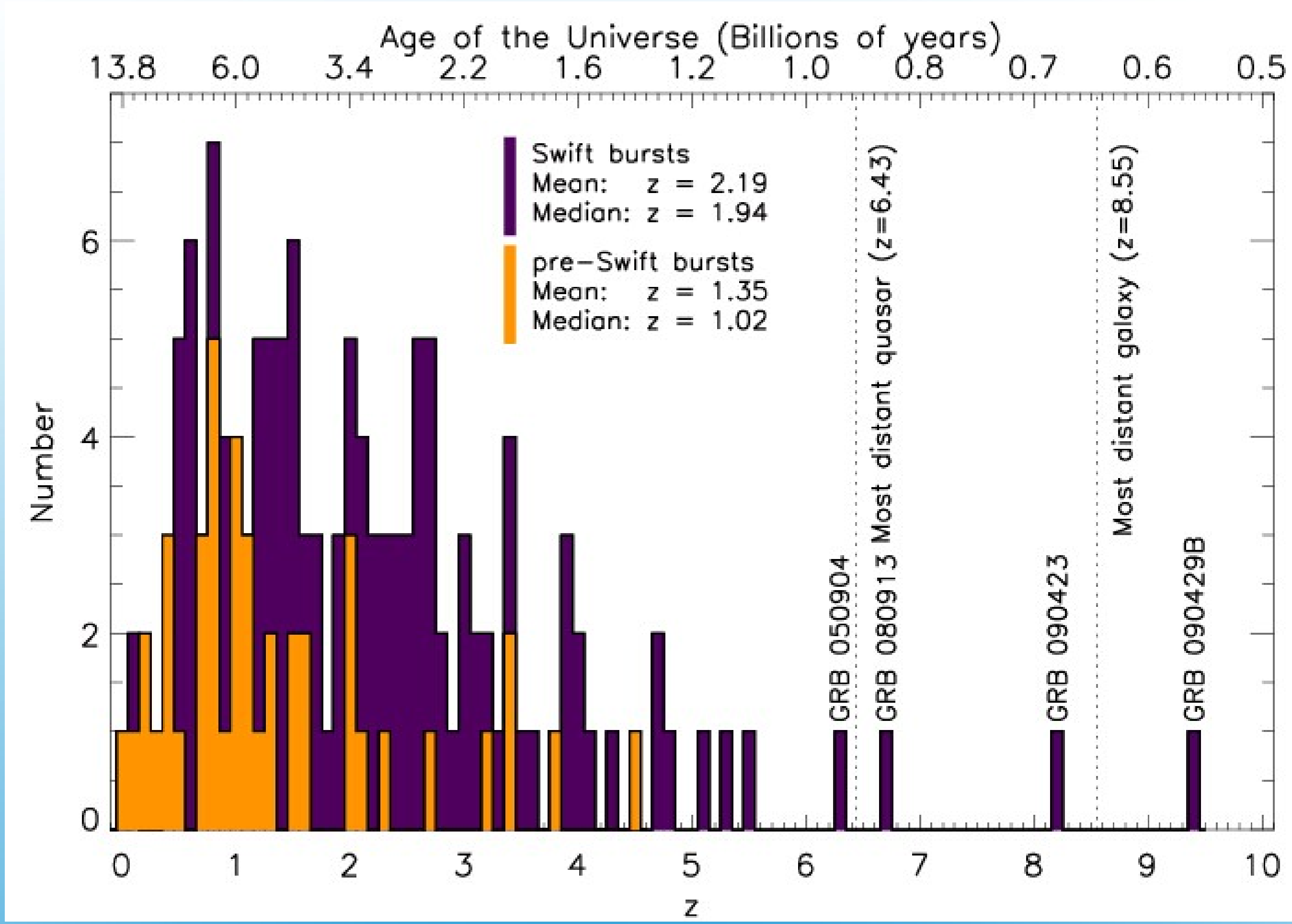
Tanvir et al. 2009, Nature



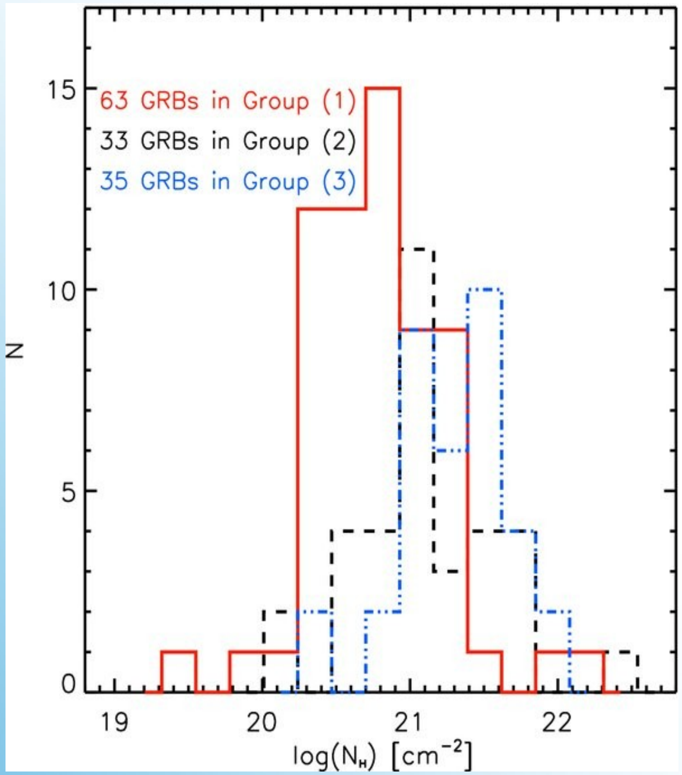


Melinder et al. 2011, ApJ

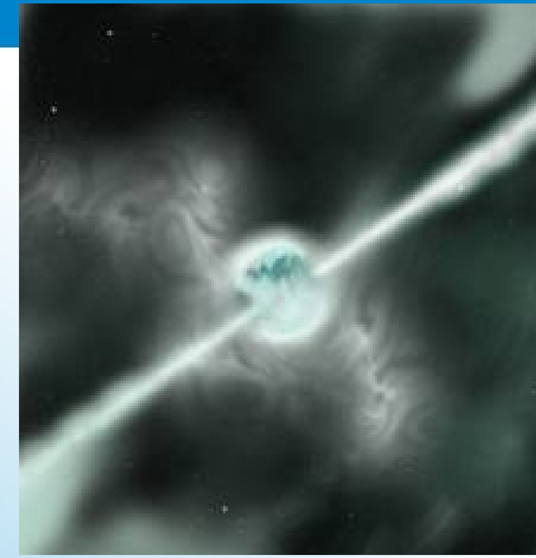
Jesper Sollerman, **Supernovae and Gamma-Ray Bursts:**
Stockholm Aug. 10 2011



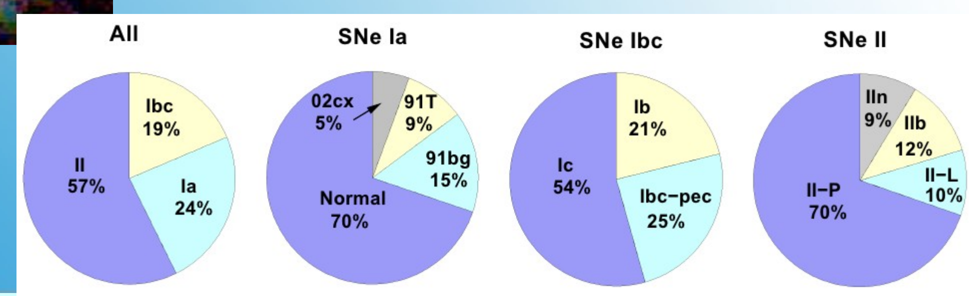
Palli Jakobsson



Johan Fynbo

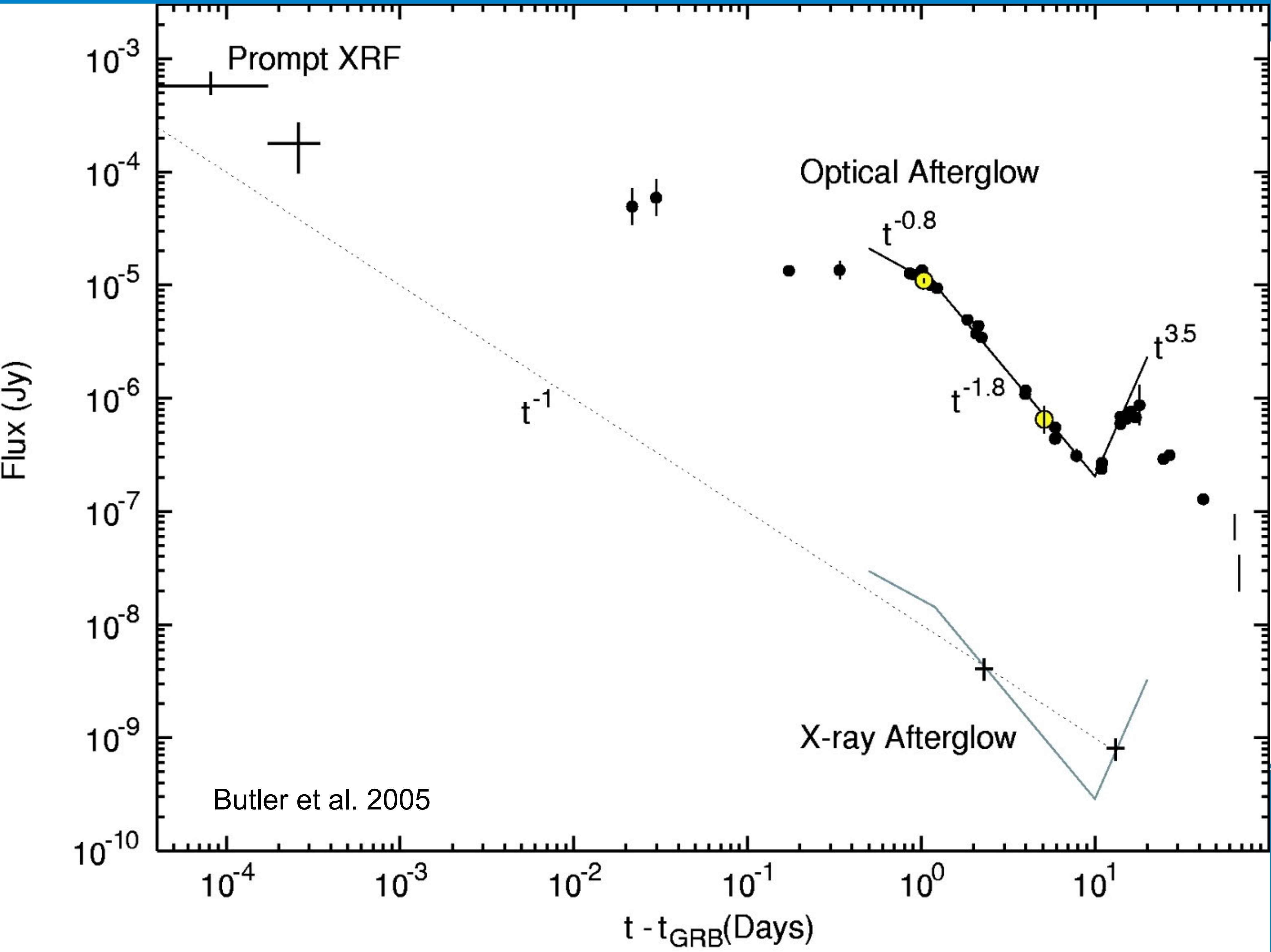


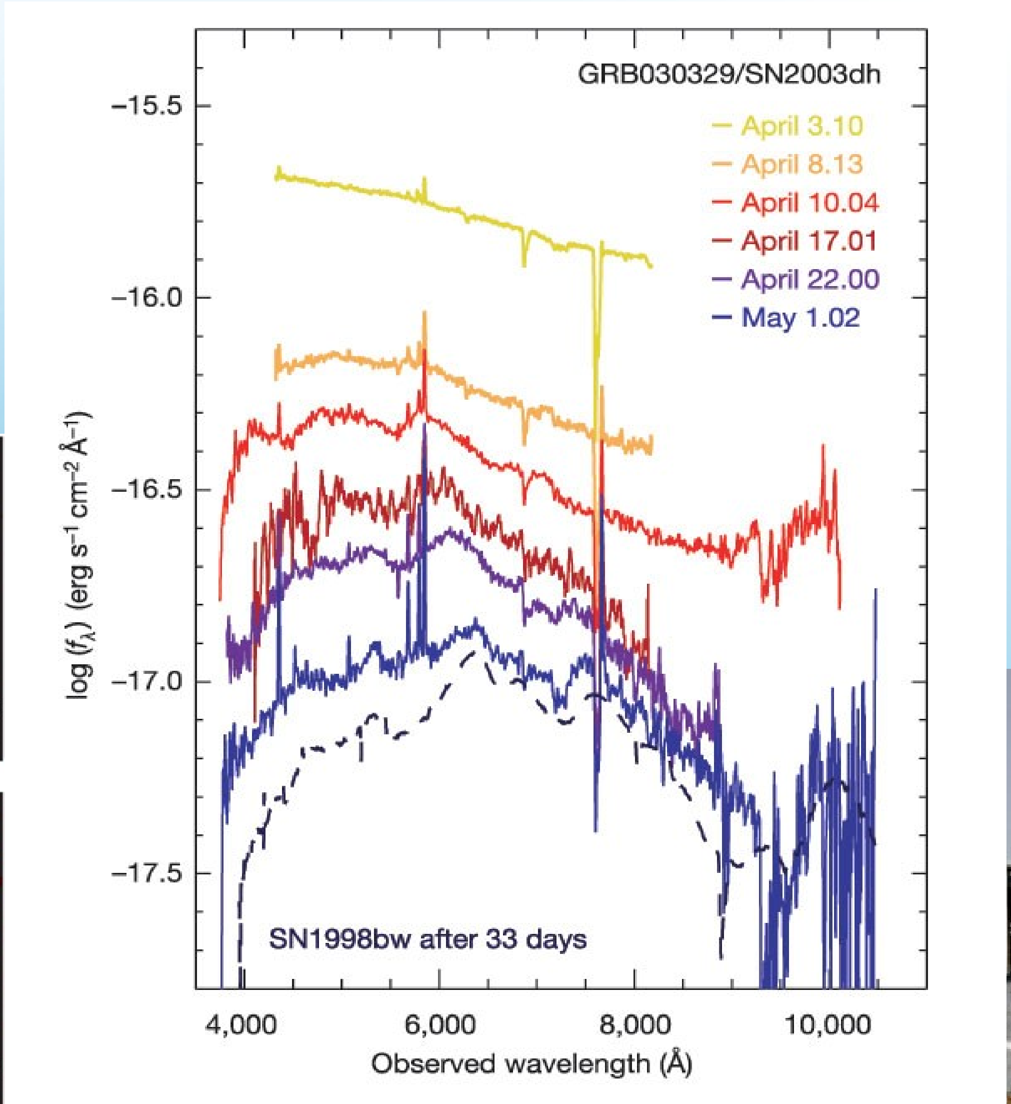
Conclusions?

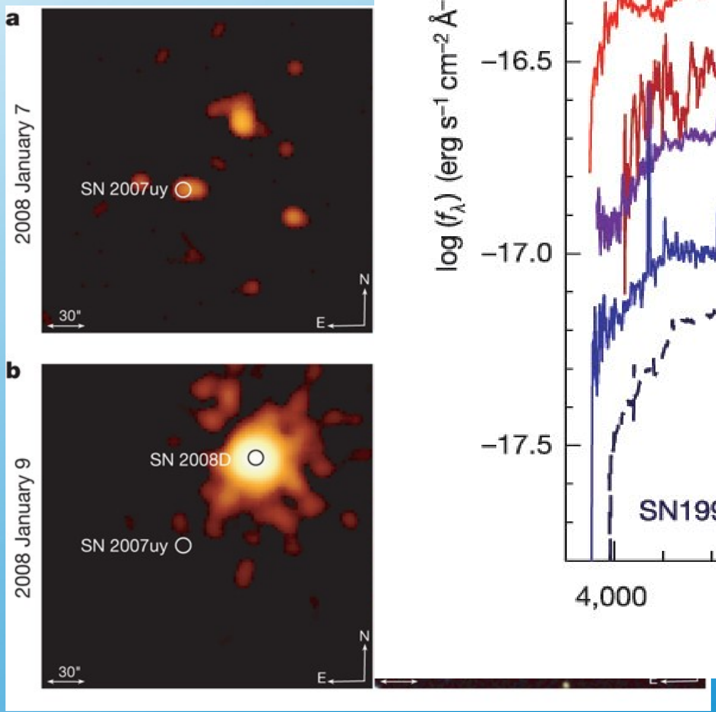


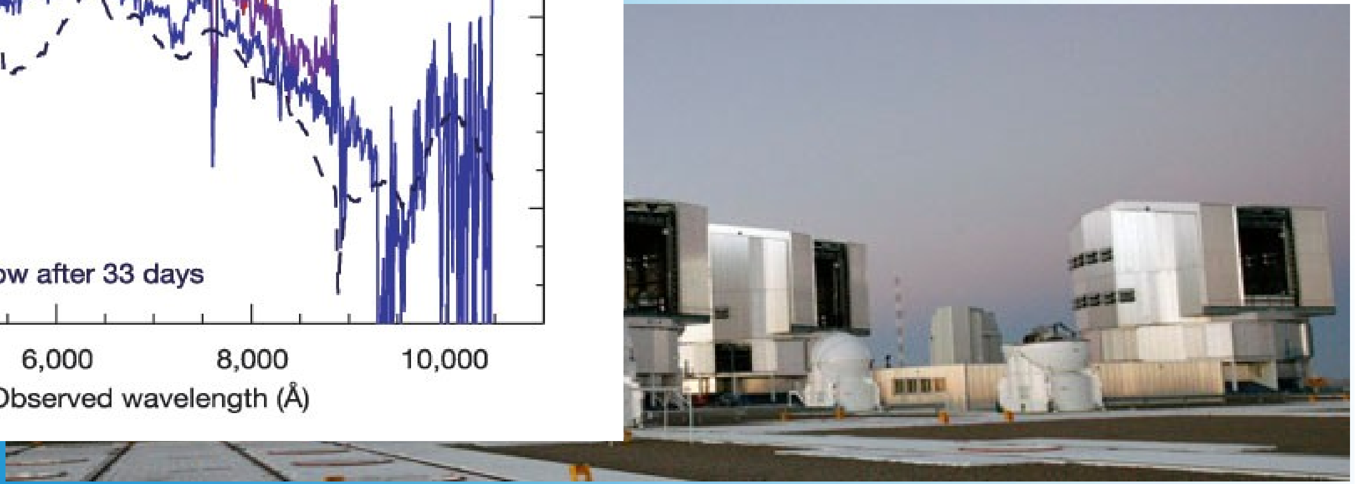
Jesper Sollerman, **Supernovae and Gamma-Ray Bursts:**
Stockholm Aug. 10 2011

Jesper Sollerman, Supernovae and Gamma-Ray Bursts:
Stockholm Aug. 10 2011


Prompt XRF
Optical Afterglow
$t^{-0.8}$
$t^{-1.8}$
$t^{3.5}$
t^{-1}
X-ray Afterglow
Butler et al. 2005
Flux (Jy)
$t - t_{GRB}$(Days)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}







Jesper Sollerman, **Supernovae and Gamma-Ray Bursts:**

Stockholm Aug. 10 2011