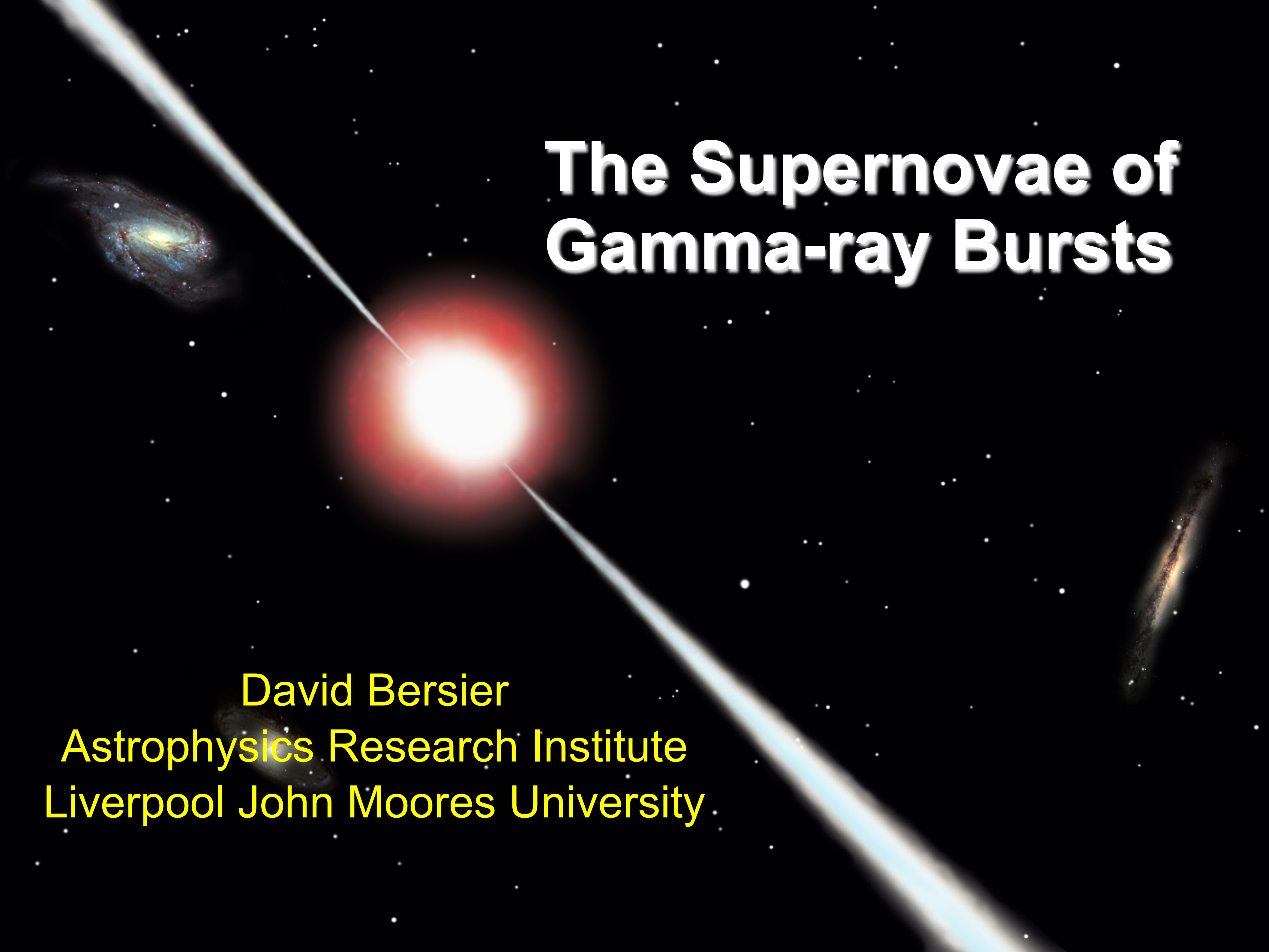


The Supernovae of Gamma-ray Bursts

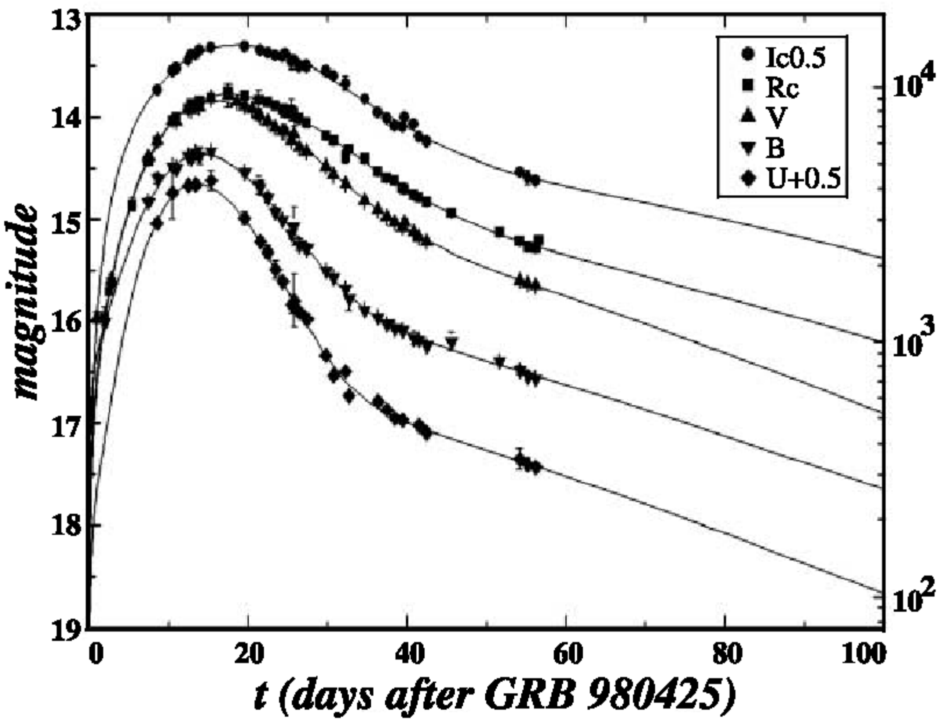
David Bersier
Astrophysics Research Institute
Liverpool John Moores University

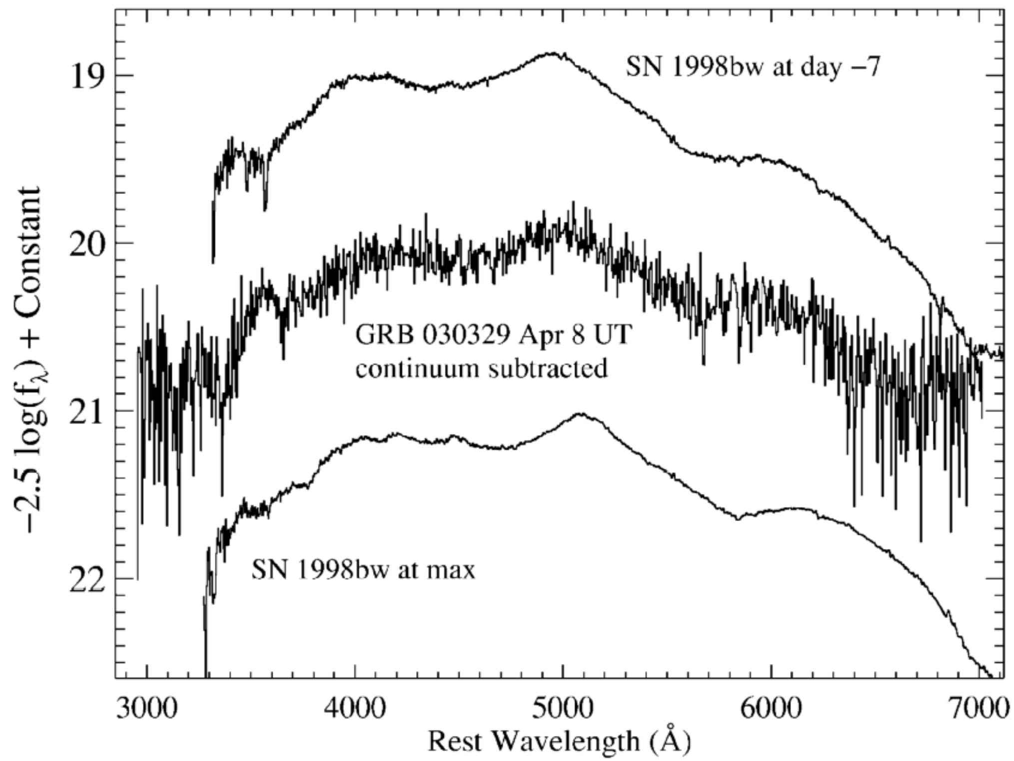
The SN connection

The connection has been on everyone's mind for a long time (Colgate 1969)

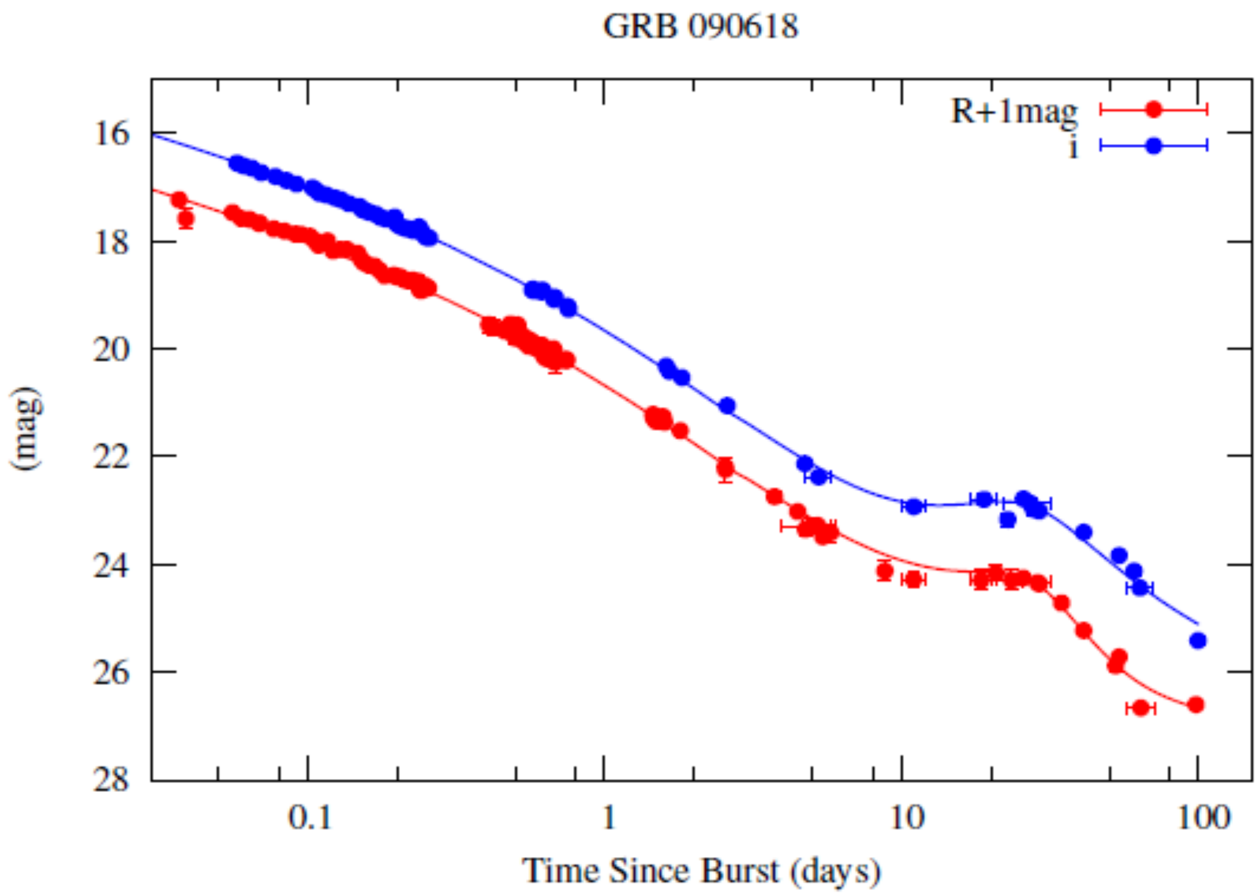
Became a belief with GRB980425 ≡ SN 1998bw (Galama+ 1998)

Proof with GRB030329 ≡ SN 2003dh (Stanek+ 2003, Hjorth+ 2003)





Bumps on light curves



GRB 090618:
Cano et al (2010)

Zeh et al (2004): in every case where we can see a bump, a bump has been seen.

SN light curves tend to resemble SN 1998bw (e.g. Ferrero+ 2006, Cano+ 2010)

Where we are now

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	spectroscopic SN	46
100316D	2010bh	0.0591	A	spectroscopic SN	47,48
100418A		0.624	D		49
101219B		0.552	B	spectral features	50,51,52
120422A	2012bz	0.28	A	spectroscopic SN	

(Hjorth & Bloom 2011)

SNe brightnesses and energies

SNe of GRBs are **broad-lined.**

More **energetic** and slightly more **luminous** than “average” SNIc (but some upper limits).

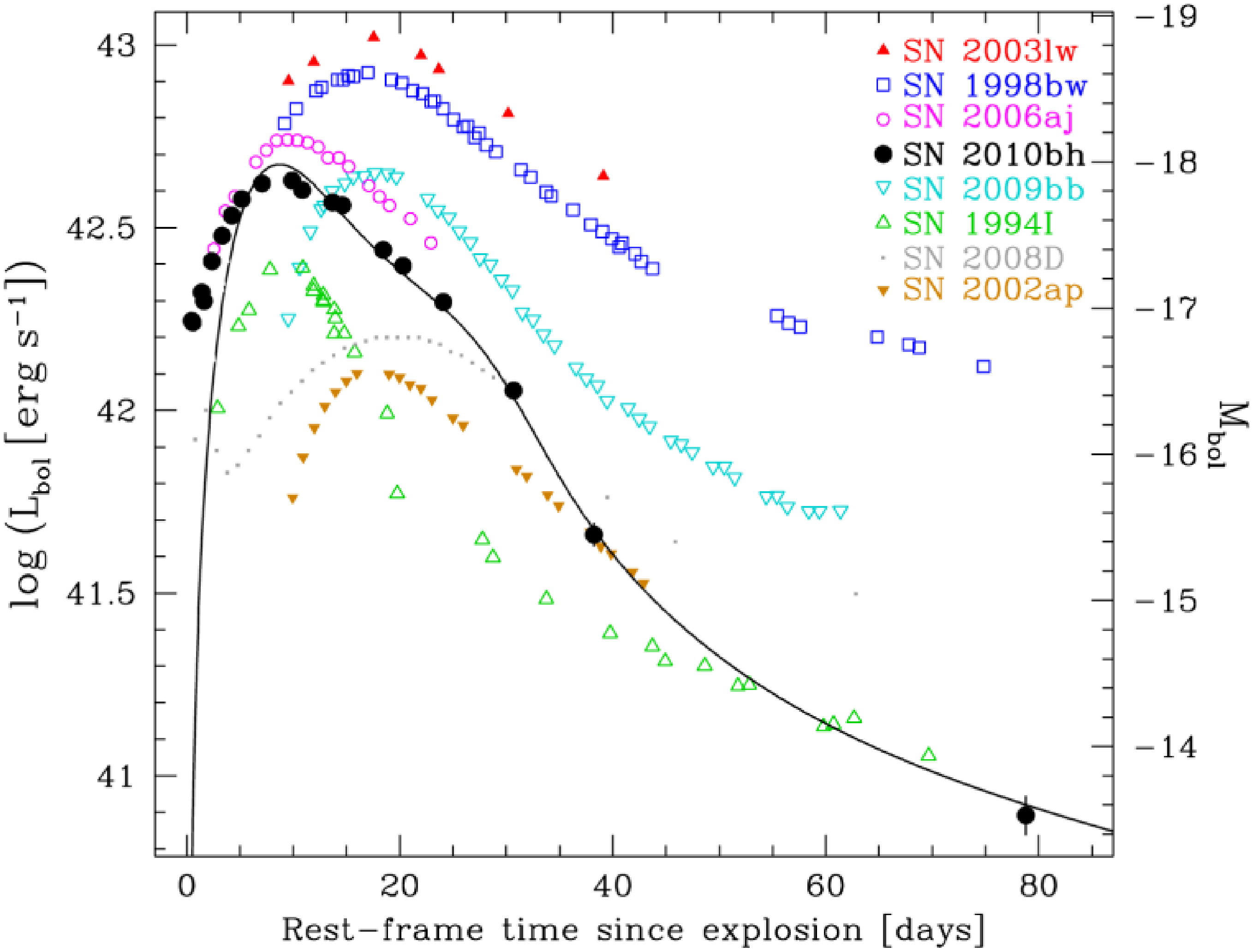
Explosion parameters
(SN 1998bw, 2003dh, 2003lw, 2006aj, 2010bh)

E_{SN} ~ 2 – 60 10^{51} erg

$M(^{56}Ni)$ ~ 0.1 – 0.7 $M_\odot$

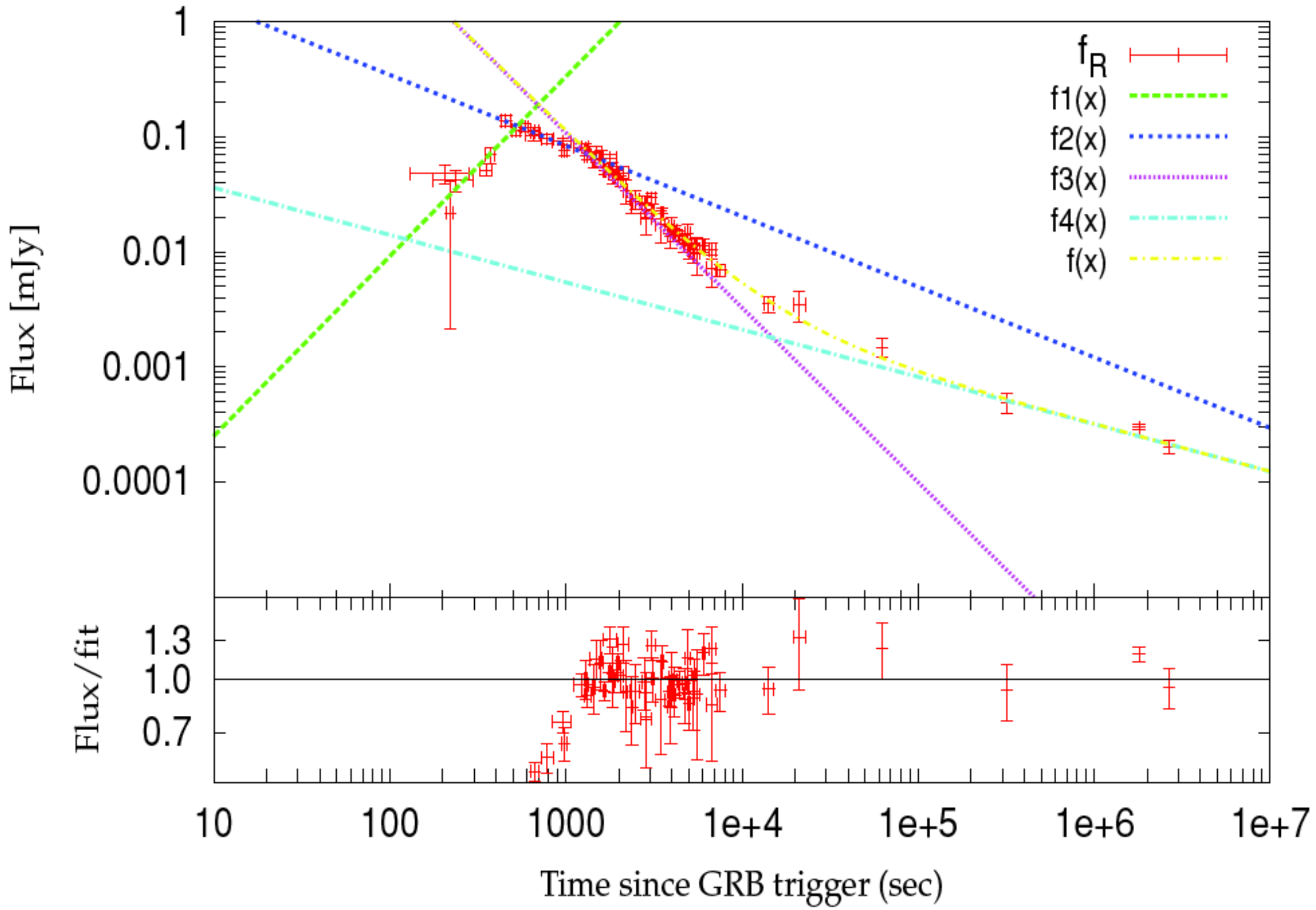
M_{ej} ~ 2 – 13 $M_\odot$

M_{ZAMS} ~ 20 – 45 $M_\odot$



Olivares+ 2012

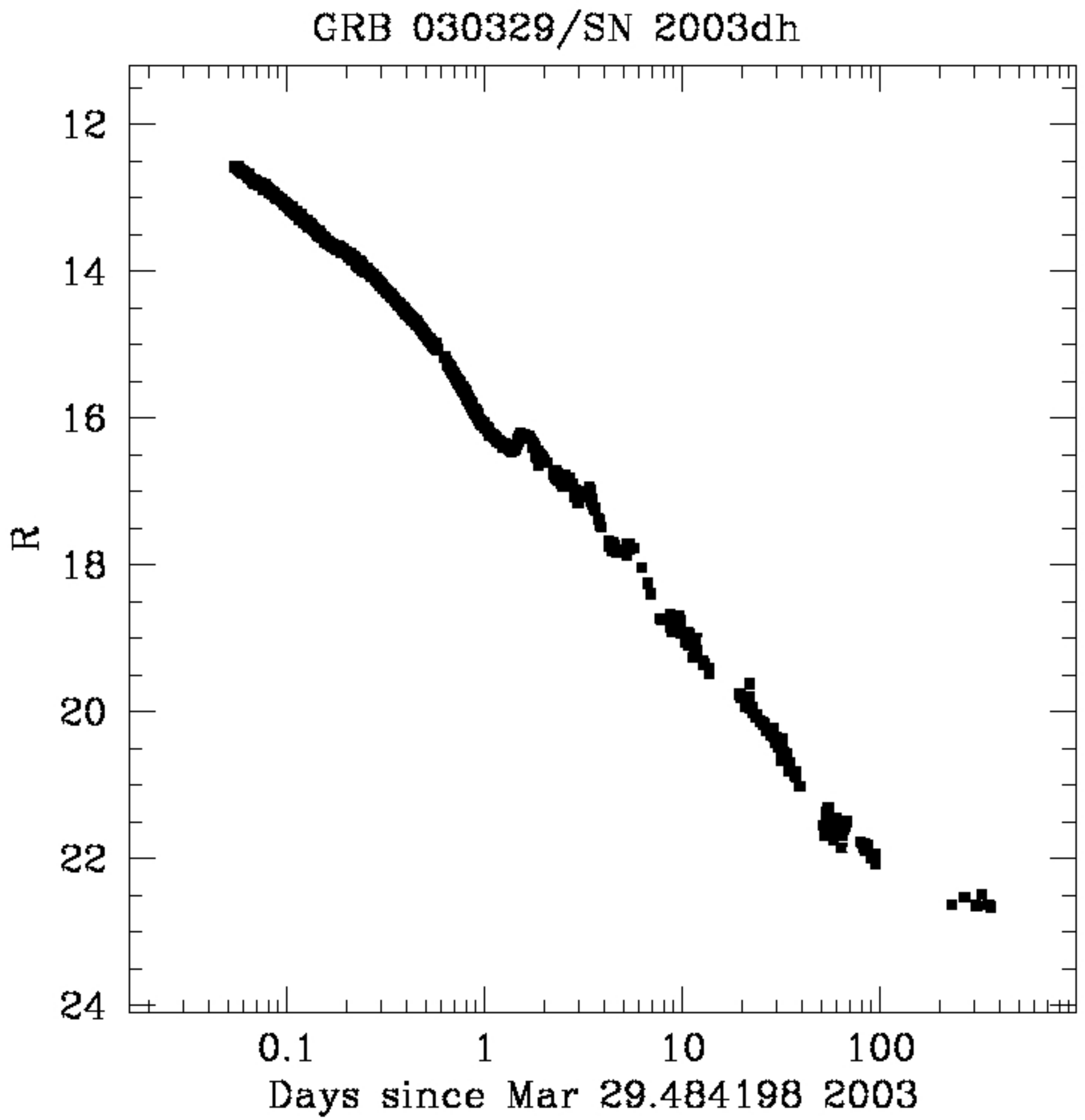
Cautionary tales



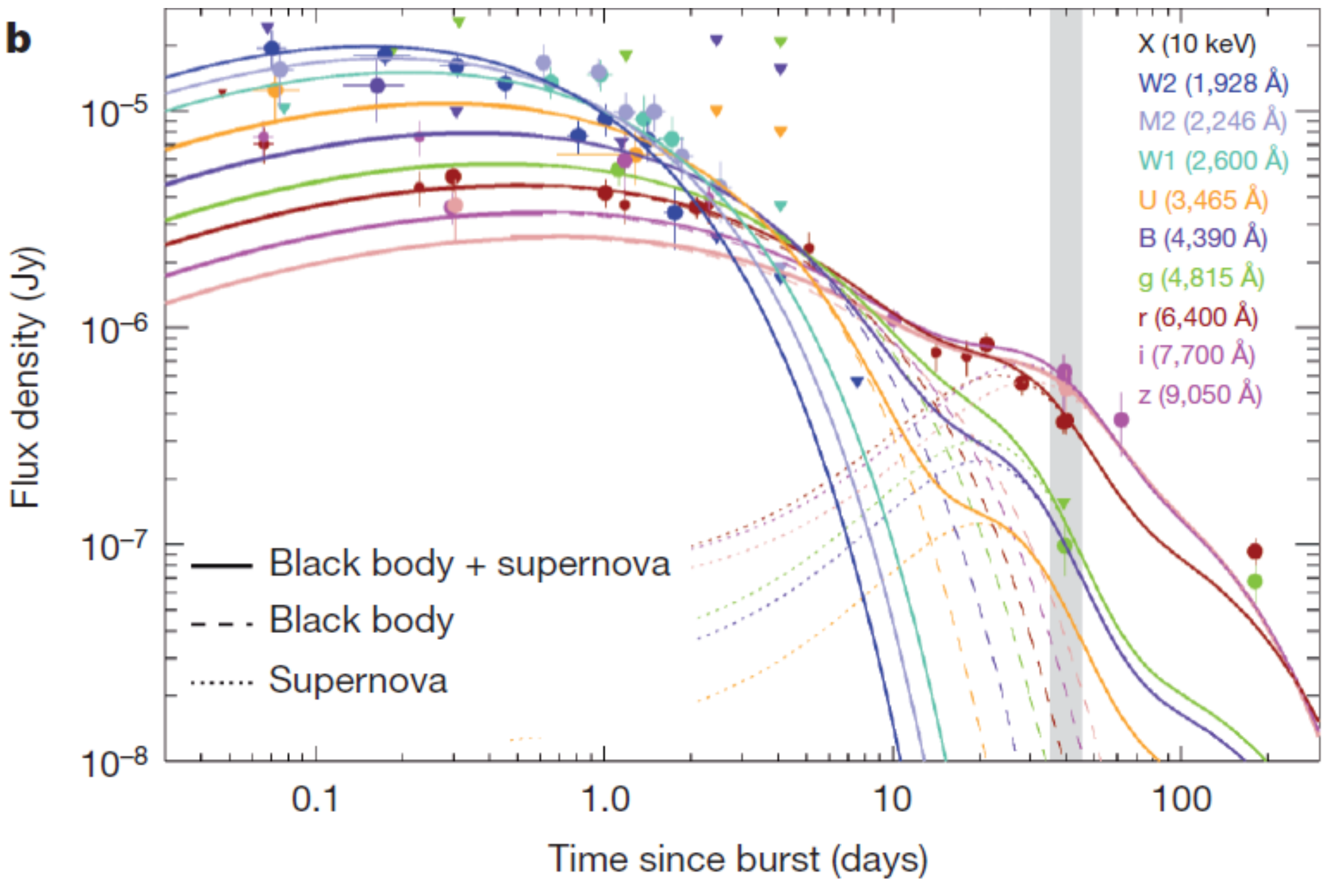
GRB070419A at z=0.97
(Melandri+ 2009)

Initial claim for a SN (Hill+ 2009) but may well be afterglow behavior.

2-3 measurements around SN peak are not enough.
Need to go well beyond peak.

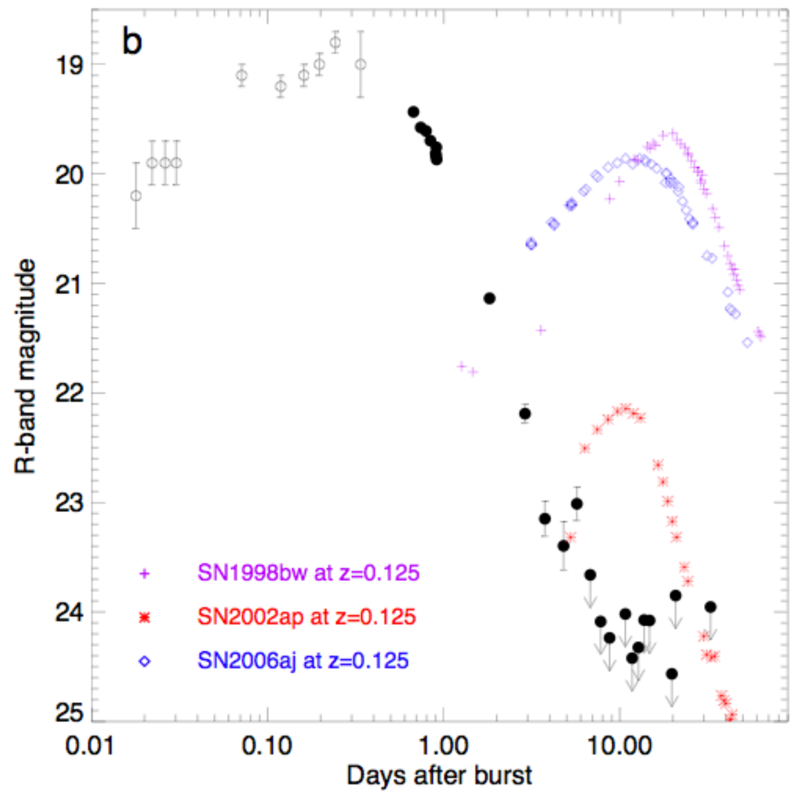


A bump (or absence of) on a light curve is **not enough**.
Need careful analysis of **AG+SN**.
Also need **spectroscopy**.



GRB101225: merger of GRB101NS-He star (Thőne+ 2011) or comet+NS (Campana+ 2011).
Spectroscopy! (again)

Even if you do everything right...



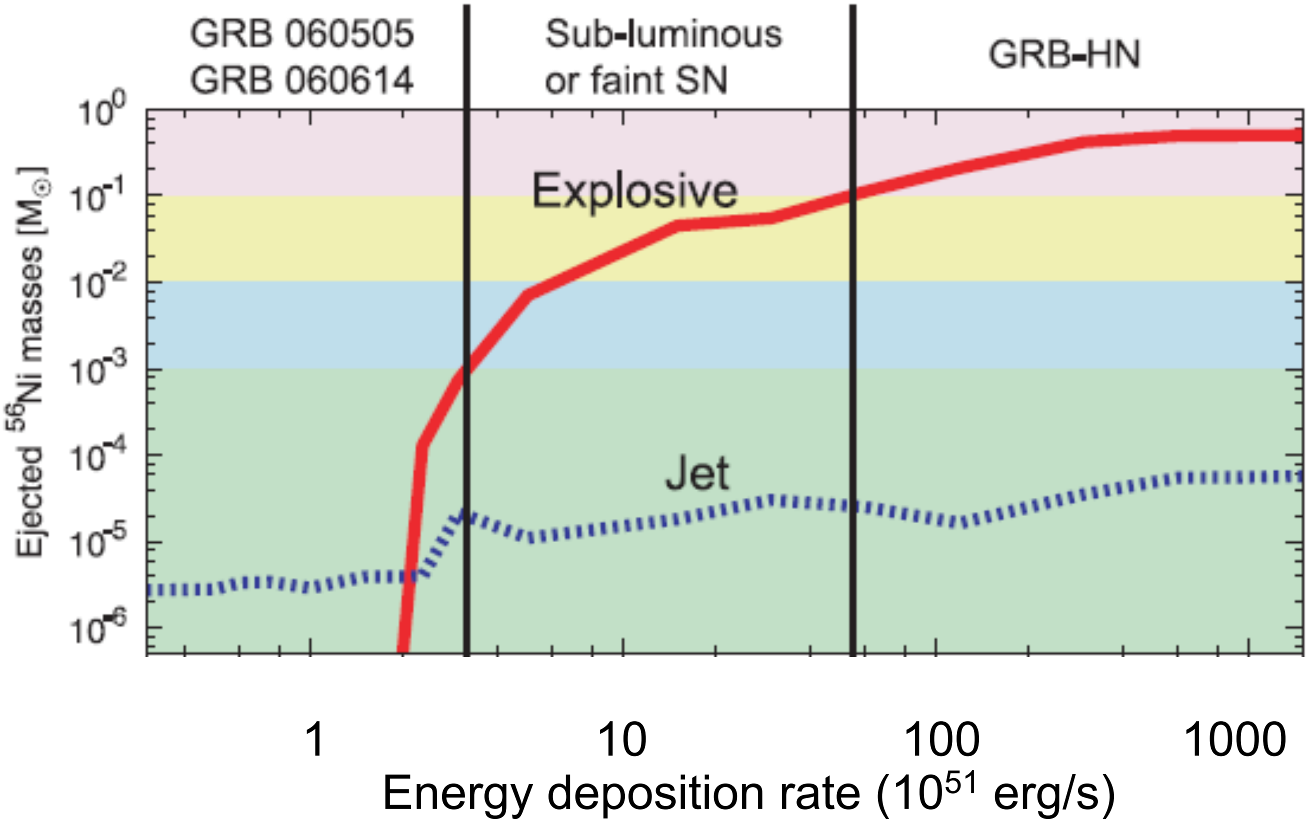
GRB060505, GRB060614 (Fynbo et al. 2006, Gal-Yam+ 2006, Della Valle+ 2006).
Other GRB/XRF without a SN (e.g. Levan+ 2005, Soderberg+ 2005)

SNe-less GRBs

It may well be possible to make a GRB (relativistic jet) without a bright SN (e.g. Tominaga+ 2007)

We should not be too surprised to find GRBs *without* a SN.

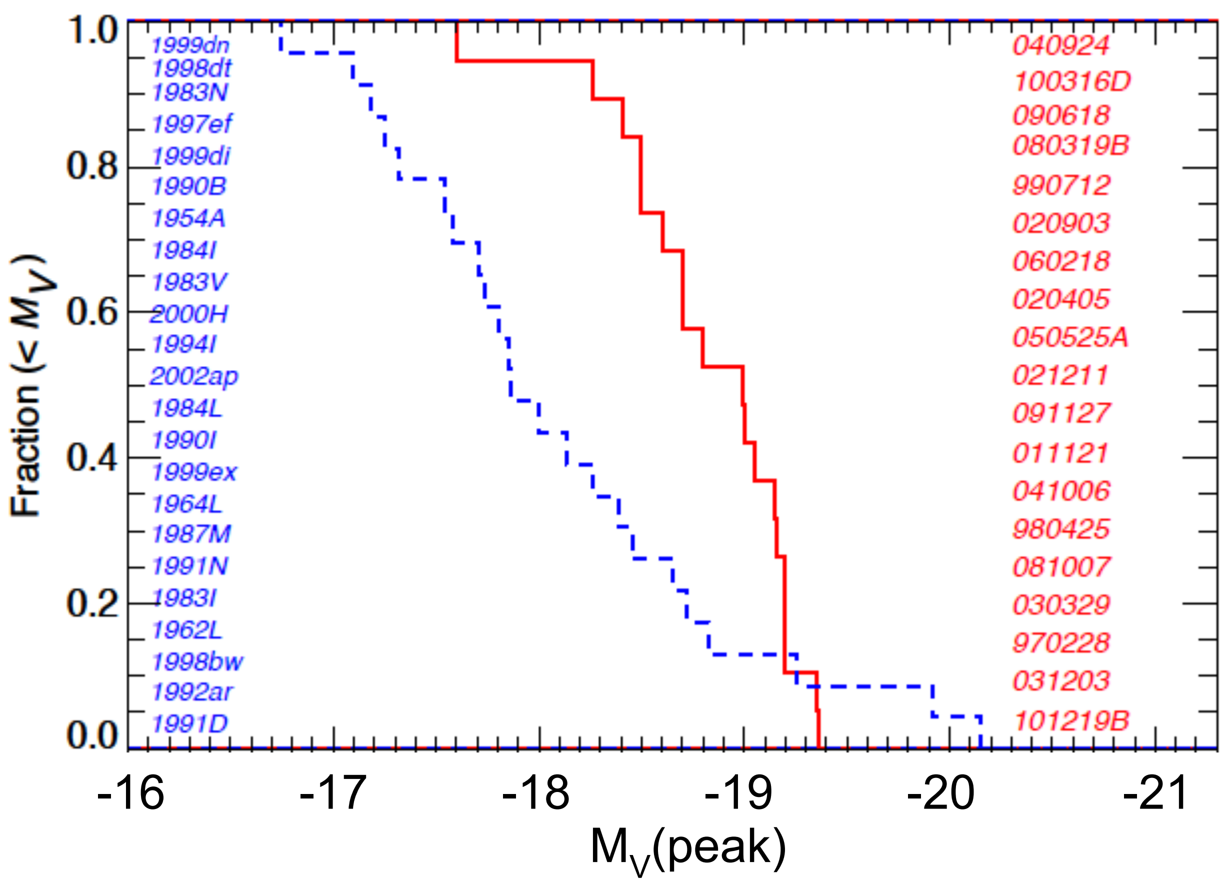
This may point to (slightly?) different progenitors/scenarios (think of long/short dichotomy)



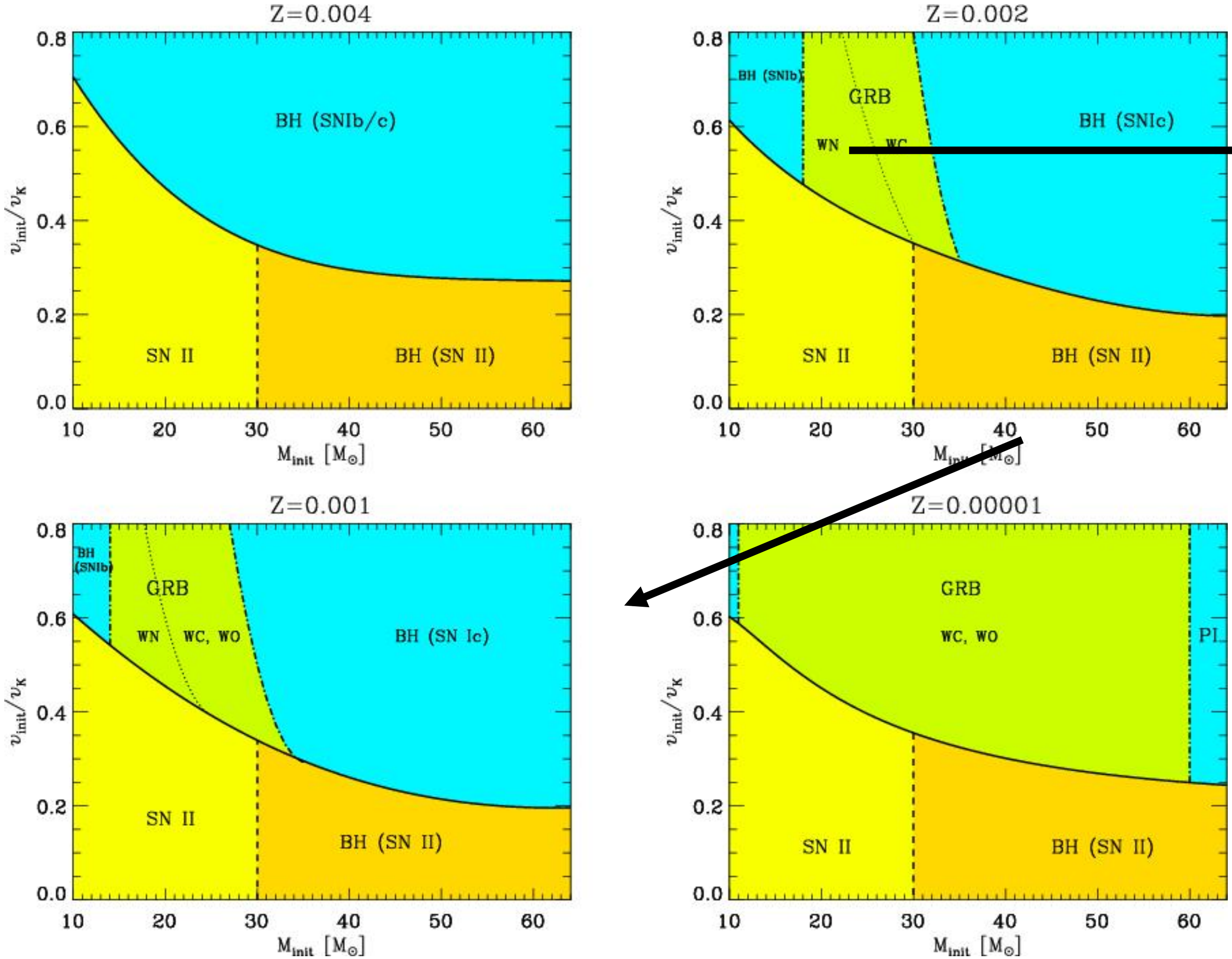
Similarities and differences between GRB/SN and local SNe

GRBs come from exploding massive stars: knowledge we can use.

To explain the SN we see with GRB – and those we don't see, it pays to put them in the more general context of all SNe



Similarities and differences between GRB/SN and local SNe

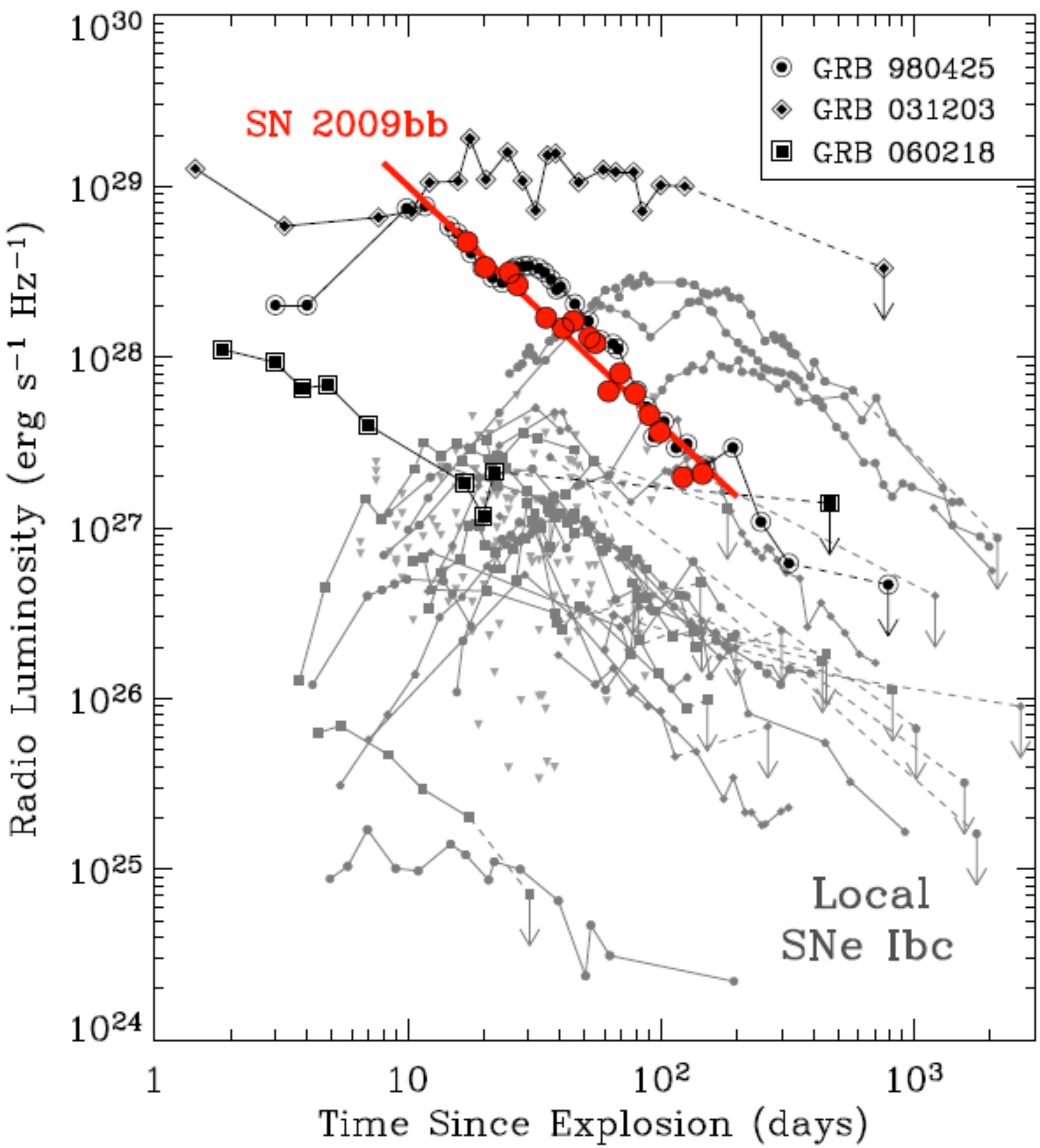


GRBs

In a global picture of the fate of massive stars, we want to know where GRBs are and how they fit in this picture.

Yoon, Langer, Norman (2006)

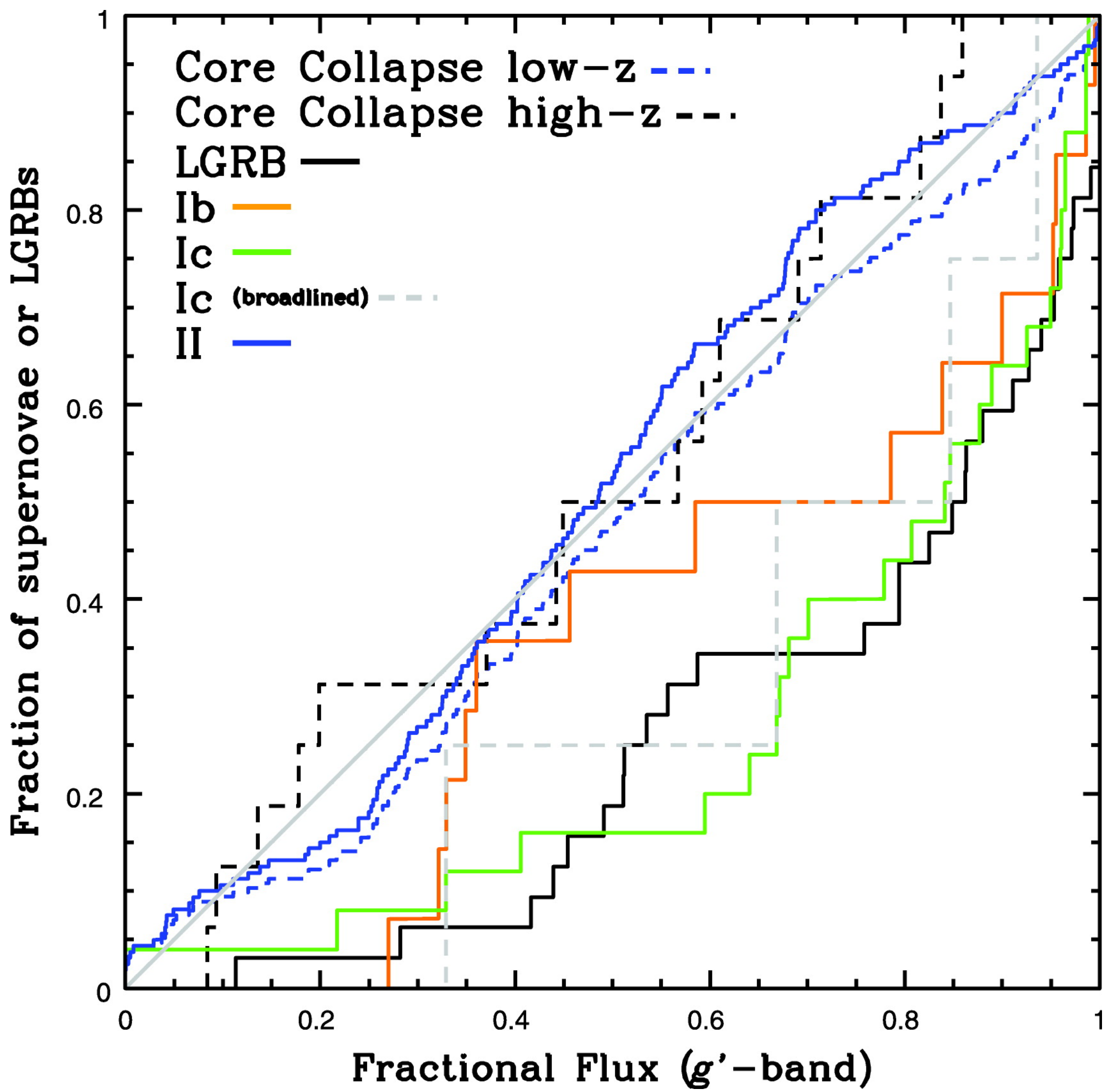
GRBs we see and those we don't



Only a few % of SNe Ib/c can have a GRB (from late time radio brightness, e.g. Soderberg+ 2006).

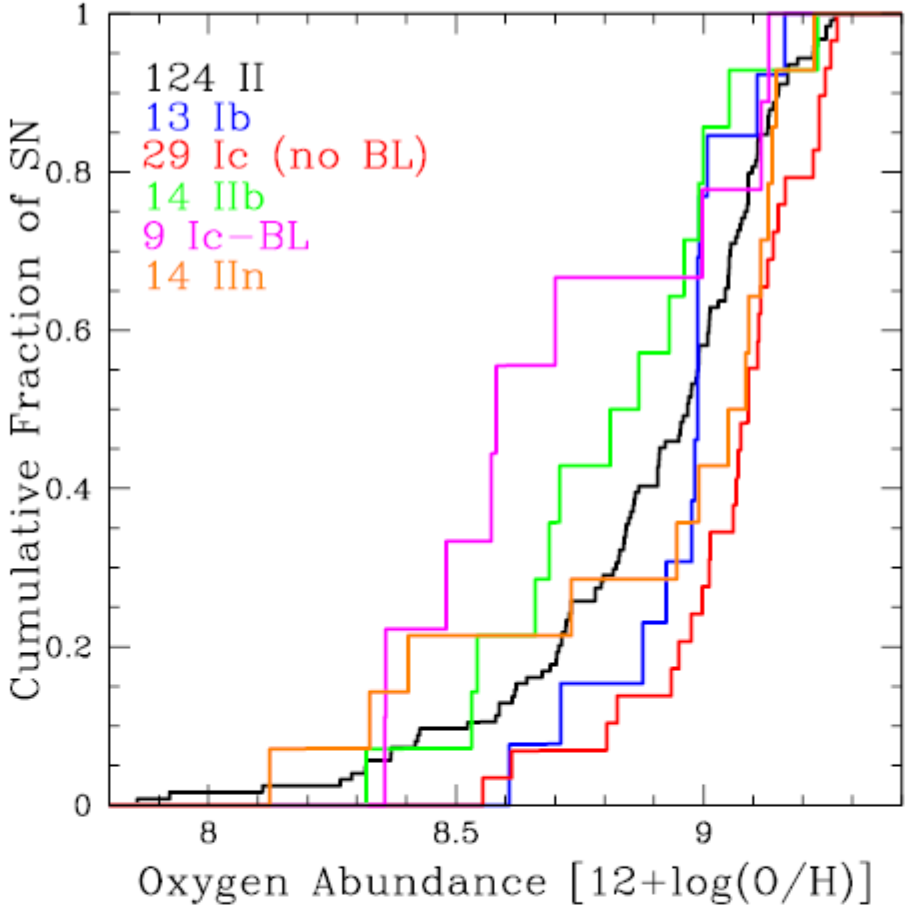
Radio observations may become a better way to find nearby GRBs. (Soderberg+ 2010)

Locations of SN Ic and GRBs

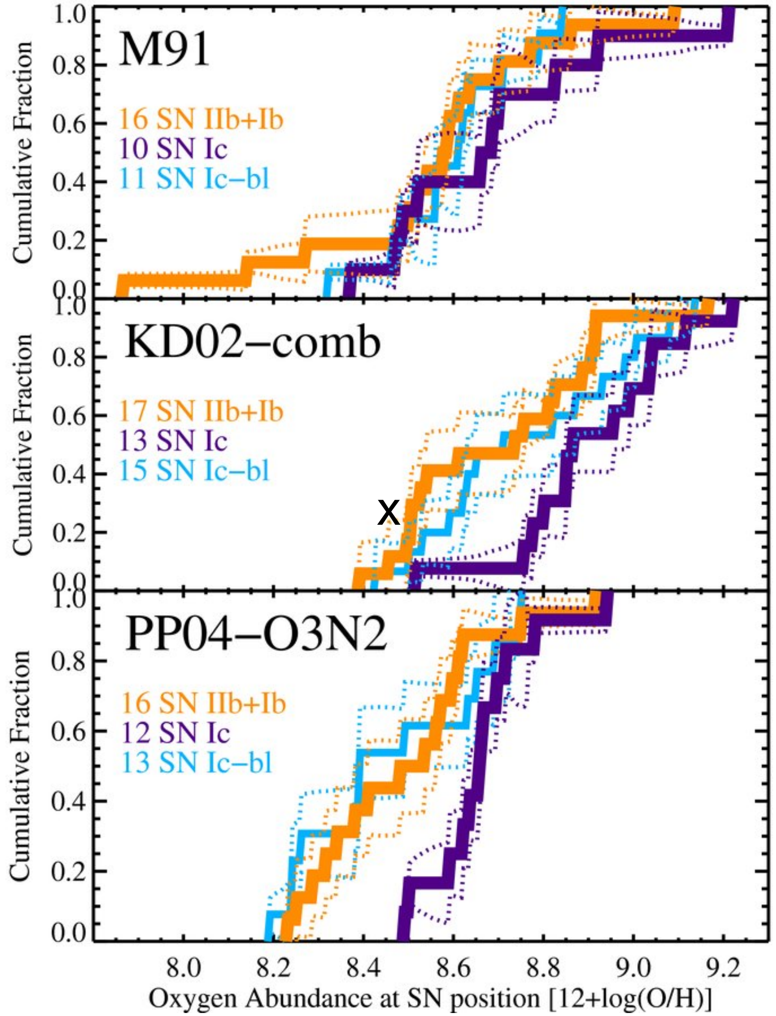


GRBs and SN Ic are more concentrated than the light. Distributions are compatible whereas GRBs and SN II come from different populations
(e.g. Kelly+ 2008).

Metallicity



Kelly & Kirshner 2011



Modjaz+ 2011

This is in line with what we see for GRBs (but see Savaglio+ 2012)

Outlook

SNe Ic-BL are more metal-poor than SNe Ic. (Most) GRB/SNe are more metal-poor than SNe Ic.

What do we want to achieve? No need for another bump-on-a-lightcurve. Five gold standard cases but spectroscopy is always needed.

Analysis of LC+spectra to estimate explosion parameters ⟶ MS mass of progenitor

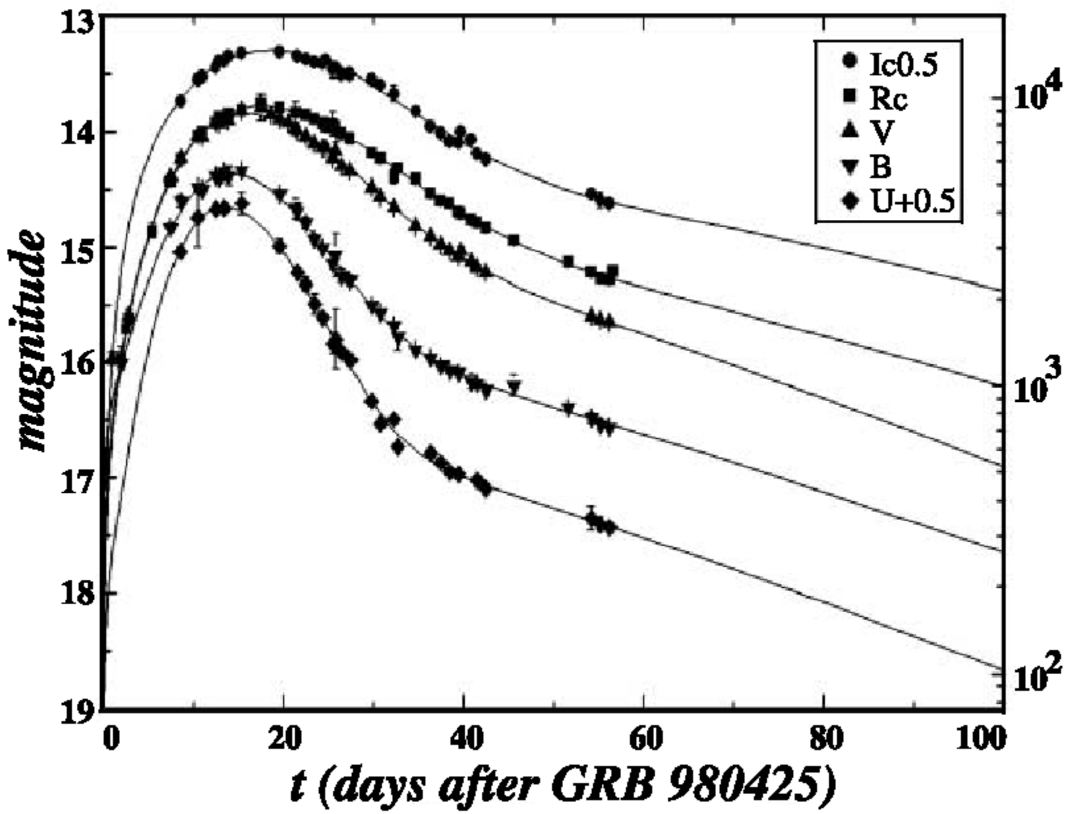
Radio monitoring of SNe is a novel way to find nearby GRBs.

There may well be more than one way to make a GRB; there may well be more than one way to make a SN. Metallicity, mass and rotation of progenitor can all play a role.

Progress will also come from observations of nearby SNe (PS, PTF, LSQ, LSST). The parameter space for making ccSNe is large, GRBs occupy a small fraction. Populating it with SNe will “corner” the GRBs.

HIDDEN SLIDES

The supernova connection (1)



GRB 980425: z=0.0085, *under-luminous* in γ-rays by several orders of magnitude.

No optical counterpart but a Type Ic SN.

It was a hyper energetic SN Ic (broad lined).

Galama et al (1998)

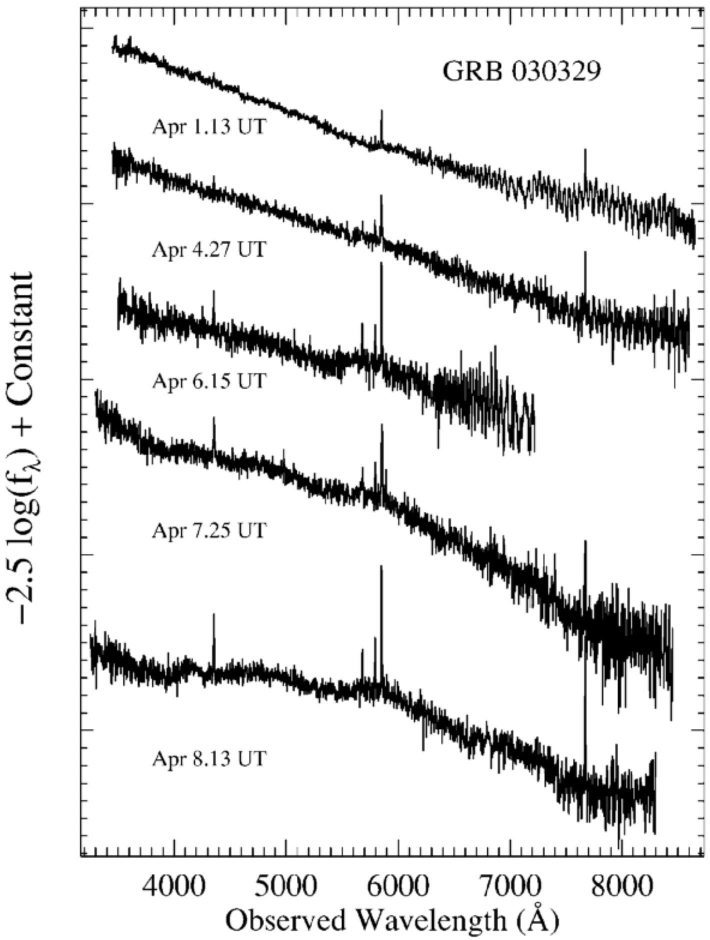
Connection GRB-supernova?

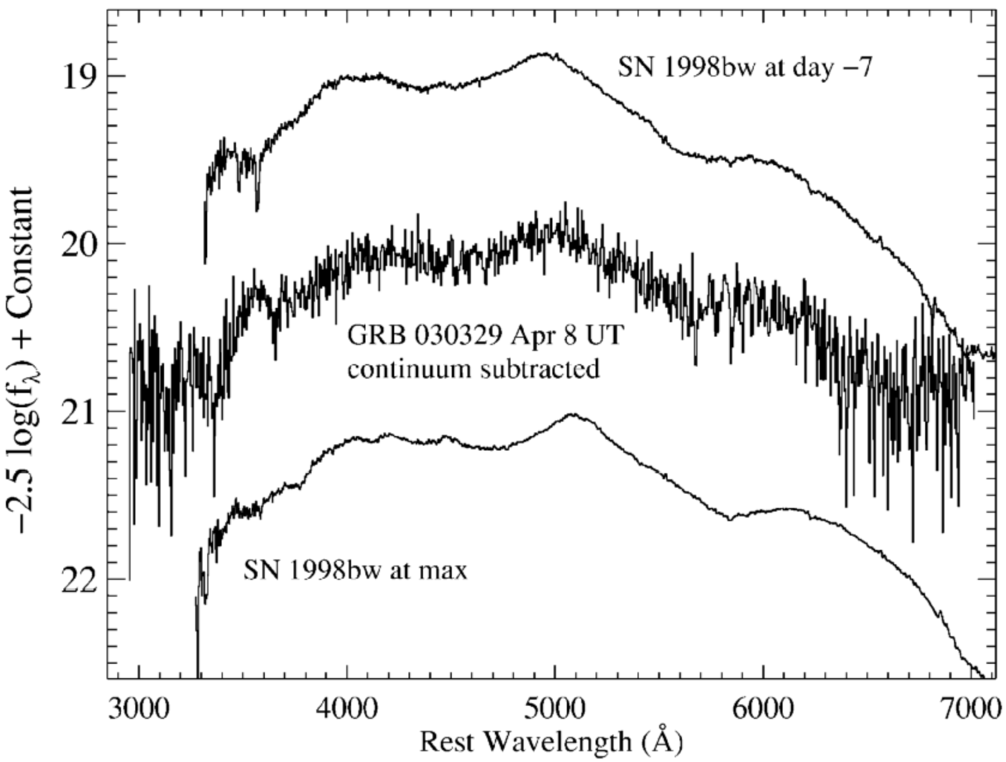
Theoretical possibility (collapsar, Woosley 1993)

But weak GRB, bright SN. Red herring?

The supernova connection (2)

GRB 030329: z=0.1685, spectroscopy possible

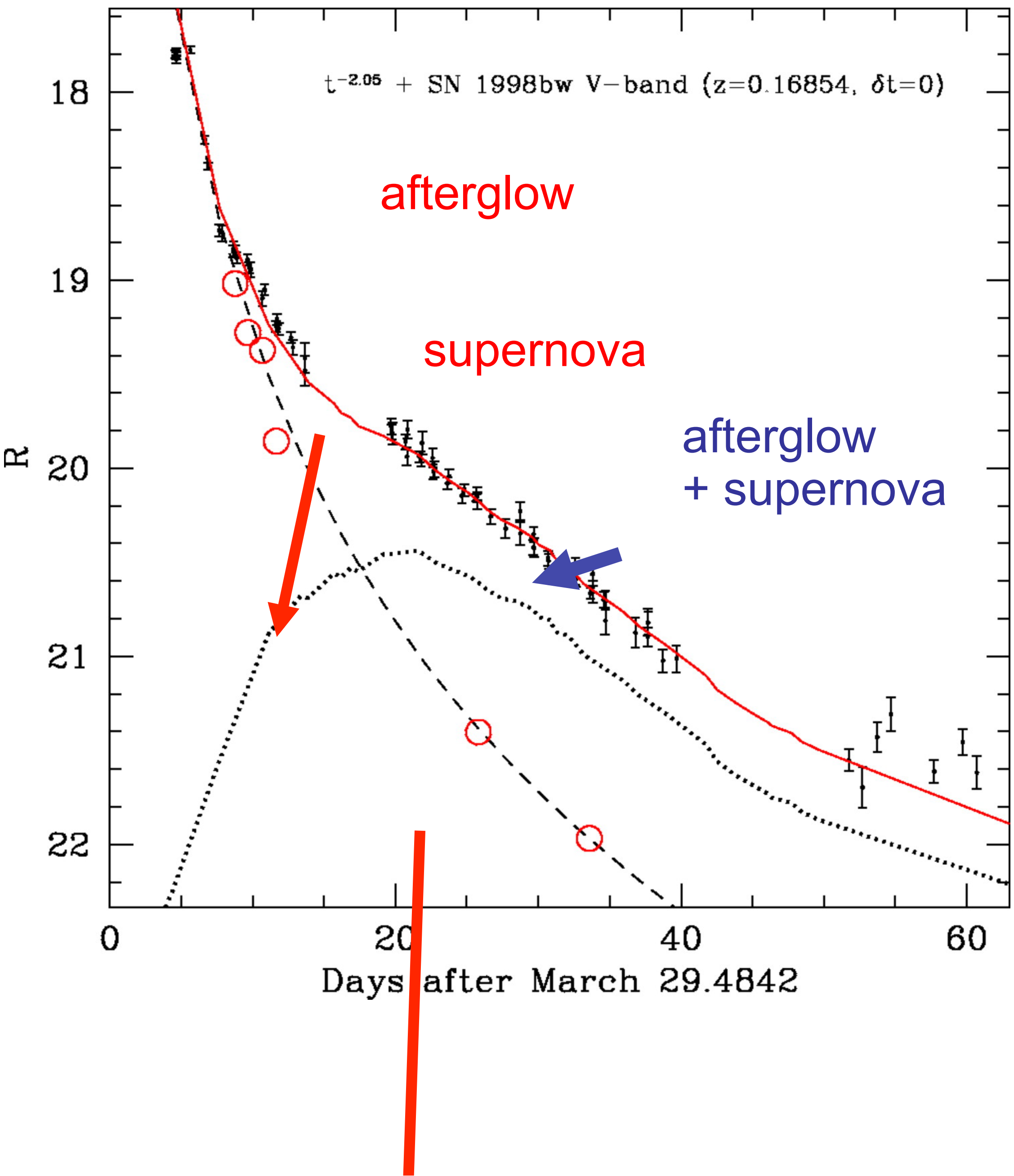




Unambiguous SN Ic signature

(Stanek et al 2003, Hjorth et al 2003)

GRB 030329



Matheson et al. (2003):
Spectral evolution of SN 2003dh very similar to SN 1998bw

Spectrosopic evidence:
980425, 030329, 031203, (020903), 060218, (081007), 100316D

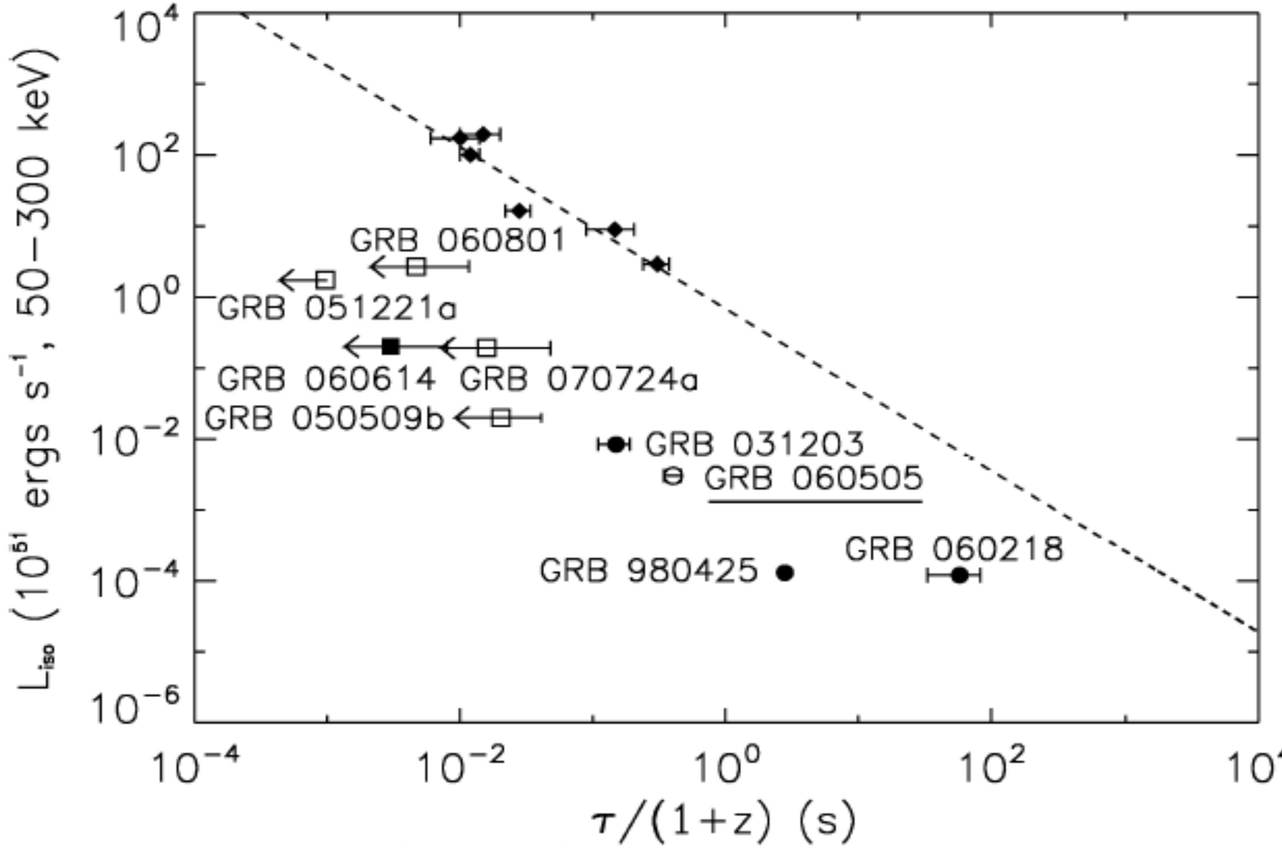
GRBs are associated with energetic SNe I/c

What are these bursts?

Are they short or long?
060614 lag (and light curve?) points towards short (Gehrels+ 2006).
GRB060505 looks long (McBreen+ 2008).

Are these bursts red herrings?
Are they a new class?

Need to find more of these!

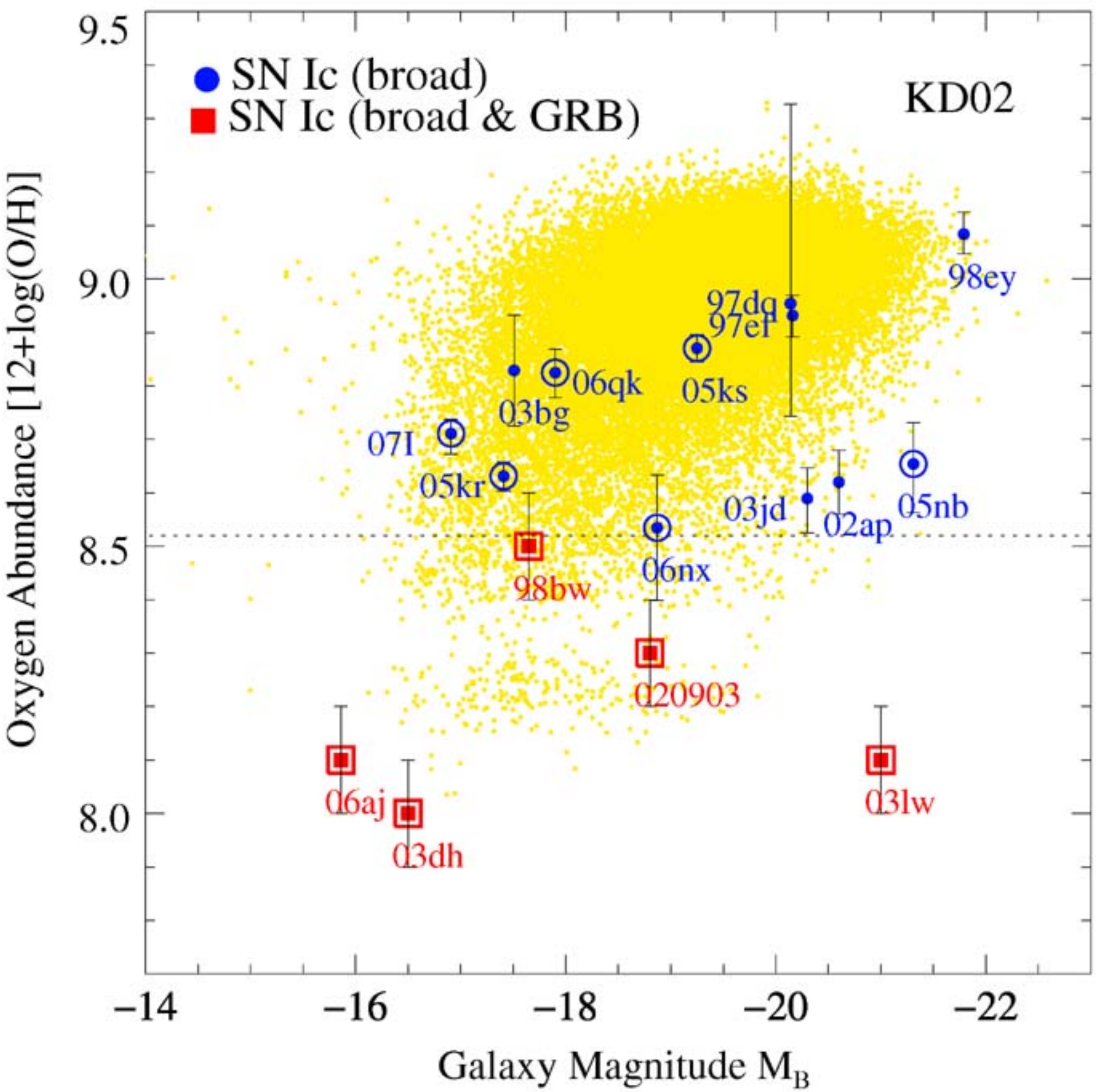


May be the only EM signature of *some* stellar explosions.

Actually possible to explode a star without making *Ni* (< 1% $M_\odot$).

May be possible to make a GRB *without* making radioactive elements.

Local SN Ic and GRBs



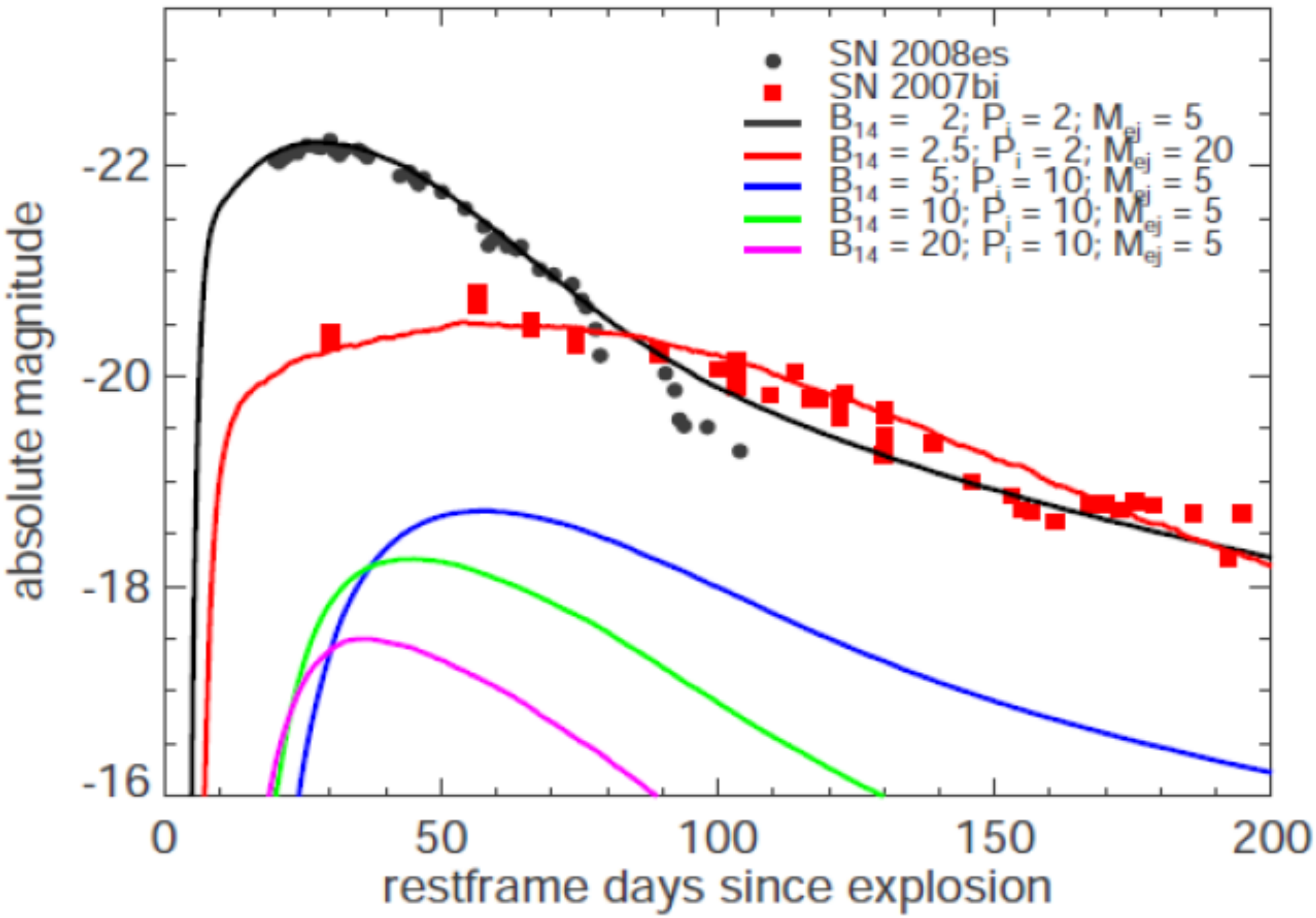
Local SNe Ic are in metal-rich galaxies.

Metallicity may well be what separates GRBs and normal SNIc, but selection effect?

(Modjaz et al. 2008, Stanek et al 2006)

SN 2009bb: relativistic outflow, [O/H]=9.0, M_B=-20

Magnetar-powered supernovae

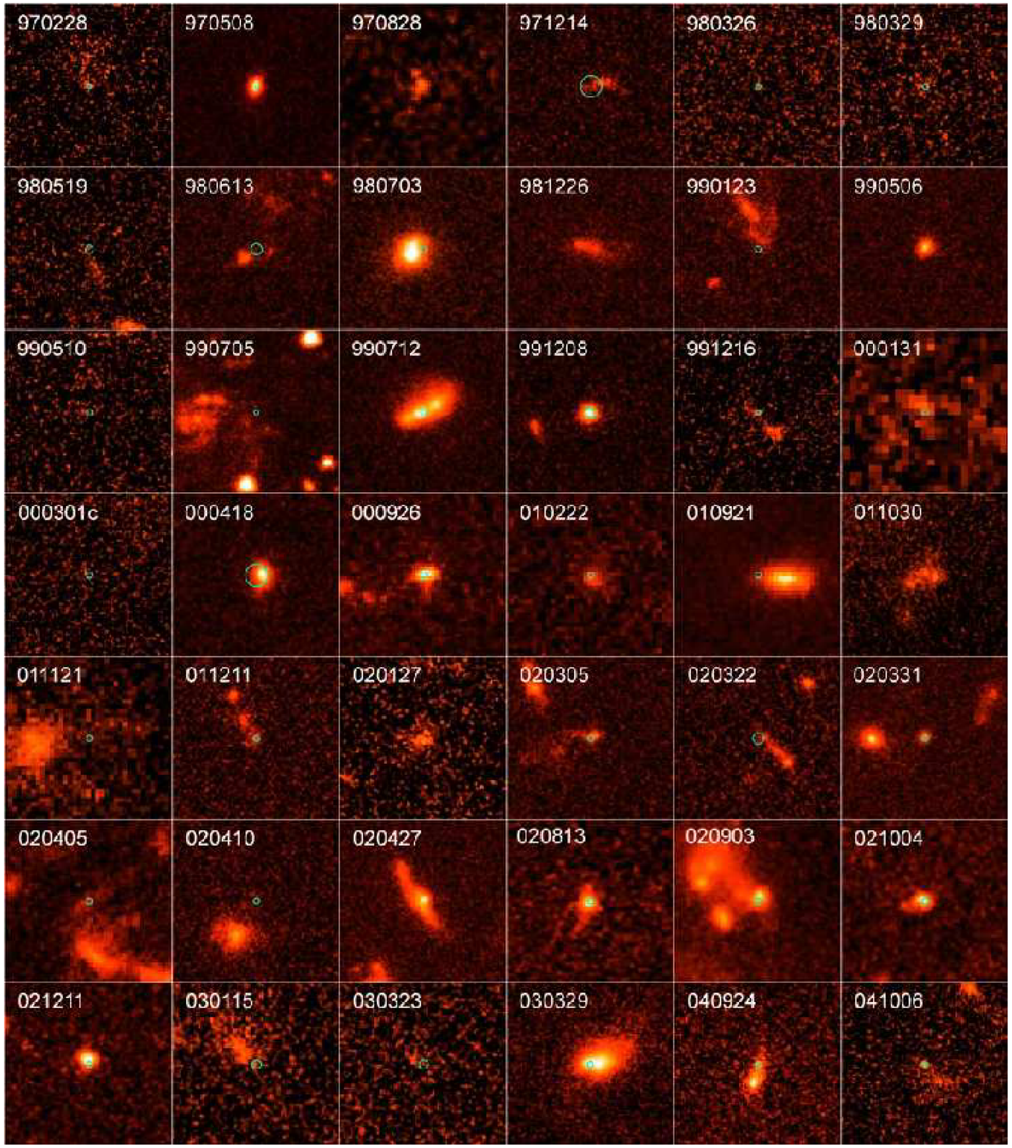


Magnetar with B_{14}>1 G, P ~ few ms formed when a massive star collapses.

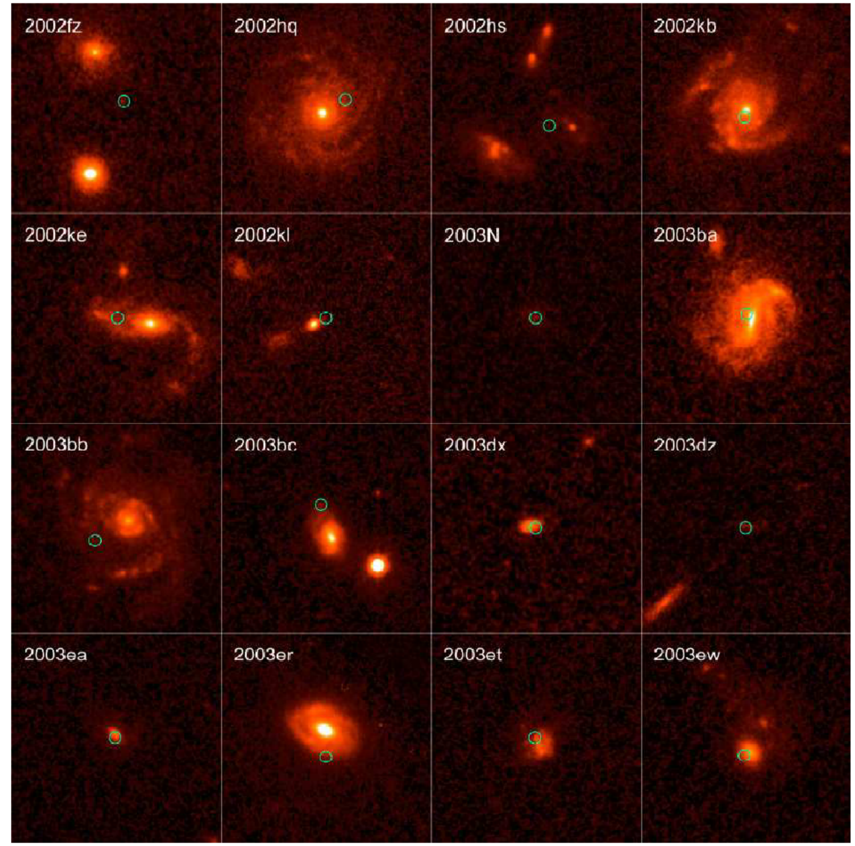
Magnetic energy deposited at bottom of ejecta, can power the SN.

Variety of rise/decay time and light curve shape. After a few hundred days, decay is *not* exponential. SN 1998bw is exponential.
(Kasen & Bildsten 2009; Woosley 2009)

GRB hosts with HST



Core-collapse hosts with HST



For $z \leq 1$:
GRB hosts fainter and smaller than cc SNe hosts (Fruchter et al 2006; see also James & Anderson 2006)

Position of GRBs and cc SNe on their hosts

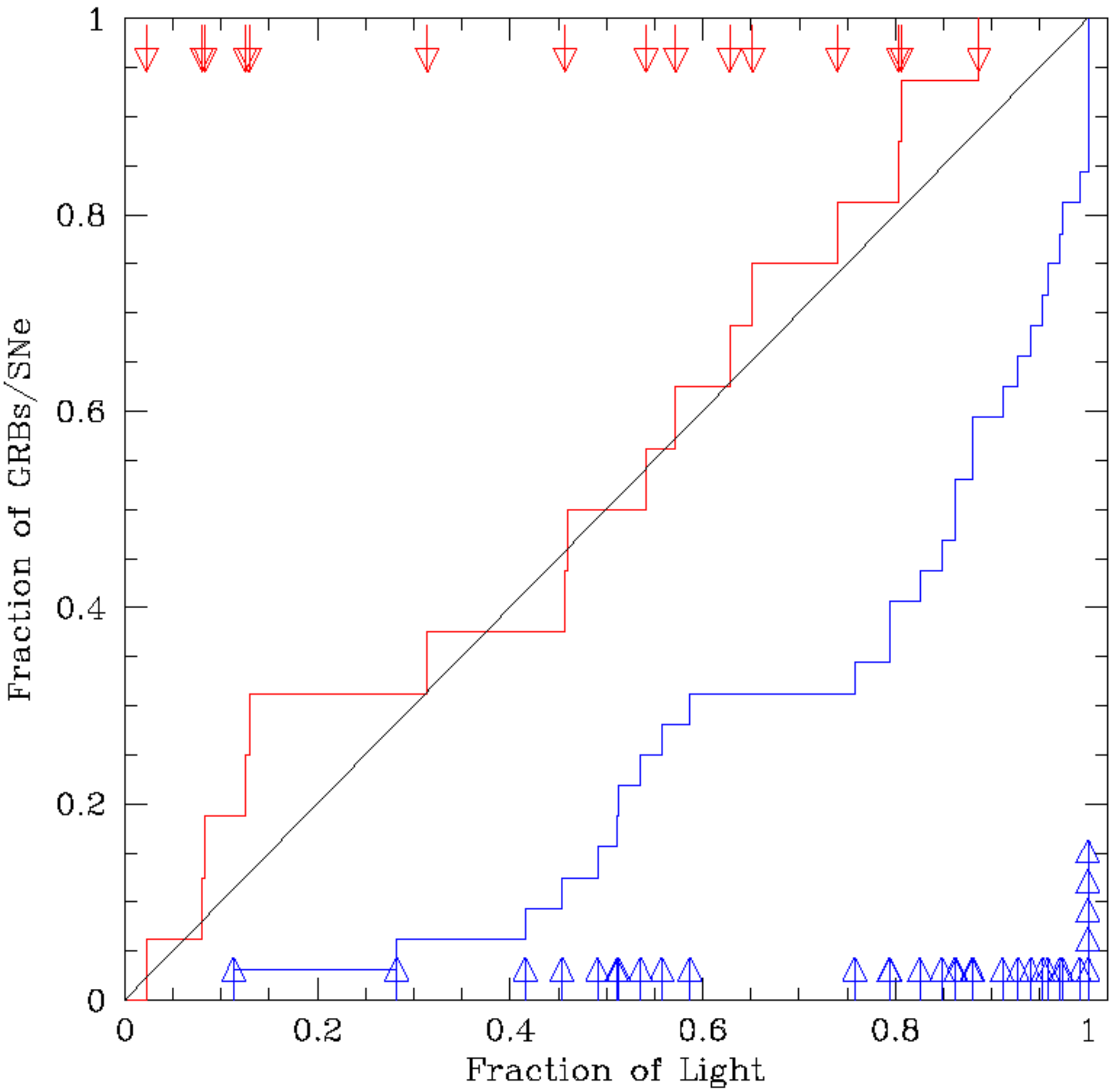
Order all host pixels from brightest to faintest.
Then ask: where does the GRB or SN fall?

GRBs

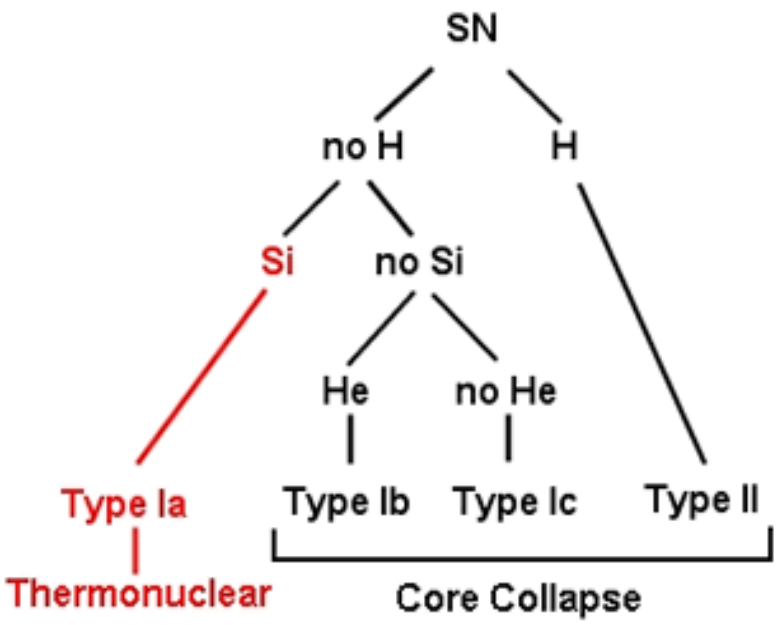
CC SNe

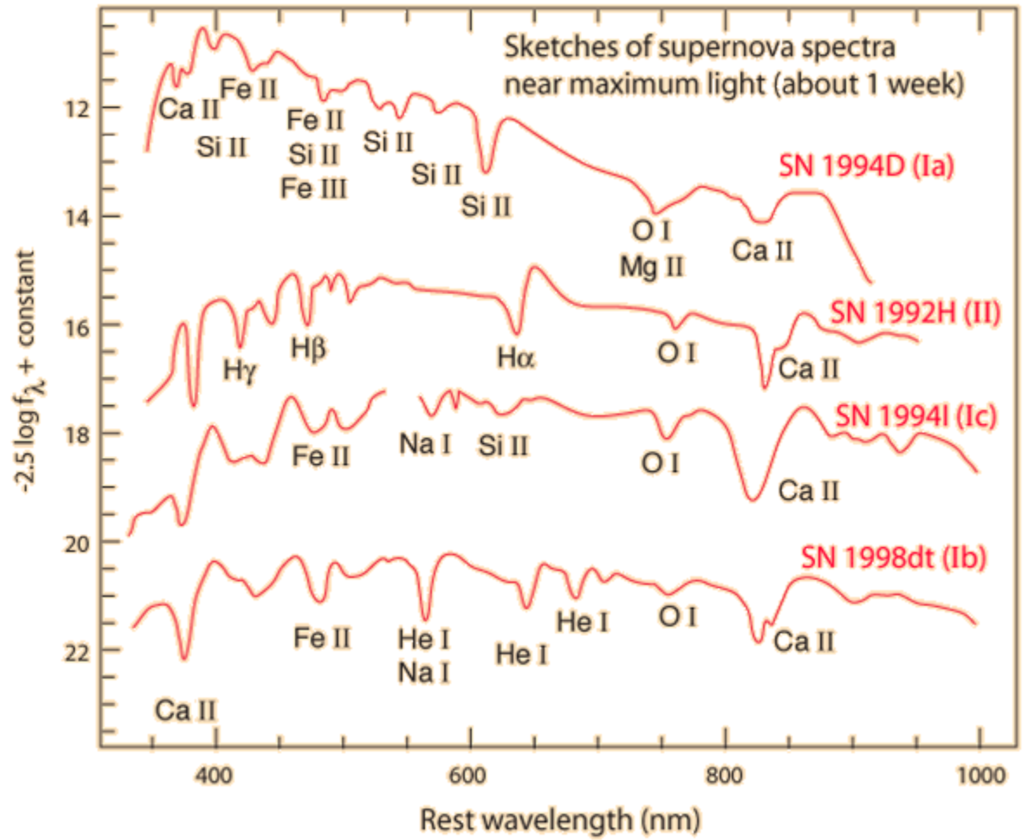
CC SNe follow the light

GRBs are much more likely to fall on a bright pixel, maybe even the brightest pixel (Fruchter et al 2006)



The supernova zoo





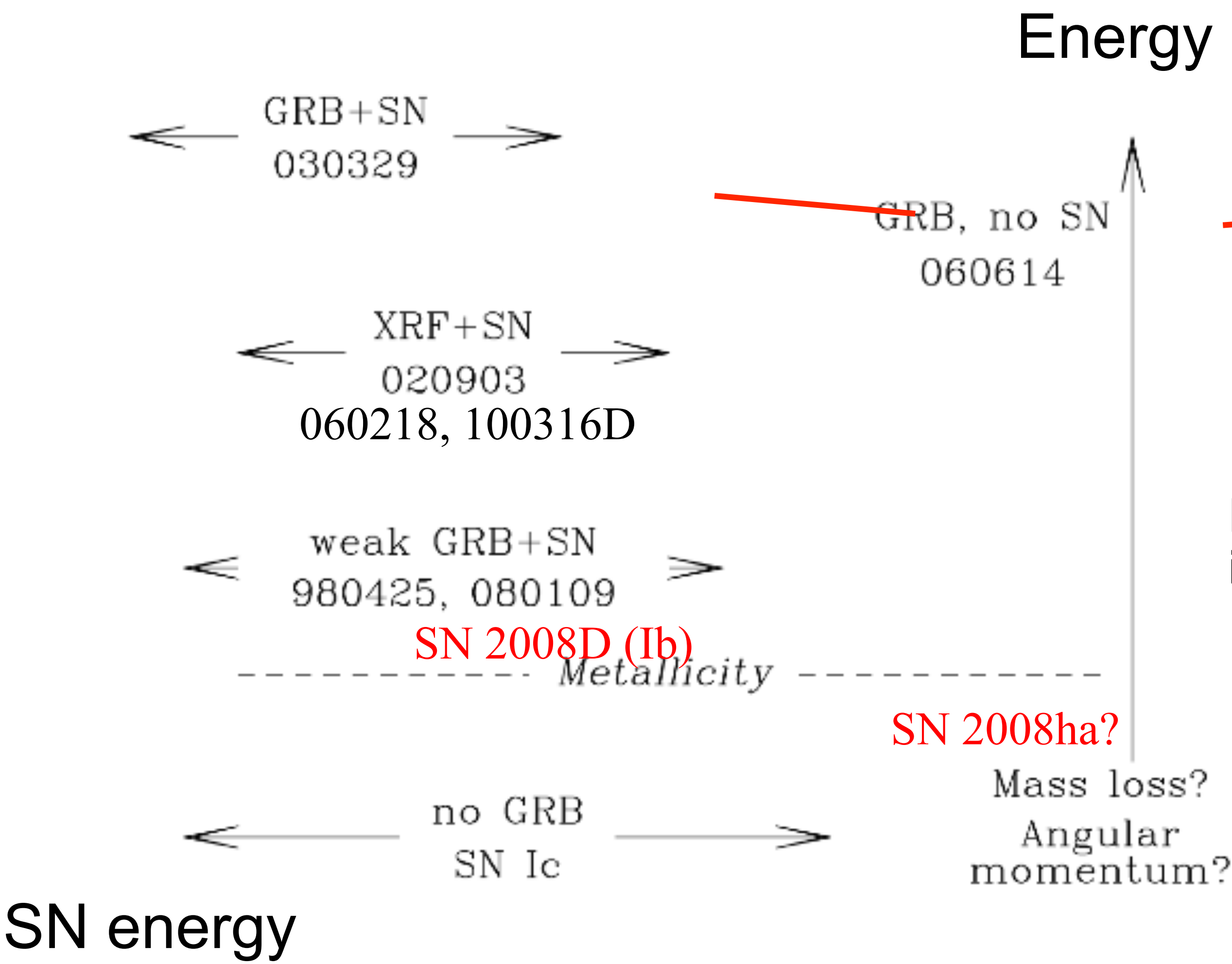
Sketches of spectra from Carroll & Ostlie, data attributed to Thomas Matheson of National Optical Astronomy Observatory.

Two basic types:

Ia: Thermonuclear explosion of a white dwarf

Ibc, II: Core collapse of a massive ($M>8M_\odot$) star

Energetic transients: from chaos to simplicity?



060614 may have a SN after all

Do SN 2008D and SN 2008ha fit in here or are they false clues?

Does 2008D fit
Is it another fals

Simplicity is tempting….

Rates

Rate calculations, accounting for GRB beaming, SN type, instrument sensitivity, etc. are still uncertain. Order of magnitude seems correct though.

Podsiadlowski+ (2004) estimated these rates: R(HN) ≈ R(GRB)
R(HN) might be overestimated (Guetta, Della Valle 2007)

TABLE 1
RATES IN AN AVERAGE GALAXY

Objects	Rate (yr^{-1})
Core-collapse SNe	7×10^{-3}
Radio pulsars (Galactic)	4×10^{-2}
SNe Ib/c	1×10^{-3}
HNe	$\sim 10^{-5}$
GRBs (for different effective beaming angles θ):	
$\theta = 1°$	6×10^{-4}
$\theta = 5°$	3×10^{-5}
$\theta = 15°$	3×10^{-6}
Massive stars:	
$>20\ M_\odot$	2×10^{-3}
$>40\ M_\odot$	6×10^{-4}
$>80\ M_\odot$	2×10^{-4}

Likely to depend on redshift (even if not tracing SFH, e.g. Yoon+ 2006).

From false(?) clues and confusion...

GRB060614 & GRB060505 (and some XRFs): may be exploding stars without Ni.

SN 2009bb: SNIc with radio strong emission (Soderberg+ 2010) but has high metallicity (Levesque+ 2010). Does it really tell us something about GRBs, or about SNe?

Theory: either too easy or very hard to make GRBs. Must fit observed rates and other constraints on massive star evolution.