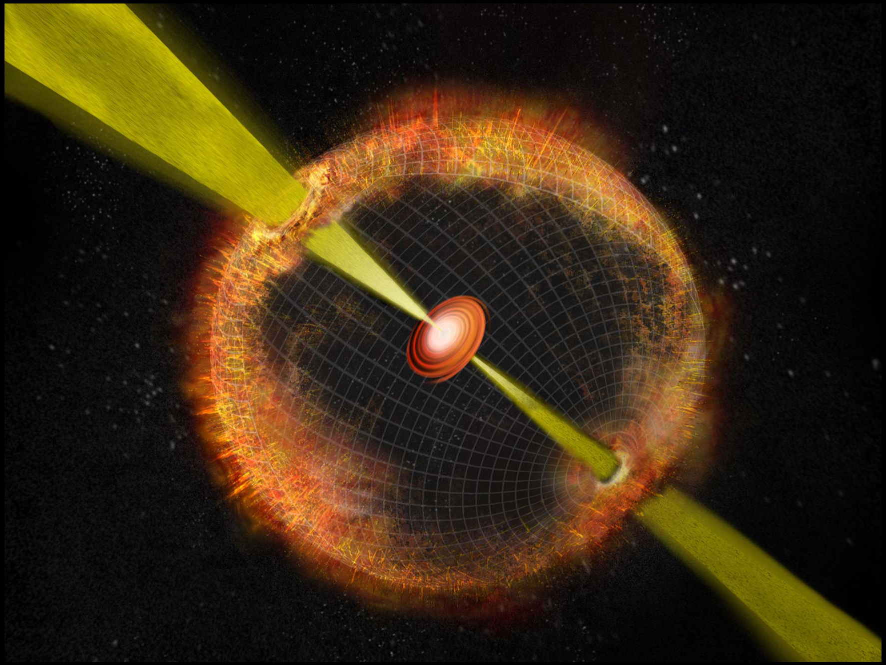
Supernova-GRB connection: the Saga continues…



Massimo Della Valle
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ICRANEt, Pescara

Summary

1. Supernova Taxonomy
2. GRB-SN properties
3. Progenitors Mass
4. GRB and SN rates
5. Conclusions & Open Issues

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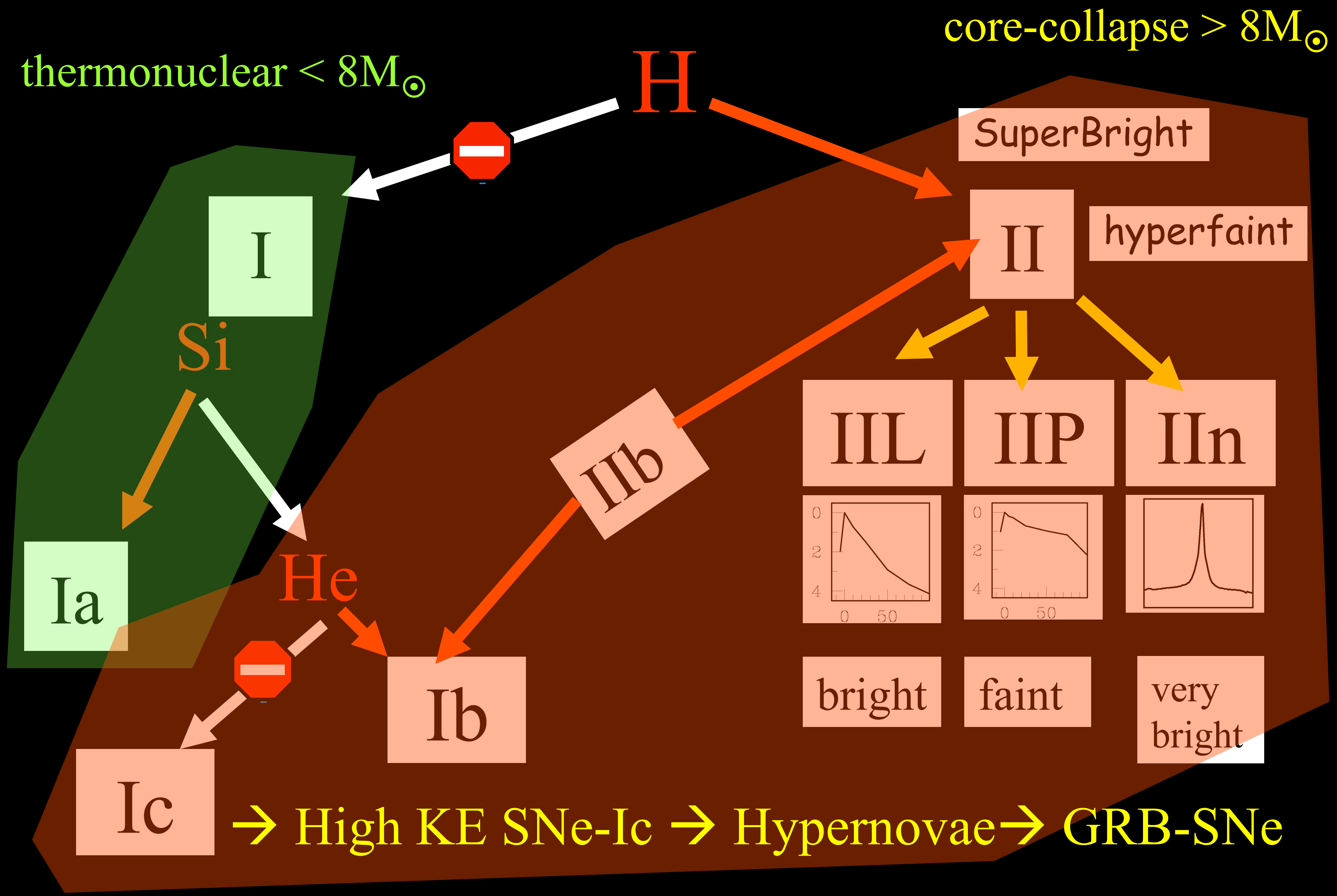
Supernova taxonomy



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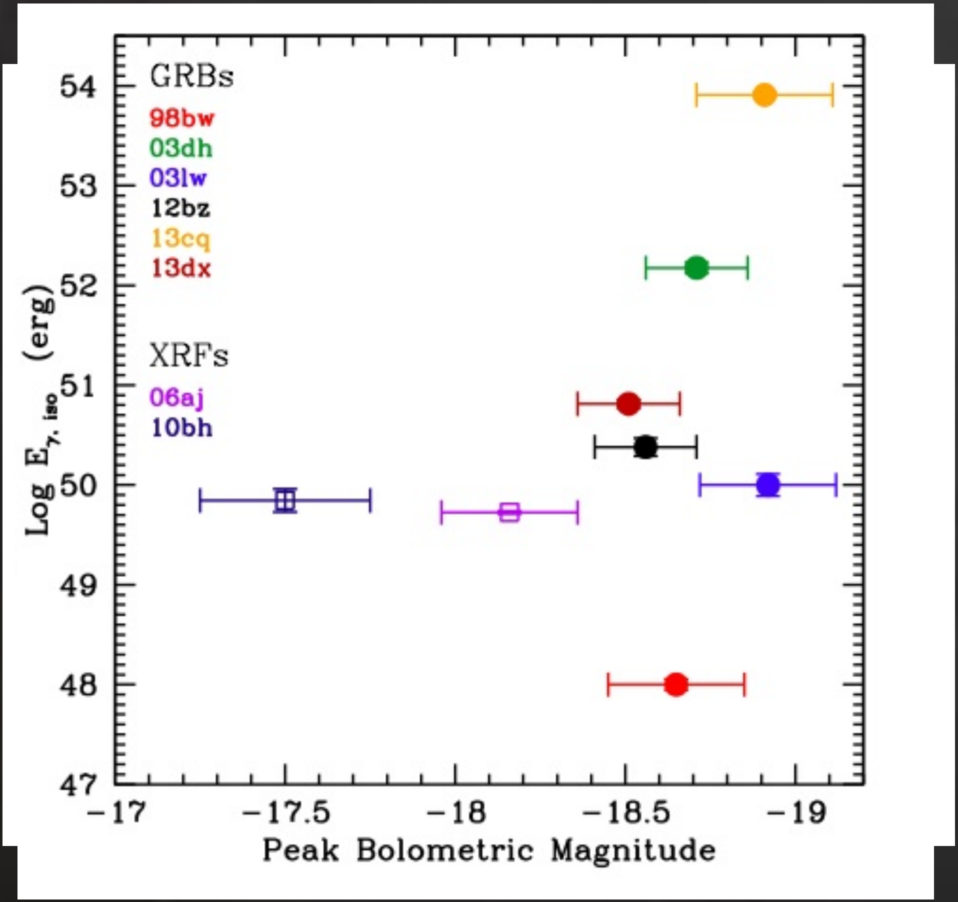
SNe & GRBs at z < 0.2

GRB	SN	z	Ref.
GRB 980425	SN 1998bw	0.0085	Galama et al. 1998
GRB 060218	SN 2006aj	0.033	Campana et al. 2006 Pian et al. 2006
GRB 080109	SN 2008D	0.007	Soderberg et al. 2008 Mazzali et al. 2008
GRB 100316D	SN 2010bh	0.06	Bufano et al. 2012 Chornock et al. 2010 Cano et al. 2011 Margutti et al. 2013
GRB 030323	SN 2003dh	0.16	Hjorth et al. 2003 Stanek et al. 2003
GRB 031203	SN 2003lw	0.11	Malesani et al. 2004
GRB 130702A	SN 2013dx	0.15	D'Elia et al. 2014

Properties of GRB-SNe (broad-lined SNe-Ic)



Lack of
SNe

Very br
expansi

Kinetic

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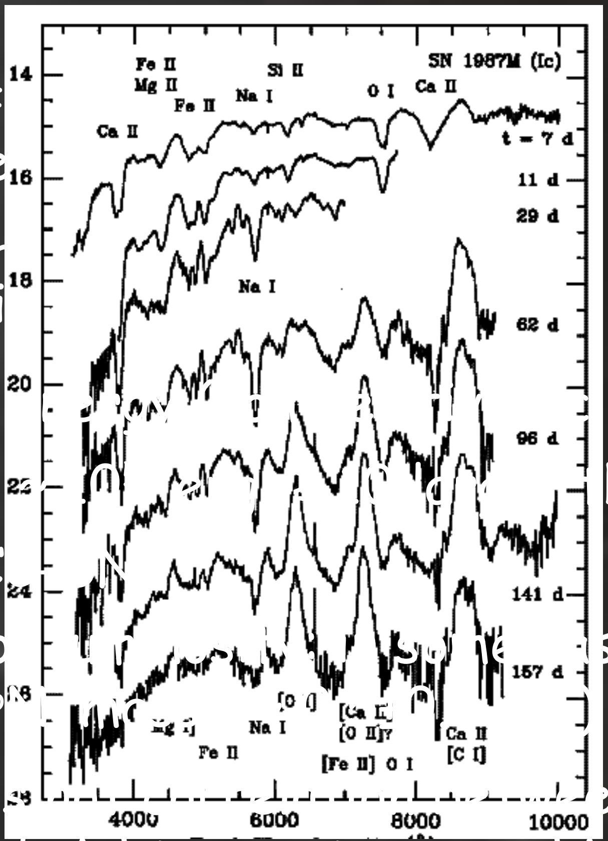
Usual C

Range o se
large ^{56}

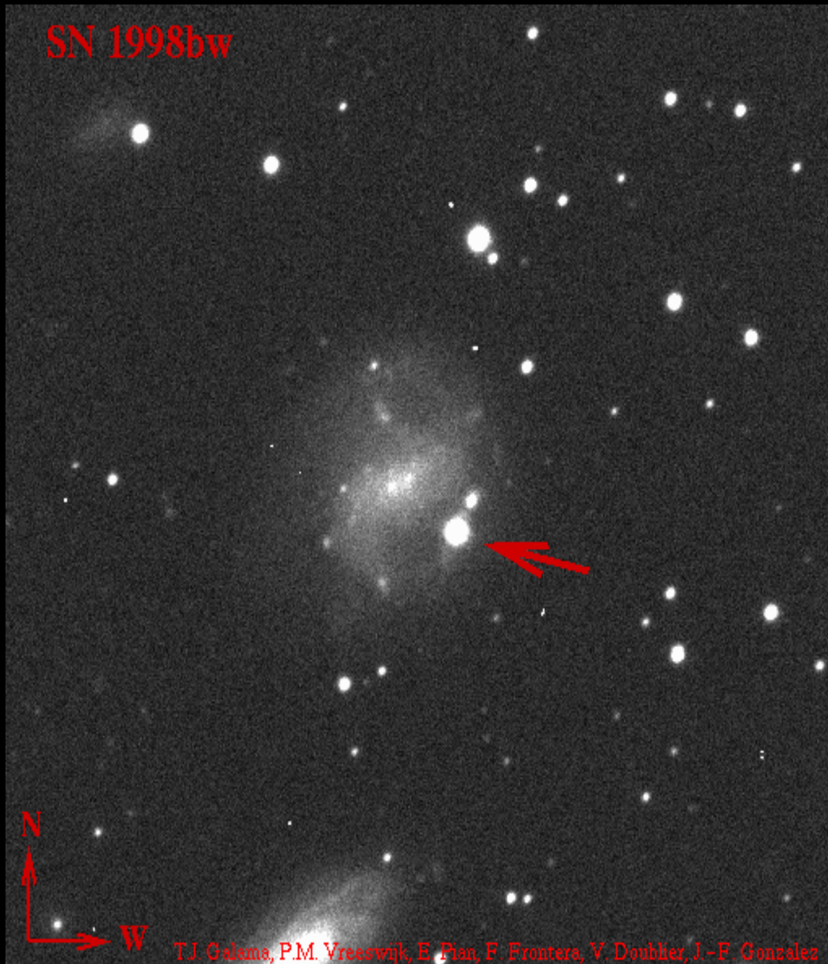
There i en



the SN brightness at max, which is nearly constant while E_{iso} spans several orders of magnitude.

Explosions are aspherical (profiles of nebular lines O vs. Fe and Polarization)

SN 1998bw **SN 1987A**

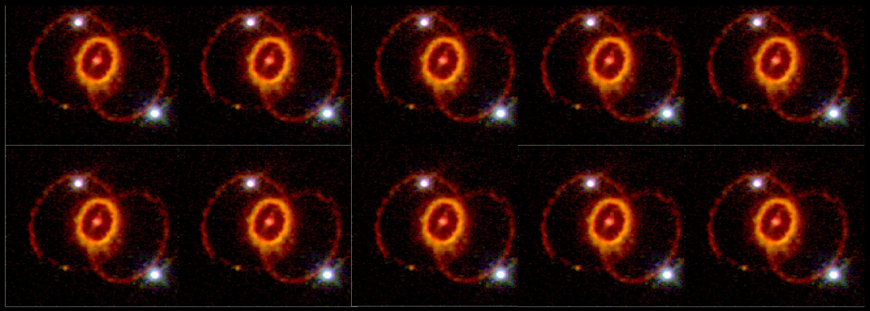


Aspherical explosion

Maeda et al. 2006, 2008

see also Tautenberger et al. 2009

=



$E_K \sim 30 \times 10^{51}$ erg

$E_K \sim 1 \times 10^{51}$ erg

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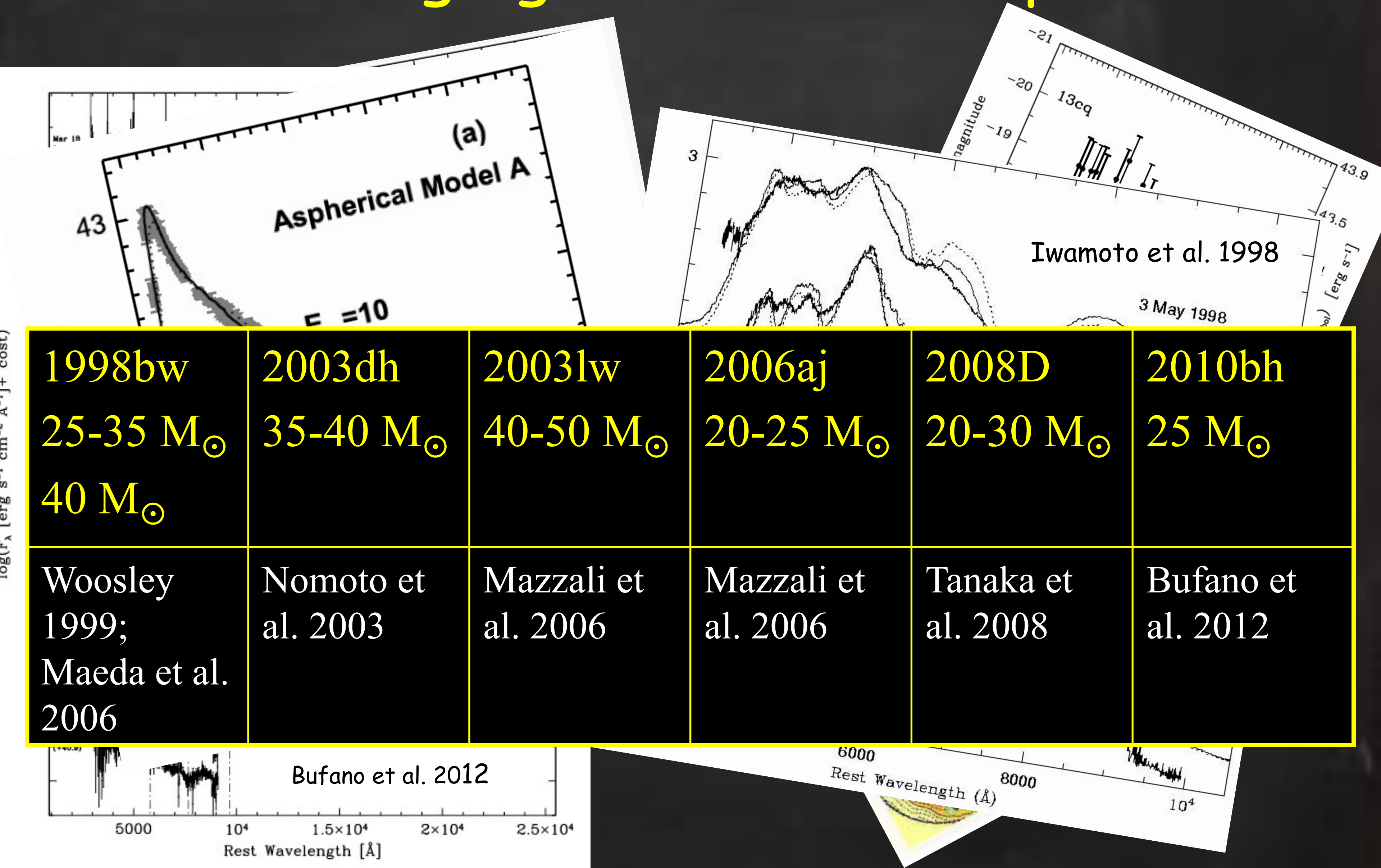
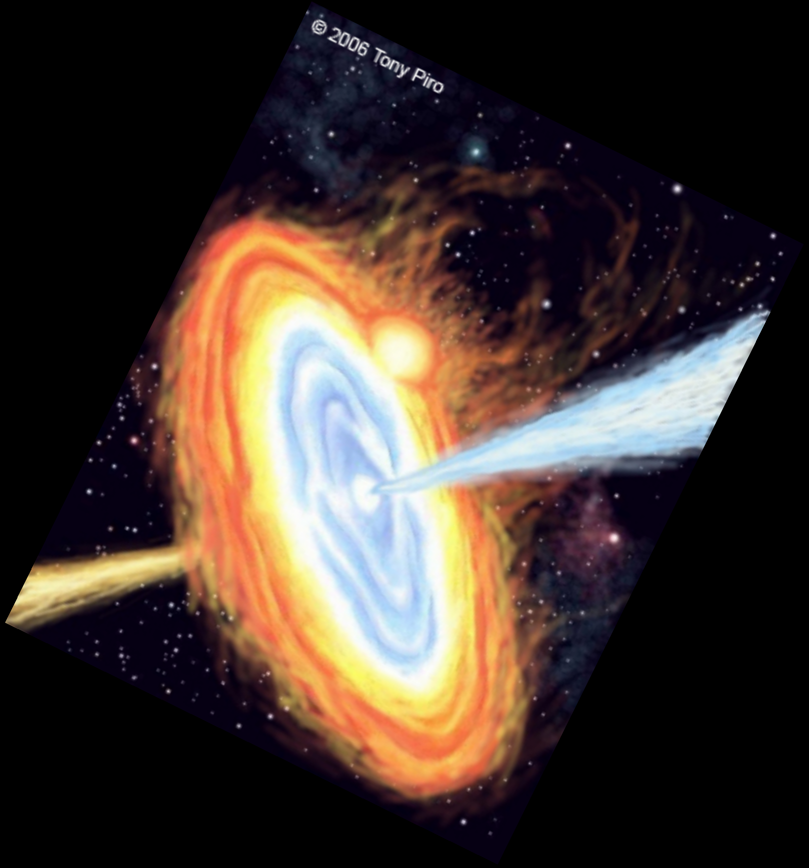
Modeling lightcurves and spectra



1998bw 25-35 $M_\odot$ 40 $M_\odot$	2003dh 35-40 $M_\odot$	2003lw 40-50 $M_\odot$	2006aj 20-25 $M_\odot$	2008D 20-30 $M_\odot$	2010bh 25 $M_\odot$
Woosley 1999; Maeda et al. 2006	Nomoto et al. 2003	Mazzali et al. 2006	Mazzali et al. 2006	Tanaka et al. 2008	Bufano et al. 2012

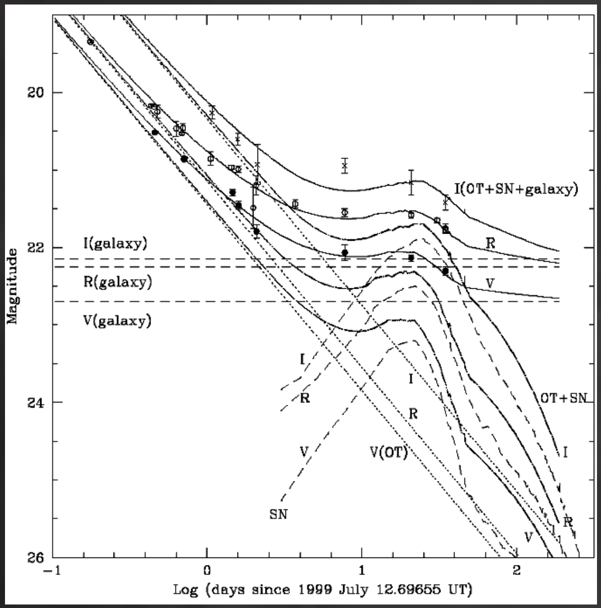


Distant GRB/SNe ?

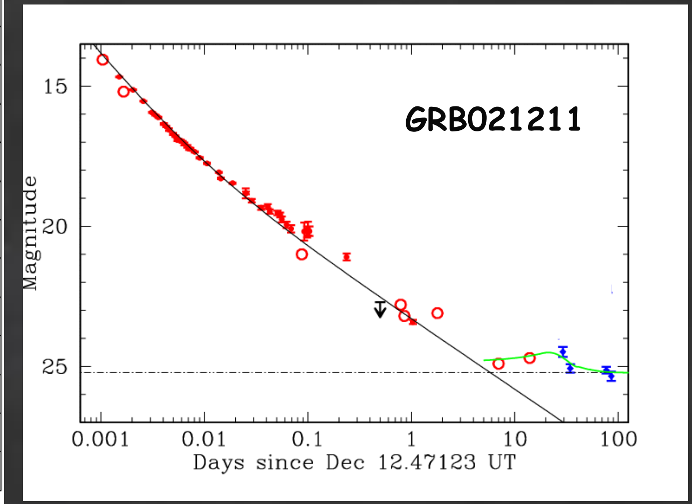
GRB census > 0.2

GRB	SN	z	Ref.
GRB 021202	SN 2002lt	1.002	Della Valle et al. 2003
GRB 050525A	SN 2005nc	0.606	Della Valle et al. 2006
GRB 101219B	SN 2010ma	0.55	Sparre et al. 2011
GRB 060729	SN no name	0.54	Cano et al. 2011
GRB 090618	SN no name	0.54	Cano et al. 2011
GRB 081007	SN 2008hw	0.53	Della Valle et al. 2008 Zhi-ping et al. 2008
GRB 091127	SN 2009nz	0.49	Cobb et al. 2010 Berger et al. 2011
GRB120714B	SN 2012eb	0.40	Klose et al. 2012
GRB 130427A	SN 2013cq	0.34	Melandri et al. 2014 Xu et al. 2013
GRB 120422A	SN 2012bz	0.28	Melandri et al. 2012
GRB 120729A; 130215A; GRB 130831A	?; SN2013ez , SN2013fu	0.8;0.6;0.48	Cano et al. 2014

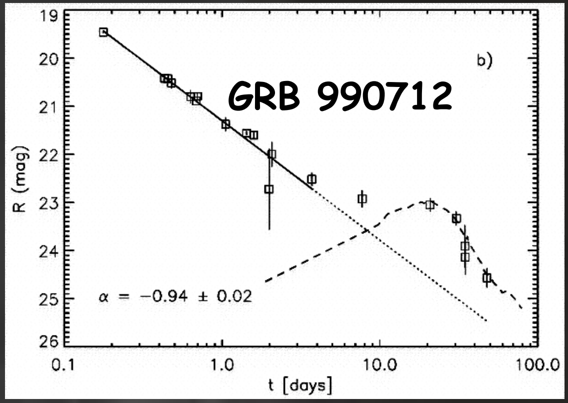
up to z ~ 1



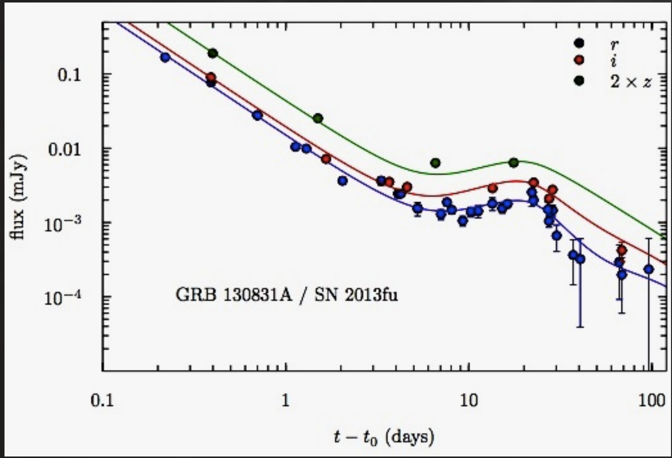
Sahu et al. 2000



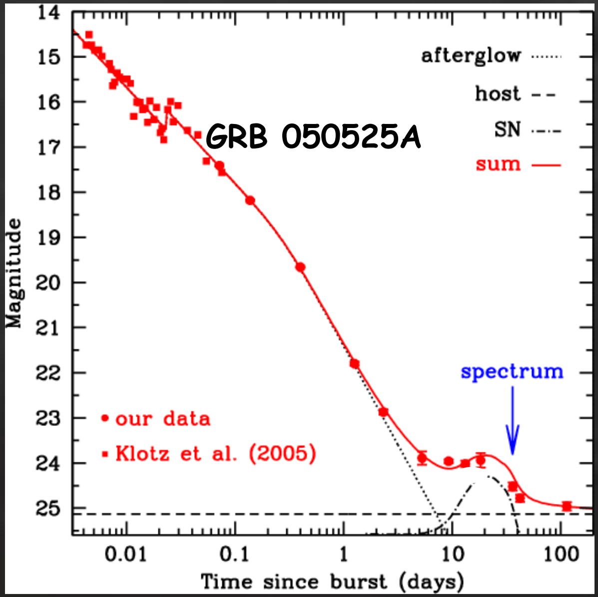
Della Valle et al. 2003



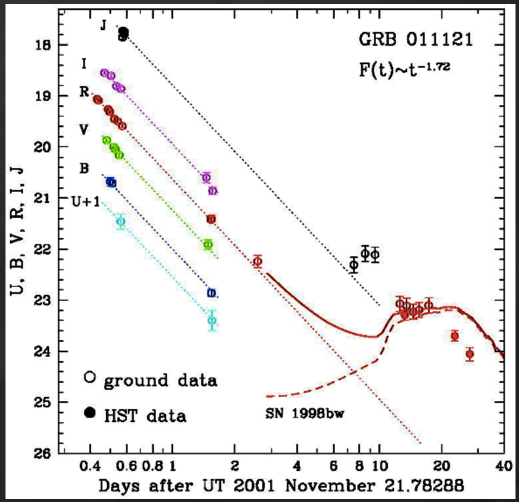
Bjornsson et al. 2001



Cano et al. 2014



Della Valle et al. 2006



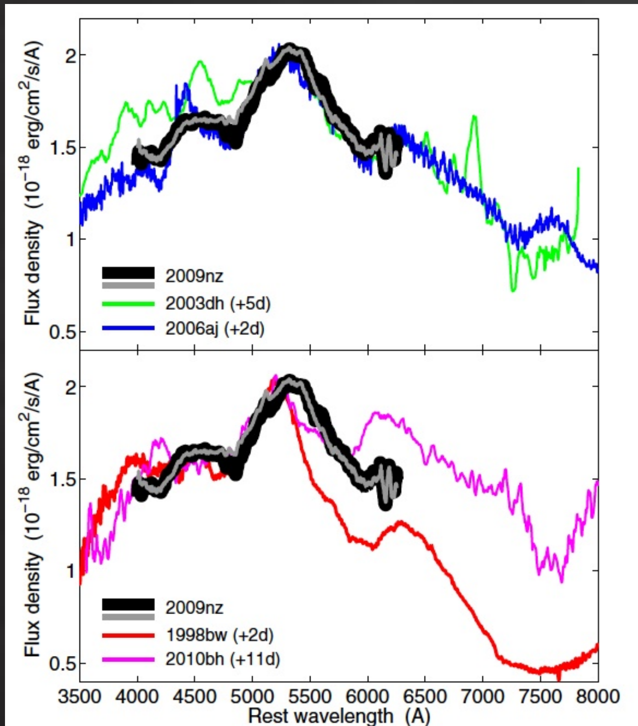
Garnavich et al. 2003

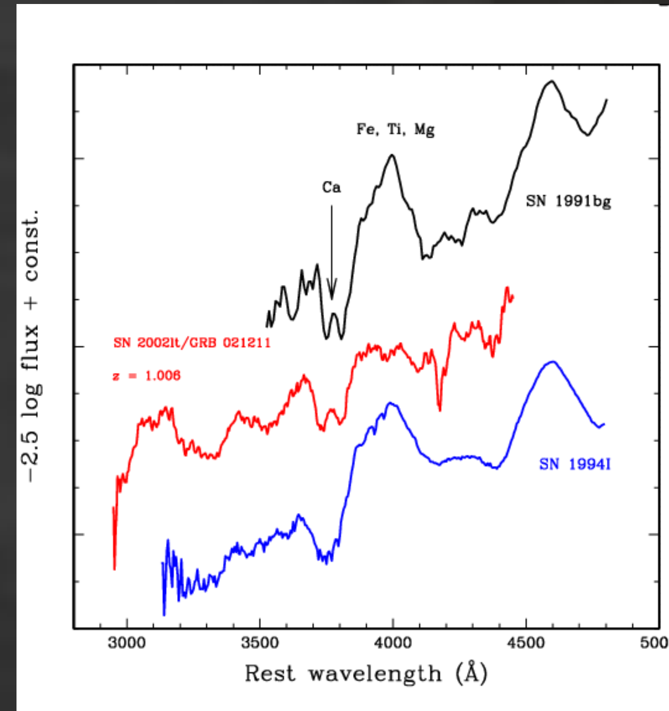
Bumps could be produced by different phenomena as dust echoes or thermal re-emission of the afterglow or thermal radiation from a pre-existing SN remnant

(e.g. Esin & Blandfors 2000; Waxman & Draine 2000; Dermer 2003)

At higher redshift secure SN identification becomes difficult because the SN gets fainter, which leads to problems of obtaining sufficient signal-to-noise in the spectra, a problem that is aggravated by contamination of the host galaxy and the afterglow

Time consuming observations: single epoch spectrum



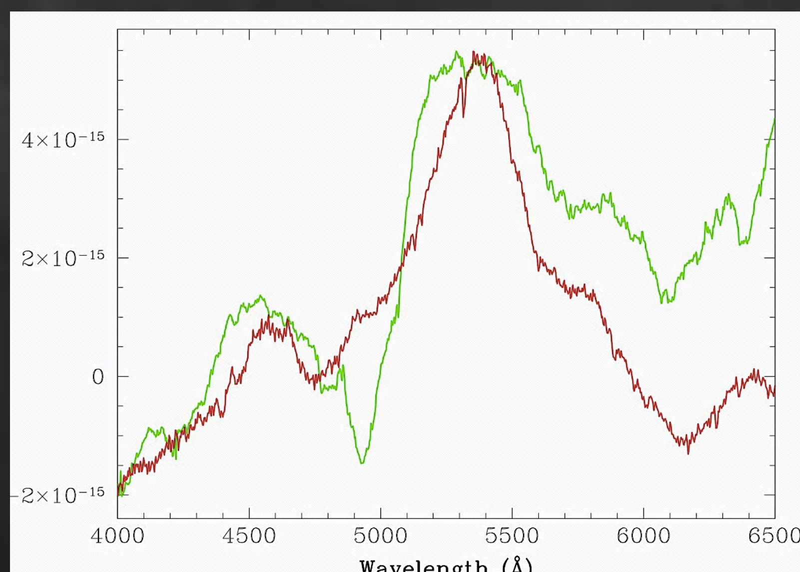


Berger et al. 2011

SN 2009nz @ z=0.49

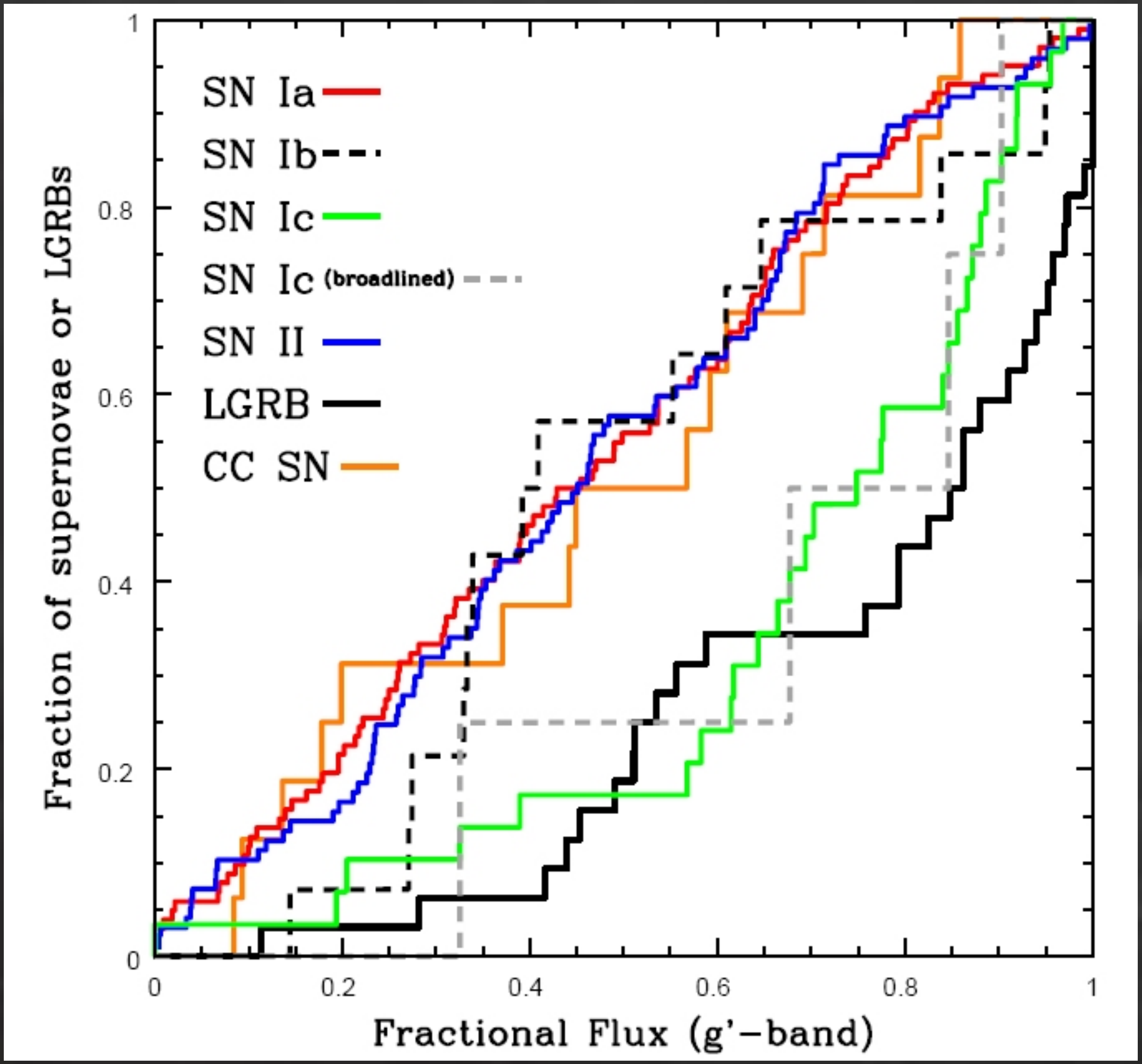
Della Valle et al. 2003

SN 2002lt @ z=1



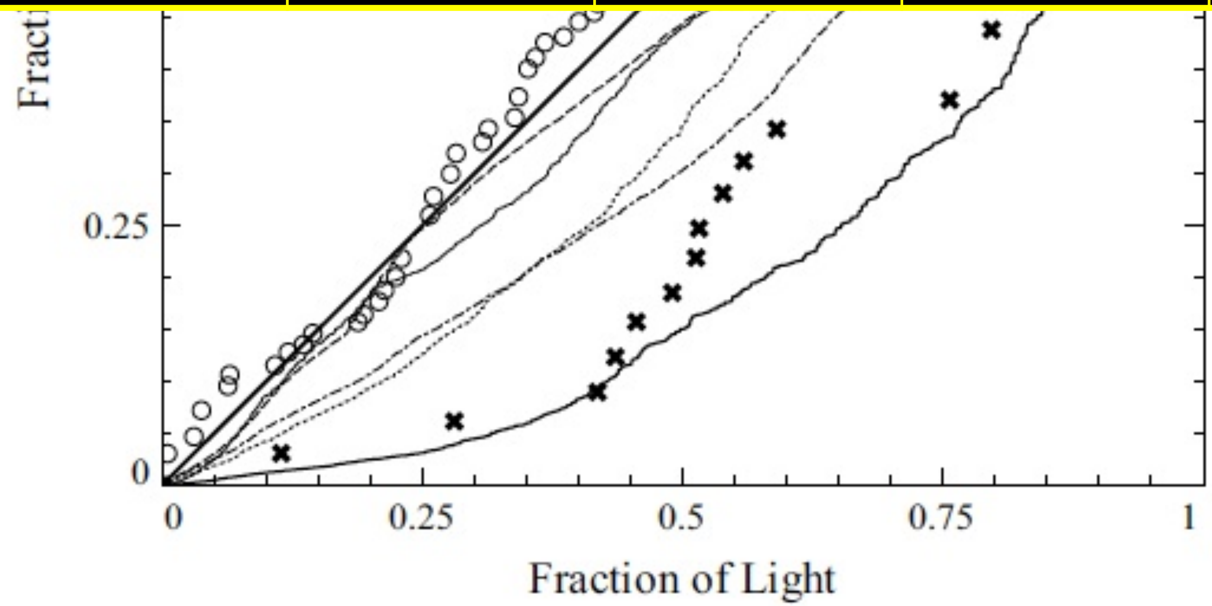
Zhi-Ping et al. 2013

SN 2008hw @ z=0.53



Kelly et al. 2008 find that SNe-Ic and LGRB erupt in the brightest regions of their hosts (see also Fruchter et al. 2006)

1998bw 40 M$_\odot$	2003dh 35-40 M$_\odot$	2003lw 40-50 M$_\odot$	2006aj 20-25 M$_\odot$	2008D 20-30 M$_\odot$	2010bh 25 M$_\odot$
Maeda et al. 2006	Nomoto et al. 2003	Mazzali et al. 2006	Mazzali et al. 2006	Tanaka et al. 2008	Bufano et al. 2012



Long-GRBs have ~ 30 - 50 M$_\odot$ Raskin et al. 2008

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What is the rate of SNe-Ib/c ?

Asiago Survey (Cappellaro et al. 1999)

galaxy type	N. SNe* Ia	Ib/c	II	rate [SNu] Ia	Ib/c	II
E-S0	22.0			0.18 ± 0.06	< 0.01	< 0.02
S0a-Sb	18.5	5.5	16.0	0.18 ± 0.07	0.11 ± 0.06	0.42 ± 0.19
Sbc-Sd	22.4	7.1	31.5	0.21 ± 0.08	0.14 ± 0.07	0.86 ± 0.35
Others#	6.8	2.2	5.0	0.40 ± 0.16	0.22 ± 0.16	0.65 ± 0.39
All	69.6	14.9	52.5	0.20 ± 0.06	0.08 ± 0.04	0.40 ± 0.19

Rate for Ib/c: 0.152 ± 0.064 SNu

Guetta & DV 2007

1.8×10^4 SNe-Ibc Gpc^{-3} yr^{-1} → **1.1×10^4 up to 2.6×10^4**

What is the rate of SNe-Ib/c ?

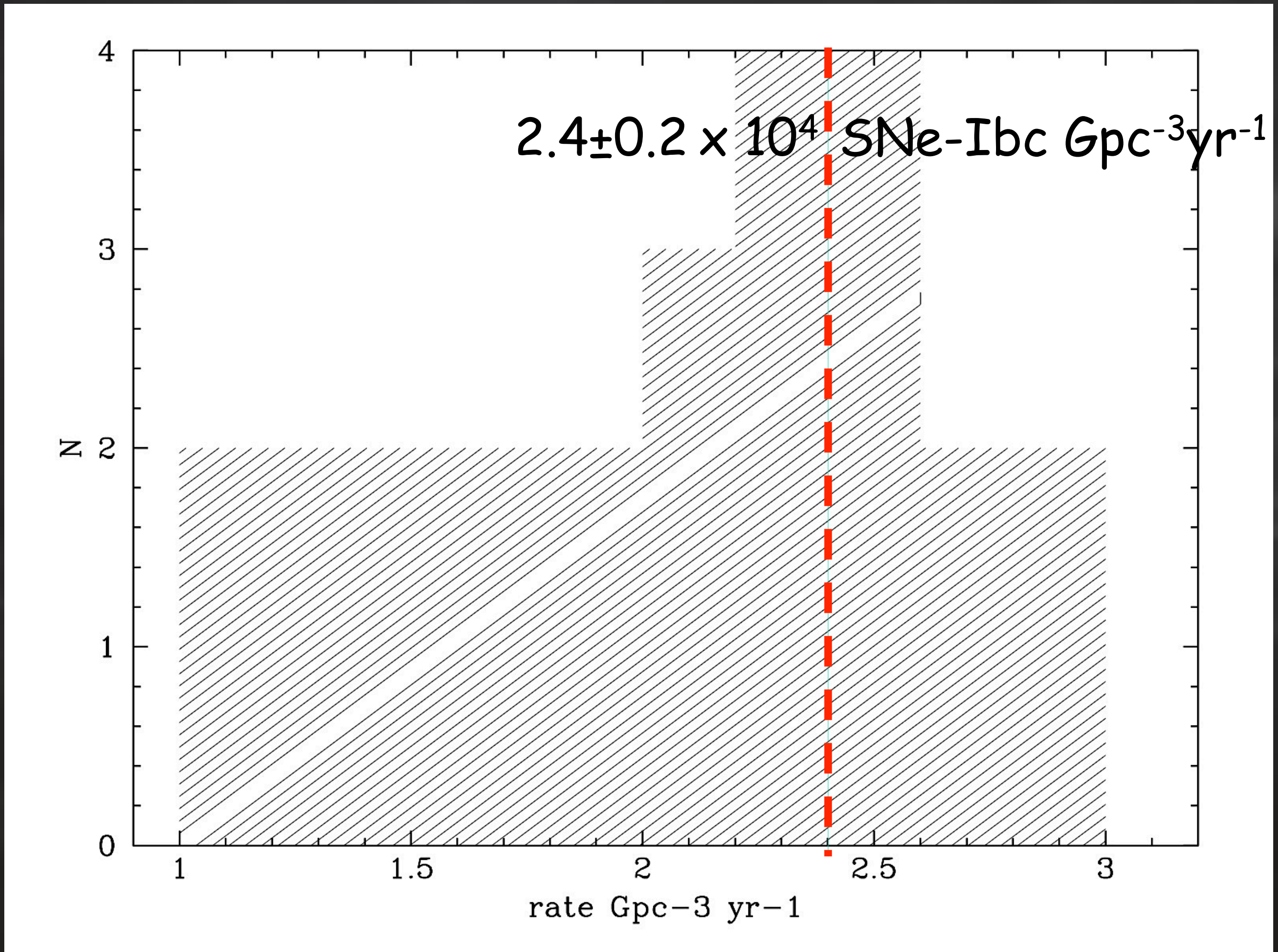
Lick Survey (Li et al. 2011)

Rate	SN Ia	SN Ibc	SN II
Early(fiducial; SNuK)	$0.064^{+0.008}_{-0.007}(^{+0.013}_{-0.013})$	$0.008^{+0.006}_{-0.004}(^{+0.002}_{-0.002})$	$0.004^{+0.003}_{-0.002}(^{+0.001}_{-0.001})$
Late(fiducial; SNuK)	$0.074^{+0.006}_{-0.006}(^{+0.012}_{-0.012})$	$0.096^{+0.010}_{-0.009}(^{+0.018}_{-0.018})$	$0.172^{+0.011}_{-0.011}(^{+0.045}_{-0.036})$
Early(LF-average; SNuK)	$0.048^{+0.006}_{-0.005}(^{+0.010}_{-0.010})$	$0.006^{+0.004}_{-0.003}(^{+0.002}_{-0.002})$	$0.003^{+0.002}_{-0.001}(^{+0.001}_{-0.001})$
Late(LF-average; SNuK)	$0.065^{+0.006}_{-0.005}(^{+0.010}_{-0.010})$	$0.083^{+0.009}_{-0.008}(^{+0.016}_{-0.016})$	$0.149^{+0.010}_{-0.009}(^{+0.039}_{-0.031})$
Vol-rate (10^{-4} SN Mpc^{-3} yr^{-1})	$0.301^{+0.038}_{-0.037}(^{+0.049}_{-0.049})$	$0.258^{+0.044}_{-0.042}(^{+0.058}_{-0.058})$	$0.447^{+0.068}_{-0.068}(^{+0.131}_{-0.111})$

Rate for Ib/c: 2.6×10^4 SNe-Ibc Gpc^{-3} yr^{-1}

$2.2 \times 10^4 \rightarrow 3 \times 10^4$ SNe-Ibc Gpc^{-3} yr^{-1}

+

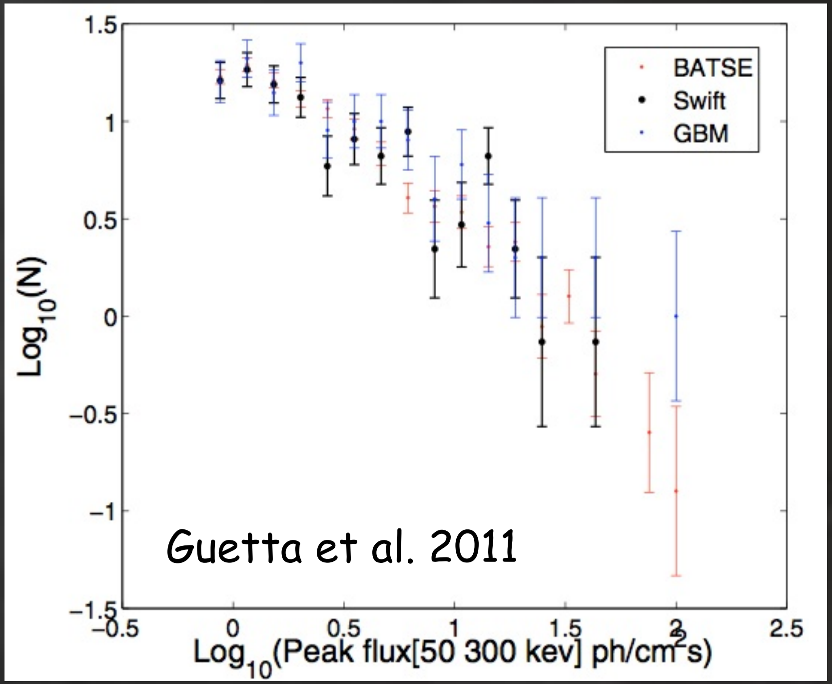


2.4±0.2 x 10^4 SNe-Ibc Gpc^-3 yr^-1
N
0
1
2
3
4
1
1.5
2
2.5
3
rate Gpc−3 yr−1

What is the rate of (long) GRBs ?

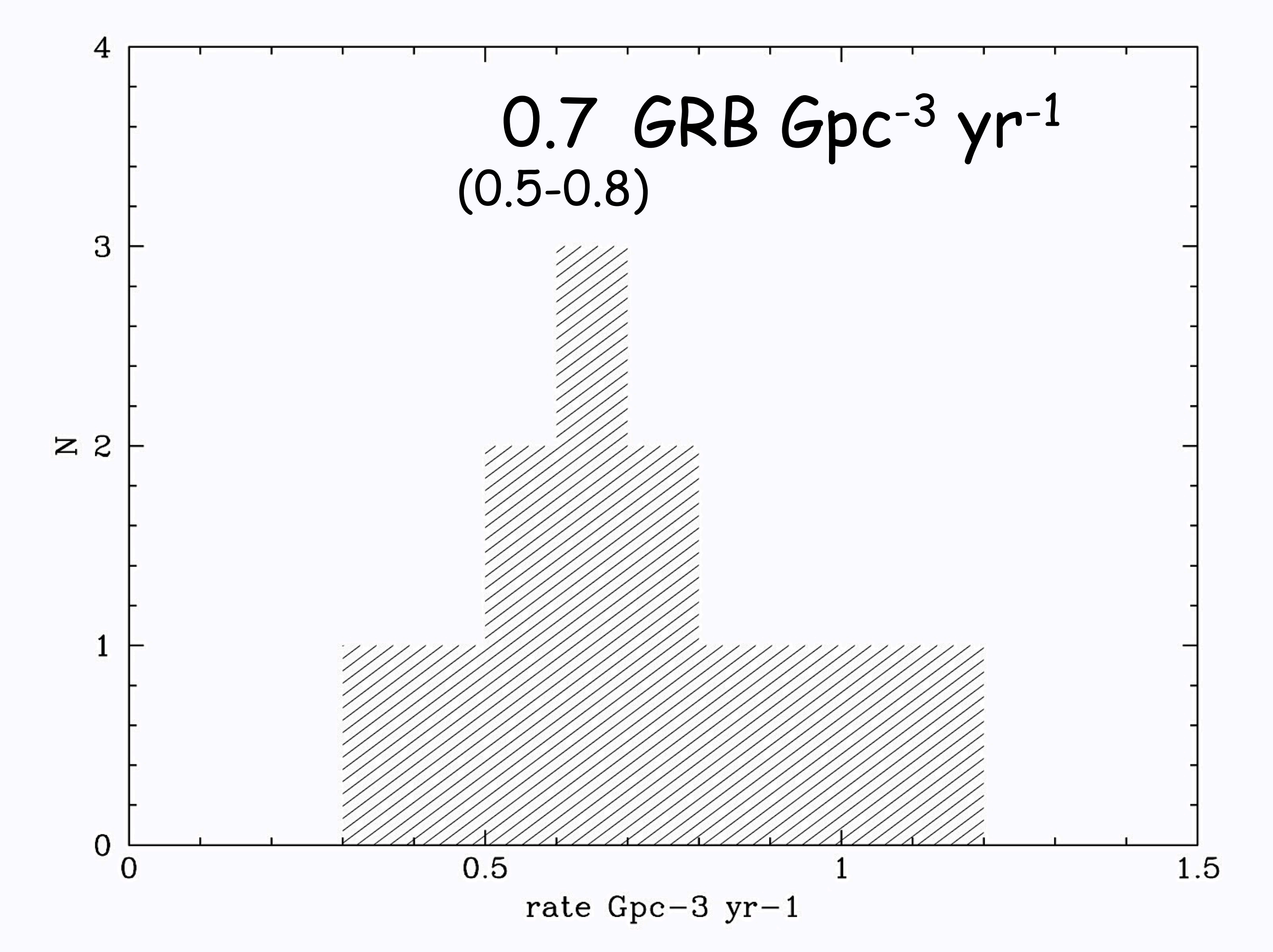
GRB Gpc^{-3} yr^{-1}

1.5	Schmidt 1999
0.15	Schmidt 2001
0.5	Guetta et al. 2005
1.1	Guetta & Della Valle 2007
1.1	Liang et al. 2007
> 0.5	Pelangeon et al. 2008
1.3	Wanderman and Piran



Sample	Rate $(z = 0)^1$ Gpc^{-3} yr^{-1}	L^* [50–300] keV 10^{51} erg/s	a_1	a_2	χ^2/d.o.f.[3]
GBM	$0.5^{+0.3}_{-0.2}$	$5.5^{+1.5}_{-2}$	$0.3^{+0.1}_{-0.5}$	$2.3^{+0.6}_{-0.3}$	1.1
BATSE	$1.0^{+0.2}_{-0.4}$	$4^{+2}_{-1.5}$	$0.1^{+0.3}_{-0.1}$	$2.6^{+0.9}_{-0.5}$	1.1
Swift	$0.6^{+0.3}_{-0.1}$	$3.3^{+2.5}_{-0.5}$	$0.1^{+0.3}_{-0.1}$	$2.7^{+1}_{-0.4}$	0.95

What is the local rate of (long) GRBs ?



What is the fraction of SNe-Ib/c which produces (long)GRBs ?

Rate for Ibc: 2.4×10^4 SNe-Ibc $Gpc^{-3}\ yr^{-1}$

GRB rate: 0.7 GRB $Gpc^{-3}\ yr^{-1}$

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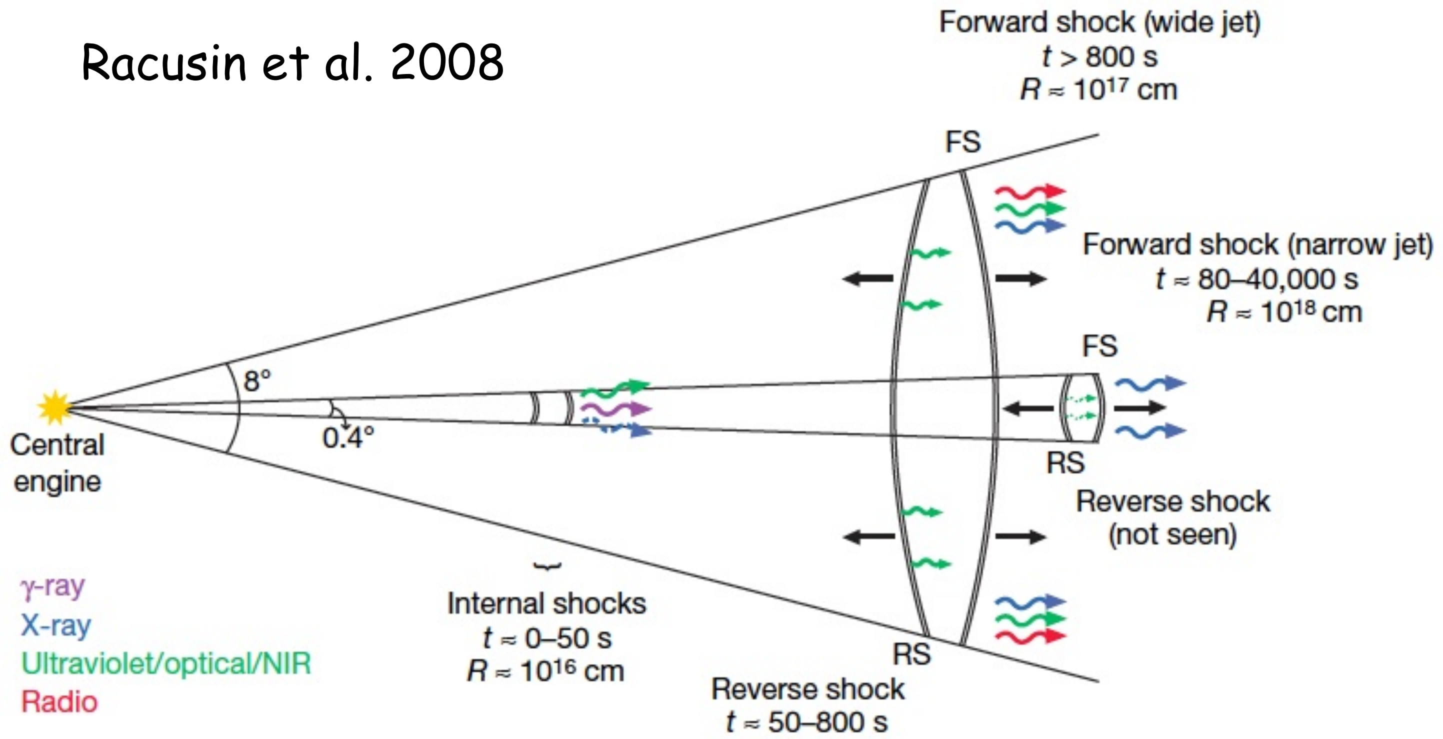
Rate for Ibc: 2.4×10^4 SNe-Ibc $Gpc^{-3}\ yr^{-1}$

GRB rate: 0.7 GRB $Gpc^{-3}\ yr^{-1}$

$\langle fb^{-1} \rangle \sim 500$	(Frail et al. 2001)	$(\vartheta \sim 4°)$
$\langle fb^{-1} \rangle \sim 75$	(Guetta, Piran & Waxman 2004)	$(\vartheta \sim 9°)$
$\langle fb^{-1} \rangle < 10$	(Guetta & DellaValle 2007)	$(\vartheta > 25°)$ for sub-lum GRBs
$\langle fb^{-1} \rangle \sim 1$	(Ruffini et al. 2006)	$(\vartheta \sim 4\,\pi)$

To BE*am* or not to BE*am*

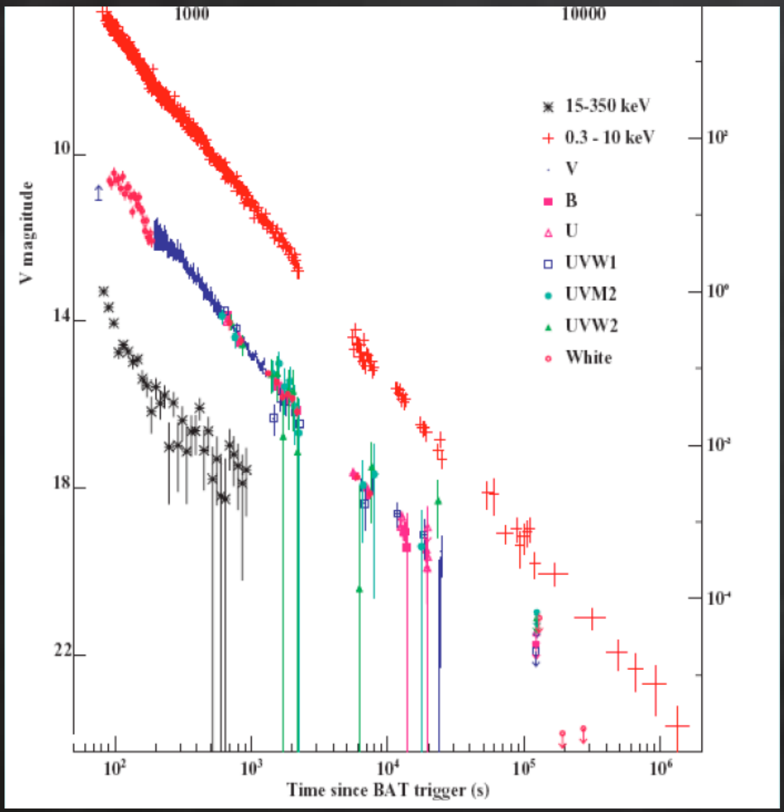
Racusin et al. 2008

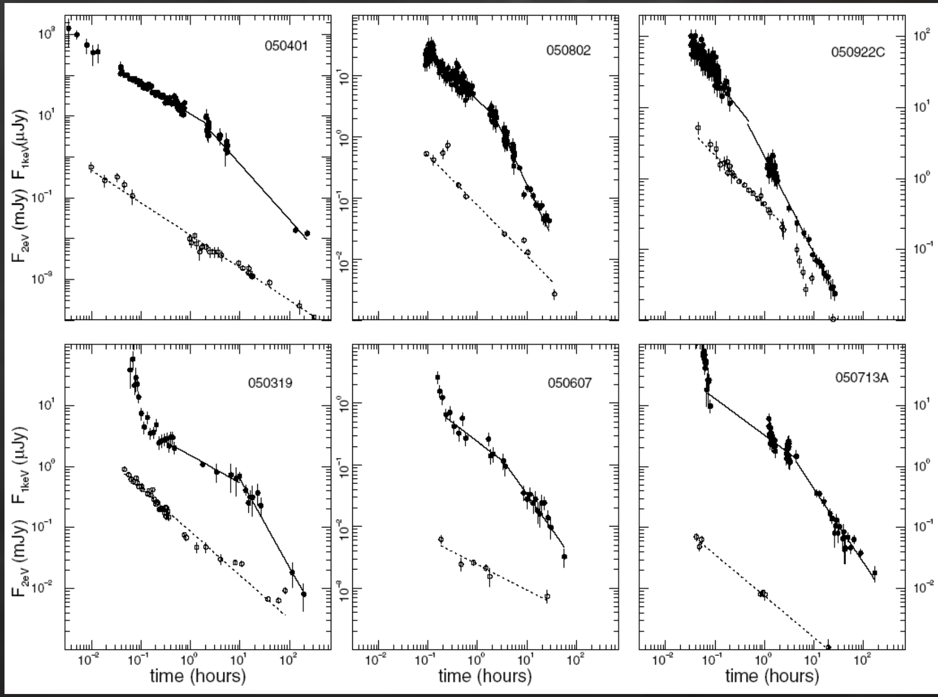


GRB 080319B

In some cases there is not evidence for beaming, i.e. an achromatic break was not detected (Covino et al. 2006; Panaitescu et al. 2006) .

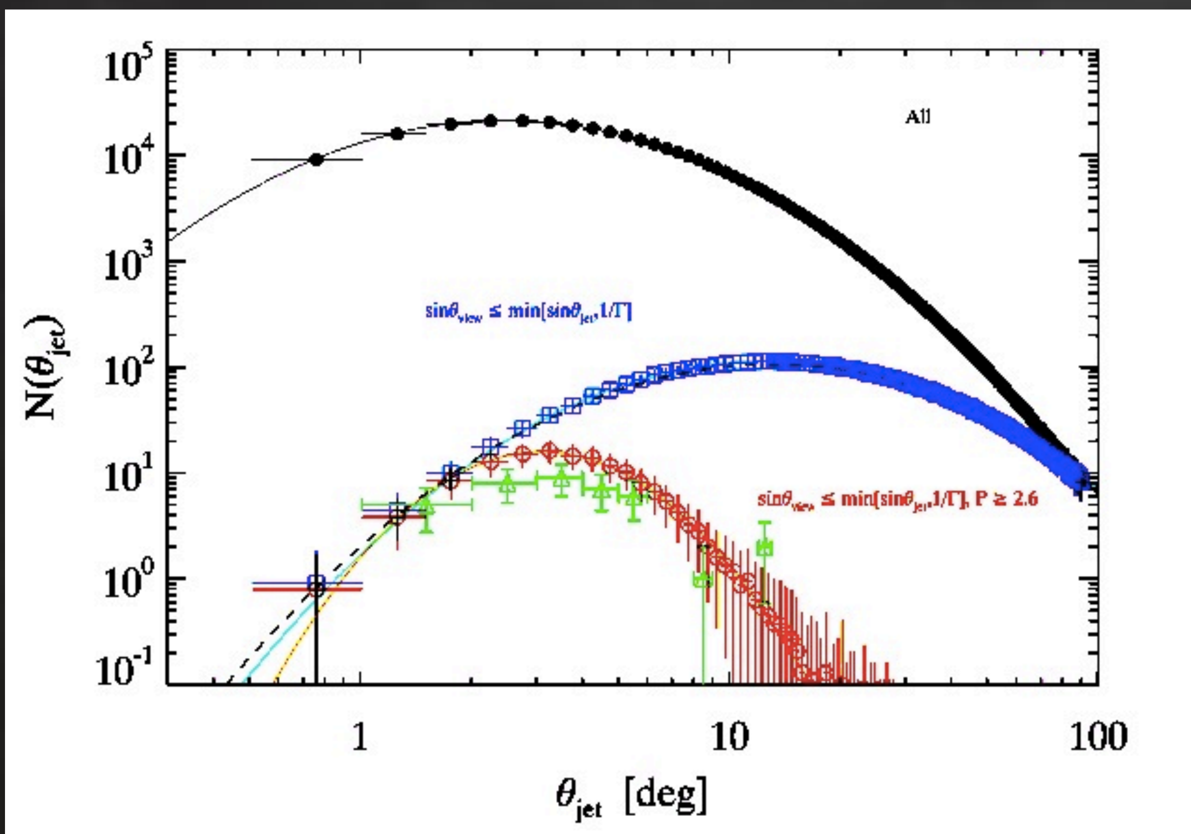
see also Willingale and Greiner talks





The faster the narrower: characteristic bulk velocities and jet opening angles of Gamma Ray Bursts

G. Ghirlanda[1*], G. Ghisellini[1], R. Salvaterra[2], L. Nava[3], D. Burlon[4], G. Tagliaferri[1], S. Campana[1], P. D'Avanzo[1], A. Melandri[1] (2013)



$1° < \vartheta < 20°$

$\vartheta_{peak} \sim 4°$

What is the fraction of SNe-Ib/c which produces (long)GRBs ?

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GRB rate: 0.7 GRB $Gpc^{-3}\ yr^{-1}$

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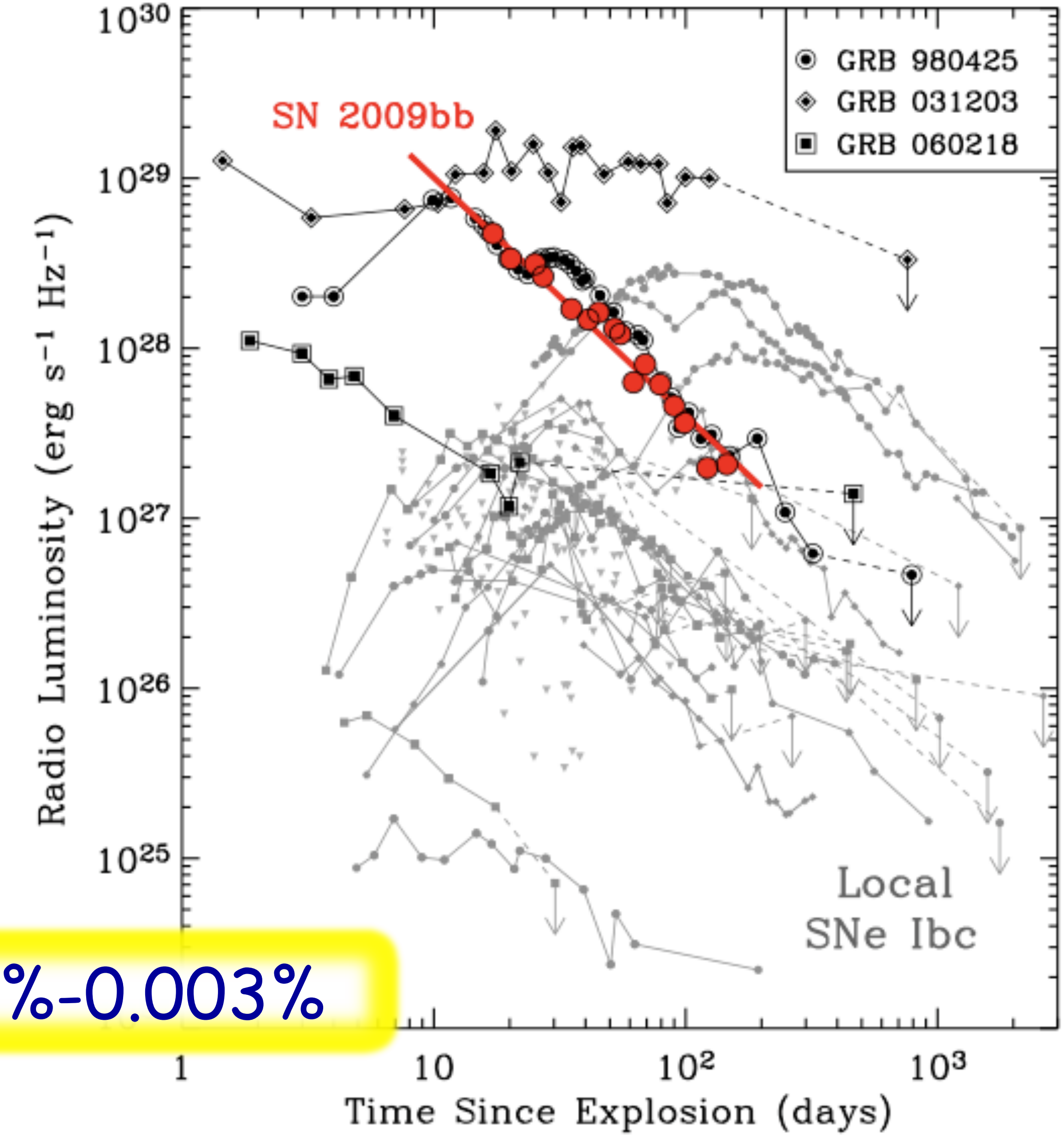
$\langle fb^{-1}\rangle \sim 1$	(Ruffini et al. 2006)	($\vartheta \sim 4\ \pi$)

GRB/SNe-Ibc: 1.5%-0.003%

Discovery of a Relati
Gamma-ray Trigger

A. M. Soderberg[1], S.
R. A. Chevalier[4], P. Chandra[5],
V. Chaplin[7], V. Connaughton[7],
N. Chugai[11], M. D. Stritzinger[12],
E. M. Levesque[1,15], J. E. Grindlay[
P. A. Milne[16], M. A. P. Torres[1]

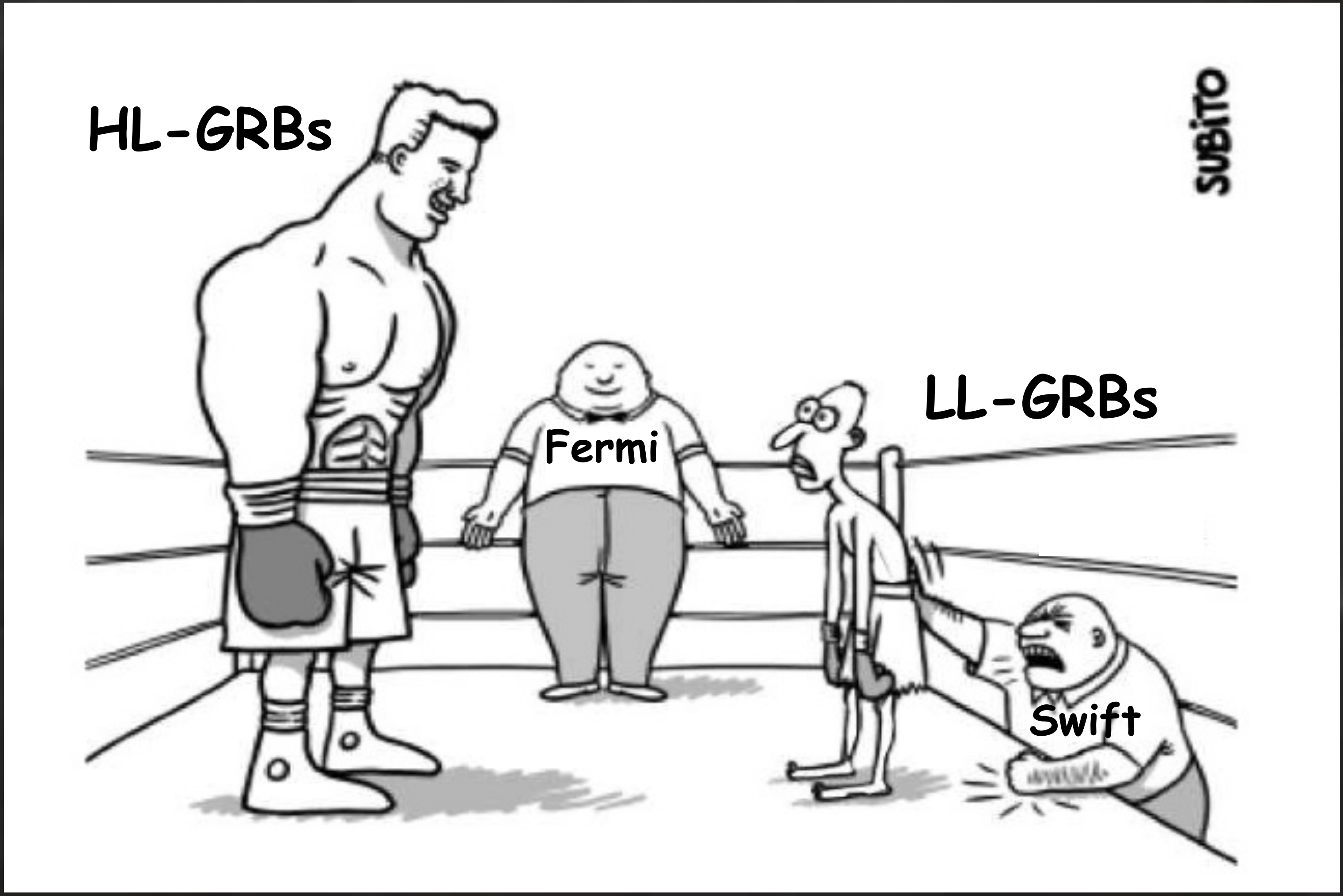


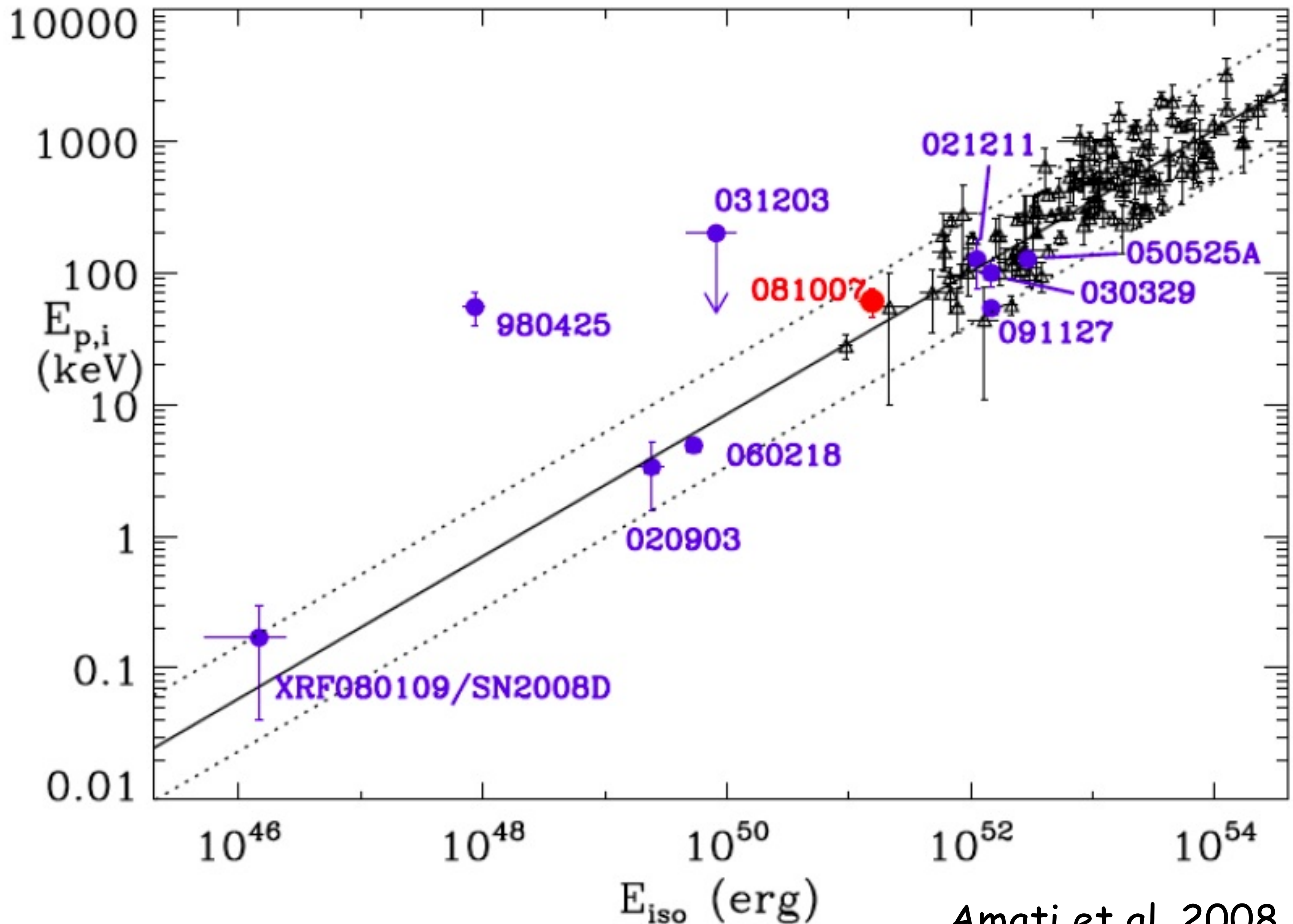
GRB/SNe-Ibc ~ 1/146
GRB/SNe-Ibc ~ 0.7%

< 5% at 99%

GRB/SNe-Ibc: 1.5%-0.003%

HL-GRBs vs. LL-GRBs





Amati et al. 2008

SNe & GRBs at z < 0.1

GRB	SN	z	E_{iso} (erg)
GRB 980425	SN 1998bw	0.0085	$\sim 10^{48}$
GRB 060218	SN 2006aj	0.033	$\sim 10^{50}$
GRB 080109	SN 2008D	0.007	$\sim 10^{46}$
GRB 100316D	SN 2010bh	0.06	$\sim 10^{50}$

LL-GRBs sample a volume $\sim 10^6$ smaller →
Rate: up to x 10^3 Gpc^{-3} yr^{-1} 0.7 GRB Gpc^{-3} yr^{-1}
(Della Valle 2005, Pian et al. 2006, Cobb et al. 2006, Soderberg et al. 2006, Liang et al. 2006, Guetta & Della Valle 2007, Amati et al. 2007)

LL vs. HL Rates

LL-GRBs ~ 71 x (1 ÷ 10) ~ 70 ÷ 700 LL-GRBs Gpc^{-3} yr^{-1}

$\langle fb^{-1} \rangle_{HL\text{-}GRBs}$ ~ 75 ÷ 500

HL-GRBs ~ 0.7 x $\langle fb^{-1} \rangle$ ~ 50 ÷ 350 Gpc^{-3} yr^{-1}

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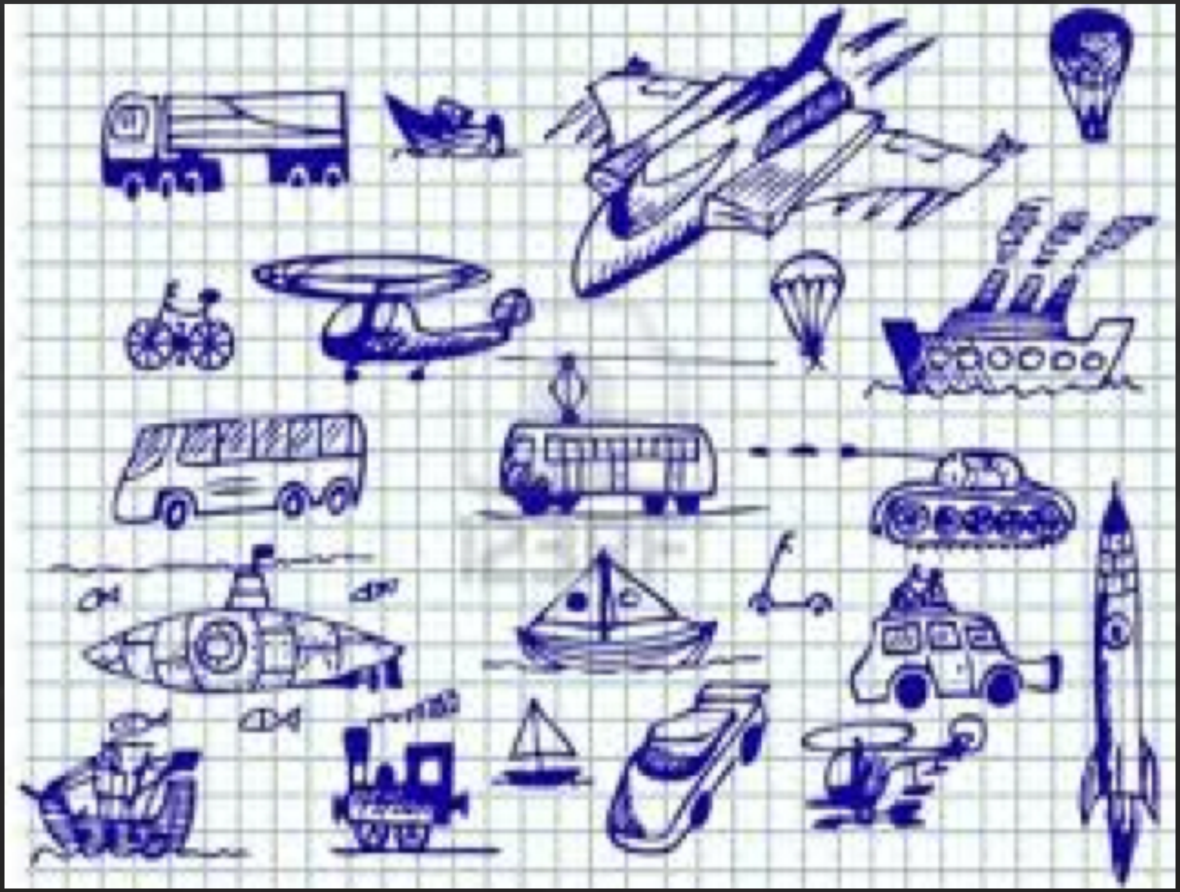
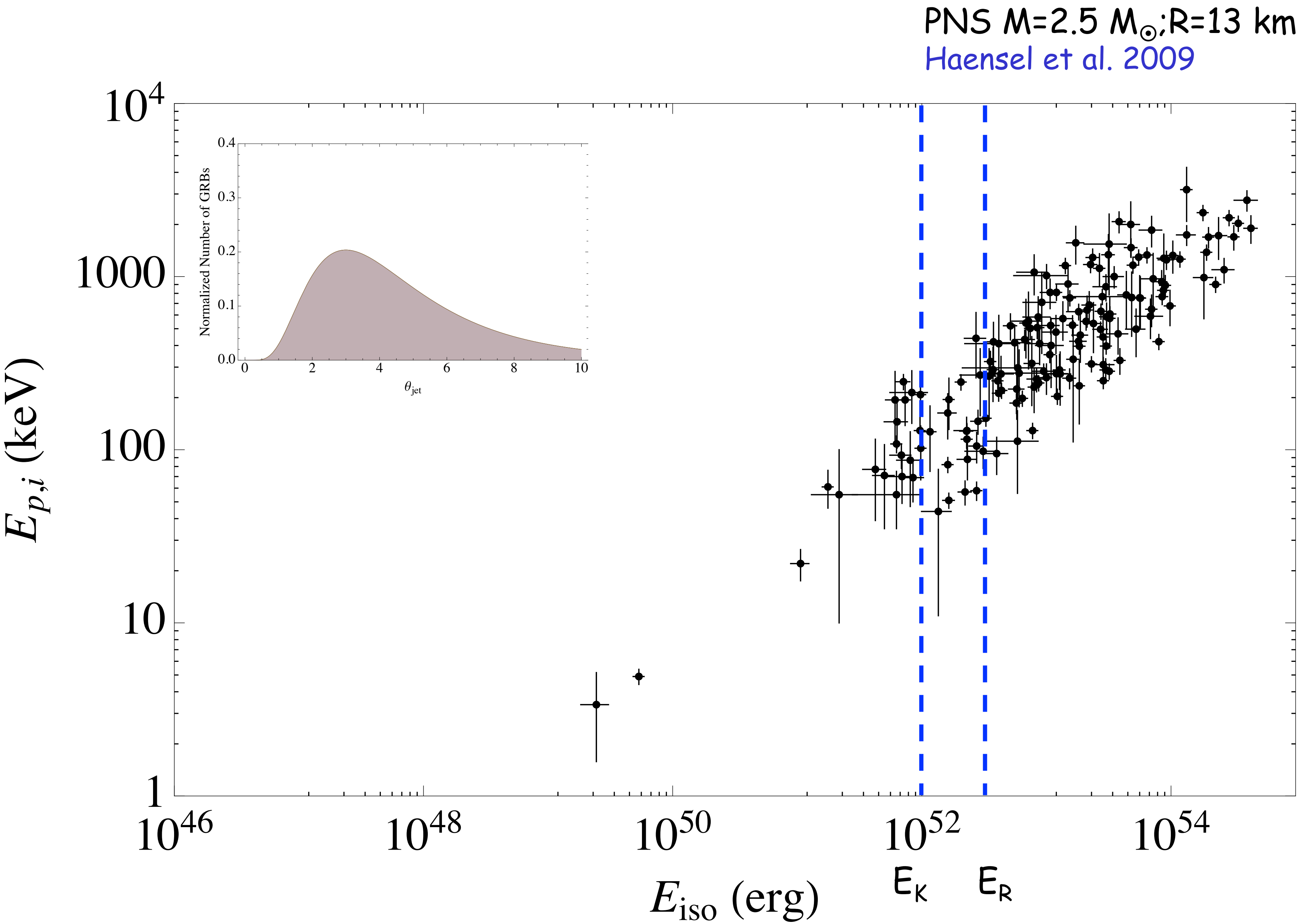
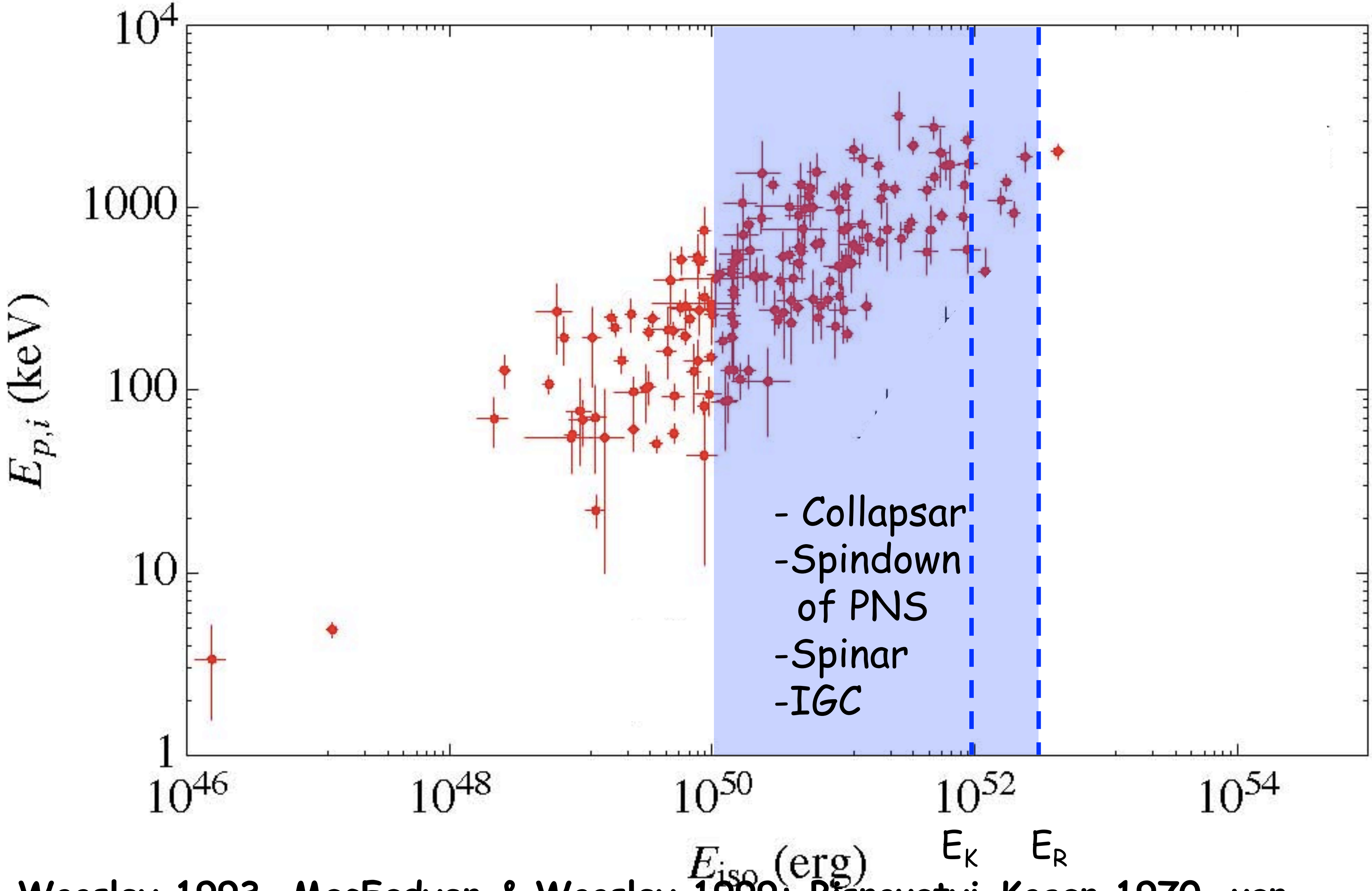
LL-GRB/*HL*-GRB < ~ 20

LL vs. HL GRBs
Clues to different central engines?



Piran et al. 2013; Tsutsui & Shigeyama 2013;

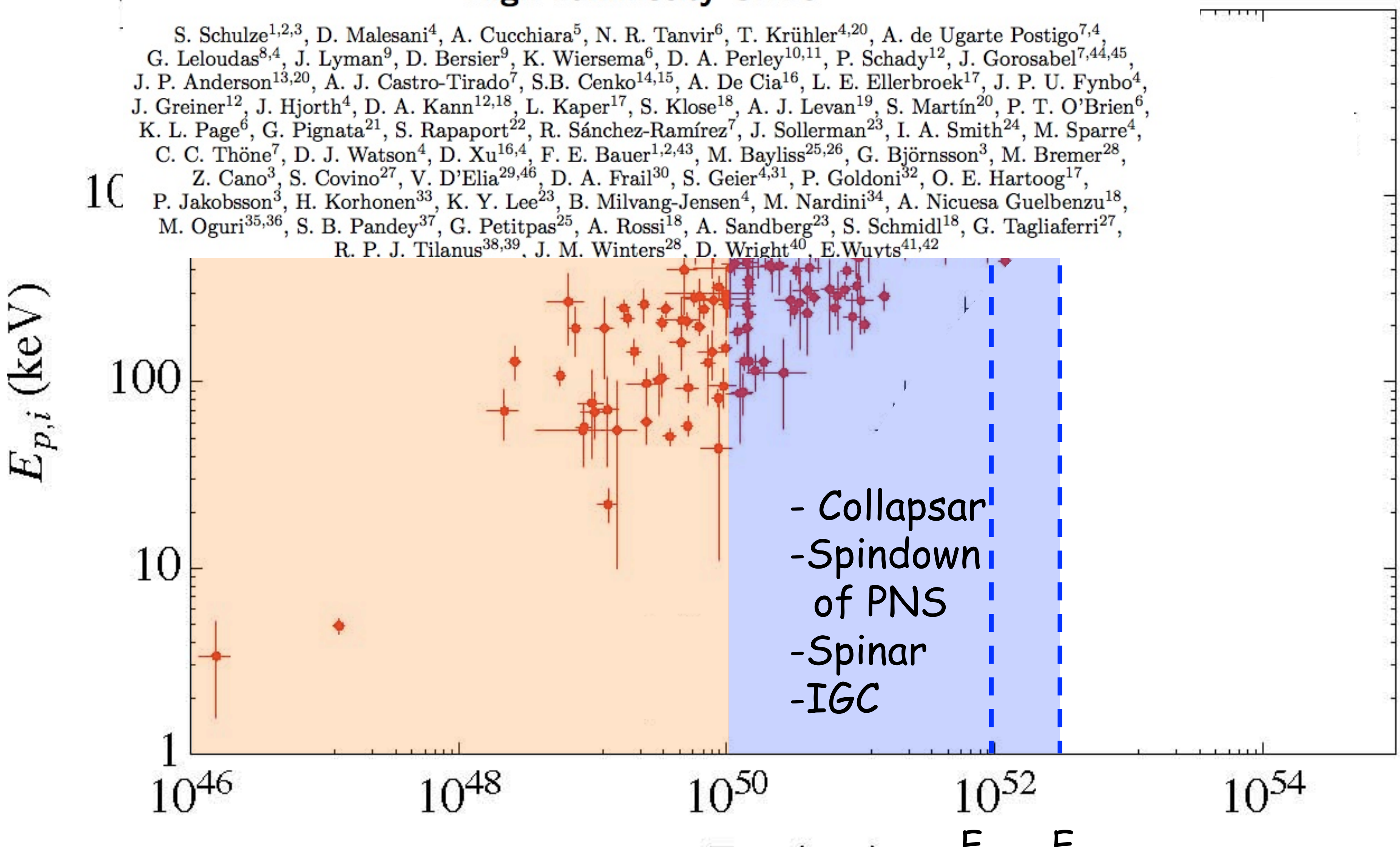

PNS M=2.5 $M_\odot$;R=13 km
Haensel et al. 2009
$E_{p,i}$ (keV)
E_{iso} (erg)
E_K
E_R
10^4
1000
100
10
1
10^{46}
10^{48}
10^{50}
10^{52}
10^{54}
Normalized Number of GRBs
θ_{jet}
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10



Woosley 1993, MacFadyen & Woosley 1999; Bisnovatyi-Kogan 1970, van Putten et al.2011; Lipunov & Gorbovskoy 2007; Fryer, Ruffini & Rueda 2014

GRB 120422A/SN 2012bz: Bridging the Gap between Low- And High-Luminosity GRBs

S. Schulze[1,2,3], D. Malesani[4], A. Cucchiara[5], N. R. Tanvir[6], T. Krühler[4,20], A. de Ugarte Postigo[7,4], G. Leloudas[8,4], J. Lyman[9], D. Bersier[9], K. Wiersema[6], D. A. Perley[10,11], P. Schady[12], J. Gorosabel[7,44,45], J. P. Anderson[13,20], A. J. Castro-Tirado[7], S.B. Cenko[14,15], A. De Cia[16], L. E. Ellerbroek[17], J. P. U. Fynbo[4], J. Greiner[12], J. Hjorth[4], D. A. Kann[12,18], L. Kaper[17], S. Klose[18], A. J. Levan[19], S. Martín[20], P. T. O'Brien[6], K. L. Page[6], G. Pignata[21], S. Rapaport[22], R. Sánchez-Ramírez[7], J. Sollerman[23], I. A. Smith[24], M. Sparre[4], C. C. Thöne[7], D. J. Watson[4], D. Xu[16,4], F. E. Bauer[1,2,43], M. Bayliss[25,26], G. Björnsson[3], M. Bremer[28], Z. Cano[3], S. Covino[27], V. D'Elia[29,46], D. A. Frail[30], S. Geier[4,31], P. Goldoni[32], O. E. Hartoog[17], P. Jakobsson[3], H. Korhonen[33], K. Y. Lee[23], B. Milvang-Jensen[4], M. Nardini[34], A. Nicuesa Guelbenzu[18], M. Oguri[35,36], S. B. Pandey[37], G. Petitpas[25], A. Rossi[18], A. Sandberg[23], S. Schmidl[18], G. Tagliaferri[27], R. P. J. Tilanus[38,39], J. M. Winters[28], D. Wright[40], E.Wuyts[41,42]



Campana et al. 2006, Soderberg et al. 2008; Fan et al. 2013, Piran et al. 2013; Tsutsui & Shigeyama 2013; Mazzali et al. 2008; Margutti et al. 2013 Campana et al. 2011

Conclusions

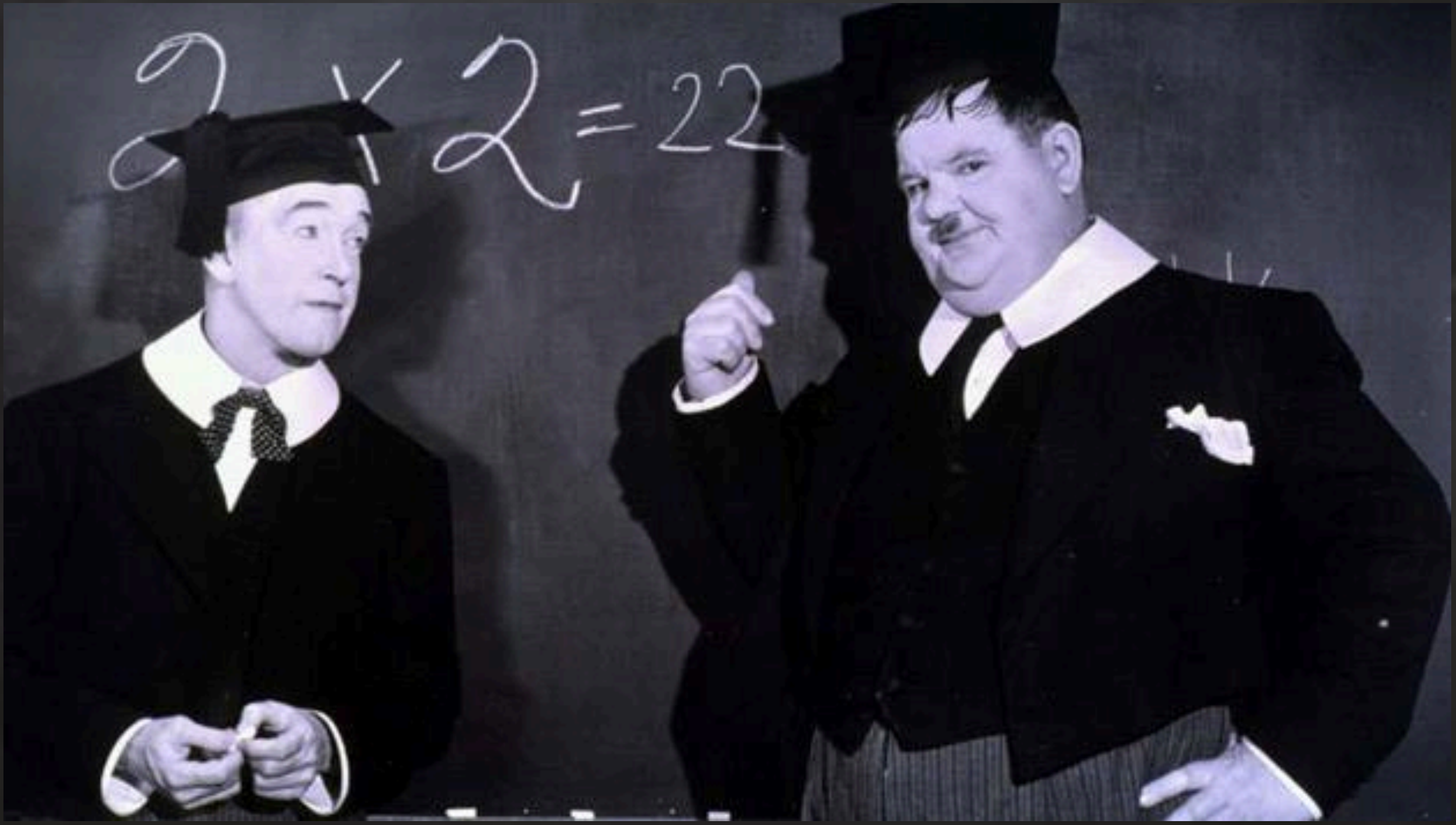
The energetic budget of most GRBs (LL-GRBs 10x) is a fraction (of a tiny fraction) of Ek of HNe. They might well be related to relatively low energy phenomena ($E_\theta < \sim 10^{50}$ erg) such as SN *shock break-out* (2006aj/060218) or *jet failed* (2008D/XRF 080109) events or *gravitational capture* (GRB 101225A) of minor bodies onto compact stellar remnants.

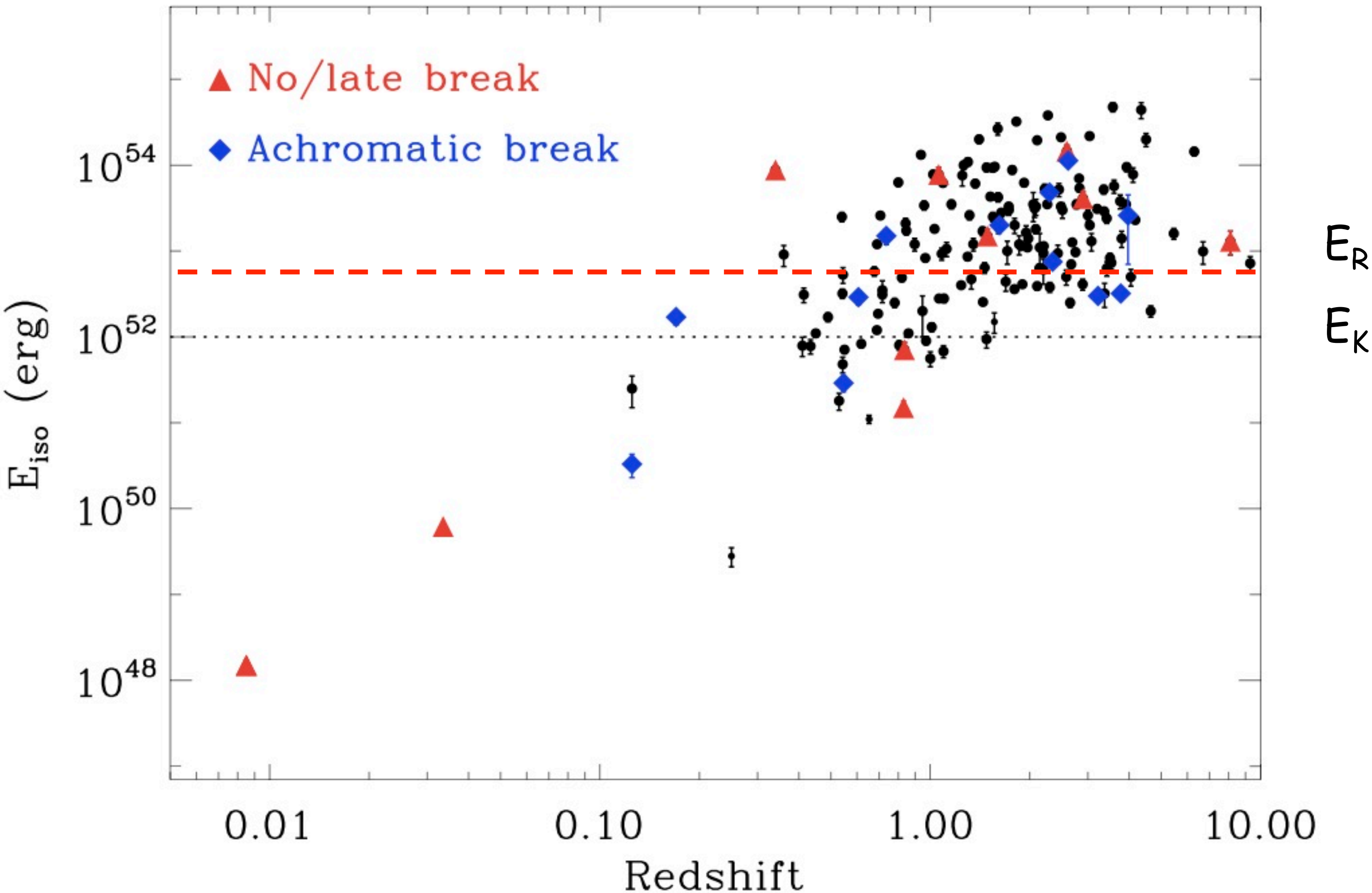
Conclusions cont'd

The so called "cosmological GRBs" $E_{iso} \sim 10^{52-54}$ erg ($E_{\theta} < \sim 10^{52}$ erg, after correction for beaming) are more energetic events that have been explained with different models.

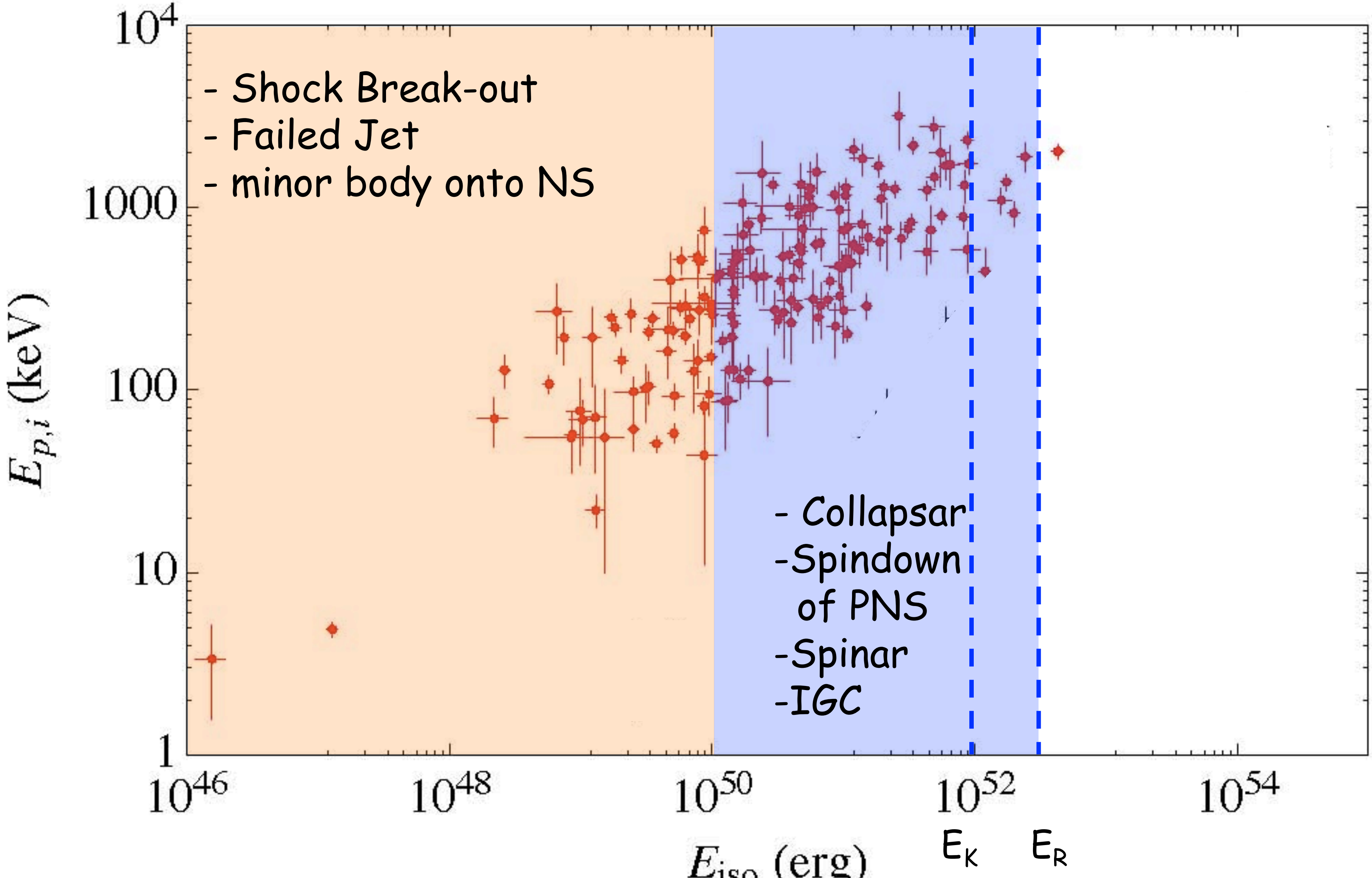
Their frequency of occurrence is small:
GRBs/SNe-Ibc = 0.003-1.5% →
HL-GRBs/HNe: 3%-20% (cfr. LL-GRBs/HNe > 40%)

Open Issues




No/late break
Achromatic break
10^{54}
10^{52}
10^{50}
10^{48}
E_{iso} (erg)
0.01
0.10
1.00
10.00
Redshift
E_R
E_K

from Amati



Campana et al. 2006, Soderberg et al. 2008; Fan et al. 2013, Piran et al. 2013; Tsutsui & Shigeyama 2013; Mazzali et al. 2008; Campana et al. 2011

Detection of very energetic ($E_\theta > \sim 10^{52 \div 53}$ erg) events require more energetic scenarios likely based on black hole formation (spin down of Kerr BH ? van Putten et al. 2011)