Supernovae shed light on GRBs

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Summary

1. Supernova Taxonomy
2. GRB-SN properties
3. Progenitors Mass
4. GRB and SN rates
5. GRB populations
6. Conclusions

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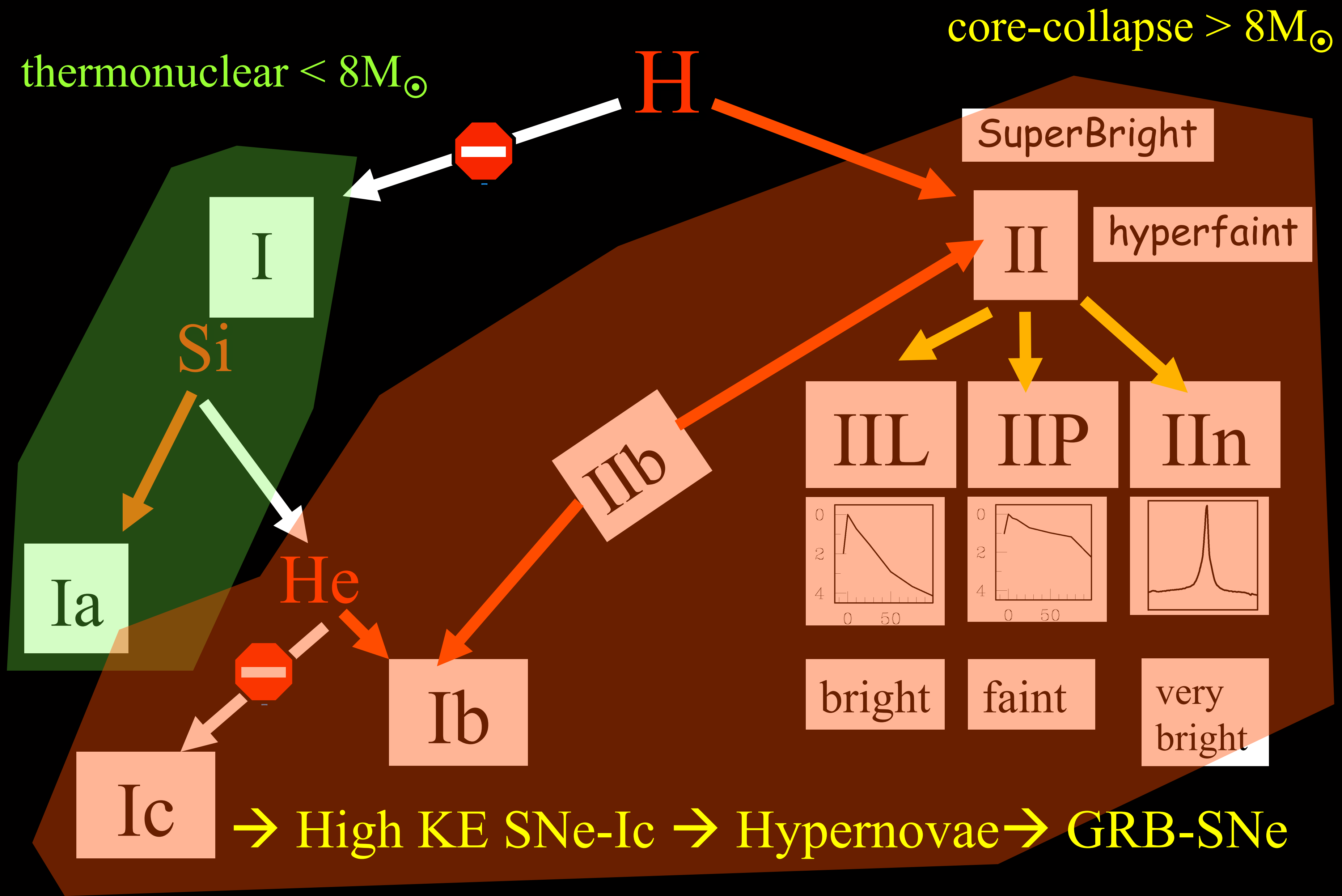
Supernova taxonomy



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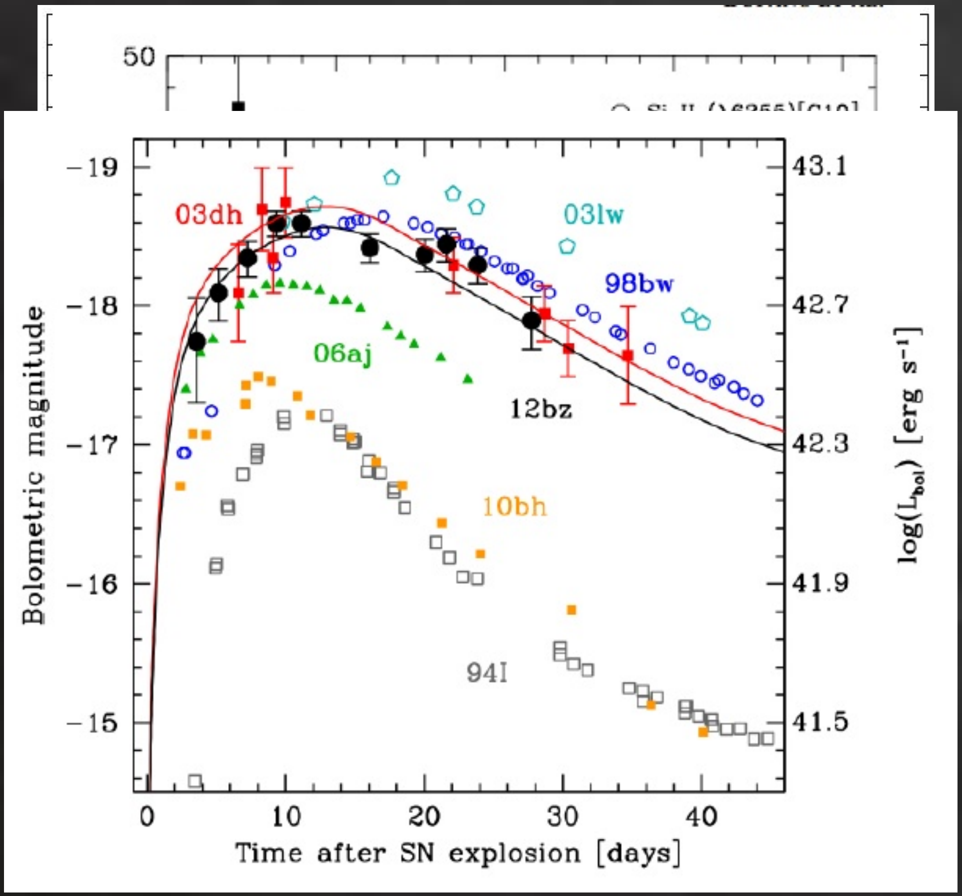
SNe & GRBs at z < 0.2

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 H and He in the ejecta: SNe-Ic

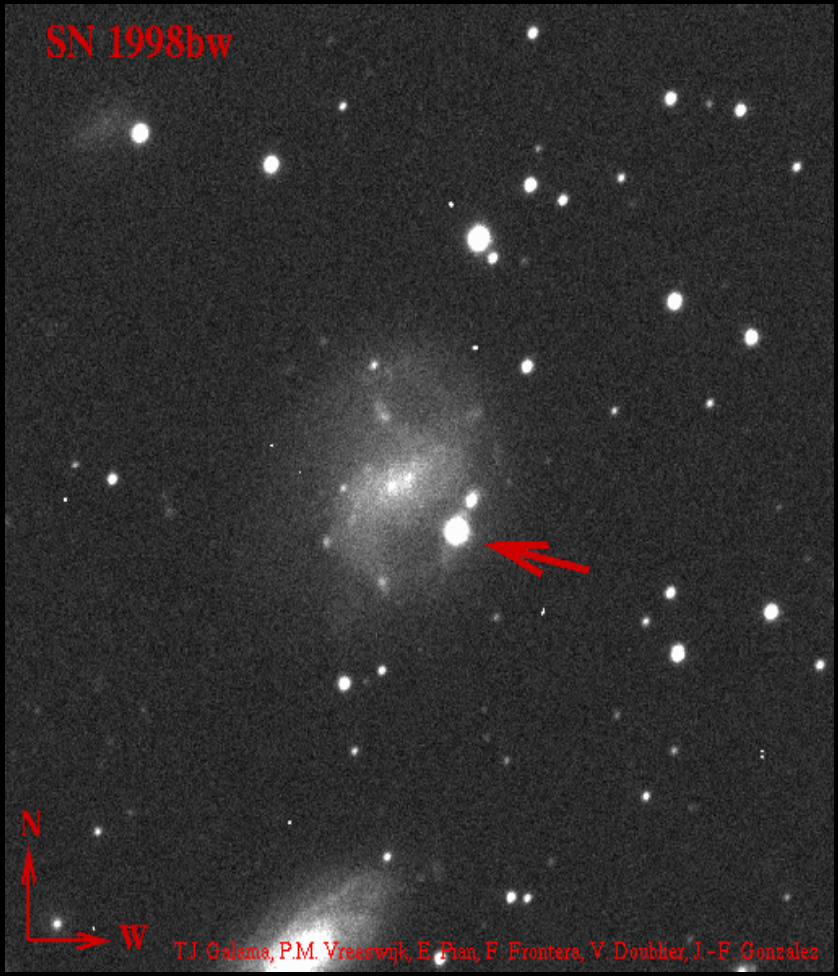
Very broad features: large expansion velocity (> 0.1c) →

Kinetic energy (non-relativistic ejecta) ~ 10^{52} erg ≥ 10 larger than usual CC-SNe

Range of luminosity: in some case large ^{56}Ni mass (~ 0.5±0.2 $M_{\odot}$)

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

SN 1998bw



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

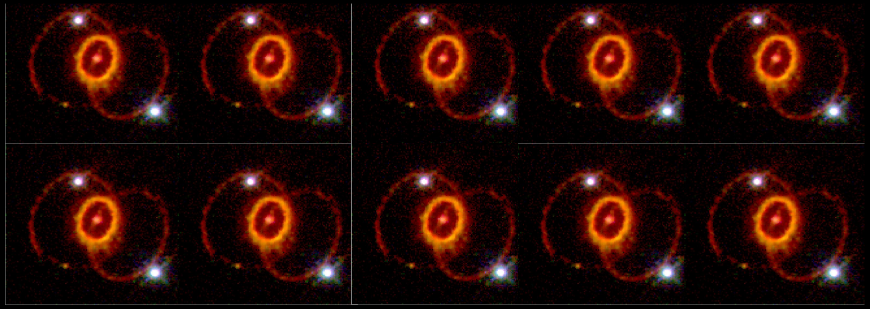
=

SN 1987A

Aspherical explosion

Maeda et al. 2006, 2008

see also Tautenberger et al. 2009



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

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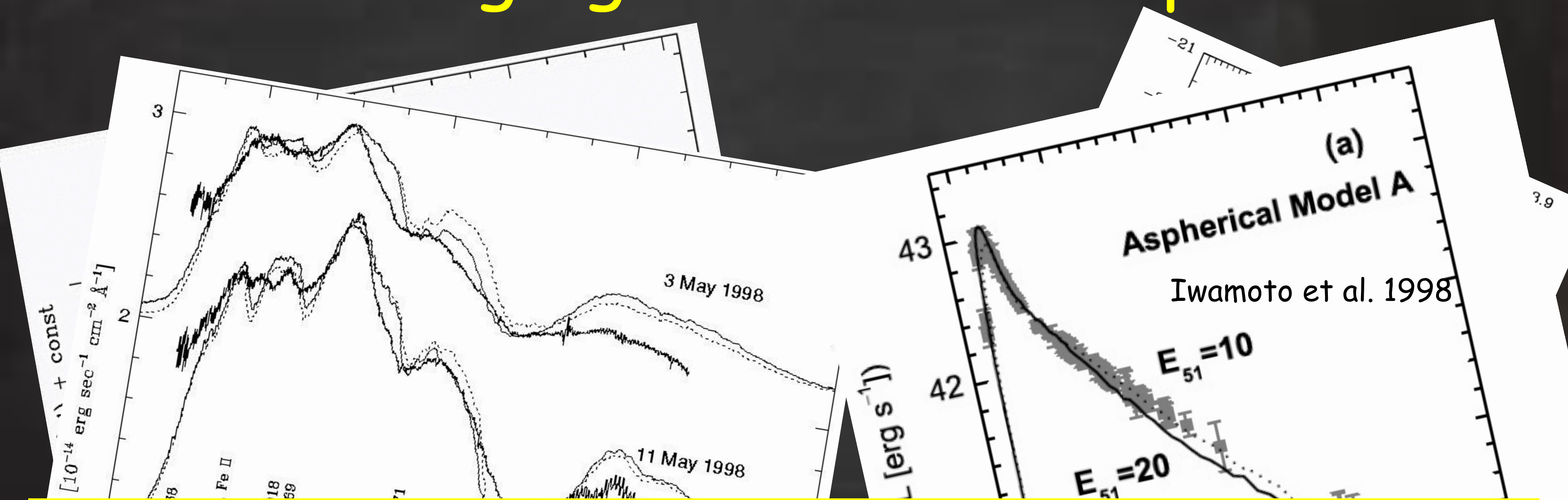
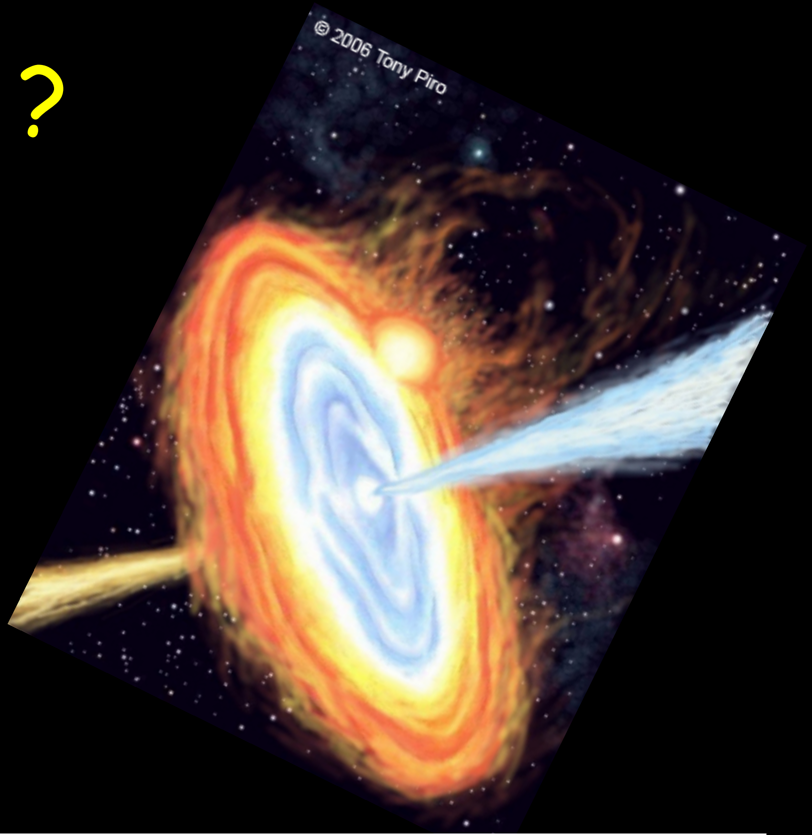
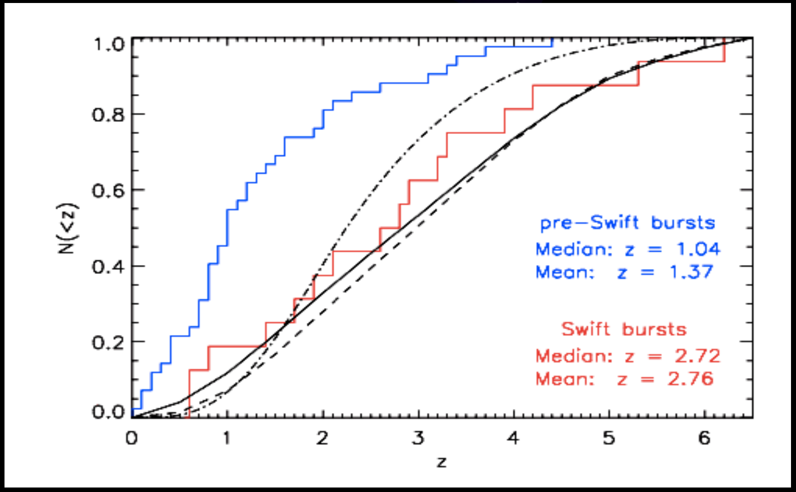
Modeling lightcurves and spectra



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 ?

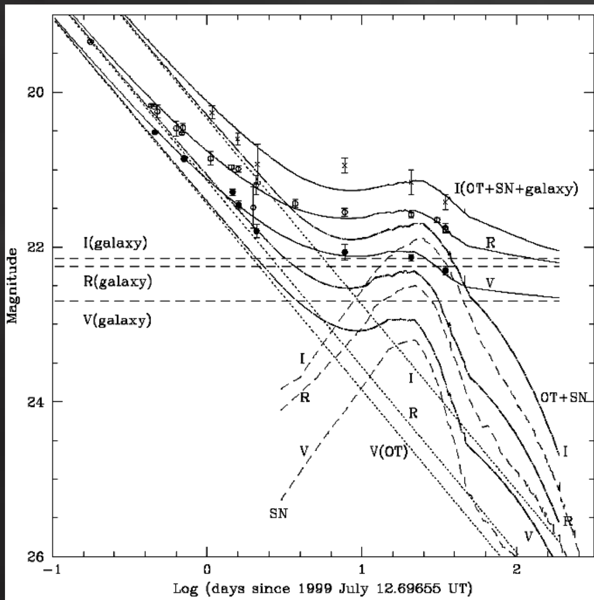




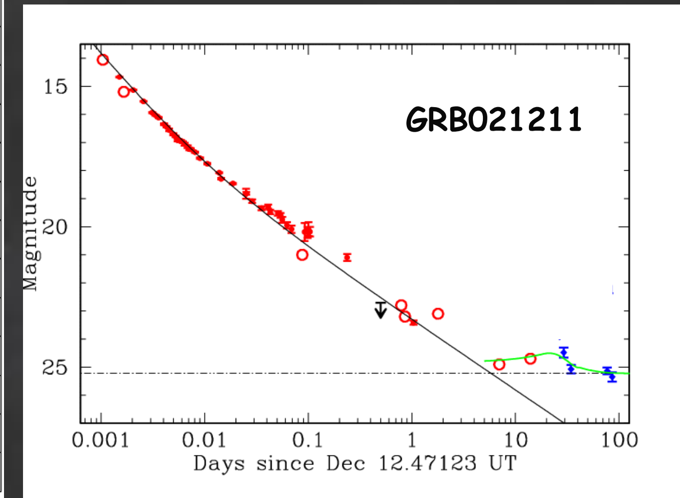
GRB census > 0.2

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

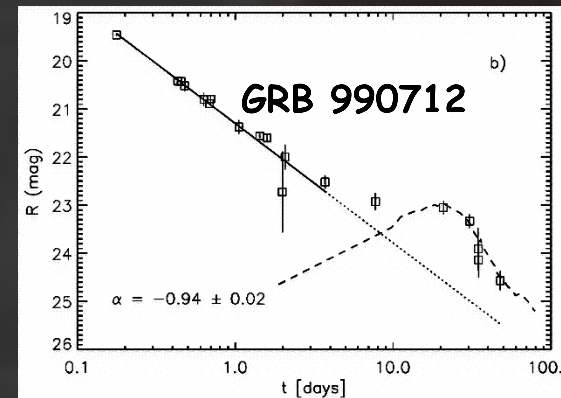
up to z ~ 1



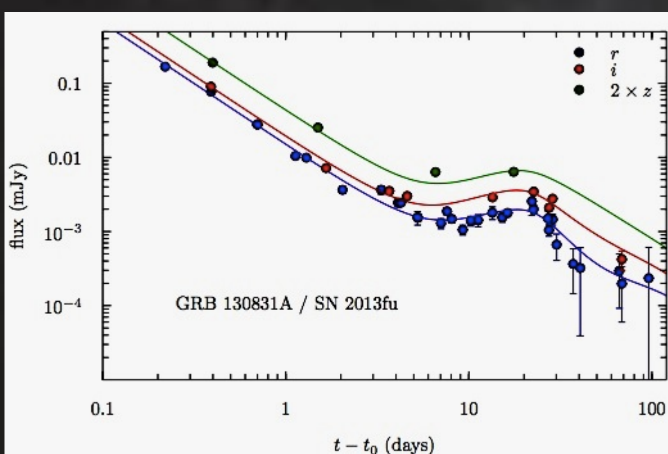
Sahu et al. 2000



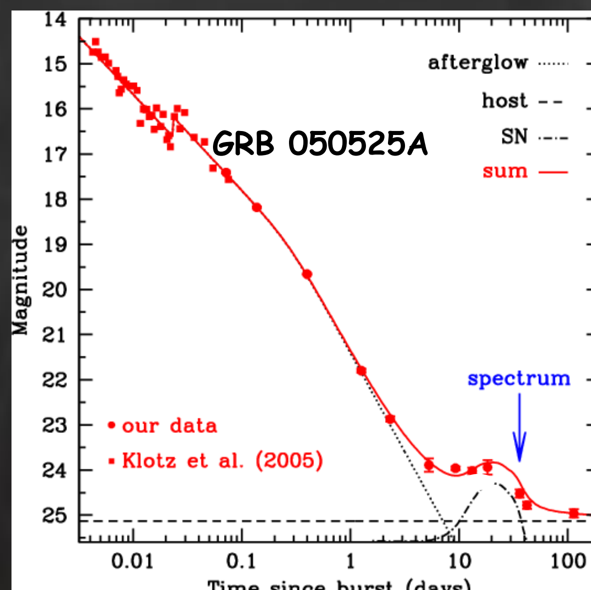
Della Valle et al. 2003



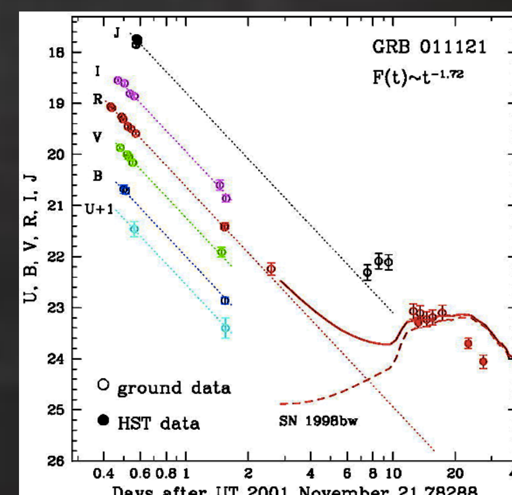
Bjornsson et al. 2001



Cano et al. 2014



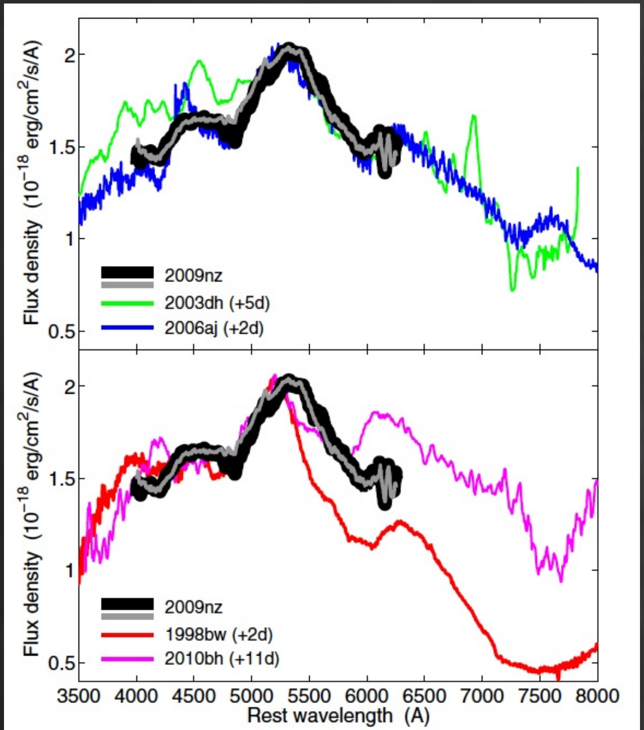
Della Valle et al. 2006

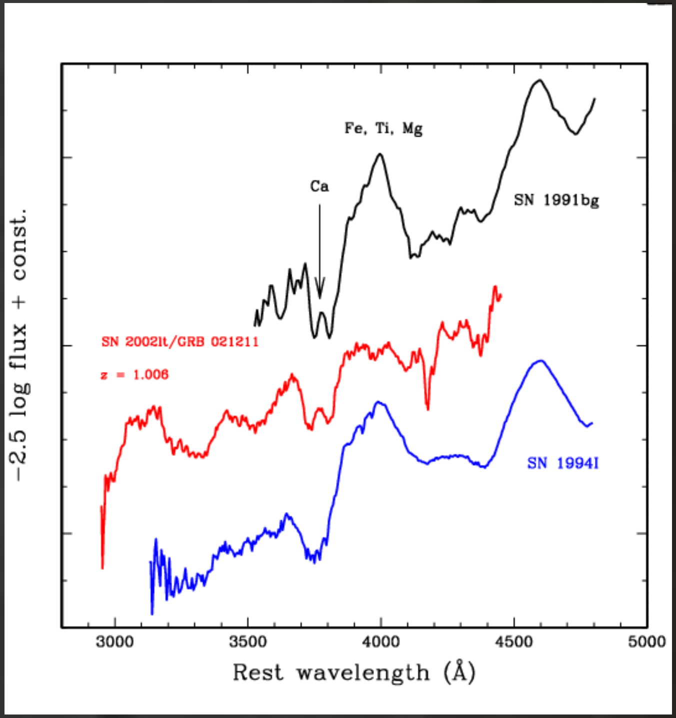


Garnavich et al. 2003

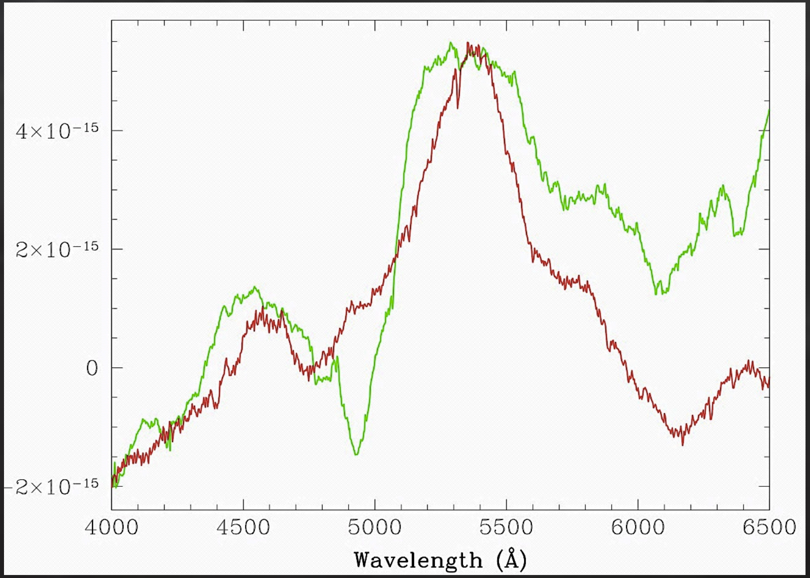
Are the bumps representative of signatures of incipient SNe?

Or they can 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) or Macronova events (see Piran's talk).



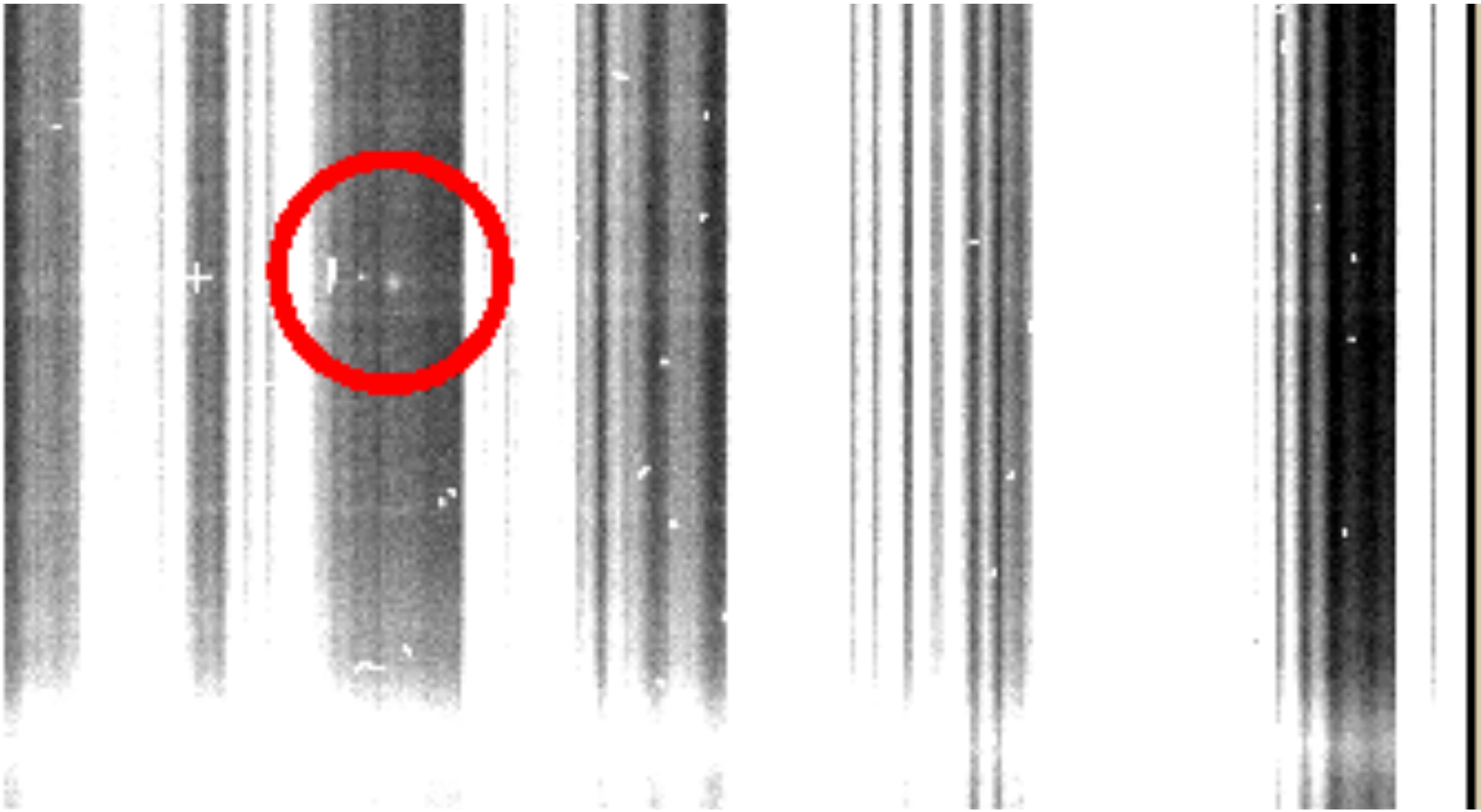


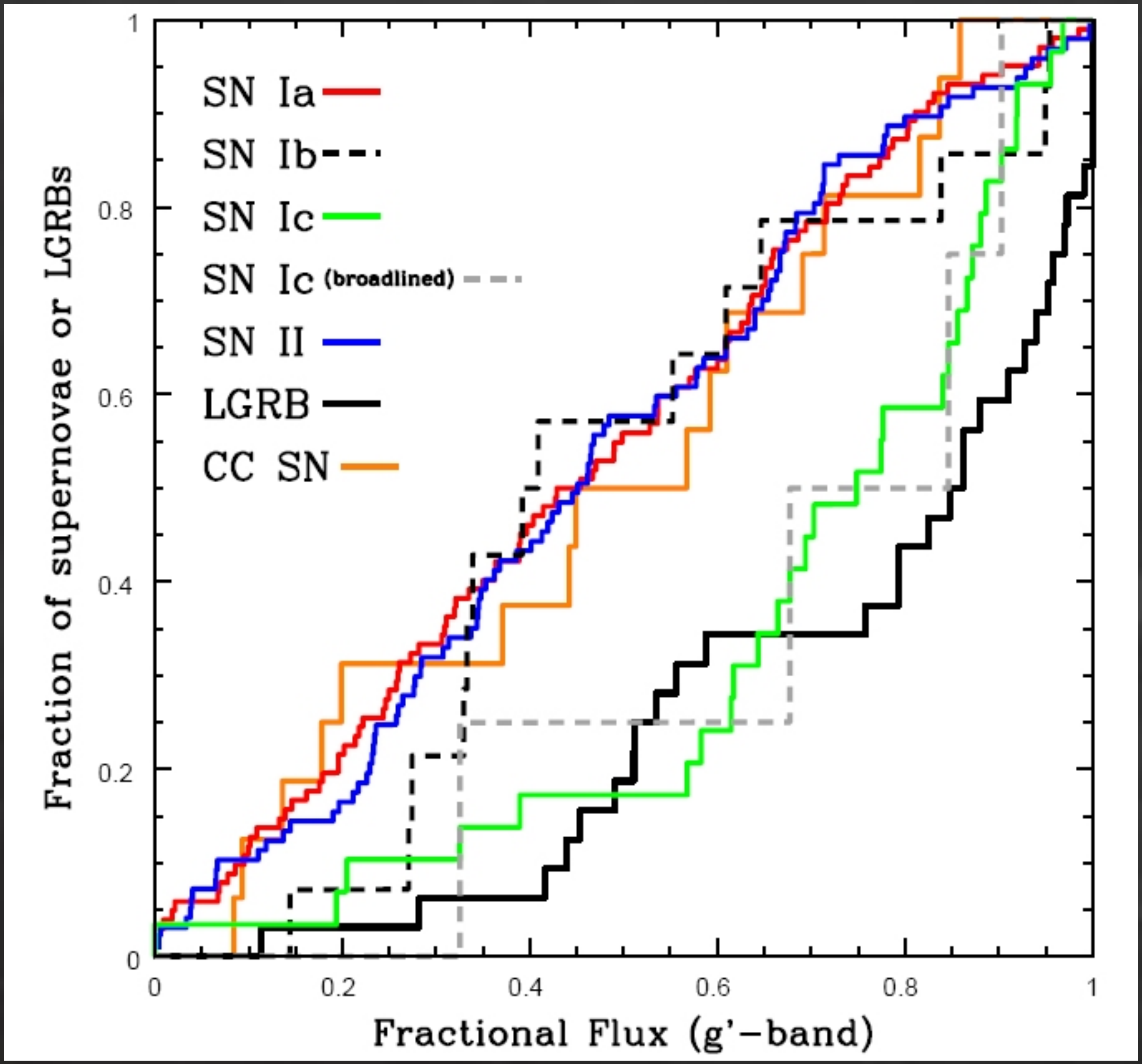
Berger et al. 2011
SN 2009nz @ z=0.49
GRB 091127



Zhi-Ping et al. 2013
SN 2008hw @ z=0.53
GRB 081007

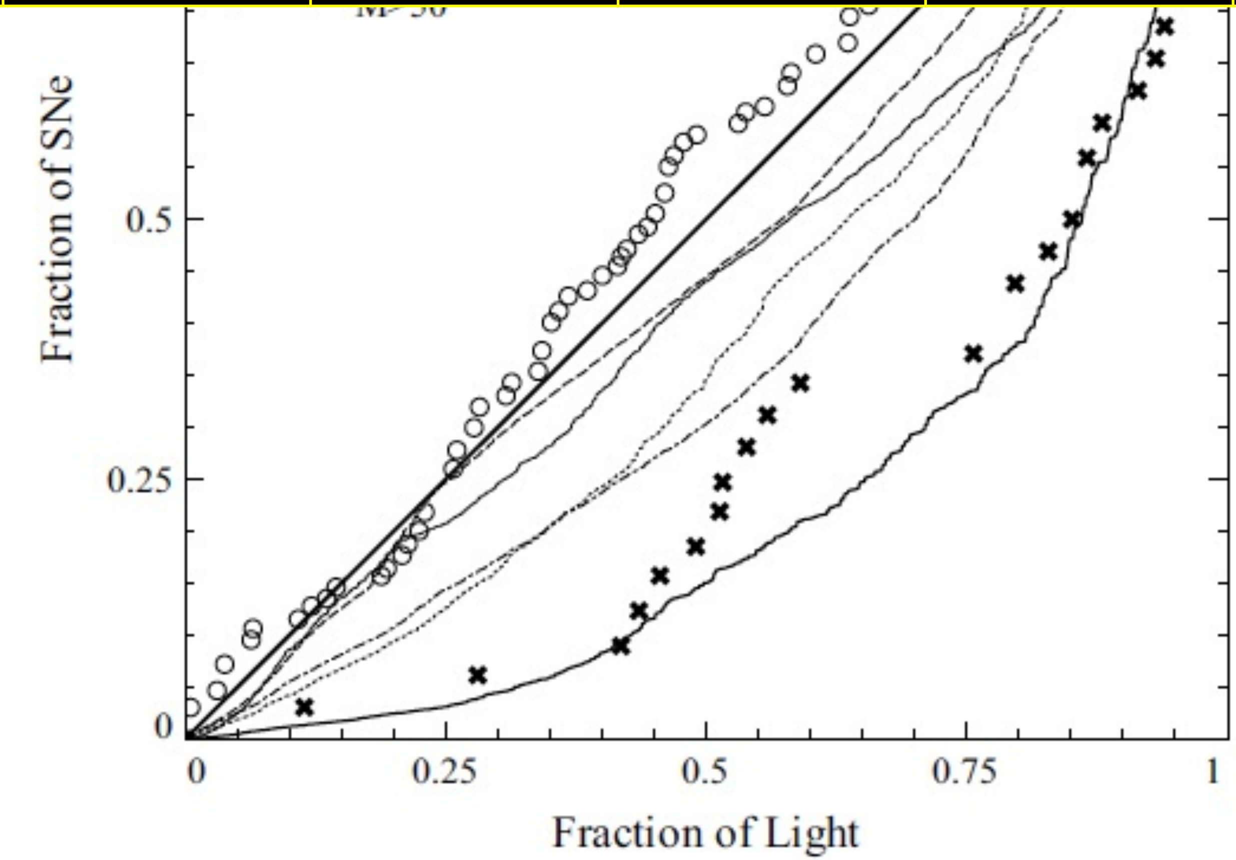
Della Valle et al. 2003
SN 2002lt @ z=1
GRB 021202





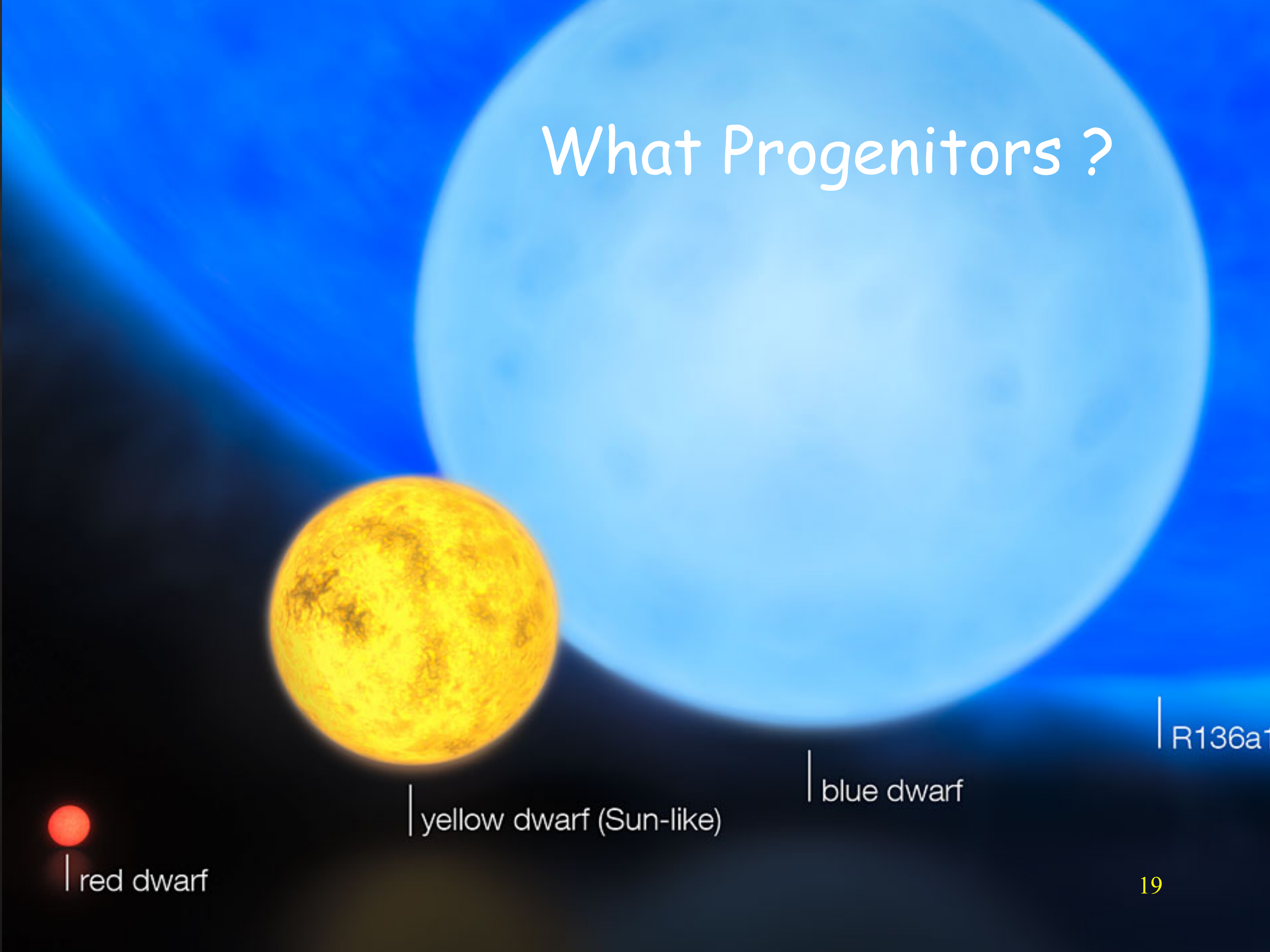
Kelly et al. 2008 find that SNe-Ic and LGRB erupt in the brightest regions of their hosts (see also Fruchter et al. 2006)

1998bw	2003dh	2003lw	2006aj	2008D	2010bh
40 $M_{\odot}$	35-40 $M_{\odot}$	40-50 $M_{\odot}$	20-25 $M_{\odot}$	20-30 $M_{\odot}$	25 $M_{\odot}$

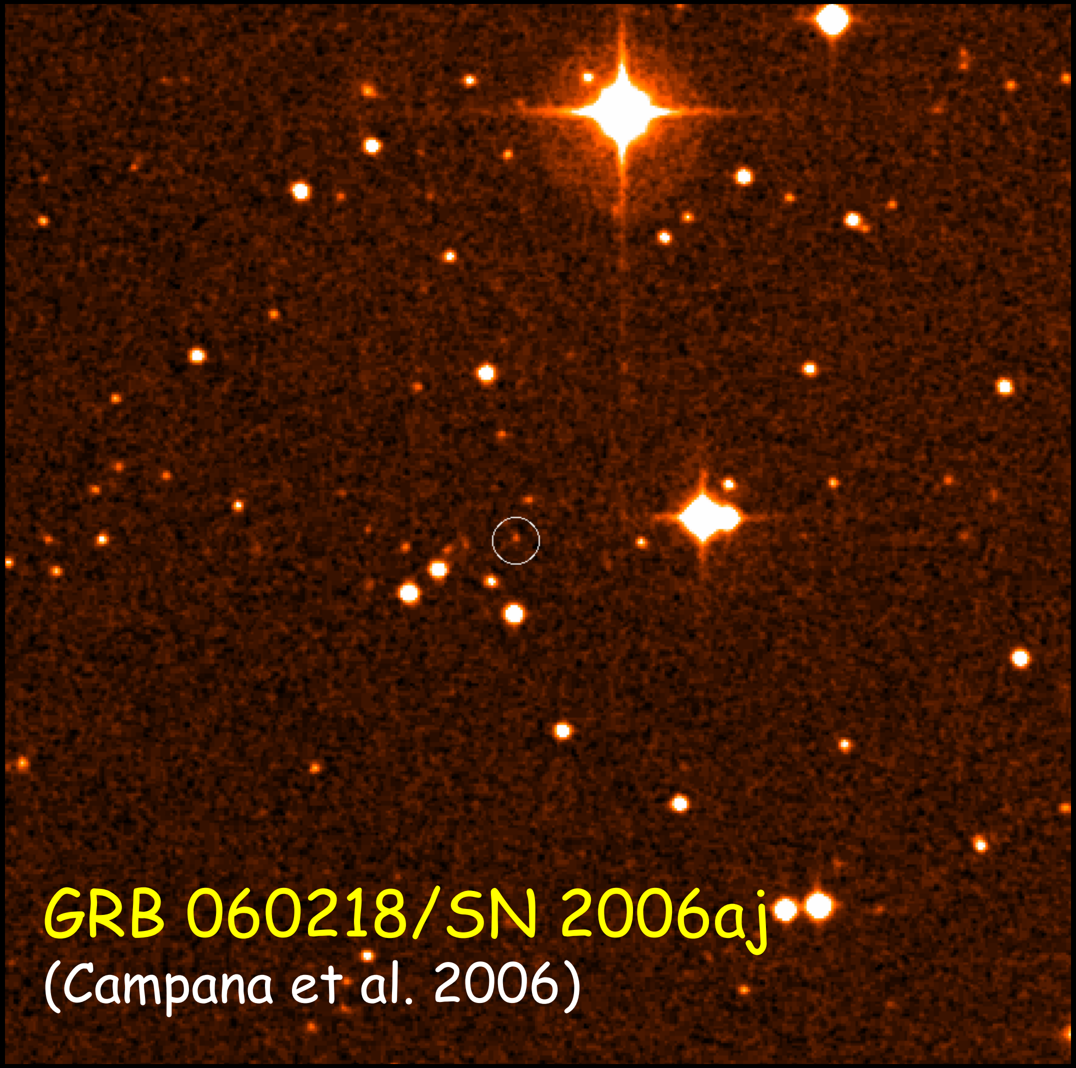


Long-GRBs have ~ 30 - 50 $M_{\odot}$ Raskin et al. 2008

What Progenitors ?



What Stars are GRB Progenitors ?



$z = 0.033$

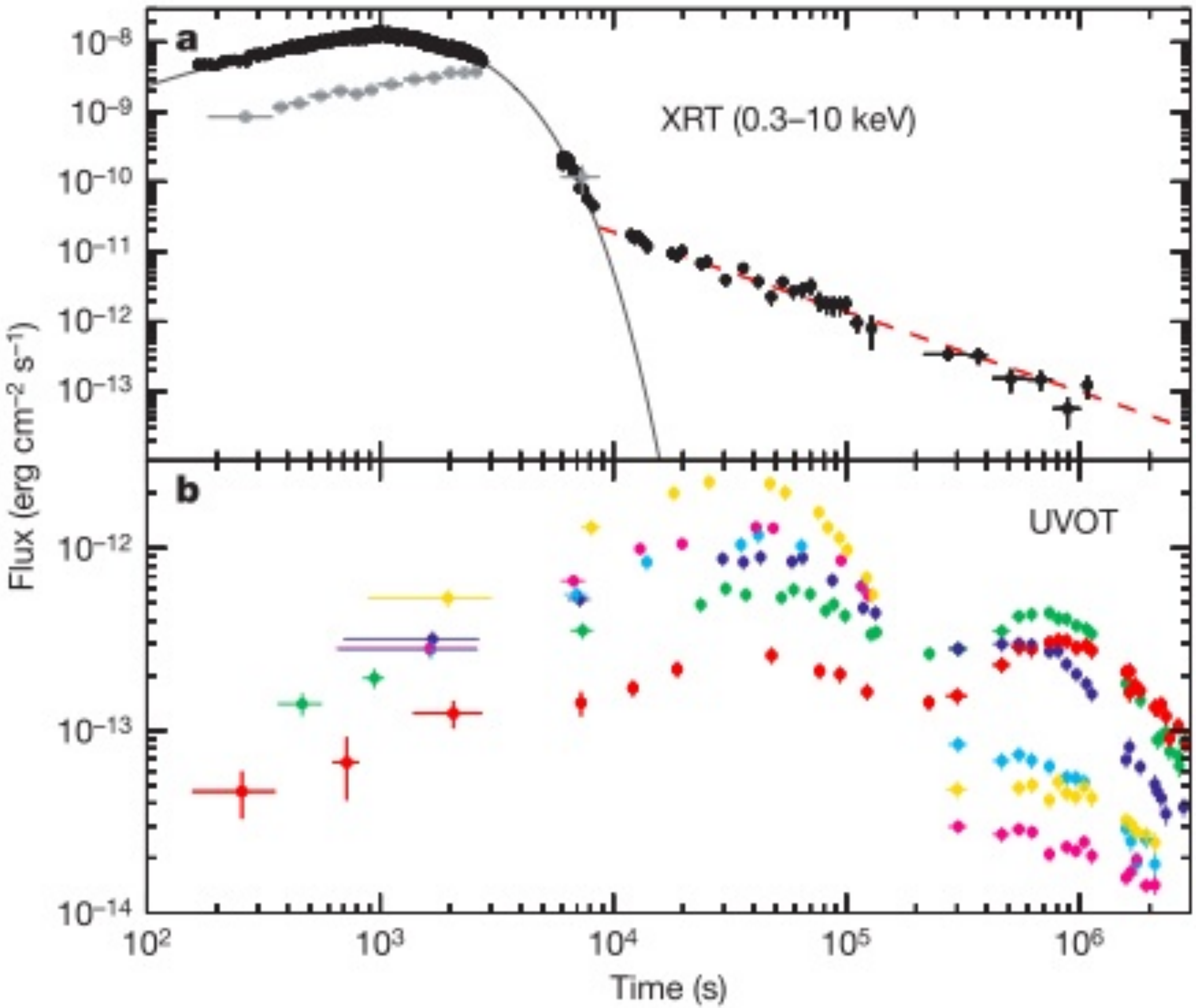
faint: $E_\gamma \sim 10^{49}$ erg

M_V (host) = -16

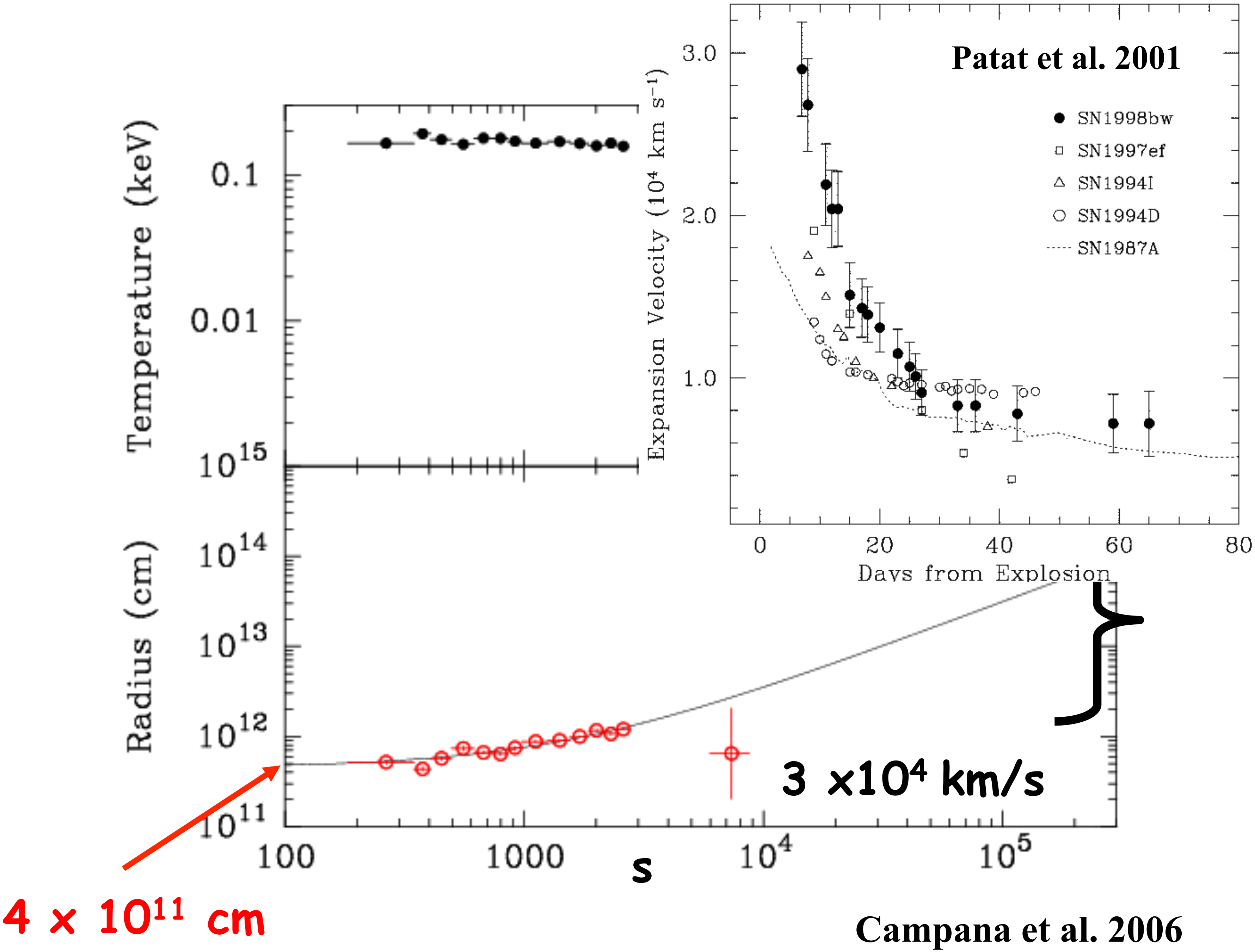
Host has brightness
Similar to SMC

$Z/Z_\odot \sim 0.3$

2006aj = SN-Ic



Campana et al. 2006



Campana et al. 2006

SNe-CC size progenitors

Red Supergiant

R~4x10^{13} cm

Blue Supergiant

R~4x10^{12} cm

The radius of the progenitor

W-R Star

R~4x10^{11} cm

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What is the rate of SNe-Ib/c ?

Asiago Survey (Cappellaro et al. 1999)

galaxy type	N. SNe*			rate [SNu]		
	Ia	Ib/c	II	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 ?

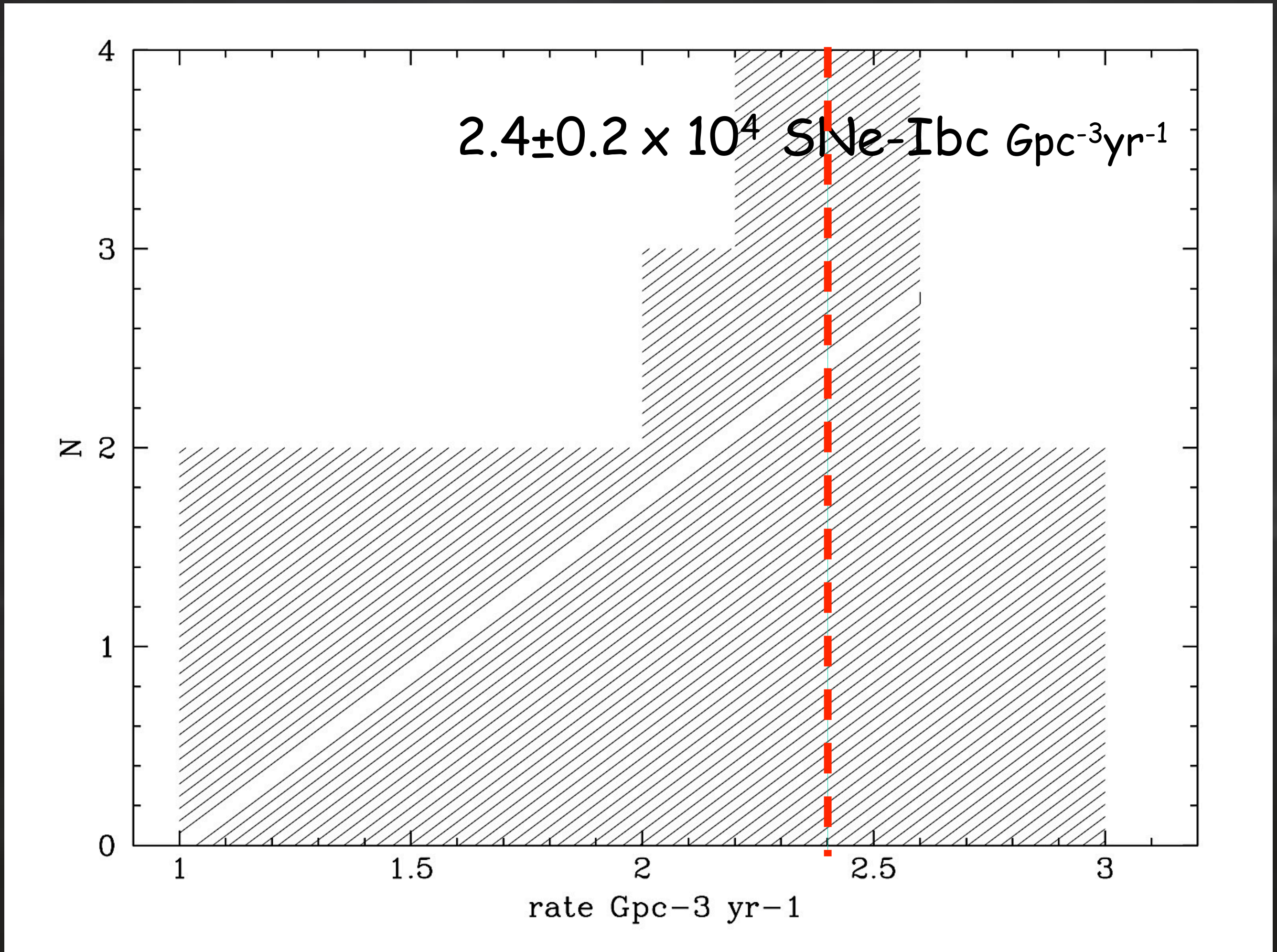
Lick Survey (Li et al. 2011)

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 x 10^4 SNe-Ibc Gpc^{-3} yr^{-1}

2.2 x 10^4 → 3 x 10^4 SNe-Ibc Gpc^{-3} yr^{-1}

+


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

What is the rate of (long) GRBs ?

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

1.5 Schmidt 1999

0.15 Schmidt 2001

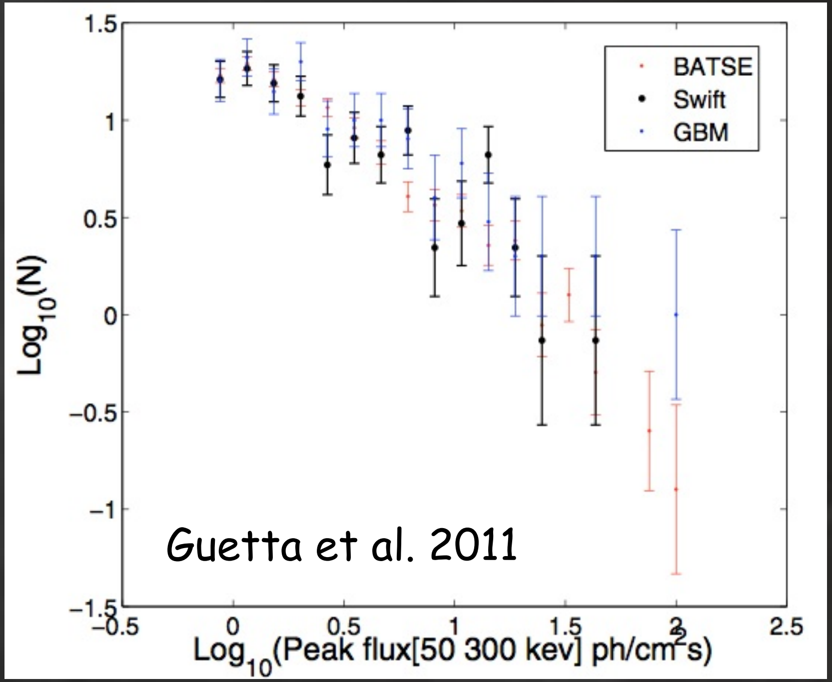
0.5 Guetta et al. 2005

1.1 Guetta & Della Valle 2007

1.1 Liang et al. 2007

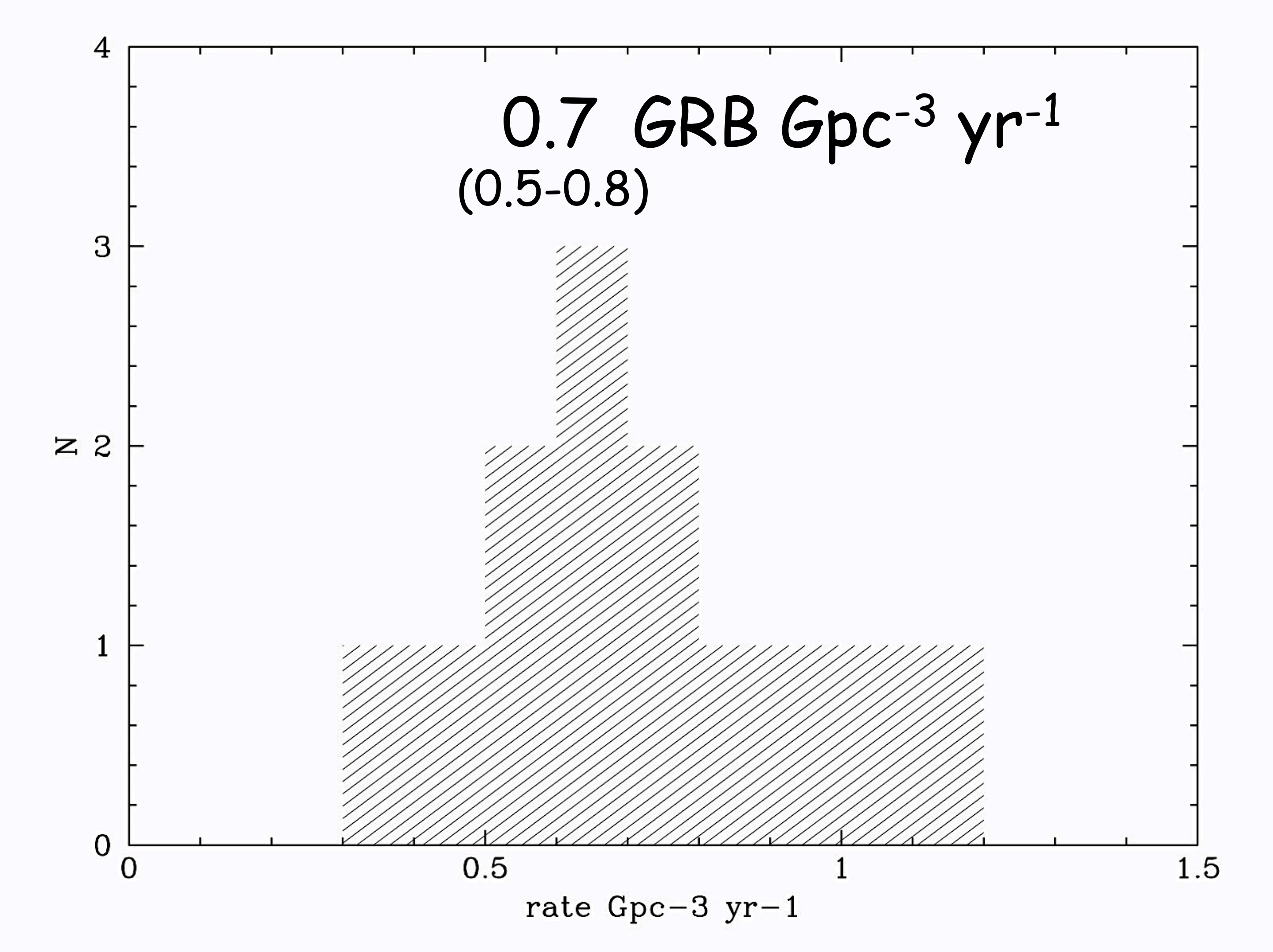
> 0.5 Pelangeon et al. 2008

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 ?



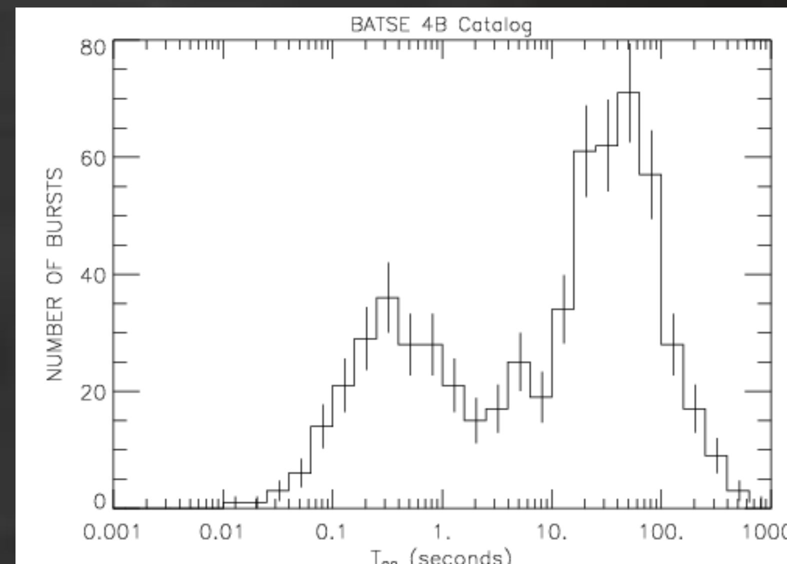
What is the fraction of SNe-Ib/c which produces (long)GRBs ?

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

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

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

Energy Crisis



Fluence : $10^{-7} \div 10^{-5}$ erg cm^{-2}

Distanza: up to z ~ 10

Energy : E_{iso} up to ~ few x 10^{54} erg

10^{54} erg ~ 1 $M_{\odot}$ ~ x 10

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 $Gpc^{-3}\ yr^{-1}$

$<fb^{-1}> \sim 500$ (Frail et al. 2001) $(\vartheta \sim 4°)$

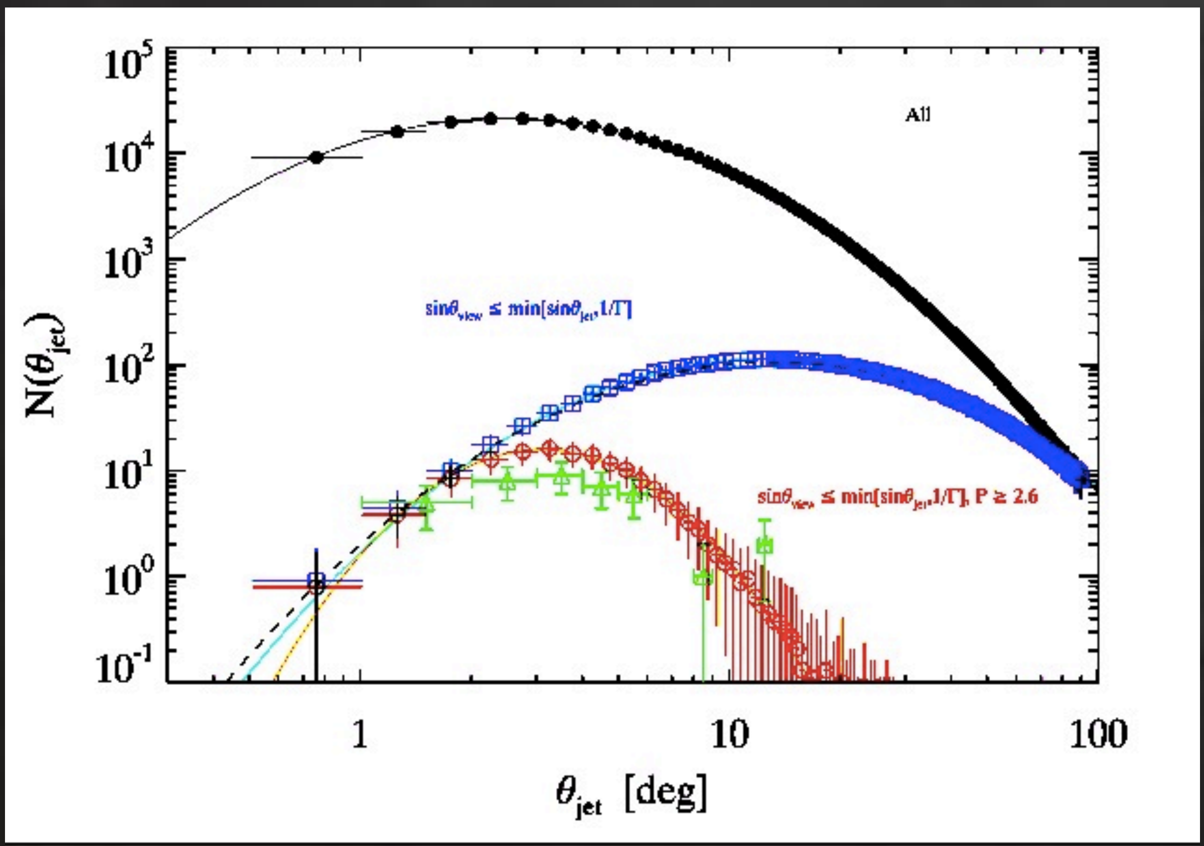
$<fb^{-1}> \sim 75$ (Guetta, Piran & Waxman 2004) $(\vartheta \sim 9°)$

$<fb^{-1}> < 10$ (Guetta & DellaValle 2007) $(\vartheta > 25°)$ for sub-lum GRBs

$<fb^{-1}> \sim 1$ (Ruffini et al. 2006) (up to $\vartheta \sim 4\ \pi$)

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° < ϑ < 100°

ϑ_{peak} ~ 4°

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

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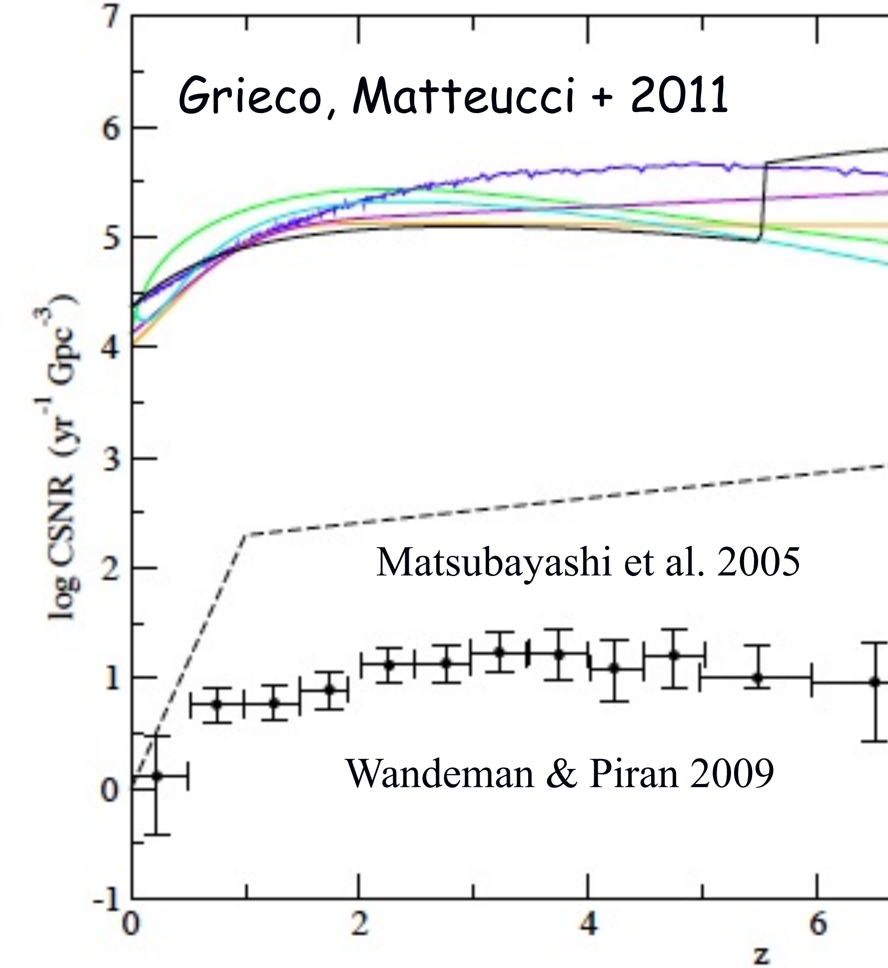
$\langle fb^{-1} \rangle < 10$	(Guetta & DellaValle 2007)	$(\vartheta > 25°)$ for sub-lum GRBs
$\langle fb^{-1} \rangle \sim 1$	(Ruffini et al. 2006)	(up to $\vartheta \sim 4\ \pi$)

GRB/SNe-Ibc: 1.5%-0.003%



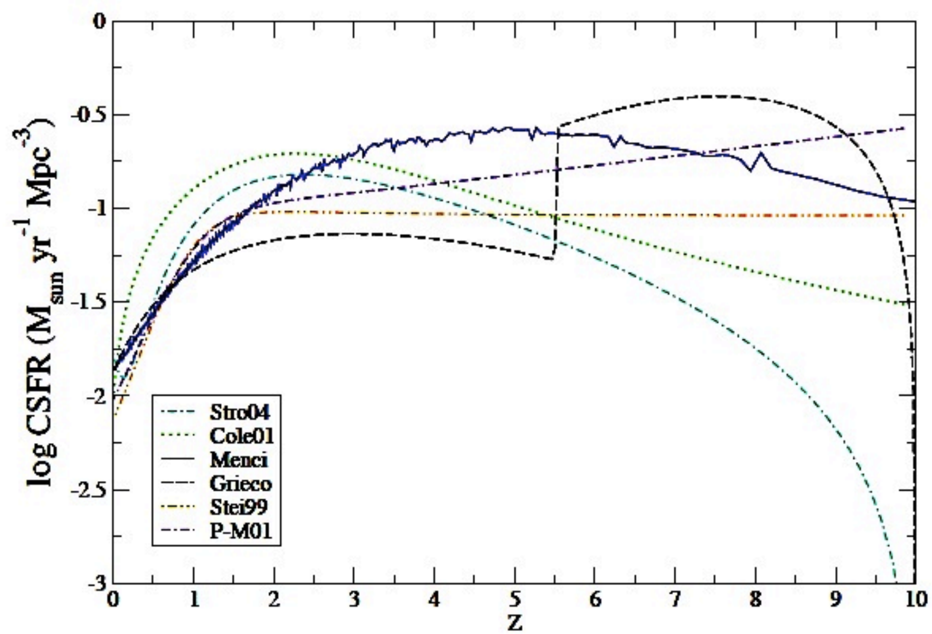
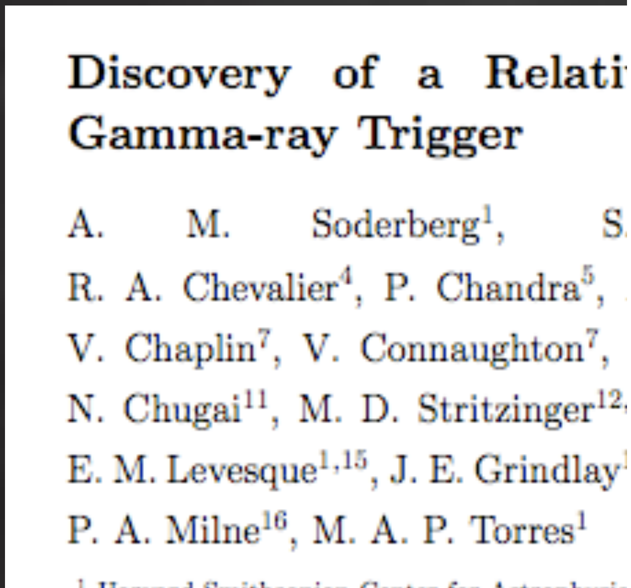


Figure 6. Evolution of different cosmic star formation rates with redshift: Menci, private communication (blue solid line), our model (black long-dashed line), Strolger 2004 (turquoise dashed-dotted line), Steidel 1999 (orange double dotted-dashed line), Porciani & Madau 2001 (violet double dashed-dotted line). The green dotted line is the fit (Cole et al. 2001) of the data collected by Hopkins (2004).

GRB/SNeIbc →0.1-0.01%

θ ~ 13°-40°

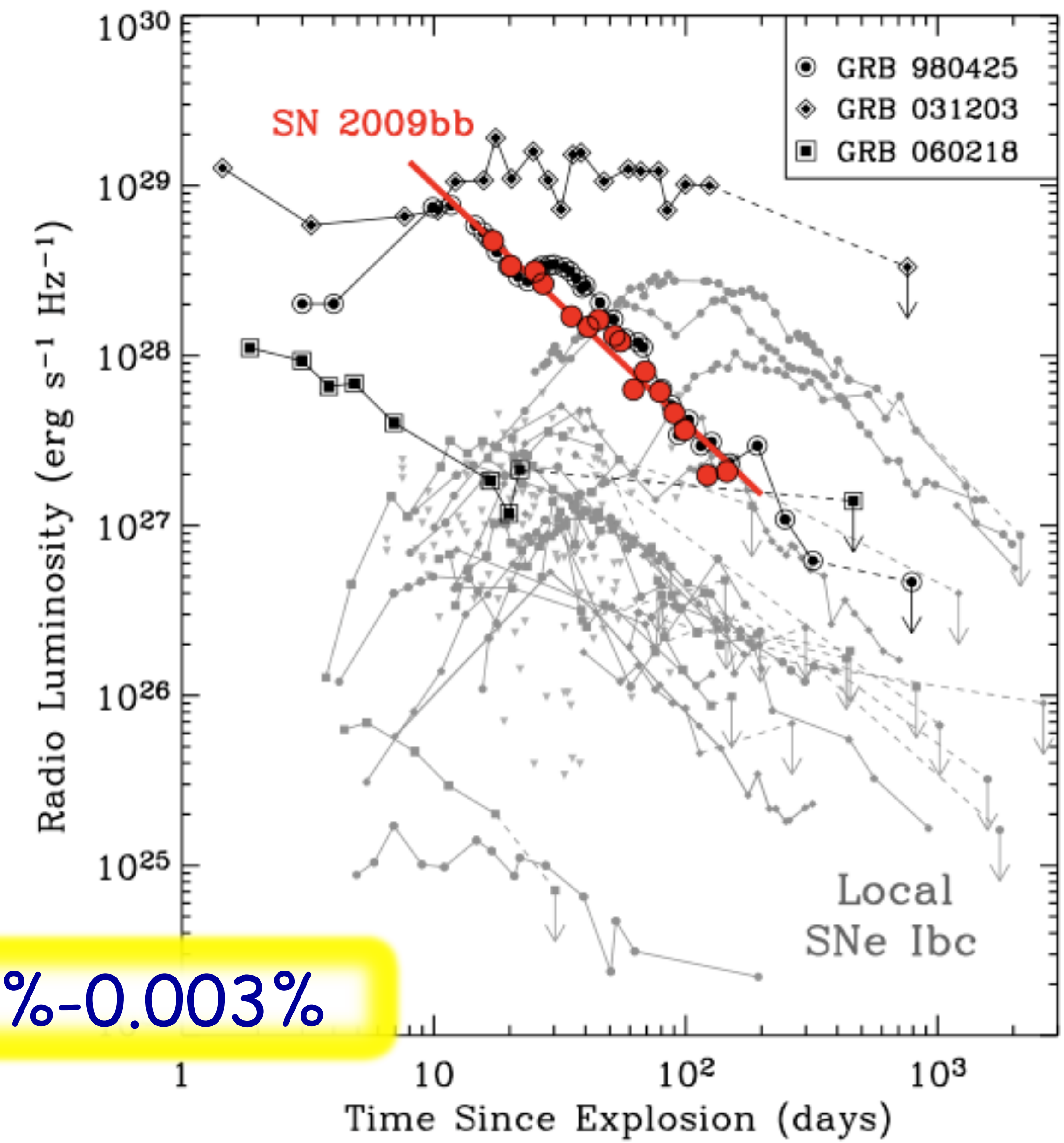


Discovery of a Relati
Gamma-ray Trigger

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[1]
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%

+

HNe/SNe-Ibc: ~ 7%

GRB/SNe-Ibc: ~ 1.5%

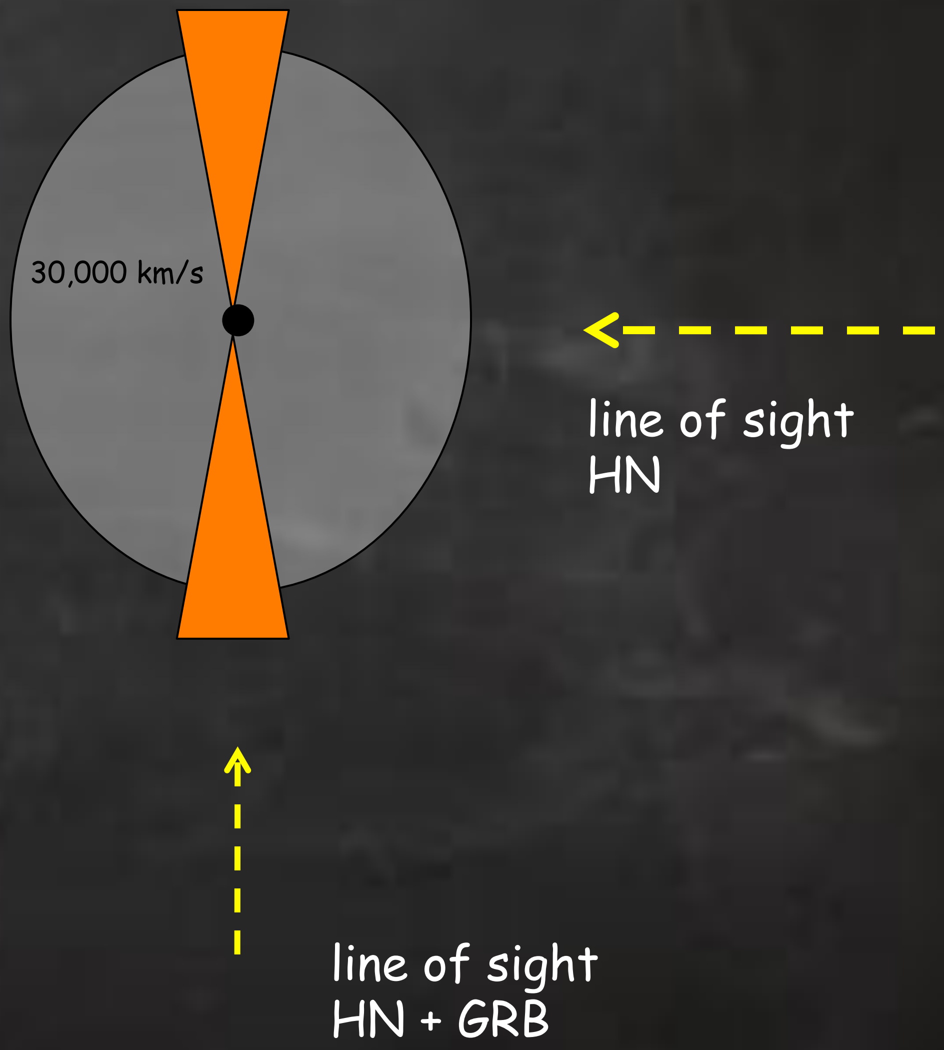
GRB/HNe: ~ 20%

A simplified (and wrong) scheme for a GRB-SN event

-an almost isotropic component carrying most energy 10^{52} erg and mass ($\sim$5-10$M_\odot$)

-highly collimated component 4°-10° for HL-GRBs containing a tiny fraction of the mass ($10^{-4/-5}$ $M_\odot$) moving at $\Gamma \sim \times 10^{2-3}$

GRB/HNe: ~ 20%



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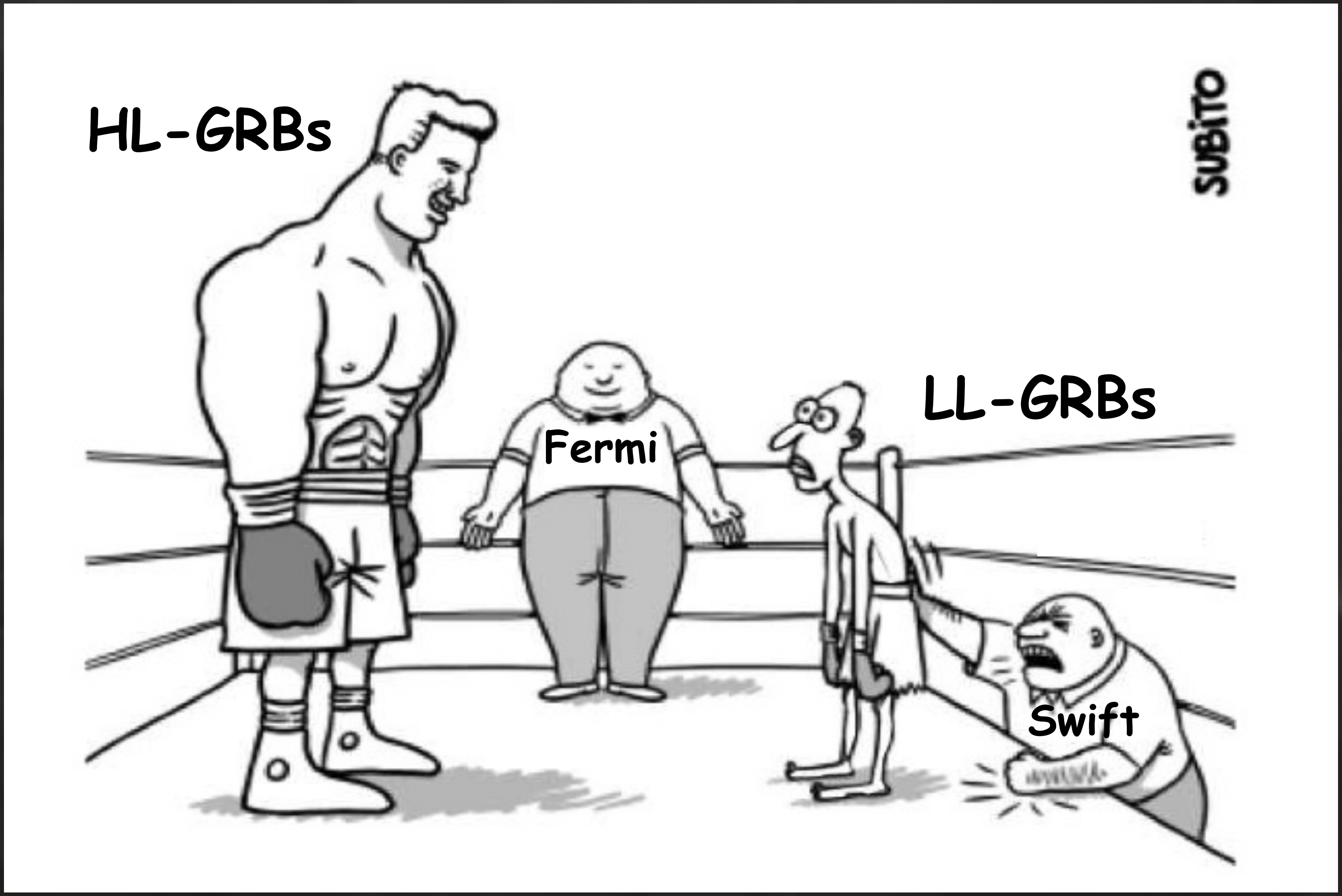
HL-GRBs vs. LL-GRBs



SNe & GRBs at z < 0.1

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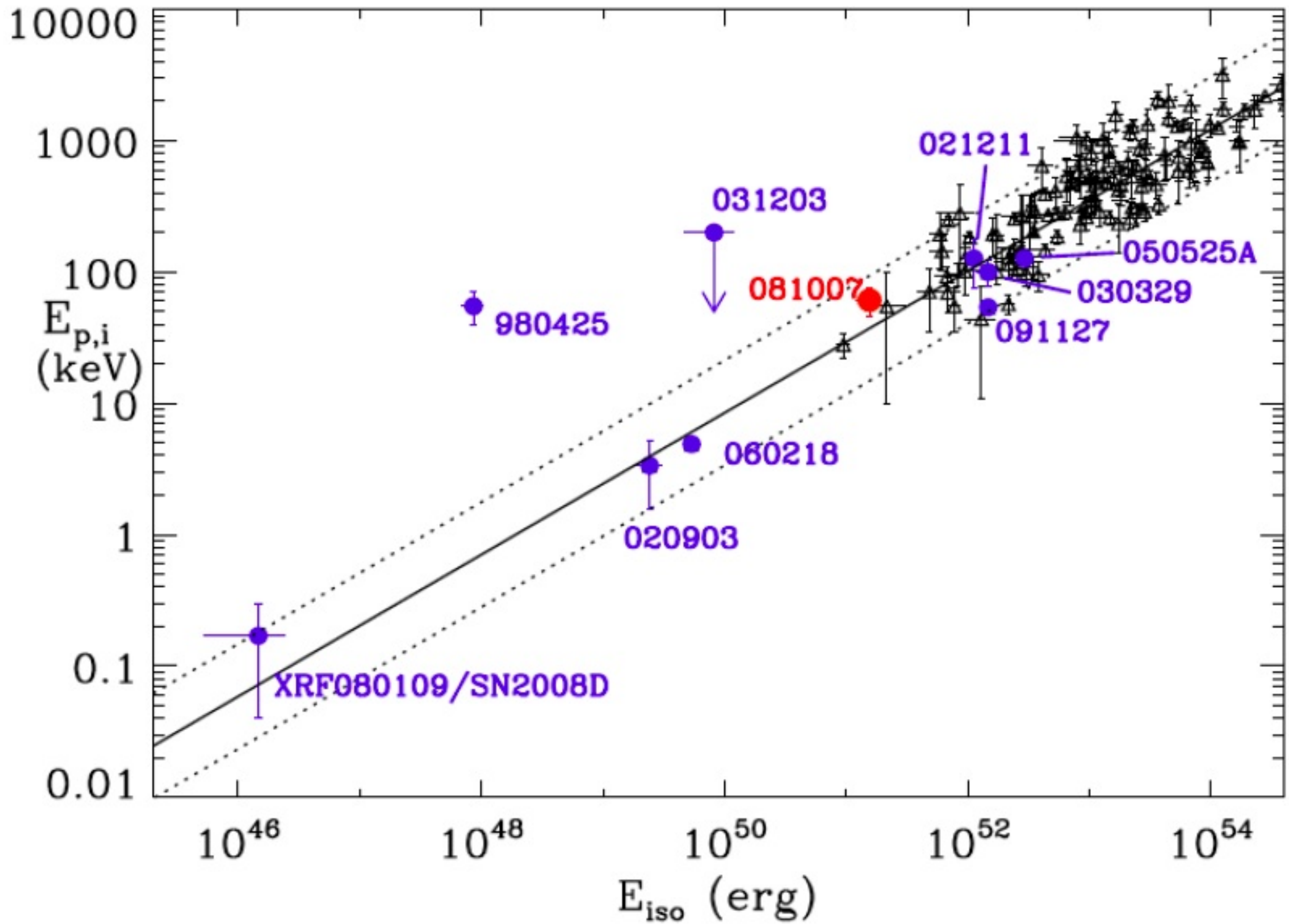
GRB 060218	SN 2006aj	0.033	$\sim 10^{50}$
GRB 080109	SN 2008D	0.007	$\sim 10^{46}$
GRB 100316D	SN 2010bh	0.06	$\sim 10^{50}$



10000
1000
100
10
1
0.1
0.01
$E_{p,i}$
(keV)
10^{46}
10^{48}
10^{50}
10^{52}
10^{54}
E_{iso} (erg)
021211
031203
050525A
081007
030329
980425
091127
060218
020903
XRF080109/SN2008D

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 ~10^6 smaller → Rate: up to x 10^3 larger

(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)

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 $Gpc^{-3}\ yr^{-1}$

$\langle fb^{-1} \rangle \sim 500$	(Frail et al. 2001; Ghirlanda et al. 2013)	$(\vartheta \sim 4°)$
$\langle fb^{-1} \rangle \sim 75$	(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)	(up to $\vartheta \sim 4\pi$)

LL vs. HL Rates

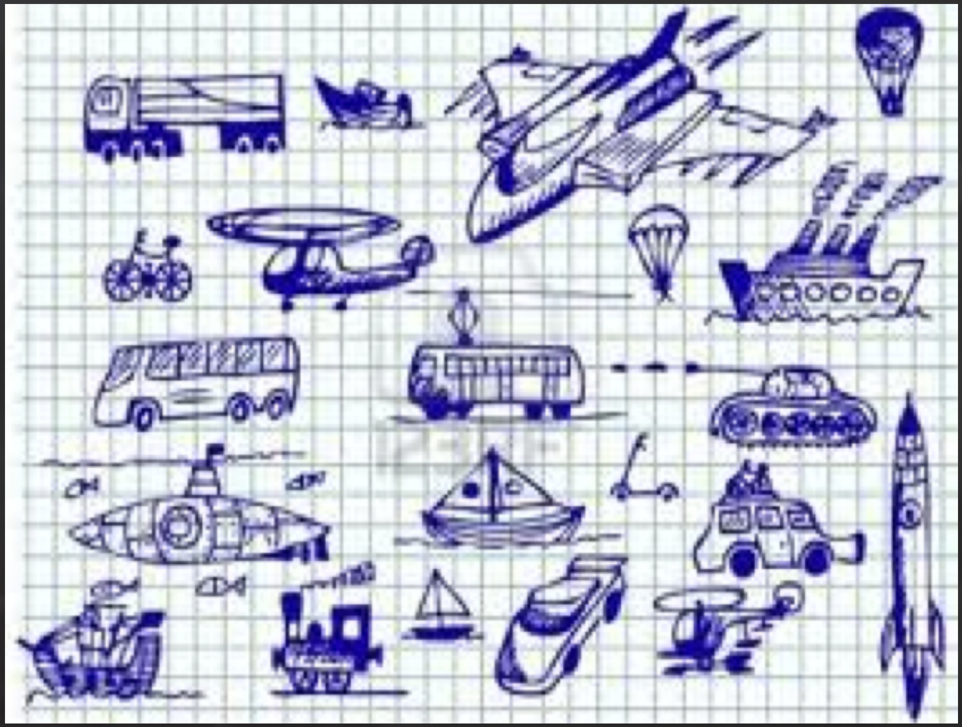
LL-GRBs $\sim 71 \times (1 \div 10) \sim 70 \div 700$ LL-GRBs $Gpc^{-3}\ yr^{-1}$

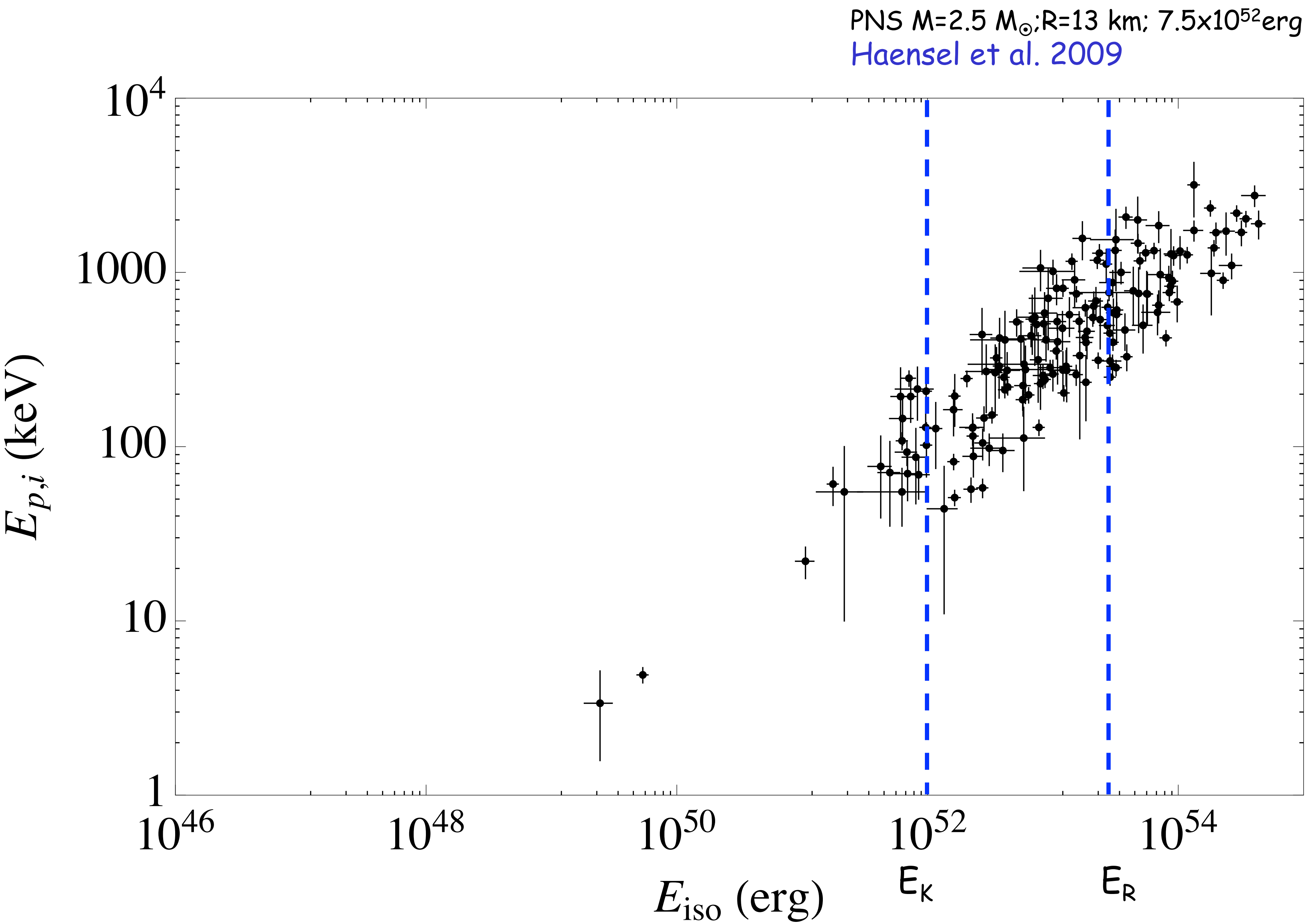
$\langle f_b^{-1} \rangle_{HL\text{-}GRBs} \sim 75 \div 500$

HL-GRBs $\sim 0.7 \times \langle f_b^{-1} \rangle \sim 50 \div 350\ Gpc^{-3}\ yr^{-1}$

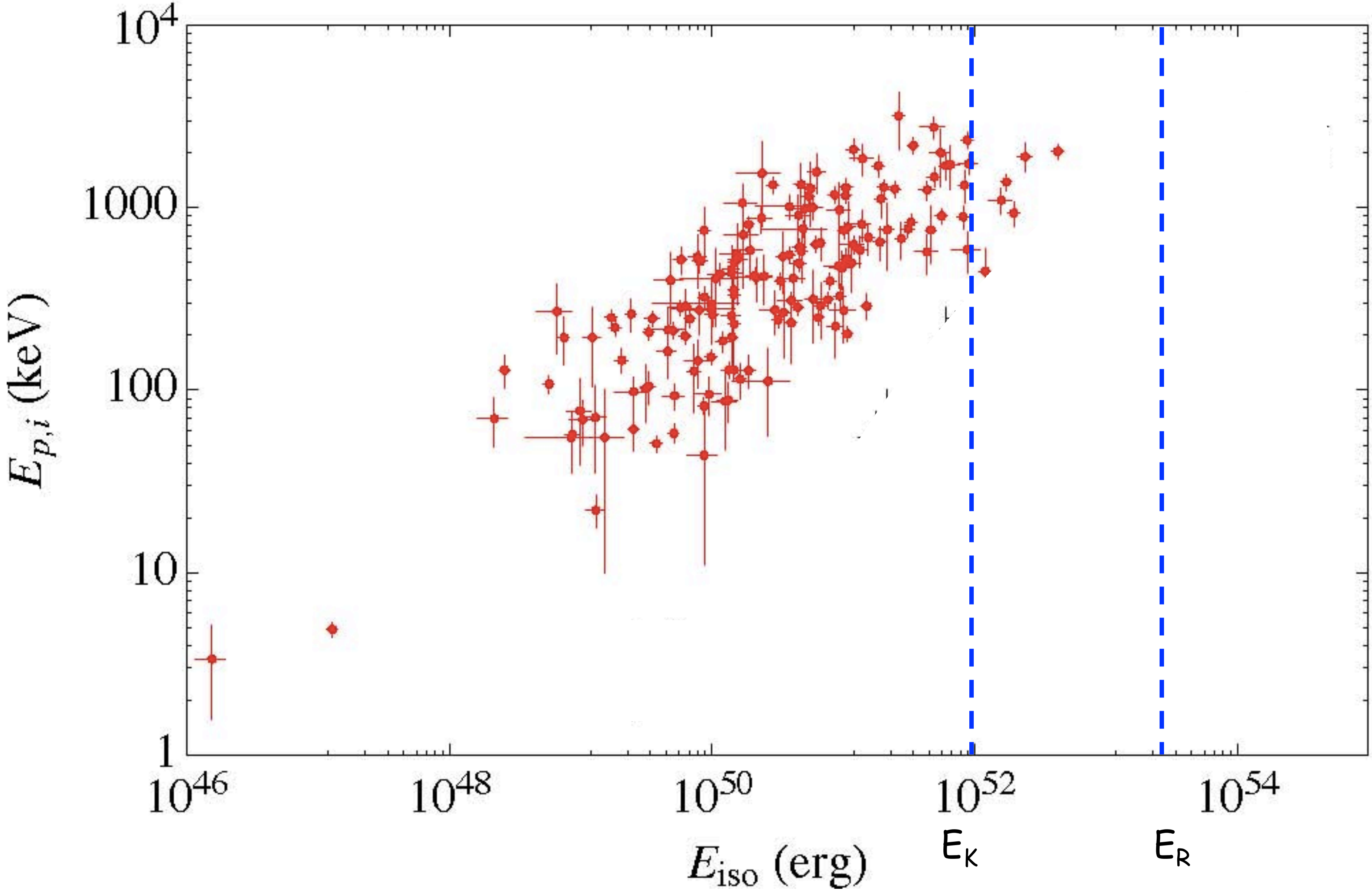
LL-GRB/*HL*-GRB $< \sim 20$

LL vs. HL GRBs
Clues to different central engines?





PNS M=2.5 $M_\odot$;R=13 km; 7.5x10^{52}erg
Haensel et al. 2009
$E_{p,i}$ (keV)
10^4
1000
100
10
1
10^{46}
10^{48}
10^{50}
10^{52}
10^{54}
E_K
E_R
$E_{\rm iso}$ (erg)



10^4
1000
100
10
1
$E_{p,i}$ (keV)
10^{46}
10^{48}
10^{50}
10^{52}
10^{54}
E_{iso} (erg)
E_K
E_R

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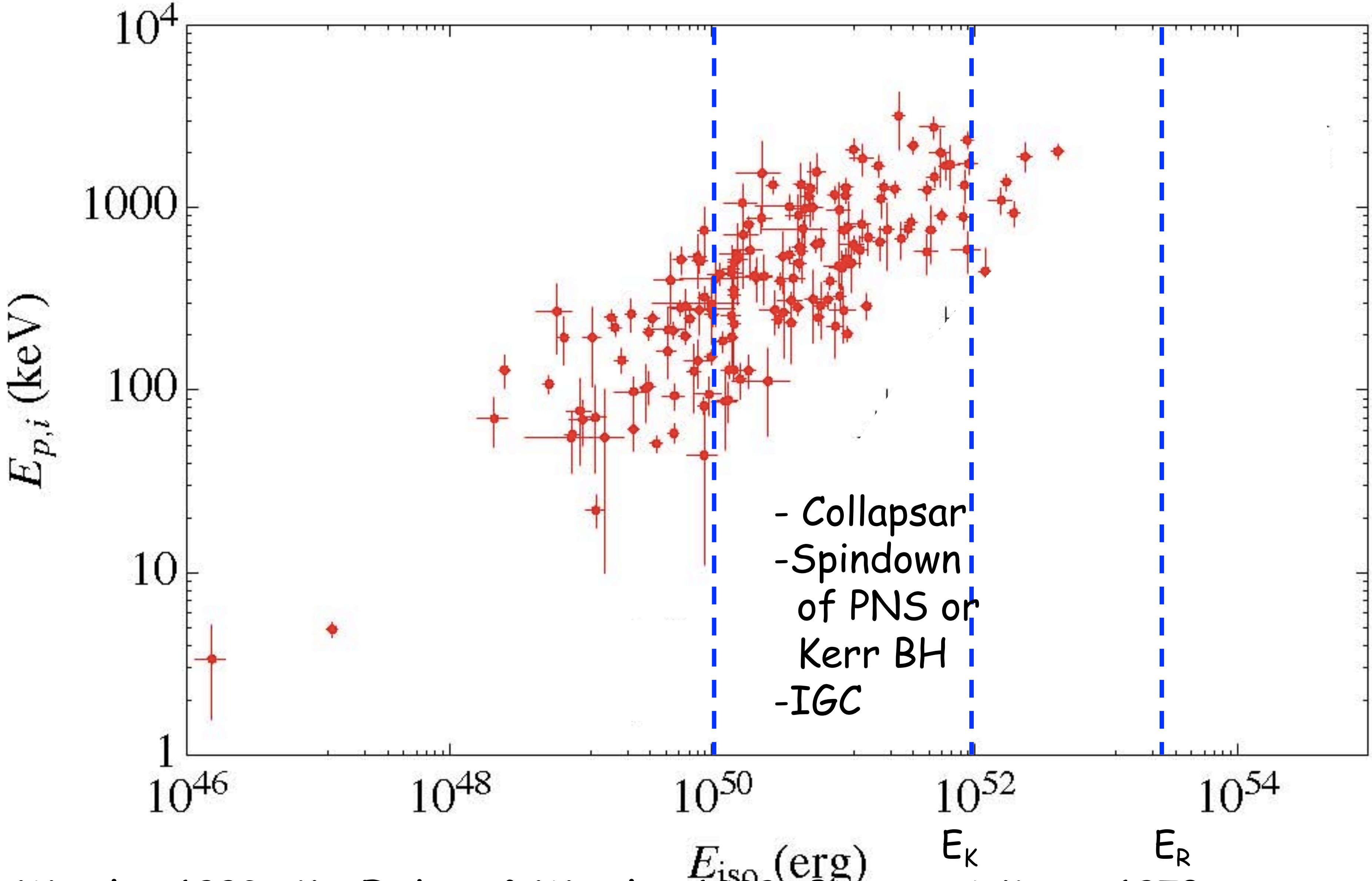
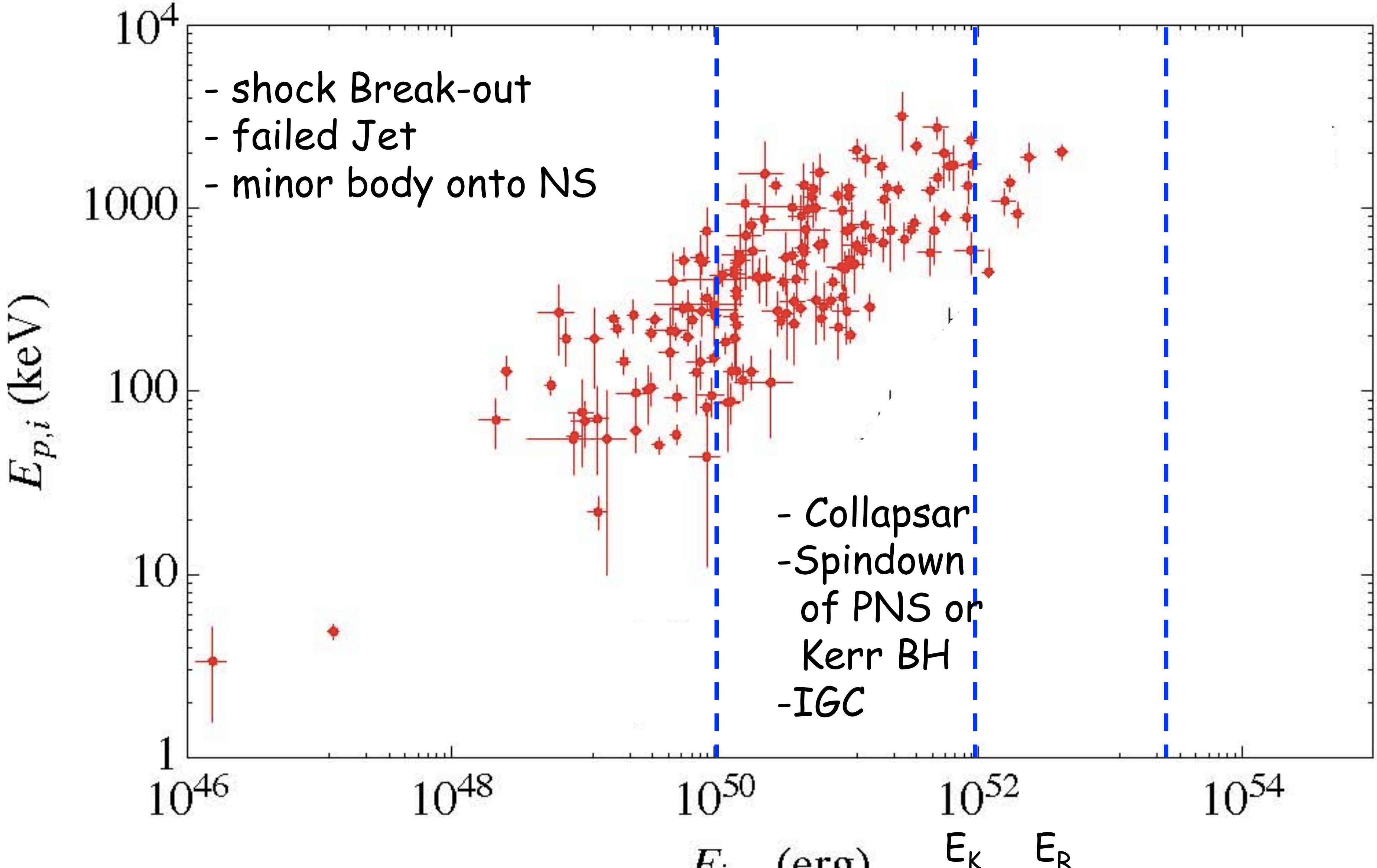


Woosley 1993, MacFadyen & Woosley 1999; Bisnovatyi-Kogan 1970, van Putten et al.2011; Lipunov & Gorbovskoy 2007; Fryer, Ruffini & Rueda 2014



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

Conclusions

Conclusions

All long duration GRBs are connected with HNe, but "viceversa" is not true. HL-GRBs / HNe <20%, LL-GRBs/HNe < 40%.

Progenitors of GRB-SNe are W-R stars (likely in binary systems).

GRBs are very rare phenomena

GRB/SNe-Ibc < 1.5% or << 1.5%

Conclusions cont'd

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_θ < ~ 10^{50} erg) such as SN *shock break-out* (2006aj/060218) or *GRB/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}~ 10^{52-54} erg (E_{θ} < ~ 10^{52} erg, after correction for beaming) are more energetic events (SN 2013/GRB 130427A) that have been explained with different models. They can be powered by the rotational energy of new-born NSs or by even more extreme scenarios, which involves BHs formation.