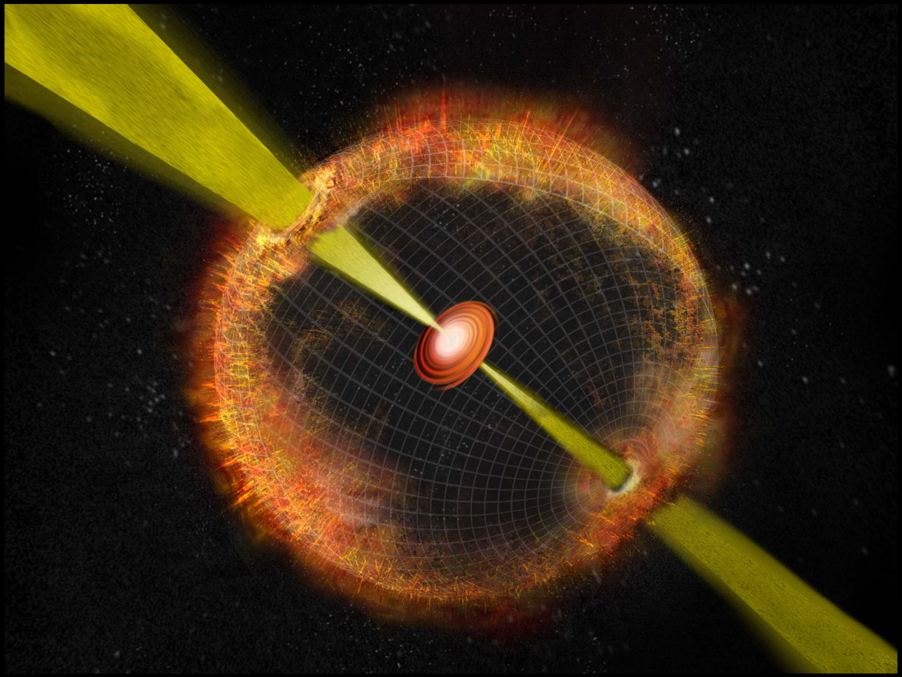
The empirical grounds of SN- GRB connection



M. Della Valle

Capodimonte Observatory INAF-Napoli

SciNeGHE 2016 –October 2016

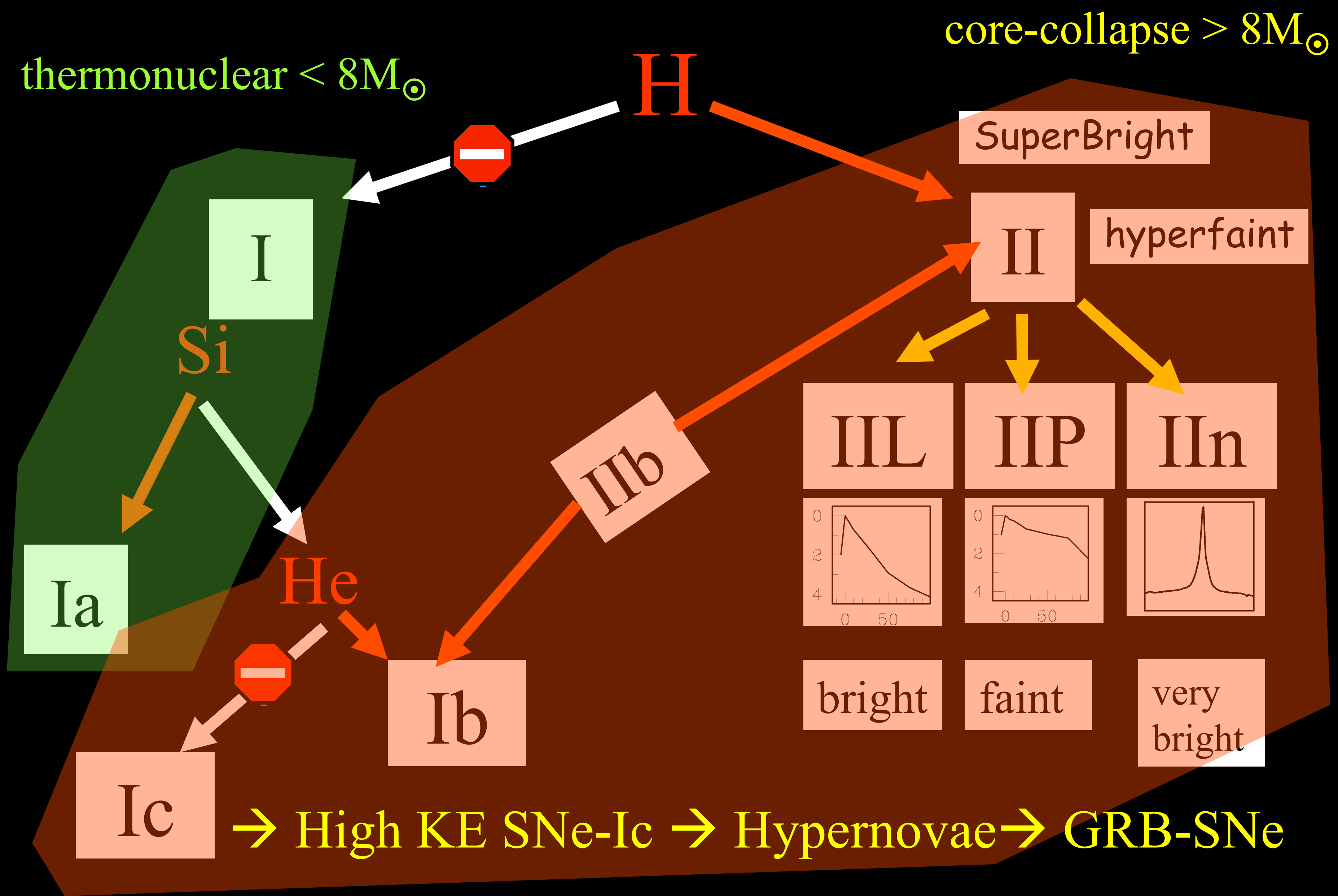
Summary

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

Summary

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

Supernova taxonomy



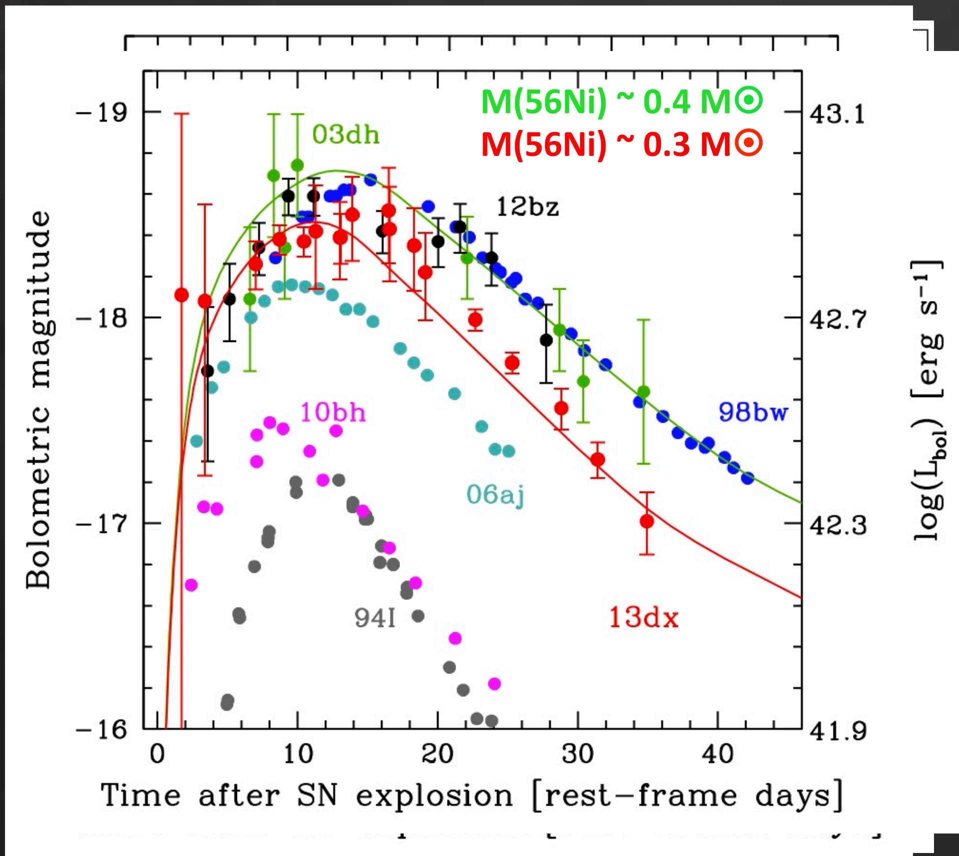
Summary

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

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

Very br
expans

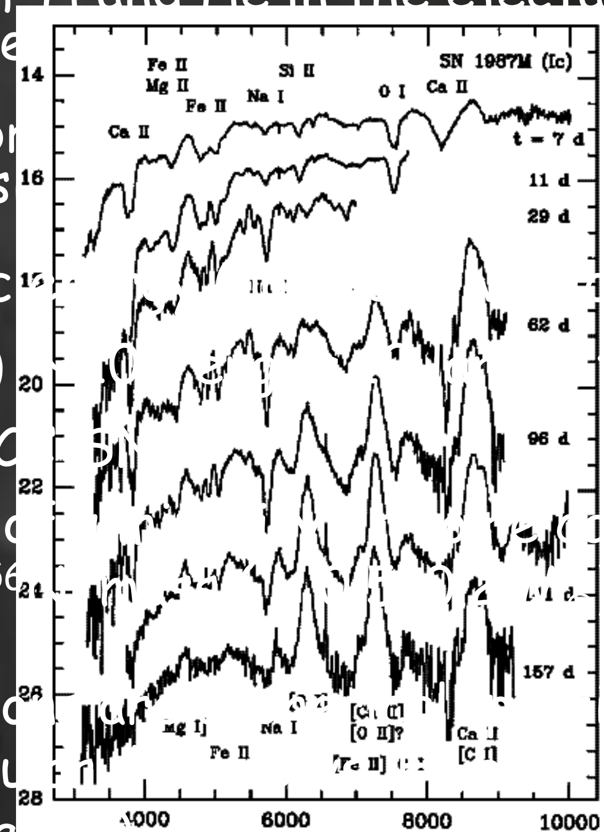
Kinetic

ejecta) than

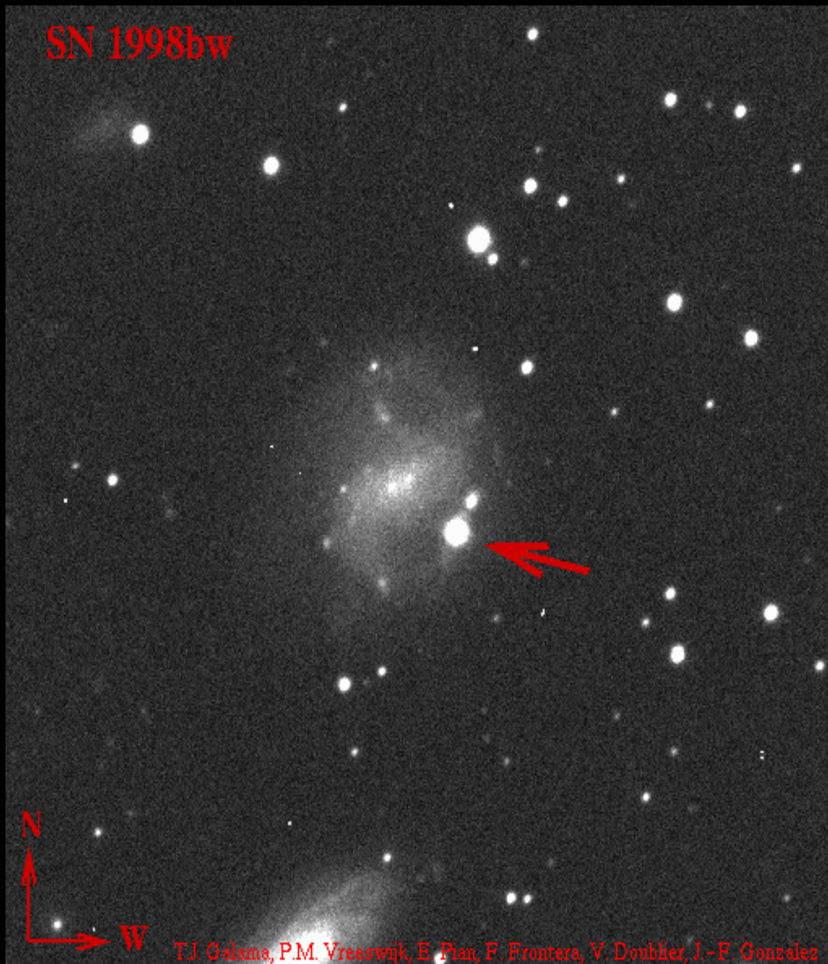
Usual C SN

Range se
large 56

Explosi les
of nebu
Polarization)



SN 1998bw



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

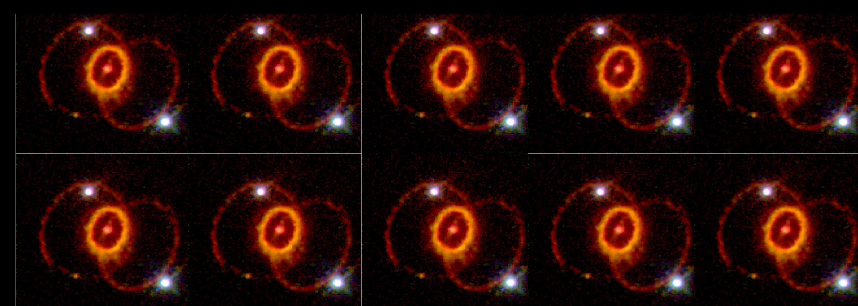
=

SN 1987A

Aspherical explosion

Maeda et al. 2006, 2008

see also Tautenberger et al. 2009

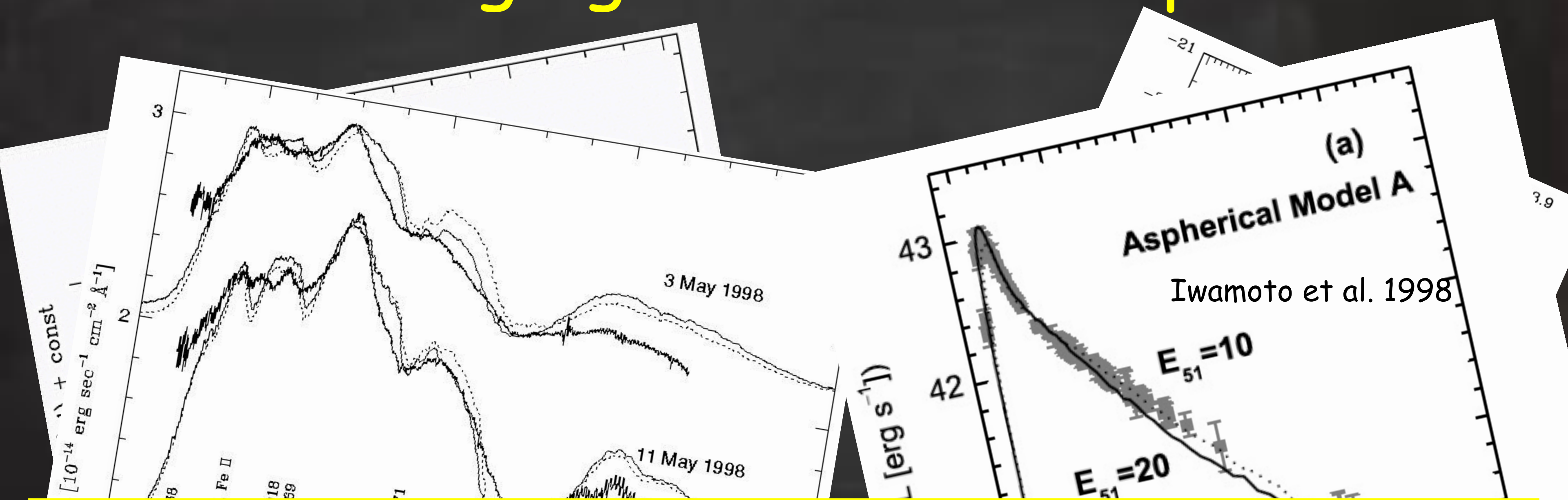


$E_K \sim 1 \times 10^{51}$ erg

Summary

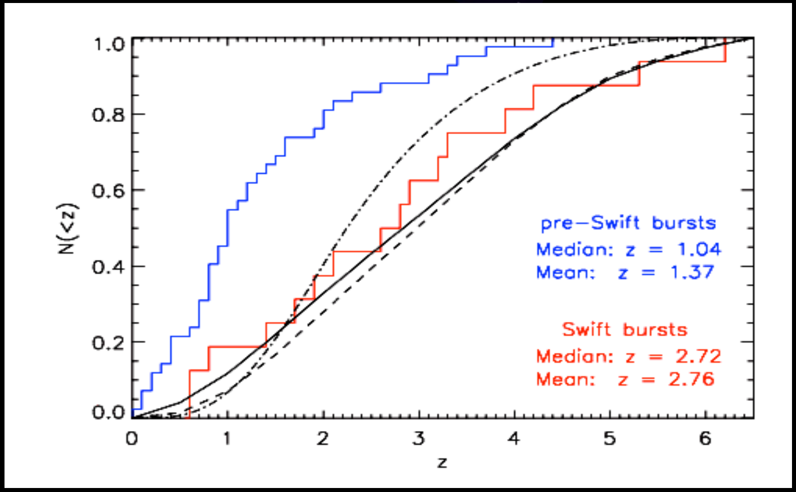
1. Supernova Taxonomy
2. GRB-SN properties
3. Progenitors Mass
4. GRB and SN rates
5. Open Issues

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

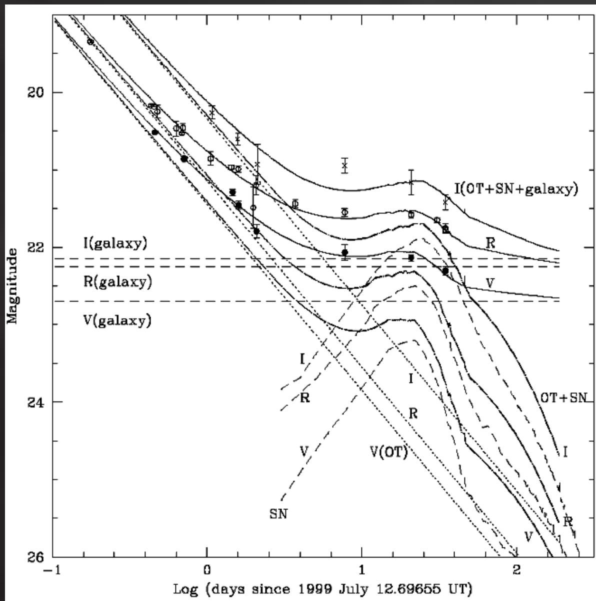
Distant GRB/SNe ?



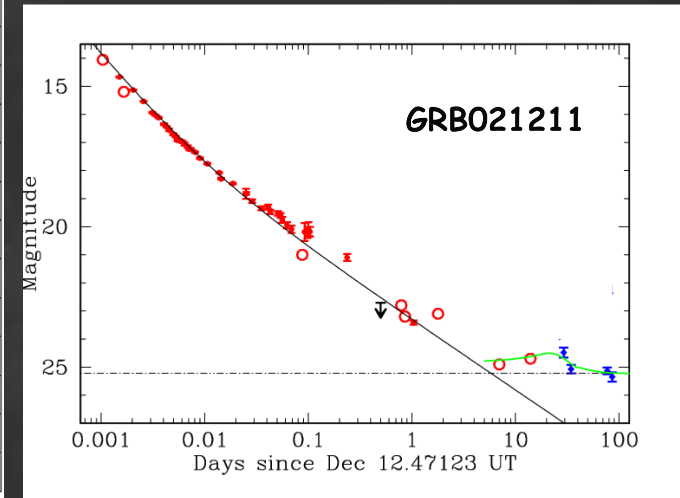
GRB census > 0.2

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

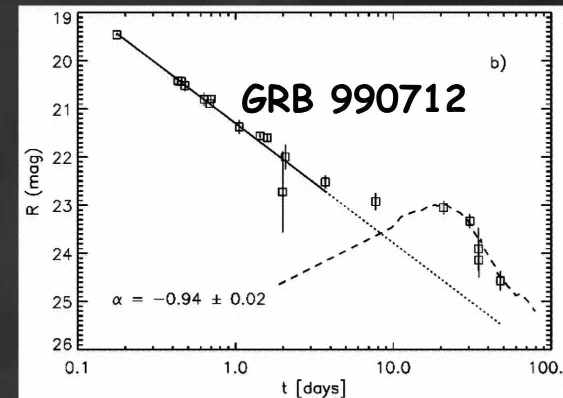
up to z ~ 1



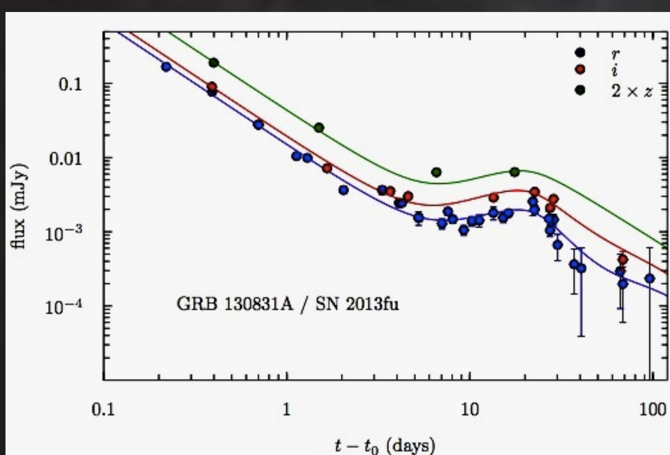
Sahu et al. 2000



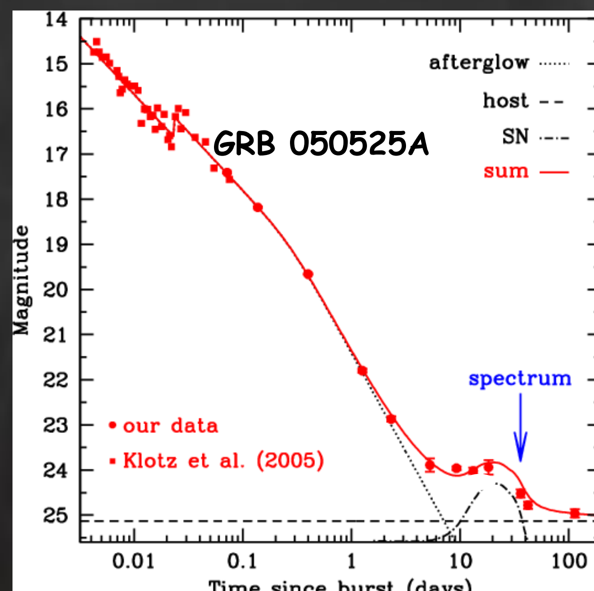
Della Valle et al. 2003



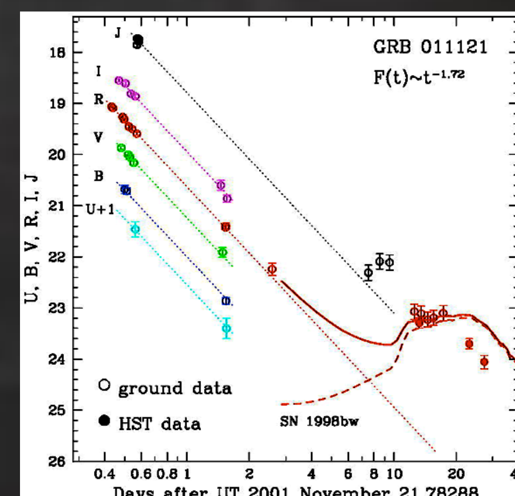
Bjornsson et al. 2001



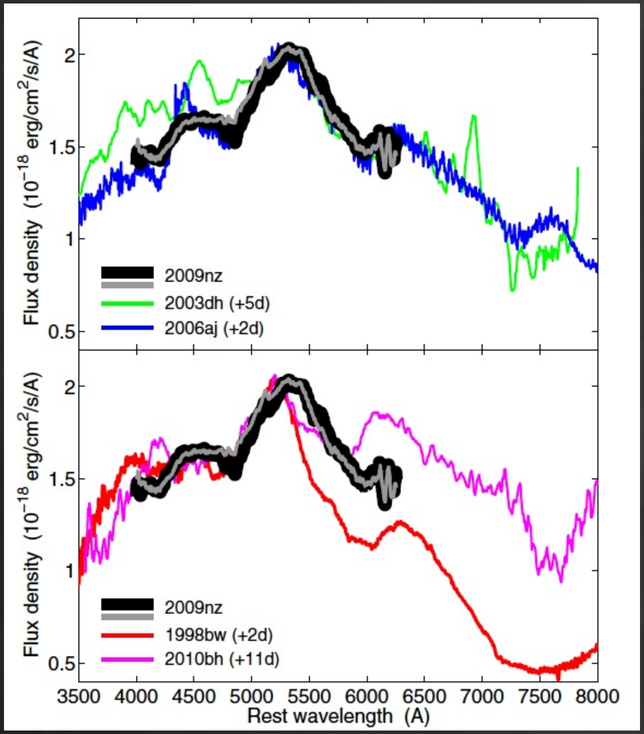
Cano et al. 2014

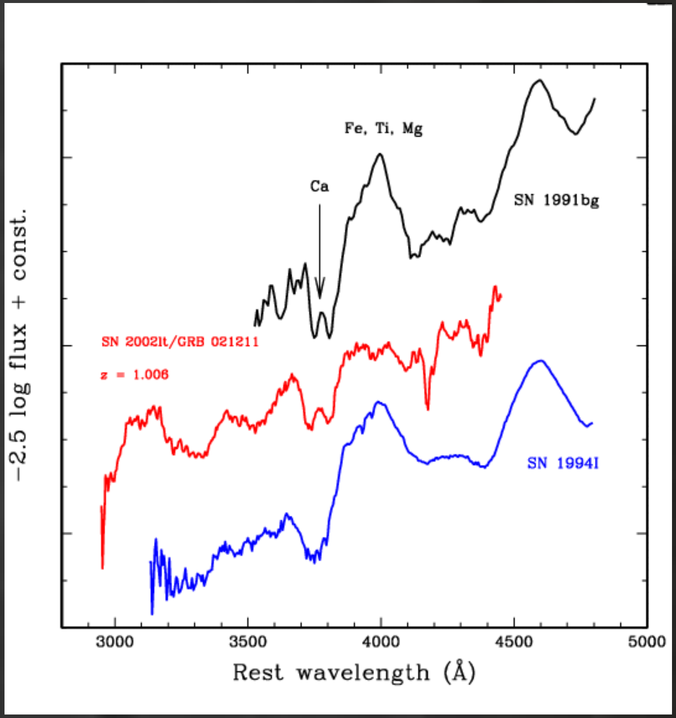


Della Valle et al. 2006



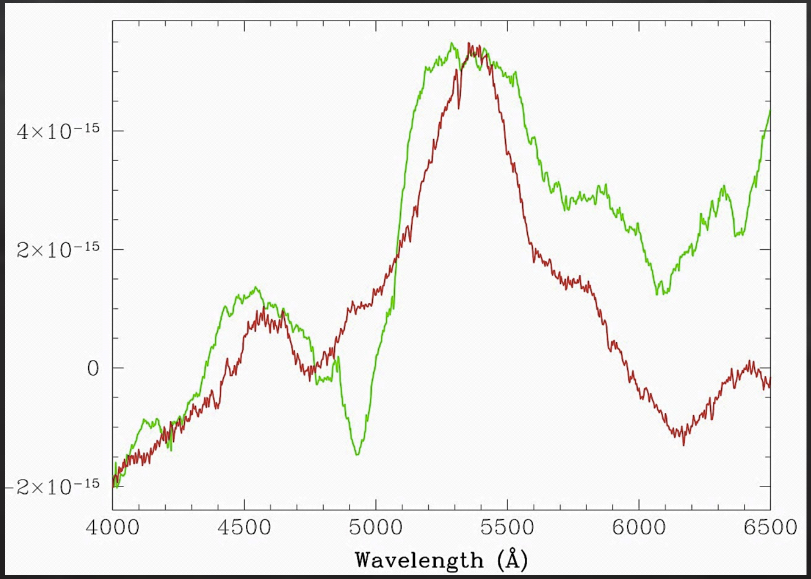
Garnavich et al. 2003



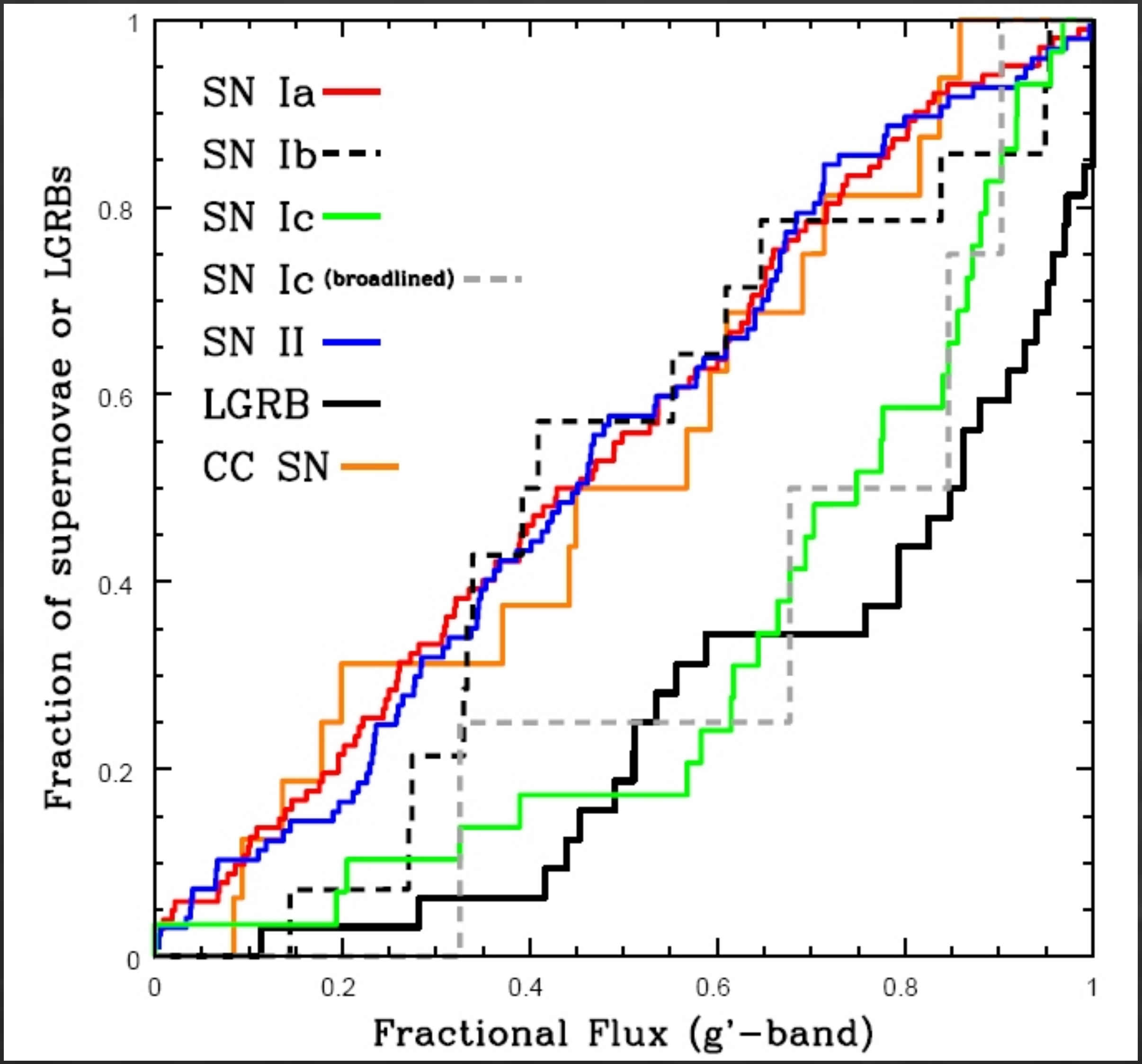


Della Valle et al. 2003
SN 2002lt @ z=1

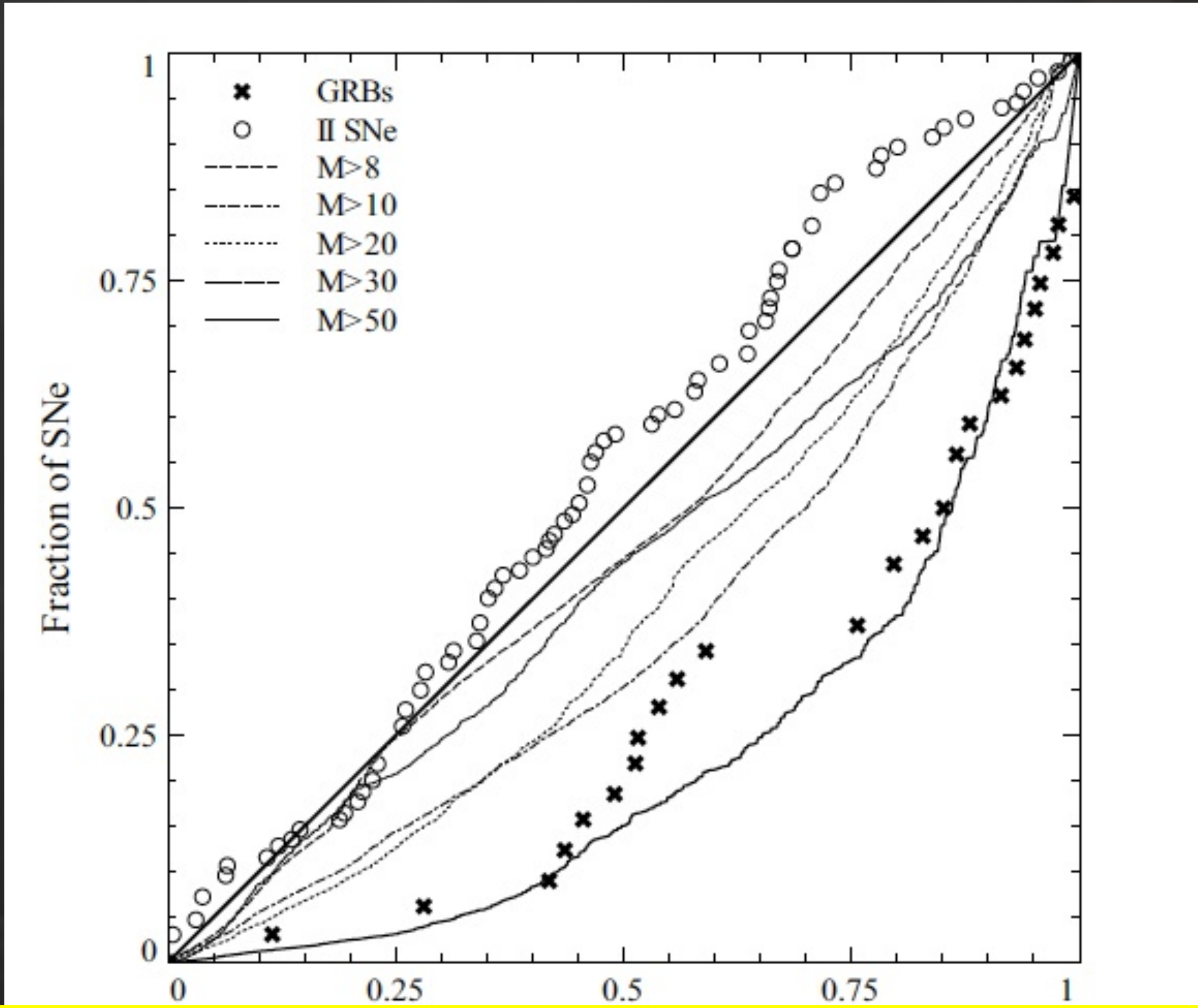
Berger et al. 2011
SN 2009nz @ z=0.49



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

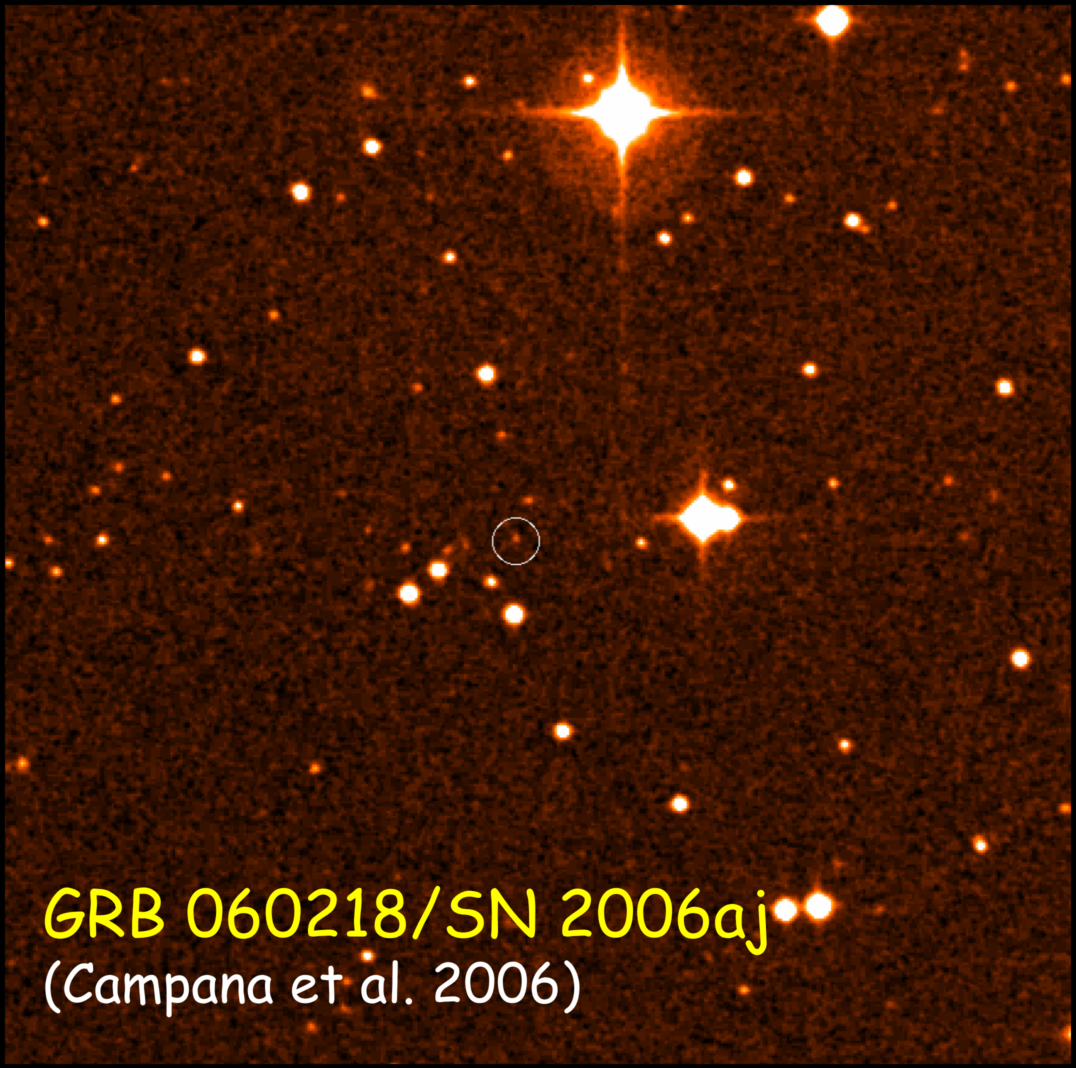


Kelly et al. 2008 find that SNe-Ic and LGRB erupt in the brightest regions of their hosts (see also Fruchter et al. 2006)



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 $M_\odot$

What Stars are GRB Progenitors ?



$z = 0.033$

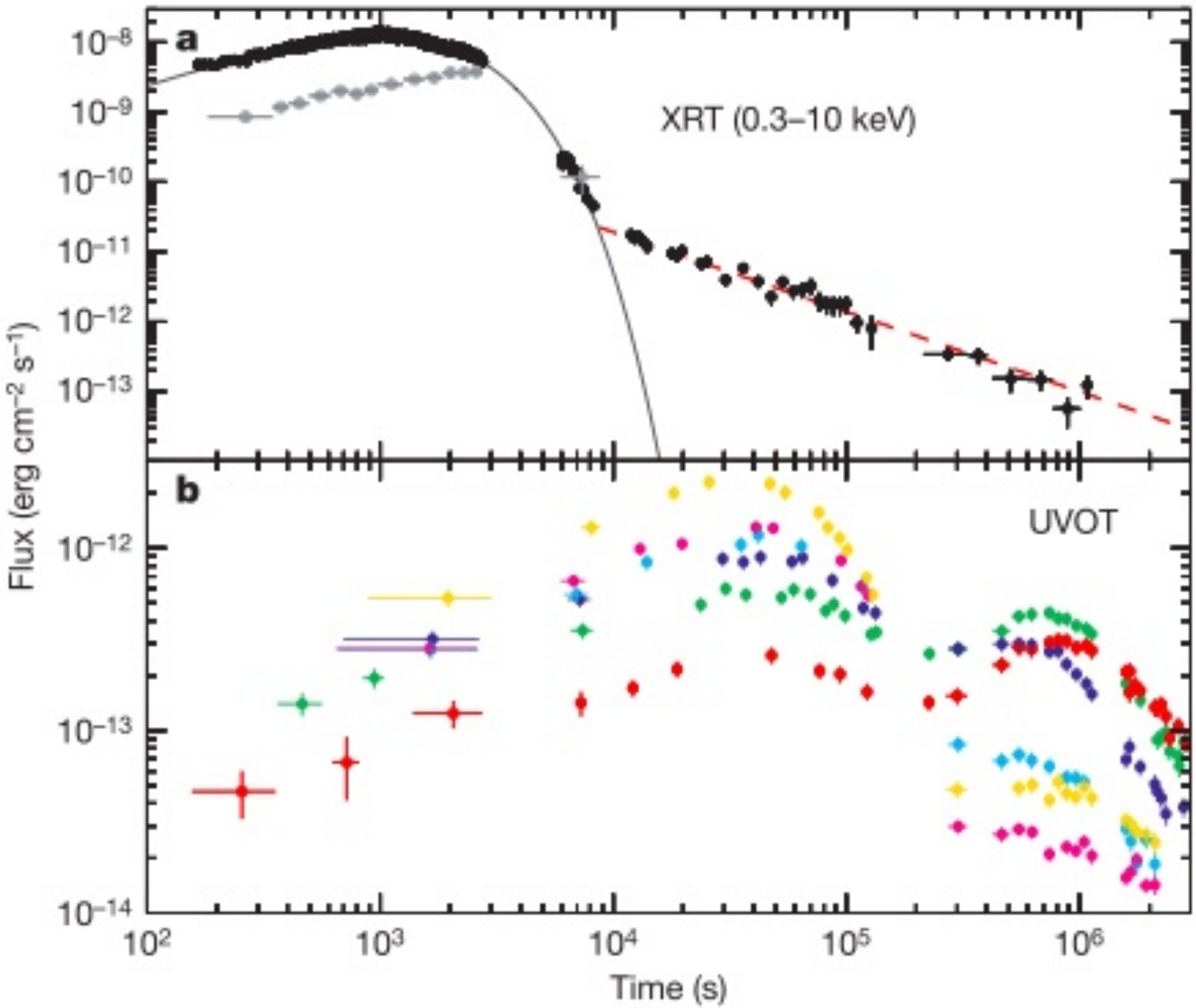
faint: $E_\gamma \sim 10^{49}$ **erg**

M_V (host) = -16

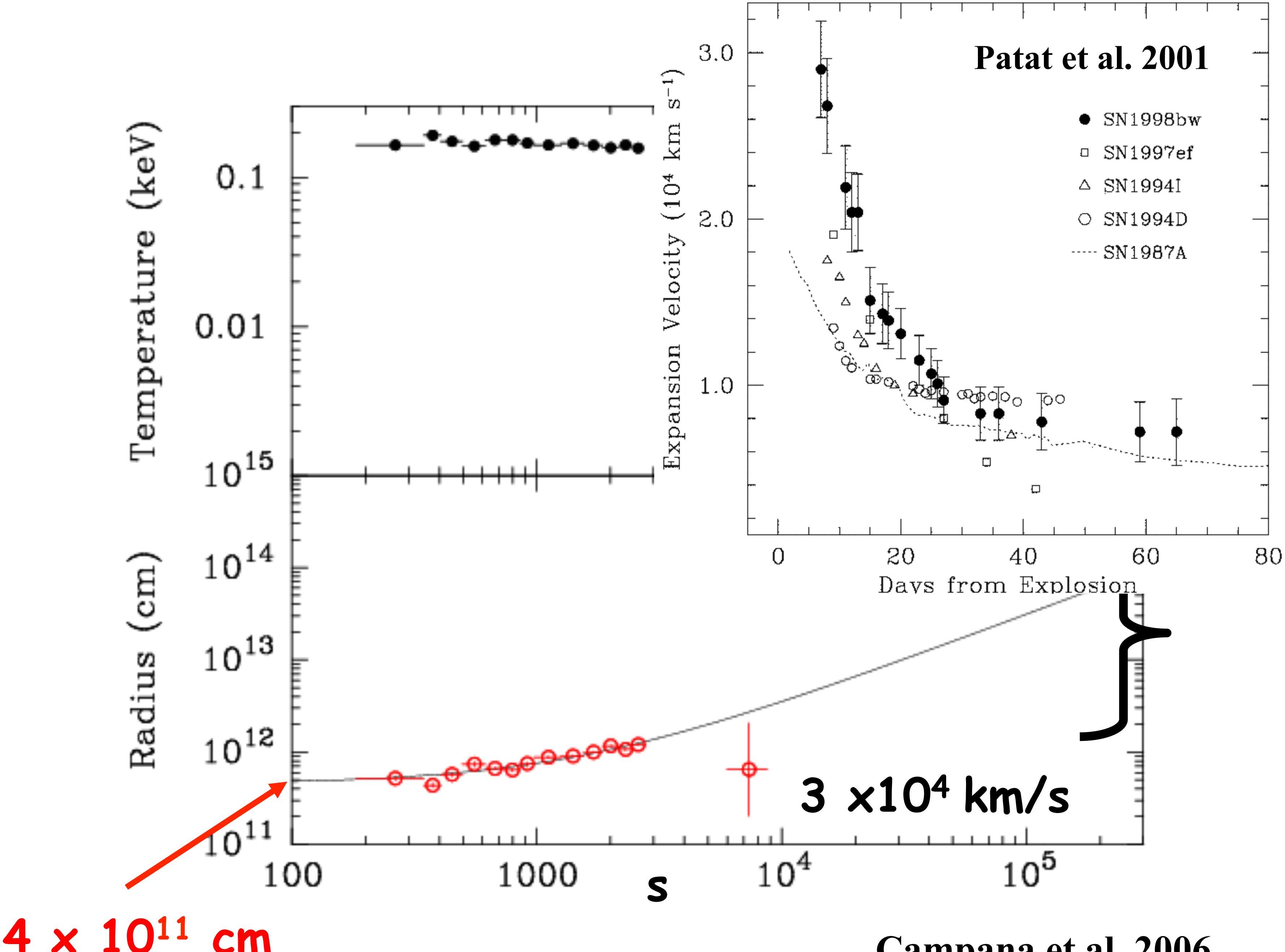
Host has brightness
Similar to SMC

$Z/Z_\odot \sim 0.3$

2006aj = SN-Ic

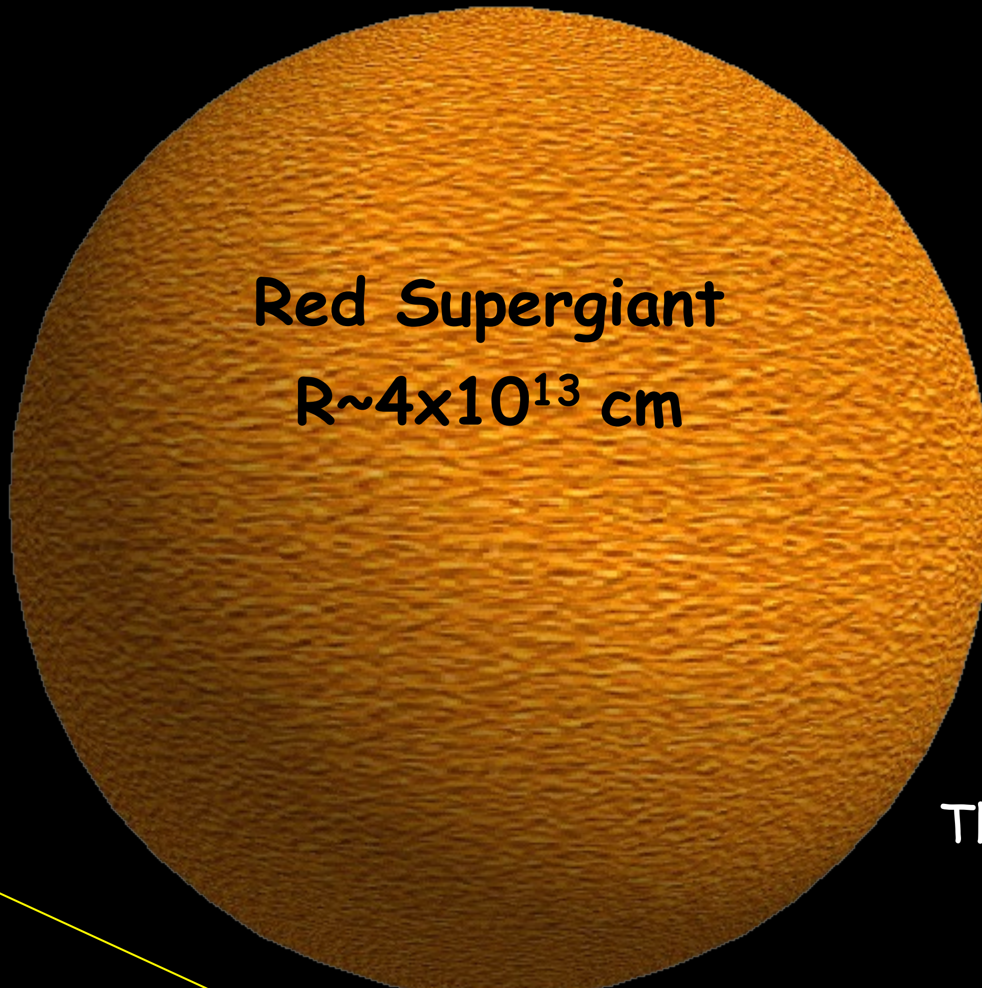


Campana et al. 2006



Campana et al. 2006

SNe-CC size progenitors



Blue Supergiant

R~4x10^{12} cm

The radius of the progenitor

W-R Star

R~4x10^{11} cm

Summary

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

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})	$0.301^{+0.038}_{-0.037}(^{+0.049}_{-0.049})$	$0.258^{+0.044}_{-0.042}(^{+0.058}_{-0.058})$	$0.447^{+0.068}_{-0.068}(^{+0.131}_{-0.111})$

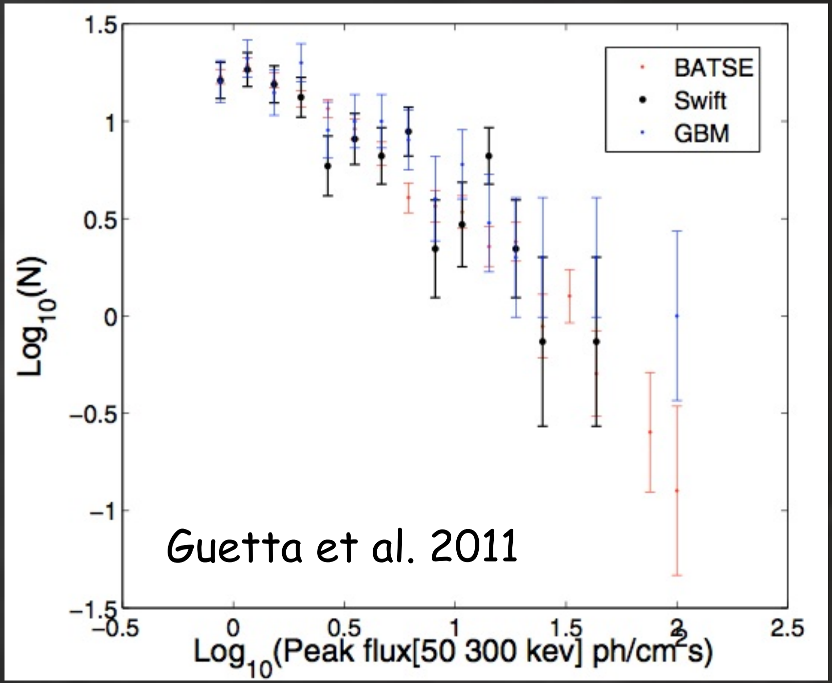
Rate for Ib/c: 2.6×10^4 SNe-Ibc Gpc^{-3} yr^{-1}

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

What is the rate of (long) GRBs ?

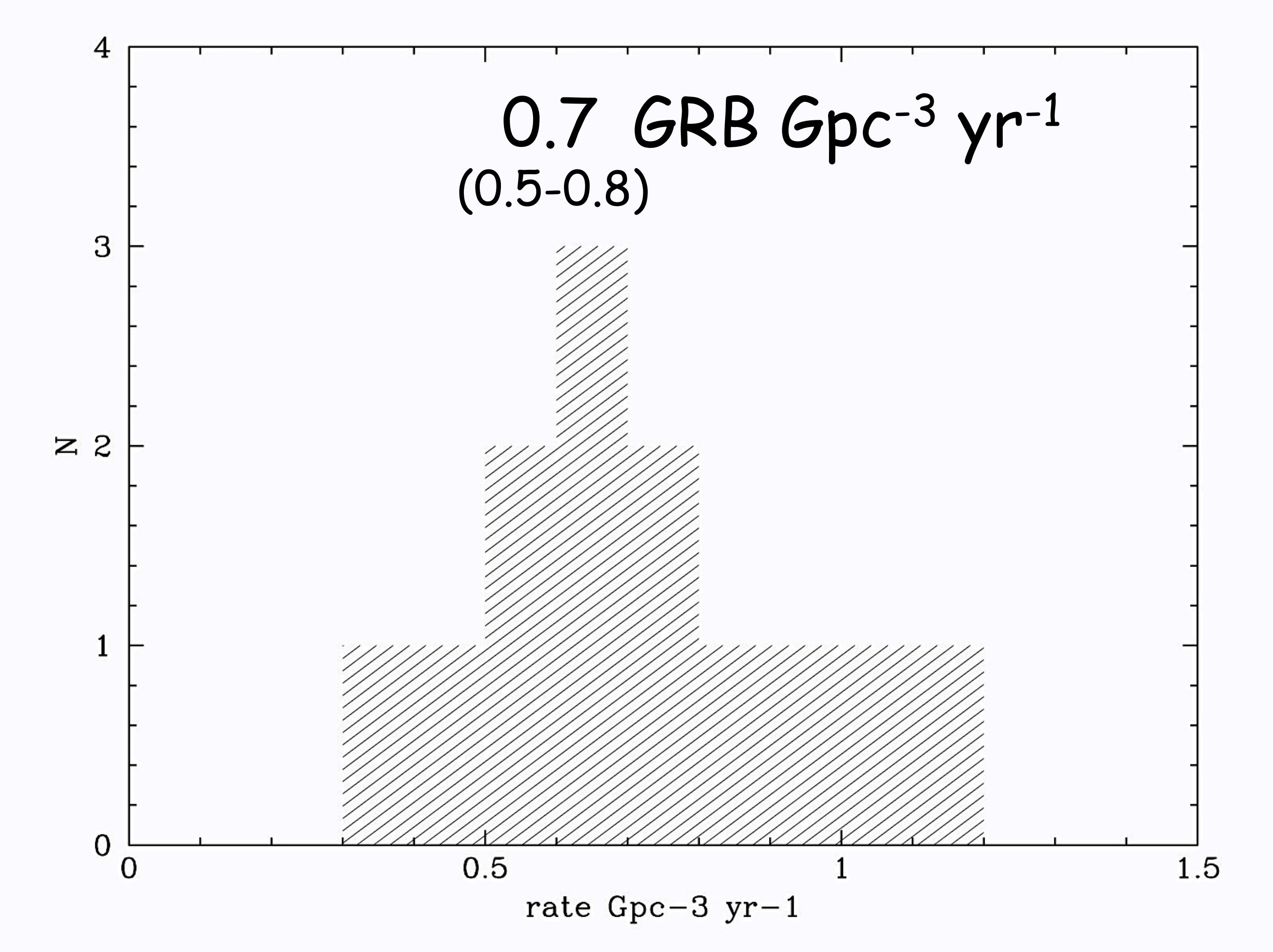
GRB Gpc^{-3} yr^{-1}

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

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

$\langle f_b^{-1} \rangle \sim 500$	(Frail et al. 2001; Ghirlanda et al. 2013)	($\vartheta \sim 4°$)
$\langle f_b^{-1} \rangle \sim 75$	(Guetta, Piran & Waxman 2004)	($\vartheta \sim 9°$)
$\langle f_b^{-1} \rangle < 10$	(Guetta & DellaValle 2007)	($\vartheta > 25°$) for sub-lum GRBs
$\langle f_b^{-1} \rangle \sim 1$	(Ruffini et al. 2006)	(up to $\vartheta \sim 4\,\pi$)

GRB/SNe-Ibc: 1.5%-0.003%

GRBs are very rare phenomena

GRB/SNe-Ibc: 1.5%
Ibc/CC ~ 0.30
GRB/CC-SN ~ 5×10^{-3}

$$\frac{N(30M_{\odot}-120M_{\odot})}{N(8M_{\odot}-30M_{\odot})} \sim 0.15 \text{ (Salpeter IMF)}$$

What causes some small fraction of CC-SNe to produce observable GRBs, while the majority do not?

Special conditions are requested to stars to be GRB progenitors:

i) to be massive ~ > 30$M_\odot$ (Maeda et al. 2006; Raskin et al. 2008; Tanaka et al. 2008)

ii) H/He envelopes to be lost before the collapse of the core, i.e. the GRB progenitor is a WR star (Campana et al. 2006)

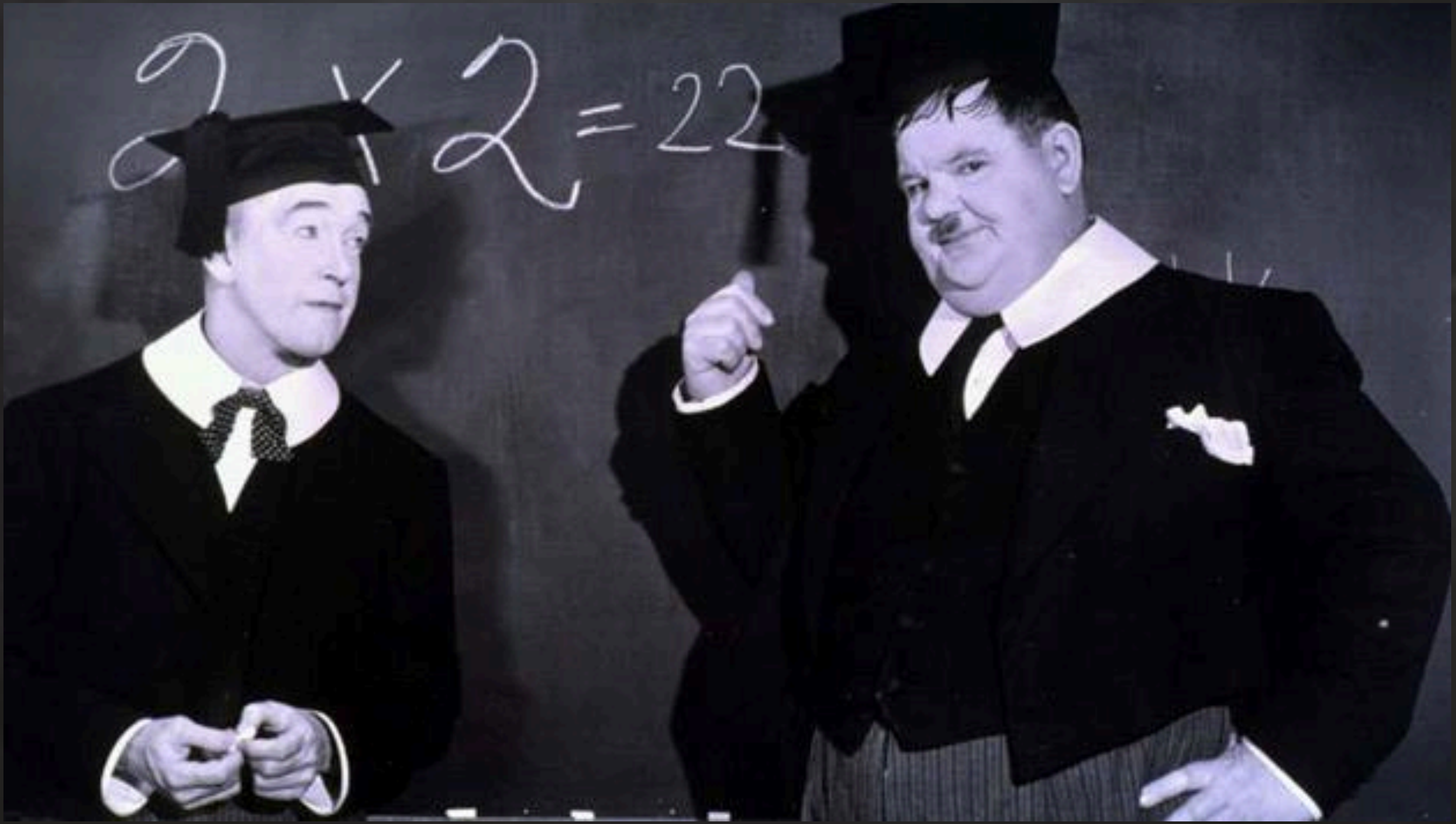
iii) low metallicity and star forming environments (Modjaz et al. 2008, Fruchter et al. 2006, Levesque et al. 2012)

iv) binarity (Panagia 1988 and Smartt et al. 2008 → a significant fraction of SNe-Ibc progenitors are binaries)

v) high rotation (Yoon et Langer 2005; Campana et al. 2008, Yoon et al. 2012)

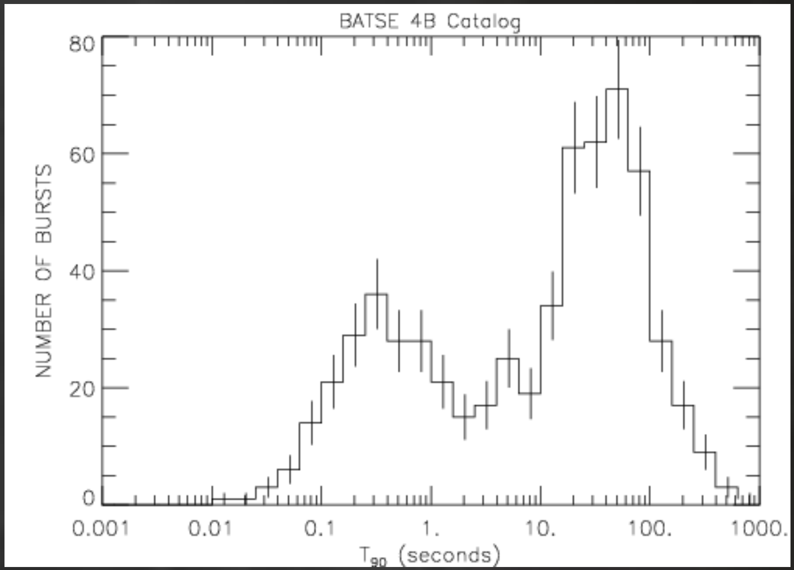
vi) asimmetryc explosion (Taubenberger et al. 2009; Maeda et al. 2008)

Open Issues



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

Energy Crisis



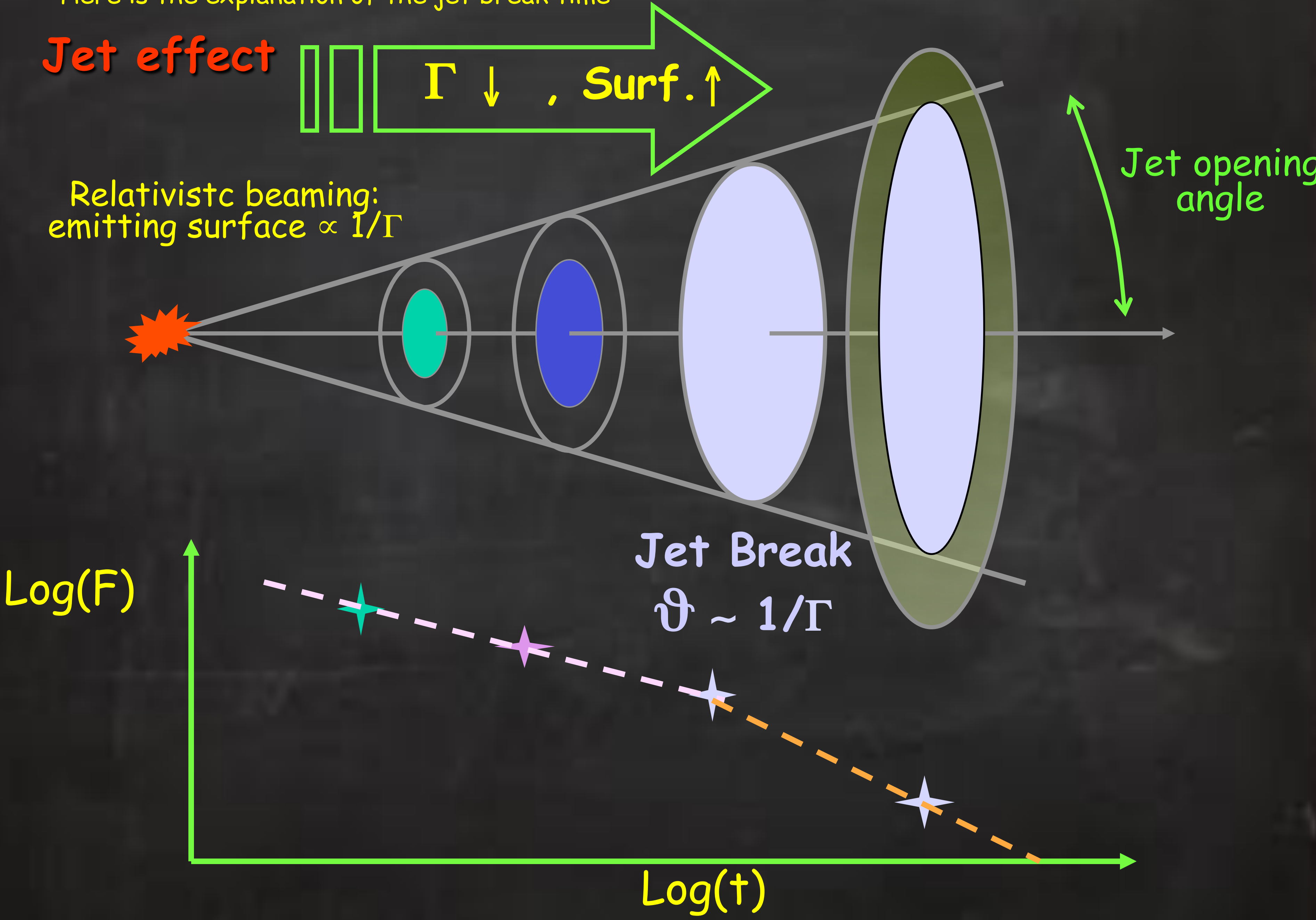
Fluence : $10^{-7} \div 10^{-5}$ erg cm^{-2}

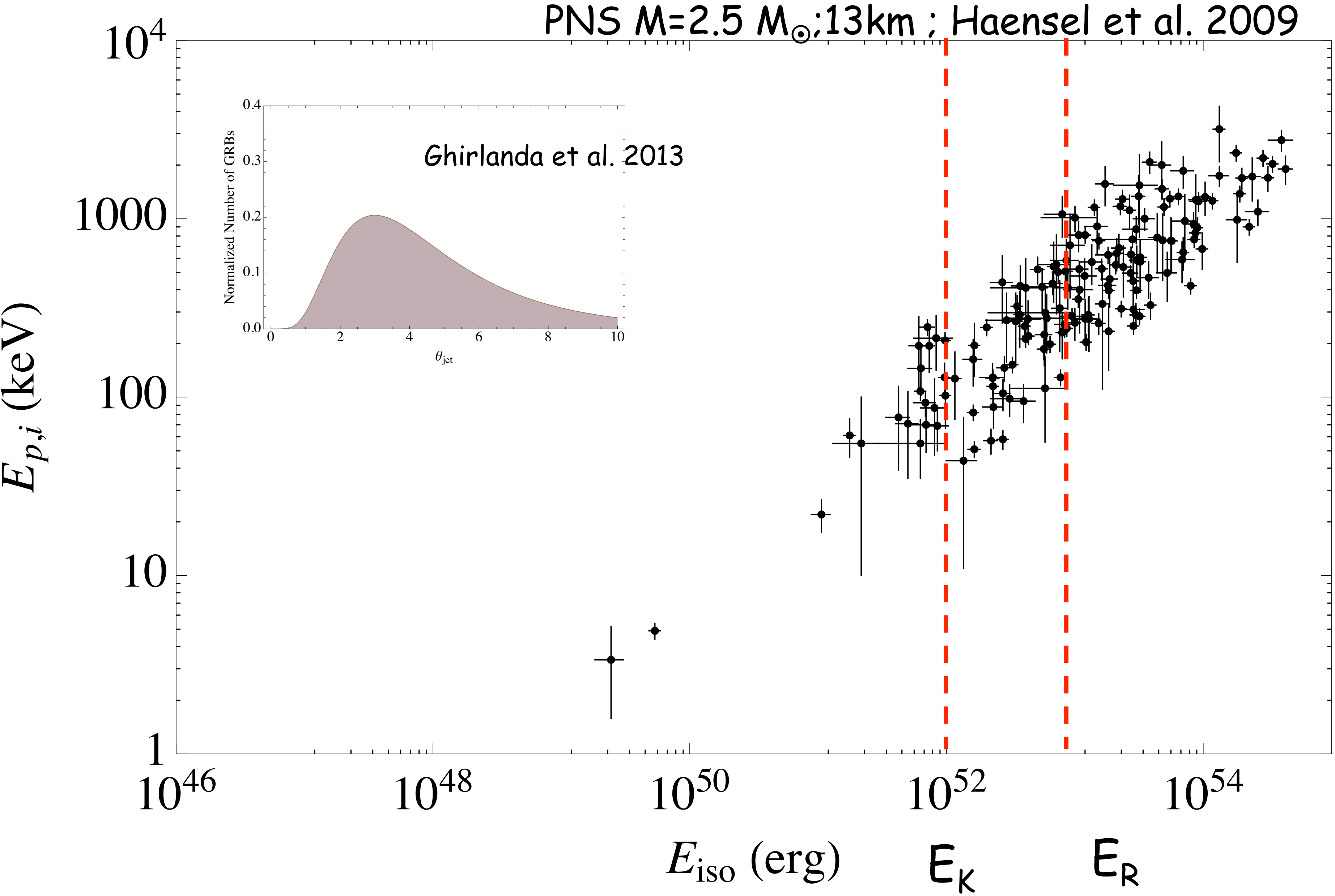
Distanza: up to $z \sim 10$

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

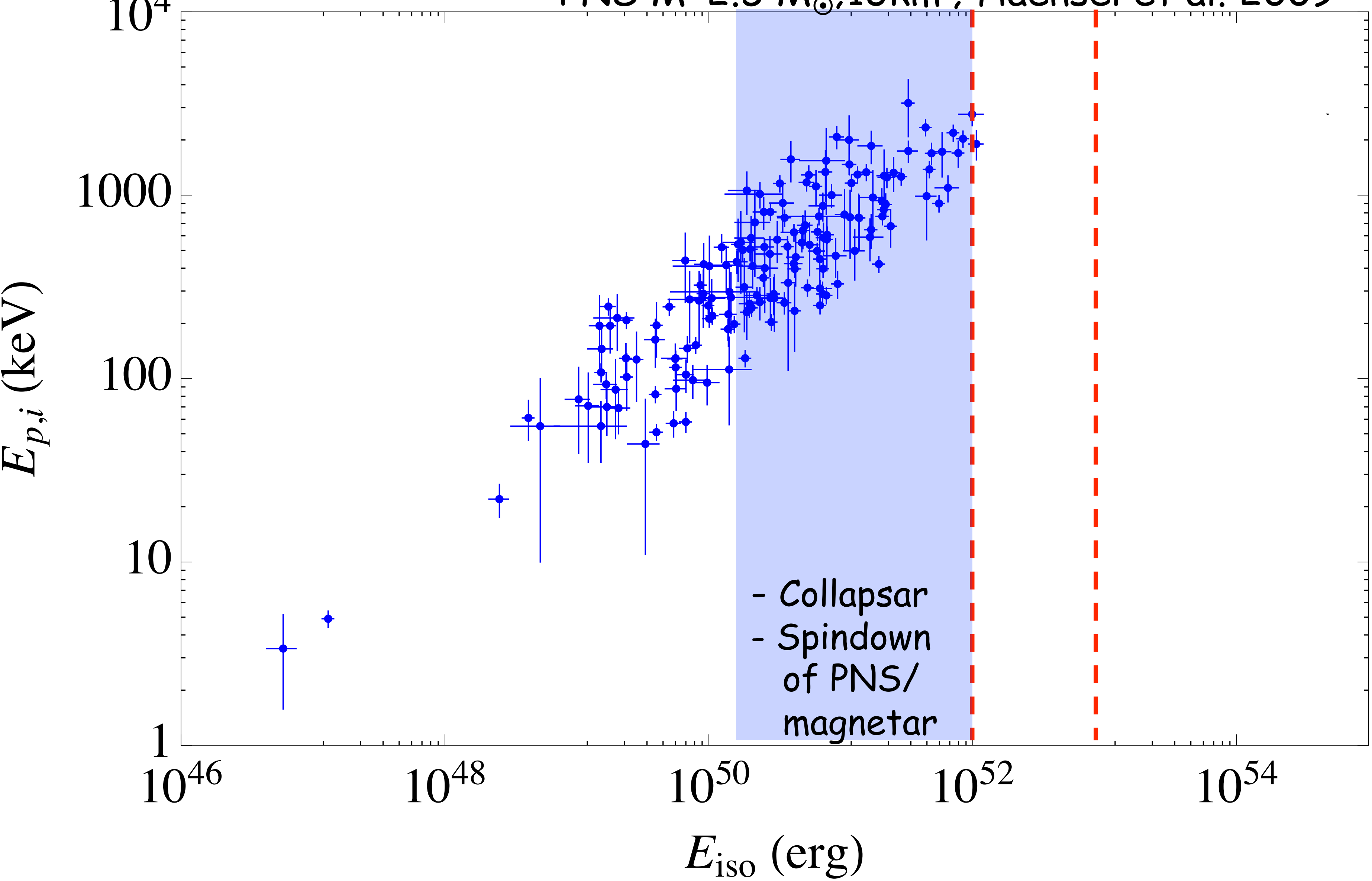
10^{54} erg ~ 1 $M_{\odot}$ ~ x 5

But similarly to other astrophysical sources also GRBs are expected to be jetted sources. If this is the case we should expect a clear signature in their light curve time decay due to the presence of a jet.... Here is the explanation of the jet break time

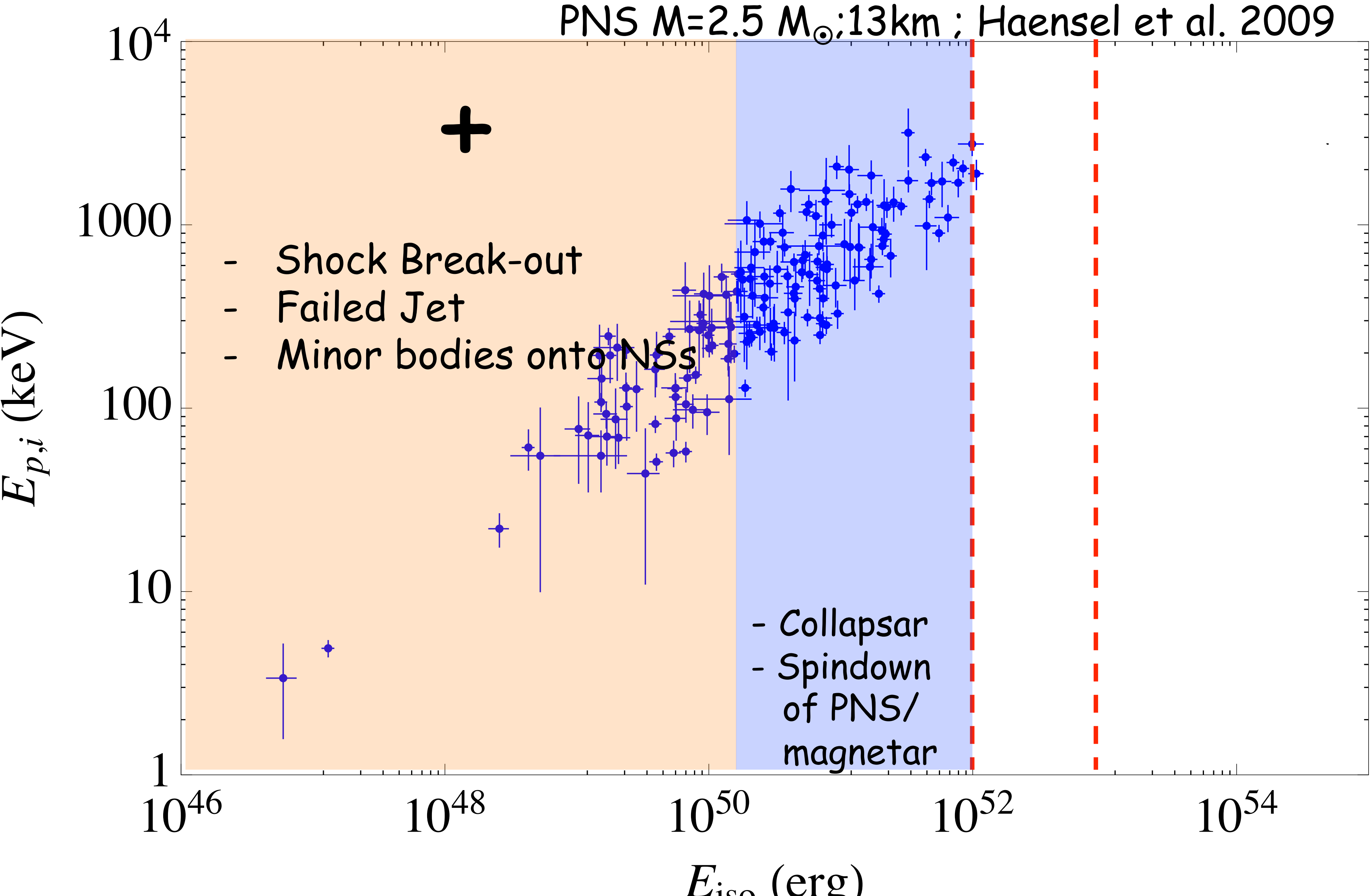



PNS M=2.5 $M_\odot$;13km ; Haensel et al. 2009
Ghirlanda et al. 2013
Normalized Number of GRBs
θ_{jet}
$E_{p,i}$ (keV)
E_{iso} (erg)
E_K
E_R
10^4
1000
100
10
1
10^{46}
10^{48}
10^{50}
10^{52}
10^{54}

PNS $M=2.5\ M_\odot$;13km ; Haensel et al. 2009



van Putten et al. 2011; Lazzati et al. 2012, Fan et al. 2013; MacFadyen & Woosley 1999; Woosley 1993, Fryer, Ruffini & Rueda 2014



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

e.g. Smartt 2009

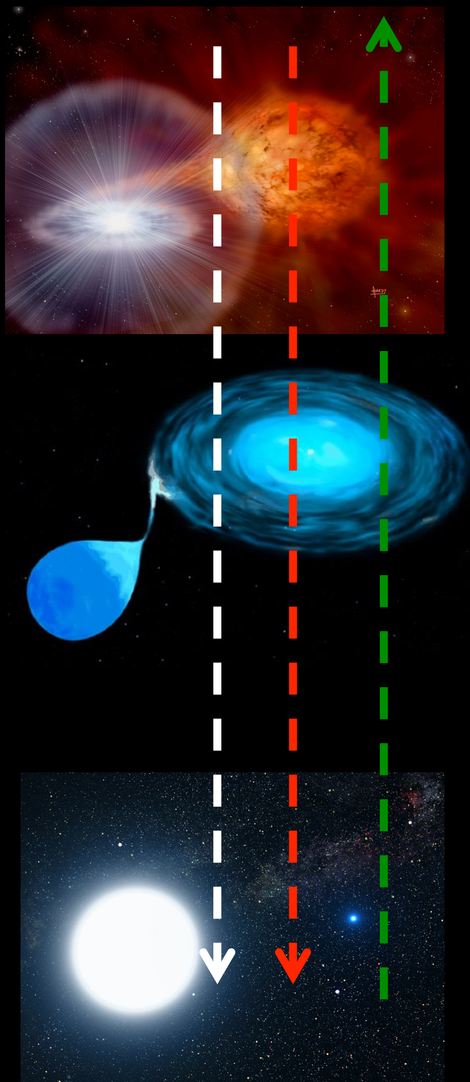
Induced Gravi

(aka binary drive

NS

Izzo et al. 2012
Penacchioni et al. 2013
Fryer et al. 2014, 2015
Ruffini et al. 2014

Stellar Explosions Sequence



Nova system:
WD + (low mass) MS star

$M_{WD} \sim 1\ M_\odot$
10^{44} erg

Rate x 10^3

Supernova Ia system:
WD + (subgiant) MS star
or WD+WD

$M_{WD} \sim 1.4\ M_\odot$
10^{51} erg

Rate =1

HL-GRB system:
NS + SN

$M_{NS} \sim 2\ M_\odot$
$10^{53\div54}$ erg

Rate $< 10^{-2}$

GRBs are very rare phenomena

GRB/SNe-Ibc: 1.5%
Ibc/CC ~ 0.30
GRB/CC-SN ~ 5×10^{-3}

$$\frac{N(30M_\odot - 120M_\odot)}{N(8M_\odot - 30M_\odot)} \sim 0.15 \text{ (Salpeter IMF)}$$

What causes some small fraction of CC-SNe to produce observable GRBs, while the majority do not?