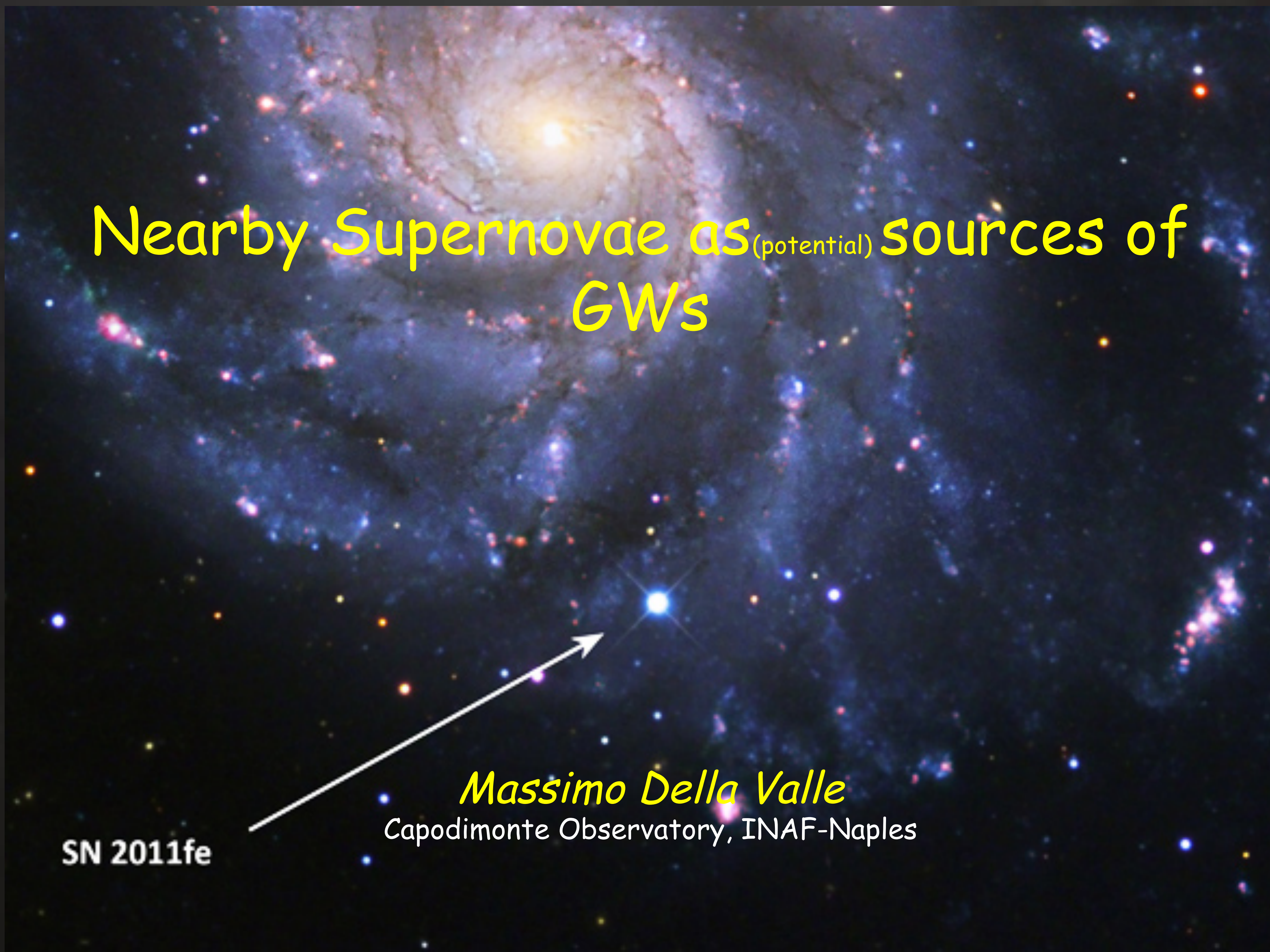
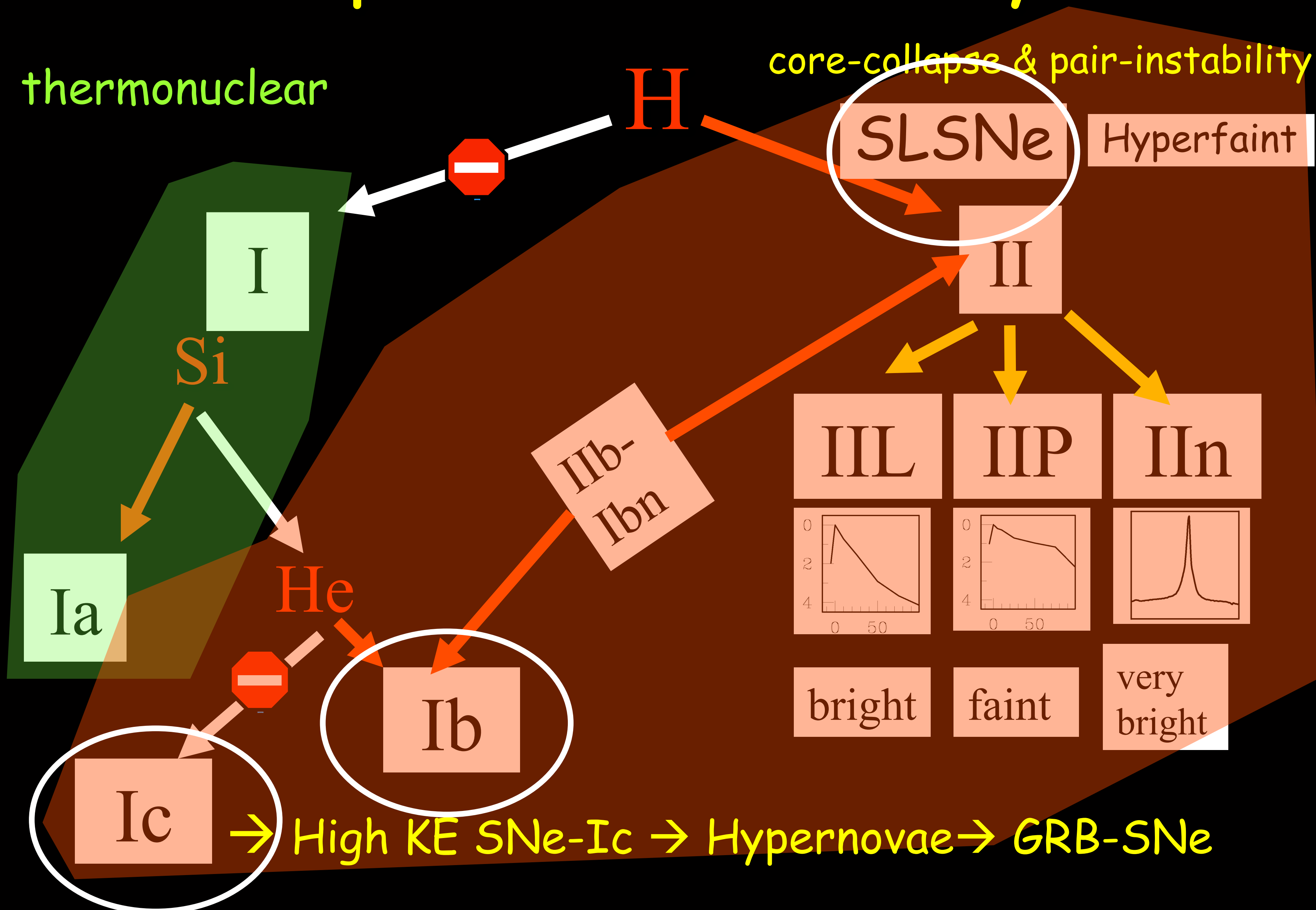
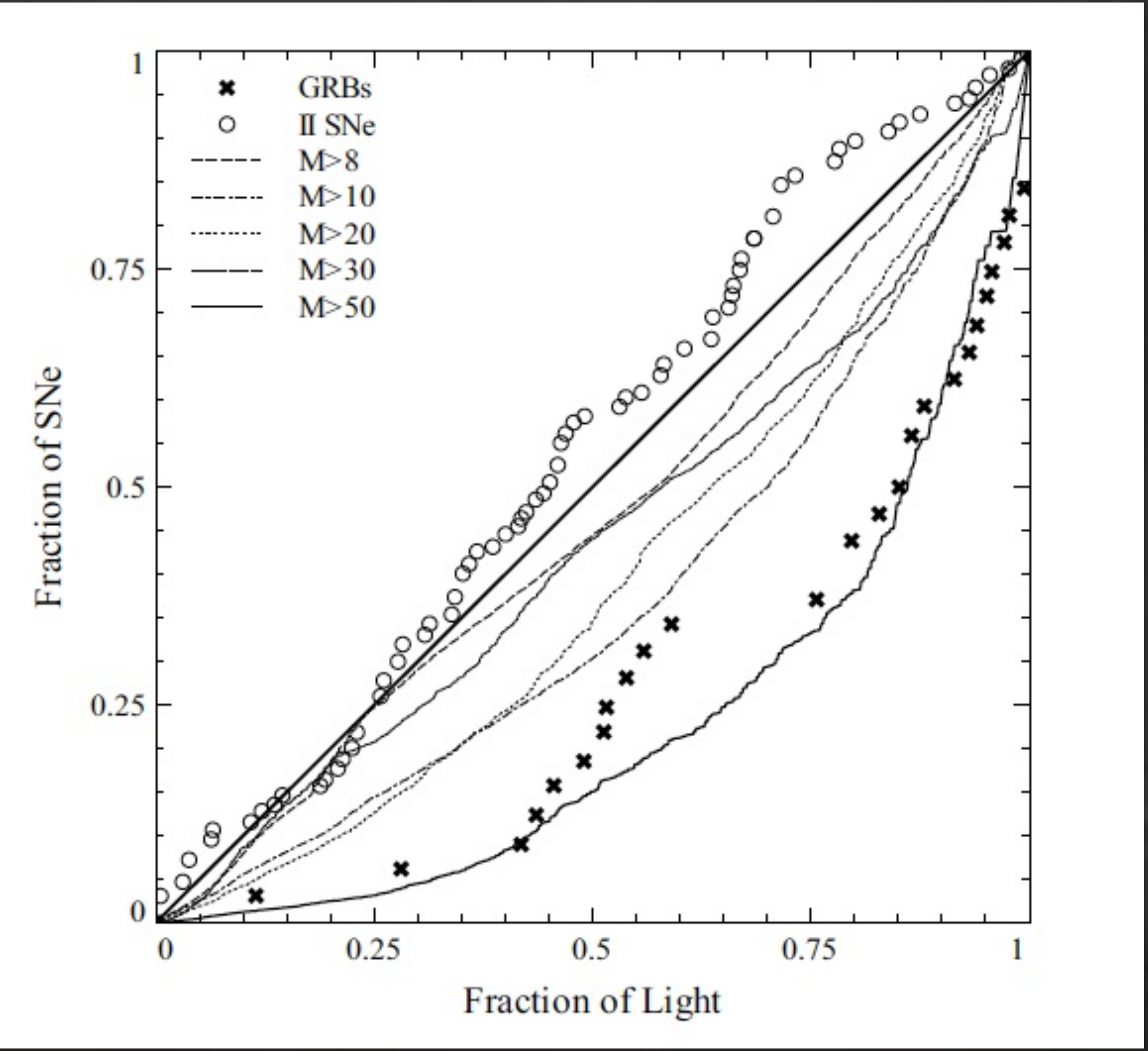
Nearby Supernovae as (potential) sources of GWs



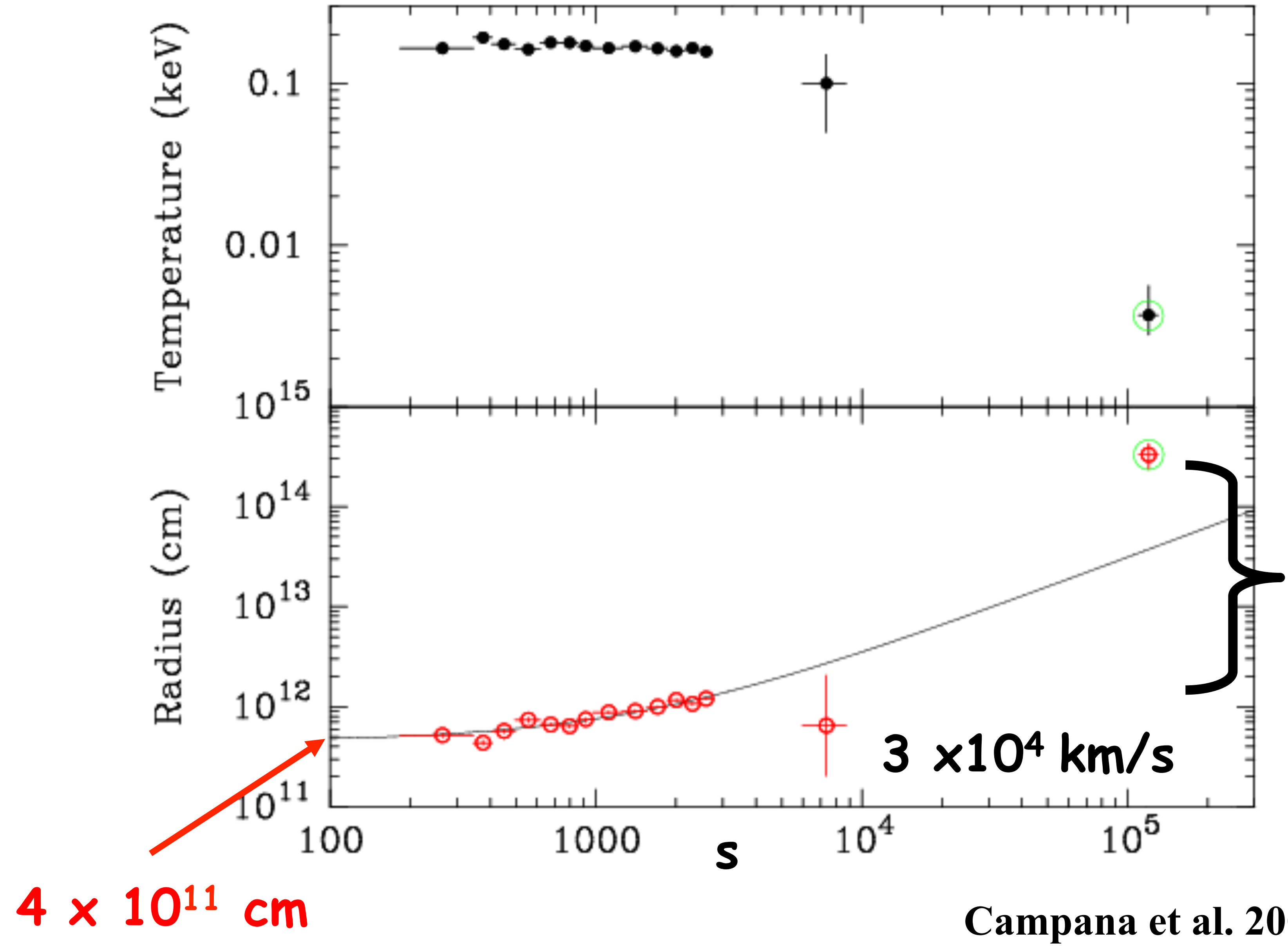
Massimo Della Valle
Capodimonte Observatory, INAF-Naples

Supernova taxonomy





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



Campana et al. 2006

SNe-CC size progenitors

Blue Supergiant

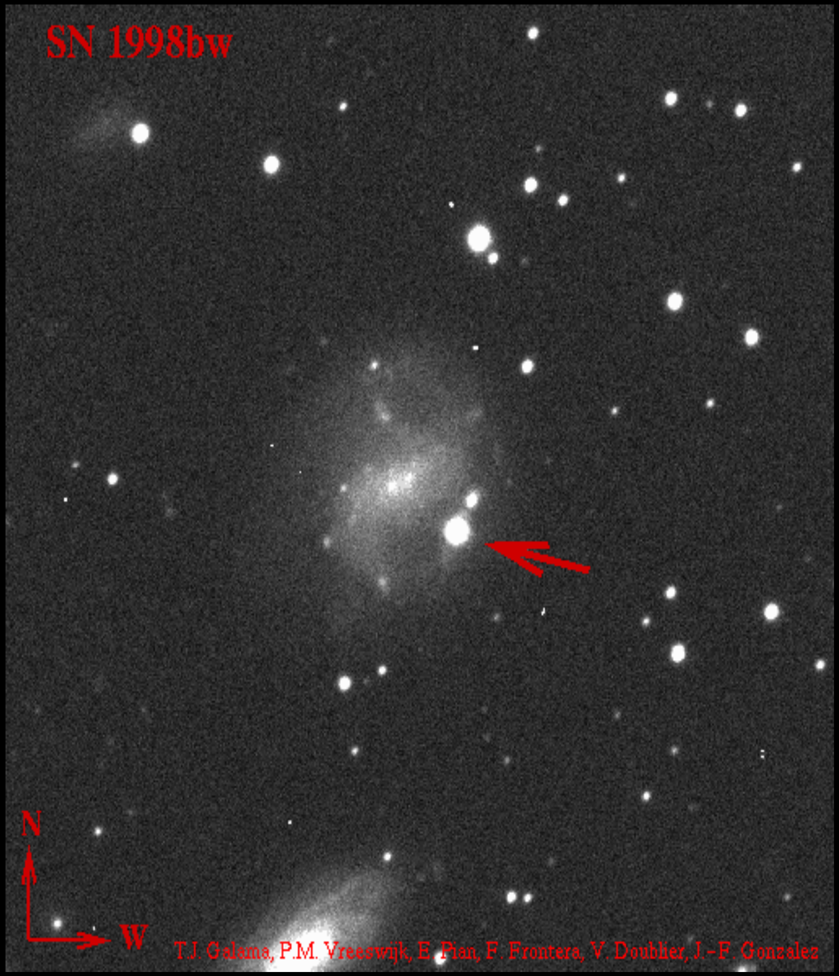
$R \sim 4 \times 10^{12}$ cm

The radius of the progenitor

W-R Star

$R \sim 4 \times 10^{11}$ cm

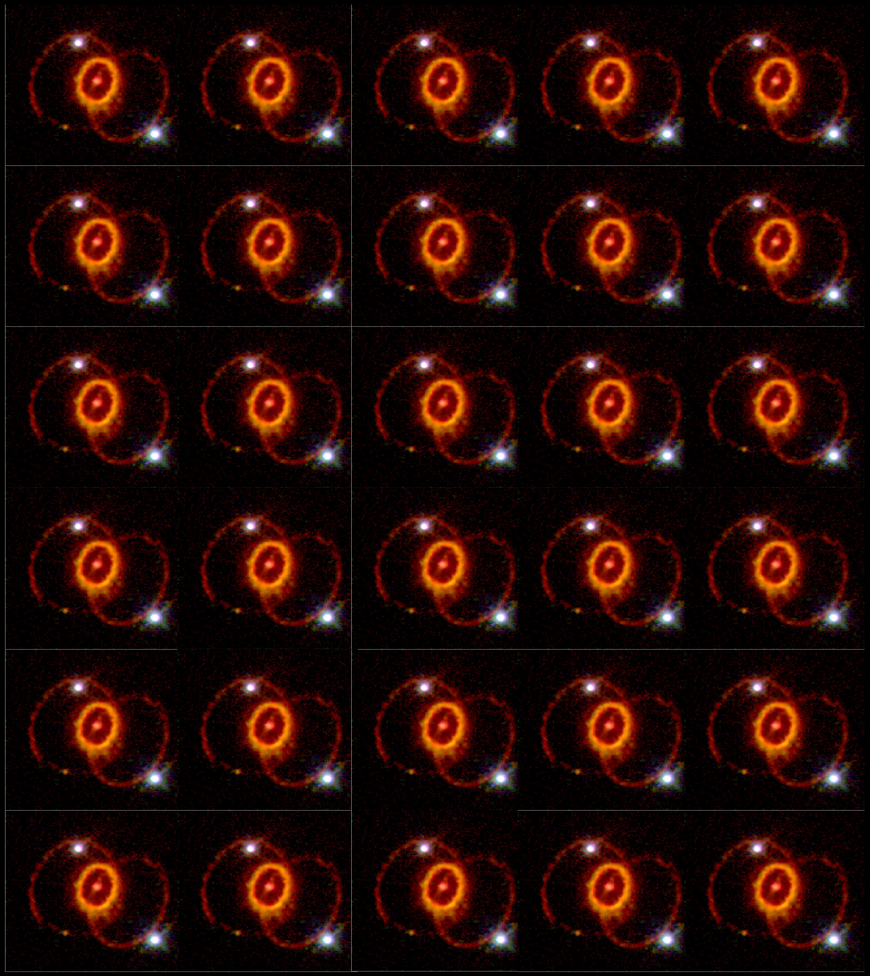
SN 1998bw



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

=

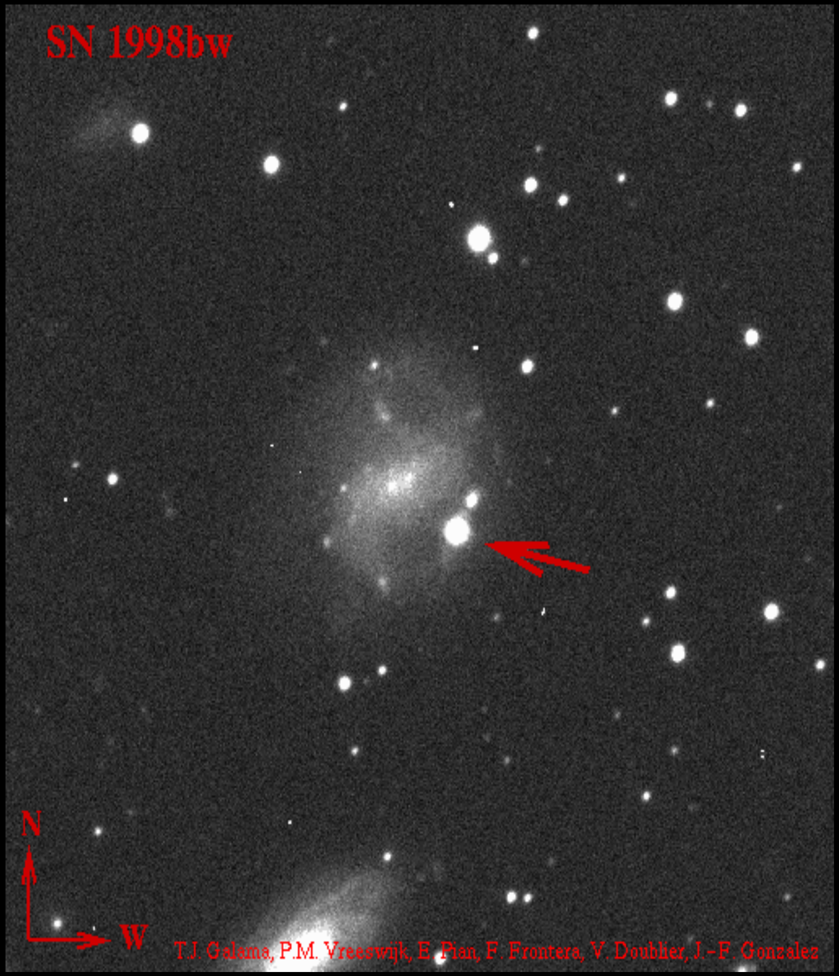
SN 1987A



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

SN 1998bw

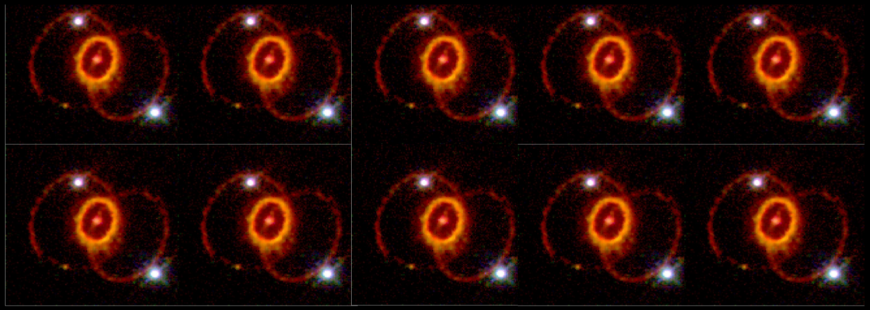
SN 1987A



Aspherical explosion

Maeda et al. 2006, 2008

=



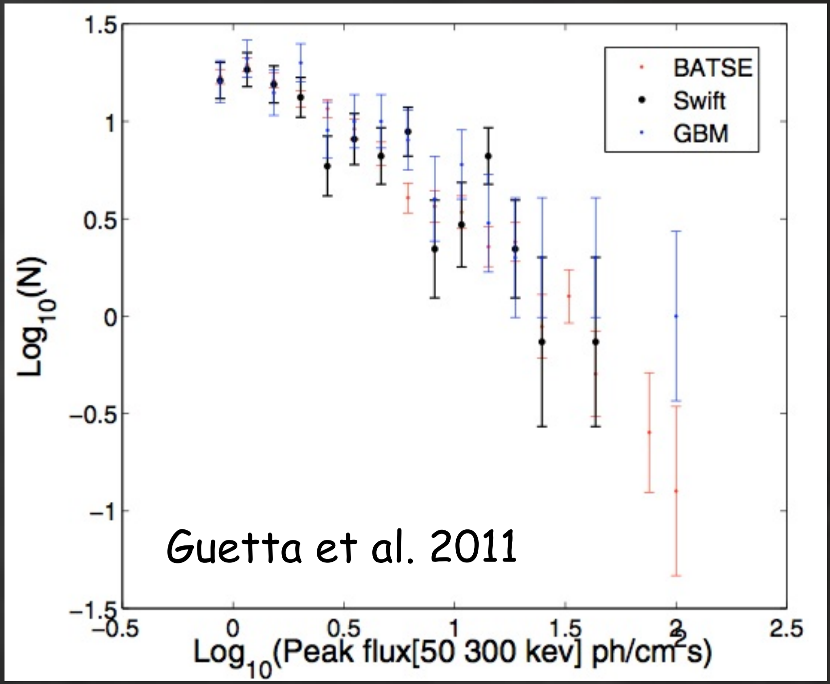
$E_K \sim 30 \times 10^{51}$ erg

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

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 rate of SNe-Ib/c ?

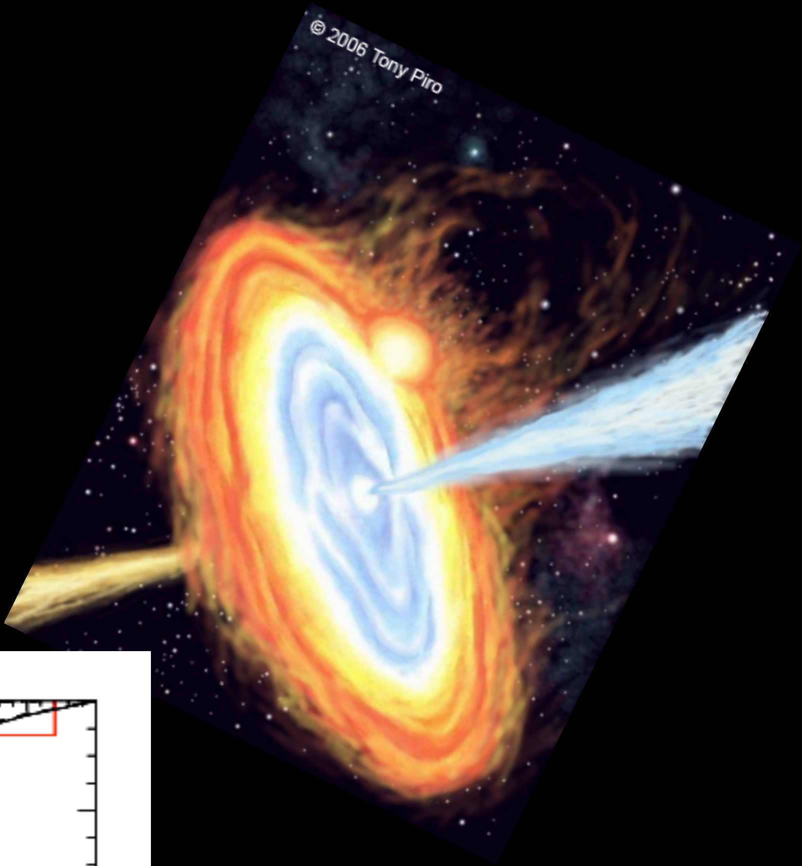
Asiago Survey (Cappellaro et al. 1999)

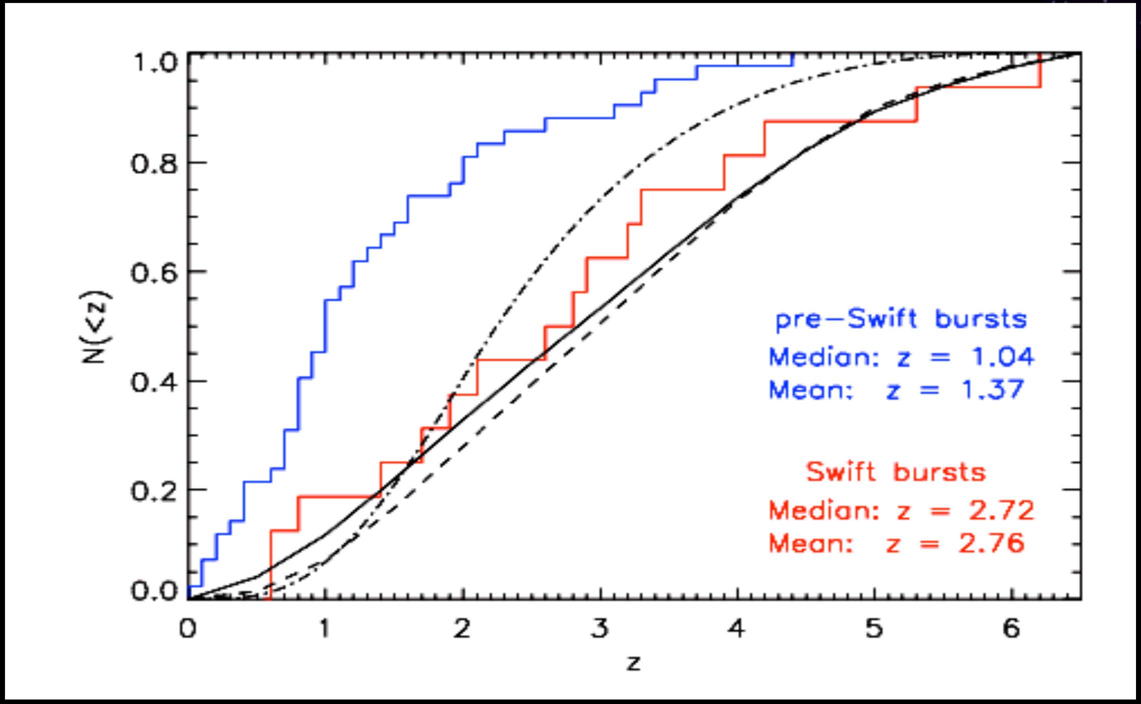
galaxy type	N. SNe* Ia	Ib/c	II	rate [SNu] Ia	Ib/c	II
E-S0	22.0			0.18 ± 0.06	< 0.01	< 0.02
S0a-Sb	18.5	5.5	16.0	0.18 ± 0.07	0.11 ± 0.06	0.42 ± 0.19
Sbc-Sd	22.4	7.1	31.5	0.21 ± 0.08	0.14 ± 0.07	0.86 ± 0.35
Others#	6.8	2.2	5.0	0.40 ± 0.16	0.22 ± 0.16	0.65 ± 0.39
All	69.6	14.9	52.5	0.20 ± 0.06	0.08 ± 0.04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

Rate for Ib/c: 0.152 ± 0.064 SNu

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

Distant GRB/SNe





Conclusions

HNe and GRB-SNe are not ideal targets for GWs hunting

Mon. Not. R. Astron. Soc. 397, 677–694 (2009) doi:10.1111/j.1365-2966.2009.15003.x

Nebular emission-line profiles of Type Ib/c supernovae – probing the ejecta asphericity

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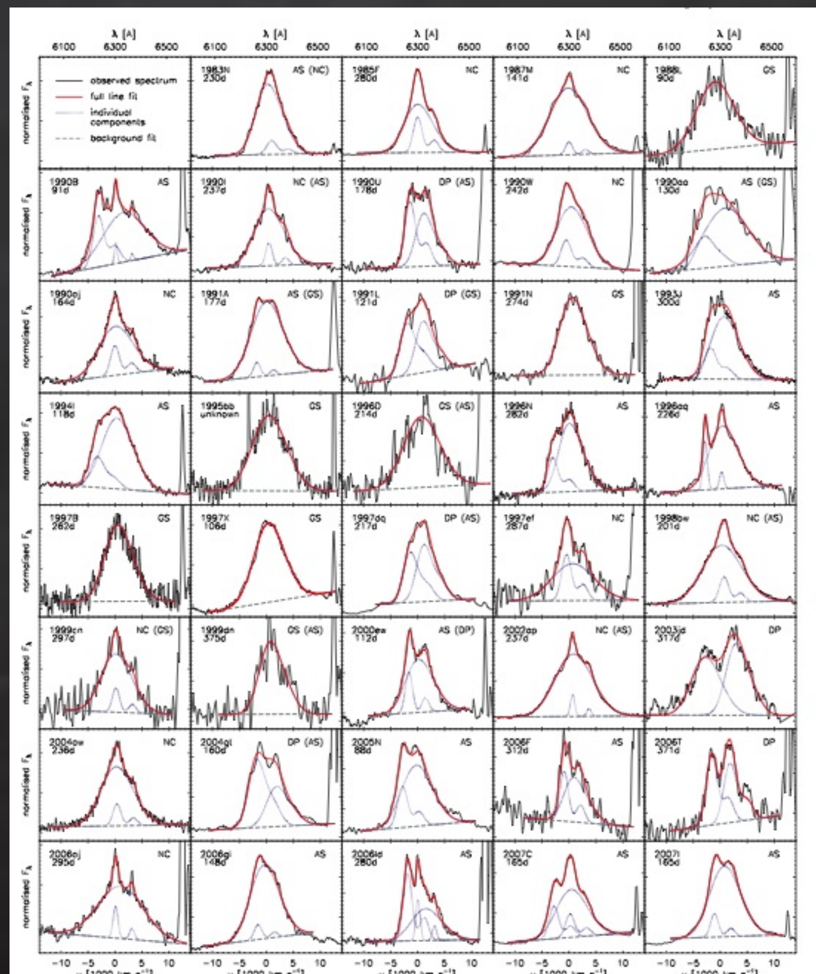


Table 3. Selected oxygen geometries and corresponding line profiles.

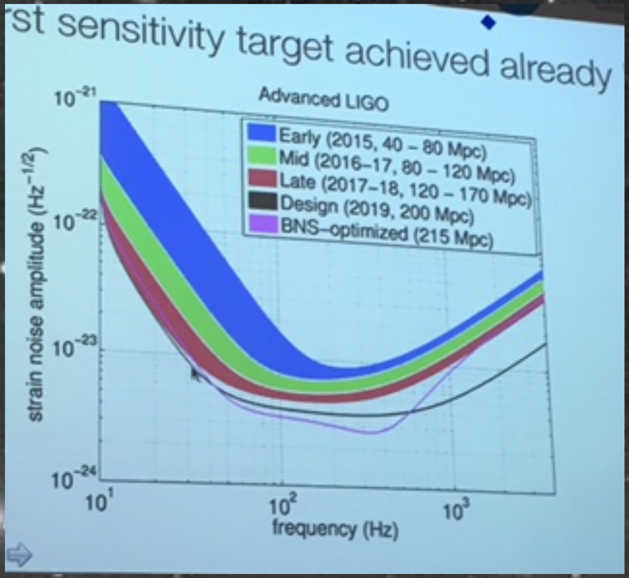
Oxygen emissivity distribution	Line profile	Global symmetry
Radial Gaussian	Gaussian	Spherically symmetric
Enhanced central density	Narrow core on top	Spherically symmetric
Hard-edged homogeneous sphere	Parabolic	Spherically symmetric
Spherical shell	Flat topped	Spherically symmetric
Torus viewed from top	Narrow core	Axisymmetric
Torus viewed from the side	Double peak, symmetric to λ_0	Axisymmetric
Torus viewed from intermediate angle	Gaussian-like	Axisymmetric
Small-scale clumpiness	Fine-structured peak	Asymmetric
Unipolar jet, one-sided blob	Extra-peaks/shoulders, shifted with respect to λ_0	Asymmetric

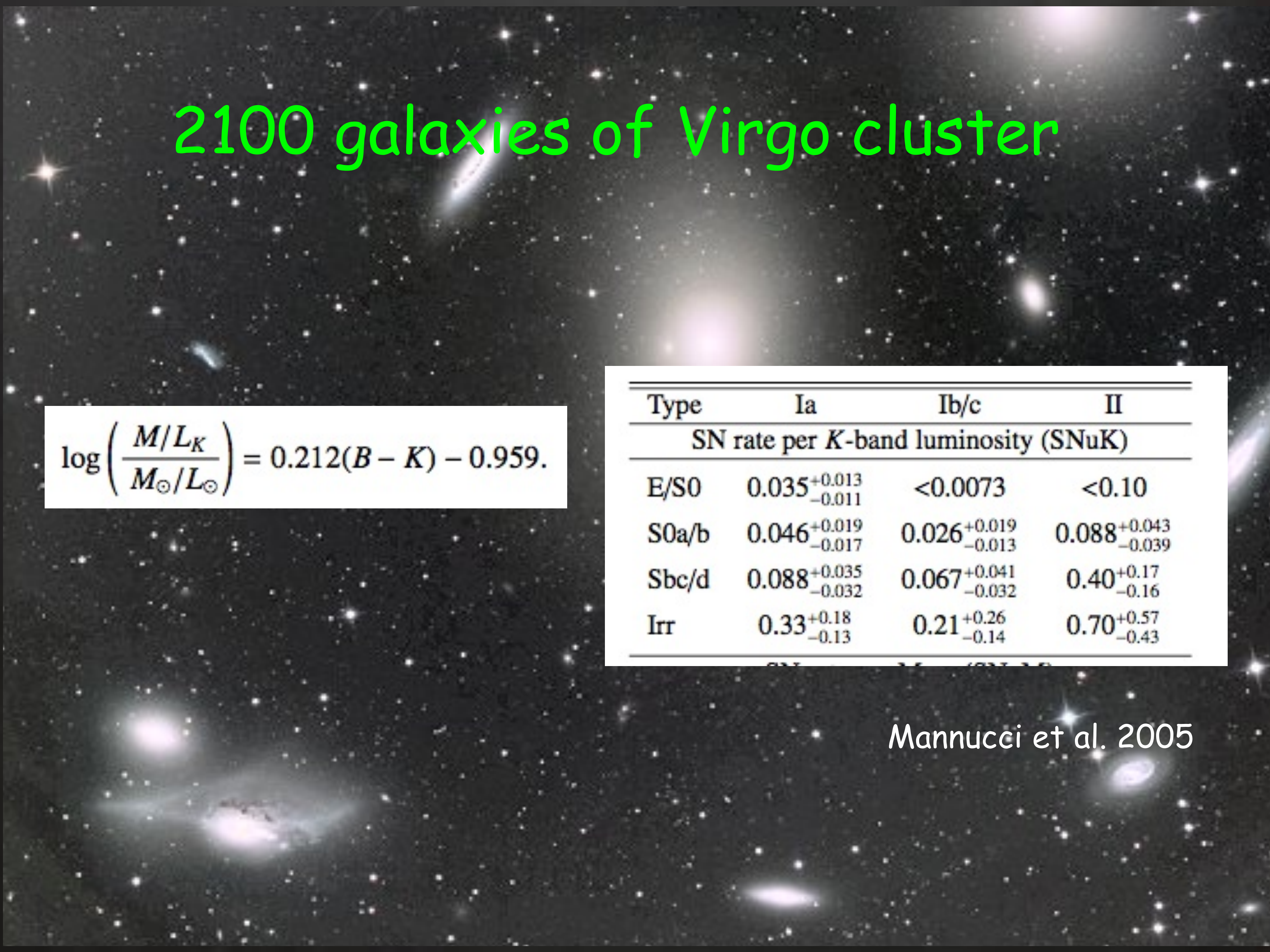
39 SNe-Ibc at least 50% are aspherical

SNe-Ibc < 10 Mpc

1994I	NGC5194	Ic
2002ap	NGC628	Icp
2005at	NGC6744	Ic
2007gr	NGC1058	Ic
2012fh	NGC3344	Ic

0.23 SNe-Ic yr-1





2100 *galaxies of Virgo cluster*

$$\log\left(\frac{M/L_K}{M_\odot/L_\odot}\right) = 0.212(B-K) - 0.959.$$

Type	Ia	Ib/c	II
SN rate per *K*-band luminosity (SNuK)			
E/S0	$0.035^{+0.013}_{-0.011}$	<0.0073	<0.10
S0a/b	$0.046^{+0.019}_{-0.017}$	$0.026^{+0.019}_{-0.013}$	$0.088^{+0.043}_{-0.039}$
Sbc/d	$0.088^{+0.035}_{-0.032}$	$0.067^{+0.041}_{-0.032}$	$0.40^{+0.17}_{-0.16}$
Irr	$0.33^{+0.18}_{-0.13}$	$0.21^{+0.26}_{-0.14}$	$0.70^{+0.57}_{-0.43}$

Mannucci et al. 2005

SNe-Ibc within Virgo circle (D=17 Mpc)

Within Virgo Circle (D=17Mpc), in 5 years, we should observe:

~ 2 SNe-Ibc
~ 0.1 HNe
~ 0.01 GRB/SNe

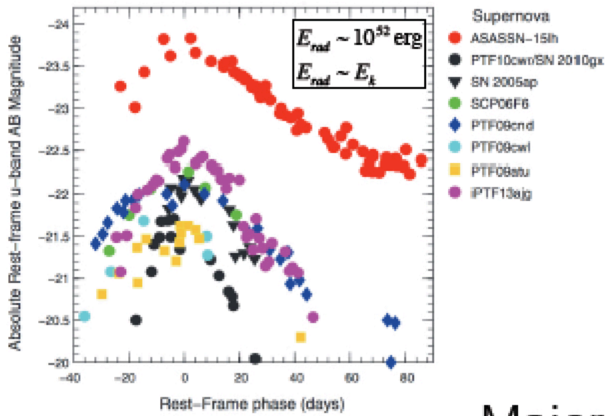
Within 30 Mpc circle, in 5 years, we should observe:

~ 11 SNe-Ibc,
~ 1HN
~ 0.1 GRB/SNe

Based on Smartt 2009 survey

~ 5 events are aspherical →

Within 30 Mpc we should observe ~ 1 event/yr
which is interesting for GWs



S. Dong et al., 2016, Science, 351, 257

ASASSN-15L stands out for

E_{rad} ~1e52 erg on par E_k

Plateau: Δm(pk-to-pl) ≅ 1.2

Major challenge to magnetars:

$$E_{rot} \leq E_c \cong (3-7)\times 10^{52}\,\mathrm{erg}$$

E_{rad} is on par with E_γ in LGRBs

ASASSN-15L from a rotating black hole?

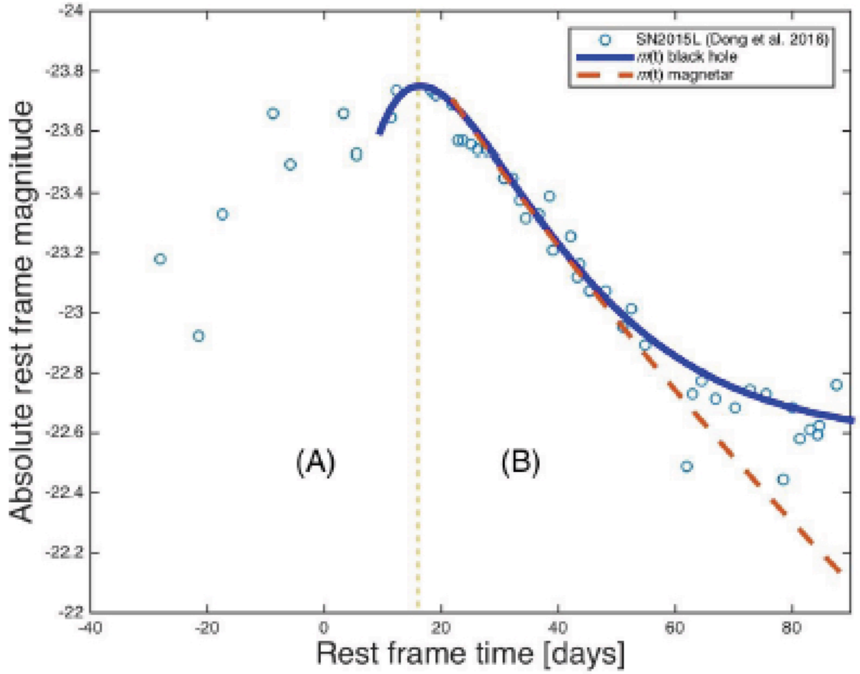
$$E_{rot} \leq E_{rot}^{max} = 6\times 10^{54}\left(\frac{M}{10 M_\odot}\right)\mathrm{erg}$$

mvp&mdv 2016

Some hyper-energetic events cannot be powered by the spindown of rapidly rotating proto-neutron stars by virtue of their limited rotational energy. They can, instead, be produced by the spindown of black holes (see also Bisnovatyi-Kogan 70's)

PISN → core 50-55 $M_\odot$ (Sukhbold & Woosley 2016)

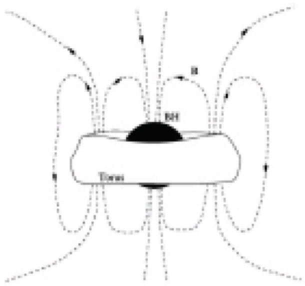
ASASSN-15L powered by dissipation of a BPJ from a rotating black hole spinning down against high density matter at ISCO



$\Delta m(\mathrm{spindown}) = 1.15$

$\Delta m(\mathrm{observed}) \cong 1.2$

$$\left(\frac{a}{M}\right)_{\square} \cong 0.36$$



$$T_{spin} \sim 1 \text{ month} \left(\frac{10^{-6.5} M}{M_{torus}}\right)\left(\frac{M}{10 M_{\odot}}\right)$$

~ 100 events Gpc^{-3} yr^{-1} within z=0.1

(see also Quimby et al. 2013)