Explosions of the most massive stars: from z~0 to 5

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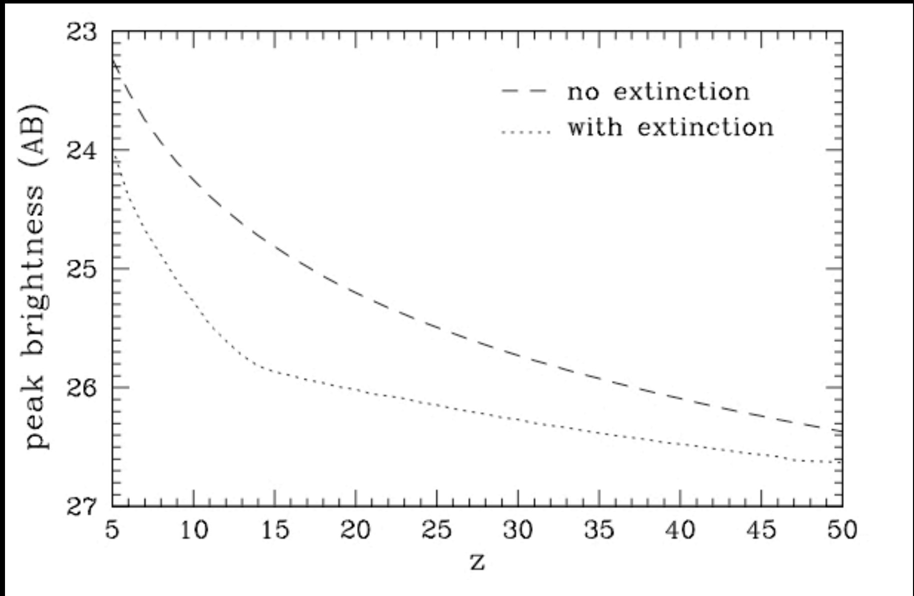
High-z SN observability ?



e.g.

- Weinmann and Lilly (2005) : 4 deg^{-2} yr^{-1} at z~15
- Heger et al. 2002 : ~250M_{sol} Pop III, metal free,
- 120M_{sol} He core, and 21M_{sol} ^{56}Ni ejected

➔JWST discovery, ELT spectroscopy

Supernova types

Supernovae are classified by their optical spectra

No hydrogen → Type I

- Si → Ia
- He → Ib
- ~~He or Si~~ → Ic

Hydrogen lines → Type II → Photometry/spectra properties → II-P, II-L, IIn, IIb, II-p

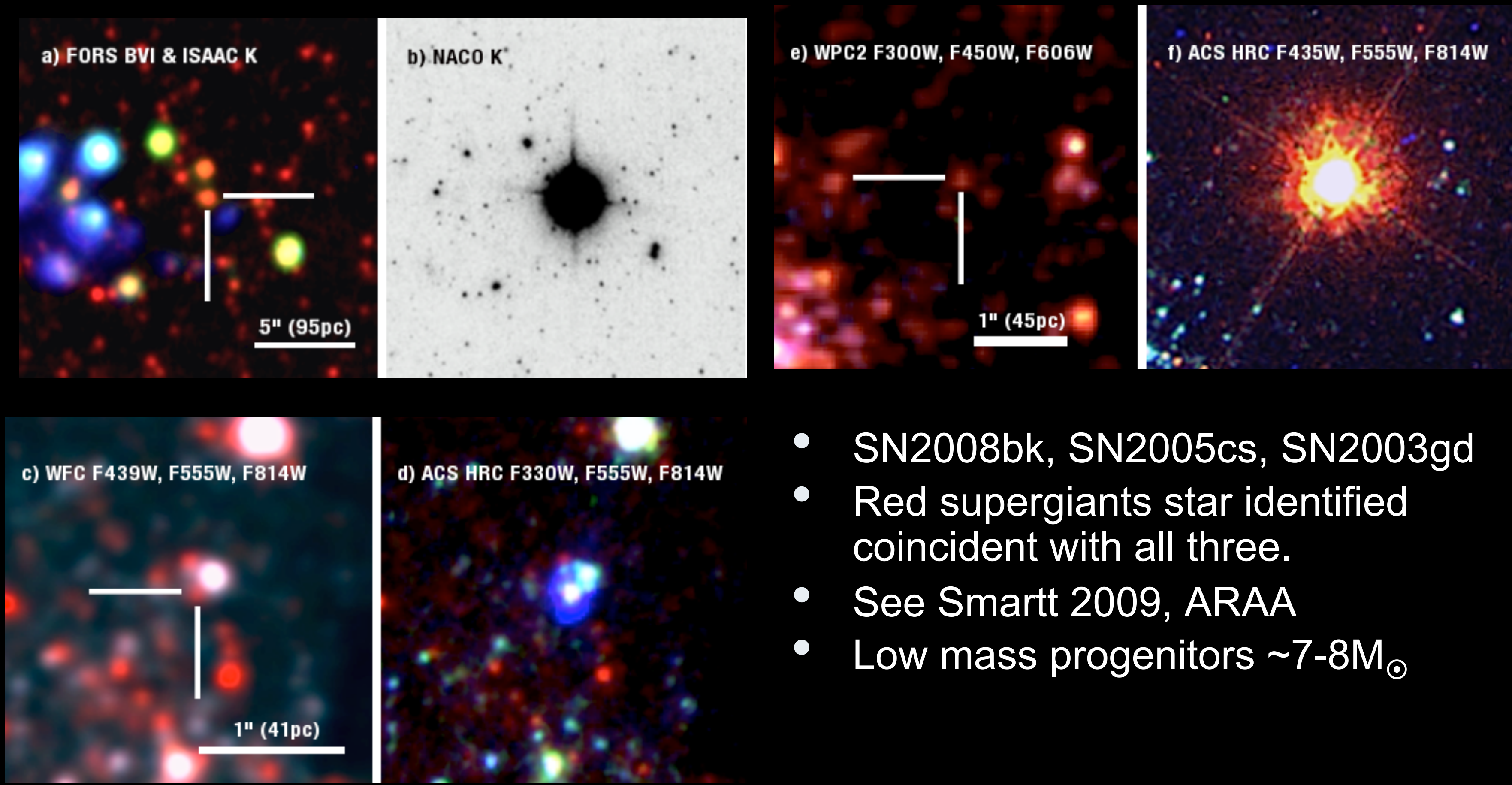
Relative SN rates 10.5 yrs

Smartt et al., 2009

Type	No.	Relative / per cent	Core-Collapse only / per cent
II-P	55	39.6	59.1
II-L	2.5	1.8	2.7
IIn	3.5	2.5	3.8
IIb	6	4.3	6.5
Ib	9	6.5	9.7
Ic	17	12.2	18.3
Ia	37	27.6	...
LBVs	7	5.0	...
Unclassified	2	1.4	...
Total	139	100	100
Total CCSNe	93	66	100

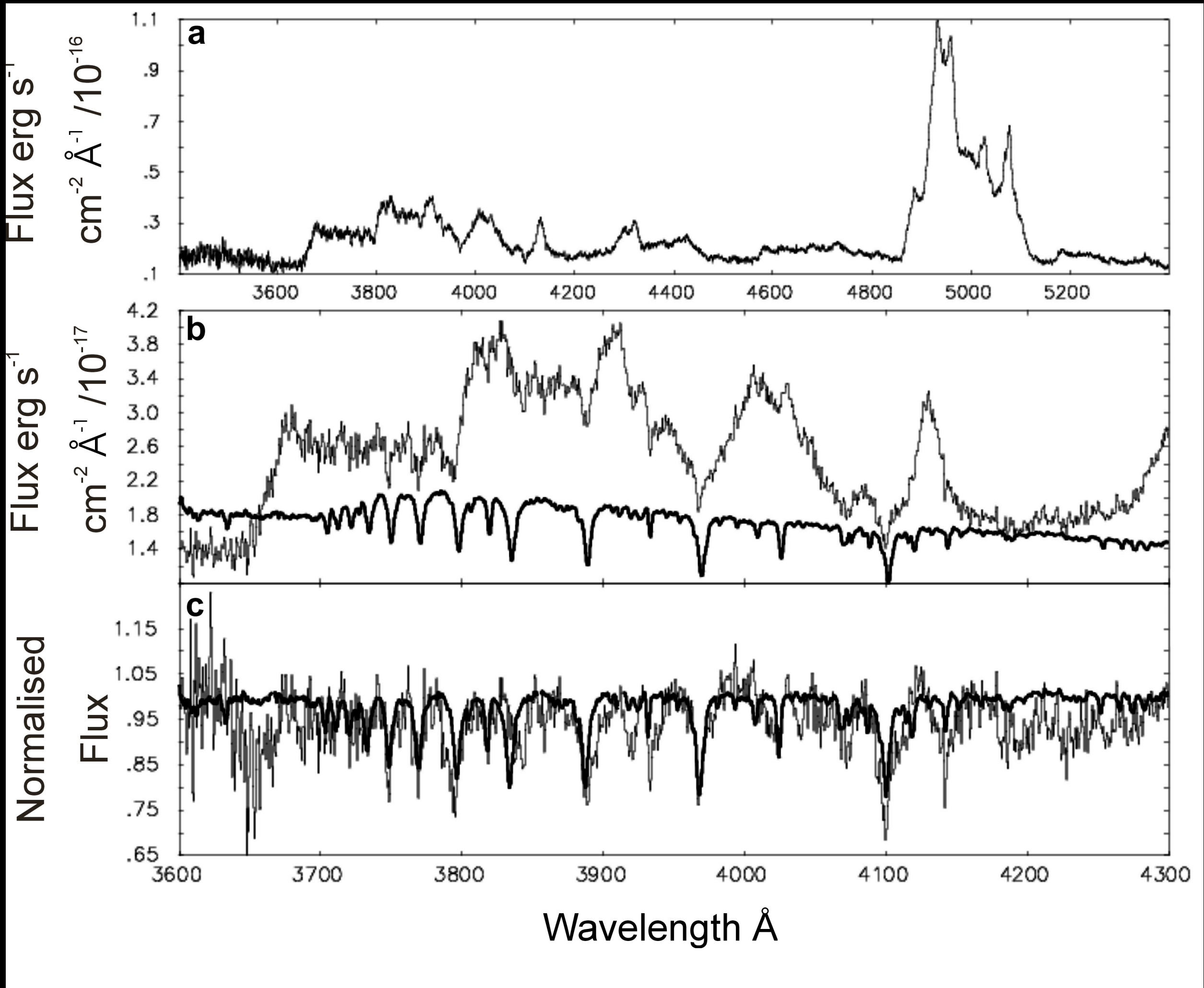
- 19980101-20080630
- 139 SNe discovered in galaxies with V_{vir}<2000 kms^{-1} (13.2 SNe yr^{-1})

Detection of progenitors



- SN2008bk, SN2005cs, SN2003gd
- Red supergiants star identified coincident with all three.
- See Smartt 2009, ARAA
- Low mass progenitors ~7-8$M_\odot$

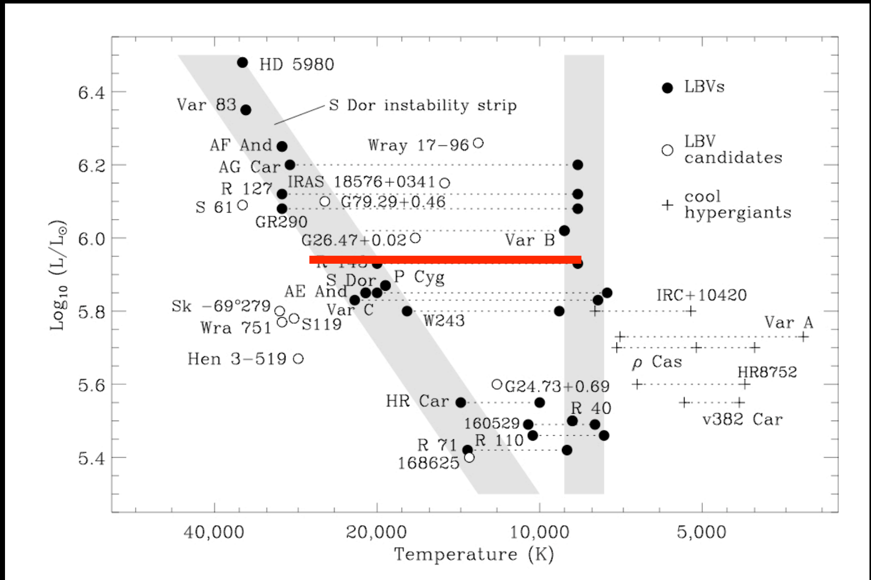
Spectrum of SN 1993J companion



- Keck I : 5.5hrs at 3Å resolution, 3200-5600Å (200 km/s)
- M81 dec = +69^o ; (airmass > 1.5)
- Wide binary (~5 yr orbit)
- 10 km/s resolution required

Maund, Smartt et al. 2004

Do Luminous Blue Variables (LBVs) explode?



LBVs are: luminous, blue, and variable (!) -

I) on timescales of a few years (S Dor variability)

II) giant outbursts e.g. Eta Car

Canonical evolutionary pathway:

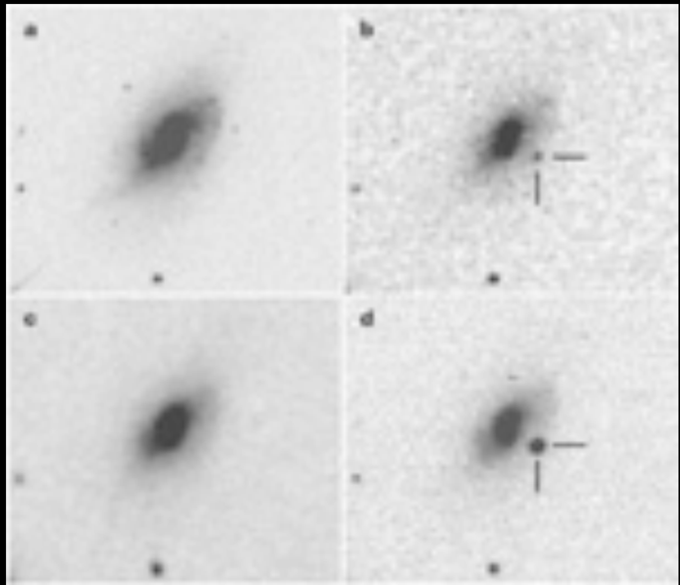
O --> LBV --> Wolf-Rayet --> Supernova via core-collapse

O --> LBV --> SN
very problematic for stellar evolution models

Smith, Vink & de Koter 2004; Kotak & Vink 2006

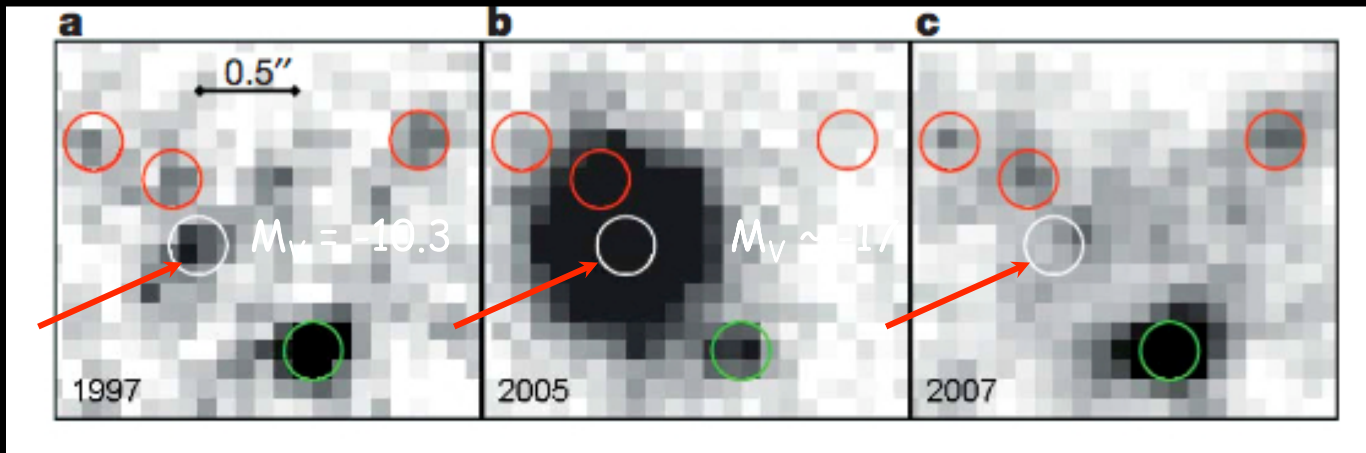
Emerging evidence from supernova observations

- Giant eruptions of LBVs?



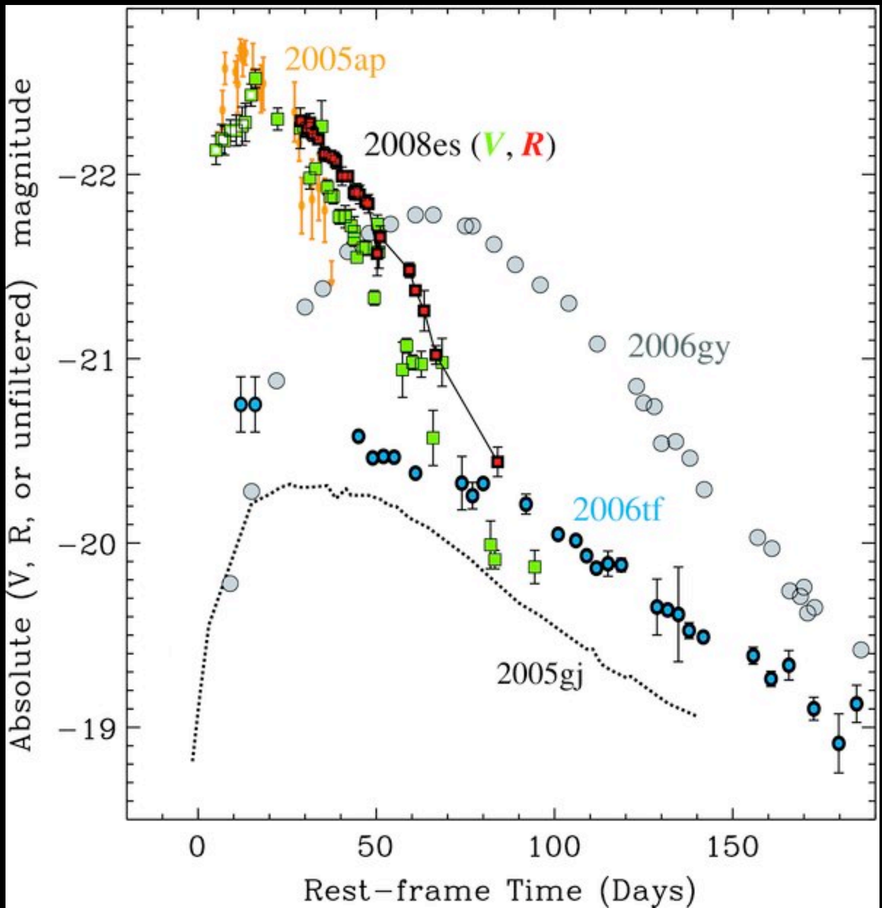
SN 2006jc (~26 Mpc; M_R < -14.3): Outburst 2 yrs prior which is coincident with SN 2006jc

LBV in outburst? SN 2005gl (~66Mpc) Progenitor gone



Pastorello et al. 07, Gal-Yam & Leonard 09

Ultra-bright type II SNe



Quimby+07, Millar+09
Gezari+09, Smith+ 07/08

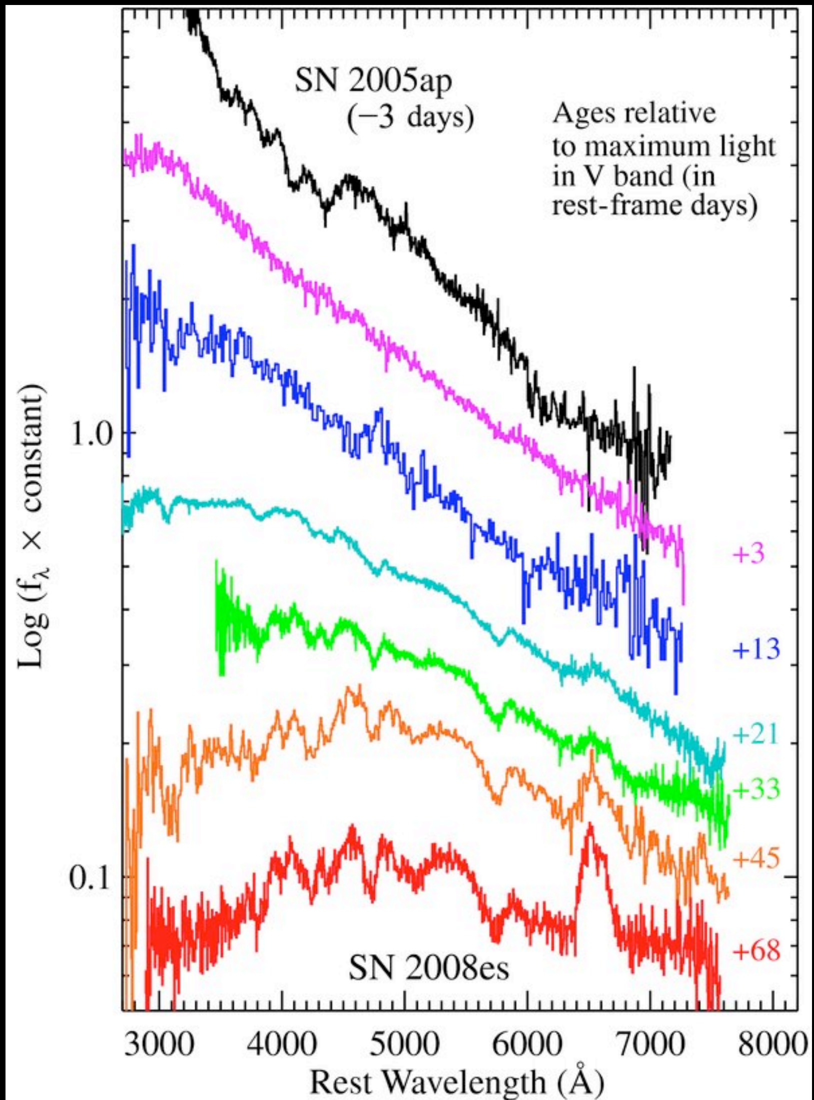
- $E_{rad} \sim 10^{51}$ erg
- $E_{kinetic} \sim 10^{51}$ erg : but uncertain as ejecta mass not reliably determined
- Origin of the extreme luminosity ?

★ $E_{kinetic}$ is thermalised in opaque, dense shell (10-20$M_\odot$ and 150 AU)

★ Opaque clumps

★ Extended CSM from dense super-wind

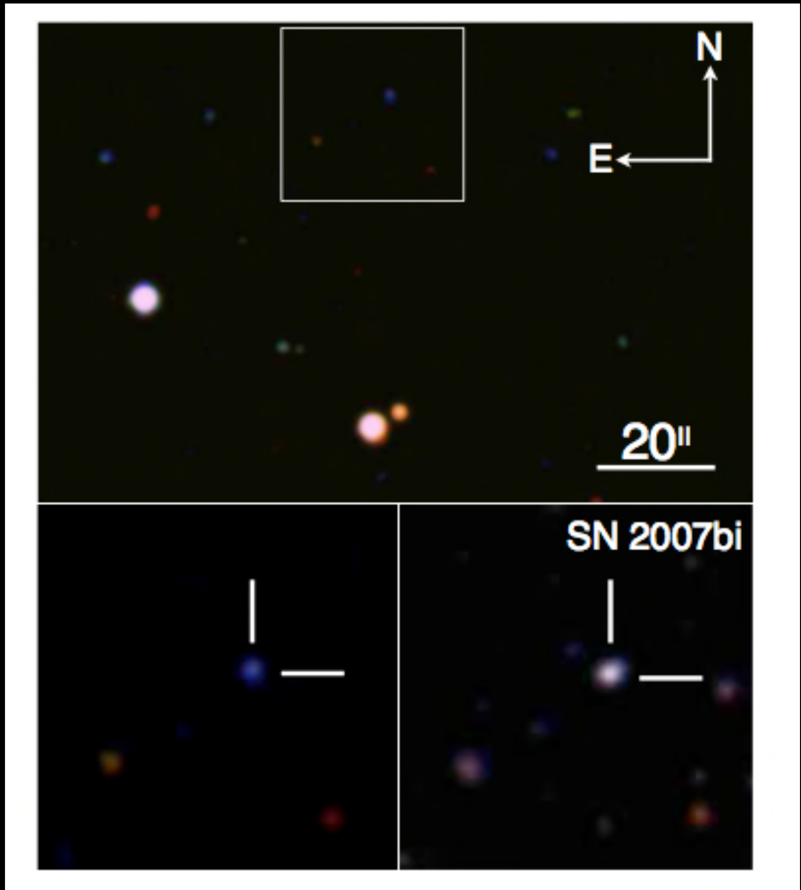
Explosion mechanisms



Miller et al. 2009

- Rest frame ages ($z = 0.213$)
- P-Cygni Hα
- $V_{ejecta} \approx 10000$ kms^{-1}
- $E_{kinetic} \sim 10^{51}$ erg
- To power the lightcurve by ^{56}Ni, $10M_{\odot}$ is needed
- Interaction of ejecta with CSM and thermalisation is favoured
- But for SN2008es (and 2005ap), no spectral signature of interaction
- Lightcurves probably too fast for ^{56}Ni decay

Ultra-bright type Ic



SDSS host : z = 0.13

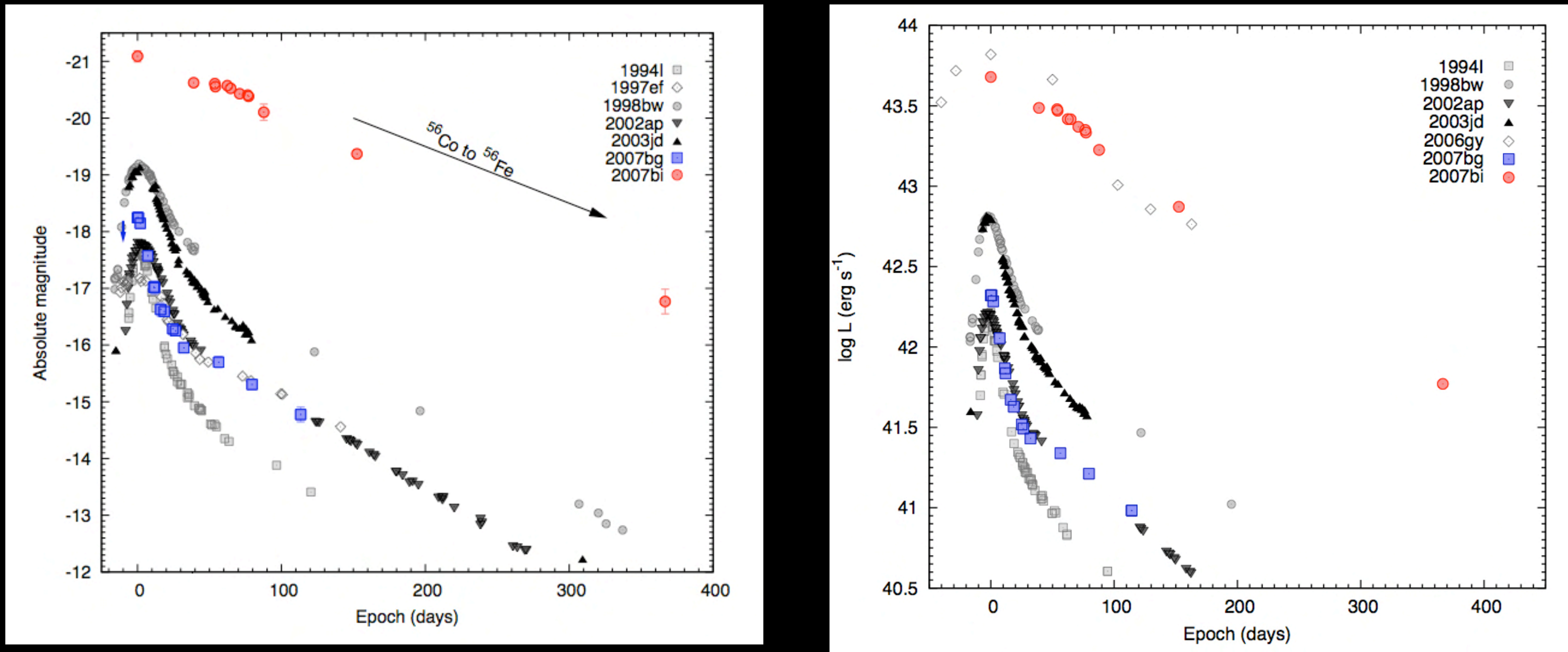
- SN2007bi discovered by NSF (r = 17.8 ; Gal-Yam et al. 09)
- Low metallicity, dwarf host
- Host M_B = -16.4± 0.2
- Metallicity :

  12 + log(O/H) = 8.1 ±0.2

  ($0.25Z_\odot$)

(Young, Smartt et al. 09)

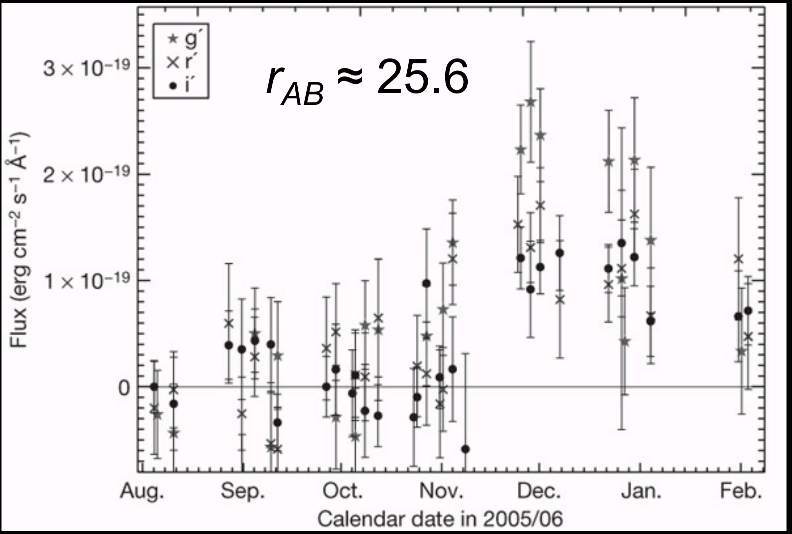
Most luminous Ic SN

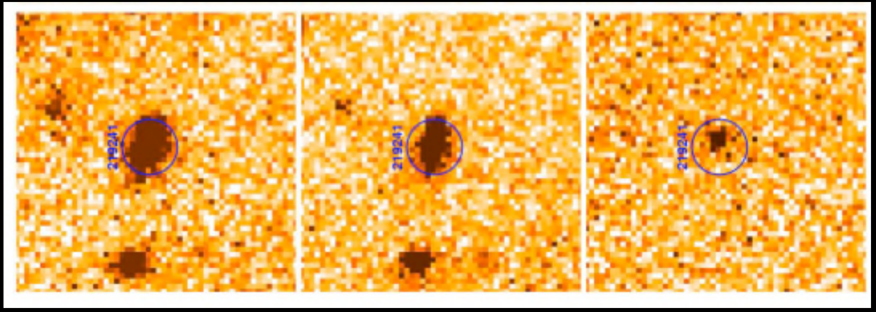


- Lightcurve model : mass of ^{56}Ni, M_{Ni} = 3.5 – 4.5$M_{\odot}$
- GRB SNe (1998bw, 2003lw) $M_{Ni} \approx 1M_{\odot}$
- Mechanism to produce this ? Core-collapse or pair-instability ?

Supernovae IIn at z≈2

- Cooke et al 09: Nat., 460, 237
- SNLS : seasonal stacks
- z≈2 galaxies monitored
- Three SNe : *z≈ 0.81, 2.01, 2.36*
- Probably IIn or II-L Sne
- $M_{UV} = -19.6 \pm 0.5$





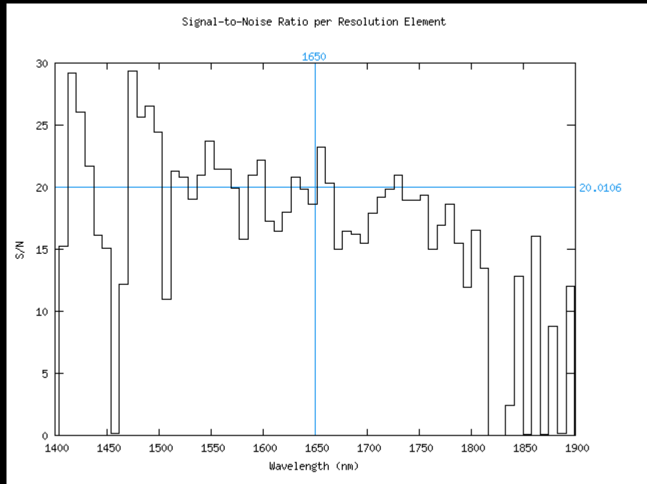
Surveys to detect ultra-bright high-z IIn

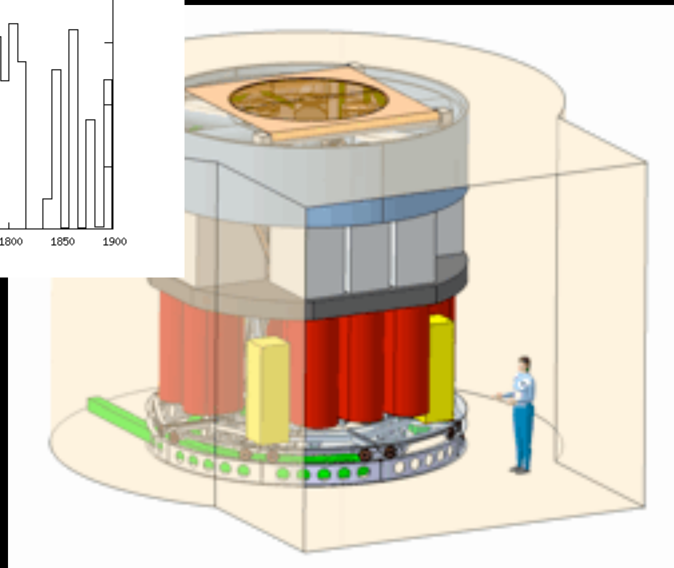
- LSST : ~20,000 deg^2 ; $r_{AB} = 26.5^m$, $z_{AB}=25.3^m$, ~50 at z~6 (Cooke et al. 2009)
- Euclid Deep : ~100 deg^2, $H_{AB} = 26^m$
- JWST : ~0.5 deg^2 , $H_{AB} = 26^m$ (~150hrs NIRCAM)
  - *Number simulations needed*

z	H_{AB}	λ_{rest} (Å)
6	26.8	2140
5	26.4	2500
4	25.3	3000
3	24.6	3750

ELT spectroscopy

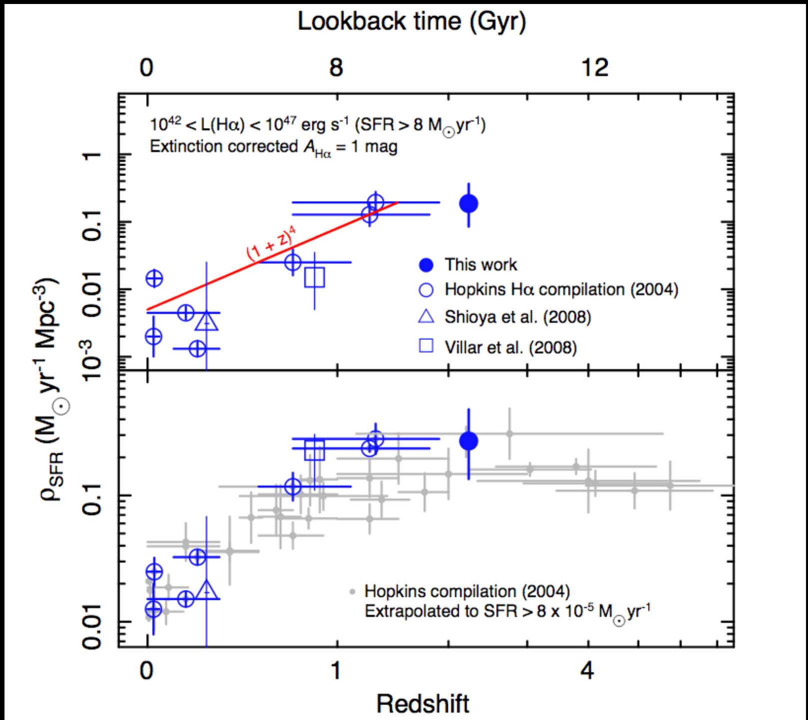
- Harmoni/Eagle/ Optimos
- H_{AB} = 26
- R ~ 100
- 5hrs
- LTAO or MCAO essential



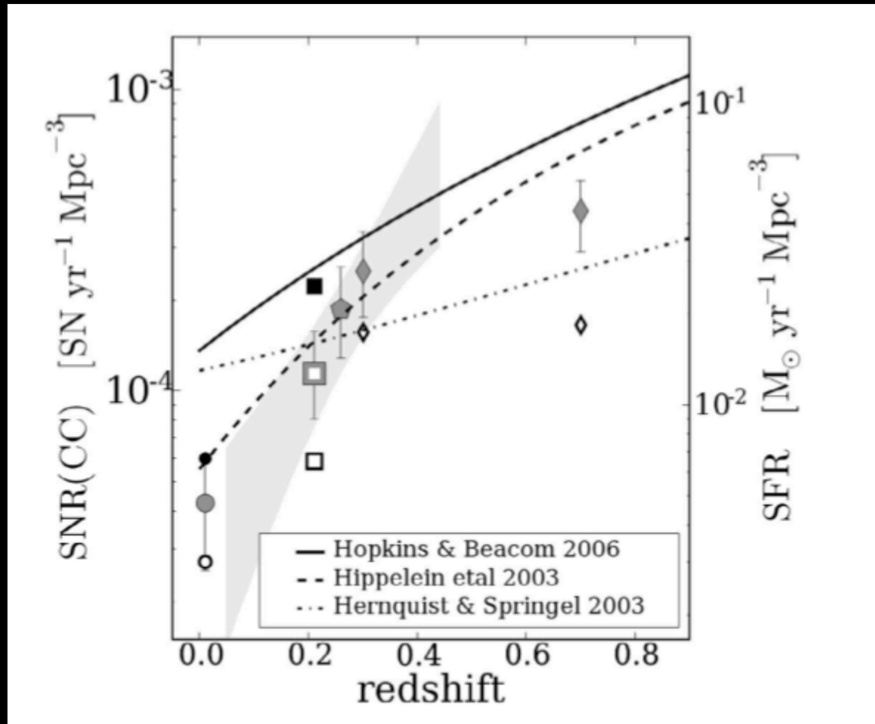


JWST NIRspec :
Equivalent calc ~ 20hr

SFR history : CCSNe



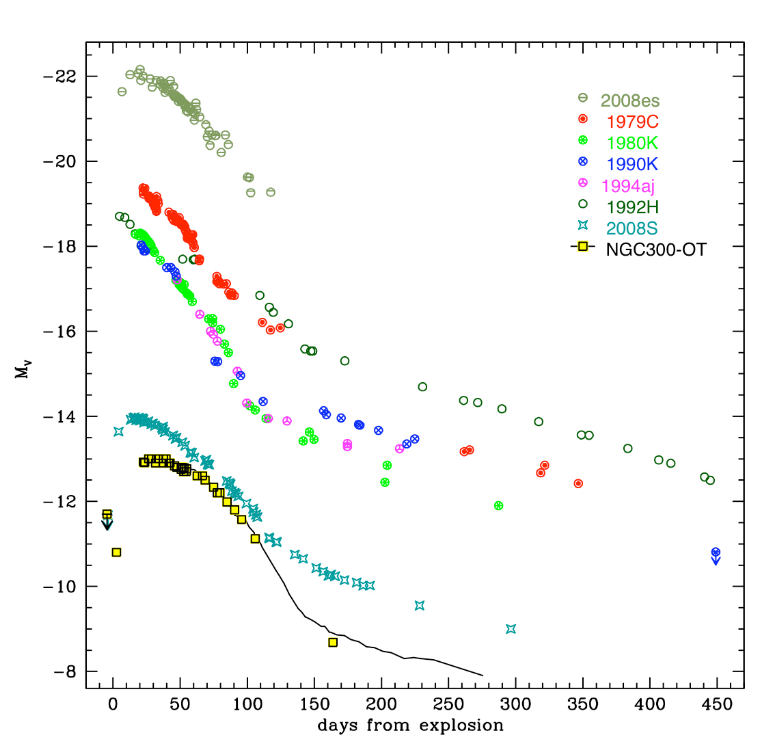
Geach et al. 2008



Botticella et al. 2008

Summary and requirements

- At z~0 : use ELT high res imaging, and spectroscopy to understand Local Population
- Not clear that z~15 SNe will be easily detected
- Detection of z~6 SNe are highly likely : spectroscopy still challenging with ELT
- SN rates with CCSNe require understanding of nearby rates at z~0 and progenitor stars
- Instrument requirement :
  - diffraction limited NIR (1-2mμ)
  - 10 km/s optical spectra
  - low-medium res NIR spectra



Credit : A. Pastorello