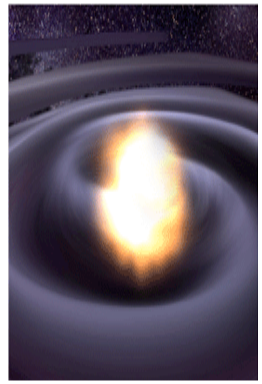


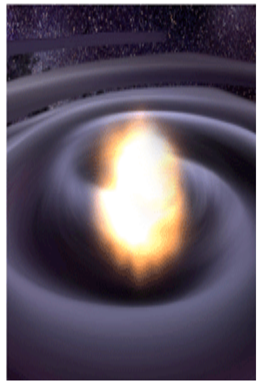
On Peculiar SN Ia

Mansi Kasliwal

KITP Seminar Presentation,

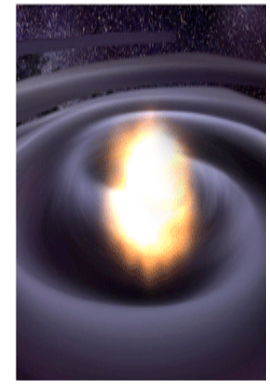
Oct 30 2007

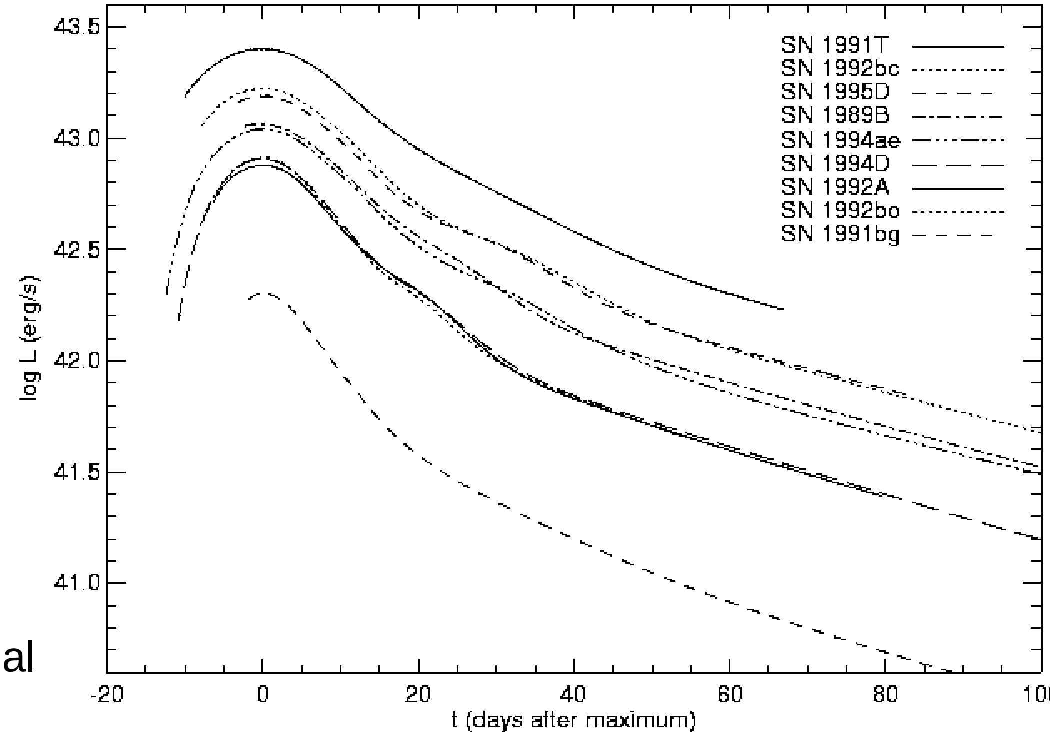
Physics of a Type Ia SN



- Single Degenerate :
  - White-Dwarf & Red dwarf/giant Binary
    - Deflagration, Detonation, Delayed Detonation
    - CO WD is near Chandrashekhar mass and accretes H or He until carbon-ignition
- Sub-Chandrashekhar Model :
    - Low-mass White-Dwarf, He shell accretion and He detonation until central carbon ignites
    - Double-detonation model (astroph/07105486) : unlikely since 0.4-0.45 Msun of Ni
- Double Degenerate
  - White-Dwarf White-Dwarf Merger

Standard Candles





Contardo et al

Arnett 1985

SN	M_B (mag)	Δm_{15}^{B} (mag)	$\log L_{bol}$ (erg s^{-1})	Δm_{15}^{bol} (mag)	M_{Ni} ($M_\odot$)	$t_{-1/2}$ (days)	$t_{+1/2}$ (days)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SN1989B	-19.37	1.20	43.06	0.91	0.57	—	13.1
SN1991T	-20.06	0.97	43.36	0.83	1.14	11.6	14.0
SN1991bg	-16.78	1.85	42.32	1.42	0.11	—	8.8
SN1992A	-18.80	1.33	42.88	1.15	0.39	8.6	10.3
SN1992bc	-19.72	0.87	43.22	0.93	0.84	10.1	13.0
SN1992bo	-18.89	1.73	42.91	1.27	0.41	8.3	9.6
SN1994D	-18.91	1.46	42.91	1.16	0.41	7.5	10.8
SN1994ae	-19.24	0.95	43.04	0.97	0.55	9.6	12.6
SN1995D	-19.66	0.98	43.19	1.00	0.77	—	12.2

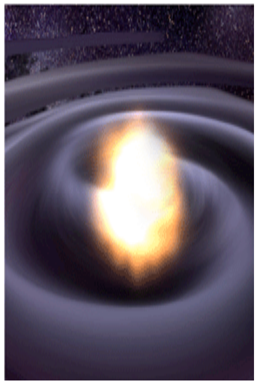
$$M_{Ni} = L_{bol}/(dS/dt\ \alpha)$$

$$\dot{S} = (6.31\times10^{43}e^{-t_R/8.8}) + (1.43\times10^{43}e^{-t_R/111})\,\mathrm{erg\,s^{-1}}\,M_\odot^{-1}$$

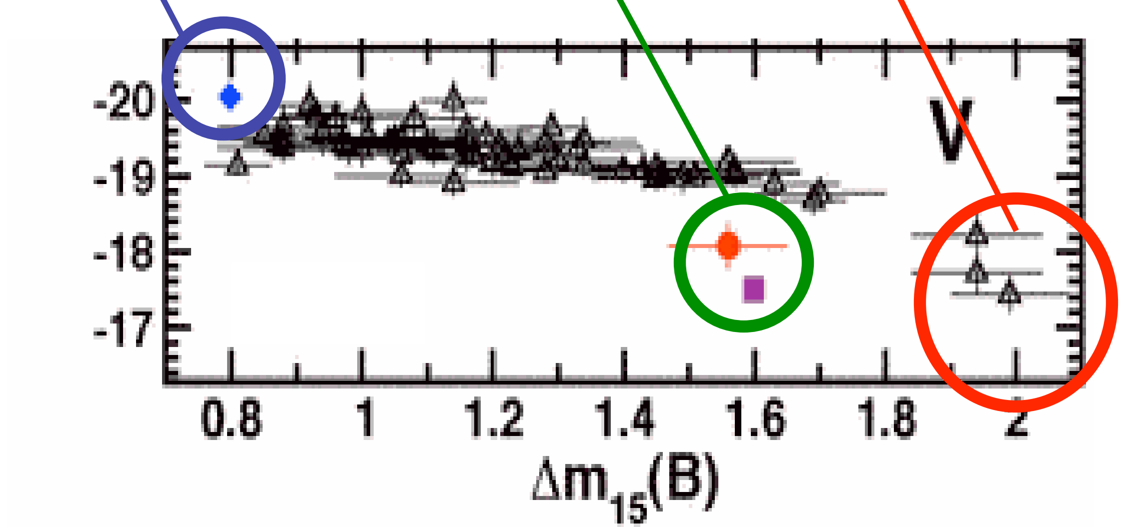
$$t_R = s \times 19.5$$

$$\alpha = L_{bol}/L_{nuc}$$

Peculiar Ia sub-classes

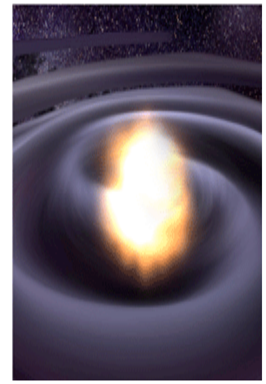


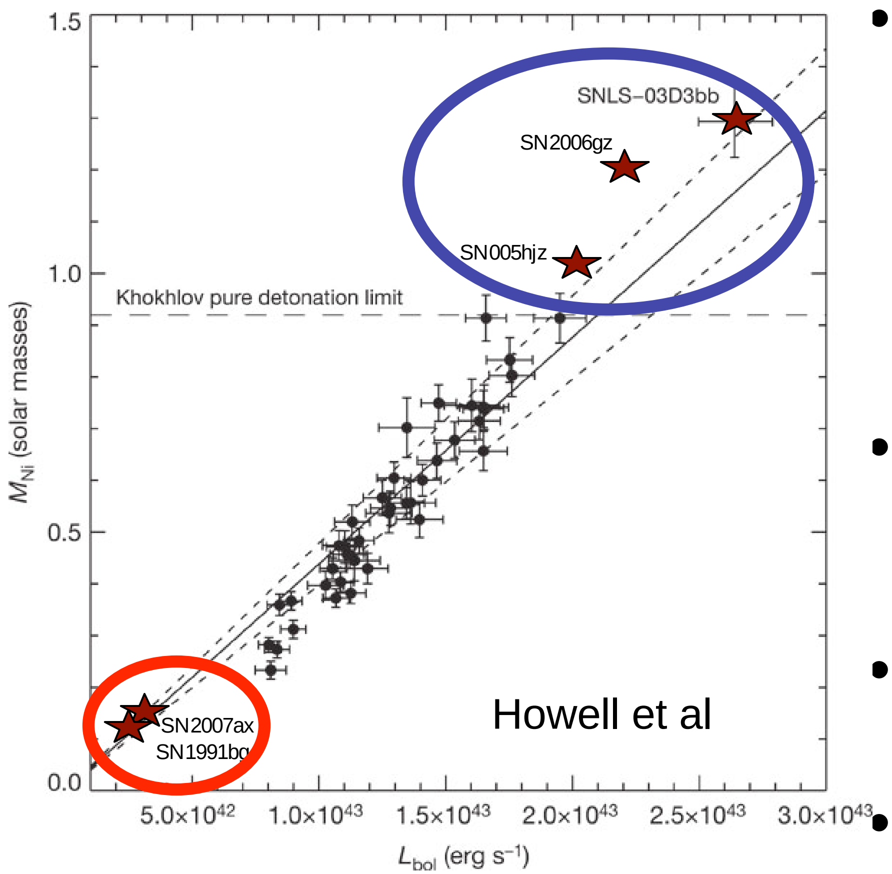
- 06gz-like : Super-luminous
- 02cx-like : Faint BUT broad
- 91bg-like : Extremely underluminous



(And ofcourse there are the extraordinarily bright 06gy and 05ap)

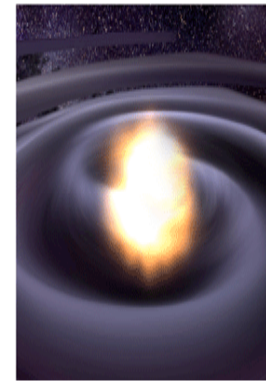
06gz-like Super-Chandrashekhar?

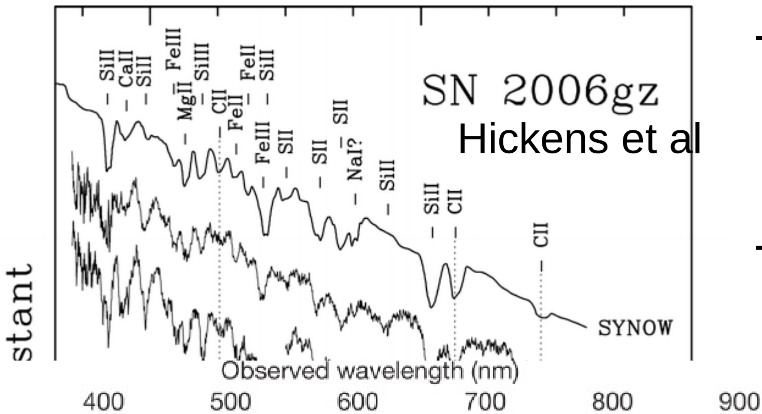


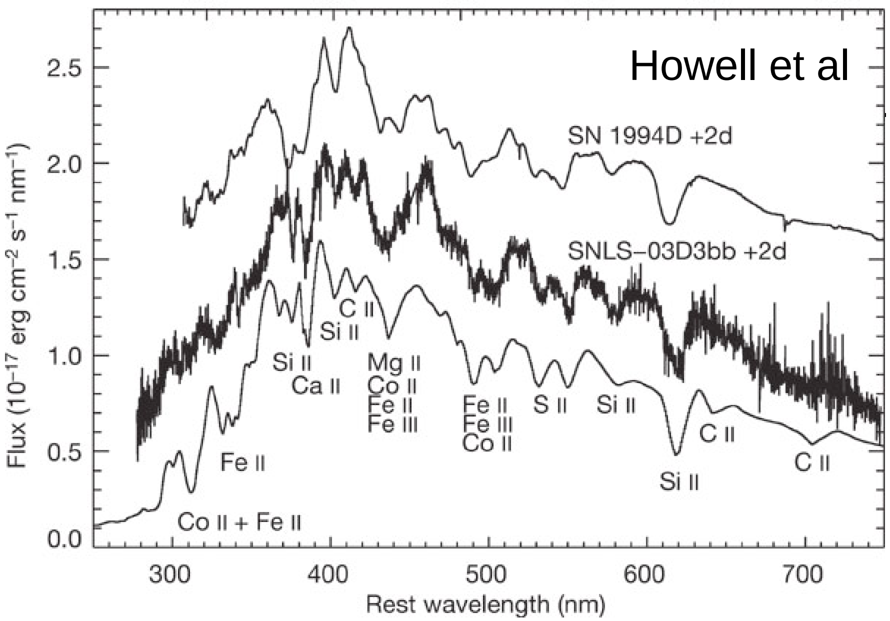


- Three Type Ia SN that are so overluminous that they suggest a super-chandrashekhar progenitor: SN2003fg, SN2006gz, SN2005hj
- Peak brightness of Mv = -19.85, -19.91, -19.53 respectively
- Very broad light curves : Δm_{15} = 0.69 for 06gz
- Rapidly Rotating WD?

06gz-like WD-WD merger

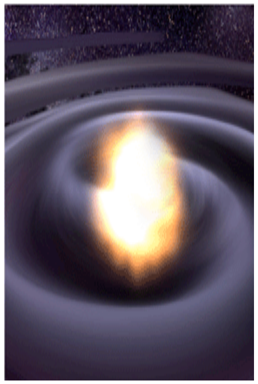


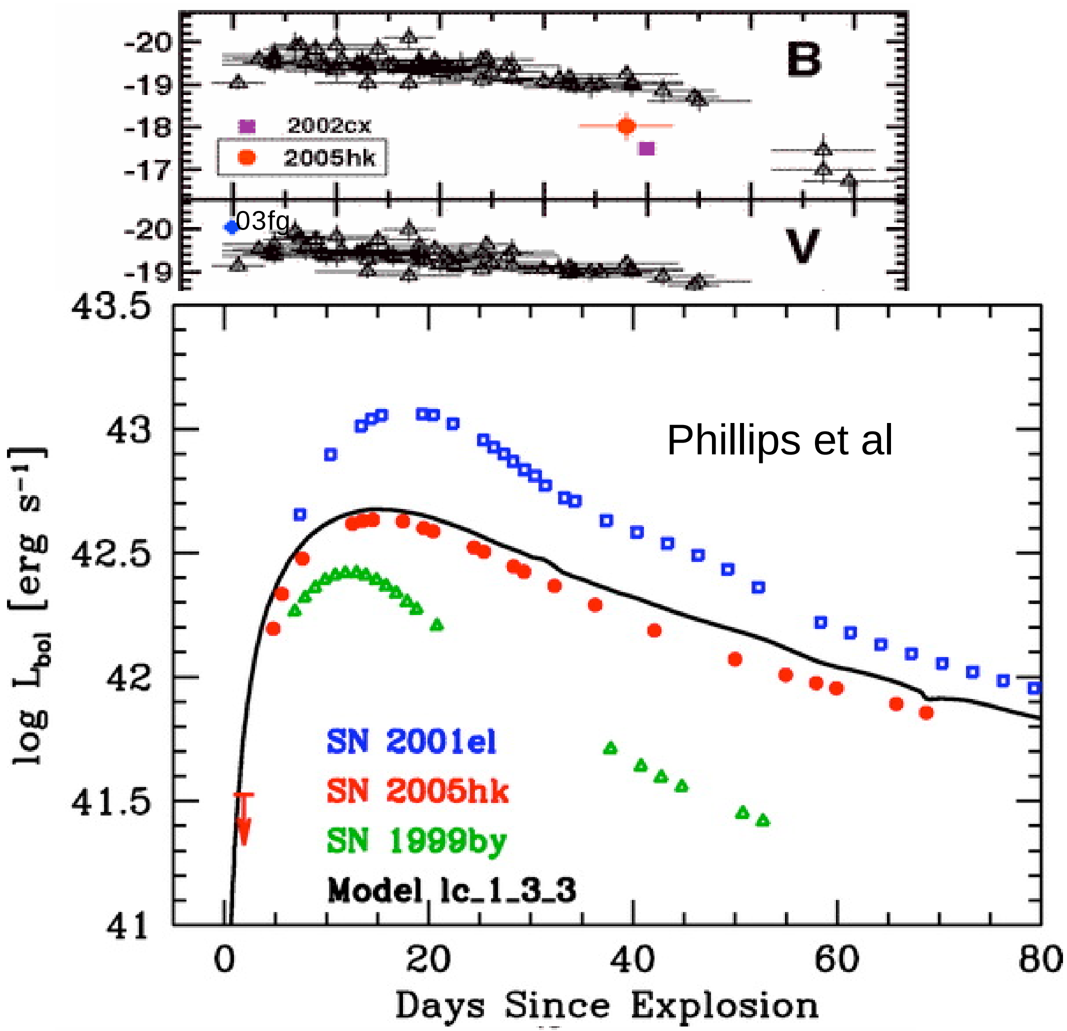




- Presence of unburned Carbon lines in spectra!
  - @ t = -14d, CII EW = 25A
- Deep, narrow, low-velocity Si II lines pre-maximum
  - 13000 km/s in 06gz @t=-14d
  - 8000 km/s in 03fg @ t=+2d
- In a DD merger:
  - The envelope decelerates the layers of exploded WD, increases density and diffusion time. Hence, suppressed Si II velocity and broad light curves.
  - Envelope of DD merger with unburned carbon is shocked and accelerated immediately after explosion

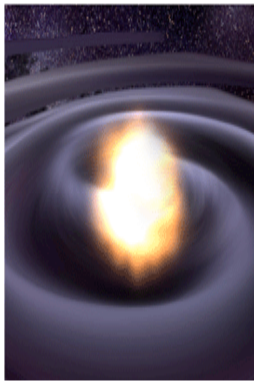
02cx-like Light Curve

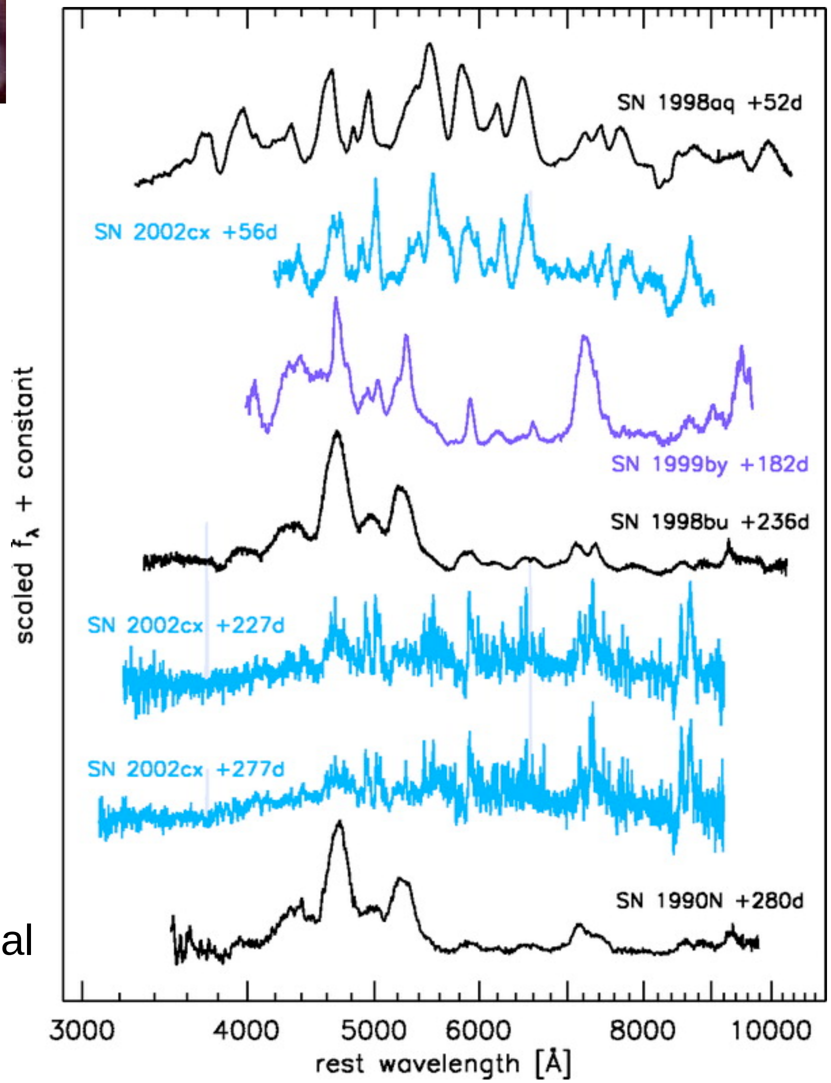




- Five Peculiar Type Ia supernovae : 2002cx, 2005hk, 2003gq, 2005P, 2005cc
- Very low peak luminosity (M_B ~ -17.5) suggesting Ni ~ 0.2 => 99by like?
- Yet, Δm_{15} ~1.29, declining so slowly suggesting it is much brighter => 91T like?
- Lack of secondary peak => mixing?

02cx-like Spectra

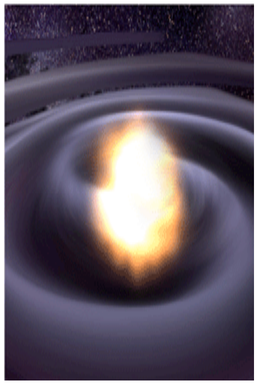


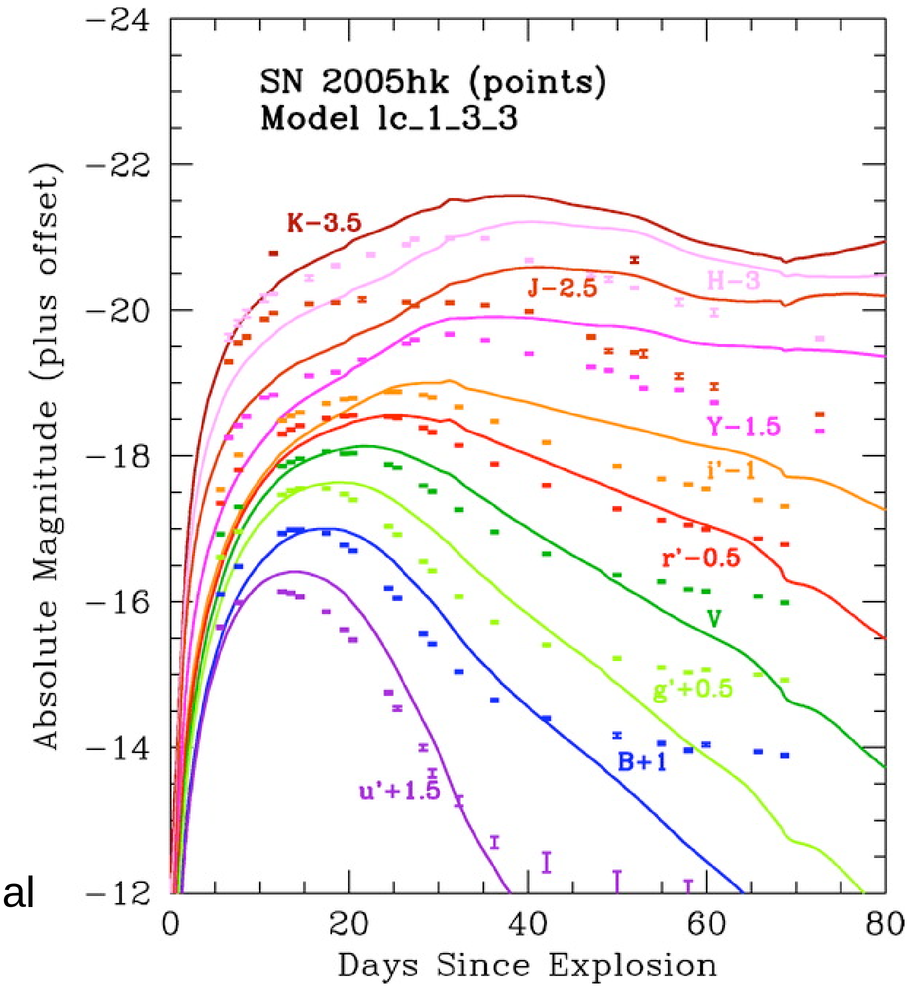


Phillips et al

- Pre-maximum spectrum has high ionization lines like 91T (Fe III, blue continuum)
- Unlike any typical Ia
- Unlike any 91bg-like subluminous Ia
- Late-time, unlike any supernova known, most similar to itself at an earlier phase (very low velocity Fe II lines)
- Features lighter than and including Fe at all epochs (Si, S, Ca, Na) => unburned material

02cx-like : Deflagration?

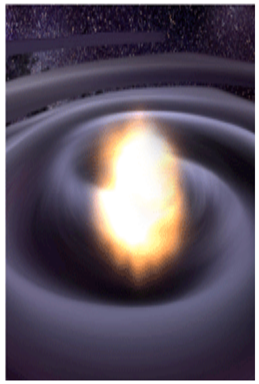




Phillips et al

- Radiation hydro-dynamics code STELLA to 3D model deflagration assuming 0.24 Msun of Ni, E_{kin} = 0.365 foe, rise-time of 15 days
- Reasonably consistent atleast for t<40days
- At late-time, decay is slower than predicted

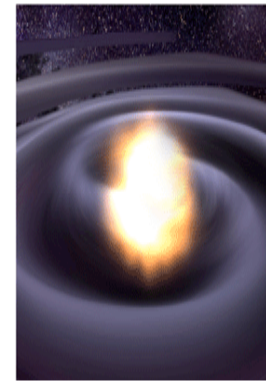
Disclaimer

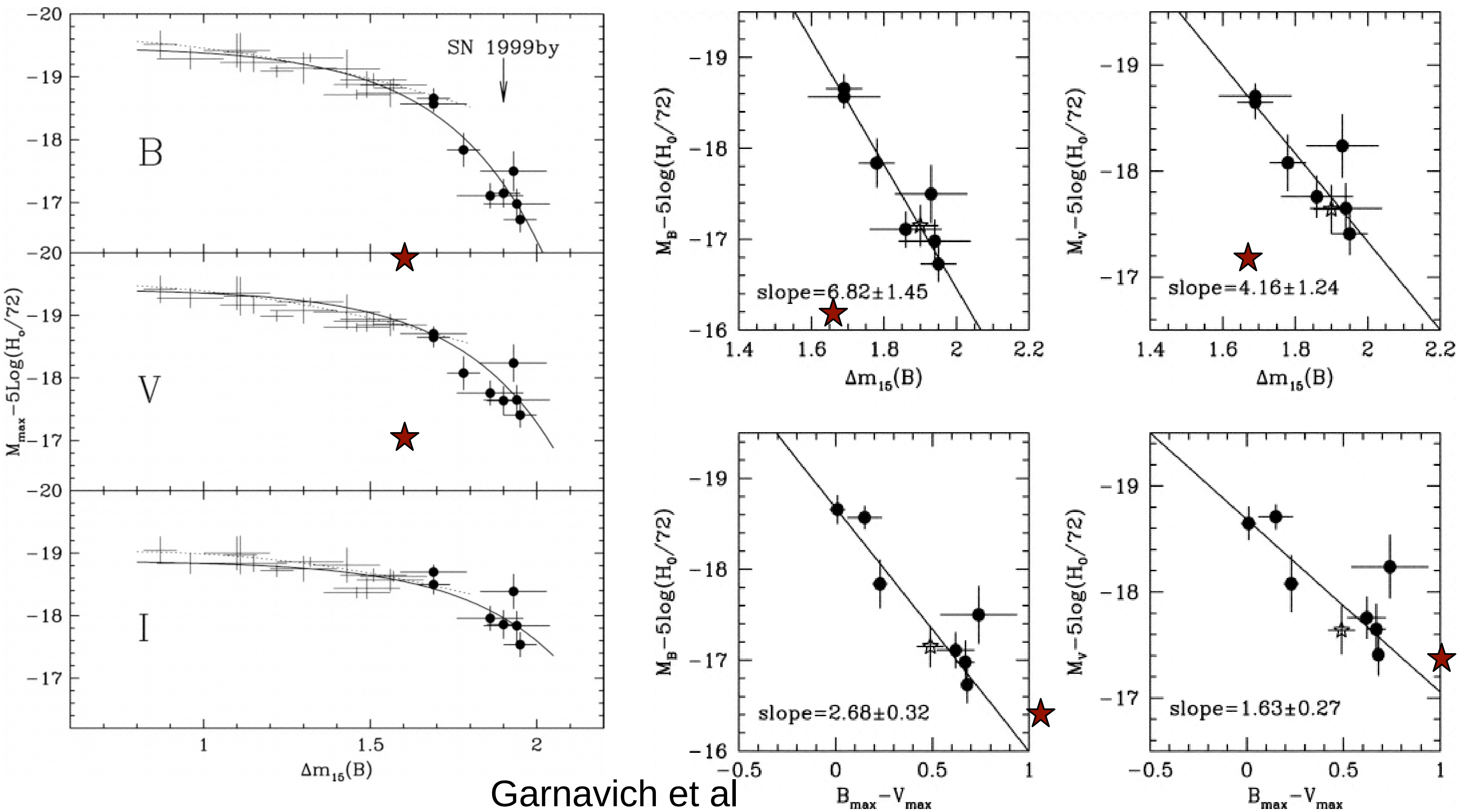


Work in Progress!

(SN2007ax : Kasliwal et al, in prep)

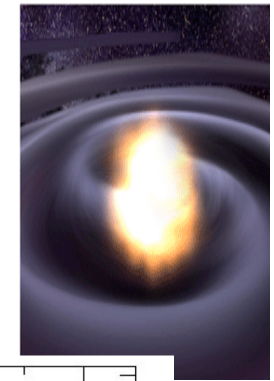
91bg-like Light Curve

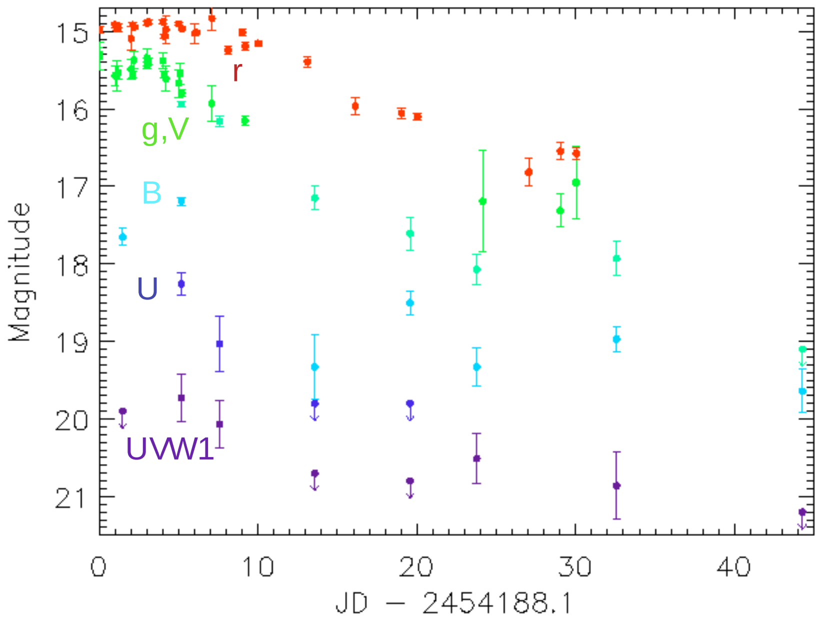


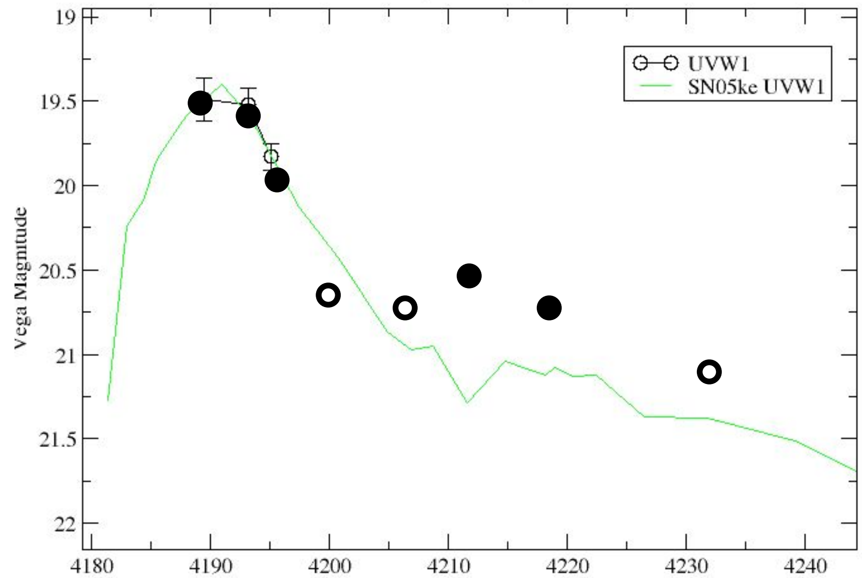


Garnavich et al

2007ax Light Curve

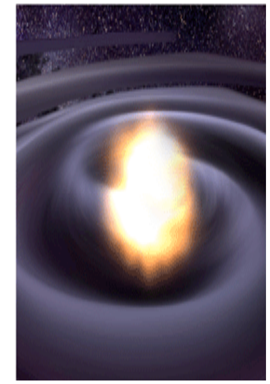


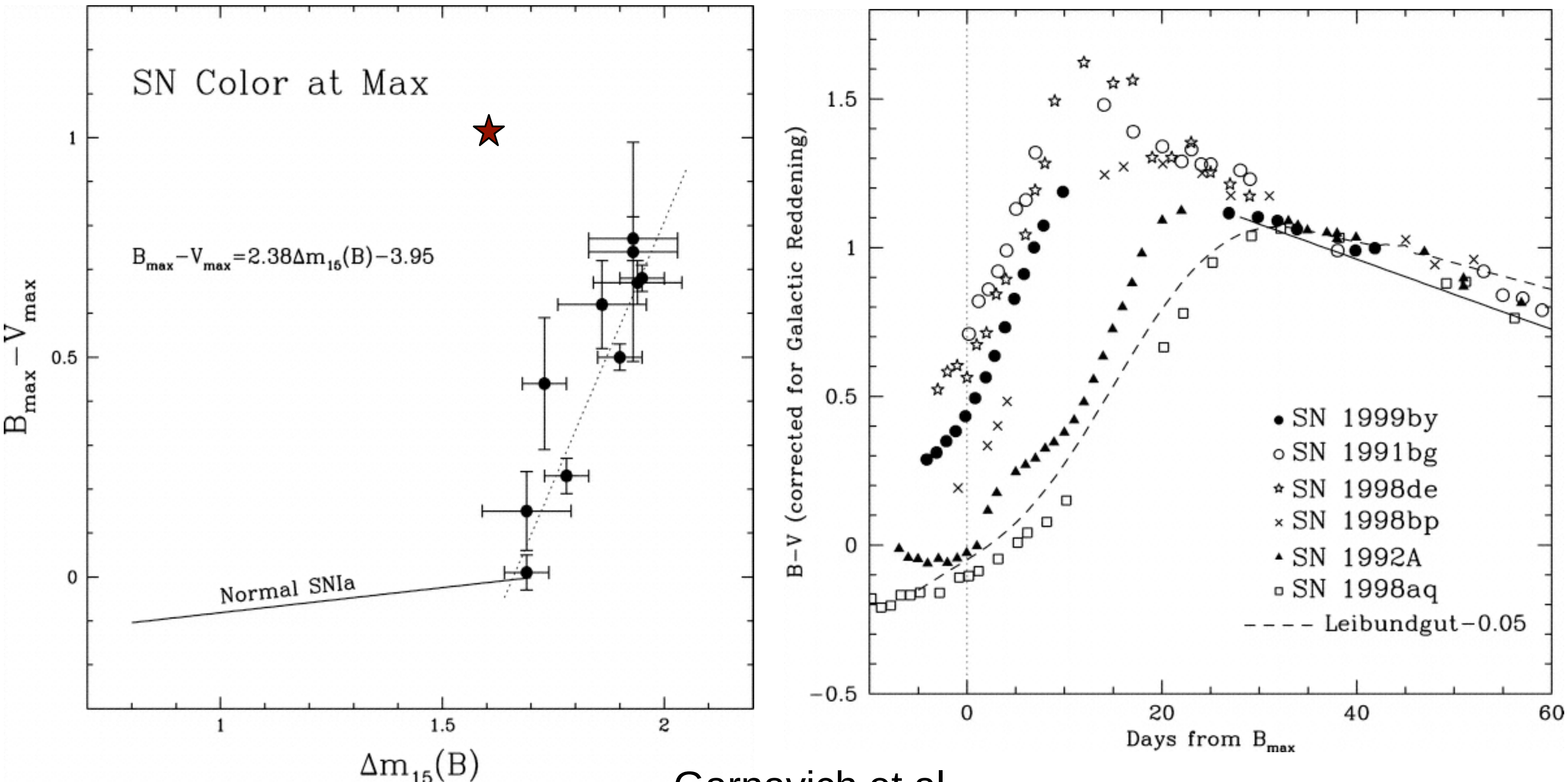




- Fast decline, not as fast as expected
- Sooner knee in Light Curve, hint of Second Peak
- UV Excess as in 05ke : lower UV opacity due to lower production of Fe group elements, CSM interaction, are all faint Ia UV-bright?

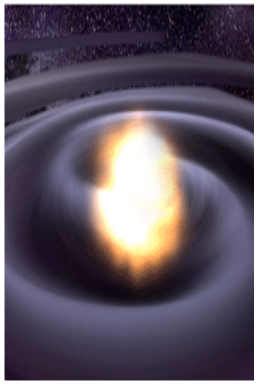
91bg-like Colors

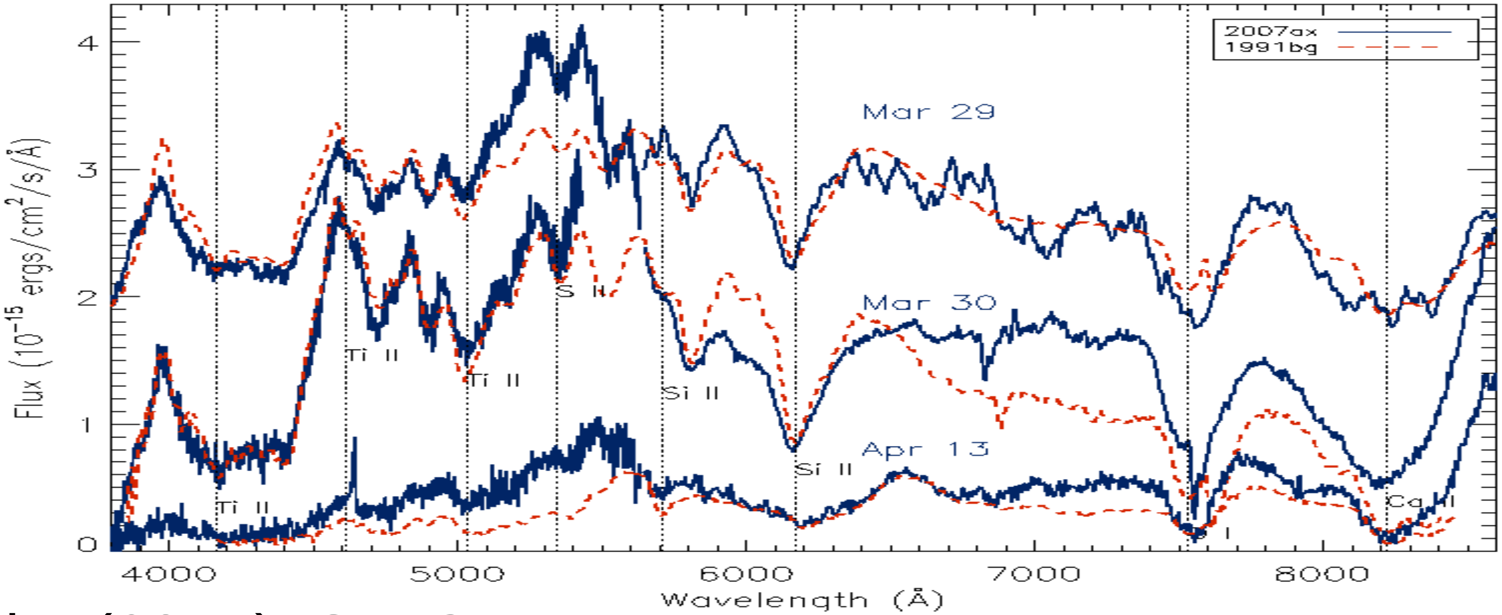




Garnavich et al

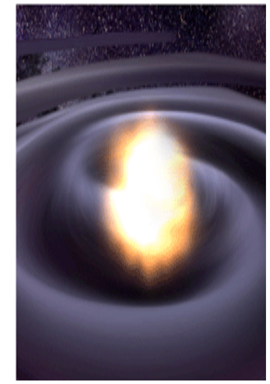
91bg-like Spectra

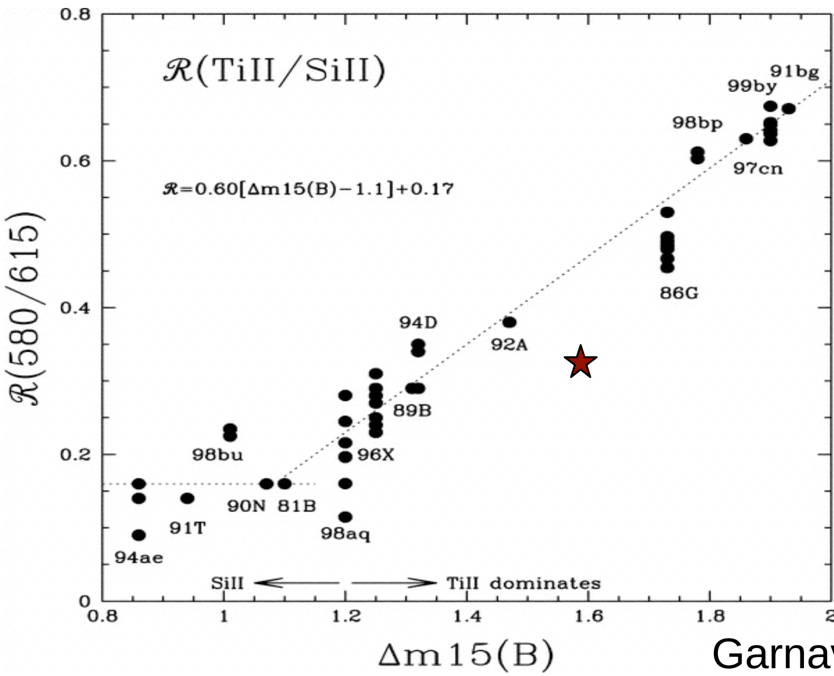


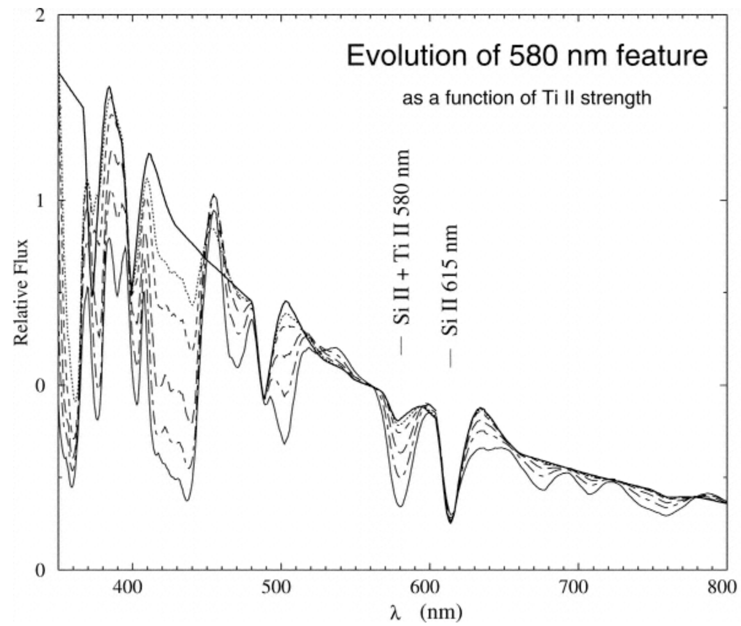


- Si II (6355), SII, Ca II => Ia
- Lack of Na D(5893) : minimal extinction
- Broad Ti II features : subluminous, low excitation temp
- Overplotted : 91bg @ t = 1,2,16 days
- OI/Mg II line : indicative of later phase?

91bg-like Temperature



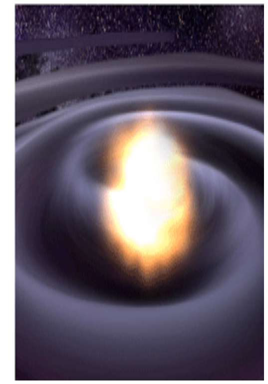


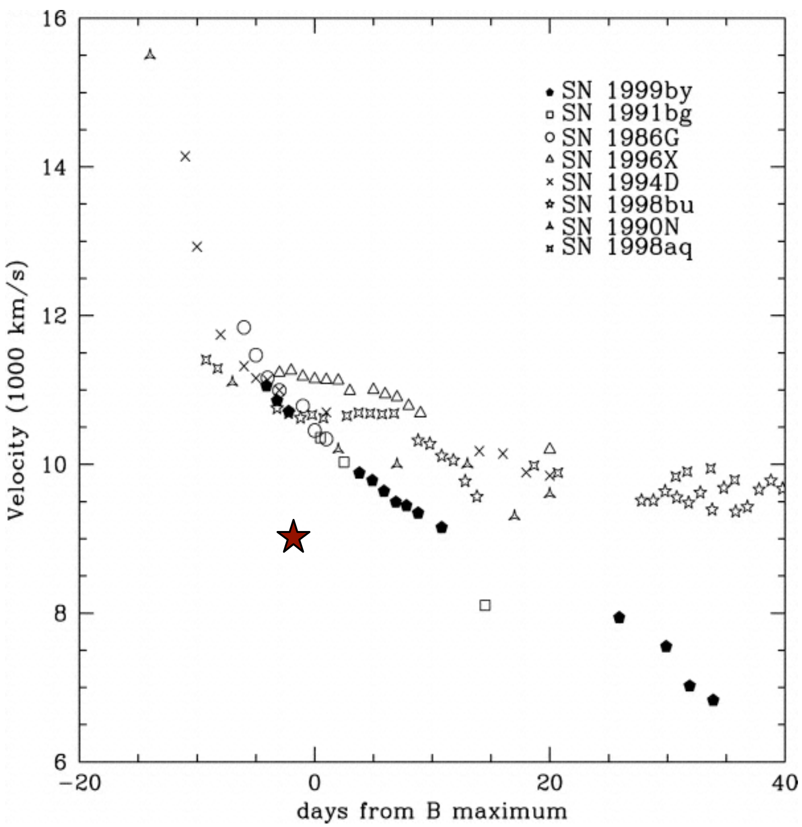


Garnavich et al

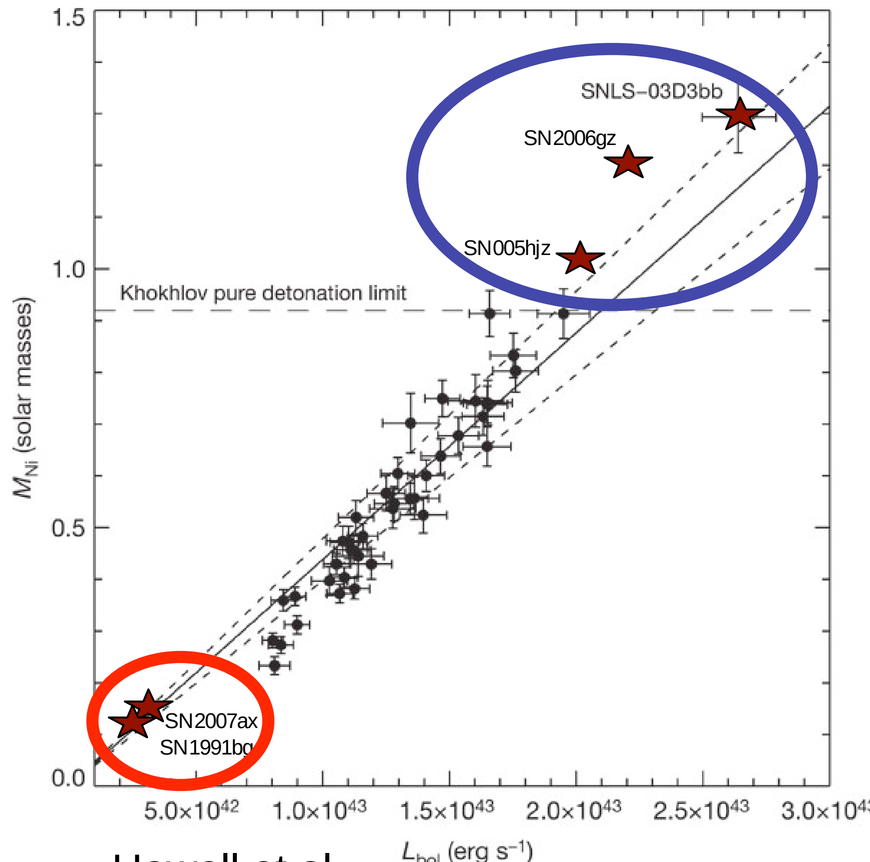
- (Right) SYNOW model of Si II and Ti II (varying) on a 12000K continuum
- (Left) Ratio of line depths of TiII/SiII as an indicator of luminosity, decline rate and temperature

91bg-like Si II Velocity and Nickel ejecta



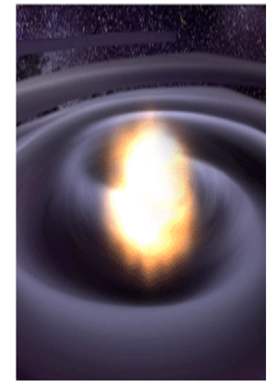


Garnavich et al



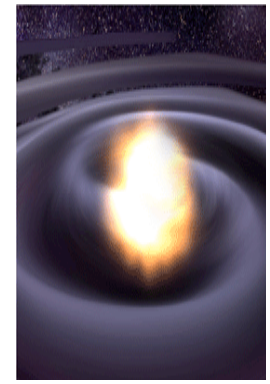
Howell et al

91bg-like Models I



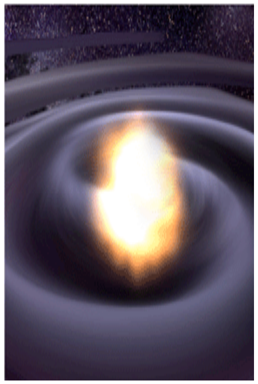
- Evidence of lower ejecta mass
  - Lower bolometric luminosity
  - Faster decline suggests less efficient trapping of γ-rays
  - Quicker knee in light-curve suggests optical depth to thermalized radiation becomes zero sooner
  - Lower ejecta velocity
- Complete detonation of a sub-Chandrashekhar mass C-O WD ?
  - BUT, too little Ni, too red at max, outer Oxygen shell
- Detonation of a O-Ne-Mg WD?
  - Smaller amount of nuclear energy and lower ejecta velocity

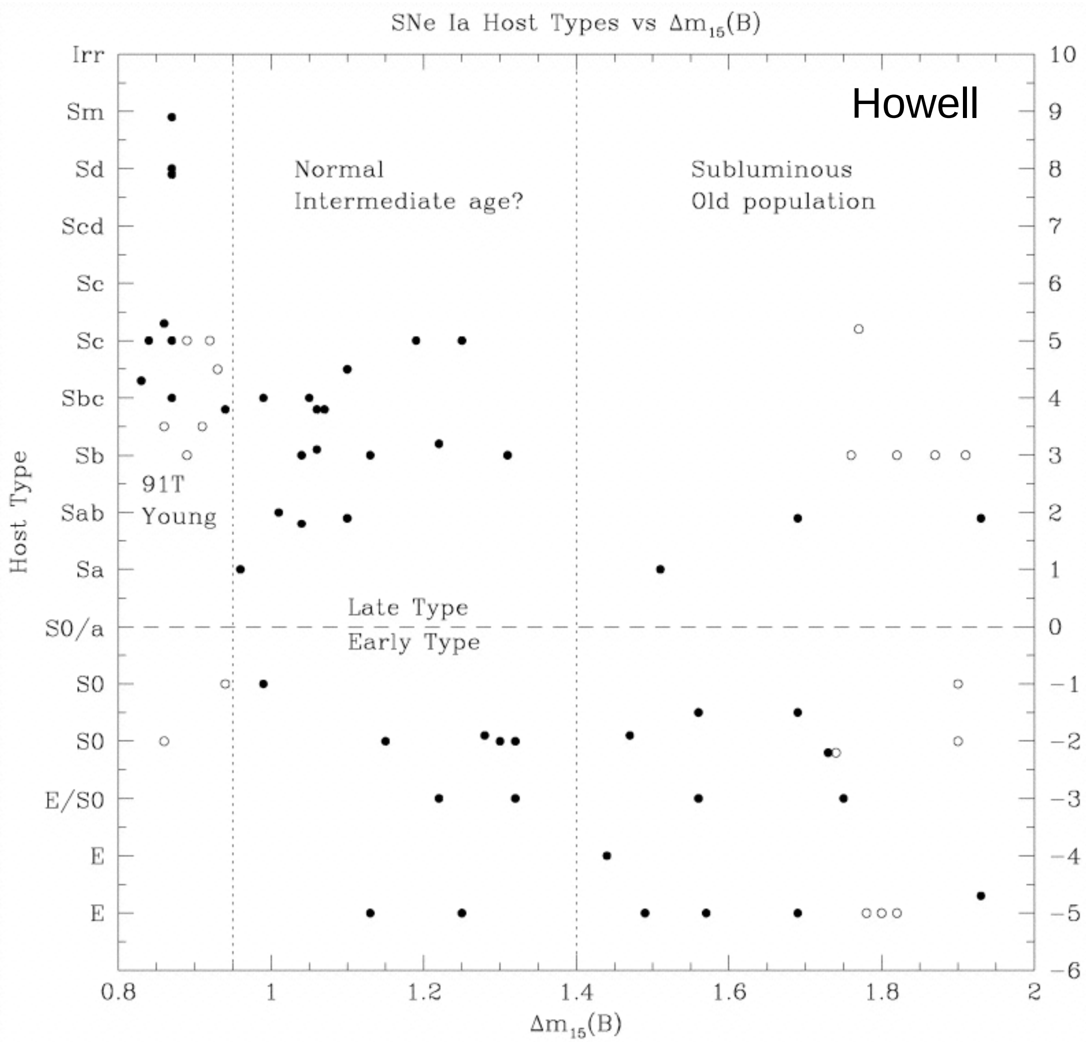
91bg-like Models II



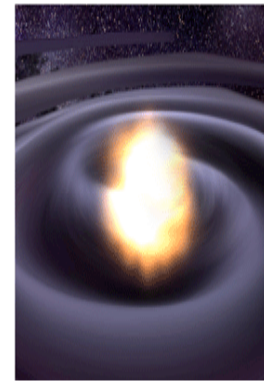
- Lazy Deflagration ?
  - Suggested by strength of elements of intermediate mass (Ti II) and deficit of Fe II
  - But, expect lower velocities of ejecta than observed
- Small-scale Deflagration ?
  - Only outer layers of a normal C-O WD binary burn
  - Only nucleus burns
- Rapid Accretion of CO from WD companion
  - Premature ignition of CO near WD surface
  - “failed Neutron Star”

Type Ia SNe Hosts



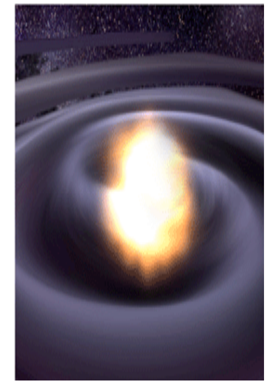


Next Generation Surveys



- Filter : VRI okay
- Cadence : <3 days
- Depth : M = -15 @ 100 Mpc is m=20.0
- Pointing : Virgo (32), Coma (35), Perseus (34.3), early-type
- Follow-Up : UBVI photometry(daily until knee, every 3 days after), spectra (@ t = -5,0,+5, +50, +200)
- Rates : 1-10%? of Normal Type Ia rate

Discussion



- WD-RD models appear to be the norm, and WD-WD models appear to be invoked to explain the extremely bright and extremely faint ends - Why?
- What determines the minimum nickel mass or ejecta mass?
- Are the numbers of faint Ia so few only because of an observational bias and constraint?
- Could some of the very peculiar SN be triples?
- Why are fainter supernovae significantly redder but possibly, UV bright? What about IR?
- What will AMCVn Ia spectra look like?