Observational Constraints on Supernova Progenitor Evolution

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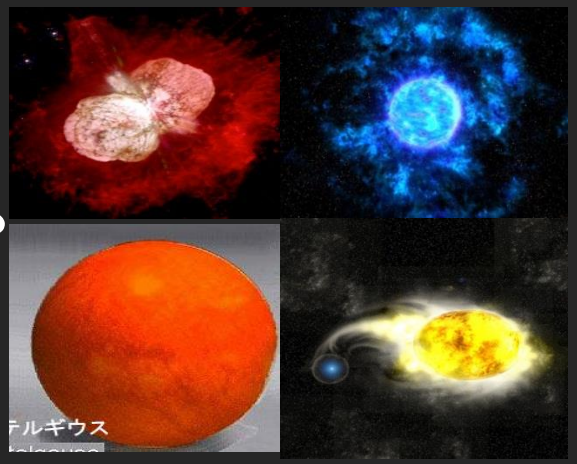
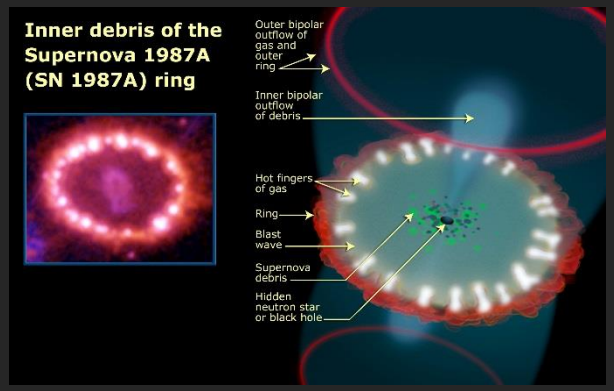
Supernova 2014J in Galaxy M82
Hubble Space Telescope ▪ WFC3/UVIS ▪ ACS/WFC

Progenitor – CSM - explosion

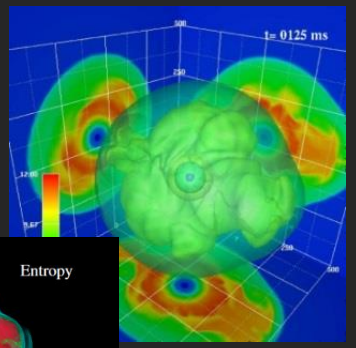


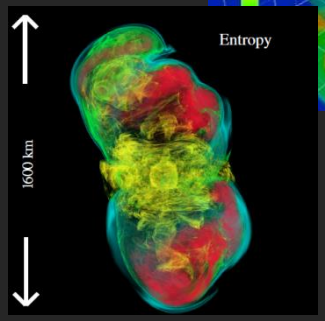
Progenitor?
Metallicity
Rotation
Binarity
…

CSM environment?
Mass loss
Stellar wind
Instabilities
Binary



Explosion?
Key mechanisms
Diversities





Goal: Uncovering the mutual links.

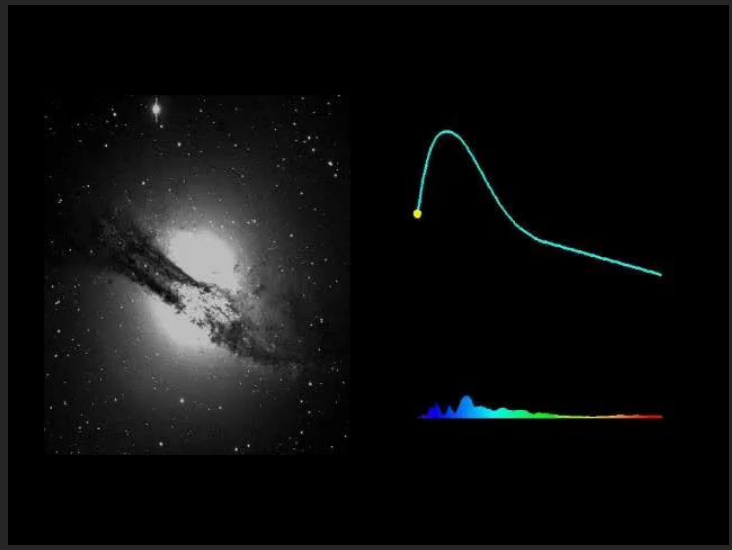
Observational Characteristics of Supernovae

- > 1000 discoveries a year (dep. on surveys).
  - **Only a part** (nearby) observed in detail.
- Distance > ~ 10 Mpc (extragalactic).

  - **Point sources** (except for a few by HST/AO/VLBI).
  - Typical maximum mag. V > ~ 16 mag（roughly）.
- Most of obs. = Optical.
  - Imaging + spectra (time-dep.)

⬇ Interpretation

Supernova Physics
（e.g., exp. mech.）



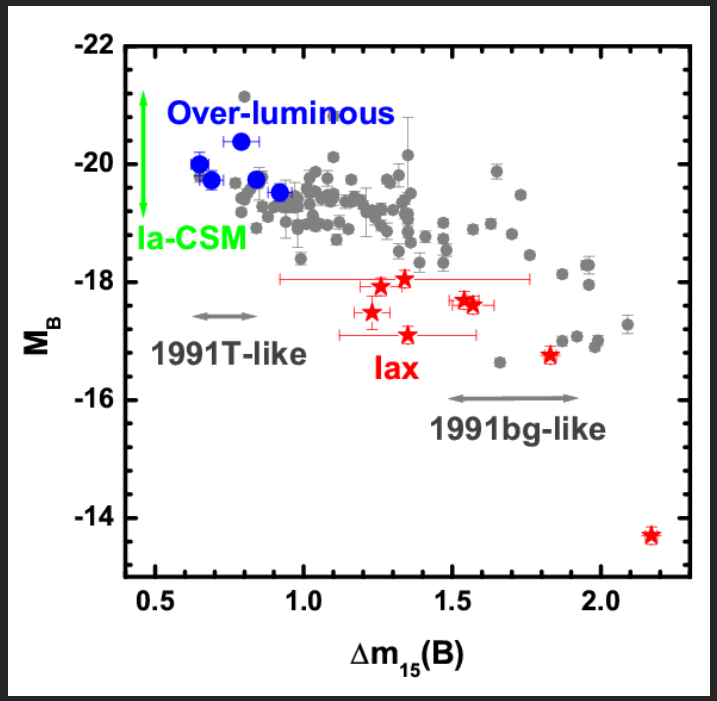
Type Ia Supernovae (SNe Ia)

- Thermonuclear explosions of a (nearly) Chandrasekhar-mass white dwarf (WD).
- **But we do not yet know what make them.**
- **Multiple populations?**

Single Degenerate (SD)

Double Degenerate (DD)

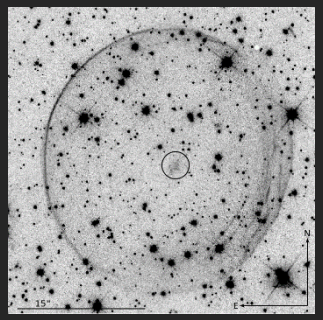
Link?



KM, Terada 2016

Keys:
Companion & CSM

SD Companions in pre-SN/SNRs

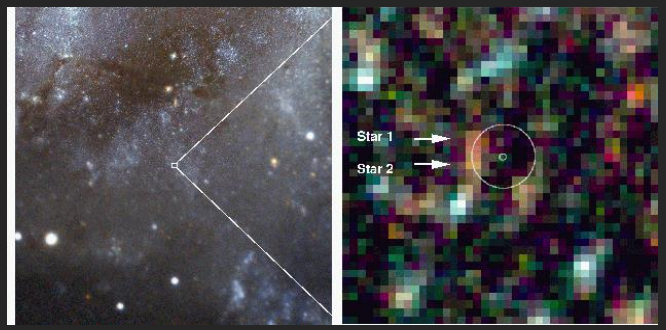


LMC SNR 0509-67.5: Against RG/MS

Schafer & Pagnotta 2010

SN 1006: Against RG González Hernández+ 2012

Tycho: Controversial Ruiz-Lapuente+ 2004, …



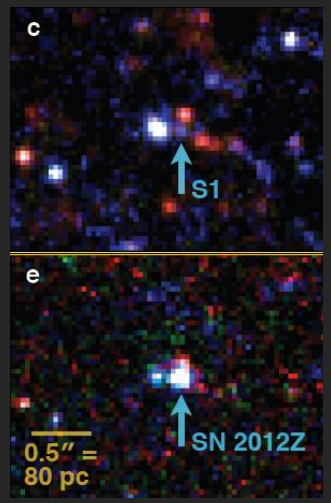
Li+ 2011

SN 2011fe: Against RG down to ~ 1 $M_\odot$

SN 2014J: Against RG down to ~ 1 $M_\odot$

Kelly+ 2014 and some He donor

So far, seems to disfavor SD for normals.



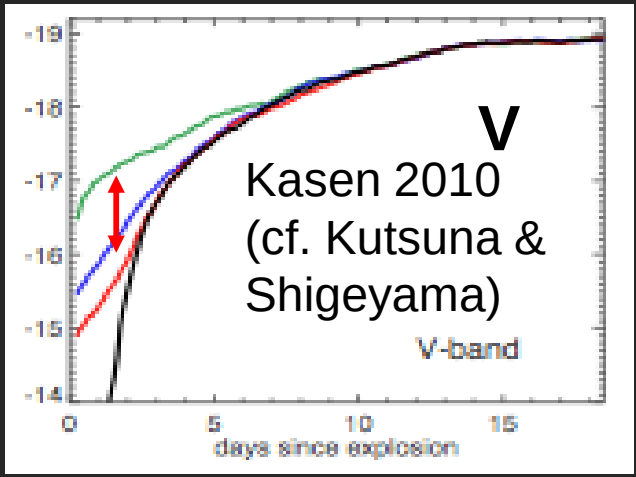
McCully+ 2014

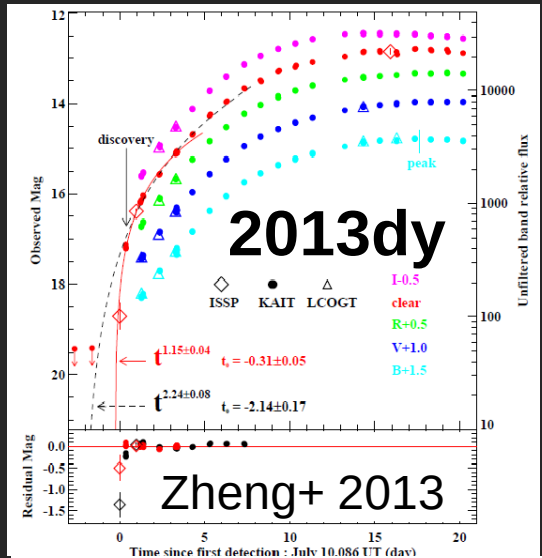
SN "Iax" 2012Z: He donor? He star progenitor?

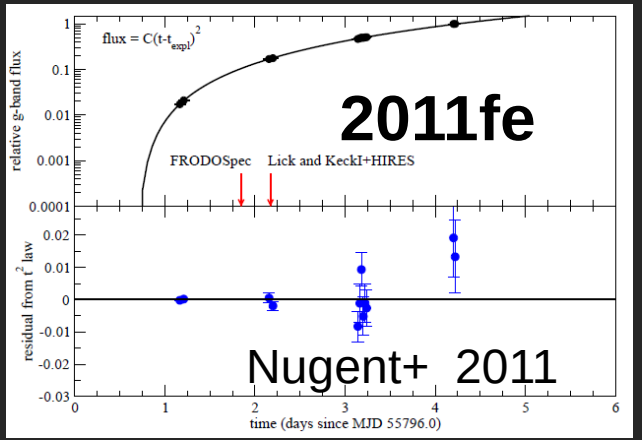
SN "Iax" 2008ha: Red source (post-SN). Foley+ 2014

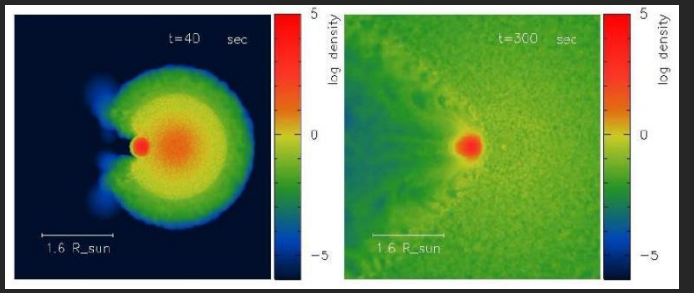
So far, seems to favor SD for outliers (SNe Iax).

No Crush of the SN ejecta w/ SD companion

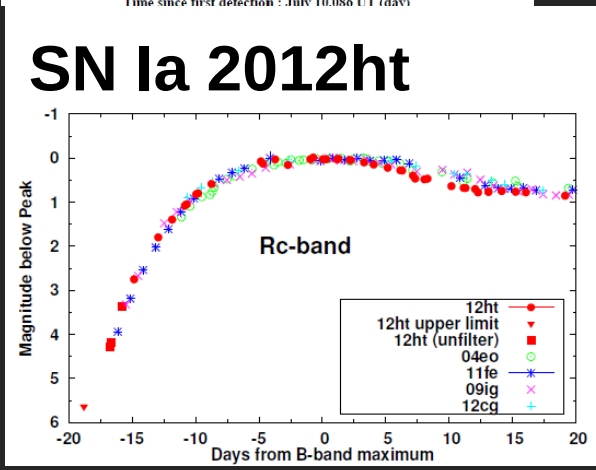


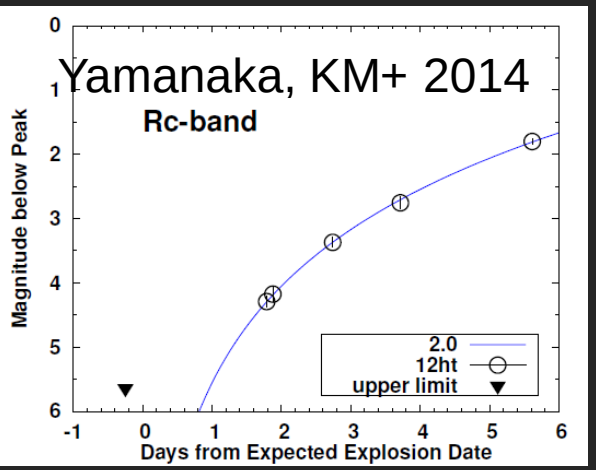






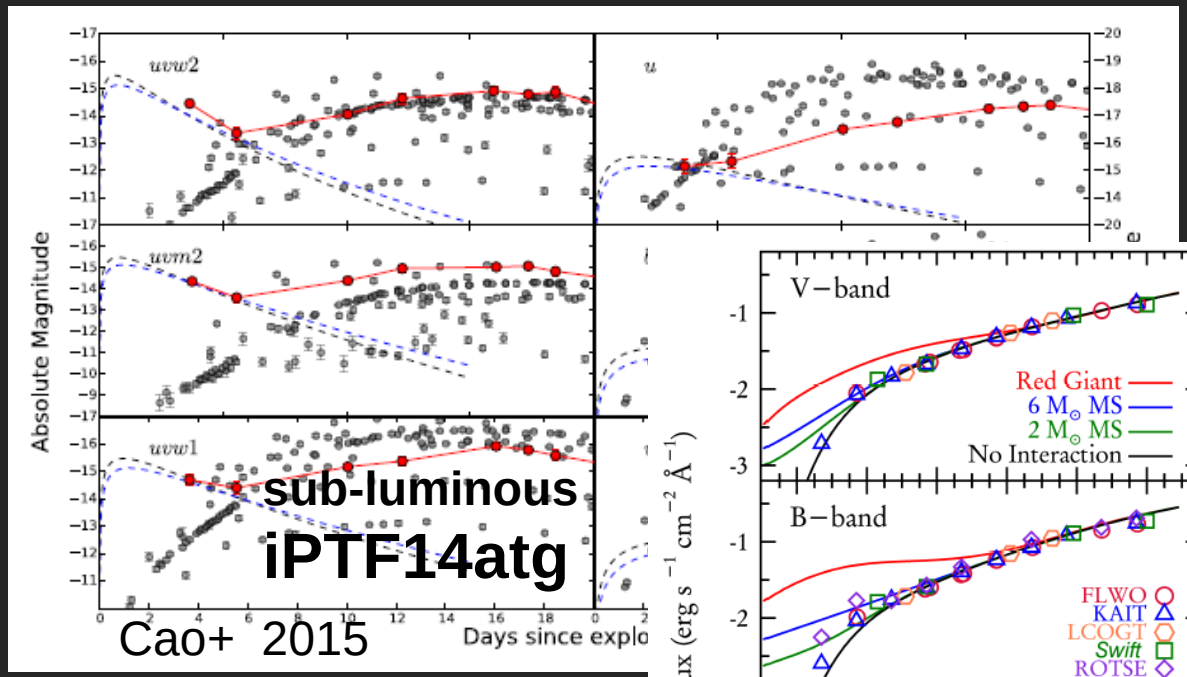
Liu, …, KM+, 2013

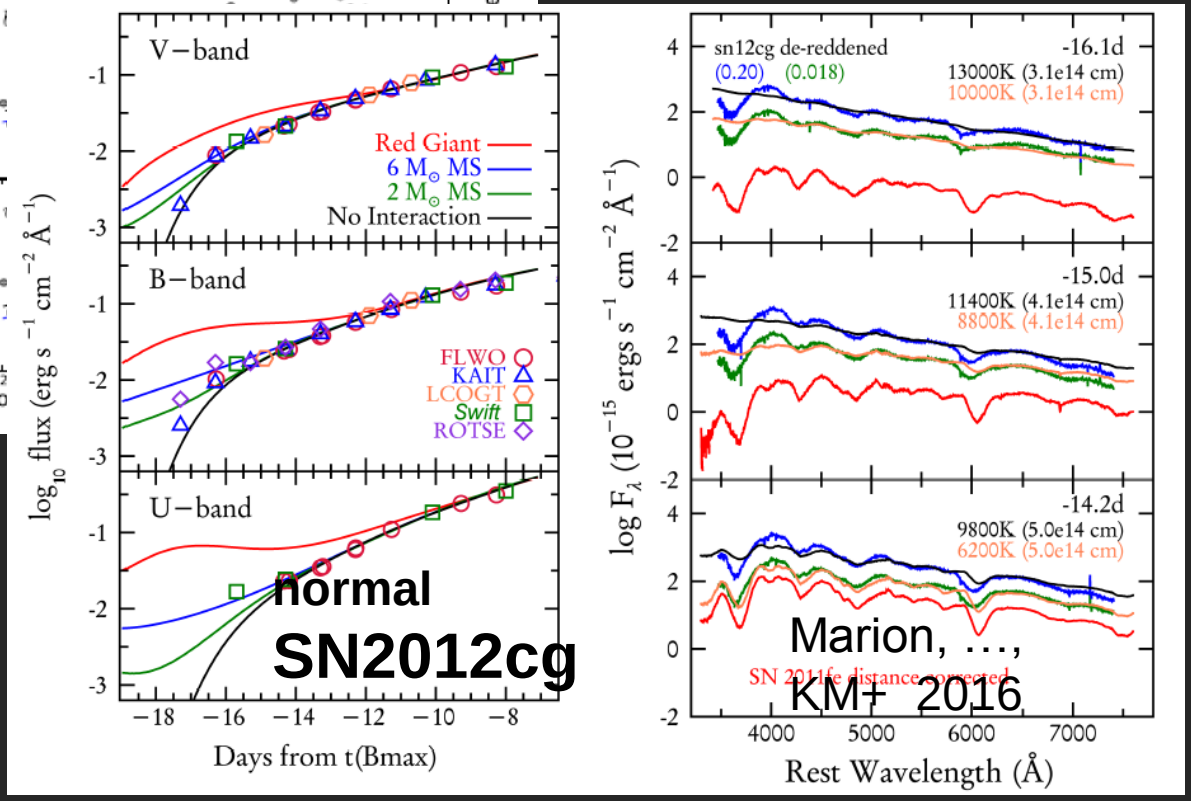




#possible – SNe 2011de (Brown 2014), 2014J (Goobar+ 2014)

Crush of the SN ejecta w/ SD companion

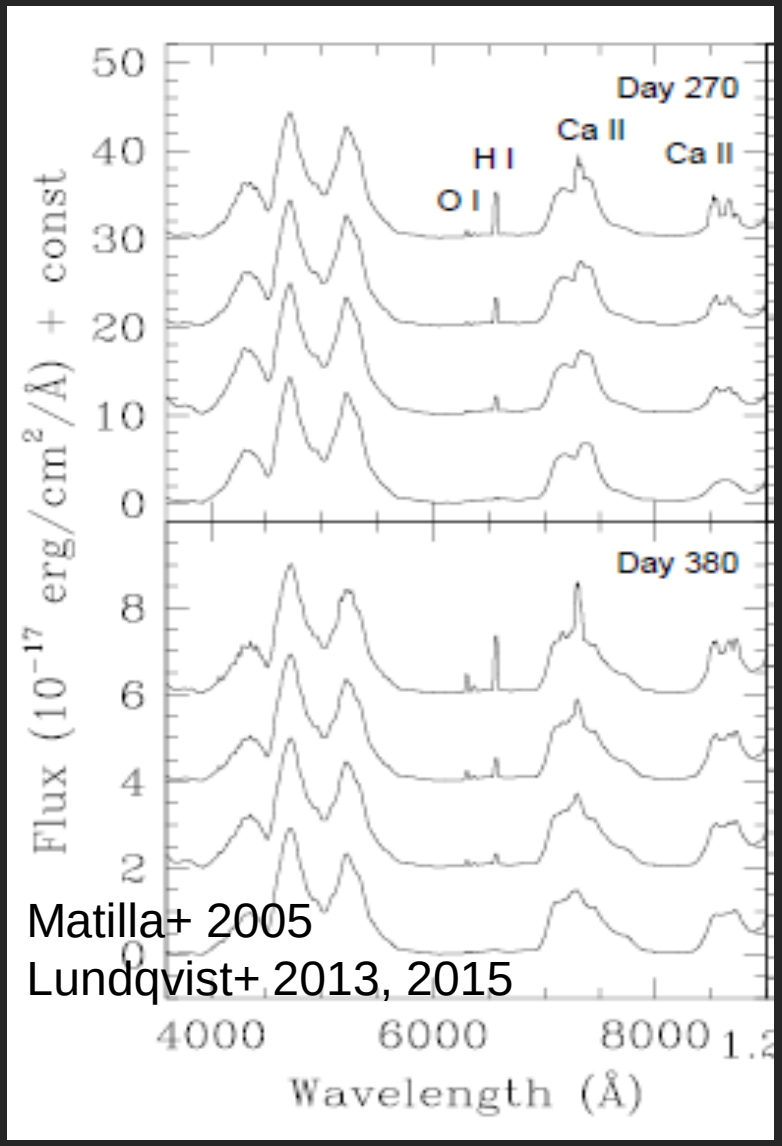




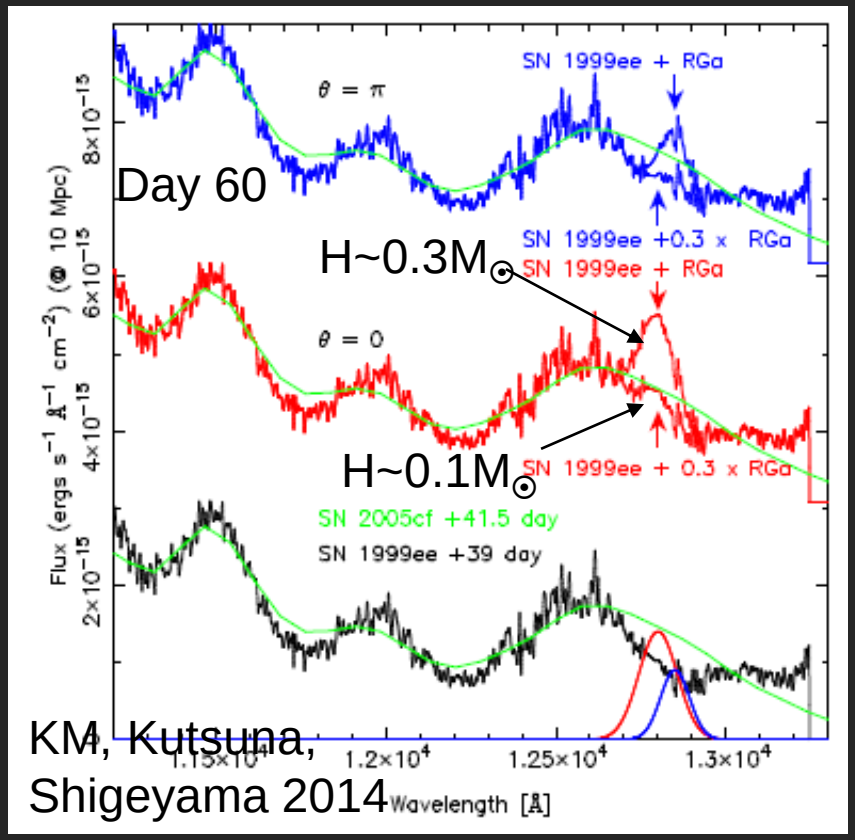
First detected for an outlier, but then for normal.
Observed only for a specific direction?

Examples with possible signatures

No Signatures of a companion in late phases



Matilla+ 2005
Lundqvist+ 2013, 2015



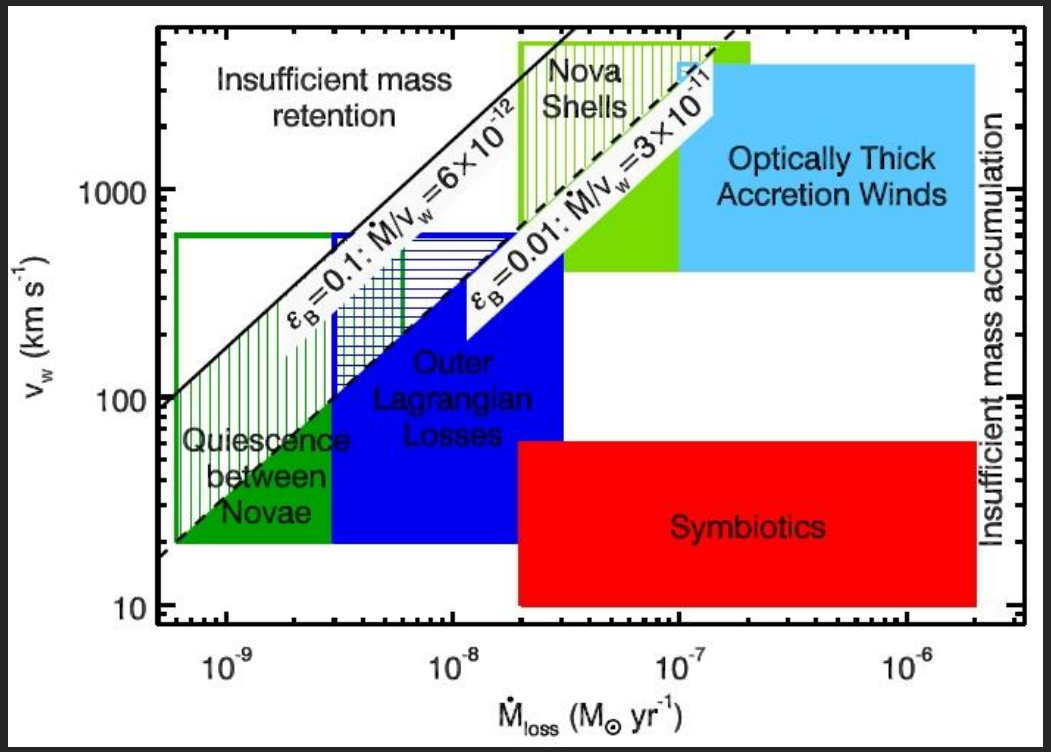
KM, Kutsuna, Shigeyama 2014

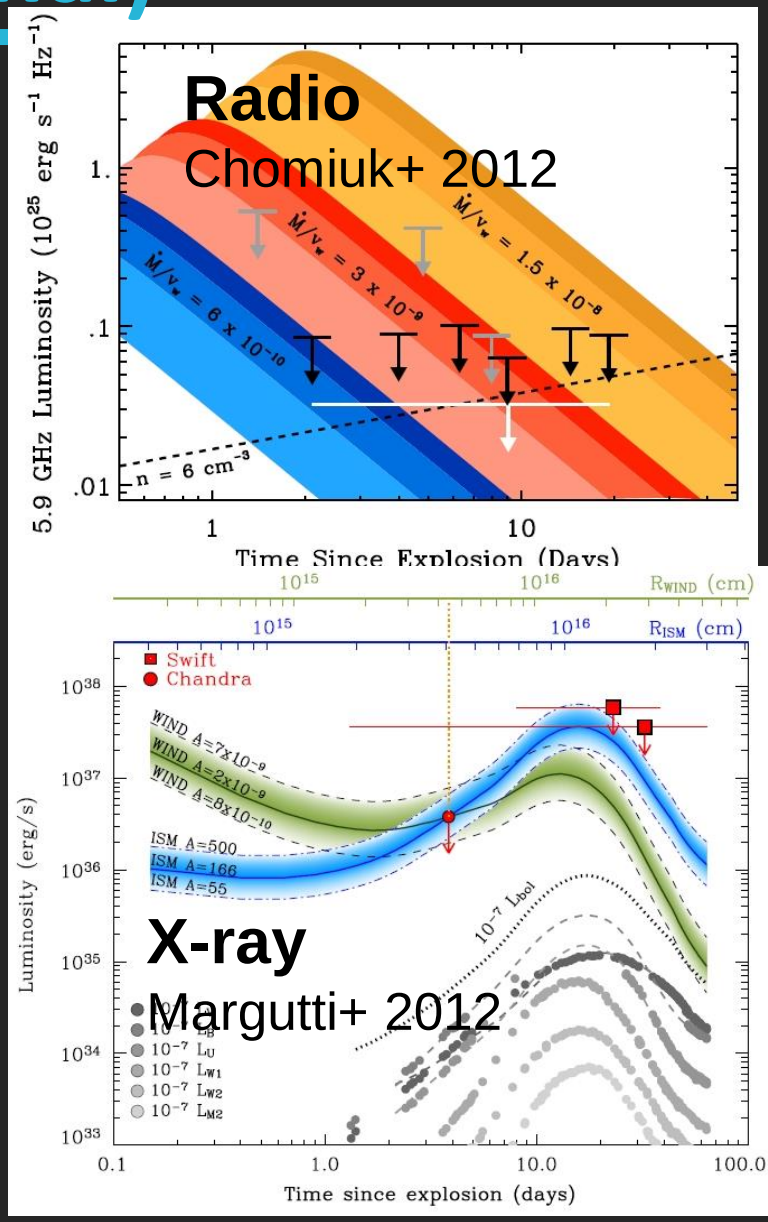
No signature of contaminated H-envelope so far
(but the observation is tough).
How consistent with the “crush”?

Back in the history of ~ 100 day x ($V_{SN}/V_{mass\text{-}loss}$) ~ 30 yrs (~ 0.01 pc)

No Crush into CSM (normal)

Tight limit for SN 2011fe (<0.01pc):
M_{dot}/v_w < ~$10^{-8} M_\odot yr^{-1}$/100km s^{-1}

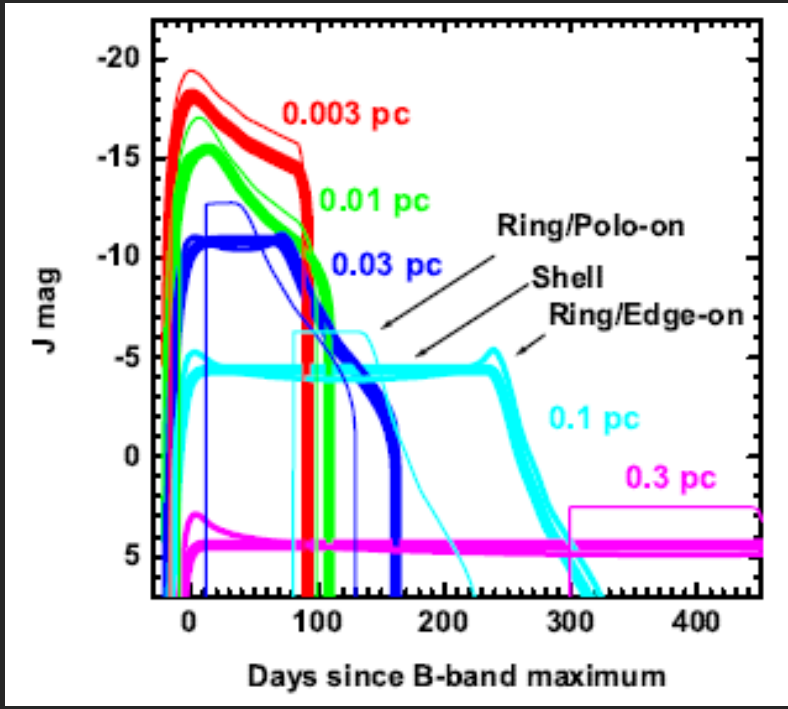


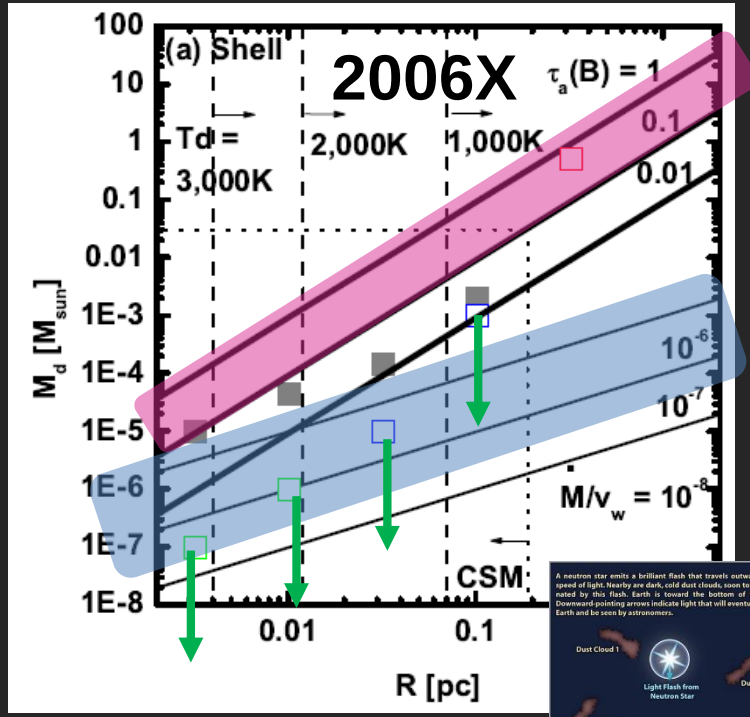


Radio: Synchrotron
X-Ray: Inverse Compton (+ thermal)

Back in the history of ~ 100 day x ($C/V_{mass\text{-}loss}$) ~ 300 yrs (~ 0.1 pc)

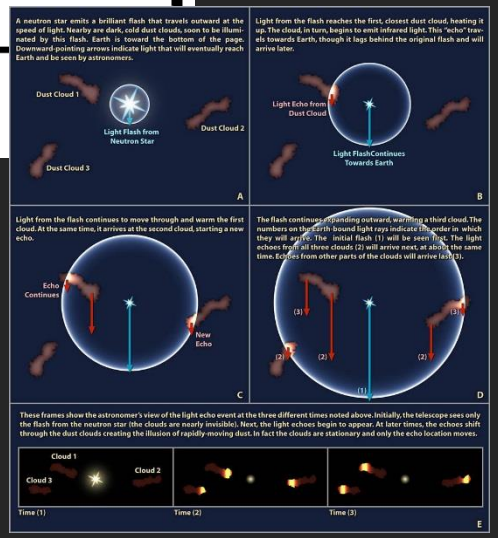
No echo by CS Environment (normal)





CSM extinction

Symbiotic Model (SD)



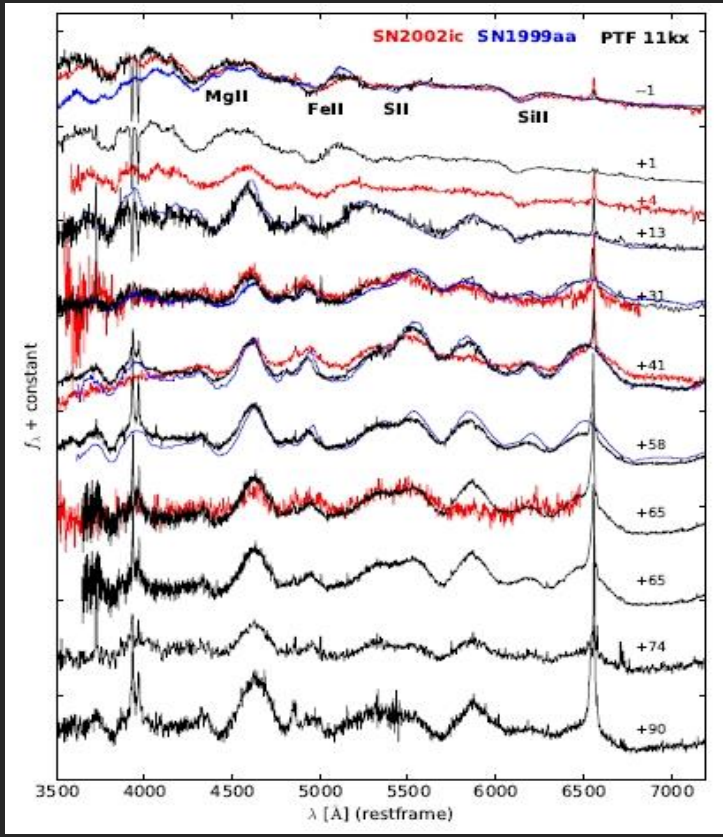
No CS-dust echo seen in (normal) SNe Ia.
There is little CSM (dust) at R < 0.5pc.

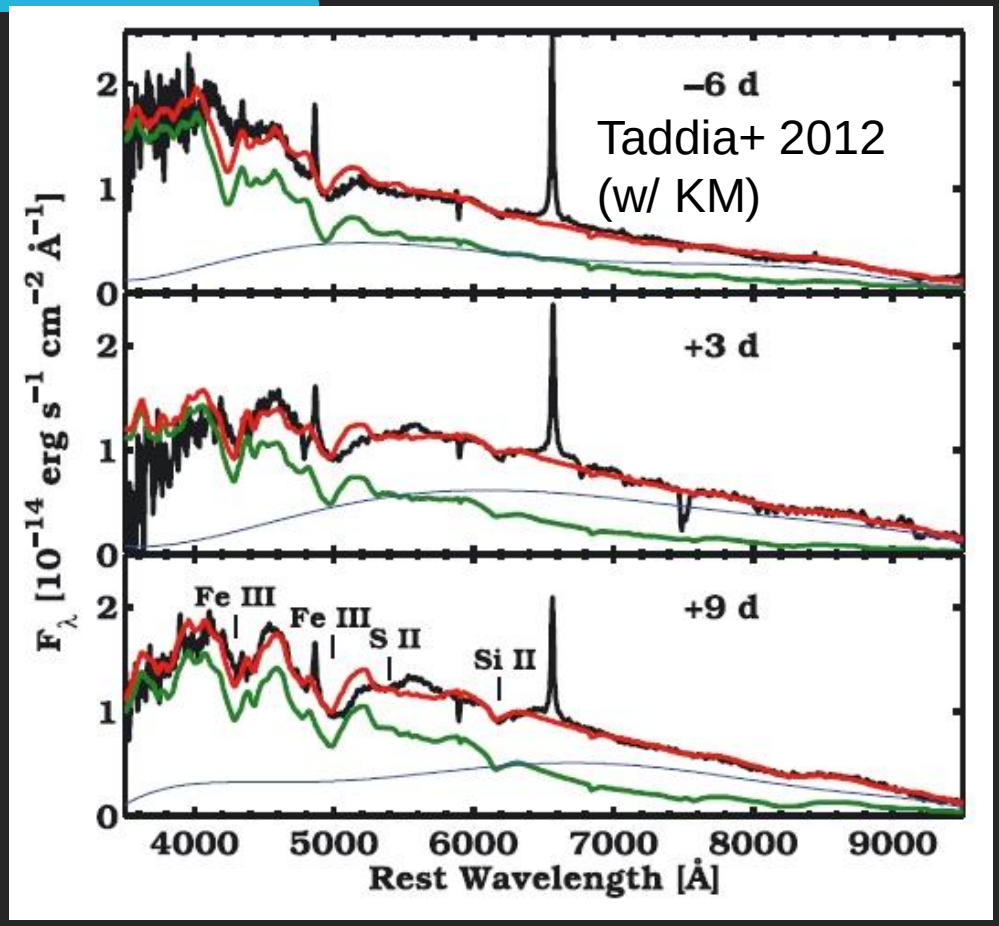
 # SNe Ia's extinction produced by CSM? (Goobar 2008) ⇒ generally not the case.

KM, Nozawa, Nagao, Motohara 15; Nagao, KM, Nozawa+ 16

Crush into CSM (Ia-CSM)

Dilday+ 2012



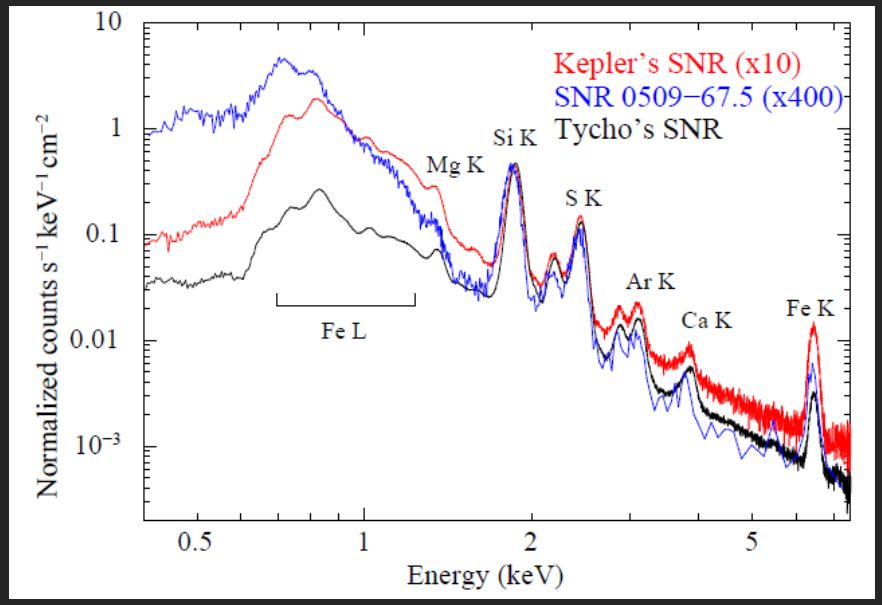


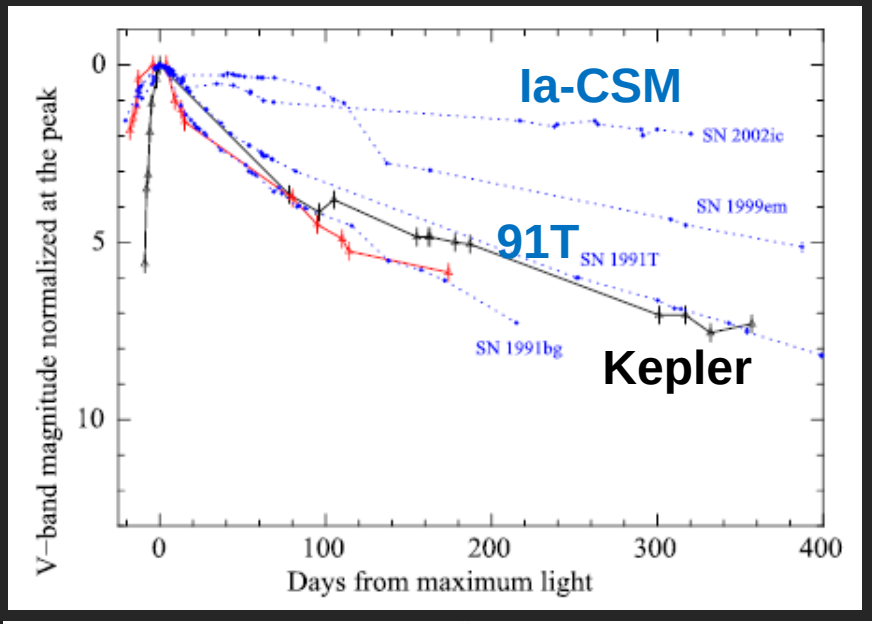
SNe Ia colliding with Nova shells? (← Single degenerate)

Associated SNe are SN 1991T-like (bright SNe Ia)

Leloudas, …, KM+ 2015

A Link between 91T-like and Ia-CSM





Kepler

Katsuda, Moti, KM+ 2015

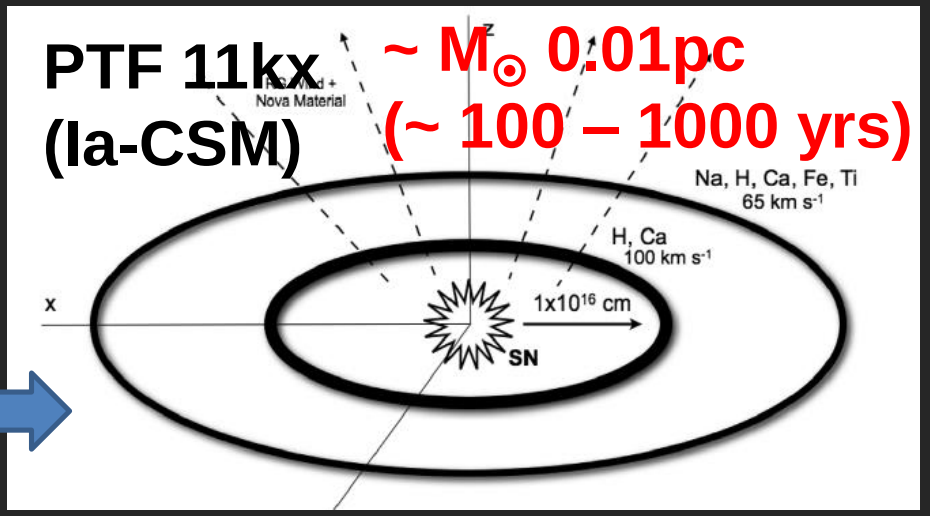
Ejecta abundance & hist. LC

⇒SN type: bright 91T-like

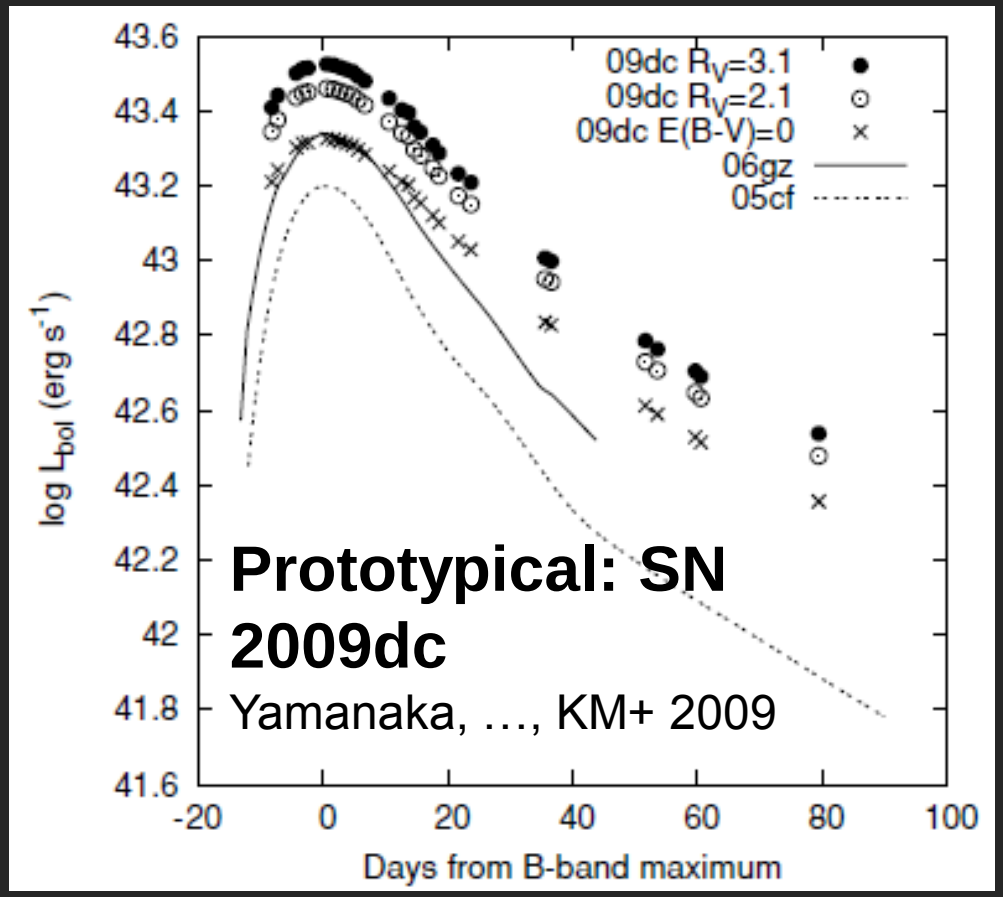
CSM amount + distribution

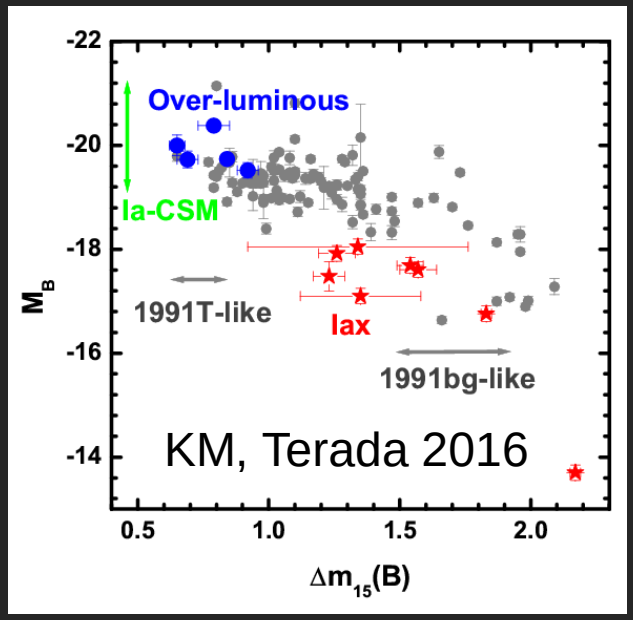
⇒Mass loss history:

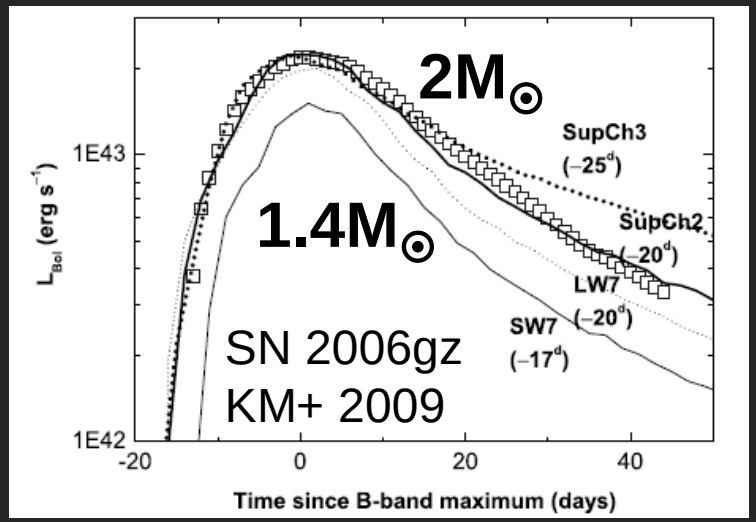
> $0.3M_{\odot}$ @ 2pc ($10^{4\text{-}5}$ yrs)



Over-luminous Ia: Super-Chandra WD?





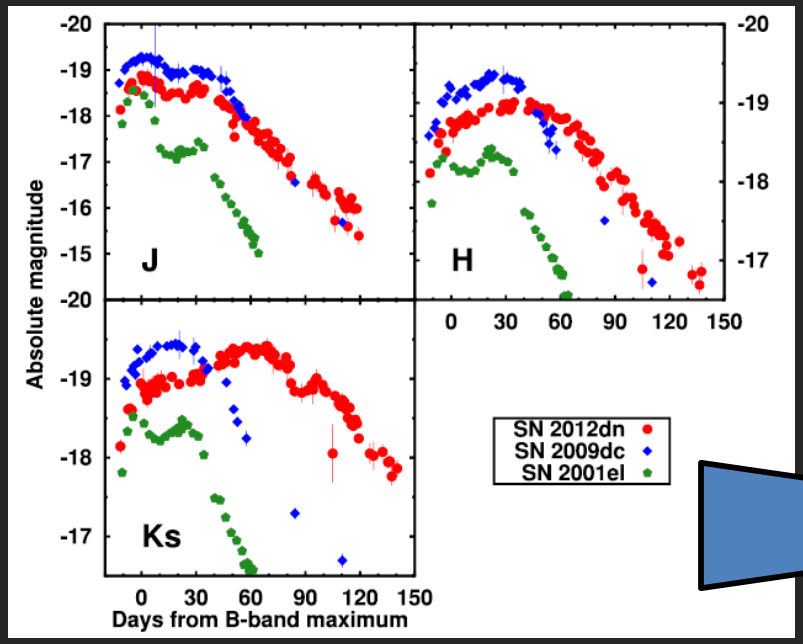


Bright, M(^{56}Ni) > 1M$_\odot$.

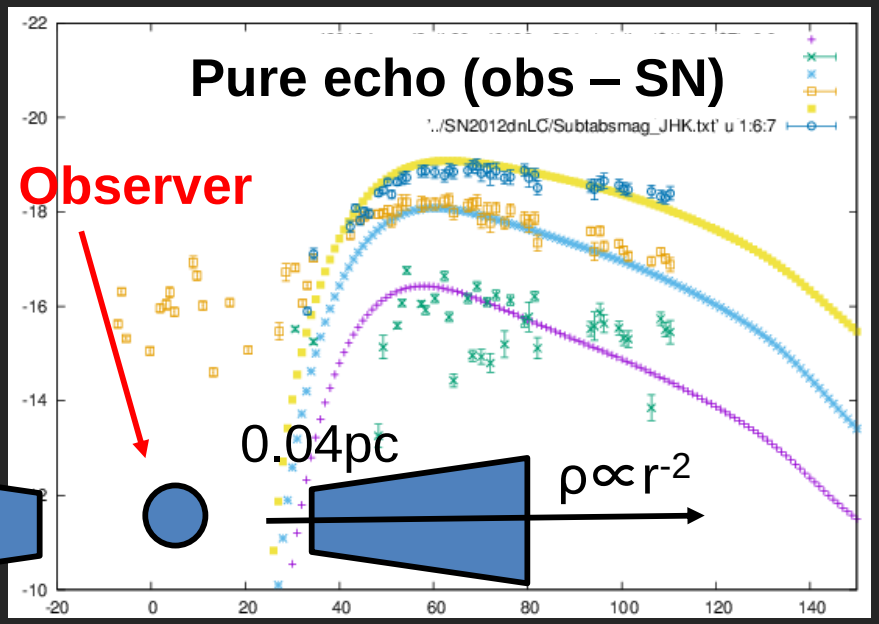
M_{ej} > 1.4M$_\odot$: “Super Chandra WD”

Echo by CS environment (over-luminous Ia)

Yamanaka, KM+ 2016



Nagao (D1), KM, Yamanaka, in prep.



Discovery of bright & Long-lasting NIR emission by OISTER ToO.

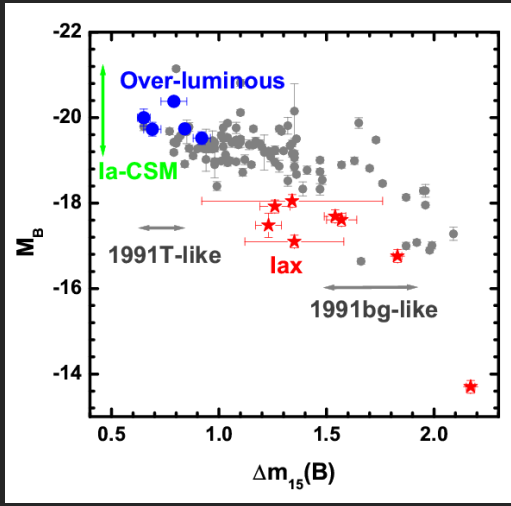
"Plateau-like evolution, ~ 1,000K thermal emission"

← As predicted for a CS echo (KM+ 2015)

⇒ More sophisticated model: geometry, etc (Nagao+, in prep.).

~ 4 10^{-6} $M_\odot$ yr^{-1} ⇒ SD for overluminous SNe?

SNe Ia: Summary



A review article by KM & Terada (2016)

Normal:
DD > SD?
Outliers:
SD?
Still incomplete.

Observations	Delayed Detonation		Failed Deflagration		Double Detonation	Violent He	Violent C
	SD[b]	DD	SD	DD	SD	DD	DD
Normal SNe Ia							
Companion							
Direct	×	○	×	○	△	○	○
Early Emission	△	○	△	○	△	○	○
Hydrogen	△	○	△	○	○	○	○
CSM							
Radio/X	×	○	×	○	×	○	○
Echo	△	○	△	○	○	○	○
Abs. Sytems	○	△	○	△	○	△	△
Explosion							
Spec./LC/pol.	○	○	×	×	△	△	△
Nucleosynthesis	○	○	×	×	×	×	×
γ-ray (2014J)	△	△	···	···	○	○	△
SNe Iax							
Companion							
Direct	△	×	△	×	○	×	×
CSM							
Echo	○	×	○	×	○	×	×
Explosion							
Spec./LC/pol.	×	×	○	○	×	×	×
Nucleosynthesis	○	○	○	○	×	×	×
Over-Luminous							
CSM							
Echo	○	×	○	×	△	×	×
Explosion							
Spec./LC/pol.	○	○	×	×	△	△	△
Ia-CSM/1991T							
CSM							
Interaction	○	×	○	×	△	×	×
Abs. Sytems	○	×	○	×	△	×	×
Explosion							
Spec./LC/pol.	○	○	×	×	○	○	○