1991T – like Supernovae (Type Ia)

M. M. Phillips,[1] C. Ashall,[2] Peter J. Brown,[3] L. Galbany,[4,5]
M. A. Tucker,[6,7,8,†] Christopher R. Burns,[9] Carlos Contreras,[1]
P. Hoeflich,[10] E. Y. Hsiao,[10] S. Kumar,[10,11] Nidia Morrell,[1] Syed A. Uddin,[3]
E. Baron,[12,13,14] Wendy L. Freedman,[15] Kevin Krisciunas,[3] S. E. Persson,[9]
Anthony L. Piro,[9] B. J. Shappee,[16] Maximilian Stritzinger,[17]
Nicholas B. Suntzeff,[3] Sudeshna Chakraborty,[10] R. P. Kirshner,[18,19]
J. Lu,[10] G. H. Marion,[20] Abigail Polin,[9,21] and M. Shahbandeh[10]

(arXiv:2405.15027v1)

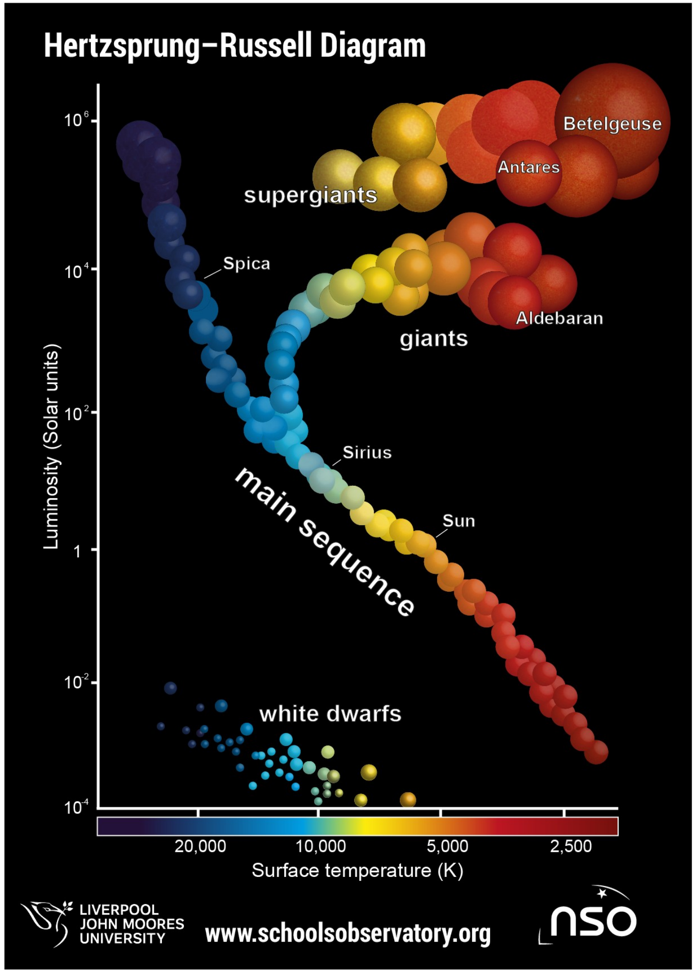
Brajesh Kumar
(Group meeting, 2024/06/28)

Type Ia supernovae (SNe)

- One of the **brightest** and most common objects in the Universe.
- These are **cosmic distance indicator**.
- The **origin of iron peak elements** (^{56}Fe, ^{56}Co, ^{56}Ni, …).
- **Thermonuclear explosions of white dwarfs (WDs),** opposite to core-collapse supernovae (explosion due to core collapse of massive stars).

White Dwarfs (WDs)

- The end products of stellar evolution for the vast (~95%) majority of stars.
- Most WDs have a C-O core (containing ~99% of the total mass) surrounded by a thin He mantle (~1% at most).
- WDs are compact cooling bodies in hydrostatic equilibrium; (gravity is balanced by the degenerate electron pressure).

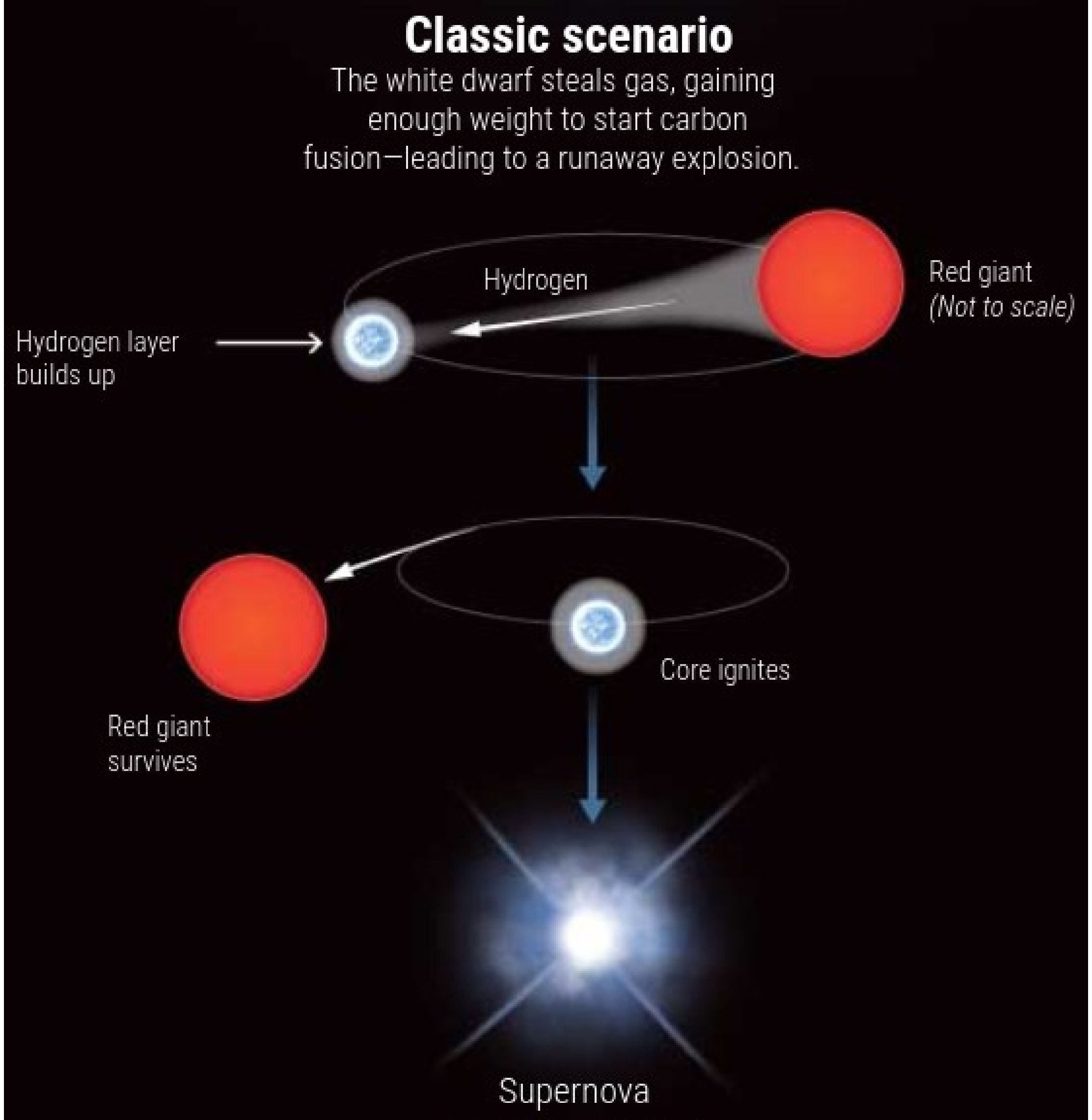


SNe Ia progenitor channel

Single-Degenerate (SD) scenario: a Carbon-Oxygen (C-O) WD (electron-degenerate) accretes H-rich or He-rich material from a non-degenerate companion star through Roche-lobe overflow or stellar wind until its mass approaches the Chandrasekhar mass limit (≈1.4 M_{Sun}), and thermonuclear explosion initiates.

Companion star: A MS star, a subgiant, a red giant, an asymptotic giant-star.

Issues ? No signatures of the swept-up H/He have been detected. Missing of surviving companion stars in SNRs.

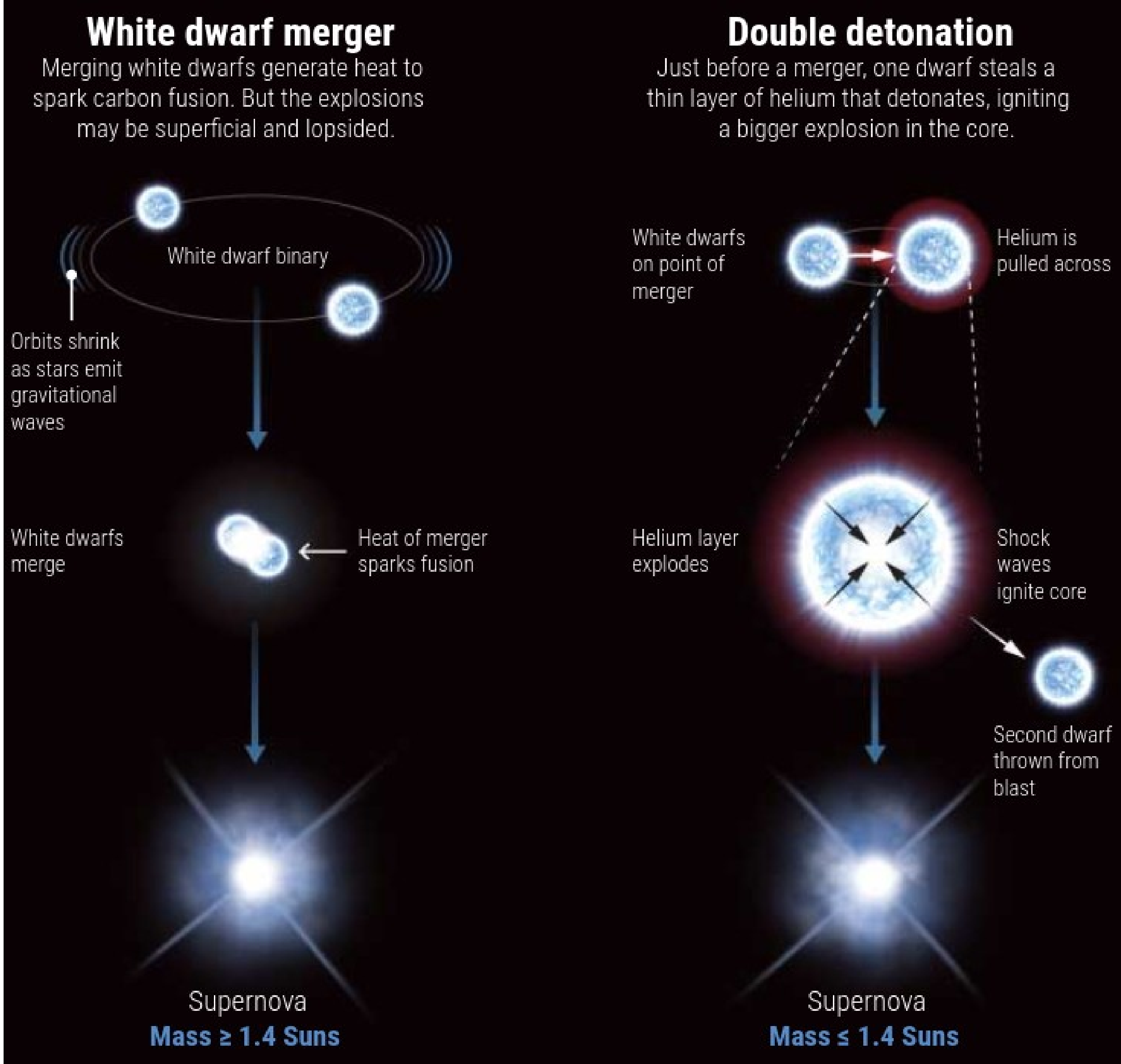


Credit: science.org

SNe Ia progenitor channel

Double-Degenerate (DD) scenario: two CO WDs in a binary system comes into contact by the emission of gravitational wave radiation and merge via tidal interaction into one single object, triggering a SN Ia explosion if the combined mass exceeds the Chandrasekhar-mass limit.

Issues ? whether the merger of two WDs could successfully lead to an SN Ia explosion.
Simulations indicate that DD model can produce ONeMg - WD but not Ia SN.



SNe Ia Explosion models

Two main models:

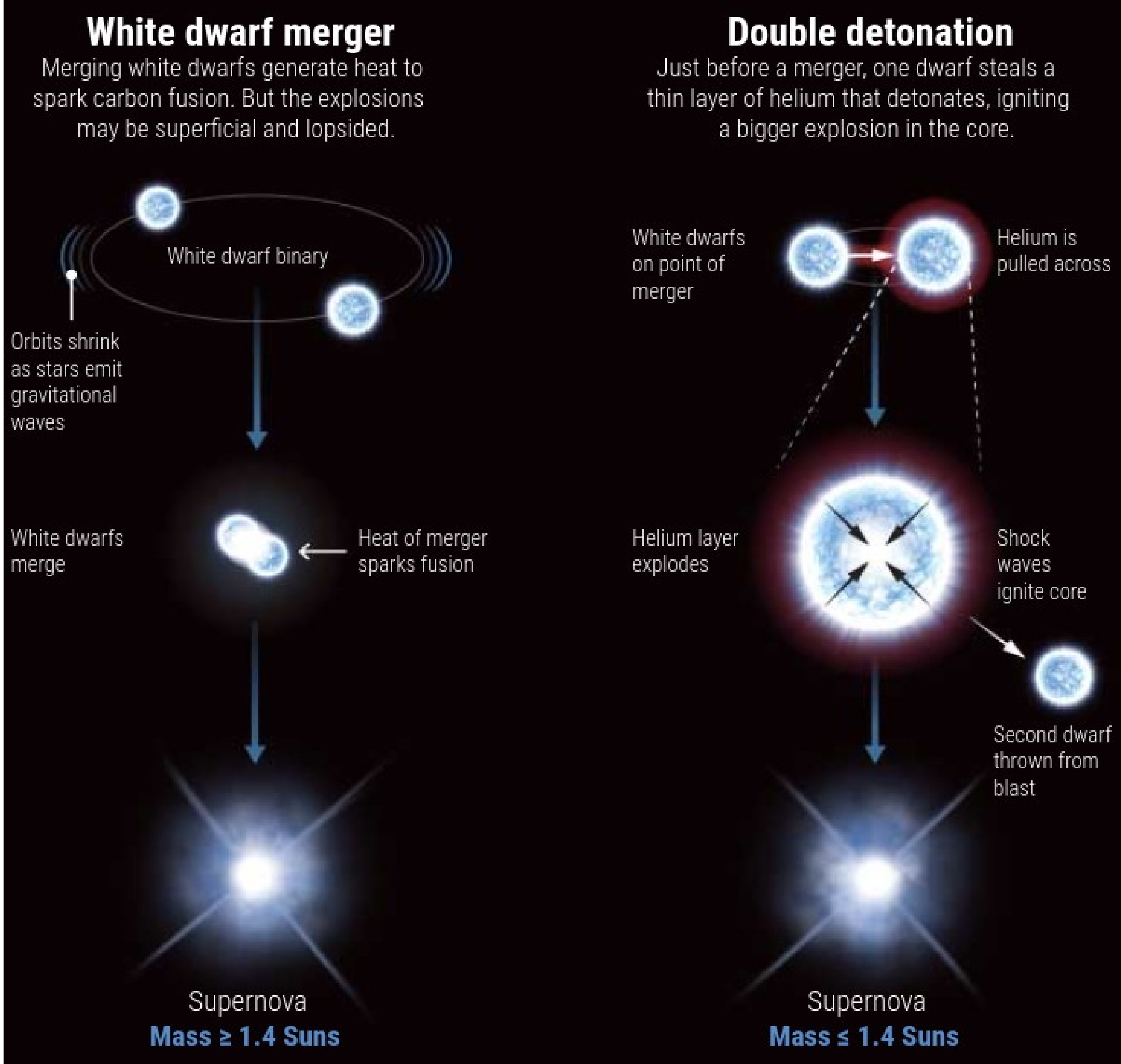
1. Deflagration (subsonic)

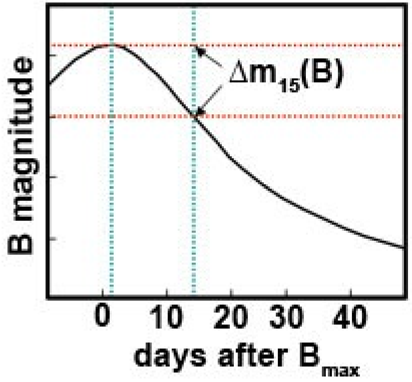
To produce the intermediate-mass elements, IMEs (Ne, Mg, Si, S), observed in Ia spectra, burning must start out as a subsonic deflagration. But **iron group elements can't** be produced**.**

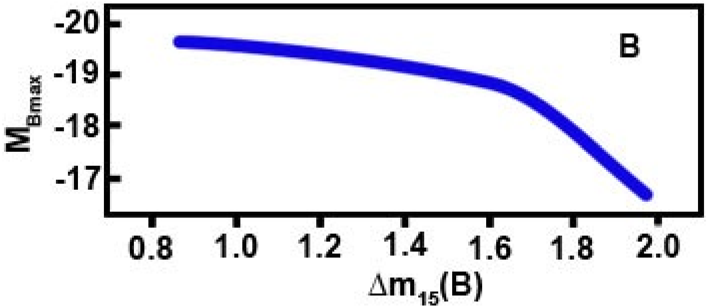
2. Detonation (supersonic)

Favourable for the iron group element production but **no IMEs.**

- **A combination of Deflagration and Detonation explosion (also known as Delayed Detonation Transition, DDT) model is favorable in Ia SNe explosion.**



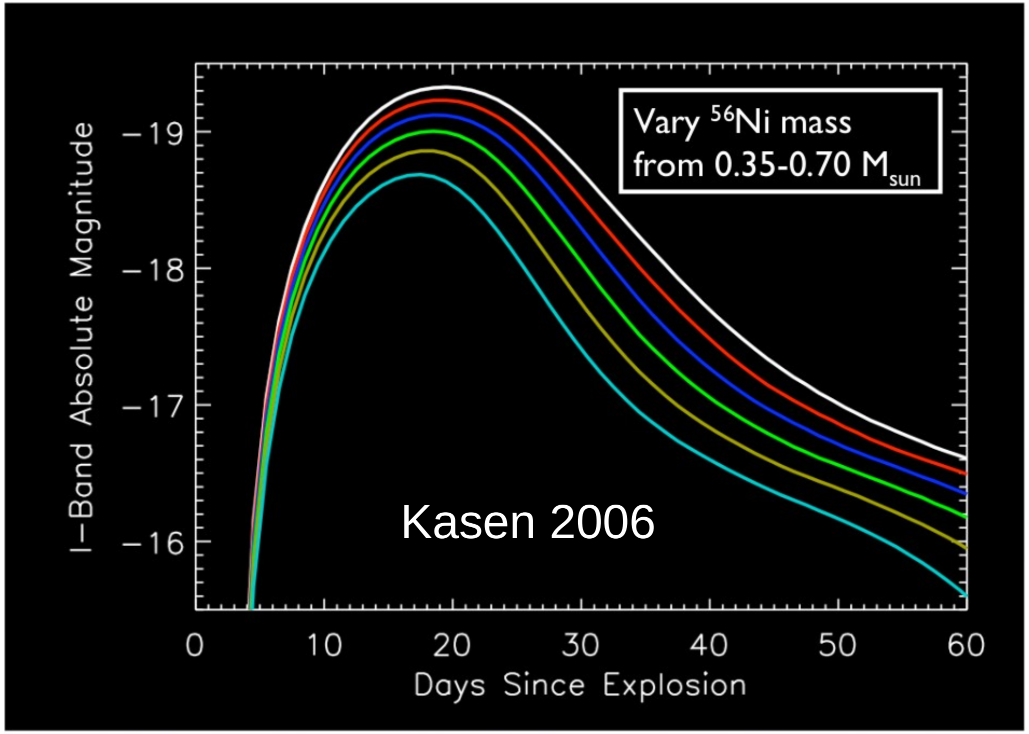




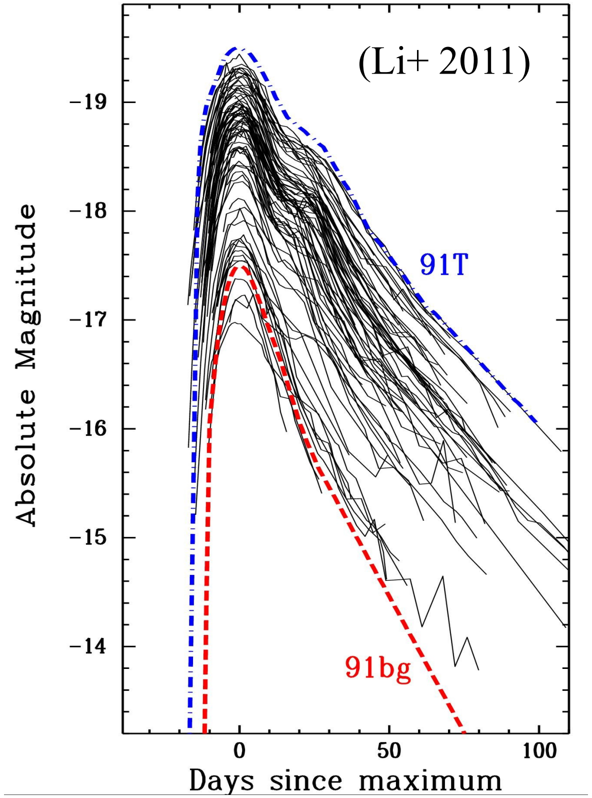
- **Δm_{15} = Magnitude decay from peak to 15 days.**
- **LC width - luminosity**

Brighter SNe decline **slowly**, and Fainter SNe decline more **rapidly**

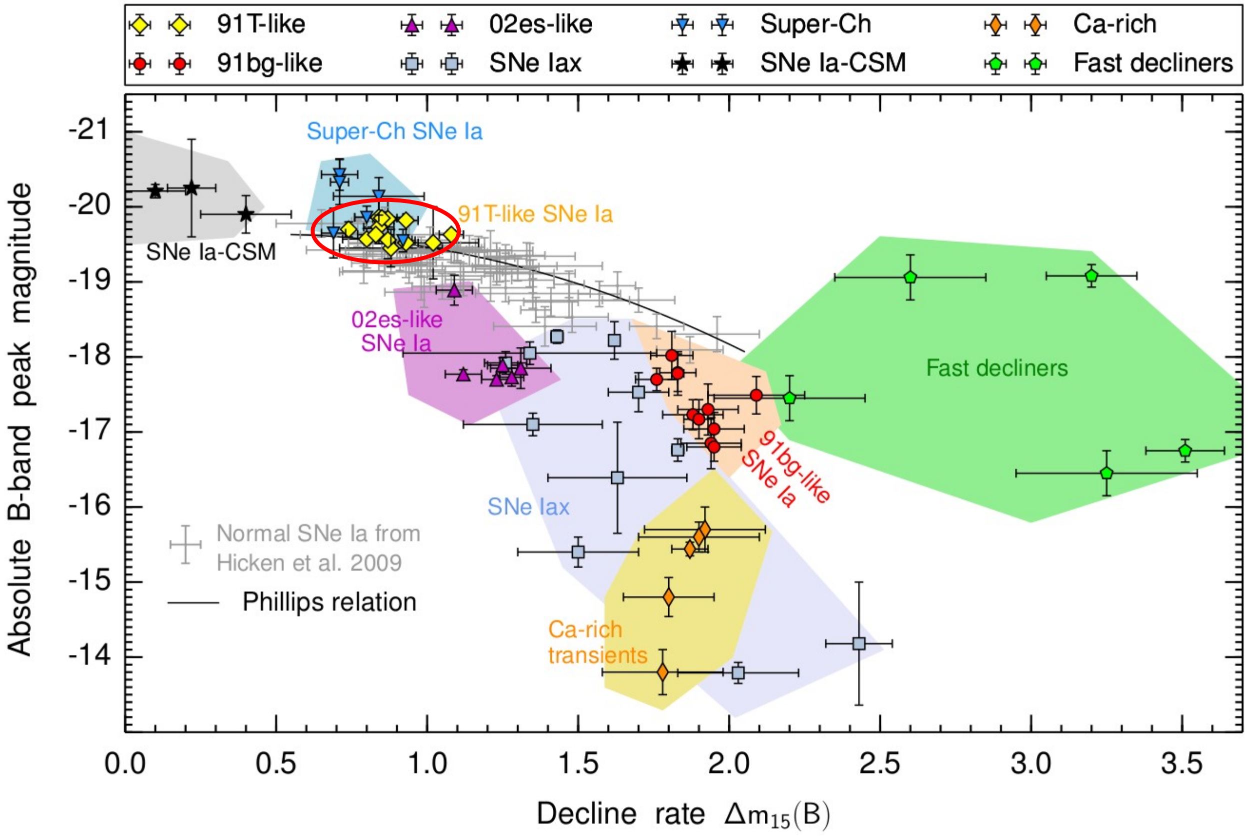
(Less $\Delta m_{15} \rightarrow$ Brighter the events)



Light curve diversity in SNe Ia



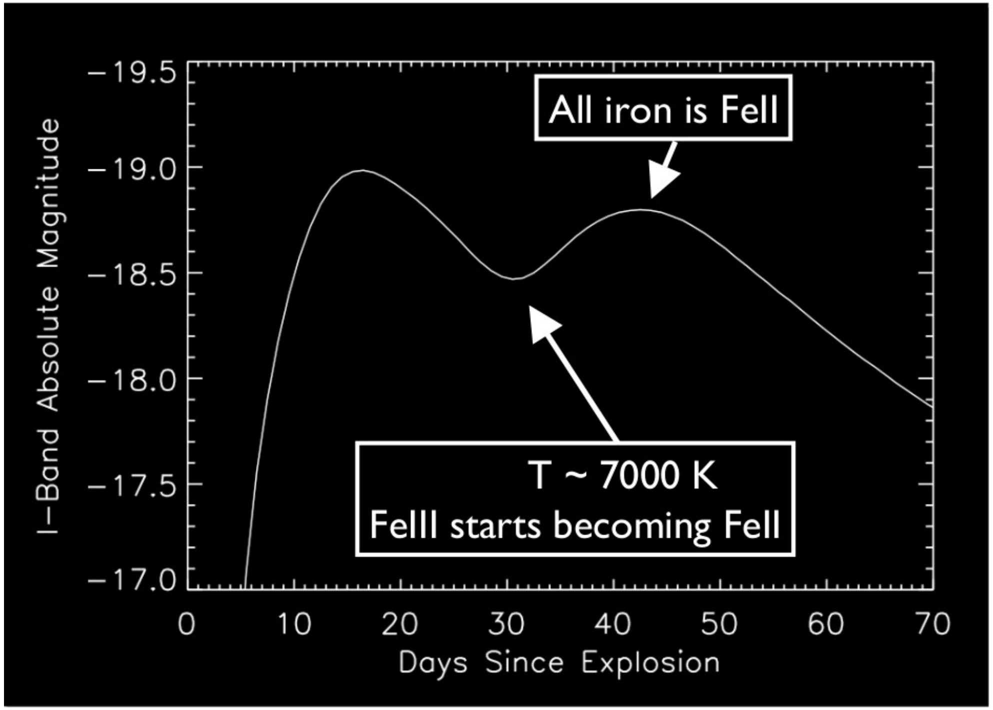
Lick Obs SN search (LOSS), 74 samples

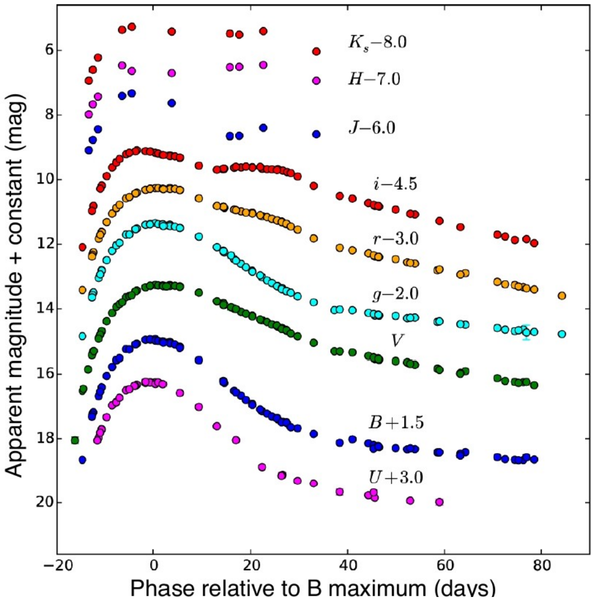


Taubenberger (2017)

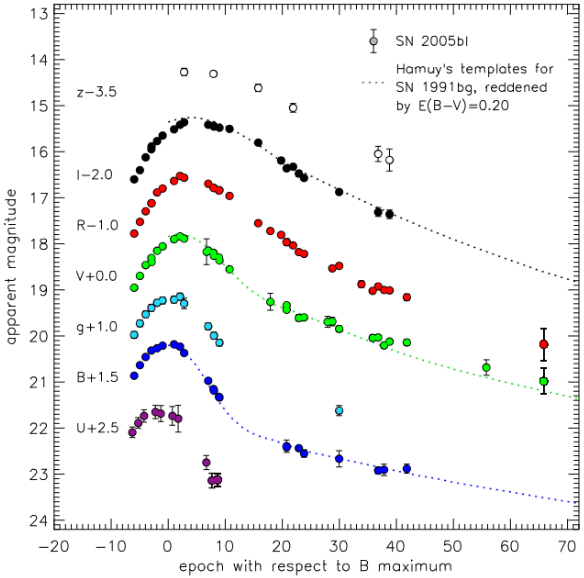
NIR double peak

The near-infrared light curves of some SN Ia are characterised by a secondary peak 20–30 days after maximum light that is not seen at bluer wavelengths, thought to be driven by the recombination of Fe III to Fe II lines.





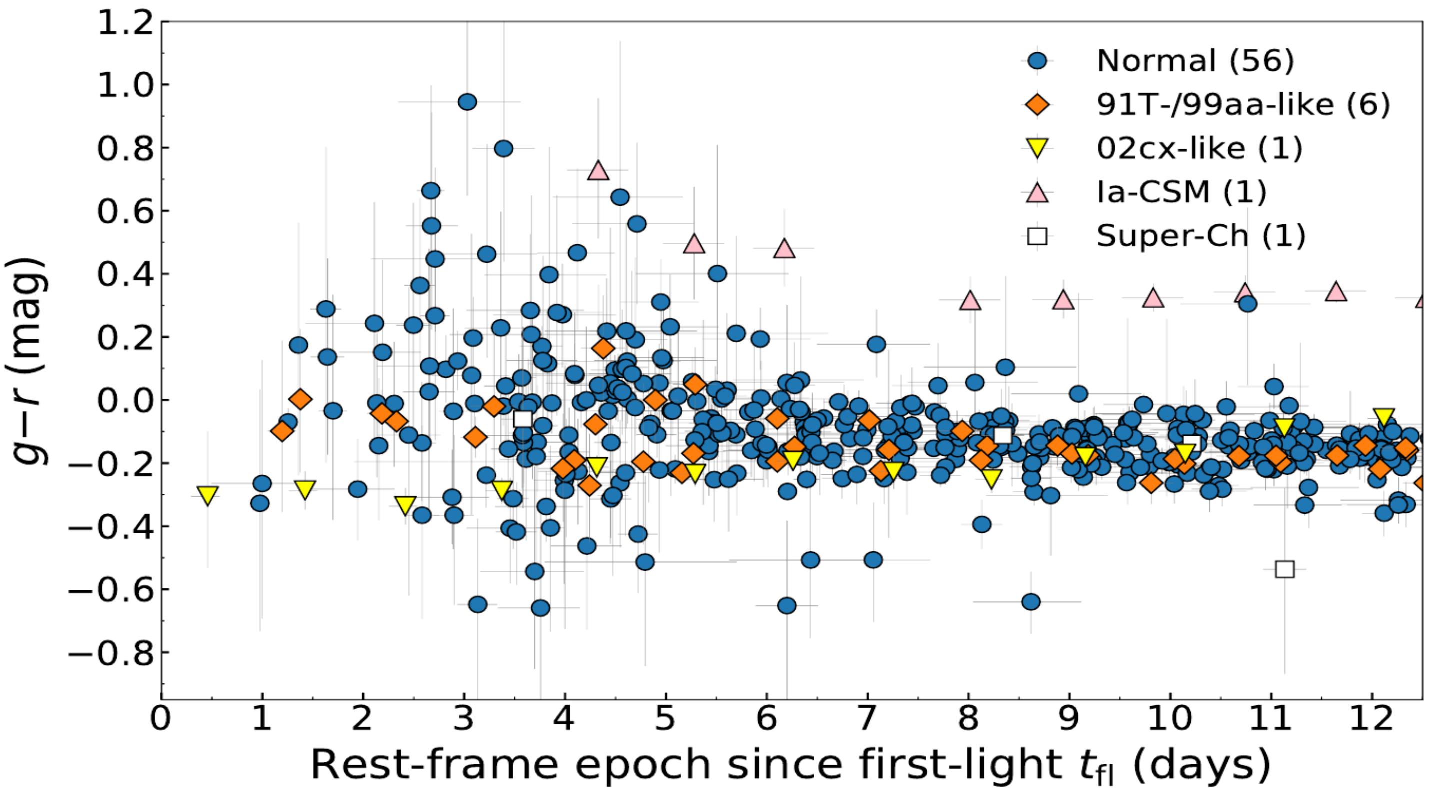
SN 2015F



SN 2005bl

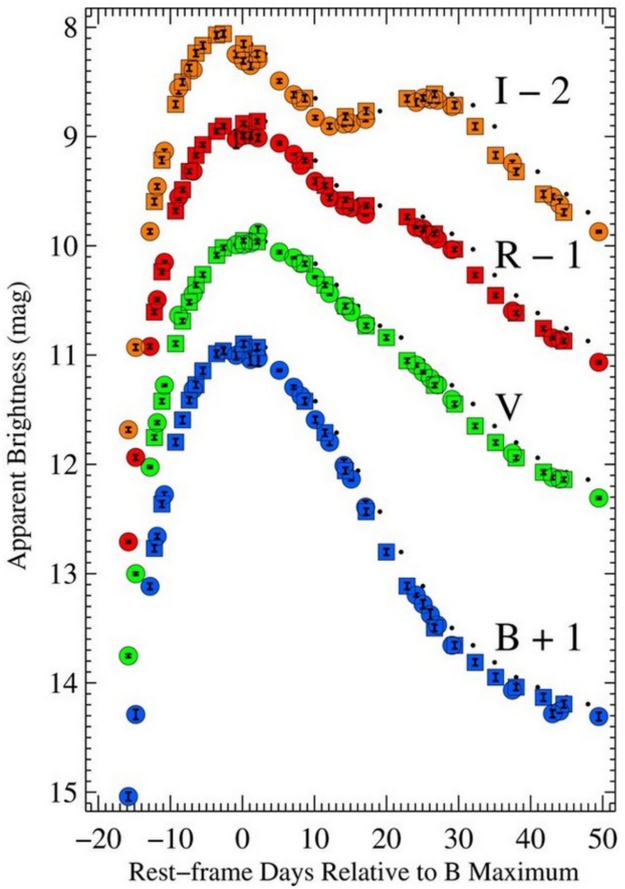
Observational diversity: Type Ia SNe

Colour evolution, ZTF sample (Bulla+ 2020)



SN 1991T like supernovae

- These events form a luminous, slow-declining subclass of SNe Ia, named after the well-observed SN 1991T (Filippenko et al. 1992a).
- Optical spectra at pre-maximum phases show extremely weak Ca II H & K and Si II λ6355 and strong Fe III λ4404, λ5129 absorption features.
- 1991T-like SNe are expected to be on average **0.2–0.5 mag more luminous than normal SNe Ia** with similar decline rate.
- They are found preferentially in late-type galaxies, suggesting that they are likely associated with young stellar populations.
- **An i/I-band or NIR light curve that reaches maximum before the epoch of B maximum and displays a clear secondary maximum.**



1991T-like, 1999aa and slow declining SNe

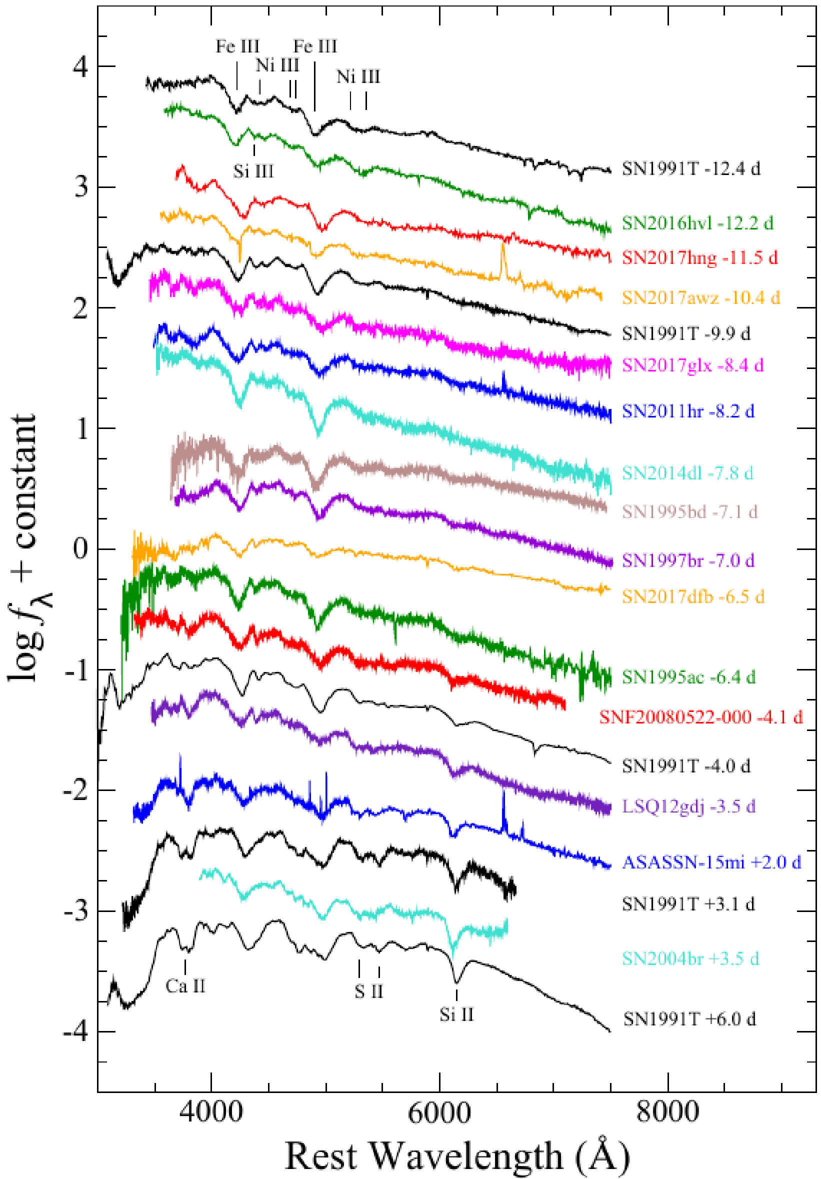
- **Δm_{15} = 0.99+-0.18 (1991T -Like)**
- **Δm_{15} = 0.93+-0.11 (1999aa-Like)**
- **Δm_{15} = 0.94+-0.09 (Slow declining CN)**

Samples: From the literature,
6.5 m Magellan telescopes
The Carnegie Supernova Project - II

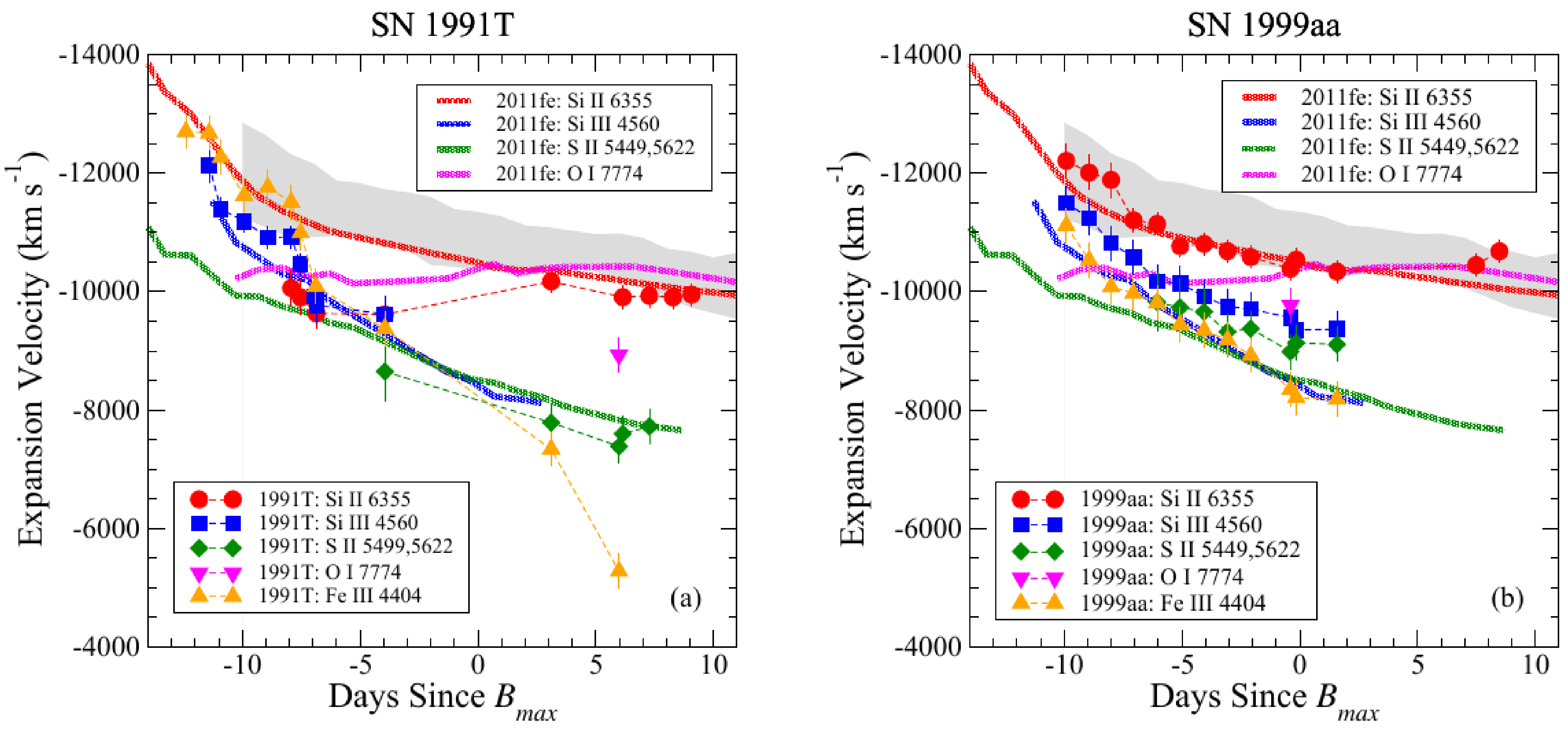
Early spectra:

Optical spectra of 15 of the literature sample of **91T-like SNe** obtained from −12 to +4 days.

Two Fe III λλ4404, 5129 features remain strong throughout these phases.

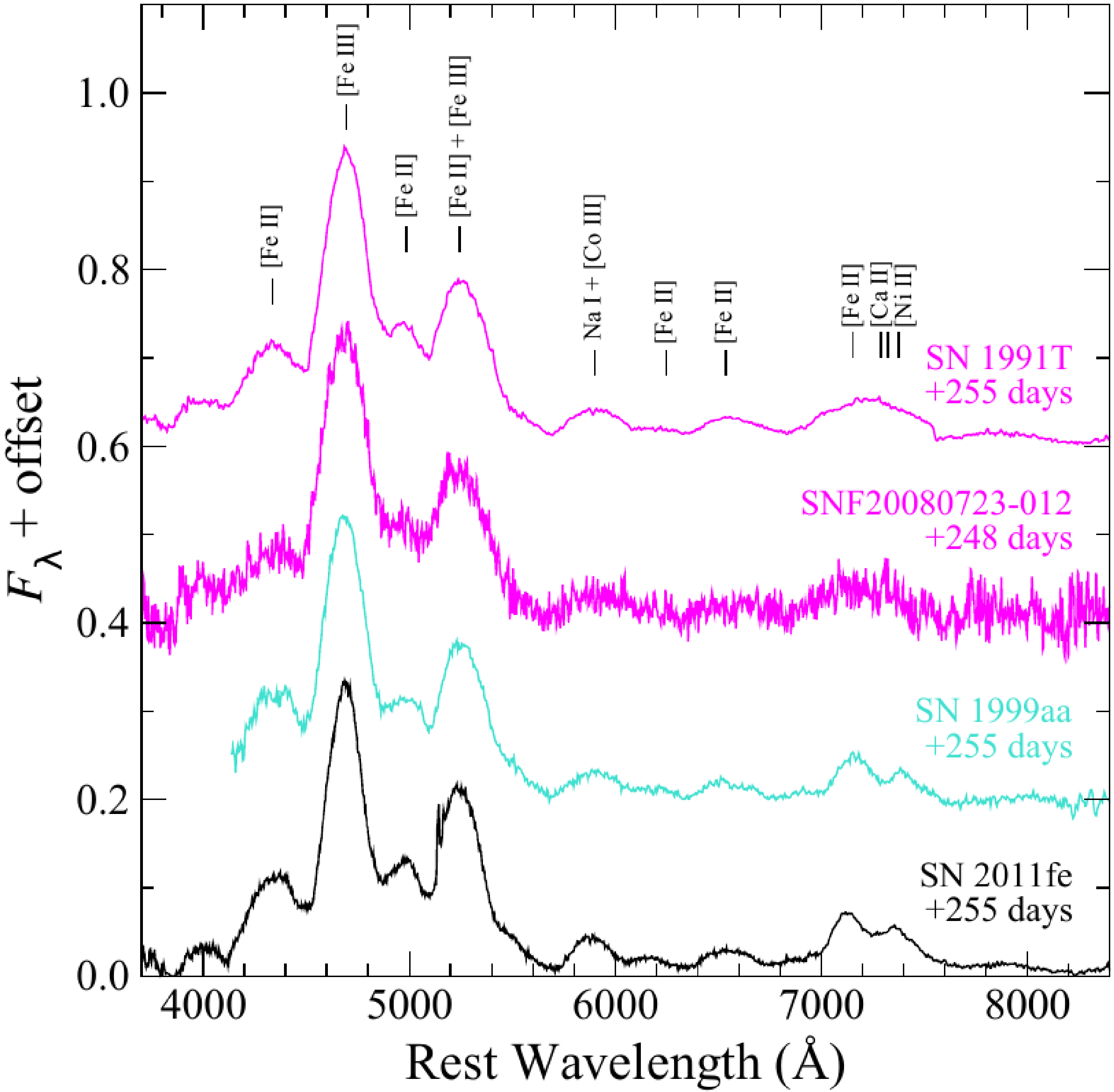


Expansion velocities



Nebular spectra:

The earlier appearance of the [Ca II] λ7291,7324 lines in 91T-like SNe may reflect the greater mixing of 56Ni into the IMEs.

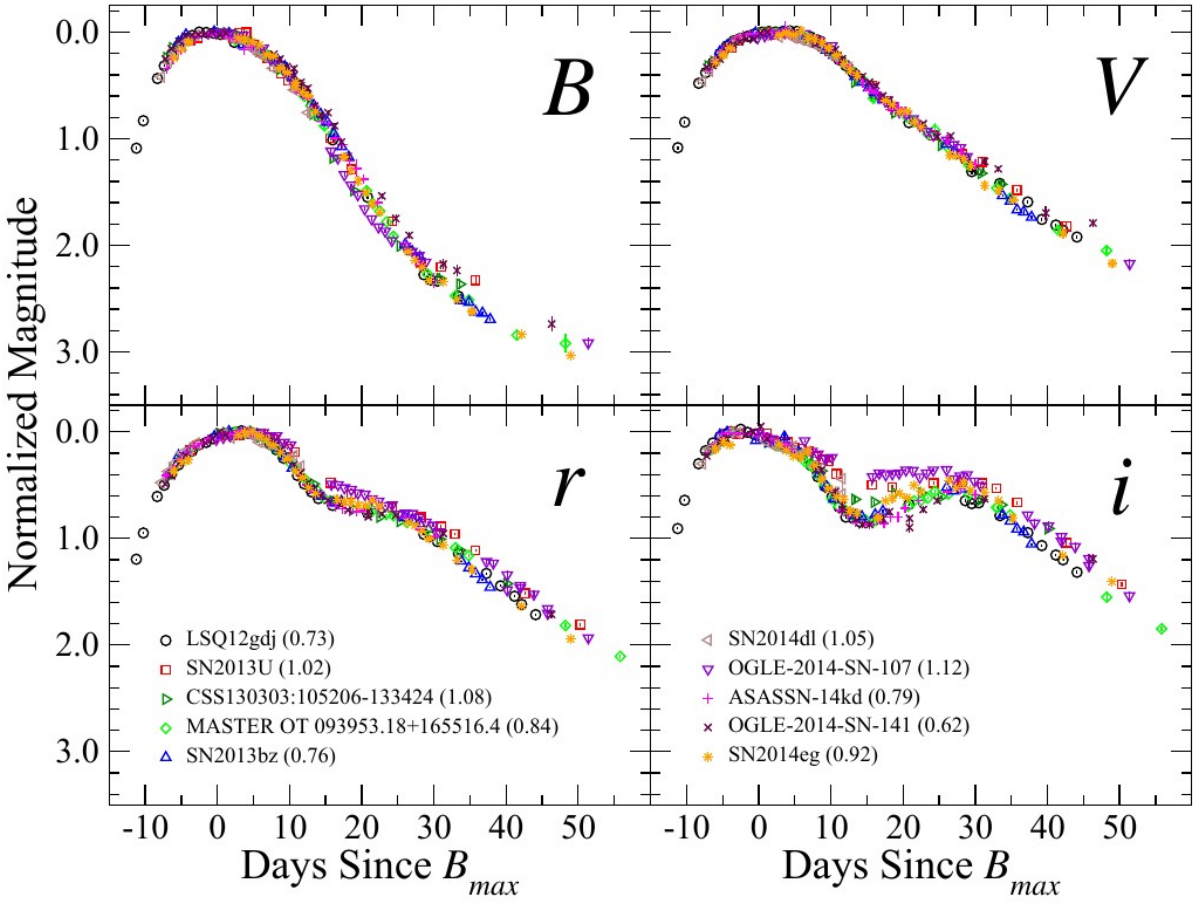


Optical Light Curve Morphology

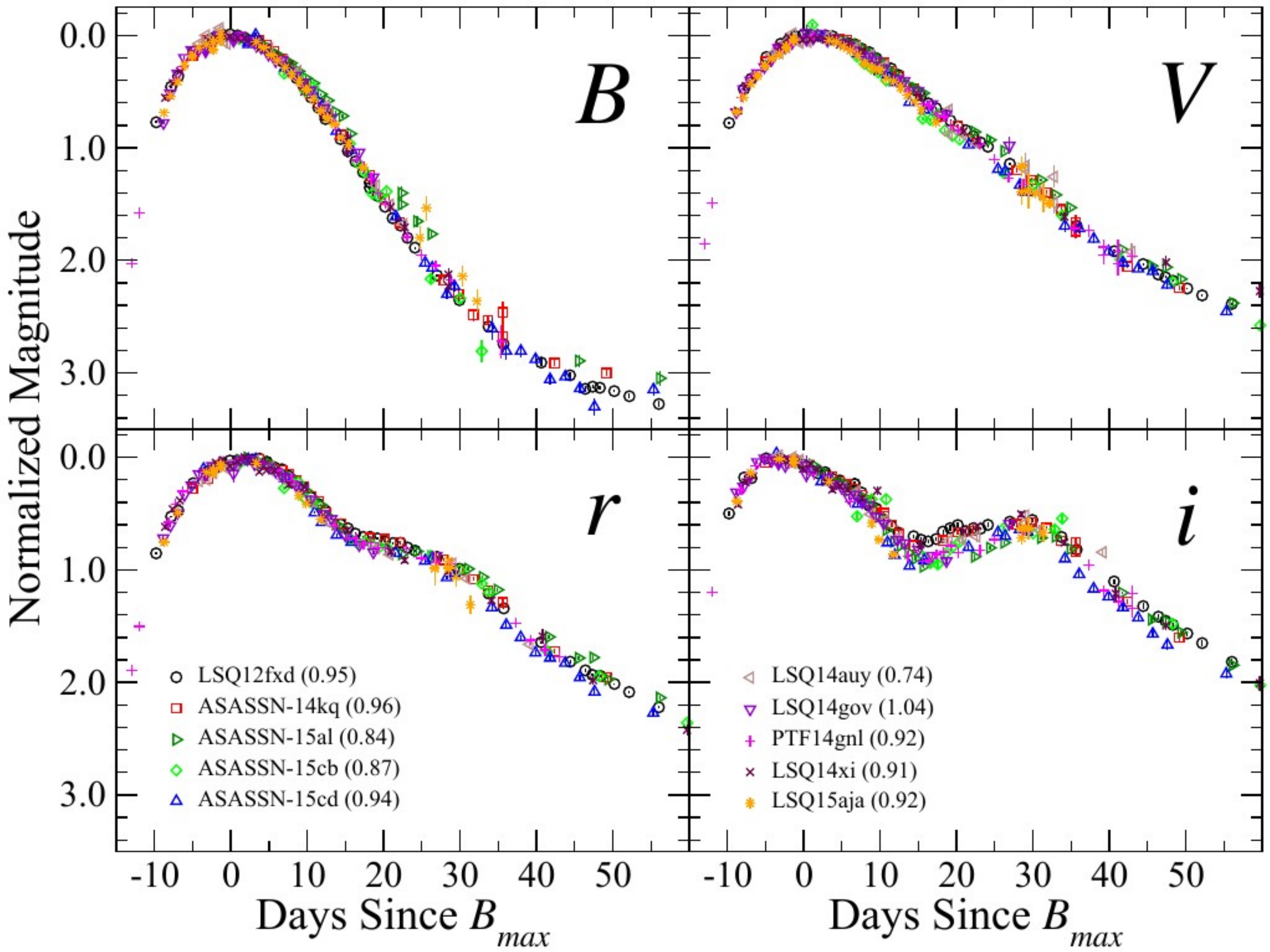
- The **B and V** light curves of the SNe show a remarkably **small amount of dispersion.**

- The **r- and i-band** light curves show a **significant diversity** in the morphology of the secondary maximum.
- **The divergence is greatest** at the epoch of the minimum between the primary and secondary maxima of the **i band,** which occurs at ~+15 days.

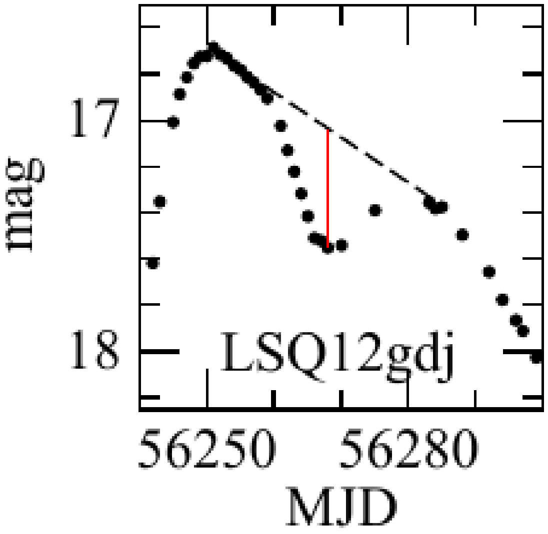
1991T Like events

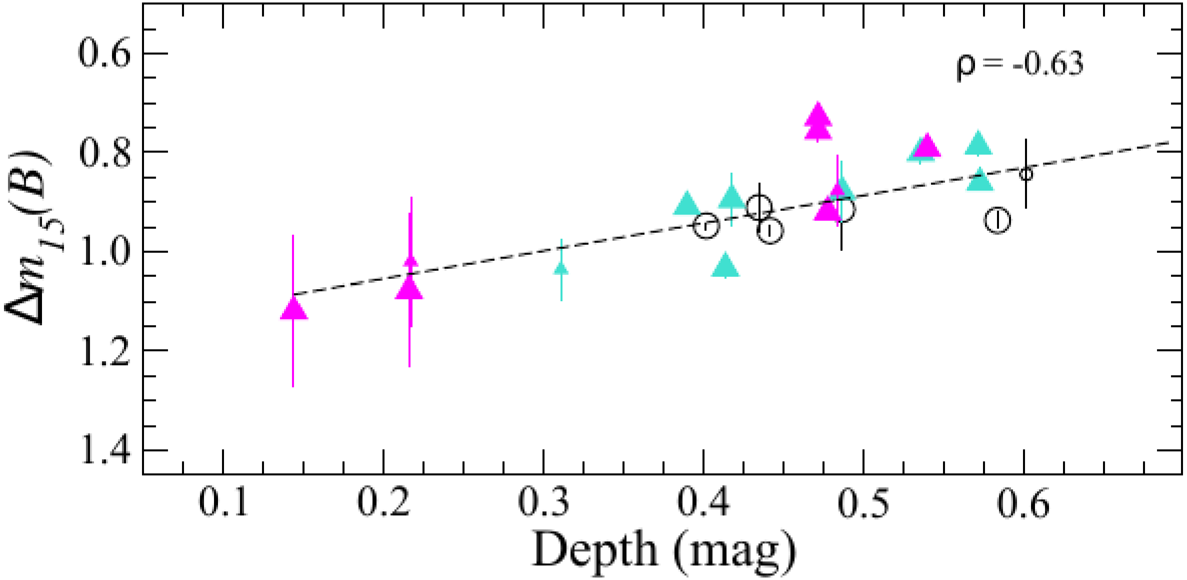


Optical Light Curve Morphology: 1999aa Like events



Depth of the minimum between the primary and secondary maxima of the i-band light curves and the Delta m15.

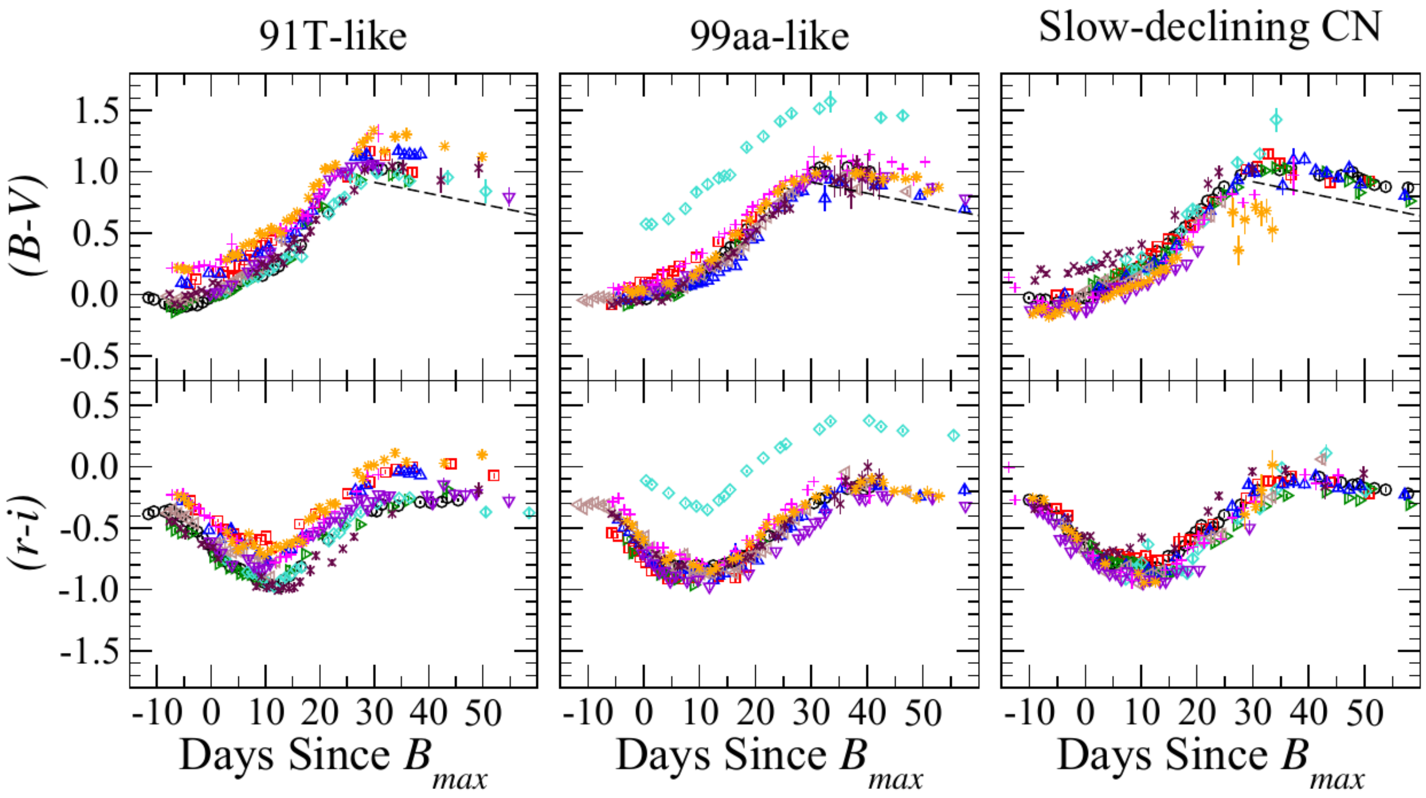




- **Weak trend: Smaller Delta m15 → smaller depth → brighter event.**

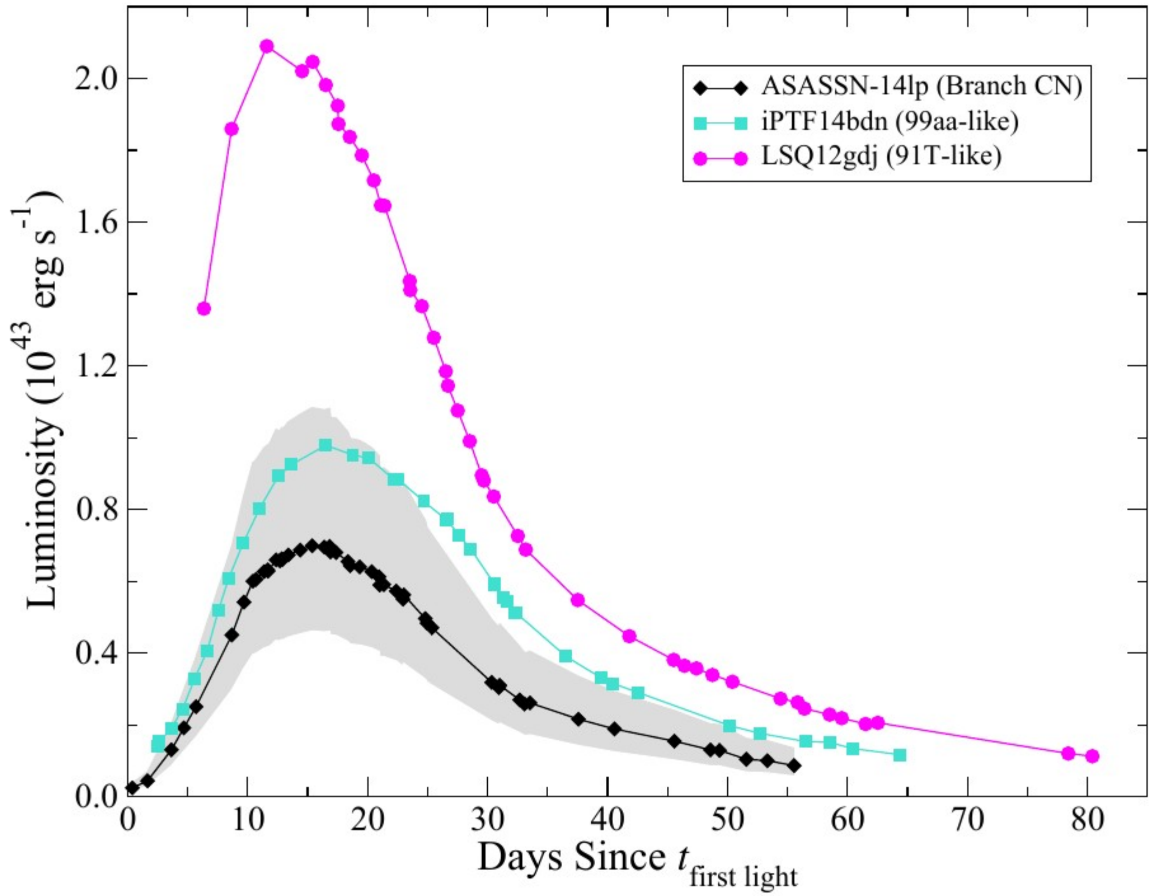
The secondary maximum strength and timing can be affected by several factors including the mass and mixing of ^{56}Ni, the abundance of stable iron-group elements synthesized in the core, the progenitor metallicity, and in particular for the i-band, the abundance of calcium in the outer layers of the ejecta.

Optical Color Evolution



The optical colors of the 91T-like SNe are **generally similar** to those of 99aa-like and slow-declining CN SNe. This is especially true **within a week of maximum light.**

Pseudo-bolometric light curves



Greater luminosity at maximum of the 91T-like LSQ12gdj, (~2–5 times greater others.

LSQ12gdj reaches maximum approximately four days before the other two SNe.

Summary

- SN 1991T Like are differentiated from 02cx-like and 03fg-like SNe in possessing i/I-band light curves that reach maximum before the epoch of B maximum, and that also display a clear secondary maximum.
- 91T-like SNe are distinguished from 99aa-like and slow-declining Branch CN SNe by a nearly flat evolution of the Si II λ6355 expansion velocity over phases ranging from −10 to +10 days with respect to B maximum.
- The S II $\lambda\lambda$5449,5622 lines of 91T-like SNe are only clearly visible at phases between −5 and +5 days.
- 1991T-like and 1999aa-like SNe, as well as many slow-declining Branch CN SNe, have strikingly similar B and V light curves, and cannot be distinguished on the basis of photometric parameters such as Δm15(B).

Summary

- Based on the findings, it could be argued that 91T-like SNe are **not "peculiar"** in the sense of being an intrinsically distinct phenomenon, but rather are connected to the larger population of luminous, slow-declining SNe Ia.
- Distinguishable property of 91T-like SNe from the 99aa-like and slow-declining Branch CN events are the **higher ionization observed** in their outer layers and their greater peak luminosities, all of which are related to the amount of 56Ni produced in the explosion and the extent to which it is mixed outward into the ejecta.
- **Mephisto multi-band observations will be very useful to study the secondry maximum (in r,i,z - bands), it's depth and consequently understanding 1991T like events.**