Exploring the global properties of SNe Ia

Paolo A. Mazzali

Max-Planck Institut für Astrophysik, Garching

Astronomy Department and
RESearch Centre for the Early Universe,
University of Tokyo

Istituto Naz. di Astrofisica, OATs

Using observables to understand SNe Ia

Questions

- Properties of SNe Ia (eg Phillips rel’n)
- Mode of explosion (deflagration, delayed detonation, other even less reasonable modes…)
- Cosmology?

Methods

- Look at/model spectra & light curves

I. Observed relations

i. The Phillips Relation (Absolute Magnitude - Decline Rate)

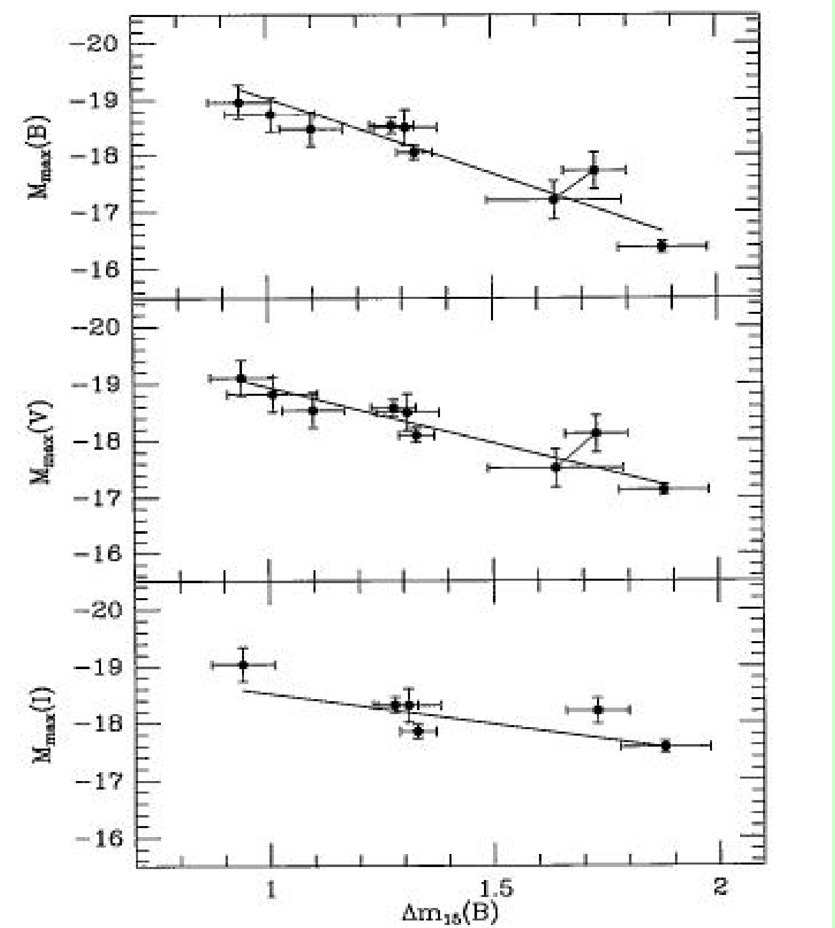
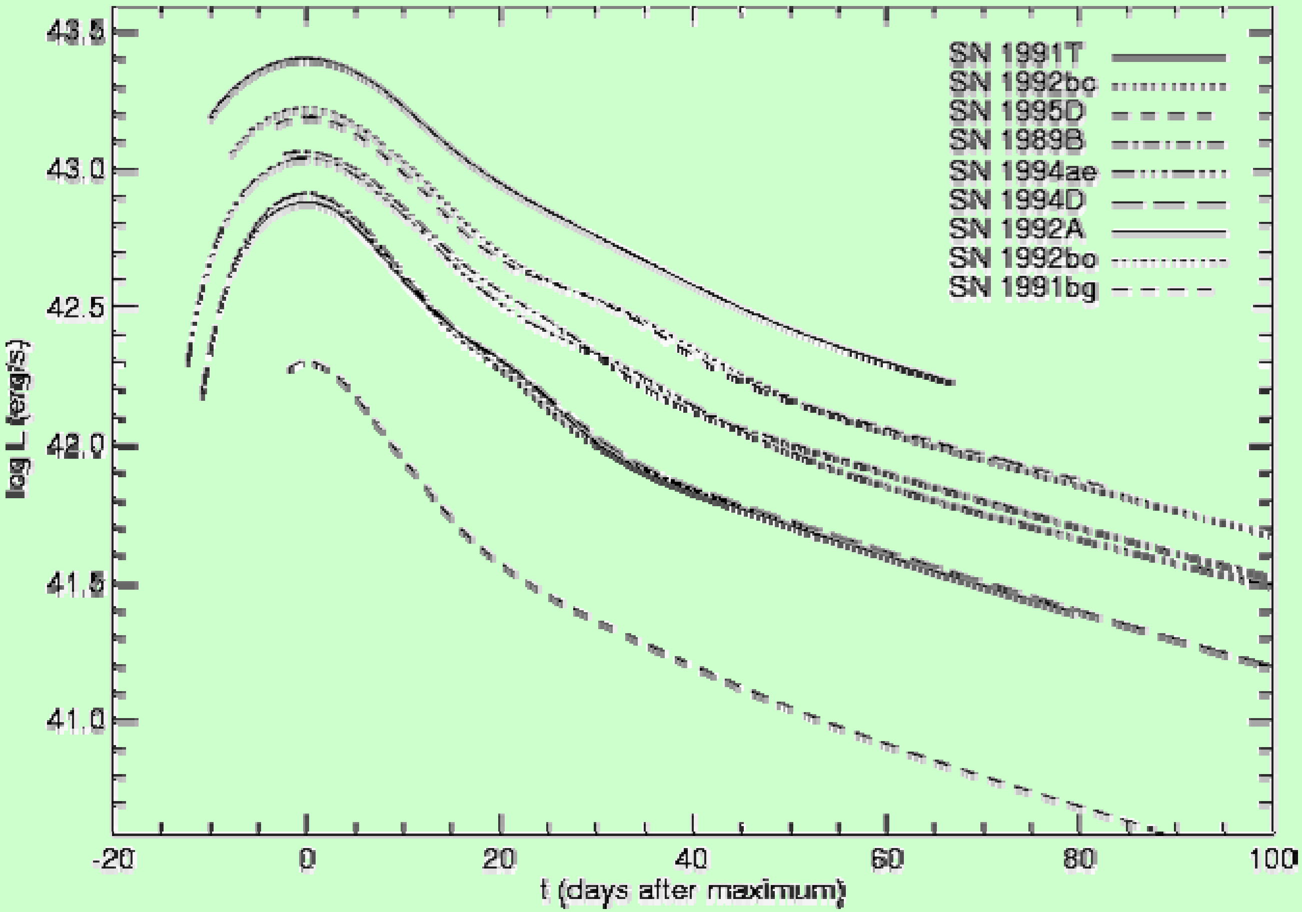


FIG. 1.—Decline rate–peak luminosity relation for the nine best-observed SN Ia's. Absolute magnitudes in B, V, and I are plotted vs. $\Delta m_{15}(B)$, which measures the amount in magnitudes that the B light curve drops during the first 15 days following maximum.

Phillips 1992

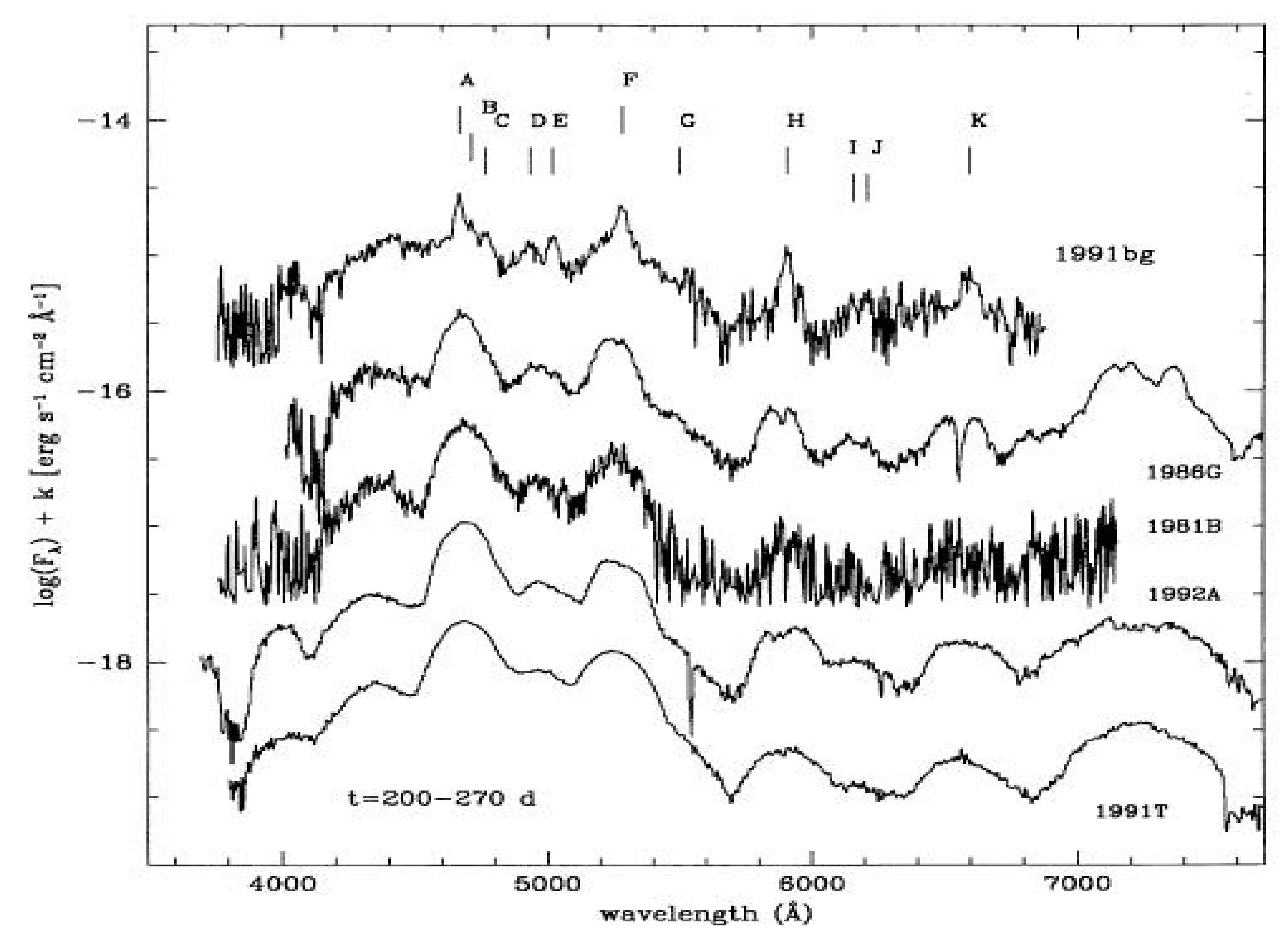
ii. Bolometric Light Curves

Lpeak - decline rate or LC shape



Contardo et al. 2000

iii. SNe Ia: late-time spectra



Δm15(B)

1.93

1.77

1.27

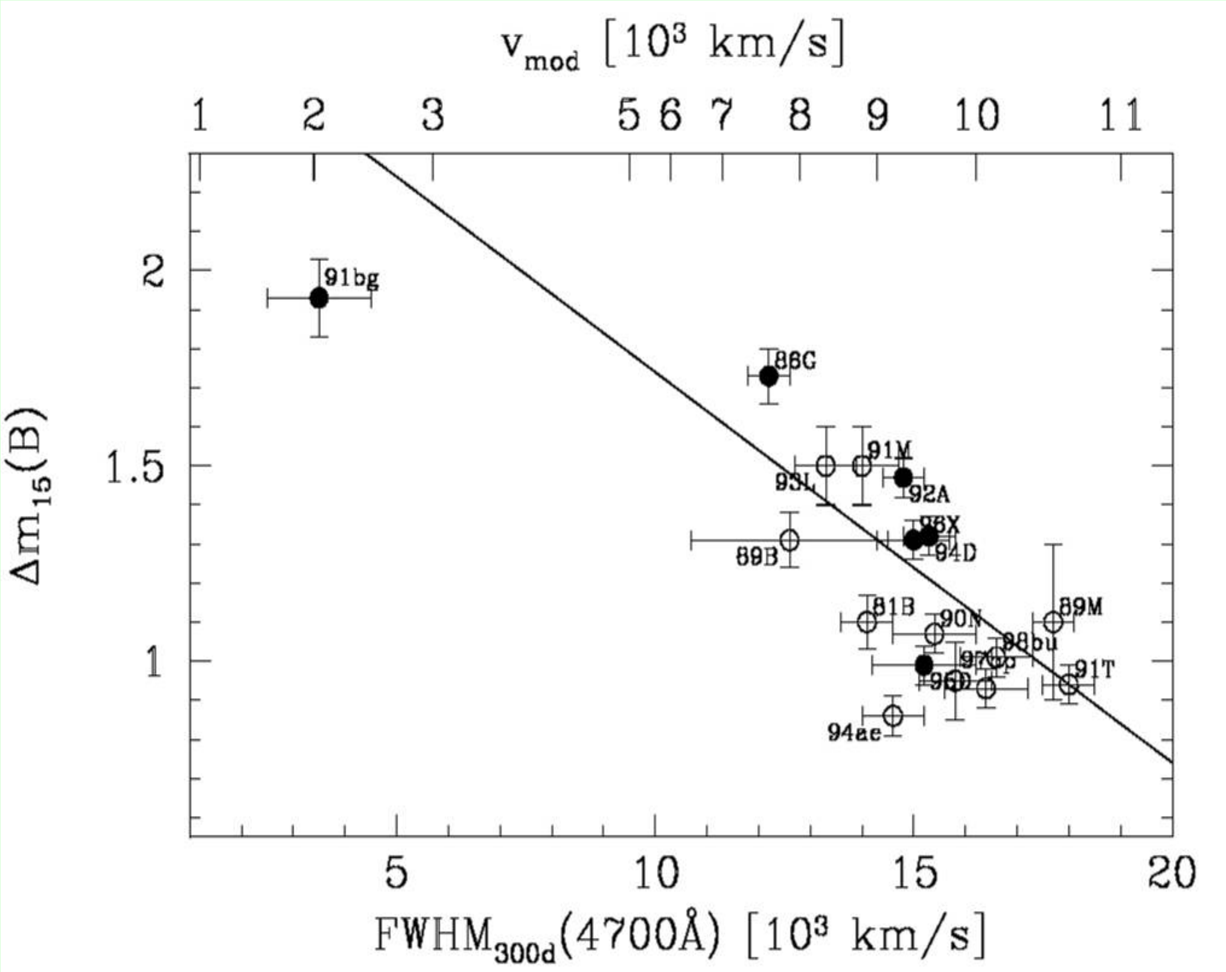
1.51

0.87

Mazzali et al. 1998

iii. Nebular line width and decline rate

^{56}Ni mass and distribution and decline rate (≡Luminosity) are related



after Mazzali et al. 1998

iv. Velocity Gradients: an alternative SN Ia classification

Benetti et al. (2005):

• Classify SNeIa according to rate of change of post-maximum photospheric velocity of SiII 6355

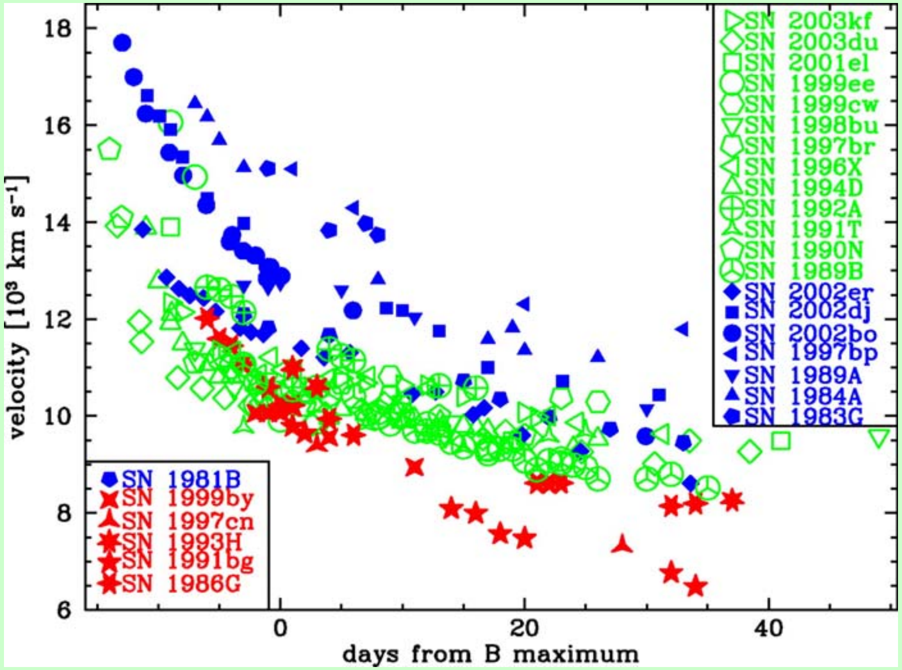
→ 3 SN groups:

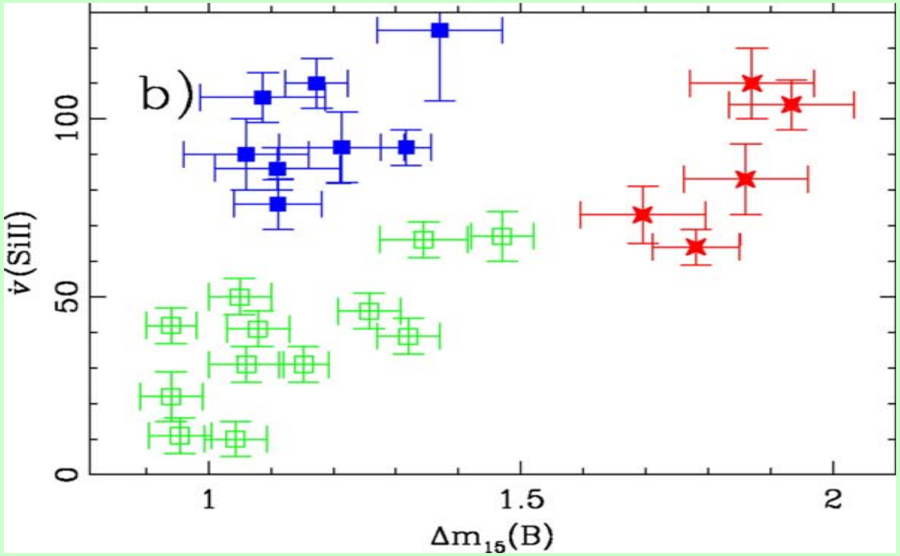
High Velocity Gradient

Low Velocity Gradient

Faint

• Groups separate out
in v-ΔM_{15}(B) plot



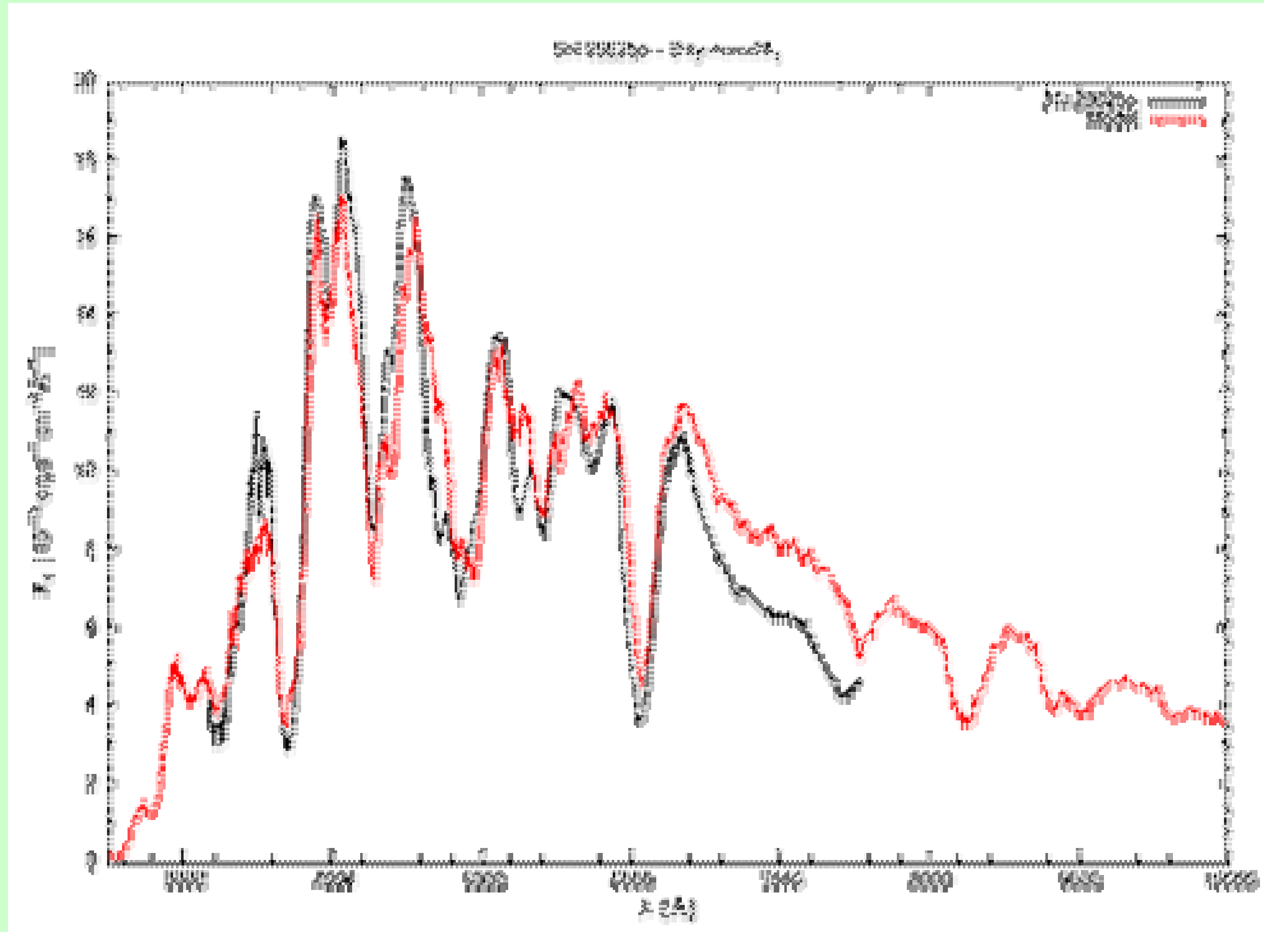


II. Radiative Transfer Models

Early-time spectra

Monte Carlo code

- Composition
- Density
- Luminosity
- Velocity

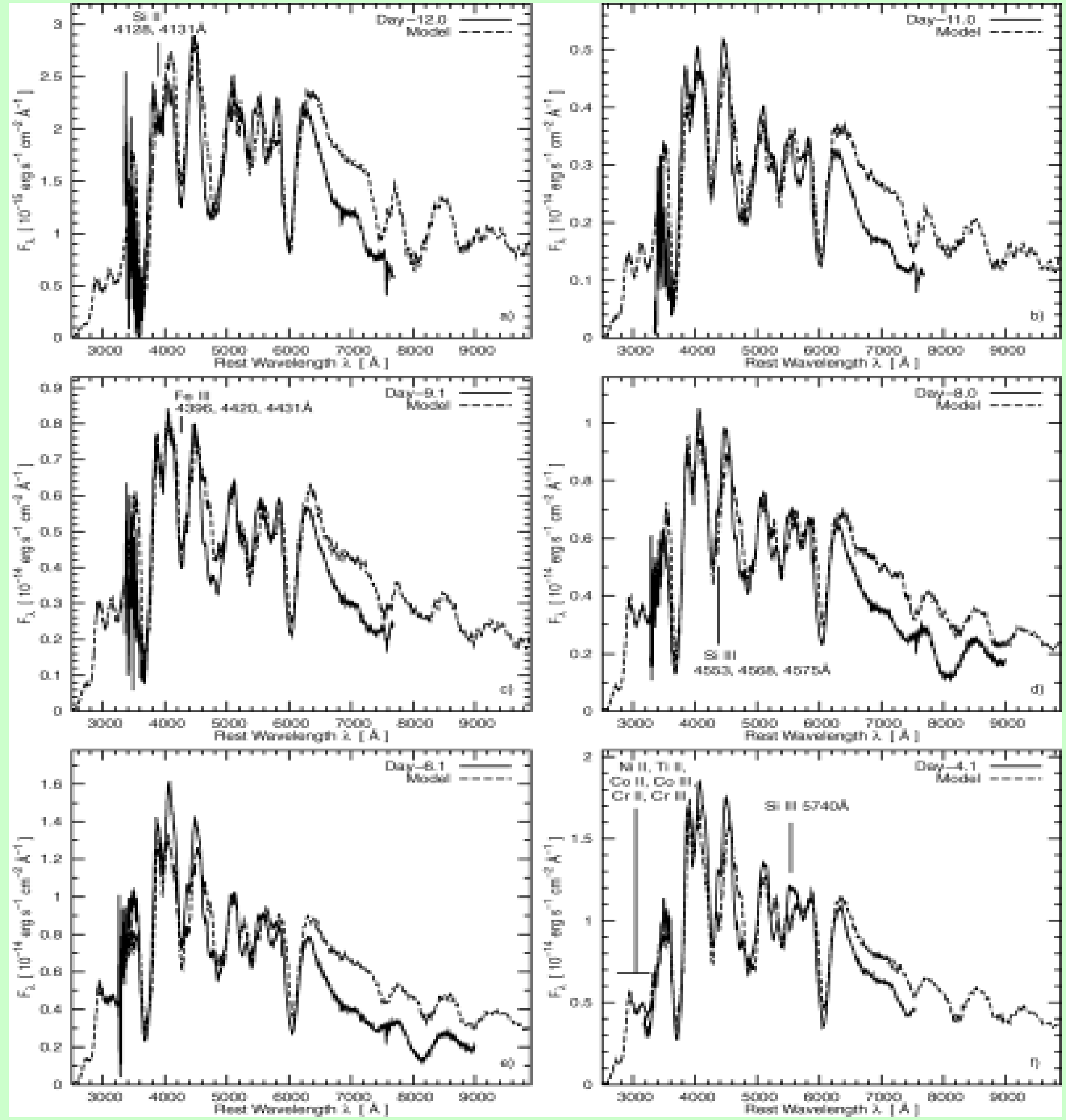


Abundance Stratification

Model sequence of spectra to derive composition layering

→How did the star burn?

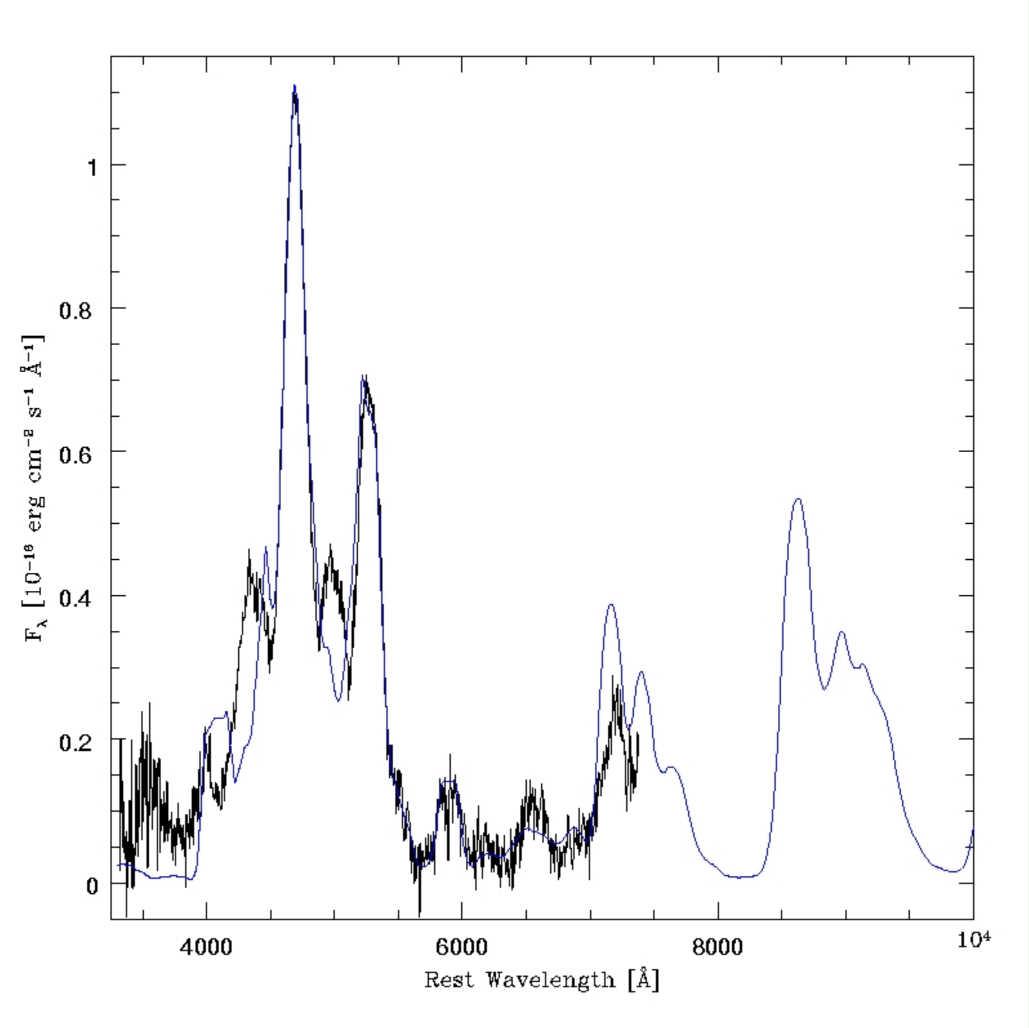
Stehle et al 2005



Late-time spectra

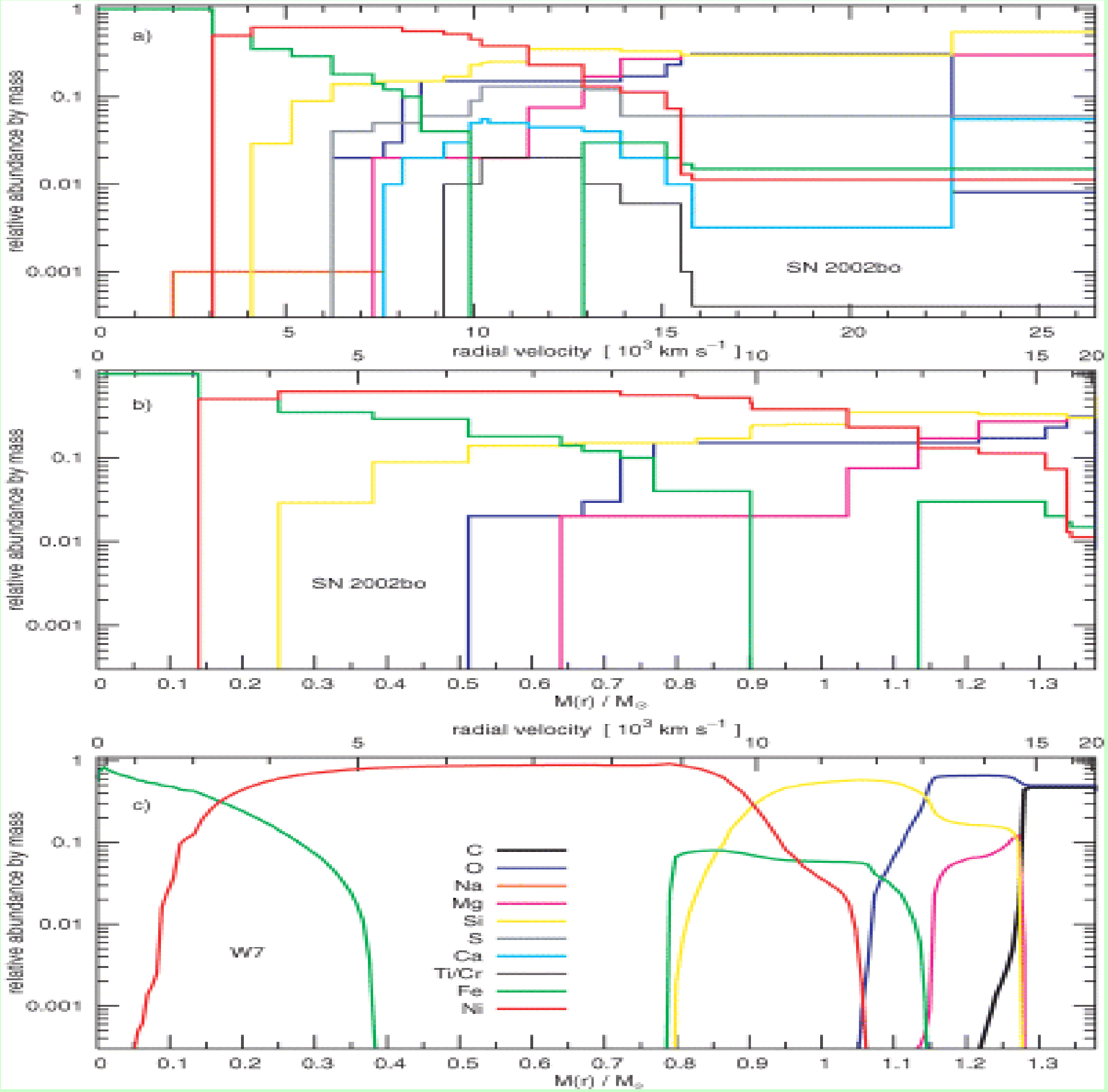
Monte Carlo LC code
+ NLTE nebular code

- No radiative transfer
- Get full view of inner ejecta (^{56}Ni zone)
- Estimate masses of inner ejecta



Composion in a typical SN Ia

- Elements more mixed than in typical 1D models
- Element distribution closer to a Delayed Det. than to a Deflagration

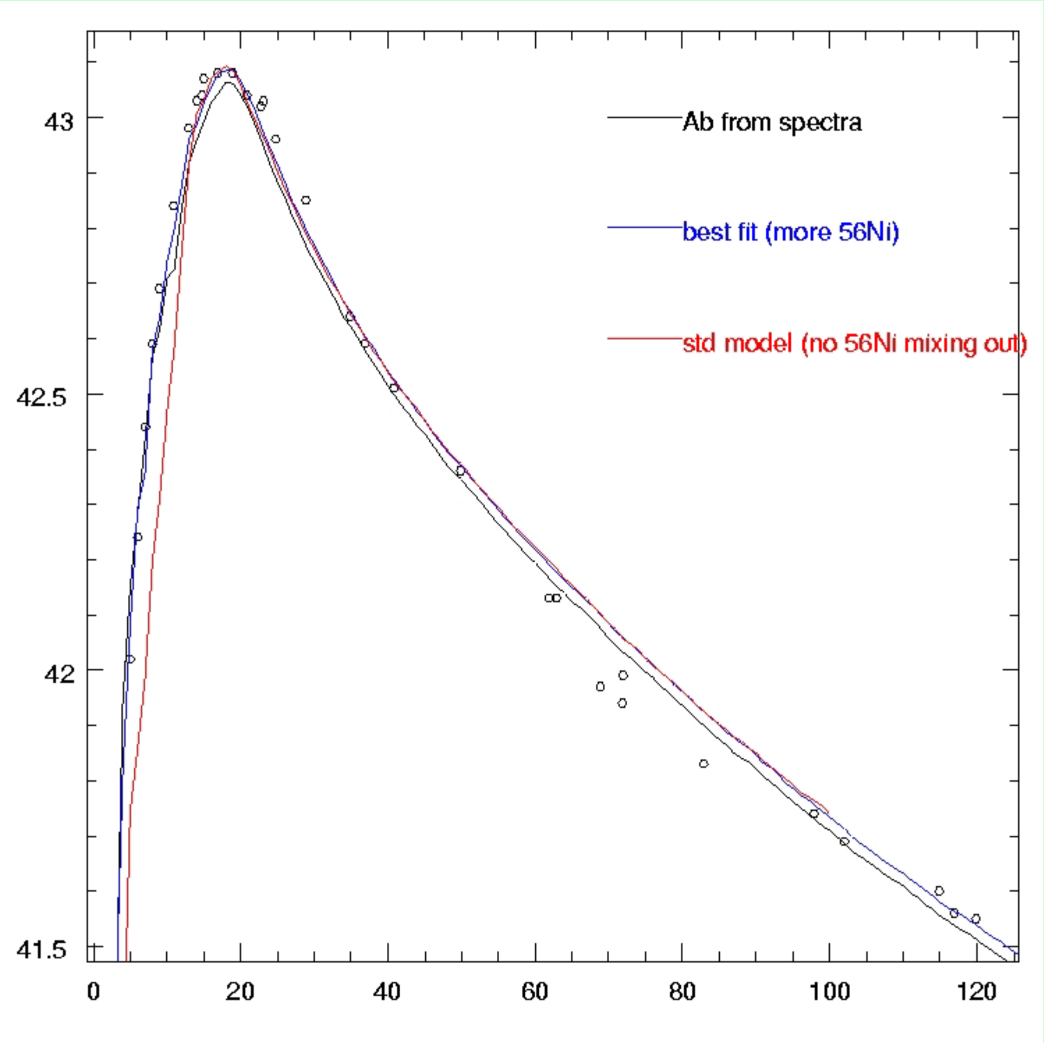


Test: Light Curve

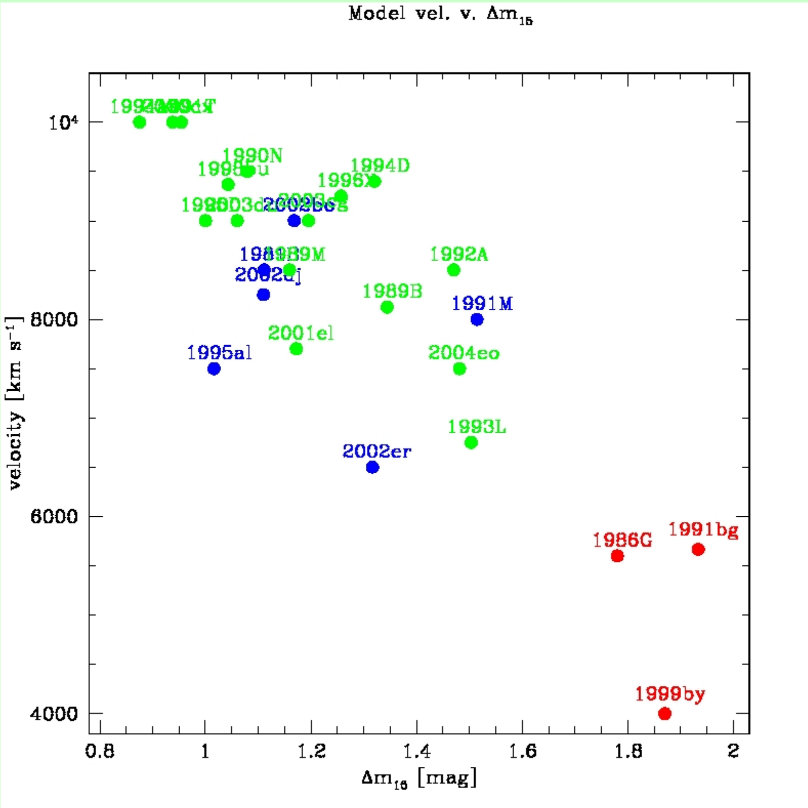
Monte Carlo code

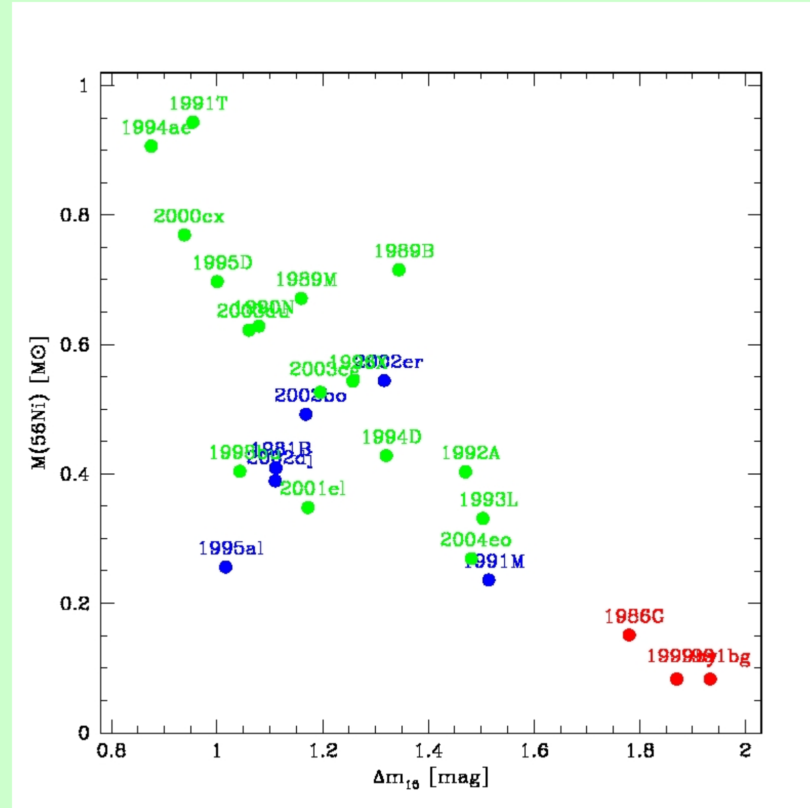
- Use W7 density
- Composition from tomography
- (^{56}Ni ~0.50M$_\odot$)

→ Model LC matches data very well



III. The Global View

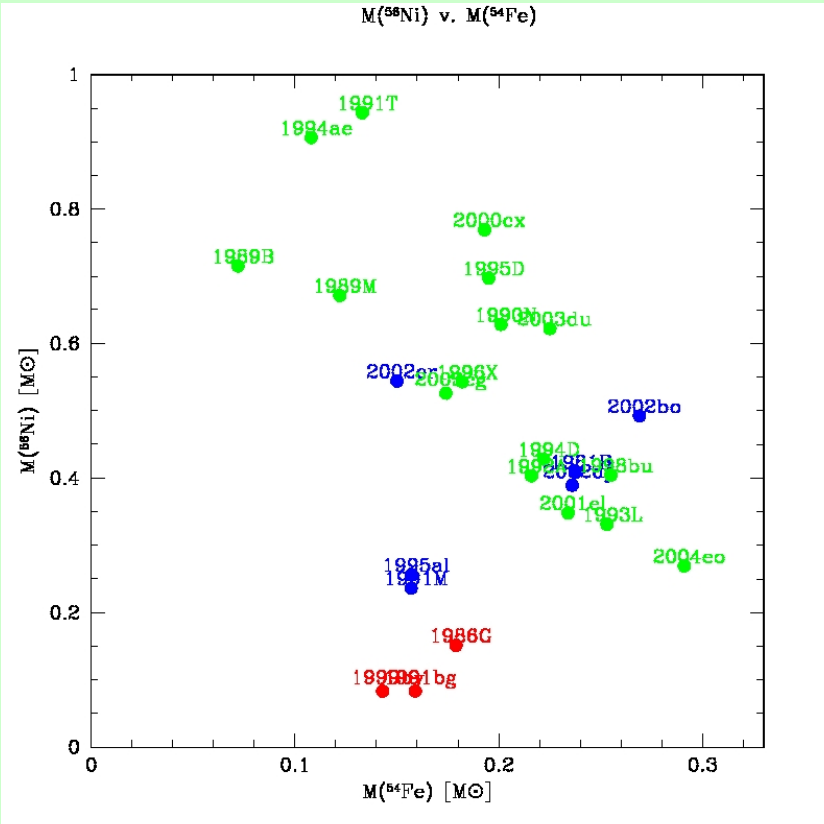


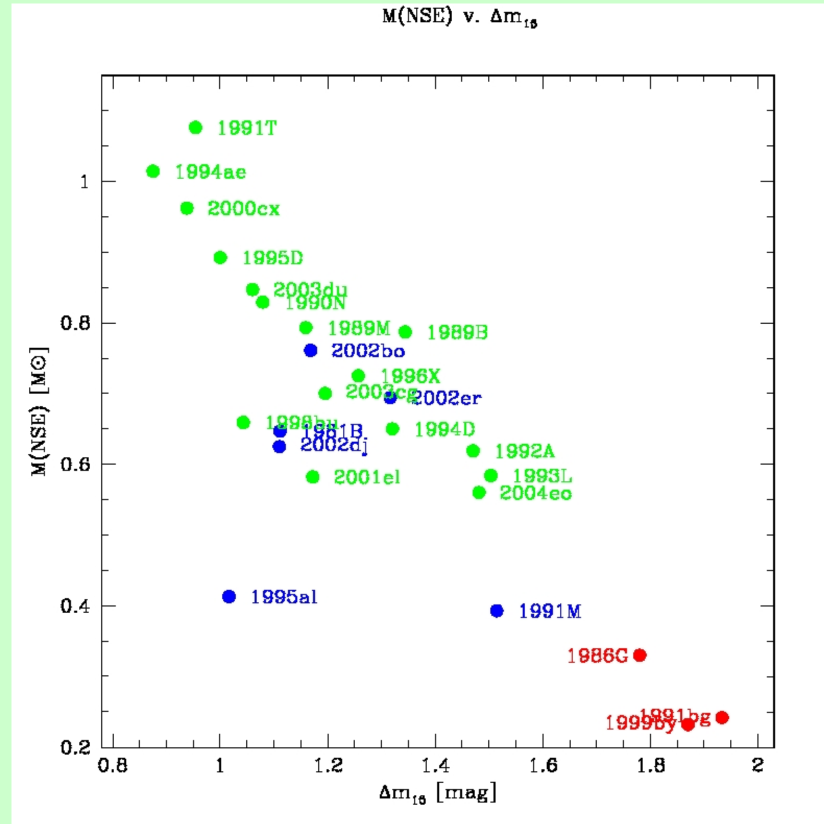


- Late time spectra suggest
  $M(^{56}Ni) \propto \Delta m_{15}(B)\ [\propto M(Bol)] \propto v(Fe)$

Role of ^{54}Fe, ^{58}Ni

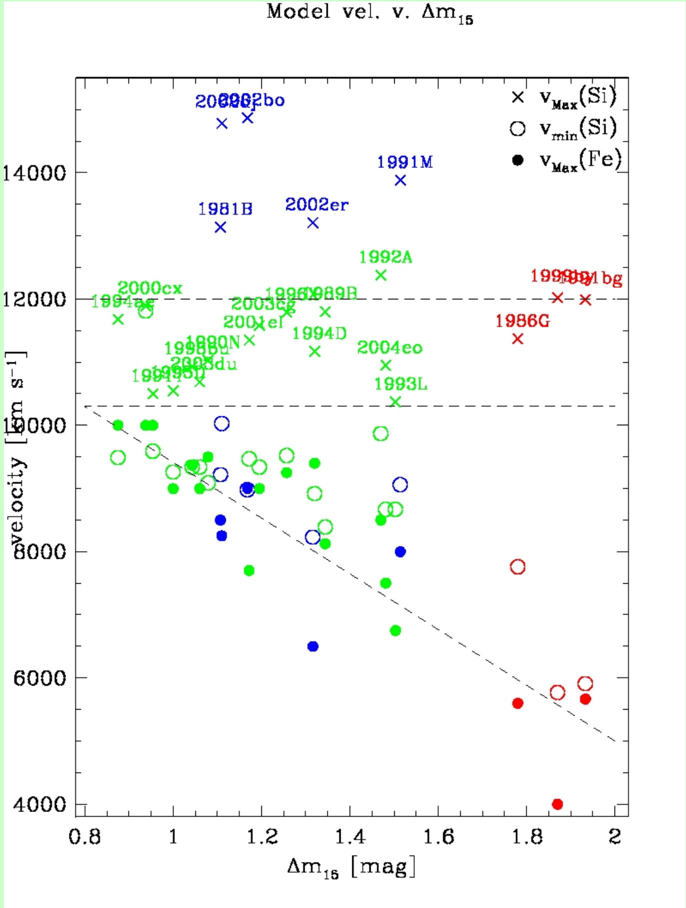
- Stable Fe group isotopes radiate but do not heat





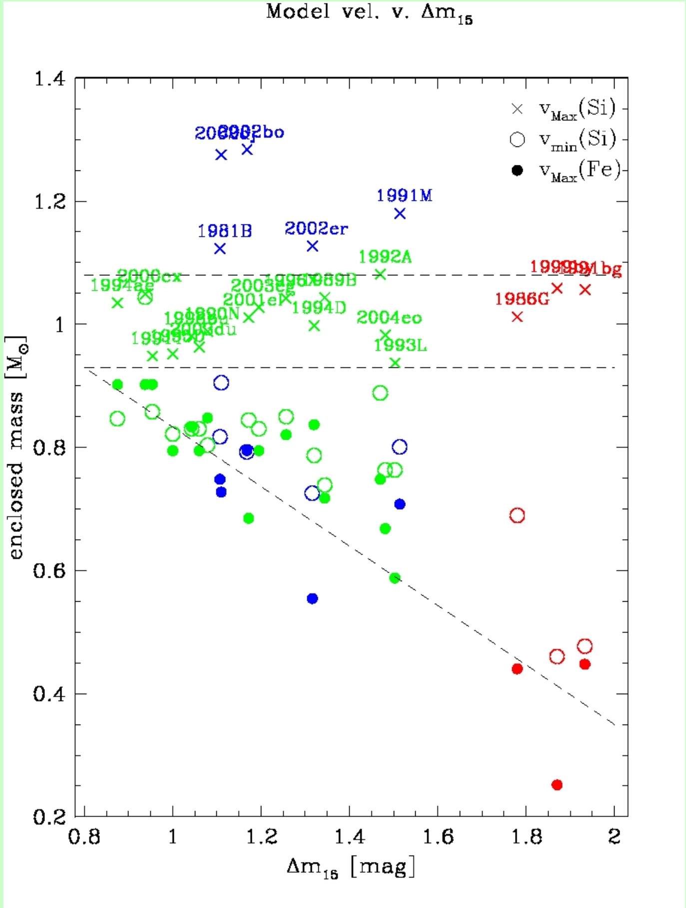
- Some anticorrelation between ^{56}Ni and (^{54}Fe, ^{58}Ni)
- Very good correlation beween Σ(NSE) and Δm_{15}(B)

Composition Layering



ρ(v):

W7



- Outer extent of Fe zone varies ($\propto \Delta m_{15}(B)$, Lum)
- Inner extent of IME matches outer extent of Fe
- Outer extent of IME ~ const.

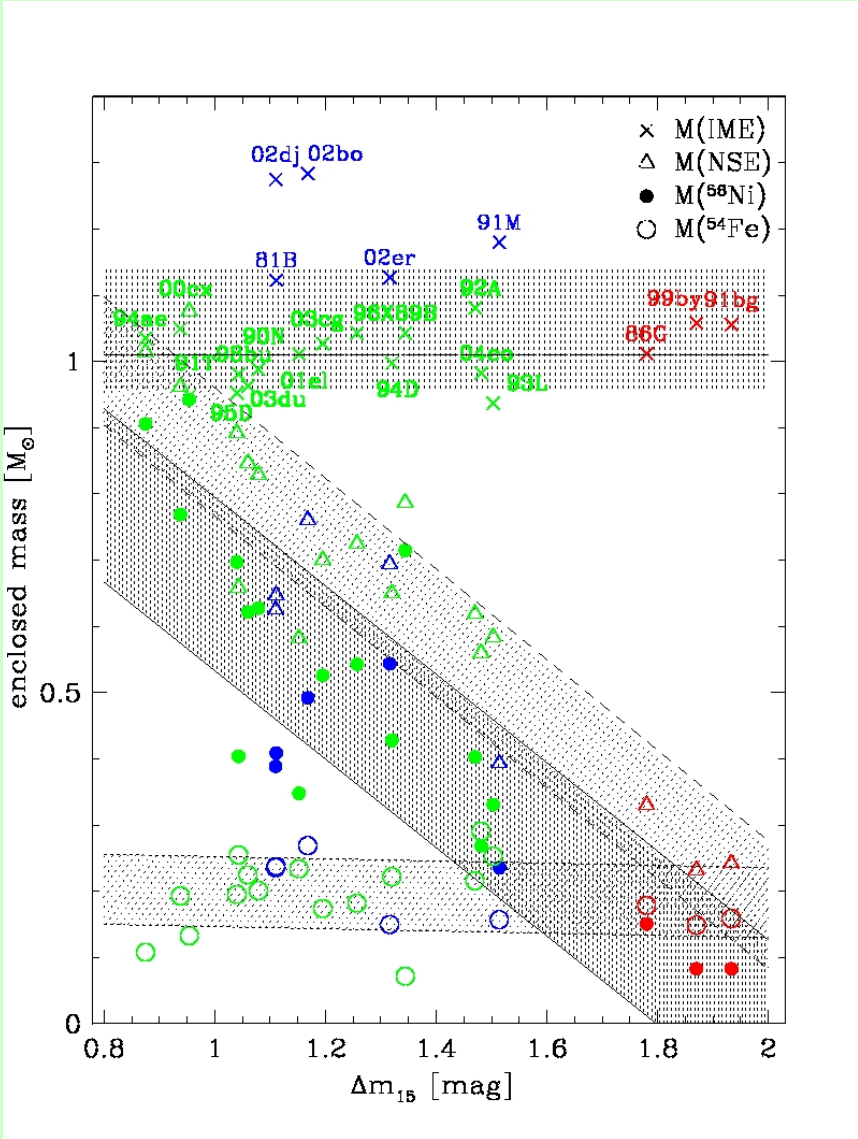
Putting it all together: "Zorro" diagram

A basic property of SNe Ia

Mass burned ~ constant

→ Progenitor mass also probably constant: MCh

→KE ~ const



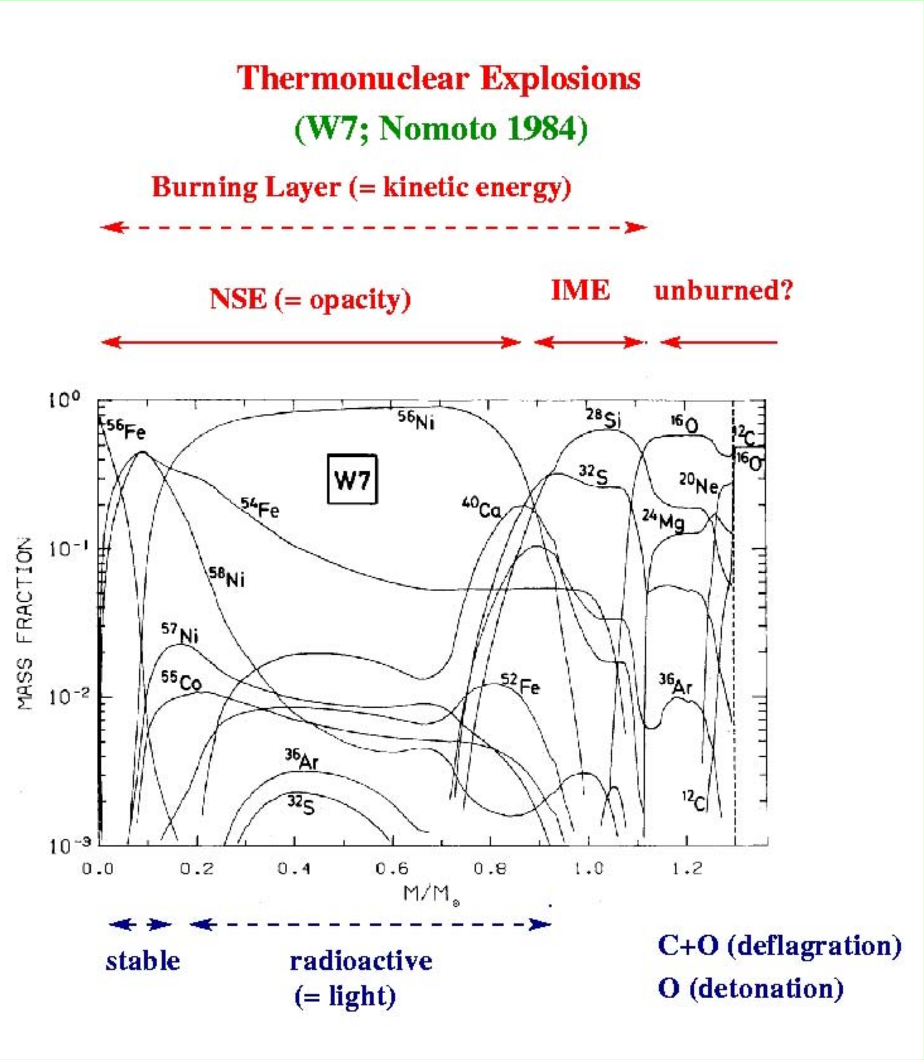
What does it all mean?

- Delayed detonation?
- Multi-spot ignited deflagration?
- Other possibilities….?

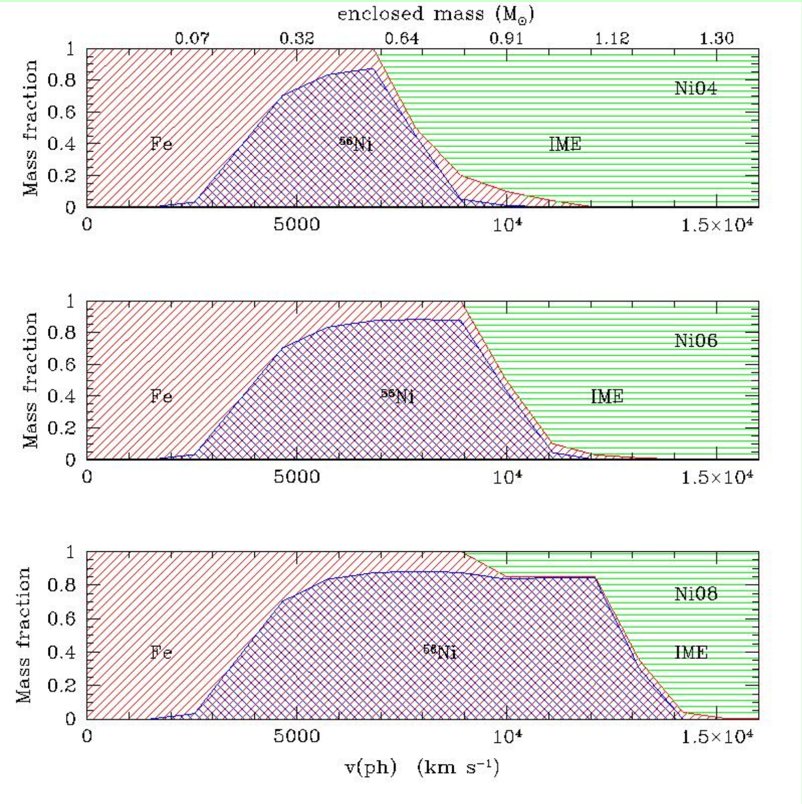
IV. Explaining observed relations

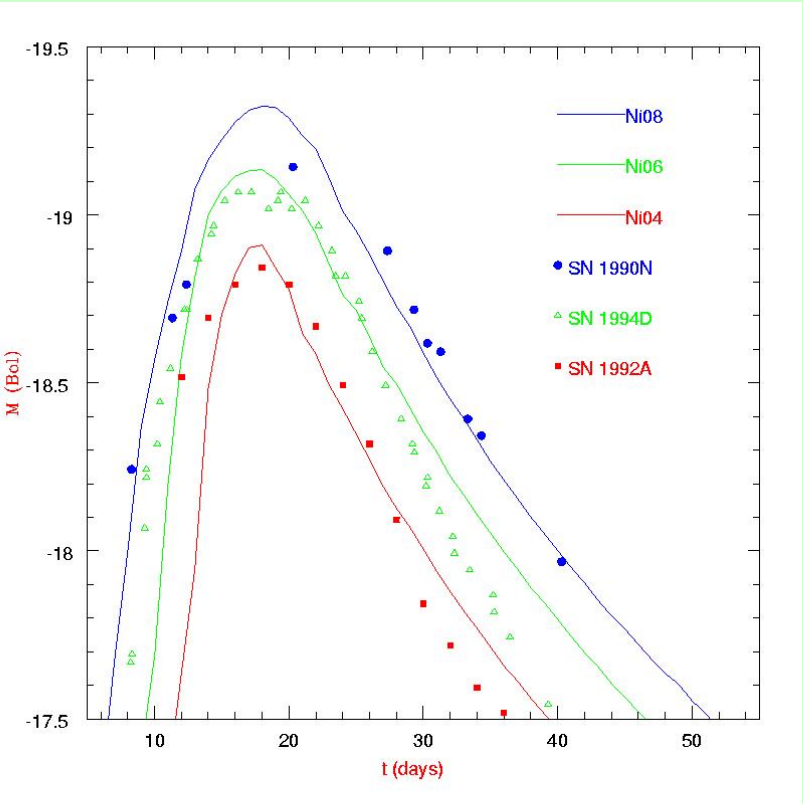
Role of Fe-group, IME on LC

- ^{56}Ni: light, opacity, KE
- ^{54}Fe, ^{58}Ni: opacity, KE
- IME: KE, (some opacity)
- CO (if any): little opacity



Explaining the Phillips' Relation





- ^{56}Ni: light, opacity, KE
- ^{54}Fe, ^{58}Ni: opacity, KE
- IME: KE, (some opacity)
- CO (if any): little opacity

Reproduce
Phillips' Relation

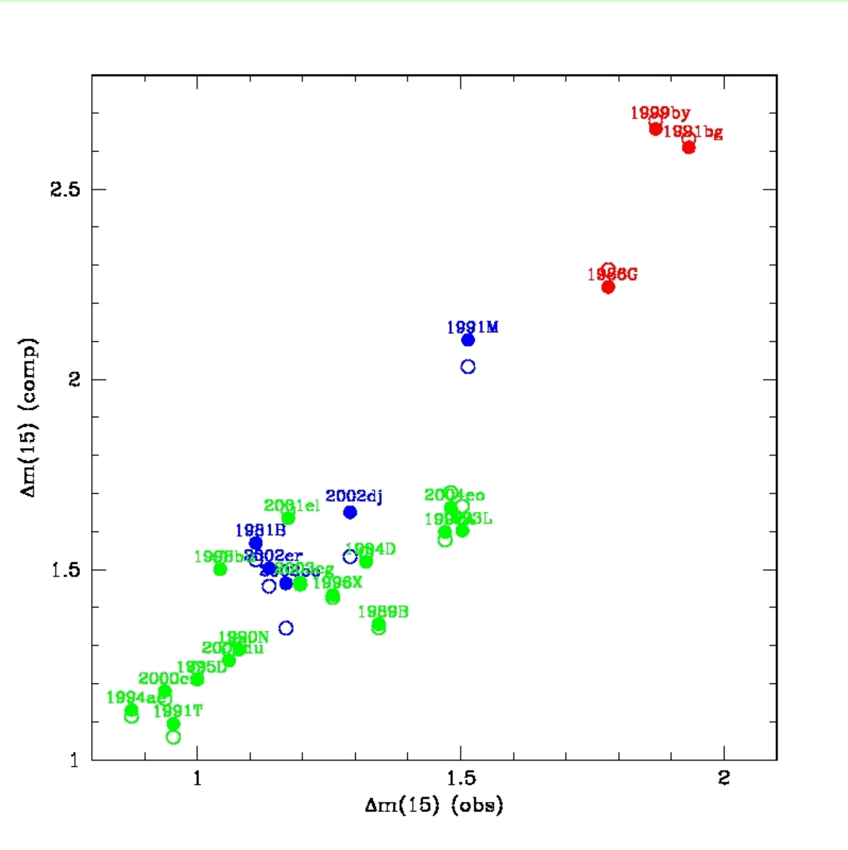
(Mazzali et al. 2001)

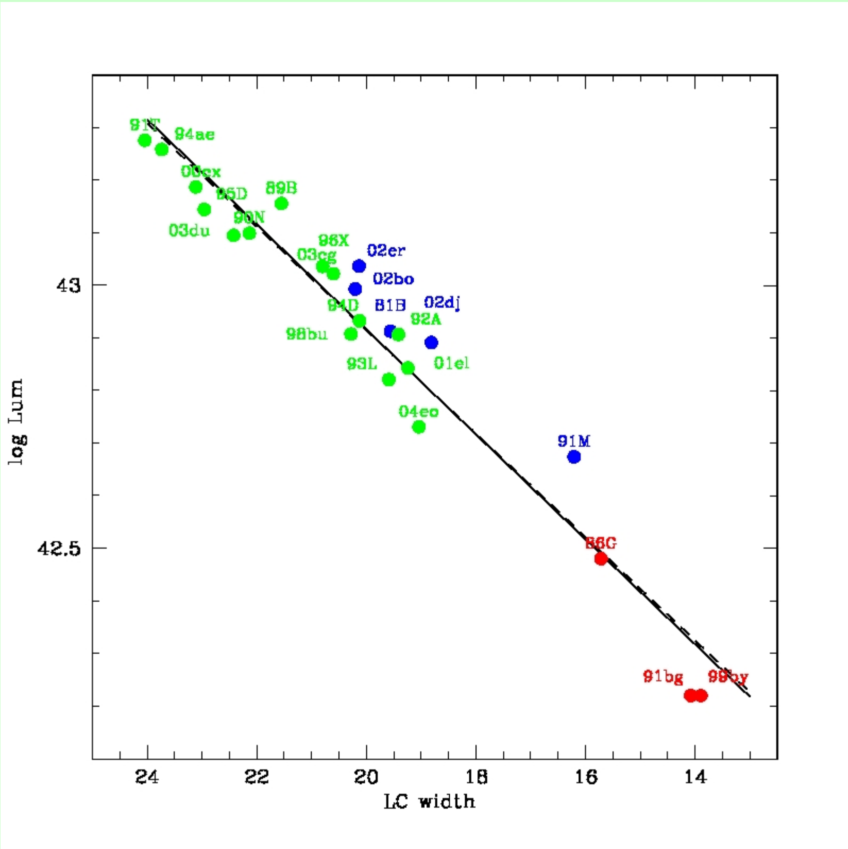
Using Zorro to reconstruct Phillips' Rel'n

- Use composition to compute LC parameters
  - $L = 2 \times 10^{43} M(^{56}\mathrm{Ni})$
  - $\tau \propto \kappa^{\frac{1}{2}} E_k^{-\frac{1}{4}} M_{ej}^{\frac{3}{4}}$
  - $E_k = [1.56M(^{56}\mathrm{Ni}) + 1.74M(stable\mathrm{NSE}) + 1.24M(\mathrm{IME}) - 0.46] \times 10^{51}\mathrm{erg}$
  - $\kappa \propto M(\mathrm{NSE}) + 0.1M(\mathrm{IME})$

- Derive Phillips Relation √

Using Zorro to reconstruct Phillips' Rel'n

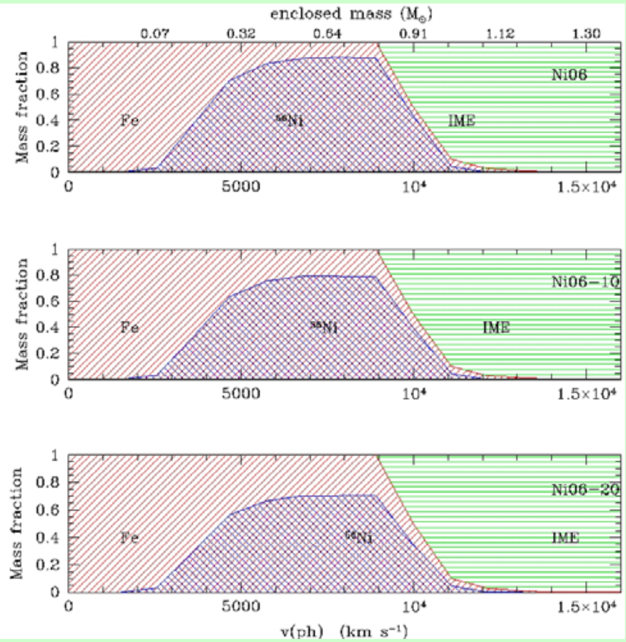


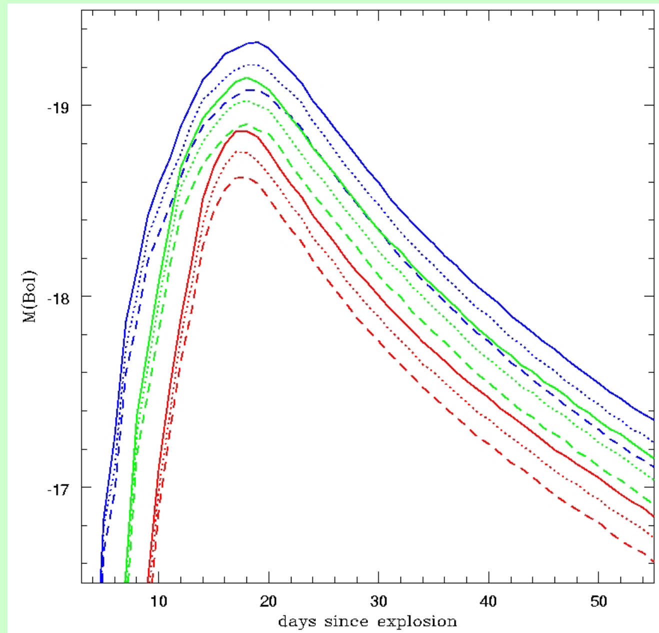


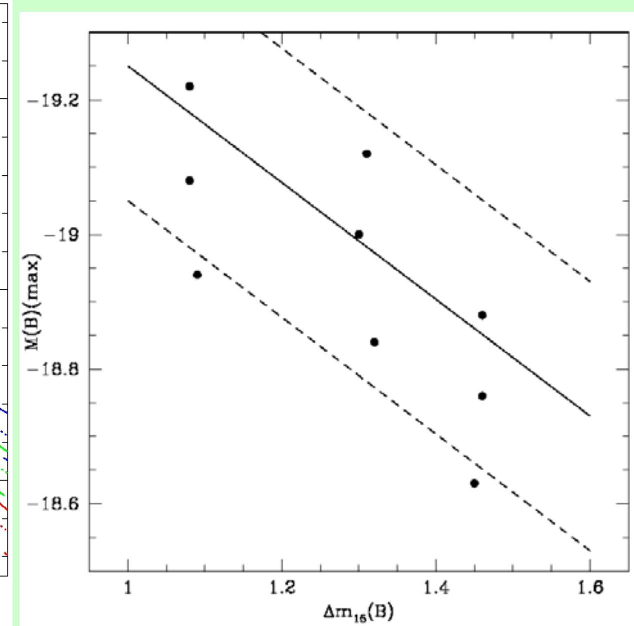
- Use composition to compute LC parameters √
- Derive Phillips Relation √

V. Hic sunt Leones…(the minefield)

Effect of ^{54}Fe, ^{58}Ni on LC-Lum rel'n







- Amount of ^{54}Fe, ^{58}Ni may be a fn. of WD metallicity (Timmes et al. 2003)
- Ratio ^{56}Ni/NSE affects light, not KE or opacity

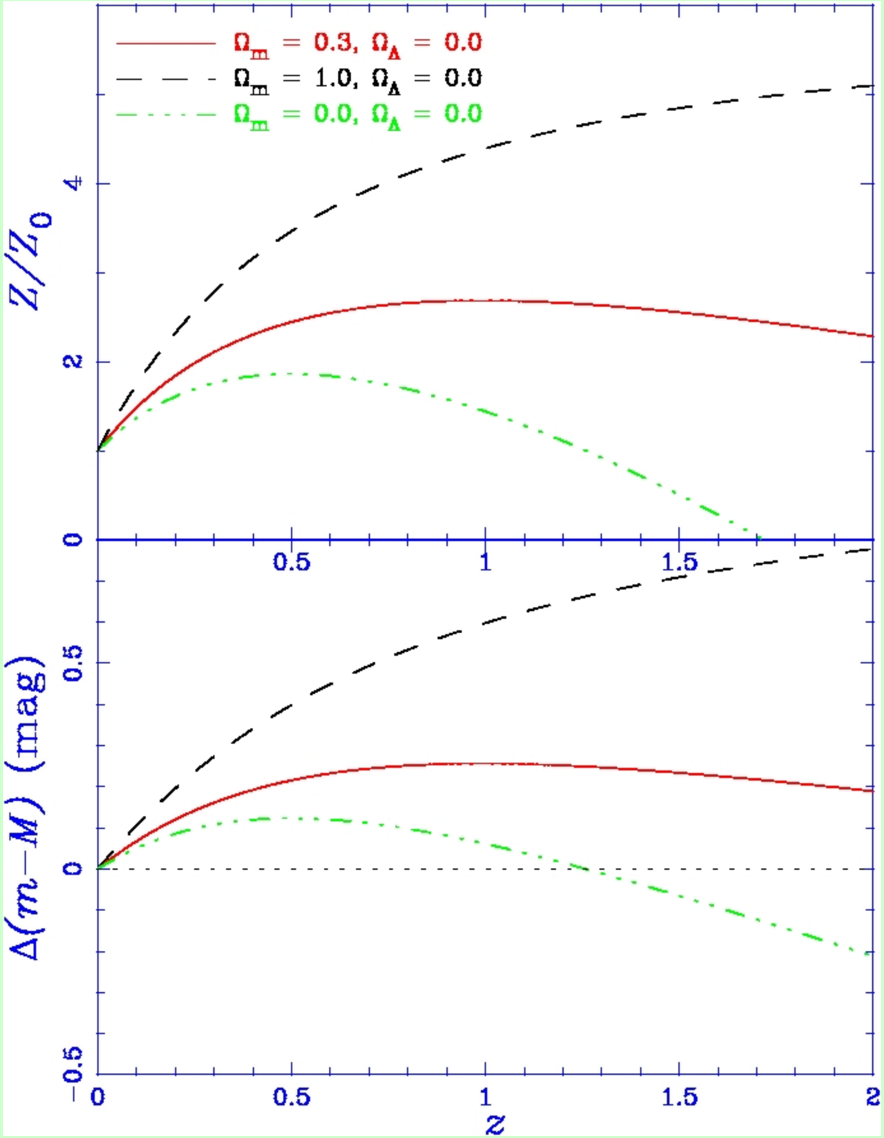
→ LCs w/ different peak brightness, same decline rate

→ May explain spread in Phillips' Relation.

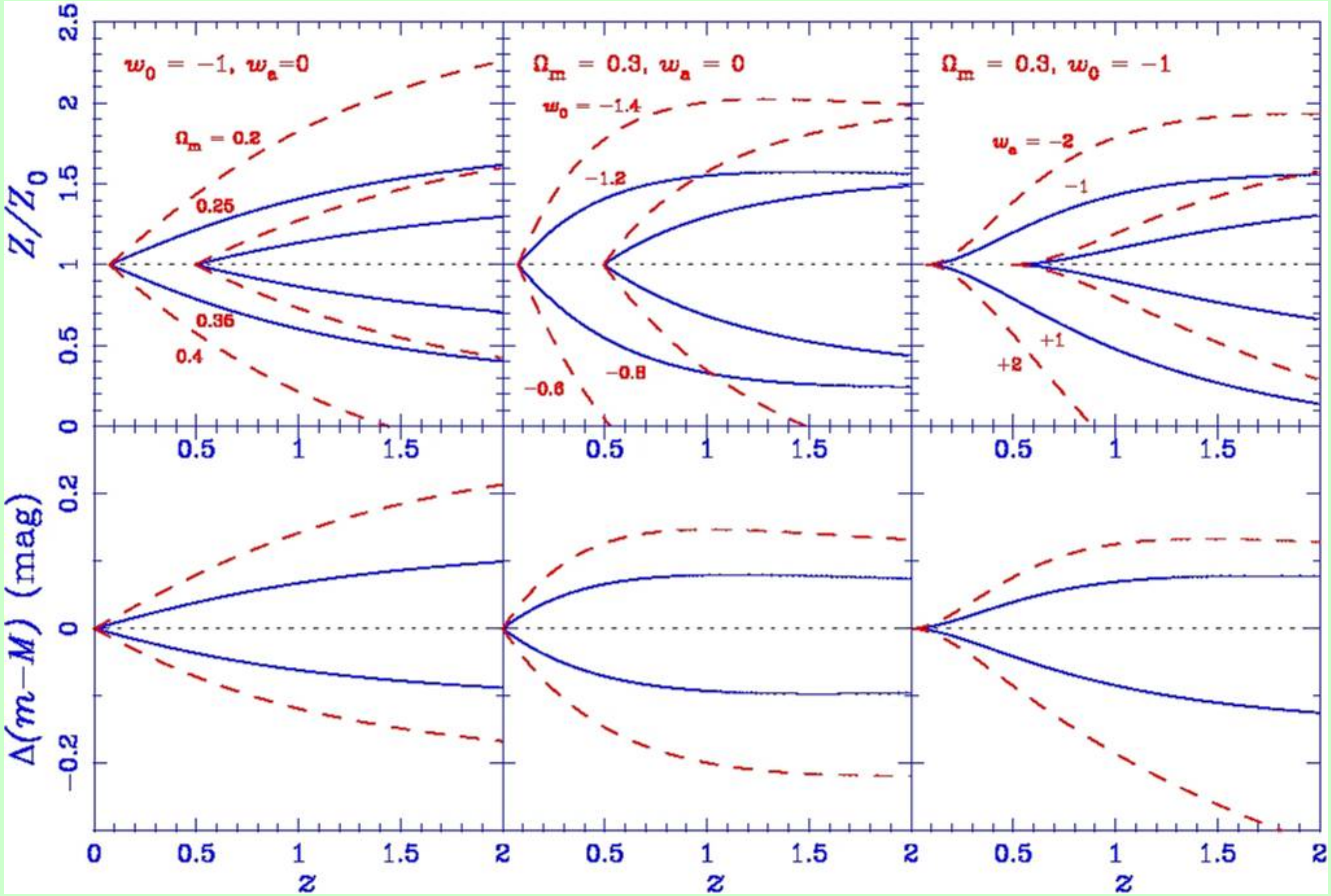
Effect on Cosmology?

- Evolution in Z may mimic cosmology
- Star-forming galaxies at z~1 may have been metal-rich w/r to present
  (Galaxy Downsizing)
- More neutronization → dimmer SNe with same LC
- May be consistent with $\Omega_m=0.3$, $\Omega_\Lambda=0.0$ Universe, but not with $\Omega_m=1$ Universe

(Podsiadlowski et al. 2006)



Uncertainty on cosmological parameters



- A variation in Z may be interpreted as a variation in Ω_m, w_0, or w_a.

Conclusions

- There is some regularity among SNe Ia (surprise surprise…)
- Ejecta reflect stratified composition of models
- Total mass burned may be constant
- ^{56}Ni determines luminosity (not new)
- Total NSE determines LC shape
- Degree of neutronization can give rise to dispersion in luminosity-decline rate relation
- Z evolution may confuse cosmological parameters

Effect on scale factor with Z

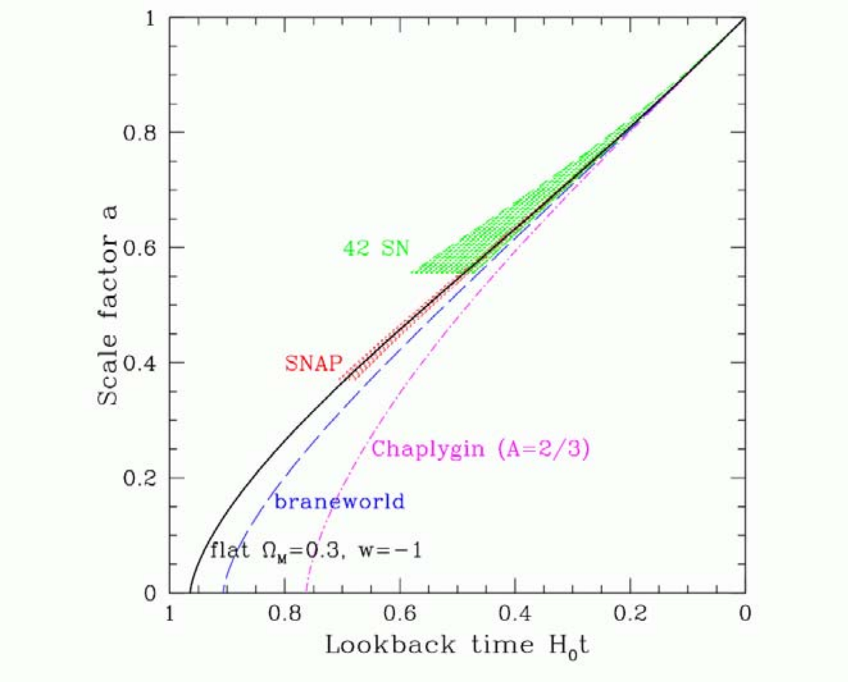
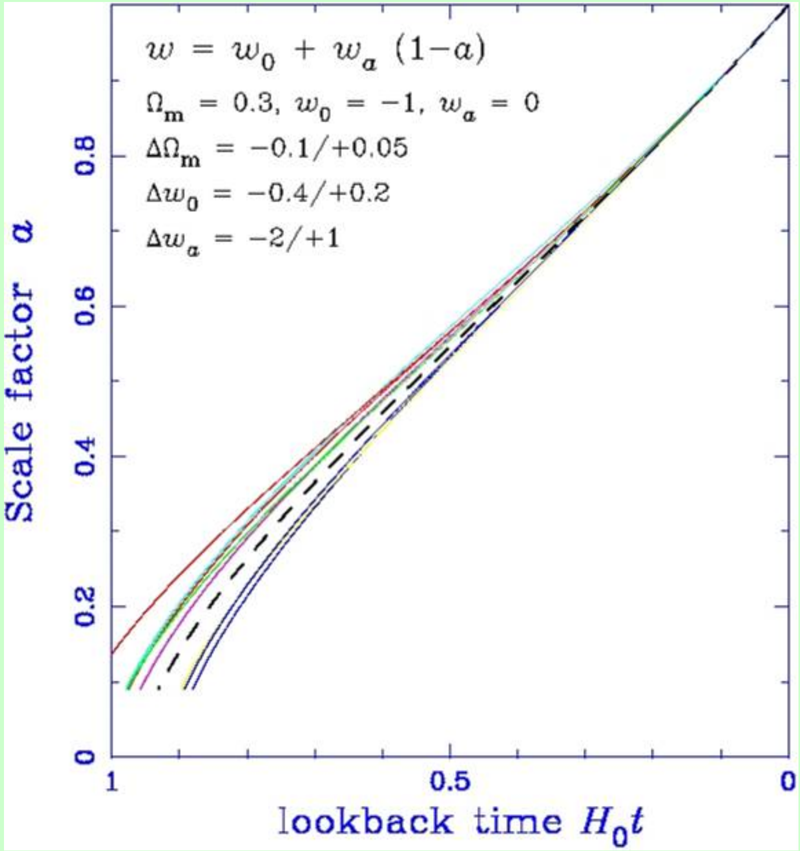


FIG. 1: Mapping the expansion history through the supernova magnitude-redshift relation can distinguish the dark energy explanation for the accelerating universe from alternate theories of gravitation, high energy physics, or higher dimensions. All three models take an $\Omega_M = 0.3$, flat universe but differ on the form of the Friedmann expansion equation.



Different cosmologies (Linder et al) v. Metallicity evolution