# Exploring the global properties of SNe Ia

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# 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)

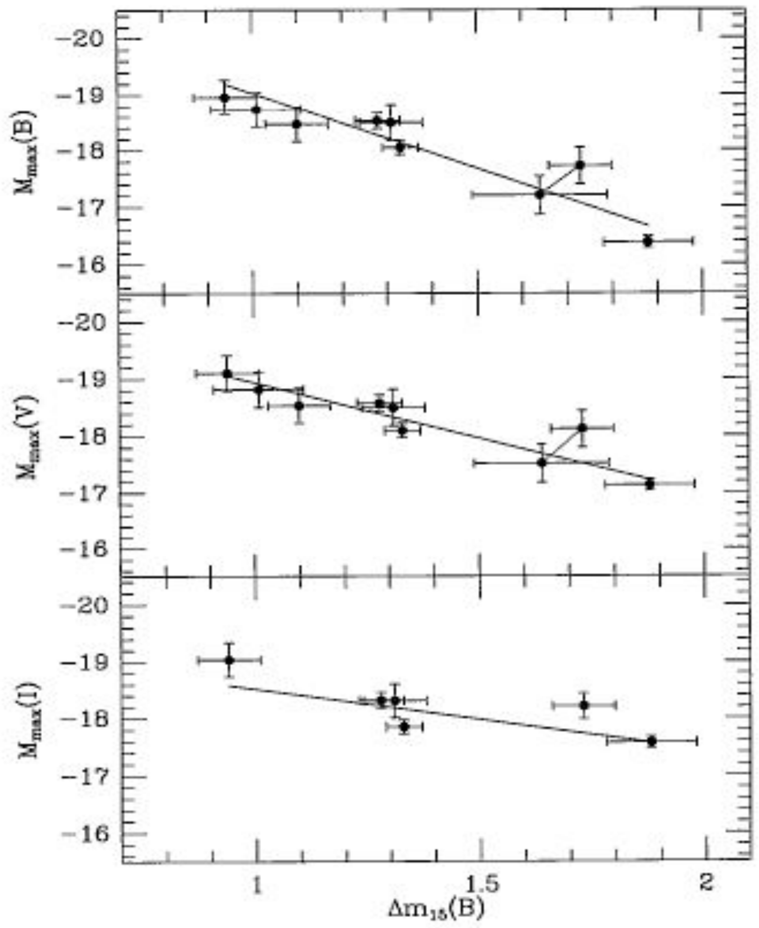
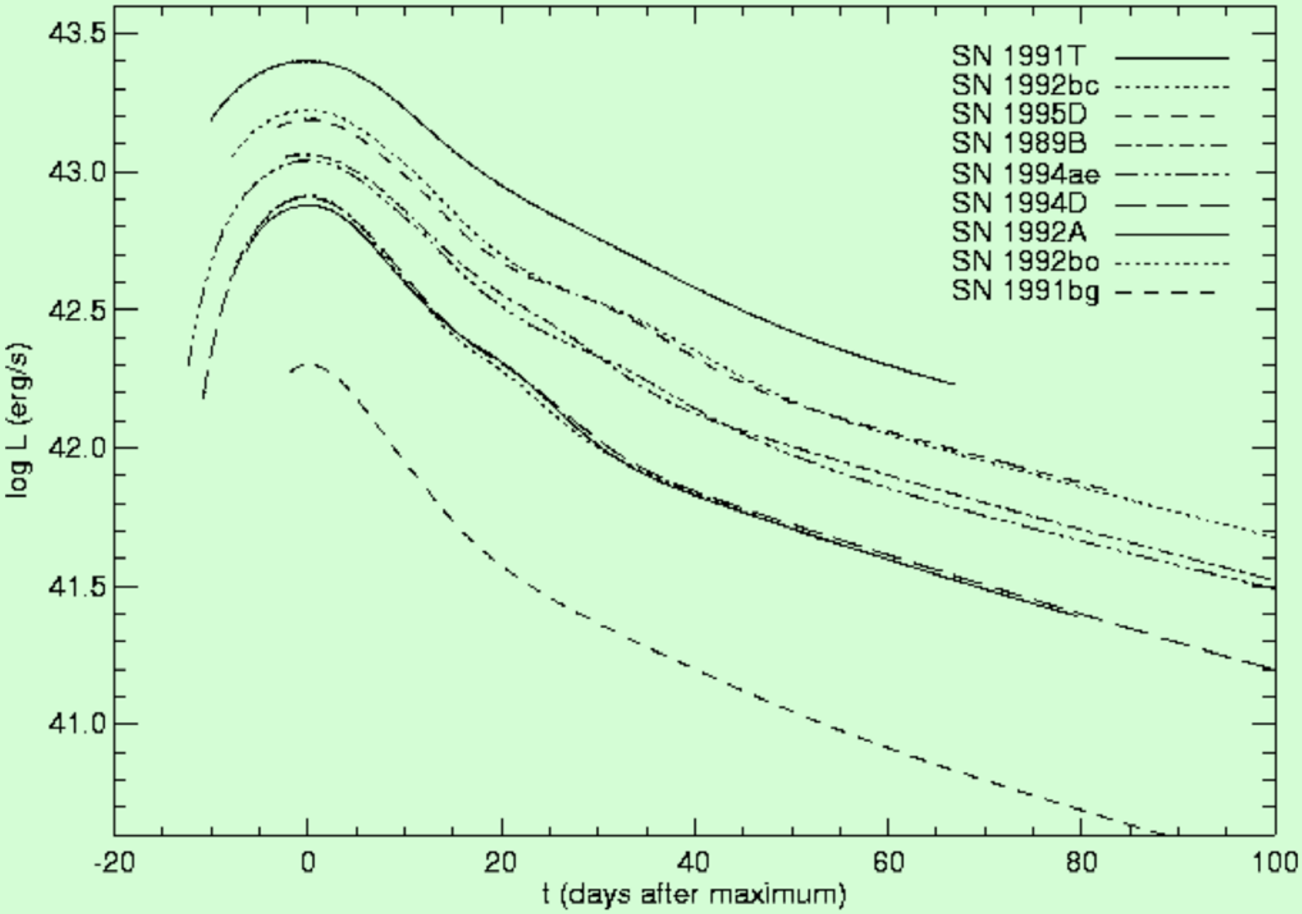


FIG. 1.—Decline rate–peak luminosity relation for the nine best-observed SN Ia's. Absolute magnitudes in *B*, *V*, and *I* are plotted vs. $\Delta m_{15}(B)$, which measures the amount in magnitudes that the *B* light curve drops during the first 15 days following maximum.

Phillips 1992

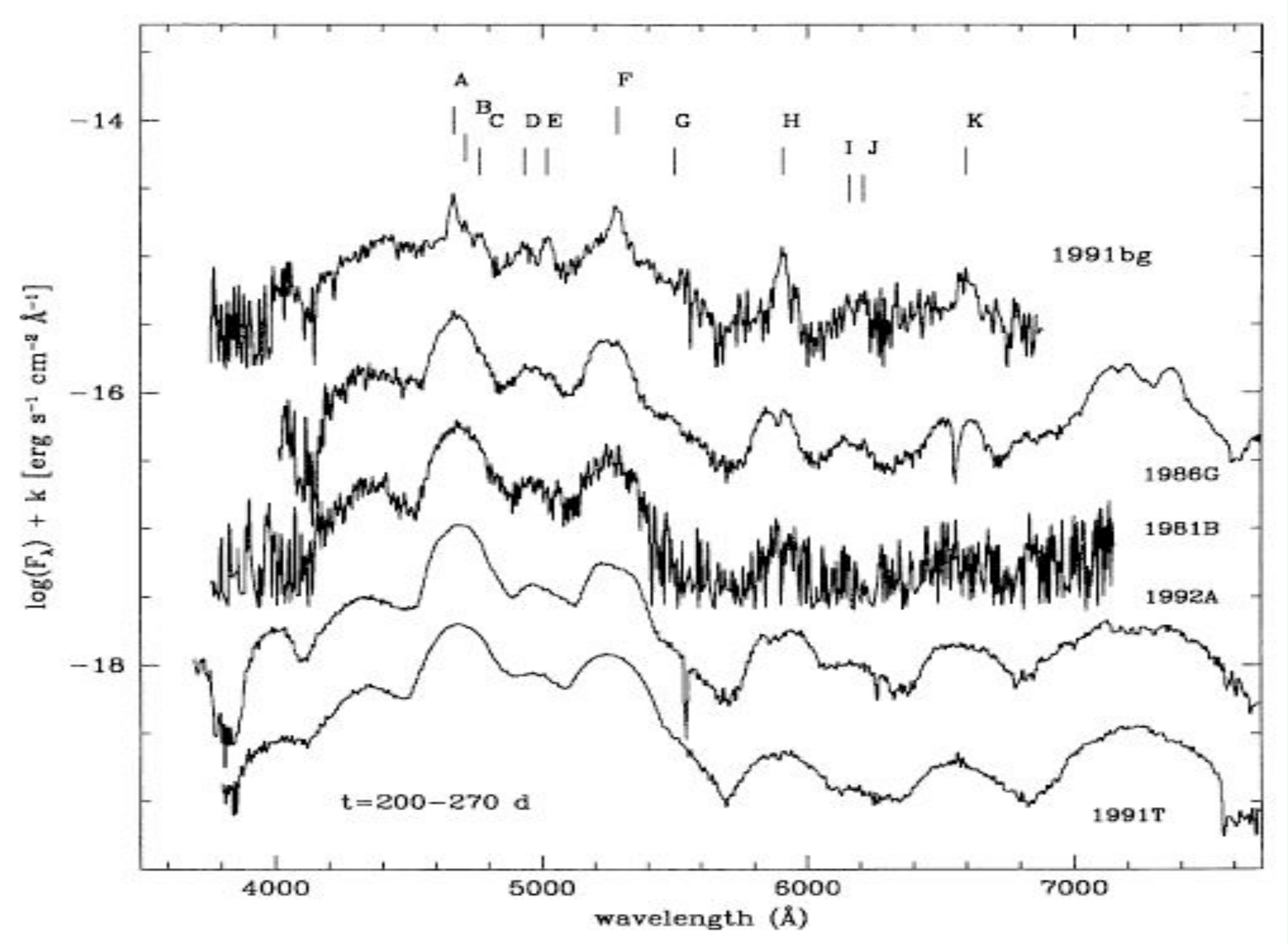
# ii. Bolometric Light Curves

Lpeak - decline rate or LC shape



Contardo et al. 2000

# iii. SNe Ia: late-time spectra



**Δm15(B)**

**1.93**

**1.77**

**1.27**

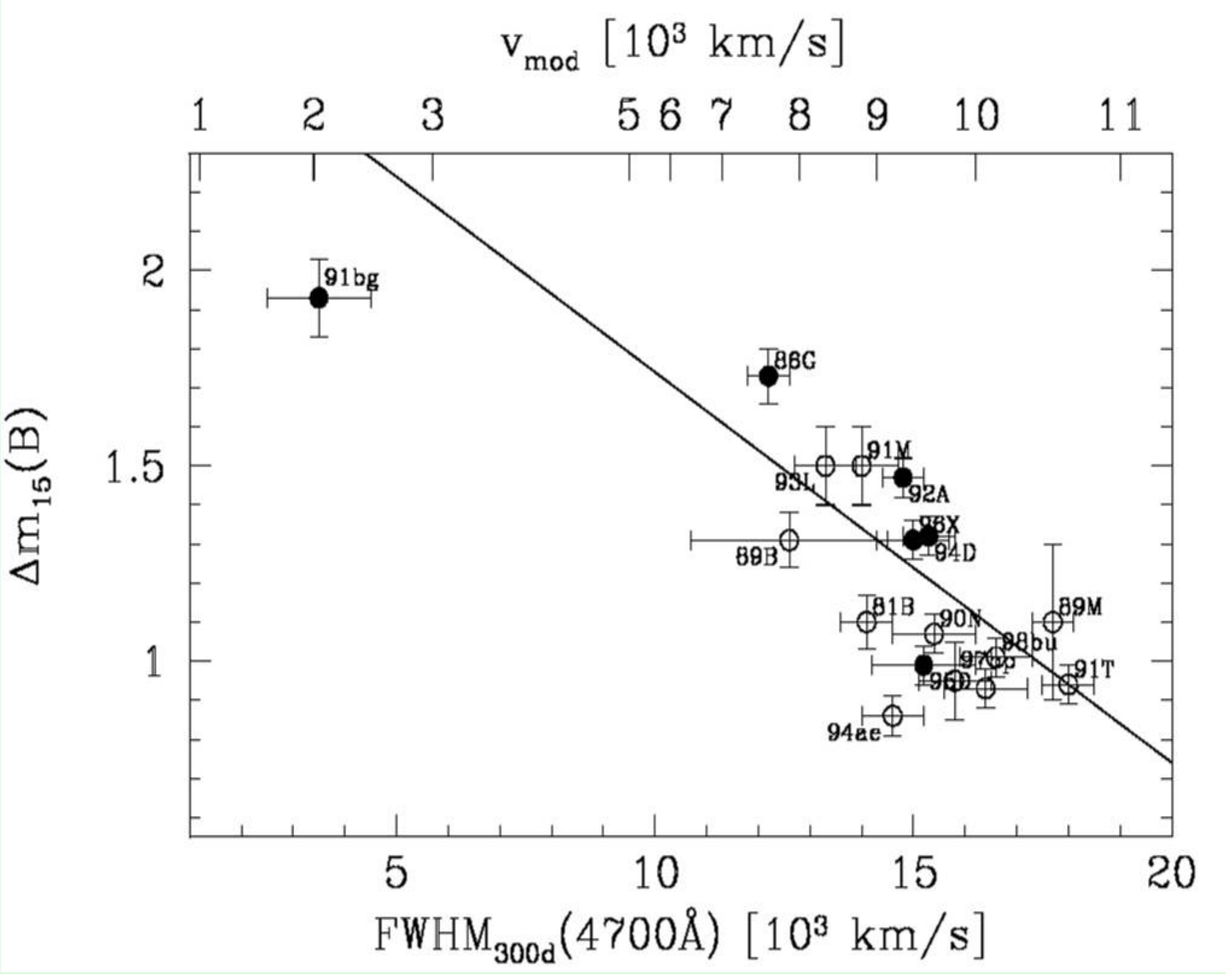
**1.51**

**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

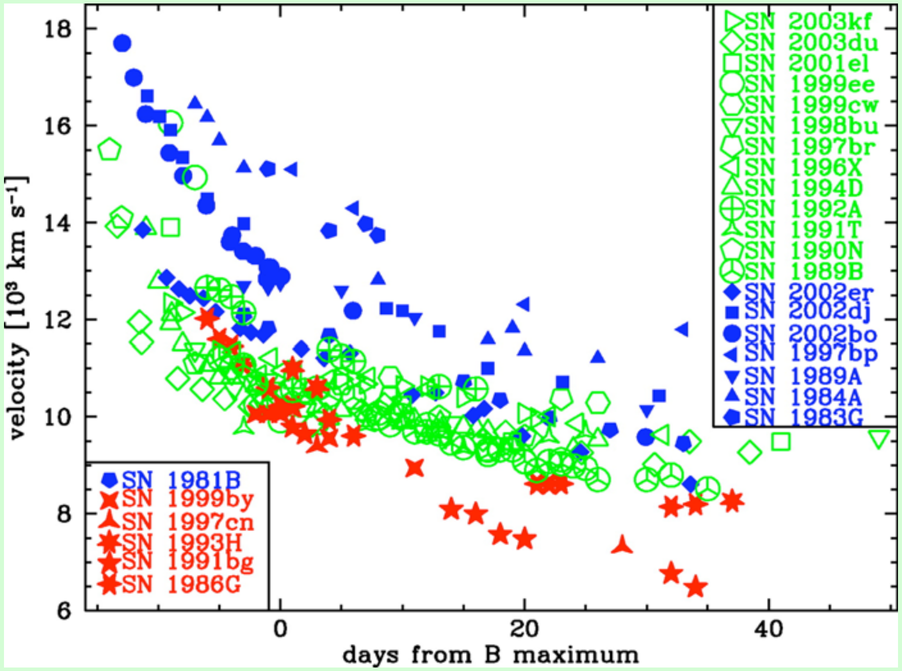
→ 3 SN groups:

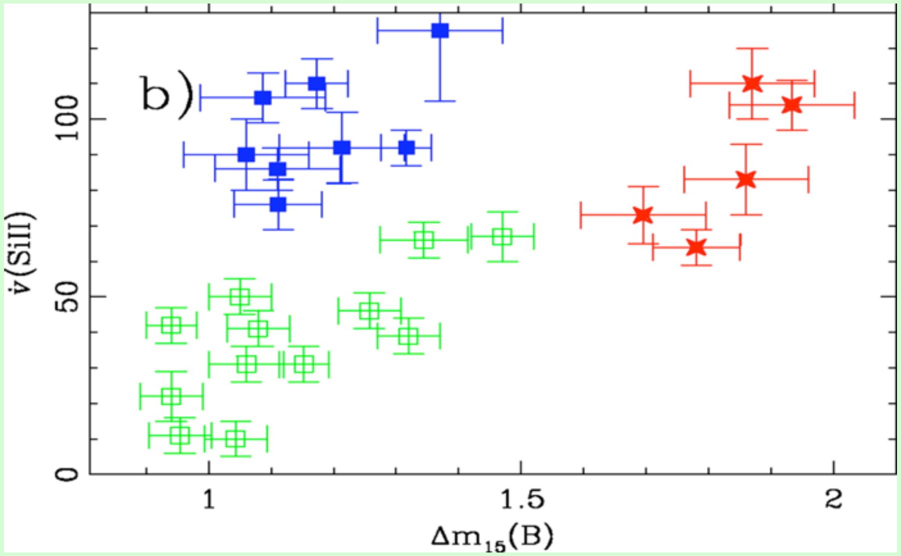
High Velocity Gradient

Low Velocity Gradient

Faint

- Groups separate out in v-$\Delta M_{15}$(B) plot



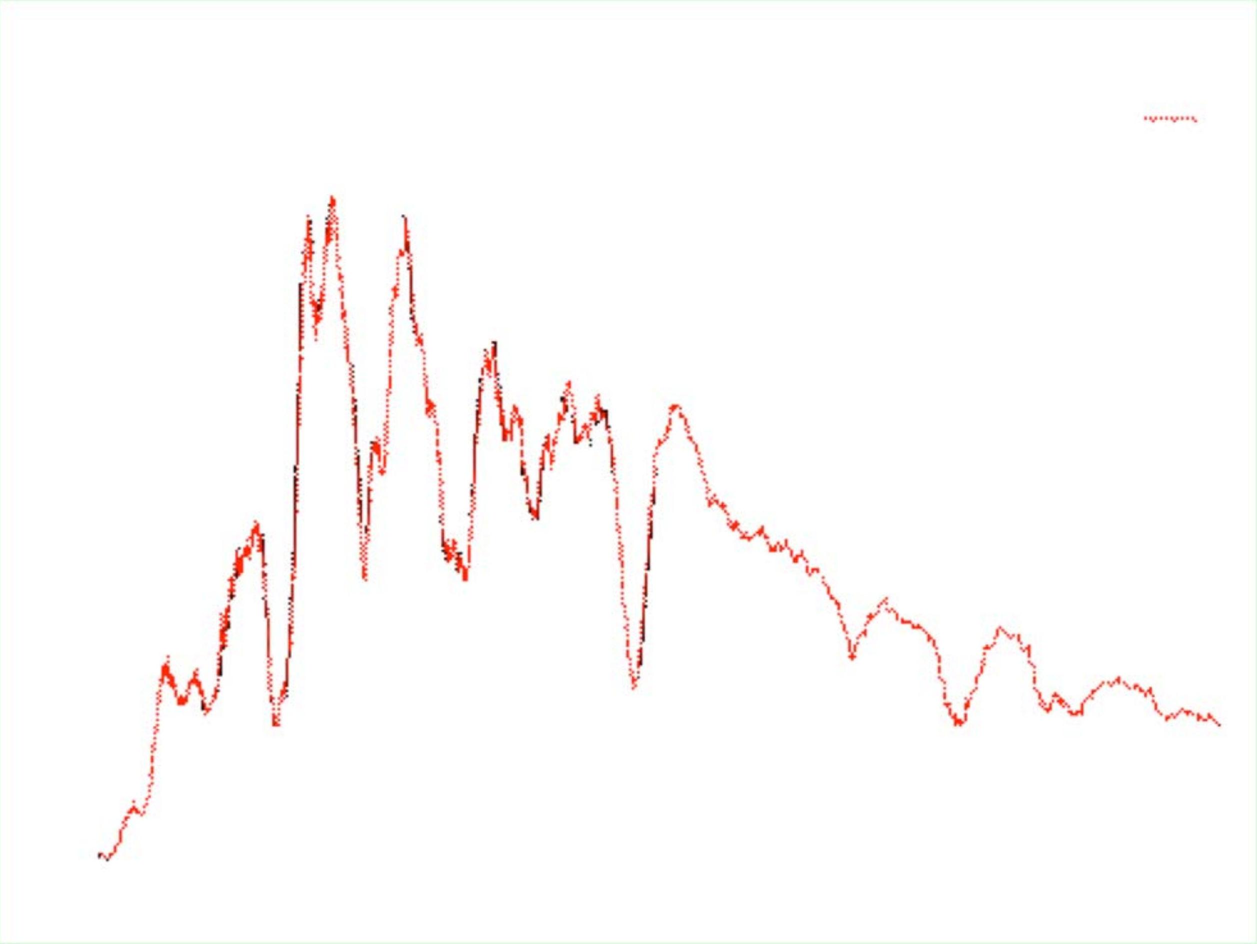


# II. Radiative Transfer Models

Early-time spectra

Monte Carlo code

- Composition
- Density
- Luminosity
- Velocity

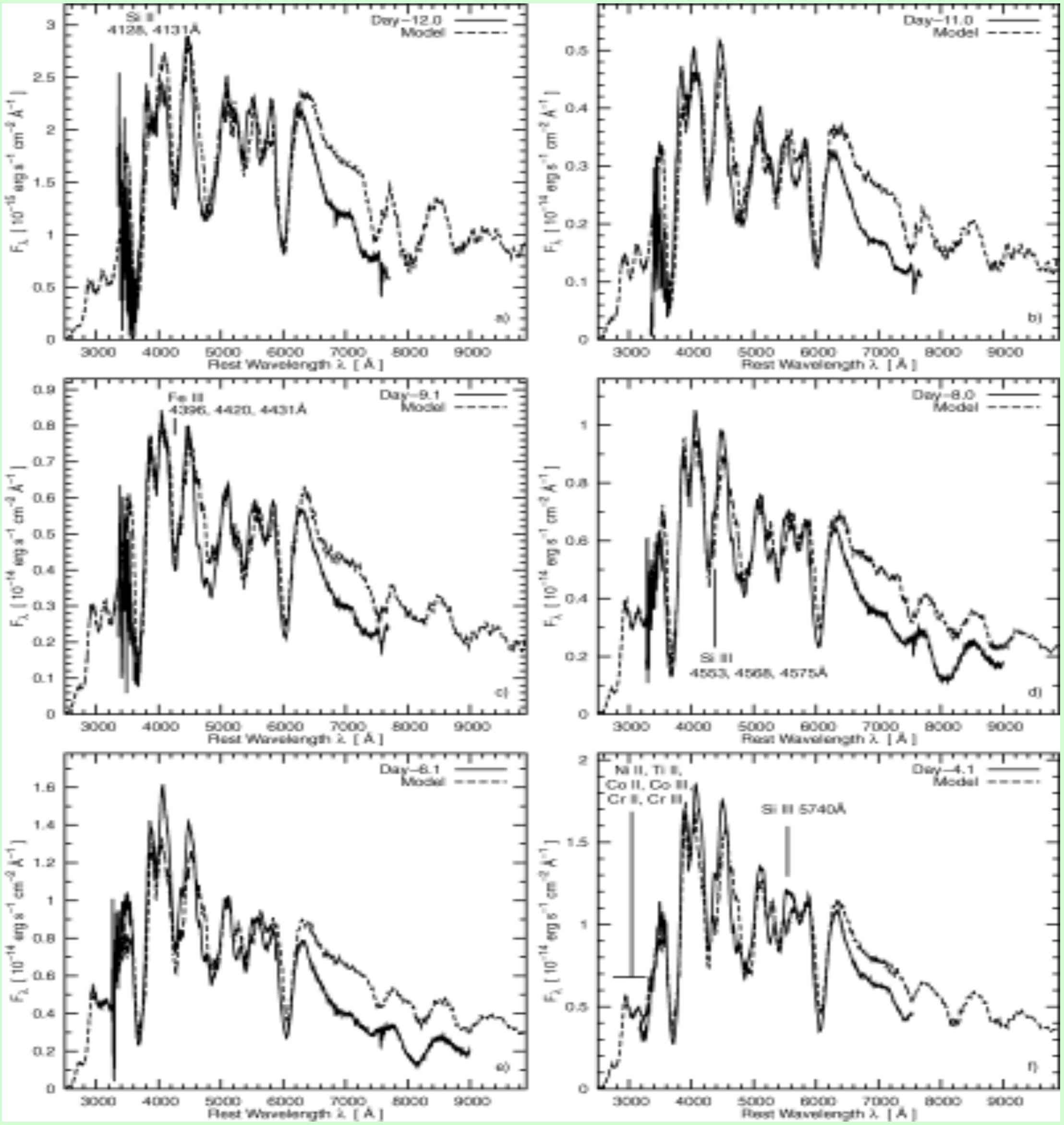


# Abundance Stratification

Model sequence of spectra to derive composition layering

→How did the star burn?

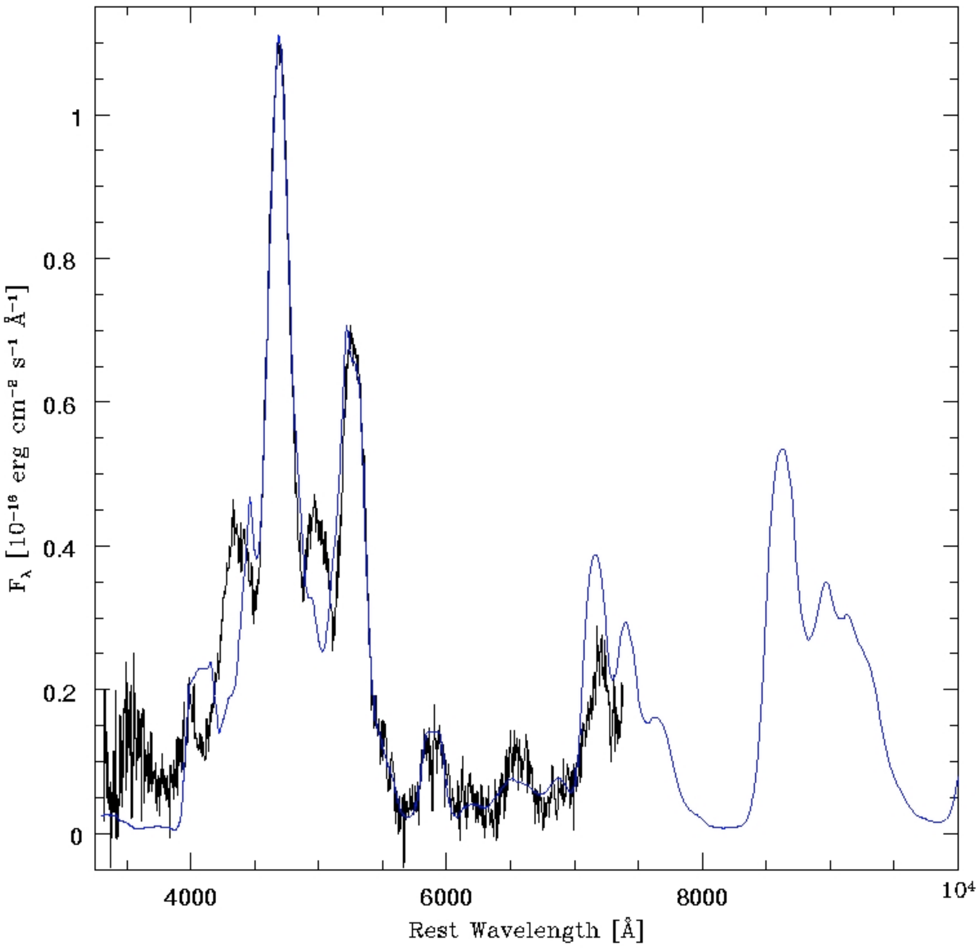
Stehle et al 2005



# Late-time spectra

Monte Carlo LC code
+ NLTE nebular code

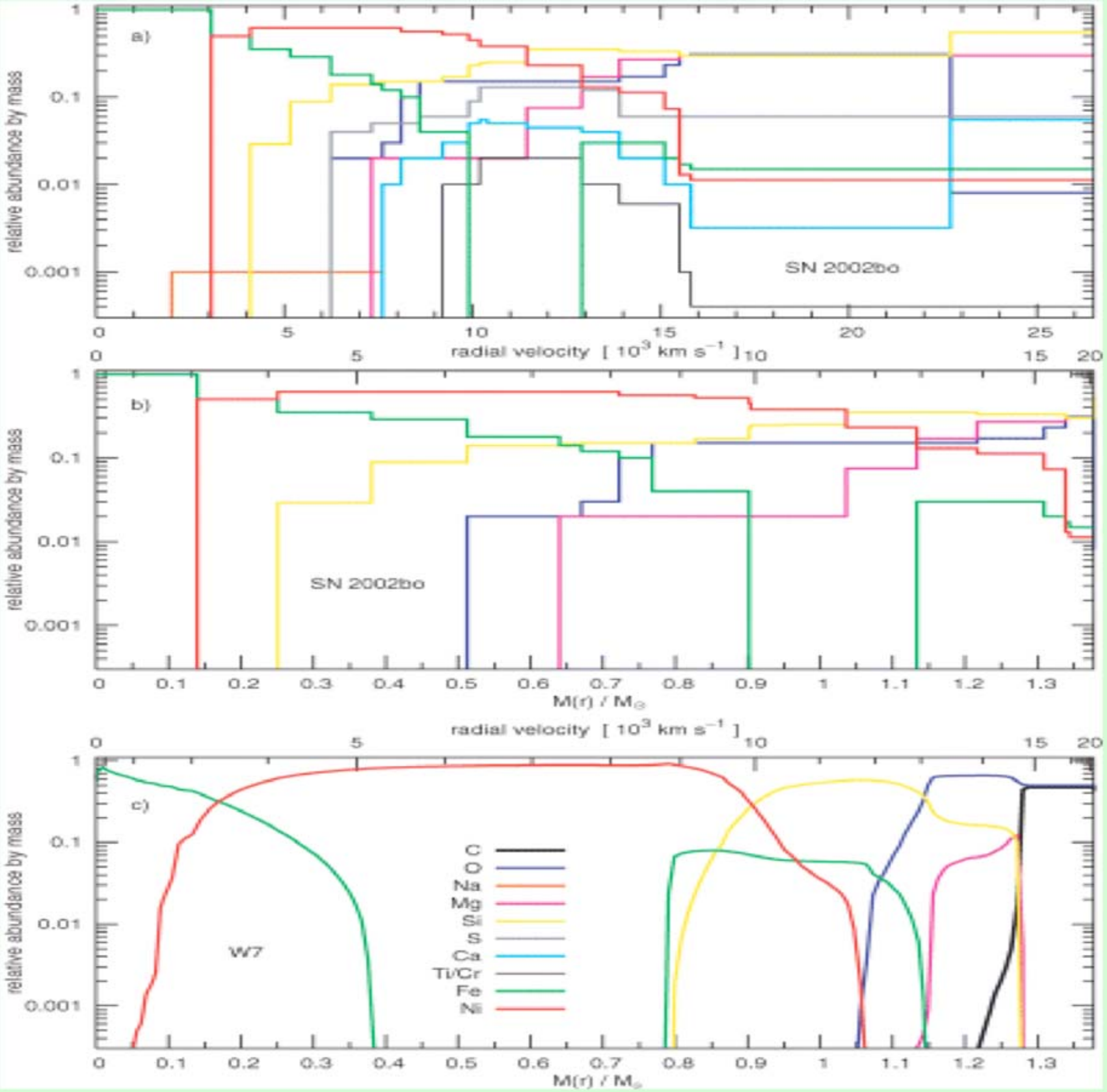
- No radiative transfer
- Get full view of inner ejecta ($^{56}$Ni zone)
- Estimate masses of inner ejecta



# 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

Stehle et al 2005

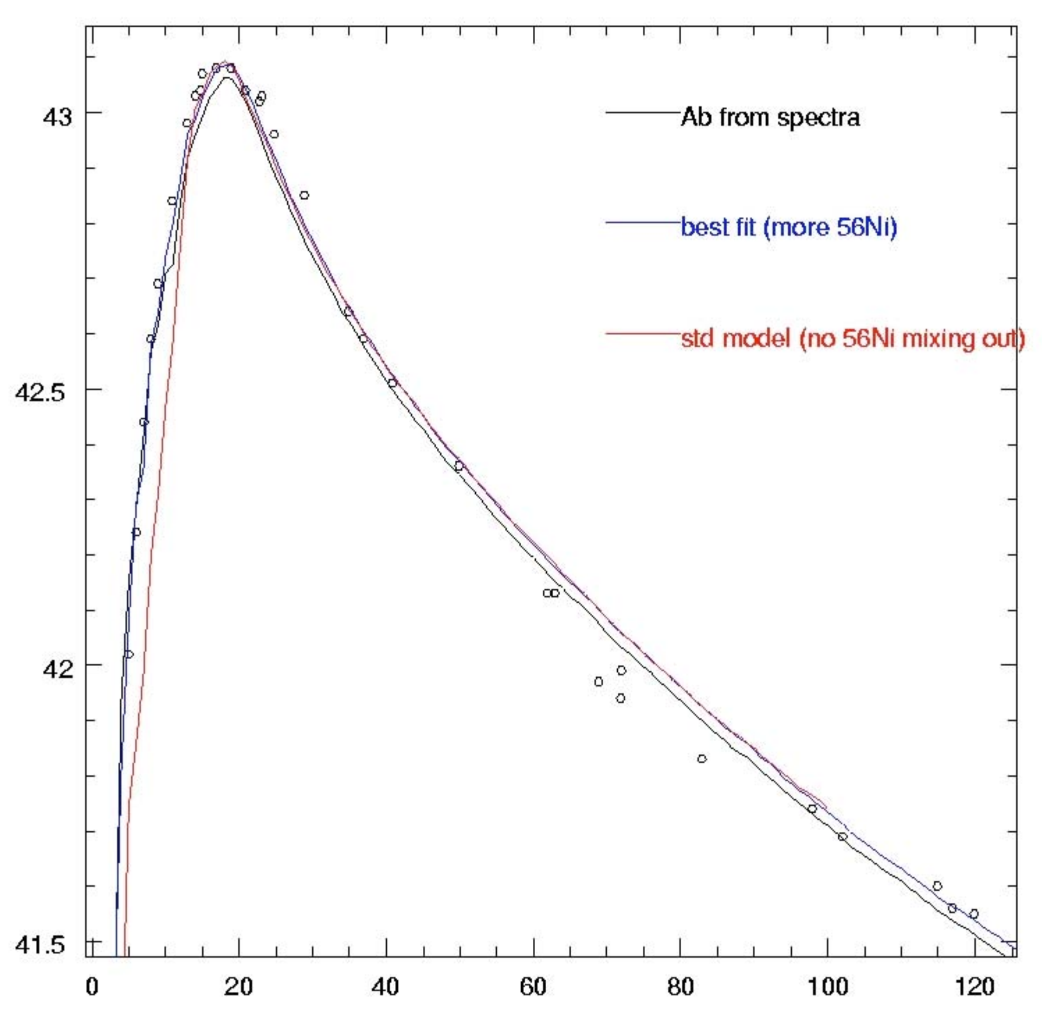


# Test: Light Curve

Monte Carlo code

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

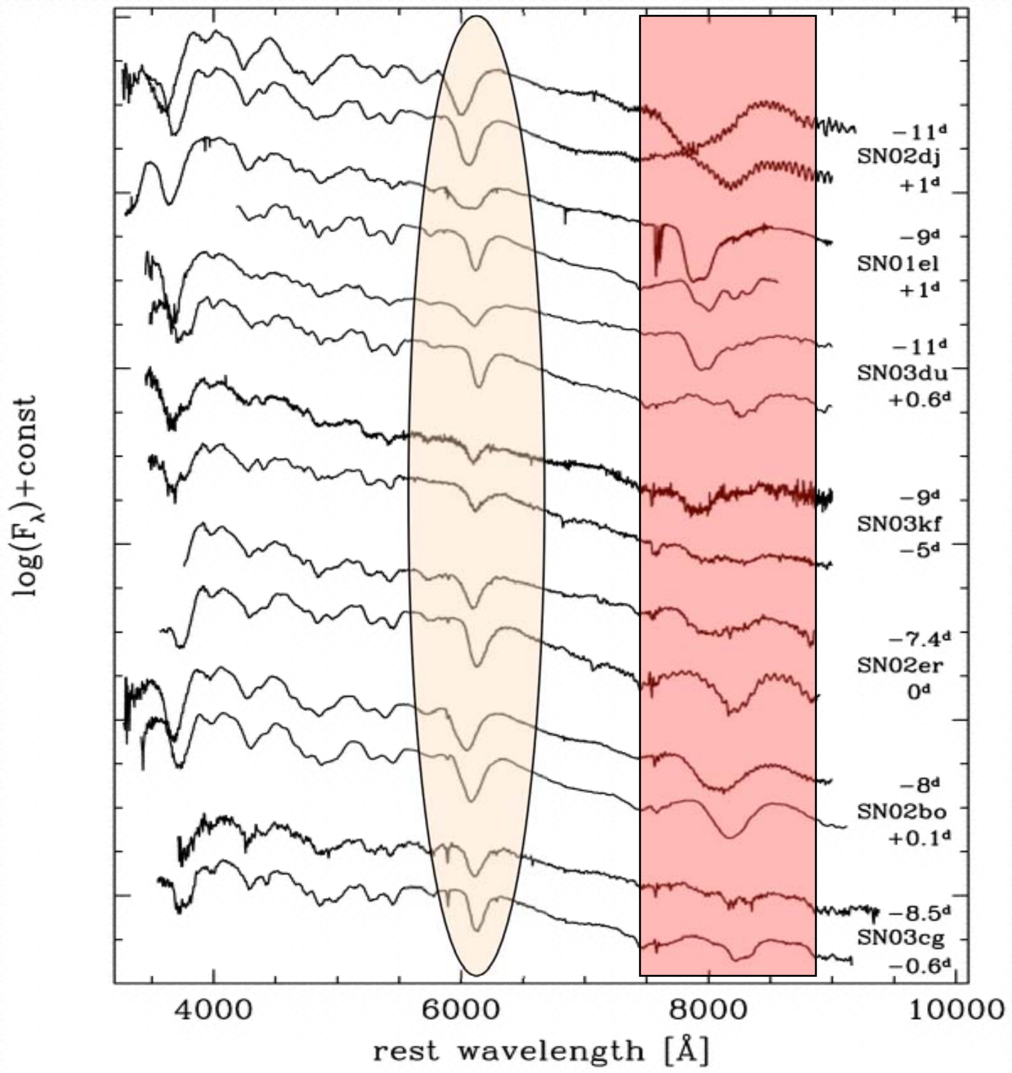
→ Model LC matches data very well



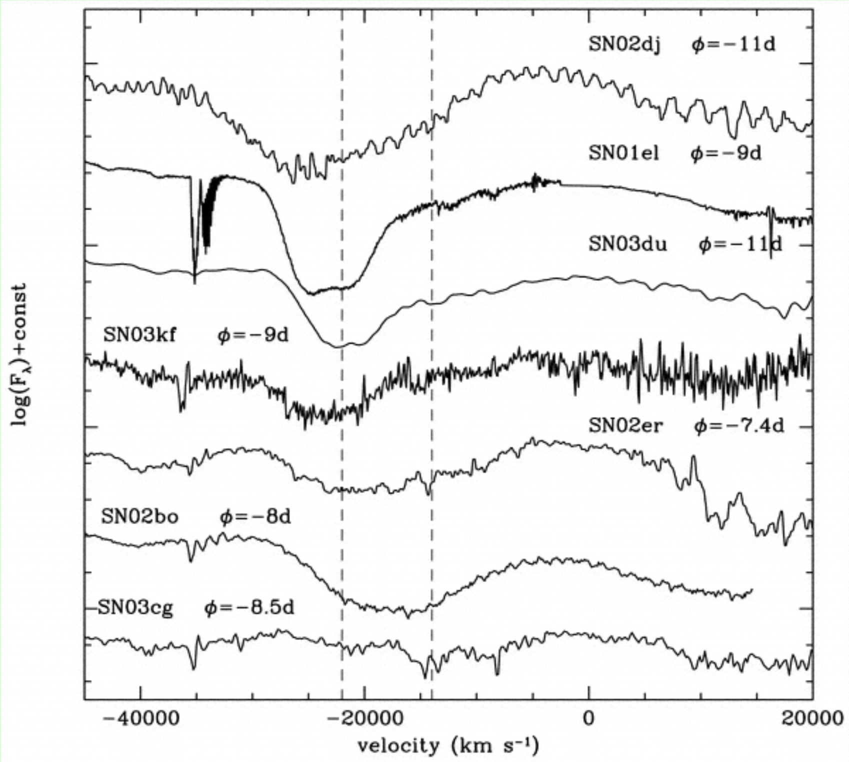
# III. Outer regions of the ejecta: HVFs

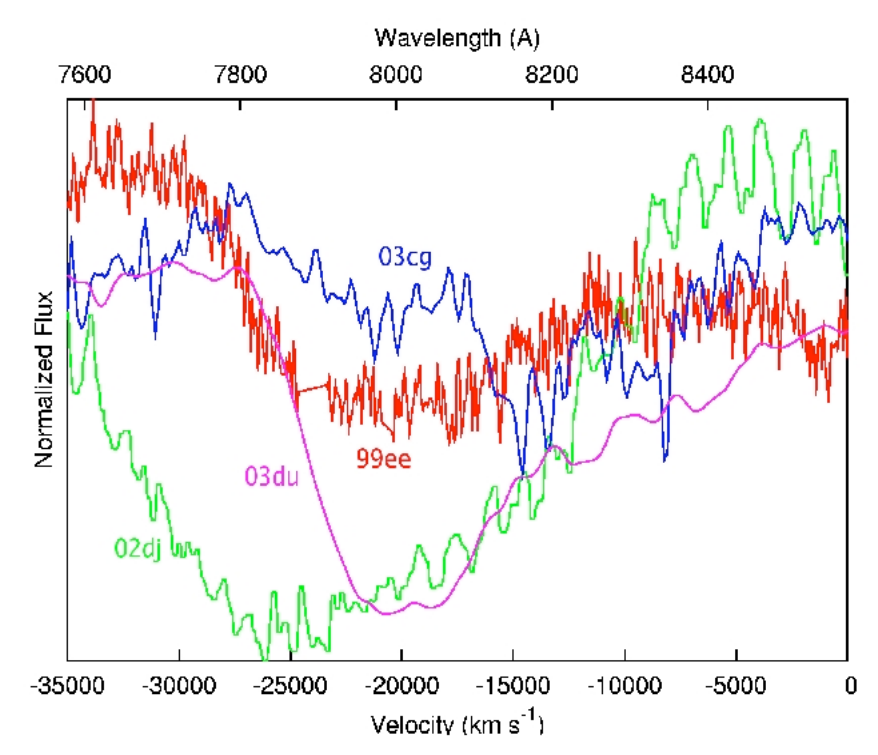
- Nearly all SNe show very high velocity (~20000 km/s) absorption features (HVF) in Ca II (some also in Si II)

Mazzali et al (2005)



# HVFs come in various forms



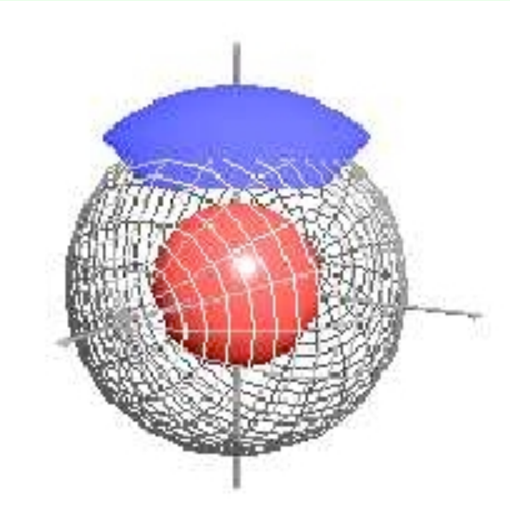


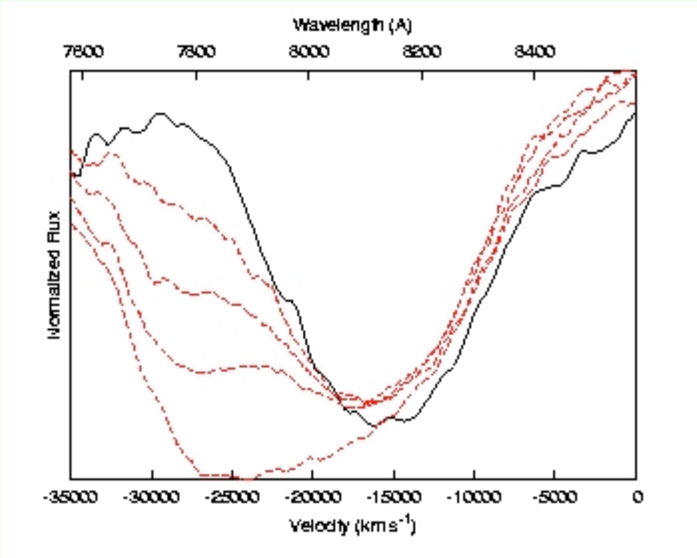
Mazzali et al. (2005)

Tanaka et al. (2006)

# What makes the HVFs

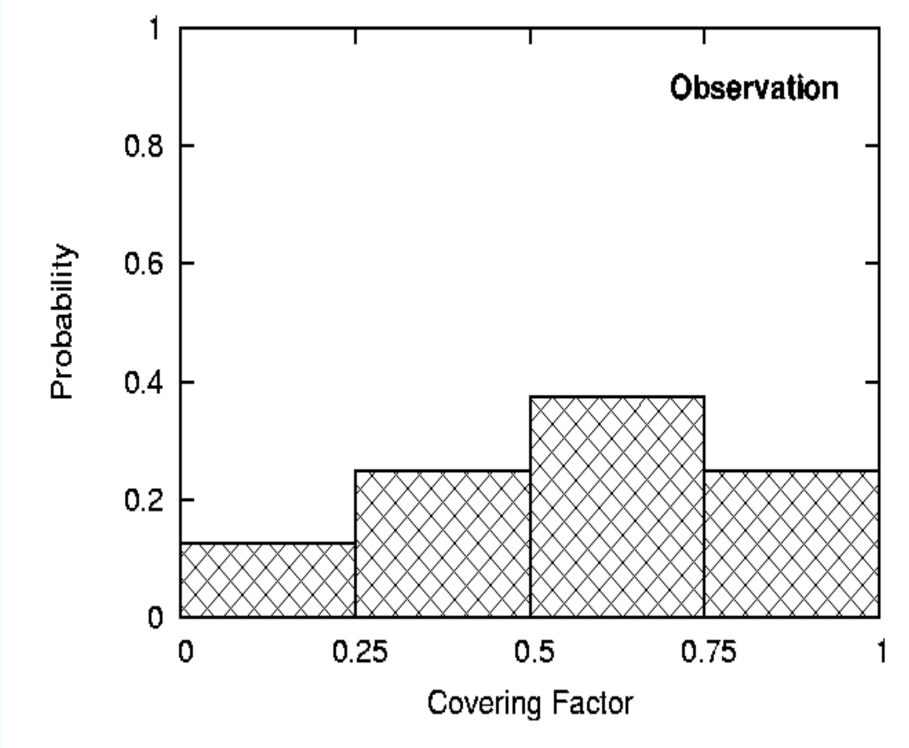
- Abundance enhancement unlikely
- Density enhancement more reasonable
- Ejection of blobs or CSM interaction?
- Blobs: line profiles depend on orientation
- 3D modelling
  Tanaka et al. (2006)



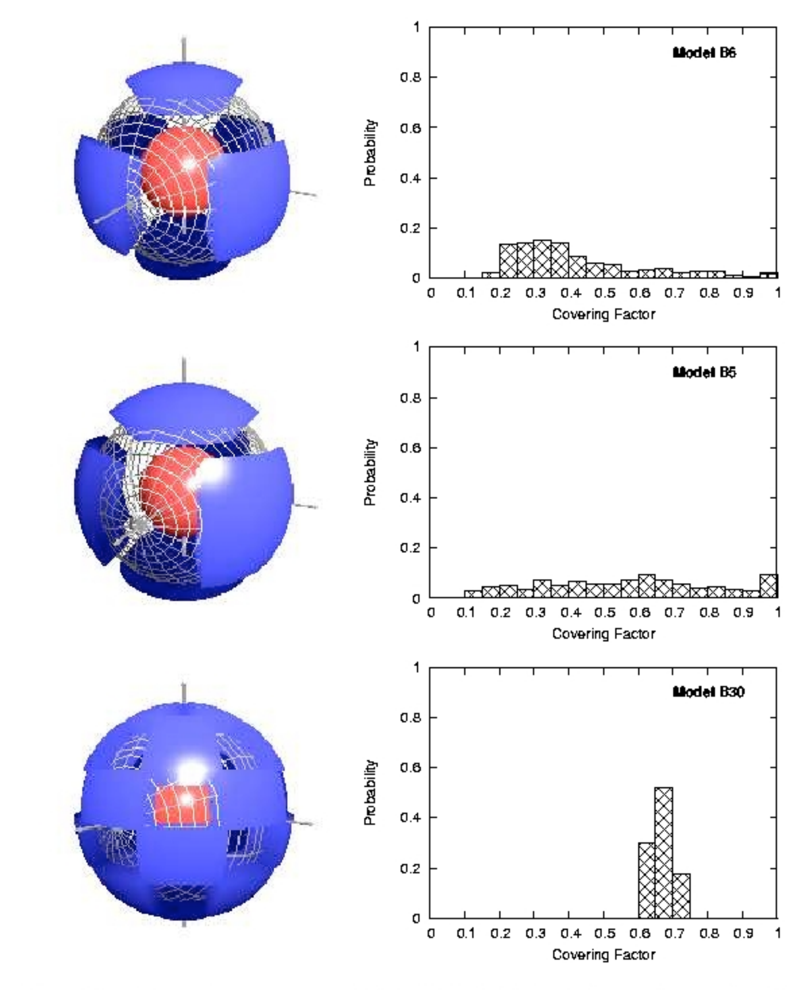


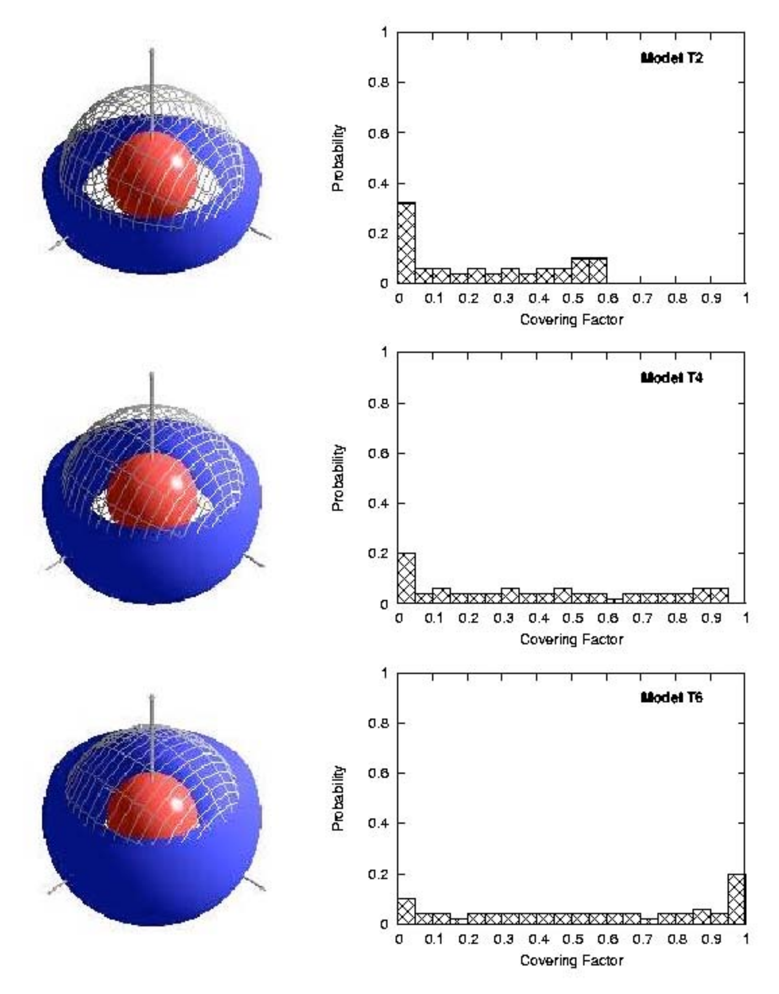
# Distribution of HVFs

- Any model should reproduce the observed distribution of HVF wavelength (blob velocity) and strength (optical depth, covering factor)
- Single blob does not



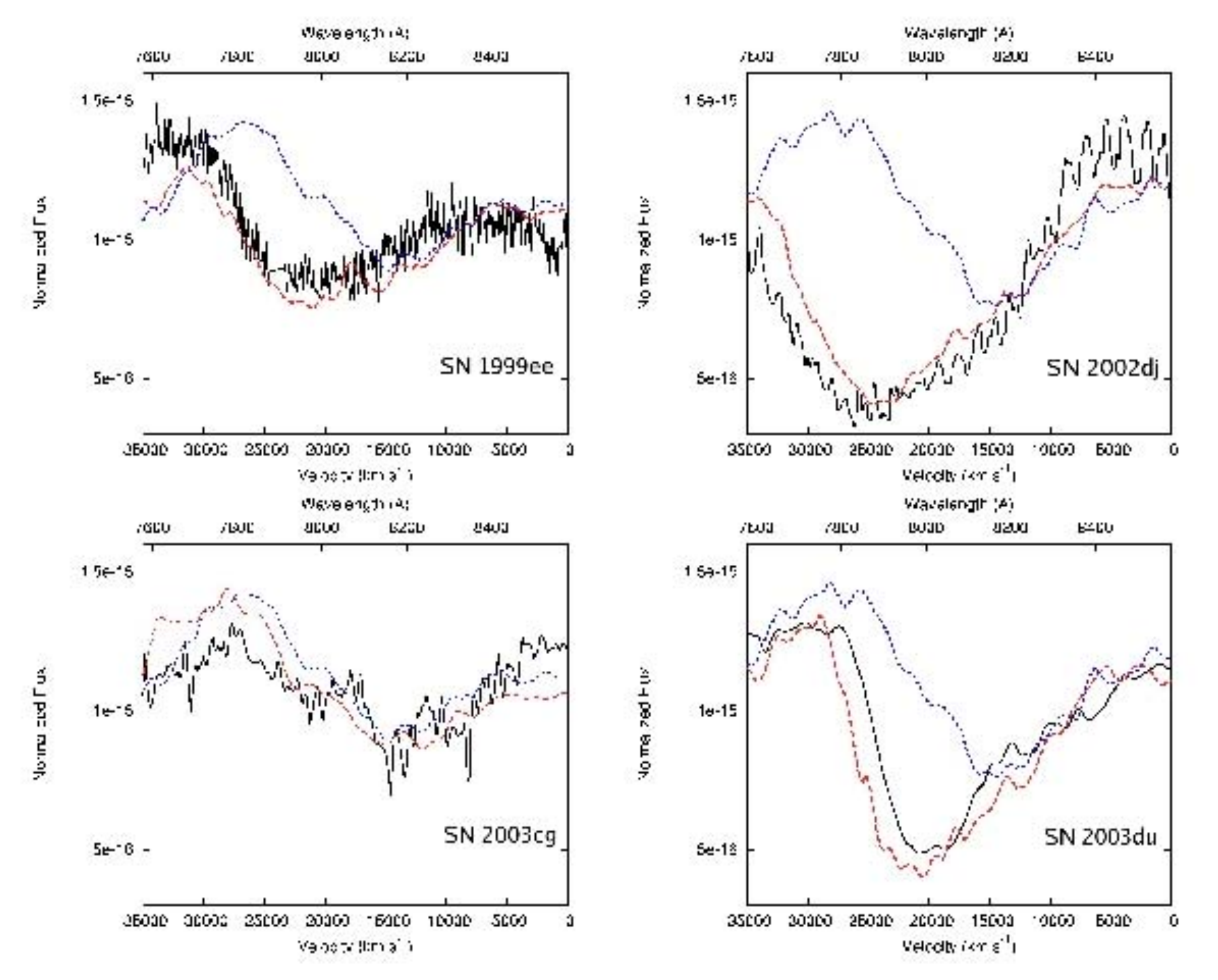
# Need a few blobs or a thick torus





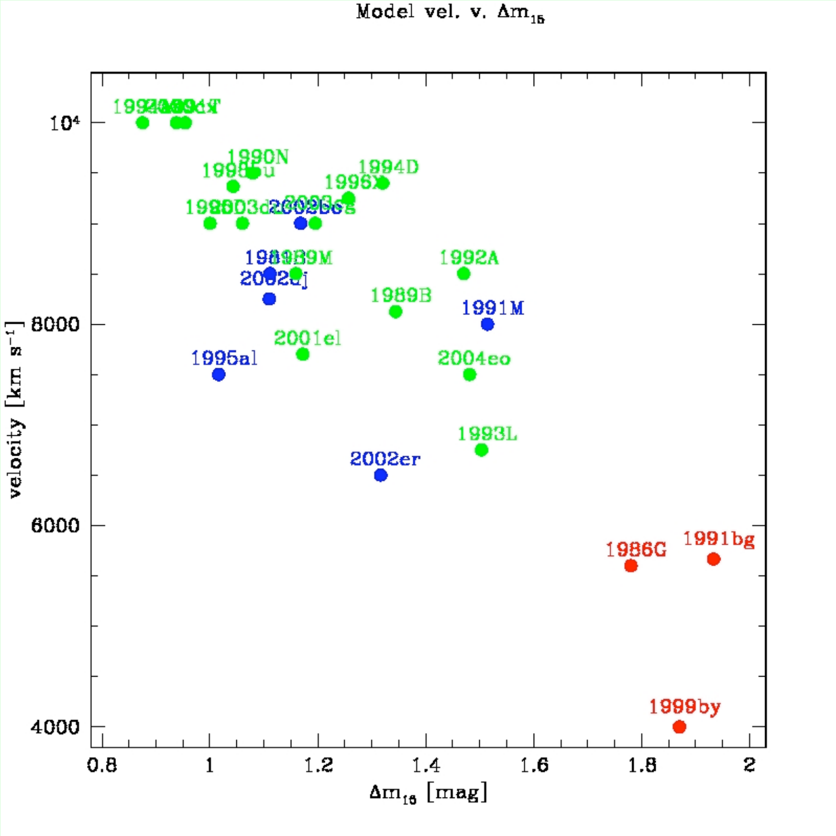
Tanaka et al. (2006)

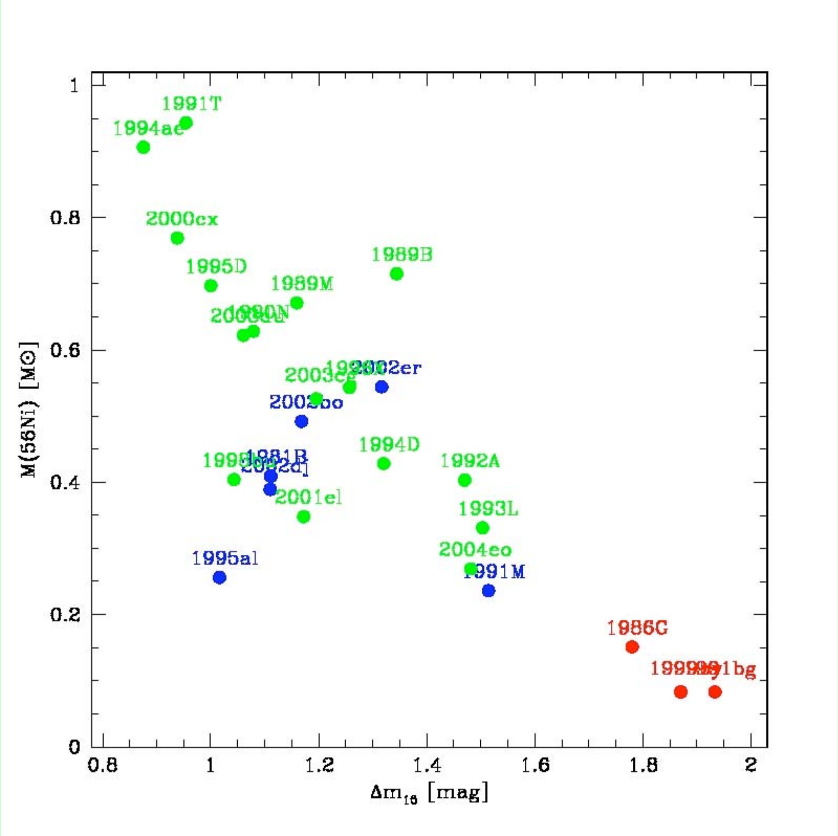
# Use blobs to fit spectra



Tanaka et al. (2006)

# IV. The Global View



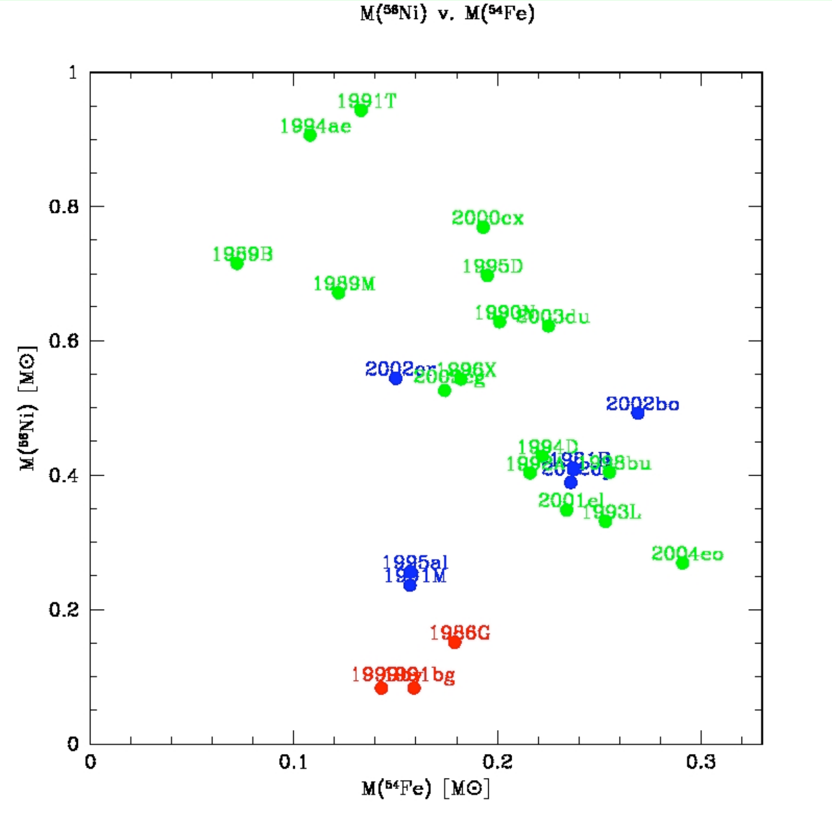


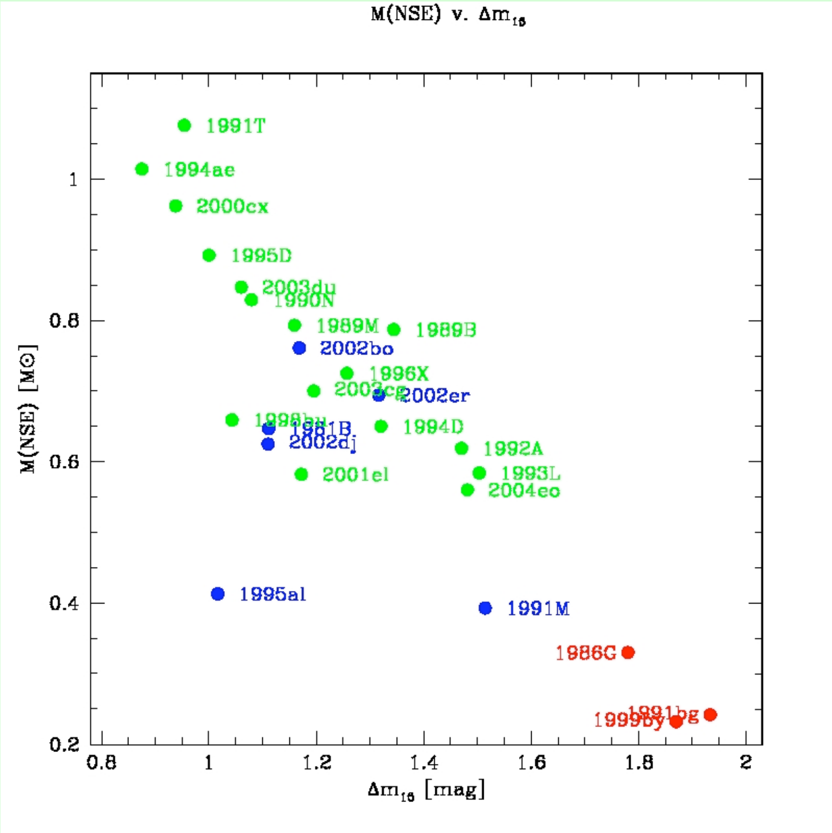
- Late time spectra suggest

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

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

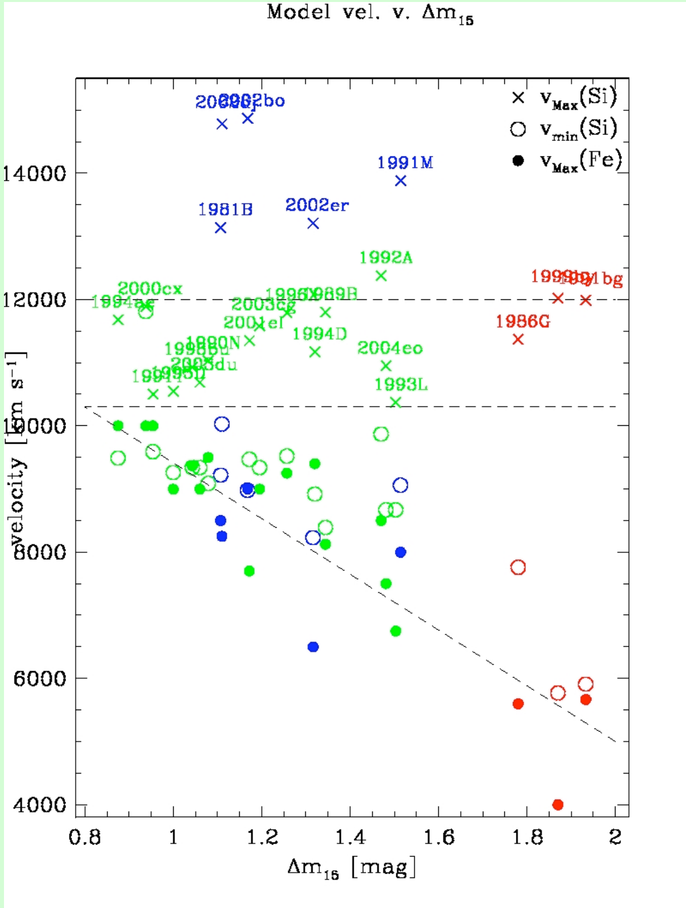
- Stable Fe group isotopes radiate but do not heat





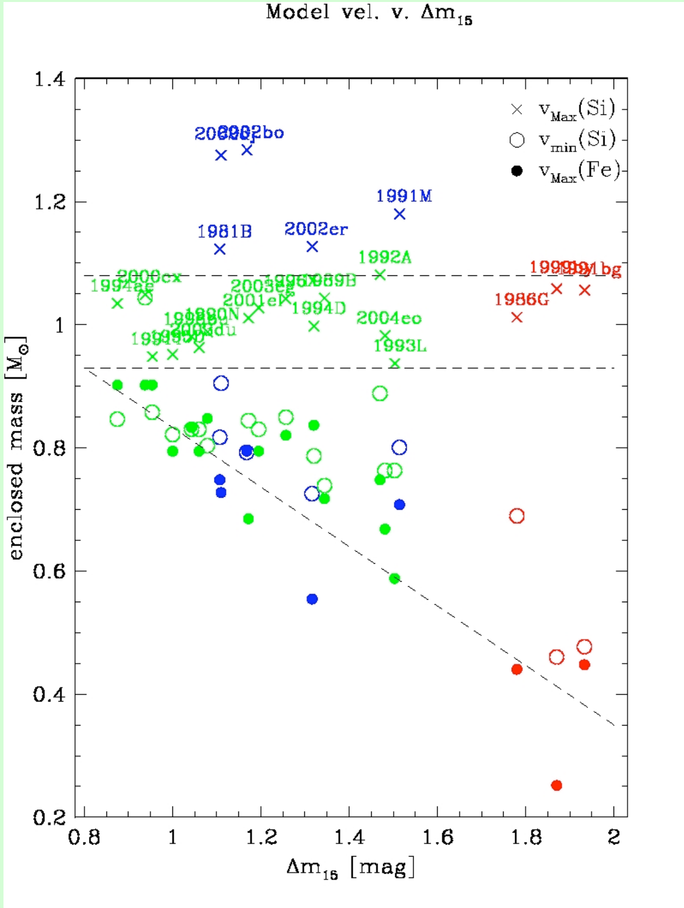
- Some anticorrelation between $^{56}$Ni and ($^{54}$Fe, $^{58}$Ni)
- Very good correlation beween Σ(NSE) and $\Delta m_{15}$(B)

# Composition Layering



ρ(v):

W7



- Outer extent of Fe zone varies (∝ $\Delta m_{15}$(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

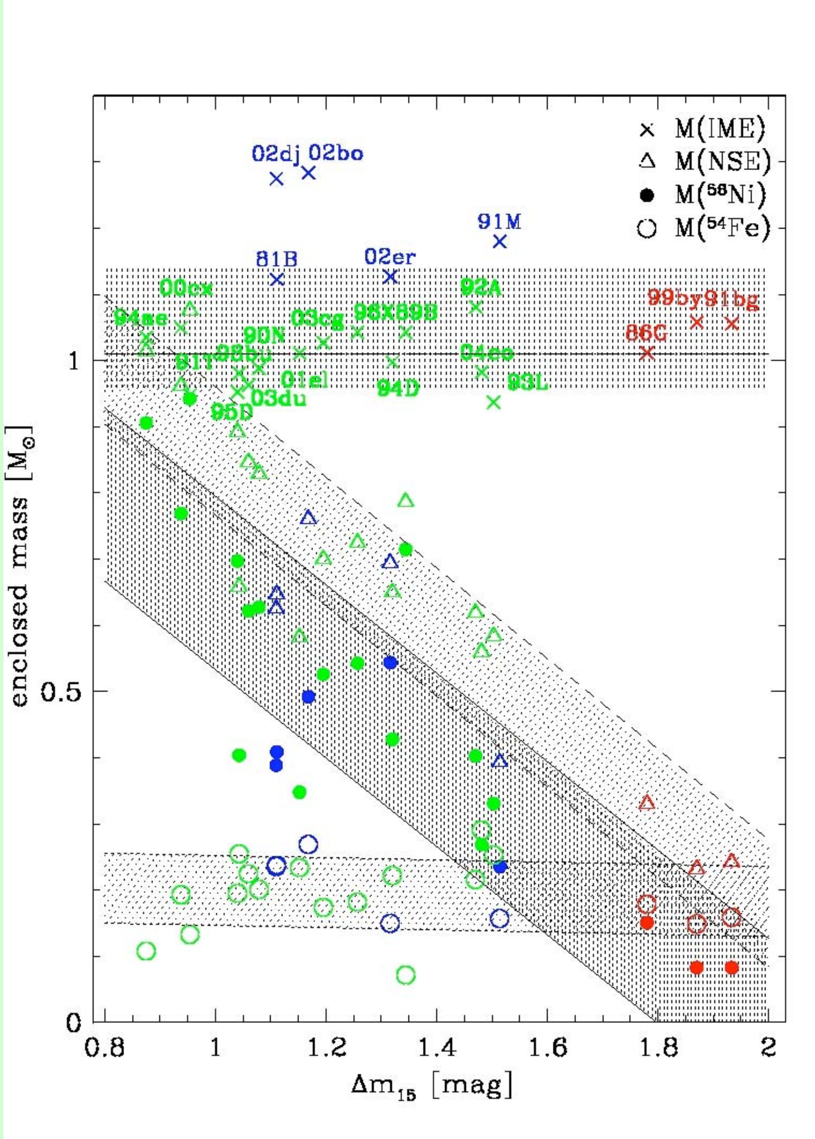
Mass burned ~ constant

→ Progenitor mass also probably constant: MCh

→KE ~ const

## What does it all mean?

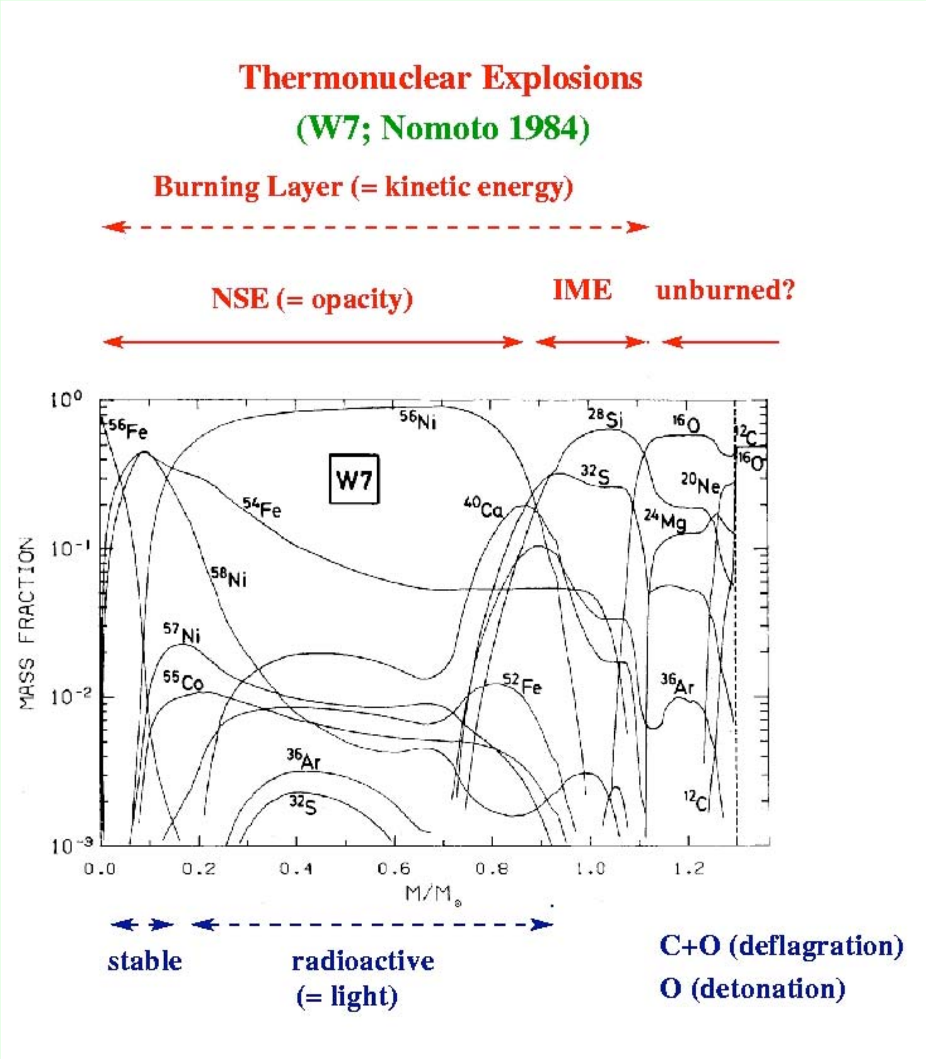
- Delayed detonation?
- Multi-spot ignited deflagration?
- Other possibilities….?



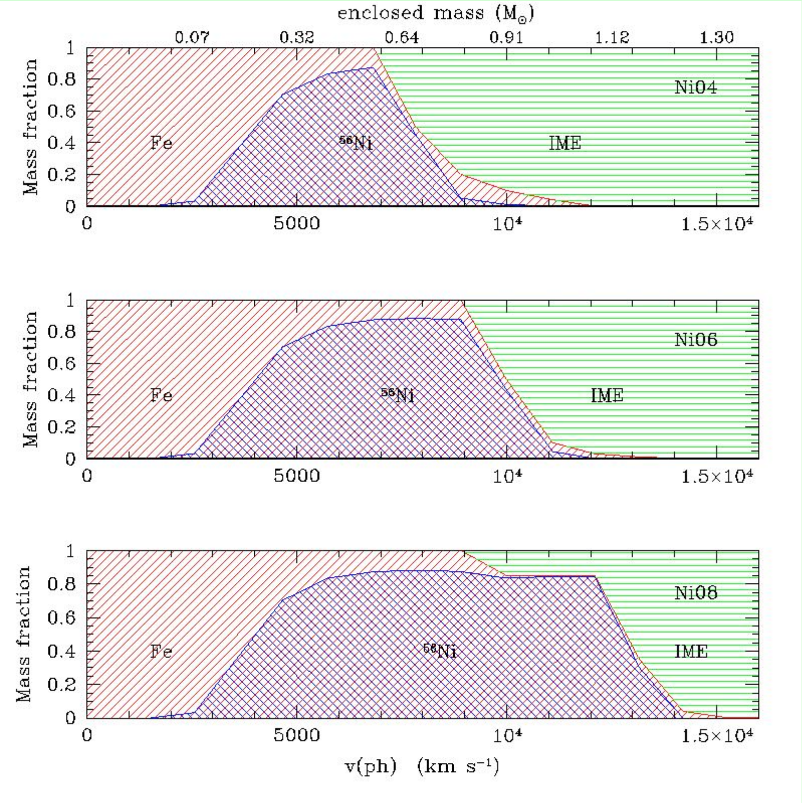
# V. Explaining observed relations

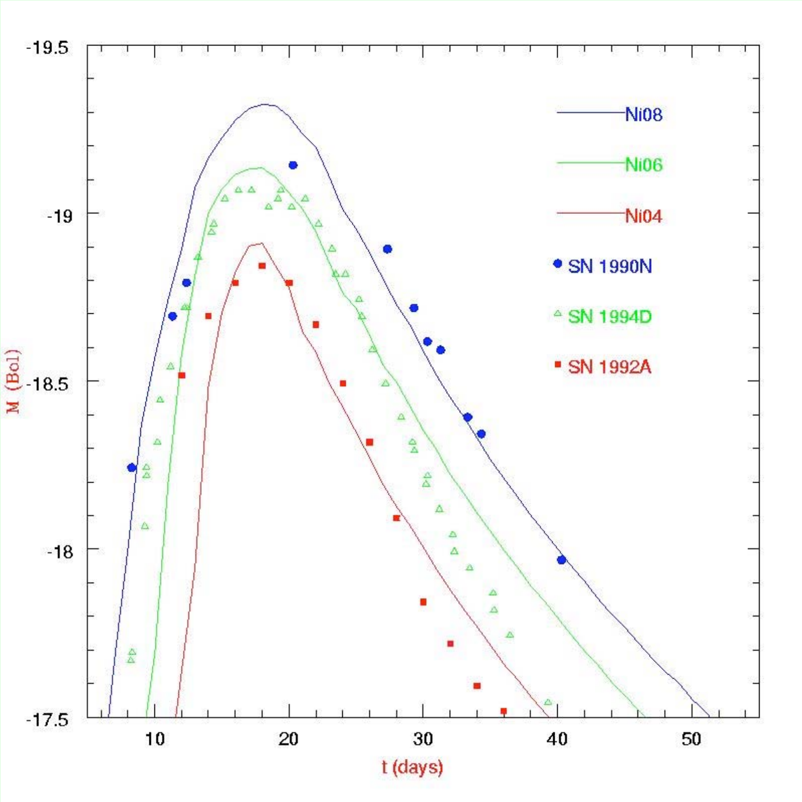
Role of Fe-group, IME on LC

- $^{56}$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

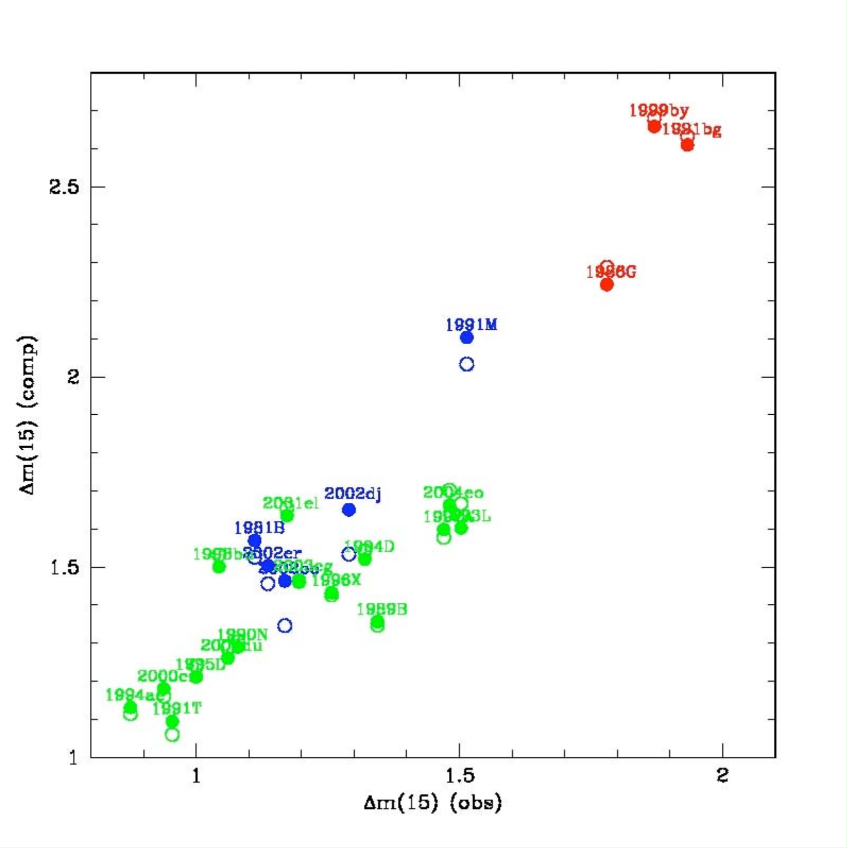
(Mazzali et al. 2001)

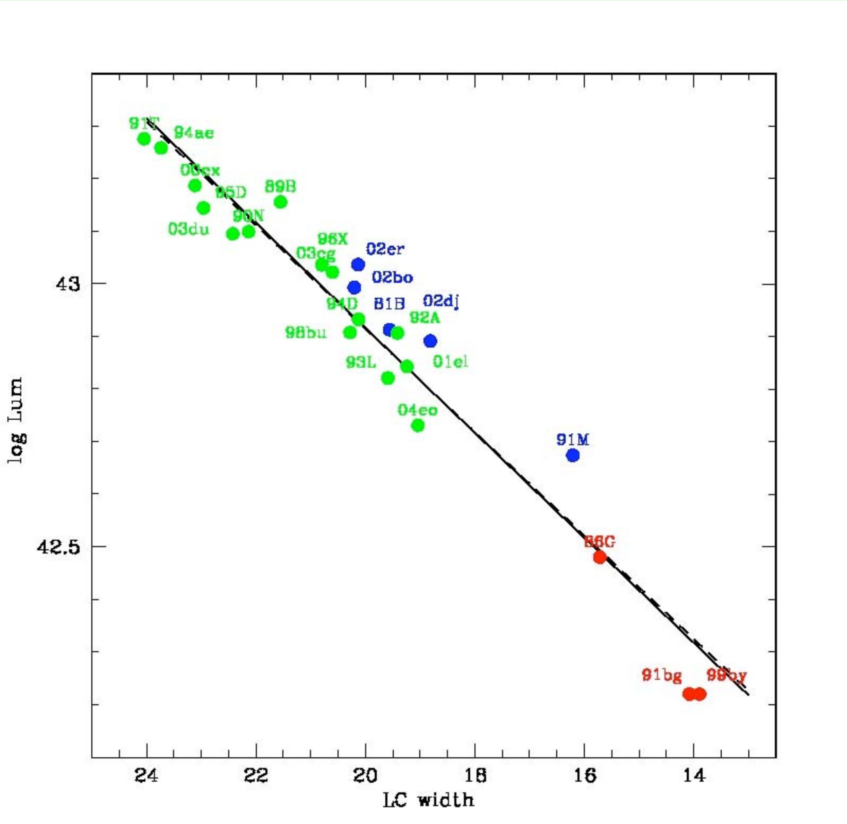
# Using Zorro to reconstruct Phillips' Rel'n

- 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 √

# 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