Physical and Observed Parameters of Type II-Plateau Supernovae

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MCSS
Millennium Center for Supernova Science

Overview

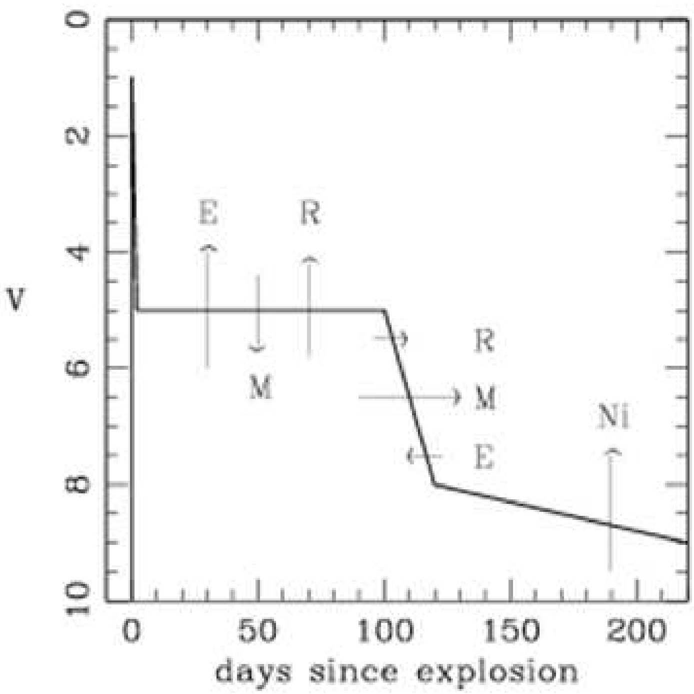
- Good distance indicators: EPM, SEAM and SCM
- Connection with final stages of stellar evolution

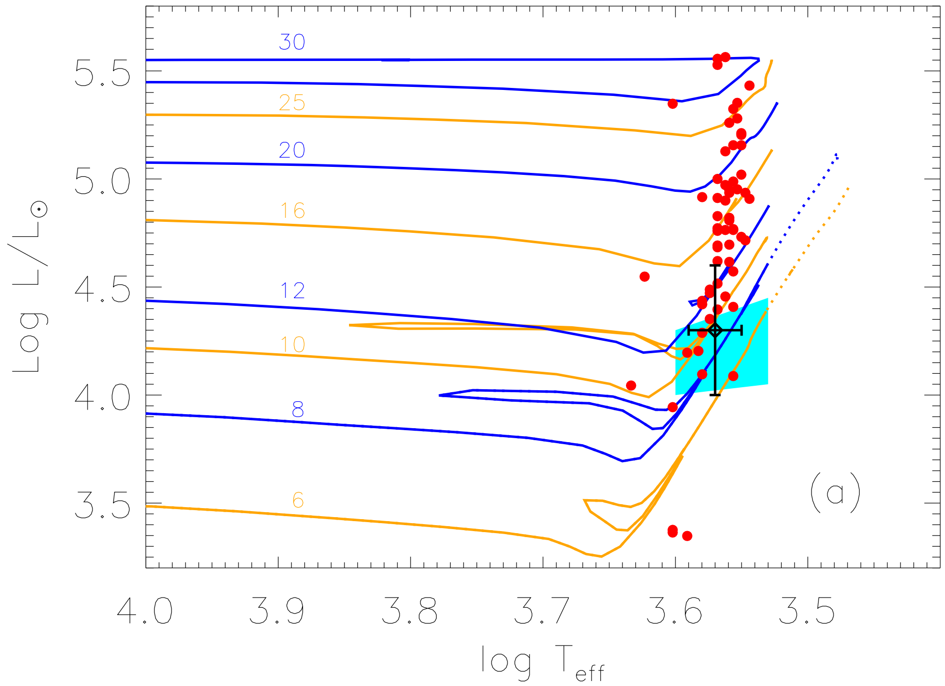
$$\Downarrow$$

Physical properties of the progenitor

SN II-P Progenitors

- Light curve **+** spectral modelling $\Longrightarrow$ $M_{\rm ej}$, R , $E_{\rm exp}$ and $M_{\rm Ni}$
- Pre-supernova imaging **+** stellar evolution models $\Longrightarrow$ $M_{\rm ZAMS}$





Smartt et al. (2009)

Overview

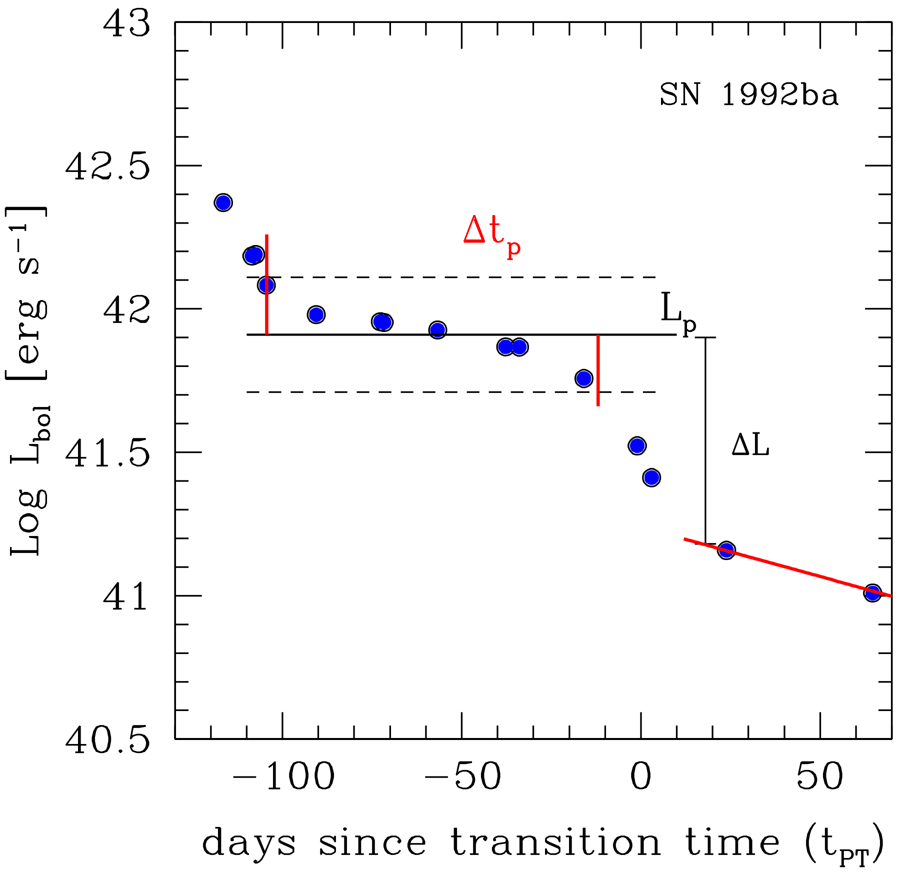
- Good distance indicators: EPM, SEAM and SCM
- Connection with final stages of stellar evolution

  Physical properties of the progenitor:

  - Red supergiant structure with H-rich envelope (Van Dyk et al. 2003)
  - Stellar evolution: $M_{\rm ZAMS}$: 8 – 25 $M_\odot$ (Heger et al. 2007)
  - Pre-SN imaging: $M_{\rm ZAMS}$: 8 – 17 $M_\odot$ (Smartt et al. 2009)
  - Hydrodynamical modelling favors high mass range (Utrobin $\&$ Chugai 2008)
- Availability of a large, high-quality dataset of SN II-P from past and ongoing surveys such as CATS and CSP

Sample of SNe II-P

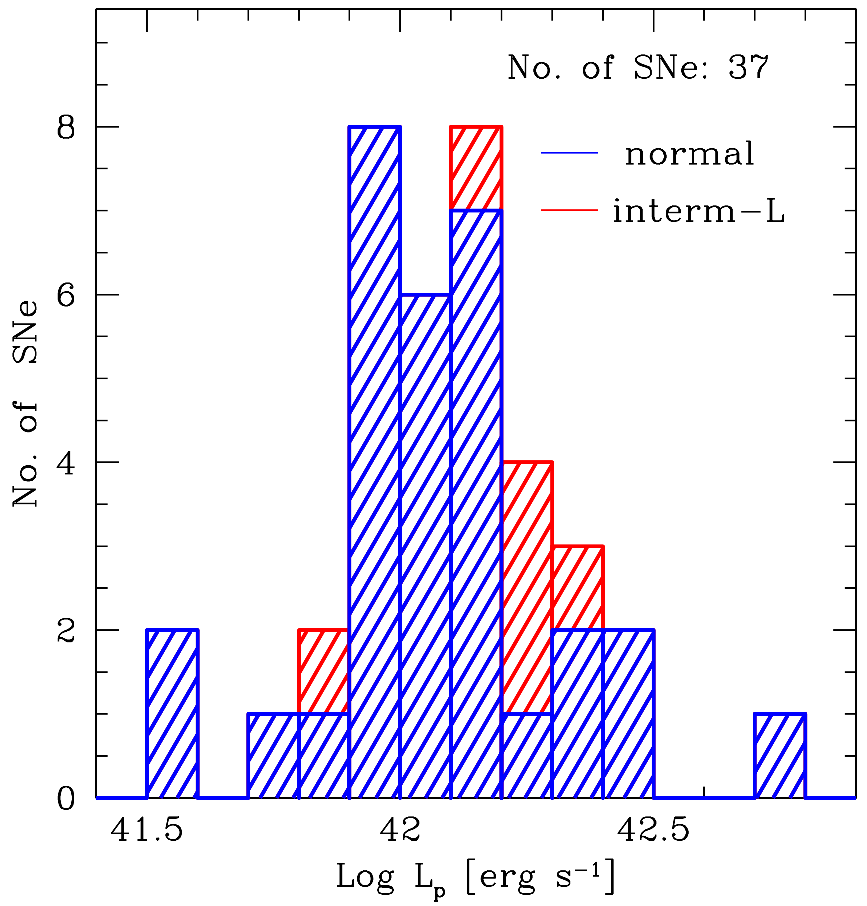
- Bolometric LCs for our sample of SNe II-P using bolometric corrections (Bersten & Hamuy 2009)
- Definition of parameters to characterize the LCs:
  - L_p: plateau luminosity
  - Δt_p: plateau duration
  - Δ log L: luminosity drop
  - $M_{\rm Ni}$: ^{56}Ni mass

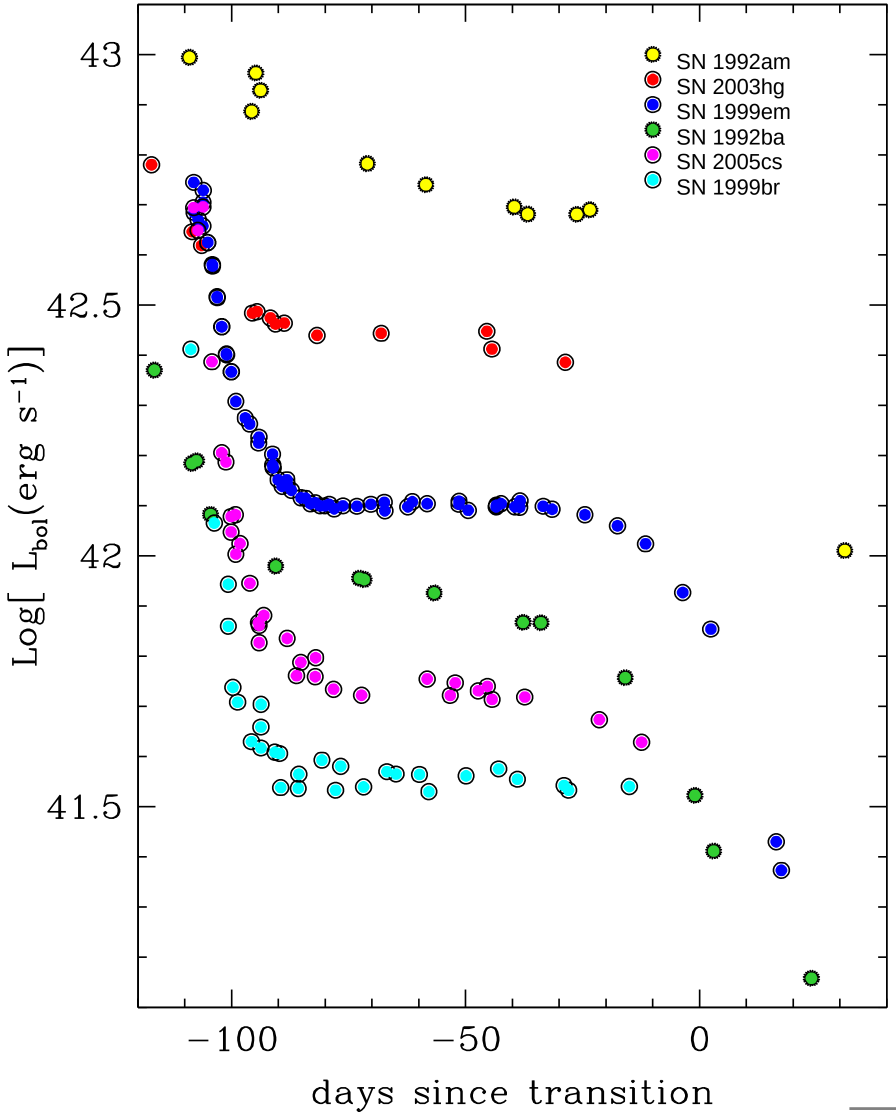


- A few SNe show a sloping LC (intermediate-L)

Bolometric Luminosity Range

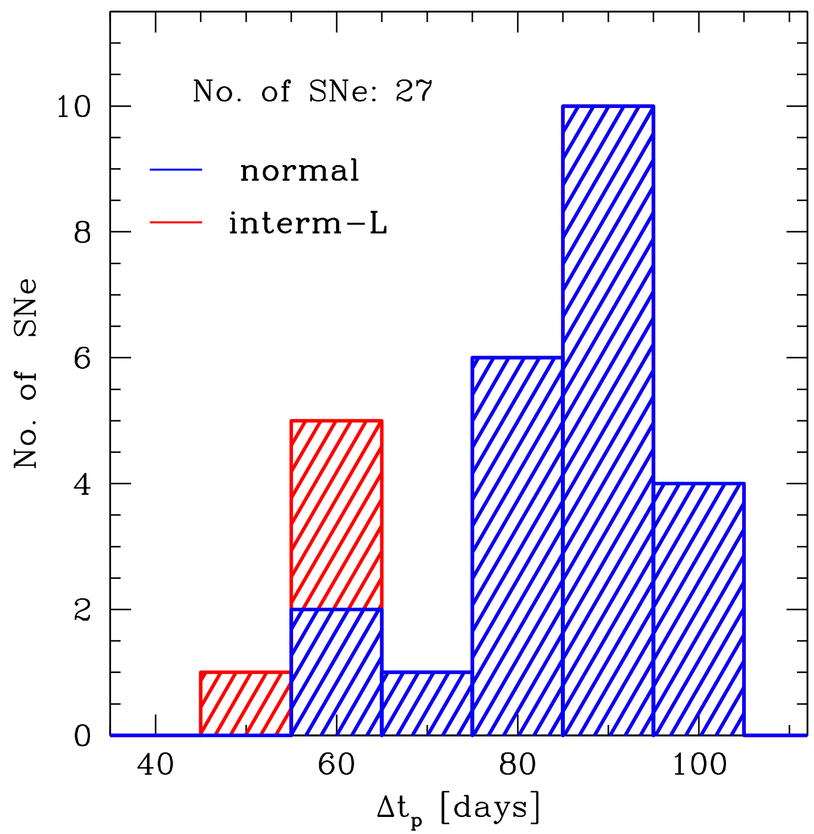
- Weighted average $\langle L_p \rangle = 1.26 \times 10^{42}$ erg s^{-1}
- Range of 1.15 dex in L_p

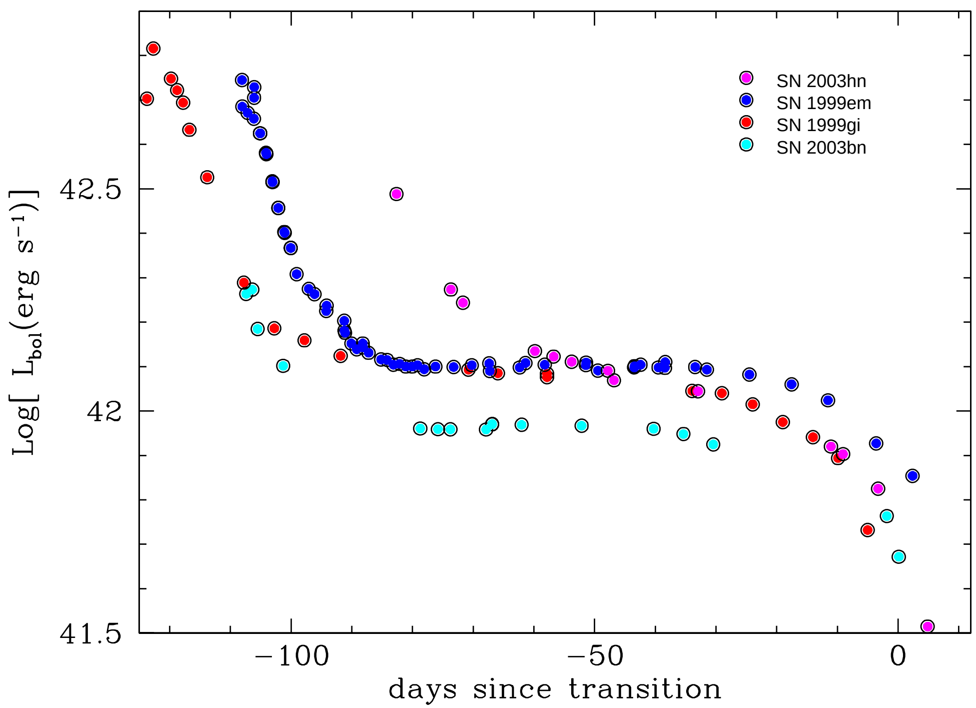




Plateau Lengths

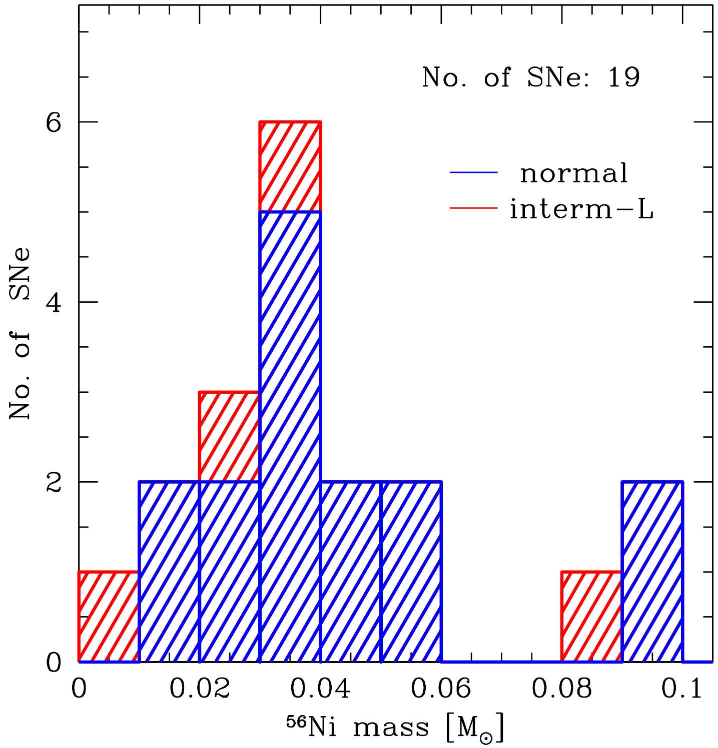
- Weighted average $\langle \Delta t_p \rangle = 90$ days
- Most SNe with Δt_p between 75 and 105 days
- Bi-modal trend in the distribution (secondary peak at $\sim$60 days)

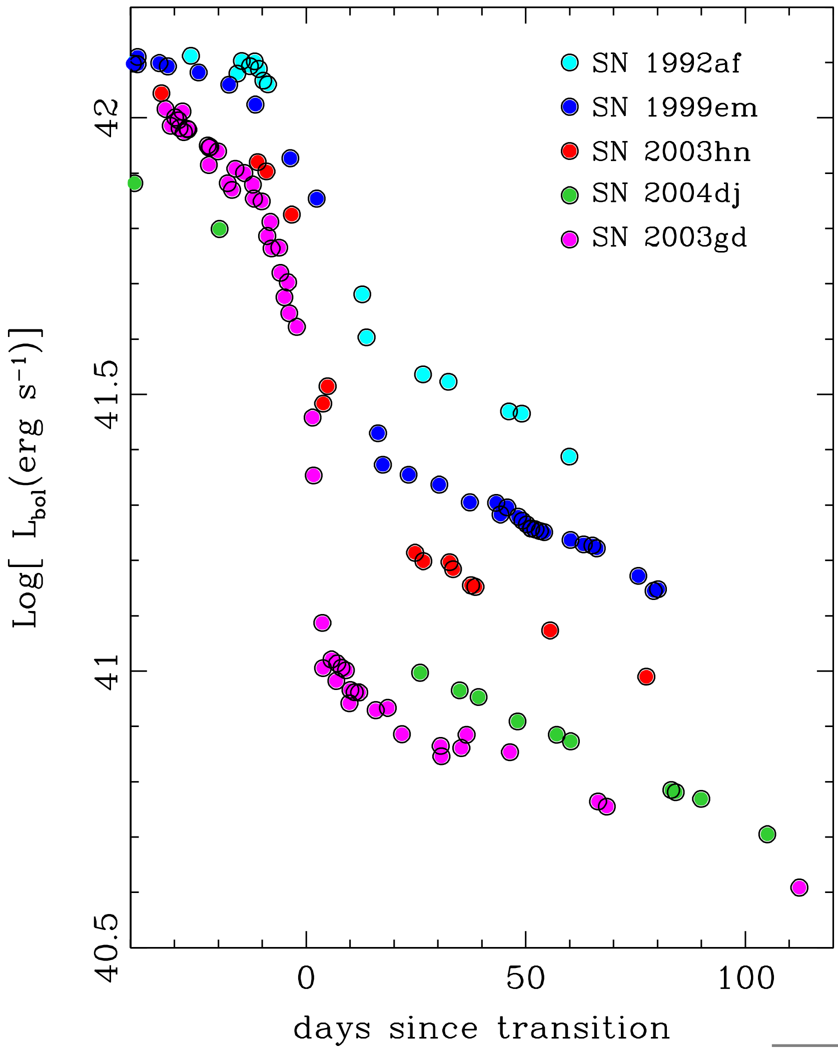




^{56}Ni mass

- $M_{\rm Ni}$ sensitive to adopted explosion time
- Assumed local deposition of gamma rays
- Weighted average $\langle M_{\rm Ni} \rangle = 0.024 M_\odot$
- $M_{\rm Ni} < 0.1 M_\odot$,
  except for SN 1992am ($M_{\rm Ni} > 0.26 M_\odot$)





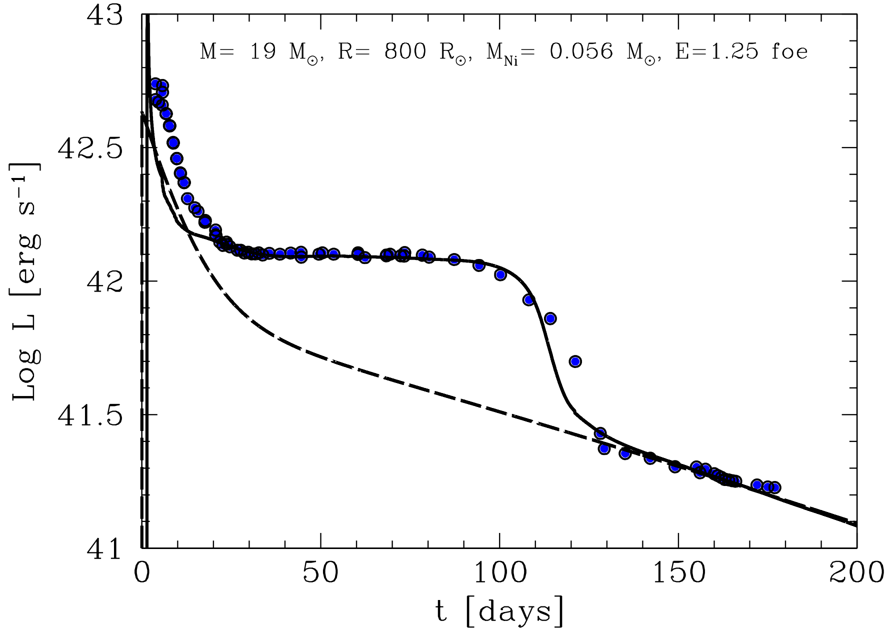
Hydrodynamical Model

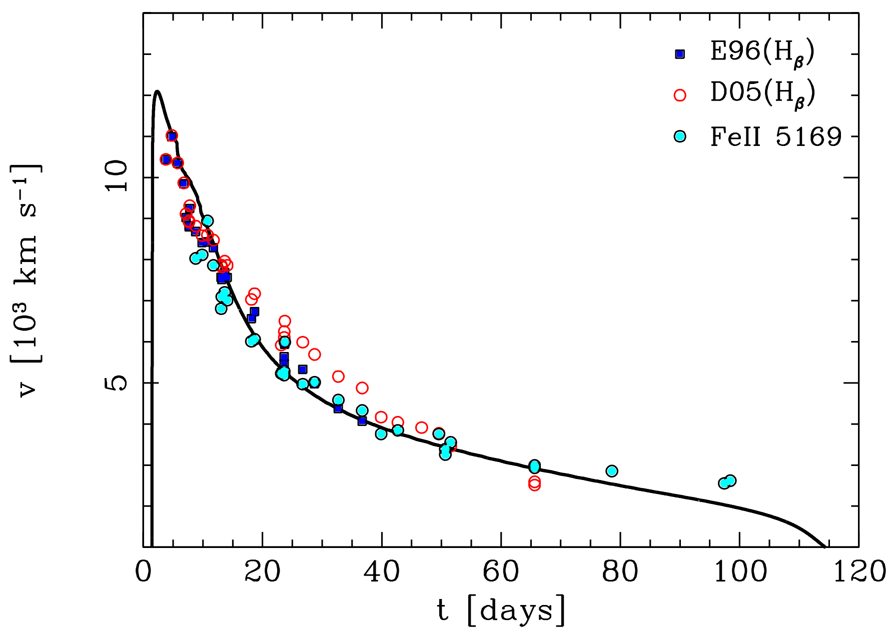
- One-dimensional Lagrangian code with flux-limited radiation diffusion
- Gray transfer for gamma-rays and arbitrary ^{56}Ni distribution
- Double-polytropic structure as initial model
  - Application to the prototypical SN 1999em
  - Grid of hydrodynamical models

Hydro-Model of SN 1999em

- Extended ^{56}Ni mixing
- Very good agreement with observations
- Physical parameters similar to previous hydrodynamical studies

  (Baklanov et al. 2005; Utrobin 2007)
- Low-mass models are not favored





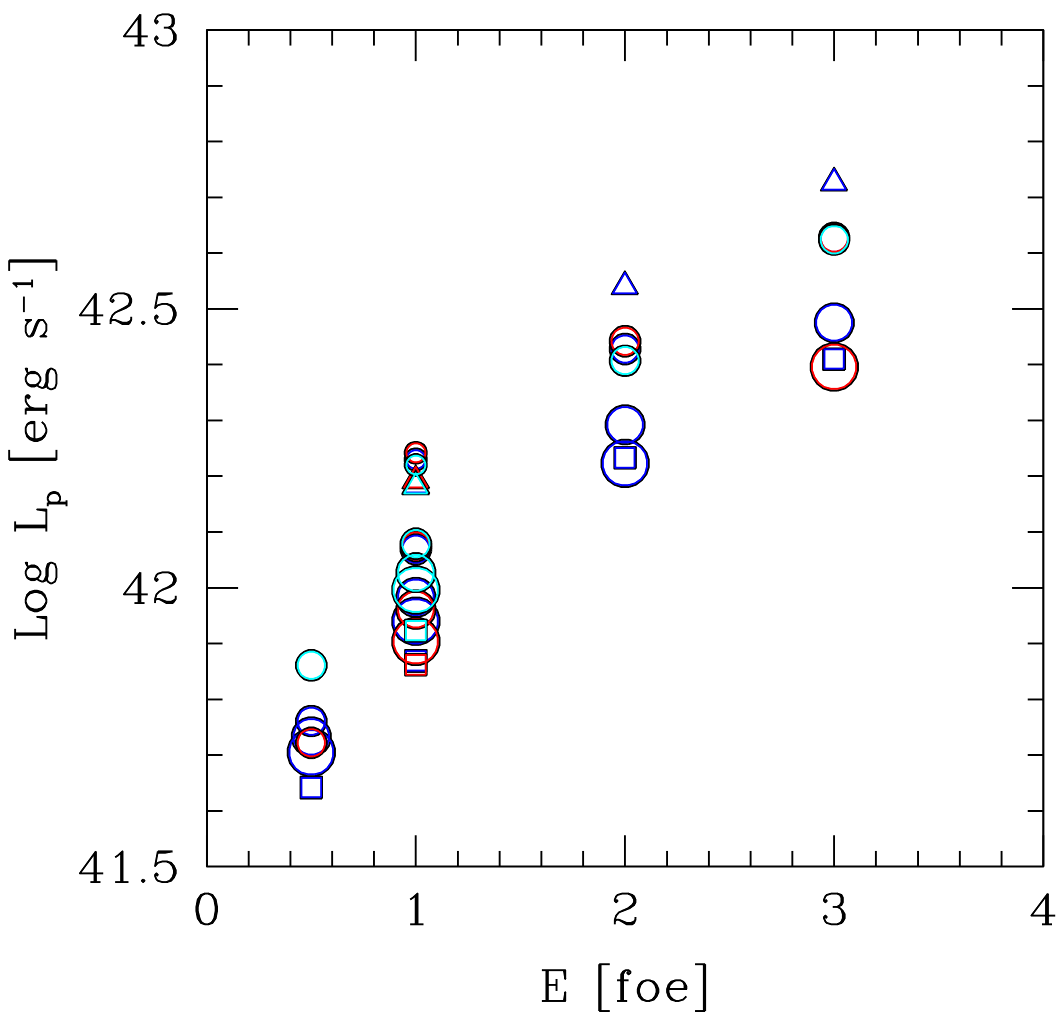
Grid of Hydrodynamical Models

- Set of 46 hydrodynamical models:
  - $M_0 =$ 10, 15, 20 and 25 $M_\odot$
  - $E =$ 0.5, 1, 2 and 3 foe
  - $R_0 =$ 500, 1000, and 1500 $R_\odot$
  - $M_{\rm Ni} =$ 0.02, 0.04 and 0.07 $M_\odot$
- L_p, Δt_p, ΔL and v_{-30} are measured consistently with observations
  - Dependence of observable parameters on physical quantities
  - Correlations between observable parameters

Model dependences

- Symbols: size proportional to M_0, shape indicates different R_0 and colors related with $M_{\rm Ni}$ (fixed mixing)

Plateau luminosity

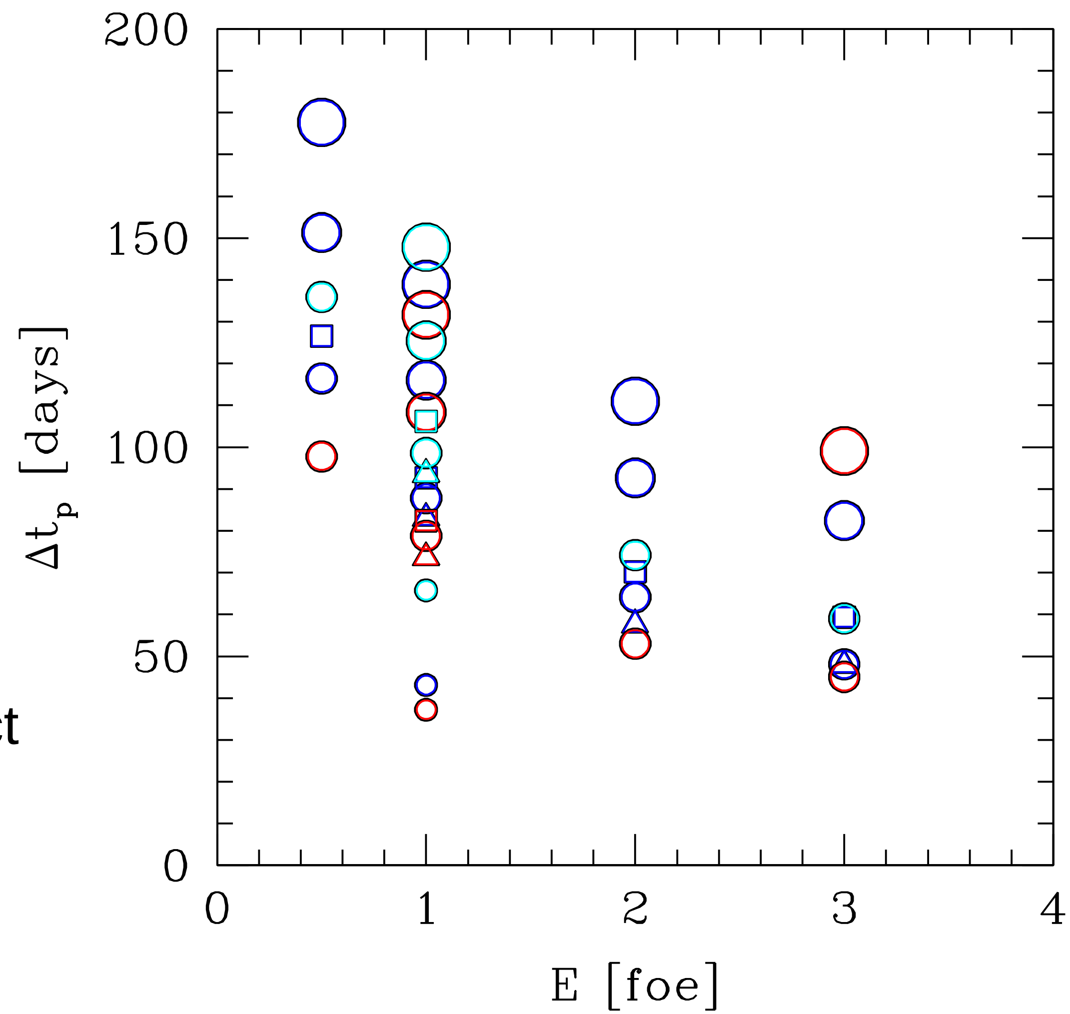


- Strong correlation with explosion energy
- $\sim$0.4 dex of dispersion mainly related to M_0 and R_0
- $M_{\rm Ni}$ (fixed mixing) is not very influential

Model dependences

- Symbols: size proportional to M_0, shape indicates different R_0 and colors related with $M_{\rm Ni}$ (fixed mixing)

Plateau duration

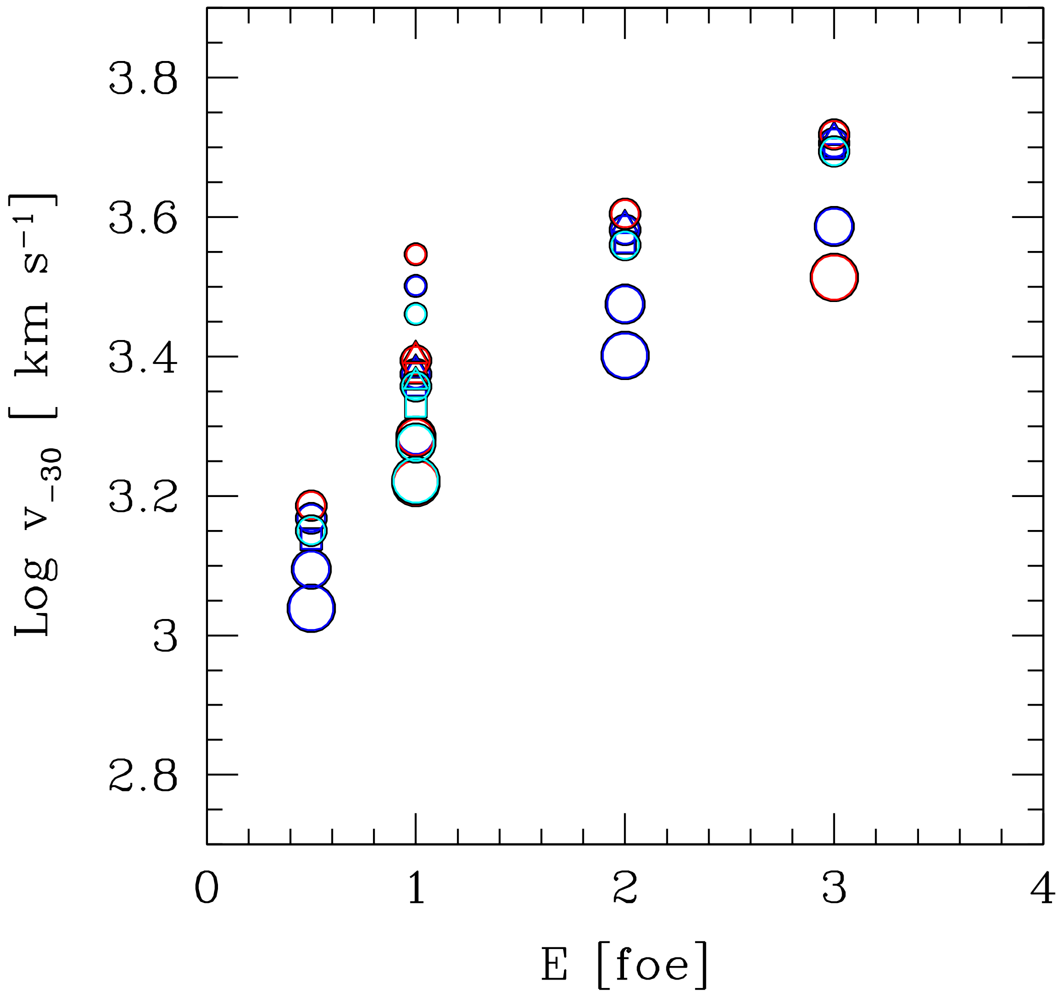


- Weaker correlation with explosion energy
- M_0 seems the most important factor but $M_{\rm Ni}$ also produces an effect
- R_0 produces a minor effect

Model dependences

- Symbols: size proportional to M_0, shape indicates different R_0 and colors related with M_{Ni} (fixed mixing)

Expansion velocity



- Strong correlation with explosion energy
- M_0 is the main driver of the dispersion
- Slight dependence on $M_{\rm Ni}$ but not on R_0

Observed and Modeled Correlations

- The Standard Candle Method (SCM):
  - Correlation between luminosity and expansion velocity during the plateau phase found by Hamuy & Pinto (2002)
  - Detailed study of this correlation for our sample of SNe II-P given by Olivares et. al (2010) leading to a precision of 13% in distance
  - Study of this correlation using our hydrodynamical models

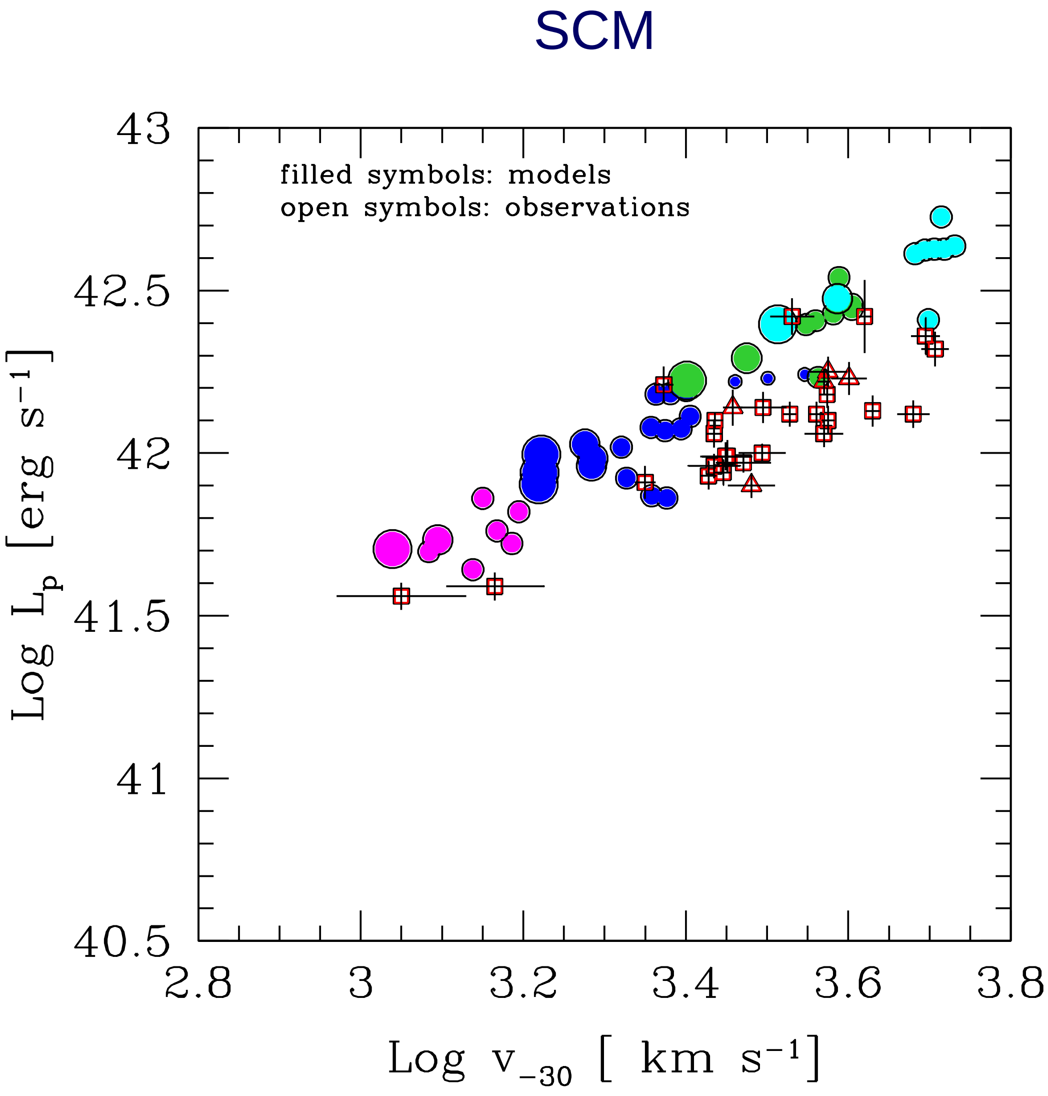
Observed and Modeled Correlations

- Symbol Colors: different explosion energies (E)

- Models reproduce very well the obverved trend

- E is the main driver

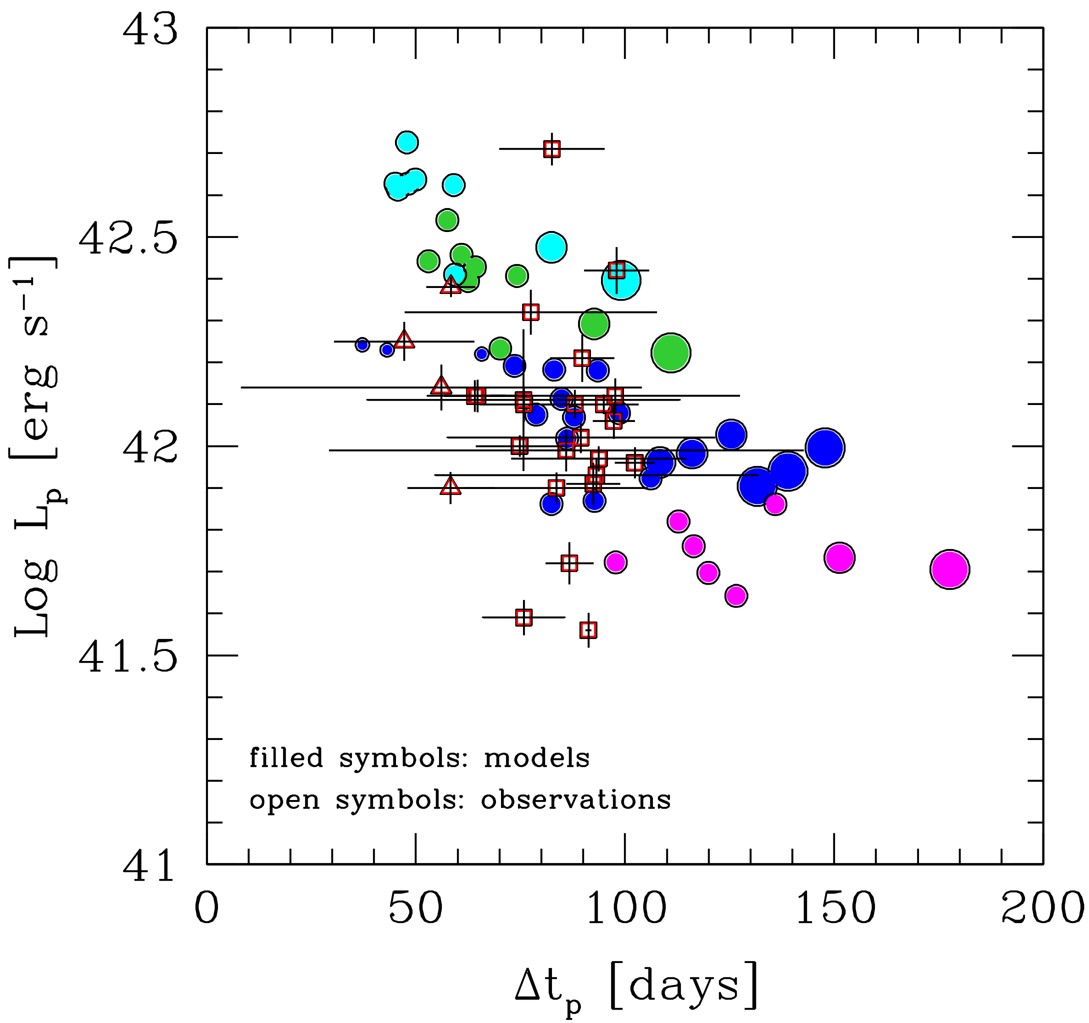
- Shift between models and observations



Observed and Modeled Correlations

- Symbol Colors: different explosion energies (E)

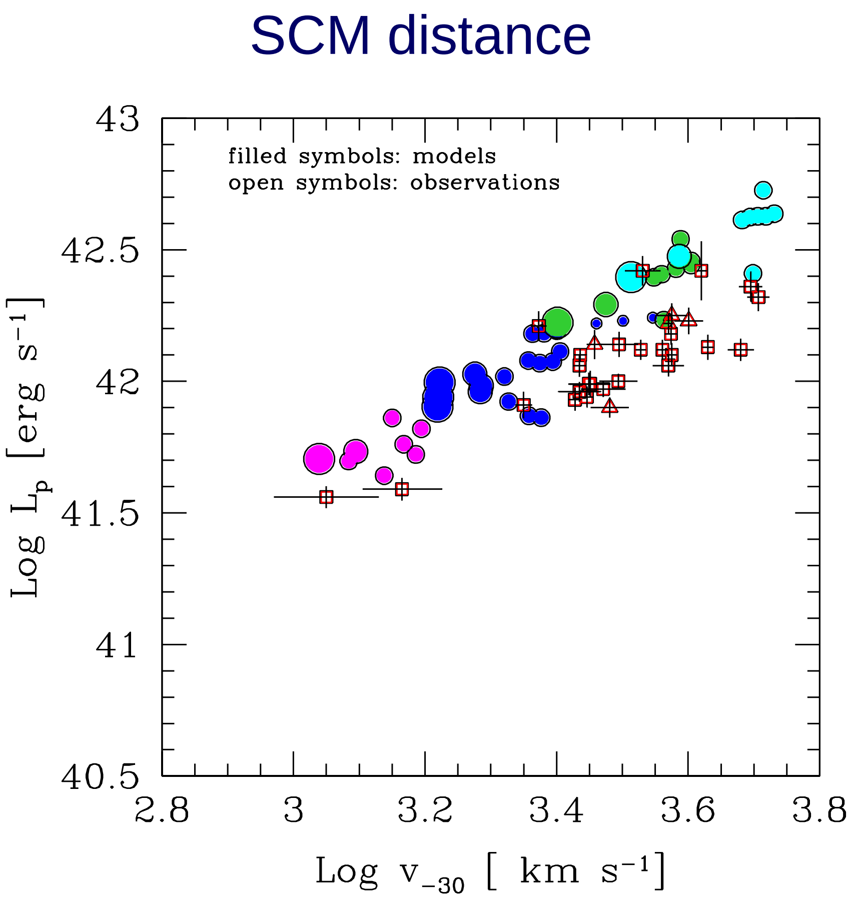
- Models show slight correlation previously noted by Kasen & Woosley (2009)
- Observations show no correlation
- Lowest E and high M are not favored

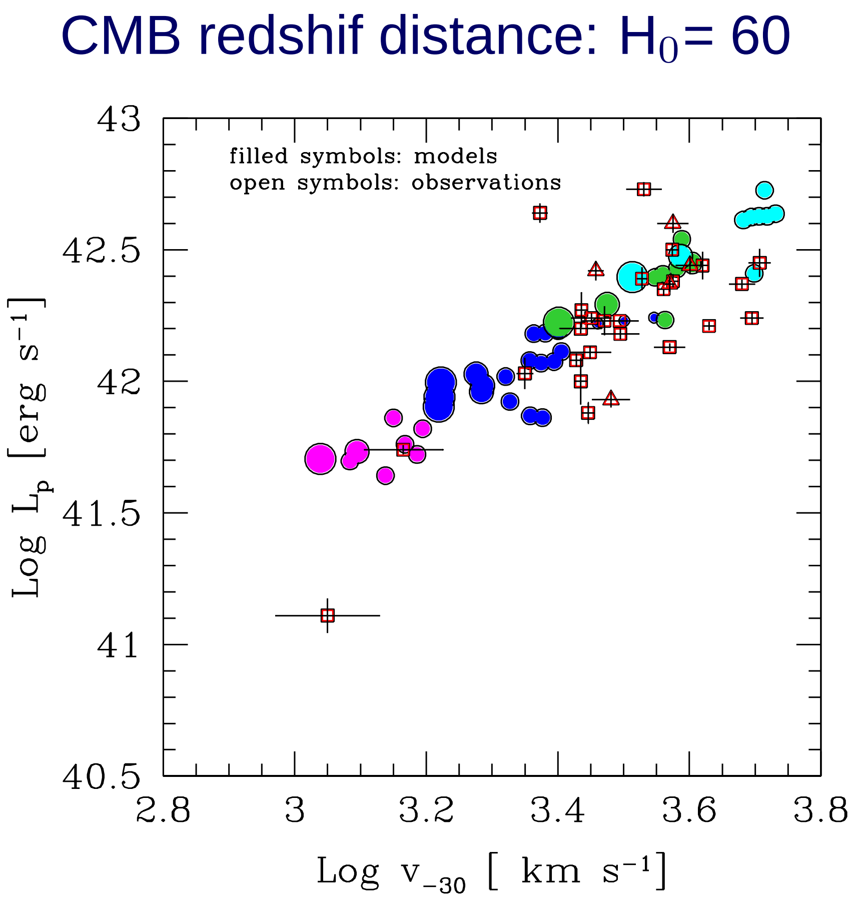


Summary

- Using our hydrodynamical code we studied SN 1999em in detail:
  - very good agreement with observations when extended mixing of ^{56}Ni is used
  - Low-mass models are not favored but not fully ruled out.
- We calculated a set of observable parameters (L_p, Δt_p, ΔL and $M_{\rm Ni}$) for our data sample and for a grid of hydrodynamical models:
  - Parameter distribution:
    - 1.15-dex range in plateau luminosities
    - Most SNe with plateau durations between 75–105 days
    - $M_{\rm Ni} < 0.1 M_\odot$, except for SN 1992am with $M_{\rm Ni} > 0.26 M_\odot$
  - Dependence on physical quantities (E, R_0, M_0 and $M_{\rm Ni}$)
  - Correlations using models and observations
    - Models confirm the SCM relation
    - Lowest E and high M are not favored

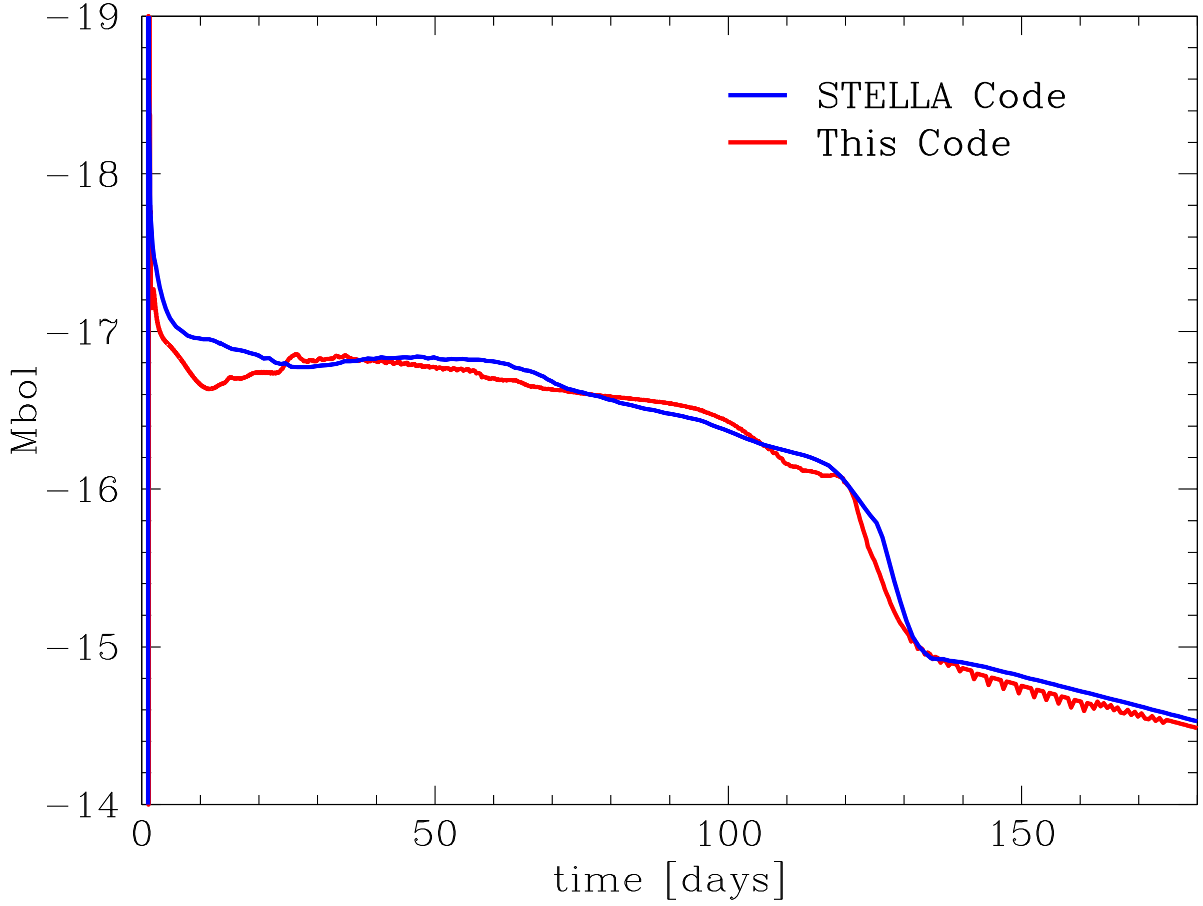
Observed and Modeled Correlations





Comparison with STELLA Code

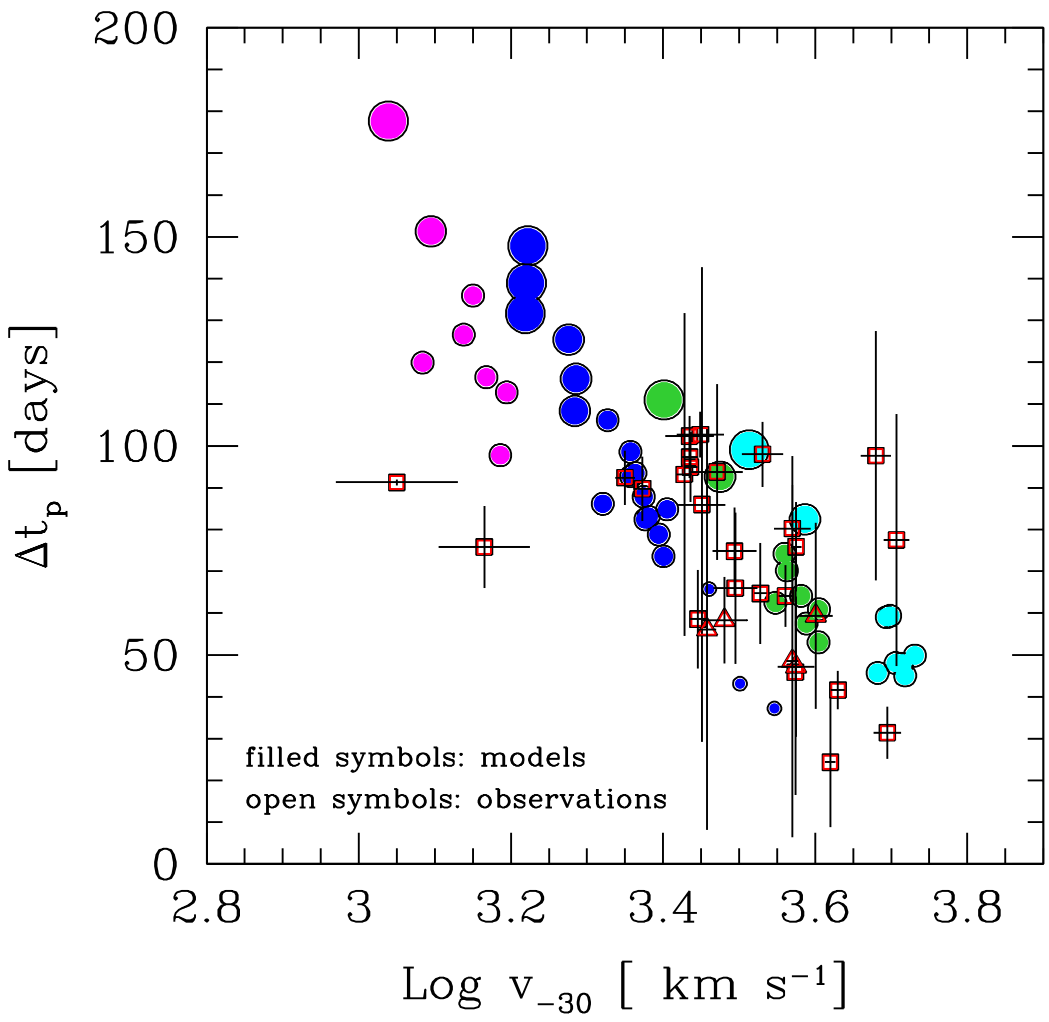
- STELLA code (Blinnikov et al. 1998; courtesy N. Tominaga):
  - implicit hydrodynamics + multi-group radiative transfer
  - includes the effect of the line opacities
- Pre-SN model from Umeda & Nomoto (2005)



Observed and Modeled Correlations

- Symbol Colors: different explosion energies (E)

- Models show correlation
- Observations show similar tendency
- Lowest E are ruled out

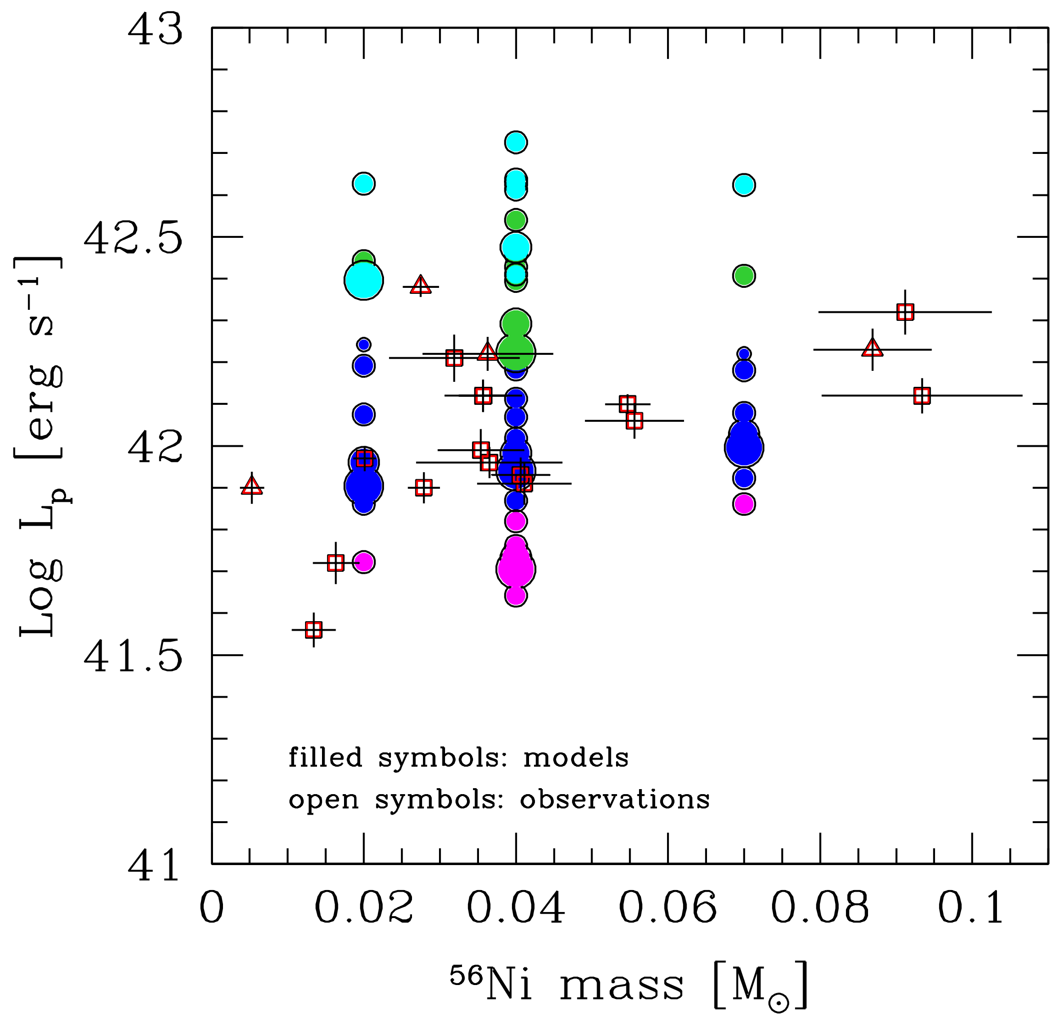


Observed and Modeled Correlations

- Symbol Colors: different explosion energies (E)

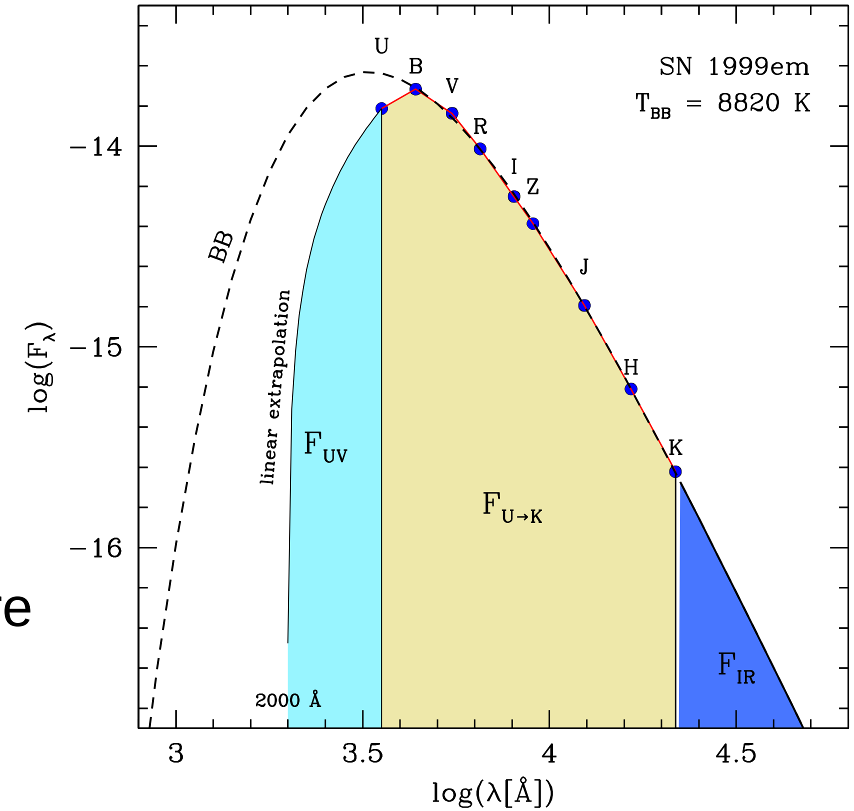
- No correlation

- Ni mass affects tail luminosity but not the plateau



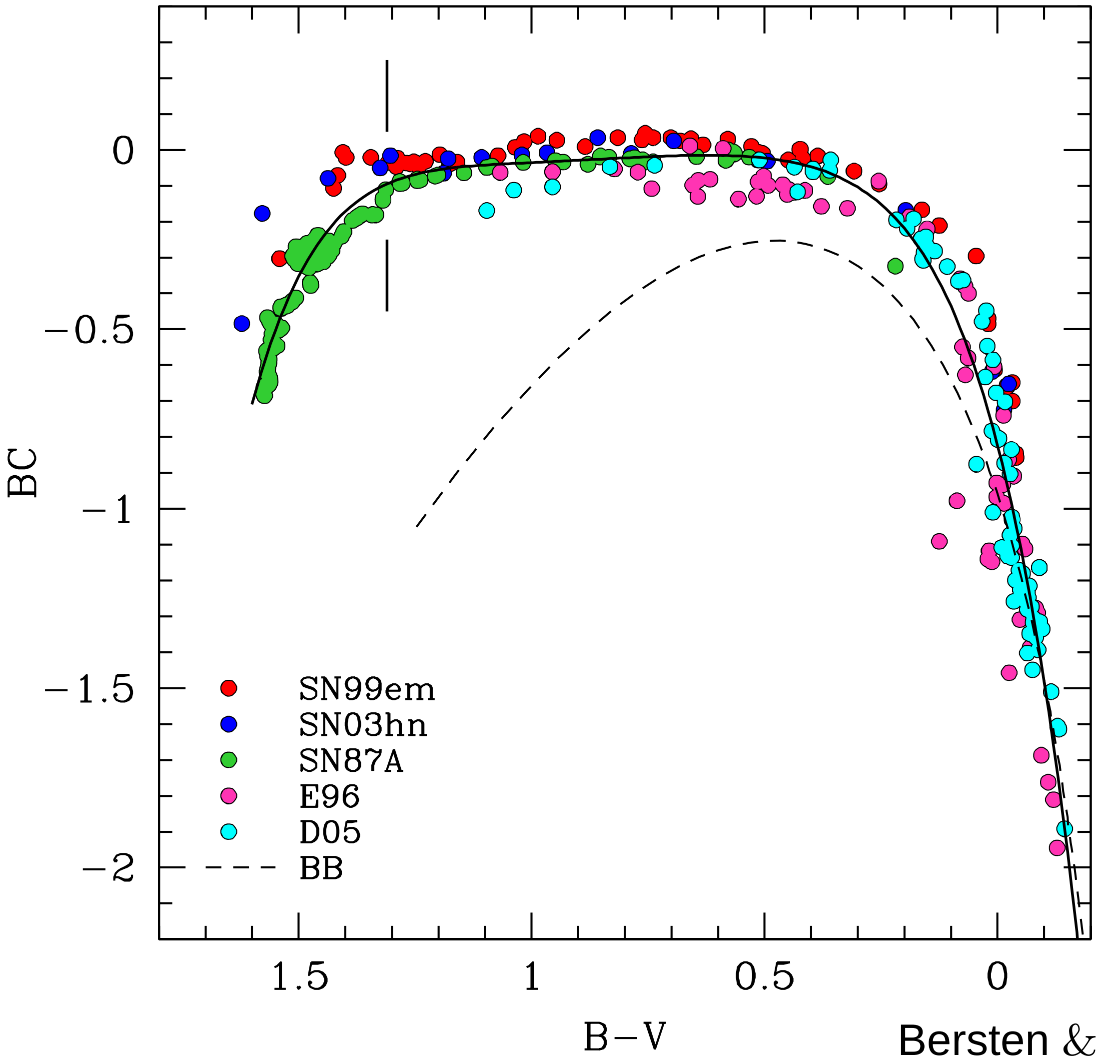
Bolometric Correction

- Three well-observed supernovae: SN 1987A, SN 1999em, and SN 2003hn
- Integration of all the available broadband data
- Estimation of the missing flux in UV and IR: blackbody (BB) fit
- Calculation of BC for two atmosphere models: Eastman et al. (1996) and Dessart & Hiller (2005)



Bolometric Correction

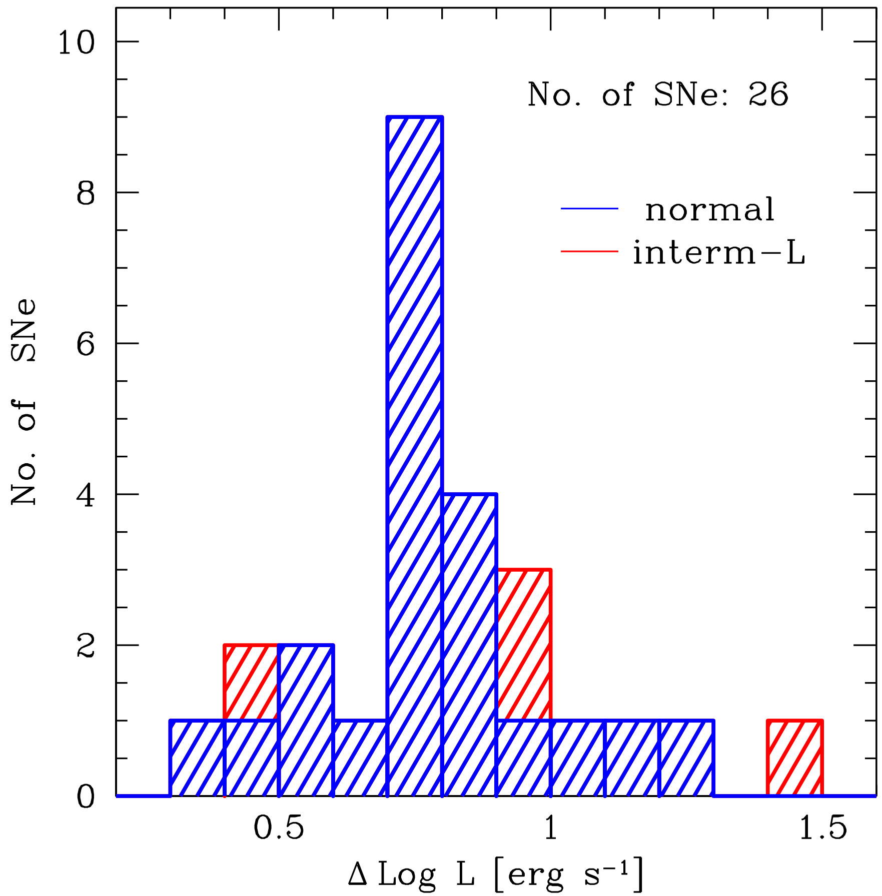
$$BC = m_{bol} - [V - A_V], \quad rms = 0.11 \text{ mag}$$

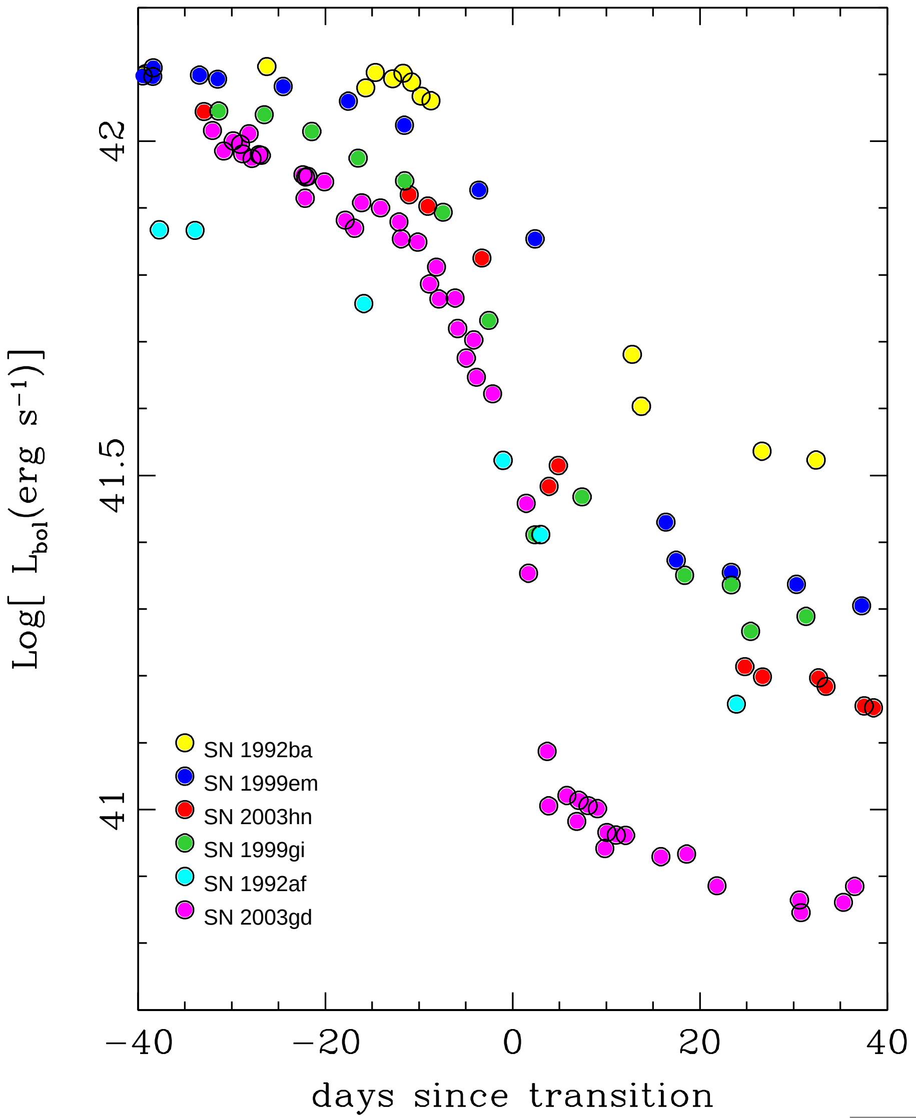


Bersten & Hamuy (2009)

Luminosity drop: Δ log L

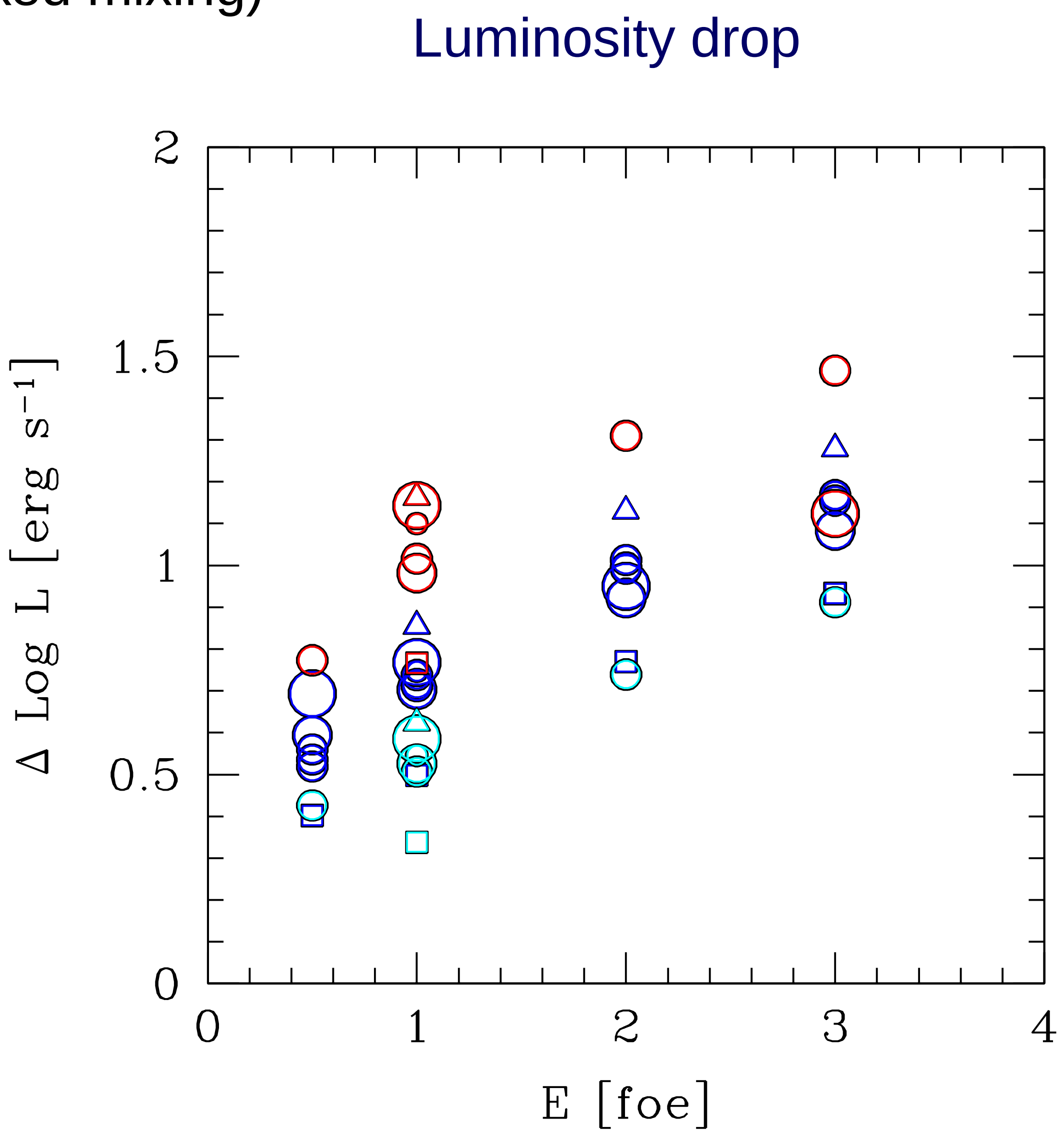
- Weighted average $\langle \Delta \log L \rangle = 0.783$ dex
- Range of 0.35–1.46 dex in Δ log L





Model dependences

- Symbols: size proportional to M_0, shape indicates different R_0 and colors related with M_{Ni} (fixed mixing)

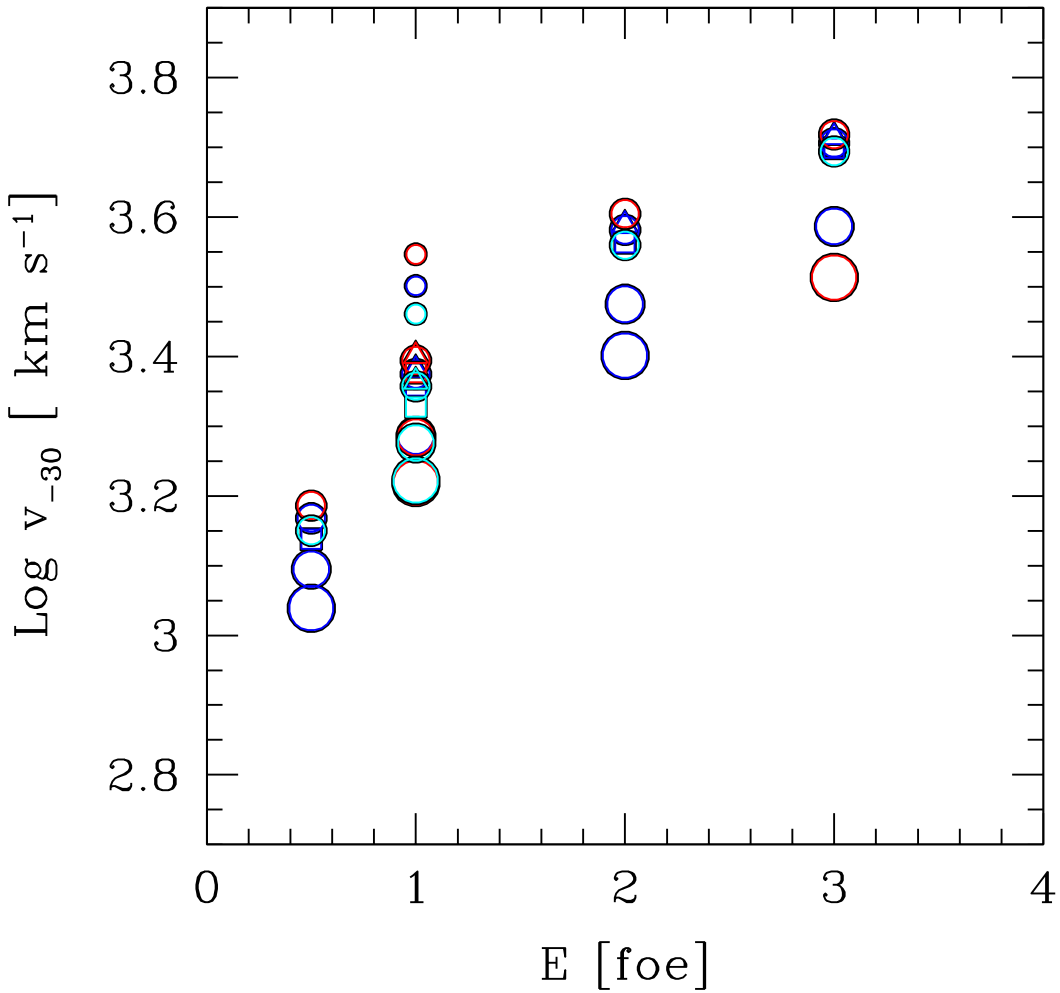


- Some dependence on explosion energy
- Strong correlation with $M_{\rm Ni}$
- Some dependence on R_0 but not on M_0

Model dependences

- Symbols: size proportional to M_0, shape indicates different R_0 and colors related with M_{Ni} (fixed mixing)

Expansion velocity



- Strong correlation with explosion energy
- M_0 is the main driver of the dispersion
- Slight dependence on $M_{\rm Ni}$ but not on R_0