Intrinsic Color Dispersion of Type Ia Supernovae

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Introduction

- Type Ia supernovae are:
  - thought to explode when their white dwarfs have almost the Chandrasekhar mass.
  - expected to have homogeneous properties.
    - almost similar luminosity
      - "correctable" standard candles in cosmology
- Their observations suggest that Type Ia supernovae have diversity.
  - When you plot the colors ($U-B$ and $B-V$) at their B-band maxima:
    - you can see intrinsic dispersion.
      - not explainable by the Galactic extinction
    - see Fig. 1.

Introduction (cont'd)

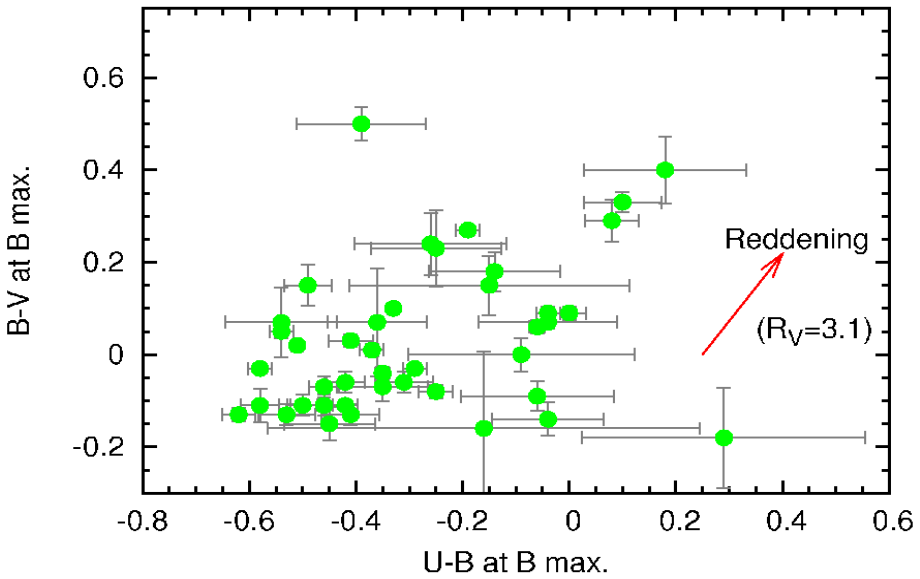


Fig. 1: Dispersion in the two-color diagram.

In this diagram, 44 nearby Type Ia supernovae are plotted. The data are taken from Takanashi+ ('08).

- To study this intrinsic dispersion:
  1. we construct models.
     - with different properties
  2. we calculate their light curves.
     - with the one-dimensional multi-frequency radiation transfer code, STELLA (Blinnikov & Sorokina '03)
  3. we plot them in the diagram.
     - to compare with the observed dispersion

Models

- W7 model
  - Fig. 2(*a*)
  - Nomoto+ (’84)
  - carbon deflagration model
  - synthesized ^{56}Ni ~ 0.6 M_{Sun}
- 56Ni-decreased models
  - e.g. Figs. 2(*b*) and 2(*c*)
  - differences of mass accretion rates and explosion models
  - change a part of ^{56}Ni to Fe or Si
    - 5 x 2 = 10 models
- Composition-mixed models
  - e.g. Figs. 2(*d*) and 2(*e*)
  - mixing in the ejecta (for three-dimensional simulations)
  - homogenize composition in the adjacent shells from the center to the surface
    - 6 degrees of mixing
      ➔ 6 models

➔ 17 models in total

Models (cont'd)

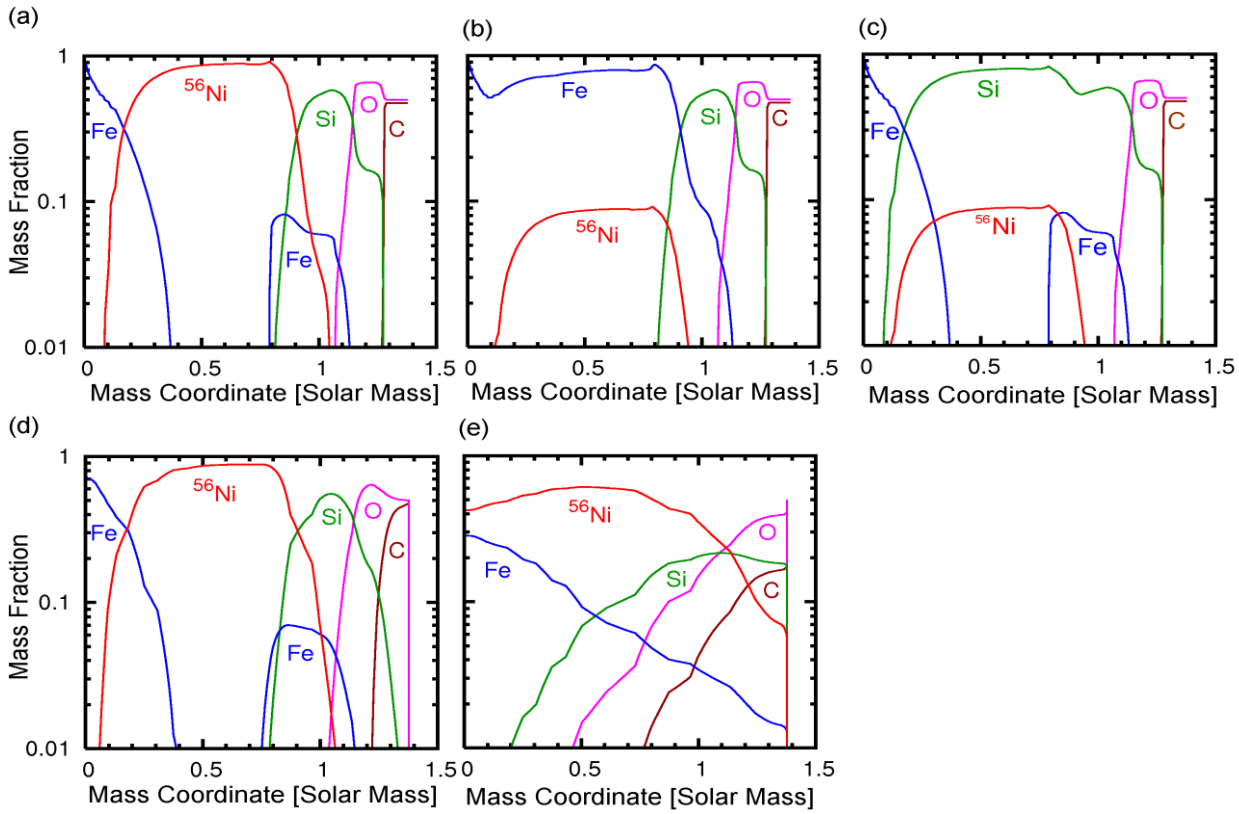


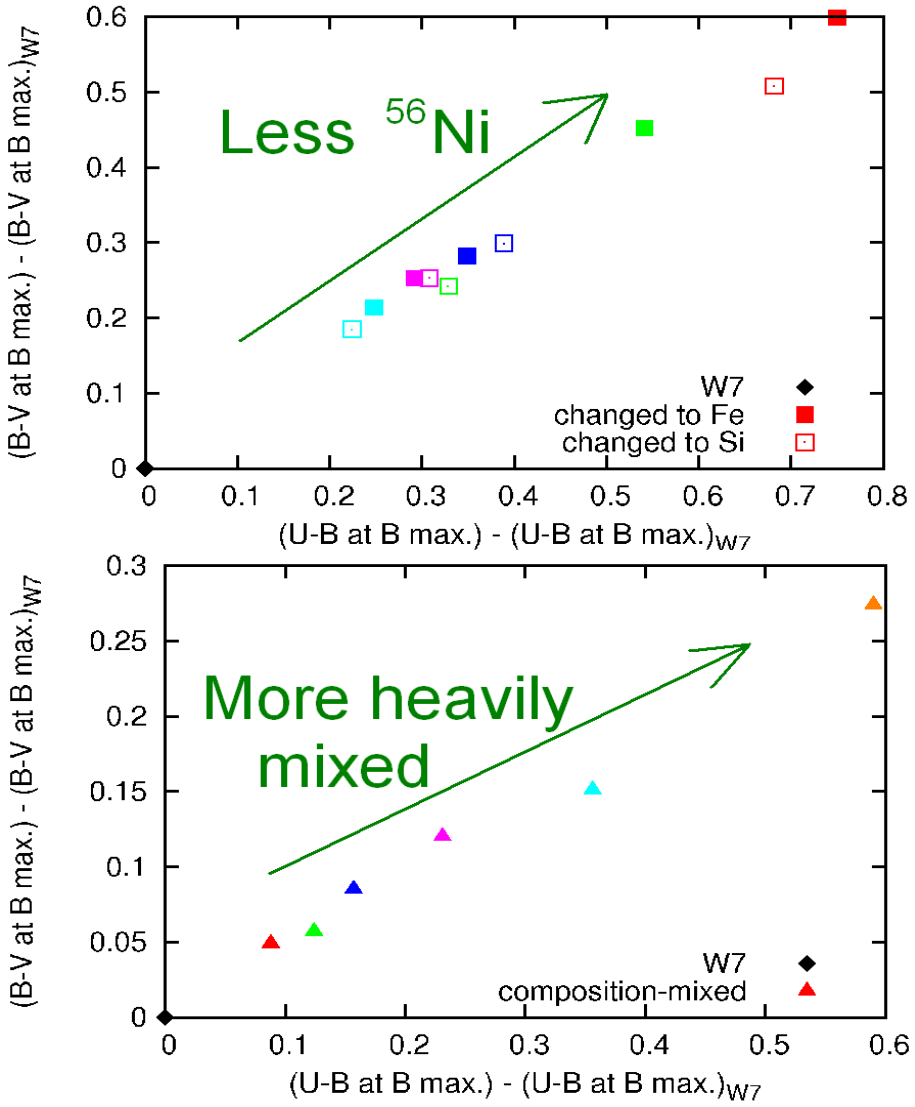
Fig. 2: Abundance distributions of models.

(*a*) W7; (*b*) ~0.54 M_{Sun} of ^{56}Ni changed to Fe; (*c*) same as (*b*) but to Si; (*d*) most mildly mixed; and (*e*) most heavily mixed.

Results and Discussions

- Dispersion caused by ^{56}Ni-decreased models
  - Fig. 3(*top left*)
  - little difference whether the decreased ^{56}Ni is changed to Fe or to Si
  - less ^{56}Ni ➔ Fainter ➔ lower temperature ➔ redder colors
    - This sequence is almost on the line of the black body radiation (not plotted).
- Dispersion caused by composition-mixed models
  - Fig. 3(*bottom left*)
  - more heavily mixed ➔ more Fe in the outer region ➔ more absorbed by Fe ➔ redder colors
- Compared to the observed dispersion
  - Fig. 3(*top right*)
  - difference in the degree of mixing ➔ dispersion
  - not-so-good opacity calculated by STELLA
    - brighter in the *U*-band

Results and Discussions (cont'd)



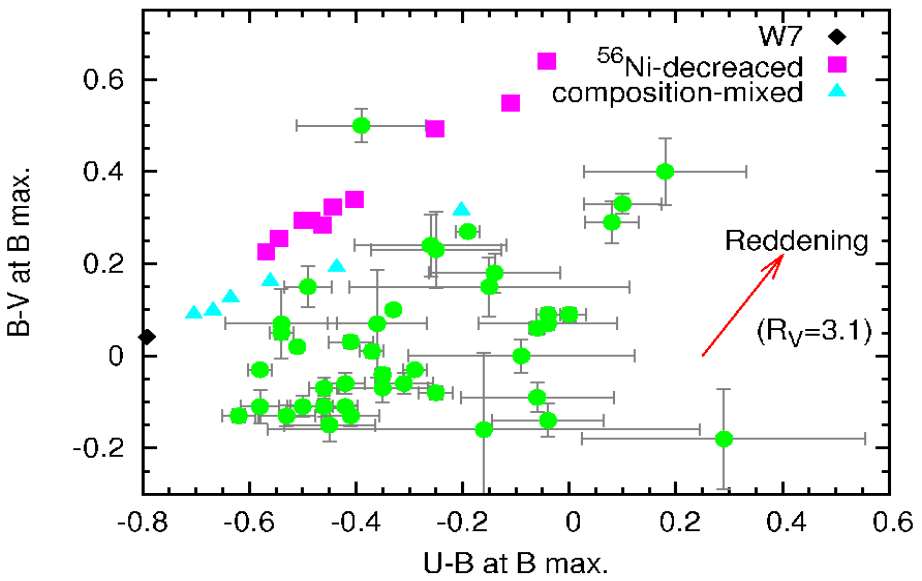


Fig. 3: Calculated dispersion in the two-color diagram.

(*top left*) ^{56}Ni-decreased models compared to that of W7; (*bottom left*) the same as (*top left*) but for composition-mixed models; and (*top right*) nearby Type Ia supernovae and models are plotted.

Conclusions

- Type Ia supernovae have the intrinsic dispersion in the (*U*–*B*)-(*B*–*V*) diagram at their *B*-band maxima.
- Differences in the amount of synthesized ^{56}Ni and degree of mixing in the ejecta can cause dispersion.
  - Especially, the mixing is more important to explain the observed dispersion.
    - The calculated models have bright *U*-band values.
    - This problem could solve by including more lines (Fig. 4).
      - now trying 115 k → 11 M
      - We could get fainter *U*-band values.

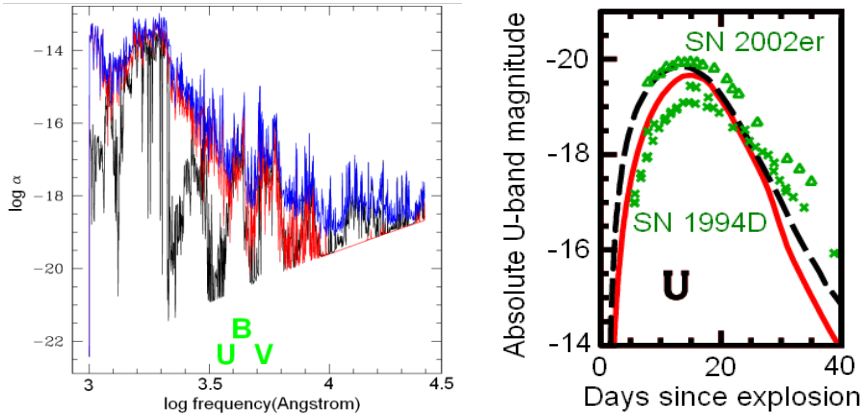


Fig. 4: Calculated absorption coefficients (*left*); and calculated *U*-band light curves of W7 model (*right*). For 115 k and 11 M lines.

- References:
  - Blinnikov, S.I. & Sorokina, E.I., 2003, A&A, 356, L30
  - Nomoto, K. et al., 1984, ApJ, 286, 644
  - Takanashi, N. et al., 2008, MNRAS, 389, 1577