The Metrology of Type Ia Supernova Lightcurves

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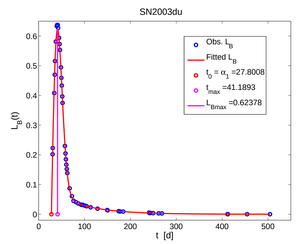
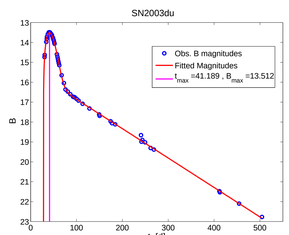
A Radioactive Decay Model for Type Ia Supernovae

$$L_B = 10^{-0.4[B-B_{ref}]}$$



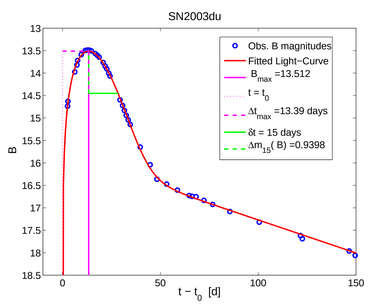
$\boxed{\hat{\alpha}_1 = t_0 = 27.80 \pm .38\ [d]}$

- Observations in B-magnitude units
- Make the fit in luminosity units



$R^2 = 0.9998$

Measuring the Rise-Time to Maximum Luminosity and the Post-Maximum Decline Rate



$\mathbf{\Delta m_{15}(B)} \equiv \left\{ \begin{array}{l} \text{Luminosity drop in first} \\ \text{15 days after maximum} \end{array} \right\}$

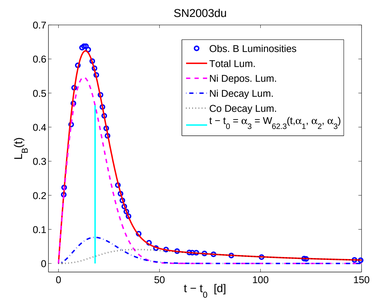
$\boxed{\hat{\alpha}_4 = 0.6621 \pm .0040}$

$\mathbf{\Delta t_{max}} \equiv t_{max} - t_0$

$\boxed{\hat{\alpha}_3 = W_{63.2}(t, \alpha_1, \alpha_2, \alpha_3) = 18.12 \pm .42}$

$\int_{t_0}^{t_0+\alpha_3} W(t\,; \alpha_1, \alpha_2, \alpha_3)dt = 0.632$

Measuring the Energies of the Pulses



$\int_{t_0}^{\infty} W(t\,; \alpha_1, \alpha_2, \alpha_3)dt = 1$

$E(\text{Ni depos.}) = \int_{\alpha_1}^{\infty} C_1 W(t)dt = C_1$

$E(\text{Ni decay}) = \int_{\alpha_1}^{\infty} C_2 N_1(t)dt = C_2$

$E(\text{Co decay}) = \int_{\alpha_1}^{\infty} C_3 N_2(t)dt = C_3$

$\frac{E(\text{Ni depos.})}{\text{nucleon}} = \frac{C_1}{C_2} \times [1.71\ \text{MeV}]$

$\boxed{\frac{E(\text{Ni depos.})}{\text{nucleon}} = 10.43\ \text{MeV}}$

$$L(t) = C_1 W(t\,; \alpha_1, \alpha_2, \alpha_3) + C_2 N_1(t; \boldsymbol{\alpha}) + C_3 N_2(t; \boldsymbol{\alpha})$$

$$\boldsymbol{\alpha} \equiv (\alpha_1, \alpha_2, \alpha_3, \alpha_4)$$

$$W(t\,; \alpha_1, \alpha_2, \alpha_3) \longrightarrow \boxed{N_1(t) \mid {}^{56}\text{Ni}} \xrightarrow{\frac{1}{8.764\alpha_4}} \boxed{N_2(t) \mid {}^{56}\text{Co}} \xrightarrow{\frac{1}{111.42\alpha_4}} \boxed{N_3(t) \mid {}^{56}\text{Fe}}$$

terrestrial half-life ^{56}Ni = 8.764 [d]
terrestrial half-life ^{56}Co = 111.42 [d]

$\boxed{\alpha_4 \equiv \text{decay rate accelerator}}$ $\boxed{0 < \alpha_4 \leq 1}$

$$\frac{dN_1}{dt} = W(t; \alpha_1, \alpha_2, \alpha_3) - \frac{1}{8.764\alpha_4} N_1\,, \qquad N_1(\alpha_1) = 0$$

$$\frac{dN_2}{dt} = \frac{1}{8.764\alpha_4} N_1 - \frac{1}{111.42\alpha_4} N_2\,, \qquad N_2(\alpha_1) = 0$$

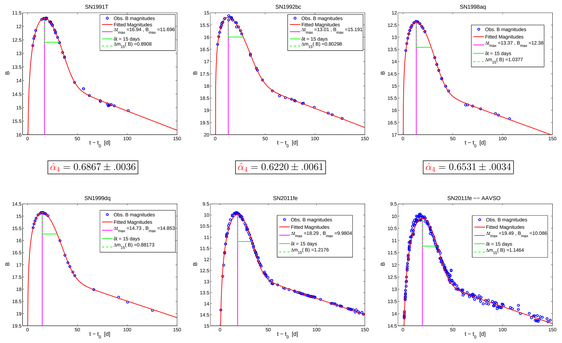
$\boxed{\alpha_1 = t_0 = \text{onset of } {}^{56}\text{Ni deposition}}$

$$\frac{dN_3}{dt} = \frac{1}{111.42\alpha_4} N_2\,, \qquad N_3(\alpha_1) = 0$$

$\boxed{\text{Weibull pdf}}$ $W(t\,; \alpha_1, \alpha_2, \alpha_3) = \frac{\alpha_2}{\alpha_3}\left(\frac{t-\alpha_1}{\alpha_3}\right)^{(\alpha_2-1)} \exp\left[-\left(\frac{t-\alpha_1}{\alpha_3}\right)^{\alpha_2}\right]$

$\left\{ \begin{array}{l} \alpha_2 = \text{shape parameter} \\ \alpha_3 = \text{scale parameter} \end{array} \right.$

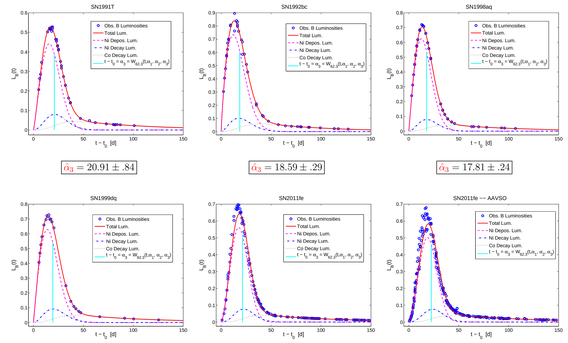
Some Other Well-Measured Lightcurves



$\hat{\alpha}_4 = 0.6867 \pm .0036$ $\hat{\alpha}_4 = 0.6220 \pm .0061$ $\hat{\alpha}_4 = 0.6531 \pm .0034$

$\hat{\alpha}_4 = 0.718 \pm .020$ $\hat{\alpha}_4 = 0.6637 \pm .0034$ $\hat{\alpha}_4 = 0.6999 \pm .0058$

Some Other Well-Measured Lightcurves

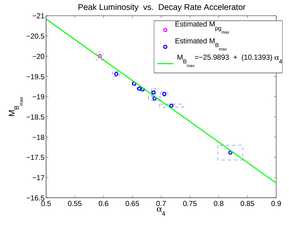


$\hat{\alpha}_3 = 20.91 \pm .84$ $\hat{\alpha}_3 = 18.59 \pm .29$ $\hat{\alpha}_3 = 17.81 \pm .24$

$\hat{\alpha}_3 = 19.4 \pm 1.0$ $\hat{\alpha}_3 = 21.38 \pm .11$ $\hat{\alpha}_3 = 22.52 \pm .16$

Calibrating the Extragalactic Distance Scale

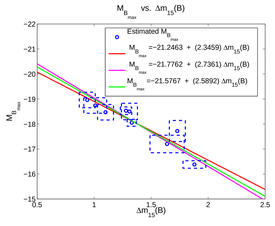
$$\mathbf{M_{B_{max}}} \equiv \mathbf{B_{max}} - (\mathbf{m} - \mathbf{M})_{\text{NED}}$$



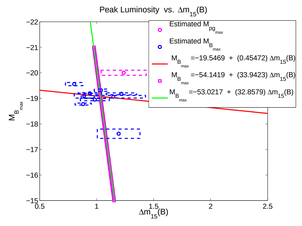
$\mathbf{M_{B_{max}}} = -25.9893 + (10.1393)\ \alpha_4$

- The distance moduli $(\mathbf{m} - \mathbf{M})_{\text{NED}}$ are the estimates for the parent galaxies given in the **NASA/IPAC Extragalactic Database**.
- The parameter α_4 is a global property of the light curve, completely determined by the fit to the observed luminosities and requiring no secondary measurements on the results.
- Since there are errors in both variables, the **straight line fit** was obtained by **major axis regression** which is also sometimes called **total least squares**.

Calibrating the Extragalactic Distance Scale ?

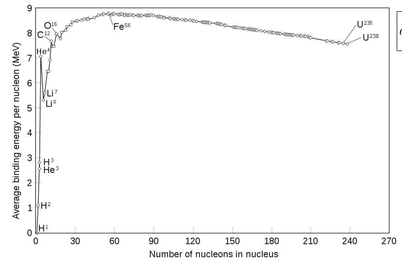


The data here are the original estimates of Phillips (1993). Since there are errors in both variables, he should have used the green major axis regression line rather than the red regression of $M_{B_{max}}$ on $\Delta m_{15}(B)$ line. The magenta line is for the regression of $\Delta m_{15}(B)$ on $M_{B_{max}}$



The $\Delta m_{15}(B)$ estimates plotted here were obtained by applying the measurement techniques described above to the same light curves that were used in the frame to the left. No extinction corrections were used in computing the $M_{B_{max}}$.

Astrophysics of the Nuclear Processes



$\boxed{av\left(\frac{E(\text{Ni depos.})}{\text{nucleon}}\right) = 8.63 \pm 3.17\ \text{MeV}}$

$\frac{E_{bind}(^{56}Ni)}{nucleon} = 8.7906\,MeV$

$\frac{E_{bind}(^{12}C)}{nucleon} = 7.680\,MeV$

$\frac{E_{bind}(^{16}O)}{nucleon} = 7.976\,MeV$

The source of the ^{56}Ni deposition must be the fusion of hydrogen (and possibly traces of helium). Carbon and oxygen could not supply the large energy/nucleon that is observed.