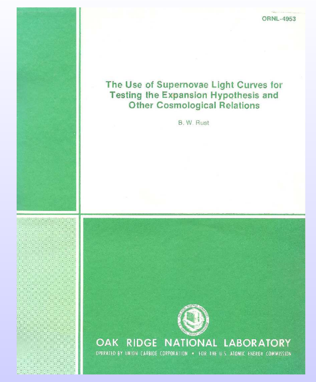

The Metrology of Supernova Lightcurves

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A Radioactive Decay Model for Type Ia Supernovae

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

terrestrial half-life ^{56}Ni = 8.764 [d]
terrestrial half-life ^{56}Co = 111.42 [d] $\Bigg\}$ $\boxed{\alpha_4 \equiv \text{decay rate accelerator}}$ $\boxed{0 < \alpha_4 \leq 1}$

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

$$\frac{dN_2}{dt} = \frac{1}{8.764\alpha_4}N_1 - \frac{1}{111.42\alpha_4}N_2\,, \qquad N_2(\alpha_1) = 0 \qquad \alpha = t_0 = \text{onset of } {}^{56}\text{Ni deposition}$$

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

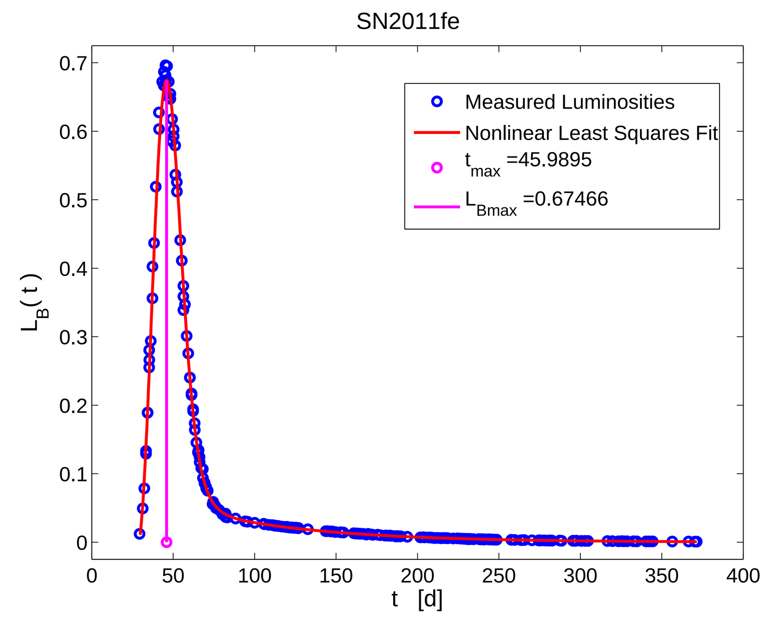
$\boxed{\text{Weibull pdf}}$ $\quad W(t;\alpha_1,\alpha_2,\alpha_3) = \frac{\alpha_2}{\alpha_3}\left(\frac{t-\alpha_1}{\alpha_3}\right)^{(\alpha_2-1)}\exp\left[-\left(\frac{t-\alpha_1}{\alpha_3}\right)^{\alpha_2}\right]$ $\quad \Bigg\{ \begin{array}{l}\alpha_2 = \text{shape parameter}\\ \alpha_3 = \text{scale parameter}\end{array}$

$$\boxed{L(t) = C_1W(t;\alpha_1,\alpha_2,\alpha_3) + C_2N_1(t;\boldsymbol{\alpha}) + C_3N_2(t;\boldsymbol{\alpha})}$$

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

Make the Fit in Luminosity Units

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



$t_0 = \hat{\alpha}_1 = 28.900 \pm .074$ [d]

$JD_0 = 2455798.9$

$JD_{max} = 2455816.9$

$\boxed{\hat{\alpha}_4 = 0.6716 \pm .0036}$

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

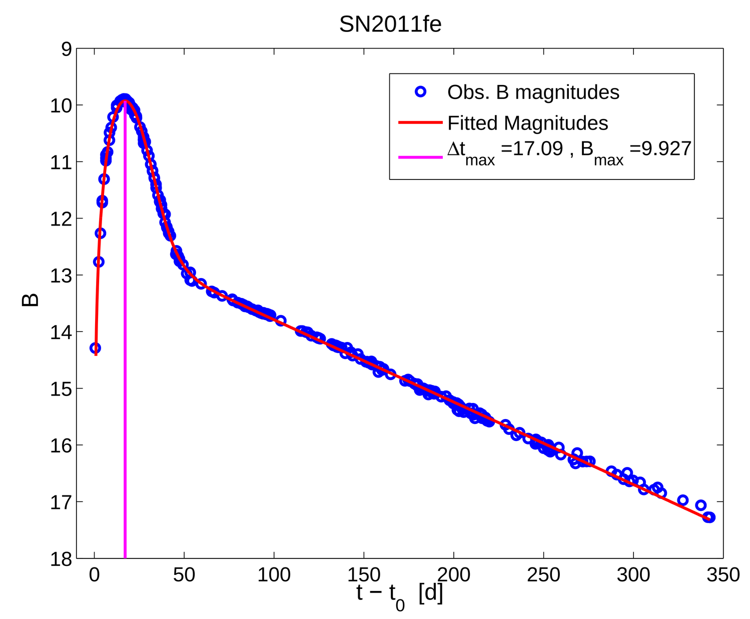
$$E(\text{Ni decay}) = \int_{\alpha_1}^{\infty} C_2 N_1(t)dt = C_2$$

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

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

An Extraordinarily Well-Measured Lightcurve

$$B = B_{ref} - 2.5\log_{10}(L_B)$$



U. Munari, A. Henden, et ANS, *New Astronomy* **20** (2013)

NGC 5457 $\quad (m-M)_{NED} = 29.13 \pm .26$

$V_r = 241 \pm 2$ [km/sec]

$B_{max} = 9.93 \quad \Longrightarrow \quad M_{B_{max}} = -19.20$

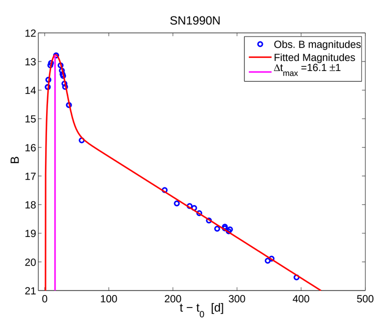
$\Delta t_{max} = JD_{max} - JD_0 = 18.0$ [d]

$\hat{C}_1 = 6.6 \pm 1.2$

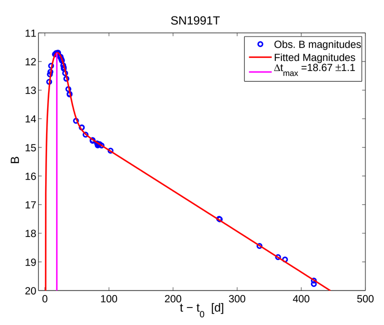
$\hat{C}_2 = 7.2 \pm 1.2$

$\hat{C}_3 = 4.044 \pm .042$

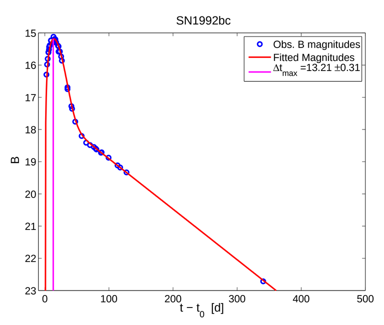
$L(t) = C_1W(t;\alpha_1,\alpha_2,\alpha_3) + C_2N_1(t;\boldsymbol{\alpha}) + C_3N_2(t;\boldsymbol{\alpha})$



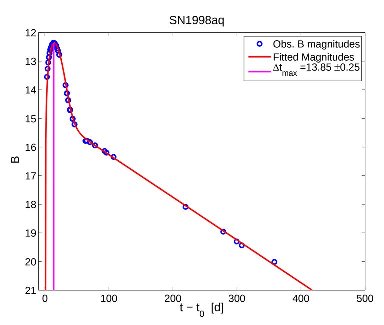
$\boxed{\hat{\alpha}_4 = 0.687 \pm .019}$



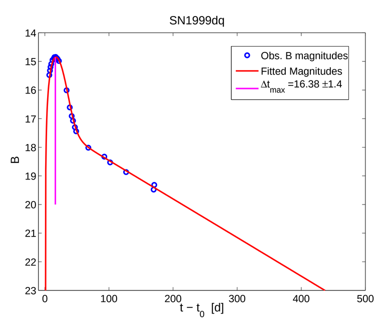
$\boxed{\hat{\alpha}_4 = 0.6867 \pm .0087}$



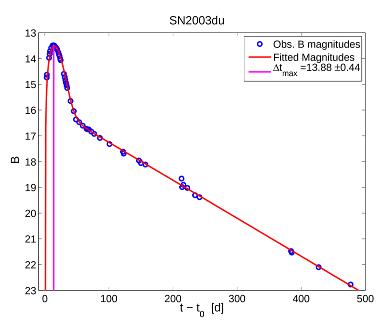
$\boxed{\hat{\alpha}_4 = 0.6220 \pm .016}$



$\boxed{\hat{\alpha}_4 = 0.6524 \pm .0073}$



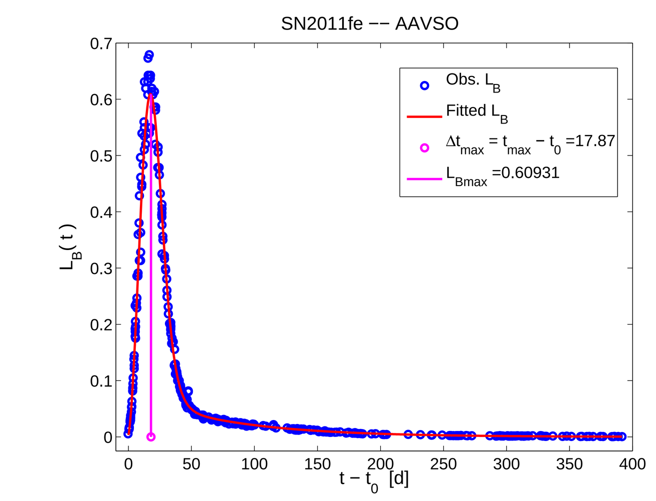
$\boxed{\hat{\alpha}_4 = 0.718 \pm .076}$

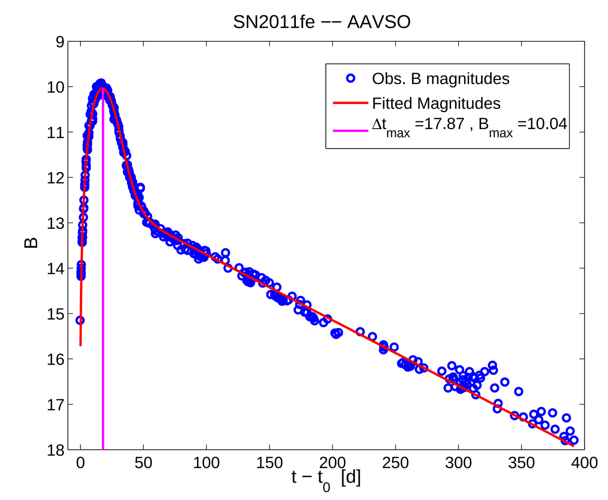


$\boxed{\hat{\alpha}_4 = 0.6621 \pm .0070}$

Kudos to the AAVSO Observers

http://www.aavso.org/access-data-section



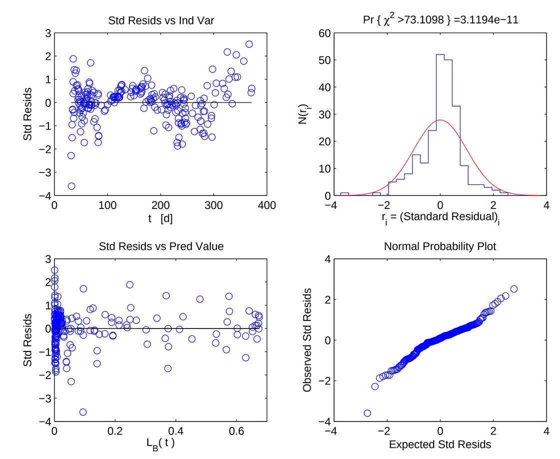


$\boxed{\hat{\alpha}_4 = 0.6749 \pm .0061}$ $\qquad B_{max} = 10.04$

$\Delta t_{max} = 17.87$ [d] $\qquad M_{B_{max}} = -19.09$

Residual Diagnostics for the Fits

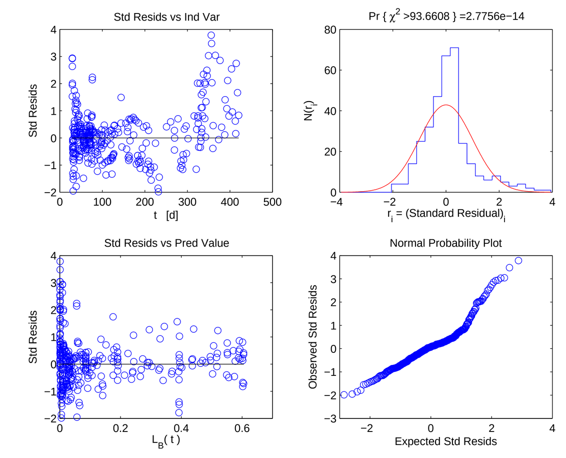
Asiago Standardized Residuals



$\sigma_{wt} = 0.0623$

$R^2 = 0.9980$

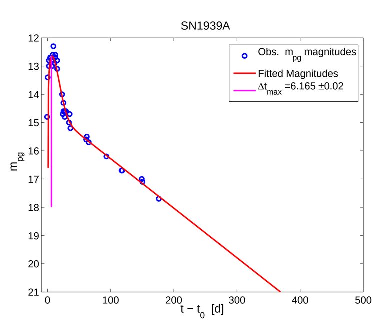
AAVSO Standardized Residuals



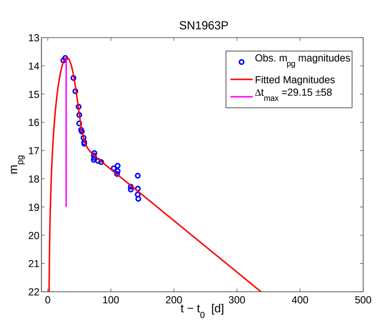
$\sigma_{wt} = 0.1437$

$R^2 = 0.9950$

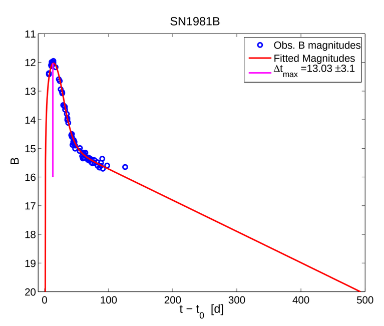
$L(t) = C_1W(t;\alpha_1,\alpha_2,\alpha_3) + C_2[N_1(t;\boldsymbol{\alpha}) + (2.146)N_2(t;\boldsymbol{\alpha})]$



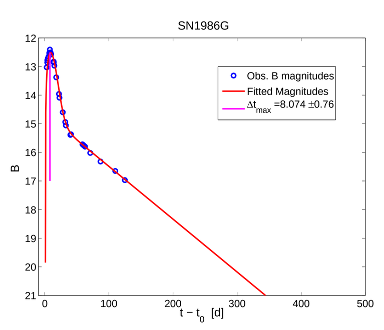
$\boxed{\hat{\alpha}_4 = 0.557 \pm .053}$ $\quad M_{B_{max}} = -18.37$



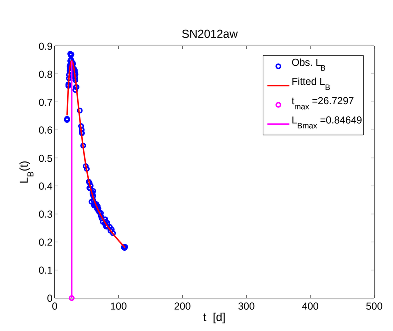
$\boxed{\hat{\alpha}_4 = 0.536 \pm .044}$ $\quad \Delta t_{max}$??



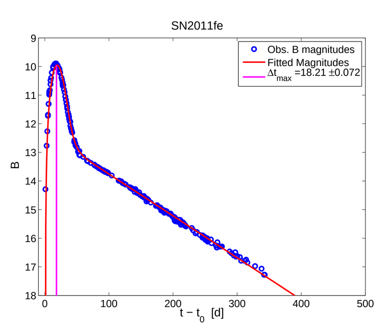
?? $\boxed{\hat{\alpha}_4 = 1.28 \pm .22}$??



$\boxed{\hat{\alpha}_4 = 0.530 \pm .017}$ $\quad M_{B_{max}} = -15.30$??

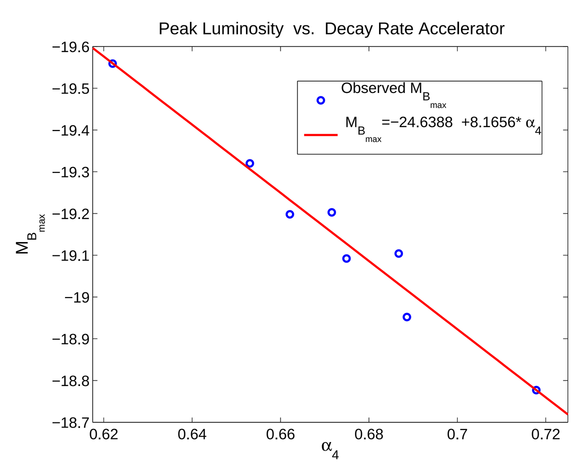


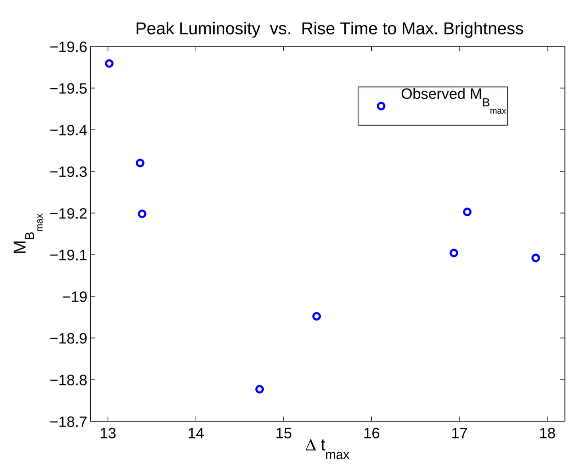
$\boxed{\hat{\alpha}_4 = 0.716 \pm .031}$ $\quad \Delta t_{max}$??



$\boxed{\hat{\alpha}_4 = 0.6637 \pm .0034}$

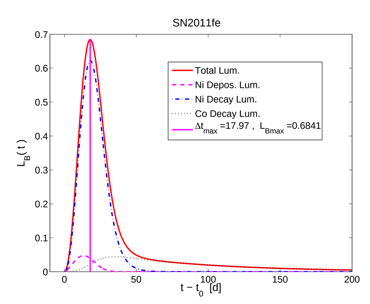
Calibrating the Distance Scale





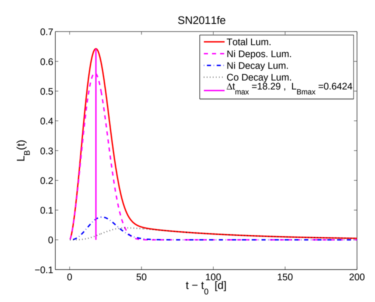
Dear Santa:
Please send me more lightcurves this year.
Sincerely,
Bert

Astrophysics of the Nuclear Processes



7-param. fit

$$\frac{E(Ni\ depos.)}{nucleon} = 0.107\ MeV$$



7-param. fit ′

$$\frac{E(Ni\ depos.)}{nucleon} = 10.78\ MeV$$

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

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

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