Evidence for Accelerated Radioactive Decay (ARD) Models of Supernova Lightcurves in the Low Redshift Universe

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James R. Van Hise, *Ap. J.* 192 (1974) 657-659

Ni-deposition pulse $\longrightarrow$ $\boxed{N_1(t) \mid {}^{56}\text{Ni}} \xrightarrow{\frac{1}{8.764\alpha_4}} \boxed{N_2(t) \mid {}^{56}\text{Co}} \xrightarrow{\frac{1}{111.42\alpha_4}} \boxed{N_3(t) \mid {}^{56}\text{Fe}}$

$$\left.\begin{array}{l}\text{terrestrial } \tfrac{1}{e}\text{-life } {}^{56}\text{Ni} = \ 8.764[d] \\ \text{terrestrial } \tfrac{1}{e}\text{-life } {}^{56}\text{Co} = 111.42[d]\end{array}\right\} \quad \alpha_4 \equiv \textbf{decay rate accelerator} \quad \boxed{0 < \alpha_4 \le 1}$$

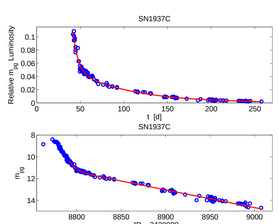
$$\frac{dN_1}{dt} = -\frac{1}{8.764\alpha_4}N_1$$

$$\frac{dN_2}{dt} = \frac{1}{8.764\alpha_4}N_1 - \frac{1}{111.42\alpha_4}N_2$$

$$\frac{dN_3}{dt} = \frac{1}{111.42\alpha_4}N_2$$

$$L_{m_{pg}}(t) = A_1 \exp\left(-\frac{t}{T_1}\right) + A_2 \exp\left(-\frac{t}{T_2}\right)$$

$$\frac{\hat{T}_2}{\hat{T}_1} = \frac{66.44}{5.60} = 11.86 \approx \frac{111.42}{8.764} = 12.71$$



Rust, Leventhal and McCall, *Nature* 262 (1976) 118-120

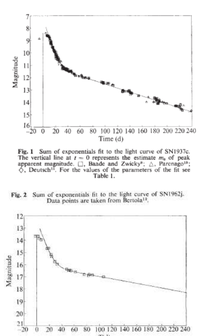


Fig. 1 Sum of exponentials fit to the light curve of SN1937c. The vertical line at $t = 0$ represents the estimate m_0 of peak apparent magnitude. □, Baade and Zwicky[8]; ○, Pavlovsky[10]; ◇, Deutsch[11]. For the values of the parameters of the fit see Table 1.

Fig. 2 Sum of exponentials fit to the light curve of SN1962J. Data points are taken from Bertola[12].

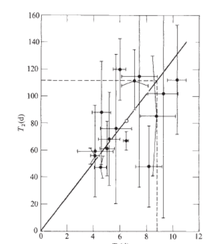
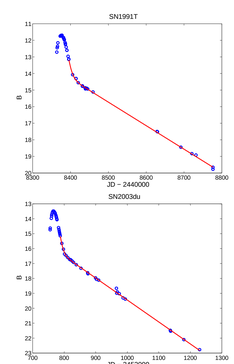
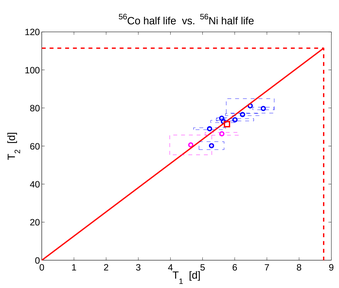


Fig. 3 Plot of the fitting parameters T_2 against T_1. The error bars represent the estimated s.d. but should not be interpreted as the major axes of error ellipsoids because the errors in T_1 and T_2 are correlated in each case.

$$\frac{\hat{T}_2}{\hat{T}_1} = \frac{81.2}{6.46} = 12.57 \approx \frac{111.42}{8.764} = 12.71$$

For a Sample of More Modern Lightcurves





$$\frac{\hat{T}_2}{\hat{T}_1} = \frac{81.2}{6.46} = 12.57 \approx \frac{111.42}{8.764} = 12.71$$

The ^{56}Ni - Deposition Pulse (a Weibull pdf)

$$W(t\,;\alpha_1,\alpha_2,\alpha_3) = \frac{\alpha_2}{\alpha_3}\left(\frac{t-\alpha_1}{\alpha_3}\right)^{(\alpha_2-1)} \exp\left[-\left(\frac{t-\alpha_1}{\alpha_3}\right)^{\alpha_2}\right] \quad \begin{cases}\alpha_1 = \text{location parameter} \\ \alpha_2 = \text{shape parameter} \\ \alpha_3 = \text{scale parameter}\end{cases}$$

$\alpha_1 = t_0 =$ onset of Ni-deposition

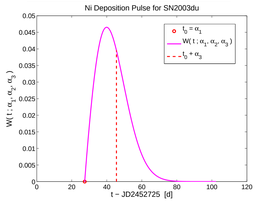
$\int_{\alpha_1}^{\infty} W(t\,;\alpha_1,\alpha_2,\alpha_3)dt = 1$

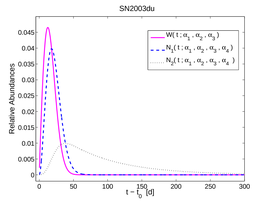
$\boxed{\int_{\alpha_1}^{\alpha_1+\alpha_3} W(t\,;\alpha_1,\alpha_2,\alpha_3)dt = 0.632}$

$N_1(t;\alpha_1,\alpha_2,\alpha_3,\alpha_4) =$ Rel. Abundance of ^{56}Ni

$N_2(t;\alpha_1,\alpha_2,\alpha_3,\alpha_4) =$ Rel. Abundance of ^{56}Co

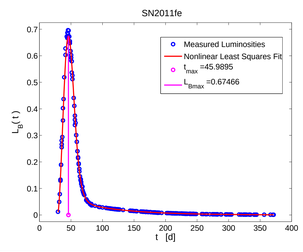
$N_1(t)$ & $N_2(t)$ also probability density functions





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

$$\boldsymbol{\alpha} \equiv (\alpha_1,\alpha_2,\alpha_3,\alpha_4)^T \quad \begin{cases}\dfrac{dN_1}{dt} = W(t;\alpha_1,\alpha_2,\alpha_3) - \dfrac{1}{8.764\alpha_4}N_1 & , \ N_1(\alpha_1) = 0 \\ \dfrac{dN_2}{dt} = \dfrac{1}{8.764\alpha_4}N_1 - \dfrac{1}{111.42\alpha_4}N_2 & , \ N_2(\alpha_1) = 0 \\ \dfrac{dN_3}{dt} = \dfrac{1}{111.42\alpha_4}N_2 & , \ N_3(\alpha_1) = 0\end{cases}$$



$$\boxed{\hat{\alpha}_3 = 18.26 \pm .61 \quad \hat{\alpha}_4 = 0.6716 \pm .0036}$$

$$E(\text{Ni depos.}) = \int_{\alpha_1}^{\infty} C_1W(t)dt = C_1$$

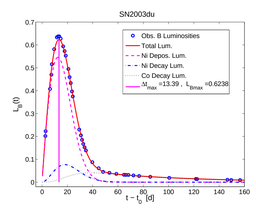
$$E(\text{Ni decay}) = \int_{\alpha_1}^{\infty} C_2N_1(t)dt = C_2$$

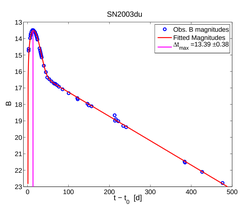
$$E(\text{Co decay}) = \int_{\alpha_1}^{\infty} C_3N_2(t)dt = C_3$$

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

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

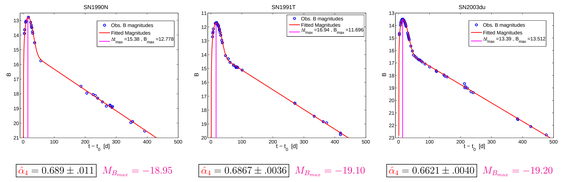
$$\frac{C_3}{C_2} = \frac{E(\text{Co decay})}{E(\text{Ni decay})} = \frac{E(\text{Co decay})/\text{nucleon}}{E(\text{Ni decay})/\text{nucleon}} = \frac{3.67 \text{ MeV}}{1.71 \text{ MeV}} = 2.146 \quad \Rightarrow \quad \boxed{C_3 = 2.146 \times C_2}$$



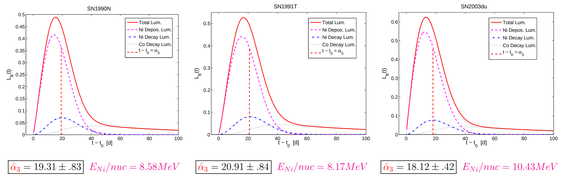


The accelerated decay rates are so stable, for such a long time, that they must occur in an almost unchanging environment – not in a turbulent expanding atmosphere. The ^{56}Ni deposition, which occurs over a period of ≈40 days, must also occur in that environment.

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

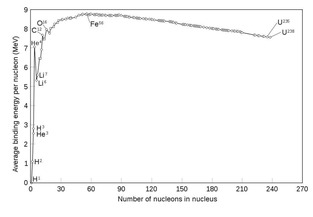


$\boxed{\hat{\alpha}_4 = 0.689 \pm .011}$ $M_{B_{max}} = -18.95$ $\boxed{\hat{\alpha}_4 = 0.6867 \pm .0036}$ $M_{B_{max}} = -19.10$ $\boxed{\hat{\alpha}_4 = 0.6621 \pm .0040}$ $M_{B_{max}} = -19.20$



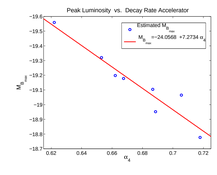
$\boxed{\hat{\alpha}_3 = 19.31 \pm .83}$ $E_{Ni}/nuc = 8.58MeV$ $\boxed{\hat{\alpha}_3 = 20.91 \pm .84}$ $E_{Ni}/nuc = 8.17MeV$ $\boxed{\hat{\alpha}_3 = 18.12 \pm .42}$ $E_{Ni}/nuc = 10.43MeV$

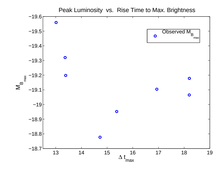
Astrophysical and Cosmological Implications



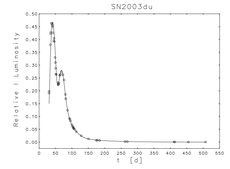
$$\frac{E_{bind}(^{56}Ni)}{nucleon} = 8.7906\,MeV$$

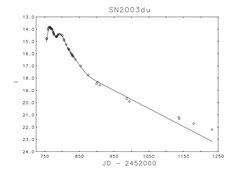
The source of the ^{56}Ni deposition must be the fusion of hydrogen (and possibly traces of helium). Carbon and oxygen could not supply the large energy/nucleon that is observed.



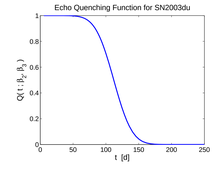


A Light Echo Model for the Infrared Lightcurve





The secondary peak is a light echo from dust in a pre-existing shell (planetary nebula?) around the white dwarf. The radius of the shell for SN2003du is ≈13.9 light days. The increasing intensity of the gamma radiation from the nuclear reactions vaporizes the dust and quenches the echo.



http://math.nist.gov/ BRust/
http://www.astro.umd.edu/people/nl.html