The Rise and Fall of SDSS-II Type Ia Supernovae

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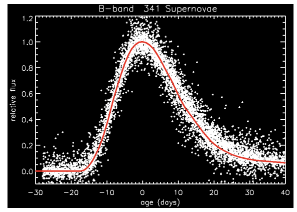
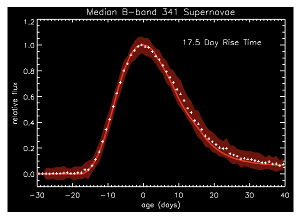
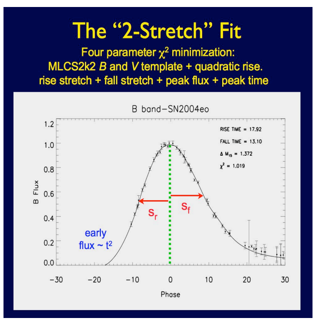
Abstract: We analyze the rise and fall times of type Ia supernova (SNIa) light curves discovered by the SDSS-II Supernova Survey. From an initial set of 341 light curves k-corrected to the rest frame *B* and *V* bands, we find a smaller dispersion in the rising portion of the light curve compared to the decline. This indicates that variations in radioactive nickel yield affect the decline time more strongly than the rise time and that a single 'stretch' correction is not an ideal model for parameterizing type Ia light curves. We select a subset of 89 light curves well-observed in both rise and fall portions of the light curves and develop a 'two-stretch' fit algorithm which estimates the rise and fall times separately. We find the time from explosion to *B*-band peak brightness for a typical type Ia supernova is 17.5 ± 0.3 days, but with a wide spread from 12 days to 23 days. This is significantly shorter than the 19.5 days found in previous studies and this reflects both the different light curve template used and the application of the two-stretch algorithm. The SDSS-II supernova set and the local SNIa with well-observed early light curves show no significant differences in their average rise time properties. The rise time minus fall time distribution appears to be bimodal, although the separation is near the limit of the SDSS-II time resolution. This bimodality was noted by Mark Strovink[1] analyzing a local set of SNIa and is suggestive of two types of progenitors or two explosion modes. In the SDSS-II set, slowest declining events tend to have faster rise times than a single stretch model would be able to measure.





Template Selection: We generated our template curve using MLCS2k2, which is trained on a large set of nearby type Ia supernovae. Few of the nearby supernovae were observed earlier than -10 days before peak brightness, so we adopted an expanding fireball model to extrapolate more than -10 days before maximum light. We generated multiple template curves with varying explosion dates, a t^2 distribution until -10 days, with the light curve remaining continuous at -10 days. The first derivative was not required to be constant at the joining point. The result of a χ^2 minimization using these different light curves led us to select the template that had a 16 day rise time. We emphasize that this is not a measure of the average rise time of a type Ia SN, but a measure of the relative shape of the light curve between the expanding fireball portion and the portion where radioactive nickel begins to dominate the light curve. Our measured average value for the SDSS-II data set rise-time is 17.5 ± 0.3 days.

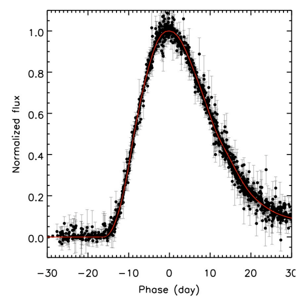


2-Stretch method: The goal of the two stretch method is to decouple the rise portion of the light curve from the fall portion of the light curve. The 2-stretch method uses the day of maximum as the separation point between rise and fall. This is a natural breaking point because the first derivative of the light curve at this point is zero. It is also useful because the supernova has an age of zero at this point, by definition, so stretching the two sides independently will maintain continuity at the joining point. Our 2-stretch fitting method has four parameters:

1) Day of maximum, denoted t_0
2) Flux of maximum, denoted f_0
3) Stretch of $t-t_0 \le 0$, denoted S_r
4) Stretch of $t-t_0 > 0$, denoted S_f

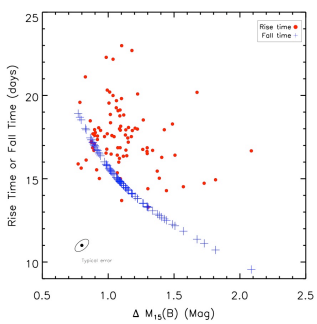
A χ^2 minimization is performed in order to obtain the best-fit parameters for our template to the data.

Previous Rise Time Determinations: Our calculated rise time to *B* maximum is 2 days shorter than that determined in the work of two others. The first was a study by Riess et al. (1999)[2] which found that the average rise time to *B* maximum was 19.5 days. In a recent paper Conley et al. (2006)[3] confirmed this result with 73 of the SNLS type Ia SNe. We analyzed the template used in the Riess et. al paper, and found that our template reaches 0.66 mags on the rise portion 1.8 days later than that of Riess et al., implying a faster rise. This difference in template shape, combined with the application of a single stretch method which does not allow the relative shape between rise and fall to be modified, is likely the cause of our 2 day difference.

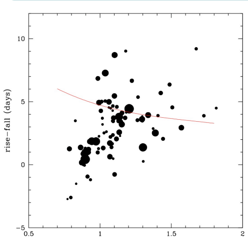


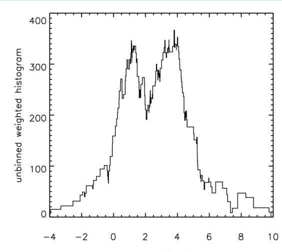
Stretch-Corrected Data: The data from all 89 Ia SN light curves used in this study, corrected using the fitting parameters found by the 2-stretch fitter so that they are all in fiducial phase. The normalized χ^2 value of this distribution is 1.01.

Progenitor Models: In Strovink (2007), a potential bimodality is discussed in the distribution of rise minus fall times in eight nearby Ia supernovae that have well-sampled light curves even well before maximum brightness. There is ongoing debate concerning the progenitors of Ia SNe, and although it is well-accepted that a white dwarf that exceeds the Chandrasekhar limit produces the explosion that we observe, the method by which the star exceeds this limit is not currently known. There are two prevailing theories; the single-degenerate model requires the white dwarf to accrete mass from a companion star, while the double-degenerate model requires the coalescence of two white dwarfs whose total mass exceeds 1.4 solar masses. This makes a potential bimodal distribution in supernova observations very interesting. Even if a bimodal distribution in rise minus fall is unable to constrain the progenitor models, it is important in the study of Ia explosions to explain how these supernovae preferentially fall into two distinct categories of light curve shape based on the rise minus fall time. Current theoretical models may not be sufficient to describe this distribution, should it prove to be the actual distribution.



Rise Times: The above figure is the plot style employed by Strovink, here applied to all 89 of the SDSS-II type Ia SNe that we analyzed. The ellipse in the lower-left corner represents the typical error in a single measurement based on the covariance between the rise time and $\Delta M_{15}(B)$. This plot indicates that there is less spread in the rise time than the fall time; we measure a range for rise times of 14-23 days, but their distribution is not as closely related to the fall time as a single stretch model would suggest.





Two Peaks? The histogram on the left is an unbinned histogram of the rise time minus fall time distribution. Every supernova is given the same total area under the histogram. However, the width each one is given is the error in rise time minus fall time, so that the supernovae with the smallest errors contribute the most to the overall distribution. This distribution is best described by a two-peaked gaussian with centers at 0.87 ± 0.3 days and 3.60 ± 0.28 days.

Definition of Rise/Fall time: In our analysis, we define the rise time, fall time, and $\Delta M_{15}(B)$ values as follows:

◆ **Rise time:** The time (in rest-frame days) required for the supernova to go from explosion to maximum brightness.

◆ **Fall time:** The time (in rest-frame days) required for the supernova to go from maximum brightness to 1.1 magnitudes dimmer, post-maximum.

◆ **$\Delta M_{15}(B)$:** The number of magnitudes that the supernova dims exactly 15 rest-frame days post-maximum brightness.

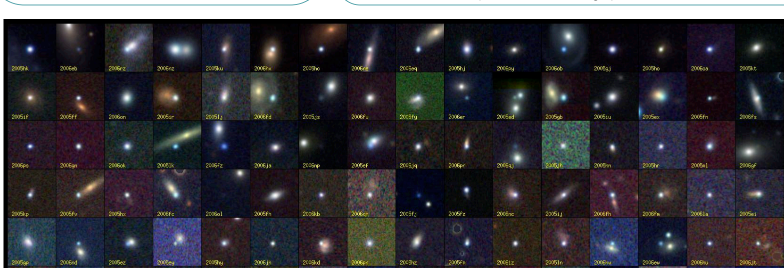
Rise – Fall Results: The above two plots display the results of our 2-stretch fit of 89 of the light curves from the SDSS-II Supernova Survey. These 89 represent the Ia SNe that passed a cut of 1.5 day error on the rise time, and 2 day error on the fall time. The plot on the left shows the distribution of rise time minus fall time versus $\Delta M_{15}(B)$. Larger points indicate smaller errors in the measurement of this value. The red line indicates the theoretical distribution that results from a 'single-stretch' model of Ia light curves. The data shows a group of the slowest-declining Ia SNe that have the fastest rise times. (continued above, right)

Conclusions:

◆ We measure an average rise time of 17.5 ± 0.3 days for the SDSS-II type Ia SNe. These rise times do not appear to be strictly correlated with the fall time.

◆ The results from our 2-stretch fitting method imply that a single stretch method does not capture the variation in rise time that occurs for a specific fall time. This could be an indication that there is different physics at work in the rise and fall of the light curves.

◆ The distribution of rise and fall times shows a double peak, which suggests two populations are present in the SDSS-II type Ia supernova data.



Just a few of the hundreds of type Ia supernovae studied by SDSS-II - image by B. Dilday

References:

[1] Strovink, M. 2007, ApJ, 671, 1084
[2] Riess, A.G., et al. 1999, AJ, 118, 2675
[3] Conley, A., et al. 2006, AJ, 132, 1707