Bolometric Light Curves of Type Ia Supernovae

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1.1 Light Curves of Type Ia Supernovae

Substantial information about the processes in supernovae is contained in their light curves. They track the temporal evolution of the energy release. The energy is generated in the explosion by burning matter to nuclear statistical equilibrium, goes into unbinding the white dwarf and is stored in radioactive material. The light curve itself is defined by the conversion of the γ-rays from the radioactive decays into lower energy photons and by the escape of the latter from the ejecta.

Because of their apparent uniformity SNe Ia were used as standard candles for distance determination and to measure cosmological parameters [1]. The standard candle approach is the simplest method. But the light curves of SNe Ia show significant differences in their shapes and maximum luminosities. Phillips [2] showed a relation between maximum brightness and $\Delta m_{15}(B)$, the difference in brightness in the B-band at its maximum and 15 days after. Hamuy et al. [3] confirmed this relation. Another one parameter model is the Multicolor Light Curve Shape (MLCS) method of Riess et al. [4], which uses a training set of well observed SNe to span a range of light curves, described by one parameter.

1.2 Fitting Method

A different approach is fitting the filter light curves independently to avoid intrinsic assumptions made in template-fitting techniques. Therefore it is ideally suited for investigating the non-uniformity of SN Ia explosions. For each supernova the light curve shape parameters (like rise time, shape around maximum, late decline etc.) are derived individually and can be searched for correlations. A descriptive model has been fitted to light curves of supernovae from the Calán/Tololo survey [5], a set of supernovae from Riess et al. [6] and other well observed, high quality data. The time evolution of the observed magnitudes is modeled as a Gaussian (for the peak phase) atop a linear decay (for the late-time decline), a second Gaussian in the V, R, and I-band (for the secondary maximum found in that curves) and an exponential rise function (for the pre-maximum segment), as applied to SN 1994D by Vacca and Leibundgut [7].

1.3 Epoches of Maxima

With these fits, parameters derived from the light curve shape can be compared more easily. For example the distribution of the times of maximum light in the different filter light curves can be examined, as shown in Figure 1. While the U-band light curve peaks before the B maximum and V and R follow the B, the I light curve reaches maximum even earlier than the U light curve. This trend is also confirmed by the IR light curves [8]. This is a very clear

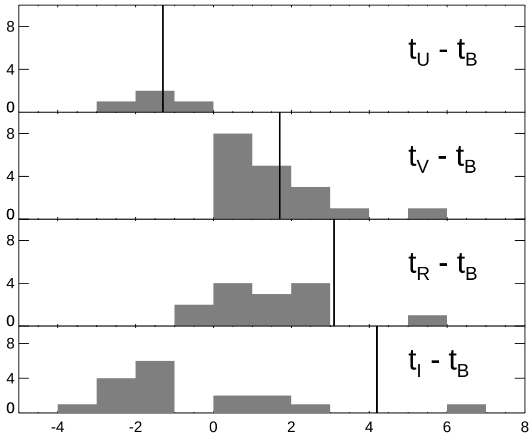

Figure 1: Relative times of maximum light in different filters. The vertical lines show an expanding, adiabatic cooling sphere [9].

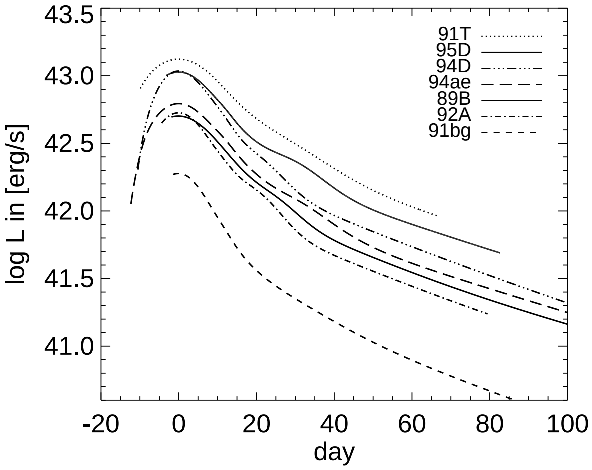

Figure 2: Bolometric luminosities.

sign of the non-thermal nature of the radiation emitted by SNe Ia. A simple model of an expanding, adiabatic cooling sphere according to Arnett [9] gives the vertical lines in Figure 1. The maxima at longer wavelengths are reached at later epoches in this model. This is clearly not seen for most SNe Ia.

1.4 Bolometric Light Curves of Type Ia Supernovae

As nearly 80 % of the bolometric luminosity is emitted in the range from 3000 to 10000 Å [10], the *UBVRI* integrated flux is a physically meaningful quantity. It depends on the nickel production, the energy deposition and the γ-ray escape, but not on the wavelengths of the emitted photons. The theoretical calculation of the bolometric light curve is much simpler than the calculation of the filter light curves, as complicated multi-group calculations of the complete spectrum can be avoided.

But not all SNe are observed in all five bands. In a first approximation it is assumed that the flux distribution is the same for all SNe. A well observed supernova (SN 1994D) is used to calculate correction factors for missing pass bands.

If this correction is applied to other SNe, and the distance moduli and reddening are taken into account [3, 4], one obtains the *UBVRI* bolometric light curves displayed in Figure 2. The absolute peak luminosities differ by a factor of 10. The second bump, which can be seen in the *R* and *I* light curves of several SNe, is still visible in the bolometric light curves. These results show, that there are fundamental differences in the energy release among individual SNe Ia.

How reliable are these bolometric luminosities and by which quantities are they affected? In a forthcoming paper [11] a more extended discussion of the errors will be given. The distance modulus only changes the absolute luminosity. As all distances used here are scaled to a Hubble constant of $H_0 = 65\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, the luminosity differences are only affected by errors in the determination of the distance modulus and not by offsets due to the different methods. If the distance modulus changes by 0.1 mag, the bolometric luminosity changes by 9 %. Reddening changes the absolute luminosity as well as the shape of the light curve.

Reddening of $E(B-V) = 0.05$ still gives 85 % (88 %) of the unreddened bolometric luminosity at $t = t_{\max}$ ($t = 20$ days $\approx$ time of second maximum in R and I), whereas at reddening of $E(B-V) = 0.35$ only 33 % (44 %) of the unreddened bolometric luminosity remains at $t = t_{\max}$ ($t = 20$ days). Differences among independent data sets introduce additional uncertainties. For typical values of < 0.05 mag [6], however, we find changes of less than 3 %. We have tested also the influence of applying the fitting routine on the individual filter light curves before constructing the bolometric luminosities by comparing it to bolometric luminosities calculated directly from the observational data. The integration method and normalization influence the bolometric luminosities up to 2 %. Finally, the error introduced by the correction factors for missing U-band is < 10 %, as has been tested by constructing artificially data with missing pass bands for SNe which are observed in U, B, V, R, and I.

1.5 Conclusions and Future Work

A sample of supernovae has been used to construct bolometric light curves from observations. These bolometric light curves can be compared to theoretical models more easily than filter light curves. Therefore, bolometric light curves are one step from observations to theoretical models.

In the future, a comparison of the bolometric light curves from observations with those from theoretical models can supply us with information about the physical processes in SNe Ia. We will derive the light curve corrections with bolometric light curves instead of filter light curves to move from an empirical classification to physically meaningful relations.

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