The Light Curve of Supernova 2004et

Tiara R. Norris, California State University, Chico
Advisor: Dr. Doug Leonard, San Diego State University

Abstract

There are only a few good published light curves for type II-Plateau (II-P) supernovae. SN 2004et, being of that type, in a relatively nearby galaxy, and possibly having an identified progenitor star, is a good candidate for a well-defined light curve. Although there was some reason to believe SN 2004et might be a peculiar type II-P supernova based on preliminary studies, the light curve derived is very similar to the "typical" type II-P supernovae SN 1999gi and SN 1999em, although some differences do exist. Color and temperature evolution diagrams were also constructed for SN 2004et and do not show significant anomalies.

Introduction

Supernovae are grouped into two main types, I and II, based on the presence (type II) or absence (type I) of hydrogen lines in the spectrum. Type II-Plateau supernovae (SNe II-P) are thought to result from the explosion of a red supergiant star with an intact hydrogen envelope. The light curves of SNe II-P are distinct from other SNe, as they are characterized by an enduring period of nearly constant optical brightness. Their light curves can be broken into two phases: the photospheric phase and the nebular phase. During the photospheric phase, which lasts for about the first hundred days after peak brightness, the optical light output of the supernova remains fairly constant. This time period is related to the expanding and cooling hydrogen envelope around the star. At the end of the photospheric phase, the hydrogen envelope has cooled to transparency, and the inner parts of the star become visible. Now in the nebular phase, the light output of the supernova quickly drops off.

SN 2004et was discovered in a spiral galaxy, NGC 6946, on September 27, 2004 by S. Moretti (Zwitter et al. 2004). Looking at previous images taken of the field, the supernova was first visible on September 22.983 UT (UT times are used throughout this paper), with an unfiltered magnitude of 15.17. An image of the field taken on September 22.017, shows no supernova down to a limiting magnitude of 19.4, thus establishing the explosion date to within one day. Based on an early, high-resolution spectrum of the supernova, an estimate of the reddening due to interstellar dust was determined: $E(B-V) = 0.41$ (Zwitter et al. 2004). By early 2005, a possible progenitor star had been identified in pre-explosion images with an estimated mass of $15^{+5}_{-2} M_{\odot}$ (Li et al. 2005). The star is believed to have been a yellow supergiant, although a multistar system could not be ruled out. Li et al. (2005) also point out some peculiarities in the early (first 25 days after explosion) light curve and spectra when compared to a "normal" type II-P supernova, SN 1999em (i.e., a somewhat slower evolution in the U and B bandpasses). The results presented in this study will address whether or not the fully reduced and extended light curves continue to show the anomalies identified in the initial data.

Data Reduction

The images used in this project were obtained through UC Berkeley from the robotic Katzman Automatic Imaging Telescope (KAIT) at Lick Observatory. Data were taken from September 30, 2004, to October 31, 2005, with a gap from December 24, 2004, to May 25, 2005, due to solar conjunction. Aside from the gap in the data, the number of data points available is excellent. Roughly two hundred images were taken in total, using standard *UBVRI* Johnson-Cousins filters. Data on two comparison SNe II-P, SN1999em and SN1999gi, were taken from Leonard et al. (2002a,b).

The program IRAF was used to reduce the data. After the images were cleaned of cosmic rays, twelve "local standard" stars (Figure 1) were chosen, whose standard *BVRI* magnitudes were determined from data taken on seven photometric nights; *U* band data were obtained on only one photometric night. Since the background of the field is complicated due to the presence of the host galaxy, point spread function (PSF) fitting was applied to each of the standards as well as the supernova. The PSF task in IRAF was used to derive the instrumental magnitudes of the supernova and local standards. These instrumental magnitudes were then transformed onto the standard system following the prescription of Leonard et al. (2005). Twelve separate light curves were then derived for the supernova, one for each of the local standards. Averages of the twelve light curves were taken to make the final light curves for SN2004et.

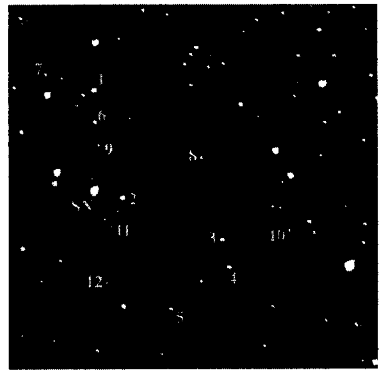

Figure 1: "Local Standards"

Analysis

The light curve for SN2004et is plotted (see Figure 2 below) along with the two comparison SNe II-P, SN 1999em and SN 1999gi. The light curve for SN2004et has a well-defined plateau, corresponding to the photospheric phase. Unfortunately, the turn-off after the photospheric phase is not visible because of the gap in the data. The two comparisons are well-studied, "typical" SNe II-P (Leonard et al. 2002a,b). Neither had a progenitor star detected on pre-explosion images, unfortunately. The comparisons were fitted by shape. The fully reduced data continue to show a somewhat slower *U* and *B* evolution when compared with SN 1999em during the first half of the plateau phase, as well as some differences in *VRI* during the later part of the plateau. However, the *BVRI* light curves are very similar to those of SN 1999gi throughout the plateau.

Based on the light curve for SN2004et and the two comparison supernovae, a diagram of the color evolution was produced (see Figure 3 below). For this graph, reddening due to interstellar dust had to be taken into consideration. Previous estimates for the degrees of reddening were used: $E(B-V)_{04\mathrm{et}} = 0.41$ mag, $E(B-V)_{99\mathrm{em}} = 0.10$ mag, $E(B-V)_{99\mathrm{gi}} = 0.21$ mag (Zwitter et al. 2004; Leonard et al. 2002a,b). These reddening amounts were used to derive unreddened magnitudes for each of the filters according to equations of the form:

$$U_{true} = U_o - R \times E(B-V)$$

with R values taken from Schlegel et al. (1998). The data for the three supernovae were also changed from "days since discovery" to "days since explosion" using previously computed values (Yamaoka et al. 2004; Leonard et al. 2002a,b). All three supernovae shift more toward the red as time goes on, as expected for a cooling atmosphere. There are two uncertainties in these values, associated with the reddening and the explosion date. The uncertainty in reddening, which has a greater effect, moves the data up or down; the uncertainty in explosion date moves the data left or right of the plot. The uncertainties may explain some of the differences among the three supernovae.

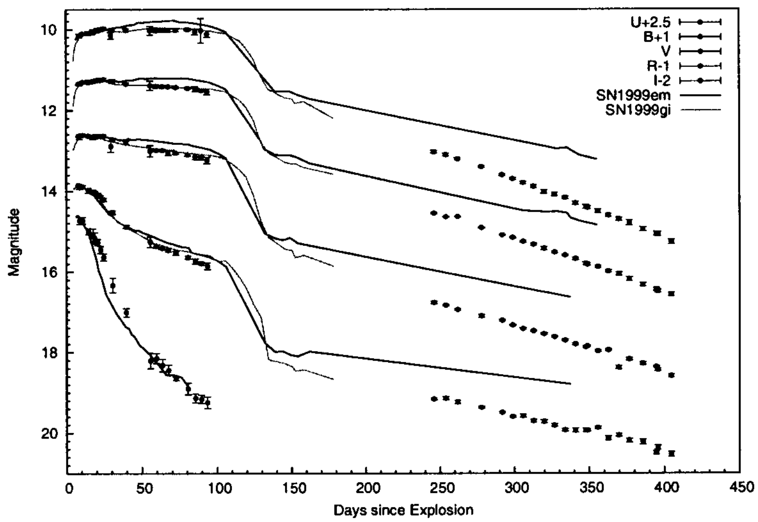

Figure 2: Light Curve for SN2004et and Comparisons

During the photospheric phase, a SN II-P can be approximated as a blackbody. The temperature for a blackbody directly relates to color through the equation (Schmidt et al. 1992):

$$T = \frac{10000K}{1.605(B-V)+0.67}$$

The supernova starts out very hot and cools off, as would be expected. The cooling levels off at approximately 4000K. At this point, the ionized hydrogen shell has started recombining and deeper shells in the envelope become visible. This graph only shows the temperature for the first one hundred days: the photospheric phase. Once the supernova enters the nebular phase, a blackbody is no longer a good approximation.

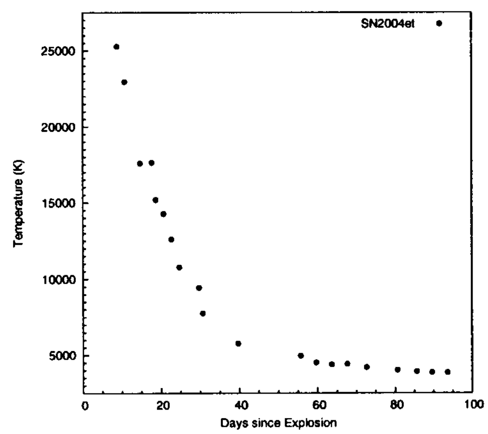

Figure 4: Temperature Evolution for SN2004et

Conclusions

The light curve of SN 2004et is nicely detailed during the photospheric and nebular phases, although the fall-off from the plateau was not caught because of the gap in the data. SN 2004et appears to be generally similar to other "typical" type II-P supernovae, especially SN 1999gi, based on the shapes of its light curves. The peculiarities tentatively identified by Li et al. (2005) in the early light curves relative to SN 1999em are also seen in the fully reduced KAIT data, indicating some individuality among the members of the SN II-P sample.

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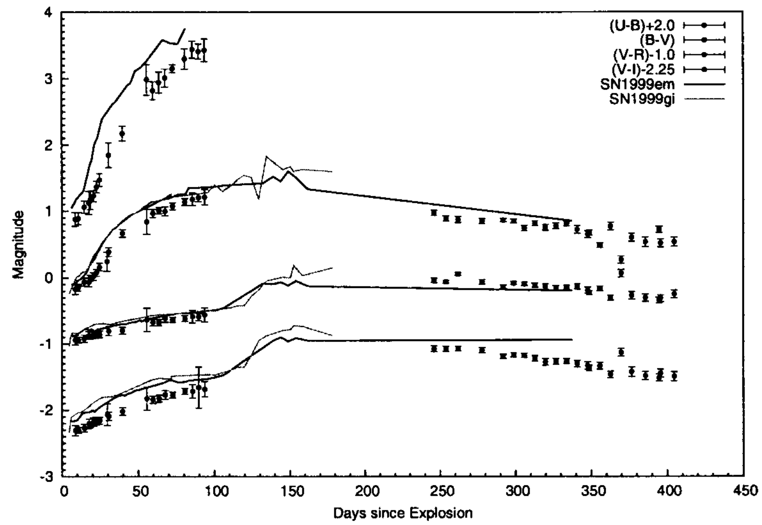

Figure 3: Color Evolution for SN2004et and Comparisons

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