Photometric and Spectroscopic evolution of Type II-P Supernova SN 2004et

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Introduction

Classification of Supernovae

Based on spectroscopy near max. light

Hydrogen rich Type II
Hydrogen deficient Type I

Explosion mechanism

Core Collapse Supernovae
IIP -- IIL -- Ib -- Ic

Thermonuclear explosion Ia

Observational Importance of Supernovae:
Type Ia – Ideal probe to be used as distance indicator.
Type II - Wide range in luminosity. Type IIP plateau luminosity is correlated with expansion velocity of ejecta.

Advantages:
Well understood progenitors
Atmosphere is dominated by Hydrogen
Type II: Core Collapse Supernovae

Massive star: Fe is fusion endpoint

\[ \gamma + ^{56}\text{Fe} \rightarrow 13 \ ^{4}\text{He} + 4n \]

Pressure drop

Collapse

Density increases

\[ p^+ + e^- \rightarrow n + \nu_e \]

Core bounces back

Shockwave \Rightarrow heating \Rightarrow expansion

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Host Galaxy - NGC 6946, already had produced 7 supernovae

Discovery – Sept. 27, 2004 (Moretti et al.)

Classification – II-P (Zwitter et al. & Filippenko et al. 2004)

Early detection in radio ==> presence of appreciable circumstellar material (Stockdale et al. 2004)

Numbered stars are the secondary standards
Observations

Photometry: Sept 29, 2004 to March 2006 (8 days to 540 days after explosion)

Spectroscopy: Oct. 16, 2004 to Dec. 2005 (25 days to 465 days after explosion)

Plateau in V, R and I bands - consequence of propagation of cooling and recombination wave

Date of explosion: Sept 22, 2004 (JD 2453270.5)

- $m_U(\text{max}) = 12.17 \pm 0.05$ (JD 2453279.9)
- $m_B(\text{max}) = 12.89 \pm 0.02$ (JD 2453280.7)
- $m_V(\text{max}) = 12.55 \pm 0.02$ (JD 2453286.6)
- $m_R(\text{max}) = 12.15 \pm 0.02$ (JD 2453291.5)
Colour evolution of SN 2004et is different from SN 1999em, $U-B$ and $B-V$ colours of SN 2004et evolve slowly than those of SN 1999em.

Equiv. width of NaI D line 1.70Å

$$E(B-V) = 0.44$$ (Munari & Zwitter).

High resolution spectroscopy

$$E(B-V) = 0.41$$ (Zwitter et al.)
Spectroscopic evolution

Photospheric Spectra

Nebular Spectra

P-Cygni lines superimposed on photospheric continuum.
Two component P-Cygni profile.

Emission dominated, nebular emission lines of [OI], [CaII].
Photospheric velocity estimated using the absorption minima of FeII lines. H_alpha and H_beta gives always higher velocity.

SN 2004et has higher expansion velocity.
V absolute magnitude

Distance of SN 2004et using the Standard Candle Method (SCM) 4.8 Mpc

Expanding Photosphere Method (Schmidt et al. 1994) 5.7 Mpc

Other estimates 5.5 Mpc, 5.4 Mpc

Distance used is 5.5 Mpc.


Light curve of SN 2004et and SN 1990E are similar.

Late time light curve is governed by $^{56}\text{Co} \rightarrow ^{56}\text{Fe}$ decay 0.98mag/100days

In the nebular phase the V band light curve deviates from the $^{56}\text{Co} \rightarrow ^{56}\text{Fe}$ decay $\implies$ leakage of gamma-rays and/or dust formation in the ejecta
Optical magnitudes are converted into fluxes.

The $UBVRI$ flux is integrated to get the bolometric flux.

Mass of $^{56}\text{Ni}$ can be estimated from the late time bolometric curve:

1. V magnitude in tail phase, correct for $A_v = 1.27$ and convert V mag in bolometric luminosity

$^{56}\text{Ni}$ mass $= 0.059 \pm 0.02 \text{ } M_{\odot}$ (Hamuy 2003)

2. Comparison of tail phase bolometric luminosity with that of SN 1987A, difference of log of bolometric luminosity is $0.198 \pm 0.02$

$^{56}\text{Ni}$ mass $= 0.048 \pm 0.01 \text{ } M_{\odot}$
3. Photometric estimate of $^{56}\text{Ni}$ mass and maximum rate of decline in V band light curve from plateau to tail is anticorrelated. (Elmhamdi et al. 2003)

Steepness parameter $0.062\pm0.02 \implies $ mass of $^{56}\text{Ni} \ 0.062\pm0.02 \ M_{\odot}$

**Properties of progenitor:**
Mass of the envelope thrown off $M$
radius of the star prior to the outburst $R$
energy of explosion $E$

**Observables** — absolute magnitude $M_v$ at the mid plateau,
velocity of photosphere at mid plateau and length of the plateau.
Plateau length $120\pm10$ days;
photospheric velocity at mid plateau $3560\pm100$ km/sec; $M_v = -17.10$

Litvinova et al. (1985) relations gives

- Explosion energy $1.20(\pm0.35) \times 10^{51}$ ergs
- Mass ejected during explosion $20\pm6 \ M_{\odot}$
- Pre-supernova radius $496\pm80 \ R_{\odot}$
- Mass of progenitor $\sim 15 - 26 \ M_{\odot}$
Probable dust formation in the ejecta

*Formation of dust in the supernova ejecta:*

a. increases the rate of decline of light curve  
b. shifts peak of optical emission lines towards blue

In SN 1987A and SN 1999em dust formation is seen ~ 400 days after explosion.

Steepening in the decline of the V band light curve ~320 days after explosion and blue shift in the emission lines indicate probable dust formation in the ejecta of SN 2004et.
Summary

1. Fast rise in the early part shows that it was caught young few days after the shock breakout.

2. Average mass of $^{56}\text{Ni}$ synthesized during the explosion is $0.061\pm0.02\ M_{\odot}$

3. Mass ejected during the explosion $\sim 20\pm6\ M_{\odot}$, Explosion energy $\sim 1.20(\pm0.35) \times 10^{51}\ \text{ergs}$, Pre-supernova radius $\sim 496\pm80\ R_{\odot}$, Mass of progenitor $\sim 15 - 26\ M_{\odot}$

4. Possible dust formation in the supernova ejecta