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THE MECHANISM OF SN1987A EXPLOSION AND ITS EJECTA MASS ENVELOPE

BAHA T. CHIAD[1], LAYTH M. KARIM[2] & LANA T. ALI[3]
[1]Department of Physics, College of science, University of Baghdad, Baghdad, Iraq
[2,3]Department of Astronomy and Space, College of science, University of Baghdad, Baghdad, Iraq

ABSTRACT

Optical spectrum of SN1987A at days 4 from the explosion and its light curve through the first 1444 days after the explosion have been studied. The hydrogen lines present in the spectrum confirms the general characteristics of Type II SN that occur due to core collapse of massive star. Each of the total mass ejected from the explosion and the amount of the total mass of Nickel radioactive isotopes that produced during the explosion as well as the initial velocity of the ejecta and the explosion energy have been determined and compared with different observed and calculated models obtained by different researchers and it's found that, about 8.8 $M_{\odot}$ of the progenitor envelope mass had been ejected during the explosion and it's mixed with 0.077 $M_{\odot}$ of Nickel radioactive isotopes are ejected with initial velocity equaled 3900 km.s^{-1} and with explosion energy equaled 1.34 x 10^{51}erg. Moreover it's found that, these results are in a good agreement with observational data.

KEYWORDS: Supernovae: Individual (SN 1987A), Supernova Remnants

INTRODUCTION

Stars are born, live, evolve, and die depends on a single parameter: mass. The mass of a star considers a fundamental parameter that determines the properties, evolution, and the final stage of the stars life; therefore, estimating the mass of the matter that ejected during a supernova (SN) explosion is an importance parameter. Besides, the determination of the kinetic energy of the ejected envelope imposes a constraint on the explosion energy. Unfortunately, even in the case of SN 1987A, the nearest and consequently the most extensively studied supernova in modern astronomy which exploded in the Large Magellanic Cloud (LMC) and that provided unexpectedly extensive astrophysical information that confirmed the whole predictions that astronomers had made about supernovae, including (Chiad 1988):

- The production of neutrinos that confirmed the core collapse of massive star.
- The production of radioactive isotopes, for example ^{56}Ni and ^{57}Ni and their subsequent decay to ^{57,56}Co and ^{57,56}Fe, or ^{44}Ti which decays to ^{44}Sc and then to ^{44}Ca, which are largely responsible for the shape of the light curves of supernovae.

The mass of the envelope of SN1987A and its kinetic energy are still open to question. In this paper, we investigate the SN 1987A explosion by studying the influence of the mass of the ejected envelope, the explosion velocity, and the kinetic energy of this remarkable supernova in order to find optimal values for these basic parameters of the phenomenon by studying the photometric and spectroscopic observations.

This is done by analyzing the bolometric light curve and the Hα line profile of the supernova during the photospheric phase. In addition to use the value of the explosion energy to calculate the mass of the Nickel radioactive isotopes which consider the basic product of the supernova explosion.

LIGHT CURVES AND THE RADIOACTIVE DECAY OF THE EJECTA

The light curve of supernova 1987A is not typical for a Type II supernova (Carroll & Ostlie 2007). Instead of coming quickly to a peak and then decaying, the star first dropped in brightness and then slowly took nearly three months to reach maximum. The reason for this was that, SN1987A was discovered so early that the early cooling phase, when the supernova ejecta cool down from the shock passage, could be observed.

However, after a month from the explosion all of the energy deposited by the shock had already been used to drive the ejecta or escaped as radiation but in the same time this supernova was still brightening at visible wavelengths until it peaked on day 85 after the explosion as shown in Figure (1).

The observations indicate that, another source of energy was providing most of the light; which was the decay of Nickel radioactive isotopes that produced in the explosion into Cobalt radioactive isotopes through the Beta-decay reaction (Carroll & Ostlie2007):

$$^{56}_{28}Ni \rightarrow {}^{56}_{27}Co + e^{+} + v_{e} + \gamma$$

The energy released by this decay will "holds up" the light curve for a time before the cobalt nuclei decay into ^{56}Fe, which is stable (Harwit 2006). So instead of fading from view in a few months, SN 1987A was steadily energized by the decay of fresh radioactive nickel.

The decline of the light curve remained constant at the rate of ^{56}Co decay and it's exactly as the same rate as the ^{56}Co decay into stable ^{56}Fe that observed in laboratories (Kajer 2007).

The fact that the supernova light decayed just as expected was the strongest confirmation of the idea that supernovae were responsible for the formation of the heavy elements in the universe and, for the first time, the amount of ^{56}Ni that produced in the explosion and mixed with the ejecta could be measure exactly and the following equations are used for this purpose (Carroll & Ostlie 2007):

$$\mathrm{N} = \left(\frac{\mathrm{E(joul)}}{\mathrm{E_{Binding}}\left(\frac{\mathrm{Mev}}{\mathrm{nucleus}}\right)}\right)\left(\frac{1\ \mathrm{Mev}}{1.6\times10^{-13}}\right) \tag{1}$$

$$\mathrm{m_{isotops}} = \mathrm{N} \times \text{mass of the nucleus}\ \ (kg) \tag{2}$$

Where N is the number of radioactive nuclei, E is the explosion energy which calculated from the brightness of the light curve tail as will be given in the next section, and $\mathrm{E_{Binding}}$ represents the binding energy of the radioactive nucleus.

The optical light from SN1987A has continued to fade for the past 25 years; the radioactive heating by Cobalt-56 has long since become negligible and the main radioactive energy source today is believed to be Titanium 44, which decays much more slowly (Gaensler 1999).

Hα LINE, EXPLOSION ENERGY, AND THE ENVELOPE MASS

The optical spectrum of SN 1987A at days 4 from the explosion, which shown in Figure (2), conforms the general characteristics of Type II SN with hydrogen lines in emission (Ashoka et al. 1987). This spectrum has a strong continuum that is rising at short wavelengths, punctuated by very broad emission and absorption lines of hydrogen and helium which is very similar to the spectrum of a hot blue star.

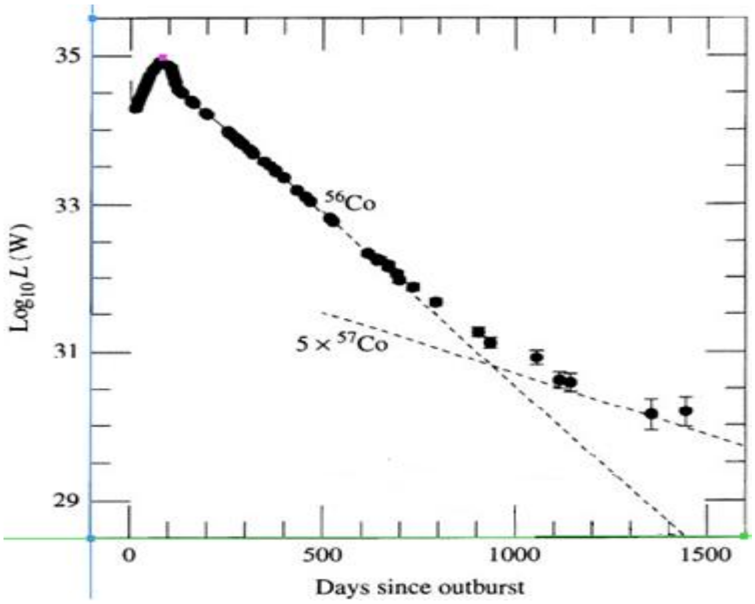

Figure 1: The Bolometric Light Curve of SN 1987 A through the First 1444 Days after the Explosion. The Dashed Lines Show the Contributions Expected from the Cobalt Radioactive Isotope Produced by the Shock Wave (Carroll& Ostlie 2007)

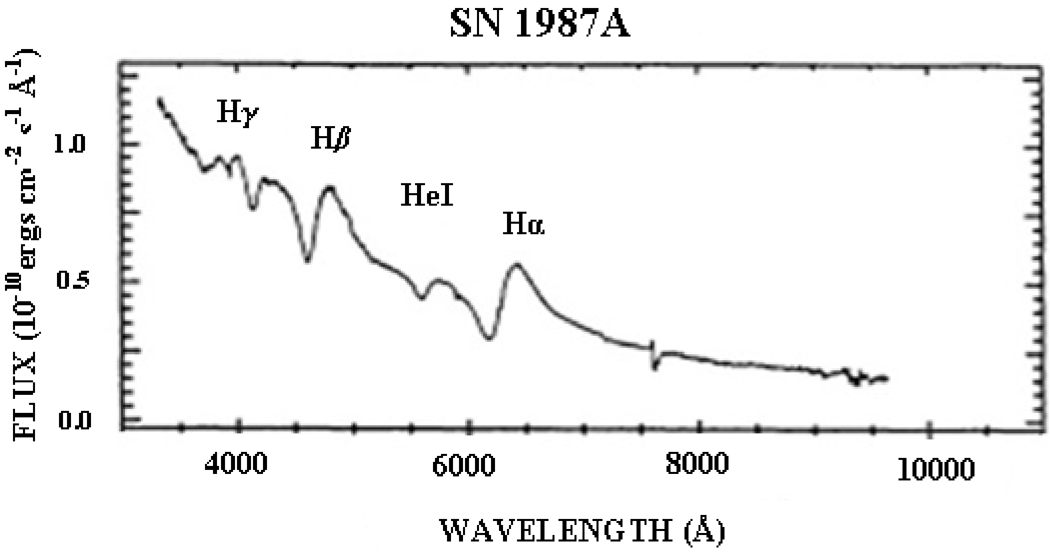

Figure 2: The Optical Spectrum of SN 1987A in the Earlier Stages from the Explosion Showing the Emission Lines of H_α, H_β, H_γ, HeI (Arnett et al.1989)

The broad absorption lines are caused by rapidly expanding gas above the photosphere which is expanding toward us (Mc Cray 2002). This spectrum has been used to measure the initial expansion velocity of the supernova remnant from the blue shifts of these absorption lines and by applying Doppler shift equation (Arny 1998):

$$\frac{v}{c} = \frac{\Delta\lambda}{\lambda_o} \qquad (3)$$

Where c represents the speed of light in vacuum, and $\Delta\lambda$ is equal to $(\lambda - \lambda o)$ where λ and λ_o are the observed and the laboratory wavelength respectively of Hα.

Beside the study of the supernova spectrum, the study of the light curve considered one of the main sources of information about supernovae properties during, and after, the explosion such as size, mass, distance, and explosion energy as well as the mass of the radioactive isotopes.

In this paper the light curve of SN 1987A (Carroll & Ostlie2007) had been used in order to calculate the explosion energy, and the mass of the ^{56}Ni radioactive isotopes.

The calculation of the supernova explosion energy (E) represent a key parameter of the SN explosion mechanism and it depend on the measurement of maximum brightness (L_{max}) of the light curve, that shown in Figure (1), in addition to the measurement of the time that need to reach this maximum brightness(t_{max}), which in our case for SN 1987A it takes about 85 days to reach this maximum brightness. Once these values become available the energy can be obtained from the following equation (Karttunen et al. 2007):

$$E_{th} = L_{max} \times t_{max} \tag{4}$$

The resulted energy (E_{th}) is a thermal energy instead of kinetic energy (E) since it produces from the thermonuclear reaction of heavy radioactive isotopes, so in order to convert this energy into kinetic energy the following relation was used (Cosmovici 1974):

$$E = 47.2\, E_{ther} \tag{5}$$

Soon after, the explosion energy and the initial velocity of the ejecta became available the mass of the ejecta (M_{ej}) can be calculated from the law of the kinetic energy which is (Karttunen et al. 2007):

$$E = \frac{1}{2} M_{ej}\, v^2 \tag{6}$$

RESULTS AND DISCUSSIONS

Astronomy is nearly entirely a study of light directly. From this single source of information, the physical conditions, compositions and processes for distant objects can be found. In this paper we analyze the photometric and spectroscopic observations of SN1987A which represented by the bolometric light curve and the Hα line profile at day 4 after the explosion respectively as shown in Figure 1 and 2. Consequently it's found that, the star Sk $^{-}69^{O}$ 202 (the progenitor star of SN1987A) had been exploded and ejected about 8.8 M_{O} from its envelope mass with initial velocity equals to 3900 km.s^{-1} and with kinetic energy equaled 1.34 x 10^{51}erg. The high kinetic energy of the ejecta is resulted from the nucleosynthesis of ^{56}Ni that produce and mixed with ejecta with mass (M_{Ni}) equal to 0.077M_{O} and this amount of ^{56}Ni is the responsible of the shape of the supernova light curve in the late stage. The amount of ejected Nickel radioactive isotopes consider the best indicator about the amount of Iron radioactive isotopes that produced and adds to the interstellar medium since the ^{56}Ni is decay into ^{56}Co which in turn decay into ^{56}Fe by time, which means that, about 0.077 $M_{\odot}$ from Iron isotopes will be produced and add to the LMC after the explosion. A comparison between our results and the results of other astronomers have been done and given in table (1). It's found that, our results about the kinetic energy, ejected mass, the mass of nickel radioactive isotope that produced during the explosion, and the initial velocity of the ejecta are very close to the values obtained by other astronomers as they used different methods in order to measure these parameters such as Utrobin (Utrobin 2005), Woosley, Shigeyama &Nomoto, and Blinnikov et .al (Bouchet 2007).

The velocity of SN1987A have long been decelerated from 3900 km.sec^{-1} to about 1200 km.sec^{-1} during the last 23 years from the explosion (Chiad, Karim & Ali 2012) as the supernova enters the dense region that represented by the triple ring system that surround the center of the supernova explosion. Furthermore it's found that, the remnant is still in the free expansion phase since the sweeping mass from the surrounding interstellar medium (which is about 3M_{O} (Chiad, Karim & Ali 2012)) is still much smaller than the ejected mass. The main radioactive energy source today is believed to be Titanium 44 with a half-life of 54 years and all of the optical and X-ray emission that observed now it's comes from the interaction between the ejecta and this dense region, but not from radioactive of Titanium. This remarkable supernova will be illuminate the space for a long time and rich the interstellar medium with newly synthesized material beside it will let us learn more about the growth of supernova remnant with time before fading from view after millions of years.

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Table 1: Results of the Standard Physical Parameters of SN1987A
Obtained by this Work in Comparison with Different Astronomers Results

Astronomers	Model	M_{ej} (M_{Θ})	E (10^{51} ergs)	M_{Ni} (M_{Θ})	v (km.sec^{-1})
Woosley (1988)[1]	evolutionary model	9.4-14.4	0.8-1.5	0.07	4000
Arnett et al. (1989) [2]	Analytical solution	4	0.4	0.075	2800
Shigeyama &Nomoto(1990) [1]	evolutionary model	11.4-14.6	1 ±0.4	0.075	4000
Al-Sarraf (1990)[3]	Postulate model	3	0.3		3000
Utrobin (1993) [1]	Hydrodynamic model	15-19	1.25-1.65	0.075	2500
Blinnikov et. al (2000) [1]	evolutionary model	14.67	1.1 ± 0.3	0.078	4200
Utrobin (2005) [4]	Hydrodynamic model	18 ± 1.5	1.5 ±0.12	0.0765	3000
Our results		8.8	1.34	0.077	3900

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