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Study of Physical Properties for Supernova 2010jl by using Poveda Model

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ABSTRACT

In this work, The physical properties were studies for (supernova 2010jl) - which discovered on 2010 Nov. 3 - depending on (Poveda Model), optical spectrum curve and by applying special mathematical equations. The physical properties represented by explosion energy, initial velocity of ejecta, mass of ejecta, mass of ^{56}Ni, distance from the earth, radius of ejecta, the momentum, temperature, expansion velocity and the age. After that the results were been arrangement in tables. We conclude the remnant is still in the free expansion phase and the remnant has expanded into a radius equal 1.27 pc during the past 2 years with current velocity 1450 km.s^{-1}.

Keywords: *supernova 2020jl , poveda model*

I. INTRODUCTION

Supernova represents the catastrophic explosion that marks the end of the life of stars that have enough mass to explode, is extremely luminous, and it cause a burst of radiation that often briefly outshines an entire galaxy before fading from view over several weeks or months [1]. During this short time a supernova can radiate as much energy as the Sun is expected to emit over its entire life. During the explosion much or all of a star's material will be ejected at a speed about (0.1c), driving a shock wave into the surrounding interstellar medium that sweeps up an expanding shell of gas and dust called a "supernova remnant" which continues to expand over millions of years until it dissolves into the interstellar medium[2,3].

The empirical classification of SNe are divided into an initial branch of Type I (hydrogen lines present) and Type II (hydrogen lines absent). The Type I class then divides into Type Ia (strong Si II 615 nm line), Type Ib (helium lines present), and Type Ic (helium lines absent). The Type II branch subdivides into Type IIP (a plateau in the light-curve), Type IIL (a linear decline of the light curve), and Type IIn (narrow lines present). [4]

In Type IIn (narrow line) supernovae , the optical luminosities are plausibly explained as being due to circumstellar interaction and the circumstellar density can be estimated from the luminosity. If narrow line widths are indicative of the presupernova outflow velocities, the typical outflow velocities are 100 - 500 km s^{-1}, leading to times of mass loss before explosion of 10-300 yr and mass loss rates of 0:02-0:1 $M_\odot$ yr^{-1}[5,6]. for typical Type IIn supernovae (SNe IIn) [7] The mass loss can be up to several $M_\odot$ extending out as far as 10^{17} cm.

The class of ultraluminous supernovae overlaps the SNe IIn, with objects like SN 2006gy that was very bright for 240 days and radiated $\geq 2 \times 10^{51}$ ergs in optical light [8]. Another group of the ultraluminous events are not SN IIn, but have spectra that resemble SNe Ic at later times [9,10]. Chevalier & Irwin [8] suggested that the ultraluminous supernovae are due to dense circumstellar interaction, but only ones with a circumstellar extent greater than the radius at which radiation can diffuse out have Type IIn characteristics. The mass loss involved can be $\geq 10 M_\odot$ and extends to $\geq 2 \times 10^{15}$ cm for Type IIn characteristics. To account for such high mass loss rates, luminous blue variable (LBV) progenitors have been suggested [11].

The implication is that SN IIn progenitors are not confined to very high mass stars, but may cover a broad range of stellar masses. These properties argue against a particular mass range becoming a supernova, and indicate that some factor other than mass plays a role. Here we suggest that the factor is binarity and that the mass loss and explosion are both driven by the inspiral of a compact object in common envelope (CE) evolution[12] .

On 2010 Nov 3 a supernova was discovered in the galaxy UGC 5189A, located about 160 million light years away. Using data from the All Sky Automated Survey telescope in Hawaii taken earlier, astronomers determined this supernova exploded in early October 2010 (in Earth's time-frame). This composite image of UGC 5189A shows X-ray data from Chandra in purple and optical data from Hubble Space Telescope in red, green and blue. SN 2010jl is the very bright X-ray source near the top of the galaxy (mouse-over for a labeled version). A team of researchers used Chandra to observe this supernova in December 2010 and again in October 2011. The supernova was one of the most luminous that has ever been detected in X-rays[13].

In optical light, SN 2010jl was about ten times more luminous than a typical supernova resulting from the collapse of a massive star, adding to the class of very luminous supernovas that have been discovered recently with optical surveys. Different explanations have been proposed to explain these energetic supernovas including (1) the interaction of the supernova's blast wave with a dense shell of matter around the pre-supernova star, (2) radioactivity resulting from a pair-instability supernova (triggered by the conversion of gamma rays into particle and anti-particle pairs), and (3) emission powered by a neutron star with an unusually powerful magnetic field [13].

II. THEORETICAL PART

From the spectrum of SN2010jl in the earlier stage, shown in (Fig 1), the initial radial velocity of the ejecta (υ) can be found by using the the emission line of H_α and substitute in the Doppler shift equation which is given by [14] :

$$\frac{\upsilon}{c} = \frac{\Delta\lambda}{\lambda_\circ} \text{..........(1)}$$

Where c represents the speed of light in vacuum, and Δλ is equal to ($\lambda - \lambda_\circ$) where λ and $\lambda_\circ$ are the observed and the laboratory wavelength respectively. And from luminosity for SN2010jl, shown in Fig.(2) the explosion energy E can be obtained from the following equations[15,16]:

$$E = E_{thermal} = L_{max} \times t_{max} \text{......(2)}$$

Where L_{max} maximum brightness of the light curve , and t_{max} represents time of maximum brightness after the explosion .

$$E_k = 47.2\, E_{thermal} \text{.........(3)}$$

Where E_k represents the kinetic energy.

$$E_k = \frac{1}{2} M_{ej} \upsilon^2 \text{........(4)}$$

M_{ej} represents mass of ejecta which is mixed with the mass of the radioactive isotopes that produced during the explosion and especially the Nickel isotope, where it can be found by using the equation[17]:

$$M(^{56}Ni)_{sn2010jl} M_{\Theta} = M(^{56}Ni)_{sn1987A} M_{\Theta} \times \frac{L_{sn2010jl}}{L_{sn1987A}} M_{\Theta} \text{...........(5)}$$

In addition to that, the distance (D) from the observer to the remnant can be measured from distance modulus equation[15]:

$$m - M = 5 \log \frac{D}{10\,pc} \text{...........(6)}$$

Where m, M represent the visual apparent magnitude and visual absolute magnitude respectively and m-M for SN2010jl equal to 33.45 mag.[18]

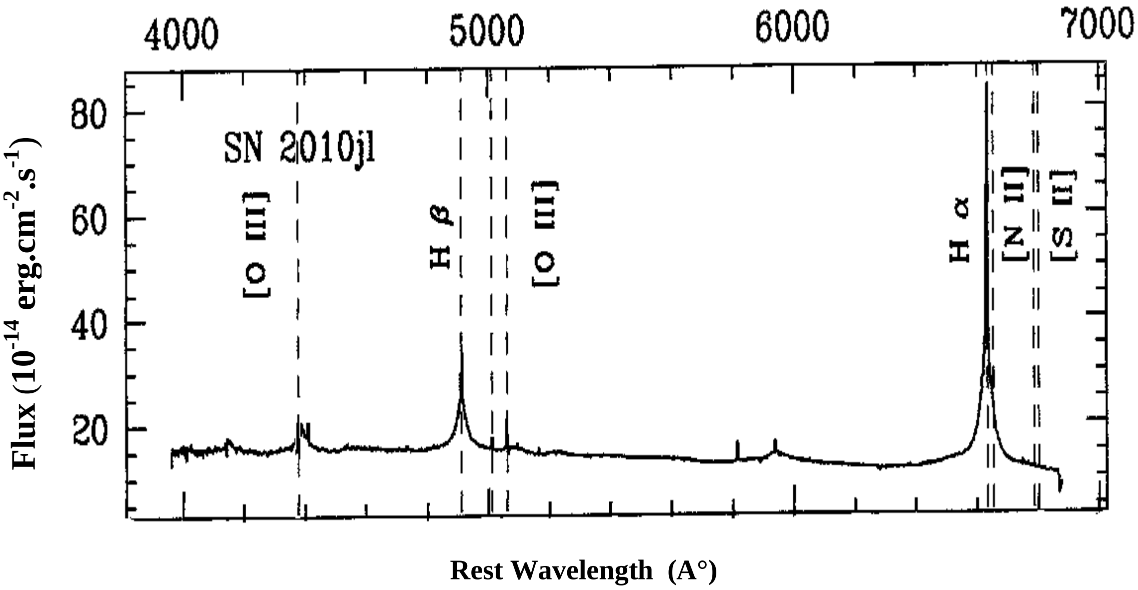

Fig. (1) Optical spectrum curve for SN2010jl [21]

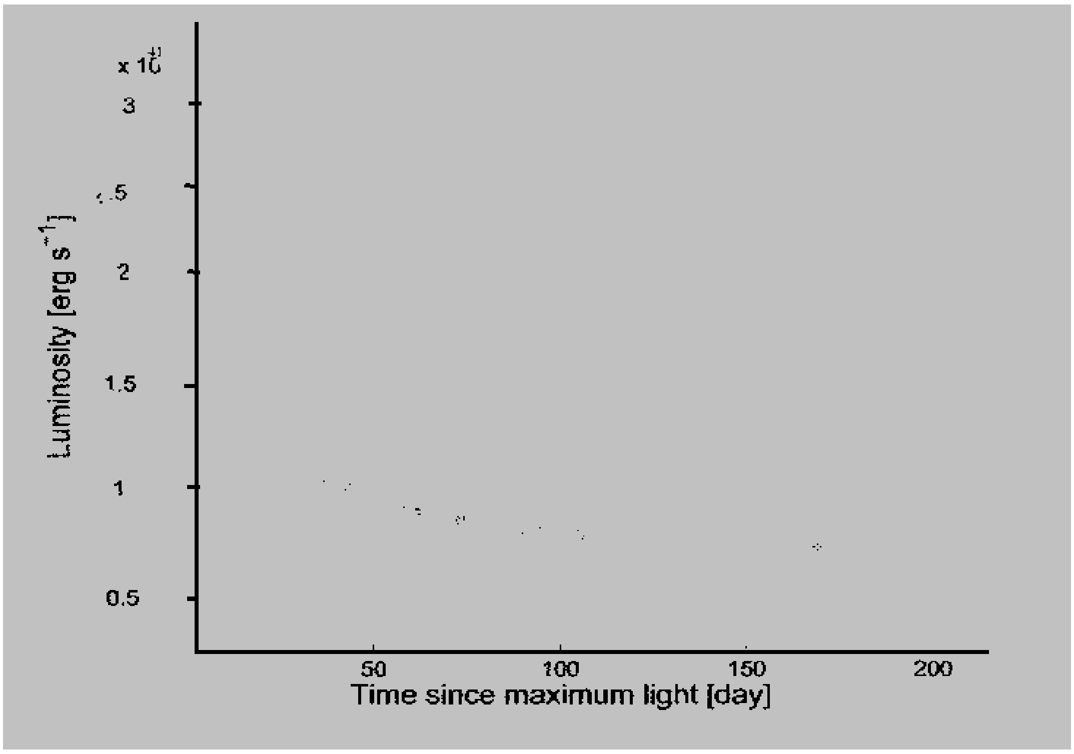

Fig.(2) Luminosity for SN2010jl [21]

Poveda Model

This model is the first model that takes consider about the slowing down and the cooling process that occurs in the envelope of the supernova remnant with time and its was first performed by Povida in 1964, who supposed that as the shell expands it will lose energy by synchrotron radiation which results from charged particles (electrons, protons) that move around the line of the magnetic field with speed near the speed of light [19].

According to Povida the total energy content of the ejected gasses is distributed in the following modes: Expansion energy, turbulence energy, thermal energy, magnetic energy and cosmic energy.

At the earlier stages the expansion and the turbulence energy become dominants, but during the first 90 days after maximum the relation between these modes will be approximately [19]:

$$E_{ther} = E_{tur} = E_{\exp} = E_{c.r.} + E_{mag} \text{.............}(7)$$

Or

$$E_{\circ} = 4E_{tur} = 5\times10^{49}\, ergs\text{.............}(8)$$

Thus the energy radiated away is about an order of magnitude larger than the energy left in the remaining modes.

As the envelope of the supernova remnant expands it will grow in mass and begin to decelerate, so from the law of conservation of energy we have [20]:

$$\upsilon_{\exp} = \left(\frac{3\alpha}{2\pi}\right)^{1/2} \left(\frac{E_{\circ}}{\rho}\right)^{1/2} R^{-3/2} \text{...............}(9)$$

Which after integration gives [19]:

$$R(t) = \left(\frac{75}{8\pi}\right)^{1/5} \left(\frac{E_{\circ}}{\rho}\right)^{1/5} t^{2/5} \text{...............}(10)$$

Where α is a factor smaller than one, which indicates how much of the total energy is invested in kinetic energy of expansion and it has a value of unity if all the energy is invested in the kinetic energy of expansion .

In addition to that the Temperature (T) of the remnant can be also calculated from the relation [15]:

$$KT = \frac{3}{4} m_H \upsilon^2_{\exp} ....(11)$$

Where m_H is the hydrogen mass, and K is the Boltzmann constant.

III. RESULTS AND DISCUSSION

Results of physical properties from Poveda Model:

By applying Poveda Model and by depending on mathematical equations with luminosity and optical spectrum curves fig.(1,3)[21], we get what it showed in table (1) and table (2). Povida assumed that most of the explosion energy will be lost in terms of synchrotrons radiation which in turn leads to the cooling process that occurring in the ejecta and since the temperature and the expansion velocity are related by the relation so the velocity will be also decelerated.

From the result of table (2) it is noticed that the expansion velocity is slowing down from 4205 km.s^{-1} to 1450 km.s^{-1} during the past 2 years from the explosion due to the cooling process that occur in the ejecta, and in the same time the radius is increasing to 1.27 pc which is due to the large density of the surrounding circumstellar medium that prevents the shock wave from expanding further.

On the other hand, it is found that the temperature of the ejecta still too high which is in order of 10^8 °K . Furthermore it was noticed that the present results are very close to the results of other astronomers, especially the results of Explosion energy, mass of ejecta and distance [21,22,23]. Also some of these results agreement with results of Smith N.,[24] for supernova type IIn(SN 2006tf) and results of Fassia, A.[25] for type IIn (SN 1998S).

Table (1): The results of some initial physical parameters of (SN 2010jl).

Quantity	Unit	Present work	Another work
Initial velocity	Km.sec^{-1}	4205	----------
Explosion energy	Ergs	$3*10^{51}$	$1*10^{51}$ R. Stoll [21]
Mass of ^{56}Ni	M_Θ	0.024	----------
Mass of ejecta	M_Θ	33	30 Smith[22]

Table (2): The results of the physical parameters of (SN 2010jl) by applying Poveda Model.

Quantity	Unit	Present work	Another work
Expansion velocity(v_2)	km. Sec^{-1}	1450	-----------
Radius(r)	Pc	1.27	-----------
Temp. (T)	°K	$1.9 * 10^8$	10^8 Smith N.[24] 10^8 Fassia, A.[25]
Momentum(P)	Gm. Cm.sec^{-1}	$1.5*10^{42}$	----------
Distance(D)	Mpc	48	50 Benetti [23]
Age(t)	Year	2	----------
Density of ISM(ρ)	gm .cm^{-3}	$8.3*10^{-22}$	-----------

CONCLUSIONS

From the study of the light curve and the spectrum of SN 2010jl it is found that this supernova has an explosion energy 3 x10^{51} erg and it ejects about 33 M_{Θ} from the mass of its progenitor star with velocity 4205 km.s^{-1}. The ejected mass is mixed with about 0.024 M_{Θ} of Nickel isotopes which is produced during the explosion. This means that, the amount of Iron that produced and added to the LMC is equal to 0.024 M_{Θ}, since the Nickel is decayed into Iron by time.

The remnant is still in the free expansion phase since the sweeping mass is still smaller than the ejected mass and The remnant has expanded into a radius equal 1.27 pc during the past 2 years with current velocity 1450 km.s^{-1}. The results appears to be generally similar to other "typical" type IIn supernova as SN2006tf and SN1998S .

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