

# Spectroscopic Study Of Light Curve And Physical Properties For SN2010jl



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## ABSTRACT

In this work, The physical properties were studied for (supernova 2010jl)- which discovered on 2010 Nov. 3-depending on (Oort 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  $^{56}\text{Ni}$ , distance from the earth, radius of ejecta, the momentum, expansion velocity and the age. Also, temperature of black body of SN2010jl during photospheric phase were calculated depending on data taken from optical spectrum curve and by applying special mathematical equation. The curve between temperature of black body and time in days were plotted, range of temperature between (7300°k–9700°k) noticed.

## Introduction

Supernova represents the catastrophic explosion that marks the end of the life of stars that have enough mass to explode, it is extremely luminous, and 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 of 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.

Supernovae are very rare events occurring once or twice per centuries in a galaxy. Historical records, particularly the careful data recorded by the Chinese, show that seven or eight supernovae have exploded over the last 2000 years in our galaxy. But even though they are very rare events, they play a

significant role in enriching the interstellar medium with heavy elements (up to iron) and they are the source of most radio waves, X-rays, and cosmic rays in the universe. In addition to that, it releases a huge amount of energy that heats up the interstellar medium and triggers the formation of stars in the galaxy [2].

As the observation techniques and astronomical instruments improved more and more, supernovae have been discovered each year, reaching by now to more than thousands of supernovae. Supernovae do not have complicated creative names; they are named after the year in which they are discovered and in the order they are discovered, consequently the first supernova discovered in the year will take the first uppercase letter in the alphabet (A) placed after the year of discovery, for example SN 1987A represent the first supernova discovered in 1987, the second supernova discovered in the same year will take the letter B and so on for other supernovae. But if more than 26 supernovae are discovered in the same year (as has been the case since the mid-eighties) the 27th is given the suffix "aa", the 28th is thus "ab" and so on.

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Once all the "a" have been exhausted, "b" are used, i.e. "ba", "bb", and so on, for example the last supernova discovered in 2010 was known as SN 2010lt which means that this supernova is number 332th supernova that was discovered in 2010 [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<sup>-1</sup>, leading to times of mass loss before explosion of 10-300 yr and mass loss rates of 0:02-0:1 M<sub>⊙</sub> yr<sup>-1</sup>[5,6]. for typical Type IIn supernovae (SNe IIn)[7] The mass loss can be up to several M<sub>⊙</sub> extending out as far as 10<sup>17</sup> 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  $\geq 10M_{\odot}$  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] .

### SN2010jl

On 2010 Nov 3.5 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.

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].

**THEORETICAL PART**

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

$$\frac{v}{c} = \frac{\Delta\lambda}{\lambda_0} \dots\dots\dots(1)$$

Where  $c$  represents the speed of light in vacuum, and  $\Delta\lambda$  is equal to  $(\lambda - \lambda_0)$  where  $\lambda$  and  $\lambda_0$  are the observed and the laboratory wavelength respectively. And from luminosity for SN2010jl, shown in Fig.(3) the explosion energy  $E$  can be obtained from the following equations[15,16]:

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

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

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

Where  $E_k$  represents the kinetic energy.

$$E_k = \frac{1}{2} M_{ej} v^2 \dots\dots\dots(4)$$

$M_{ej}$  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]:

$$M(^{56}\text{Ni})_{\text{sn2010jl}} M_{\odot} = M(^{56}\text{Ni})_{\text{sn1987A}} M_{\odot} \times \frac{L_{\text{sn2010jl}}}{L_{\text{sn1987A}}} M_{\odot} \dots\dots\dots(5) \quad \text{In}$$

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

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

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

**1- Oort Model:**

Oort model is a model that was performed by Oort in 1951 and it basically depends on the law of conservation of momentum, which assumes that the expansion of the supernova remnant will be decelerated with time as a result of increasing the mass of sweeping material from the surrounding medium that added to the ejecta[19].

If we suppose that the mass and the velocity of the ejected material are respectively  $m_1$ ,  $v_1$  and ( $r$ ) is the radius of the supernova remnant and ( $t$ ) is the time, then the law of conservation of momentum ( $P$ ) will be given by :

$$P = m_1 v_1 = (m_1 + m_2) \frac{dr(t)}{dt} \dots\dots\dots(7)$$

Where  $m_2$  represents the mass of sweeping material from the surrounding medium after time  $t$  and is given by [14]:

$$m_2 = \frac{4}{3} \pi \rho r^3 \dots\dots\dots(8)$$

Substituting equation (8) in equation (7) and integrate, we get:

$$r = \left( \frac{3m_1 v_1}{\pi \rho} \right)^{\frac{1}{4}} t^{\frac{1}{4}} \dots\dots\dots(9)$$

Subsequently the expansion velocity is given by [15]:

$$v_2 = \frac{m_1 v_1}{m_3} \dots\dots\dots(10)$$

Where  $m_3$  represent the current mass of the remnant and is given by:

$$m_3 = m_1 + m_2 \dots\dots\dots(11)$$

**2- Temperature of Black Body**

During the photospheric, an SN II can be approximated as a blackbody. The temperature for a blackbody relates directly to color through the equation[20]:

$$T = \frac{10000 \text{ }^\circ\text{K}}{1.605(B - V) + 0.67} \dots\dots\dots(12)$$

Where T: Temperature of Black Body

B,V: filter band

## **RESULTS AND DISCUSSION**

### **1- Results of physical properties from Oort Model:**

By applying Oort Model and by depending on mathematical equations with luminosity and optical spectrum curves fig.(1,3)[21], we get tables (1) and table (2). Oort model is considered to be one of the simplest models that concern about the physical properties of the supernova and it basically depends on the law of conservation of momentum. Although this model is primary and simple but it gives a good approximation about the properties of the remnant in the earlier stage from the explosion where the ejected mass is much greater than the mass swept from the surrounding medium and this results agree with results of other astronomers like Stoll [21], Smith [22], Benetti [23]. From the results of table (1,2) it is found that the expansion velocity of the remnant is decelerated from 4205 km.s<sup>-1</sup>, which is the initial velocity of the ejecta, to 2920 km.s<sup>-1</sup> during the past 2 years and this is due to the increasing the mass of sweeping material from the surrounding interstellar medium. The current studies show that the ejected materials have increasing in mass by large amount as a result of entering the shock wave into a very dense region that surround the exploded star, so according to that the mass increased during the past 2 years.

On the other hand the radius of the remnant is relatively small and has a current value about 0.186 pc, and this is also due to the large density of the

surrounding circumstellar medium that prevents the shock wave from expanding further.

### **2- Results of Temperature of Black Body**

According to Fig. (2)[24],and by get data program we get tables (3) and (4), after that we plot between values of (B-V) and time in days Fig.(4), also between temperate of black body for SN2010jl with time in days Fig.(5). The supernova starts out very hot and cools off, as would be expected. The cooling leves off at approximately 6000°k . 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.

From Fig (4), the color curves kept nearly a constant for SN 2010jl during the phase from t ≈ 29 days to t ≈ 176 days after the maximum. That the shape of the continuum spectra did not change significantly during this period, which is consistent with that the blackbody temperature from the spectra stays at range ≈( 7000°K – 9000 °K) at similar phases.

## **CONCLUSION**

\_The remnant is still in the free expansion phase since the sweeping mass is still smaller than the ejected mass. The remnant has expanded into a radius equal 0.186 pc during the past 2 years with current velocity 2920 km.s<sup>-1</sup>. The BVRI light curve of SN2010jl appears to be generally similar to other "typical" type II<sub>n</sub> supernova .

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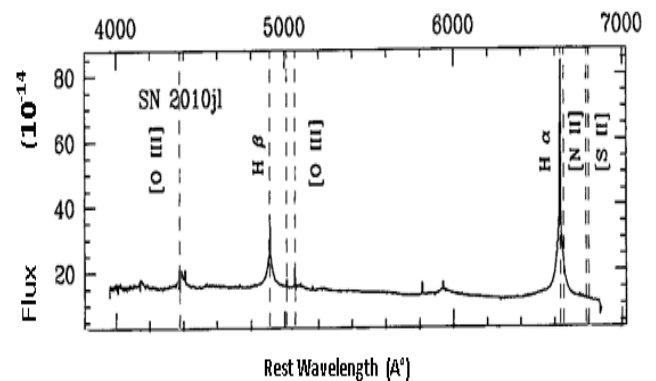


Fig. ( 1 ) Optical spectrum curve for SN2010jl [21].

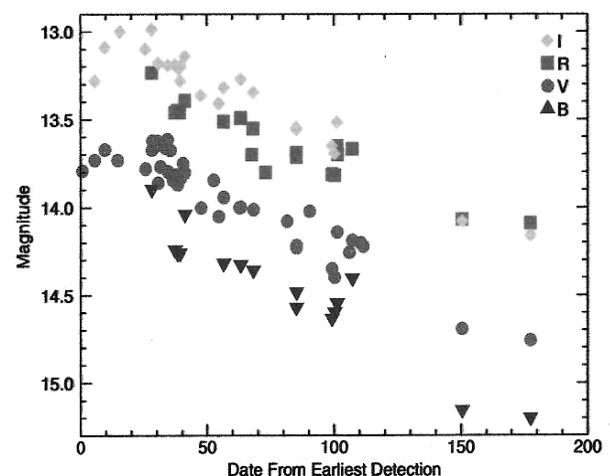


Fig. ( 2 ) BVRI light curve of SN2010jl [ 24].

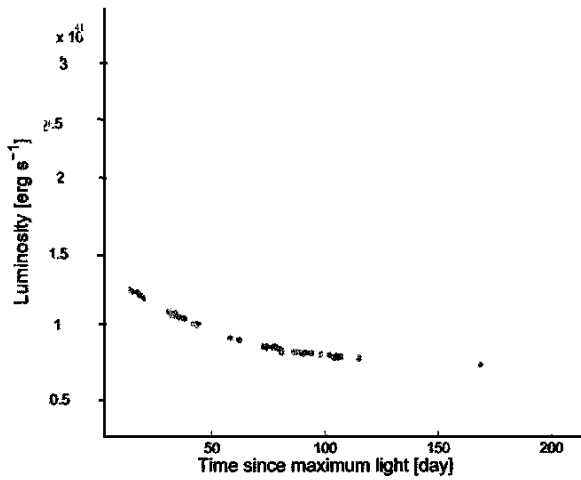


Fig.(3) Luminosity for SN2010jl [21]

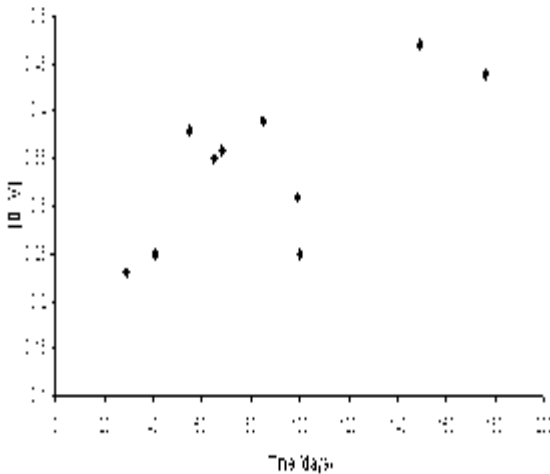


Fig.(4) Colour curve of SN2010jl.

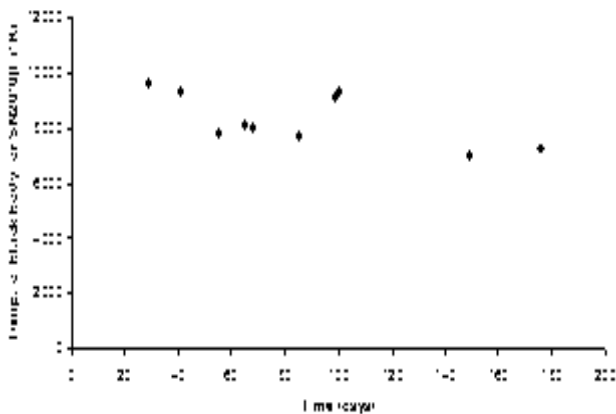


Fig.(5) Relationship between Temperature of black body for SN2010jl during the photospheric phase and time

Table ( 1 ): The results of some physical parameters of (SN 2010jl) from others astronomers.

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

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

Quantity	Unit	Present work	Another work
Expansion velocity(v2)	Km.sec-1	2920	-----
Radius(r)	Pc	0.186	-----
Momentum(P)	gm. Cm.sec-1	$1.5 \times 10^{42}$	-----
Distance(D)	Kpc	48	50 Benetti [23]
Age(t)	Year	2	-----
Density of ISM( $\rho$ )	Gm .cm-3	$8.3 \times 10^{-22}$	-----

Table ( 3 ) BVRI Observations of SN2010jl

Age (days)	B	V	R	I
29	$13.90 \pm 0.01$	$13.67 \pm 0.01$	$13.25 \pm 0.01$	$13.09 \pm 0.01$
41	$14.5 \pm 0.01$	$13.80 \pm 0.01$	$13.40 \pm 0.01$	$13.15 \pm 0.01$
55	$14.32 \pm 0.01$	$13.94 \pm 0.01$	$13.51 \pm 0.01$	$13.32 \pm 0.01$
65	$14.35 \pm 0.01$	$14.00 \pm 0.01$	$13.50 \pm 0.01$	$13.26 \pm 0.01$
68	$14.37 \pm 0.01$	$14.01 \pm 0.01$	$13.70 \pm 0.01$	$13.35 \pm 0.01$
85	$14.60 \pm 0.01$	$14.21 \pm 0.01$	$13.70 \pm 0.01$	$13.55 \pm 0.01$
99	$14.67 \pm 0.01$	$14.36 \pm 0.01$	$13.79 \pm 0.01$	$13.66 \pm 0.01$
100	$14.65 \pm 0.01$	$14.40 \pm 0.01$	$13.81 \pm 0.01$	$13.69 \pm 0.01$
149	$15.16 \pm 0.01$	$14.69 \pm 0.01$	$14.09 \pm 0.01$	$14.08 \pm 0.01$
176	$15.20 \pm 0.01$	$14.76 \pm 0.01$	$14.19 \pm 0.01$	$14.16 \pm 0.01$

Table ( 4 ) Calculation of Temperature of Black Body of SN2010jl during photospheric phase

Age (days)	B-V	V-R	R-I	$T_{\text{black body}} (^{\circ}\text{K})$
29	0.23	0.42	0.16	9623.24
41	0.25	0.40	0.25	9334.88
55	0.38	0.43	0.19	7813.11
65	0.35	0.50	0.24	8118.53
68	0.36	0.31	0.35	8014.1
85	0.39	0.51	0.15	7716.34
99	0.31	0.67	0.13	9111.2
100	0.25	0.59	0.12	9334.88
149	0.47	0.62	0.01	7020.74
176	0.44	0.67	0.03	7266.38

## دراسة طيفية للمنحني الضوئي والخواص الفيزيائية للمستعرة العظمى SN2010JL

عادل نعمة عياش

زياد عدنان صالح

### الخلاصة:

في هذا البحث تم دراسة بعض الخواص الفيزيائية للمستعرة العظمى (SN2010jl) والمكتشفة بتاريخ (2010Nov.3) بالاعتماد على النموذج النظري المسمى (أورت موديل) والمنحني البصري ومعادلات رياضية خاصة. تمثلت الخواص بكل من طاقة الانفجار، السرعة الابتدائية للمقذوفة، كتلة المقذوفة، كتلة النظير الإشعاعي ( $^{56}\text{Ni}$ )، البعد عن الأرض، نصف قطر المقذوفة، الزخم، سرعة التمدد إضافة إلى العمر. كذلك تم حساب حرارة الجسم الأسود للمستعرة (SN2010jl) بالاعتماد على بيانات مستنتجة من المنحني الضوئي البصري وتطبيق معادلة رياضية خاصة. بعدها تم رسم علاقة بيانية مابين حرارة الجسم الأسود والزمن بالأيام وجد ان قيم الحرارة تقع في المدى مابين ( $9700\text{ }^\circ\text{K} - 7300\text{ }^\circ\text{K}$ ).