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Spectroscopic Study of Electron Density and Electron Temperature for Supernova 2010jl

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ABSTRACT

In this work, The electron density and electron temperature were calculated for periods 2010 Nov. 5 to 2011 May12 of (supernova 2010jl)-which discovered on 2010 Nov. 3 -depending on forbidden spectral lines ([SII] λ 6717A°,λ 6731A°), ([OIII]λ 4959A° , λ 5007A°,λ 4363A°) and optical spectrum curve for SN2010jl which was taken from global data and by applying special mathematical equations. After that, we plot the curve between electron temperature and time in days and observed inverse relationship. Also, we plot curve between electron density and time in days which was inverse relationship too.

Key words: *Supernova 2010jl, Forbidden lines, Electron Density and Electron Temperature*

1. 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 0.1 from the speed of light (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. 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^{-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

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and radiated ≥2 * 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 ≥ $10M_{\Theta}$ and extends to ≥ 2 * 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 3.5 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].

2. THEORETICAL PART

2.1 Forbidden lines

We call forbidden lines the spectral lines which are emitted by atoms undergoing energy transitions that not normally allowed by the selection rules of quantum mechanics. Although the transitions are nominally "forbidden", there is a small probability of their spontaneous occurrence. Such an excited atom will make a forbidden transition to a lower energy state per unit time. Nevertheless, "forbidden" transitions are only relatively unlikely, states that can only decay in this way (so-called meta-stable states) usually have lifetimes of the order milliseconds to seconds, compared to less than a microsecond for decay via permitted transitions.

Forbidden emission lines have only been observed in extremely low-density gases and plasmas, either in outer space or in the extreme upper atmosphere of the Earth. Even the hardest laboratory vacuum on Earth is still too dense for forbidden line emission to occur before atoms are collisionally de-excited. However, in space environments, densities may be only a few atoms per cubic centimeter, making atomic collisions unlikely. Under such conditions, once an atom or molecule has been excited for any reason into a meta-stable state, then it is almost certain to decay by emitting a forbidden-line photon. Since meta-stable states are rather common, forbidden transitions account for a significant percentage of the photons emitted by the ultra-low density gas in space [14] .

Forbidden line transitions are noted by placing square brackets around the atomic or molecular species in question, e.g. [OII],[OIII],[SII]. Forbidden lines of nitrogen ([NII] at 654.8 and 658.4 nm), sulfur ([SII] at 671.6 and 673.1 nm), and oxygen ([OII] at 372.7 nm, and [OIII]at 495.9 and 500.7 nm) are commonly observed in astrophysical plasmas. These lines are extremely important to the energy balance of such things as planetary nebulae and H II regions. Also, the forbidden 21-cm hydrogen line is of the utmost importance for radio astronomy as it allows very cold neutral hydrogen gas to be seen [15].

2.2 Electron Temperature

The Astronomers are use the equation below to measurement electron Temperature and depended on forbidden spectral lines flux as [OIII]. And from comparing ratio of [OIII] λ4959A°, λ5007A°,λ 4363A°) they find the electron temperature , this equation is[16]:

$$[OIII]\frac{(\lambda 4959A^{\circ} + \lambda 5007A^{\circ})}{(\lambda 4363A^{\circ})} = 8.32e^{3.29\times10^{4}T_e^{-1}} \qquad (1)$$

Where [OIII]: is ratio of flux .

Te : is electron temperature .

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2.3 Electron Density

The Astronomers are use the equation below to measurement electron density and depended on forbidden spectral lines flux as [OII] , [SII] . And from comparing ratio of [SII]/[SII] or [OII]/[OII] they find the electron density , this equation is[16]:

$$[SII]\frac{(\lambda 6717A^{\circ})}{(\lambda 6731A^{\circ})} = \frac{1.01+5.61e^{\frac{-1.40}{t}} + X(1.97+2.84e^{\frac{-1.40}{t}})}{1.2+3.74e^{\frac{-1.40}{t}} + X(7.9+7.42e^{\frac{-1.40}{t}})} \ldots\ldots\ldots\ldots\ldots(2)$$

$$X = 10^{-2} N_e / T_e^{1/2}$$

$$t = 10^{-4} T_e$$

Where [SII] is ratio of flux .

Ne is electron density.

Te is electron temperature .

* The periods of (supernova 2010jl) from 2010 No. 5 to 2011 May 12 , optical spectrum curve and forbidden spectral lines ([SII] λ 6717A° , λ 6731A°) , ([OIII]λ 4959A°, λ 5007A°,λ 4363A°) are taken from global data (table 1 , Fig 1) [17,18].

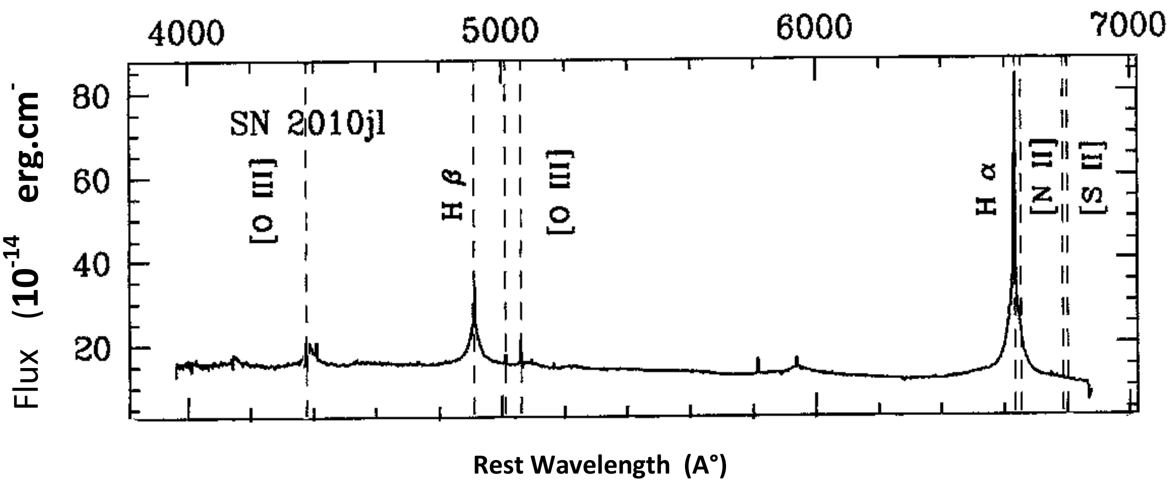

Fig. (1) Optical spectrum curve for SN2010jl [17]

Table (1) Spectroscopic Observation of SN2010jl (Lines Flux 10-14 erg.cm-2.s-1)

Date	H_α λ6563A°	[OIII] λ 4959 A°	[OIII] λ5007 A°	[OIII] λ 4363A°	H_β λ 4861A°	[SII] λ 6717A°	[SII] λ 6731A°	[NII] λ 6584A°
2010 Nov. 5	8.50	1.92	1.88	2.20	3.50	1.52	1.42	2.29
2010 Nov. 7	7.63	1.52	1.50	1.83	2.99	1.15	1.07	2.21

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2010 Nov. 15	6.84	1.29	1.22	1.61	2.80	0.90	0.83	1.75
2010 Nov. 30	6.18	1.15	1.11	1.55	2.55	0.71	0.67	1.70
2011 Jan. 4	5.52	0.85	0.78	1.15	2.20	0.44	0.39	1.25
2011 Jan. 26	4.81	0.63	0.59	1.01	2.10	0.30	0.25	1.10
2011 Feb. 2	3.91	0.39	0.36	0.65	1.81	0.21	0.16	0.88
2011 Feb. 9	3.11	0.25	0.19	0.55	1.67	0.16	0.12	0.71
2011 Mar. 31	2.45	0.20	0.17	0.49	1.62	0.11	0.09	0.62
2011 May 12	1.68	0.13	0.11	0.48	1.18	0.08	0.05	0.49

3. RESULTS AND DISCUSSION

3.1 Electron Temperature

Results of electron temperature for SN2010jl is presented in table (1). Results are calculated by Get Data Program on optical spectrum curve and applying the equation (1). The curve between electron temperature and time in days is shown in Fig.(2).

Table (2) Calculation of electron temperature from ratio of [OIII] lines

Date	Day	[OIII](λ 4959A°+ λ5007A°)/ λ 4363A°	T_e (°K)
…2010 Nov, 5	2	1.72	20875
2010 Nov, 7	4	1.65	20335
2010 Nov, 15	12	1.55	19578
2010 Nov, 30	27	1.45	18831
2011 Jan. 4	62	1.41	18534
2011 Jan. 26	84	1.20	16990
2011 Feb. 2	91	1.15	16625
2011 Feb. 9	98	0.80	14048
2011 Mar. 31	148	0.75	13672
2011 May 12	190	0.50	11700

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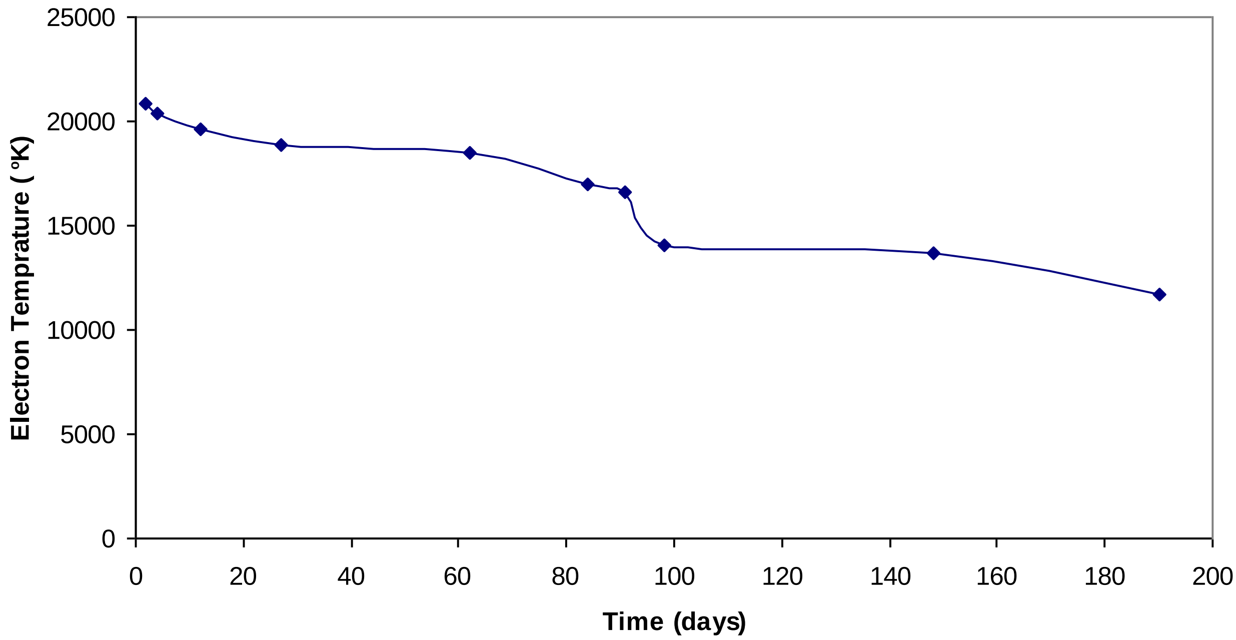

Fig.(2) Relationship between electron temperature and time in days for SN2010jl

We conclude from table (2) that electron temperature is decrease when the age of supernova 2010jl increase (time) where in very early days (2 days) we observe high temperature (20875 °k) which corresponding high ratio of [OIII](λ 4959A°+ λ5007A°)/ λ 4363A°, after that temperature begin by decrease to reach to minimum of temperature (11700 °k) at ratio minimum (0.5) that is mean happen cooling and decrease in the interaction inside this remnant for supernova 2010jl , also the ratio of flux for forbidden spectral lines become brightness less through time evolution . This result is agreement with results of other researchers with another type II as Stephen, Maran and Georg Sonneborn [19]. And Osterbrock, and Ferland [20].

3.2 Electron Density

Results of electron density for SN2010jl is presented in table (3). These results are calculated by Get Data Program on optical spectrum curve and applying the equation (2). The curve between electron density and time in days is shown in Fig.(3).

Table (3) Calculation of electron density from ratio of [SII] lines

Date	Day	[SII](λ 6717A°)/ λ 6731A°	N_e (cm^{-3}) * 10^3
2010 Nov, 5	2	1.070	3.480
2010 Nov, 7	4	1.074	3.415
2010 Nov, 15	12	1.084	3.266
2010 Nov, 30	27	1.099	3.189
2011 Jan. 4	62	1.128	2.706
2011 Jan. 26	84	1.200	1.933
2011 Feb. 2	91	1.312	1.600
2011 Feb. 9	98	1.333	1.355
2011 Mar. 31	148	1.375	1.032
2011 May 12	190	1.400	1.006

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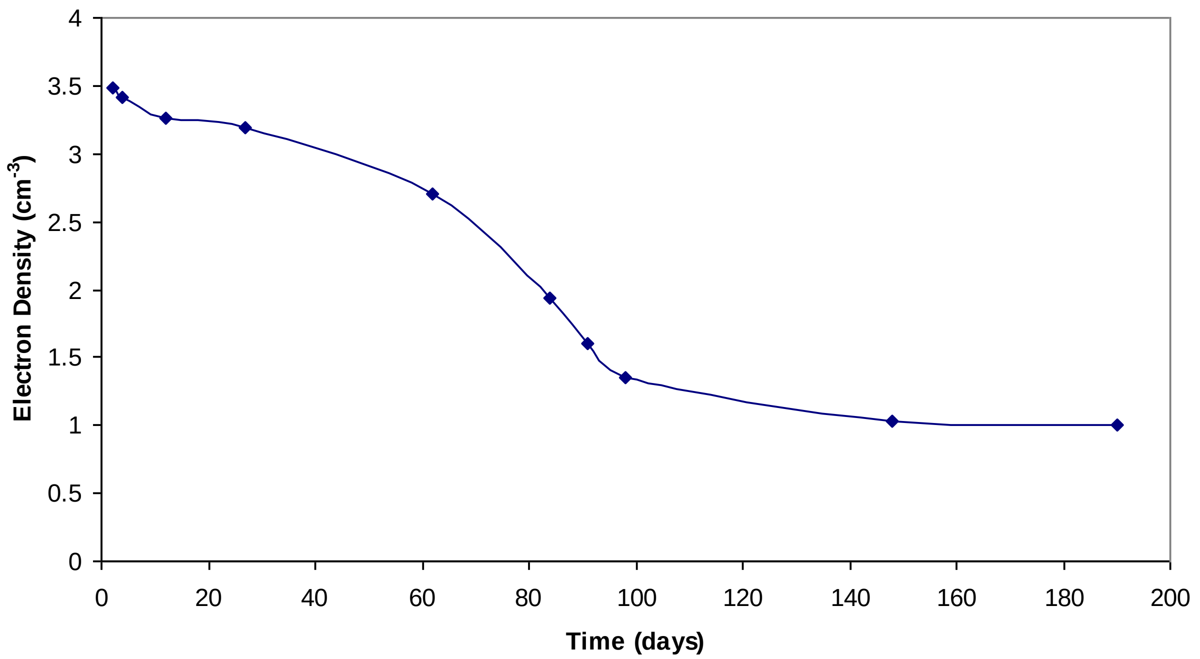

Fig.(3) Relationship between electron density and time in days for SN2010jl

We conclude from table above that electron density is decrease when the age of supernova 2010jl increase (time) where in very early days (2 days) we observe high density (3.480 *103 cm^{-3}) which corresponding high ratio of [SII](λ6717A°/λ 6731A°), after that the density begin by decrease to reach to minimum of value (1.006 *103 cm^{-3}) at ratio minimum (1.400) that is mean happen large collision for expansion of shell of ejecta with instellar medium matter which is caused high temperature after that back to be low in end of shell.This result is agreement with results of other researchers with another type II as (Stupar and Parker) [21] and (Stephen and Sonneborn) [19].

4. CONCLUSION

We found that electron temperature decrease with time evolution and we found that electron density decrease with time evolution.

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