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Studying the Physical Properties of type Ia and II Supernova Remnants

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ABSTRACT

Supernova remnants (SNRs) are remarkable astronomical objects which are a diffuse, an expanding nebula of gas that is a direct result of a star's explosive death, resulting in a supernova explosion. SNRs play a vital role in the scattering of tough elements which are made in the supernova explosion into the interstellar medium and provide much amount of energy that heats the ISM, as well as its responsible for enormous differences in physical process and properties. In the present work, we study the physical properties, performance, and behavior of dynamical growth of several types (SNR Ia and II) specifically after an explosion of a supernova, and explore how the density of the interstellar environment affects the physical properties and eternity of each SNRs. To achieve such goals, we have utilized the method known as Counting Pixels Method, which has been applied to the SNRs images as well as a new pattern that has been suggested to calculate some of the physical properties such as the expansion velocity and the radius of the chosen remnants, which are based on the age of SNRs and the density of the surrounding medium. The outcomes of the study have depicted that each chosen SNRs type Ia and II likewise in performance and behavior after a long period of explosion Nevertheless, they are displaced either upwards or downwards based on the interstellar density. However, we noted that SNRs are exploded in the lower density environment and expanded without restriction to make a regular shape. We have concluded that further study is required particularly on the physical properties of SNRs when inserted into the radiative phase.

Keywords: Supernova remnants, Supernova, Explosion of Massive Stars, Phases of Supernova remnants, Radiative phase.

1. Introduction

Supernova remnants (SNRs) are quite significant to explore in astrophysics because they help us understand how energy and materials are injected into the interstellar medium (ISM)[1]. The main goal of studying (SNRs) research is to understand the physical properties of such types of supernova remnants, as well as their massive explosion causing mass insertion and releasing much amount of energy into the interstellar medium, in addition, to exploring the expansion rate of the remnants that have been influenced by the density of the surrounding medium. In our Galaxy, over 400 SNRs have been discovered[2]. Numerous previous supernova remnants have been used with hydrodynamic models[3]. It has been conventional to use a basic Sedov concept with estimated energy and ISM density for many different SNRs. To obtain correct energy, densities, and ages from measurements, improved modeling is necessary. By using hydrodynamic computations, a variety of SNR models for spherically symmetric SNRs have been constructed, and the outcome of this model will be able to calculate the physical properties of SNRs[4]. The destiny of a star is decided by its composition, rotation rate, binarity, and mass, the mass of the star is the most significant parameter and plays an important role in determining its lifetime. The primary mass of almost all massive stars is located between 8 $M_\odot$ and 140 $M_\odot$ and will develop and produce an iron core through all burning steps. These high-mass stars go through a portion of similar steps as the stars in the medium mass. In the first place, the external layers grow out into a giant star and are significantly greater forming a red supergiant. Secondly, the core begins to shrink out and then turns to be so hot and dense[5]. Stars are considered to be the nuclear reactor of nature during their main sequence lifetime and above the beyond. The luminous sphere of massive stars of plasma fuse lighter elements into a heavier one from hydrogen to iron the most massive of stars as shown in figure 1. As a result, a supergiant star which is similar to a stellar onion consists of an element with a mass gradient in levels across the star. Then, helium begins to fuse into carbon in the core[6]. At the point when the provided helium ends up, the inner core will expand once more. Nevertheless, because the inner core has more massive, it will get sufficiently hot and dense to allow the fusion of carbon into neon. Once provided carbon is

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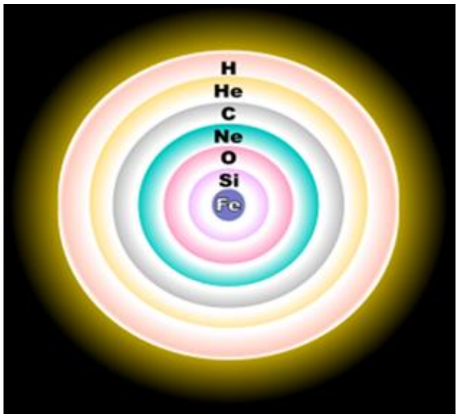

Figure 1: A large, developed star's onion-like layers before core collapse. (Source: Wikipedia).

depleted, further fusion events take place til the inner core is loaded up with the element of Iron atoms. Until now, the fusion events have produced enough energy to allow the star to defy gravity. Although fusing iron necessitates the provision of energy, the star would lose the battle opposing gravity if it abandons energy generation with an iron core[7]. The temperature at the core of the star rises by more than 100 billion degrees when all the iron atoms are destroyed together. When an iron core is fixed, more nucleosynthesis changes to endothermic and is not automatically supported anymore. When the core's mass arrives at the Chandrasekhar mass ($M \sim 1.4\ M_\Theta$), the core becomes unable of upholding weight for itself[8]. When there are no more nuclear reactions provided to balance out the tremendous gravity of the star and keep hydrostatic equilibrium, the force of gravity overcomes due to the repulsive force between positively charged nuclei, as well as the core escapes from the center of the star in an outburst called a shock wave. The shock wave blasts material far from the star in a huge blast known as a supernova, which is one of the most stunning events in the cosmos. which releases an amount of energy of about 10^{53} ergs, this releasing energy mostly in the form of kinetic and neutrinos. However, rapid rotating very massive stars around solar metallicity are considered a strong mass loss and are expected to be the end of their lives. As a result, the material ejects off into the interstellar medium. Nearly 75% mass of the star was deported from the supernova into space. The remaining star's core's fate is determined by its mass. The remaining star will collapse into a neutron star if its core mass is between 1.4 and 5.0 times that of our Sun. If the star core becomes too large, it will collapse into a black hole. Before the explosion, it must have a mass of 7 to 20 times that of the Sun to become a neutron star[9]. The structure of the study is presented in the following parts. In part 2 we will explain how supernovas are classified in terms of whether or not hydrogen emission lines can be seen in their spectra. In part 3 we will explore the three possible phases that occurred during the evolution of supernova remnants. Moreover, the mathematical calculations and the discussion of the results are presented in part 4. Finally, the summary of the paper can be seen in part 5.

2. Classification of Supernova

Supernovas are explosions that can over shined the whole galaxy. They are the last point of the lifetime of specific stars and they cooperate in the chemical growth of their host galaxies. lots of stars explode and eject the materials back into the interstellar medium. These explosions release an amount of energy in the form of visible light called supernova[10]. Supernova plays an important role in modern astronomy, particularly in staller reactions, molecular clouds as well a new generation of stars. A supernova can be categorized into two types: type I and type II. The condition for the two types of supernova is whether or not hydrogen emission lines can be seen in their spectra. Type I supernovae have no hydrogen emission lines and are classified as type Ia, Ib, and Ic supernovae. However, these subdivisions meet the differences in their spectra. Two spectral lines have been identified in Type I supernovas, one of which is a conspicuous Si II absorption line, and a slew of emission lines, both of which are from the iron peak element. There are no Si II absorption lines in Type Ib and Ic supernovae. The type Ia supernova is regarded as one of the most reliable standard candles for cosmological purposes[11]. The reason for this is that the peak luminosities of this type are essentially very stable with little dispersion. The second reason is that this dispersion can be furthermore corrected. In the past, our galaxy stewarded supernovas that were explored by and named after Tycho Brahe and Johannes Kepler, respectively. These two events were the brightest objects among other objects at peak luminosity in the sky, they were visible to the naked eye. However, Both incidents belong to the same group of supernova type Ia[12]. Supernovas are also classified according to their spectra and can be subdivided into two primary groups: Group one is known as core-collapse objects including types II, Ib, and Ic supernovas, whose has lack spectra in Si lines but usually show H or He lines. Group two is known as thermonuclear explosions including type Ia supernova, which has a lack in H and He lines, but presents powerful (Si – Fe) lines, as shown in figure 2[13]. In this study, we will explore the effect of density of the surrounding medium for the chosen SNRs type Ia and II including SN 1987 A, G1.9+0.3, Cassiopeia A, Kepler's Nova, Tyco's Nova, Crab Nebula, SN 1006, Cygnus Loop, IC 443. Furthermore, we will have a mathematical model to calculate the radius and the expansion velocity of SNRs type Ia and II when arriving at the radiative phase.

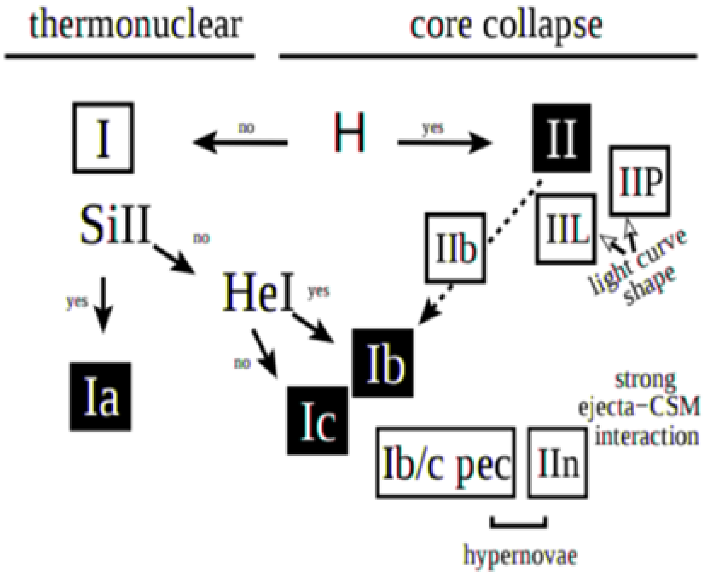

Figure 2: shows a classification strategy for supernovae.

3. Life Phases of Supernova Remnant (SNR)

A supernova remnant is a direct result of a supernova explosion that is caused by the explosive death of a star. Nearly 10^{51} erg of energy was released from the explosion of a supernova and is mainly moved into the interstellar medium[14]. The circling medium, or even the general time sequence of events that follow the supernova explosion, determines how supernova remnants evolve, which include the supernova remnant can be split into a different number of phases of evolution stages. The first phase is called the ejecta-dominated phase or free expansion phase, which is the earliest phase of the evolution of supernova remnant, the ejecta expands with a uniform velocity, and this phase leaves a lower power density profile of inner space[15]. The period of this phase is determined by the expansion velocity and mass of the ejecta and the density of the surrounding medium. It lasts a few hundred years; this phase is expressed by a constant expansion velocity of the shell and constant temperature within the supernova remnant. The ejecta expansion ends when the mass of the shocked interstellar swept up by the ejecta is similar to the original ejecta mass[16]. In the second phase, the supernova remnants enter a period of adiabatic expansion known as Sedov – the Taylor phase. The shock wave begins to slow down equivalent to the time when the shock achieves a radius so that the swept mass is equal to the ejecta mass. Throughout the Sedov – Taylor phase, the radius of the supernova remnant is given by[17]:

$$R = 13 \times (E_{51} / n_0)^{1/5}\, t_4^{2/5} \quad (\mathrm{Pc}) \qquad (1)$$

Where E_{51} represents the initial energy in units of 10^{51} erg. And n_0 is the surrounding number density in a unit of Cm^{-3}. T_4 is the time in units of 10^4 years[18].

The period of this phase lasts for about 10000 to 20000 years unless the temperature of the inner gas has cooled down for about 1000000 K, on the other hand, the pressure is reduced at the backside of the blast wave. At this moment the recombination process starts to reconnect electrons with the surrounding atoms and radiative losses turn significant. During this phase, the supernova remnant's primary shell becomes Rayleigh – Taylor unstable, and the ejecta dominated by SNR becomes mixed up with the materials and gas and is shocked by the first shock wave. As a result of this mixing, the magnetic field inside the SNR shell improves[19]. To produce a shock is to add a very big quantity of energy into a tiny volume. This occurs whenever a supernova explodes in the interstellar medium, let's assume that an explosion instantly releases a certain quantity of energy into a uniformly dense environment. It is believed that a very tiny volume contains the first energy release. However, a circular shock front then will extend into the surrounding medium. At the beginning of the process of extension, the shock's internal pressure is considerably higher than the surrounding atmosphere's pressure, and any radiation from the shock is far less powerful than the energy from blasts, the energy is steady throughout this phase and is called as the blast wave phase[20]. Another hypothesis has been applied for calculating the solution of blast wave called the energy produced by the explosion was higher than the radiation energy lost. The radiative phase starts happening at:

$$t = 1.9 \times 10^4\, E_{51}^{3/14}\, n_0^{-4/7} \quad (\mathrm{year}) \qquad (2)$$

When the radius is

$$R = 16.2 \times E_{51}^{2/7}\, n_0^{-3/7} \quad (\mathrm{PC}) \qquad (3)$$

The amount of energy emitted throughout the phase is nearly 10^{51} erg therefore, we anticipate that losing radiation will lead to the energy of the blast wave being conserved Even though the radiating shell is not formed fully yet. A thick shell grows after the radiative shock, so the blast wave stage of the enlarging supernova remnant eventually gives way to the snowplow stage as shown in figure 3[21]. The snowplow phase starts after the shell has cooled down, and the material of the surrounding interstellar medium sweeps by the extending dense shell therefore electrons begin to reconnect with the heavier atoms like O, C, and N, so the shell can radiate energy more efficiently. Due to the cooling, the shell shrinks and becomes denser. The SNR eventually grows into a thin shell and radiates much of its energy farther away as optical light. While the momentum conservation is naturally retained across all phases, this phase is also referred to as the momentum conserving or snowplow. This is differentiated from the previous phases in which both the momentum of the system and energy are conserved. The velocity diminishes when the radiative phase ends, and the outer expansion ceases, causing the SNR's gravity to collapse. The phase can last only a few hundreds of thousands of years; therefore, the SNR will be engaged in the interstellar medium after millions of years[22]. Next part of the study, we will have a mathematical model to calculate the radius and the expansion velocity of SNRs type Ia and II when arriving at the radiative phase.

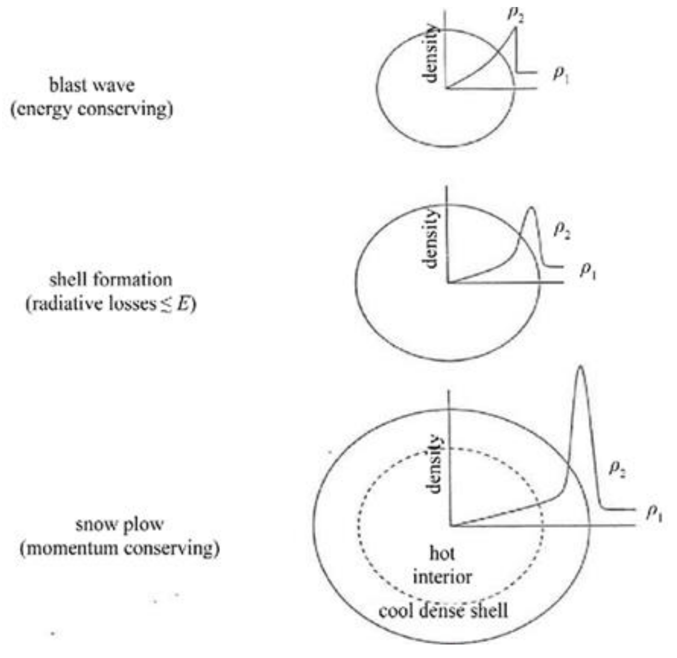

Figure 3: shows the transition from the blast wave to the snowplow phase of an expanding supernova remnant.

4. Mathematical Calculations and Results Discussion

A supernova remnant is a structure resulting from the explosion of a star in a supernova. SNRs are the primary source of heavy elements like oxygen, as well as the primary source of interstellar gas heating (energy). The spreading cloud emits as much energy in a single day as the Sun has done in the preceding three million years during the brightest phase of the outburst. In this study, we have got several supernova remnants of type Ia and type II. For type Ia SNRs such as Kepler's Nova, Tyco's Nova, SN 1006, and G1.9+0.3. For the type II SNRs such as SN 1987 A, Cassiopeia A, Crab Nebula, Cygnus Loop, and IC 443. We have provided a table that contains some SNRs including type Ia and type II along with their physical properties such as distance, density, age, velocity, and radius. In this work, we will be able to solve and explore the expansion rate of the remnants that have been influenced by the density of the surrounding medium. To achieve our goal, we have utilized the method known as Counting Pixels Method[23], the method has been applied to the SNRs images which are provided earlier. Consequently, we will be able to calculate the radius of each remnant along with the mathematical equations we can calculate the explosion energy of each remnant within table 1[24].

Table 1: shows the physical parameters of several type Ia and II supernova remnants.

SNR	Distance (Pc)	ISM density (Cm^{-3})	Age (Year)	Radius (Pc)	Velocity (Km/s)
SN 1987 A	51000 ± 1.2 [23]	10 – 11.2 [25]	25 – 26	0.21 - 0.39 [23]	3900 ± 100 [25]
G1.9+0.3	8200 ± 300 [26]	0.03 ± 0.01 [26]	100 – 140	2.2 – 4.7 [26]	13600 - 14000 [26]
Cassiopeia A	3400 - 3550 [27]	1.5 – 1.92 [27]	330 – 358	2.4 - 2.6 [27]	1000 – 1500 [27]
Kepler's Nova	5000 – 6400 [28]	0.1 – 0.4 [29]	407 ± 3	2.5 – 3.8 [28]	1550 – 2000 [30]
Tyco's Nova	1500 – 3100 [31]	0.2 – 1.0 [31]	442 – 450	3.7 ± 0.3 [31]	1500 – 2800 [31]
Crab Nebula	2000 ± 500 [32]	0.5 – 1.0 [32]	958 – 1001	3.4 – 3.9 [32]	1400 – 1500 [33]
SN 1006	2180 ± 80 [34]	0.1 – 0.3 [28]	1000 – 1016	7.1 – 7.5 [34]	2800 ± 200 [34]
Cygnus Loop	770 ± 70 [35]	0.1 – 0.2 [36]	10000 – 17000	21.5 – 27 [37]	200 – 300 [38]
IC 443	1500 - 2000 [39]	10 – 20 [39]	3000 – 30000	9.6 [40] – 15 [41]	65 – 100 [39]

The explosion energy (E) equation is given by

$$E = 3.2 \times 10^{51}\, n_0\, R^5\, t^{-2} \quad (\text{erg}) \tag{4}$$

Where E represents the explosion energy, n_0 is the number density of the surrounding medium, R represents the radius of the remnant in a unit of pc and t represents the age of the remnant in a unit of the year. The outcomes from the Counting Pixels Method and the equation (4) are given in table 2.

Table 2: displays the results of utilizing the counting pixels method to some SNR images.

SNR	Radius (Pc)	Explosion Energy (Erg)
SN 1987 A	0.5 ± 0.2	1.47×10^{48}
G1.9+0.3	4.6 ± 0.6	1.97×10^{49}
Cassiopeia A	5.2 ± 1.0	1.42×10^{50}
Kepler's Nova	4.1 ± 0.3	2.20×10^{48}
Tyco's Nova	5.8 ± 1.2	2.15×10^{49}
Crab Nebula	3.22 ± 0.7	6.03×10^{47}
SN 1006	17.6 ± 1.6	5.40×10^{50}
Cygnus Loop	9.41 ± 0.4	1.63×10^{47}
IC 443	11.35 ± 1.4	1.33×10^{49}

Regarding the radius, we can also calculate the velocity (v) and the mass (m) of the remnants from the following equations respectively.

$$V = (R / t) \quad (\text{Km/s}) \tag{5}$$

$$m = \frac{4}{3} \pi \rho R^3 \quad (\text{Kg}) \tag{6}$$

Where ρ represents the density of the interstellar medium.

Subsequently, to study the performance and behavior of the expansion velocity and the radius of each supernova remnants type Ia and type II along with the taken time of the explosion, the average time is taken from 100 years up to 30 000 years. The results are illustrated in figure 4. (a), (b) for the Type Ia supernova remnants as well as in figure 5. (a), (b) for the Type II supernova remnants. From analyzing behavior and performance of our graph in fig. 4 and fig. 5 of the chosen supernova remnants, we concluded that a new pattern that can calculate the expansion velocity and the radius of the chosen supernova remnants, which is based on the age of the SNRs and the density of the surrounding medium. The radius equation of supernova remnants is given by:

$$R = 0.34332\ t^{0.4}\ n^{-0.2} \quad (\text{pc}) \tag{7}$$

The expansion velocity equation of SNRs is given by:

$$V = 149666.25\ \eta\ t^{-0.601}\ n^{-0.2} \quad (\text{Km/s}) \tag{8}$$

$$\eta = \frac{Vb}{Rb/t} \tag{9}$$

Where η represents the expansion factor of equation (8), R_b and V_b are the radius and velocity of the blast wave. The outcomes that we have got from equation (7) and equation (8) have been illustrated in both figures 6. (a),(b) for the Type Ia SNRs and figure 7. (a),(b) for the Type II SNRs.

Eventually, the outcomes that we have got earlier from the equations (4) and (5) along with their graphs for the Type Ia and II supernova remnants in comparison with those results are obtained from the equations (7) and (8) also along with their graphs for the Type Ia and II of SNRs, we have discovered that our findings appear more sensible with experience-based data (Mathematical equations) than whose findings in Counting Pixels Method as shown in Table 3 (a) and (b).

Table 3: (a). Demonstrate our findings in radius of SNRs in comparison with the other researchers finding.

SNR	**Radius (Pc)**		
	Counting Pixels	**Our Finding**	**Researchers finding**
SN 1987 A	0.5 ± 0.2	0.73 ± 0.12	0.21 - 0.39
G1.9+0.3	4.6 ± 0.6	4.21 ± 0.30	2.2 – 4.7
Cassiopeia A	5.2 ± 1.0	3.37 ± 0.41	2.4 - 2.6
Kepler's Nova	4.1 ± 0.3	5.6 ± 1.1	2.5 – 3.8
Tyco's Nova	5.8 ± 1.2	4.9 ± 0.6	3.7 ± 0.3
Crab Nebula	3.22 ± 0.7	5.8 ± 1.3	3.4 – 3.9
SN 1006	17.6 ± 1.6	9.2 ± 1.7	7.1 – 7.5
Cygnus Loop	9.41 ± 0.4	21.4 ± 2.2	21.5 – 27
IC 443	11.35 ± 1.4	12.9 ± 0.8	9.6 – 15

Table 3: (b). Demonstrate our findings in velocity of SNRs in comparison with the other researchers finding.

SNR	**Velocity (Km/s)**		
	Counting Pixels	**Our Finding**	**Researchers finding**
SN 1987 A	4175 ± 75	6011 ± 600	3900 ± 100
G1.9+0.3	12105 ± 45	14142 ± 70	13600 - 14000
Cassiopeia A	3610 ± 500	1819 ± 113	1000 – 1500
Kepler's Nova	2016 ± 250	2622 ± 27	1550 – 2000
Tyco's Nova	3247 ± 180	2381 ± 11	1500 – 2800
Crab Nebula	1421 ± 35	1340 ± 21	1400 – 1500
SN 1006	3895 ± 540	1832 ± 36	2800 ± 200
Cygnus Loop	246 ± 22	272 ± 31	200 – 300
IC 443	113 ± 17	92 ± 4	65 – 100

According to our findings in Table 3, some of the supernova remnants do not go under the very beginning of their evolutionary phases when we apply our model or mathematical equations to them, such as Cassiopeia A and SN 1987 A, Although the expansion energy of these phases is dominant and make the remnant to the maximum velocity, Nevertheless in terms of time as the effect of the expansion energy decreases the mass of the remnant increases and the remnant is slowed down, in agreement with the density of the surrounding medium as a primary parameter that has the impact in the evolving of each remnant and their lifetime, for instance when the IC 443 enters to the dense molecular cloud which is located in the northern part of the remnant has made the mass of the remnant growing to reach the value of nearly 1400 $M_\odot$. Accordingly, the expansion velocity of the IC 443 SNR has been decreased to a rate of nearly 92 Km/s, and its radius of about 12.9 pc. Moreover, we can demonstrate that when the SNRs of Type II inserts into the radiative phase then we can calculate the physical properties of the chosen remnants with the help of equations (2) and (7). The outcomes are shown in Table 4.

Table 4: Depicted some of the physical properties of SNRs Type Ia and II at the initiate of the radiative phase.

SNR	**Mass ($M_\odot$)**	**Temp. (K)**	**Velocity (Km/s)**	**Time (year)**	**Radius (pc)**
SN 1987 A	557	3.5×10^6	394 ± 21	2.2×10^4	18.0 ± 1.5
G1.9+0.3	255	1.8×10^6	280 ± 11	23.7×10^4	64.2 ± 3.0
Cassiopeia A	336	2.86×10^6	355 ± 32	1.22×10^4	13.3 ± 0.3
Kepler's Nova	25	1.77×10^6	279.5 ± 9.0	7.4×10^4	19.1 ± 1.9
Tyco's Nova	135	3×10^6	364 ± 13	7.9×10^4	27.0 ± 1.0
Crab Nebula	279.5	0.6×10^6	163.6 ± 10.5	5.1×10^4	18.2 ± 1.1
SN 1006	3321	3.9×10^6	417 ± 27	24.6×10^4	101.7 ± 4.1
Cygnus Loop	217.6	1.35×10^6	244.6 ± 17	4.0×10^4	22.5 ± 0.5
IC 443	389	1.7×10^6	277 ± 11.2	1.6×10^4	6.9 ± 0.2

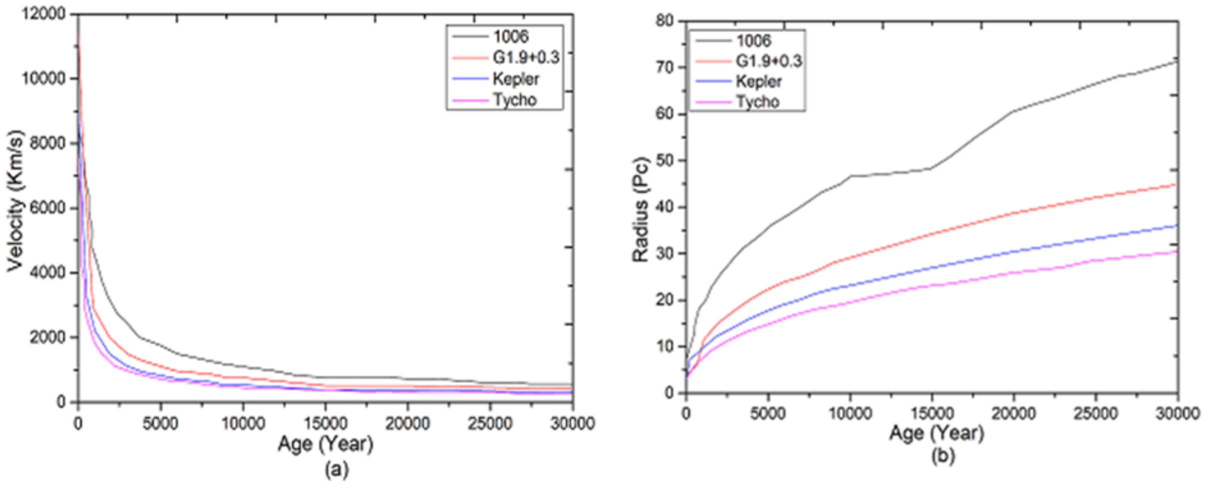

Figure 4: (a), (b) shows the differences in velocity and radius, as well as age, for Type Ia SNRs; these are the outcomes of equations (4) and (5).

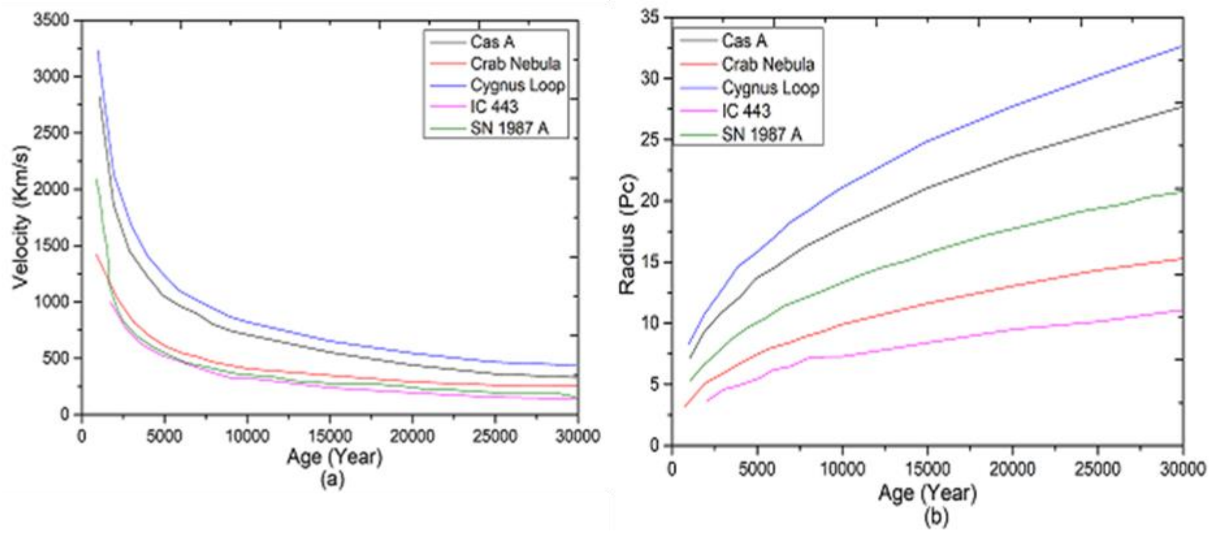

Figure 5: (a), (b) Depict the variation in velocity and radius, as well as age, for Type II SNRs, as a result of both equations (4) and (5).

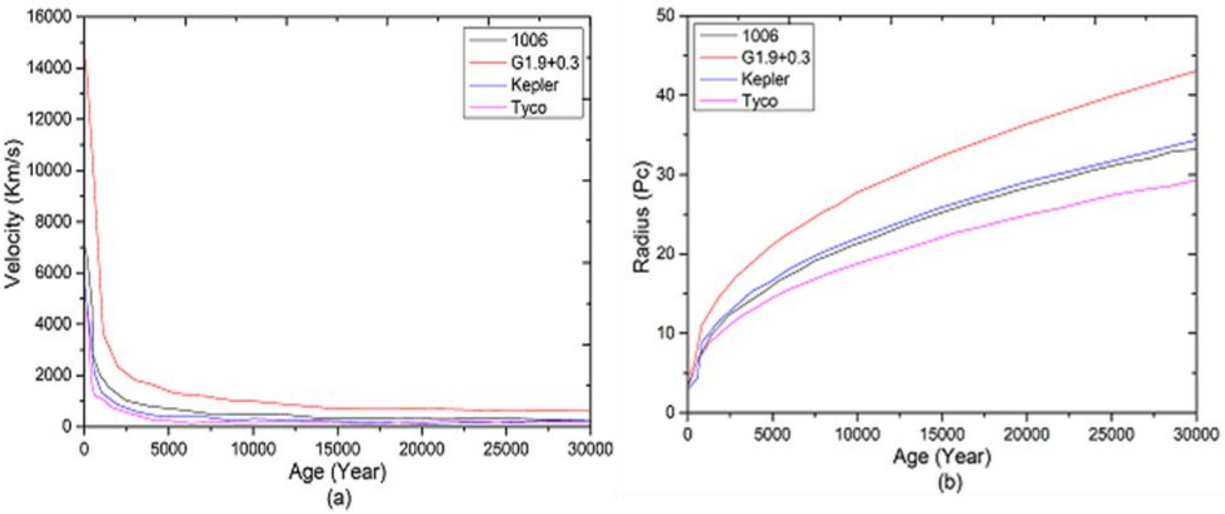

Figure 6: (a), (b) Display the variations in velocity and radius as compared with age for Type Ia SNRs. The graphs are produced using the results of both equations (7) and (8).

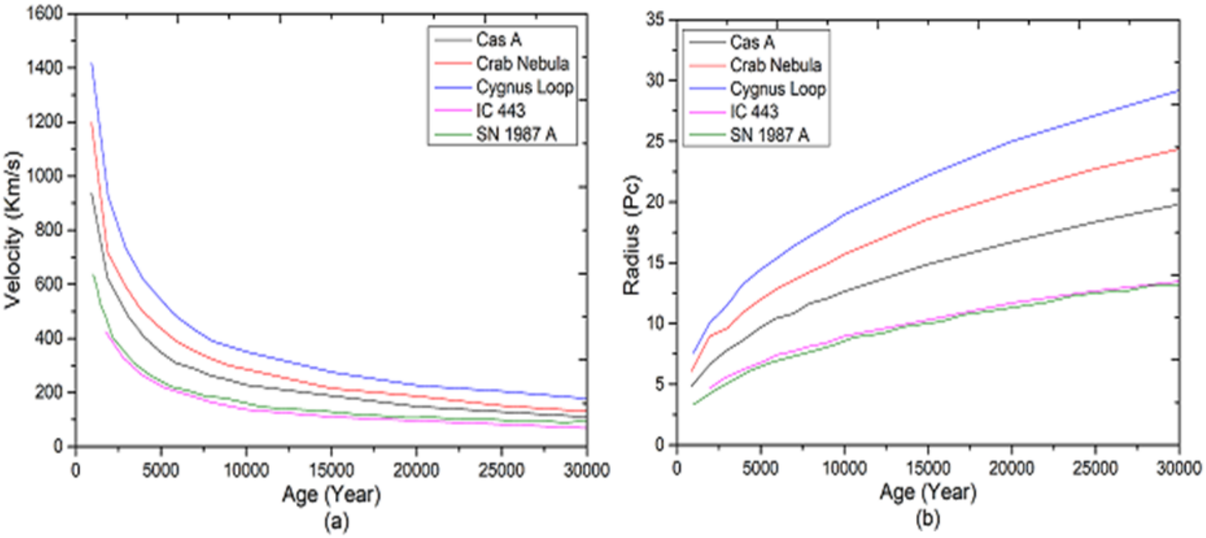

Figure 7: (a), (b) Demonstrates the variation of velocity and radius, along with the age, for Type II SNRs generated by equation (7) and equation (8).

The supernova remnants from Table 4. Can tell us which remnant enters into the radiative phase earlier, for instance, the remnants of IC 443 go through the radiative phase earlier than the other remnants even earlier than SN 1987 A despite having the same interstellar density. Due to the partially lesser explosion energy of remnant IC 443 inserted to the radiative phase earlier than the remnant of SN 1987 A. The density of the medium is not the single parameter to find out the period of transition to the radiative phase nevertheless, there is another significant parameter called the explosion energy that can also perform a considerable role in the period of transition such remnants are Cygnus loop and Crab nebula as we previously showed according to their interstellar density and explosion energy, they will take longer time to insert into the radiative phase.

5. Conclusion

In this paper, we have depicted that all the supernova remnants type Ia and type II including SN 1987 A, G1.9+0.3, Cassiopeia A, Kepler's Nova, Tyco's Nova, Crab Nebula, SN 1006, Cygnus Loop, IC 443 have the similar performance after a long period of explosion nevertheless, they are displaced either upwards or downwards based on the interstellar density which is the single parameter that has an impact on the improvement of eternity for each remnant which they explode, considering after this time the explosion energy won't have the force effected on the expansion, particularly in the radiative stage. As per our modeling, we can find out the radius and the expansion velocity of each SNRs type Ia and type II after a long period we have noted that supernova remnants are blow-up in the lower density circumstance and expanded without restriction to make a regular shape, these remnants including several SNR type II-like Cassiopeia A, and the Crab Nebula in addition to nearly all the type Ia SNRs, however, these remnants spend longer time to be inserted into the radiative phase. In contrast, the remnant that expands mainly in the clumpy media such as SN 1987 A and IC 443 will have an irregular shape or be disarticulated. When those remnants engage with the dense clump, it means that the molecular shock fronts are directed by extensive excess pressure in comparison with the remaining remnant pressure, as a result, those remnants with the excess pressure will be inserted into the radiative phase earlier as compared with the low-pressure remnants.

Conflict of interests

None

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