The Range of Sizes of Galactic Supernova Remnants

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Abstract

The traditional creationist model allows a very brief time for the growth in size of galactic supernova remnants. In this statistical study, I determine the expected range of supernova remnant sizes that have up to 6,000 years of expansionary growth. I show that the resulting size ranges are compatible with the published characteristics of the population of galactic supernova remnants that are of known size. Hence, the range of sizes of these supernova remnants is compatible with a creationist assumption that the galaxy is young.

Introduction

An average supernova remnant (SNR) is a vast and truly spectacular object. The diameter of a mid-sized SNR can be as much as twenty parsecs. To put this size into perspective, the distance from the Earth to the star Alpha Centauri is about three-fourths of a parsec. An average SNR is therefore sufficiently large to potentially contain a star cluster containing thousands of stars within its extended volume. The straightforward question that is posed in this paper is whether the observed range of sizes of these huge objects matches the sizes that would be expected in a galaxy that is everywhere less than 6,000 years old.

We will use a "five-number summary," and illustrative "box charts," to provide an easy and effective way to represent the observational data and to compare the data with the predicted range of sizes for galactic SNRs assumed to have been formed in the brief time frame of 6,000 years.

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Five-Number Summaries

A five-number summary (we will just call them summaries for the rest of the paper) involves dividing each of the data sets to be compared into four parts with each part containing just a quarter of the data. The five boundary points are:

1. The lowest value in the data set.
2. The lower quartile Q_1. One fourth of the data set will lie below this boundary point.
3. The median Q_2 . One half of the data set will lie below the median.
4. The upper quartile Q_3. Three quarters of the data set will lie below this boundary point.
5. The maximum value in the data set.

A typical box-chart graphical representation of a five- number summary is shown in Figure 1.

Calculation of Summaries for the Observed Range of Sizes of 62 Galactic SNRs

The most recent radio surveys (Brogan et al., 2006) have now brought the total estimate of known SNRs in the galaxy to around 265. Measurements have been made of the distances to about 62 of these. The complete set of these 62 SNRs is listed in Table III using observational details taken from the comprehensive 2004 catalog of galactic SNRs of David Green (Green, 2004). This set of 62 SNRs is a most important data set. Without the distance to an SNR, it is impossible to determine its size and thus to formulate and confirm models of how they develop and grow. The 62 SNRs of Table III are shown in order of the size of their diameters, which will allow us to read the quartile and median values directly from the table.

The results from our set of 62 SNRs follow:

- The smallest diameter is taken as zero.
- The lower quartile Q_1 is the number 15 SNR in the table.

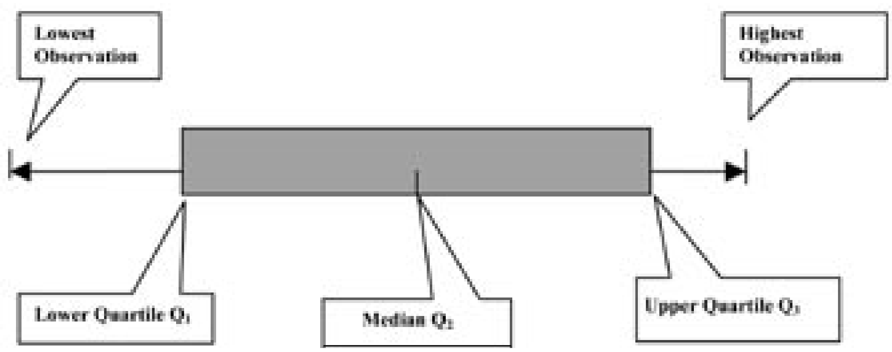

Figure 1. A box ch-art representation of a five-number summary

Observations show that its diameter is 13 parsecs.

- The median Q_2 is the 31st. Its diameter is 24 parsecs.
- The upper quartile Q_3 is the 47th. Its diameter is 47 parsecs.
- The largest SNR in the table has a diameter of 186 parsecs.

Establishing Creationist Predictions for the Range of SNR Sizes Expected in the Galaxy

The summaries for the creation model of this investigation are obtained by applying the well-accepted Sedov model for the growth of second stage SNRs. Details of the Sedov model, together with the published range of values of associated parameters, can be found in our Technical Appendix A and Technical Appendix B. We have used 10^{51} ergs for the initial expansion energy of an average SNR, since this value is the accepted value often quoted in the literature. On the other hand, the value for the average density of the interstellar medium (ISM) environment of SNR's is not so well established. Two sample sets of summaries will be given for two possible values of ISM density, n =~0.3 and n =~ 0.001, where n is defined as the number of "particles" in one cubic centimeter of the ISM. Further details are found in technical Appendix A.

- A *creationist prediction for the lowest value in the data set.* The lowest diameter is taken as zero.
- A *creationist prediction for the lower quartile Q_1 of the range of sizes of galactic SNRs.* In this creationist 6,000-year model, Q_1 is the diameter of an average second-stage SNR of age 1,500 years. Using a sample ISM density given by $n = 0.3$ gives an expected value for $Q_1 = 16$ parsecs (See Technical Appendix B). Using a sample ISM density of $n = 0.001$ gives a value of Q_1 =51 parsecs.
- A *creationist prediction for the median Q_2 of the range of sizes of galactic SNRs.* In the creationist model, Q_2 is the diameter of an average second-stage SNR of age 3,000 years. Using a sample ISM density given by $n = 0.3$ gives a value of 21 parsecs. With $n = 0.001$ we obtain Q_2 =67 parsecs.
- A *creationist prediction for the upper quartile Q_3 of the range of sizes of galactic SNRs.* In the creationist model, Q_3 is the diameter of an average second stage SNR of age 4,500 years. For $n = 0.3$ we obtain Q_3 =25 parsecs. With $n = 0.001$ we calculate Q_3 =78 parsecs.
- A *creationist prediction for the largest value of the range of sizes of galactic SNRs.* The largest size expected for SNRs in this creationist model would be for an age of 6,000 years with an initial energy that is in the higher range of published values. We will use an initial expansion energy of 10^{52} ergs for this calculation (details of the range of values of initial expansion energies are supplied in Technical Appendix A). Using a sample ISM density of $n = 0.3$ gives an expected largest diameter of around 45 parsecs. Using a sample ISM density of $n = 0.001$ gives an expected largest diameter of around 140 parsecs.

Results

Our results are shown in charts given as Figures 2, 3 and 4. We note that:

- There will always be the possibility that an observational bias might be present in the way that astronomers decide which SNRs are chosen for observations that will provide distance estimates. For example there could be an observational bias toward selecting brighter remnants over fainter ones. However, an SNR can appear particularly bright either because it is inherently a bright object or because it is particularly near the observer. Also, the 62 SNRs of Table III form a reasonably large sample, and a variety of methods are regularly used in order to obtain the distances to individual SNRs. This brings us a measure of confidence that the table is representative. Indeed, the processes of finding the distance to an individual SNR can sometimes be more serendipitous than selective.

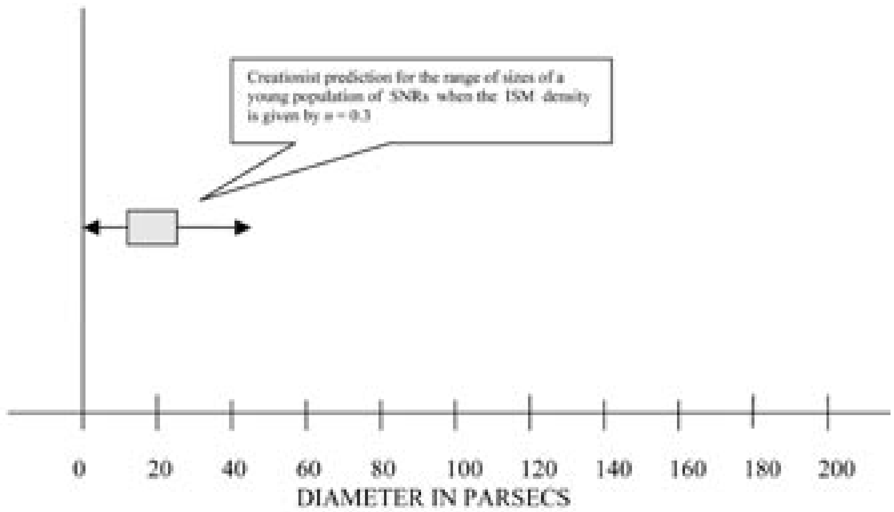

Figure 2. This box-chart represents creationist predictions for the range of sizes of SNRs of average expansion characteristics moving through an ISM of density corresponding to n = 0.3. This particular density has been estimated as applying to 20% of the ISM.

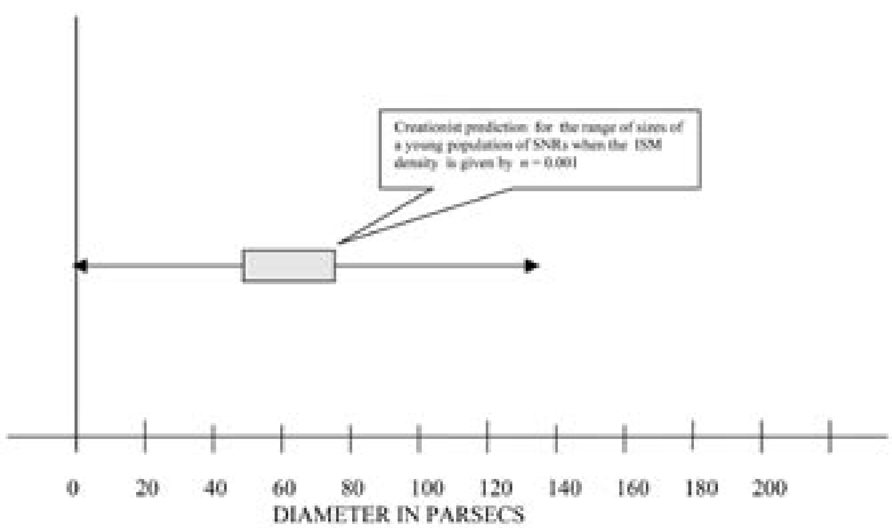

Figure 3. This box chart represents the creationist predictions for the range of sizes of SNRs of average expansion characteristics moving through an ISM of density corresponding to n = 0.001. This density has been estimated as applying to 70% of The ISM.

- The expected size achievable by an SNR over a period of 6,000 years is small in comparison to the range of sizes expected for galactic SNRs in an old-universe model. Even if we restrict our comparisons of the two models to the shorter but more readily observable second-stage of SNR development, the difference is still substantial. The median age of a second stage SNR is around 60,000 years and this, by equation (2) of the Sedov model would represent an SNR whose diameter would be 71 parsecs if we use n =0.3, or 221 parsecs if we use n= 0.001. Recall that, in comparison, the median diameter of the observed set of 62 SNRs is only 24 parsecs. It also should be noted that SNR radio emissions increase in power for the entire duration of the second stage. This important fact makes it likely that the range of sizes observable at radio wavelengths should include representatives of the entire theoretical range of second-stage SNRs.
- The two technical appendices provide only the very basic theoretical background required for an appreciation of the way that the five-number summaries are calculated. A more detailed theoretical analysis, together with a list of research topics and links to web-based sources of SNR data, is available upon request to kdavies1@hotmail.com

We can conclude that the creationist assumption that the galaxy is everywhere less than 6,000 years old is not in conflict with the range of sizes of currently observed galactic SNRs of known distances.

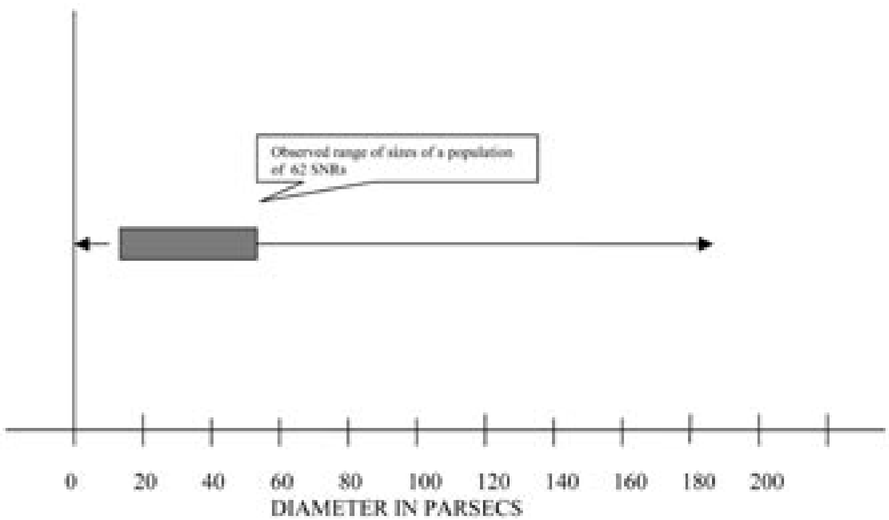

Figure 4. This box chart shows the observed range of sizes of the 62 SNRs of Table III.

Technical Appendix A

The Sedov Model and Related SNR Data

This appendix looks at the Sedov model for SNR growth and includes a review of the data, both observational and derived, that usually form part of the models of SNR development.

The Initial Kinetic Energy of an SNR

This is a significant expansion parameter and its value has a sensitive effect on the future development of any SNR. It will be labeled E_0 and will be measured in ergs. Published values are in range from 10^{50} to 10^{52} ergs, although some individual SNRs might have even higher values (Dyson, 1978, p. 155; Arbutina and Urosevic, 2005). Most SNRs are assumed to have an initial expansion energy that does not deviate significantly from 10^{51} ergs (Arbutina and Urosevic, 2005, p. 79). This is the value that will be used throughout this article for the value of E_0 for an "average" SNR. The value used for the highest expected value for E_0, will be 10^{52} ergs.

The Density of the Interstellar Medium that an SNR Passes Through

This will be represented by n, the number of "particles" per cubic centimeter.

Density is measured in this unusual way, but it allows meaningful comparisons to be made of the very low densities encountered in space. In the near vacuum of the interstellar medium, the density range is wide but is of the order of *one particle per cubic centimeter*. In the even sparser intergalactic medium, the standard of comparison is *one particle per cubic meter*. A "particle" in this context is an individual molecule or ion or, in the case of a dust cloud, an individual grain of dust.

The range of values for n in the galaxy is very wide. A small number of SNRs will be found in dense molecular clouds, where n can be greater than 100. However, for many years, an average value for n of just one particle per cubic centimeter was assumed in the literature. There are now good reasons for assuming that this estimate is incorrect and that a realistic average value for the ISM density is smaller than n =1. One text (Mihalas and Binney 1981, p. 181) on galactic astronomy makes the following assertion:

- About 3 % of the volume of the ISM is associated with $n \sim 20$
- About 10 % of the volume of the ISM is associated with $n > 0.5$
- About 20% of the volume of the ISM is associated with $n \sim 0.3$
- About 70 % of the volume of the ISM is associated with $n \sim 0.001$

The values that will be used throughout this article as the best values for this important expansion characteristic of an average SNR are the two values above that together appear to apply to about 90% of the ISM, $n \sim 0.3$ and $n \sim 0.001$. The use of other values for these parameters, within the usually accepted ranges of average values, can be researched further but is not expected to show any significant changes in the findings of this paper.

The Age of an SNR

This will be labeled t and will be measured in years.

The Distance from the Earth to an SNR

This will be labeled d and will be measured in parsecs. Astronomers can measure the angular size of SNRs to a good degree of accuracy, but unfortunately this is not the case with measurement of the distances to individual SNRs. Any study of successive catalogs of galactic SNRs will reveal that some have had their published distances amended by a substantial factor.

The Angle Subtended by an SNR at the Earth

This will be labeled θ and will be measured in minutes of arc. This observational data can be used in conjunction with *d* to find the actual diameter of individual SNRs.

The Diameter of an SNR

This will be labeled D and will be measured in parsecs.

Modeling the Size of Second-Stage SNRs

The Sedov model is named after the astronomer who, in 1959, laid the foundations for the theoretical analysis of the long second stage of SNR expansion, which begins a few hundred years after an SNR is formed. The approach of Sedov is widely used. The Sedov relation assumes that the diameter of an SNR will approximate $D \propto t^{2/5}$ rather than the $D \propto t$ relation of the relatively brief first stage (Mihalas and Binney 1981, p. 543).

We can write the Sedov relation as

$$D = k\, t^{2/5} \qquad \text{Equation (1)}$$

A theoretical estimate for the value of *k* can be obtained from an analysis of the physical factors that underpin its value. Such an analysis has been carried out (Clark and Caswell 1976, p. 279). The relation is expressed as:

$$D = 4.3 \times 10^{-11} (E_0/n)^{1/5}\, t^{2/5} \qquad \text{Equation (2)}$$

The Duration of the Second Stage

The length of time an SNR will remain in its second stage of expansion will be determined by its initial expansion characteristics and the characteristics of the medium it is moving through. One estimate (Cioffi and McKee 1988, p. 435), using $E_0 = 10^{51}$ ergs for the initial energy and $n = 0.1$ for the density of the interstellar medium it passes through, gives the duration of the second stage as 120,000 years.

The Radio Luminosity of Second-Stage SNRs

A useful theoretical study (Cioffi and McKee 1988) has shown that the total luminosity of an average SNR will ***increase*** by nearly 200 times during the second-stage period of 120,000 years. It will increase from about 10^{36} ergs s^{-1} to 1.9×10^{38} ergs s^{-1} (or 10^{29} watts to 1.9×10^{31} watts). This important characteristic of a second-stage SNR—the continual increase in power through the duration of the stage—occurs because the SNR sweeps up increasing amounts of dust and gas. This will then increase the numbers of individual electrons that are emitting synchrotron radiation.