THE DISTRIBUTION AND BIRTHRATE OF GALACTIC SNRs

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Abstract: In this paper we find that the spatial distribution of SNRs shows a peak in the range R = 4-6 kpc; the total number of SNRs in the Galaxy is 749±104; and the birthrate of SNRs is one in every 18±3 years.

Introduction: The distribution of supernova remnants (SNRs) in our Galaxy has been investigated by Ilovaisky and Lequeux (1972) and Kodaira (1974). Since their investigations only gave the distribution for SNRs which have diameters D<30 pc, it is not possible to estimate the total number and the birthrate of SNRs from their work.

We improve the method of Kodaira (1974) and adopt the catalogue of SNRs given by Li (1985). It contains 155 SNRs of which there are 7 without values of angular diameter and flux density. So our statistical sample has 148 SNRs.

1. Discussion of Observational Selection Effects

Ilovaisky and Lequeux (1972) suggested that three selection effects must be considered: (1) limiting angular diameter; (2) limiting surface brightness; (3) limiting flux density. To attempt to correct for these selection effects, they limited their sample to sources with angular diameters larger than 2 minutes of arc; distances to the Sun d<6.3 kpc; D<30 pc; and flux densities larger than 10 Jy at 1 GHz.

We do not adopt these criteria since to do so would remove many SNRs, more than 50%, from our sample. Kodaira (1974) used an alternative approach in which the incomplete counting is regarded as caused by confusion with noise. The degree of the confusion was to be empirically determined as a function of distance from the observer, independent of the direction. However, he still chose only SNRs with D<30 pc.

We improve the method of Kodaira to correct for the selection effects. We need not remove those SNRs with D<30 pc and S<10 Jy from our sample. Thus we obtain a larger statistical sample.

2. Statistical Method and Determination of the Surface Density

Because most of the SNRs are distributed in a flat system, the galactic plane, we consider only the surface density of SNRs. We assume that the surface density is symmetric around the galactic center (i.e. is a function of distance to the galactic centre (R) only). Secondly, we assume that the observations of SNRs are complete within 2 kpc of the Sun. In this region the selection effects are not a factor.

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Figure 1 The relation $N(<r)/\pi r^2$ with r

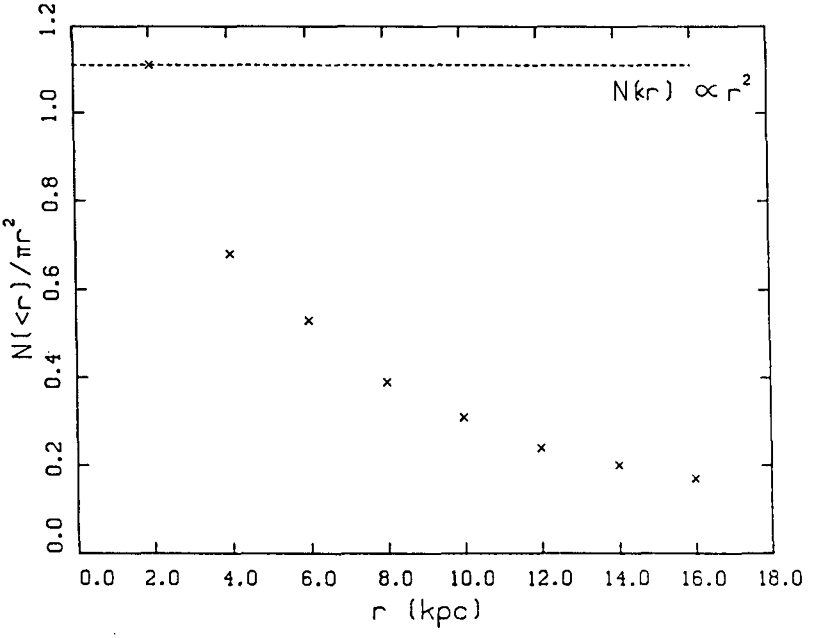
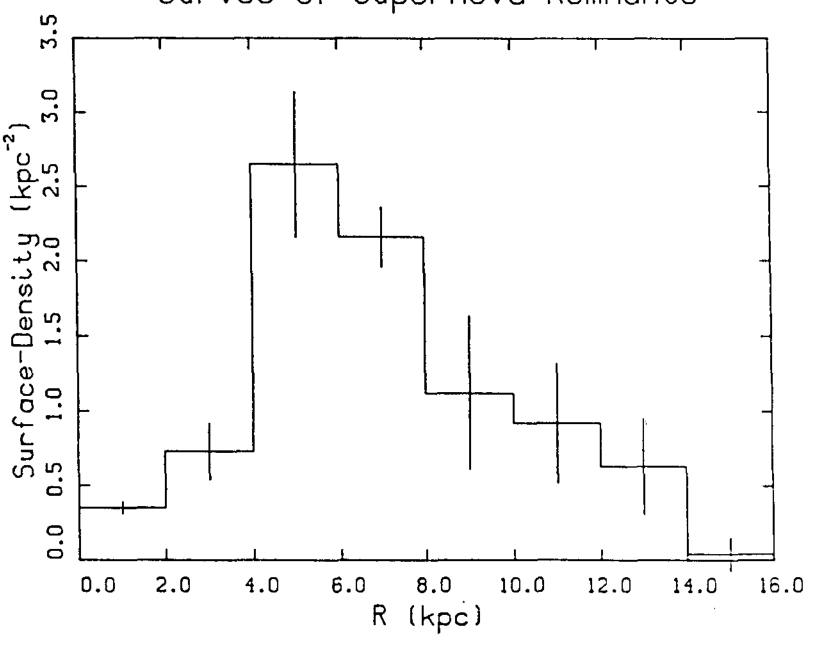


Figure 2 Present Results of Surface-Density Curves of Supernova Remnants



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We first obtain the apparent surface density of SNRs. We adopt the distances given by Li (1985). For the remainder we use the Σ_{1GHz} - D relations given by Li and Wheeler (1984):

$$\Sigma_{1GHz} = 3.1 \times 10^{-17} D_{pc}^{-2.4} \text{ W m}^{-2} \text{ Hz}^{-1} \text{ sterad}^{-1} \text{ for crablike SNRs}$$

$$\Sigma_{1GHz} = 1 \times 10^{-16} D^{-2.77} \text{ W m}^{-2} \text{ Hz}^{-1} \text{ sterad}^{-1} \text{ for shell SNRs}$$

If SNRs were uniformly distributed throughout the galactic disk we should expect $N(<r)$, the number of SNRs with distance less than r, to increase as r^2 and expect $N(<r)/\pi r^2$ to equal a constant independent of r. The values of $N(<r)/\pi r^2$ are not constant with distance r. The result shown in Figure 1 largely reflects the fact that the incomplete counting due to observational selection becomes more serious with increasing distance from the Sun.

Now we consider the derivation of correction factors for the effects of incomplete counting. According to our second assumption the observations of SNRs are complete within 2 kpc of the Sun, so the true surface density is equal to the apparent surface density in this distance range. According to the first assumption, the surface density of SNRs is symmetric around the galactic center. So the surface density of SNRs must be the same within each ring of R to R + ΔR. We use these two assumptions to calculate the correction factors for each counting range. Figure 2 shows the distribution of surface density corrected for observational effects with $\pm 1\sigma$ error bars. This distribution shows a peak in the range of R = 4-6 kpc.

3. The Estimation of Total Number and Birthrate of SNRs

The total number of SNRs in the Galaxy obtained by an integration over the galactic radial distribution of Figure 2 is 749±104.

In order to derive the birthrate of SNRs, we must know the average lifetime of SNRs. Using the formula for shock radius versus time from the adiabatic phase in the standard Sedov model and considering the effect of the three component medium on $R_s(t)$ without cloud evaporation (Cox 1979), we have an age versus diameter relation:

$$t = \left(\frac{D}{22.4\text{pc}}\right)^{2.5} \left(\frac{n_h f_h}{\varepsilon}\right)^{0.5} \times 10^4 \text{ years} \qquad (1)$$

For calculating ages we choose f_h (filling factor) = 0.75, ε (blast energy in units of 0.75 x 10^{51} ergs) = 2/3 and n_h (hot intercloud medium density) = 0.005 cm^{-3}.

However young SNRs expanding in the ISM will not have swept up enough mass to have reached the self-similar phase of evolution. For these remnants the expansion is approximately linear with age (Gull 1973). The transition between linear and self-similar phases occurs when the swept up mass from the hot medium is of order one solar mass.

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This gives a transition radius of $R_0 = 11.2(n_h/0.005)^{-1/3}$ pc. For an adopted value of n_h, matching $R = V_{ej}t$ to formula (1) at 11.2 pc gives an ejection velocity of 14700 km s^{-1}, in good agreement with SN models (10,000 to 20,000 km s^{-1}). Thus, for remnants less than 11.2 pc in radius we calculate age from the linear formula.

The average age for our SNR sample is 6.8 x 10^3 years. As a check on the method, the calculated ages for historical supernova remnants are compared with true ages in Table 1. We see that the ages agree very well with the true ages for SN 1604 and SN 1572, and reasonably well for SN 1188 and SN 185. Exceptions are: Cas A, located in a higher density region of ISM; SN 1006, at large distance from the galactic plane (lower density); SN 1054 (the Crab SNR), powered by a central pulsar. This agreement, with explained exceptions, indicates that the formula for age we have chosen gives correct age estimates.

Table 1 Historical SNRs

	Cas A	SN1604	SN1572	SN1188	SN1054	SN1006	SN185
True age (years)	~325	383	415	806	933	981	1902
Calculated age (years)	65	295	398	389	90	4470	2820

Generally, the average lifetime is twice the average age. Using the result for the total number in the Galaxy, the birthrate of SNRs is one in every 18 ± 3 years. This birthrate is higher than most previous estimates which range from one in every 50 to 150 year (Caswell, 1970; Clark and Caswell, 1976), but near the result (one in every 22 yr) of Srinivasan and Dwarakanath (1982). This result is also consistent with the SN birthrate (one in every 11 yr to 30 yr) derived by Clark and Stephenson (1977), Katgert and Oort (1967), and Tamman (1977). This result also agrees with results for pulsar birthrates.

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