ON THE INITIAL ENERGY OF SUPERNOVA REMNANTS

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Abstract. An examination of the histogram of the supernova remnants radii allows one to deduce: (1) some support for the existence of a fairly dense galactic halo at least up to a few kpc from the galactic plane; (2) a first approximation for the initial energy distribution. Although the precise shape is still in doubt and various possibilities exist, one can conclude that the supernova rate should be no less than 1/150 SN yr\(^{-1}\), and no more than 1/70 SN yr\(^{-1}\); the average initial energy should be larger than \(1.4 \times 10^{49}\) erg.

1. Introduction

The main lines of the evolution of supernova remnants (SNR) are fairly well known by now, although a large number of details remain to be explained. A comprehensive review has been given in recent works by Downes (1971), Ilovaisky and Lequeux (1972a, b) and Woltjer (1972) among others, and the necessary refinements have been pointed out in more or less detail in the same papers.

However, even the most elementary theory is affected by a considerable uncertainty about the values of the three fundamental parameters \(E_0\), \(M\), and \(n\), where \(E_0\) is the initial energy, \(M\) is the mass of the ejected shell, and \(n\) is the density of the interstellar medium against which the SNR expands. From the values directly estimated in a few cases it is apparent that these parameters are quite broadly distributed, and this circumstance causes a considerable hindrance to the understanding of a number of properties of the SNR, both as individuals and as a class.

In the present paper we attempt to establish a function \(p(E_0)\ dE_0\) which assigns the probability that a SNR started out with an initial energy between \(E_0\) and \(E_0 + dE_0\). We shall restrict ourselves to the most elementary theory, and therefore the results will only assume an indicative value. C.g.s. units will be used throughout unless otherwise stated.

2. Reduction to a Single Parameter \(E_0\)

In order to have a theory which can be handled, we must first of all reduce all data to one single parameter. This can be done under two assumptions:

(i) The dependence of \(n\) upon \(z\) (the elevation above the galactic plane) is well represented by \(n(z) = n_0 \exp \left(-z/z_0\right)\), where, according to the latest estimates, \(n_0 = 0.8\) cm\(^{-3}\), and \(z_0 = 128\) pc.

(ii) Most observed radio remnants are in the second phase of their evolution, i.e. they are expanding adiabatically. This assumption allows one to eliminate the parameter \(M\) since the time dependence of the SNR radius in the second phase is \(R = \ldots\).
We can thus eliminate the parameter $n$ from all remnants, since we assume to know with a fair approximation the distance of the remnants and, therefore, their elevation above the galactic plane. This is done by means of an empirical relationship $\Sigma \propto R^{-k}$, where $\Sigma$ is the surface brightness and $R$ is the radius of the remnant. The estimates by Downes (1971) have been adopted in this paper.

We shall first proceed to test both assumptions. This is done by observing that the final radius of the second phase is given by $R_{\text{max}} = 5.14 \times 10^{4} n^{-7/17} E_{0}^{5/17}$. Therefore, if the remnant really is in the second phase, it must be $R_{\text{obs}} \leq R_{\text{max}}$, or, equivalently, $E_{0} \geq \varepsilon = 9.6 \times 10^{-17} R^{17/5} n^{7/5}$. For remnants which already are close to the end of the second phase, the value of $\varepsilon$ approximates $E_{0}$. On the contrary for remnants which are in the early second phase, or even in the first phase, $\varepsilon$ gives a rather low bound for $E_{0}$. Figure 1 gives the histogram of the $\varepsilon$, which we shall call a 'symbolic $E_{0}$'.

3. Consequences of the $N(\varepsilon)$ Distribution

An examination of the values of the symbolic initial energy is rewarding. First of all one sees a distribution of energies concentrated between $10^{48}$ and $10^{52}$ erg. The maximum initial energy seems to be of the order of $2 \times 10^{51}$ erg; only five out of 113 SNR require an $E_{0} \geq 2 \times 10^{51}$ erg; the largest amount ($8.35 \times 10^{51}$ erg) is required by Monoceros. This would be a considerable portion of the total energy available in the