# $\Sigma$-*D* RELATIONS AND MAIN GALACTIC RADIO LOOPS

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**Abstract.** This paper represents the updated empirical Galactic and extragalactic $\Sigma - D$ relations (relations between the surface brightness $\Sigma$ and the diameter $D$) for supernova remnants (SNRs), with checking the connection of the main Galactic radio loops (Loop I, II, III and IV) with these relations. We present results which suggest, once again, that the radio loops may have an SNR origin. The updated relations for old SNRs have been measured to have slopes, $\beta \approx 2$ in log-log space. The best $\Sigma - D$ relations for M31 and M33 galaxies were derived and these relations are shown to be flatter ($\beta \lesssim 2$) than those for Galactic SNRs alone. A $\Sigma - D$ relation with 168 reliable calibrators (both Galactic and extragalactic) is derived.

**Keywords:** supernova remnants, $\Sigma$-$D$ relation, galactic radio loops

## 1. Introduction

In this paper, we present the brief review of the updated relations between the radio surface brightness $\Sigma$ and the diameter $D$ (so called $\Sigma - D$ relation) for supernova remnants (SNRs). The $\Sigma - D$ relations have been used to investigate the origin of the main Galactic radio loops (Loop I, II, III and IV). Berkhuijsen (1973) showed that Loops fit galactic $\Sigma - D$ relation of that time. An extensive analysis of all Galactic and extragalactic $\Sigma - D$ relations is in Urošević (2000).

### 1.1. THE $\Sigma - D$ RELATION

### 1.1.1. *The Theoretical Relation*

The $\Sigma - D$ relation is a convenient method for investigation of the radio brightness evolution of supernova remnants (SNRs). Shklovsky (1960a) theoretically analyzed synchrotron radiation of a spherical adiabatic expanding nebula and the $\Sigma - D$ relation is the result of that theoretical analysis. It has the form:

$$\Sigma = AD^{-\beta}, \tag{1}$$

with slope $\beta = 6$ ($\alpha = 0.5$ – the average spectral index for SNRs, used in all determinations of the theoretical $\Sigma - D$ slopes). Spectral index is defined by $S_\nu \propto \nu^{-\alpha}$. The relation with $\beta = 5.8$ was derived theoretically by Lequeux (1962). Poveda and Woltjer (1968) derived the relation with $\beta = 3$. The slope $\beta = 4.5$

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was derived by Kesteven (1968). An updated theoretical derivation of this relation for shell-like SNRs is reported by Duric and Seaquist (1986, hereafter D&S). The D&S model gives $\beta = 3.5$ for SNR diameters $D \gg 1$ and $\beta = 5$ for $D \ll 1$.

If we suppose spherically expanding SNR with constant luminosity – $L_\nu$ ( or independent of the SNR diameter), relation has a form:

$$\Sigma_\nu \propto L_\nu D^{-2}. \tag{2}$$

This relation represents the 'trivial' theoretical $\Sigma - D$ form.

### 1.1.2. *The Galactic Relation*

Early observations suggested the existence of a $\Sigma - D$ relation in the form the Shklovsky theory had predicted. The first empirical $\Sigma - D$ relation was determined by Poveda and Woltjer (1968). Using the $\Sigma - D$ relation Shklovsky (1960b) presented a way for determining the distances to SNRs as surface brightness is independent of the distance to the radio source. Milne (1970) derived an empirical $\Sigma - D$ relation and calculated distances to all observed SNRs in our Galaxy (97 in total).

During the 1970s and the early 1980s, Galactic $\Sigma - D$ relations were determined by many authors (e.g. Ilovaisky and Lequeux, 1972; Clark and Caswell, 1976; Sakhibov and Smirnov, 1982). Critical analysis of this relation began with Allakhverdiyev et al. (1983) and continued with the research of Green (1984) and Allakhverdiyev et al. (1986). Berkhuijsen (1986) showed that the shape of the $\Sigma - D$ relation can be explained by variations in gas density of the surrounding medium. Once again, Green (1991) showed that calibrators are too scattered on the $\Sigma - D$ diagram so that no valid relation can be derived. However, this view was challenged by Case and Bhattacharya (1998, hereafter C&B). This paper is based on the calculations of new distances to the calibrators (37 of them), with the help of new galactic constants. The result was a much flatter slope for the Galactic $\Sigma - D$ relation.

### 1.1.3. *Extragalactic Relations*

Constructions of the extragalactic $\Sigma - D$ relations are very useful because all calibrators are approximately at the same distance. Therefore the distance determination problem does not exist, if we know the distance to the galaxy. If we identify a SNR, that SNR becomes a calibrator. Furthermore, an extragalactic set of SNRs does not suffer from Malmquist bias (distance dependent selection effect). However, sensitivity becomes an issue and most extragalactic SNRs have therefore been detected in the nearby galaxies (the Large and Small Magelanic Clouds (LMC and SMC), M31, M33).

The first empirical extragalactic $\Sigma - D$ relation was constructed by Mathewson and Clarke (1973) for LMC. Braun and Walterbos (1993) identified 51 SNRs in M31 using VLA. Also, Duric et al. (1995) identified 53 SNRs in M33 using VLA.

In general, the extragalactic relations were found to be flatter than the Galactic relations.

### 1.2. SELECTION EFFECTS

Data sets of Galactic SNRs suffer from strong Malmquist bias. Simply put, this means that intrinsically bright SNRs are favored because they are sampled from a larger spatial volume in any given flux limited survey. The result is a bias against low surface-brightness remnants such as highly evolved old SNRs which could make the $\Sigma - D$ relation too steep. On the other hand, data sets made up of extragalactic SNRs do not suffer from Malmquist bias because all SNRs are at the same distance and are therefore sampled from the same volume. Though extragalactic data sets are generally better behaved relative to Galactic samples, they do suffer from other selection effects. These effects are connected with sensitivity, resolution and confusion leading to data sets that span a shorter range of diameters and surface brightness.

The Malmquist bias causes a surplus in the number of smaller and younger SNRs. As the radio loops are big (evolved) objects, they could moderate this selection effect if they are indeed old SNRs. Radio loops are important objects, and could be used as calibrators for valid $\Sigma - D$ relation. Therefore, the radio loops should on the $\Sigma - D$ relation for shell-type SNRs. It could be another way for showing of the SNR origin of the radio loops. Berkhuijsen (1973) showed that this is indeed the case.

We test extragalactic relations together with the radio loops. It is one way for moderation of the selection effect which origin is in the radio telescope sensitivity (surface brightness limit). In the future, we will be able to try to detect the low brightness SNRs (loops-like objects) in the other galaxies, if we want to establish the valid set of calibrators and valid $\Sigma - D$ relation.

### 1.3. MAIN GALACTIC RADIO LOOPS

For more then three decades it has been known that some radio spurs can be joined into small circles. The set of spurs belonging to such a circle is referred to as a loop. By the early seventies four major galactic loops were recognized in this way. They can be seen clearly in all-sky radio continuum images. The most precise determination of the parameters of these loops was performed by Salter (1970) and published in Berkhuijsen et al. (1971). Salter used the best data available at the time, at 408 MHz, 404 MHz, 240 MHz and 178 MHz. A detailed review of the subject was also published by Salter (1983).

Although our understanding of these intriguing objects still contains a considerable number of loose ends and question marks, the supernova theory of their origin acquired an enhanced respectability. The SNR radio loop hypothesis originated in the work by Brown et al. (1960). The first radio loop model supportive of the SNR hypothesis can be attributed to Berkhuijsen et al. (1971). It is based upon the geometry of radio loops (follow a small circle on the sky) (Salter, 1970); (later on confirmed in the paper by Milogradov-Turin and Urošević, 1997) through observations of intensity gradients in the brightest part of the spur, HI regions attached to the outer edges of the remnants, runaway stars and spectral indices typical for non-thermal geometric.

These pioneering investigations led to many others that supported the SNR radio loops hypothesis (e.g. Salter, 1983; Kosarev et al., 1994; Egger and Aschenbach, 1995; Sembach et al., 1997). Naturally, there were other models which explained the origin of radio loops in completely different manner (e.g. Mathewson, 1968; Sofue, 1977, 1994).

### 1.4. THE BASIC EVOLUTION THEORIES OF THE SNRS' RADIO EMISSION AND THE RADIO LOOPS

There are two traditional evolution theories of the SNRs' radio emission: the Shklovsky theory (1960a,b) and the van der Laan theory (1962a,b). The main difference between these two is the following: according to van der Laan, the SNR magnetic field is amplified by compression of the interstellar magnetic field (due to the interaction between the shock wave and the envelope ejected by the explosion) and the SNR radiates from the edge of the cloud whereas the magnetic field remains constant with the expansion of the remnant. Contrary to that opinion, the Shklovsky theory claims that the whole expanding sphere is radiating and the magnetic field (frozen in it) decreases with the square of radius. It is evident that the radio loops model (assuming that the loops are local SNRs) should be supported by van der Laan theory due to the shell-like remnant geometry and the constant magnetic field that should extend to greater dimensions easily. Spoelstra (1972, 1973) compared the parameters received from his polarization observations of the radio loops (also, showing the loops are nearby objects) with the parameters given by van der Laan theory and reached a 'reasonable' fit. Only at first glance, the updated D&S theoretical interpretation of the initial Shklovsky theory does not explain the nature of the radio loops, but if we use empirical $\Sigma - D$ relations, loops however could be explained as supernova remnants in the sense of McKee and Ostriker's (1977) SNR model – a big SNR still in the adiabatic phase.

Section 2 contains analysis of the all updated $\Sigma - D$ relations. The discussion is in section 3. The main conclusions derived from this paper are in section 4.

## 2. Analysis and Results

In this section, we update and analysis Galactic and extragalactic $\Sigma - D$ relations in two ways. First, we add radio loops to the updated Galactic relation to determine if the loop properties are consistent with a SNR origin. Second, we compile the latest data and derive the M31, M33 and 'master' relations.

The review of all Galactic and extragalactic $\Sigma - D$ relations, with variants of the original calibrators to which supplement loops or some the other evolved SNRs are added, is given by Urošević (2000).

We have accepted surface brightness (at 1 GHz) and diameters (in pc) for four main radio loops from the Berkhuijsen (1986) study. All initial calibrators along with the radio loops, which define the following $\Sigma - D$ relations, are assumed to have equal statistical weight. The least square fit is used. The fit quality is defined as percent of residuals about mean explained.

The parameters of the all updated relations at 1 GHz (without and including Loops) are listed in the Table I.

### 2.1. THE UPDATED GALACTIC RELATION

More recently an updated Galactic $\Sigma - D$ relation was constructed by C&B. Thirty seven galactic shell-like remnants with reliably calculated distances were taken as calibrators. Whenever the kinematic method was required for determination of the distances to the calibrators, a rotation model based on the values of galactic constants $R_\odot = 8.5$ kpc and $V_\odot = 220$ km/s was used. Two $\Sigma - D$ relations were derived. The first one is referring to all thirty seven remnants and the other one to thirty six remnants (without Cas A which deviates greatly from the best-fit line). C&B considered the latter relation more representative since Cas A is unusual compared to other Galactic, shell-like remnants. They found a flatter slope ($\beta = 2.38 \pm 0.26$) using the thirty-six calibrators, and concluded that this result is in good agreement with $\Sigma - D$ relations for LMC and SMC.

### 2.2. THE UPDATED EXTRAGALACTIC RELATIONS

#### 2.2.1. *Relation for M31*

Using the catalogue by Braun and Walterbos (1993), we derived updated relation for M31. Relation was derived on the basis of the quoted quality of the data for the 51 detected SNRs in M31. The catalogue does not contain the spectral index information. Therefore, we have used an average spectral index of $\alpha = 0.5$ for the SNRs using the observed flux density at 1465 MHz. The diameters were obtained from the optical measurements (Braun and Walterbos, 1993).

Using their 30 calibrators (24 best radio identified SNRs with signal-to-noise ratios greater than 5, along with 6 low quality identified SNRs – 5 > signal-to-noise ratio in flux density > 3), we obtained relation at 1465 MHz in form $\Sigma \propto D^{-1.69\pm0.27}$.

#### 2.2.2. *Relation for M33*

Using the new sample of radio-selected and optically confirmed SNRs in M33 by Gordon et al. (1999), we derived updated relation for M33. There are 51 detected SNRs at the 1465 MHz. We adopted $\alpha = 0.5$ for 9 SNRs which had no spectral index information. The diameters are from the optical measurements.

Using 51 SNRs, we obtained relation at 1465 MHz in form $\Sigma \propto D^{-1.74\pm0.19}$.

### 2.2.3. *Relation for M82*

The starburst galaxy M82 is very interesting object because in it contains many young SNRs. Fifty SNRs were identified by Huang et al. (1994). All remnants are less than 6 pc in diameter. The same authors constructed the $\Sigma - D$ relation for these remnants at 8.4 GHz and they obtained $\beta = 3 \pm 0.3$. They used 39 remnants with precisely determined angular diameters and flux densities. In this paper, we have chosen 11 calibrators with the spectral indices calculated from observations (in range $0 < \alpha < 1$). For 11 remnants with reliable diameters and calculated spectral indices, the relation obtained at 8.4 GHz has the form $\Sigma \propto D^{-3.61\pm0.30}$.

## 2.3. COMBINING THE GALACTIC AND EXTRAGALACTIC RELATIONS – THE 'MASTER' RELATIONS

In this section we will derive relations for the combination of Galactic and extragalactic SNRs. The first relation is constructed for 36 C&B Galactic calibrators (without Cas A remnant) along with calibrators from the Large (without 0505-679 SNR) and Small Magellanic Clouds. The calibrators from Magellanic Clouds are adopted from Berkhuijsen (1986). We use 29 calibrators from LMC and 11 from SMC, 30 radio detected calibrators from M31 and 51 from M33 galaxy. For 157 remnants from our Galaxy, LMC, SMC, M31 and M33 galaxies, obtained 'master' relation at 1 GHz has the form:

$$\Sigma_{1\mathrm{GHz}} = 8.59^{+5.13}_{-3.21} \times 10^{-18} D^{-2.07\pm0.13}, \tag{3}$$

with a 61% fit quality.

If we add the Galactic loops to the set of 157 calibrators, the following relation is derived:

$$\Sigma_{1\mathrm{GHz}} = 8.43^{+4.49}_{-2.93} \times 10^{-18} D^{-2.06\pm0.12}, \tag{4}$$

with a 65% fit quality. For 168 remnants from our Galaxy, LMC, SMC, M31, M33 and M82 galaxies, obtained 'master' relation at 1 GHz has a form:

$$\Sigma_{1\mathrm{GHz}} = 3.47^{+1.42}_{-1.01} \times 10^{-16} D^{-3.10\pm0.10}, \tag{5}$$

with a 85% fit quality – Figure 1. If we add the Galactic loops to the set of 168 calibrators, the following relation is derived:

$$\Sigma_{1\mathrm{GHz}} = 2.76^{+1.10}_{-0.79} \times 10^{-16} D^{-3.02\pm0.10}, \tag{6}$$

with a 85% fit quality – Figure 2.

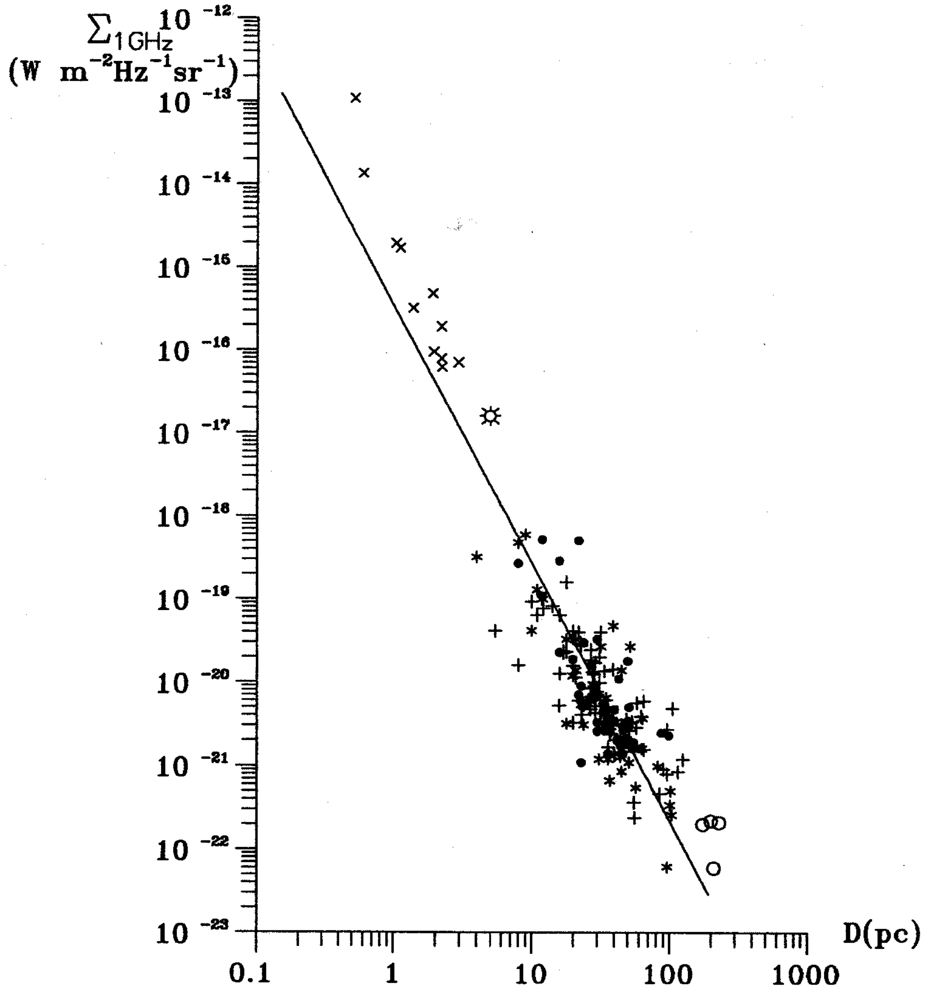

*Figure 1.* The combined $\Sigma - D$ diagram at a frequency of 1 GHz. The SNRs are represented by: asterisks (C&B), full dots (LMC and SMC), pluses (M31 and M33), crosses (M82). Cas A remnant is drawn in. Loops are represented by circles. The fit is without the loops.

## 3. Discussion

The previous tests for particular updated $\Sigma - D$ relations show that the large radio loops fit on the $\Sigma - D$ relation and therefore could be consistent with large, evolved supernova remnants. The big loops diameters could not present a problem yet, because expanded SNR in hot and thin environment could reach huge diameter and still be in the adiabatic phase (McKee and Ostriker, 1977), for which the theoretical relation was defined.

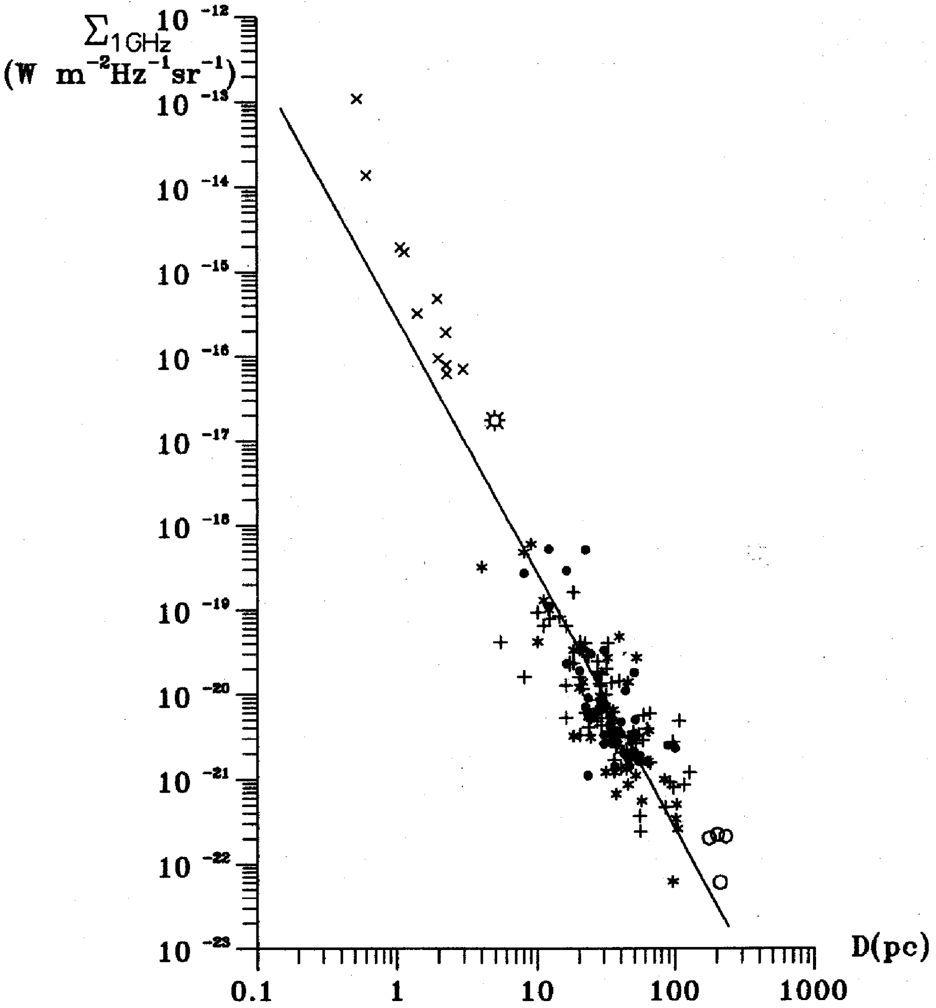

*Figure 2.* Same as in Figure 1 (the fit including the loops).

The combined $\Sigma - D$ relation contains two distinct components. For diameters less than 10 pc the relation has a steep slope with $\beta \approx 4.1$ (Table I) while for larger SNRs the slope is significantly shallower with $\beta \approx 2.1$ (relations 3 and 4). The Galactic loops are clearly part of the shallower component.

The Galactic $\Sigma - D$ relation is atypically steep relative to the 'master' $\Sigma - D$ relation (not including the very young SNRs in M82). This result supports the contention that the Galactic sample of SNRs is subject to severe selection effects and is, therefore, suspect for the purposes of calculating $\Sigma - D$ relations. These results suggest that even the modestly steep relation of C&B may be too steep,

TABLE I

The fit characteristics of the updated $\Sigma - D$ relations at 1 GHz

| galaxy | $\beta$ (–loops)<br>fit quality | $\beta$ (+loops)<br>fit quality | SNRs No.<br>(comments) |
|---|---|---|---|
| M31 | $1.69 \pm 0.27$<br>59% | $1.78 \pm 0.18$<br>75% | 30 |
| M33 | $1.76 \pm 0.19$<br>62% | $1.92 \pm 0.15$<br>77% | 51 |
| "Milky Way" | $2.38 \pm 0.26$<br>71% | $2.23 \pm 0.20$<br>76% | 36<br>(–Cas A) |
| M82 | $4.08 \pm 0.39$<br>92% | $3.12 \pm 0.10$<br>99% | 11 |
| "Master" | | | |
| | $2.07 \pm 0.13$<br>61% | $2.06 \pm 0.12$<br>65% | 157<br>(–M82) |
| | $3.10 \pm 0.10$<br>85% | $3.02 \pm 0.10$<br>85% | 168 |

possibly a result of Malmquist bias. These findings favor the interpretation of Green (1991).

The best $\Sigma - D$ relations for extragalactic SNRs are derived. In the process demonstrated in this paper, beyond any doubt, the slopes for the M31 and M33 $\Sigma - D$ relations are flatter ($\beta \lesssim 2$) than for the ‘master’ relation (not including the very young SNRs in M82). This result confirms that selection effects, especially connected with sensitivity and confusion, may play an role in data-sets made up of the M31 and M33 SNRs.

We do not conclude from this analysis that a difference in density of the ISM between Galaxy and M31 or M33 produces the difference in slopes ($\Delta\beta \approx 0.6$). This variation in $\beta$ defines the variation in spectral index $\Delta\alpha = 0.12$ using the D&S theoretical relation. This value is within the uncertainty of measured spectral index in M33 (see Duric, 2000b). Therefore, the selection effects are responsible for the difference in slopes.

The $\Sigma - D$ relation for M82 is anomalously steep relative to ‘master’ relation and the SNR diameters are uniquely small compared to the other SNRs in the master sample. The measured slope for the smaller SNRs is $4.1 \pm 0.4$ while that of the remaining SNRs in the master relation is $2.1 \pm 0.1$. The change in slope for small diameter remnants is in the same sense and comparable in magnitude to that predicted by the theoretical $\Sigma - D$ relation of D&S. However, the actual values of the slope are different. Some of this discrepancy could be accounted for if the SNRs are expanding in widely differing media. From the theory, the surface brightness of the SNR is a function of the density of the gas of the medium that the SNR is interacting with (Duric, 2000a). The dependance has a form

$$\Sigma \propto B^{1+\alpha} n_e D^{-2}, \tag{7}$$

where $B$ is the magnetic field strength and $n_e$ is the number density of pre-shock thermal gas. In any case, the M82 result supports the previous observations that the SNRs in M82 are younger and follow a different evolutionary track in the $\Sigma - D$ plane. Furthermore, the severe slope of the M82 relation is not resulted by the selection effects, because the difference in slopes is approximately three time greater than that known selection effects could produce in the Galaxy or in the M31 and M33 data-sets.

If we compare tests in this paper, we deduce: (1) if in initial relation $\beta \lesssim 2$, after loops addition $\beta$ will increase and (2) if in initial relation $\beta \gtrsim 2$, after loops addition $\beta$ will decrease. These tests results are supported value $\beta \approx 2$ (e.g. Mills, 1983; Mills et al., 1984; C&B; Urošević 2000). The $\Sigma - D$ relation in D&S form is not correct, if $\beta = 2$ in the empirical relation. In that case theoretical relation gets the 'trivial' form (2). In future, with detection of greater number of the low brightness Galactic and especially extragalactic SNRs, theoretical relations will be much better interpreted. Those results could explain does or does not D&S theoretical $\Sigma - D$ relation have correct form?

In spite of the many problems connected with the empirical $\Sigma - D$ relation, it is still necessary for the distance determination to the Galactic SNRs. In our Galaxy, we could identify 231 SNRs (Green, 2001). Some 59 SNRs have a distances estimating on some different, more precisely way. For 172 SNRs only way is $\Sigma - D$ relation. Therefore, we must tend to determine better $\Sigma - D$ dependence and to surpass many problems connected with this relation.

## 4. Summary

(i) The addition of the Galactic loops to the relations extends the range of parameters to larger diameters. The absence of any significant change in the relations is consistent with the loops being large SNRs that represent more advanced stages of evolution. However, the small number of loops used and the lack of a clear understanding of the selection effects that affect them precludes any strong conclusions on this matter.
(ii) The addition of the Galactic radio loops moderate severe effects of Malmquist bias in Galactic data-set, and selection effects connected with sensitivity and confusion in M31 and M33 data-sets.
(iii) The addition of the Galactic loops push both the Galactic and extragalactic $\Sigma - D$ relations to a slope, $\beta = 2$. This suggests that SNRs with diameters greater than 10 pc form a $\Sigma - D$ relation in which $\Sigma \propto D^{-2}$. Such a relation is consistent with SNR luminosity that are statistically independent of $D$ (the trivial relation).

This result is consistent with a scenario in which the SNRs evolve in widely differing media. Alternatives to the trivial relation will be explored in a future papers.
(iv) The 'master' $\Sigma - D$ relations are derived. The SNRs are compiled to the set of 172 calibrators (with 11 M82 SNRs and 4 radio loops). The 'master' relation for 157 SNRs with diameters greater than 10 pc form relation with $\beta = 2.07$.
(v) The Galactic $\Sigma - D$ relation is atypically steep relative to the 'master' $\Sigma - D$ relation (not including the very young SNRs in M82). This result supports the contention that the Galactic sample of SNRs is subject to severe selection effect – Malmquist bias. Also, the flatter slope relations ($\beta \lesssim 2$) for M31 and M33 may to confirm that selection effects (especially connected with the sensitivity and the confusion), may play an role in data-sets made up of the M31 and M33 SNRs.
(vi) The change in slope for small diameter remnants from M82 is in the same sense and comparable in magnitude to that predicted by the theoretical $\Sigma - D$ relation of D&S, and it is not a result of the selection effects.

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## References

Allakhverdiyev, A.O., Amnuel, P.R., Guseinov, O.H. and Kasumov, F.K.: 1983, *Ap&SS* **97**, 261.
Allakhverdiyev, A.O., Guseinov, O.H., Kasumov, F.K. and Yusifov, I.M.: 1986, *Ap&SS* **121**, 21.
Berkhuijsen, E.M., Haslam, C.G.T. and Salter, C.J.: 1971, *A&A* **14**, 252.
Berkhuijsen, E.M.: 1973, *A&A* **24**, 143.
Berkhuijsen, E.M.: 1986, *A&A* **166**, 257.
Braun, R. and Walterbos, R.A.M.: 1993, *A&AS* **98**, 327.
Brown, R.H., Davies, R.D. and Hazard, C.: 1960, *Observatory* **80**, 191.
Case, G.L. and Bhattacharya, D.: 1998, *ApJ* **504**, 761. (C&B)
Clark, D.H. and Caswell, J.L.: 1976, *MNRAS* **174**, 267.
Duric, N.: 2000a, in: E.M. Berkhuijsen, R. Beck and R.A.M. Walterbos (eds.), *Proceedings 232*, WE-Heraeus-Seminar 22-25 May 2000, Bad Honnef, Germany, The Interstellar Medium in M31 and M33, p. 127.
Duric, N.: 2000b, in: E.M. Berkhuijsen, R. Beck and R.A.M. Walterbos, (eds.), *Proceedings 232*, WE-Heraeus-Seminar 22-25 May 2000, Bad Honnef, Germany, The Interstellar Medium in M31 and M33, p. 179.
Duric, N., Gordon, S.M., Goss, W.M., Viallefond, F. and Lacey, C.: 1995, *ApJ* **445**, 173.
Duric, N. and Seaquist, E.R.: 1986, *ApJ* **301**, 308 (D&S).
Egger, R.J. and Aschenbach, B.: 1995, *A&A* **294**, L25.
Gordon, S.M., Duric, N., Kirshner, R.P., Goss, W.M. and Viallefond, F.: 1999, *ApJS* **120**, 247.
Green, D.A.: 1984, *MNRAS* **209**, 449.
Green, D.A.: 1991, *PASP* **103**, 209.

Green, D.A.: 2001, *A Catalog of Galactic Supernova Remnants* (2001 December version), Mullard Radio Astronomy Observatory, Cambridge, United Kingdom (available on the World Wide Web at: http://www.mrao.cam.ac.uk/surveys/snrs/index.html).

Huang, Z.P., Thuan, T.X., Chevalier, R.A., Condon, J.J. and Yin, Q.F.: 1994, *ApJ* **424**, 114.

Ilovaisky, S.A. and Lequeux, J.: 1972, *A&A* **18**, 169.

Kesteven, M.J.L.: 1968, *Aust. J. Phys.* **21**, 739.

Kosarev, L.B., Loseva, T.V., Nemtchinov, I.V. and Popel, S.I.: 1994, *A&A* **287**, 470.

Lequeux, J.: 1962, *Ann. D'Astrophys.* **25(4)**, 221.

Mathewson, D.S.: 1968, *ApJ* **153**, L47.

Mathewson, D.S. and Clarke, J.N.: 1973, *ApJ* **180**, 725.

McKee, C.F. and Ostriker, J.P.: 1977, *ApJ* **218**, 148.

Mills, B.Y.: 1983, in: J. Danziger and P. Gorenstein (eds.), *IAU Symposium 101, Supernova Remnants and their X-ray Emission*, Reidel, Dordrecht, p. 551.

Mills, B.Y., Turtle, A.J., Little, A.G. and Durdin, J.M.: 1984, *Aust. J. Phys.* **37**, 321.

Milne, D.K.: 1970, *Aust. J. Phys.* **23**, 425.

Milogradov-Turin, J. and Urošević, D.: 1997, *Bull. Astron. Belgrade* **155**, 41.

Poveda, A. and Woltjer, L.: 1968, *AJ* **73**(2), 65.

Sakhibov, F.Kh. and Smirnov, M.A.: 1982, *Sov. Astron. Lett.* **8**(3), 150.

Salter, C.J.: 1970, *Ph.D. Thesis*, Manchester.

Salter, C.J.: 1983, *Bull. Astr. Soc. India* **11**, 1.

Sembach, K.R., Savage, B.D. and Tripp, T.D.: 1997, *ApJ* **480**, 216.

Shklovsky, I.S.: 1960a, *Astron. Zh.* **37**(2), 256.

Shklovsky, I.S.: 1960b, *Astron. Zh.* **37**(3), 369.

Sofue, Y.: 1977, *A&A* **60**, 327.

Sofue, Y.: 1994, *ApJ* **431**, L91.

Spoelstra, T.A.Th.: 1972, *A&A* **21**, 61.

Spoelstra, T.A.Th.: 1973, *A&A* **24**, 149.

Urošević, D.: 2000, *Ph.D. Thesis*, Belgrade.

van der Laan, H.: 1962a, *MNRAS* **124**, 125.

van der Laan, H.: 1962b, *MNRAS* **124**, 179.