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MAIN RADIO LOOPS AND THEIR CONNECTION WITH UPDATED $\Sigma - D$ RELATION

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Abstract. The origin of the main galactic radio loops (Loop I, II, III and IV) was examined using updated $\Sigma - D$ relation – relation between the surface brightness – Σ and the diameter – D for the supernova remnants (SNRs). Test result is in a very good accordance with SNR hypothesis of the radio loops origin.

1. INTRODUCTION

For more than three decades it is known that some radio spurs can be joint into small circle. The set of spurs belonging to the same small circle is referred to as a loop. By early seventies four major galactic loops were recognized. They can be seen clearly in all-sky radio continuum pictures. Although our understanding of these objects still contains a considerable number of loose ends and question marks, the supernova remnant (SNR) theory of their origin acquired an enhanced respectability. SNR radio loops hypothesis originated in the work by Brown *et al.* (1960). The first radio loop model supportive of the SNR hypotesys belongs to Berkhuijsen *et al.* (1971). These pioneer investigations led to many more others that supported the SNR origin of loops (e.g. Salter 1983, Sembach *et al.* 1997). There were other models which explained the origin of radio loops in completely different manner (e.g. Sofue 1994).

One way for understanding of SNR evolution is studying the relation between the surface brightness and the diameter of SNR ($\Sigma - D$ relation). Shklovsky (1960) developed the first theoretical $\Sigma - D$ relation. It has the form

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

Updated empirical $\Sigma - D$ relation is determined by Case & Bhattacharya (1998, hereafter 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, the new rotation model of our galaxy was applied to their calculation. This model is based on the values of galactic constants $R_\odot = 8.5$ kpc and $V_\odot = 220$ km/s. 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 remnant extremely dispersed from the fit line). C&B

considered second relation (case of thirty six calibrators) more representative since Cas A isn't the most ordinary SNR in comparison to other galactic, shell-like remnants. Flatter slope relation ($\beta = 2.38 \pm 0.26$) was derived in the case of thirty-six calibrators, and C&B concluded that this result shows good agreement with $\Sigma - D$ relations for the other galaxies.

In this paper, radio loops are affixed to C&B calibrators and the variation of the quotient β is examined. The result of this test could confirm SNR origin of the radio loops.

2. ANALYSIS AND RESULTS

If we accept surface brightness (at 1 GHz) and diameters (in pc) for four main radio loops from the Berkhuijsen (1986) study, and affix them to the set of the initial 36 C&B calibrators, the following relation is derived by the best fit method:

$$\Sigma_{1\mathrm{GHz}} = 1.31^{+1.46}_{-0.69} \times 10^{-17} D^{-2.23 \pm 0.20}. \qquad (2)$$

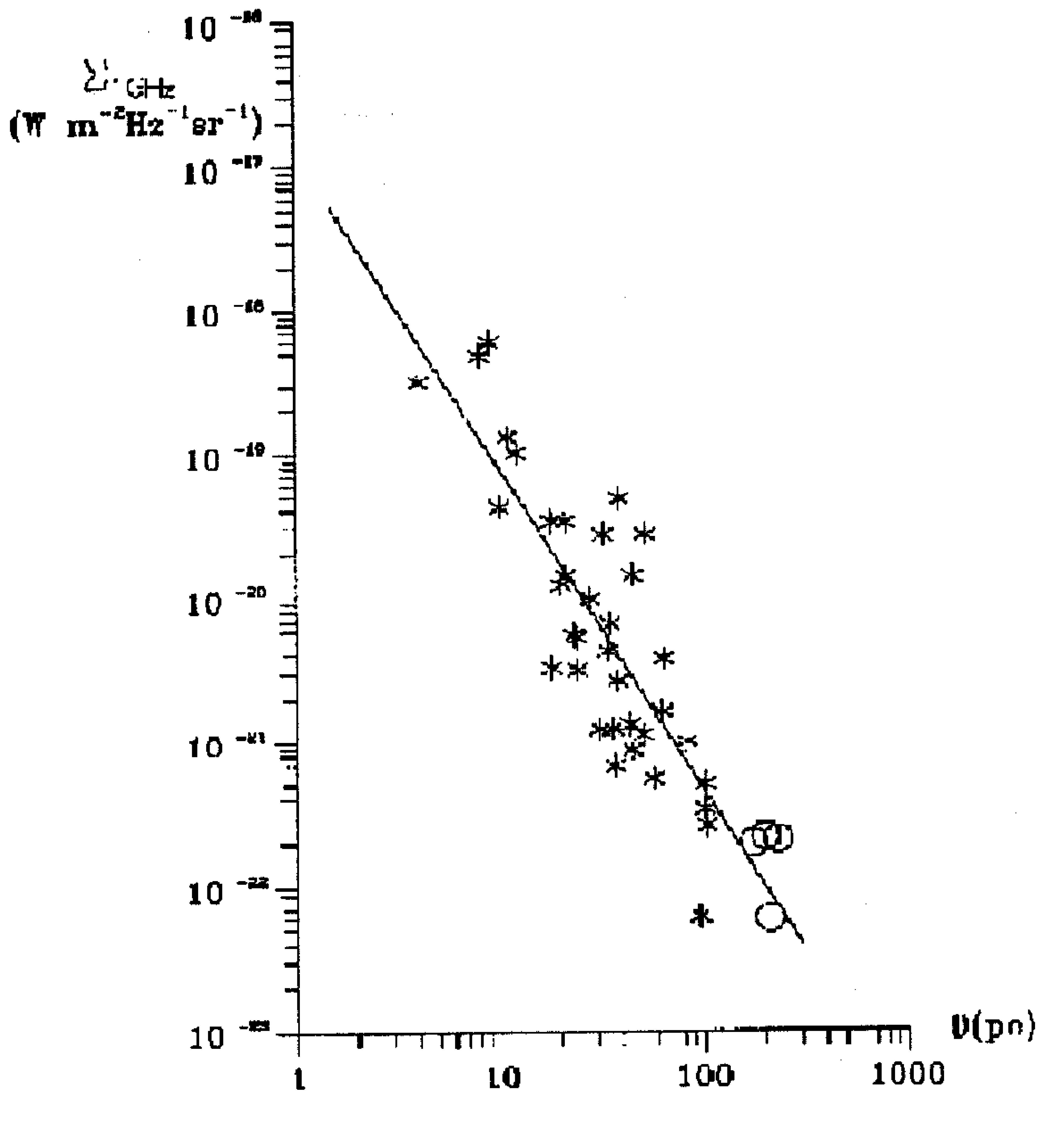

Fig. 1. $\Sigma - D$ diagram at frequency of 1 GHz. C&B calibrators are represented by asterisks and loops by circles.

All forty objects defining the relation (2) are of equal statistical weight. Quotient variation $\Delta\beta$=0.15 is easily noticeable as well as the fact that it corresponds to the interval predetermined by this quotient's error. This means that affixation of the loops to other calibrators alters the slope of the original relation keeping it in the permitted range of values. This test was done by Berkhuijsen (1973) only that at the time the latest empirical relation of Ilovaisky & Lequeuix (1972) was taken as the initial one. In her test, variation of β quotient in the case of the equal statistical weights is $\Delta\beta \approx 1$. Original calibrators were supplemented with Loop I and Origem loop.

$\Sigma - D$ diagram associated with relation (2) defined for thirty six calibrators along with four main radio loops is showed in Fig. 1.

3. DISCUSSION

With loop affixation, fit quality is rising up by 5% (from 71% to 76%). Scattering is noticeable but basically explained by the facts that remnants are evolving in different interstellar medium, they have different energy of explosions, unreliably calculated calibrators distances, possibility that the set of calibrators contains supernova remnants of Type I and Type II at the same time (e.g. Dickel *et al.* 1993). Loops are occupying lower right area of $\Sigma - D$ diagram (see Figures 1 and 2) and balancing the relation. Errors of quotients A and β are reduced with loop affixation. Loop IV has smaller diameter than the average diameter defined by relation (2).

C&B $\Sigma - D$ diagram for thirty six calibrators with in-drawings of main loops is shown in Fig. 2. Loop IV is at the fit line which means it is an ordinary remnant considering $\Sigma - D$ dependence. It is obvious from Fig. 2 that Loop I (diameter 230 pc) is closer to the line than Cas A (the drawing is also attached to the diagram). It leads to the conclusion that Loop I is more normal remnant than the supernova remnant Cas A, considering the connection between surface brightness and the remnant diameter. Since Loop I is the one with the largest diameter, the fact it is more normal means that the other three loops are more normal, too. Besides, Cas A isn't the only remnant away from the fit line. Another five calibrator remnants are showing more distant from the fit line (W51, CTB37A, KES67, CTB37B, and G349.7+0.2). It means that for their brightness, these remnants have larger diameters than Loop I has for its brightness. Remnants SN1006, CTA1 and G156.2+5.7 are more distant too, but from the left of the fit line, i.e. in the minimum diameter area.

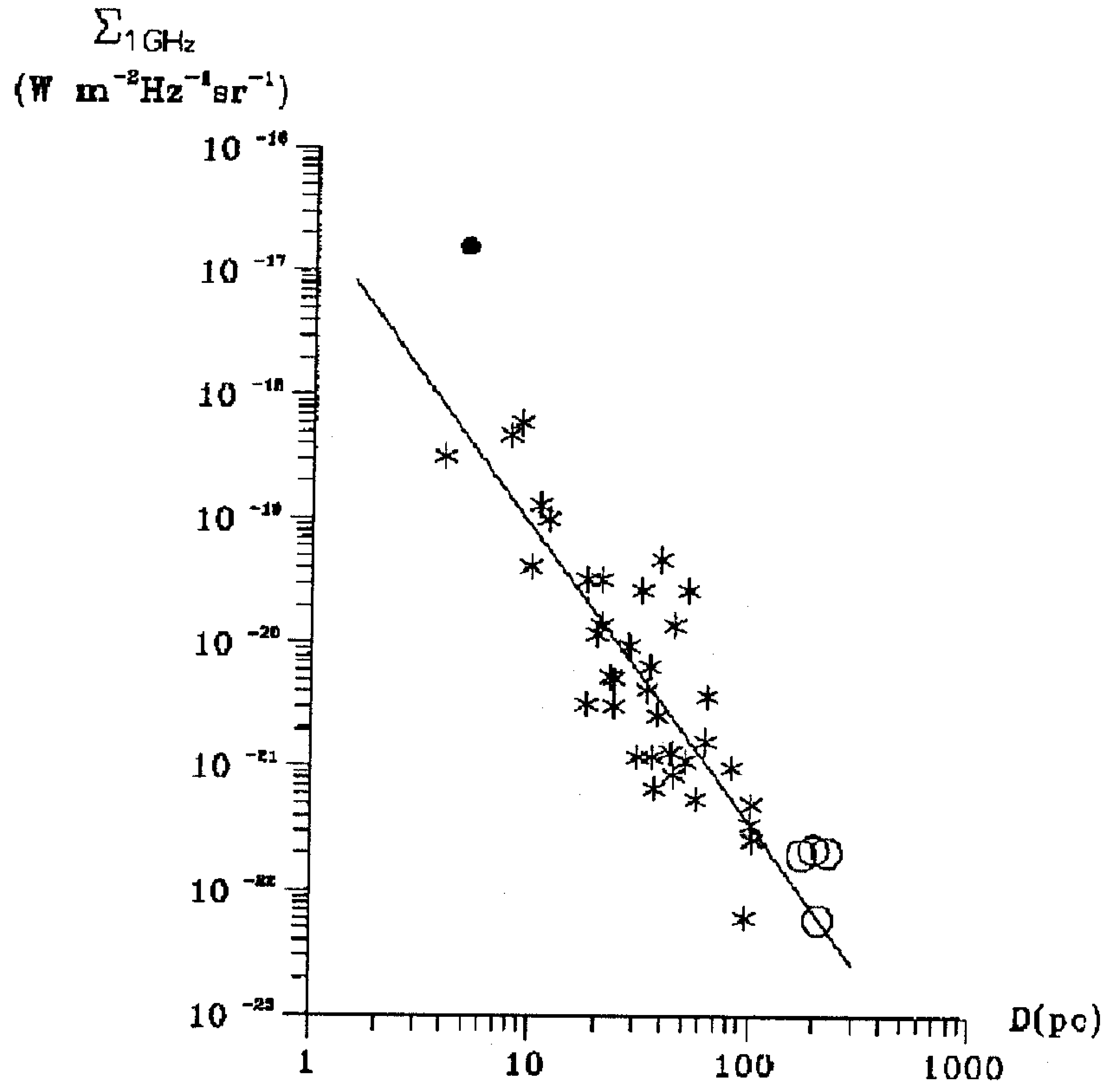

Fig. 2. $\Sigma - D$ diagram at frequency of 1 GHz is showing C&B dependence derived using thirty six calibrators with in-drawings of main loops and Cas A remnant. Asterisks are representing C&B calibrators, circles are representing loops and full circle stand for Cas A remnant.

4. CONCLUSION

All the above stated can be concluded as follows: low brightness and large diameters of the main loops shouldn't be a problem present ever since the loop discovery. Such test result is supporting the SNR origin of the radio loops.

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