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DISTANCES TO THE ORIGEM AND THE MONOCEROS LOOPS

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SUMMARY: Using the Supernova Remnants (SNR) hypothesis for the radio loops, distances of the Origem and the Monoceros loops were calculated from the surface brightness and the angular diameters at 1420 MHz. The data were taken from the northen sky radio continuum survey at 1420 MHz (Reich and Reich, 1986) while the surface brightness-diameter $(\Sigma - D)$ relation for SNR was taken from Berkhuijsen (1973). The distances of two loops determined here are larger than earlier ones, have radio astronomical roots and smaller relative errors.

1. INTRODUCTION

Distances to radio sources are determined mostly by joining optical results, for example by using identification of a radio source with the corresponding source in the optical part of the spectrum. In this paper, we have applied a radio astronomical method for determination of the distances to the Origem and the Monoceros radio loops.

The Origem loop was the first radio loop discovered (Berkhuijsen, 1973) after the major four radio loops (e.g. Salter, 1970; Berkhuijsen et al., 1971). It is much smaller in angular size, rather difficult to detect. Its name reflects the fact that it lies on the border of Orion and Gemini. The Monoceros filamentary loop nebula although already studied at optical (Morgan et al., 1965), and radio waves, at 237 MHz (Davis, 1963) and 470 and 635 MHz (Milne and Hill, 1969), was not considered as an object similar to major loops untill 1973 when Spoelstra included it in his study of galactic loops as supernova remnants (SNR) expanding in the local galactic magnetic field. Results from this model calculations were based on the Van der Laan's model (1962). Observational aspects of the Origem loop as pointed out by Berkhuijsen, 1974, suggest that it is a SNR. The Monoceros loop was suspected already by Davies (1963) to be a SNR, while Gebel and Shore (1972) developed this idea into a more detailed study.

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

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

The first empirical $\Sigma - D$ relation was derived by Milne (1970). The subject was discussed later by Woltjer (1972), Clark and Caswell (1976), Caswell and Lerche (1979), Green (1984), Huang and Thaddeus (1985), but no one of them used loops as calibrators of SNR. Berkhuijsen (1973) was the first one to include the Origem loop (and Loop I) in its first $\Sigma - D$ relation. All main radio loops (Loops I, II, III and IV) were included in the study of the $\Sigma - D$ relation of SNR at known distances by Berkhuijsen (1986), but the Origem loop was not considered there. The $\Sigma - D$ line in Berkhuijsen (1986) is plotted in such a way that it lies on the side of maximum observable diameters and thus does not represent a regression line.

Distances up to then available SNR were determined by many authors: (e.g. Ilovaisky and Lequeux (1972,a,b), Clark and Caswell (1976), Milne (1979), Göbel, Hirth and Fürst (1981), Lozinskaya (1981)), and used for $\Sigma - D$ calibration. The mentioned authors have investigated the distances using optical methods: kinematic distances, proper motions of near stars, proper motions and radial velocities of optical filaments, etc. Distances to the Monoceros loop and the Origem loop were estimated, by combining the kinematic distances and the proper motions of some near stars, to be about 1 kpc away.

Spoelstra (1973) treated the Lupus loop as an object similar to the main loops.

2. ANALYSIS

In order to determine distances to these two loops, we used radio continuum survey at 1420 MHz (Reich and Reich, 1986) as the best available. We derived the geometrical parameters (angular diameters) of this two loops (Milogradov-Turin and Urošević, 1996), surface brightness and applied them within the $\Sigma - D$ relation of Berkhuijsen (1973).

The Lupus loop doesn't belong to the part of the sky covered by this survey and therefore we could not take it into account.

Since the 1420 MHz survey has a resolution of $35'$, brightness temperatures were read at every $18\overset{'}{.}75$. The Origem loop was sampled at 58 points and the Monoceros loop at 95 points along the main ridges. Background radiation was substracted for every profile of constant galactic latitude. Average brightness temperatures for the Origem and the Monoceros loops are $T_{Origem} = 0.07 \pm 0.01\,\mathrm{K}$ and $T_{Monoceros} = 0.17 \pm 0.01\,\mathrm{K}$. Temperatures at 1 GHz were calculated using the spectral indices given by Berkhuijsen (1974) for the Origem loop, and by Milne and Hill (1969) for the Monoceros loop. We calculated the surface brightness applying the relation

$$\Sigma_{1\,GHz} = 2KT_{1\,GHz}\frac{(1\,\mathrm{GHz})^2}{c^2}. \qquad (2)$$

The distances were calculated using the $\Sigma - D$ relation of Berkhuijsen (1973),

$$\Sigma_{1\,GHz} = 0.45 \times 10^{-15} D^{-3.1}, \qquad (3)$$

and angular diameters. Geometrical parameters of all radio loops at 1420 MHz (Urošević, 1996, Milogradov-Turin and Urošević, 1997) are in good agreement with the results of other authors (Salter, 1970, Berkhuijsen et al., 1971).

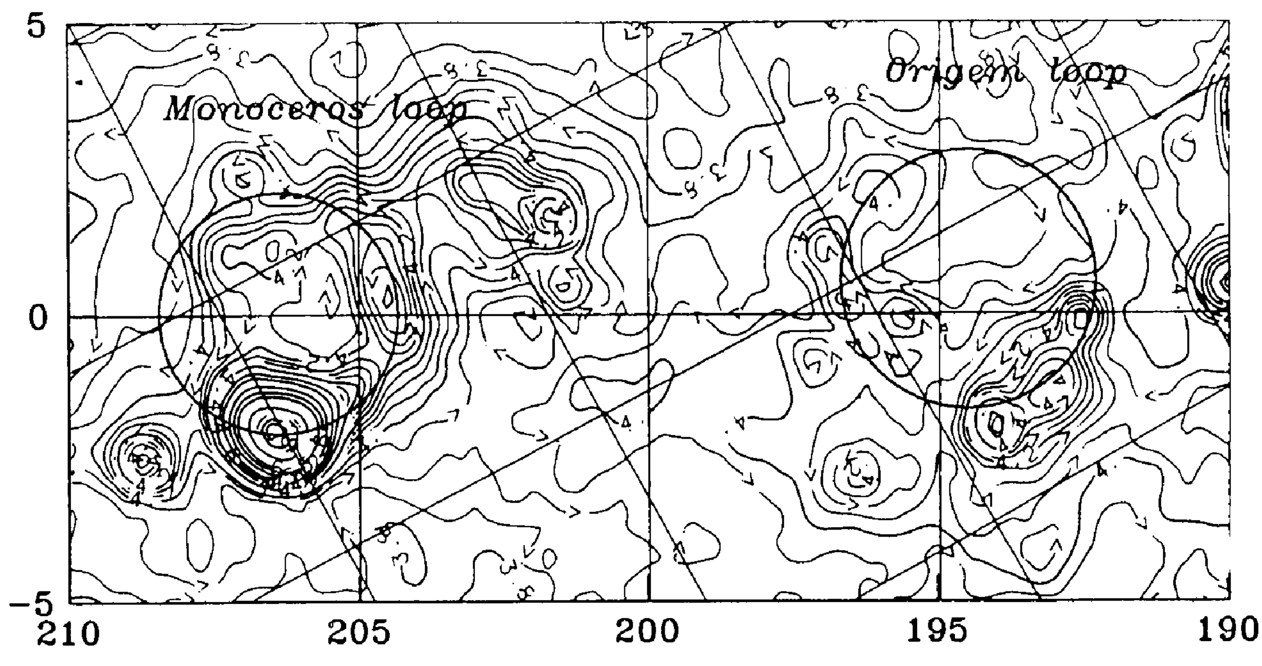

Fig. 1. *The small circles of the Origem and the Monoceros radio loops in galactic coordinates at 1420 MHz (Milogradov-Turin and Urošević, 1996) superposed on the relevant part of the 1420 MHz survey of Reich and Reich (1986).*

3. RESULTS

The results are presented in Table 1.

Table 1. Surface brightness at 1 GHz, linear diameters (using $\Sigma - D$ relations (Berkhuijsen,1973)), angular diameters (Milogradov-Turin and Urošević, 1996), and distances to the Origem and the Monoceros loops derived in this paper.

Loop	Surface brightness (1 GHz) W $Hz^{-1}m^{-2}sr^{-1} \times 10^{-22}$	Linear diameter (pc)	Angular diameter (°)	Distance (pc)
Origem	0.5 ± 0.1	175 ± 10	4.4 ± 0.5	2300 ± 400
Monoceros	1.2 ± 0.05	130 ± 2	4.2 ± 0.5	1800 ± 250

4. DISCUSSION

The distances to the Origem and the Monoceros loops (Table 1) are greater than earlier determined and have smaller relative errors. Our relative errors in distances to these two loops are under 20%. The earlier relative errors of distances derived by optical methods were between 25% to 50%. We estimated the accuracy of reading the brightness temperatures at 0.01 K, and by using relation (2), we calculated absolute errors for surface brightness. Using relation (3), we calculated absolute errors for diameters. Relation (3) has given very small absolute errors for diameters because of a power law $\Sigma - D$ dependence. We calculated errors of distances using errors of the angular diameters and linear diameters. The distances errors have stronger dependence on the errors of angular diameters than on the linear diameter calculated from the $\Sigma - D$ relation. Basically, the errors of reading of the brightness temperatures (estimated here) and the errors of angular diameters (calculated by Milogradov-Turin and Urošević, 1996) were included in the errors of distances. The other errors were formal errors derived from the used relations.

The biggest problem in this method for determination of the distances is the $\Sigma - D$ relation. The empirical $\Sigma - D$ relations have different coefficients A and β (equation (1)), posing a problem in selection of the appropriate relation. We chose the relation of Berkhuijsen (1973) because, for this relation, loops had equal treatment with the other SNR. The relation of Berkhuijsen (1986) had loops too, but she derived there a $\Sigma - D$ relation based mainly on the upper limits of the SNR distances. These distances were defined by the line of the maximum observable diameters. We have obtained approximately two times larger distances (compared with the results in Table 1) to the Origem and the Monoceros loops by using the $\Sigma - D$ from the paper of Berkhuijsen (1986) relation than by using the one from Berkhuijsen (1973).

The other $\Sigma - D$ relations were not derived by using the loops. We found that diameters to the Origem and the Monoceros loops calculated from them are smaller and thus give smaller distances. The $\Sigma - D$ relation by Caswell and Lerche (1979) and Huang and Thaddeus (1985) gave us somewhat larger distances.

A future research of the $\Sigma - D$ relation and the combination with the radio astronomical observations might give better distances to the loops.

This paper has two postulates. First – all radio loops are SNR (Berkhuijsen et al., 1970, Berkhuijsen, 1971, Shklovskii and Sheffer, 1971, Bunner et al., 1972., Spoelstra, 1972, 1973, Borken and Iwan, 1977, Iwan, 1980, Heiles et al., 1980, Sarkar, 1982, Salter, 1983). Second – the Origem and the Monoceros loops are objects similar to the major loops (Spoelstra, 1973, Berkhuijsen, 1973, 1974). There is no certain proof for this hypothesis, but the majority of authors accept it.

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ДАЉИНЕ ДО ORIGEM И MONOCEROS ПЕТЉЕ

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Оригинални научни рад

Претпостављајући хипотезу да су радио-петље остаци супернових звезда, израчунате су даљине до Origem и Monoceros петље користећи површински сјај и угловне дијаметре петљи. Рад је базиран на прегледу радио-неба на 1420 MHz (Reich and Reich, 1986) и вези између површинског сјаја и дијаметра петљи ($\Sigma - D$ релација) за остатке супернових, Берхујсенове (1973). Даљине одређене у овом раду су веће од раније објављених, али имају радиоастрономске корене и мање релативне грешке.