ON THE EVOLUTION OF RADIO EMISSION OF THE TYCHO BRAHE'S SUPERNOVA REMNANT (3C10)

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ABSTRACT. Basing on long-term (1966-1998) measurements at the frequency 86 MHz the mean rate of the secular decrease of Tycho Brahe's supernova remnant (SNR) radio emission flux density has been estimated as $(0.92 \pm 0.70)\% \, \mathrm{yr}^{-1}$. The decrease of Tycho Brahe's SNR radio emission is not uniform in time. The rate of the secular decrease of this SNR radio emission is frequency independent in the limits of the errors. The weighted mean value of the rate of the secular decrease of the Tycho Brahe's SNR radio emission in the frequency range 86-5000 MHz is $(0.41 \pm 0.02)\% \, \mathrm{yr}^{-1}$.

Key words: Supernova remnants; individual: Tycho Brahe, 3C10.

1. Introduction

The supernova 1572 remnant (Tycho Brahe's SNR) is a well known shell radio source 3C10 with an angular diameter of $8'$ (Strom and Duin 1973, Duin and Strom 1975, Strom et al. 1982, Klein et al. 1979, Vinyajkin et al. 1987). The source spectrum is straight in the interval 12.6-15000 MHz with the spectral index $\alpha = 0.61 \pm 0.03$, flux density $S_\nu \propto \nu^{-\alpha}$, $S_\nu(370 \text{ MHz}) = 100 \pm 7$ Jy (Vinyajkin et al. 1987). The secular decrease of the radio emission of Tycho Brahe's supernova remnant was investigated by Stankevich et al. (1973) at 952 MHz, Dickel and Spangler (1979) at 1400 MHz, Ivanov et al. (1982) at 952 MHz, Strom et al. (1982) at 1415 MHz, Vinyajkin et al. (1987) at 86 MHz and Stankevich et al. (1997) at 5000 MHz. In these papers the values of the secular decrease rate

$$d = S_\nu^{-1} dS_\nu/dt \tag{1}$$

of the radio flux density S_ν were obtained by two-three different epochs measurements separated by intervals from 8 up to 27 years.

The aim of this work is to estimate the value of d at 86 MHz according a more long than in the paper of Vinyajkin et al. (1987) interval between the first and final epochs of measurements. A more reliable value of d at 86 MHz will be useful for study of possible frequency dependence of the secular decrease rate of 3C10 radio emission. Such dependence is observed in the radio emission of another young SNR Cassiopeia A (Dent et al. 1974, Stankevich 1977, Baars et al. 1977, Vinyajkin et al. 1980, Ivanov and Stankevich 1987, O'Sullivan and Green 1999).

2. Observations

The measurements of Tycho Brahe's SNR flux density at 87 MHz relative to radio galaxy 3C20 (this is a steady radio source) were carried out in August 1998 at Pushino radio observatory (PRAO) using the DKR-1000 east-west antenna. This antenna was divided into two equal parts (with dimensions of about 500×40 m), which then made a two-element correlation interferometer. The interference fringes of both 3C10 and 3C20 were registered near their upper culminations. The upper culmination zenith angles of 3C10 and 3C20 at the latitude of Pushino are equal correspondingly to $\approx 9°$ and $\approx 3°$. Such measurements are described in more detail by Vinyajkin et al. (1987). A little alteration of frequency (87 MHz instead of 86 MHz) was caused by man-made interference. Both sources 3C10 and 3C20 were observed on 5 consecutive nights during 1998 August with registration of signal in both sine and cosine channels of correlation receiver. For each night the ratio

$$\frac{A_{3C10}}{A_{3C20}} \equiv r \tag{2}$$

(where A_{3C10} is an amplitude of 3C10 interferometric response and A_{3C20} is an amplitude of 3C20 interferometric response) was computed for both sine and cosine channels. As a result the mean value of $r = 2.75 \pm 0.09$ for the epoch 1998.6 was derived from these measurements (a little correction was made to obtain the value of r for $\nu = 86$ MHz). For the epoch 1966.7 $r = 3.48 \pm 0.16$ (Artukh et al. 1968) and for the epoch 1983.6 $r = 3.64 \pm 0.09$ (Vinyajkin et al. 1987).

It should be stressed that the values of r for all three epochs (1966.7, 1983.6 and 1998.6) were derived from measurements of r using the same radio telescope and the same method. The values of r are plotted against epoch in Fig.1, where the straight line shows weighted least-squares fit. The straight line corresponds to the following mean rate of the secular decrease for $S^{3C10}_{86\,\mathrm{MHz}}$ for the time period 1966.7-1998.6.

$$d^{3C10}_{86\,\mathrm{MHz}} = -(0.92 \pm 0.70)\%\,\mathrm{yr}^{-1} \tag{3}$$

We can see from Fig.1 that the decrease of the flux

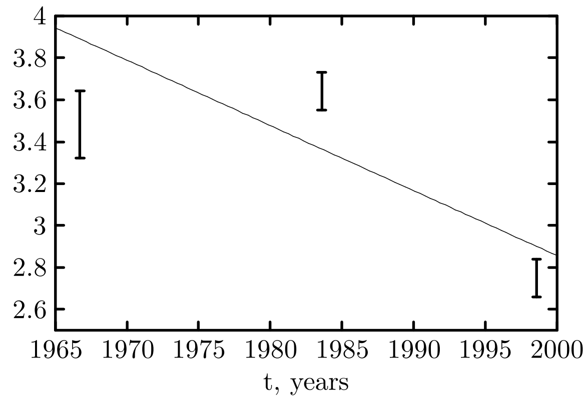

Figure 1: Amplitude of 3C10 interferometric response relative to that of 3C20 at 86 MHz. The straight line shows weighted least-squares fit.

density of 3C10 with time is not uniform. In 1966-1983 $S^{3C10}_{86\,\mathrm{MHz}}$ was constant in the limits of errors. Since 1983 up to 1998 the decrease of radio emission of 3C10 was occurring: $S^{3C10}_{86\,\mathrm{MHz}}(1998.6)$ is $(24\pm4)\%$ lower than $S^{3C10}_{86\,\mathrm{MHz}}(1983.6)$. It should be noted that the amplitude of interferometric response slightly decreases with time due to the expansion of Tycho Brahe's SNR but this effect provides only a small decrease near 1% for 15 years for our observations. The temporal nonuniformity of the 3C10 flux density decrease was observed at 952 MHz by Stankevich et al. (1973) and Ivanov et al. (1982): $d^{3C10}_{952\,\mathrm{MHz}}(1964-1972) = -(0.8\pm0.1)\%\,\mathrm{yr}^{-1}$, $d^{3C10}_{952\,\mathrm{MHz}}(1964-1981) = -(0.5\pm0.15)\%\,\mathrm{yr}^{-1}$.

It should be noted that the measurements of the flux density of Cas A relative to that of Cyg A were made by the author using the same radio telescope at the same frequency on the same nights. The ratio of the flux densities of Cyg A and 3C20 $S^{CygA}_{87\,\mathrm{MHz}}/S^{3C20}_{87\,\mathrm{MHz}} = 216\pm11$ was derived from these measurements (a correction for different angular sizes of Cyg A and 3C20 was made and it increased the measured ratio by 1.5 %). This may be compared with the ratio 228 ± 20 which can be computed from the value of $S^{CygA}_{87\,\mathrm{MHz}} = 15500\pm700\,\mathrm{Jy}$ (Baars et al. 1977) and the value of $S^{3C20}_{87\,\mathrm{MHz}} = 68\pm5\,\mathrm{Jy}$ (Kuhr et al. 1981). One can see a good agreement between these two values of the ratio of the flux densities of two steady radio sources Cyg A and 3C20.

3. Discussion

Let us compare the measured value (3) 3C10 radio flux density secular decrease rate at 86 MHz with the values of d at a more higher frequencies. Table 1 lists and Fig.2 shows values for d at 5 frequencies including (3).

Table 1

ν, MHz	Period, years	$-d$, $\%\,\mathrm{yr}^{-1}$	Ref.
86	1966.7-1998.6	0.92 ± 0.70	This paper
952	1964-1981	0.5 ± 0.15	Ivanov et al. 1982
1400	1963-1978	0.4 ± 0.5	Dickel and Spangler 1979
1415	1971-1979	0.23 ± 0.19	Strom et al. 1982
5000	1967.4-1994.8	0.41 ± 0.03	Stankevich et al. 1997

The weighted mean of d from Table 1 is

$$d_{wm} = -(0.41\pm0.02)\%\,\mathrm{yr}^{-1} \tag{4}$$

The straight line in Fig.2 is determined by weighted

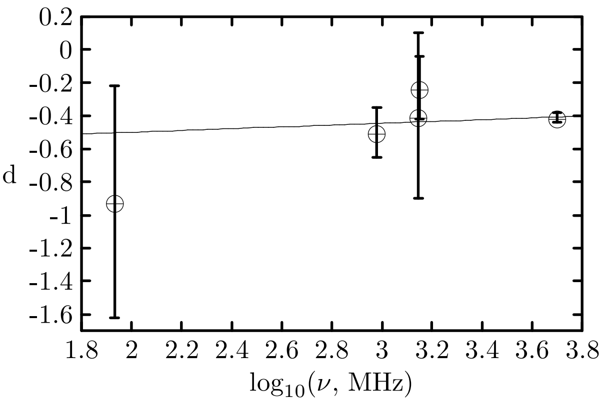

Figure 2: The variation of 3C10 radio flux density secular decrease rate $d(\%\,\mathrm{yr}^{-1})$ with $\log_{10}$(frequency, MHz). The straight line shows weighted least-squares fit.

least-squares fit to the data from Table 1 and is described by the following equation

$$d = (0.05\pm0.12)\log_{10}\frac{\nu(\mathrm{MHz})}{1000} - (0.445\pm0.08) \tag{5}$$

We can see from (5) that the rate of 3C10 radio flux density secular decrease is frequency-independent within errors.

Let us compare the value (4) with the prediction of Shklovsky's (1960) model. According to the model of

Shklovsky (1960)

$$d = -p\frac{4\alpha + 2}{T}, \quad (6)$$

where p-is a power index in a dependence of a source radius R from an age T of a source ($R \propto T^p$), α is a spectral index of a source ($S \propto \nu^{-\alpha}$). Substituting the values of $p = 0.462 \pm 0.024$ (Tan and Gull 1985), $\alpha = 0.61 \pm 0.03$ (Vinyajkin et al. 1987) and $T = 411$ years (411 years is the age of Tycho Brahe's SNR for the mean epoch 1983 of the observations) into Eq.(6) yields the value of $d = -(0.50 \pm 0.02)\%\,\mathrm{yr}^{-1}$ which coincides with (4) in the limits of near 2σ.

4. Conclusion

As a result of long-term measurements of the radio flux density of 3C10 relative to 3C20 at 87 and 86 MHz using a single radio telescope DKR-1000 and the same method we find the following mean secular decrease rate of the radio flux of 3C10

$$d^{3C10}_{86\,\mathrm{MHz}} = -(0.92 \pm 0.70)\%\,\mathrm{yr}^{-1}$$

Based on this value of d and the values of d at 952, 1400, 1415 and 5000 MHz of other authors the weighted mean value of d

$$d_{wm} = -(0.41 \pm 0.02)\%\,\mathrm{yr}^{-1}$$

is obtained that can be understood in the framework of Shklovsky's (1960) model.

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