Astronomical and Astrophysical Transactions (*AApTr*), 2012, Vol. 27, Issue 3, pp. 421–424,
ISSN 1055-6796, Photocopying permitted by license only, ©Cambridge Scientific Publishers

Physical conditions in nuclei of classical double radio galaxies

V.S. Artyukh*

Pushchino Radio Astronomy Observatory, P.N. Lebedev Physical Institute, Russian Academy of Sciences, Pushchino, Moscow Region, 142290, Russia

Received 20 November, 2008

This is a concise review of investigations of classical double radio galaxies at different stages of their cosmological evolution. It is shown that strong non-uniform magnetic field distributions exist in nuclei of the radio galaxies. Magnetic field strengths in the center of galactic nuclei on the scale 0.01–0.1 pc are very high (up to $H \sim 10^4$ G) and at periphery H are 4–5 orders weaker. Magnetic field strengths at the scale ~ 1 pc are approximately the same in the nuclei of old and young radio galaxies but the relativistic electron density in young jets of the radio galaxy 0108+388 is much higher than in the nuclei of old radio galaxies. Magnetic field energy in nuclei of old radio galaxy (at the scale ~ 1 pc) is higher than the relativistic electron energy, in contrast to what is found in 0108+388. It is argued that the young jets in 0108+388 are shock waves.

Keywords: Radio galaxy; Active galactic nucleus; Physical conditions; Non-uniform synchrotron source

1 Introduction

Phillips and Mutel (1982) suggested that compact double gigahertz peaked-spectrum (GPS) radio sources evolve into compact steep spectrum sources and then later into classical double radio galaxies (FRII type). Carvalho (1985) presented an analytical model of the evolution of classical double sources and showed that the known properties of compact doubles are consistent with such a scenario. To comprehend the nature of the radio galaxies it is necessary to know the physical conditions in their nuclei. Also it is very important to know how the physical conditions change in the course of cosmological evolution.

Many compact radio sources located in AGNs have low frequency cutoffs in their spectra. An analysis of the physical mechanisms responsible for the spectral cutoffs has shown that synchrotron self-absorption of the radiation is the most likely mechanism for many radio sources. In that case we can estimate magnetic field strengths, relativistic electron number densities, and corresponding magnetic field and relativistic plasma energies in the AGNs where these radio sources are located. The method for the estimation of the physical parameters has been developed in Artyukh & Chernikov

*Email: art@prao.ru

(2006). We present results of the investigations of the physical conditions in cores of nearby (old) radio galaxies 3C 111, 3C 465 and distant GPS radio galaxy 0108+388.

2 The method of the physical parameters estimations

To estimate physical parameters of radio sources we use the method developed in Artyukh & Chernikov (2006). Distributions of the magnetic field strength and the relativistic electron density are approximated by the functions:

$$H(r) = \frac{H(0)}{1 + k_H \left(\frac{r}{R}\right)^m}, \text{ if } r \leq R, \text{ and } H(r) = 0, \text{ if } r > R, \tag{1}$$

$$N(E, r) = E^{-\gamma} \frac{N(0)}{1 + k_H \left(\frac{r}{R}\right)^n}, \text{ if } r \leq R, \text{ and } N(E, r) = 0, \text{ if } r > R, \tag{2}$$

where R is the source model radius.

Thus, radio source model is characterized by the following physical parameters: γ, R, $H(0)$, m, k_H, $N(0)$, n, k_N. According to Condon & Dressel (1973), De Bruyn (1976) and Artyukh & Chernikov (2001), the spectrum of such a synchrotron source consists of three parts. At high frequencies the flux density is $S \sim \nu^{-\alpha}$ in transparent region ($\nu > \nu_{\rm hf}$), where $\nu_{\rm hf}$ is the frequency of the high-frequency break of the spectrum. At low frequencies S is $\sim \nu^{2.5}$ in the opacity region ($\nu < \nu_{\rm lf}$), where $\nu_{\rm lf}$ is the frequency of the low-frequency break of the spectrum. In many cases the spectrum at intermediate frequencies ($\nu_{\rm lf} < \nu < \nu_{\rm hf}$) can be also described by the power function $S \sim \nu_{\rm lf}^{-\alpha}$, where $-2.5 < \nu_{\rm lf}^{-\alpha} < \alpha$.

Source physical parameters shall be calculated as follows. From observations at higher frequencies, where a source is transparent and $S \sim \nu^{-\alpha}$, we have $\gamma = 2\alpha + 1$.

The parameter k_H is determined by the frequency interval length $\nu_{\rm hf} - \nu_{\rm lf}$. We have it from the model catalog (Artyukh & Chernikov (2001)) if we know $\nu_{\rm hf} - \nu_{\rm lf}$ from observations. Spectral index $\alpha_{\rm lf}$ we have from observations (within the range of $\nu_{\rm lf} < \nu < \nu_{\rm hf}$). From De Bruyn (1976),

$$\alpha_{\rm lf} = \frac{13 - 5n - 3m - 2m\gamma + 2\gamma}{2 - 2n - 2m - m\gamma}. \tag{3}$$

Knowing $\alpha_{\rm lf}$ and γ, the linear relation between m and n can be derived from (3). As shown in Artyukh & Chernikov (2001), parameters m and n belong to the finite interval of values that corresponds to physically realizable source models. To simplify the work we will choose the model with a uniform distribution of particles, i.e. $n = 0$ and $N(E) = N_0 E^{-\gamma}$. Thus we derive m directly from (3). As shown in Artyukh & Chernikov (2001), in this case we deal with the source model with minimum magnetic field $H(0)$ and maximum particle density N_0. It should be noted that another marginal model with $m = 0$ offers maximum magnetic field that depends on the model itself. Maximum magnetic field in models close to uniform is, by an order of magnitude, greater than the minimum field, and in highly non-uniform models – by almost two orders. Minimum density of particles is an order of magnitude smaller

than the maximum density. It follows that actually we've got interval estimation of the parameters by obtaining minimum estimation of magnetic field strength $H(0)$ and maximum estimation N_0.

To estimate parameters N_0, R and $H(0)$ we use the following set of equations:

$$\tau\left(\nu_{\mathrm{hf}}\right)=\int\limits_{-R}^{R} c_6\left(\gamma\right) N_0 H^{\frac{\gamma+2}{2}}\left(x\right)\left(\frac{\nu_{\mathrm{hf}}}{2C_1}\right)^{\frac{-\gamma-4}{2}} dx\approx 1, \tag{4}$$

$$I\left(\nu_\theta, r_\theta\right)/I\left(\nu_\theta, 0\right)=\frac{1}{2}, \tag{5}$$

$$S\left(\nu_i\right)=\int\limits_{\Omega} I\left(\nu_i,\omega\right)\cos\theta d\omega\approx\int\limits_{\Omega} I\left(\nu_i,\omega\right) d\omega, \tag{6}$$

where Ω is the solid angle of a radio source. It is necessary to emphasize that because of the paucity of observation data it is possible to obtain only interval estimations of the physical parameters.

3 Results of the investigations

Using the new method, we have investigated the physical conditions in nuclei of the nearby ($z < 0.05$) radio galaxies 3C 111 and 3C 465 (Chernikov et al. 2006). A strong non-uniform magnetic field distribution in the nuclei of these radio galaxies was found. In the central regions of the nuclei at the scale $r \leq 0.1$ pc the magnetic field strengths lie in the interval of $10^2 < H < 10^4$ G. The minimum mean H in 3C 111 is $\langle H\rangle \sim 10^{-2}$ G at the scale 20 pc and in 3C 465 $\langle H\rangle \sim 10^{-1}$ G at the scale 4 pc. The relativistic electron density is $10^{-5} < n_{\mathrm{e}} < 10^{-4}$ cm^{-3}. No energy equipartition was found in nuclei of the radio galaxies. Everywhere in the nuclei the magnetic field energy is bigger than the relativistic electron energy.

As was noted above, probably GPS radio galaxies are the first stage of the cosmological evolution of classical radio galaxies. Of interest is the GPS radio galaxy 0108+388 ($z = 0.67$). The compact radio source in the nucleus of the galaxy consists of two jets (N–E and S–W) that have spectra that turn over at frequencies lower than 5 GHz. The kinematic age of the radio jets is ~ 370 years (Owsianik et al. 1998). This implies that pc-scale structure of 0108+388 is very young. Estimations of physical parameters of these jets were obtained with the same method (Artyukh & Chernikov (2006)). It was found that magnetic fields in these jets (at parsecs scale) are nearly uniform with $10^{-2} < H < 10^{-1}$ G. This is very close to the magnetic field strength in nuclei of old radio galaxies. The relativistic electron density $10^1 < n_{\mathrm{e}} < 10^2$ cm^{-3} is much higher than that in old radio galaxies (Artyukh et al. 2008). By contrast with 3C 111 and 3C 465 everywhere in the jets of 0108+388 the relativistic electron energy is higher than the magnetic field energy, but when taking the estimated uncertainties into account it is possible that energy equipartition is in effect. Magnetic field strength of the central (unresolved) component was estimated as $\sim 7\cdot 10^4$ G (Taylor et al. 2000).

The sound speed in interstellar medium, where the jets of 0108+388 are propagating, is $v_1 \sim 10^6$ cm/s if the medium is the thermal plasma (HII region) or $v_1 \sim 10^5$ cm/s if the medium is HI region. The apparent separation velocity of the outer jet components is 0.2c (Artyukh et al. 2008). If the advance of the jets is symmetrical, then for the advance speed of every jet we have $v_2 = 0.1$ c. The sound speed inside jets (relativistic plasma) is $v_3 = \mathrm{c}/3$. This implies that $v_3 > v_2 > v_1$. This is the necessary condition for a shock wave (Landau & Livshits 1986). It follows from Taylor et al. (2000) that jet magnetic fields are distributed almost uniformly, hence jet boundaries demonstrate abrupt magnetic field jumps. This is in accordance with the shock wave concept too. It may be that the jets are propagating in the interstellar medium like shock waves.

References

Artyukh, V.S., & Chernikov, P.A. (2001) Astron. Rep., 45, 16.
Artyukh, V.S., & Chernikov, P.A. (2006) Astron. Rep., 50, 194.
Artyukh, V.S., Chernikov, P.A. & Tyulbashev, S.A. (2008) Astron. Astrophys., 486, 735.
De Bruyn, A.G. (1976) Astron. Astrophys., 52, 439.
Carvalho, J.C. (1985) MNRAS, 215, 463.
Chernikov, P.A., Artyukh, V.S., Tyulbashev, S.A. & Lapaev, K.A. (2006) Astron. Rep., 50, 202.
Condon, J.J. & Dressel, L.L. (1973) Astrophys. Letters, 15, 203.
Landau, L.D. & Livshits, I.M. (1986) Hydrodynamics, Moscow, Nauka.
Owsianik, I., Conway, J.E. & Polatidis, A.G. (1998) Astron. Astrophys., 336, L37.
Phillips, R.B. & Mutel, R.L. (1982) A&A, 106, 21.
Taylor, G.B., Marr, J.M., Pearson, T.J., & Readhead, A.C.S. (2000) Astrophys. J., 541, 112.