EXPANSION OF COCOONS AND PHYSICAL FEATURES OF THE FRI-FRII MORPHOLOGY OF EXTRAGALACTIC RADIO SOURCES

N.O. Tsvyk

Institute of Radio Astronomy of NASU
4, Chervonopraporna, Kharkiv 61002, Ukraine, *tsvyk@ira.kharkov.ua*

ABSTRACT. It is shown that the morphological different FRI-FRII structures arise in depending on the type of interaction of the relativistic electrons with MHD cocoon turbulence, on velocity of turbulence dissipation, and on the power of extragalactic radio sources. FRII cocoon is filled with the Alfven solitary wave train which keeps the relativistic electrons within the slow cocoon flow and moves the same as the cocoon boundary. FRI cocoon (galo) arises due to anomalous diffusion of the relativistic electrons through the turbulence with stochastic week waves. It forms the halo which size is increasing with reduce of observation frequency, as is really observed.

Key words: radio galaxies: cocoon; MHD waves; diffusion; individual: 3C405 (Cygnus A), M87, 3C216.

1. Introduction

The usual assumption is the morphologically difference of FRI-FRII extragalactic radio sources appear in depending on how great jet power is to form the shock wave in the cocoon (De Young 2002). On the other way, the type of the source is determined by the character of interaction between the broadening of relativistic electrons in the cocoon and the form of cocoon turbulence.

The accent should be made on the question what type of waves fills the cocoon. The relativistic electrons interact differently with a single wave of various type.

There are many types of waves which can arise in the cocoon plasma. Here are: simple waves, shock waves, solitary waves (solitons).

The turbulence ordinary corresponds to the stochastic waves, arising and broken in the medium with strong dissipation processes. So, in condition with not strong dissipation, the cocoon turbulence can be described not only as stochastic simple waves, but as the solitary waves, or the weak shock waves.

The cocoon turbulence provides transportation of hot plasma flowing from the jet into the source galo, that is a cocoon periphery, through the inter cluster medium (ICM). The relativistic electrons flowing from the jet is transported through it.

It is assumed that FRII extragalactic sources are connected with the solitary wave train, contained into the cocoon bounded by strong shock wave. It keeps a cocoon as compact structure that expands with a slow velocity. An example is Cygnus A (Kaiser 2000, Wilson et al 2006).

FRI extragalactic sources are connected with weak shock waves or with week stochastic waves, forming "diffuse" cocoon - galo of large size (like M87 (Owen et al 2000) or 3C216 (Meng et al 2001)), changing with observation frequency.

2. FRII: the keeping of the relativistic electrons by MHD solitons

FRII extragalactic sources are power sources which is bounded by hydrodynamical shock wave. The observations show that FRII cocoons answer the spectral aging model (Kaiser 2000) in which relativistic electrons aging as far as they move off the hotspot. In this model the diffusion of relativistic electrons is absent; and the relativistic electrons lose energy only due to synchrotron and inverse Compton emissions and to the adiabatic expansion of the cocoon.

The problem arised: how are cocoon relativistic electrons kept within the flow that runs with a small velocity, $u_c < 0.1c$?

In this work this problem is solved in the assumption that the turbulence of FRII cocoon is built in the MHD solitary wave train. These waves naturally arise in the sources of great power. They may be exited in the processes when the jet shock wave goes round compact regions like clouds near the hotspot.

The relativistic particles (relativistic electrons) move nearly along the magnetic field lines. On that reason they mainly interact with MHD and Alfven solitary waves, that easily can be formed in FRII cocoons.

A dissipation of Alfven solitary wave is minimum when Mach number is $M_a = 3$ (Sagdeev 1964).

The solitary wave profile comes back to the initially state, so that it gives us the conditions for good reflection of relativistic electrons without change in its energetic spectra. So, the relativistic electrons flow with the same velocity as the solitary wave train.

This model has a good consideration with the data for the extragalactic radio source of Cygnus A. There are such cocoon parameters of Cygnus A (Wilson et al 2006) (received from the analysis of X-ray data by *Chandra*): $n_c \sim 0.065$ cm^{-3} - cocoon particle density, $T_c \sim 7 \cdot 10^7$ K - the temperature, $B_c \sim 6 \cdot 10^{-5}$ G - the average magnetic field (from the radio emission data), $u_s \sim 1100$ km/s - the cocoon sound velocity, $u_c \sim 0.05c$ (1000 km/s$< u_c <$ 2150 km/s) - the velocity of cocoon boundary hydrodynamical shock wave, $u_c/u_s \sim (1{\div}2)$.

It means: $u_a \approx 500$ km/s, $3u_a \approx 0.05c$. That coincides exactly with the model when Alfven solitary waves with $M_a \approx 3$ move with the same velocity as the cocoon boundary velocity (u_c).

3. FRI: anomalous diffusion of the relativistic electrons throughout the turbulent plasma

FRI cocoons are formed by the turbulence, and they are bounded by the weak shock wave train of broken type, dissipating in interaction with ICM. This gives us the condition when the relativistic electrons are anomaly diffused into the galo of extragalactic radio sources (Chuvilgin, Ptuskin 1993).

Diffusion process of the relativistic electrons is determined by those parameters:

$\gamma \simeq c \cdot p/$ 1 MeV - electron energy (relativistic γ-factor), p is an electron momentum;

$\lambda \simeq 10^{18}(\gamma \cdot 10^{-3})^{0.3}$ cm - free path of the relativistic electron; $\lambda/c \simeq 3 \cdot 10^7(\gamma \cdot 10^{-3})^{0.3}$ s;

v_a - Alfven velocity; for the cocoon concentration of $n_c = 0.03$ cm^{-3} and the average magnetic field of $B_c \sim 3 \cdot 10^{-6}$G, it is $v_a \simeq 30$ km/s;

$L_1 \sim 1$ pc $= 3 \cdot 10^{18}$ cm - characteristic length scale of the small-scale random magnetic field;

$\tau \simeq L_1/c$ - characteristic scattering time of the relativistic electron on small-scale inhomogeneity;

$L_2 \sim 100$ pc $= 3 \cdot 10^{20}$ cm, $\tau_2 = L_2/v_a$ - characteristic spatial and time scales of the large-scale random field;

$\kappa_\parallel$, $\kappa_\perp$ - longitudinal and perpendicular components of the diffusion tensor in the normal diffusion process (in a state medium); $\kappa_\parallel = \lambda c/3$, $\kappa_\perp = \kappa_\parallel/(1 + \omega_B^2 \tau^2) << \kappa_\parallel$;

$\tau_d \simeq L_2^2/\kappa_\parallel \sim 3 \cdot 10^{12}$s - characteristic diffusion time.

Diffusion process for relativistic electrons in the cocoon is an anomalous diffusion because the electrons are transported in the medium with turbulence (Chuvilgin, Ptuskin 1993). The values of L_2 and L_1 are the characteristic spatial scales of that turbulence spectrum.

In FRI cocoons: $\tau_2 > \tau_d >> \tau$. It gives us the coefficient of anomalous diffusion (Chuvilgin, Ptuskin 1993):

$$D(\gamma) = A^2 \sqrt{\kappa_\perp \kappa_\parallel} + A^2(u_a L_2) + 0.5 A^4 \kappa_\parallel, \quad (1)$$

where $A = B_2/B_0$ is an amplitude of the large scale fluctuation of the magnetic field.

The velocity of the anomalous diffusion flow is

$$u_{diff} = \sqrt{D(\gamma) c/\lambda(\gamma)}, \quad (2)$$

$$u_{diff} \approx (0.1 A(\gamma \cdot 10^{-3})^{-0.15} + 0.2 A^2) c. \quad (3)$$

It is about $u_{diff} \sim 0.1c$. So, FRI age in this model is about $t_{age} = R_c/u_{diff} \simeq 10 R_c/c$, where R_c is the cocoon radius.

When relativistic electrons interact with the galo turbulence, there change of its energy distribution. This interaction changes the galo size (that is FRI cocoon size) increasing it when observational frequency is reduced. This fact is really observed (Meng et al 2001).

Thus, FRI extragalactic sources with great galo are explained by the mechanism of anomalous diffusion of the relativistic electrons. For example, the extragalactic source of 3C216 has $R_c \sim 200$ kpc (Meng et al 2001)(the angular size is $20''$, the source distance is 2700 Mpc), and this model gives us its age, $t_{age} \simeq 6 \cdot 10^7$ yr. For M87: $R_c \sim 60$ kpc (Owen et al 2000), and it gives us the age $t_{age} \simeq 2 \cdot 10^7$ yr.

References

Chuvilgin L.G., Ptuskin V.S.: 1993, *Astron.Astroph.*, **279**, 278.

De Young D.S.: 2002, *The physics of extragalactic radio sources*, the University of Chicago Press.

Kaiser C.R.: 2000, *Astron.Astroph.*, **362**, 447.

Meng A.V., Braude S.Ya., et al.: 2001, *Kinemat. Fiz.Neb.Tel (Ukraine)*, **17**, 195.

Owen F.N., Eilek J.A., Kassim N.E.: 2000, *Astron.Astroph.*, **543**, 611.

Sagdeev R.Z.: 1964, *in The Questions of Plasma Theory*, eds. Leontovich M.A, **v.4**, 20, Moscow.

Wilson A.S., D.A. Smith, A.J. Young: 2006, *ApJ L*, **644**, L9.