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Effects of Synchrotron Loss on the Low-Frequency Spectra of Extragalactic Radio Sources with Inhomogeneities

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Abstract. In this work we explain the integrated spectrum measurements (Braude et.al.,1978-1995) in terms of the synchrotron theory and the the recent measurements of radio fine structure in different classes of sources (Carilli et.al.,1991). This provides a new method of investigating extragalactic radio sources

The injection site of synchrotron radiating electrons is related to the location of the jet's instabilities. The electrons are frozen into the magnetic field. Thus, the source is steadily filled with filaments of electrons, without mixing, and the properties of the radio source as a function of separation from the injection site as $r(t) \propto GT^{\beta}$, are dependent on the age $t = Tt_0$. The magnetic field strength inside the filaments decreases rapidly due to adiabatic expansion and emission of a microwave radiation into external space also decreases. The magnetic field strength may stabilize to value H_0 for FR II sources, while in FR I it may continue to decrease : $H(T) = H_0 h(T)$, $h(T) = T^{\psi}(1 + T_{\xi}/T)$. The parameter ψ is determined by the injection conditions and field expansion process, $1 < T < T_a$, $t_a = T_a t_0$ is the age of the source, T_{ξ} is the parameter of the growth of the magnetic field strength at the point of injection from the value of $H_0(1 + T_{\xi})$.

At the site of injection the electrons have an isotropic power law spectrum: $N(E) \propto K_0 E^{-\gamma}$. The synchrotron energy losses render the pitch angle distribution anisotropic and the synchrotron intensity spectrum at any later time T will change its slope at a frequency $\nu_B(T)$.

$$\nu(T) = \nu_B(T)/\nu_{B0} = h(T)\left(\int_1^T h^2(T)dT\right)^{-2},\ \nu_{B0} = 10^{11}/(H_{0\,mkG}^{3} t_{0\,Myr}^{2}).$$

Note that this frequency depends only with magnetic field evolution curve $h(T)$, and not on the expansion mechanism of the particles $K(T)$ ($K \propto T^{-\delta}$).

The 'optical thin' of the integrated spectrum will not change for any synchrotron loss model (KP,JP) (Carilli et.al.,1991). It will be modified approximately with the inhomogeneity parameters of the source as

$$F(\nu) \approx Const\ \nu^{(1-\gamma)/2} \int_1^{T_b(\nu)} h(T)^{(1+\gamma)/2} dT^{3\beta},$$

where $T_b(\nu)$ is given by $\nu = \nu_B(T_b)$. The integrated spectral index is dependent on the frequency range, the inhomogeneity parameters (T_{ξ}, β, δ, ψ) and the boundary parameters (E_{min}, T_a).

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At the frequencies $\nu > \nu_1 \approx \nu_{B0}/T_\xi^3$ we have $\alpha \approx \gamma/2$. At much lower frequencies the index becomes $\alpha \approx (\gamma-1)/2 + 3\beta/2 - \delta/2$. The actual variation of the spectral index will be determined by ithe given input parameters. In the range of $\nu < \nu_a \approx \nu_B(T_a)$, we may have a new break of the integrated spectrum to $\alpha_{(\nu<\nu_a)} = (\gamma-1)/2$, and the spectrum conserves this value till $\nu_{[MHz]} > \nu_c(E_{min}) = 10^{-5}\ E_{min}{}^2_{[MeV]} H_{[mkG]}$ or till any any other process absorbs the radiation.

The parameters β and δ define the time dependences of the source properties: the total number of electrons, $N(T) \propto T^{3\beta-\delta-1}$; the density, $n(T) \propto T^{-\delta}$ and the velocity $v(T) \propto T^{\beta-1}$. Using the adiabatic expansion coefficient a_1 (Kaiser & Alexander,1997)and the exponent of external density gradient β_* as per King's model, $(density) \propto (distance)^{-\beta_*}$, we get: $\beta = 3/(5-\beta_*)$; $\delta = 9/(5-\beta_*) - 4\alpha_1/3$.

Sources with slow spectral inhomogeneity $(0 < \beta_* < 2, \beta < 1)$ may be classified as FRII type, and the sources with fast spectrum inhomogeneity $(\beta_* > 2, \beta > 1)$ may be classified as FRI type. The parameters ψ and T_ξ are connected with magnetic field inhomogeneity.

Alternative reasons on spectrum index variations: A maser amplification process may operate in the vicinity of the energy cut-off. Although no efficient, it may increase the spectrum at those frequencies by 1-2 orders of magnitude (Kochanov, 1991). A shocked gaseous medium may also influence the spectrum. This matter may have a much steeper energy distribution index $\gamma >> 2$ compared to the index of the cocoon plasma. So, in sources with much turbulence (FR I type), shocked gas may constitute bulk of the source material, and the new "source" will contribute to the integrated spectrum at low frequencies (Tsvyk, 1998).

References

Carilli, C.L., et.al. 1991, ApJ, 383, 554

Braude, S.Ya., et.al. Decametric survey of discrete sources in the northern sky. apss, 1978:IV, 59, 145; 1979: VI, 64, 127; 1981: VIII, 76, 279; 1985:X, 111, 237; XII, 1995:226, 245

Kaiser,C.R. & Alexander P. 1997, MNRAS, 286, 215

Kochanov, A.E. 1991, DAN Ukrainy, No.5, 67

Tsvyk N. 1998, in Materials of the II Science Conference: "Some questions of the astronomy and astrophysics", Lviv, 196