INTERACTION OF THE BEAMS OF ACTIVE GALACTIC NUCLEI WITH THEIR ENVIRONMENT AT HIGH REDSHIFTS

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Aiming at a physical interpretation of the cosmological evolution of radio galaxies, we extend to a high redshift our analytical model for the propagation of relativistic beams first through a hot gaseous halo of the parent elliptical galaxy and then through an even hotter, but less dense, diffuse IGM, after crossing a pressure-matched interface between the two media[1-5]. This model, verified by quasi-hydrodynamical numerical simulations[5] has earlier explained : (1) the current mean size of classical double radio sources (D ~350 kpc), (2) their steep linear-size evolution with redshift, z : $D \propto (1+z)^{-3}$, (3) the correlation between size and radio luminosity (at fixed z) : $D \propto P^{0.3}$, (4) the number and <P> of giant radio galaxies, and (5) the break in the local radio luminosity function (LRLF), occurring near $P \sim 10^{24}$W.Hz^{-1} at 1 GHz ($H_\circ$ = 50 kms^{-1} Mpc^{-1}). Inputs to the model are observationally based average parameters of the halo[1] $\{kT_h \sim 1$ keV, $n(r) \sim 10^{-2}\text{cm}^{-3}[1+(r/2\text{kpc})^2]^{-3/4}\}$, IGM[7] $\{kT_{IGM} \sim 18$ keV $(1+z)^2$, $n_{IGM} \sim 7.10^{-7}\text{cm}^{-3}(1+z)^3\}$ and the beam[4] {opening angle Θ (radian) = 0.02 + 0.03 [29 - log P(t=0)]}. We assume a reasonable value of ϵ = 0.1 for the initial efficiency of conversion of the beam power, L_b (Watts) into (total) radio output $P_t \sim 10^{10}.P(\text{W.Hz}^{-1})$. A gradual weakening of magnetic field within the expanding source raises the significance of inverse Compton losses against the Cosmic Microwave Background (CMB), leading to a reduced radio efficiency (RRE)[3,2].

The entry of the beam into a far less dense medium, as it crosses the halo-IGM interface at a distance $R_h \sim 171$ kpc $(1+z)^{-10/3}$, is modelled by considering two extreme conditions[1,3] : (1) Constancy of Θ, implying an increased velocity, V_h, of the beam's head, and (2) continuity of V_h, implying the beam's flaring and deceleration. Since the relic phase of radio galaxies appears to be much shorter[8] than the nuclear active lifetime[9,10] $t_N \sim 10^8$yr, we assume that the radio lobes quickly fade out when $t > t_N$, or when V_h becomes sonic, inhibiting the supply of relativistic plasma to the lobes via backflow.

Fig. 1 shows the LRLF computed[4] using the above model, adopting a simple form: $\Phi(L_b) \propto L_b^{-1}$ for the beam power function. The excellent agreement with the data[11,12,4] enabled us to argue that[4]: (1) the same $\Phi(L_b)$, could well extend to much lower L_b, without conflicting with the observed flattening of the LRLF below $P \sim 10^{24}$ W.Hz^{-1}, and (2) the

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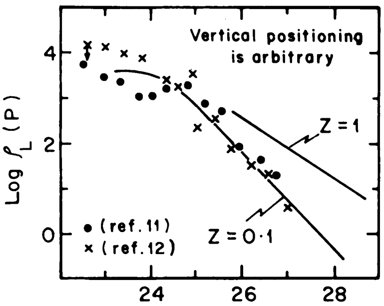

Fig(1). Log P (W Hz^{-1} at 1 GHz)

different radio morphologies exhibited by sources above and below this luminosity[13,14] need not imply generically different engines. We now compute the RLF for a high redshift of 1, following the same procedure and keeping the same form for $\Phi(L_b)$, as well as retaining the various other input parameters as defined above. The main differences at the high z are related to the beams' interaction with the environment. Firstly, the much smaller halo (~35 kpc at z=1), hastens the beam's encounter with the IGM whose sound velocity has, moreover, risen by (1+z). Secondly, the fall in density across the halo-IGM interface has increased further by $(1+z)^2$. Even for quite powerful sources, these changes are found to accentuate the beam flaring, thereby advancing the radio fading, aided by an enhanced RRE due to a stronger CMB. The computed RLF(z = 1; Fig. 1) is considerably flatter than the LRLF, consistent with the notion of differential evolution inferred from radio source counts and the luminosity-volume test[15].

The apparently ubiquitous X-ray halos around early-type galaxies[6,16], presumably heated by supernovae, seem to require an external confining medium[16]. In case a diffuse, hot IGM did not exist[17] (see, however, refs. 18, 5, 2, 1), a plausible alternative could be an intracluster medium (ICM) similar to the hot, 'primordial' gas now thought to pervade the outer parts of the Coma cluster[19]. Such an outer ICM would probably be still in a state of free expansion[20], like the putative diffuse IGM, and may well turn out to be relevant for powerful radio galaxies, since they normally occur outside the cores of clusters.

1. Gopal-Krishna, Wiita, P.J., MNRAS **226**, 531 (1987)
2. Wiita, P.J., Gopal-Krishna, Proc. Georgia State Univ. Conf. (1988)
3. Gopal-Krishna, Wiita, P.J., Saripalli, L., MNRAS (Submitted)
4. Gopal-Krishna, Wiita, P.J., Nature **333**, 49 (1988)
5. Rosen, A., Wiita, P.J., Ap. J. **330**, 16 (1988)
6. Forman, W., Jones, C., Tucker, W., Ap. J. **293**, 102 (1985)
7. Guilbert, P.W., Fabian, A.C., MNRAS **220**, 439 (1986)
8. Giovannini,G.,Feretti,L.,Gregorini,L.,Parma,P., A. A. **199**,73 (1988)
9. Stockton, A., MacKenty, J.W., Ap. J. **316**, 584 (1987)
10. Hutchings, J.B., Ap. J. **320**, 122 (1987)
11. Subrahmanya, C.R., Harnett, J.I., MNRAS **225**, 297 (1987)
12. Oort, M.J.A., Ph.D. Thesis, Leiden (1987)
13. Fanaroff, B.L., Riley, J.M., MNRAS **167**, 31P (1974)
14. Bridle, A.H., Can. J. Phys. **64**, 353 (1986)
15. Kellermann, K.I., Wall, J.V., Proc. IAU Symp. No. **124**, 545 (1987)
16. Canizares,C.R., Fabbiano,G., Trienchieri,G., Ap. J. **312**, 503 (1987)
17. Giacconi, R., Zamorani, G., Ap. J. **313**, 20 (1987)
18. Barcons, X., Fabian, A.C., MNRAS **230**, 189 (1988)
19. Hughes, J.P., Gorenstein, P., Fabricant, D., Ap. J. **329**, 82 (1988)
20. Stocke, J.T., Perrenod, S.C., Ap. J. **245**, 375 (1981)

DISCUSSION

BEALL What were the principal energy-loss mechanisms of the beam and the γs of the beam particles? Also, Scott did some early work on particle beam propagation which Rose, Beall, Guillory, and Kainor (*Ap. J.*, **280**, 1984; *Ap. J.*, **314**, 95, 1987) extended. That analysis shows that the beam propagation lengths do not exceed ~ 1 kpc for e^- p beams. I don't think the beams can propagate as far as you claim.

GOPAL-KRISHNA We have considered the usual synchroton and expansion losses and explicitly modelled the inverse Compton losses expected due to the cosmic microwave background. The composition of the beam material is not critical to our model but we have assumed a relativistic bulk motion. This is supported by the recent observational evidence (reviewed by P.A.G. Scheuer in "Superluminal Radio Sources," Cambridge University Press, 1987; R. C. Walker, *et al.* *Ap. J.*, in press, 1988).