INTERACTIONS OF JETS WITH INTERSTELLAR AND INTERGALACTIC MEDIA

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Jets emanating from AGN propagate first through an isothermal, but roughly power-law in density, galactic halo and then into a hotter, less dense, and uniform intergalactic medium (IGM) or intracluster medium (ICM). We use a three-dimensional boundary-following code (Mitteldorf & Wiita 1988), altered to allow for a two-phase external medium. We vary the beam power, P, the redshift, z, the radius of the galactic halo/IGM interface, R_h, the steepness of the power-law fall-off within the halo, *n*, and the temperature ratio of the IGM (or ICM) to the halo, T_r to estimate the average linear sizes of extragalactic radio galaxies (RGs). Good agreement is obtained with regard to the relationships between the overall linear size of such radio sources and both the total radio power (at fixed redshift) and the cosmological redshift (at fixed power). These numerical models tend to support recent analytical models (Gopal-Krishna & Wiita [GW] 1987, 1988).

X-ray observations of some isolated massive early type galaxies of the type likely to engender powerful radio sources indicate that hot (kT ≈ 1 keV) gaseous halos surround these objects (Forman, Jones & Tucker 1985). Further, an analysis of the X-ray background from 5-200 keV supports the hypothesis that an even hotter (T_{IGM} = 11-25 keV at this epoch), low-density ($n_{IGM} = 6\text{-}9\times10^{-7}$ cm^{-3}) intergalactic medium (IGM) exists (Guilbert & Fabian 1986). A simple analytic model considering the propagation of a beam through a pressure-matched interface at the radius of the halo yielded good agreement with the linear-size *vs.* redshift relation for RGs (GW87). By including inverse Compton losses both the shape of the local luminosity function of radio galaxies (GW88) and many of the properties of the giant RGs (Gopal-Krishna, Wiita & Saripalli 1988; Wiita & Gopal-Krishna 1988) could be explained.

We have modified the relativistic fluid boundary following code (Mitteldorf & Wiita 1988) to check and expand upon these analytical models (Rosen & Wiita 1988a,b [RW]). Assumptions and details are given there. Here we summarize over 100 additional computations of jets plowing across the interface between a galactic halo and either an IGM or an ICM and summarize the dependences of the maximum distance the jet can travel, D_{max} against various parameters. D_{max} is determined by either the nuclear activity cutoff time, t_N ($t_1 = 1\times10^8$ yr, $t_2 = 2\times10^8$ yr) or by when the beam becomes subsonic ($V_{head} < c_s$) (GW87,RW).

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Table I gives average slopes of fits using single power laws of linear-size against most of the parameters we have considered. We summarize the general behavior of beams after crossing the interface: initially the head of the beam accelerates causing a higher degree of collimation, but eventually, the acceleration slows and the beam begins to decelerate and spread out. The variations of D_{max} with T_r, R_h and n can be basically understood in terms of the ram pressure exerted by the final external medium on the head of the jet. For example, smaller R_h implies that n_{IGM}/n_o is greater and the cross-sectional area is smaller. Thus the maximum velocity after crossing the interface is higher and the ram pressure and concomitant deceleration are larger, leading to smaller values of D_{max} as determined by the c_s criterion.

Key conclusions of this work are that quasi-hydrodynamical numerical simulations of a beam propagating through a pressure matched halo-IGM interface confirm the effects of both redshift and luminosity on the overall sizes of radio sources predicted by the simple analytic models of GW. The analytic work predicts that the size of these sources should fall off as $(1+z)^{-\sigma}$, with σ between 2.5 and 3.5 and this numerical work (Table I) agrees. Both are good matches to the latest determinations from observational data by Oort *et al.* (1987) and Singal (1988) which give $\sigma \approx 3$. Kapahi (1985) and Oort *et al.* (1987) found $d(\log D)/d(\log P) \approx 0.3$, so our work also agrees well with the luminosity-size relationship in powerful RGs.

These good results provide new insights on the conditions of RG jets and also support the existence of a significant IGM. Future high resolution X-ray telescopes should find smaller galactic halos at larger redshifts since the IGM was denser and hotter in the past.

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TABLE I Values of $d(\log D_{max})/d(\log \text{Variable})$

Criterion\Variable	P	z	T_r	R_h
c_s	0.25±0.06	3.19±0.48	−0.17	0.93
t_1	0.30±0.08		0.15	
t_2	0.27±0.08	2.28±0.43	0.19	

References

Forman, W., Jones, C. & Tucker, W. 1985, *Ap. J.*, **293**, 102.
Gopal-Krishna & Wiita, P.J. 1987, *M.N.R.A.S.* **226**, 531 (GW87).
Gopal-Krishna & Wiita, P.J. 1988, *Nature* **333**, 49 (GW88).
Gopal-Krishna, Wiita, P.J. & Saripalli, L. 1988, submitted to *M.N.R.A.S.*
Guilbert, P.W. & Fabian, A.C. 1986, *M.N.R.A.S.*, **220**, 439.
Kapahi, V. K. 1985, *M.N.R.A.S.*, **214**, 19P.
Mitteldorf, J. & Wiita, P.J. 1988, in *Active Galactic Nuclei*, (hereafter *AGN*) eds. R.H. Miller & P.J. Wiita (Springer-Verlag), p. 378.
Oort, M.J.A., Katgert, P., Steeman, F.W.H. & Windhorst, R.A. 1987, *Astr. Ap.*, **179**, 41.
Rosen, A. & Wiita, P.J. 1988a, *Ap. J.*, **330**, 16 (RW).
Rosen, A. & Wiita, P.J. 1988b, in *AGN*, p. 383.
Singal, A.K. 1988, *M.N.R.A.S.*, **233**, 87.
Wiita, P.J. & Gopal-Krishna. 1988, in *AGN*, p. 388.