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The environments of double radiogalaxies

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Abstract

I discuss simple methods by which the densities and pressures of the gas confining double radiogalaxies can be estimated from optical and X-ray data. By applying these methods to an unbiased sample of nearby ($z < 0.5$) double radiogalaxies, I quantify the empirical relation between the external confining pressure and the internal pressure of the lobes as inferred from the minimum energy argument. This relation is explained by an analytic model in which the lobes are statically confined by ambient material pre-heated in the bow-shock of the advancing radiosource. Such a model allows one to: (a) estimate source expansion speeds from a combination of radio and environmental data; and (b) estimate properties of the environment from radio data alone providing expansion speeds can be estimated from multifrequency observations.

1 The empirical relation between internal and external pressure

In a study of the effects of the environment on the properties of radiosources three different classes of ambient material must be considered, namely the ISM, the ICM and the IGM. The detection of X-ray haloes out to radii $\sim$ 100 kpc around nearby giant elliptical galaxies [1] indicates that the lobes of radiogalaxies (typically $\sim$ 300 kpc total size) will be confined by this circum-galactic material unless the galaxy is in the core of a reasonably rich cluster; only for low-redshift giant radiosources do we need to consider the effects of the IGM. Therefore, I have classified the environments of the unbiased sample of 39 double radiogalaxies studied optically by Rawlings et al. [2] according to the number of galaxies (N_{250}) with $M_V < -21$ within 250 kpc of the radiogalaxy; the environments with $N_{250} > 5$ are termed cluster core (C) and those with $N_{250} < 4$ termed isolated (I), the remaining intermediate cases are termed group (G). Although crude, this classification scheme is systematic, repeatable and unbiased with respect to redshift; furthermore it was found to be almost perfectly correlated with the X-ray data available for the sample objects. Using the standard formulae relating X-ray properties to gas pressure as a function of radius [1,3], and where necessary estimating the X-ray properties from established correlations with optical properties [1,4], I estimated the pressure external to the source using the null hypothesis that properties of the ambient material are not influenced by those of the radiosource. Completely independent estimates of the *internal* pressure of the radio-emitting plasma were made by applying the standard minimum energy arguments [5] to the radio data. I plot the external pressure versus the minimum internal pressure in Fig. 1 obtaining a strong empirical correlation. Two further aspects of Fig. 1 deserve emphasis: for the sources in clusters there is a rough equality between minimum-internal and external pressure while for those associated with isolated galaxies over-pressures in the lobe of $\sim$ 10 are the norm. I now outline an analytic model that explains these features by rejecting the null hypothesis and allowing the radiosource to influence its own environment.

2 An analytic model for radiosource confinement

The similarity of derived internal and external pressures in the cluster doubles, as seen in cluster sources with other structures, argues strongly that the minimum-lobe pressure is in fact a reasonable approximation to the true internal pressure. With this in mind it is constructive to consider the model source of total linear size D illustrated in Fig. 2. I assume that the volume of gas shocked by the radiosource (ϕ_{bs}) as it expands supersonically into the ambient medium is a fraction f of the maximum (ϕ_{max}) obtained by considering a sphere of radius D/2 centred on the radiogalaxy. Thus

$$\phi_{bs} = \frac{\pi D^3 f(2R_T^2 - 3)}{12R_T^2}$$

By assigning an average pressure $\bar{p}$ to the gas in the shocked region, its gain in internal energy is

$$U_{bs} = \frac{3\pi D^3 f((2\bar{p}R_T^2 - 3\bar{p}) - 2p_0 R_T^2}{24R_T^2}$$

If this energy is supplied adiabatically by the work done on the gas by the expanding heads of the source then

$$U_{bs} = \frac{\pi D^3 \eta^2 V^2 \rho_0}{4R_T^2}$$

where η is the ratio of the width of the working surface (the compact hotspot?) to the width of the lobes. Thus in a constant pressure and density atmosphere

$$\frac{\bar{p}}{p_0} = \frac{\frac{1.4m_p\eta^2V^2}{kT} + fR_T^2}{f(R_T^2 - 1.5)}$$

For $V^2 < \frac{fR_T^2 kT}{1.4m_p\eta^2}$ this pressure enhancement factor tends to unity whereas for larger V we obtain

$$\frac{\bar{p}}{p_0} = \frac{1.4m_p V^2 \eta^2}{fkTR_T^2} \qquad (1)$$

which for typical values of the parameters ($V = 0.05c; T = 3keV; R_T = 5; f = 0.1; \eta = 0.1$) gives over-pressures of ~ 10; this value will increase with the Mach number of the jet principally as f and V^2 vary.

Thus this simple analytic model can explain the distribution of sources in Fig. 1 by allowing the rapidly expanding isolated radiosources to modify their own environments and thereby obtain static pressure balance between the lobe plasma and the shocked ambient gas in the bow-shock. A source with similar jet properties in a cluster will expand at a slower speed and will not have an apparent over-pressure in the lobe. *Thus the resulting shapes and luminosities of the lobes of double radiosources are influenced by the properties of both the powering jets and those of the surrounding environment.* These features also appear, although in a less immediately accessible form, in numerical simulations of double radiosources [6].

By assuming that the lobes are in static pressure balance (e.g. measured lobe minimum pressure $\approx \bar{p}$) it is possible, using a suitably calibrated version of equation 1, to estimate the expansion speed of a radiosource using radio and environmental data. Furthermore, if V is known from the spectral ageing analysis of multifrequency radio data [8], then radio data alone can be used to estimate the properties of the environment at all redshifts. Further details of these methods and their uses will be presented at the Conference.

References

[1] Forman W. *et al.* Ap.J. 293, 102 (1985) [2] Rawlings S. *et al.* MNRAS, in press. [3] Jones C. & Forman W. Ap.J. 276, 38 (1984). [4] Bahcall N. Ap.J. 238, L117 (1980). [5] Miley G. Ann.Rev.Astron.Astrophys. 18, 16 (1980). [6] Leahy J. & Williams A. MNRAS 210, 929 (1984). [7] Rawlings S. & Saunders R., IAU 134, in press. [8] Alexander P. & Leahy P. MNRAS 225, 1 (1987) [9] Guilbert P. & Fabian A., MNRAS 220, 439 (1986).

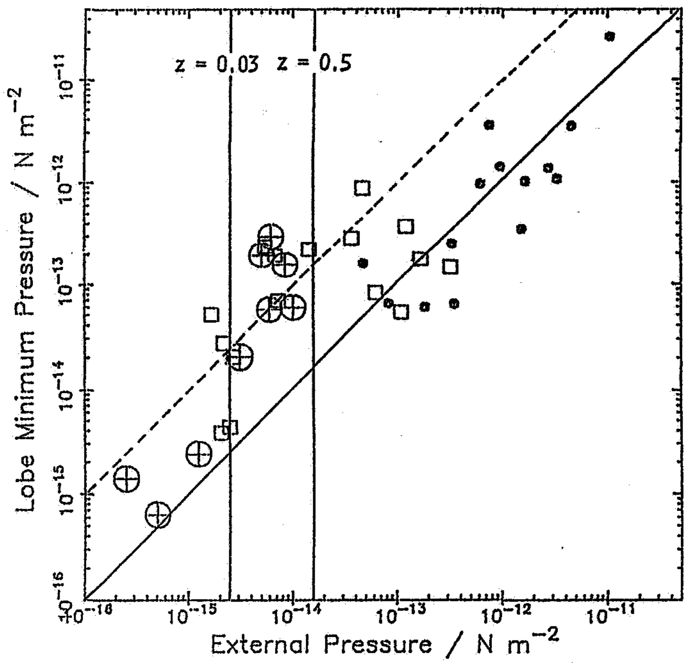
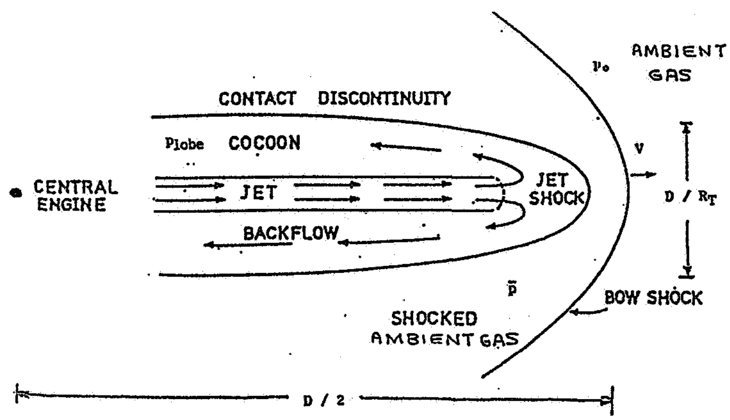


Fig.1 Lobe mimimum pressure versus external pressure for sources in clusters (circles), groups (squares) and those that are isolated (crossed-circles). The vertical lines mark the pressure of the IGM at the redshift limits of the sample assuming the model of Guilbert & Fabian [8]; the diagonal lines mark apparent pressure balance and a lobe over-pressure of $\sim$ 10.



D = largest projected linear size

Plobe = pressure in the radio lobe

p_o = pressure of undisturbed ambient gas

<p> = average pressure in the shocked gas

ρ_o = density of undisturbed ambient gas

R_T = ratio of largest projected size to width half way along the lobes

T = temperature of undisturbed ambient gas

V = rate of growth of the source, the true advance speed

Fig.2 Schematic diagram of the analytic model.