ROTATING GAS AND THE SHAPES OF RADIO SOURCES

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The power for a strong extragalactic radio source comes from deep within the nucleus, but the extended radio structure is clearly related to the larger-scale properties of the galaxy in which it lives. Very large sources are found in elliptical rather than spiral galaxies, and big galaxies have stronger radio sources than small ones. The narrow jets mapped in weaker radio galaxies do not expand with a constant opening angle, but become better focussed along their length, suggesting that they are confined by an external pressure. This paper discusses how the rotation of a radio galaxy affects the distribution of gas within it, and consequently the radio structure in elliptical and Seyfert galaxies. A model is proposed which leads to a specific prediction, relating the width of radio jets to the rotation speed of the galaxy in which they lie.

Gas lost from aging galactic stars flows back into the interstellar medium, and is heated by collisions to a temperature approximately corresponding to the stellar velocity dispersion. This material can fall into the nucleus to fuel an accreting black hole; how much of it reaches the center depends on how hot it is, and how it rotates. If the galaxy rotates, the ejected gas shares that motion, and spins faster and faster as it nears the center. Centrifugal forces push the gas away from its rotation axis, leaving a partially emptied channel there. The angular width of this evacuated funnel increases with the galactic rotation speed V_R approximately as V_R/σ, where σ is the stellar velocity dispersion; this is 6-12° for an elliptical galaxy.

VLBI observations suggest that the energy for radio emission is supplied as a relativistic beam of plasma shot out from the innermost parsec of a radio galaxy; theoretical arguments indicate that this should point along the angular momentum vector of whatever material is falling onto the nucleus. In an isolated system this will be the galactic spin axis, so that the beam is injected along the centrifugally-emptied funnel. A fast-moving beam is unstable to disturbances at its interface with stationary material; the more so, the less the flow or the denser the surrounding gas. Growing instabilities may give rise to

D. S. Heeschen and C. M. Wade (eds.), Extragalactic Radio Sources, 25–26.

shocks, which disrupt the ordered motion and accelerate particles, producing a radio-bright 'hot spot'. If this process occurs within the emptied channel, and the ambient gas pressure is sufficient, radiating particles will be confined near the galactic spin axis. The radio-emitting plasma then drifts outwards, filling a jet, the width of which is set by the galactic rotation speed. In the more powerful radio sources, the beam must carry more energy and may be denser or faster, and so more stable against surface disturbances; the 'hot-spot' marking its disruption will occur further from the nucleus. Beams in the strongest souces will remain relativistic until they meet the intergalactic medium in a 'working surface' far outside the galaxy. In spiral galaxies, which contain interstellar gas a thousand times denser than that in ellipticals, the relativistic beam is likely to be disrupted before it has left the galactic bulge; dense galactic gas then confines the radiating particles to small double lobes similar to those observed in Seyfert galaxies (A.S. Wilson, this volume).

This model has a number of immediate consequences. Most obviously, galaxies with radio jets must contain gas extending beyond their nuclear regions, exerting sufficient pressure to balance that of the radiating plasma. Extended radio doubles should point along the spin axis of the gas confining them; this need not be the galactic rotation axis if the galaxy has recently merged or, for example, if the gas in the bulge of a disk system does not share the general galactic rotation. Radio jets and small double-lobed sources should show opening angles which increase with the rotation speed of the galaxy; this could easily be checked with presently-available optical telescopes and VLA radio maps. The jets should be focussed by the pressure of the surrounding gas, rather than expanding freely away from the nucleus.

Details of the calculations will appear in the Astrophysical Journal.

DISCUSSION

TOHLINE: It's dangerous to assume that the gas will settle to an orientation in which its spin axis aligns with the spin axis of the stars. As Tohline, Simson and Caldwell (1982, Ap. J., 251, 000) have argued, the gas--irrespective of the initial orientation of its angular momentum vector--will respond to the global shape of the galaxy's potential well and will align its angular momentum vector with the symmetry axis of a spheroidal galaxy. Cen A may be an example, and NGC 5363 more likely is, of a "tumbling prolate" galaxy in which the spin axis of the gas is orthogonal to the spin axis of the stars.

SPARKE: I agree that, in a galaxy which rotates about an axis which is not one of symmetry, the angular momentum of the gas may not be parallel to that of the stars; then, the radio jets should lie along the spin axis of the gas surrounding them. However, radio galaxies tend to be round, so that the gas and stars spin about the same axis.