MAGNETIC FIELDS & IONIZED GAS IN ELLIPTICAL GALAXY HALOS

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ABSTRACT. Faraday depolarization estimates of thermal densities within the components of double radio sources agree well with estimates from X-ray observations of hot halos around early-type galaxies, provided magnetic field strengths are close to their equipartition values. Internal Faraday dispersion is the main cause of the depolarization observed.

1. Introduction

It has been clear for many years that depolarization by the Faraday effect can potentially tell us much about thermal gas associated with radio sources (Burn, 1966). Among the correlations found between depolarization and the properties of extragalactic double radio sources is one based on integrated polarization measurements which implies that the larger sources are associated with a lower density of thermal material (Strom, 1972; 1973). Following up a polarization study done at several wavelengths of the components of sources drawn from a complete sample (Conway *et al.*, 1983), Strom and Conway (1985) mapped the brightness distributions at 49 cm of sources which suffered little depolarization at the shorter wavelengths. The resulting polarization maps exhibited one striking feature in particular: central bridge emission is invariably unpolarized, and the region of low polarization is generally well-centered on the parent galaxy. This is almost certainly related to the earlier finding that large sources suffer much less depolarization than compact ones.

Subsequently, Strom and Jägers (1988) investigated several sources which had been mapped at two frequencies (Jägers, 1987) and found that their bridges are more strongly polarized at 21 cm, as expected from the Faraday effect. In two sources the depolarization rate, and hence the line of sight product of magnetic field strength and electron density, could be determined at various distances from the central galaxy. Assuming an equipartition magnetic field strength, Strom and Jägers (1988) were able to show that the densities obtained are consistent with the outer parts of hot halos observed around other giant elliptical galaxies in X-rays (Forman *et al.*, 1985), for gas in hydrostatic equilibrium. Here I consider depolarization effects in radio sources at smaller distances from the parent objects.

2. Results and Discussion

The X-ray density determinations (Forman *et al.*, 1985) cover radial distances from the parent object of a few to somewhat more than 10 kpc, while the radio sources investigated

R. Beck et al. (eds.), Galactic and Intergalactic Magnetic Fields, 459–462.

https://doi.org/10.1017/S0074180900190874 Published online by Cambridge University Press

go from about 60 to nearly 200 kpc (Strom and Jägers, 1988). There are several ways to fill in the 10−50 kpc gap. One could try to determine the depolarization at shorter wavelengths along the inner bridge in the sources studied previously, but both the nonthermal spectrum and small beamwidth required will result in weak signals. An obvious alternative is to look at the depolarization of sources with components in the desired distance range.

Spencer *et al.* (1989) have recently investigated a sample of compact (generally $<$ several ″arc) radio sources, with a median linear size near 9 kpc. A well-matched set of extended sources drawn from those observed by Conway *et al.* (1983) has a median linear size of 180 kpc. Values of the integrated polarization at 6 cm (Tabara and Inoue, 1980) are available for 44 of the compact sources and 70 of the extended ones. Most of the compact sources are relatively unpolarized at 6 cm (median degree of polarization of under 2 %), which contrasts strikingly with the degree of polarization of the extended ones (median near 6 %). There is a very low probability (< 0.001 %) that the two samples were drawn from the same population. The low degree of polarization observed in the compact sources is probably the result of depolarization by Faraday dispersion, as shown by the greater polarization found at shorter wavelengths in those sources for which measurements exist.

For typical values of depolarization rate, component size and equipartition magnetic field strength, the electron densities implied at a distance of ~ 10 kpc from the nucleus are $\sim 0.003\ \mathrm{cm}^{-3}$, similar to those obtained from X-ray observations. The radio depolarization data on both compact and extended double radio sources, ranging in size from under 1 kpc to more than 200 kpc, are thus consistent with these objects having extensive gaseous halos such as those observed in X-rays around early-type galaxies (Forman *et al.*, 1985).

3. Concluding Comments

The consistency found between the densities obtained from X-ray and radio depolarization measurements implies that magnetic field strengths in the radio components do not deviate greatly from their (assumed) equipartition values. The magnetic fields in compact, high brightness sources are thus much stronger than in extended, diffuse components. The depolarization observed in source bridges, being invariably centered upon the optical object, must arise from Faraday dispersion caused by gas which is coextensive with the radio emitting region and does *not* rely upon the effect of an intervening Faraday screen. Similarly, the fact that component edges depolarize less rapidly than their centers (*e.g.*, Jägers, 1987) is evidence for internal dispersion rather than differential rotation in a Faraday screen.

4. References

Burn, B.J. (1966) *Mon. Not. Roy. Astr. Soc.* **133**, 67–83.
Conway, R.G., Birch, P., Davis, R.J., Jones, L.R., Kerr, A.J. and Stannard, D. (1983) *Mon. Not. Roy. Astr. Soc.* **202**, 813–823.
Forman, W., Jones, C. and Tucker, W. (1985) *Astrophys. J.* **293**, 102–119.
Jägers, W.J. (1987) *Astr. Astrophys. Suppl.* **67**, 395–422.
Spencer, R.E., McDowell, J.C., Charlesworth, M., Fanti, C., Parma, P. and Peacock, J.A. (1989) *Mon. Not. Roy. Astr. Soc.* (in press).
Strom, R.G. (1972) *Nature Physical Science* **239**, 19–21.
Strom, R.G. (1973) *Astr. Astrophys.* **25**, 303–312.
Strom, R.G. and Conway, R.G. (1985) *Astr. Astrophys. Suppl.* **61**, 547–571.
Strom, R.G. and Jägers, W.J. (1988) *Astr. Astrophys.* **194**, 79–99.
Tabara, H. and Inoue, M. (1980) *Astr. Astrophys. Suppl.* **39**, 379–393.

KRONBERG: Is it reasonable to make the general inference that, for arcminute-scale e.g.r.s., *internal* depolarization sets in at $\lambda \approx 50$ cm, whereas external screens, where they occur, cause depolarization at the shorter wavelengths?

STROM: I agree with the general sense of your question that there are two competing Faraday depolarization mechanisms, viz. by internal dispersion (along the line of sight through the source) and in a screen (side-to-side depolarization by beam smearing), that the former dominates in the extended radio sources I have been studying and that the latter has been seen in some objects at short wavelengths. I would like to emphasize that I do not claim that depolarization by internal dispersion operates to the exclusion of other mechanisms but that it *dominates* in the sources I have considered here.

PERLEY: In my view, you cannot claim any depolarization until you have mapped the RM distribution at higher resolution and frequency. I think the depolarization you observe is likely due to simple beam depolarization due to galactic gas. Claiming internal depolarization in the objects you have observed is merely guilt by association, and is not proof. The only way to eliminate doubt is to measure the RMs. Will you do this?

STROM: Let me first restate the evidence for internal Faraday dispersion in the sources we have observed. The depolarization "holes" in the radio source bridges coincide with the optical object, which itself always falls on the bridge, so its gas *must* be coextensive with the bridge material. The X-ray observations tell us that halo gas peaks on the galaxy and its density is in good agreement with that required to produce the observed depolarization. To invoke depolarization by a screen would require a relatively high density shell, in the case of the extended sources 50–100 kpc from the galaxy, which is both *ad hoc* and unnecessary in view of the gas which we know to be present from the X-ray measurements. I doubt that RM determinations would provide a conclusive test, as there are so many unknown and unmeasurable parameters (magnetic field strength and particle density variations, field reversals, etc.). The best observatioal proof would be to resolve the cells of the purported Faraday screen and show that they are strongly polarized. While I would like to carry out the RM measurements you suggest, at the long wavelengths where our sources depolarize (49, 92 cm) we are unable to observe at enough frequencies to make them really meaningful.

CONWAY: We heard yesterday from Dr. Perley of the very large RM in for example Cyg A, say 1000 rad m^{-2}, which occur in a surrounding screen. The RM needed to depolarize the bridges of sources in your sample is only about 10–20. Can I ask what is the maximum *internal* RM that would be possible in Cyg A?

STROM: I understand from Dr. Perley that his polarization measurements of Cyg A do not extend longwards of 6 cm, so they put an upper limit on the *internal* RM of about 500 rad m^{-2}, given that no significant line-of-sight depolarization occurs.

KAHN: Can the density distribution $\rho \propto r^{-3/2}$ which you find be due to an accretion flow with constant mass rate M? The −3/2 power law is characteristic of such flows.

STROM: We have no knowledge of the gas dynamics in these halos, but it is certainly true that they could be cooling flows. I adopted $\rho \propto r^{-3/2}$ because it is what Forman et al. found from their X-ray observations. I would point out that gas in hydrostatic equilibrium in the gravitational potential of a dominant central mass will display the same density profile.

https://doi.org/10.1017/S0074180900190874 Published online by Cambridge University Press