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Dark Spots, Bubbles, and Shells in the Lobes of Extragalactic Radio Sources

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Abstract. Based on maps of the extragalactic radio sources Cyg A, Her A, Cen A, 3C 277.3 and others, arguments are given that the twin-jets from the respective active galactic nucleus ram their channels repeatedly through thin, massive shells. The jets are thereby temporarily choked and blow radio bubbles. Warm shell matter in the cocoon shows up radio-dark through electron-scattering.

Key words: jets—lobes—shells around galaxies—Cyg A—Her A—radio bubbles

1. Introduction

Maps of extragalactic radio sources with high dynamic range and radio-optical overlay maps have shown considerable fine structure of the lobes (radio, Cyg A: Perley, Dreher & Cowan 1984; Dreher *et al.* 1984; Her A: Dreher & Feigelson 1984; 3C 310: van Breugel & Fomalont 1984; 3C 382: Strom, Willis & Wilson 1978; 3C 219: Perley *et al.* 1980; 3C 433: van Breugel *et al.* 1983; optical, 3C 277.3: van Breugel *et al.* 1985b; NGC 541: van Breugel *et al.* 1985a; NGC 7385: Simkin, Bicknell & Bosma 1984; Fornax A: Schweizer 1980, Ekers *et al.* 1983; 3C 293: van Breugel *et al.* 1984). There are clear to likely indications that the radio hotspots are associated with optical continuum radiation (Cyg A: Kronberg, van den Bergh & Button 1977; 3C 33 S: Rudnick *et al.* 1981; Meisenheimer & Röser 1986; 3C 273: Röser & Meisenheimer 1986; further: Crane, Tyson & Saslaw 1983).

The radio fine structure of Cyg A shows two (narrow) jets in emission, cylindrical and loop-like emission 'filaments', and two hotspots in each lobe (*cf.* Figs 1a, b). It also shows 'dark spots' associated with the hotspots, and perhaps dark lanes at right angles to the jets (Fig. 1c). We shall interpret these radio-dark features as due to electron-scattering by filamentary matter whose mass amounts to at least $10^{10}\, M_{\odot}$. The filamentary matter is thought to traverse the halo in the form of thin, heavy partial shells, as evidenced by the mentioned radio-dark lanes in the case of Cyg A, by optical emission in the case of Cen A (Malin, Quinn & Graham 1983) and by radio depolarization in the case of 3C 277.3 (van Breugel *et al.* 1985b). These partial shells appear to be rather common (Malin & Carter 1983; Quinn 1984; Schweizer 1986). In the case of Cen A, Gopal-Krishna & Saripalli (1984) have presented overlay evidence that the shells interact with the jets. Kundt & Krause (1985) have argued that the shells consist of filamentary matter ejected supersonically by the galactic nucleus during active epochs—which matter is continually reionised by ram-pressure heating and/or background UV.

These thin, massive partial shells in the haloes of galaxies can make their appearance directly, as quasi-circular radio or optical lanes. Indirectly they are indicated by the large mass needed to give rise to the radio-dark spots of Cyg A, and also by the radio 'bubbles' seen in Her A, 3C 310, 3C 277.3, 3C 219 and others. Such bubbles are thought to be the results of 'jet-choking' (van Breugel & Fomalont 1984): A thin layer of heavy material temporarily reduces the advance speed of the beam's head considerably, in proportion to $\rho^{-1/2}$. As a result of such temporary choking, or stalling, the beam head does not advance at a constant speed but rather at two very different speeds, like a drill eating its way through a sandwich door (at constant thrust). During shell crossing, a huge amount of beam plasma is dumped in a short beam segment. Its explosive expansion sweeps thermal plasma and magnetic fields out in the shape of a strongly magnetised quasi-spherical layer: a radio bubble. These bubbles are reminiscent of a glass-blower's craft. They are observed to have circumferential magnetic fields, in accordance with the suggested explanation (*e.g.* Dreher & Feigelson 1984; van Breugel & Fomalont 1984). We believe that many observed lobe morphologies can be understood as the result of a steady beam ramming its channel through a strongly inhomogeneous environment.

Another environmental effect, not elaborated in this communication, is channel destruction by shear motion of the IGM, in particular at the edge of a galactic halo.

2. The radio-dark spots of Cyg A

In Fig. 1c we have drawn what we consider dark spots, and dark lanes, in the lobes of Cyg A. Most remarkable is the dark spot in front of radio hotspot B, in the north-preceding component (*cf.* Alexander, Brown & Scott 1984). It has less than 10 per cent of the peak brightness of the adjacent hotspot B, most clearly obtained from an intensity cut (personal communication by John Dreher; see also Fig. 2 of Hargrave & Ryle 1976). It is hugging hotspot B. It may or may not coincide with an optical source of J-magnitude 22 (Kronberg, van den Bergh & Button 1977, in particular the erratum; also R band CCD image of P. Hiltner 1986, personal communication).

It is highly unlikely that the synchrotron-emitting lobes have cylindrical holes aligned with the line-of-sight and correlated with the hotspots. We interpret the radio-dark spots as (front-side) pockets, or cushions, of warm matter scattering the radio photons out of the line-of-sight. As we shall see, the alternative possibility of free-free absorption would imply intolerably high optical emission.

A scattering screen of optical depth τ reduces the intensity by the factor $e^{-\tau}$. For the dark spot hugging B we need $\tau \gtrsim 1$, hence

$$1 \lesssim \tau_{sc} = \sigma_T \int n_e \, ds = (\int n_e \, ds)_{24.2} \tag{1}$$

where σ_T = Thomson cross-section and n_e = electron number density. This estimate envisages the dark spot as a combined effect of scattering plus absence of emission, *i.e.*,