The parsec-scale central components of FR I radio galaxies

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**Abstract.** A majority of a complete sample of 3CR FR I radio galaxies show unresolved optical nuclear sources on the scales of 0.″1. About half of the 3CR FR II radio galaxies observed with the HST also show Compact Central Cores (CCC). These CCCs have been interpreted as the optical counterparts of the non-thermal radio cores in these radio galaxies (Chiaberge, Capetti, & Celotti 1999). We show that the optical flux density of the CCCs in FR Is is correlated with the radio core prominence. This correlation supports the argument of Chiaberge et al. that the CCC radiation is of a non-thermal synchrotron origin, which is relativistically beamed along with the radio emission.

1. Introduction

*Radio Galaxies* are radio-loud \( (S(\nu)_{5\text{GHz}}/S(\nu)_{\text{BBand}} > 10) \) Active Galactic Nuclei (AGN) found in hosts that are elliptical galaxies. Their radio structure is made up of two lobes of radio-emitting plasma situated on either side of an unresolved radio core and connected to the core by plasma jets. The radio morphologies fall in two distinct sub-classes: the Fanaroff-Riley type I (FR I) with extended plumes and tails having \( L_{178} < 2 \times 10^{26} \text{ W/Hz} \) and the Fanaroff-Riley type II (FR II) with narrow jets and hotspots having \( L_{178} > 2 \times 10^{26} \text{ W/Hz} \) at 178 MHz.

Within the *unification scheme* for radio-loud AGN, FR I and FR II radio galaxies are thought to represent the parent populations of BL Lac objects and radio-loud quasars, respectively. BL Lac objects show clear evidence for relativistic beaming resulting from the bulk relativistic motion of the plasma moving close to the line of sight. If FR I radio galaxies are the plane-of-sky counterparts of BL Lacs, FR I jets should also have bulk relativistic motion.

The core prominence parameter \( R_c \), which is the ratio between core and extended radio flux density, is a beaming indicator. This is because if the core is the unresolved relativistically beamed jet and the lobes are unbeamed then \( R_c \) becomes a statistical measure of orientation. \( R_c \) has indeed been shown to correlate with other orientation-dependent properties in the case of FR IIs (eg. Kapahi & Saikia 1982) and in FR Is (eg. Laing et al. 1999). The jet-to-counterjet surface brightness ratio \( R_j \), is one such parameter, where differences in the surface brightness between the jet and counterjet at a given distance from the nucleus are interpreted as effects of Doppler beaming and dimming respectively, on intrinsically symmetrical flows.

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The primary motivation for our work comes from the discovery of unresolved optical nuclear components at the centres of radio galaxies by the Hubble Space Telescope. The optical flux of these Central Compact Cores (CCC), (Chiaberge et al. 1999), show a striking linear correlation with the radio core emission. Chiaberge et al. suggest that the CCCs are the optical counterparts of the relativistic radio jet. We study the relationship between the CCC flux densities of FR Is and FR IIs and the core prominence parameter, $R_c$, the jet-to-counterjet surface brightness ratios, $R_j$; and the X-ray core flux densities.

2. The sample and the data

We used the sample of 27 3CR FR Is in Chiaberge et al. (1999), with their data for the CCC flux densities. In addition, the CCC flux densities for the FR Is NGC 7052 and NGC 6251 are from Capetti & Celotti (1999) and Hardcastle & Worrall (2000) respectively. The FR II radio galaxies and their CCC optical flux densities are taken from the sample of 26 3CR FR IIs of Chiaberge et al. (2000). The set of BL Lacs and their optical core flux densities are from Capetti & Celotti (1999). The VLBI jet-to-counterjet surface brightness ratios come from the VLBI observations of the sample of Giovannini et al. (1990). (Giovannini et al. 1999 and references therein). The jet-to-counterjet surface brightness ratio, $R_j = B(\text{jet})/B(\text{cjet})$, are for distances of a few pc from the core. The X-ray core flux densities are from the ROSAT data in Hardcastle & Worrall (2000). The core prominence, $R_c = S(\text{core})/S(\text{extended})$, was calculated using the total and core radio flux densities at 5 GHz.

3. Results

3.1. Optical CCCs in FR I radio galaxies

The CCC optical flux density $F_o$, is well correlated with radio core prominence $R_c$, the significance of the correlation being at the 0.001 level (Spearman rank test). See Figure 1a. Given that $R_c$ is a statistical measure of angle to the line of sight, the correlation suggests that the CCC flux density is orientation dependent in the same way as the core radio emission and it may thus constitute the optical counterpart of the radio synchrotron jet. In Figure 1a we have included a set of BL Lacs, whose extended radio luminosities span the same range as the FR Is, for comparison. The BL Lacs extend the correlation to higher $R_c$, as would be expected if FR Is are the parent population of BL Lacs. The optical flux density of CCCs $F_o$, and the jet-to-counterjet surface brightness ratios $R_j$, at 5 GHz for FR I radio galaxies show a correlation significant at the 0.01 level (Spearman rank correlation test). See Figure 1b. This further substantiates the claim that the optical CCC is a part of the jet.

3.2. Optical CCCs in FR II radio galaxies

The optical core flux density for the sample of FR II radio galaxies shows a weaker correlation with radio core prominence than the FR Is (significance level 0.1; Spearman rank correlation test). See Figure 2.
3.3. X-ray core components in radio galaxies

We examine the correlation between the X-ray core flux density and the radio core prominence. See Figure 3. This seems weaker than the previous correlations. The correlation is significant at the 0.2 level for FR Is taken alone while it is significant at the 0.1 level for FR Is and FR IIs taken together.

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Figure 2. Radio core prominence $R_c$, versus CCC flux density $F_0$ ($\mu$Jy), for FR II (NL=Narrow-line, WL=Weak-line, BL=Broad-line) radio galaxies. Arrows denote upper limits in CCC flux density.

Figure 3. Radio core-prominence $R_c$, versus X-ray core flux density $F_x$ (nJy), for FR I and FR II radio galaxies. Arrows denote upper limits in X-ray core flux density.