STEEP SPECTRUM RADIO CORES AND FAR-SIGHTEDNESS [+]

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1. INTRODUCTION

Quite naturally so, VLBI'ers tend to be somewhat far-sighted: because of the very high resolutions, and poor UV-coverages, obtained with current VLBI networks only distant objects can be suitably studied. Unfortunately one thus tends to oversee some basic properties of a very popular class of objects, namely the compact, steep-spectrum radio cores. I would like to put these objects in their proper perspective.

2. STEEP SPECTRUM CORES (SSC's): A PHYSICAL DEFINITION

I define steep spectrum radio cores to be radio source components which have a spectral index $\alpha \geqslant 0.50$ ($S_\nu \sim \nu^{-\alpha}$) in a frequency range of at least 1 GHz - 15 GHz and which have linear sizes of approximately 0.1 kpc - 10 kpc, i.e. much smaller than a galaxy diameter but larger than the very compact (and often flat-spectrum) components associated with galaxy or quasar nuclei. Note that this definition is more general, and physically more meaningful, than the loose definition usually used by VLBI'ers (namely small [< 1"] steep spectrum sources, which can be mapped with VLBI).

3. PROPERTIES OF NEARBY SSC's

Defined as above, nearby and low luminosity SSC's comprise Seyferts such as NGC 1068 (Wilson and Ulvestad 1983). More powerful SSC's, which are somewhat further away, are 3C 305, 3C 293 and 4C 26.42 (e.g. van Breugel and Heckman 1982). Some objects have associated radio emission on a much larger scale (3C 293) and, in fact, even the largest radio galaxy known (3C236) has a SSC.

Nearby SSC's are accessible to spatially resolved optical studies. Presently known properties are (see for example, Miley 1981; van Breugel et al. 1983):

(1) SSC's have associated narrow-line regions of comparable size

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and which are often spatially related.

(2) Their radio luminosities are correlated with both the luminosities and widths of the [OIII] λ5007 lines.

(3) The asymmetries of the [OIII] λ5007 lines are correlated with the Balmer line decrements which may be interpreted as gas and dust outflow, presumably caused by jets and expanding radio components.

(4) The radio emission has a very low degree of polarization, even at short wavelengths. This appears to be anti-correlated with the presence of optical line emission.

(5) The parent galaxies show all evidence for a dense interstellar medium: gaseous disks and dustlanes (3C 305, 3C 293), neutral hydrogen (3C 293, NGC 3801, NGC 1167), and a cooling X-ray core (4C 26.42).

(6) In Seyferts 3C 305 and 3C 293, the SSC's are embedded in rotating gaseous disks which are capable of breaking and bending the jets. This may account for their S-shaped morphologies, although precession of jets also remains a viable explanation.

4. DISTANT SSC's (QUASARS): MORE OF THE SAME

SSC's are also found in some quasars (such as 3C 48, 3C 147, 3C 286, etc.), which may be more powerful but otherwise similar objects. I mention the following circumstantial evidence for this:

(1) There may be some evidence that the radio power/narrow line width correlation for SSC's can be extrapolated to the more distant and more powerful objects (Heckman et al. 1981).

(2) A high resolution VLA survey of a sample of distant SSC's (van Breugel et al. 1983) suggests that they have similar properties as nearby SSC's: a low degree of polarization, typical sizes of 0.3 - 24 kpc, complex morphologies (i.e. large misalignments between central core components and more distant 'lobes').

(3) Optical imaging of quasars suggests that a fair fraction (> 30% ?) of them may reside in spiral galaxies and that the quasar phenomenon may be triggered by interactions with nearby companions (e.g. Hutchings and Campbell 1983). This would provide for the dense environments in quasar SSC's and might explain their complex morphologies (Section 3, point 6).

(4) Quasars are profuse optical line emitters, thus showing off these gas reserves. Also, in 3C 48 the narrow line region extends roughly in the same direction as the SSC.

5. LOW FREQUENCY TURNOVERS IN SSC's: FREE-FREE ABSORPTION

The radio spectra of many SSC's are turning over at low frequencies (Peacock and Wall 1982). Examples are, in order of radio luminosity: NGC 1068, 3C 293 and 3C 286. These turnovers are generally ascribed to synchrotron self-absorption. I believe, however, that free-free absorption of the radio emission by the line emitting gas (entrained?) may provide a more natural explanation.

The optical depth (τ_ν) to thermal free-free-absorption at a frequency ν is

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$$\tau_\nu = T_e^{-1.5}\ \nu^{-2.1}\ \varepsilon \qquad \text{(c.g.s. units)}$$

where T_e is the electron temperature, ν is the frequency and $\varepsilon = n_e^2\ \phi \ell$ is the emission measure of the ionized gas (electron density n_e, volume filling factor ϕ, line of sight through the source ℓ).

Taking NGC 1068 as an example, I find that the spectrum turns over ($\tau_\nu \simeq 1$) near $\nu \simeq 100$ MHz (Kuhr et al. 1981). Assuming that the free-free absorption is due to the ionized gas of the line emitting clouds one further has $T_e \simeq 10^4$ K, so that the emission measure is $\varepsilon = 6 \times 10^{22}$ cm^{-5}. In NGC 1068, on average, $n_e \simeq 10^3$ cm^{-3} (Alloin et al. 1981) and the radio source 'lobes' have dimensions of ~ 0.4 kpc ($H_o = 75$; Wilson and Ulvestad 1983). The filling factor for the clouds must then be $\phi \simeq 10^{-4}$, which is entirely reasonable.

Similar order of magnitude estimates can be made for other SSC's and I conclude that free-free absorption by line emitting clouds is naturally to be expected. These clouds, which may have been entrained and are ionized by the source as its jets plough through the dense interstellar medium, will exhibit a range in densities, temperatures and velocities: small clouds will be accelerated and heated more by the jets than heavier clouds. Thus the absorption turnover will occur over a relatively broad region, rather than having a steep drop-off on the low frequency side which would occur for free-free absorption by a single, uniform cloud.

Because the emission measure for free-free absorption and optical line emission is the same, the turnover frequency (ν_T) and brightness of the optical line emission are correlated: $\varepsilon \sim \nu_T^{2.1}$. Thus brighter emission line objects (quasars) are expected to have higher turnover frequencies. This might also explain the redshift dependence of the low frequency turnovers in a sample of quasar SSC's found by Menon (1983).

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