SPECTRAL SHAPES OF COMPACT EXTRAGALACTIC RADIO SOURCES

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ABSTRACT

Possible mechanisms for producing the observed broad radio spectra of compact extragalactic radio sources are discussed. The explanations considered are: (a) superposition of the spectra of sub-components, (b) inhomogeneous synchrotron sources, and (c) synchrotron radiation from "non-standard" energetic electron spectra. These three models have been compared with results of spectral and VLBI observations. These comparisons indicate: (1) if the "superposition" hypothesis is correct, then the subcomponents themselves must be inhomogeneous synchrotron sources, (2) there is apparently no general inhomogeneous synchrotron source which characterizes compact extragalactic sources, and (3) many compact sources have spectra which resemble synchrotron radiation from a relativistic Maxwellian electron spectrum, but the inferred electron energies and magnetic fields have a wide range of values. VLBI observations of a selected sample of sources generally favor a single component model, but cannot distinguish between models (b) and (c).

The opaque synchrotron source model of compact extragalactic radio sources has been quite successful in accounting for observed properties of these objects, such as the relation between angular size and frequency of flux density maximum. However, for more than a decade it has been realized that this model, in its simplest form, cannot account for a very important observed property of compact sources. A homogeneous synchrotron source with a power law energetic electron spectrum has a power law radio spectrum at frequencies below that of flux density maximum, with a spectral index of 5/2. Almost no sources are observed to have an optically-thick spectral index this large. Out of a sample of 136 sources studied by Owen, Spangler and Cotton (1980), only one (0552+398) had a low frequency spectral index consistent with this value. A typical observed value was 0.3 - 0.5. This fact has been recognized for over a decade. At least three suggestions have been made to account for this observation. (1) Subcomponent Superposition According to this viewpoint, the integrated spectra are blends of subcomponent spectra. Each subcomponent is

D. S. Heeschen and C. M. Wade (eds.), Extragalactic Radio Sources, 297–299.

assumed to have the spectrum of a homogeneous synchrotron source, with a different frequency of maximum. The result would be a broad integrated spectrum which contains no information on the physics of the subcomponents. (2) Inhomogeneous Synchrotron Sources It seems unlikely that a source would have a uniform energetic electron density and magnetic field strength throughout the source (the definition of a homogeneous synchrotron source). It may be shown (Marscher 1977) that a source possessing radial gradients in these qualities will have a power law spectrum at frequencies below maximum, with a spectral index which is in general less than 5/2 and is dependent on the functional form of the inhomogeneities. The appealing feature of this model is that measurement of a global, observationally-accessible property of a source (the optically-thick spectral index α_T) can provide information on the functional form of the source inhomogeneity, and thus the physics of the source. (3) Non-Standard Energetic Electron Spectra A sharply-peaked radio spectrum with $\alpha_T = 5/2$ is a characteristic of a homo-geneous synchrotron source with a power law energetic electron spectrum. If the electron spectrum has a narrow spread in energy about a mean value, as is the case in a relativistic Maxwellian (Jones and Hardee, 1979), then the resultant radio spectrum can be quite different.

In an attempt to distinguish between these three possibilities, a program of multifrequency radiometric and VLBI observations was undertaken and is still in progress. The radiometric observations consisted of nearly simultaneous flux density measurements at 11 frequencies between 0.318 and 90 GHz, thus obtaining broadband "snapshot" spectra of 136 compact sources. The hope was that with such a large sample of high quality source spectra, one could investigate such questions as whether there was a preferred type of radio source inhomogeneity (manifested by preferred values of α_T), etc.

The principal feature of the subcomponent superposition model to be tested was the necessity for a fixed frequency spacing of the subcomponents. In a computer study, Cook and Spangler (1980) found that if the subcomponents had the spectrum of a homogeneous synchrotron source, then a highly regular and obviously artificial spacing of the subcomponent turnover frequencies was required to produce the observed spectra. This was not so much the case if the subcomponents possessed inhomogeneous source spectra. Thus, a hybrid of the superposition hypothesis and the inhomogeneous synchrotron source model would appear to be capable of matching the observed properties of compact extragalactic radio sources.

The principal goal of the inhomogeneous source analysis was to see if a "preferred" value for the optically thick spectral index could be found. This, in turn, would point to a predominant form of source structure. No such preferred value for the optically thick spectral index was found (Spangler 1980), giving no support to the idea that there is a general type of compact source structure. It is, of course, possible that a substantial number of compact sources are inhomogeneous synchrotron sources, but it would appear that different sources would then have to possess different types of inhomogeneity.

A comparison of observed spectra with the spectrum of synchrotron

https://doi.org/10.1017/S0074180900027959 Published online by Cambridge University Press

radiation from a relativistic Maxwellian electron spectrum revealed many cases in which very close agreement was found (Spangler 1980, Fig. 2). This is encouraging for the alternate electron spectrum model, but there are nonetheless difficulties. The inferred characteristic electron energies span a huge range. Furthermore, the relativistic Maxwellian synchrotron spectrum declines exponentially for sufficiently high frequencies, in apparent contradiction with observations. It seems probable that this difficulty could be overcome by a power law electron spectrum with a low energy cutoff.

The results of the analysis using only the radio spectral data were, therefore, somewhat ambiguous. All three of the hypotheses could, with certain qualifications, explain the statistical properties of the spectral sample.

It was therefore decided to make VLBI observations of a selected subsample of these sources. VLBI observations, used in concert with broadband spectral measurements, can, in principal, distinguish between the various spectral models. Ten sources were observed whose spectra indicated that they consisted of a single component. Observations were made with a four-element, continental baseline interferometer at 6 and 18 cm. Dual frequency observations were made to search for the frequency-dependent angular size expected for an inhomogeneous synchrotron source. Of the ten sources, one (2134+00) was found to definitely possess a double structure. Another object (0202+31) showed an indication of beating between subcomponents. For these two objects, it seems most probable that the observed spectrum is a blend of the subcomponent spectra. For the remaining objects, the VLBI observations were consistent with the sources consisting of a single unresolved or slightly resolved component. There therefore remains the possibility that the integrated spectra of these sources contain useful information on the physics of these objects. Three frequency observations, utilizing more stations and transcontinental baselines, are currently in progress.

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DISCUSSION

O'DEA: When you fit the relativistic Maxwellian spectra, what additional component is needed to explain the discrepancy at the lower frequencies?

SPANGLER: I believe the departure of the observed spectrum from the model spectrum at low frequencies is due to extended, steep spectrum components associated with the compact sources. Support for this opinion may be found in Owen, Spangler, and Cotton (A. J., 85, 351, 1980), in which a correlation was found between "decimetric excesses" and the existence of structure resolvable by the VLA.

https://doi.org/10.1017/S0074180900027959 Published online by Cambridge University Press