The Presidential Address

EXTRAGALACTIC RADIO SOURCES AND COSMOLOGY

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INTRODUCTION :

One of the current aims of observational cosmology is to distinguish between geometric and evolutionary effects and thus narrow down the range of acceptable world models. It is well known that the predictions of various models differ significantly only for redshifts greater than about 0.5. But for large cosmic epochs there also seem to be present many evolutionary effects for both optical and radio galaxies, being much more prominent for the latter. However, since a majority of the catalogued radio galaxies lie at cosmological distances, their observed properties are also affected appreciably by the geometry of the Universe. For discerning these two effects, it is necessary to observe the characteristics of radio sources over a wide flux density range.

Here, I first review briefly some cosmological interences that have been derived hitherto from radio astronomical data. I shall then describe some results derived from angular size statistics of extragalactic radio sources, based on occulation observations made at Ooty. It is shown that angular size-flux density counts of radio sources provide an independent evidence for the the big bang model.

RADIO ASTRONOMY AND COSMOLOGY:

Studies of radio source counts made by Ryle and his colleagues at Cambridge about 20 years ago provided the first evidence for an evolutionary universe and rejection of the steady state hypothesis. This conclusion got a strong support from the discovery of the microwave background emission by Penzias and Wilson in 1965. Nevertheless there have been controversies about the value of radio source counts for cosmological investigations, due to uncertainty of distances of radio sources, possible anisotropies in their spatial as well as spectral distributions and, particularly, some doubts about cosmological origin of redshifts of quasars. However, there has been recently much progress in radio source surveys which was reviewed extensively at the IAU symposium No. 74 on Radio Astronomy and Cosmology (Jauncey 1976). Although there were some suggestions of anisotropy at the level of about two standard deviations based on the 5 GHz Parkes and NRAO surveys, a detailed statistical analysis of many recent surveys by Webster (1976), using the powerful approach of power-spectrum analysis, has not revealed any significant evidence for anisotropy. Also, there has been a remarkable progress in optical identification and redshift measurement for 3CR radio sources (Smith 1977; Kristian 1977). For nearly 15 years, the largest available redshift for a radio galaxy was 0.461 for 3C 295. Recently, redshifts > 0.461 have been measured for 10 radio galaxies, the lagrest value being 0.752 for 3C 318 (as of July 1976). Only 20% 3CR sources have remained unidentified and it seems clear that most of these are galaxies at cosmological distances (Longair 1975; Smith 1977). About 20% 3CR sources are quasars which show strong evolutionary effects (Schmidt 1968). But their cosmological nature is still not well established (Burbidge 1973).

Recently, it has been shown that the median value of angular sizes, θ_m, of extragalactic radio sources decreases statistically with their flux density, S (Swarup 1975). Combining this relation, θ_m (S), with angular size distribution $(N > \theta)$ for 3CR sources, Kapahi (1975) has found independent evidence of evolution in radio source properties with epoch. It is shown that density of high luminosity sources increases with redshift similarly to that found from the log N-log S data and the physical sizes of radio sources evolve with redshift z as $(1+z)^{-1}$. The evolution is required even if the identified quasars are excluded.

ANGULAR SIZE STATISTICS OF EXTRAGALACTIC RADIO SOURCES :

Occultation observations of over 1000 radio sources have been made with the Ooty Radio Telescope over a period of about 5 years. Data reduction is over for about half of these sources. Most of these sources lie in the flux density range of about 0.3 to 5 Jy at 327 MHz. Resolution achieved has been about 1 to 2 arcsec for the stronger sources (unless they are considerably extended) and 6 to 10 acrsec for the weaker sources.

From the occultation observations made at 327 MHz during 1970-71 and 1973-74, we have selected a sample of 283 sources for which strip scans were available for at least 2 position angles separated by more than 30° but less than 150°. From these data we found the "largest angular size" of each source (Miley 1971; Swarup 1975). For some of the published 1970-71 observations, revised values have been used as determined by Subrahmanya (1975) using his Optimum Deconvolution Method (private communication).

In Fig. 1 are shown the observed angular size distributions, N (S,θ), for 8 different intervals of flux density. The definite values are shown by crosses and upper limits by bars. The values given are for the 283 Ooty radio sources, 62 radio sources with $S_{408} \gg 16.5$ Jy from the All-sky catalogue in 10.2 ster of the sky (Robertson 1973) and 195 sources from the complete sample of 3CR sources in 4.2 ster of the sky (Mackay 1971; Longair and Gunn 1975) including 28 sources with $S_{408} > 16.5$ Jy on Wyllies' scale, which form part

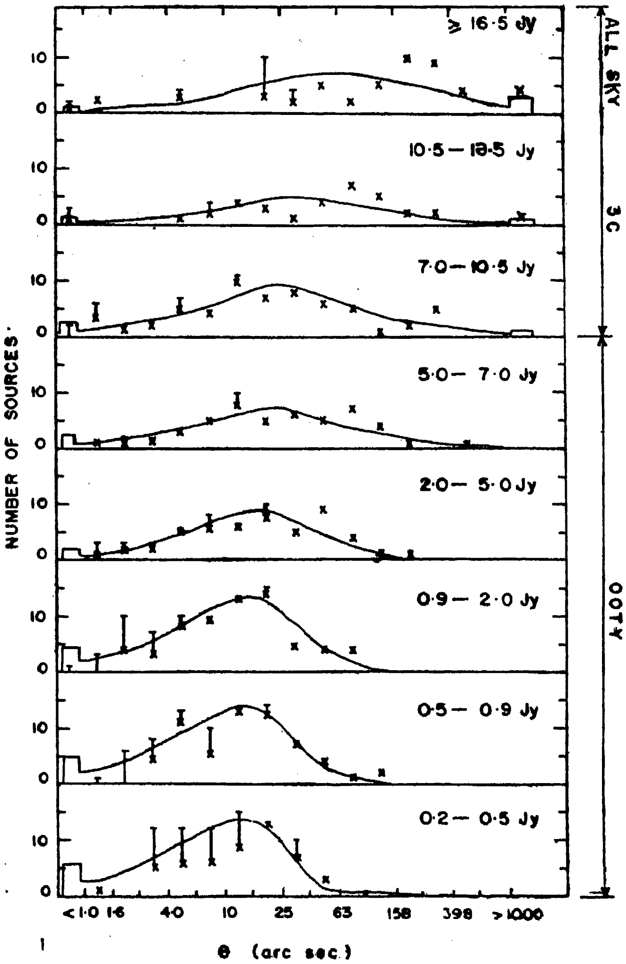

Fig. 1 The observed and theoretically predicted angular size distributions of the All-sky, 3C and Ooty sources are shown for 8 different flux density intervals. The observed definite values are shown by crosses, upper limit by bars and theoretical predictions by full-line curves. Some 3C sources have flux below 5 Jy and are included in 2 to 5 Jy range and a few Ooty sources with flux > 5 Jy are included in 5 to 7 Jy range.

of the above All-sky sample. Angular size data for 3CR sources have been taken mostly from the recent observations made with the Cambridge 5 km radio telescope (Pooley and Henbest 1974; Riley and Pooley 1975; Jenkins et al. 1977).

It is seen from Figure 1 that the angular sizes of radio sources decrease statistically with their flux densities. As has been shown by Kapahi (1975) and Swarup and Subrahmanya (1977), the observed θ_m—S relation or N (S,θ) distribution does not fit predictions of any standard non-evolutionary models. The solid curves in Fig. 1 are for a simple evolutionary model assumed by Kapahi (1975, 1977) and are based on Einstein-de Sitter cosmology with a deceleration parameter $q_0 = \frac{1}{2}$, for a three-slope luninosity function, a density evolution of highest luminosity sources as $(1+z)^{\beta}$ and a linear size evolution as $(1+z)^{-n}$. For values of β= 5.5 and n=1 we find a good fit between the theoretical values and the observational data as may be seen from

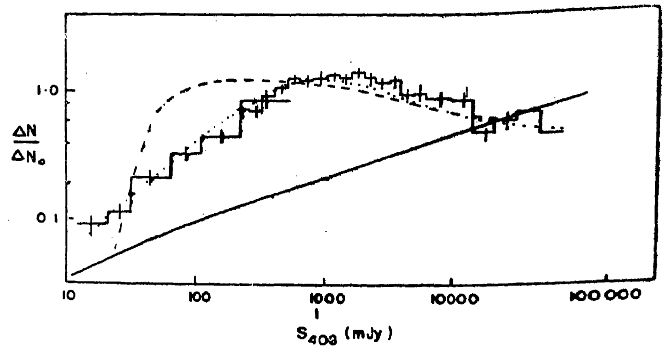

Fig. 2 The 408 MHz source counts. Solid curve non-evolutionary, source conserving model; dotted : model 5 (optimized) by Wall et al. (1977) ; dashed : 3 slope luminosity function by Kapahi (1977).

Fig. 1. For a statistical test, we have grouped the data given in Fig. 1 into 48 separate bins so that the predicted number of sources in each bin is > 6. For these 48 bins, there are 40 degrees of freedom since the theoretical curves were normalized so as to correspond to the observed number of sources in each flux density range. For β = 5.5, the Chi-square test gives values of 39, 38, 42, 81 for n=1.0,1.1, 1.2 and 1.5 respectively, corresponding to a probability of fit of about 50% for the first 3 values of n and $\backsim 10^{-4}$ for the last. For β=6, the probability of fit is about 30% for n=1.0 and 20% n=1.1. The results do not change significantly as the number of bins is increased from 48 upto 72.

In Fig. 2 we have compared the predictions of the above evolutionary model with the 408 MHz source counts as given by Wall et al. (1977). It is seen that the simple evolutionary scheme adopted by Kapahi predicts too many sources at low flux-density levels. As is well known, a good fit to the source counts requires an evolutionary function in which the evolution parameter β increases gradually rather than abruptly with luminosity (Longair 1966; Wall et al. 1977). An attempt is being made to find a function which provides a good fit to both angular size and flux density counts and this will be reported elsewhere.

DISCUSSION :

Although there exists a large spread in both the intrinsic luminosities and linear sizes of radio sources, it is possible to derive cosmological inferences from N (S,θ) statistics because of the availability of large data samples covering a wide flux density range. The overall angular sizes as well as the sizes of the compact scintillating components decrease with decreasing flux density, indicating that the weaker sources are located farther away (Swarup 1975 ; Swarup and Bhandari 1976). The median value of angular sizes is about 100 arcsec for $S_{408} \sim 25$ Jy and decreases to a constant value of $\backsim$ 10 arcsec for $S_{408} \sim 1$ Jy to 10 mJy (Swarup 1975 ; Ekers 1977). As described above, the radio data indicate that density of high luminosity sources was more and their linear sizes were smaller at earlier cosmic epoch.

As shown by Miley (1971) and later by Wardle and Miley (1974), the upper envelope of the "largest angular size" distribution of quasars varies inversely with redshift ($\theta \propto z^{-1}$), indicating that their linear sizes were smaller at earlier epochs. A similar result has been recently reported for radio galaxies by Grueff and Vigotti (1977). For an Einstein-de Sitter model, the (θ, z) data indicates $l = l_0 (1 + z)^{-n}$ where $n \approx 1.5$ to 2 (van der Kruit 1973; Ekers 1977). However, the present N (S, θ) data indicate a value of $n = 1.0 \pm 0.2$. The difference could be explained by assuming that the value of deceleration parameter q_0 is less than that in Einstein-de Sitter model. On the other hand, it may not be reasonable to compare value of n from N (S, θ) data for all sources with that derived from θ(z) data for quasars alone. Recently a comparison of 3C and 4C quasars by Riley et al. (1977) indicates that their observations are consistent with the hypothesis that the overall physical sizes of the most powerful quasars do not change with cosmological epoch. This would imply a difference in evolution of overall physical sizes for radio galaxies and quasars.

It may also be noted that the above interpretations of N (S, θ) and θ (z) data are based on the assumption of homogeneous universe. As pointed out by Roeder (1975), θ (z) relation has a markedly different behaviour for an inhomogeneous universe in which the major fraction of its matter is in the form of discrete galaxies rather than diffuse intergalactic matter.

Wardle and Miley (1974) and van der Kruit (1973) have given explanations for the apparent linear size evolution of a radio source. In all Friedmann models, the density of intergalactic medium increases as $(1 + z)^3$ and energy density of the microwave background as $(1 + z)^4$. Therefore, if a double radio source is confined by the ram pressure of intergalactic medium, separation between its two components $l = l_0 (1 + z)^{-4/5}$ (De Young 1971). Considering ram pressure and also inverse Compton losses against the microwave background, the model by Rees and Setti (1968) predicts $l = l_0 (1 + z)^{-3/2}$. It is interesting that the value of n derived from N (S, θ) data of Fig. 1 is consistent with these theoretical predictions. Jackson (1973) has explained the θ (z) relation by assuming a correlation between intrinsic luminosity and linear size of a radio source. Similarly, it may be noted that N (S, θ) data can also be explained by assuming a correlation between luminosity and linear size of a radio source because only the sources of high luminosities are observable for high values of z in a survey with a given flux density limit (Kapahi 1975). Although no correlation is apparent between luminosity and linear size for 3CR radio galaxies (Mackay 1973; Kapahi 1977), some correlation has been noted for quasars by Riley et al. (1977). These aspects need further investigation.

Before one could hopefully discriminate between evolutionary and geometric effects, further accurate measurements ot angular sizes are required for different classes of radio sources, for low as well as high luminosity quasars and radio galaxies. There is also a possibility that the detailed structures and spectra of different components of radio sources may depend on cosmic epoch as a result of the epoch dependance of intergalactic density and microwave background in the Friedman models. For distinguishing these effects we require observations with still higher resolutions not only at centimetre wavelengths as would be provided by the VLA under construction in USA but also at metre wavelengths. This would be possible by further exploitation of the occultation method. With this aim, we are planning to increase the sensitivity of the Ooty radio telescope by a factor of about 4, by putting lower noise amplifiers, a lower loss dipole array using diode phase-shifters and by increasing the existing bandwidth of 4 MHz to 12 MHz using 16 amplifiers of 0.75 MHz width.

Hewish's suggestion (1974) that the hot spots in the powerful double sources appear to have lower intrinsic linear size dispersion and hence could be useful as a standard rigid rod, also needs detailed investigation using the method of interplanetary scintillations and long baseline interferometers that provide resolution of about 0.1 arcsec at metre wavelengths.

In summary, the angular size data for extragalactic radio sources have provided further evidence that the weaker sources are statistically located further away. Although our present understanding of the physics of origin and evolution of radio sources is still uncertain, the radio measurements have provided a clear evidence of large evolution with cosmic epoch.

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