OBSERVATIONS OF THE RADIO SOURCE PKS 0123−01 AT 5000, 408, AND 80 MHz

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[Manuscript received 1 May 1972]

Abstract

Observations of PKS 0123−01 (3C 40) have been made at 5000, 408, and 80 MHz with telescopes of comparable beamwidth. The value of the spectral index for the frequency intervals 5000–408 and 408–80 MHz has been calculated for a grid of points covering the source spaced at approximately half-beamwidth intervals. For both frequency intervals the spectrum of emission is found to be significantly steeper for the regions of the source furthest from the associated galaxies NGC 545–547 than for the regions nearest the galaxies. Some implications of this result are discussed. The age and energy requirements of the source have also been estimated.

I. Introduction

The radio source PKS 0123−01 (3C 40) is a complex region extending $\sim 20'$ arc in the north–south direction and $\sim 10'$ arc in the east–west direction and is associated with the galaxies NGC 545–547 and NGC 541, the three brightest members of cluster Abell 194 (Mills 1960). Several low resolution observations of the source have been made during general sky surveys by Mills, Slee, and Hill (1958), Bennett (1962), Pauliny-Toth, Wade, and Heeschen (1966), and Shimmins *et al.* (1966), while observations at higher resolutions have been made by Maltby and Moffet (1962) at 960 MHz and by Fomalont (1968), who determined the east–west brightness distribution at 1425 MHz with a fan beam of half-power width 45″ arc. The observations reported in the present paper were made with pencil beams of comparable resolution at frequencies of 5000, 408, and 80 MHz. The telescopes used were the Parkes 64 m reflector (5000 MHz), the 1 mile Molonglo Cross (408 MHz), and the Culgoora radioheliograph (80 MHz), whose half-power beamwidths at the declination of PKS 0123−01 are $4'\cdot 0\times 4'\cdot 0$ arc, $2'\cdot 86\times 3'\cdot 46$ arc, and $3'\cdot 75\times 4'\cdot 28$ arc respectively. The observations are part of independent programs at the three observatories to investigate the structure of extragalactic radio sources.

Subsections (*a*), (*b*), and (*c*) of Section II contain descriptions of the instruments and methods of observation at the three frequencies employed while polarization effects are discussed in Section II(*d*). Some comments on the contour maps are given in Section III(*a*) and this is followed in Section III(*b*) by a description of the basic structure of the source and the changes in this structure with frequency. The variation in the spectral index over the source is considered in Section III(*c*)

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and discussed in relation to theoretical predictions for the evolution of the spectral index. The minimum total energy at the present epoch, the equipartition magnetic field, the initial minimum energy, the age, and the rate of supply of energy to the component have been calculated from models proposed in the literature and are given in Section III(d).

II. Observations

(a) *5000 MHz*

The Parkes 64 m reflector was operated at 5000 MHz using a single-channel receiver in which the first two stages were cryogenically cooled parametric amplifiers which gave an overall bandwidth of 500 MHz. The system noise temperature was 90 K, and with an output time constant of 1 s this gave a peak-to-peak noise fluctuation (as measured on a record) of 0·035 f.u.* The receiver was switched between two feeds, one producing an on-axis beam $4'\cdot 0 \times 4'\cdot 0$ arc and the other a slightly broader off-axis beam displaced by $20'$ arc. The position angle was chosen so that the off-axis beam did not encounter the source during any scan. The alignment of the on-axis feed is slightly incorrect, producing a coma lobe $3'$ arc off-axis which amounts to $\sim 2\%$ of the on-axis response, but the effect of this on the present observations is negligible. The observations were made by pairs of forward–reverse scans at a rate of $0^\circ\cdot 25$ min^{-1} in (1) declination at each of eight right ascensions and (2) right ascension at each of four declinations. The r.m.s. scatter between the smoothed forward and reverse scans (due principally to short-term gain variations) was found to be $\sim 0\cdot 015$ f.u. A calibration signal of ~ 1 K was injected at the receiver input at the start of each scan pair. The value of this calibration signal in flux units was established by observation of PKS 0915−11, for which a flux density of 13·50 f.u. was assumed. This scale is believed to be correct to within 5% (Shimmins, Manchester, and Harris 1969). The estimated standard error in position is $20''$ arc.

(b) *408 MHz*

The Molonglo Cross telescope (Mills *et al.* 1963) is a meridian transit instrument which has 11 pencil beams covering a declination zone of $10 \times 1\cdot 43 \sec Z$ minutes of arc, Z being the zenith angle; the centres of adjacent declination zones are separated by $5 \times 1\cdot 43 \sec Z$ minutes of arc. At a declination of $-1^\circ\cdot 6$ the half-power widths of each pencil beam are $2'\cdot 86 \times 3'\cdot 46$ arc and the declination zone covered by the 11 beams is $17'\cdot 3$ arc. Since PKS 0123−01 extends $20'$ arc north–south, observations of three adjacent zones were required to completely map the source. Two observations of each zone were made to improve the signal to noise ratio.

The measurements were calibrated both for flux density and position by observation of a series of calibration point sources. The flux density calibration is based on an absolute flux density scale established by Wyllie (1969) and the standard error including scale uncertainties is $\sim 7\%$. The flux density scale was related to a brightness temperature scale using the work of Shaver and Goss (1970). A comparison of the computed radio positions for the calibration sources with the positions of their optical counterparts shows that the standard error in the pointing of the telescope

* 1 flux unit (f.u.) = 10^{-26} W m^{-2} Hz^{-1}.

for a single transit is $\sim 3''$ arc in both coordinates (Hunstead 1972). The r.m.s. noise for these observations was $0\cdot020$ f.u.

(c) *80 MHz*

The Culgoora radioheliograph (Wild 1967) generates in a north–south line 48 independent beams each of which is elliptical, with half-power widths (at declination $-1^\circ\cdot6$) of $3'\cdot75\times4'\cdot28$ arc, and separated by $2'\cdot45$ arc from adjacent beams. Observations may be made either by rapidly scanning the beams electronically in the east–west direction, as for solar observations, or by setting them to a predetermined position and allowing the Earth's rotation to scan the desired area of sky.

At a frequency of 80 MHz ionospheric refraction effects are appreciable, causing both distortions in the brightness distribution and displacements from the true source position. In order to minimize the distortion effects (Lockhart 1971), the rapid scanning method of observation was used and the source was mapped several times. Each map was produced by computer from digital integration of 1800 successive images recorded near meridian transit. The final map shown in Figure 1(*c*) was obtained by averaging three maps which exhibited minimum ionospheric distortion.

Ionospheric refraction limits the accuracy of position measurements to $\sim 1'$ arc. The position of the contours in Figure 1(*c*) was therefore determined by comparison with the 5000 and 408 MHz maps, assuming that the position of the southern peak near $01^{\mathrm{h}}23^{\mathrm{m}}30^{\mathrm{s}}$, $-01^\circ 40'$ is independent of frequency; it does not change between 5000 and 408 MHz.

The flux density of PKS 0123−01 was obtained by comparison with several strong calibration sources for which accurate flux densities have been measured at a frequency near 80 MHz (Yates, Wielebinski, and Landecker 1967; Parker 1968). The standard error in flux density including scale uncertainties is $\sim 12\%$.

(d) *Polarization*

Gardner, Morris, and Whiteoak (1969) found the linear component of polarization in PKS 0123−01 to be $< 1\cdot5\%$ at 2650 MHz and $1\cdot5\%\pm1\%$ at a position angle of $173^\circ\pm15^\circ$ at 1410 MHz, while at 5000 MHz the polarizations for the two resolved components were $\sim 2\%\pm1\%$ and $0\cdot4\%\pm0\cdot6\%$ at position angles of $44^\circ\pm9^\circ$ and 42° respectively (Gardner, Whiteoak, and Morris 1969). Since the linear polarization is small it has been assumed that restriction to observation in one (linear) polarization at both 5000 and 408 MHz does not affect the position of the contours. At 80 MHz negligible polarization effects are expected.

III. Results

(a) *Contour Maps*

The 408 and 80 MHz contour maps were produced by computer from standard programs available at each observatory. The 5000 MHz map was produced by hand analysis of the analogue records. In order to calculate spectral indices for different regions of the source, we have smoothed the original 408 MHz map so that the effective beamwidth is the same as for the 80 MHz map; the beamwidths at 5000 and 80 MHz are very similar. The 5000 MHz map, the smoothed 408 MHz map, and the 80 MHz map are shown in Figures 1(*a*), 1(*b*), and 1(*c*) respectively. They have been drawn to the same angular scale and the effective half-power beam shape is indicated in each figure. The original unbroadened 408 MHz map is shown in Figure 4 in relation to the results of Section III(*c*).

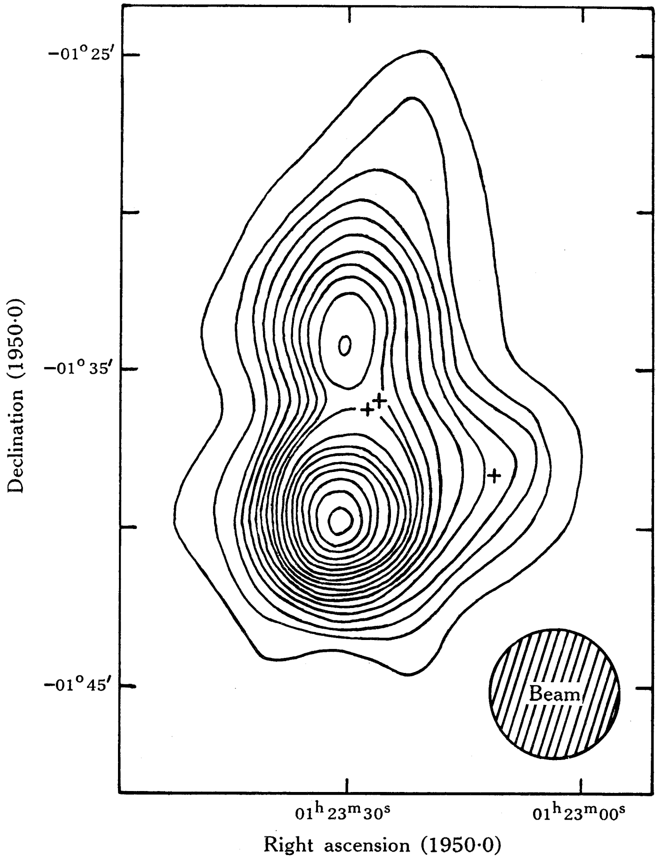


Fig. 1(*a*).—Map of PKS 0123−01 at 5000 MHz. The outermost contour is 0·05 K and the contour interval is 0·05 K. The crosses mark the positions of the 13^m double galaxy NGC 545–547 and the 13^m galaxy NGC 541.

(*b*) *Description of the Source*

The structure of PKS 0123−01 is complex and varies with frequency. Common to all three maps of Figure 1 are two main peaks, an extended arc-like structure to the north and an extension to the west of the southern peak. The latter region is resolved at 408 MHz into a separate component 4′·4 arc from the southern peak at position angle 294° (see Fig. 4). The 408 and 80 MHz maps have an extension to the south-west which barely appears at 5000 MHz. Other features peculiar to individual maps are the low level structure to the east of the region between the main peaks at 408 MHz and that to the west of the northern peak at 80 MHz. A further change in structure with frequency is indicated by the progressively greater separation of the two main peaks with decreasing frequency. This separation is $5'\cdot5$ arc at position angle 179° at 5000 MHz, $6'\cdot6$ arc at 177° at 408 MHz, and $7'\cdot8$ arc at 174° at 80 MHz. The results of Section III(*c*)(ii) indicate that the change in separation is due to the arc-like region in the far north of the source being of steeper spectral index than the northern peak with which it is blended.

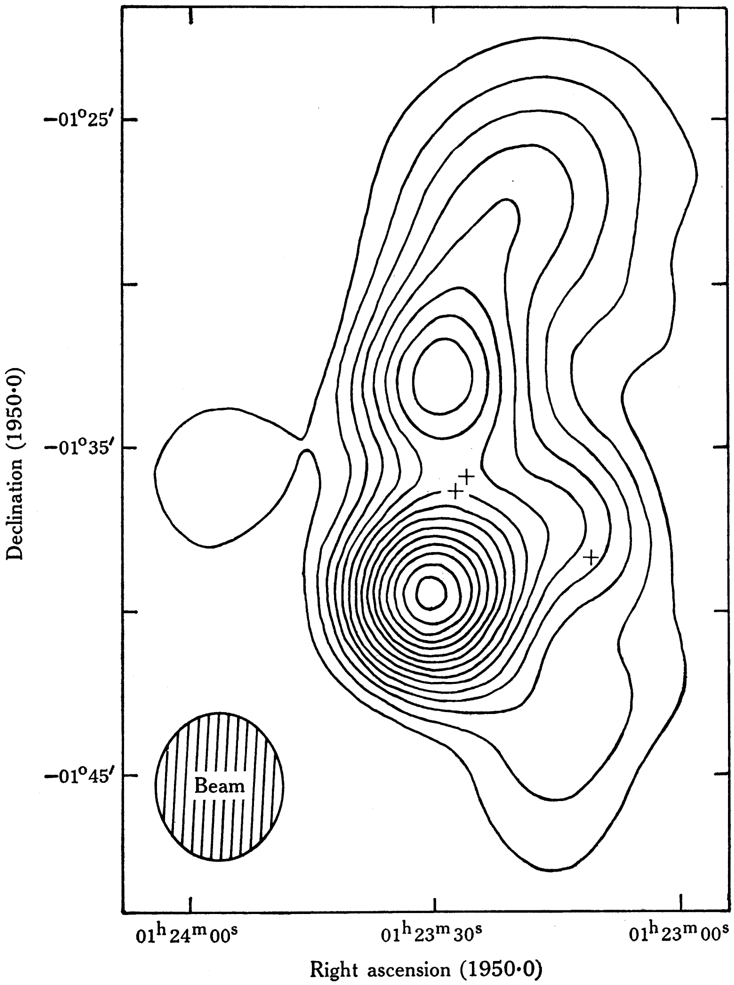


Fig. 1(*b*).—Map of PKS 0123−01 at 408 MHz. The outermost contour is 28 K and the contour interval is 43 K. The crosses mark the positions of the associated galaxies. This map was obtained by smoothing the original 408 MHz map to the same effective beamwidth as the 80 MHz map.

The source is associated with the double galaxy NGC 545–547 (Mills 1960) which is a pair of closely spaced 13^m elliptical galaxies classified as cD4 by Matthews, Morgan, and Schmidt (1964). A third 13^m elliptical galaxy, NGC 541, lies $4'\cdot6$ arc to the south-west of the double galaxy and well inside the radio contours. Accurate positions for all three galaxies have been measured by Griffin (1963). They are the brightest members of the cluster Abell 194 at a distance of ~ 53 Mpc (Matthews, Morgan, and Schmidt 1964), assuming a Hubble constant of $100\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$. At this distance the dimensions of the radio source are ~ 260 kpc north–south by ~ 110 kpc east–west, and the separation of the main components is ~ 85 kpc at 5000 MHz, ~ 102 kpc at 408 MHz, and ~ 120 kpc at 80 MHz.

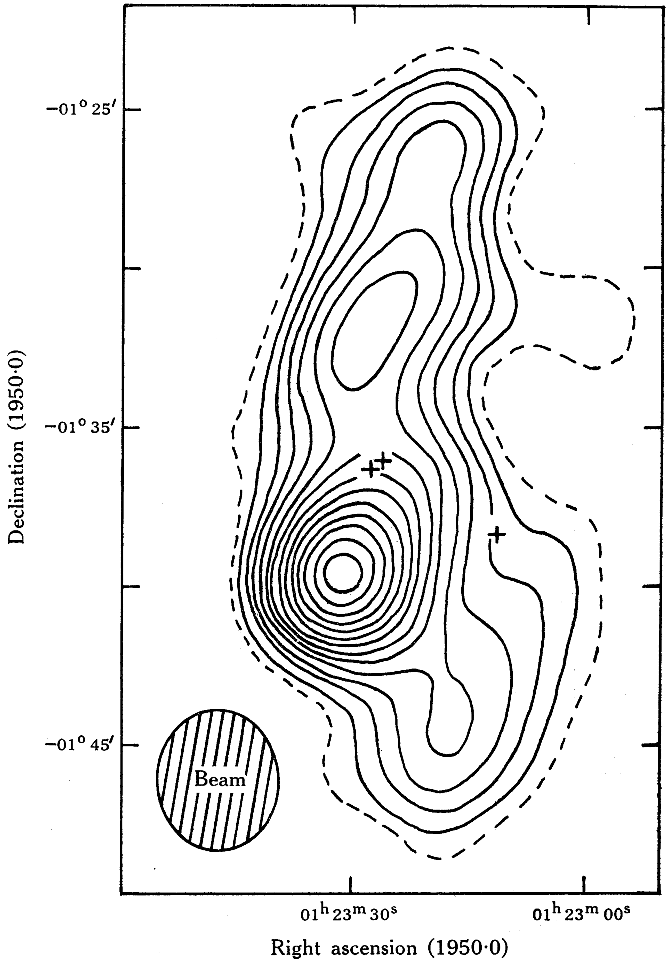


Fig. 1(c).—Map of PKS 0123−01 at 80 MHz. The outermost (dashed) contour is 4000 K and the contour interval is 2667 K. The crosses mark the positions of the associated galaxies.

NGC 541 may also be a radio galaxy. The 5000 and smoothed 408 MHz maps show a pronounced feature in the region of this galaxy, and the unbroadened 408 MHz map shows NGC 541 to be 1′·2 arc to the south-west of the western peak of the radio distribution. The fan beam observations of Fomalont (1968) at 1425 MHz (Fig. 2) show a weak western component comprising two blended peaks; the right ascension of the westernmost peak agrees well with that of NGC 541 while the right ascension of the centroid agrees well with that of the western peak of the unbroadened 408 MHz map. Preliminary observations at 3 cm by Wall (unpublished data) using the Parkes 64 m dish show a peak in the radio emission very nearly coincident with the position of NGC 541. This general agreement in position indicates that NGC 541 is probably associated with the complex western region.

According to Zwicky and Humason (1964) there is a luminous bridge connecting NGC 545–547 to 541, with a fainter extension to NGC 535, a spiral galaxy 8′·9 arc to the south-west of NGC 545–547. This suggests that there is some interaction between these galaxies. It is possible that the radio emission from NGC 541 has been generated by relativistic particles incident from NGC 545–547. Ryle and Windram (1968) suggested that such an interaction occurs between NGC 1275 and 1265 in the Perseus cluster.

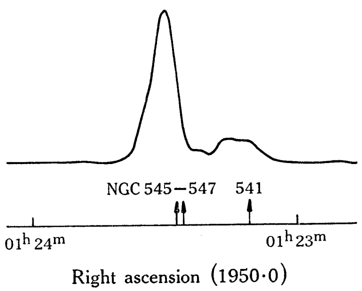


Fig. 2.—East–west brightness distribution of PKS 0123−01 at 1425 MHz from Fomalont (1968). The arrows indicate the optical right ascensions of the associated galaxies.

(c) *Spectrum of the Source*

(i) *Spectrum of Integrated Emission*

The integrated flux densities of PKS 0123−01 at 5000 and 408 MHz were obtained by planimetry of the contour maps. The sampling at 80 MHz was such that the integrated flux density could be calculated directly from the digital recording of the observations of PKS 0123−01 and of the calibration sources (Lockhart 1971). At 5000 MHz the flux density is $2\cdot25\pm0\cdot2$ f.u., at 408 MHz it is $18\cdot9\pm1\cdot9$ f.u. (the errors in both flux densities include an estimate of the error due to the planimetry), and at 80 MHz it is 58 ± 7 f.u.

Figure 3 shows a plot of the above values together with published flux densities at other frequencies. Braude *et al.* (1969) made the measurements at frequencies between 12·6 and 25 MHz except for one made at 22·5 MHz by Roger, Costain, and Lacey (1969). The 85, 178, 605, 960, and 8000 MHz flux densities were obtained by Mills, Slee, and Hill (1958), Gower, Scott, and Wills (1967), Sramek (1970), Moffet (1962), and Stull (1971) respectively. All remaining measurements are from Kellermann, Pauliny-Toth, and Williams (1969). From Figure 3 it is apparent that within three standard errors the power law dependence of the flux density on frequency holds over the entire frequency range.

(ii) *Spectral Index Variation over the Source*

Investigations by a number of observers have not revealed any systematic variation in the spectral index* of emission across extended sources. Kellermann

* The spectral index α is defined by the relation $S \propto \nu^{-\alpha}$, where S is the flux density and ν the frequency.

(1964) suggested that the spectral index of double radio sources increased with increasing intrinsic separation of the components. However, Ekers (1967) found no such correlation for his sample of sources. Mackay (1969) and Lockhart (1971) noted that in some complex extended sources those regions furthest from the associated optical object tended to have the steepest index. In contrast, Macdonald, Kenderdine, and Neville (1968), Mitton and Ryle (1969), and Seielstad and Weiler (1971) have reported observations of double sources in which the spectrum appears steeper in the regions closest to the associated optical object than for the source as a whole.

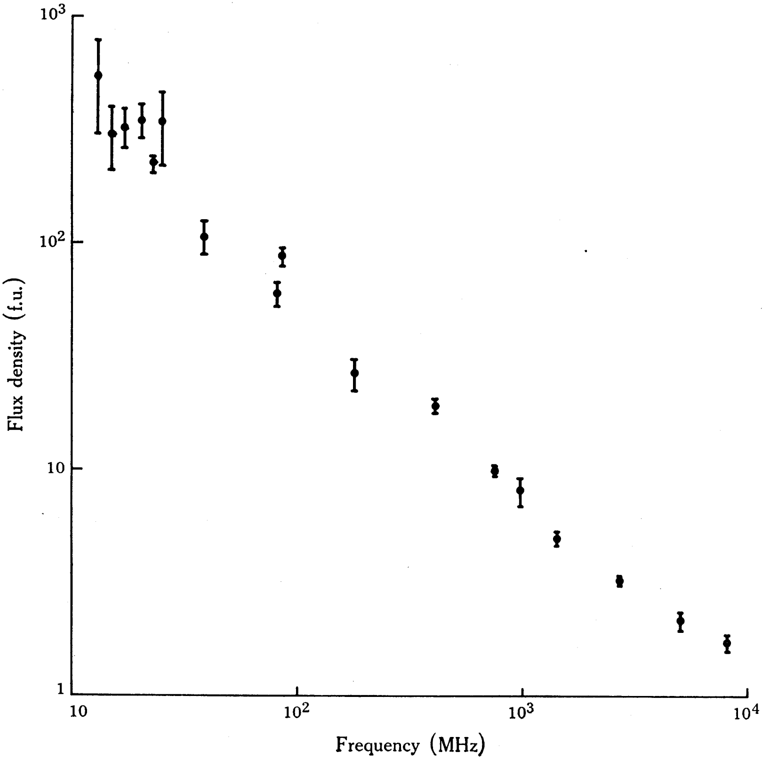
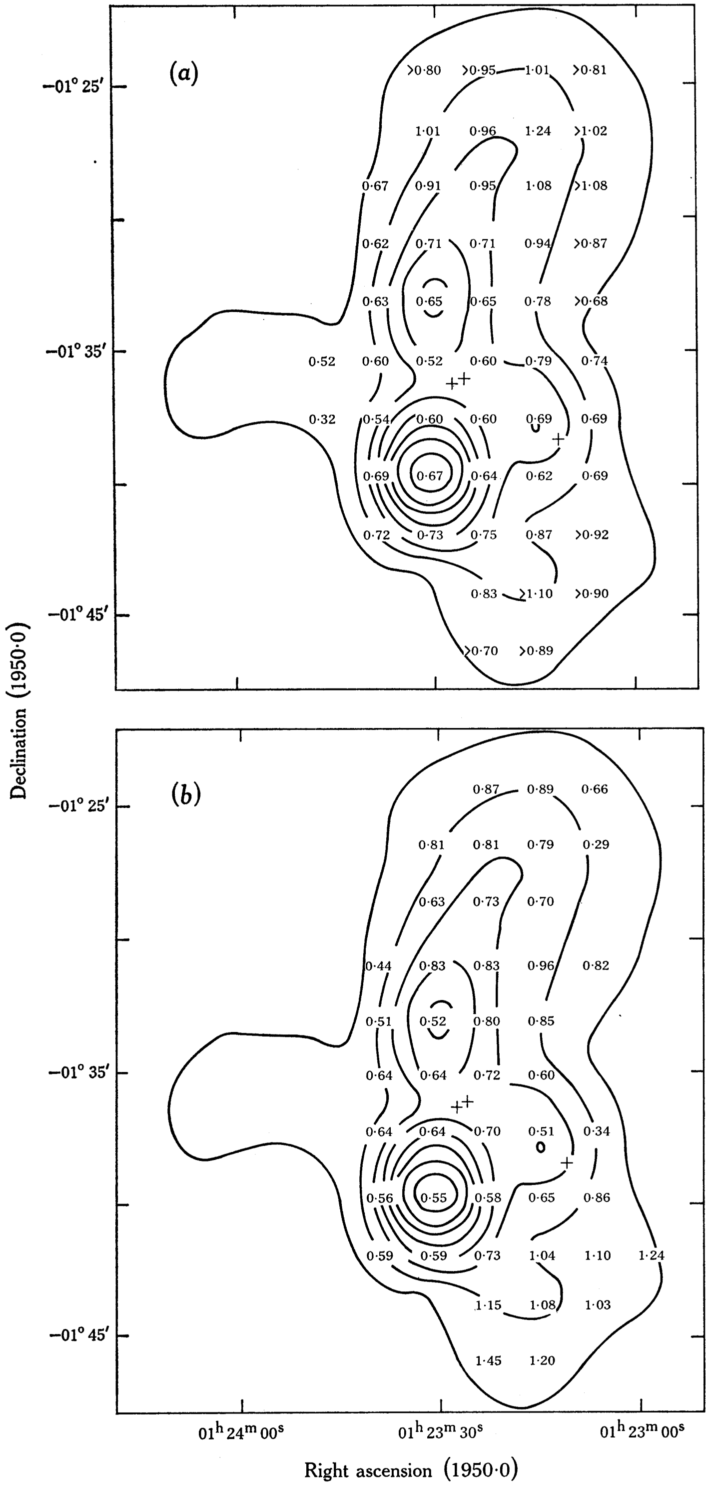


Fig. 3.—Integrated spectrum of PKS 0123−01.

The frequency-dependent structure of PKS 0123−01 shown in the three maps of Figure 1 is indicative of variations in the emission spectrum across the source. The map at 5000 MHz (Fig. 1(*a*)) depicts two components and a small extension to the north associated with NGC 545–547, while the maps at 408 and 80 MHz (Figs. 1(*b*) and 1(*c*)) depict four components associated with the galaxies, two resolved inner components and two partially resolved outer components. We suggest that this structure is the result of two major phases of activity in the nucleus of the parent

Fig. 4 (*opposite*).—Values of the spectral index for the frequency intervals (*a*) 5000–408 MHz and (*b*) 408–80 MHz superimposed on the unbroadened 408 MHz map, for which the outermost contour is 21 K and the contour interval is 120 K. The crosses mark the positions of the associated galaxies.


(a)
>0·80 >0·95 1·01 >0·81
1·01 0·96 1·24 >1·02
0·67 0·91 0·95 1·08 >1·08
0·62 0·71 0·71 0·94 >0·87
0·63 0·65 0·65 0·78 >0·68
0·52 0·60 0·52 0·60 0·79 0·74
0·32 0·54 0·60 0·60 0·69 0·69
0·69 0·67 0·64 0·62 0·69
0·72 0·73 0·75 0·87 >0·92
0·83 ≥1·10 >0·90
>0·70 >0·89
(b)
0·87 0·89 0·66
0·81 0·81 0·79 0·29
0·63 0·73 0·70
0·44 0·83 0·83 0·96 0·82
0·51 0·52 0·80 0·85
0·64 0·64 0·72 0·60
0·64 0·64 0·70 0·51 0·34
0·56 0·55 0·58 0·65 0·86
0·59 0·59 0·73 1·04 1·10 1·24
1·15 1·08 1·03
1·45 1·20
−01° 25′
−01° 35′
−01° 45′
Declination (1950·0)
01h 24m 00s
01h 23m 30s
01h 23m 00s
Right ascension (1950·0)

galaxy (or galaxies). The apparent change in structure with frequency is then basically the result of the outer (unresolved) pair of components having a steeper spectrum than the inner components.

To investigate in detail the apparent differences in the emission spectrum over the source, spectral indices have been calculated at a grid of points spaced $2'\cdot0$ arc in right ascension and $2'\cdot2$ arc in declination. One of the points was made to coincide with the relatively compact southern peak, the position of which appears to be independent of frequency. The spectral index α at a point for a frequency interval ν_1 to ν_2 was calculated from the relation

$$T_{\nu_1}/T_{\nu_2} = (\nu_1/\nu_2)^{-2-\alpha},$$

where T_{ν_1} and T_{ν_2} are the brightness temperatures (at the grid point) determined from the two contour maps. The results are shown in Figures 4(*a*) and 4(*b*) superimposed on the unbroadened 408 MHz map.

The significance of any conclusions drawn from these results must be based on analysis of the local errors in spectral index. These have been estimated in five regions of the source: (1) the far northern region, (2) the northern main peak, (3) the western region, (4) the southern main peak, and (5) the south-western region. The standard error in the brightness temperatures in any region was first estimated and then used in the determination of the standard error in the spectral index. The results may be summarized as follows.

Frequency range	Region (1)	Region (2)	Region (3)	Region (4)	Region (5)
5000–408 MHz	$\pm0\cdot06$	$0\cdot04$	$0\cdot05$	$0\cdot03$	$0\cdot09$
408–80 MHz	$\pm0\cdot13$	$0\cdot19$	$0\cdot14$	$0\cdot04$	$0\cdot18$

Flux scale uncertainties have not been included in these calculations as they do not affect relative changes in index across a source.

Figure 4 shows that for both frequency intervals the inner components (regions (2) and (4)) have a spectral index of $\sim 0\cdot6$. The spectra of the outer regions are significantly steeper with indices of $\sim 1\cdot0$. In region (5) and at the northern edge of region (1) no emission was detected at 5000 MHz (see Fig. 1(*a*)); lower limits for α(5000–408) were calculated on the assumption that the emission at 5000 MHz is less than three times the r.m.s. noise. The emission appears to have a straight spectrum over most of the source, the possible exceptions being region (5) and the northern edge of region (1). The apparent curvature in region (3) is not significant within the errors.

If it is assumed that (i) the initial energy spectrum of the relativistic electrons after ejection from the nucleus is the same for both outbursts and (ii) the successive pairs of components evolve similarly, then the steeper emission spectrum observed for the outer (and presumably older) components might be interpreted as the result of age. However, radiation theory predicts that at the higher frequencies the spectrum of radio emission becomes exponential with increasing age due to synchrotron emission and inverse Compton interactions with photons of the local and universal radiation fluxes. Since such a spectrum has not been observed for any source, it is probable that other energy loss mechanisms (such as adiabatic expansion of the gas clouds containing the relativistic electrons and diffusion of the electrons across the magnetic field trapped in the gas clouds) modify the scale of the predicted steepening. In a discussion of the possible modes of source evolution, van der Laan and Perola (1969) conclude that the problem of the lack of exponentially steep spectra at high frequencies can be overcome if relativistic electrons are removed from the radio emitting plasmas by energy-independent diffusion and the plasmas are re-supplied by multiple non-cumulative injections of new particles. The present observations do not entirely support this model since it is difficult to envisage the outer components being supplied with new particles once the inner components have formed. Ryle and Windram (1968) in a discussion of the spectrum of the source component 3C 84A(iii) (associated with NGC 1275) proposed that an energy-dependent diffusion mechanism could remove high energy particles and thus produce the steep spectrum of this component. However, the details of such a mechanism have not been examined. Scheuer and Williams (1968) considered the possibility that synchrotron losses modified by adiabatic expansion could be responsible for the steep spectra of some very extended sources of low surface brightness. Such a process may operate in the far northern region of PKS 0123−01 (see Fig. 1(*b*)).

We note that a simple synchrotron "ageing" process modified by diffusion or adiabatic expansion to remove some of the energy of the particles may not provide the complete explanation for all observations of variations in spectral index. As suggested by some observers the local physical conditions (and the magnetic field structure in particular) may play an important role in determining the spectrum of the emission. Mitton and Ryle (1969) observed a steep spectrum in the inward extensions of the components of Cygnus A, and reported a suggestion by Scheuer that the explanation may lie in a large variation in the magnetic field strength between the outer edge of a component and its inward extension: as the relativistic electrons lost energy by radiation at a rate proportional to the square of the field strength, the change in the energy spectrum would produce a change in the spectral index of the emission and could cause the spectrum to flatten at the outer edge compared with the inward extension. Such a model does not seem applicable to PKS 0123−01 because the spectral indices appear to be constant (within the errors) over each component, and the changes between the regions of differing index take place on angular scales of the order of one beamwidth. Moreover, these regions of large gradient in spectral index appear to coincide with the boundaries of the emission components.

The details of the magnetic field in PKS 0123−01 could be inferred from high resolution observations of the distribution of linear polarization over the source. If changes in the spectral index were to correlate in position with large variations in the degree and position angle of the polarization then a large difference in the degree of ordering of the local magnetic field between the regions of different spectral index would be indicated. In several extended sources measurements of linear polarization at 5000 MHz have been carried out by Gardner and Whiteoak (1971). The observations showed that up to 70% linear polarization could occur in the low brightness extensions of the sources, and that in these regions the alignment of the field was usually perpendicular to the axis of elongation. There is limited evidence in support of a similar model for PKS 0123−01. At 5000 MHz, Gardner, Whiteoak, and Morris (1969) found the polarizations of the central components to be small ($2\% \pm 1\%$ and $0 \cdot 4\% \pm 0 \cdot 6\%$, both along position angle $\sim 45°$), implying the presence of disordered fields in these components. At 1410 MHz, Gardner, Morris, and Whiteoak (1969) found a linear polarization of $1 \cdot 5\% \pm 1\%$ along position angle $173° \pm 15°$. If the low brightness outer components are significantly polarized, they may dominate this measurement because of the relatively large (14′ arc) beamwidth used. Moreover, the position angle indicates a magnetic field approximately perpendicular to the axis of elongation, a feature also observed for some other extended radio sources associated with less luminous galaxies (Gardner and Whiteoak 1969; Seielstad and Weiler 1971).

Without a knowledge of the detailed structure of the magnetic field, we feel that the most plausible interpretation of the steeper spectrum for the outer components of PKS 0123−01 is an "ageing" effect: the original electron energy distribution of these components has been changed by synchrotron radiation which has itself been modified by processes of diffusion and/or adiabatic expansion.

(*d*) *Parameters of the Source*

For each component we have estimated the minimum total energy required to account for the luminosity at the present epoch, the equipartition magnetic field, the initial minimum energy, the age, and the rate of supply of energy to each component. The minimum total energy U_{min} can be calculated from the relation (Scheuer 1967)

$$U_{\text{min}} = 6 \times 10^{41} \, \nu_8^{2/7} P^{4/7} V^{3/7} \quad \text{ergs},$$

(for $\alpha = 0 \cdot 75$) where ν_8 (in units of 10^8 Hz) is the lowest frequency at which the spectrum of a component appears linear, P ($\text{W Hz}^{-1} \text{sr}^{-1}$) is the radio luminosity, and V (kpc^3) is the volume of the component. From Figure 3 ν_8 appears to be $\leqslant 10$ MHz, and we have assumed the volume of a component at 10 MHz is similar to that at 80 MHz, since we can estimate the latter volume from the map in Figure 1(*c*). No allowance has been made in the above expression for energy which may be present as high energy protons. The calculations of luminosity and volume for each component are approximate since the components are not completely separate, and the distance to the source and its thickness in the line of sight are uncertain. The half-power widths and position angle for each component were estimated from the 80 MHz map and deconvolved (Wild 1970) to remove the effects of beam smoothing. The volume was then calculated from the deconvolved half-power widths assuming cylindrical symmetry. The resulting values of the minimum total energy for four of the regions together with values of the magnetic field strength B calculated assuming equipartition between particle and field energy were:

	Region (1)	Region (2)	Region (4)	Region (5)
U_{min} (10^{57} ergs)	0·8	2·0	1·5	1·3
B (10^{-6} G)	1·8	1·6	2·1	1·5

It can be seen that the minimum total energy requirements for each component and also their equipartition magnetic fields are similar.

The work done by each component in travelling through the intergalactic medium has been calculated, following Mitton and Ryle (1969): if the density of the intergalactic medium is $\sim 10^{-30}\,\mathrm{g\,cm^{-3}}$ then $\sim 7\times10^{57}$ ergs have been expended by the inner components and $\sim 10^{58}$ ergs by the outer components. Thus it appears that each "event" which produced a pair of components supplied an initial minimum energy of $\sim 10^{58}$ ergs.

Our estimates of the age of this source based on several published models range from $\sim 10^{6}$ to $\sim 10^{7}$ yr. On Ryle and Longair's (1967) model the inner components are $\sim 1\cdot6\times10^{6}$ yr old and the outer components $\sim 4\cdot5\times10^{6}$ yr (assuming the line of the components lies at 30° to the plane of the sky); the speed of ejection is estimated to be $\sim 0\cdot1\,c$. The time required for the energy spectrum of a relativistic electron to steepen above 80 MHz is $\sim 2\times10^{8}$ yr (for $z = 0$) if it loses energy by synchrotron emission alone (van der Laan and Perola 1969). Allowance for inverse Compton scattering and adiabatic expansion will shorten this estimate of the lifetime, and so it can be regarded as an upper limit. Rees and Setti (1968) have estimated that a time of $\sim 2\times10^{7}$ yr is required for a cloud to reach a radius of ~ 100 kpc.

If we take $\sim 5\times10^{6}$ yr as the period of injection for the components then the average rate of supply of energy to them has been $\sim 5\times10^{51}\,\mathrm{ergs\,yr^{-1}}$. This is a similar rate to that estimated for NGC 1275 in the Perseus cluster by Ryle and Windram (1968) and for NGC 4874 in the Coma cluster by Willson (1970).

IV. Conclusions

The present observations of PKS 0123−01 show that the source has a complex radio structure which changes with frequency. The spectrum is found to be significantly steeper in the regions furthest from the associated galaxies NGC 545–547 than in the regions nearest the galaxies. It is suggested that the observed steepening is due to the synchrotron emission of the relativistic electrons being modified by diffusion and/or adiabatic expansion.

Radio emission has also been found in the region of the nearby galaxy NGC 541, and it is suggested that this emission has been generated by relativistic particles incident from NGC 545–547 in a manner similar to that proposed by Ryle and Windram (1968) for the interaction between NGC 1275 and 1265 in the Perseus cluster.

Estimates of the age and energy requirements of PKS 0123−01 are found to be similar to those of the radio-emitting regions associated with NGC 1275 (Ryle and Windram 1968) and with NGC 4874 in the Coma cluster (Willson 1970).

V. Acknowledgments

The authors would like to thank Professor B. Y. Mills, Dr. W. B. McAdam, and Dr. J. A. Roberts for valuable discussions and criticisms of the manuscript, and Dr. D. J. McLean for assistance with the computer reductions. One of us (R.T.S.) wishes to acknowledge support from a Commonwealth Postgraduate Studentship and from grants by the Australian Research Grants Committee, the Sydney University Research Grants Committee, and the Science Foundation for Physics within the University of Sydney. The second author (I.A.L.) wishes to acknowledge support from a Research Scholarship from the Australian National University during this work.

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