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THE 20 YEAR SPECTRAL EVOLUTION OF THE RADIO NUCLEUS OF NGC 1275

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ABSTRACT

We present flux density measurements at five radio frequencies of the variable radio source 3C 84 in the nucleus of the Seyfert-like galaxy NGC 1275, covering a time span of 20 yr. We discuss evidence that 3C 84 is embedded in a thermal gas of density $\sim 2 \times 10^3$ cm^{-3} which depolarizes the radio emission and cuts off the spectrum of the compact core below ~ 2 GHz. We deconvolve the spectrum of the compact core into several homogeneous components and suggest a possible scenario for their evolution. The compact core consists of several expanding centimeter wavelength components which evolve toward lower frequencies with time without exhibiting the large decrease in amplitude expected for a simple adiabatically expanding region. A prolonged (though clearly variable) supply of relativistic particles or *in situ* reacceleration is necessary to explain the observed spectral evolution. Compact components at millimeter and submillimeter wavelengths are necessary to account for the flux density and variability at these wavelengths. These components may be supplying energy to the centimeter wavelength components seen in VLBI maps.

Subject headings: galaxies: individual — galaxies: nuclei — galaxies: Seyfert — radio sources: galaxies

I. INTRODUCTION

3C 84 is the radio source associated with the Seyfert-like galaxy NGC 1275. Its redshift, $z \approx 0.018$, puts it at a distance $R \approx 110$ Mpc if $H_0 = 50$ km s^{-1} Mpc^{-1}. Because of its relative proximity, it is one of the strongest extragalactic radio sources. The source is variable at radio (Dent 1966; Epstein *et al.* 1982) and infrared (Lebofsky and Rieke 1980) wavelengths on time scales of weeks to years. At optical frequencies, 0.5 mag outbursts have been observed with time scales of ~ 60 days (Kingham and O'Connell 1979). Night-to-night variations in the optical continuum flux (Geller, Turner, and Bruno 1979) and in percent polarization and position angle (Martin, Angel, and Maza 1976) have been reported. Searches for periodicities and optical-radio correlations have so far been inconclusive (e.g., Epstein, Pomphrey, and Fogarty 1979). The optical linear polarization is about 2% (Martin, Angel, and Maza 1976). At centimeter wavelengths, both linear and circular polarization are less than a few tenths of a percent (e.g., Aller 1970; Seielstad and Berg 1975; Kapitzky 1976; Altschuler and Wardle 1976). Cash, Malina, and Wolff (1976) report 3C 84 to be a strong point source of X-ray emission, and Rothschild *et al.* (1981) suggest that the X-ray emission from 3C 84 is produced by the synchrotron self-Compton process with a variability time scale of order 1 yr.

The radio structure is complex, consisting of: a compact core of three or more nearly collinear $\sim 0''.001$ diameter components (Pauliny-Toth *et al.* 1976, 1978, 1981; Preuss *et al.* 1979; Romney *et al.* 1982; Unwin *et al.* 1982; Readhead *et al.* 1983, hereafter RHEWR), at a position angle of $\sim -10°$ which dominate the spectrum at centimeter wavelengths; an elongated, probably double $0''.020$ component (Wilkinson *et al.* 1979) with similar position angle centered on the core and whose spectrum becomes self-absorbed near 600 MHz; a surrounding $15'' \times 40''$ diameter component (Noordam and de Bruyn 1982; Miley and Perola 1975); and an extended steep spectrum $5'$ halo (Ryle and Windram 1968; Gisler and Miley 1979). Preuss *et al.* (1979) suggest that the individual components in the core appear to be expanding at a rate of about 15,000 km s^{-1}, while their relative separation velocities are less than 10,000 km s^{-1}. Romney *et al.* (1982) confirm the transverse expansion noted by Preuss *et al.* (1979) but suggest that the central and southern components may be separating at 0.58*c*. The brightness temperatures of the compact components at 10.7 GHz are about $T \sim 10^{11}$ K (Preuss *et al.* 1979), which is less than the limit set by inverse Compton quenching.

In this paper we present flux density measurements at five radio frequencies obtained over a 20 yr period. We discuss evidence that 3C 84 is embedded in a thermal gas which depolarizes the radio emission and cuts off the spectrum of the compact core below ~ 2 GHz. We deconvolve the spectrum of the compact core into three to five homogeneous components and suggest a possible scenario for the long-term evolution of the components seen in VLBI maps.

II. OBSERVATIONS AND RESULTS

Observations of 3C 84 were made as part of an extensive study of the radio variations in a sample of 100 extragalactic radio sources. Flux density measurements were made at 2.7 GHz with the National Radio Astronomy Observatory 91 m

[1] The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

telescope (Kapitzky 1976), at 7.9 and 15.5 GHz with the Haystack Observatory 120 ft (37 m) antenna (Dent and Kapitzky 1976), and at 31.4 and 89.6 GHz with the NRAO 36 ft (11 m) telescope (Dent and Hobbs 1973; Hobbs and Dent 1977). The telescope parameters and observing techniques are described in the above references.

We have combined these measurements with a few additional measurements from the literature and present in Figures 1 and 2 plots of the flux density versus time from 1960 to 1981. The 90 GHz measurements of Epstein *et al.* (1982) used in Figure 2 were averaged over a time interval of ~ 6 months prior to 1970, and afterwards over 2–3 months in order to improve the signal-to-noise ratio.

At 7.9 and 15.5 GHz the flux density rose nearly linearly from 1961 to 1975 and leveled off thereafter. Superposed on these general trends are slope changes and smaller modulations in flux density. At 2.7 GHz the onset of the rise was delayed by several years, becoming approximately linear about 1973. There was no observed long-term rise at 31.4 and 89.6 GHz, but the flux density varied considerably on time scales of the order of a few months to weeks (Hobbs and Dent 1977; Epstein *et al.* 1982; Balonek 1982). The amplitude of these short-term variations increases with increasing frequency. It appears that a large increase in the flux density at millimeter wavelengths must have taken place prior to 1966, before it was possible to observe at these wavelengths.

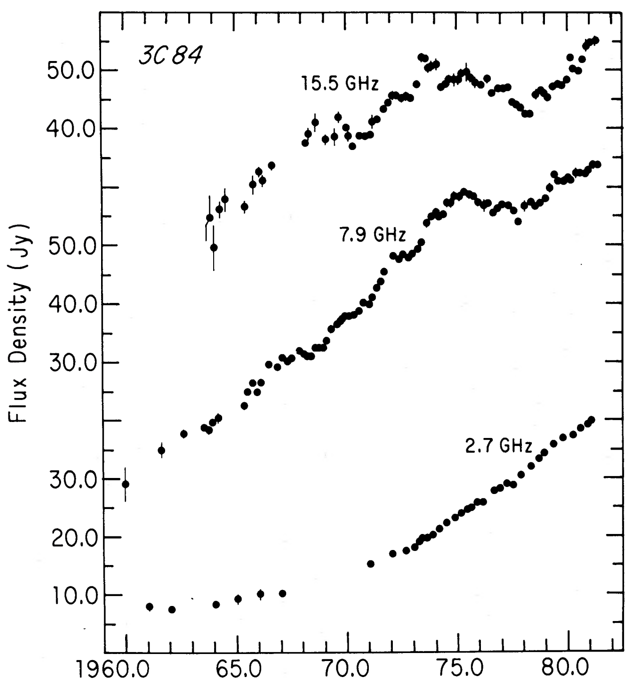

FIG. 1.—The flux density of 3C 84 at 2.7, 7.9, and 15.5 GHz as a function of time. The 7.9 GHz data prior to 1974.5 are from Heeschen (1961), Dent (1966), and Dent and Kapitzky (1976). The 15.5 GHz data between 1969 and 1973 are from Dent, Kapitzky, and Kojoian (1974). The measurements of Allen, Barrett, and Crowther (1968) have been included in the 7.9 and 15.5 GHz data. The 2.7 GHz measurements prior to 1972 are taken from Kellermann and Pauliny-Toth (1968) and Altschuler and Wardle (1976). A 3 Jy correction was applied to the Altschuler and Wardle measurements because of the partial resolution of 3C 84 by their interferometer.

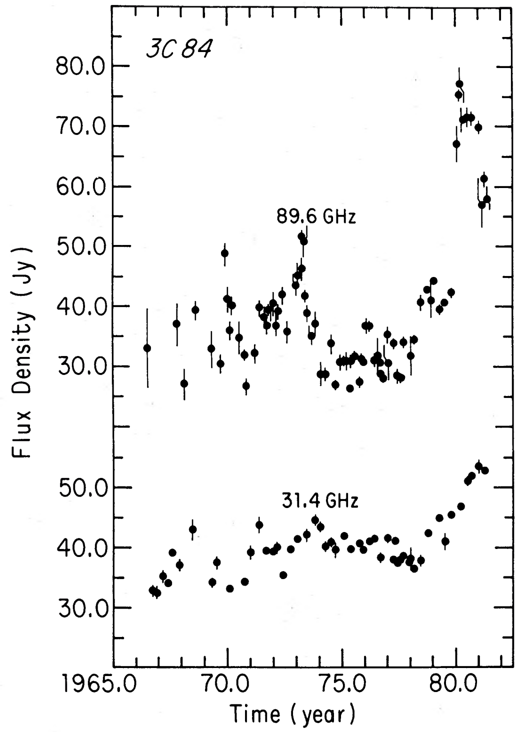

FIG. 2.—The flux density of 3C 84 at 31.4 and 89.6 GHz as a function of time. The data at 31.4 GHz prior to 1970 are taken from Waak and Hobbs (1977) and at 89.6 GHz prior to 1973 from Epstein *et al.* (1982). The measurements of Epstein *et al.* (1982) were averaged over a time interval of typically 6 months prior to 1970 and 2–3 months afterwards in order to improve the signal-to-noise ratio. A few additional measurements at 31.4 GHz are taken from Owen, Spangler, and Cotton (1980), and at 89.6 GHz from Ulrich (1980), Owen, Spangler, and Cotton (1980), Owen *et al.* (1978), Pushcell and Owen (1980), and Howard (1980).

In order to investigate the spectral evolution of the variable components in the compact core of NGC 1275, it is necessary to subtract from the total observed flux density the contribution of the extended, and presumably nonvariable, components. Measurements prior to 1965 (compiled by Kellermann and Pauliny-Toth 1968) show that the source flux density at 0.75, 1.4, and 2.7 GHz was constant. These observations define a power-law spectrum which has the form $S = 17\nu^{-0.75}$ Jy (where ν is in GHz) and represents the combined spectra of the several nonvariable and extended components. This "base spectrum" agrees well with the sum of the resolved extended component spectra from interferometric studies but is more accurate. The base flux at 7.9 GHz defined in this manner is 3.6 Jy. A linear extrapolation of the increase in the 7.9 GHz flux density back to a flux density of 3.6 Jy predicts early 1959 as the time of origin for the present activity.

In Figure 3 we show the spectra of the compact components derived from the measurements in Figures 1 and 2 at five epochs between 1967 and 1980. The small contribution from the constant base spectrum has been subtracted. Since simultaneous measurements at all frequencies were not always possible, the epochs of the spectra represent average epochs for the data. The evolution of the compact core spectrum is complicated by the short-term variability at the higher frequencies,

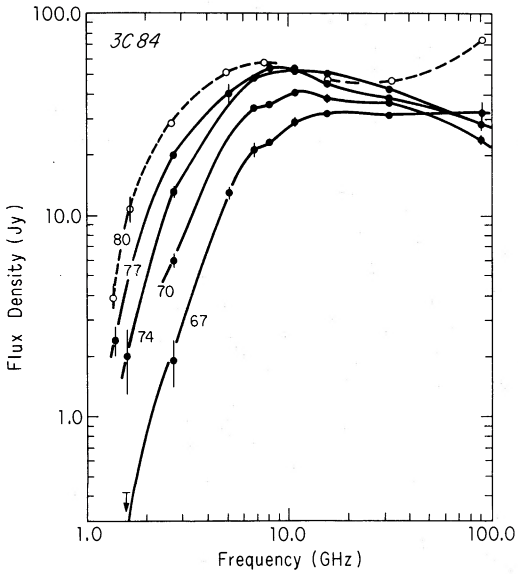

FIG. 3.—The compact core spectrum of 3C 84 (after subtraction of the contribution from the nonvariable components) at five epochs: 1967.0, 1971.0, 1974.0, 1977.0, and 1980.0. The data points at 6.7 and 10.7 GHz are taken from Andrew *et al.* (1978) and Medd *et al.* (1972). The 1.4 GHz measurement in 1967.0 is from Kellermann, Pauliny-Toth, and Williams (1969). The 1.67 GHz measurements in 1974.0, 1977.0, and 1980.0 are from Webber, Yang, and Swenson (1980). The 4.8 GHz measurement in 1980.0 is from Aller, Aller, and Hodge (1981).

but in general, the entire spectrum rose steadily at all frequencies, while the spectral peak evolved toward lower frequencies.

III. DISCUSSION

a) *Evidence for External Absorption*

The slope of the total spectrum of the core components (Fig. 3) below the low-frequency turnover is greater than $\nu^{2.5}$ at all epochs and is consistent with an exponential of the form $S \propto \exp(-\nu^{\beta})$, where $\beta \sim 2$. Since the steepest slope permitted by any internal source of opacity is 2.5, the steep low-frequency spectrum implies the existence of an external source of opacity. Because the spectrum of the elongated ($\theta = 0\farcs020$) component does not show any evidence of this external absorption, we can place limits of $3 < D < 10$ pc on the diameter of the absorbing region. The mechanism could be either synchrotron or free-free thermal absorption.

Assuming the former, the synchrotron emission from the absorbing region, S_a, is a function of the magnetic field, B, the angular diameter, θ, and the opacity, τ, as

$$S_a \propto B^{-1/2}\theta^2(1 - e^{-\tau}) \qquad (1)$$

and must contribute less than a few janskys in order for its contribution to the total spectrum to be negligible. If S_c is the flux density of the core, then

$$S_a/S_c = (B_c/B_a)^{1/2}(\theta_a/\theta_c)^2(1 - e^{-\tau_a})/(1 - e^{-\tau_c}) \ll 1 \; . \qquad (2)$$

Since $\theta_a/\theta_c \approx 2$, $\tau_a \approx 1$, and $e^{-\tau_c} < 1$, the magnitude field in the absorbing region would have to be several orders of magnitude greater than that of the compact core. Thus, in order for the absorbing region to have both a large opacity and low flux density, its magnetic field must be very much larger than in the core. This is probably unlikely.

For this reason, and also because strong emission lines are observed in the nucleus of NGC 1275 (e.g., Shields and Oke 1975; Kent and Sargent 1979), it is more likely that the absorber is a thermal gas. To produce the required opacity of unity near 2.2 GHz, an emission measure $n_i n_e L \sim 21T^{1.5}$ is necessary, where n_i and n_e are the number densities of ions and electrons in cm^{-3}, T is the temperature in kelvins, and L is the source thickness in pc (e.g., Spitzer 1978). Since $1.5 < L < 5$ pc, $n_e \sim n_i$, and $T \sim 10^4$ K, an electron density of $\sim 2 \times 10^3$ would provide the required opacity. This is comparable to the density of the region required to produce the forbidden emission lines (e.g., Kent and Sargent 1979). Thus it is probable that the same gas is both absorbing the low radio-frequency emission from the core and producing the forbidden emission lines.

Any intrinsic linear polarization of the core would be heavily depolarized by differential Faraday rotation in this external gas and could explain why this source is so unpolarized at radio wavelengths. The rotation measure of this gas would be $8 \times 10^5 n_e BL = 8 \times 10^7$ rad m^{-2}, assuming $B = 10^{-2}$ gauss, $n_e = 2 \times 10^3$ cm^{-3}, and $L = 5$ pc; and the core would be unpolarized at wavelengths longer than 0.1 mm.

b) *The Spectral Deconvolution of the Total Flux Density Spectrum*

We have attempted to find a model for the spectral evolution of the individual components seen in the VLBI maps which is consistent both with the flux density variations observed at microwave frequencies and with the structural changes in the compact components.

Each component of homogeneous synchrotron emission can be specified by four parameters: B, n_0, θ, and γ. The spectrum of each component is given by

$$S = c_1 \nu^{5/2} B^{-1/2}\theta^2 \times [1 - \exp(c_2 n_0 B^{(\gamma+2)/2} \nu^{-[(\gamma+4)/2]}\theta)] \exp[-\tau_{\rm ff}(\nu)] \; , \qquad (3)$$

where $\tau_{\rm ff}(\nu)$ is the opacity due to the external absorber; and c_1 and c_2 are known constants which depend slightly on γ (Pacholczyk 1970). The energy index γ is related to the spectral index α of the individual components by $\alpha = (1 - \gamma)/2$. The presence of several compact components which become self-absorbed at progressively higher frequencies will flatten the total spectrum and mask the spectral index of the individual components (Marscher 1977; Cotton *et al.* 1980). We have adopted $\alpha = -0.75$ ($\gamma = 2.5$) for all components because it is the spectral index of the base spectrum and the $\sim 0\farcs020$ component (Wilkinson *et al.* 1979; Shaffer 1980), and it is consistent with the VLBI data (Unwin *et al.* 1982).

The total spectrum of the compact components can be written as the sum of the flux densities of the N individual components modified by the common external absorption:

$$S(\nu) = \exp[-\tau_{\rm ff}(\nu)] \sum_{i=1}^{N} X_i \nu^{5/2}[1 - \exp(-Y_i \nu^{-[(\gamma+4)/2]})] \; . \qquad (4)$$

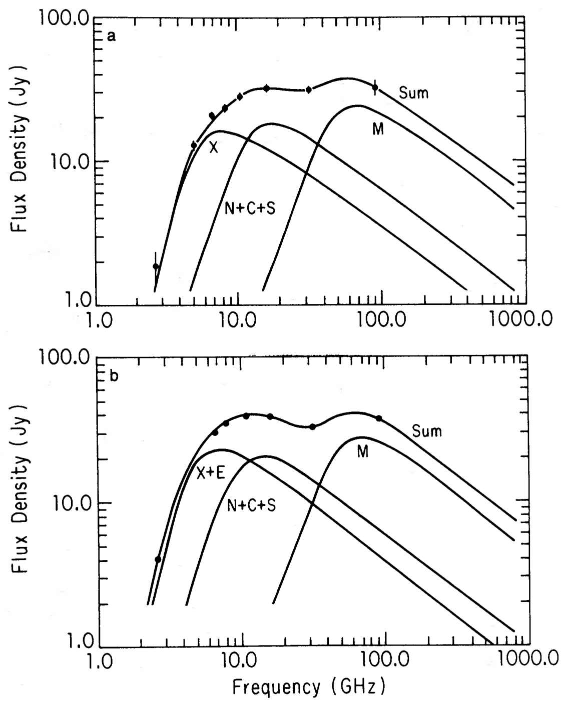

FIG. 4.—(*a*) The decomposition of the 1967.0 spectrum into three homogeneous components. The solid circles are observed total flux densities minus the contribution from the extended structure. The sum of the fitted components is also shown. (*b*) Same as Fig. 4*a*, for three components at epoch 1970.0.

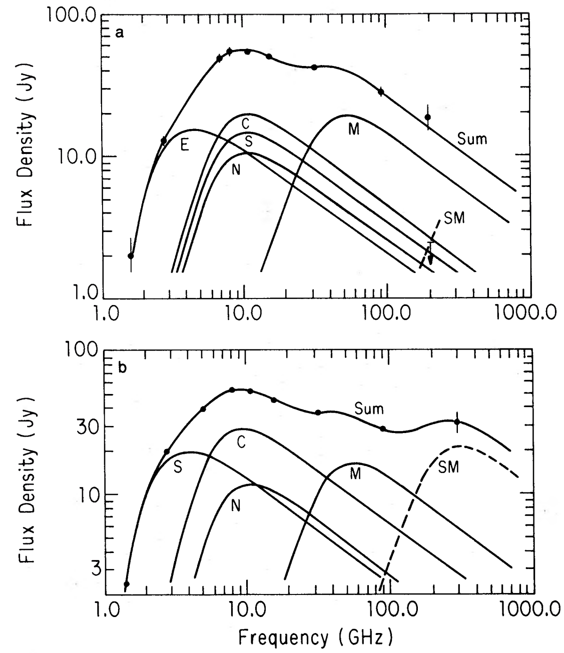

FIG. 5.—(*a*) Same as Fig. 4*a*, for five components at epoch 1974.0. The 1.6 mm point is taken from Clegg, Ade, and Rowan-Robinson (1976). (*b*) Same as Fig. 4*a*, for four components at epoch 1977.0. The 1 mm point is taken from Elias *et al.* (1978).

The frequency ν_m and the flux density S_m at the spectral peak (where the opacity $\tau = 0.5$) can be written as

$$\nu_m = (2Y)^{2/(\gamma+4)} , \tag{5}$$

$$S_m = 0.393 X \nu_m^{2.5} . \tag{6}$$

A gradient search least squares program based on the program CURFIT (Bevington 1969) was used to fit equation (4) to the total flux density minus the contribution from the extended structure (i.e., the spectra in Fig. 3). An initial guess for the frequency at a free-free opacity of unity, ν_{ff}, in the thermal gas and the values of S_m and ν_m (or equivalently X and Y) for each component were input to the program. Where possible, estimates of ν_m and S_m based on the VLBI maps (see below) were used. The results were not very sensitive to our initial guesses (i.e., the solutions were very stable). Within the assumptions of the model, the estimated uncertainties in both ν_m and S_m are typically $\sim 10\%$. The spectrum was fitted at yearly epochs between 1967 and 1981. The values obtained for ν_{ff} were consistent with a constant value of 2.2 GHz (or, equivalently, $n_i n_e L/T^{1.5} \approx 21$), implying that the absorbing region has been relatively stable for over 14 yr. The final deconvolutions of the spectra (discussed below) were done assuming this value to be constant. Given n measurements defining the total flux density spectrum at each epoch, we were constrained to fit for no more than $N = (n-1)/2$ components. With data at seven frequencies we could solve for three components. At epochs where VLBI maps at two frequencies were available, we could use this spectral data to solve for more components.

The long-term evolution of the components is illustrated by the epochs 1967.0, 1970.0, 1974.0, 1977.0, and 1979.8 (shown in Figs. 4–6). The components N, C, and S (North, Center, and South) are identified with the prominent VLBI components which have been seen during the past decade. The low-frequency cutoff in the spectrum is dominated by the free-free absorption, which causes the lowest frequency component to peak at a higher frequency and with a lower flux density than we find in our fits.

Once S_m and ν_m were obtained, the magnetic field and relativistic particle density were solved for in terms of the source diameter, i.e., $B = B_0 D^4$ gauss, and $n_r = n_{ro}/D^{(2\gamma+5)}$ cm^{-3}, where D is in pc. The values of B_0 and n_{ro} are given in Table 1 for our spectral fits at the 1974.0, 1977.0, and

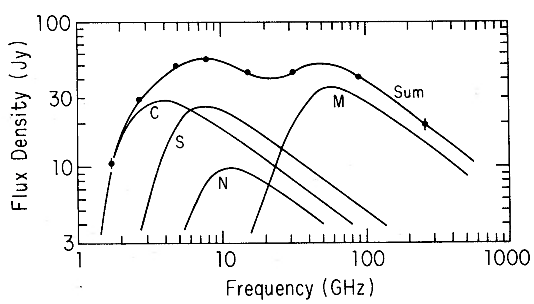

FIG. 6.—Same as Fig. 4*a*, for four components at epoch 1979.8. The 1 mm point is an average of a measurement from Sherwood (1981) and Ennis, Neugebauer, and Werner (1982).

TABLE 1

PARAMETERS OF THE COMPONENT MODEL FITS

Component	Epoch	ν_m (GHz)	S_m (Jy)	B_0 (gauss pc^{-4})	n_{ro} (cm^{-3} pc^{10})
N	1974.0	10	12	8×10^0	4×10^{-3}
	1977.0	10	12	8×10^0	4×10^{-3}
	1979.8	11	10	8×10^0	4×10^{-3}
C...........................	1974.0	10	20	5×10^{-1}	1×10^0
	1977.0	8.6	30	1×10^{-1}	2×10^1
	1979.8	1.8	54	1×10^{-4}	8×10^8
S	1974.0	10	15	8×10^{-1}	3×10^{-1}
	1977.0	1.9	36	4×10^{-5}	7×10^6
	1979.8	7	28	4×10^{-2}	9×10^2
M	1974.0	50	19	9×10^3	9×10^{-8}
	1977.0	54	16	3×10^3	5×10^{-7}
	1979.8	56	16?	...	...
SM	1977.0	300	21	6×10^7	7×10^{-14}
	1979.8	56	19?	...	...
E...........................	1974.0	2	30	5×10^{-4}	7×10^4

NOTE.—The frequency and flux density at the spectral peak, and magnetic field and relativistic particle density coefficients of the model components.

1979.8 epochs. The typical uncertainties in B_0 and n_{ro} are estimated to be factors of ~ 4 and 10, respectively. In the high-frequency components, M (millimeter) and SM (submillimeter), where $D \leq 0.1$ pc, we derive $B \sim 1$ gauss and $n_r \sim 10^2$–10^4 cm^{-3}. In the components S, C, and N (where $D \sim 1$ pc) the magnetic field is in the range 1 to 10^{-2} gauss, and the relativistic particle density is on the order of 1 to 10^{-2} cm^{-3}. The 0\".020 (= 10 pc) component outside the core has a brightness temperature $T = 9 \times 10^{10}$ K and $\nu_m = 600$ MHz (Wilkinson *et al.* 1979), implying B is about 0.1 gauss and $n_r \sim 10^{-3}$ to 10^{-4} cm^{-3}. (Note that if the spectral turnover of the 0\".020 component is influenced by free-free absorption, lower values for both B and n_r are required.) Thus the particle density decreases with increasing component size as might be expected, while the magnetic field decreases as $\sim r^{-1/2}$ over a size scale of about 0.1–10 pc. This decrease is much slower than $B \propto r^{-2}$, which is the case if conservation of magnetic flux is assumed.

c) *Evidence for Compact Millimeter and Submillimeter Components*

We have fitted for three or more compact components at approximately yearly epochs from 1967 to 1981. We find that without exception, a spectral component with a maximum of about 20 Jy near 60 GHz is required to fit the spectrum at the higher frequencies. Unless the millimeter component has a spectrum flatter than -0.25, an additional submillimeter component is needed to account for the ~ 20 Jy flux density observed at frequencies near 300 GHz by Elias *et al.* (1978) and Hildebrand *et al.* (1977) (e.g., the 1977.0 epoch spectra in Fig. 5*b*). This submillimeter component could be associated with the strong millimeter outburst in 1980.2 (Balonek 1982; Ennis, Neugebauer, and Werner 1982; Dent *et al.* 1983).

d) *A Scenario for the Evolution of Individual Components*

i) *1959–1974*

The present radio-frequency components in the nucleus originated in 1959. The total spectrum rose vertically to a flux density of about 21 Jy by 1964 as electrons were accelerated to relativistic speeds. Because of the absence of measurements at millimeter wavelengths, the frequency of the spectral peak at early epochs is not known, but was probably near 30 GHz by 1964.

By 1967 and 1970 several inflections were evident in the total flux density spectrum, revealing that the radio nucleus already consisted of multiple compact components. We were able to deconvolve the earlier 1967.0 and 1970.0 spectra into only three components (Figs. 4*a* and 4*b*). At these early epochs the first (lowest peak frequency) spectral component peaks at higher frequencies than it does at later epochs. Its peak frequency evolves from 7.6 GHz in 1967.0, to 6.4 GHz in 1970.0, and 2.0 GHz in 1974.0; while the flux density at the peak increases monotonically from 18 Jy to 25 Jy to 30 Jy. The identity of this component, X in Figure 4, is unknown since its flux density at centimeter wavelengths is very small in 1974 when the first multifrequency VLBI maps were obtained. The spectrum of the X component could be associated with a northeast extension to the Central component (E), which was fading rapidly in 1974 (Preuss *et al.* 1979; Pauliny-Toth *et al.* 1981).

The second spectral component also shows a similar evolutionary pattern evolving from $\nu_m = 17$ GHz to 14 GHz between 1967.0 and 1970.0 and 10 GHz by 1974. This spectral component is very likely a blending of the South, Center, and North components seen in the 1974 VLBI map. Collectively, their spectra have risen in flux density from $S_m = 18$ Jy in 1967 to 47 Jy in 1974.

As discussed in the preceding section, a third, "millimeter" (M) component of unknown spatial location is necessary to fit the total spectrum. Its spectrum, which peaks at 67 GHz, is stationary between 1967.0 and 1970.0. The absence of any flux density measurements above 100 GHz prior to 1974 precludes any knowledge about the existence of a submillimeter component, at the early epochs.

ii) *1974–1981*

The deconvolutions of the 1974.0, 1977.0, and 1979.8 spectra were facilitated by the VLBI maps and hence are more reliable than the earlier epochs. The 1974 maps at 5.0 (Pauliny-Toth *et al.* 1981) and 10.7 GHz (Preuss *et al.* 1979) show that the North component peaks at ~ 10 GHz with a flux of ~ 12 Jy. We held the N component fixed at $\nu_m = 10$ GHz and $S_m = 12$ Jy and fitted for four additional components (Table 1). The first component (Fig. 5*a*) can be identified as the East component in the maps. Our deconvolution shows the Center and South components peaking near 10 GHz with flux densities of 20 Jy and 15 Jy, respectively, consistent with the VLBI data. The millimeter spectral component peaks at 50 GHz and $S_m = 19$ Jy in 1974. Because its flux density at 10.7 GHz is only 1 Jy and hence would not be seen on the VLBI map, its spatial relationship to the other radio components in the nucleus of NGC 1275 is not known.

At 1977.0, the 10.7 (Preuss *et al.* 1979) and 22 GHz (Pauliny-Toth *et al.* 1978) maps show that the North component has not changed much since 1974 and still peaks near 10 GHz. The East component has faded away, and the South component is now weaker and more extended than the Central component. A component west of the Central component is seen in the 22 GHz maps (Pauliny-Toth *et al.* 1978; Matveenko *et al.* 1980) but not in the 10 GHz map. If this component is real, it is probably self-absorbed at 22 GHz.

With the N component fixed at $\nu_m = 10$ GHz and $S_m = 12$ Jy, we were again able to fit for four additional components. The spectral deconvolution (Fig. 5*b*) shows that the spectral peak of the South component has evolved to lower frequencies, the Central component has increased in strength as its peak shifted to lower frequencies, and the millimeter component, M, is the same as it was in 1974.0. At 1977.0 we find that a submillimeter component, SM (peaking at 300 GHz), has appeared since 1974.

The spectrum in 1979.8 just prior to the large outburst at 3 mm was deconvolved aided by 5.0 and 10.7 GHz VLBI maps and spectral indices obtained by Unwin *et al.* (1982) near this epoch. The N component was fixed at $\nu_m = 11$ GHz and $S_m = 10$ Jy, and we fitted the S, C, and M components. Our spectral deconvolution (Fig. 6) of the S and C components agrees well with the Unwin *et al.* results. While the submillimeter component has disappeared between 1977.0 and 1979.8, we find that the millimeter component has increased significantly, from 16 to 35 Jy, in peak flux density. This 19 Jy increase in the M component appears to be due to a leftward horizontal evolution of the 1977 SM component such that the two components are blended by 1979.8.

RHEWR present VLBI observations made in 1981.4 at 10.7 and 22 GHz. The spectra which they obtain for the components are based on only these two frequencies and differ from our spectra in Figure 6. In the $1\frac{1}{2}$ yr between the maps upon which our 1979.8 spectra are based (Unwin *et al.* 1982) and the 1981.4 RHEWR maps, the total flux density has increased significantly (~ 12, ~ 8 Jy, and ~ 33 Jy at 15.5, 31.4, and 89.6 GHz, respectively). An important constraint in our fits is that the components must reproduce the total flux density spectrum (minus the contribution from the extended structure). This constraint is not present in the RHEWR spectral fits and for these reasons caution must be used in comparing our spectra with theirs.

A comparison of the flux density of our N component (~ 7 Jy at 22 GHz in 1979.8) with the B component of RHEWR (~ 20 Jy at 22 GHz in 1981.4) suggests that this component was the source of the flux density increase between 1979.8 and 1981.4. The flux density and spectral index of the very compact A component of RHEWR imply that it is the same as our compact M component.

Although we show the C component turning over at a lower frequency than RHEWR do, their flux density measurements are also consistent with our spectrum. The spectra of our S component and RHEWR's D component are similar, suggesting that it has remained relatively constant between the two epochs.

In summary, the evolution of the individual components is as follows. From 1974 to 1979.8 the VLBI maps show that the North (RHEWR's A + B) component was constant. However, between 1979.8 and 1981.4 the A component underwent a flux density increase at millimeter and then at centimeter wavelengths due to the horizontal evolution of an outburst which began in 1977 near 300 GHz. A similar but much stronger outburst occurred again in 1980 (Dent *et al.* 1983). This activity in the A component supports the conclusion that it is the energy-generating core at the end of the jet.

The Central (C) component evolved to lower frequencies between 1974.0 and 1981.4 with a steadily increasing peak flux density. The South (RHEWR's D) component at the end of the jet evolved to lower frequencies as the peak flux density increased between 1974.0 and 1977.0. However, between 1977.0 and 1979.8 particle injection or reacceleration occurred in the South component, reversing the direction of its evolution by shifting its spectral peak to higher frequencies, where it has remained as of 1981.4. The VLBI maps show that this component also became more compact between 1977.0 and 1979.8 (Romney *et al.* 1982). Since the South component is also moving away from the northern components (Romney *et al.* 1982), it seems likely that this is the location where the relativistic particles at the end of the jet are impinging on the external medium, compressing the source and reversing its spectral evolution (O'Dell 1982).

IV. CONCLUSIONS

An exponential cutoff at the low-frequency end of the compact core spectrum as well as the very low polarization at radio frequencies in 3C 84 implies the existence of a thermal gas of density $\sim 2 \times 10^3$ cm^{-3} surrounding the core.

Very compact components whose spectra peak at millimeter and submillimeter wavelengths are necessary to account for the flux density and variability at these wavelengths.

The relatively flat total flux density spectrum between 3 and 300 GHz is well fitted by three to five simple steep-spectrum homogeneous components. The steady rise in flux density at 2.7, 7.9, and 15.5 GHz prior to 1975 is due to the continuing migration toward lower frequencies of a progression of spectral components that originated in 1959 and shortly thereafter. The centimeter wavelength spectral components evolve primarily "horizontally," moving to lower frequencies without experiencing the large decrease in peak flux density expected in the simple van der Laan (1966) model. A prolonged (though clearly variable) supply of relativistic particles to the various components or *in situ* reacceleration can account for their monotonically increasing peak flux densities (e.g., Peterson and Dent 1973; Pacholczyk and Scott 1976).

Outbursts first observed at frequencies above 50 GHz occur in the northernmost radio component in the nucleus. This is the probable location of the energy-generating core, which supplies relativistic particles to the other emitting components located along a jet.

The progressive evolution of spectral components toward lower frequencies might be a consequence of the decreasing magnetic field strength encountered by the particles as they move away from the core where they are first accelerated.

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