RADIO NUCLEI IN NEARBY GALAXIES

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This review is an attempt to summarize VLBI continuum observations at cm- and dm-wavelengths of active galactic nuclei at distances $\lesssim$ 100 Mpc (H_0 = 50 km s^{-1} Mpc^{-1}). 'Nearby galaxies', thus defined, are close enough for achieving the highest possible spatial resolution. Galaxies at these distances, however, typically do not show extreme and rare forms of nuclear activity such as powerful radio sources, the cores of which are relatively easy to map with VLBI, and which are therefore the subject of most of the VLBI work done so far (see e.g. Preuss, 1983). Nearby active galaxies show rather more 'ordinary' forms of nuclear activity; they include a few of the weaker classical 'radio galaxies', but most of them are Seyfert galaxies and mildly active 'normal galaxies'. Their total radio emission is typically weak (P(5 GHz) $\lesssim 10^{31}$ erg s^{-1} Hz^{-1}) and so are their compact radio nuclei (if any). The highest available sensitivity is therefore required for their study and the current instrumental performance is just becoming sufficient to tackle the strongest of them in the hope of obtaining maps.

The linear resolution for a fringe spacing of 0".001 at a distance of 20 Mpc is about 0.03 pc $\sim 9 \times 10^{16}$ cm, i.e. a few 100 Schwarzschild radii of a 10^9 $M_\odot$ object. This means that VLBI of nearby galaxies is sensitive to size scales which are certainly comparable to those of broad line emission regions and which may even be characteristic of accretion discs or other fundamental scales near the origin of radio sources. VLBI observations of radio nuclei in nearby galaxies have a bearing on a number of fundamental topics such as the central energy source in active nuclei, the process providing the energy supply to the extended emission regions well outside the nuclear environment, the radiation mechanism and the relation between manifestations of nuclear activity in different spectral regimes. In fact the nature of the basic physical constituents just mentioned is not clear in many cases. Given the braod range in power $\gtrsim 10^8$:1 and in other characteristic properties of otherwise similar nonthermal radio sources, the important question arises: Can most of the apparent variety be understood in terms of scaling the characteristic properties of a few universally operating mechanisms such as the 'central engine' and the energy supply process to outer emission regions; or more specifi-

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cally: Is accretion of material onto massive compact objects (see e.g. Blandford, this volume) the primary energy releasing process operating in many, if not all, active nuclei? Or are, e.g. bursts of star formation (Biermann and Fricke, 1977) more important for weaker forms of nuclear activity? To what extent is continuous collimated outflow in the form of 'jets' a universal phenomenon governing the evolution and structure of nonthermal radio sources? Universality of the principal mechanisms is often suspected or hypothesized but it is only now that we can go about checking this assumption observationally for the low power radio nuclei.

Straightforward questions to be answered by observations and relevant to the more fundamental topics mentioned, are the following: What are the size and power scales in nearby radio nuclei? Are they smaller than the cores of strong sources? Are they elongated and is their direction related to those of larger scale features or any characteristic directions revealed in other spectral ranges? How does their detailed structure compare with more powerful radio cores? Are they simpler? How does their flux density and structure depend on frequency and time?

In what follows I will try to summarize results of pertinent VLBI observations which have been made so far. Table 1 lists 40 'nearby galaxies' and it is intended to include all objects from VLBI papers which have come to my attention and which meet the following 2 criteria: a) they are detected at least at one wavelength on an angular scale $\lesssim 0\farcs05$ and b) the object is closer than 100 Mpc ($50/H_o$) <u>or</u> the total radio emission is weak ($P(5\ \mathrm{GHz}) \lesssim 10^{31}$ erg s^{-1} Hz^{-1}).

Table 1 is based on the results of VLBI observations made at wavelengths between 2.8 and 21 cm and reported in 23 papers, 16 of which have appeared during the past 2 years. 14 papers deal with individual objects (M81, M82, CENA, M87, NGC315, NGC1052, M104, NGC3894, see refs in table 1), 3 report results of pilot observations of mixed selections (van Breugel et al., 1981; Graham et al., 1981; Preuss et al., 1977), the remaining 6 papers report results for samples selected by the following criteria: Seyfert galaxies (Neff & de Bruyn, 1983), broad line emission regions (Preuss & Fosbury, 1983), pairs of galaxies (Biermann et al., 1981), optically bright galaxies with strong core sources (Crane, 1979, Jones et al., 1981) and spiral galaxies (Hummel et al., 1982). The only relatively nearby object (distance 110 Mpc) mapped at 1.3 cm (Readhead et al., 1983) is the strong radio core in NGC1275.

At least 28 (70%) of the objects in Tab. 1 are at distances $\lesssim$ 100 Mpc. The list includes 3 (M81, M82, CENA) of the 179 galaxies known to be within 10 Mpc (Kraan-Korteweg & Tammann, 1979).

A breakdown of all galaxies listed according to optical morphological and spectroscopic type reads as follows:

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	no emission lines	emission lines (no Seyfert spectrum)	Seyfert galaxies
E/SO	17	6	1
S	4	1	6
Other	2	1	2

Considering the normal (non-Seyfert) galaxies: there are 23 (74%) early type (E/SO) and 5 Spiral galaxies. This is certainly statistically significant in the sense that relatively strong radio nuclei ($\lesssim$ 0.″05) are predominantly associated with early type galaxies. A certain statistical significance of table 1 results from the fact that a major fraction of it is effectively the combined detection yield of a number of well defined samples of bright galaxies associated with strong radio cores on a $\sim$ 1″ scale. This can be shown by tracing back the routes of source selection to the radio surveys (see e.g. Ekers, 1981) of galaxies by means of single dishes and local interferometers. See also the contribution by Bagri & Ananthakrishnan (this volume) who find most of their scintillating components (IPS at 327 MHz) in nearby galaxies of type E/SO.

What are the characteristic sizes of the smallest radio components detected in the objects listed? At least 34 (85%) show structure on a scale $\lesssim$ 1 pc, 16 (40%) on a scale $\lesssim$ 0.1 pc, and 3 (M81, M82, CENA) on a scale $\sim$ 0.01 pc. The median correlated flux density of the 20 sources detected at 6 cm on a scale $\lesssim$ 1 pc is about 90 mJy. The 10 brightest radio nuclei with scale sizes $\lesssim$ 1 pc in normal galaxies (excluding classical radio galaxies and Seyfert galaxies) are N1052, N4278, N2911, M104, N3894, N3998, M89, M81, M82 and N6500. M81 is the best studied object with very small scale structure and the paper by Bartel et al. (1982) is the first one based on observations with the broad band (56 MHz) Mark III VLBI system. Almost 100% of the nuclear emission in M81 originates in an elongated region of extent $\sim$ 1000 x 4000 A.U. (scale $\sim 10^{16}$ cm). Even smaller is the radio nucleus (SAG A) in our own Galaxy with a size $<$ 100 A.U. $\sim 10^{15}$ cm (see Lo this volume).

The radio luminosity of the core sources in objects of table 1 (plus SAG A) covers a range of 10^7:1 typified by the following objects: SAG A: 10^{34}, M81:10^{38}, M104:10^{39}, M87:10^{40}, and NGC315:10^{41} erg/s. Peak brightness temperatures are typically a few 10^{10} K.

The conclusion to be drawn from flux and size measurements is: Very compact nuclei with sizes $\lesssim$ 1 pc occur quite commonly in the centres of low luminosity active galaxies over a wide range of power scales. There is a high VLBI detection probability for flat spectrum radio sources in any kind of galaxy. This supports the idea that the prevailing radiation mechanism is synchrotron emission of relativistic electrons. It looks as if intrinsically weak objects have smaller radio cores than strong radio sources. To rule out the possibility that this is a selection effect, a cross-check on the powerful (distant) sources with baselines larger than the earth-diameter (Satellite VLBI) is needed.

Table 1: Nearby Galaxies detected with VLBI (as of June 1983)

Name (1)	Name (2)	Distance (Mpc) (3)	Optical type (4)	(5)	L.A.S. (6)	S.A.S. (7)	References VLBI (8)	other (9)	Remarks (10)
0017+296	N0076	153	Compact			5	1		
0046+316	N0262	90	S/S0	SEY2	<0".5	1 *	2,3,4	33	Mk348; variable, HI detected
0055+300	N0315	100	E		30' D	1 *	5,6		Giant radio galaxy
0238-084	N1052	28	E	EM	20" D	5 *	7,8,31,36	33	HI detected,variable
0240-002	N1068	22	S	SEY2	14" D	50*	1,4,9	13 33	M77, 3C71
0305+039	N1218	172	S0	EM	2".5	5 *	1	10	3C78
0359+229	N1497		S0			5	1		
0609+710	Mk3	83	S	SEY2	1".5 D	30	2,4	11	4C70.05
0645+744	Mk6	106	S0	SEY1	1" D	50	2,4	12	IC450
0840+504	N2639	67	S		0".7	20	14		
0931+103	N2911	60	S0	EM	<1"	5	1,3,7		
0951+693	N3031	3.25	S	SEY1	>1"	1 *	1,9,15,20	35	M81
0951+699	N3034	3.25	Irr	EM	15"	1	1,2,8,16	17	M82, 3C231
1122+39	N3665	40	S0		30" D	20	7	18	dust lane
1139+267	N3826	181	E			5	1,3		
1146+596	N3894	66	E		2'	1 *	19,31,32		in galaxy pair
1155+557	N3998	24	S0		4' D	20	14		variable
1208+396	N4151	19	S	SEY1	10" D	20	2,7	13 21 22	in galaxy pair
1216+061	N4261	44	E		9' D	1	1,9		3C270
1217+29	N4278	21	E	EM	≲1"	5 *	1,7,8,31	12	HI detected
1222+131	N4374	22	E		2'.4 D	1 *	1,9	10	M84, 3C272.1,dust lane
1228+126	N4486	22	E	EM	50" D	1 *	23,24,25, 37	26 27	M87, 3C274, VIR A 10' radio halo
1233+128	N4552	22	E		<1"	5 *	1,7,9	10	M89, variable
1237-113	N4594	18.6	S	EM		5	8,28		M104, "Sombrero"
1254+571	Mk231	248		SEY1	10"	1	2,4	12	variable
1317-12	N5077	50	E	EM		20	7		
1322-427	N5128	5	E		10° D	1 *	29,36		CENA, dust lane
1348+339	N5318	85	S0?			5	1,3		brightest in a group
1351+405	N5353	46	S0		<0".2	10	14		
1353+054	N5363	22	Irr		5"	5	1,3,14		
1353+186	Mk463	304		SEY2	1".3	50	4	12	double nucleus
1426+276	N5635	78	S		<1"	5 *	1	10	variable source
1430+365	N5675	86	S		2".5	5 *	1,3	10	
1553+246		260	E			20	3,19		in galaxy pair
1717+490	ARP102B	150	E	SEY1		1	19		in galaxy pair
1753+183	N6500	64	S		5".3	1 *	1,3,7, 19	10 30	in galaxy pair
2116+262	N7052	99	E			5	1,3		
2303+338	N7485		S0			5	3		
2322+282		138	S0			5	1,3		
2337+268	N7728	189	E		4"	5 *	1,3	10	NRAO 716

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Meaning of columns (where not self-explanatory):
column (3): Distances taken from the references given or from Huchra et al. (1983); c/H_0 = 6000 Mpc, q_0 = 0.5
column (5): SEY1 and SEY2: Seyfert type 1 and 2, EM = Emission lines present
column (6): L.A.S. = largest radio angular size, D = double source
column (7): S.A.S. = smallest angular scale on which radio structure has been detected by VLBI; a star "*" means: VLBI structure is elongated with position angle given in one of the references

References to table 1

1 Jones et al. (1981a)
2 Preuss & Fosbury (1983)
3 Crane (1979)
4 Neff & de Bruyn (1983) and this volume
5 Linfield (1981)
6 Preuss et al., in prep.
7 van Breugel et al. (1981)
8 Shaffer & Marscher (1979)
9 Preuss et al. (1977)
10 Jones et al. (1981b)
11 Wilson et al. (1980)
12 Ulvestad et al. (1981)
13 Wilson & Ulvestad (1982)
14 Hummel et al. (1982)
15 Kellermann et al. (1976)
16 Geldzahler et al. (1977)
17 Kronberg et al. (1981)
18 Kotanyi & Ekers (1979)
19 Biermann et al. (1981)
20 Bartel et al. (1982)
21 Johnston et al. (1982)
22 Booler et al. (1982)
23 Pauliny-Toth et al. (1981)
24 Cotton et al. (1981)
25 Reid et al. (1982) and this volume
26 Owen et al. (1980)
27 Charlesworth & Spencer (1982)
28 Graham et al. (1981)
29 Preston et al. (1983)
30 Hummel et al. (1983)
31 Jones et al. (1983)
32 Wrobel, this volume
33 Bagri & Ananthakrishnan, this volume
34 Pedlar et al. (1983)
35 Crane, this volume
36 Kellermann et al. (1975)
37 Kellermann et al. (1977)

What is known about the morphology of the objects in table 1? For about 6 of them (M87, N315, Mk348, N3894, N4278, N1052) there are VLBI maps available and models of the brightness distribution for another 10 objects. There is enough information to determine the position angle of any elongated or jet-like structure in 15 cases (indicated by '*' in column 7 of table 1). At least 24 (60%) of all objects listed show extended ($\gtrsim$ 1") radio structure (column 6), in 12 cases in the form of double structure associated with galaxies of E/S0 or Seyfert type. The list includes 5 of about 15 Seyfert galaxies which are known to have double structure on the $\sim$ 1 kpc scale (Ulvestad, 1983). A comparison of small and large scale structure in these objects leads to the conclusion: Elongated, linear structure of radio nuclei and their alignment with larger scale features seems to be the rule, rather than the exception, also for mildly active galaxies. Jones et al. (1981) report alignment between pc- and kpc scale features for N1218, N4374, N5675, N6500, and N7728. See also Jones et al. (1983) and Neff & de Bruyn (this volume). The maps or models of the radio nuclei in nearby galaxies are as yet not sufficiently detailed to allow a proper comparison with the core structures of powerful radio sources. There is also as yet no information available on the structural variability of

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these objects. In any case there is a growing body of evidence that the extended radio sources associated with mildly active nuclei or Seyfert nuclei are powered by the same mechanism as radio galaxies or quasars, by collimated outflow ('jets') of nonthermal material originating on scales < 1 pc. Both pieces of evidence, the small sizes and the linear structure of the radio nuclei in nearby galaxies speak against the star burst hypothesis but, rather, favour accretion models with quasi-continuous outflow. But at this stage of the observations it is to early to tell whether this will turn out to be the case universally.

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