RADIO CONTINUUM OBSERVATIONS OF THE NUCLEUS OF OUR GALAXY AND OTHER NORMAL GALAXIES

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1. INTRODUCTION

The radio properties of the nuclei of normal galaxies have been reviewed by Ekers (1974, 1978a, 1978b) and of the Galactic Centre by Oort (1977). In this report I will concentrate on material available since then. The following paper by Van der Hulst extends this review with more information on the structure of the central sources in normal galaxies.

2. OUR GALAXY

2.1. Sgr A

No complete high resolution maps of Sgr A have been made since the "WORST" map (Ekers et al. 1975) so I will use it as a reference for the new information which is available. At the lower frequency of 327 MHz there have been a series of occultation measurements by Gopal-Krishna and Swarup (1976). These again show the separation into two components; a nonthermal Sgr A East and a thermal Sgr A West. In addition they show some spatial variation in the nonthermal spectral index and also suggest that the nonthermal source extends over the entire region of Sgr A. From observations using the RATAN telescope Parijskij (private communication) also suggests that the Sgr A East component might just be a peak on a more symmetrical nonthermal source which is centred on Sgr A West. RATAN observations are in progress in the wavelength range from 2-6 cm and these confirm the thermal nature of Sgr A West. As the VLA elements come into operation along more than one arm of the Y it becomes possible to use it to map Sgr A. 5 and 15 GHz maps (Brown, Lo and Johnston 1978 and private communication) with a resolution of a few seconds of arc resolve the Sgr A West source into a number of components with an overal size of $\sim 1' \times 30'$ elongated along the galactic plane and centred on the Sgr A West point source (Balick and Brown 1974). The VLA maps of Sgr A West agree well with the inner contours of the WORST map and this distribution of emission is similar to that seen in the 53μ map (Harvey, Cambell and Hofmann 1976). Such an association is common in HII regions and is consistent with the thermal nature of Sgr A West.

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2.2. The point source

The point source in Sgr A West, which is generally assumed to be the actual nucleus of our galaxy, has been the subject of a number of observations. Flux density measurements between 1 and 22 GHz indicate a spectrum of the form $S \propto \nu^{+0.3}$ (Davies et al 1976, Brown et al 1978, Lo private communication). VLBI and long baseline interferometer observations have confirmed the λ^2 dependance expected if the diameter is determined by interstellar scattering as proposed by Davies, Walsh and Bethe (1976). Consequently, the observed diameter of 0".01 (2×10^{15} cm) at 8 GHz (Lo et al 1977) is an upper limit to the true size. A small fraction of the flux density of the point source comes from a core <0".01 (Kellermann et al 1977, Geldzahler et al 1979) but this still could be consistent with scattering (Backer 1978) in which case the intrinsic size of the point source is $\leqslant$0".01 (2×10^{14} cm). Since this is only a few light hours flux density variations might be expected and these would give information on the central engine. It is difficult to obtain high quality data on the variability because it is necessary to resolve out the much greater flux density coming from Sgr A and the only telescopes which can do this at present are in the Northern Hemisphere where Sgr A has to be observed at very low elevations. Various observations taken from the literature (Ekers et al 1975, Lo et al 1977, Brown et al 1978) show no variation in excess of 20% between 1973 and 1978. Westerbork observations (Ekers and Sanders, private communication) and RATAN observations (Parijskij, private communication) also show no variations greater than 20% on time scales between milliseconds and a few days. However, Brown and Lo (quoted in Brown et al 1978) do claim significant variability at this level.

The nature of this point source is still unclear. Assuming that the measured angular size is the intrinsic size Brown et al (1978) present arguments against a synchrotron model with self absorption and suggest instead an analogy with radio binaries. Others have commented on the similarity with the Ryle et al (1978) class of compact sources (including SS433). It is also reasonable to draw an analogy with the compact sources seen in other galaxies (based on its location, spectrum, size and lack of strong variability) but then we have to consider models capable of supplying millions of times more energy.

The properties of the main radio continuum emission from the central region of our galaxy are summarised in Table I together with data for a few nearby spiral galaxies. This shows that all the radio components seen in our galactic centre are also seen in other spiral galaxies.

3. NORMAL GALAXIES

3.1. Surveys

Although we can always obtain the most detailed information from observations of our galactic centre we cannot tell whether these features

TABLE I. Radio Nuclei of Nearby Spirals

	Luminosity (erg sec^{-1})	Diameter (PC)	Spectral Index, α
The Galaxy	10^{37}	200	?
	10^{36}	10	-0.5
	10^{33}	10^{-4}	+0.3
M 31	10^{36}	250	-0.7
M 33	$<10^{35}$	-	-
M 51	2×10^{38}	750	-1.1
M 81	2×10^{37}	$<6 \times 10^{-2}$	+0.2

$S(\nu) \propto \nu^{+\alpha}$

are peculiar to us without looking at other galaxies. In most cases the linear resolution available for a study of external galaxies is not better than a few hundred parsecs so I will use the term "central sources" when referring to structures on this scale, reserving the term "nucleus" for those sources known to be less than a few parsecs in size.

A number of excellent radio surveys have been recently completed and their properties are summarised in Table II. Not all of these have sufficient angular resolution to distinguish the central sources from the disk emission. Noteworthy among these are the large sample of pairs in the

TABLE II. Normal Galaxy Surveys since 1977

	Optical Selection				Radio Observations		
	Ref.	Mp	δ	No	Freq (GHz)	Res.^{n}	Flux limit (mJy)
Crane (1977)	1.	<12	$>-20^o$	181	2.7	10"	20
Carlson (1977)	2.	-	-	58	2.7,8.0	2"	~30
Disney and Wall (1977)	3.	-	$<0^o$	181	5.0	4!0	12
Stocke et al. (1978)	4.	<15.7	$>-3^o$	603	2.7	2!5	40
Dressel and Condon (1978)	5.	<14.5	$0,37^o$	2095	2.4	2!7	15
Condon and Dressel (1978)	6.	<14.5	$0,37^o$	168	2.7	6"	35
Hummel (1979)	7.	<12	$-30^o 30^o$	400	1.4	20"	10 point
		<13	$<30^o$				50 disk

1 mJy = 10^{-29} Wm^{-2} Hz^{-1}

Ref.: 1. RCBG (S + Irr), 2. Various, 3. RCBG E,SO, 4. Karachentsev pairs, 5. UGC, 6. UGC, 7. RCBG.

survey of Stocke et al. (1978) which gave the first strong indication of enhanced emission from multiple systems (see later discussion), the very large and sensitive survey of galaxies in the Arecibo declination range

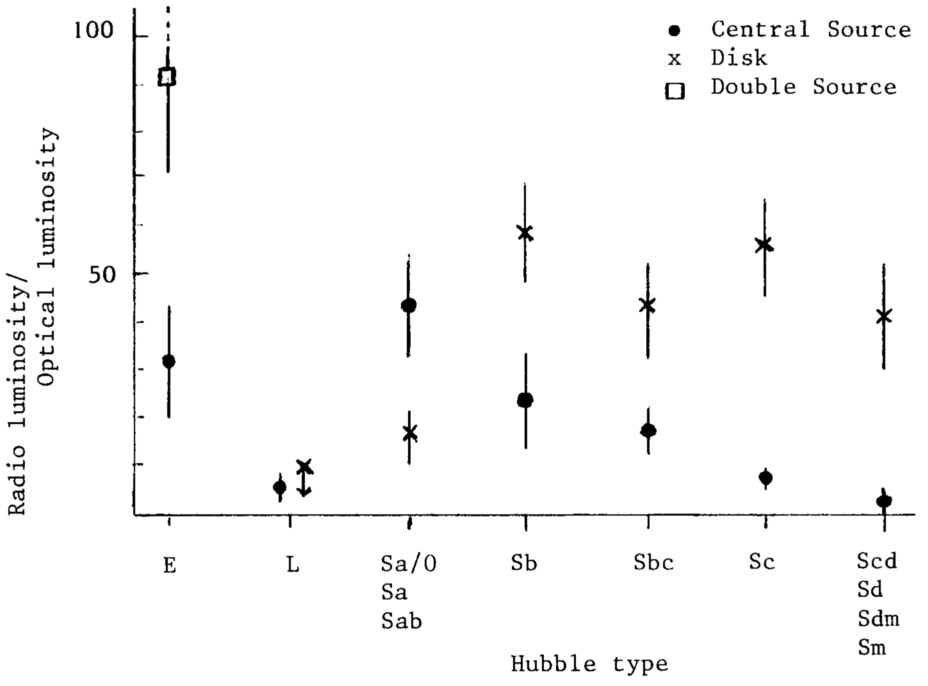

Fig. 1. The 10 percentile of the radio luminosity/optical luminosity distributions for various Hubble types (i.e. 10% of the galaxies of a given type have a ratio larger than the value plotted).

(Dressel and Condon 1978) and the recent Westerbork survey by Hummel which has sufficient angular resolution to separate disk and central components for the whole sample.

3.2. Optical Correlations

The survey by Hummel (1979) shows that the central source contributes only about 20% to the average flux density of a galaxy, consequently low resolution surveys essentially refer to the radio properties of the disks of galaxies. Hummel has searched for the effects of various galaxy properties on the radio power by constructing the radio luminosity functions for various sub-samples. Such a procedure is needed to correct for the selection effects. An approximately linear correlation is found both for disk and for central sources between the radio power and the total optical luminosity. After removal of this correlation by using the ratio of radio to optical luminosity he finds a clear dependance on Hubble type (Figure 1). The power of the central source increases towards earlier types while the disk luminosity is constant or decreasing. Even though the central sources of the lenticular galaxies have lower power than suggested by this trend they have no detectable disk component at all and so still fit into a sequence in which the dominance of the central region increases toward earlier types.

3.3. Nuclear Radio Sources

This increasing dominance of the central sources with earlier type is accompanied by a flattening of the average spectral index (Ekers 1978b but NB incorrect sign of the spectral index in the figure) and an increasing number of cases in which the central source is known to contain a very compact component <0.1 parsec in size (Kellerman et al. 1976, Crane 1979, Hummel and Schilizzi private communication). Most of these nuclear radio sources are found in E and SO galaxies. In a few cases they show strong variability on time scales of a few years (NGC4552 - Sramek 1975, NGC1052 and NGC5077 - Ekers and Heeschen private communication) but most have remained constant for the last 10 years. Weak variability has been suggested for two of the spiral galaxies with nuclear sources, M81 and M104, (de Bruyn et al. 1976) but these two sources have been relatively stable over longer periods.

3.4. Multiple Galaxy Systems

The survey of Karachentsev pairs by Stocke et al. (1978) gives the first convincing evidence that multiple systems have stronger continuum radio emission than expected from the individual galaxies. In a small sample from the Arecibo survey Condon and Dressel (1978) note that five of the six spiral galaxies with small diameter sources are in paired systems. These effects are confirmed by the results of Hummel (1980) who shows that the excess emission is caused by the central sources in the individual members of multiple systems, and furthermore that there is almost no enhancement of the emission from the disk of these systems. A natural conclusion to draw from this is that the gravitational interaction has increased the fuel supply for the central engine without having any drastic consequences on the rest of the disk. Models involving accretion of gas into the central regions also receive some support from the observation that the central sources are stronger in the more spherical systems Hummel (1980), Disney and Wall (1977).

3.5. HI in Elliptical Galaxies with Nuclear Radio Sources

Little additional information is available to reassess the possible correlation between the HI seen in the elliptical galaxies and the presence of a nuclear source (Ekers 1978a,b). However it might be noted that this correlation is about as strong as could be expected given the small difference between M_H for the detected galaxies and the limits on M_H for those not detected.

	Number	$\langle M_H \rangle$	<Radio continuum power>
HI detected :	6	$3 \times 10^8\ M_\odot$	4×10^{20} w Hz^{-1} ster^{-1}
Best HI limits:	6	$<1 \times 10^8\ M_\odot$	$<1.2 \times 10^{20}$ w Hz^{-1} ster^{-1}

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