THE LARGE SCALE DISTRIBUTION OF RADIO CONTINUUM IN E AND SO GALAXIES

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If we look at the radio properties of the nearby ellipticals we find a situation considerably different from that just described by van der Kruit for the spiral galaxies. For example NGC 5128 (Cen A), the nearest giant elliptical galaxy, is a thousand times more powerful a radio source than the brightest spiral galaxies and furthermore its radio emission comes from a multiple lobed radio structure which bears no resemblance to the optical light distribution (e.g. Ekers, 1975). The other radio emitting elliptical galaxies in our neighbourhood, NGC 1316 (Fornax A), IC 4296 (1333-33), have similar morphology. A question which then arises is whether at lower levels we can detect radio emission coming from the optical image of the elliptical galaxies and which may be more closely related to the kind of emission seen in the spiral galaxies.

Since elliptical galaxies are less numerous than spiral galaxies we have to search out to the Virgo cluster to obtain a good sample. Some results from a Westerbork map of the central region of the Virgo cluster at 1.4 GHz (Kotanyi and Ekers, in preparation) is given in the Table.

Radio Emission from Galaxies in the core of the Virgo Cluster

Name NGC	Hubble Type	m_p	Flux density (10^{-29} W m^{-2} Hz^{-1})	
4374	E1	10.8	6200	3C 272.1
4388	Sc	12.2	140	
4402	Sd	13.6	60	
4406	E3	10.9	< 4	
4425	SO	13.3	< 4	
4435	SO	11.9	< 5	
4438	S pec	12.0	150	

This result is typical for spiral and elliptical galaxies and illustrates the different properties quite well. All the spiral galaxies in this field are easily detectable and have radio brightness similar to those

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discussed by van der Kruit. One of the ellipticals NGC 4374 (3C 272.1) is 100 times brighter than the spiral galaxies whereas the other, NGC 4406, which is optically one of the brightest Virgo cluster elliptical galaxies, is at least 10 times weaker than even the relatively small spiral galaxies in this field. Neither of the two SO galaxies are detected.

If we compare the ratio of radio to optical luminosity for a larger sample of elliptical and spiral galaxies we find that the spiral galaxies have a scatter of about a factor of ten in this ratio but this ratio for the elliptical galaxies ranges from very much greater than the spiral galaxy values down to significantly less. This very broad range in radio power from elliptical galaxies compared with that from spiral galaxies is a consequence of the flatter radio luminosity function for elliptical galaxies (Ekers, 1976). The new result which I want to stress here is that there are also a number of elliptical galaxies with less radio emission than the spiral galaxies. A similar conclusion is reached by Dressel and Condon (preprint) from analysis of the new Arecibo Survey of 2000 galaxies from the Uppsala General Catalogue.

In another field of the Virgo cluster one of the brighter elliptical galaxies, NGC 4472, is detected at a brightness level comparable to that seen in the normal spiral galaxies, but Ekers and Kotanyi (1977) have shown that this still has a morphology typical of the radio galaxies although in this case it is smaller than the optical diameter of the galaxy.

Finally some comments on radio emission from SO galaxies. In general they have radio properties similar to the elliptical galaxies; i.e. some are double sources, they have compact nuclear sources (see discussion on the radio nuclei) and have a wide range of luminosity. However, the total number of detected SO galaxies is small and the sample of radio emitting SO's contains a number of peculiar objects whose classification is not entirely clear (e.g. Cen A, Fornax A, NGC 2911). Because of this classification difficulty in individual cases it is better to look at some general statistical results. Ekers and Ekers (1973) had suggested that the distribution of axial ratios for radio detected SO's was different from that of all SO's. Since this distribution is determined by the random projection angles (e.g. van den Bergh, 1977) it requires a rather implausible anisotropy in the radio emission to explain this result if these radio SO's are drawn randomly from the total SO population. This effect persists in the new Westerbork data and is also seen in a larger and independent sample from Dressel and Condon (preprint). The major difference is an absence of radio detected SO galaxies which are seen edge on. This could be explained if many of the radio emitting galaxies are E or D systems misclassified as SO. Alternatively, the radio emitting SO's may contain a relatively large bulge component which could increase the minor axis diameter of an edge-on SO.

To conclude, I would like to reemphasize that the continuum emission from elliptical and SO galaxies is completely different from that for the spiral galaxies. We have no cases where the radio emission from ellipticals is anything like the distribution of light. We also have found some elliptical galaxies where the radio emission is substantially less than that from the spiral galaxies. The lack of an equivalent to the type of radio emission seen in the spiral galaxies may result from a difference in the source of relativistic electrons but is more likely to be related to the lower gas densities and hence lower magnetic fields in the body of the elliptical galaxies.

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DISCUSSION FOLLOWING PAPER I.5 GIVEN BY R.D. EKERS

VAN WOERDEN: From Dr. Ekers' discussion it appears that the radio continuum properties of spirals are predictable, while ellipticals show great variety and lenticulars possibly as well. The situation with neutral hydrogen appears similar: for spiral galaxies, the ratio M_H/L_B of hydrogen mass to blue luminosity varies by roughly a factor 10 within one morphological (sub) type; for lenticulars (SO galaxies) it varies at least a factor 100, and similarly for ellipticals [see below].

VAN DER LAAN: In spirals the radio power is the cumulative result of many stellar-scale events. In ellipticals the radio emission seems always attributable to spectacular events in the nucleus. It is not surprising then that the distribution of L_R/L_{opt} is much broader for the ellipticals than for the spirals.

OORT: But why do ellipticals not have SN-events?

EKERS: I don't know, but even if there are as many relativistic particles in ellipticals as in spirals they are poorly contained because there is no gas to hold the magnetic field. So the electrons can escape without radiating in the disk of the galaxy.

GALLAGHER: Isn't it true that the ellipticals you detect are the ones <u>with</u> interstellar matter? So I don't see how your previous point about the absence of interstellar matter follows.

EKERS: The mass of interstellar matter seen in these elliptical galaxies is still much less than that in the large spiral galaxies with which I was making the comparison. However, I do agree that if you want to argue that the interstellar matter is the critical parameter then we would have to say that both too much and too little inhibit the formation of this type of radio continuum emission.

WIELEBINSKI: You used Centaurus A and 3C31 as examples of ellipticals. Both have unusually large radio continuum emission features; Centaurus is known to be over 1 Mpc in linear size. Our recent observations of 3C31 at 11 cm show emission over 45 arc min, i.e. $\sim$ 1.5 Mpc. Can those two unusual ellipticals be considered normal?

EKERS: They are not normal ellipticals. They come into the sample because they are close, not because they are large. Centaurus A and 3C31 are weak radio galaxies.

BALDWIN: In how many elliptical galaxies could the radio observations have detected emission of the same surface brightness as we see in spirals?

EKERS: The only quantitative answer I can easily give is based on the distribution of the ratio of total radio-to-optical luminosity which I showed. From this we see that there are about 30 elliptical or SO galaxies with limits on this ratio which are less than the value for the majority of spiral galaxies. Since the diameters of these elliptical galaxies are usually less than those for the spiral galaxies, this result should also apply for surface brightness.

FREEMAN: How many unambiguous SOs have double radio sources?

EKERS: None! But how many unambiguous SOs are there?

TOOMRE: After your nice compact talk, I am left bothered that we don't seem to see any good in-between cases at all as far as the continuum radio pictures are concerned. We seem to find only the continuum disks or else the double radio sources, but not both in one and the same system.

VAN WOERDEN: Van den Bergh says that the SOs are not a transition between ellipticals and spirals; they are gasless spirals (or rather: gasless disks), forming a sequence parallel to those of gasrich spirals and gaspoor (anemic) spirals. And that's not true either: as I'll show you some SOs are gasrich!

VAN WOERDEN: THE GAS CONTENT OF LENTICULAR GALAXIES

With the 64-meter radiotelescope at Parkes, we have made a survey of neutral hydrogen in all southern ($\delta < -18^o$) lenticular (SO or SO/a) galaxies of diameter $D \geq 2$ arcmin in the Reference Catalogue. Among 55 objects observed, we have 16 strong detections, unconfused by other galaxies in the beam. Their (distance-independent) hydrogen-to-blue-luminosity ratios M_H/L_B range from 0.05 (and < 0.03) to 1.4. For comparison, the average values per morphological type found by Balkowski (1973, A.A. 29, 43) are: 0.1 for Sa, 0.3 for Sc, 0.9 for Im. Clearly, M_H/L_B varies widely among galaxies of quite "early" type (van Woerden

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1977, "Topics in Interstellar Matter", ed. van Woerden, p. 261).

Inspection of deep Siding Spring Schmidt plates shows that some of the galaxies classified SO or SO/a in the Reference Catalogue have well-developed spiral arms, though these are rarely bright; NGC 6902 is an outstanding example (van Woerden et al. 1976, P.A.S.A. 3, 68). Others, such as NGC 1533 and NGC 5102, while rich in gas, show no trace of spiral structure. We have looked for correlations of M_H/L_B with colour, bulge-to-disk ratio, and luminosity, but without success. So far, gas richness in lenticular galaxies appears unrelated to any other property.

Several lines of further investigation may be pointed out. As shown by Gallagher during this Symposium, deep large-scale photographs may throw light on the morphology and structure of these objects. Colorimetry would help to analyze the stellar composition. Photographs through Hα filters could locate HII regions and bring evidence of recent star formation. Spectroscopy could then reveal the chemical composition of the gas. Aperture-synthesis HI studies could provide the large-scale distribution and motions of gas in these systems; this would contribute to an understanding of their evolution. A vital question is why these gasrich systems have little or no spiral structure.

A detailed account goes to Astronomy and Astrophysics.

KERR: HI OBSERVATIONS OF A LARGE SAMPLE OF ELLIPTICAL GALAXIES

In cooperation with G.R. Knapp and B.A. Williams a very sensitive observational search was made for HI emission from 38 early-type galaxies, mostly ellipticals, using the Arecibo 305-meter telescope. Ellipticals are especially interesting because they contain very little interstellar matter, and it is useful to set better limits for their gas content.

Thirty-two of the galaxies were not detected: using estimates of the velocity width for each galaxy scaled to its luminosity, very low upper limits were set for the HI content in each case. These limits are inconsistent with the amounts predicted from stellar mass loss, and they are also inconsistent with continuing star formation in the galaxies. They support the suggestion that gas is continuously removed from these galaxies by a galactic wind mechanism.

Six of the observed galaxies were detected. Only one of these was a normal elliptical galaxy, namely NGC 4278, which has been previously detected in HI by Bottinelli and Gouguenheim (1977, A.A. 54, 641) and Gallagher et al. (1977, Ap.J. 215, 463). NGC 4278 was mapped, showing that the gas lies in a rotating disk which extends well beyond the visible body of the galaxy. The HI rotation curve for this galaxy is flat, and its M/L ratio is greater than 20. This observation shows that this elliptical, like many spiral galaxies, is embedded in a massive, low-luminosity halo.

No signal was apparent from NGC 5846, a detection of which was recently reported by Huchtmeier et al. (1977, A.A. 57, 313) with the Bonn 100-meter telescope.

BERTOLA: How do you reconcile the rotation curve of NGC 4278 derived from HI measurements with the velocity gradient observed along the major axis in the optical emission lines?

KERR: The optical and radio rotation curves seem to be independent of each other, as if the HI disk and the elliptical are semi-separate entities.

GALLAGHER: HI IN NGC 1052 AND NGC 4636

The elliptical galaxy NGC 1052 (E4) has been measured with the NRAO 300-foot telescope in 21-cm line emission. The HI mass is $(8 \pm 3) \times 10^8$ $M_\odot$ and $M_{HI}/L_{pg} = 0.06$. The properties of NGC 1052 are very similar to those of NGC 4278 in regard to nuclear activity, HI content, the absence of detectable star formation, and galaxy group characteristics. This suggests the two unique features of these galaxies, large HI content and nuclear activity, are physically related. The data and a more complete discussion are given in a paper by Knapp et al. (submitted to Ap.J.).

We have also obtained a more marginal measurement for HI in NGC 4636 (E0), which confirms the tentative detection of HI by Huchtmeier et al. (1975, A.A. 42, 205) and is in agreement with the recent results obtained by L. Bottinelli and L. Gouguenheim with the Nançay radiotelescope.

VAN WOERDEN: Can the analogy between NGC 1052 and 4278 be extended further? I believe that NGC 4278 too is a member of a pair.

GALLAGHER: Yes, NGC 4278 forms a pair with NGC 4274, an Sa with a fair amount of HI, about 20' north of NGC 4278.

KOTANYI: Would you say that, as previously suggested for NGC 4278, the HI profile in NGC 1052 is indicative of a turbulent disk?

GALLAGHER: I wouldn't; I don't know.

MEBOLD: We confirm the detection of the 21-cm emission line at the position of NGC 1052 (Fosbury et al. 1977). At a position 8' to the NE of NGC 1052, i.e. on the side away from NGC 1042, we detected a line with about the same parameters. As to the confusion with NGC 1042 we can add that we mapped the emission of NGC 1042. The result proves that the flux of NGC 1042 that is picked up by the telescope if pointed at the position of NGC 1052 is less than 10% of the line of NGC 1052.

GIOVANELLI: I would like to enter a note of caution. Observations of Haynes and myself have revealed a "cloud" of HI with similar properties to your profile of NGC 1052, a few diameters away from M51. Therefore the possible relation to NGC 1042 should not be underestimated. I shall describe this later [see Discussion V.2].

VAN WOERDEN: Another possible example of dust (and gas) being accreted may be the pure lenticular NGC 5102. The hydrogen in this system is not widespread (angular size < optical diameter). We found a pronounced dust lane reaching right into the nucleus. A point of dif-

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ference with the ellipticals is that this SO has blue colours indicating recent star formation.

CAPACCIOLI: THE DISCONTINUITY BETWEEN ELLIPTICAL AND DISK GALAXIES
Since a few years a number of rotation curves of elliptical and SO galaxies were made available. For some of these galaxies the rotation curve extends far enough to give a reliable estimate of the turnover velocity (for references see Bertola and Capaccioli, in prep.). After proper corrections to the observed velocities, the main value of the turnover velocities for ellipticals turns out to be almost one third of that for SOs. On the other hand SO galaxies exhibit maximum rotational velocities in the range of values typical of spirals of comparable masses. Therefore a strong dynamical discontinuity exists between elliptical galaxies on one side and SOs and spirals on the other, i.e. between galaxies having only the spheroidal component and those having, in addition, a disk. The presence of such a discontinuity is also indicated by other evidence concerning: M/L ratio, photometric properties, intrinsic flattening, HI content, HI parameters and morphological characteristics. In conclusion, several physical reasons suggest to group the morphological classes of the Hubble sequence according to the fact that the disk is present or not.

WIELEN: In measuring the rotation curve of elliptical galaxies, one is probably measuring essentially the "peak velocity", i.e. the velocity where the maximum in the velocity distribution occurs. It is possible to construct self-consistent models of ellipticals in which this peak velocity (corresponding to the center of the absorption line) differs significantly from the mean rotational velocity which determines the angular momentum. Hence, the possibility should be kept in mind that ellipticals may have a larger angular momentum than is derived from identifying the peak velocity with the mean rotational velocity. The problem may be settled by obtaining high-dispersion spectra in which the absorption line profiles should reflect the possible asymmetries in the velocity distribution.