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Observations of Radio Emission from Interacting Galaxies at 1415 MHz

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Summary. 1415 MHz observations of seven optically selected peculiar galactic systems have been made with the Westerbork Telescope. Radio emission has been detected for six of them. In no case was this emission associated with bridges or tails suggesting that magnetic fields are relatively unimportant in maintaining these structures. For NGC 4038/4039 the radio source is located between the galaxies and its intensity may have been enhanced due to compression of plasma and magnetic field during an encounter.

Key words: interacting galaxies – radio emission

I. Introduction

The optical counterparts of extragalactic radio sources usually show evidence of very violent events. Many are quasars or galaxies with compact nuclei, while others, such as the double galaxy associated with Cygnus A, have a highly disturbed appearance. In an effort to understand the physical processes involved it seemed worthwhile to approach the problem from the other new direction and to search for radio emission from other systems whose optical forms alone are suggestive of highly energetic phenomena.

Such system often show delicate bridges and tails and it has been suggested that non gravitational forces such as magnetic fields are important in maintaining their ordered structure. (Arp, 1966). Since radio emission from astrophysical plasmas is frequently associated with and indeed often dependent on magnetic fields, the location of significant radio emission in these features would support such a hypothesis. On the other hand Toomre and Toomre (1972) and Wright (1972) have independently shown, that in idealized models gravitational interactions alone can produce the narrow filaments and tails, and the failure to detect radio noise from them would be evidence in favour of this viewpoint.

II. Observations and Reductions

The Westerbork Telescope (Baars and Hooghoudt, 1973; Casse and Muller, 1973) consists of twelve 25-meter parabaloids in a 1.6 km east-west line. Ten of these are fixed and the remaining two can be moved along a 300 m railtrack. The outputs of each movable dish is correlated with those of every fixed dish giving a total of twenty simultaneous interferometer baselines in length increments of 72 m. A Fourier transform of the fringe visibility data gives a map of the radio brightness distribution of a region defined by the primary antenna pattern, ($\sim 37'$ at 1.4 GHz) whose resolution depends on the synthesised beam.

For a twelve-hour observation of a source at declination δ reduced with the standard gaussian grading function, the synthesised beam is elliptical with half power diameters 22″ in right ascension by 22 cosec δ'' in declination. Each object was observed for a full twelve hours, except for NGC 4038/4039 which because of its declination could only be tracked for about 7 h. The beamshape for this source was therefore somewhat degraded.

Inspection of our initial maps showed that in a few cases diffraction grating rings of some strong sources intersected the region of the galaxy under study. These rings were removed by a source subtraction program, which assumes the offending source is unresolved and removes its response entirely from the map, using the appropriate synthesized beam. In all cases this procedure was sufficient to allow examination of the point of interest with an accuracy limited only by random noise. Since, at the centre of the primary beam, the rms noise level was $\sim 1.5 \times 10^{-29}$ Wm^{-2} Hz^{-1}, sources stronger than $\sim 6 \times 10^{-29}$ Wm^{-2} Hz^{-1} could be detected with certainty. The standard Westerbork calibration procedure was used (Brouw, 1971) and systematic errors in the intensities on the maps do no exceed 5%.

III. Results

The observed systems are listed in Table 1. For all except IC 356 redshifts were available (de Vaucouleurs, 1961; Burbidge and Burbidge, 1961; Burbidge and

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Table 1

System	Alternative names	No. of members	Mean velocity (km s^{-1})	Distance (Mpc)	1415 MHz Position (1950.0) Right ascension h m s	Declination d m s	1415 MHz Flux density (10^{-29} W m^{-2} Hz^{-1})	1415 MHz Luminosity (W Hz^{-1} $sterad^{-1}$)
NGC 4038/4039	Arp 244, VV 117	2	1435	19	11 59 20.9 ± 0.1	−18 36 02 ± 10	230 ± 50	8.4×10^{20}
					11 58 44.3 ± 0.1	−18 45 25 ± 10	120 ± 20	see text
					11 59 38.3 ± 0.1	−18 43 43 ± 10	132 ± 15	see text
					11 59 52.5 ± 0.1	−18 36 59 ± 10	42 ± 5	see text
					12 00 35.9 ± 0.1	−18 53 04 ± 10	118 ± 13	see text
NGC 4676A/ 4676B	Arp 242, VV 224	2	6567	87	12 43 44.3 ± 0.1	+31 00 15 ± 2	27 ± 15	2.0×10^{21}
NGC 2444/2445	Arp 143, VV 117	2	3951	53	07 43 31.9	+39 08 24	20 ± 5	5.6×10^{20}
NGC 3718	Arp 214	1	1128	15	(11 29 49.9	+53 20 38)	20 ± 5	4.5×10^{19}
VV 150	Arp 322	4	7300	97	11 29 55.3 ± 0.2	+53 13 36.3 ± 3	22 ± 5	2.4 ± 10^{21}
Seyfert's Sextet	NGC 6027A–D	5	4405	59	15 56 59.4	+20 53 49	27 ± 7	9.4×10^{20}
IC 356	Arp 213	1		72			< 8	$< 4.2 \times 10^{21}$

Sargent, 1971) and the distances were derived using a value of 75 km s^{-1} Mpc^{-1} for the Hubble Constant. The distance of IC 356 was estimated on the basis of its similarity to NGC 4699, by comparing the angular sizes of the two systems.

Figures 1 to 6 show the radio positions of the five systems we have detected marked on the optical photographs (Arp, 1966; Burbidge and Sargent, 1971). The positions are marked to an accuracy of about 10″ arc. We shall discuss each object individually.

NGC *4038/4039* (Arp 244)

This is a close pair of galaxies with two beautifully symmetric curved tails. The morphology was reproduced with remarkable success by the Toomres (1972) on the assumption that the galaxies were undergoing a gravitational encounter. Of all the systems we observed, its radio flux density was the strongest.

Despite the poor beam shape caused by the low declination and small hour angle coverage, the radio centroid could be located with an accuracy of a few seconds of arc. The radio source is centred on the very dense absorbing patch midway between the two galaxies. No emission was detected from either of the galactic bodies or from any part of the tails.

By assuming that the major component was a point source and subtracting it from the map, the extent of the radio emission was estimated. The source is ex-

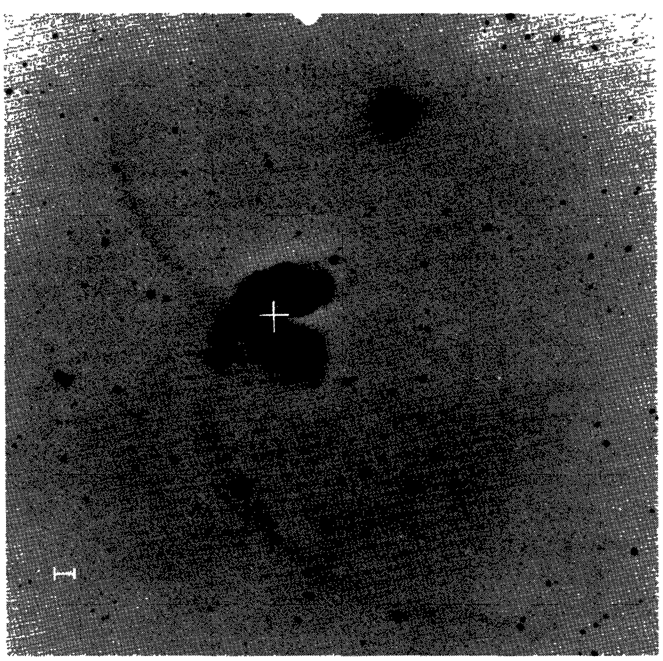

Fig. 1. NGC 4038/4039 (Arp 244). The cross marks the position of the radio source and the bar represents 30″

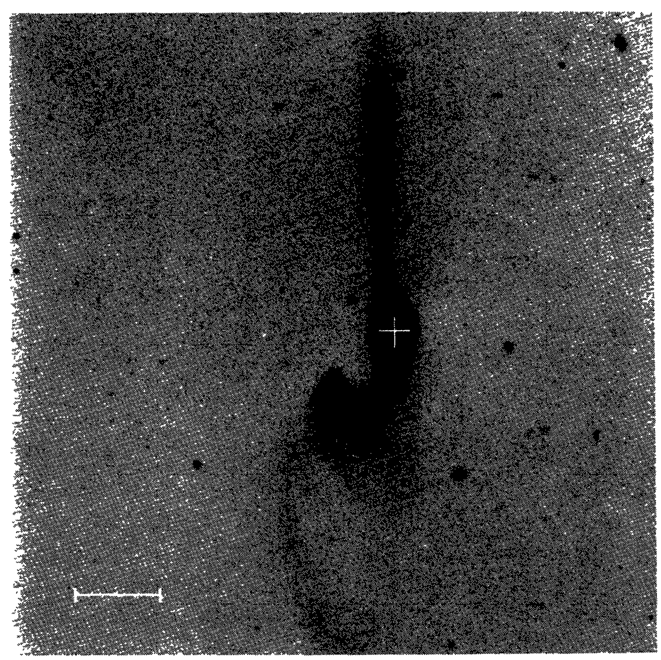

Fig. 2. NGC 4676 (Arp 242). The cross marks the position of the radio peak and the bar represents 30″

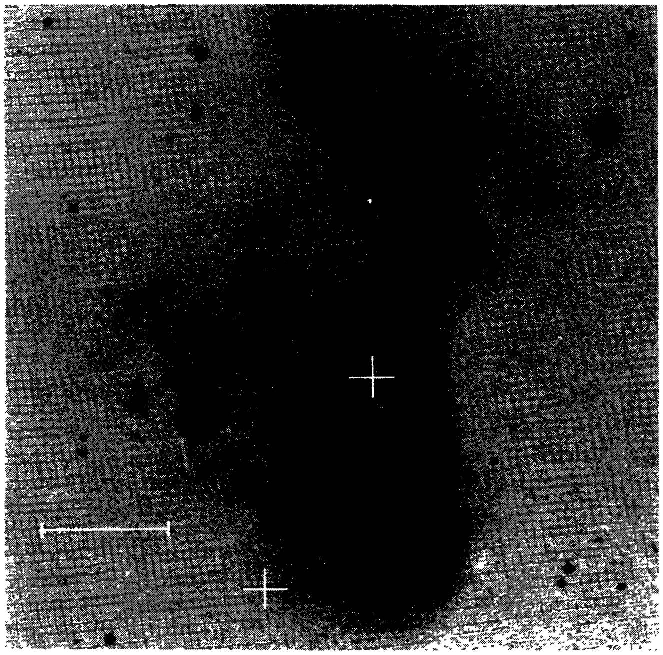

Fig. 3. NGC 2444/2445 (Arp 143). The cross marks the position of the two radio peaks and the bar represents 30″

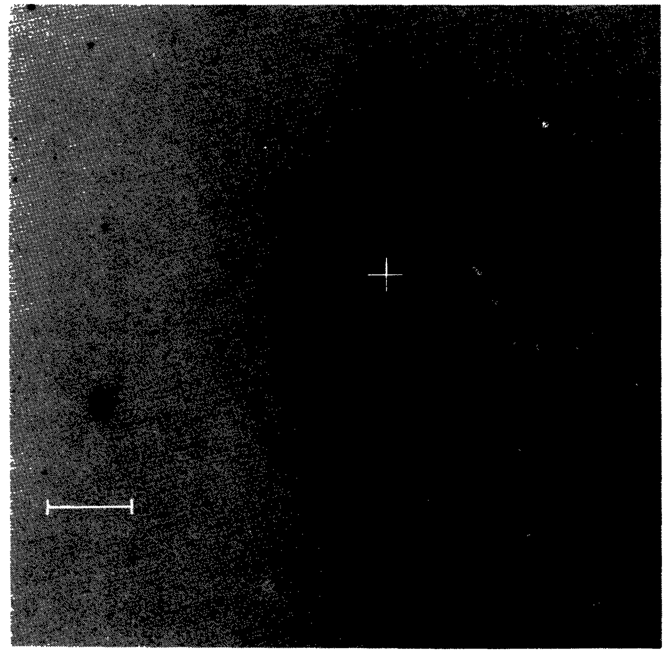

Fig. 4. NGC 3718 (Arp 214). The cross marks the position of the radio source and the bar represents 30″

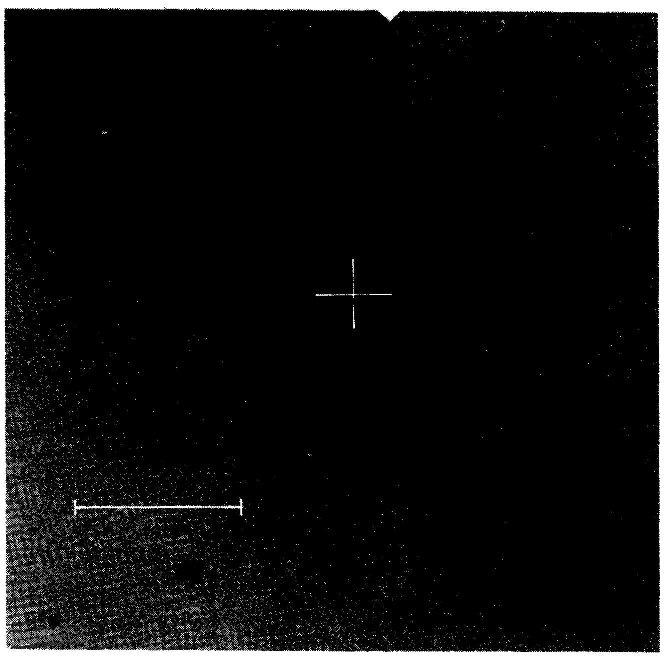

Fig. 5. VV 150 (Arp 322). The cross marks the position of the radio source and the bar represents 30″

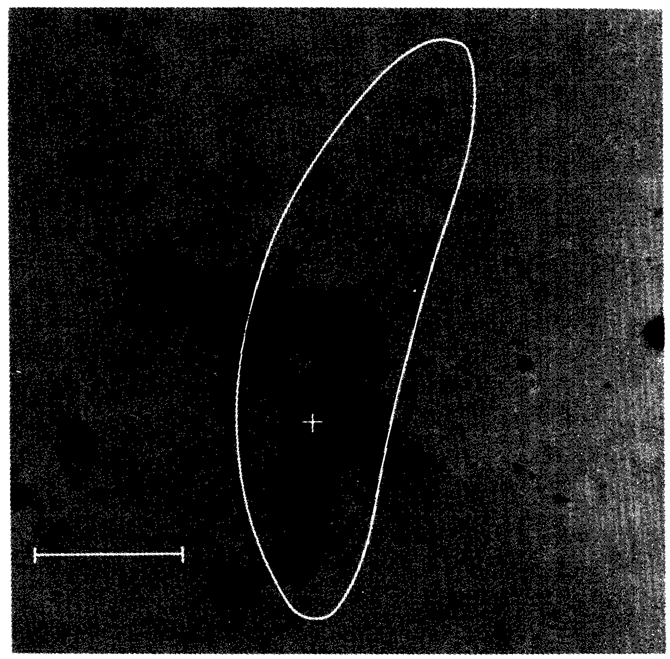

Fig. 6. Seyfert's Sextet. The radio extent is outlined and the radio peak is marked with a cross. The bar represents 30″

tended by about 1′ in the east-west direction but no north-south elongation could be detected. Allowing for the inferior north-south resolution, a reasonable model for the source is a point contributing two thirds of the flux, imbedded in a halo whose east-west extension is 40″ to 60″ and which is smaller than 60″ in the northsouth direction.

In Table 1 we also list several strong point sources that are close to NGC 4038/4039. Although one is located only 1′ below the top of the southern optical tail there is no strong evidence that any of them are associated with the galaxies. However they will certainly have confused several of the measurements of this system made with instruments of lower resolution (Heeschen and Wade, 1964; Kuril'chik, 1966; Tovmassian, 1968; la Beaujardière *et al.*, 1968; Kazès *et al.*, 1970; Whiteoak, 1970; Cameron, 1971; Lequeux, 1971, and Purton and Wright, 1972) and several of the listed flux densities must be severely overestimated. Because of this it is difficult to derive spectral information for the galaxy source.

NGC *4676* (Arp 242)

Vorontsov-Velyaminov (1956) first called attention to this pair which he called the "mice". The Toomres have shown that their morphology can also be interpreted as produced by a colliding pair of galaxies viewed in the correct projection. The radio source is elongated with about 80% of the radio flux coming from the more northern galaxy of the pair and a weak south-east extension coincident with the southern member. This is in marked contrast to the NGC 4038/4039 pair, which although dynamically rather similar has its radio emission concentrated between the galaxies.

NGC 2444/2445 (Arp 143)

This double system differs significantly from the previous two pairs since the southern galaxy seems to consist almost entirely of H II regions. The Burbidges (1959) suggested that this object might be a young galaxy which has been ejected from the northern elliptical member. However, the radial velocity difference between the pair is not more than 300 km s^{-1}. The radio noise comes from a slightly extended region near the centre of the H II complex and the peak coincides closely in position with the brightest central H II knot. The observed radiation cannot be thermal bremsstrahlung from the H II regions however, since the specific luminosity is $\sim$5000 times greater than that of 30 Doradus.

NGC *3718* (Arp 214)

It is not clear whether this system is merely a barred spiral with rather more dust than usual or whether it is an active galaxy ejecting matter. The dark absorbing lane is similar to that of NGC 5128 but this galaxy is optically much less luminous. The radio emission comes from an unresolved source close to the centre of the galaxy and there is no evidence that the radio source is extended along the dust bar or along the thin spiral arms. The radio luminosity exceeds that of most normal galaxies but is at the lower end of the range of Seyfert galaxies studied by van der Kruit (1971).

VV *150* (Arp 322)

This multiple system lies close to NGC 3718 but has a much larger redshift and is presumably more distant. The radio source is unresolved and coincides with the brightest galaxy of the group. No radio noise was detected from the bridge that seems to join the brightest galaxy to its neighbour. The Burbidges (1961) note that this bright galaxy is of the Seyfert type.

Seyfert's Sextet

Sargent and Burbidge (1971) found that the small spiral just south of the brightest member of the group, NGC 6027, has a redshift of 19930 km/s in marked contrast to the redshifts of the other members, which vary from 4140 to 4580 km/s. The radio emission appears to come from an elongated region that extends from the southernmost galaxy northward to about 1′ beyond the cluster itself. The location of the ridge-line depends critically upon the positions of the galaxies, and if we adopt the positions given by Galloët and Heidmann (1971), the ridge is not centered on the North-South string of galaxies but lies about 5″ to one side, in the direction of NGC 6027. The two positions given by Galloët and Heidmann are not quite consistent with the optical photograph, and we have adopted the more compact of the two designated "*b*" by Burbidge and Sargent, as the member most likely to have its position accurately determined. The east-west extension of the radio ridge was not resolved, and is less than 15″.

IC *356* (Arp 213)

No radio noise was detected from this galaxy, which is optically the least remarkable of the objects we have studied. The dust lanes that flare from the center in Arp's photograph are faint, there is no significant distortion of the spiral structure, and there are no companion galaxies.

Conclusions

At first sight it is curious that the range of 1.4 GHz luminosities for the systems listed in Table 1 is so small. However, this is not so remarkable since strong radio galaxies have been excluded from our program and in most cases the radio emission would not have been detected if it was more than a factor of two weaker. The results presented here have been combined elsewhere with other Westerbork data to provide a sample of nine interacting systems. For this sample it has been shown that interacting galaxies are neither significantly stronger or more frequent radio emitters than normal galaxies. (Allen *et al.*, 1973).

Allen and Sullivan (1973) have recently reported no radio emission from the bridge connection NGC 2798/99. Our failure to detect radio emission from the bridges and tails of any of the systems considered here is further evidence that magnetic fields are unimportant in maintaining these ordered structures and lends some support to the "gravitational encounter" viewpoint. The radio source located between NGC 4038 and 4039 may well be enhanced radio emission produced by compression of the magnetic fields and plasmas during the encounter.

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