RADIO OBSERVATIONS OF GIANT EXTRAGALACTIC HII REGIONS

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Giant extragalactic HII regions are found in the disks of nearby spiral and irregular galaxies, in the nuclear regions of spiral and elliptical galaxies, and in a variety of peculiar and interacting systems. At radio wavelengths they may emit thermal continuum radiation from the ionized gas and/or nonthermal synchrotron radiation if high energy electrons and magnetic fields are present. In some instances line radiation from associated molecular and neutral hydrogen clouds may also be detected. Table 1 illustrates the sorts of objects in which radio HII regions are observed and indicates the range of radio parameters found. Columns 1 and 2 give the galaxy and specific HII regions within the galaxy. Column 3 is the adopted distance of the galaxy. Column 4 indicates whether the emission is thermal (T) or nonthermal (N-T); column 5 is the 20 cm luminosity, and column 6 the linear size of the radio emitting region. For thermal sources the electron density, derived from the luminosity and size, is listed in column 7. The final column gives references. Note that almost all of the observational information obtainable from radio continuum observations is contained in columns 4, 5, and 6. Very occasionally there may be additional data concerning polarization or variability.

All of the sources listed in Table 1 are associated with regions that have Hα emission and/or other optical or uv indicators of HII. The first three objects are nearby galaxies. One or two typical HII regions in each galaxy are listed, and, in the case of the two spirals one or two structural components within each HII region are also given. Many HII regions in the disks of nearby galaxies have now been studied at radio wavelengths. In these and other nearby galaxies the radio emission is almost always thermal emission from HII. It is rare for nonthermal radio emission to be associated directly with an HII region. Two possible cases are listed in the table, but in both the nonthermal nature of the emission is still uncertain.

The next three objects in the table are irregular galaxies. IIZw40 and IIZw70 are blue dwarf irregulars, called isolated HII regions by Sargent and Searle (1970). Markarian 8 is a giant irregular, also

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Table 1

Galaxy	Source	D Mpc	Spectrum	L_{20} 10^{18} W Hz^{-1}	d pc	N_e cm^{-3}	Ref
LMC	30 Dor.	0.055	T	4.1	120	22	1
	30 Dor. B		N-T?	0.68			2
M33	NGC 604	0.72	T	3.8	230	6.1	1
	604A			0.15	14	84	3
M101	NGC 5471	7.2	T	70	360	13	3
	5471A		N-T?	15	<100		4
	5471B		T	15	<100	>43	4
IIZw40		9.1	T?	80	<230	>28	5
IIZw70		17.9	N-T?	180	<900		6
Mkn 8	A	46	T	660	760	11	7
	A1		T?	50	<90	>68	7
Mkn 297	A	63	N-T	3,000	<95		7
NGC 3690	A	44	N-T	25,000	<130		8
	C		N-T	8,500	700		8
NGC 7714	nucleus	39	N-T	3,600	600		9

References to Table 1:

1. Viallofand et al., 1982.
2. Mills et al., 1978.
3. Israel et al., 1982
4. Skillman, 1982.
5. O. Connell et al., 1978.
6. Balkowski et al., 1978.
7. Heeschen et al., 1983.
8. Gehrz et al. 1982.
9. Weedman et al., 1981.

very blue. These types of objects have not yet been studied much at radio wavelengths, but, as in the case of the spirals, the radio emission is predominantly thermal.

The final three galaxies in the table are all peculiar, probably interacting, systems. Although the radio sources are in every case coincident with regions of Hα emission, the radio emission in these cases is nonthermal and far more intense than that of the other sources in the table. Thus, while the optical properties of the HII regions in these galaxies are, at least superficially, similar to those of the other galaxies listed in the table, their radio properties are fundamentally different.

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All of the sources in Table 1 have associated HI clouds, as evidenced by 21 cm line emission, and all of the galaxies have a broad distribution of nonthermal radio emission which dominates the total radio emission of the galaxy and within which the individual radio HII regions are situated. These latter two features are characteristic of radio HII regions and the galaxies in which they are found. It is clear from inspection of the table that radio HII regions occur in a variety of galaxy types and exhibit a wide range of radio properties.

Several hundred HII regions in the disks of some 30 nearby galaxies have now been studied at radio wavelengths. The present state of these studies is well described by Israel (1980) and Viallefond et al. (1981, 1982), while Mills et al. (1978) gives the most recent observations of 30 Dor. The radio observations have been particularly useful in determining the (nonuniform) distribution of dust across the HII regions, in delineating their complex structure, and in investigating the important interactions between HII and the associated HI clouds.

There is also much work currently in progress and with the increased resolutions available new insights into these problems can be anticipated. For example, Sramek and Weedman (1982) have obtained 20 cm VLA observations of NGC 604, an HII region in M33, with a linear resolution of 3 parsecs. The two major radio components of NGC 604 each break up into several knots, none of which appear to match any specific optical features. The radio structure is extremely complex, and only generally related to the optical structure.

HII regions in the disk of our own galaxy are usually associated with molecular clouds which can be observed at centimeter and millimeter wavelengths via the line emission of CO, H_2O, and a variety of other molecular species. Lines of CO, H_2O and a few other molecules have been detected in several galaxies but thus far the available sensitivities and resolutions have been too poor to allow the detection of specific extragalactic HII regions. The 2.6 mm line of CO, for example, has been observed in only 2 extragalactic HII regions (Blitz et al. 1981; Huggins et al. 1975). However, CO has been shown to be a good tracer of gas distributions in galaxies, and there is currently much activity in this area (Young and Scoville 1982; Elmegreen and Elmegreen 1982). Observations of extragalactic molecular lines, especially of CO, should take on increasing importance in the next few years.

The nuclear regions of bright spiral galaxies contain HII regions, just as do the disks, but the radio emission associated with these nuclear regions is quite different from the radio emission of disk HII regions. The general radio properties of spiral galaxy nuclear regions have been studied by Hummel (1980), Condon et al. (1982), and others. Nuclear radio emission appears to be enhanced in interacting systems, compared with that in isolated spiral galaxies. The radio emission is not specifically correlated with HII regions but occupies the same volume as HII regions and supernova remnants (SNR), roughly the central region of about 1 km diameter. The radio emission is probably due to SNR, or in some cases a mixture of SNR emission and thermal HII emission. SN rates of about 1 yr^{-1}, occasionally up to 100 yr^{-1}, are required to account for the radio emission. There is also evidence that the radio output of these extragalactic SNR may be 10 times that of galactic SNR (Condon et al. 1982).

Detailed radio-optical studies have been made of the nuclear regions of a number of galaxies; for example, M82 (Kronberg et al. 1981), NGC 2146 (Kronberg and Biermann 1981), and NGC 7714 (Weedman et al. 1981). While they differ in detail, all of these have certain features in common. All are peculiar or interacting systems; all have nonthermal nuclear radio emission, which the investigators attribute to SNR and derive SN rates of one to a few per year; and in each case the radio-optical data are interpreted in terms of bursts of star formation involving the rapid birth of large numbers of massive stars.

The nuclear regions of some elliptical galaxies also contain many of the same constitutents found in spiral galaxy nuclear and disk HII regions, including HII, HI and dust. However, radio emission, if observed, is nonthermal, often variable, and usually originates in a very compact region. It appears to be a rather different phenomenon from that of spiral disks or nuclear HII regions, not readily explained either by SNR radiation or thermal emission (Condon and Dressel 1978).

In general, nonthermal radio emission is found associated with nuclear HII regions while disk HII regions appear to emit predominantly thermal emission. Two possible exceptions to this were noted earlier; 30 Dor B and NGC 5471A, both listed in Table 1, are HII regions in the disks of nearby galaxies which have associated radio emission that may be nonthermal, although the nonthermal nature of the radio emission is not yet firmly established in either case. These are the only two disk HII regions in nearby galaxies which are presently thought to emit nonthermal radiation. On the other hand, two interacting systems have now been found to contain nonthermal sources associated with HII regions outside the nuclei. They are Mkn 297 and NGC 3690/IC 694. Each has radio sources with properties that are currently unique among radio sources associated with HII regions.

NGC 3690 has three radio sources, two coincident with HII regions in the disk of the galaxy and one coincident with the nucleus. All three have nonthermal radio spectra and their luminosities are more than an order of magnitude greater than those of any other non-nuclear HII region except that of Mkn 297. Gehrz et al. (1982) discuss their extensive optical, IR and radio observations of this interesting system in terms of bursts of star formation.

Mkn 297 is a giant irregular galaxy which may be an interacting system (Alloin and Duflot 1979). It has a single compact radio source of nonthermal emission coincident with one of the many optical HII clumps visible in the galaxy. At 6 cm wavelength the flux density of the source increased by a factor of about 3 in a 27-month time interval (Heeschen et al. 1982). It is at present the only known variable non-nuclear radio source associated with an HII region. Heeschen et al. suggest that the variability may be the result of very recent supernovae.

Radio observations of nuclear HII regions, and now of non-nuclear regions as well, in peculiar/interacting systems provides a powerful tool, when combined with observations in other wavelength regions, for studies of star formation. The detection of variability in Mkn 297 adds a new dimension to these studies. The higher resolutions now available at Westerbork and the VLA, and soon in the south with the Australian synthesis telescope, and the improved millimeter wavelength capabilities for molecular line work being developed at various places, all promise that the next few years should be an exciting and fruitful time in this field.

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