arises from continuum, Brackett $\gamma$, and molecular hydrogen lines (Storey 1982).

**Conclusions**

Mapping of HII regions in the 2.2 $\mu$m continuum is an effective way to establish the distribution of ionised gas and to locate the underlying stars. In the absence of a high resolution synthesis radio telescope in the southern hemisphere, 2.2 $\mu$m continuum mapping and infrared line observations are the only techniques suitable for obscured regions and capable of resolutions of a few arcseconds. The development of new software for the AAT enables infrared images to be observed in real time, thus offering a significant gain in convenience. We have used this technique to produce high resolution 2.2 $\mu$m images of four southern HII regions.

**Data Base**

The present spectral study is based on a substantially complete sample of 147 sources selected from several general surveys of Abell clusters with declinations south of $+35^\circ$; the selection of clusters was made to suit the coverage of the Culgoora circular array (CCA), which was used to obtain 80 and 160 MHz flux densities for all sources. We utilized the following cluster surveys: (i) sources from Owen (1974) with S$_{800}$ $\geq$ 0.2 Jy; (ii) sources from Owen (1975) with S$_{800}$ $\geq$ 0.12 Jy; (iii) and all Mills and Hoskins (1977) 408 MHz sources; (iv) Slee and Quinn’s (1979) 80 MHz survey of strong X-ray clusters: (v) an unpublished survey at 80 MHz with the CCA of 130 very rich clusters was made to suit the coverage of the Culgoora circular array (CCA), which was used to obtain 80 and 160 MHz flux densities for all sources. We utilized the following cluster surveys: (i) sources from Owen (1974) with S$_{800}$ $\geq$ 0.2 Jy; (ii) sources from Owen (1975) with S$_{800}$ $\geq$ 0.12 Jy; (iii) and all Mills and Hoskins (1977) 408 MHz sources; (iv) Slee and Quinn’s (1979) 80 MHz survey of strong X-ray clusters: (v) an unpublished survey at 80 MHz with the CCA of 130 very rich clusters; (vi) a 2700 MHz survey at Parkes (Wilson and Slee — in preparation) of a complete sample of 80 Abell clusters out to distance 4. A total of 640 Abell clusters, each of which was surveyed out to at least 0.5 Abell radius from the cluster centre, were included in the above surveys.

**Criterion for cluster membership:** It has been established by Pilkington (1964), Wills (1966), McHardy (1979) and by our own 2700 MHz survey (Wilson and Slee — in preparation) that the source density inside 0.40 Abell radius of the centres of clusters significantly exceeds the density of general field sources; within this distance our 2700 MHz survey, which extends out to 1.5 Abell radii, shows that the average source density is ~4 times the background of field sources. The source distribution is similar at 2700 and 178 MHz (McHardy 1979). We have therefore accepted 147 sources from the surveys we have already mentioned as cluster radio galaxies; all these sources have more than three measurements of flux density between 80 MHz and 5 GHz and are within 0.40 Abell radius of cluster centres. Figure 1 shows the numbers of sources within 0.2 Abell radii, shows that the average source density is ~4 times the background of field sources.

**Introduction**

There has been considerable speculation in recent years about the evolution of radio galaxies in clusters. The discovery of powerful X-ray emission with an apparently thermal spectrum from a considerable number of clusters has been attributed to a hot ($10^8$K) intracluster gas with an electron density of $\sim 10^3$ cm$^{-3}$ at the cluster centre (see e.g. McHardy 1978). Such a gas surrounding a radio galaxy may conceivably retard the expansion or diffusion of the relativistic electrons and thus allow the source to retain its identity for longer intervals than is the case for field galaxies. This would eventually result in a steepening of the radio spectrum caused by synchrotron radiation losses. Surveys of clusters identified with powerful X-ray emitters by Erickson et al. (1978), Slee and Quinn (1979) and Dagkesamansky et al. (1982) have indeed shown that the spectra of radio sources near the centres of such clusters are much steeper than those of field galaxies.

This paper extends such spectral observations to a large sample of Abell clusters (Abell 1958), most of which are not powerful X-ray emitters, in order to determine whether steep radio spectra are common to all clusters.
Figure 1. Distribution of radio galaxies in the present sample with distance from the cluster centre. Each bin subtends the same solid angle as far as each individual cluster is concerned. The dashed line is the expected source count at 160 MHz due to field radio galaxies (see text for details).

Figure 2 shows that the spectral index of cluster sources is highest near the cluster centre. Analysis of variance between and within each sample shows that the indices are unlikely to belong to a common population ($p = 0.05$). The difference between the means of the inner and outermost bins is significant at $p = 0.01$ on a two-sided test (Hughes and Crawoig 1971). This is the first convincing demonstration that spectral index decreases systematically with distance from the cluster centre.

Figure 2. Variation of the mean spectral index with distance from the cluster centre. The number of sources in each mean and the standard error of the mean are shown.

Radio Spectra of Sources in Clusters

Variation of spectral index with distance from cluster centre:

Spectral index and cluster richness: Figure 3 shows that spectral index appears to increase with richness but an analysis of variance within and between the three samples fails to show that the indices have been drawn from different populations. A ‘t’ test on the difference between the mean spectral indices of the richest and poorest clusters is not significant; if we pool the sources in richness classes 0 and 1 and test the pooled mean against that of richness class > 2 the difference is significant at $p = 0.06$ on a two-sided test. The data are suggestive of an increase in spectral index in the richest clusters, but more work is needed to show the increase conclusively. McHardy’s (1979) analysis of 4C cluster sources showed a significant increase of spectral index with richness, but his sample contained less than one-third of the number of sources in our present sample.

Spectral index and optical morphology: Figure 4 shows that radio galaxies in clusters of Bautz-Morgan (B-M) morphological class I possess much higher spectral indices than those in each of the later morphological classes; these differences are significant at $0.01 < p < 0.05$ on two-sided tests. This result agrees with the analysis of the 4C sample by McHardy (1979).

It has already been shown by Erickson et al. (1978),
Figure 4. Variation of mean spectral index with the optical morphology of the cluster. The number of sources in each mean and the standard error of the mean are shown.

McHardy (1978), Slee and Quinn (1979) and Dagkesamansky et al. (1982) that radio sources in powerful X-ray emitting clusters, which are predominantly of B-M morphological class I, have very high spectral indices. Since only 6 of the 20 radio sources in B-M I clusters from the present sample are in powerful X-ray clusters, it follows that X-ray luminosity is not the decisive factor in determining whether a cluster will contain a steep spectrum source.

Discussion and Conclusions
The spectra of radio galaxies in Abell clusters should be compared with the corresponding spectra of field radio galaxies. We have a general sample in the Culgoora-3 list of radio sources (Slee 1977); subsequent analyses of its statistical properties have been made by Slee et al. (1982) and Slee (1981, 1982). A legitimate comparison is possible because the flux data in the two sets of observations have been subjected to identical analyses. Table 1 lists the mean spectral indices of the Culgoora-3 sample of radio galaxies (Slee 1981, 1982) and various samples of cluster sources.

It is clear that, on the whole, sources in clusters have significantly steeper spectra than the field radio galaxies. However, Table 1 shows that this higher index is due to the high mean indices of sources near the cluster centre and of sources in clusters of B-M morphological class I; the mean indices of sources between 0.20 and 0.40 Abell radius from the cluster centre and of those in B-M III clusters are not significantly different from that of the field radio galaxies.

Table 1 suggests that sources within 0.10 Abell radius of the

Table 1
Spectral Indices of Cluster and Field Radio Galaxies

<table>
<thead>
<tr>
<th>Type of sample</th>
<th>No. of sources</th>
<th>Mean spectral index</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Culgoora-3 field sample*</td>
<td>127</td>
<td>-0.809</td>
<td>0.017</td>
</tr>
<tr>
<td>(b) This cluster sample</td>
<td>147</td>
<td>-0.864</td>
<td>0.023</td>
</tr>
<tr>
<td>(c) Sources within 0.10 radius of cluster centre</td>
<td>57</td>
<td>-0.927</td>
<td>0.035</td>
</tr>
<tr>
<td>(d) Sources between 0.20 and 0.40 radius of cluster centre</td>
<td>45</td>
<td>-0.778</td>
<td>0.040</td>
</tr>
<tr>
<td>(e) Sources in B-M I clusters</td>
<td>20</td>
<td>-1.033</td>
<td>0.063</td>
</tr>
<tr>
<td>(f) Sources in B-M III clusters</td>
<td>62</td>
<td>-0.838</td>
<td>0.040</td>
</tr>
<tr>
<td>(g) Sources in both (c) and (e)</td>
<td>10</td>
<td>-1.292</td>
<td>0.095</td>
</tr>
</tbody>
</table>

*All identified sources in the Culgoora-3 list with 0.02 ≤ z ≤ 0.20.
centre of B-M I clusters may be expected to have particularly steep spectra. Ten of the present sources fulfil this condition: they have a mean spectral index of $-1.292 \pm 0.095$ and six of these ten sources are also in powerful X-ray emitting clusters.

It is clear that our results support the hypothesis that the spectra of radio galaxies near the centres of clusters will be steepened by the confining influence of a hot, relatively dense electron gas. In fact, the steepening of the radio spectrum provides a more sensitive method of detecting this gas than does the use of existing X-ray telescopes: a significant steepening of the spectrum is detectable in most sources near the centres of clusters whether or not the cluster is a strong X-ray emitter.


Wills, D., Observatory, 86, 140 (1966).

Observations of the 1—0 Transition of CO Towards Southern HII Regions

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The 4-m radio telescope of the CSIRO Division of Radiophysics at Epping is being used to survey the line emission associated with the 1—0 transition of CO (rest frequency 115.271 GHz) in the southern Milky Way. The programme includes mapping the CO distribution across giant molecular-cloud/HII-region complexes. As a first stage the emission has been observed towards bright southern HII regions. These results will not only serve as a basis for future extensive mapping but will also provide data which is directly comparable with observations of other molecular lines that have been made towards the HII regions. In particular, the combination of CO emission, molecular-line absorption against the HII region, and H recombination-line emission from the HII region itself is extremely useful for removing ambiguities in the kinematic distances of HII regions at galactic longitudes within 90° of the galactic centre. We present here a catalogue of the initial observations; a more extensive comparison with the results of other line studies will be made elsewhere.

The observations were made during the period September-November 1981. The telescope had a beamwidth of 2.8 arc and an estimated pointing accuracy of 30°—40° arc. The receiving equipment and observing procedure have been described elsewhere (McCutcheon et al. 1981; Robinson et al. 1982). The cooled mixer receiver had a double-sideband temperature of about 500 K. The CO spectra were obtained with an acousto-optical spectrograph (Milne and Cole 1979) with a radial velocity coverage of 244 km s$^{-1}$ and a velocity resolution of 0.6 km s$^{-1}$. The typical integration period on-source was 4 min. To remove baseline curvature in the final spectra, reference spectra were obtained at positions away from the HII regions.

The mode of observation yielded line intensities corrected for the mean atmospheric absorption for the two receiver sidebands. However, the absorption at the CO frequency was significantly higher than the mean value and a further correction was necessary. This, and a conversion of intensities to a scale of 'corrected antenna temperature' (which corresponds to beam brightness temperature in the Rayleigh-Jeans limit), was achieved by means of CO observations of OMC1 at a series of different elevations, assuming a corrected temperature of 65 K for the CO of this molecular cloud. On this scale the final spectra had an r.m.s. noise of about 1 K.

The observed positions were chosen from a set used in a survey of galactic 4.8 GHz H$_2$CO absorption (Whiteoak and Gardner 1974). The selection was on the basis of high 4.8 GHz continuum intensity of high H$_2$CO line/continuum ratio.

The CO results, for a total of 79 positions, are listed in Table 1. Parentheses indicate uncertain parameters; they may occur with features which have low intensity or merge with other features. The effective limit of detection is about 2 K. It can be seen that in most cases the lines of sight pass through several CO clouds; the CO nearest the HII regions is usually the most intense (see later). For comparison purposes the table also contains 4.8 GHz H$_2$CO and H recombination line velocities. These were taken from Whiteoak and Gardner (1974) or from unpublished H$_2$CO observations by Whiteoak and Gardner. The H$_2$CO values in italics are for the strongest absorption features. In the table these velocities are aligned with the corresponding CO features. Figure 1 shows a typical pair of corresponding spectra. The table may not adequately describe the CO distribution for positions where the emission is more or less continuous over its total velocity range, or where line features are narrow compared with the instrumental velocity resolution of 0.6 km s$^{-1}$.

CO observations of southern HII regions have been previously made by Gillespie et al. (1977). However, only the emission near the recombination line velocities was observed. For objects in common the temperature ratio $T_{co}$ (present)/$T_{co}$...