Chapter 4

The Seyfert Galaxies:– NGC 7674 & NGC 7469

4.1 Introduction

In order to understand the fuelling and triggering mechanisms behind starburst and Seyfert activity, it is essential to determine the distribution and dynamics of their neutral interstellar medium (ISM). Neutral atomic hydrogen (HI) is one of the best tracers of low density neutral gas and can often be observed via both emission and absorption in the 21 cm line.

The angular resolution of HI emission studies are limited by the sensitivity of existing radio interferometric arrays and hence HI emission is currently not detectable with angular resolutions smaller than a few arcseconds (Mundell et al. 1999). Nevertheless, HI emission measurements can be used to uniquely determine the global dynamics of galaxies together with effects of tidal interactions.

HI absorption observations are particularly valuable in these sources since they enable neutral atomic hydrogen to be observed with sub-arcsecond angular resolution - corresponding to linear resolutions of a few tens of parsecs in the nearest galaxies. Unlike emission studies the sensitivity of HI absorption observations is determined largely by the brightness temperature of the background radio continuum source. Hence HI absorption studies are well suited to detect neutral gas close to the nucleus, and test the standard model in which the difference between Seyfert-1 and 2 nuclei is due to absorption by a dusty torus (Antonucci 1993; Ward 1996). In this model, Seyfert-2 galaxies are expected to show more localised HI absorption against the nucleus, whereas detection of HI absorption against Seyfert-1 nuclei would be less likely.

Unlike a number of radio galaxies (e.g. NGC 4261 - van Langevelde et al. 2000), high resolution HI absorption observations against Seyfert nuclei (Gallimore et al. 1998 & 1999, Cole, Mundell & Pedlar 1998a) have, in general, not provided convincing evidence for localised absorption consistent with a dusty torus. Much of the HI absorption seen in Seyfert galaxies can be attributed to rings or disc-like structures with sizes of a few hundred parsecs, significantly larger than the narrow line region associated with the Seyfert nucleus. These absorption features, while providing crucial constraints to possible fuelling mechanisms via the transport of gas towards the nucleus, are usually too large to be considered as a true 'dusty tori' (i.e. obscuring the broad line, but not the narrow line region). Gallimore et al. (1999) suggest that the apparent lack of HI absorption by a neutral dusty torus could be due to the nuclear 1.4 GHz continuum of Seyfert nuclei being free-free absorbed by ionised gas.

However, highly localised HI absorption has been previously detected close to Seyfert nuclei, in particular against NGC 4151 (Mundell et al. 1995). In this chapter neutral hydrogen absorption observations of a further two Seyfert galaxies (NGC 7674, NGC 7469) which show localised HI absorption within an arcsec of their Seyfert nuclei will be presented. These results are discussed in the context of the dusty torus model. In the case of NGC 7674 a lower resolution study of HI

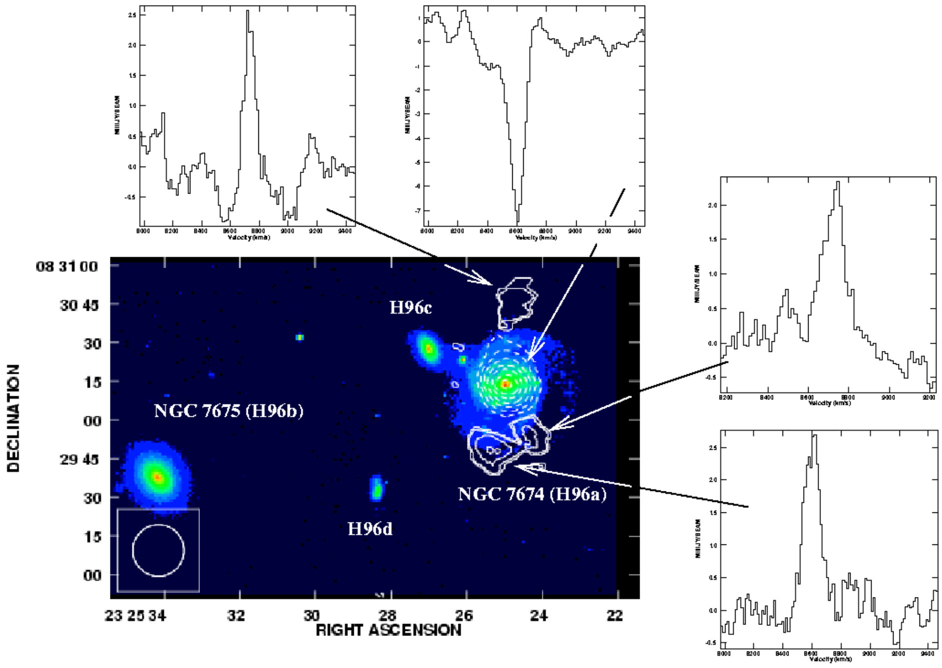

Figure 4.1: False-colour CHFT R-band image of Hickson compact galaxy group No. 96, overlay GMRT contours of HI emission and absorption with selected spectra included. The contour levels are set at -145, -125, -105, -85, -65, -45, -25, 1, 2, 4, 8, 16 & 32 $\times$ 10 mJy (beam ms^{-1})$^{-1}$. The spectra shown have a velocity resolution of $\sim$32 km s^{-1}. The radio data have been convolved with a circular beam of 20 arcsec FWHM.

emission from the outer parts of this galaxy, providing further information on the interaction that the source appears to have undergone, are also reported upon.

4.1.1 Background – NGC 7674 & NGC 7469

NGC 7674 (Mkn 533, Arp 182) is a type-2 Seyfert galaxy at a distance of 115 Mpc (1″=571 pc, assuming H_0=75 km s^{-1} Mpc^{-1}) which is classified as Sbc pec (de Vaucolouleurs et al. 1976). This galaxy is the brightest member of a Hickson com-

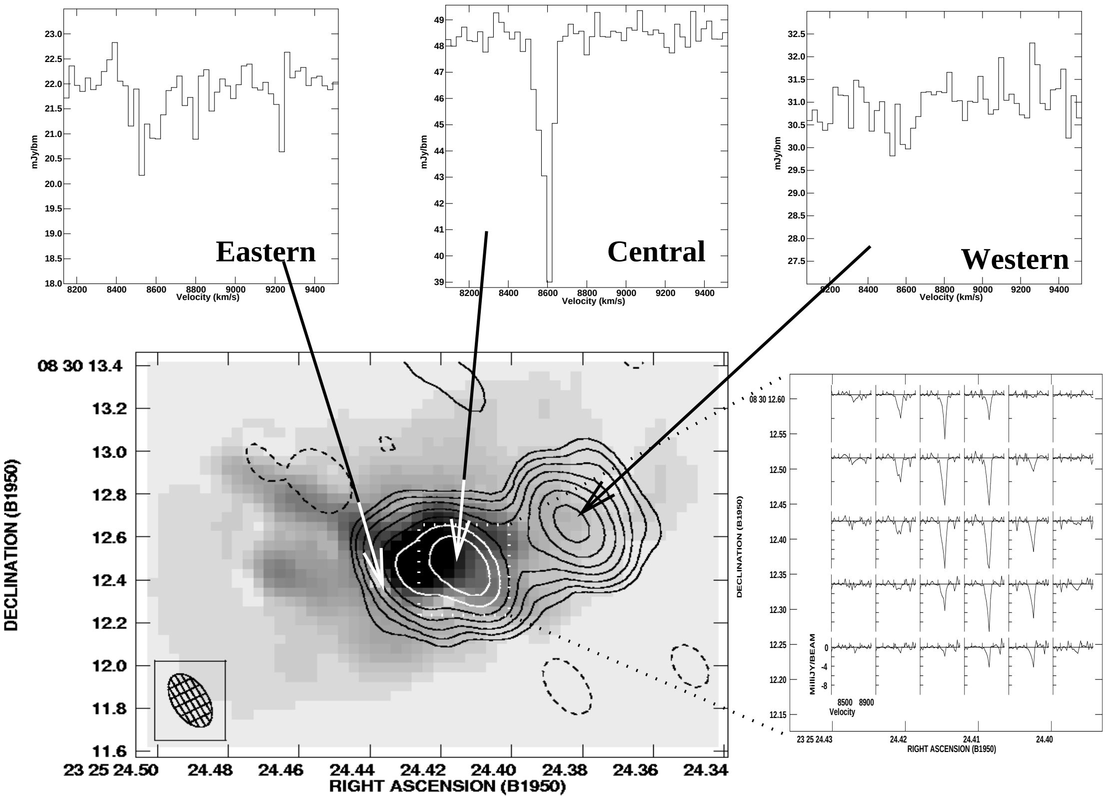

Figure 4.2: NGC 7674 uniformly weighted MERLIN contour image with a arbitrarily grey-scaled *HST* WFPC-2 (filter: *F547M*). Radio contours levels are 0.482 (3σ) $\times$ -1, 1, 2, 4, 8, 16, 32 and 64 mJy bm^{-1} with a beam size of 0.27$\times$0.15 arcsec^2. Also presented are several HI absorption spectra taken against the main area of radio continuum and set of 35 spectra extracted from the nuclear region each of these spectra is integrated over an area of 4 pixels.

pact galaxy group, Hickson 96 (Hickson 1982). Hickson group 96 consists of at least 4 interacting galaxies, the largest of which are NGC 7674 (H96a) and NGC 7675 (H96b) which are separated by a projected distance of 2.2 arcminutes. All four galaxies in the group have similar redshifts with a velocity dispersion of σ_V=160 km s^{-1} (Verdes-Montenegro et al. 1997). The group is relatively isolated with no galaxies of similar optical brightness as either NGC 7674 or NGC 7675 within 1 Mpc (Verdes-Montenegro et al. 1997).

NGC 7469 (Mrk 1514, Arp 298) is a well studied type-1 Seyfert galaxy with a Hubble classification of (R′)SAB(rs)a, which contains a circumnuclear starburst ring (Wilson et al. 1991). NGC 7469 has a close irregular counterpart,

Region	R. A. (B1950) $23^h\ 25^m$	Dec. (B1950) $08^\circ\ 30'$	$S_{1.4GHz}$ mJy	$S_{8.4GHz}$ mJy	S_{15GHz} mJy	Spectral Index α
Eastern	$24^s.43$	$12''.4$	29.8	-	2.3	0.9
Central	24.41	12.4	97.6	27.0	8.8	1.1
Western	24.38	12.6	64.0	12.8	3.3	0.8

Table 4.1: Summary of radio continuum properties of central region of NGC 7674.

IC 5283 which is ~1.3 arcminutes away (Burbidge, Burbidge & Prendergast 1963; Márquez & Moles 1994). The distance to NGC 7469 is 66 Mpc ($1''$=330 pc). This starburst/Seyfert hybrid galaxy has been observed to contain considerable concentrations of molecular gas (CO and HCN) and dust making it an ideal candidate for the study of HI absorption (Genzel et al. 1995; Tacconi et al. 1996; Papadopolus & Allen 2000).

Both NGC 7469 and NGC 7674 have large infrared flux densities of $L_{fir}=10^{11.30}$ and $10^{11.24}$ $L_\odot$ (Scoville et al. 2000; Genzel et al. 1995; Mirabel & Sanders 1988) respectively and both have been shown to have neutral hydrogen absorption by single dish observations (Mirabel 1982; Mirabel & Sanders 1988). The observed properties of both of these galaxies have been affected by their recent and ongoing gravitational interactions with their companion galaxies. The result of these interactions may, in both of these cases, have induced the Seyfert activity that is observed in the cores. The main differences between these two galaxies are Seyfert type (NGC 7469 is type-1 and NGC 7674 is type-2) and the presence of a starburst ring surrounding the nucleus of NGC 7469.

4.2 Observations and Image Processing

4.2.1 MERLIN

MERLIN (Thomasson 1986), including the 76 m diameter Lovell telescope, was used to observe NGC 7674 for approximately 10 hours with regular observations of the nearby phase calibration source 2325+093 on November 12^{th} 2000. Throughout the observation dual hands of circular polarisation were observed over an 8-MHz band which were correlated into 64 spectral channels, centred on optical-heliocentric velocity 8881.1 km s^{-1}. Each channel has a width of 125-MHz corresponding to a velocity resolution of 26.3 km s^{-1}. A single observation of OQ208 was used to obtain bandpass solutions along with a 30 minute observation of 3C 286, which was assumed to have a flux density of 14.99 Jy at 1379.4 MHz (Baars et al. 1977) and was subsequently used to calibrate the flux density scale.

NGC 7469 was observed with MERLIN for 8 hours on May 10^{th} 1998. The observational setup was essentially the same as that used for NGC 7674, although the bandpass was centred on the heliocentric optical velocity of 4837.5 km s^{-1}, and was phase calibrated from observations of nearby calibrator source 2306+095.

Initial editing and calibration of both NGC 7674 and NGC 7469 were carried out using standard MERLIN software. Followed by further editing and bandpass calibration were applied to the data sets using tasks within AIPS. Phase corrections obtained from the phase calibrators were applied to the data along with further corrections derived from self-calibration of NGC 7674 & NGC 7469. The u, v data sets were Fourier transformed to produce both uniform and naturally weighted 512×512×63 spectral line cubes. Line free channels were combined to produce continuum images which were subsequently subtracted from the spectral line cubes. The continuum maps and continuum-subtracted cubes were deconvolved with the telescope beam to remove the instrumental response using a

Region	$\tau_{\rm peak}$ ($\rm km\,s^{-1}$)	$V_{\rm HI}$ ($\rm km\,s^{-1}$)	FWHM ($\rm km\,s^{-1}$)	$\int\tau dV$ ($\rm cm^{-2}$)	N_H $\times10^{21}$ (atoms $\rm cm^{-2}$)
Eastern	<0.07	-	-	-	-
Central	0.21±0.03	8623±5	114±7	21.3±3	5.0±0.7
Western	<0.06	-	-	-	-

Table 4.2: Summary of HI properties of central region of NGC 7674. Column densities for individual components have been calculated using $N_H = 1.823 \times 10^{20} \int \tau dV$, and assuming a spin temperature of 100 K.

CLEAN based algorithm (Hogböm 1974). The cleaned continuum images were recombined with the continuum-subtracted cubes and further analysis of these data were undertaken using standard spectral line tasks within AIPS.

4.2.2 GMRT

NGC 7674 was observed using the GMRT on November 12$^{\rm th}$ 2000. The GMRT (Swarup et al. 1991) is an aperture synthesis instrument consisting of 30 fully steerable 45 meter diameter parabolic antennae. The array is irregularly distributed with 12 antennae situated within a compact cluster, called the 'central square'. The baselines within the 'central square' range between ~100 m to ~1 km. The remaining antennae are located along three arms in an approximately 'Y' shaped array giving baselines of up to 25 km.

All 30 telescopes of the GMRT were used for 10 hours to observe NGC 7674 interspersed with regular observations of the bright calibrator 2212+018 (J2000) which was used for both phase and bandpass calibration. Dual hands of circular polarisation were observed over 8-MHz and correlated into 128 channels (62.5-kHz per channel: 13.3 $\rm km\,s^{-1}$ per channel) centred upon the heliocentric velocity of 8650 $\rm km\,s^{-1}$. Hanning smoothing was applied to the data to produce a final

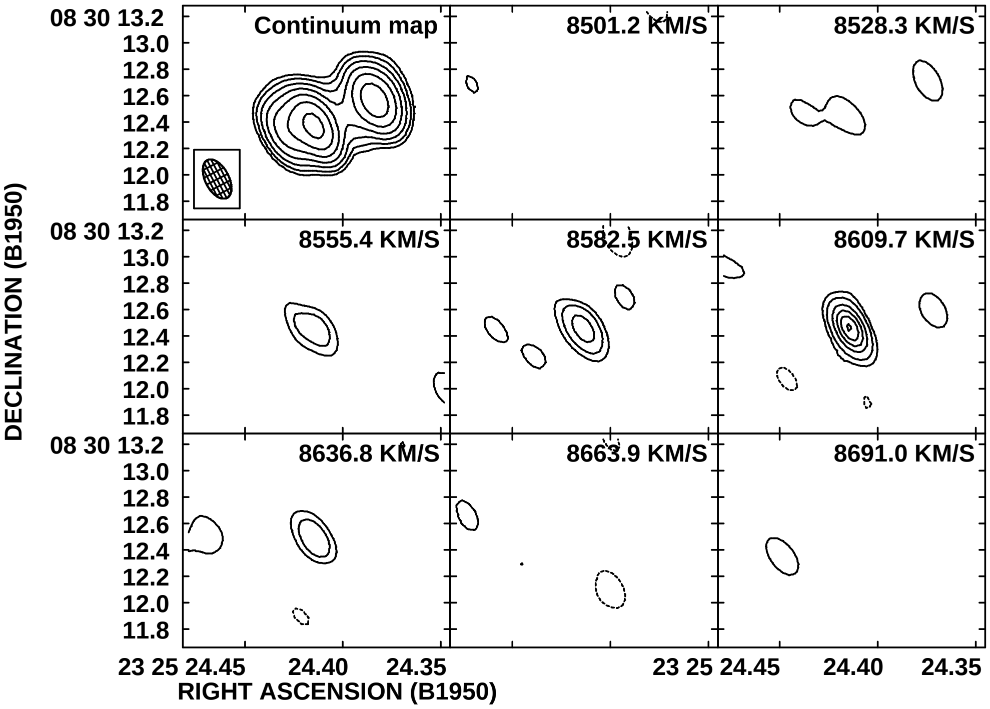

Figure 4.3: Single channel maps of the HI absorption detected against NGC 7674. Each channel map is contoured with the levels -12, -10, -8, -6, -4, -2, -1, 1 ×1.7 mJy beam^{-1} and has been extracted from the naturally weighed spectral line cube. For positional reference a naturally weighted continuum image is included in the top left hand frame together with the naturally weighted MERLIN beam ($0\farcs32\times0\farcs18$).

velocity resolution of 32 km s^{-1} with a noise level of 1.2 mJy beam^{-1} channel^{-1}. Although most of the telescopes were used throughout the experiment, the total number of antennae used in the final data analysis was between 13–15 over the duration of the observing run with resulting angular resolution of $\sim$20″. The absolute flux density scale was achieved using a single 30 minute observation of 3C 286.

The data from the GMRT were converted into FITS format using software packages available at the GMRT site and further analysis was achieved using standard spectral line processes within AIPS as described in section 4.2.1 and chapter 2.

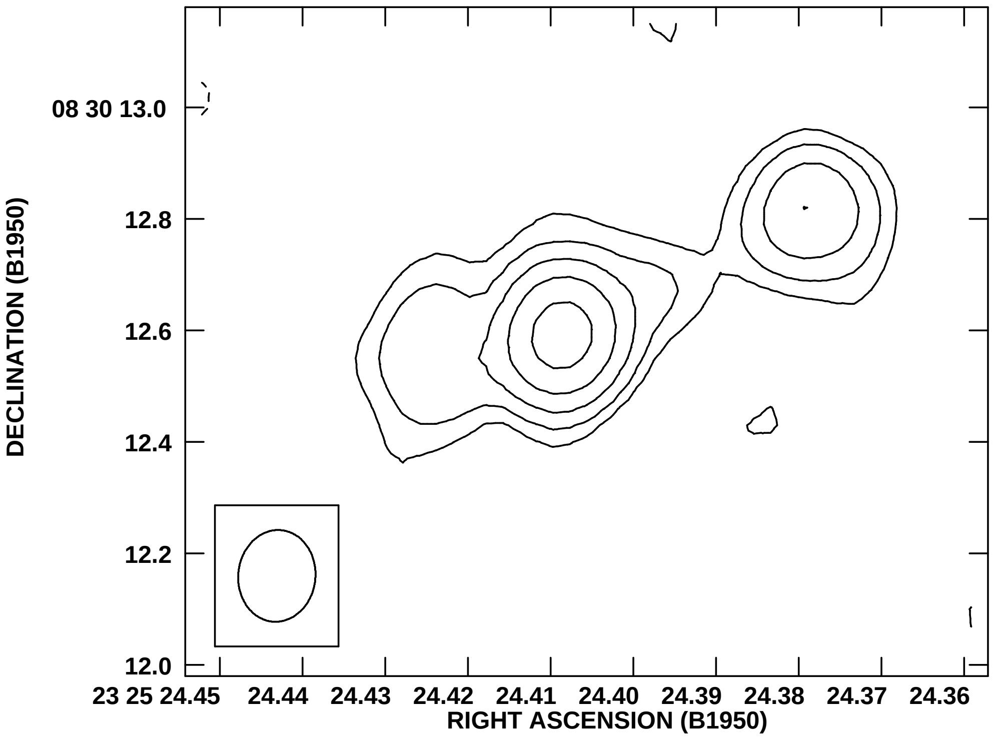

Figure 4.4: Naturally weighted 15 GHz VLA image of NGC 7674 from Unger et al. (1988). The contour levels are -1, 1, 2, 4, 8, 16 and 32 $\times(3\sigma)$ 0.294 mJy beam^{-1} with a beam size of 0."16×0."14.

4.2.3 HST

Broadband *HST* WFPC-2 optical images of both NGC 7674 & NGC 7469 from the *HST* archive have been used to provide an optical comparison at a similar resolution to the MERLIN radio images. The NGC 7674 data (U5DF0201A) uses a broadband *F547M* filter centred on the wavelength λ5446Å whereas the image of NGC 7469 (U33Z1901B) comprised of two 1200 second long integrations using an *F218W* filter. Both of these data sets were reduced using STSDAS and STARLINK software packages before being exported as FITS files. Accurate astrometry was applied to the *HST* image of NGC 7674 by assigning known coordinates, derived from the US Naval Observatory star catalogue, to 10 stars found within the image. By applying a linear transformation and rotation to the image the residual errors of these positions were minimised and hence an absolute positional accuracy of <0.″2 was achieved. Unfortunately the *HST* image containing NGC 7469 did not contain a suitable number of stars and as a result the alignment of the radio and optical frames was achieved, after a suitable rotation had been applied to the *HST* image, by assuming that the brightest continuum components of both the radio and optical images were spatially coincident.

4.3 Results & Discussion

4.3.1 NGC 7674

The kiloparsec Scale HI Study

NGC 7674 is situated in the compact galaxy group (Hickson 96) of ∼4 dynamically interacting galaxies. Fig. 4.1 shows an *R*-band false-colour image taken with the Canada France Hawaii Telescope (CHFT) of this galaxy group, with contours of integrated HI emission and absorption around NGC 7674 superimposed. The HI emission and absorption contours shown in this image are derived from GMRT observations which have been convolved with a 20″circular beam. Selected HI spectra are also presented in this figure showing examples of the deep absorption associated with NGC 7674, and examples of the HI emission extending north and south of NGC 7674. Note that the spectra have been Hanning smoothed resulting in a velocity resolution of 32 km s^{-1}.

Previous lower resolution (33″×25″), higher sensitivity HI observations of this galaxy group using the VLA (Verdes-Montenegro et al. 2001a) detected neutral hydrogen surrounding and extending approximately 1′ to the north-east of NGC 7674 (H96a), H96c and towards H96d (see Fig.4.1) with no HI detected within NGC 7675 (H96b). These features are consistent with the GMRT ob-

Region	R. A. (B1950) $23^{\mathrm{h}}\ 00^{\mathrm{m}}$	Dec. (B1950) $08^{\circ}\ 36'$	$S_{1.4-\mathrm{GHz}}$ mJy	$S_{8.4-\mathrm{GHz}}$ mJy/bm	$S_{15-\mathrm{GHz}}$ mJy	Spectral Index α
Nucleus	$44^{\mathrm{s}}.41$	$15''.9$	45.7	12.1	8.0	0.73
A	44.48	16.8	2.7	0.42	-	1.04
B	44.44	16.2	1.3	-	-	-
C	44.32	14.8	4.3	0.48	-	1.22

Table 4.3: Summary of radio continuum properties of NGC 7469.

servations presented here. The extended nature of the HI emission detected is characteristic of tidal interactions between members of this physically compact group. Single dish and VLA HI observations of Hickson 96 and other Hickson Compact Groups (HGCs) have found them to be, in general, HI deficient (Huchtmeier 1997; Verdes-Montenegro et al. 2001b). Although, Hickson group 96 does seem to be HI deficient, with only ~65% of the predicted HI mass detected (Huchtmeier 1997), HI in both absorption and emission is observed on all resolution scales towards NGC 7674. It has been suggested that the general deficiency in HI observed in HGCs can be attributed to tidal interactions removing the HI gas from within the galaxies where it can subsequently be more easily heated and dissipated (Verdes-Montenegro et al. 2001b). Approximately 30% of the HI mass within Hickson group 96 exists in tidal features. If this process is in action in Hickson group 96 it would appear that NGC 7674, the largest and only spiral galaxy in the group, has managed to retain some of its associated neutral ISM at least within its central region where high angular resolution MERLIN HI absorption observations detect HI column densities of $\sim 5\times 10^{21}$ atoms cm^{-2} (see Table 4.2).

High angular resolution study - 1.4 GHz radio continuum & *HST* image

These 1.4 GHz MERLIN observations enable us to study the relativistic plasma, as well as the HI, associated with the nucleus with a comparable angular resolution to the *HST*. Hence Fig. 4.2 shows a grey-scale *HST* WFPC-2 broadband image of the centre of NGC 7674 overlayed by a uniformly weighted MERLIN 1.4 GHz radio contour map along with selected HI spectra. The MERLIN image has a resolution of $0\farcs27\times0\farcs15$, a noise level of 0.16 mJy beam^{-1}, and is spatially aligned with *HST* WFPC-2 to within $0\farcs2$. The position angle of both the MERLIN and *HST* images agree. The 1.4 GHz MERLIN radio continuum is consistent with the 15 GHz image (Fig. 4.4) of Unger et al. (1988) and shows that NGC 7674 resolves into three continuum components, labelled as eastern, central and western (Fig 4.2) following Unger et al. (1988).

In Table 4.1 the positions and 1.4 GHz flux densities of these components are given. Table 4.1 also includes the 8.4 GHz and 15 GHz measurements of Unger et al. together with an estimate of their spectral index. Spectral indices were calculated between all of the available observation at 1.4→8.4→15 GHz and combined into a best value assuming $S_\nu \propto \nu^{-\alpha}$. A large uncertainty is inherent in the spectral indices quoted (Table 4.1) due to the differing resolutions of the three observations used and the extended nature of the source. Considering this uncertainty these values should be used cautiously, although it is clear that none of these radio components display a flat spectrum. The brightest of these radio components was tentatively identified by Unger et al. (1988) as associated with the Seyfert-2 nucleus. This was not only based on its central location, but also on 1.6 GHz VLBI observations (Unger et al. 1988) which showed it to be unresolved on scales of $\sim$ 10 mas. Although the 1.4 GHz continuum observations presented here are broadly consistent with this conclusion, it is important to bear in mind the results of more recent observations. Gallimore et al. (1999) suggested that the 1.4 GHz continuum from many Seyfert nuclei are free-free absorbed, and Mundell

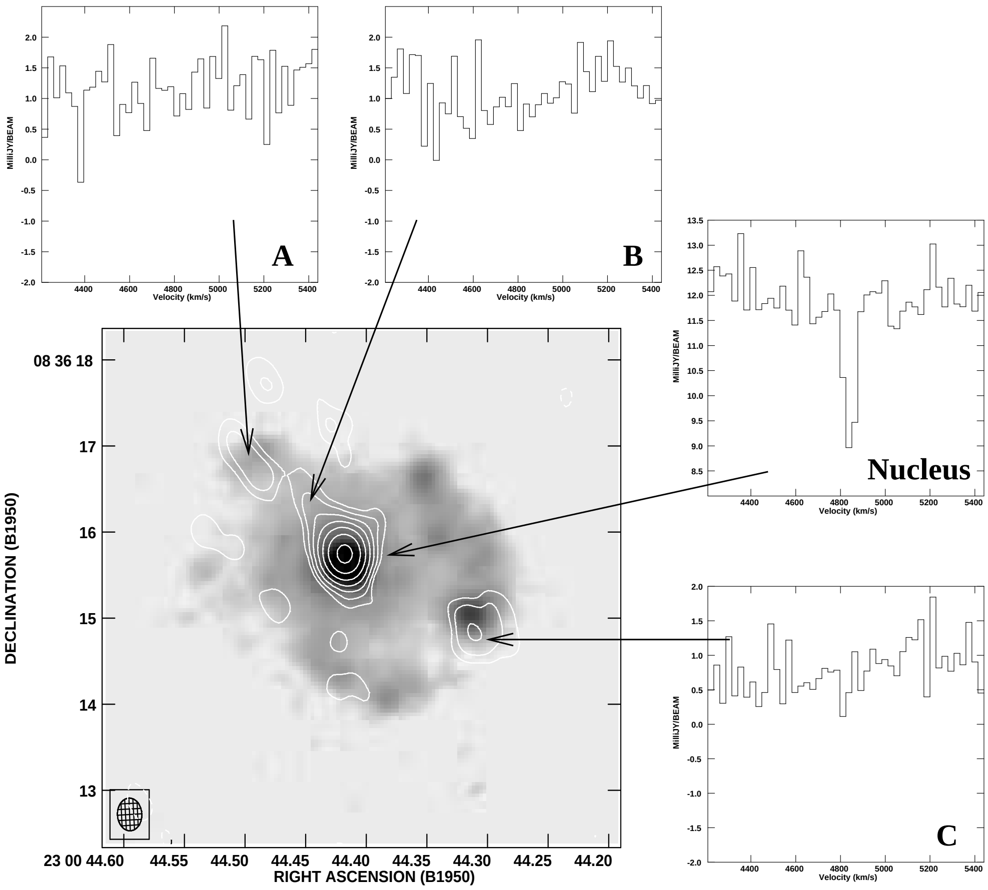

Figure 4.5: NGC 7469 MERLIN contoured image overlaid upon a similar resolution arbitrarily grey-scale *HST WFPC2* (*F218W* filter) image with selected HI absorption spectra against the main radio components. The radio contours are 0.4686 (3σ) $\times$ -1, 1, 2, 4, 8, 16, 32, 64 mJy beam^{-1} with a naturally weighted beam size of 0.38$\times$0.30 arcsec^2.

et al. (1995), in a study of NGC 4151, ruled out a nuclear origin for the central bright 1.4 GHz component, and suggested it is an ejected plasmon or a shock in the jet.

In the case of NGC 7674, this data (Table 4.1) shows the central component to have a steep spectral index, with little evidence for free-free or synchrotron self absorption. While this does not rule out an AGN origin for the component, the spectral index could also be consistent with a lobe or shock in a jet. Further evi-

Region	$\tau_{\rm peak}$	$\int \tau {\rm d}V$ ($\rm km\,s^{-1}$)	$\rm N_H$ ($\times 10^{21} \rm cm^{-2}$)
Nucleus	0.25±0.03	19.5±2	3.6±0.4
A	-	-	-
B	-	-	-
C	-	-	-

Table 4.4: Summary of HI properties of NGC 7469. Column densities for individual components have been calculated using $\rm N_H = 1.823 \times 10^{20} \int \tau dV$, and assuming a spin temperature of 100 K.

dence for such a scenario can be seen in Figure 4.2, in which the brightest optical emission appears offset to the east of the central component, and may even be aligned with the weaker eastern component. However, the displacement is close to the uncertainties in position of the *HST* image (0.2 arcsec), and furthermore, such a displacement could be caused by dust extinction which is already considered to be responsible the strong asymmetric blue wing in the [OIII] spectrum of this galaxy (e.g. Unger et al. 1988). Clearly a combination of higher frequency VLBI and more accuracy in the *HST* positions can resolve some of the above ambiguity. Nevertheless there seems little doubt that the central component is within 0.2 arcsec (<100 pc) of the nucleus and for the discussion below concerning the localised nature of the HI, I shall assume them to be closely associated.

High resolution study - HI absorption

NGC 7674 is a Seyfert-2 galaxy which, if orientation dependent unified schemes (reviewed by Lawrence 1987; Antonucci 1993; Ward 1996) for Seyfert galaxies are followed, implies that this source is viewed at a large angle to the radio jet axis, with the central engine being, to some degree, obscured by a dusty torus. Hence this galaxy is a good candidate in which to investigate HI absorption as evidence supporting the concept of such a dusty torus.

In Fig. 4.2 examples of the HI spectra seen against the continuum components of

NGC 7674 are shown. The most striking feature is the deep ($\tau = 0.21$) absorption at 8623±5 km s^{-1} seen against the central component which has no counterpart in either the east or west components. If a feature of comparable optical depth was present in the east or west components it would show peak absorption of ~ 6 and ~ 12 mJy respectively. Given the relatively narrow width of the absorption (114±7 km s^{-1}) it would be readily detected by the present observations against either component.

The quality of the data cube is further illustrated in the grid of spectra shown in Fig. 4.2 and the channel maps shown in Fig. 4.3. An analysis of the channel maps shows the spatial extent of the HI absorption against the central component to be unresolved by the MERLIN beam. Possible weak (∼1.7 mJy) features at ∼8530 km s^{-1} with a broader velocity width can be seen in spectra and channel maps in the direction of the east and west components, although their reality cannot be confirmed given the sensitivity and baseline uncertainties of the present observations.

In Table 4.2 the central velocity, FWHM, peak opacity and column densities of the HI seen in absorption against NGC 7674 are listed. Column densities have been calculated using $N_H = 1.823 \times 10^{20} \int \tau dV$, assuming a spin temperature of 100 K. The central velocity and width of the absorption line were determined by Gaussian fitting.

The central velocity of the HI absorption seen against the central component is comparable to the velocity of HI absorption observed with the GMRT and with Arecibo (Mirabel & Sanders 1988) but is blueshifted compared to the peaks of observed optical emission lines ([OIII] λ5007Å, 8740 km s^{-1}, Unger et al. 1988) and with respect to the systemic velocity of 8660 km s^{-1} (obtained from optical ionised emission lines; Verdes-Montenegro et al. 1997). The averaged velocity of HI emission observed with the GMRT is 8699±20 km s^{-1} which can be considered as an independent measure of the systemic velocity of NGC 7674, although this has a large uncertainty due to the dynamical interactions of nearby galaxies and the rotational motions of NGC 7674 itself. This HI systemic velocity is consistent with other recently published results which find it to be 8713 km s^{-1} (Mundell 2001). The velocity of HI observed in emission, with the GMRT, is consistent with the HI emission seen in previous single dish spectra (Mirabel & Sanders 1988) which show the global HI velocity. Both this single dish spectrum and the GMRT observations presented here show the HI emission to be redshifted relative to the observed HI absorption and blueshifted relative to optical emission lines. The observed discrepancy in velocity of the HI absorption and the optically observed systemic velocity could be interpreted as infall of gas along the line of sight of the core of NGC 7674. Although, it should be noted that optical redshifts are determined from ionised emission lines which are strongly influenced by infall and outflow. Results from interferometric observations of HI absorption towards AGN have noted that the HI velocities derived, have some tendency towards being blueshifted with respect to the observed optical systemic velocity (Morganti et al. 2001a). More accurate values for the systemic velocities of these sources, maybe provided by low resolution HI emission observations, are needed to determine whether actual infall is being observed or if these apparent discrepancies are merely the result of uncertain values for the systemic redshifts.

As was discussed above the HI absorption in NGC 7674 appears to be highly localised and is within 0.2 arcsec of the line of sight to the active nucleus. As far as I am aware the only other Seyfert galaxy which shows such localised HI absorption is NGC 4151 (Mundell et al. 1995) which Pedlar et al. (1998) interpret as possible evidence for the photo- dissociation of a molecular 'dusty torus' surrounding the nucleus. In fact the evidence for localisation is somewhat stronger in NGC 7674 as significant limits can be set on both sides of the detected absorption, whereas in NGC 4151 limits on the components east of the detection were marginal. As in NGC 4151, it is possible that some of the lack of absorption is due to one (either east or west) being in front of the absorbing HI, but in this case the other

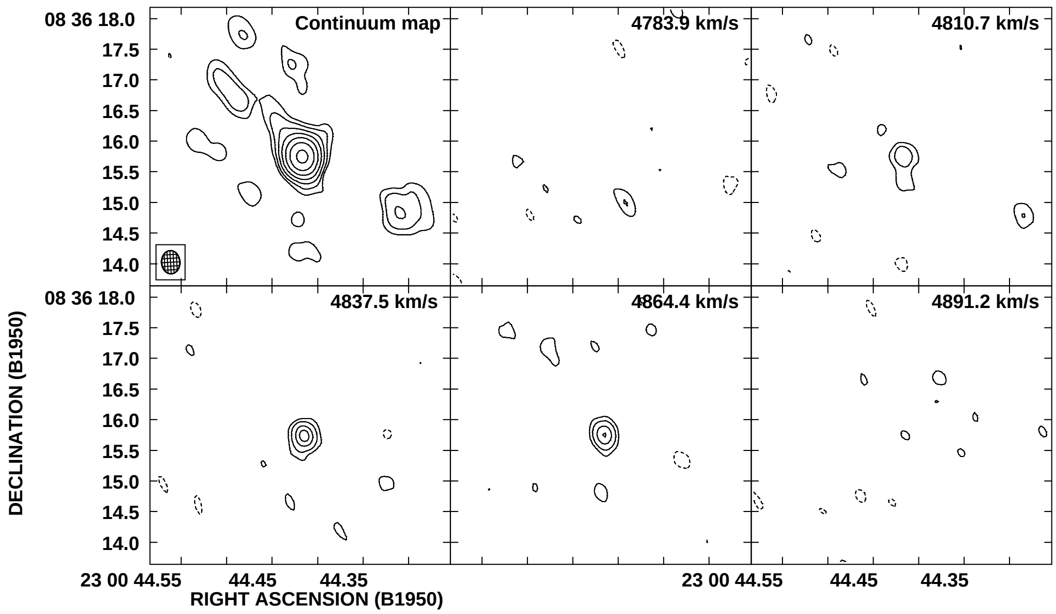

Figure 4.6: Naturally weighted absorption maps of NGC 7469 across five spectral line channels. Contour levels in each channel map are 1.5 × -6, -4, -2, -1 and 1 mJy beam^{-1}. The continuum image shown in top left hand panel is identical to the image shown in Fig. 4.5.

component would be expected to be behind. Hence, if the eastern component is assumed to be behind the HI, the extent of the absorbing medium must be less than 0.2 arcsec, and even if the western component is behind, the absorbing medium cannot be larger than 0.6 arcseconds. Hence, the HI must be confined to a region less than 100 pc (or at most 300 pc) of the nucleus which is a strong indication that the HI may be associated with a neutral torus. Using the estimate of the column density (Table 4.2), then assuming an extent of 100 pc, an upper limit upon the mass of the HI of $\sim 4 \times 10^5 M_\odot$ is determined.

Another indication of nuclear association, which is often used to distinguish between nuclear and galactic gas, is observations of relatively large line widths in, for example, the narrow-line regions and molecular gas. These are often typical of rotational velocities which can be estimated to be $\sim$600 km s^{-1} for gas $\sim$100 pc from a 10^7 $M_\odot$ black hole. Hence how can the observed velocity width of ~100 km s^{-1} be reconciled with the neutral gas being situated within a few hundred parsecs of the centre? This apparent inconsistency can be explained if we are viewing a rotating disc of HI almost edge-on with only a small section illuminated, and hence will only show small rotational broadening. It is important to note the compact nature of the central illuminating radio component in NGC 7674. Unger et al. (1988) have shown that 63 mJy of the flux density at 1.66 GHz originates from a region smaller than 10 mas, and hence the bulk of the 1.4 GHz continuum must originate from an area only a few parsecs in extent. Clearly this would intercept only a small part (unresolved by this experiment) of an edge-on rotating disc/torus, hence readily account for the narrow velocity width.

These observations alone do not prove that gas associated with a 'dusty torus' is present in NGC 7674 and it is indeed possible that the HI absorption is due to a cloud in the outer part of the galaxy which happens to lie on a fortuitous line of sight. However, given the similarity of this result to the NGC 4151 case (Mundell et al. 1995), this is unlikely. Also these data only constrain the size to less than a few hundred parsecs, and ideally the torus should be only a few parsecs in extent. However there is clearly a range of sizes in ring/discs of neutral gas structures seen in the centres of many galaxies, which may, or may not, be related to the 'dusty tori' required for the unified schemes. Clearly further investigations of this galaxy, such as VLBI observations of HI absorption and sub-arcsecond observations of molecules, are necessary to establish the nature of the neutral interstellar medium close to the active nucleus.

4.3.2 NGC 7469

Radio Continuum and *HST* image

In Fig.4.5 a naturally weighted MERLIN 1.4 GHz contour map overlaying a grey-scale broadband *HST* WFPC-2 image is shown. The image has been formed by integrating absorption-free channels within the cube. The angular resolution of the radio image is $0\farcs38\times0\farcs30$ with a noise level of 156 μJy beam^{-1} . The radio continuum properties of NGC 7469 derived from this MERLIN image and flux density measurements obtained from the literature are presented in Table 4.3. Spectral indices for the radio components were calculated assuming $S_\nu \propto \nu^{-\alpha}$.

The continuum image shown is dominated by a barely resolved source which is surrounded by series of weak areas of diffuse continuum emission. This is consistent with similar angular resolution, higher sensitivity (broadband continuum) observations made using the VLA at 5 GHz (Wilson et al. 1991) and 8.4 GHz (Colina et al. 2001a). Both of these observations show a relatively bright unresolved nucleus with a halo of diffuse radio emission extending $\sim1''\rightarrow2\farcs5$ from the nucleus. The grey-scaled *HST* WFPC-2 (which has an almost identical angular resolution to the MERLIN image) resolves the starburst ring into a series of bright clumpy structures, a few of which are approximately coincident with the MERLIN continuum components.

The spectral index of the core is found to be 0.73 which is consistent with non-thermal radio emission and is typical of a Seyfert nucleus. The radio components labeled A & C in Fig. 4.5 and Table 4.3 appear to show steeper spectral indices of $\sim$1 which may be consistent with the radio emission resulting from radio supernovae (RSNe) shock accelerated electrons. Colina et al. (2001a) discovered one of the brightest recorded radio supernova (RSN) yet observed in their 2000 epoch data situated $1\farcs65$ northwest of the nucleus, confirming that the diffuse radio structure around the Seyfert nucleus is the result of a circumnuclear starburst.

HI Absorption

Spectra were extracted from the naturally weighted cube, and examples from four positions which contain significant ($> 6\sigma$) 1.4 GHz continuum are shown in Fig. 4.5. The spectra in Fig. 4.5 show narrow (FWHM=$65\pm6\,\mathrm{km\,s^{-1}}$) HI absorption against the central core but no significant absorption against any of the clumps of radio continuum emission within the starburst ring. As an alternative method of displaying the line data selected single channel contour maps are also shown (see Fig. 4.6) which confirm that the HI absorption is limited to the nuclear continuum. The noise level in each channel of this cube is $0.6\,\mathrm{mJy\,beam^{-1}}$ with an angular resolution identical to the image. The optical depth and column density against the components were calculated in the same manner as NGC 7674, and the results are given in Table 4.4.

As in NGC 7674, HI absorption is only detected against one component; however, unlike NGC 7674, the other continuum sources in the NGC 7469 image are too weak to give useful limits. Even if the HI in the front of components A, B or C had the same column density as the HI in front of the nucleus, it would be $\leq 1\,\mathrm{mJy}$ deep and hence not be detectable. Hence, although these measurements give an accurate estimate of the HI column density against the radio nucleus, they do not constrain the extent of the absorbing cloud. Gaussian fits to the deep absorption seen in the channel maps shown in Fig. 4.6 and the continuum nucleus suggest that the HI absorption may be arising from a marginally smaller area than the 1.4 GHz continuum. This requires confirmation with higher resolution (VLBI) observations, but if confirmed would provide evidence that the HI absorption is localised within 0.1 arcsec and hence, like NGC 7674, would provide a candidate for gas associated with a dusty torus. However, as NGC 7469 has a Seyfert-1 nucleus, and hence following the simple unified scheme it is not expected have significant neutral torus gas along the line of sight to the AGN, it may be necessary to propose a similar geometry to that proposed by Mundell et al. (1995) for HI absorption seen from NGC 4151 – which is also a Seyfert-1 galaxy.

Another explanation for the existence of HI absorption in this Seyfert-1 galaxy is that the narrow absorption arises due to the fortuitous location of a cloud of obscuring gas from outside the nuclear region. This would be similar to the explanation for the observed narrow HI absorption seen against some quasars, for example PKS 1545-79 (Morganti et al. 2001b). NGC 7469 is a gas rich galaxy and, as such, the presence of a cloud of HI gas no bigger than ~50 pc that may be obscuring this Seyfert-1 nucleus is a plausible explanation for the observed characteristics. Of course this obscuring cloud could easily be part of a wider 'screen' of HI gas that is lying in front of the radio source but is not observed against the rest of the radio components within the sensitivity of this experiment.

4.4 Conclusions

Both MERLIN and the newly operational GMRT have been used to observe neutral hydrogen in two Seyfert nuclei, NGC 7674 and NGC 7469. These sources, although both Seyfert galaxies, display considerable physical differences and, as such, each source has been considered independently of the other.

NGC 7674

Sub-arcsecond MERLIN resolution observations of the nuclear region of the Seyfert-2 galaxy NGC 7674 have detected a 1.4 GHz continuum structure consistent with previous observations by Unger et al. (1986, 1988). Two dominant radio continuum components are detected with the brightest of these components tentatively associated with the Seyfert nucleus. It is concluded that this radio structure results from collimated ejection from the nuclear component.

H I absorption is detected with MERLIN against the strongest sub-arcsecond radio component in NGC 7674, which is believed to be associated with the nucleus. Against the strongest part of the radio continuum structure the H I is observed with column densities of $5.0\pm0.7\times10^{21}$ atoms cm^{-2} and a FWHM of $\sim$114$\pm$7 km s^{-1}. Limits on the opacity of H I in front of the east and west components of $\tau < 0.07$ & 0.06 respectively are set and interpreted as evidence that the H I is localised within the central few hundred parsecs of the Seyfert-2 nucleus, similar to that observed against the Seyfert nucleus of NGC 4151 (Mundell et al. 1995), with an upper H I mass limit of $\sim4\times10^5$M$_\odot$. Follow up higher resolution H I absorption observations using the EVN will determine whether this H I gas is associated with a dusty torus.

NGC 7469

The 1.4 GHz radio continuum structure of the Seyfert-1 galaxy NGC 7469 at sub-arcsecond resolutions showing the nucleus and the most compact areas of radio emission in its circumnuclear starburst ring is observed. Using these new MERLIN data and information from the literature a spectral index of the core component of NGC 7469 of 0.73 is calculated. The detected radio continuum components in the starburst ring of NGC 7469 possess steeper spectral indices of $\sim$1 which are consistent with the radio emission originating from radio supernovae in the starburst ring, a conclusion which is also supported by the recent detection of a bright radio supernova in this source (Colina et al. 2001a).

Narrow (FWHM=65$\pm$5 km s^{-1}) and unresolved H I absorption is detected against the nucleus of NGC 7469. This H I gas has an opacity of τ=0.25 and column density of $3.6\pm0.4\times10^{21}$ atoms cm^{-2}. Unfortunately due to the lack of strong radio continuum observed, at this resolution, in the starburst ring it was not possible to set significant limits upon the HI optical depth against any of the radio continuum components associated with the starburst ring, and hence, it was not possible to constrain the size of the absorbing gas. Higher resolution EVN observations will be made later this year which should further constrain the size and location of the HI absorbing gas against the nuclear region.