Neutral hydrogen absorption in nearby active galaxies

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Abstract. We report on neutral hydrogen absorption measurements using MERLIN. Results on a number of Seyfert and starburst galaxies are summarised. The existence of neutral gas close to the active nucleus is established in some Seyfert nuclei although it is unclear whether this gas is associated with the dusty torus responsible for hiding the BLR and collimating the UV. Some of the absorption appears to be associated with larger galactic structures such as molecular rings. H1 absorption has been measured against individual SNR in the starbursts M82 and NGC3628 which can be used both to model the starburst and to investigate the ISM in these galaxies on parsec scales.

1. Introduction

Observational studies of active galactic nuclei (AGN) and starbursts have largely concentrated on studies of ionised (eg emission lines) and relativistic plasma (eg synchrotron emission). However, it has also emerged that neutral gas is intimately involved in both AGN and starbursts. The neutral component is now readily accessible on arcsecond scales using mm-arrays to study molecular emission, and decimeter synthesis instruments (eg MERLIN, VLA, AT) to study atomic hydrogen (H1) and molecular absorption. In AGN, particularly Seyferts, these observations constrain models involving the fuelling of the activity, test current unified schemes and set upper limits to the mass of the central engine. In the case of starbursts the neutral gas is crucial in determining the dynamics of the neutral gas which is fuelling the starburst. In this contribution we will summarise a number of recently completed or ongoing absorption studies mainly involving MERLIN. Because of instrumental constraints the objects described here are at relatively low redshifts. Nevertheless the resulting studies give highly detailed information on active galaxies on linear scales and sensitivities which are not available for their high redshift counterparts.

2. Observations

Most of the observations have been carried out using MERLIN (Wilkinson 1992) and a more detailed description of the spectral line reduction technique is summarised in Mundell et al (1995). With a range of baselines between 6 and 210km, MERLIN has an angular resolution at 20cm of ~ 0.15 arcsec depending on declination. A range of bandwidths and spectral resolutions is available, although most results reported here have been observed with a bandwidth of 8MHz and 64 channels resulting in a velocity resolution of 26 km s^{-1} for the 21cm H1 line. In typical imaging runs ranging between 12 and 18hours this velocity resolution results in an rms noise of ~ 0.5 mJy/beam per channel. Initially filters limited the MERLIN lower frequency range to 1380MHz, although recently new filters have been retro-fitted resulting in the range being lowered to 1330MHz. Hence the redshift range has been increased from z=0.03 to 0.06 which has enabled studies of higher redshift Seyferts and radio galaxies (eg 3C305, 3C293) to be carried out.

3. Hydrogen absorption studies of Seyferts

MERLIN H1 absorption studies have been carried out on a number of Seyferts. Many Seyferts are known to contain significant quantities of neutral hydrogen from emission studies (eg Brinks & Mundell 1996, Mundell 1997), although the angular resolution is limited by the brightness sensitivity of current instruments to be several arcseconds. Absorption studies, however, whilst limited to regions with continuum emission, can give information on the neutral gas associated with these nuclei on subarcsecond scales. Dickey(1986) detected H1 absorption from a number of Seyferts using the VLA, and Gallimore et al (1994) made a detailed VLA study of NGC1068 in H1 absorption. A major science driver for H1 absorption observations is to investigate the existence of a neutral torus which is proposed to explain the differences between Seyfert 1 (broadline) and Seyfert 2 nuclei simply as a consequence of orientation (eg Antonucci & Miller 1985). Irrespective of the model, H1 absorption measurements give unique information on neutral gas in the central 100pc of active galaxies.

The first major MERLIN H1 absorption study was of the archetypal Seyfert 1 galaxy NGC4151 (Mundell et al 1995) in which localised H1 absorption was detected close to the active nucleus. This was tentatively interpreted as evidence for neutral hydrogen associated with the compact 'dusty molecular torus' required for the unifying schemes described above. Further high resolution VLBA observations are in progress to investigate this possibility.

Recent observations of Markarian 6 (Gallimore et al. 1997) have shown localised H1 absorption (Figure 1) against the bright compact component at the northern end of the radio jet . Although this superficially looks like a core of a core-jet structure, there is clear evidence that this component is an outer lobe and the Seyfert 1 nucleus appears to be ~ 1 arcsec south at the centre of a two sided jet. Hence the absorption, as discussed by Gallimore et al., is possibly associated with a neutral ring several hundred parsecs in extent present on HST images as dust extinction.

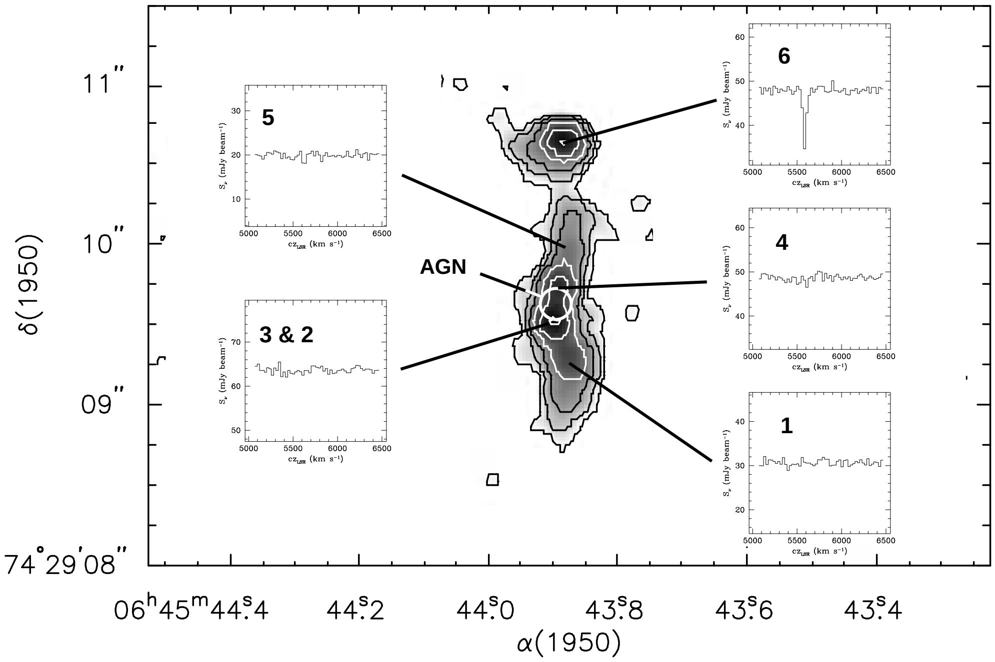

Figure 1. A selection of MERLIN H1 absorption spectra from the central 2 arcsec of Markarian 6. The 21cm continuum image is displayed as contours over greyscale and the white circle the position of the optical AGN. Note that only the northern component displays significant absorption.

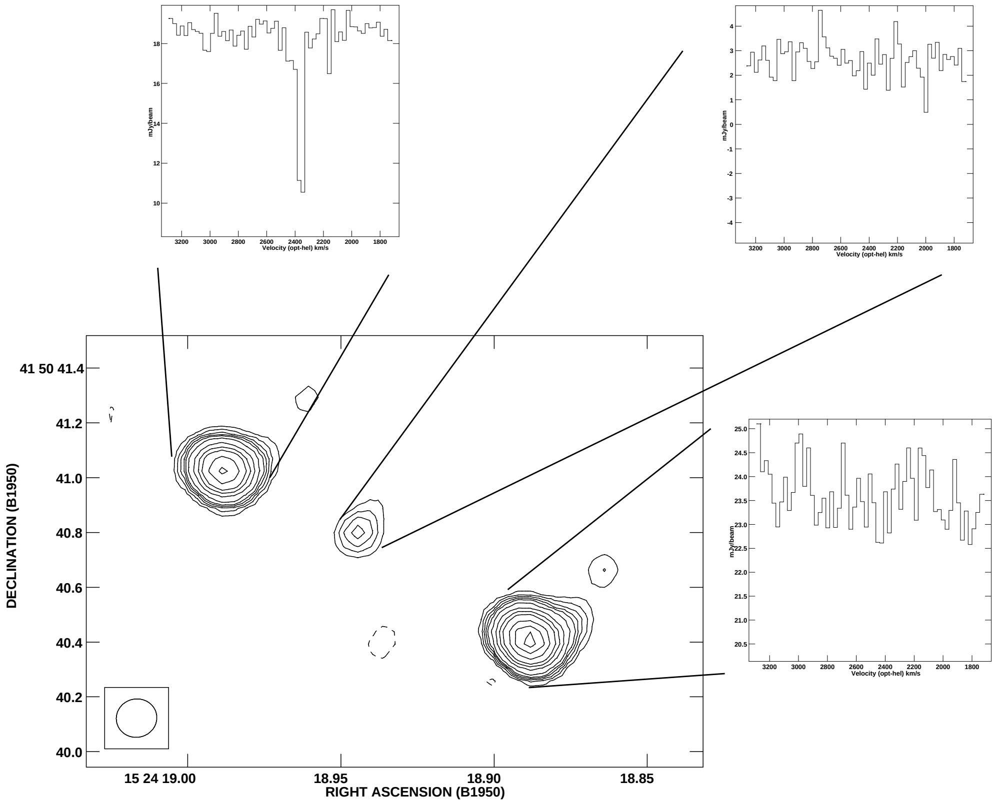

Figure 2. H1 absorption spectra seen from the compact triple radio source at the centre of NGC5929

A similar result has been found in the compact triple structure seen in the Seyfert 2 nucleus of NGC5929 (Figure 2) in which only the NW component shows H1 absorption although the weakness of the central nuclear component does not give strong upper limits. The absorption appears to be associated with a dust feature several 100pc in extent seen in HST images.

A very different result was found in the edge-on active galaxy NGC3079. H1 absorption, with a velocity field consistent with rotation, was found to extend over several hundred parsecs in NGC3079 (Pedlar et al 1996) and may represent the photo-dissociated inner part of a molecular ring approximately a kpc in extent.

The H1 absorption measurements, so far, have not revealed unambiguous evidence for a dusty torus. Ideally Seyfert 2 nuclei should show H1 absorption against the nuclear radio component and Seyfert 1 should not. In practice much of the H1 absorption seems to be associated with structures several hundred parsecs in extent which may be associated rings, arms or bars as well as tori in the vicinity of the active nuclei. However work continues in this area and some of the uncertainties will be resolved by higher sensitivity, higher resolution and observations of more objects.

4. Hydrogen absorption studies of starbursts

Starburst galaxies show completely different H1 absorption properties than Seyferts. Most Seyferts show highly localised H1 absorption, whereas starbursts show absorption over several hundred parsecs. At the MERLIN angular resolution, most of the continuum emission from nearby starbursts consists of individual supernova remnants (SNR) and absorption spectra can be measured against these. The best studied example, so far, has been M82 (Figure 3) in which H1 absorption measurements have been made against 33 SNR (Wills et al. 1998). As most of the SNR are only a few parsecs in extent (Muxlow et al. 1994) then the absorption measurements are probing the interstellar medium on scales which are not otherwise accessible in external galaxies. As the SNR are distributed almost randomly across the central 500pc of M82 they can be used to sample the dynamics of the neutral gas in front of the SNR. By comparing these observations with CO emission measurements (eg Shen & Lo 1995) it is possible to both constrain the 3-D positions of the SNR (and hence trace the starburst) as well as investigating the gas dynamics of the neutral gas closely associated with the starburst. The absorption spectra show a velocity gradient which could be interpreted as rotation, however in a number of the spectra there is velocity splitting (see Figure 3) which would be inconsistent with a simple rotating of neutral gas (eg Weliachew et al. 1984). Although modelling is still in progress, most of the H1 absorption spectra are consistent with a bar type structure and dynamics similar to that proposed by Achtermann & Lacy (1995).

A similar result to M82 has been found in the starburst galaxy NGC3628 in which 16 distinct components have been identified (Cole et al 1998). The H1 absorption appears to form two separate structures. One shows a velocity gradient of 1270km s^{-1} kpc^{-1}, whereas the other appears to be an arm of gas expanding away from the centre of the galaxy.

5. Conclusions

Atomic hydrogen absorption measurements on subarcsecond scales are proving a powerful technique for investigating the dynamics and distribution of neutral gas in the inner parts of AGN, particularly Seyfert galaxies. Higher redshift MERLIN observations of a number Seyferts and radio galaxies are already underway. Extensive absorption has been seen against SNR in nearby starburst galaxies and measurements of absorption in more distant starbursts (eg Arp220 & NGC6240) are in progress.

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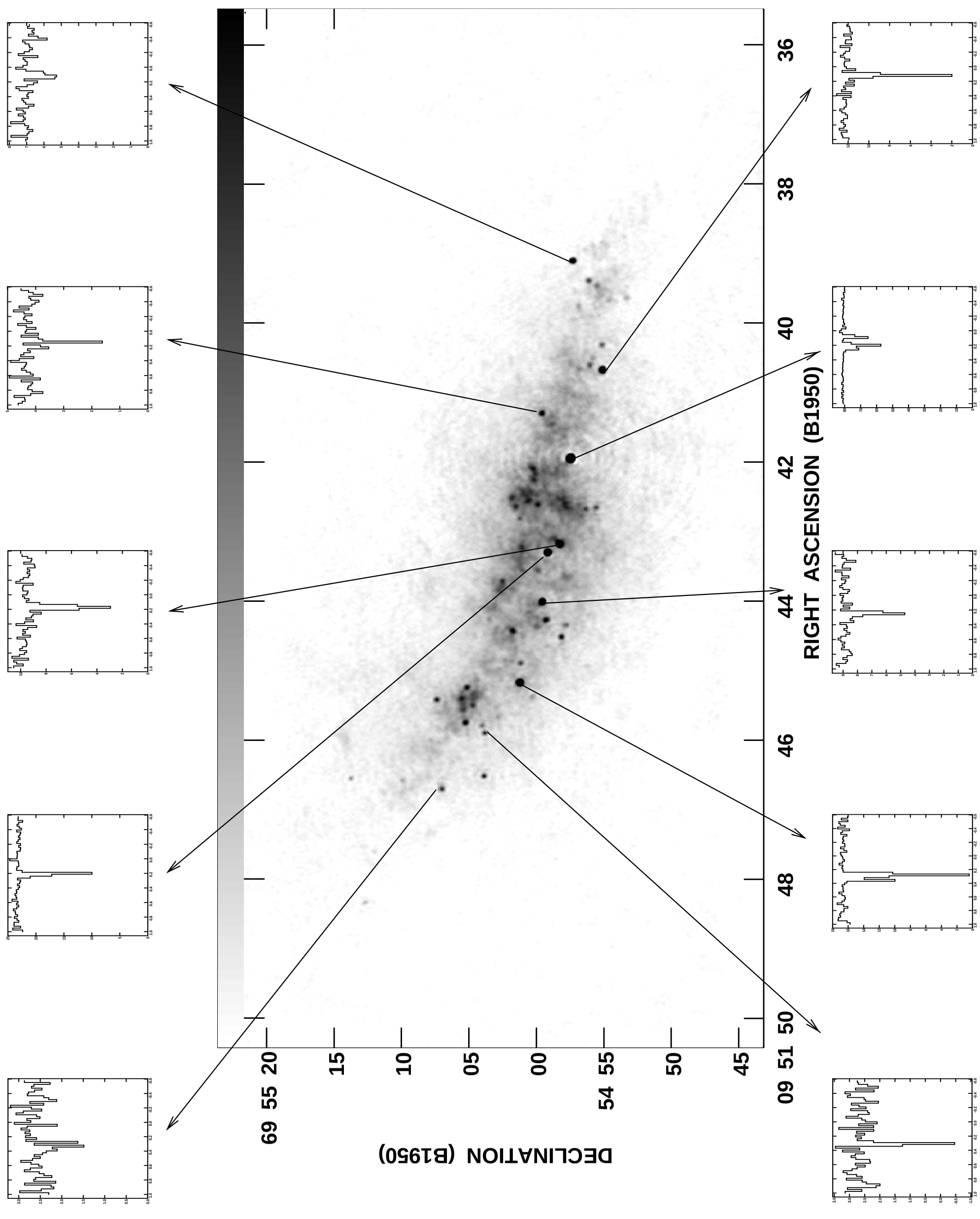

Figure 3. A montage showing a 1.4GHz MERLIN+VLA image of M82 and a selection of absorption spectra from 10 of the ~50 detected supernova remnants. See Wills et al 1998 for details.

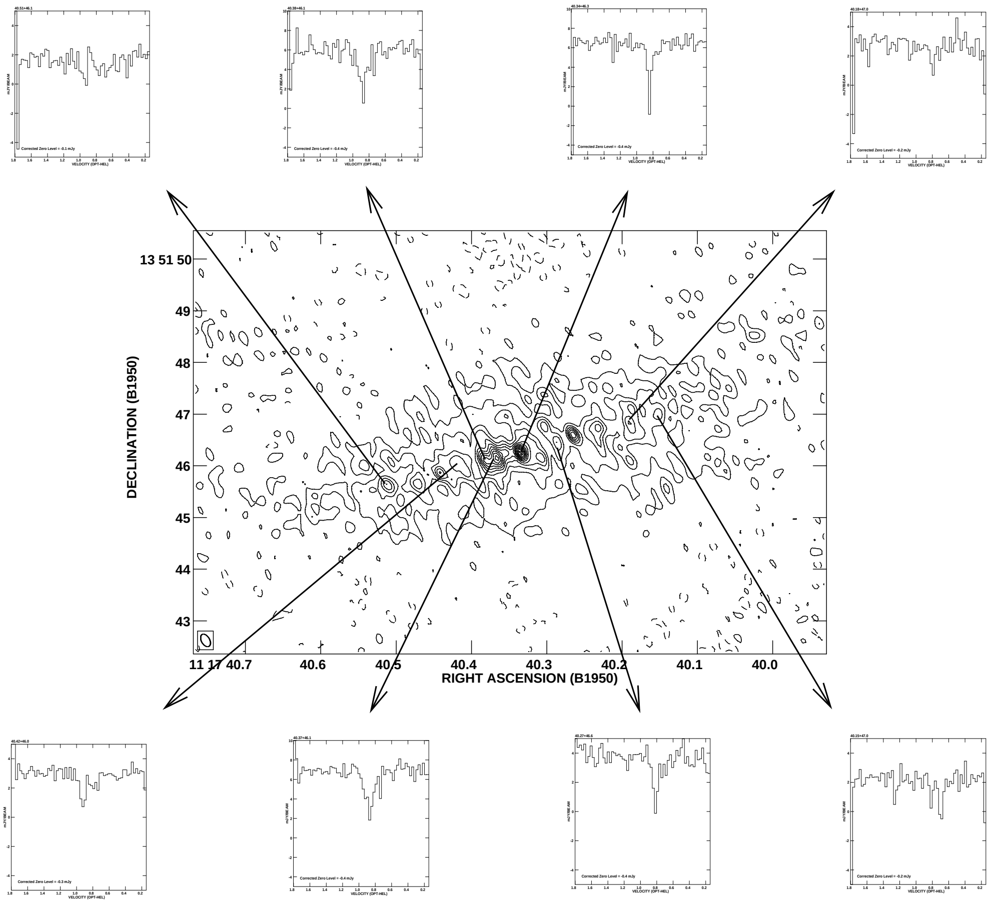

Figure 4. A selection of H1 absorption spectra seen against continuum components in the starburst galaxy NGC3628. The continuum image has an angular resolution of 0.26 X 0.16 arcsec.

References

Achtermann J.M. & Lacy J.H. 1995 ApJ 439 163

Antonucci R.R.J. & Miller, JS, ApJ 454, L95

Brinks E. & Mundell C.G. 1997 in 'Minnesota Lecture series on Extragalactic H1', A.S.P Conference Series Vol. 106, p268

Cole, G.H., Mundell, C.G., Pedlar, A. 1997 submitted to MNRAS.

Dickey J.M., 1986 ApJ 300, 190

Gallimore,J.F., Baum,S.A, O'Dea,C.P., Brinks,E., Pedlar,A. 1994, ApJ 422 L13

Gallimore J.F., Holloway A.J., Pedlar A., Mundell C.G. 1997 A&A (in press)

Mundell C.G., Pedlar A., Baum S.A.,O'Dea C.P., Gallimore J.F, Brinks E. 1995 MNRAS 272 355

Mundell C.G., in 'Quasar Hosts', ESO/IAC Confreren

Muxlow T.W.B., Pedlar A., Wilkinson P.N., Axon D.J., Sanders E.M, deBruyn A.G., 1994 MNRAS 266, 455

Pedlar,A., Mundell,C.G.,Gallimore,J.F.,Baum,S.A., O'Dea,C.P.,1996 VA 40, 91P

Shen, J. & Lo, K.Y. 1995 ApJ, 445, L99

Weliachew, L., Fomalont E.B., Greisen E.W. 1984 A&A, 137, 335.

Wilkinson, P.N.,1992 in 'Subarcsecond Radio Astronomy' , CUP P.422

Wills K.A., Pedlar, A., Muxlow T.W.B. 1998 MNRAS (In Press)