NEUTRAL HYDROGEN ABSORPTION STUDIES OF ACTIVE GALAXIES

A thesis submitted to the University of Manchester
for the degree of Doctor of Philosophy
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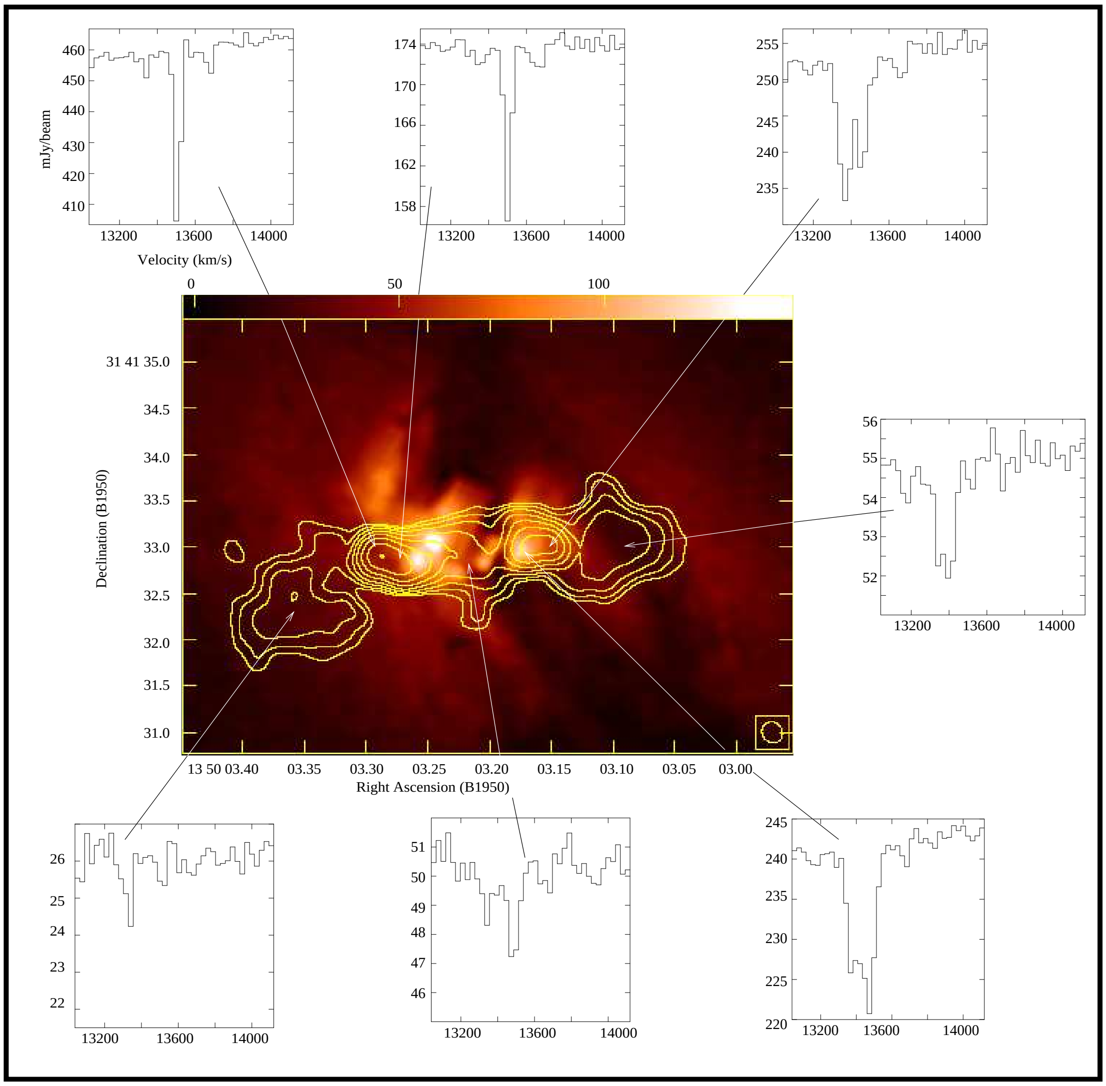

Frontispiece

Probing the Neutral Gas and Dust at the Centre of an Active Galaxy at the Highest Resolutions:- a montage of 1.4 GHz MERLIN radio continuum and false-colour *HST* image of the radio galaxy 3C 293 with selected HI absorption spectra.

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Abstract

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ABSTRACT OF THESIS submitted by **Robert J. Beswick** for the Degree of Doctor of Philosophy and entitled **Neutral Hydrogen Absorption Studies of Active Galaxies**

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Observations of neutral hydrogen (HI) absorption in the central regions of eight active galaxies are reported. These observations represent the most detailed studies of the neutral hydrogen component so far made of these sources, providing information on the HI gas distribution and kinematics on scales of $\sim 0\farcs2$, corresponding to linear scales of tens of parsecs in the nearest galaxies observed. The sample of active galaxies presented here consists of the radio galaxy 3C 293, two Seyfert galaxies NGC 7674 and NGC 7469, and five luminous infrared galaxies; NGC 6240, III Zw 35, UGC 2369, IR 0335+1523 and Zw 049.0. In each of these galaxies MERLIN has been used to provide the highest angular resolution observations of the neutral hydrogen content in these sources made to date. In addition to these high resolution HI studies the newly operational Giant Meterwavelength

Radio Telescope has also been used to provide arcsecond resolution observations of the HI gas content in two of the MERLIN sources, 3C 293 and NGC 7674.

Against the central few kiloparsecs of the radio galaxy 3C 293 both the neutral hydrogen distribution and the radio continuum emission is imaged on linear scales of ~150 pc. The distribution and velocity structure of the HI gas against this radio galaxy is attributed to two gas structures. One of these gas structures is indicative of quiescent gas lying ~10 kpc from the galaxy centre and is physically associated with both ionised gas and dust lanes in the galaxy. The second HI velocity structure is situated within 600 pc of the active galactic nucleus (AGN) and is observed to form a circumnuclear disc with a velocity gradient of 179 km s^{-1}arcsec^{-1}. This circumnuclear disc of gas is shown to enclose a mass of $\mathrm{M_{dyn}}(<600\,\mathrm{pc}) \leq 3.9 \times 10^{9}(\sin^{-2} i)\,\mathrm{M_{\odot}}$, where i represents the inclination of the disc.

Extremely localised HI absorption is observed against the unresolved nuclei of the Seyfert galaxies NGC 7674 and NGC 7469. In the case of the Seyfert-2 galaxy NGC 7674, it is shown that the HI is distributed within a 100 pc of the AGN. Against the unresolved Seyfert-1 nucleus of NGC 7469 the HI absorption is thought to either result from quiescent gas in the outer parts of this galaxy or from gas close to the nucleus. The HI absorption distribution in both of these sources is consistent with the absorption arising in circumnuclear dusty tori.

Of the five luminous infrared galaxies observed, HI absorption is detected in four cases. The observations of III Zw 35, IR 0335+015 and Zw 49.0 all revealed unresolved 1.4 GHz radio continuum structure against which HI absorption is detected. However, against the prototypical luminous infrared merger NGC 6240 extensive radio continuum is resolved and imaged. It is concluded that the radio continuum structure of NGC 6240 is consistent with the radio emission arising from both a starburst region and one or two AGN existing in the remnant nuclei of the merging galaxies. Extremely broad HI absorption is detected against the two dominant radio continuum components. The HI gas structure is consistent with a neutral gas disc forming between the two merging nuclei as they orbit around each other.

Declaration

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The Author

The author graduated from the University of Manchester in July 1999 with a first class honours masters degree in Physics with Astrophysics. The work presented in this thesis has been carried out between October 1999 and June 2002 at Jodrell Bank Observatory, The University of Manchester.

Publications

Refereed Publications

Beswick R. J., Pedlar A., Mundell C. G, & Gallimore J. F.,
A MERLIN neutral hydrogen absorption study of the luminous infrared merger NGC 6240, 2001, MNRAS, **325**, 151

Beswick R. J., Pedlar A. & Holloway A. J.,
A radio study of neutral gas and dust in the radio galaxy 3C 293, 2002, MNRAS, **329**, 620

Beswick R. J., Pedlar A. & McDonald A. R.,
Sub-arcsecond atomic hydrogen absorption in the Seyfert galaxies NGC 7674 & NGC 7469, 2002, MNRAS, in press

McDonald A. R., Muxlow T. W. B., Wills K. A., Pedlar A. & Beswick R. J.,
A parsec-scale study of the 5/15 GHz spectral indices of the compact radio sources in M82, 2002 MNRAS, in press

Jackson N. J., Beswick R. J., Pedlar, A., Cole G. H. J., Sparks, W. B., Leahy, J.P. & Holloway, A. J.
Observations of neutral gas and dust in the radio galaxy 3C 305, 2002, MNRAS, submitted

Non-refereed Publications

Gallimore J. F. & Beswick R. J.,

Possible Radio Supernova in NGC 6240, 2001, IAUC, 7428

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Abbreviations & Conventions

Throughout this thesis the following conventions and abbreviations have been used:

HI : Neutral Atomic Hydrogen.

MERLIN : Multi Element Radio Linked Interferometric Network.

GMRT : Giant Meterwavelength Radio Telescope.

VLA : Very Large Array.

VLBI : Very Long Baseline Interferometry.

EVN : European VLBI Network.

VLBA : Very Long Baseline Array.

HST : Hubble Space Telescope.

WFPC-2 : Wide Field Planetary Camera 2.

CHFT: Canada Hawaii France Telescope.

ISM : Interstellar Medium.

AGN : Active Galactic Nucleus.

ULIRG : Ultra Luminous Infrared Galaxy.

LIRG : Luminous Infrared Galaxy.

SED : Spectral Energy Distribution.

RSN : Radio Supernova.

SNR : Supernova Remnants.

SFR : Star Formation Rate.

RFI : Radio Frequency Interference.

IR : infrared.

UV : ultraviolet.

The Hubble constant, H_0, is assumed to be $75\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$.

Units have been stated explicitly wherever possible.

The unit of flux density used is $1\,\mathrm{Jy}=10^{-26}\ \mathrm{W\,m^2\,Hz^{-1}}$.

All of the sources observed for this thesis have recession velocities less than $14\,000\,\mathrm{km\,s^{-1}}$; redshifts have been calculated assuming the approximation $z = v/c$ and cosmological effects have been ignored.

"I do not know what I may appear to the world; but to myself I seem to have been only like a boy playing on the sea-shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay undiscovered before me."

Isaac Newton, *Brewster's Memoirs of Newton. Vol II. Chap. XXVII.*